Field Monitoring of Curved Girder Bridges with Integral Abutments

tech transfer summary

The long-term objective of this effort is to establish guidelines for the use of integral abutments with curved girder bridges with a specific interest on the relationship between bridge curvature and overall behavior.

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RESEARCH PROJECT TITLE

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SPONSORS

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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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Background and Problem Statement

Nationally, there is concern about 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 a National Cooperative Highway Research Program (NCHRP) research problem statement was developed and given high priority for funding.

Project Objectives and Scope

The primary objective of this work was to monitor and evaluate the behavior of six in-service, horizontally curved, steel-girder bridges with integral and semi-integral abutments. In addition, the influence and behavior of fixed and expansion piers were considered.

Research Methodology and Description

A number of steps were performed to meet the project objectives. First, a national state department survey was conducted and a literature review was performed to capture the state-of-the-art regarding these types of structures. Second, a monitoring program was developed and installed on six bridges located at the Interstate 35 (I-35), I-235, and I-80 interchanges northeast of Des Moines, Iowa. Third, a monthly survey was conducted on each bridge with the purpose of tracking the bridge movements. Finally, the data gathered during the monitoring period of the project were post-processed.

The bridges were monitored over a period of approximately 18 months for the long-term health assessment. During this period, the strains, temperatures, and displacements were recorded under a variety of loading conditions. In addition, the short-term behavior was investigated by conducting a series of live load tests.

Using the collected data, simple analytical models were developed and validated. These models could then be extrapolated to other design conditions (e.g., geometry, , etc.) that may provide information on other hypothetical situations.

Instrumentation and Monitoring of Six In-Service Bridges

The intersection of I-80, I-35, and I-235, also known as the northeast mix-master (NEMM), on the northeast side of Des Moines, Iowa was the location for the testing associated with this work. The reconstruction of the NEMM provided the opportunity to monitor the behavior of straight and horizontally curved, steel-girder, integral-abutment bridges.

There were six 26 ft wide roadway bridges included in this work. The interchange design was such that two straight-girder bridges were constructed with integral abutments, two curved-girder bridges were constructed with semi-integral abutments with expansion joints, and two curved-girder bridges were constructed with integral abutments.

The typical instrumentation plan for each bridge consisted of four girder strain gauges at the mid-span of exterior girders on select spans, temperature sensors embedded into the concrete deck, and expansion meters placed strategically between the bottom flange of the girders and the pier cap and the abutment cap. On one bridge, six abutment piles were also instrumented with strain gauges approximately 10 inches below the bottom of the pile cap, long-range displacement meters were installed at each abutment and pier, and pressure cells were installed on the back face of the abutment backwalls. The bridges were monitored for a period of approximately 18 months.

Along with the electronic instrumentation placed on the bridges, each of the six bridges was outfitted with eight prismatic reflectors for the purpose of performing monthly surveys of the bridges. These reflectors were placed on the bottom flange of the exterior girders near both abutments and both piers.

Key Findings

- There was no measurable difference between the horizontally curved bridges and straight bridges used in this work with regard to bridge behavior under thermal effects; internal strains were recorded in the composite girders as a result of thermally induced restrained expansion and contraction and, of the recorded strains, axial strain showed the largest ranges; the bridges expanded and contracted with seasons and showed more expansion and contraction near expansion piers than fixed piers.
- The equivalent cantilever method of steel pile analysis fell short of accurately predicting the relationship between weak axis bending strain in the piles and the pile head displacement; the measured internal stress in the abutment piles due to expansion and contraction of the bridge were generally below 50 percent of yield stress; and the soil pressures on the abutment backwalls were generally below approximate passive soil pressures.
- With regards to the live loading, moment distribution factors were heavily influenced by the amount of curvature and the V-Load equation provided an approximation of lateral bottom flange bending with minimal bridge skews.
- The analytical analysis of the bridges produced substantially large lateral bottom flange bending moments and axial forces in the girders due to temperature effects.
- Special attention has been drawn to the fixed pier location as thermal loads may produce an additional stress up to 3.0 ksi.
- Since AASHTO requires a three-dimensional analytical model of the bridge and support conditions to calculate lateral bending stresses for the final design of all curved bridges, this model should also be used to calculate thermal stresses for final design of the curved bridge. However, with a 10 degree skew and 0.06 radians arc span length to radius ratio (i.e., meeting the geometrical requirements to ignore curvature for strong axis bending), the curved and skew integral abutment bridges can be designed as a straight bridge if a stress tolerance of 10% is acceptable.
- An expansion pier does reduces the thermal stresses in the girders of the straight bridge but does not appear to absolutely reduce the stresses in the girders of the curved and skew bridge even though the overall restraint is reduced.

Implementation Readiness and Benefits

This effort 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 long-term objective of this effort is to establish guidelines for the use of integral abutments with curved girder bridges. The following recommendations are extracted and summarized from the final report for this study:

- The relationship between abutment steel pile internal axial strain and effective bridge temperature varied depending on the pile location with respect to the abutment pile cap and this behavior could impact design and further investigation into the phenomena should be undertaken.
- From the results of this study, the piles used for support of the integral abutments at the NEMM had sufficient resistance to thermal expansion; however, this is without considering the effects of other loading conditions, so further investigation into the behavior of abutment piles of horizontally curved integral abutment bridges is suggested.
- Based on the results from the live load field testing and assessment, diaphragms were found to be subjected to both bending and tensile axial forces, indicating that the outermost girder is tending to expand radially more than the innermost girder, which is an important point to note in outer versus inner girder design approaches.
- Analytical analysis results indicate that temperature is an essential consideration when addressing member forces; however, it is more important in design to determine the level of stress produced in the section.
- With regards to stresses, special attention has been drawn to translationally restrained locations, such as fixed piers, for exterior girders given that lateral bottom flange bending has become more prevalent. These findings are not alarming; however, thermal loading may require further consideration in the future design of horizontally curved bridges that incorporate restrained supports with increasing degrees of curvature and skew.
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