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Behavior of curved and skewed bridges with integral abutments

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ABSTRACT

Horizontally curved steel girder bridges are being designed with integral abutments due to their merits in terms of cost, constructability and maintenance. This type of bridges is relatively new in the United States and their performance evaluation is deemed difficult. Especially, the behavior of such bridges under thermal load conditions is not well understood and relevant code guidelines are not sufficiently provided. The purpose of this study was to investigate the behavior of a curved and skewed bridge with integral abutments through a numerical analysis and field monitoring-oriented program. A newly constructed, one lane, three span, horizontally-curved, integral abutment bridge was instrumented using a field monitoring system to capture the bridge behavior under change in ambient conditions and was tested using a dump truck traveling across the bridge at a walk pace. A three dimensional FE model was established and its predictions were reasonably compared with the collected data. Subsequently, a parametric study was performed to investigate the influence of curvature and skew on the bridge behavior under design loading conditions. It was found that the stresses in girders varied with changes in skew and curvature significantly. With a 10° skew and 0.06 radians arc span length to radius ratio, the curved and skewed integral abutment bridges can be designed as a straight bridge if a 10% increase is applied to the total induced stresses. Thermal stress and its magnitude relative to the maximum stress can reach up to 3 ksi and 15% of the maximum stress, respectively.

1. Introduction

The National Cooperative Highway Research Program (NCHRP) raised concerns regarding the design, fabrication, and erection of horizontally curved steel girder bridges [1]. These concerns centered around difficult-to-predict girder displacements, fit-up issues, and unintended locked-in stresses, including thermal stresses. The major reason for the concerns is that up to one-quarter of the steel girder bridges in the United States incorporate curvature in their design, and thus having a better understanding of actual behavior – and therefore having better design methodologies – is of notable importance. However, additional complications arise when analyzing and designing I-girders in curved bridges compared to straight girder bridges and range from the individual plates to the constructed girder as a whole [2].

To complicate matters even more, horizontally curved steel girder bridges are being designed with integral abutments, given that integral abutments are less expensive and easier to construct, simple to detail in design, and require less maintenance along with elimination or reduction of deck expansion joints [3]. Although the combined use of horizontally curved steel girder bridges with integral abutments stands to be a promising design, this combination is relatively new to the United States. Further, this combination can be more difficult to understand and analyze as compared to an equivalent straight girder bridge [4]. Importantly, the behavior of horizontally curved bridges with integral abutments during thermal loading is not well understood. Unfortunately, the current version of the AASHTO LRFD Bridge Design Specifications [5] does not provide sufficient guidelines for thermal behavior of bridges with integral abutments.

Thermal behavior of horizontally-curved bridges was studied by Moorty and Roeder [6] and Hall et al. [1]. Thermal behavior of straight IABs was also investigated by Abendroth and Greimann [7], Kim and Laman [8], and Shah [9] through field monitoring program and finite element (FE) simulations. As indicated by Kim and Laman [8], the difficulties in predicting the performance of integral abutment bridges are generally due to the complexity of daily and seasonal temperature variations, nonlinear soil structure interaction, and time dependent effects.

Recent studies on thermal behavior of curved integral-abutment bridges were completed by Thanasattayawibul [10], Doust [4], and Kalayci et al. [11]. Thanasattayawibul [10] performed a parametric study using a three-dimensional FE model to investigate the effect that different parameters (i.e., bridge length, temperature, soil profile type, span length, radius, and pile type) would have on the behavior of horizontally curved, steel-girder, integral-abutment bridges.

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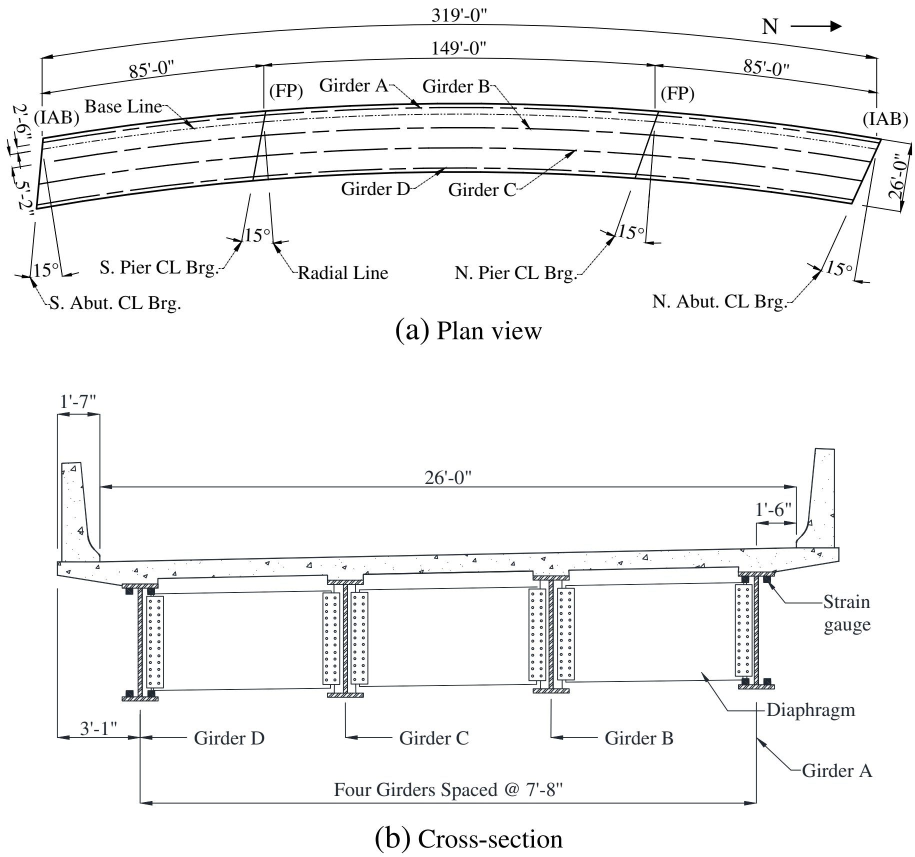

Fig. 1. Bridge 309 (1 ft = 0.30 m; 1 in. = 25.4 mm).

Conclusions and recommendations were made for future research and for the design of this type of bridges. To investigate the thermal behavior of horizontally-curved, steel-girder, integral-abutment bridges, Doust [4] established multiple bridge models with varying horizontal curvatures and total bridge lengths, considering different loading conditions including gravity loads, lateral loads, temperature effects, concrete shrinkage, and earth pressure. The author found that for bridges longer than a specific length, the internal forces due to expansion are smaller in a horizontally-curved bridge than in a straight bridge of similar length. Kalayci et al. [11] established a rigorous three dimensional FE model to evaluate the thermal behavior of curved integral abutment bridges. The effects of bridge curvature, abutment backfill soil type, degree of lateral restraint from the U-shaped wing walls on the seasonal response of two span curved IABs were investigated. They found that: (1) as the curvature increased, longitudinal displacements, earth pressures and weak axis bending moment on piles decreased, and the lateral displacements

Table 1
Dimensions and section properties of instrumented sections.

		t_{ft} (in.)	b_{ft} (in.)	t_w (in.)	h_w (in.)	t_{fb} (in.)	b_{fb} (in.)
Girder A	North/South span	1	20	7/16	48	1	20
	Center span	7/8	20	7/16	48	1.375	20
Girder D	North/South span	7/8	18	7/16	48	1	18
	Center span	3/4	18	7/16	48	1.375	18

Note: t_{ft} — top flange thickness; b_{ft} — top flange width; t_w — web thickness; h_w — web height; t_{fb} — bottom flange thickness; b_{fb} — bottom flange width; 1 in. = 25.4 mm.

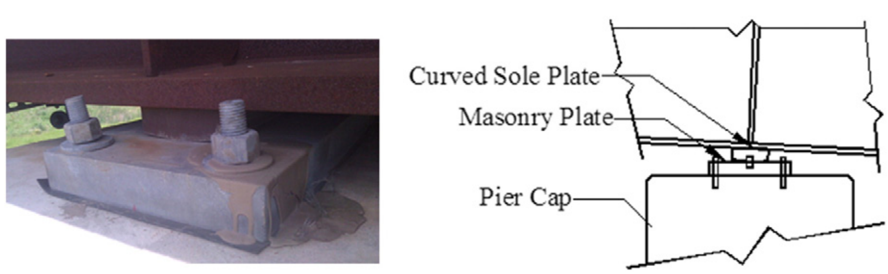

Fig. 2. Fixed pier bearing.