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Mitigating the bridge end bump problem: A case study of a new approach slab system with geosynthetic reinforced soil foundation

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ABSTRACT

The Louisiana Department of Transportation and Development (LA DOTD) has initiated a major effort to minimize the bridge end bump problem associated with the differential settlement. As a result, a new design for the approach slab was proposed, which requires increasing the slab flexural rigidity (EI), and using reinforced soil foundation (RSF) to support the slab and traffic loads at the roadway pavement/approach slab joint (R/S joint). The Bayou Courtableau Bridge was selected as a demonstration project to monitor, evaluate, validate, and verify the new bridge approach slab design method. The west approach slab was designed using the proposed design method with slab thickness of 406 mm, while the east approach slab was designed using the traditional design method with slab thickness of 305 mm. The pavement end side of the west approach slab was supported by a 1.2-m wide strip footing with the soil underneath it was reinforced by six layers of geogrid placed at a vertical spacing of 305 mm. Two static load tests were conducted on both the west and east approach slabs at two different times after construction. The test results indicated that the east approach slab (with traditional design) kept losing its contacts from the underneath embankment soil starting from the bridge side towards the pavement side after about a year and half. Meanwhile, the west approach slab (with new design) lost most of its supports from the underneath embankment soil, but with less observed faulting at the R/S joint and improved rideability [i.e., lower International Roughness Index (IRI) values]. The field monitoring program at Bayou Courtableau Bridge demonstrated much better performance of the new approach slab design system (west approach slab) compared to traditional design (east approach slab).

1. Introduction

1.1. Background and problem

Bridge approaches are normally constructed with reinforced concrete slabs that connect the bridge deck to the adjacent paved roadway. The slab is usually supported on one side by the bridge abutment and on the other side by the embankment. Their function is to provide a smooth and safe transition of vehicles from roadway pavements to bridge structures and vice versa. However, complaints about the ride quality of bridge approach slabs still need to be resolved. The complaints usually involve a "bump" that motorists feel when they approach or leave bridges (Cai et al., 2005). This problem is commonly referred to as the bump at the end of the bridge mainly resulted from the differential settlement of the concrete approach slab relative to the bridge deck (Long et al., 1998; Dupont and Allen, 2002; Lenke, 2006). It results in uncomfortable rides, dangerous driving conditions, and frequent repairs. Field observations indicated that either faulting at the roadway pavement/approach slab joint (R/S joint) or a sudden change in the slope grade at the approach slab/bridge deck joint (S/D joint) (as shown in Fig. 1) causes this "bump" (Cai et al., 2005).

The settlement of the natural soil under the embankment, the compression of the embankment fill, and the stiffness of the concrete approach slabs contribute to the development of such a bump problem. Concrete approach slabs can lose their contacts and supports from soil due to the settlement of embankment soil on which the slabs are built (Fig. 1). When settlement occurs, the slab will bend in a concave manner that causes a sudden change in slope grade of the slab. Traffic loads will be redistributed to the ends of the slab. Due to the redistribution of loading, vertical faulting at the R/S joint and a sudden change in the slope of grade at the S/D joint

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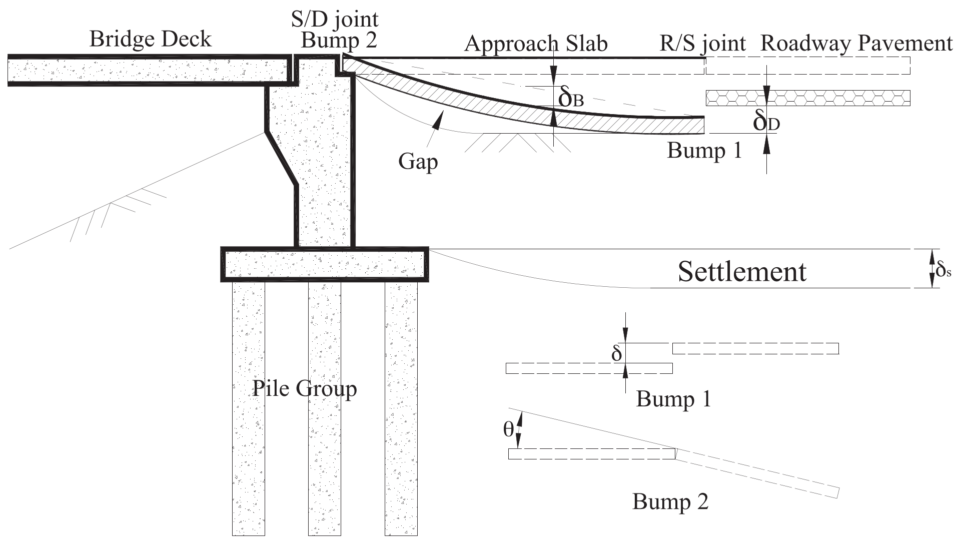

Fig. 1. Illustration of approach slab and its interaction with soil.

may occur. Eventually, the rideability of the bridge approach slabs will deteriorate with time.

The bump at the end of a bridge problem affects 25% of the bridges in the United States (approximately 150,000), and the amount of money spent every year on the repair of this problem nationwide is estimated to be at least $100 million (Briaud et al., 1997). There are several ways, such as pile supported embankment, lightweight embankment fill, etc., were tried to reduce the bump at the end of the bridge (Helwany et al., 2007; Puppala et al., 2009). However, the cost of a particular solution may be prohibitive or exceed the life-cycle costs. The best current practices optimize the balance between proper design, proper construction, and acceptable maintenance while satisfying budget constraints and safety levels (Briaud et al., 1997).

1.2. Potential solution

The Louisiana Department of Transportation and Development (LA DOTD) has launched a major effort to solve the bridge bump problem by changing the design of approach slabs where differential settlement is expected. The objective is to find a feasible solution that makes approach slabs strong enough to allow them to lose a portion or all of their contact supports without causing detrimental deflection. In this solution, the flexural rigidity (EI) of the approach slabs is increased through increasing both the slab thickness and the reinforcement ratio. Consequently, some embankment settlement will be allowed without decreasing the ride quality. As a result, the slab dead load and traffic live loads will be carried by the two ends of the slab rather than distributed over the length of the slab. Accordingly, the local soil pressures beneath the strip footing increase, resulting in an increase in the faulting deflection (δ_D in Fig. 1). Geosynthetics can be used to reinforce the soil beneath the footing, thereby increasing the soil's bearing capacity, helping redistribute the load to wider area, and hence reducing the footing's settlement.

Several research projects were initiated by LA DOTD in response to this need (Cai et al., 2005; Abu-Farsakh et al., 2007; Martinez, 2009). Cai et al. (2005) investigated the effect of embankment settlements on the performance of the approach slab using a 3-D finite element analysis. The results showed that with the increase in slab thickness and reinforcement ratio (stiffer), the slab deformation can be well controlled. Therefore, considering different levels of embankment settlements, an engineer can either use a thicker approach slab and/or more reinforcement (stiffer) to allow partial or full separation between the embankment and the approach slab. The recommended approach slab thickness and major reinforcement (bottom layer in the span direction) for flat approach slabs with a span length of 12 m are presented in Table 1.

Meanwhile, extensive experimental studies, including small-scale laboratory model tests and large-scale field tests, were conducted on geosynthetic reinforced soils by the authors in several research studies (Chen, 2007; Chen et al., 2007, 2009; Sharma et al., 2009; Abu-Farsakh et al., 2007, 2008, 2013; Chen and Abu-Farsakh, 2015) and also by other researchers around the world (e.g., Binquet and Lee, 1975; Huang and Tatsuoka, 1990; Adams and Collin, 1997; Tafreshi and Dawson, 2010; Bai et al., 2013; Demir et al., 2013; Chakraborty and Kumar 2014, Miao et al., 2014; Naeini and Gholampoor, 2015). The influences of different variables and parameters contributing to the improved performance of reinforced soil foundation (RSF) were examined in these tests. This includes the depth of the first reinforcement layer (u), the total depth of reinforcement (d), the vertical spacing between reinforcement layers (h), the length of reinforcement (l), the tensile modulus of reinforcement (J), and the type of reinforcement. The recommended parameters for layout of the reinforcement are presented in Table 2.

To validate the findings and the design recommendations developed in these research studies and to update the design and construction guidelines of LA DOTD for bridge approach slabs to mitigate bridge end bump problem, the Bayou Courtableau Bridge was selected to demonstrate the new approach slab design system. The field performance, including deformation and internal stresses of the concrete slabs, contact stresses between slab and embankment, stress distributions within the reinforced soil foundation, and strain distributions along the geogrid, was monitored along a period of one and half year, and the results will be presented and discussed in this paper.

2. Site description and characterization

The Bayou Courtableau Bridge as part of Louisiana Highway 103 in St. Landry Parish is located 3.2 km east of I-49. Replacement of