BRIDGE APPROACH SETTLEMENTS—AN ISSUE DUE TO DESIGN OR CONSTRUCTION PRACTICES?

Sireesh Saride  
*Post Doctoral Fellow, Department of Civil Engineering, The University of Texas at Arlington, Arlington, Tx–76019, USA.  
*E-mail: sireesh@uta.edu

Anand J. Puppala  
*Professor, Department of Civil Engineering, The University of Texas at Arlington, Arlington. Tx–76019, USA.  
*E-mail: anand@uta.edu

Ekarut Archeewa  
*Doctoral Student, Department of Civil Engineering, The University of Texas at Arlington, Arlington, Tx–76019, USA.  
*E-mail: ekarut@uta.edu

ABSTRACT: Bridge approaches provide a smooth and safe transition of vehicles from highway pavements to bridge structures and vice versa. Settlement at the end of the bridge and highway pavements also known as a ‘bump’ in the roadway, causes not only inconvenience to passengers but also increases the maintenance and repairing work/costs to the highway agencies. In the United States, state Departments of Transportations (DOTs) have been spending over $100 million to alleviate the bump problems every year. Many researches had been carried out to study the causes of the bump problem and they are summarized in this paper. To identify factors leading to the bump problem in Texas, a survey questionnaire was send to all twenty five districts in Texas. In addition field investigations were conducted at bridges in Quanah, Arlington and Cleburne. Results from this study reveal that the subsurface void development, erosion and compressibility of fill material were found to be the main contributing factors to the bridge approach settlement in the State of Texas.

1. INTRODUCTION

Bridge approaches provide smooth and safe transition of vehicles from highway pavements to bridge decks and vice versa. However, settlement and/or heave related movements of bridge approach slabs relative to bridge decks usually create a bump in the roadway (Briaud et al. 1997). This is a typical occurrence at the end of the bridge decks and requires a solution, because this uneven transition may cause severe damage to bridge decks, inconvenience to passengers, reduced steering control for travelers, distraction to drivers, lower public perception of transportation agency’s image, and constant delays to rehabilitate the distressed lanes (Briaud et al. 1997; Puppala et al. 2009).

The bump problem also increases the maintenance cost to transportation agencies worldwide. State Departments of Transportation (DOTs) in the United States have been spending over $100 million to repair the damaged bridges nationwide (approximately 150,000 bridges) every year (Briaud et al. 1997). Besides, bump repair and maintenance works often result in traffic delays and congestion problems.

There have been many studies employed across the states in the United States to study the causes of the problem and the methodologies to solve it (Hopkins 1969; Stewart 1985; Laguros et al. 1990; Kramer & Sajer 1991; Jayawikrama et al. 2005; White et al. 2007; Puppala et al. 2009). The causes can be very variable and and too complex to identify them easily. Following sections describe the mechanisms causing the bump phenomenon from the available case histories reported in the literature and present case studied carried out in the State of Texas.

2. MECHANISMS CAUSING THE FORMATION OF THE BUMP

2.1 Lessons Learned From Available Case Studies

The bump phenomenon is not a new issue to the State transportation agencies nationwide as well as worldwide. In a wide survey on the conditions of existing bridge approaches conducted between 1964 and 1968 in Kentucky, Hopkins (1969) identified and reported that the type and compressibility of the soil or fill material used in the embankment and foundation; thickness of the compressible foundation soil layer; height of the embankment and type of abutment were the main contributing factors for differential settlements at the end of the bridge. The factors were concurred later by Kramer & Sajer (1991) and Briaud et al. (1997) based on extensive surveys of various State DOTs in the USA.

Ardani (1987) identified several other contributing factors to this problem which includes (1) poor drainage and soil erosion around the abutment, and (2) poor compaction of
embankment fill. According to a wide survey conducted by Laguros et al. (1990) on 758 bridge approaches in Oklahoma State, reported that the age of the approach slab, height of embankment, skewness of the bridge and traffic volume influences the bridge approach settlements. In addition, the flexibility of the approach pavement has a considerable influence as well. Laguros et al. (1990) observed greater differential settlement in flexible pavements than rigid pavements during initial stages following the construction (short term performance), while both pavement types performed similarly over the long term.

In another study, Arsoy et al. (1999) performed a survey in Staunton district of Virginia to observe the behavior of integral bridges. They reported that for an integral bridge, the seasonal temperature changes cause a void development under the approach slab, which eventually leads to the bump at the end of the bridge. They also concluded that the settlement of the approach fill can be alleviated by using a properly compacted well-drained backfill, but it cannot be eliminated.

Ha et al. (2002) conducted a detailed investigation of two bridges in Houston, Texas and concluded that the higher water content of soil resulted in the lower strength of soil near the abutment and the higher soil compressibility lead to a bump phenomenon. Seo (2003) prepared a survey questionnaire on approach settlements and distributed among the 25 districts of the Texas DOT. The responses from TXDOT officials show that the causes of the bump are the settlement of the embankment fill, followed by the loss of fill by erosion. The results also show that the bump problem will be more serious if the embankment is high and the fill is of clay type soil.

Jayawikrama et al. (2005) performed field investigations in four districts in Texas. They reported four major contributors to approach settlement problem which are: (1) the time-dependent settlement (primary/secondary consolidation) of foundation soil beneath the embankment and the approach slab embankment, (2) the poor compaction of embankment adjacent to the abutment, (3) erosion of soil at the abutment face, and (4) poor drainage system around the abutment.

White et al. (2005) claimed that subsurface void development caused by collapse and erosion of the granular backfill, water infiltration through unsealed expansion joints, and poor construction practices were found to be the main contributing factors of the bridge problems including approach slab settlements based on a field study of 74 bridges in Iowa state in US. Figure 1 depicts the void formed under the approach slab.

A recent study conducted by White et al. (2007) summarized all the factors those contribute to the differential settlements of the approach slabs in a pictorial representation (Fig. 2). Other study from Australia (Hsi 2007) has shown that the bump at the end of the bridge was a major concern in highway and freeway constructions due to very soft estuarine and marine clays in subsoils.

2.2 Lessons Learned From Present Site Investigations

In this study, a survey questionnaire was first prepared and distributed to all 25 District offices in Texas to help identifying the bridge approach related problems. Out of 25 district offices, 17 district offices responded immediately to the questionnaire. A majority of respondents (94%) reported that they encountered bridge approach settlement or heaving problems in their districts. The causes for this problem outlined by the respondents are many (Fig. 3) and can be ranked in the following order. (1) Compaction of the embankment fill (2) Construction practices (3) Drainage and soil erosion and (4) Void formation. In addition to the information gathered from the questionnaire, research team has also visited a few bridge sites where the bump problem has been acute for many years. The following sections describe the aspects and mechanisms observed by the research team.

2.2.1 SH 6 Bridge Site, Quanah, Texas

A relatively new bridge along the State Highway 6 (SH 6) located in Quanah, Texas has experienced an acute bump problem. The bridge abutment is a non-integral type and the height of embankment is about 40 feet. Locally available low PI (Sandy Loam) material was used to build the embankment as the fill material was offered to the Department at no cost.
During the site visit, uneven settlement of the guardrail on the embankment at both the ends of the bridge revealed the obvious settlement problems on this bridge site (Fig. 4a). Severe soil erosion and loss of embankment material in the form of gully drains was also observed in many locations on the embankment slopes as shown in Figure 4b. The soil erosion problem observed to be more severe near the abutments where a void was formed and a differential settlement between the bridge deck and the bridge approach was visibly noticed. The void found could have a depth of 8 inch or more. Besides, numerous longitudinal cracks were observed on the pavement surface.

From this field investigation, it could be said that the inferior quality of the embankment material triggered the problem of bump at the end of the bridge. The void formation behind the abutment was found at all four corners of the bridge abutments. This is a result of backfill collapse after the construction. These erosion problems reveal the problem of inefficiency of redirecting surface runoff and infiltrated water behind the abutment.

The Texas Department of Transportation (TxDOT) personnel reported that a severe rainfall occurrence immediately after the construction of the highway embankment caused the erosion of just seeded top soil along the slopes of the embankment. After this event, TxDOT tried several other remedial techniques such as reseeding, wire mesh protection along the slopes and asphalt overlay on the pavement surface. Despite of these remedial measures, the bump problem is still persisting. The asphalt overlay is generally a short term solution and the seeding and wire mesh covering is clearly seen as an inefficient method for this bridge site. Further investigations using non destructive testing methods are recommended to further visualize this problem.

**2.2.2 SH 360 Bridge Site, Arlington, Texas**

In a highway extension project (State Highway 360) in south Arlington, Texas, a new bridge was proposed to build on a soft clay subgrade soil. Preliminary geotechnical investigations reveal that the foundation soil is highly expansive and compressible. The report recommended that the weak soil must be excavated and removed or stabilized with lime/cement or to opt for both the alternatives. TxDOT wanted to experiment with a lightweight fill (Expanded Clay Shale, ECS) material on one end of the bridge embankment. The counterpart of the bridge embankment used a normal fill (a low PI material). The subgrade soil was stabilized with 6% lime on both the sides of the bridge. Initially during construction of the embankment with normal fill, erosion issues were noticed as shown in the Figure 5a. The ECS embankment was instrumented with inclinometers to verify any movements due to traffic loading. Both the embankments were monitored for their settlements using pavement surface profiling with a total station. Results from the pavement surface profiling show that the normal fill embankment has encountered the settlement problems than the ECS embankment. The differential settlement at the end of the bridge was obviously seen under the concrete barrier (Fig. 5b). The asphalt overlay was done to mitigate the settlement problem on the normal fill embankment for twice since the construction of the embankment. From these observations, it can be concluded that the embankment with normal fill has imposed more pressure on the foundation soil which might have lead to settlements on the pavement surface. In addition, the soil erosion in normal fill embankment also triggered the surface settlements due to loss of embankment material. The embankment with normal fill has no issues owing to its lightweight nature and high frictional coefficient.
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2.2.3 US Highway 67 Bridge Site, Cleburne, Texas

To divert heavy traffic from downtown Cleburne, Texas, two lane bypass road US highway 67 was constructed in 1995 with four bridges crossing a railroad, two highways and a creek. All four highway bridges experienced differential movements within six months after construction. This problem is severe on bridge crossing SH 174. The differential settlements were over 12 to 15 inch near approach slabs. This bridge is a non-integral type with a 35 ft. high embankment. The bridge construction records reveal that the construction sequences were significantly different. The header wall (geosynthetics reinforced soil was, GRS) with concrete block facings was first constructed and followed by the installation of drilled shafts for the abutments. Pea gravel was used as backfill in the GRS wall system with alternate layers of uniaxial and biaxial geogrids as reinforcement forms. The flexibility of the GRS wall should allow for any differential settlements expected near the approach slab. However, the flexibility of the GRS wall concurred with the loss of fill material and worsened the bump problem in this case as witnessed from the Figure 6. Severe subsurface soil erosion and loss of fill material behind the abutment caused by water infiltration through joints and cracks into the embankment were also observed. The eroded material can be seen beneath the four-foot opening on the GRS wall (Fig. 6). Besides, the pullout failure of geosynthetics layers depicts that the use of insufficient length of reinforcement. In summary, it is clearly understood that the soil erosion is still a major factor causing the bump problem on this bridge site. In addition, the poor design of the GRS structure, high density of heavy traffic volume; inferior properties of fill material and, inadequate compaction practices also aggravate the differential settlement at the end of the bridge.

3. REMEDIAL MEASURES

From the detailed field investigations, it can be seen that the asphalt overlay method is normally chosen as a mitigation method for the bump problems. However, this method is not a permanent solution and it cannot prevent the settlements and loss of fill material. Therefore, other promising techniques such as use of lightweight fills, Geofoam and flowable fill materials for the embankment construction, and Deep Soil Mixing (DSM) and similar foundation soil treatment methods could be used to alleviate the approach settlement problems.

4. CONCLUSIONS

From the available case studies, it can be summarized that the major contributing factors to the bump phenomenon are the consolidation settlement of foundation soil, poor compaction and consolidation of backfill material, incorrect materials specification, poor drainage and soil erosion, seasonal temperature variations and types of bridge abutments. Some of those factors were also concurred from the present field inspections. Consolidation of the backfill material, void development under the approach slab due to erosion of the backfill, weak foundation soil and high traffic volume are considered as major causes for this problem in the State of Texas. It has to be noted that those abovementioned factors can cause the bump at the end of the bridge; however, not all the factors contribute to the formation of the bump concurrently.

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