Settlement Mitigation of a Distressed Embankment in Texas by Utilization of Lightweight EPS Geofoam Material

Pinit Ruttanaporamakul, Ph.D.
Box 19308, Department of Civil Engineering
The University of Texas at Arlington
Arlington, Texas 76019

Anand J. Puppala, Ph.D., P.E.
Distinguished Professor
Box 19308, Department of Civil Engineering
The University of Texas at Arlington
Arlington, Texas 76019

Aravind Pedarla, Ph.D.
Faculty Research Associate
Box 19308, Department of Civil Engineering
The University of Texas at Arlington
Arlington, Texas 76019

Tejo V. Bheemasetti, Ph.D.
Post-Doctoral Fellow
Department of Civil Engineering, Box 19308
The University of Texas at Arlington
Arlington, Texas 76019

Richard S. Willammee, Jr., M.S., P.E
District Materials Engineer
Fort Worth District
Texas Department of Transportation
P.O. Box 6 Fort Worth, TX 76115

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ABSTRACT

Approach slab settlement occurring at the start of a bridge super structure is one of the most common problems in many states across USA, resulting in rider discomfort and unsafe riding conditions. Federal and State transportation agencies continue to spend millions of dollars annually to repair the ‘bump’ problem. Major factors contributing to these settlements are the long term compressibility of backfill materials as well as the erosion of backfill material. This paper documents a distress occurred at the approach slabs on each end of the US 67 bridge over SH 174 in Johnson County, Cleburne, Texas. This approach slab had experienced more than 16 in. (406 mm) of settlement in 16 years since its initial construction. Current study highlighted the factors causing distress in the embankment and evaluated the remedial technique adopted at this site. Native fill material at the top of the embankment was replaced with lightweight expanded polystyrene (EPS) geofoam blocks. This technique considerably reduced the magnitude of overburden stresses transferred to the underlying layers as well as the erosion of embankment fill soil. This remediation also mitigated further settlements of the embankment fill and foundation soils. Field monitoring studies using inclinometers and pressure plates have been conducted at regular time intervals for a period of three years to study the long term performance of EPS geofoam under live traffic. The long-term settlements of the rehabilitated embankment were predicted by using the field measured data with the hyperbolic method. These studies were validated using measured field settlement data. Based on the current study, the effectiveness of adopting EPS geofoam as the embankment fill material near a bridge approach slab is evaluated.

Keywords: Bump at the end of the bridge, Embankment settlement, Bridge approach embankment, Expanded Polystyrene (EPS) geofoam
INTRODUCTION AND BACKGROUND

The existence of the differential settlement or ‘bump’ at the end of bridge, not only presents an unsafe driving condition but also results in agencies spending millions of dollars on maintenance costs annually. A survey carried out in Kentucky by Hopkins and Deen (1) revealed that 78% of several hundred highway bridge approaches required some maintenance activities to remedy the problem of the bump at the end of the bridge. Briaud et al. (2) reported that 30 percent of the bridges in Texas (i.e., 13,800 out of 46,000 bridges) encountered the problem of differential settlement at the bridge ends and at least USD 100 million was spent on annual maintenance cost for state departments of transportation (DOTs). Seo (3) presented that approximately USD 7 million was spent annually on the bump problem repairs in Texas. Recent studies show that many state DOTs have insufficient funds for the maintenance costs spent on bridge repairing activities (4). This trend clearly shows the strong need for effective and durable construction techniques for approach slab embankments near bridges.

Several studies were conducted to identify the possible cause of the ‘bump’ at the end of the bridge problem and also many studies focused on designing the most effective techniques for mitigating the ‘bump’ problem (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13). Researchers concluded that the primary factors of the settlement problems of the bridge approach pavements are void development from backfill collapse, backfill material consolidation, severe backfill erosion, poor soil compaction and construction practices, poor surface and subsurface water management.

Many techniques have been proposed to mitigate the differential approach slab settlement (3, 4, 8, 11, 13, 14, 15, 16, 17). Some of which are improvement of foundation soil, improvement of backfill material, design of bridge foundation, design of approach slab and provide effective drainage and erosion control methods (11, 13).

In the current research, the embankment for the bridge of a 40-ft. (12 m) high situated on US 67 over SH 174 in Johnson County, Texas, had experienced more than 16 in. (406 mm) of settlement in 16 years, since its construction.

From initial site analysis, it was found that the major factor contributing to the settlement is the consolidation of the foundation soil due to its self-weight. Apart from current ground improvement techniques, novel light weight fill materials such as expanded polystyrene (EPS) geofoam material was found to be optimal for the current rehabilitation project and were evaluated for performance in this research.

Expanded Polystyrene (EPS)

According to ASTM D 6817-07, EPS geofoam is defined as a block or planar rigid cellular foam polymeric material used in geotechnical engineering applications. The first use of this material was in 1972 for the construction of an embankment adjacent to a bridge founded on piles in Norway (18). However, the use of EPS geofoam for lightweight fill in the US dates back to the 1980’s (19). The method of improvement of embankment backfill using expanded polystyrene (EPS) geofoam material to mitigate the settlement problem has been well adopted worldwide (18, 19). Because of its lightweight property, using EPS geofoam as an embankment fill can reduce the loads on underlying soils and consequently, minimize the total settlement of the soils and differential settlement at the bridge ends (20). The density of the EPS geofoam varies from
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0.70 to 2.85 pcf (11.2 to 45.7 kg/m$^3$), which is approximately 100 times lighter than most soils and at least 20 to 30 times lighter than other lightweight fill alternatives (20).

Previous literature reported that EPS geofoam blocks can be effectively used in highway embankment construction (18, 21, 22). Frydenlund and Aaboe (18) evaluated the embankment construction for a temporary bridge, the Lokkeberg Bridge, in Norway, where site investigation indicated that the foundation soil with low bearing capacity. EPS geofoam blocks were considered for use as the fill material for the bridge approaching embankment. After being open to traffic for 12 years, deformation of 6 cm (2.4 in) was all that was observed in the EPS embankment, and most of the deformation occurred during the construction phase.

In a more recent application, EPS geofoam was adopted by the Utah Department of Transportation (UDOT) in reconstructing a 27.4 km (17.03 miles) portion of Interstate Highway 15 (I-15) in Salt Lake City, Utah (23). From past observations along I-15, settlements of up to 55 in. (1400 mm) were documented over a period of 30 years for embankment height ranging from 20 to 33 ft. (6 to 10 m) (24). The reconstruction involved the widening of the interstate embankment from 8 lanes to 12 lanes, where an extensive deposit of compressible lake bottom sediment exists. After successful construction, Bartlett et al. (2012) concluded that EPS geofoam successfully reduced the soil settlement to 0.98 in. (25-mm) over a 5-year period after the highway was open to traffic.

The objective of the current research is to evaluate the effectiveness of using lightweight EPS geofoam to mitigate the settlement of the bridge approach embankment at US 67 site, Texas and to predict the long term settlement behavior of EPS geofoam.

**BRIDGE REHABILITATION AT US 67**

US 67 bridge over SH 174 was constructed in 1995, using pre-stressed concrete beams and abutments were supported by drilled shaft foundations. Approach slabs were constructed on the embankments adjacent to the bridge ends. Clay soil with moderately high plastic index (PI) was used as the embankment backfill, retained by the concrete block walls, as presented in FIGURE 1.

![FIGURE 1: Schematic of the US 67 bridge over SH 174 in Johnson County, Texas](image)

16 years since the initial construction, the approach embankments on each end of the bridge had experienced more than 16 in. (406 mm) of settlements, as illustrated in FIGURE 2. Several treatment methods, including overlays, foam slab jacking, and compaction grouting were attempted and found not effective in mitigating the settlements. According to the field investigations conducted in 2000, it was found that the significant factors contributing to the
settlements experienced at this site include insufficient compaction of soils associated with abutment construction, erosion and settlement of the embankment fill soil underlying the approach slabs, and the movement of the concrete block retaining wall.

FIGURE 2: Settlement at US 67 bridge approach slab over 16 years since the initial construction (Courtesy of TxDOT, 26)

SITE CONDITIONS OF TEST SECTION

BASED ON THE DATA OBTAINED FROM FIELD INVESTIGATIONS, THE SUBSURFACE STRATIGRAPHY UNDERNEATH THE PAVEMENT SYSTEM CONSISTS OF THE EMBANKMENT WHICH COMPRISSES OF 30 FT. (9 M) OF CLAY FILL OVER 10 TO 20 FT. (3 TO 6 M) OF NATURAL CLAY SOILS EXTENDED TO A LAYER OF LIMESTONE. THE COMPRESSIBILITY PARAMETERS OF THE SOILS OBTAINED FROM THE TEST ARE PRESENTED IN

TABLE 1: Variation of Soil Parameters at US 67 bridge site over a period (2000 to 2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Embankment fill soil</td>
<td>Foundation soil</td>
</tr>
<tr>
<td>Natural moisture content, $\omega$</td>
<td>%</td>
<td>27.2</td>
</tr>
<tr>
<td>Dry unit weight, $\gamma_{dry}$</td>
<td>pcf</td>
<td>96.9</td>
</tr>
<tr>
<td>Liquid limit, LL</td>
<td>%</td>
<td>61</td>
</tr>
<tr>
<td>Plastic index, PI</td>
<td>%</td>
<td>40</td>
</tr>
<tr>
<td>Initial void ratio, $e_o$</td>
<td>-</td>
<td>0.739</td>
</tr>
<tr>
<td>Compression index, $C_c$</td>
<td>-</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Recompression index, $C_r$

<table>
<thead>
<tr>
<th></th>
<th>-</th>
<th>0.10</th>
<th>0.06</th>
<th>0.07</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overconsolidation ratio, OCR</td>
<td>-</td>
<td>1.00</td>
<td>10.29</td>
<td>10.10</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Consolidation test was performed on the representative embankment fill and foundation soil and test results showed that the natural foundation soils are overconsolidated (OCR = 10.29). During this time period, the void ratio decreased with an increase in the dry unit weight.

**DESIGN, CONSTRUCTION, AND INSTRUMENTATION OF EPS GEOFOAM EMBANKMENT TEST SECTION**

In 2012, the rehabilitation project on US 67 bridge over SH 174 was initiated by TxDOT to repair bridge beams, and renew 150 ft. (46 m) of approach slabs and pavement on each bridge. Approximately 35,000 ft$^3$ (990 m$^3$) of EPS 22 geofoam blocks were placed at the top 6-ft. (1.8-m) of the bridge approach embankments. The use of EPS geofoam was expected to reduce the settlements and erosion of the embankment fill and consequently reduce the approaching slab settlement and bump at the end of the bridge problems. Preliminary design for the EPS geofoam used in the US 67 bridge rehabilitation was conducted in accordance to NCHRP Report 529 (19). The wheel loads of a standard truck used in a bridge design, HS-20 (AASHTO, 2012), was considered in the design.

The approximate analysis of soil settlement showed that in order to reduce the settlement of the embankment to be less than 1 in. (25 mm), almost all of the existing backfill soil has to be replaced by EPS geofoam. However, excavating and replacing all embankment backfill soil is neither practical nor economical. From NCHRP report guideline and the preliminary design, the height of 6 ft. (1.8 m) of EPS geofoam was adopted. With this depth of EPS geofoam, about 2.5 in. (63.5 mm) settlement was estimated to be occurred on the embankments.

The rehabilitation work started in January 2012 and was completed at the end of February 2012. The pavement structure along with underlying 10 feet of embankment material was removed. The underdrain systems were installed at the bottom of the excavation. Following that, 2 to 6 in. (50 to 152 mm) of a sand-leveling layer was compacted on the underdrain systems and then, the 6-ft. (1.8-m) high stack of three layers of the EPS22 geofoam was installed on the compacted sand blanket, as illustrated in Error! Reference source not found.. To protect the EPS geofoam from water infiltration, a layer of impermeable geomembrane was used in encapsulating the installed geofoam blocks, as presented in FIGURE. Finally, about 2 ft. (0.6 m) height of the pavement structure, including lightweight aggregates, flex base, hot mix asphalt concrete (HMAC), and concrete pavement, was constructed on top of the embankment.
Utilization of EPS geofoam as the backfill material not only enhanced reduction in settlement but also decreased the overall cost of construction. This is due to the easy handling and reduced labor and installation costs of EPS geofoam blocks, without any necessity of having heavy compaction equipment (11). To evaluate the effectiveness of EPS geofoam material in mitigating the settlement problem of the embankment system, the test site was instrumented with horizontal inclinometer device for monitoring the vertical movement of the embankment. During the rehabilitation, the total four inclinometer casings of diameter 3.34 in. (8.5 cm) were placed on top of the EPS geofoam layer (i.e., about 2 ft. (0.6 m) below the pavement surface. The length of each casing is more than 22 ft. (6.7 m). The locations of the installed inclinometer casings are shown in Error! Reference source not found..
Settlement Behavior of the EPS Geofoam Embankment Test Section

The vertical movements at the top of EPS geofoam layer were monitored at every 2 ft. (0.6 m) intervals. Collected data is presented in the form of graphs plotted between the vertical displacements, recorded cumulatively from the initial reading at the time of casings installation (01/30/2012). Error! Reference source not found. to 8 present the data of the vertical movements measured from the horizontal inclinometer casings US 67_1 to US 67_4, respectively. Due to some damage caused during initial construction, casing US 67_2 had to be replaced. Data from Figure 6, US 67_2 were missing in the time range of November 2013 to May 2014. The variation of maximum vertical movements of the test embankment with time, measured at the middle of pavement, is presented in FIGURE . The plot includes two sets of the displacement data, which are the total vertical displacement and the post-construction vertical displacement. Post-construction vertical displacement can be determined by subtracting the settlement that occurred from initial 28 days of construction from the total vertical settlement that had occurred at that time. It can be observed from the plots that during almost three years after opening to traffic, less than 1.5 in. (38 mm) of post-construction settlement had occurred.
FIGURE 5: Vertical displacement data plot from horizontal inclinometer US 67_1

FIGURE 6: Vertical displacement data plot from horizontal inclinometer US 67_2
FIGURE 7: Vertical displacement data plot from horizontal inclinometer US 67_3

FIGURE 8: Vertical displacement data plot from horizontal inclinometer US 67_4
Prediction of long term settlements in the test embankment is attempted using the Lin and Wong (25) hyperbolic method. Based on the assumption that the rate of settlement is decreasing hyperbolically with time, the relationship between the settlement and time can be presented by the hyperbolic equation, as provided in following:

\[ \frac{t}{S} = \alpha + \beta(t) \]  

where \( t \) is time from the start of embankment fill (days); \( S \) is measured settlement as any specific time (mm); \( \beta \) is gradient of the straight line between \( t \) and \( \frac{t}{S} \); and \( \alpha \) is intersection of the straight line on the \( \frac{t}{S} \) axis.

By plotting the average of total vertical movement at the middle of pavement with a function of time-settlement ratio and using linear regression analysis, the values of parameters \( \beta \) and \( \alpha \) can be estimated, as presented in FIGURE 3.

The equation for estimating the settlements magnitude at a specific time \( (t) \) of the test embankment can be generated by substituting the parameters \( \beta \) and \( \alpha \) back into Eq. 1 and rewriting Eq. 2 and 3 as follows:

\[ S = \frac{t}{(\alpha + \beta t)} \]  

\[ S = \frac{t}{(7.5838 + 0.024 t)} \]

According to Eq. 3, the plot of the predicted vertical displacement which will occur in the test embankment at the specific time interval can be provided, as illustrated in FIGURE . Similarly, it is possible to predict the long term post-construction vertical displacement of the test embankment, as plotted in FIGURE 4. The field data and its best-fit curves are also plotted in the figures.
FIGURE 9: Variation of average vertical displacement of the test embankment versus time

FIGURE 3: Relationship between time-settlement ratio of the test embankment with time
It can be observed from the plots that the vertical displacement/settlement of the test embankment predicted by hyperbolic method is in good agreement with the best-fit curve of the measured field data from the horizontal inclinometer surveys. Based on the hyperbolic method, the total and post-construction vertical displacements which will occur on the test embankment at 10 years interval are predicted to be 1.5 in. (38 mm) and 1.3 in. (34 mm) respectively. This clearly shows that minimal settlement from the compression of EPS geofoam material over the 10 year period, where the majority is contributed from post construction settlement.
SUMMARY

From the monitoring studies conducted at US 67 embankment over the past three years and corresponding settlement prediction analysis conducted, it is recommended to adopt EPS geofoam material as an embankment fill where high compressible and collapsible subsoil exists. EPS material proved to be effective in mitigating the vertical stresses transferred to the foundation soil thereby reducing any further increase in settlement.

Settlement prediction analysis conducted is consistent with the monitored data obtained from horizontal inclinometer until the three year period. The maximum post-construction vertical displacement occurring at the center of pavement, atop the EPS geofoam layer of the rehabilitated US 67 bridge embankment was about 1.0 to 1.1 in. (25 to 28 mm).

Total settlement of 1.5 in. (38 mm) and post-construction settlement of 1.3 in. (34 mm) were predicted to occur on the test embankment after 10-year time period. These settlements are considered low, as they can cause only a slight bump at the bridge deck-approach slab interface, which does not affect the riding quality. In the current rehabilitation project only top 6 feet of the embankment section is replaced with EPS geofoam blocks. Studies are being conducted to evaluate the optimal placement of EPS geofoam blocks in the embankment section for effective performance.

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REFERENCES

Ruttanaporamakul et al.

16 project, Salt Lake City, Utah.” Report No. UT-1X.XX, Utah Department of
Transportation, UT.

Department of Transportation Research Division Report No. UT-03.17, UT.

Bridge Approaches.” Journal of Geotechnical and Geoenvironmental Engineering,

District Staff., Texas Department of Transportation, Fort Worth District.