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Deformation Analysis of Missouri Bridge Approach Embankments

Jonathan L. Robison¹ and Ronaldo Luna²

Abstract

Missouri has recently experienced below expectation performance or “the bump-at-the-end of the bridge” phenomena at bridge approach slab transitions. Information on approach slab performance was collected state wide to assess if the problem was limited to regional or geological distribution. Finite element analysis was then used to explore the soil embankment-bridge structure differential settlement in two Missouri bridges; MoDOT Bridge A6031 in Livingston County, and MoDOT Bridge A5834 in Pulaski County. These two cases are indicative of the types of soil conditions encountered in the Northern Glaciated Plains region (deeper compressible foundation soils) and the Southern Ozarks region (shallow rocky clays) of Missouri. The construction sequence was tied to the analysis by applying the embankment and slab loading following the construction records. The finite element method results compared well with observed displacements. Recommendations for construction sequence are provided.

Introduction

The problem often referred to as the “bump at the end of the bridge,” is well known in the highway engineering community. This discontinuity in grade caused by differential settlement is sometimes dramatic. It can result in driver distraction and discomfort, and it can impair safety as well as cause automobile damage. Nationwide this problem is estimated to affect 25% of all bridges (approximately 150,000 bridges) resulting in expenditures of at least \$100 million per year (Briaud, et al., 1997) and Missouri is certainly not immune to this problem. In a recent survey of statewide geotechnical problems, Missouri Department of Transportation (MoDOT) geologists and engineers ranked the settlement of bridge approaches second only to slope instability in order of importance (Bowders, et al., 2002).

This paper is a product of MoDOT sponsored research at the University of Missouri-Rolla. It examines the problem of bridge approach settlement within the context of two different geological zones of Missouri and with the application of the computer finite element program PLAXIS® Brinkgrave (2002). The finite element method was chosen to model the construction phases and subsequent compression and consolidation of both the new embankment and the underlying foundation soils at two sites, one in Northern Missouri and one in Southern Missouri. Field settlement data was compared with the predictions of the finite element method to establish the accuracy of the chosen computational method.

In order to appreciate the causes of the deformations next to the abutments at bridge ends, an introduction to the approach is warranted. In 1993, MoDOT adopted the use of a concrete bridge approach slab as shown in Figure 1. The end abutment of the bridge is supported on a deep foundation driven to rock or a firm bearing strata. So, on one end the BAS is supported on the abutment and on the other end it rests on sleeper beam at grade. This design results in one structural

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member being supported by two very different foundation systems. The sleeper slab may be on firm ground, a cut or a rock bluff, but often they are supported on an embankment fill.

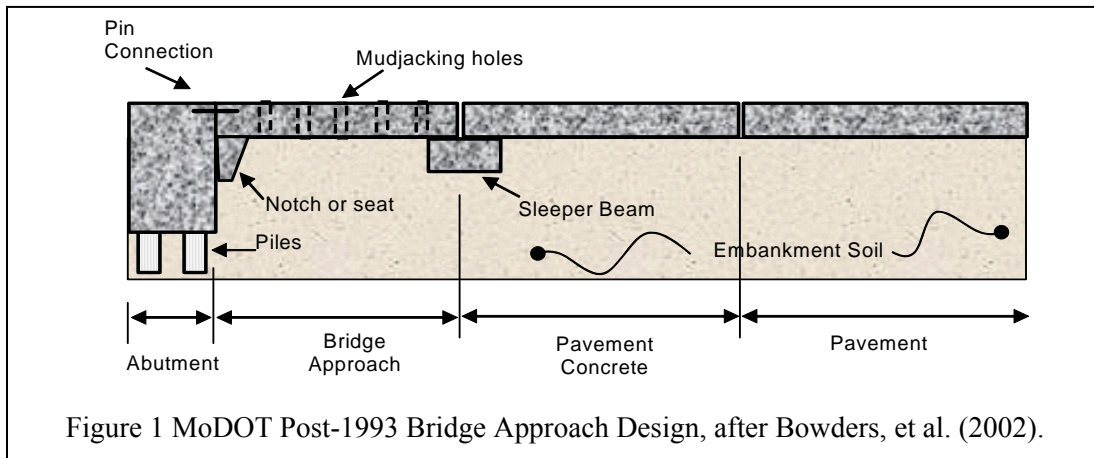


Figure 1 MoDOT Post-1993 Bridge Approach Design, after Bowders, et al. (2002).

This research project studied correlations between geographical location and geological condition in Missouri and the severity of the bridge approach settlement problem. A group of MoDOT Resident Engineers, dispersed in 43 offices throughout the state, were contacted to respond to a simple survey regarding their experiences with post-construction performance of the bridge approach components. Fourteen of the 43 RE offices responded to the survey resulting in a response rate of 33%. Data from 185 bridges was collected and returned by the RE offices. The statewide breakdown of responses is as follows. No detectable movement of the bridge approach: 68 %. Some minor movement that has not required corrective action: 17%. Enough movement of the approach that repair work has been done or is required: 15%. Overall, Missouri soils present a large variety of challenges over a number of geological and geographical ranges, all of which have experienced problems with bridge approach settlement.

Case Study Approach

Two MoDOT bridges (one approach each) were selected for detailed numerical deformation analysis based upon observed settlement of their respective approach slabs. The finite element modeling program PLAXIS® was selected to evaluate settlement with respect to time while taking into account the various stages of the construction sequence. The locations of the two bridges are shown in Figure 2. These bridges were built after 1993 using the current MoDOT sleeper slab, bridge approach slab, and approach pavement design (Figure 1).

The Northern site, Bridge A6031 (Livingston County US 36 over the Grand River), was chosen because it typifies soil conditions likely to be encountered in the Northern Missouri Glaciated Plains region. The Glaciated Plains region of Missouri is characterized by glacial deposits of till with clays, silts, sands, gravels and boulders heterogeneously scattered throughout. The embankment of Br. A6031 is composed of silty clay and rests atop alternating layers of clay and sand of moderate depth (approximately 24 meters).

The Southern site, Bridge A5834 (Pulaski County Route 133 over Bear Creek), was chosen because it typifies soil conditions in the Missouri Ozarks region. The Ozarks region is characterized by rough, karst topography, cherty, residual soils, solution activity, red, gray, and brown clays, with occasional very problematic clays (liquid limits >100). The embankment fill of Br. A5834 is composed of rocky clay and rests on a shallow clay foundation soil.

Initial soil reports and plan balance areas made for the original design and construction process were reviewed, so the basic composition of both fills was known. These fills were both constructed of CL material (inorganic clays of low to medium plasticity). The Naval Facilities Engineering Command Design Manual 7.01 (NAVFAC, 1986) and Kulhawy and Mayne (1990) give the following average strength and modulus parameters for a typical engineered CL fill. Young's Modulus (E) = 1.03×10^4 kPa, Poisson's Ratio (ν) = 0.35, Cohesion (c) = 86 kPa, Angle of Internal Friction (ϕ) = 28° , and Permeability (k) = 10×10^{-9} m/s (4.4×10^{-4} m/day).

In addition to the soil models, the properties of the structural elements supported by the soil were determined. The beam in Figure 1 was used to approximate the bridge approach sleeper beam for the embankments modeled in the deformation analysis.

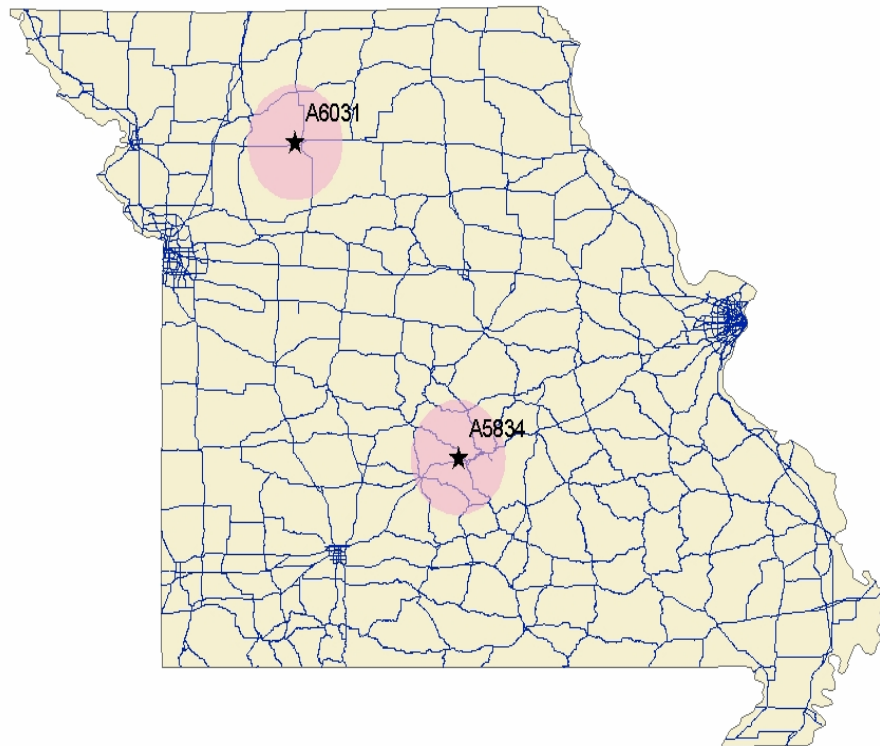


Figure 2- Case Study Locations.

PLAXIS® requires the input of an axial stiffness (EA) and a flexural rigidity (EI) for a plate loading. The beam input parameters are $EI = 2.6 \times 10^5$ kNm²/m, and $EA = 1.2 \times 10^7$ kN. Once these structural properties are determined, the loading of the plate was estimated. H-20 truck loading (40 kip) was used since it fits entirely on the approach slab, AASHTO (1996). It was assumed that the soil settled out from beneath the approach slab and so the slab is forced to span a void from the abutment to the sleeper beam (commonly observed if embankment built rapidly). The ultimate loading or increase in stress applied to the approach embankment is a combination of one half of the approach slab, the self-weight of the sleeper beam, and the traffic loading. This was estimated to be 56 kPa. The ultimate load discussed above was used for initial analysis runs to determine the stability of the approach embankment. With no stability problems noted, a long-term consolidation loading was needed that would not include the transient truck loading. For this long term consolidation

loading a distributed pressure of 25 kPa was calculated to represent the sleeper beam weight and one half of the approach slab weight.

MoDOT Bridge A6031, Livingston County US 36

Construction work on job J2P0476C in Livingston County began in August of 2000 and ended in November of 2002. The project included the construction of bridges and embankments to widen 8.9 kilometers of the existing two-lane US 36 to four lanes with paving to be completed under a different contract in the summer of 2003. The twin bridges A6031 and A6032 were built to span the Grand River flood plain. Both bridges are approximately 550 meters long and rely on a combination of driven H-pile and drilled pier foundations with their end abutments both founded on H-piling.

The East abutment (bent 24) approach of Bridge A6031 has experienced the worst settlement (almost 2-inches) of the four approaches and will be emphasized for this case study. Figure 3 is an excerpt of the design drawings of the East abutment.

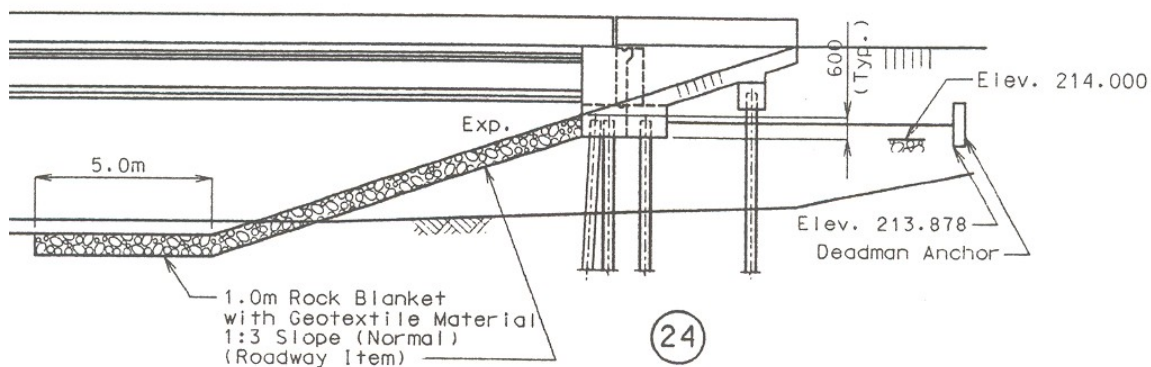


Figure 3 - Br. A6031 East Abutment Side View Design (MODOT, 2000)

The East abutment embankment fill was built consisting of approximately five meters of local soils from November 30 to December 12, 2000. The sleeper beam and slab were not built until the following year, being constructed between in the beginning of September 2001. This allowed for an interlude of 9 months for compression to occur before the placement of the roadway.

The soil conditions for this site are typical of the Northern Missouri glaciated plains region. The topography is gently rolling upland dissected by the broad, nearly level flood plain of the Grand River. Soil exploration of the site revealed the presence of till, loess, and residual soils consisting primarily of stiff to very stiff lean to fat clays. The foundation soils beneath the east abutment of Bridge A6031 consist of a combination of clay, silt, and sand layers.

Based on construction records, four stages were used for the deformation analysis: (1) construction of the embankment (10 days), (2) waiting period of 270 days, (3) construction of the bearing beam and approach slab (15 days), and (4) consolidation for many years to come. This allows the engineer to apply judgment to the calculated values for each construction stage.

Numerous computer runs were made using the program PLAXIS® varying Young’s modulus (E), undrained shear strength (S_u or c), angle of internal friction (ϕ), and drainage condition. The results presented herein are designated as “low bound” (LB) and “high bound” (HB). The high and low bound refer to the relative values of the strength and compressibility parameters. The clay layers were modeled as undrained and the sand layers were modeled as drained for all runs. As anticipated, the majority of the deformation occurred during the initial embankment construction. Figure 4 shows the displacement along the center of the sleeper beam at the center of the embankment.

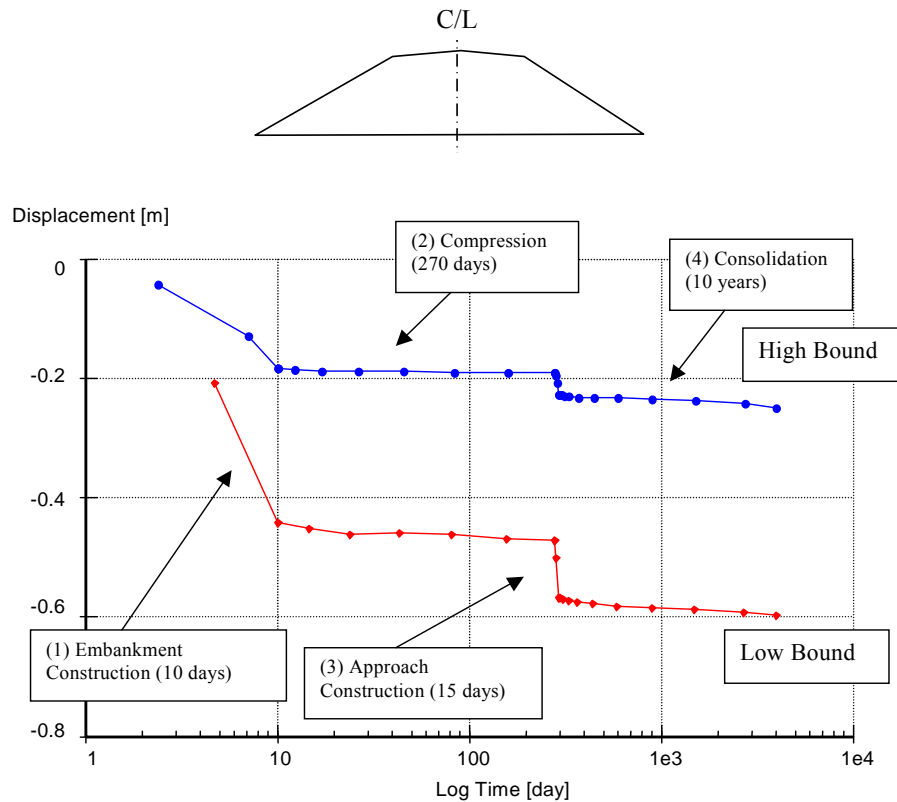


Figure 4- High and Low Bound Displacement Curves East Abutment Embankment Br. A6031

The observed displacements generally noted by highway construction and maintenance personnel are differential settlements between the pile supported abutment and embankment supported approach. These deformations occur following the construction of the approach slab. These settlements are structurally important deflections and are designated as δ from the time that the slab was built to when it stopped settling. The concept of structurally important deflections is emphasized in Figure 5 and shown as the calculated low bound curve.

The time at which the approach slab is complete or, in other words, the moment when final roadway grade is built, is estimated to be half way in the construction period or approximately 7 days through the approach slab construction stage, based on the available construction records. Delta (δ) then is equal to one half of the approach construction settlements and the long-term consolidation settlement. This yields a structurally important deflection on the order of 0.07 meters for the low bound condition. Field survey observations taken at the joint between the bridge approach slab and

the pavement concrete just above the sleeper beam indicate that after 2 years this deflection (δ) is equal to two inches or 0.05 meters relative to the bridge abutment.

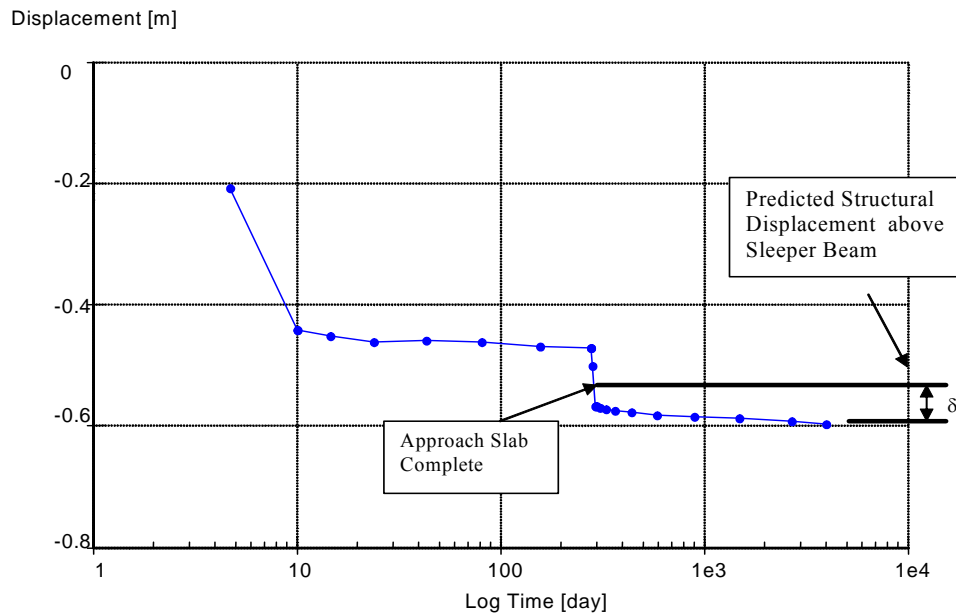


Figure 5- A6031 Low Bound Vertical Deflection Curve Showing “Structurally Important Deflection”

MoDOT Bridge A5834, Pulaski County Route 133

In 1999, Rte. 133 in Pulaski County was realigned to bypass an older, substandard bridge over the Gasconade River. Bridge A5834 was built in conjunction with this project over the Bear Creek just north of the Gasconade River. The bridge spans a typical Ozarks scene; from a rock cut in a bluff on the south end to a gently rolling creek bottom with a fairly substantial fill (approximately 12 meters) on the north end. The north end of the bridge will be the focus of this discussion although some problems did exist on the south end. The abutment design is typical of a MoDOT Ozarks bridge. The pile cap is supported by H-piling driven through new embankment and existing soils to refusal on solid rock.

Very soon after completion of this project, settlement of the approach was noted. When a site inspection was made in May of 2001, maximum settlements of approximately 0.24m were recorded beneath the pile cap (see insert in Figure 7). The differential settlement between the approach slab in the area of the sleeper slab (δ) was found to be approximately 0.03m.

Based on construction records, four input stages are considered for the finite element run: (1) construction of lower 10m of embankment (30 days), (2) waiting period of 6 months, (3) addition of last 2m of embankment and approach slab (15 days), and (4) consolidation for 10 years. The result from the PLAXIS® run is a predicted displacement of a little less than 0.2 meters (see Figure 6).

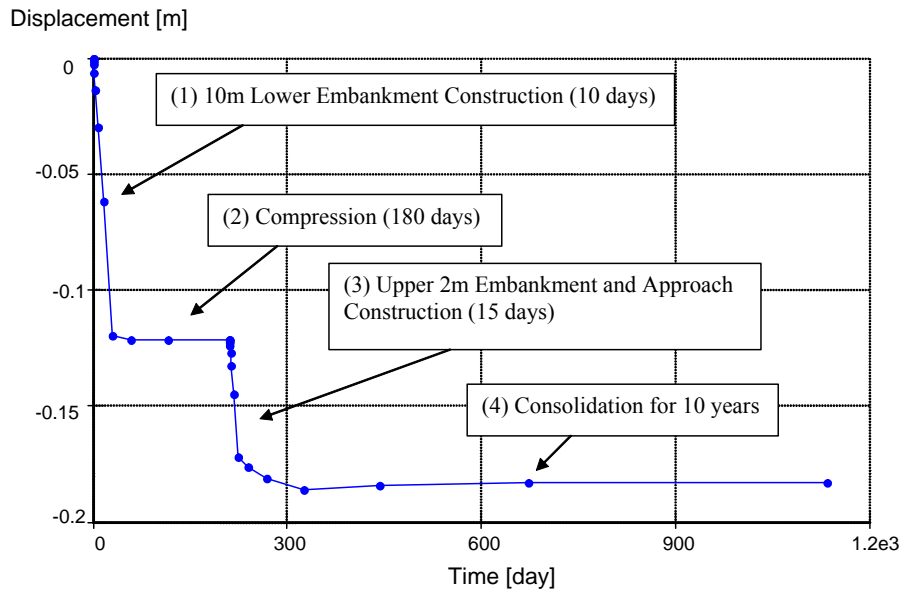


Figure 6- Vertical Displacement with Time for Br. A5834 North Abutment.

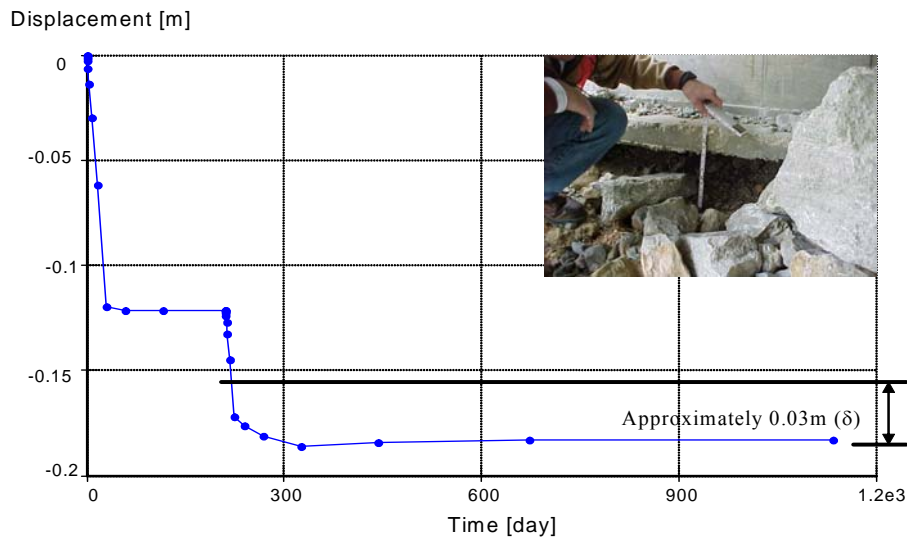


Figure 7- Vertical Displacement with Time for Br. A5834 North Abutment Embankment, showing δ . Insert photograph of observed gap below the abutment.

Conclusions

Two case histories were presented for different geomorphologies in Missouri. The conventional methods used for exploration and characterization of these sites were not mentioned in this paper, however they consisted of conventional SPT and undisturbed tube sampling. Laboratory tests were limited to strength parameters from UCT and direct shear tests. Using available correlations the deformation parameters were obtained and estimated as low and high bound. Even

though the characterization techniques were not sophisticated, the improvement in the deformation analysis approach using staged construction and finite element method allowed for acceptable results. The computational method was tied to the actual construction stages based on the construction records and the deflections modeled for the bridge approach slabs were found to be in general accordance to the observed measurements with time. This has implications for the design phase, as future construction operation timetables may be estimated and settlements computed. Operations may then be staged in such a way as to minimize loss of support to structural elements through embankment settlement, with the ultimate goal of reducing the “bump at the end of the bridge”.

Currently, these sites are being characterized using the seismic cone penetrometer to see how the characterization of the low-strain properties of the embankment and foundation soils will affect the analysis. Additionally, recommendations on the design and alternative construction methods on the embankment below the bridge approach slab are being prepared for the state of Missouri DOT. The recommendations range from well-compacted fills with the appropriate staged construction sequence to fills placed with geotextiles to improve drainage and assure compaction.

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