TRC9705

Settlement of Bridge End Embankments

Prepared by the
Research Section
of the
Arkansas Highway and Transporation Department

Final Report

2011

SETTLEMENT OF BRIDGE END EMBANKMENTS

FINAL REPORT

TRC-9705 SETTLEMENT OF BRIDGE END EMBANKMENTS

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

PLANNING AND RESEARCH DIVISION

SEPTEMBER 2011

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FINAL REPORT

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
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TITLE: TRC-9705 SETTLEMENT OF BRIDGE END EMBANKMENTS

1. Problem Statement:

Settlement of ACHM/Base Course/Subgrade immediately adjacent to bridge ends or bridge approach slabs causes necessary maintenance repairs after opening the roadway to traffic. Settlement of roadway pavement surfaces in the vicinity of highway bridge abutments often leads to abrupt grade differences at the abutments. These grade differences subject traveling vehicles to a “bump” which leads to driver discomfort and potentially unsafe driving conditions, causes vehicle wear and damages sensitive cargo, subjects the bridge structure to repeated impact loads, and requires costly and repeated maintenance work that usually impedes the flow of traffic.

To eliminate the bump at the end of the bridge, other agencies often install an approach slab with one end supported on the bridge and the other on a support beam at some distance from the end of the bridge. Approach slabs are often, but not always, effective in improving vehicle ride characteristics at bridge approaches subject to settlement. A review of previous research indicated numerous potential causes of bridge approach distress, indicating that bridge approach settlement is largely a site specific problem.

2. Background and Literature Review:

Considerable research has been done to devise ways to eliminate the "bump at the end of the bridge". Many of these studies consisted of comparisons between different structural systems, such as structural approach slabs versus flexible approach pavements, without regard to the underlying causes. Several of the studies, however, included case histories with long-term measurement of approach settlement and detailed investigation of the contributing factors. Performance studies of various methods intended to eliminate approach settlement have also been conducted or are currently underway. Some of the original literature reviewed when this project was started is as follows.

Based on the results of the field studies, 1975, Nebraska recommended conducting foundation investigations for approach embankments greater than 20 feet high and implementing measures to control post-construction settlement. The recommended measures included partial excavation of unsuitable foundation soils and greater use of surcharges.[1]

The Wisconsin study, 1983, concluded that most reinforced approach slabs provide good performance through at least 8 years, while a large percentage of non-reinforced slabs were in poor condition within 2 years after construction. The performance of flexible approach pavements were considered to be quite poor.[2]

In 1961, based on the Ohio survey, design policies were revised to require that abutments be supported on piles that extend through the approach fill. Construction specifications were also revised to require a greater degree of compaction of the approach fill. In 1975, a second survey was conducted to evaluate the revised design and construction policies. The overriding consideration in preventing damage to the structure necessitates the use of pile-supported abutments, even though this aggravates differential settlements of the bridge approach.[3]

Based on Kentucky's investigation in 1968, the following conclusion were made: consolidation of the approach embankment foundations can contribute significantly to overall approach settlement if adequate delay is not provided between embankment construction and paving, improper compaction of approach embankments may lead to settlement of the approach pavement, lateral movements due to shear may lead to approach settlement when the factor of safety of the slope is low, erosion of materials from behind and around the abutment can contribute to the settlement of the pavement, and reinforced concrete slabs do not eliminate the differential settlement between the approach pavement and the bridge deck, but they can provide a smoother transition.[4,5,6,7]

The 1985 Kentucky survey found that most of the states using reinforced concrete approaches feel that they are successful. Many of the states have special requirements for backfill behind abutments.[8,9]

Caltrans has implemented the new approach slab concept to require select backfill for 150 feet from the structure. The slab itself is 30 feet long and 14 inches thick, reinforced with top and bottom steel, and is attached to the abutment. A fabric is provided between the slab and a 6-inch-thick treated permeable base. The sides of the reinforced slab cantilever over the wing walls and support a bridge railing. The pavement end of the slab rests on a sleeper beam, integrally cast with a 15-foot-long pavement section. This research would continue through 1993.[12,13]

Wyoming research, 1983, extensively instrumented test bridges to evaluate different methods. Geosynthetic Reinforced System (GRS) walls can be effective at reducing the lateral pressure on abutments; this method does not completely eliminate settlement of the approach.

Maryland's study, 1987, concluded that settlement is caused primarily by subsidence of the original ground below the fill, settlement within the fill, lateral movement of the abutment, and poor design of structural components.[15]

Oklahoma's study, 1986, identified major causative factors were the embankment foundation and the type of material and method of compaction of the approach embankment. The causes of approach settlement cannot be generalized for all sites or for all states in the country.[10]

3. Project Plan:

From these researched solutions to the "bump at the end of the bridge", flowable fill was selected to be tested on approach embankments to four bridges in Arkansas. All four of these two-lane bridges were new construction. At each of the bridges, one bridge embankment was selected to be constructed with flowable fill while the other embankment was constructed using standard construction techniques and materials. Location information for the bridges studied can be seen in Table 1 below and in Figure 1.

Bridge	Bridge #	County	Route	Section	Logmile	Year Built
DeRoche Bayou Bridge near Bismarck	6717	Hot Spring	84	6	2.01	1999
Raymar Rd. overpass on I-30	6711	Saline	30	22	124.4 (I-30)	1999
Chicot Rd. overpass on I-30	6710	Pulaski	30	23	131.8 (I-30)	1999
Crow Creek Bridge near Forrest City	6755	St. Francis	284	3	7.43	2000

Table 1. Location for bridges studied.

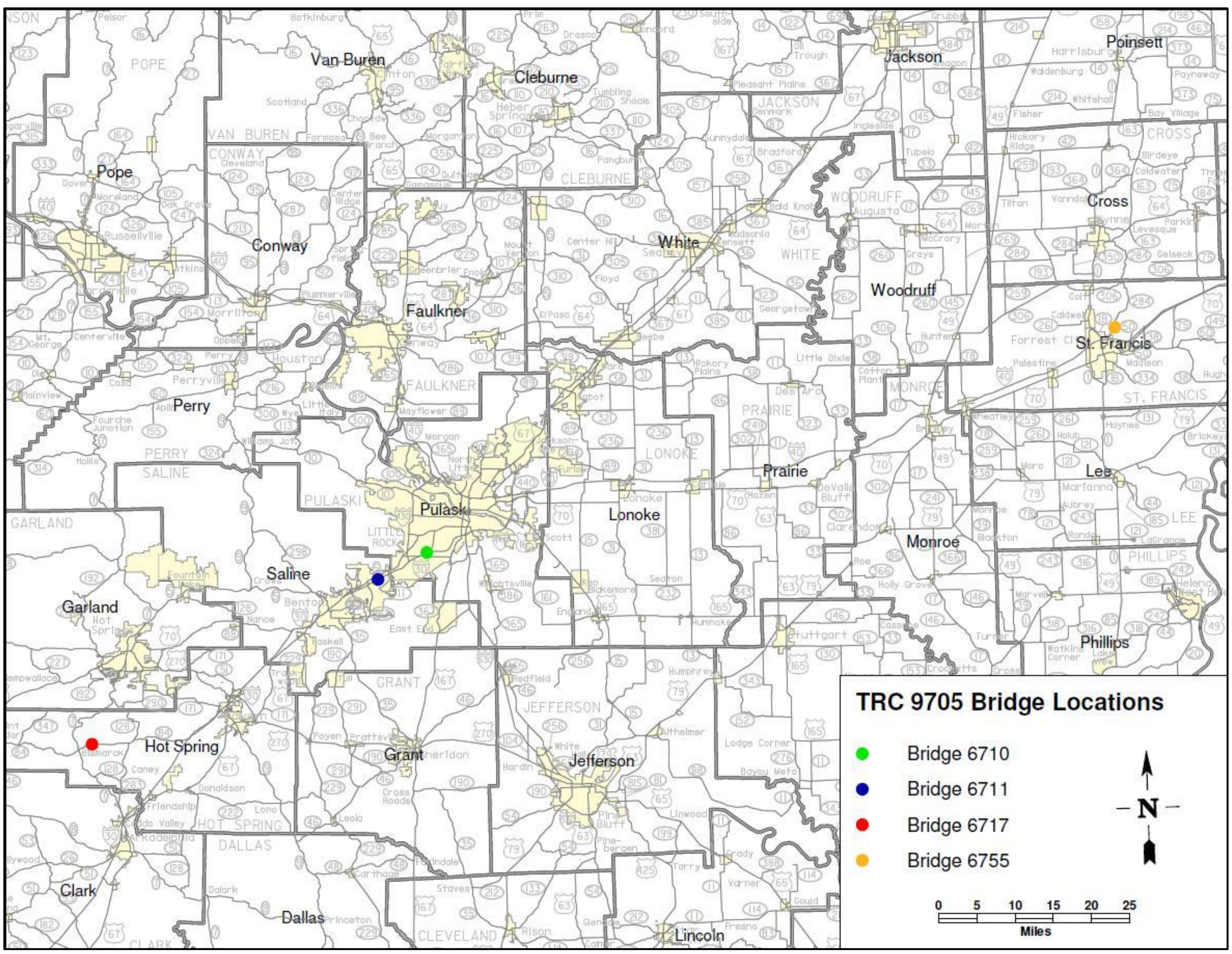


Figure 1. Locations of bridges studied.

4. Objectives:

The original objectives for this project were as follows:

1. Identify recommended “solution” from the background research materials and other alternatives.
2. Incorporate recommended “solutions” such as those listed below in selected new construction jobs.
    a. Use of geotextile blanket wraps
    b. Use of low plasticity specified material
    c. Use of flowable fill
    d. Increased compactive effort
    e. Surcharge
    f. Use of perforated pipes or prefabricated drainage systems on abutment walls
    g. Approach slabs with flexible pavement
3. Monitor and evaluate selected jobs in terms of settlements, traffic, and subsurface and embankment characteristics.

However, it was later determined that this project would be better served to just try and evaluate one of the many suggested causes for the “bump at the end of the bridge”. Flowable fill was selected to be the tested solution.

Flowable fill is a low-strength mixing concrete used as a backfill behind the abutment wall to reduce the possibility of approach settlements near the surface, resulting from the compression of the backfill itself. The low-strength mixing concrete works well to prevent erosion of the backfill and to improve constructability/compactability of the fill behind the walls and around corners. The self-leveling ability property allows the flowable fill material to fill voids without the need of any compaction.[11]

5. Description of Work:

Settlement plates were installed in the abutment excavations for all four bridges included in this project. These excavations were then backfilled with either compacted fill or flowable fill. The settlement plates were either constructed of steel or PVC plastic. The plates and risers were constructed out of steel at the DeRoche Bayou Bridge and the Raymar Road Bridge. For these two bridges the base measured 2.0’x2.0’x0.25” and the riser was a Schedule 40 5.0’x3” I.D. pipe. The plates and risers for the Chicot Road Bridge and the Crow Creek Bridge were constructed out of PVC. For these, the base measured 2.0’x2.0’x0.5” and the riser was a Schedule 40 5.0’x3” I.D. pipe. The dimensions for the settlement plates and risers can be seen in Figure 2 along with a photograph of a steel settlement plate setup. Once the fill was completed, either flowable or compacted earth, the risers were cut off near the fill surface.

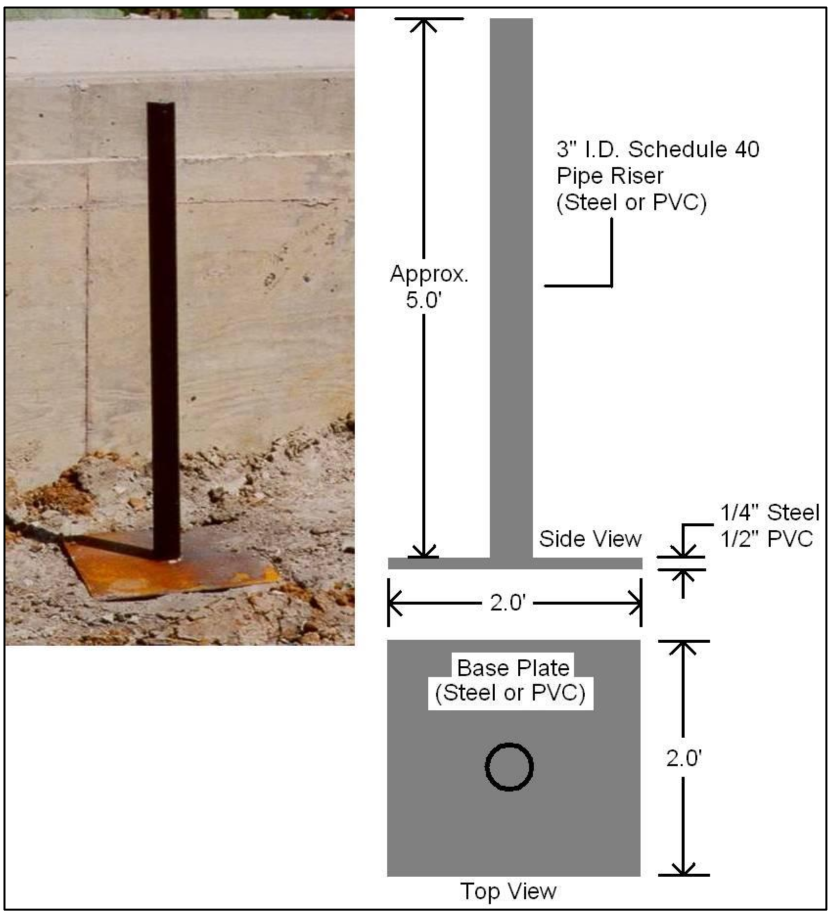


Figure 2. Settlement plate dimensions.

Once the final road surface was in place, AHTD personnel went back and installed access tubes by coring through the pavement. The access tubes consisted of 18” long piece of 5” diameter Schedule 40 PVC pipe. Around the insides of the tubes, stops were placed in order to keep the cap from being pushed further down into the tube by traffic or other loads. The caps were made by Research personnel and consist of a polypropylene body with two O-ring seals. Long pieces of polypropylene were milled down to the inner diameter of the 5”PVC pipes and then cut into 2” thick segments. Two grooves were then milled into the body of the cap for the O-rings. Finally, a threaded cap was installed into the caps to be used for extracting the caps from the access tubes. A diagram of the access tube can be seen in Figure 3 and an uninstalled cap can be seen in Figure 4.

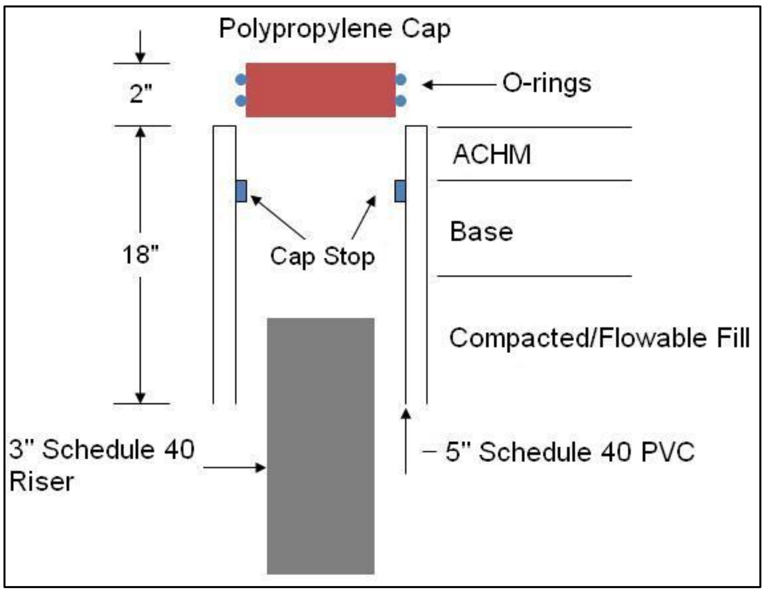


Figure 3. Access tube components.

Figure 4. Access tube cap.

Along with the settlement plates, horizontal inclinometers were installed in the abutment excavations on the Chicot Road Bridge and the Crow Creek Bridge. An inclinometer and data acquisition system was built in-house for this project and can be seen in Figure 5. The inclinometers were used in these two bridges for several reasons. The inclinometer setup allowed for data acquisition by one person and did not require traffic control for taking settlement measurements. These were also non-destructive to the pavement surface.

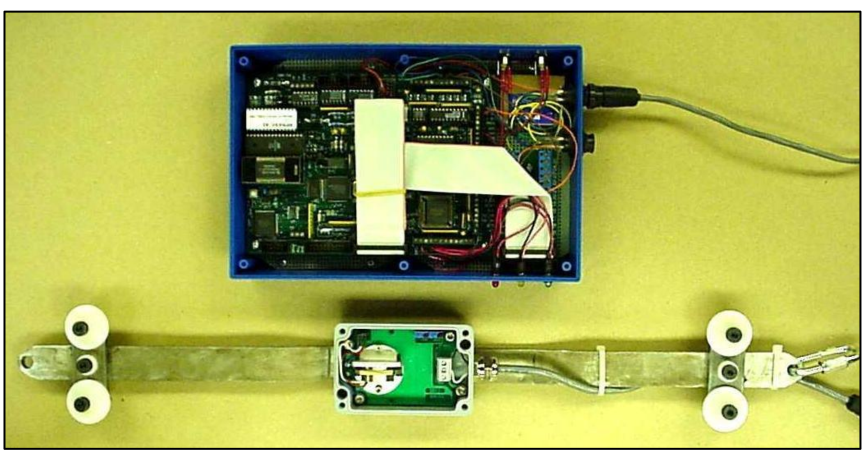


Figure 5. Horizontal inclinometer setup, data logger (upper) and inclinometer sensor (lower).

5.1 DeRoche Bayou – Bridge #6717

The DeRoche Bayou Bridge was constructed during May-June 1999 as part of Job 060455. The bridge runs in an east-west direction. The east embankment was the control embankment and was constructed with the standard compacted fill. The west embankment was the test embankment and was constructed using flowable fill. The settlement plate general locations can be seen in Figure 6.

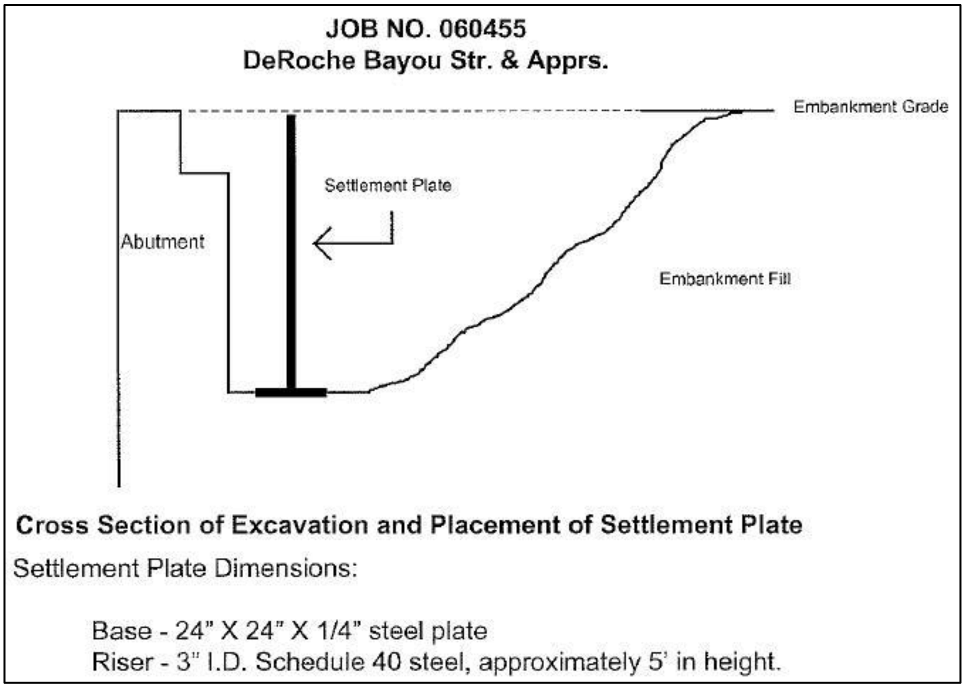


Figure 6. DeRoche Bayou general settlement plate locations.

The exact locations of the settlement plate risers were recorded so that they could be located after the road surface was placed. This bridge was chosen to be the low embankment height bridge for the study, with an embankment height of approximately 10-foot. The settlement plates were set and leveled on sand and then staked into place with rebar, as seen in Figure 7. The trench made for the flowable fill end of the bridge was approximately 3-foot wide and 4-foot deep running the entire width of the bridge. Approximately 22 cubic yards of flowable fill was used at this bridge end. Figure 8 shows the concrete flowing into the embankment. At the other end of the bridge, the compacted earth fill was dug out to install the settlement plates then re-compacted after the settlement plates and risers were in place, as shown in Figure 9.

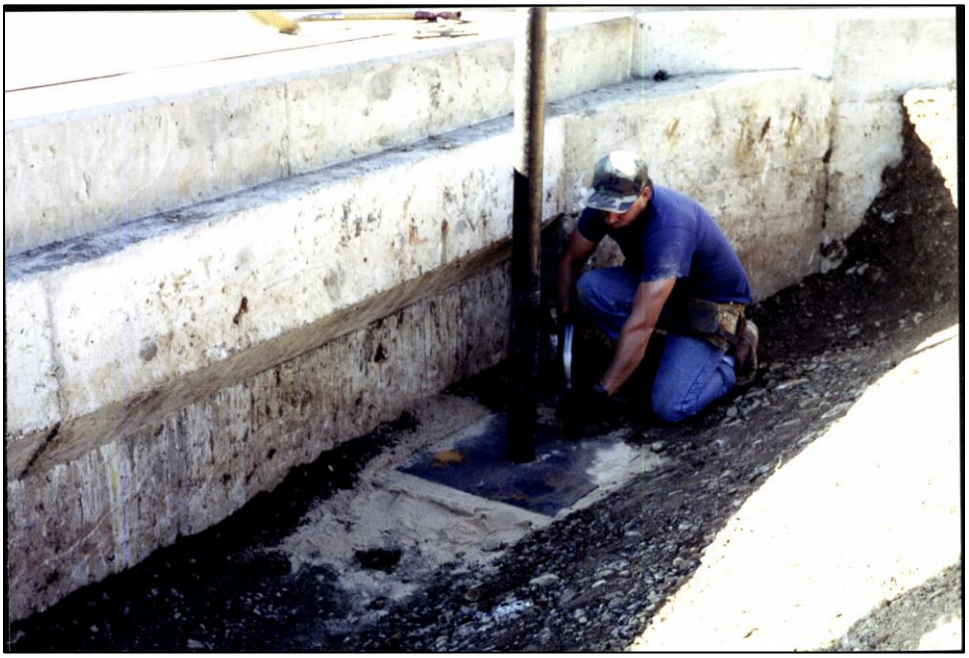


Figure 7. The settlement plates were bedded on sand and staked with rebar.

Figure 8. Flowable fill filling the embankment trench at the west embankment of the DeRoche Bayou Bridge.

Figure 9. Compacted fill at east emabankment of the DeRoche Bayou Bridge.

To keep the concrete and compacted earth from sticking to the steel and allowing a smooth rise and/or fall with settlement, the risers were well-greased before the compacted fill was placed and before the flowable fill was poured. The copious amounts of grease can be seen in Figure 10.

Figure 10. The grease used to keep the steel risers from sticking to the surrounding medium can be seen.

5.2 Raymar Road – Bridge #6711

The Raymar Road Bridge over Interstate 30 was constructed in April-May 1999 as part of Job 060688. The bridge runs in a north-south direction. The south embankment was the control embankment and was constructed with the standard compacted fill. The north embankment was the test embankment and was constructed using flowable fill. The general locations for the settlement plates can be seen in Figure 11.

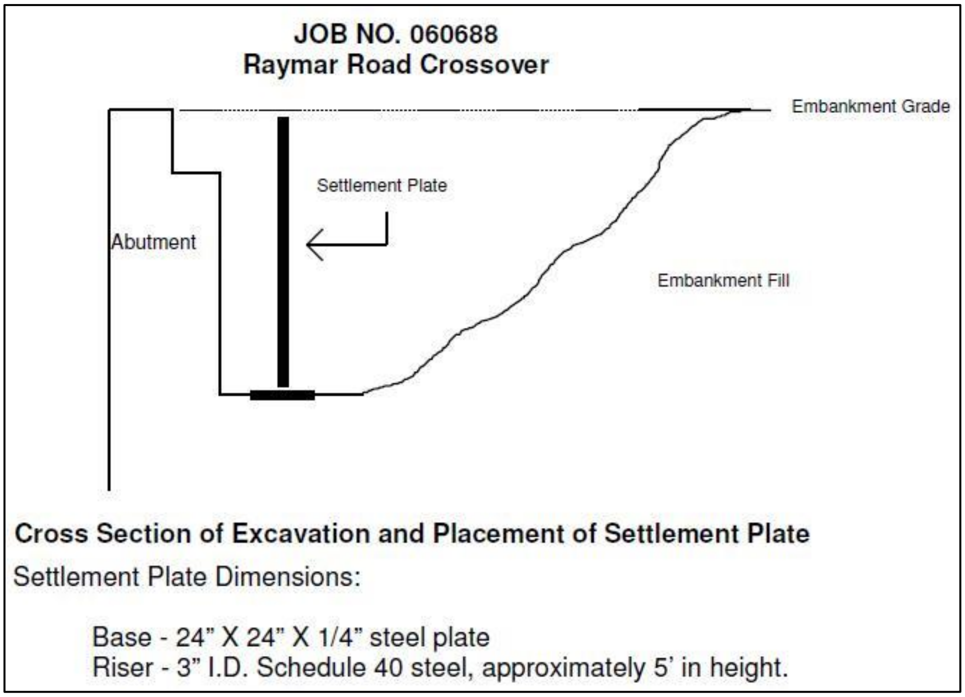


Figure 11. Raymar Road general settlement plate locations.

As with the DeRoche Bayou Bridge, the exact locations of the settlement plate risers were recorded so that they could be located after the road surface was placed. This bridge was chosen to be the medium embankment height bridge for the study, with an embankment height of approximately 22-foot. The compacted earth embankment was constructed first following the same method used in the DeRoche Bayou Bridge. Equipment can be seen compacting the earth around the settlement plate and riser in Figure 12.

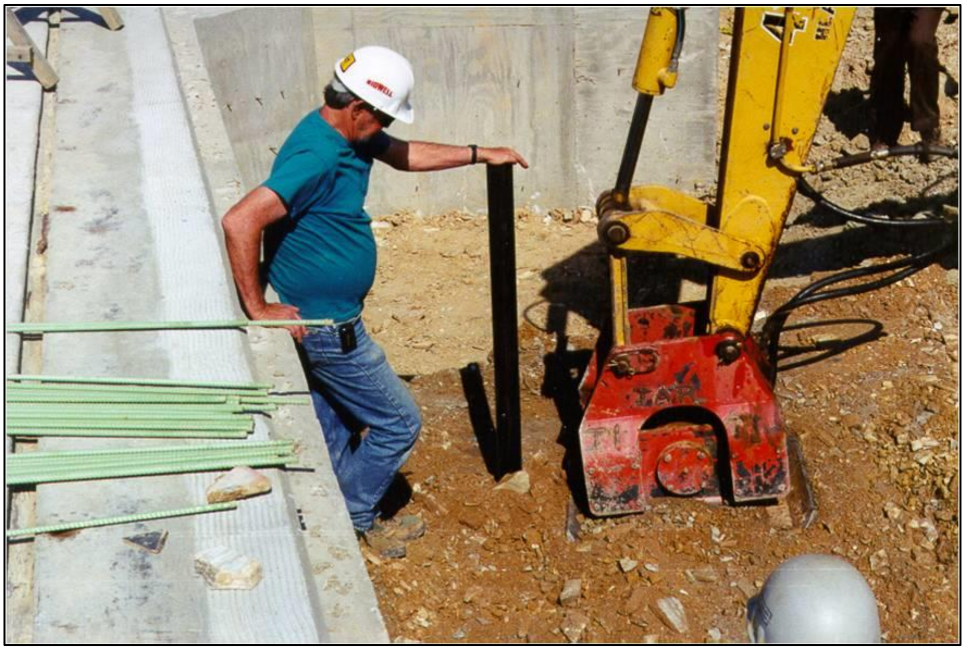


Figure 12. Compacting the earth around a steel riser at Raymar Road.

Unlike the DeRoche Bayou site, the flowable fill on the north embankment of this bridge required forms. The trench on this embankment for the flowable fill appeared to be 6-foot deep by approximately 3-foot wide running the width of the bridge. The in-place forms and the placement of the settlement plate risers can be seen in Figure 13, also showing the flowable fill being added. This bridge end required approximately 45 cubic yards of flowable fill concrete. Figure 14 shows the flowable fill concrete after it had started to cure. The risers at this bridge location were greased as well.

Figure 13. Flowable fill being added to the north embankment of the Raymar Road Bridge.

Figure 14. The flowable fill after it had started to cure.

5.3 Chicot Road – Bridge #6710

The Chicot Road Bridge over Interstate 30 was constructed in 1999 as part of Job 060851. The bridge runs in a north-south direction. The south embankment was the control embankment and was constructed with the standard compacted fill. The north embankment was the test embankment and was constructed using flowable fill. The settlement plate and horizontal inclinometer general locations can be seen in Figure 15.

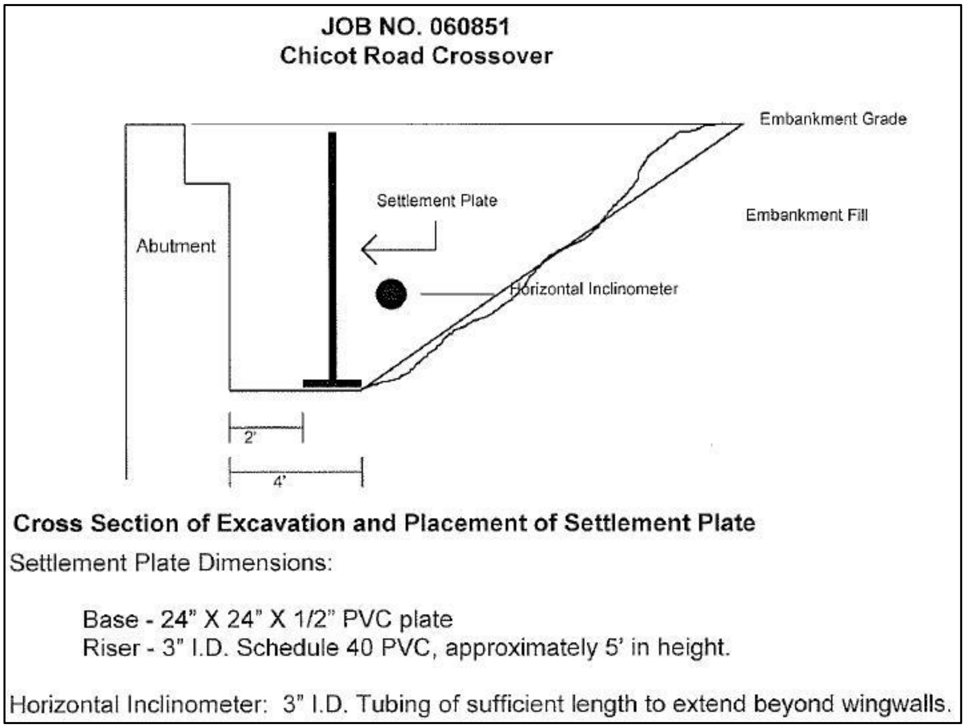


Figure 15. Chicot Road general settlement plates and horizontal inclinometer locations.

The exact locations of the settlement plate risers were again located so that they could be found after the road surface was placed. The Chicot Road Bridge has an approach embankment height of approximately 4-foot. The settlement plates and risers for this bridge were changed to PVC from steel as it was believed that PVC would perform adequately under the assumed stresses but allowed for easier to transport to site. The compacted fill embankment was mostly constructed when it came time to place the settlement plates and horizontal inclinometer, so the compacted earth had to be dug out and then re-compacted with the equipment in place. Also changed for this project site, the risers were not greased on the compacted fill end; instead a larger PVC tube was placed around the riser and capped. The theory behind this was that even if the compacted earth attached itself to the outer PVC pipe, the inner pipe (riser) could still move freely with the settlement of the abutment. A photo of a PVC riser in the compacted embankment can be seen in Figure 16.

Figure 16. PVC riser in the compacted fill embankment at Chicot Road.

For the installation of the horizontal inclinometers on each end of the bridge, holes had to be drilled through the wingwalls in order to have an exit point for the inclinometer tube. A worker can be seen drilling a hole in one of the wingwalls in Figure 17 and the finished tube can be seen extending through the wall in Figure 18. Figure 19 shows the final placement of the horizontal inclinometer tube and the settlement plates on the compacted fill end.

Figure 17. Drilling through a wingwall for horizontal inclinometer installation.

Figure 18. Horizontal inclinometer tube protruding from a wingwall.

Figure 19. Installation locations at the south end of the Chicot Road Bridge.

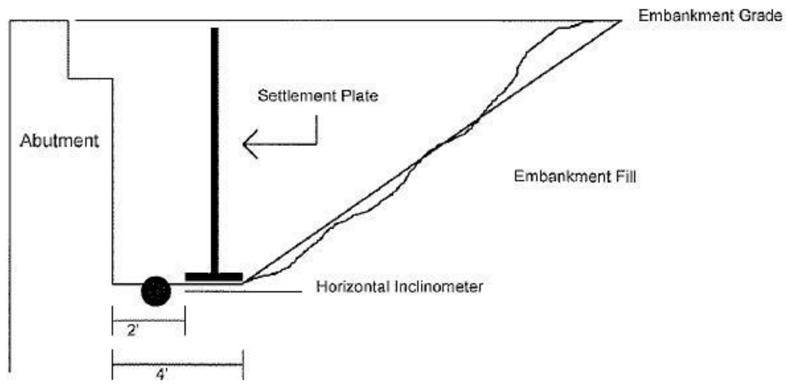
The trench at the flowable fill end of this bridge was approximately 4-foot deep by approximately 3-foot wide running with full width of the bridge. A photo showing the installation locations for the horizontal inclinometer tube and the settlement plates with risers can be seen in Figure 20. The risers on the flowable fill embankment were greased like those in the previous bridges. The trench at the north embankment of this bridge required approximately 40 cubic yards of flowable fill concrete.

Figure 20. Installation locations at the north end of the Chicot Road Bridge.

5.4 Crow Creek – Bridge #6755

The Crow Creek Bridge was constructed in early 2000 as part of Job 110329. The bridge runs in a northeast-southwest direction. The southern embankment was the control embankment and was thus constructed with standard compacted fill. The northern embankment was the test embankment and was constructed using flowable fill concrete. These general placement locations for the settlement plates and horizontal inclinometers can be seen in Figure 21.

JOB NO. 110329
Crow Creek Str. & Apprs.



Cross Section of Excavation and Placement of Settlement Plate

Settlement Plate Dimensions:

Base - 24" X 24" X 1/2" PVC plate
Riser - 3" I.D. Schedule 40 PVC, approximately 5' in height.

Horizontal Inclinometer: 3" I.D. Tubing of sufficient length to extend beyond wingwalls.

Figure 21. Crow Creek general settlement plates and horizontal inclinometer locations.

The exact locations of the settlement plate risers were again recorded so that they could be located after the road surface was placed. The Crow Creek Bridge appears to have an approach embankment height of approximately 5-foot. The settlement plates and risers for this bridge were changed to PVC for the same reasons stated for the Chicot Road Bridge. Also, like part of the Chicot Road Bridge methodology, the risers for this bridge were not greased; instead a larger PVC tube was placed around the riser and capped. As with the Chicot Road Bridge, for the installation of the horizontal inclinometers on the northern end of the bridge, holes had to be drilled through the wingwalls in order to have an exit point for the inclinometer tube.

The trench at the flowable fill end of this bridge appeared to be approximately 5-foot deep by approximately 3-foot wide at the bottom, running with full width of the bridge. A photo showing the installation locations for the horizontal inclinometer tube and the settlement plates with risers can be seen in Figure 22. Because the truck receipts were not kept for this job, we do not know how much flowable fill was placed in the trench at this bridge end.

Figure 22. Final placement of the horizontal inclinometer tube and settlement plates at the southern embankment of the Crow Creek Bridge.

This bridge did have something different; both ends have an approximately 35-foot-long, 9-inch thick, reinforced concrete approach slab. The settlement plates are installed in the shoulder area of this bridge, also differing from the typical wheel-path location.

Because of these approach slabs, the method of placing the risers had to be altered. As Research personnel would not be allowed to drill through the concrete slabs as they had the asphalt pavements on the other bridges, the access tubes and caps had to be cast into the concrete with the rest of the setup. Figure 23 shows the access tube and riser sleeve setup after the flowable fill was initially poured.

Figure 23. Flowable fill poured at the southern embankment of the Crow Creek Bridge.

After the flowable fill dried and the northern embankment was compacted, gravel was positioned to level the surface and the reinforcement for the approach slabs was placed, allowing the settlement plate risers to stick up between the pieces of rebar, Figure 24. Before the concrete could be poured for the approach slabs, the settlement plate access tubes were positioned so that they would be correct at final road grade. The left image in Figure 25 shows the PVC riser positioned in the access tube, all imbedded in concrete. The right image shows the cap just before the concrete was poured. The polypropylene caps had to be thoroughly greased to keep the concrete from firmly attaching to them.

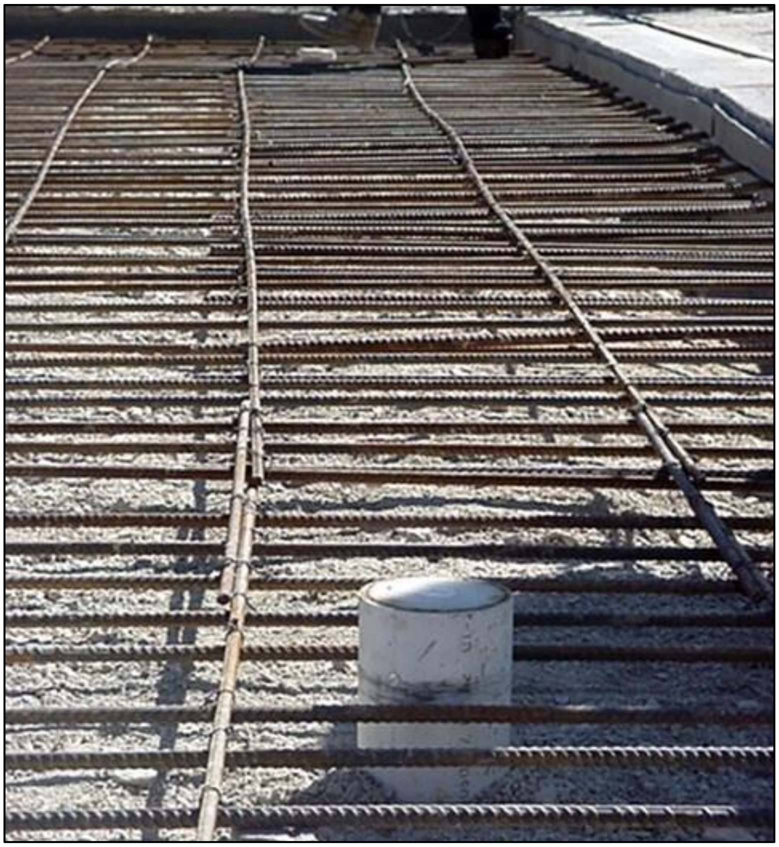


Figure 24. Capped access tubes sticking up between reinforcing members.

Figure 25. PVC riser in the access tube (left) and a greasy polypropylene cap (right).

6. Project Monitoring:

6.1 Settlement Plate Readings

The original plans for project monitoring on this project were to take quarterly readings on the settlement plates and the horizontal inclinometers. This, however, did not happen. A couple of readings were taken at each site and then the readings seem to have stopped. We are unsure why the readings were halted, but there was little data collected at these sites for several years.

In 2011, Research personnel went back to the bridge end locations to see if the settlement plates were still accessible. The polypropylene seemed to hold up well to ten years of weathering and traffic except for the threads on the removal slot, making them very difficult to remove in the intended method. For the most part, the caps had sealed in place after roughly ten years with the lack of new grease to lubricate the cap sides. It would be very difficult to remove the caps in order to take readings anymore. A very dilapidated cap can be seen in Figure 26. The settlement plate data that was collected can be seen in Appendix 9.1.

Figure 26. Dilapidated cap after ten years of neglect.

6.2 Profilograph Data

There were two different types of profilographs used to monitor this project. A California profilograph was used to get an initial profile on the Chicot Road Bridge, the Raymar Road Bridge and the Crow Creek Bridge. Research personnel can be seen taking making an original profile using the Department's California profilograph at the Chicot Road Bridge before it was opened to traffic in Figure 27.

Figure 27. California profilograph at Chicot Road Bridge.

In 2008, the Research Section started using a lightweight profilograph to monitor the bridge end sites; more specifically, a Lightweight Inertial Surface Analyzer from Ames Engineering. A list of dates for the jobsites profiled can be seen in Appendix 9.2, along with a comparison of the different profile runs.

6.3 ARAN Data

The Automatic Road Analyzer (ARAN) owned by the Department and employed by the Pavement Management Section of the Planning and Research Division keeps logs of most major highways in the state. The vehicle collects and analyzes video, roughness measurements and rut measurements from the roadways over which it is run. For this project, the ARAN had limited use but was used to track International Roughness Index (IRI) data for some of these bridges.

The ARAN analyzed Highway 84, Section 6, including the DeRoche Bayou Bridge, in 2002, 2006 and 2008. It analyzed Highway 284, Section 3 in 2005 and 2007; however, the data was corrupt and could not be analyzed. Because the Chicot Road and Raymar Road Bridges are just crossovers over an interstate and not state highways themselves, they were never analyzed. Some of the collected ARAN data can be seen in Appendix 9.3.

6.4 3D Laser Surface Scan

In 2010, Research personnel thought of a new way to record and analyze the bridge end sites. Through another research project at the Department, TRC 0802 – Laser Scan Produced Measured Drawings for Bridges, a time-of-flight 3-dimensional laser scanner (Leica Scanstation) was purchased. After the project was concluded, the laser scanner was transferred to the Surveys Division to utilize and maintain.

The Surveys Division was contacted and agreed to scan the bridge ends. In April of 2010, a survey crew took the laser scanner and mapped the bridge ends of the Chicot Road Bridge and the Raymar Road Bridge. The survey crew is shown scanning the Chicot Road Bridge ends in Figure 28.

Figure 28. First laser scanner at the south end of the Chicot Road Bridge.

Between the first scans and early 2011, the Survey Division traded in the laser scanner for a newer, more advanced model. With this new scanner, in February and April of 2011, the survey crew re-scanned the Raymar Road and Chicot Road bridges and got first-time scans for the DeRoche Bayou Bridge and the Crow Creek Bridge. Then, in September 2011, all four bridges were scanned again. A survey crew with the new Scanstation can be seen scanning the DeRoche Bayou Bridge in Figure 29.

Figure 29. Survey crew using the new laser scanner at the DeRoche Bayou Bridge.

Because using the 3D laser scanner to document these bridge ends is relatively quick and cheap, it is the intention of the Research Section to continue monitoring these bridge ends into the immediate future.

7. <u>Conclusions and Recommendations:</u>

In order to reach any type of consistent recommendation, another round of monitoring must be instituted with more in-depth testing methods. Due to the lack of consistent data and irregularity in data acquisition, and the variableness of soil types and construction methods, any conclusions or recommendations should be made on-site and be a 'case by case' decision.

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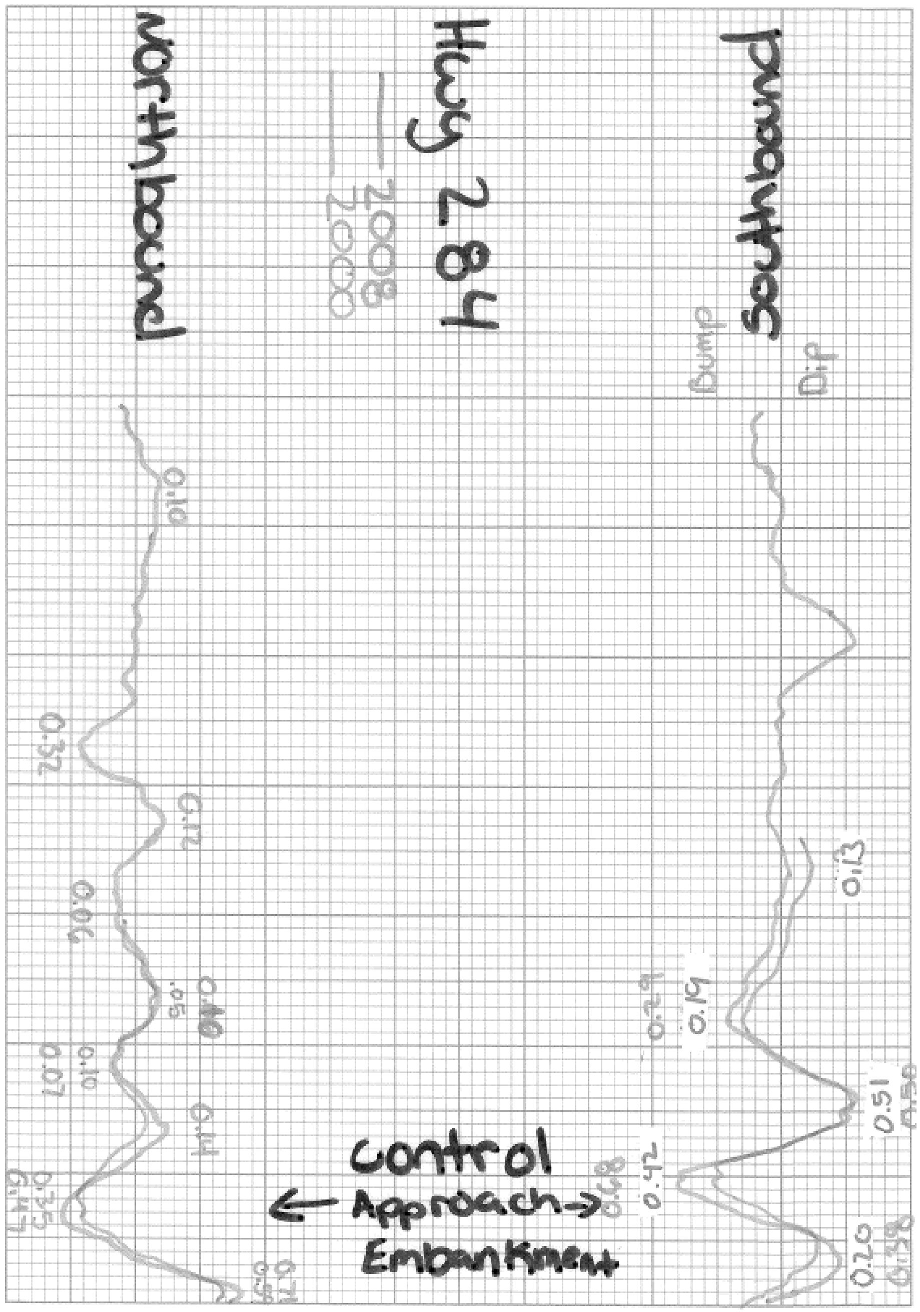
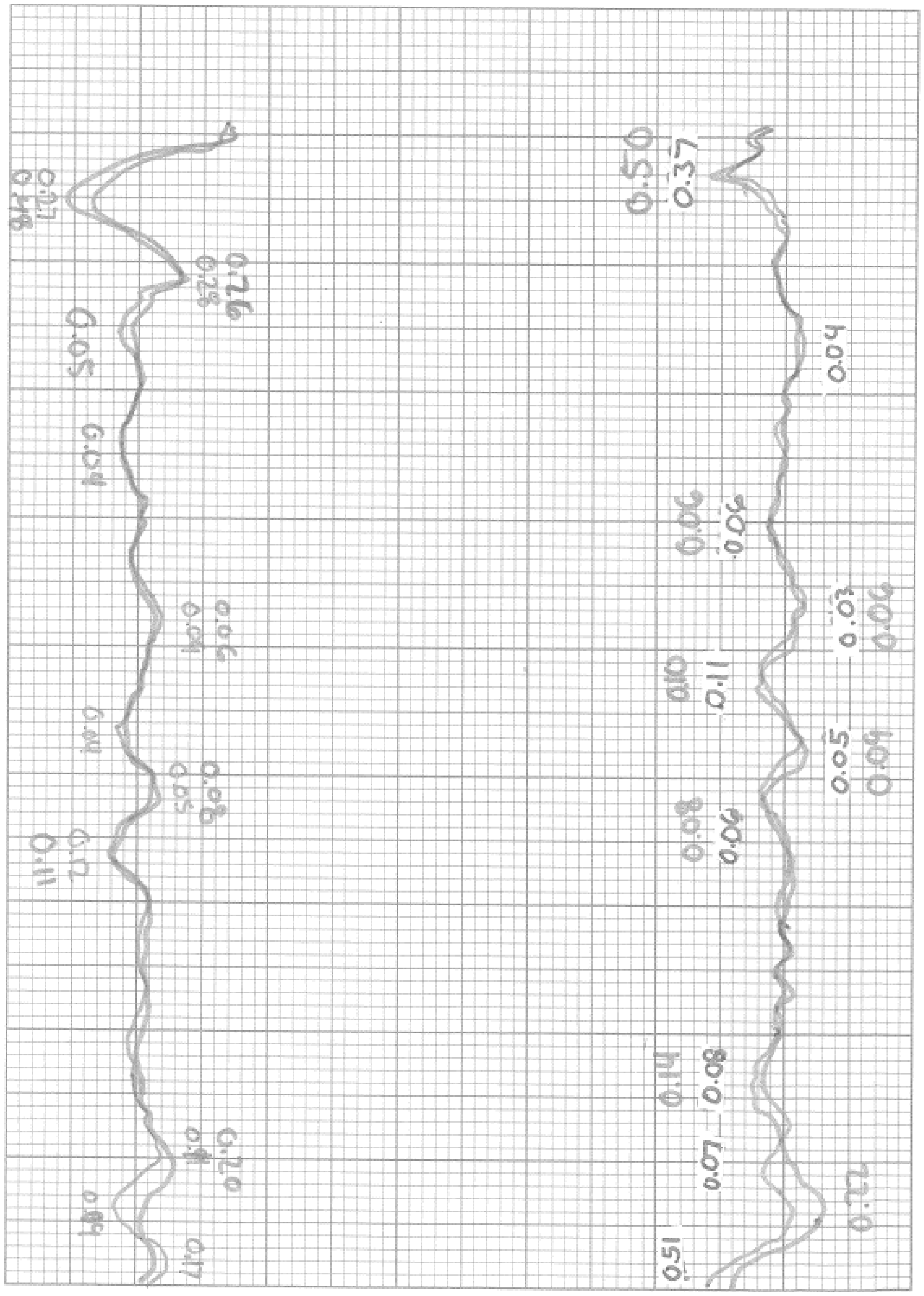
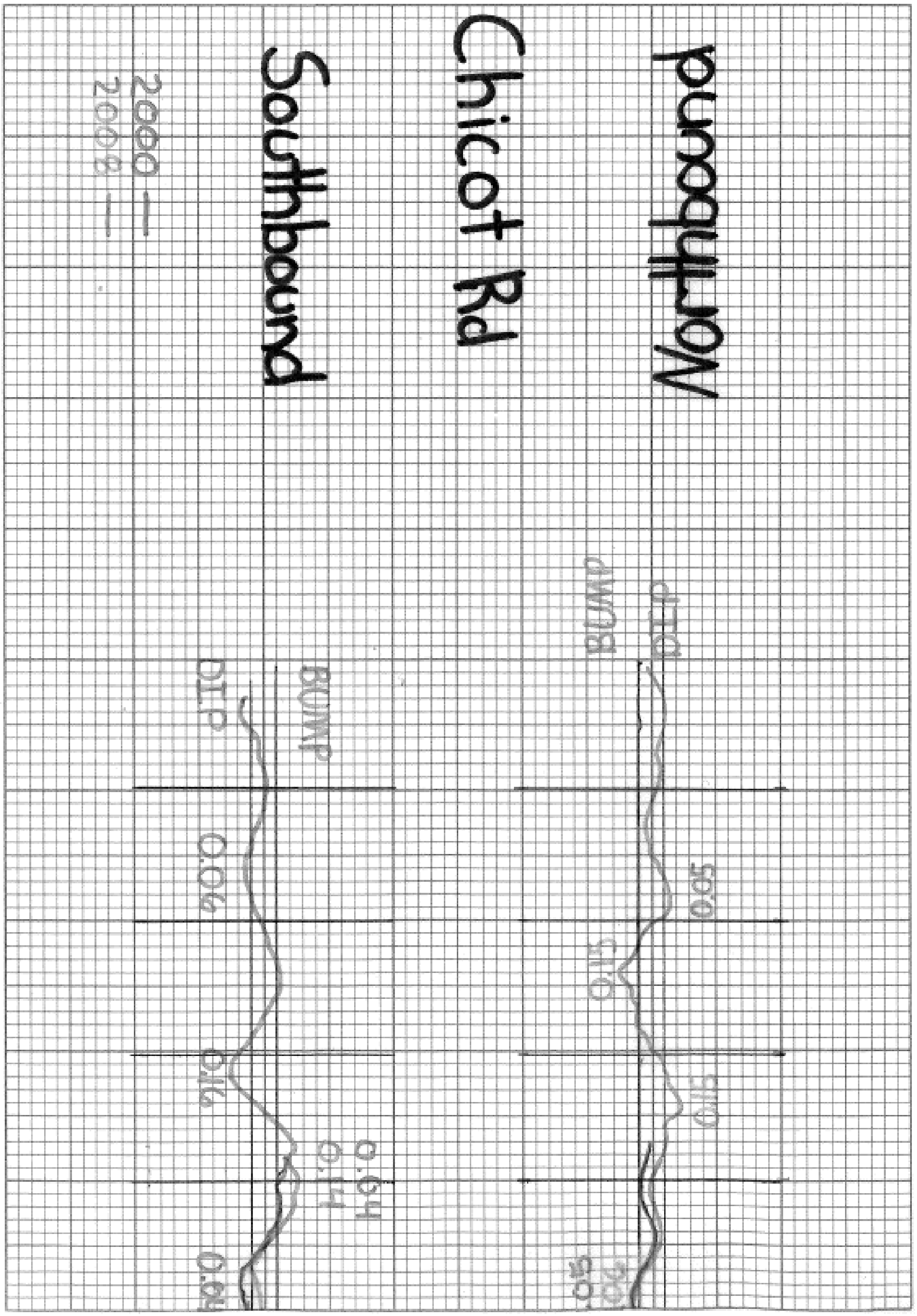
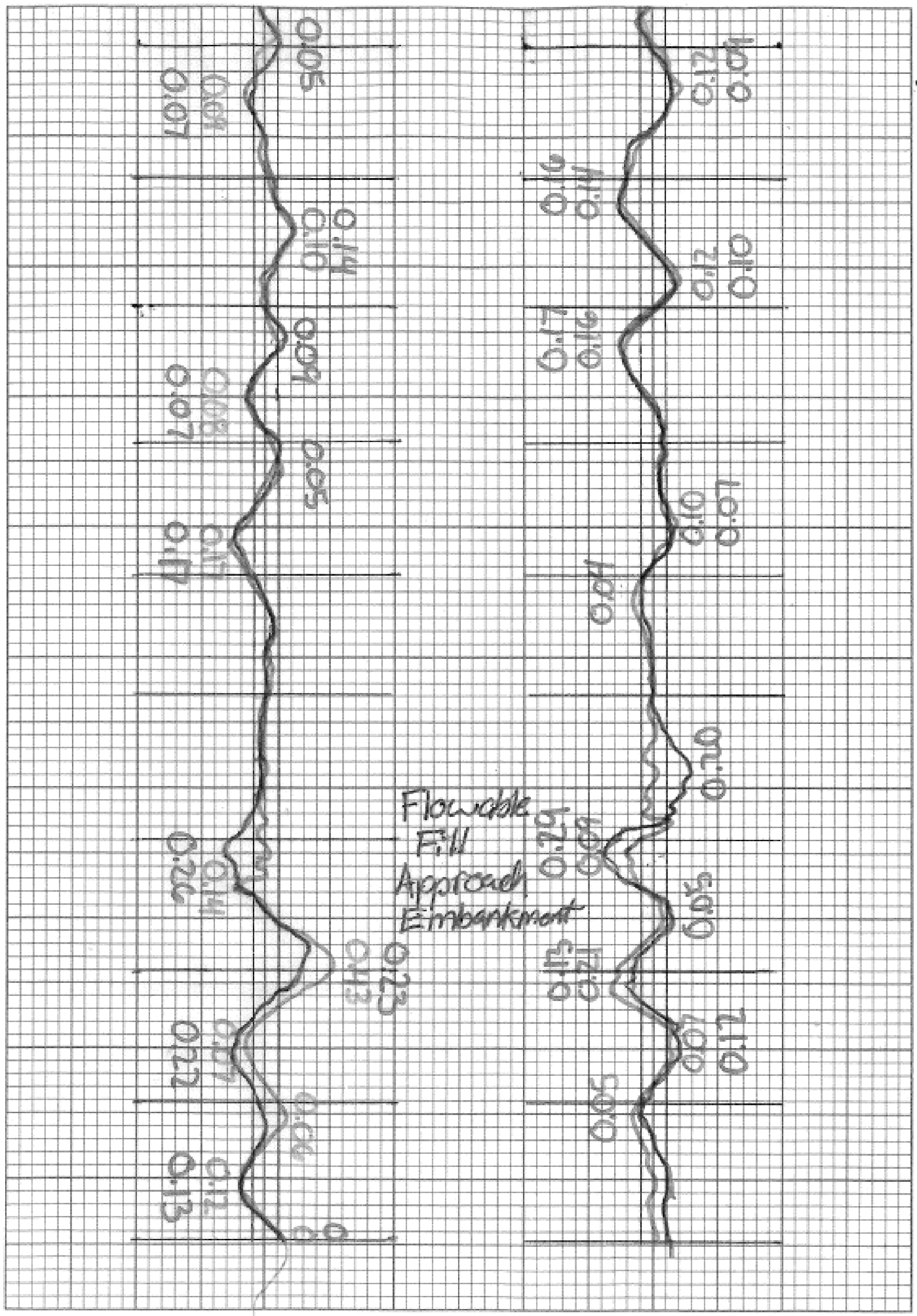
Appendix 9.1

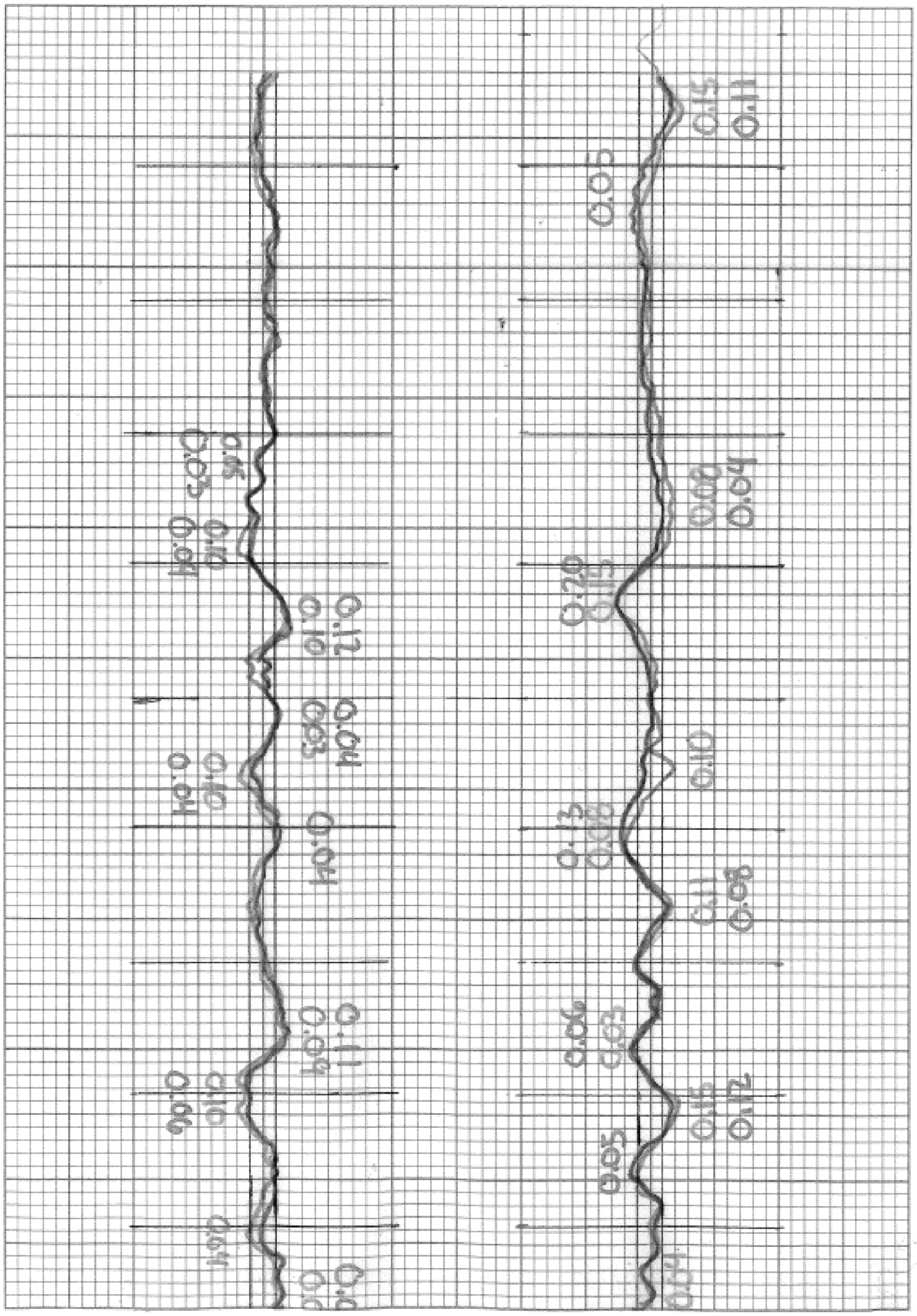
Profilograph Data





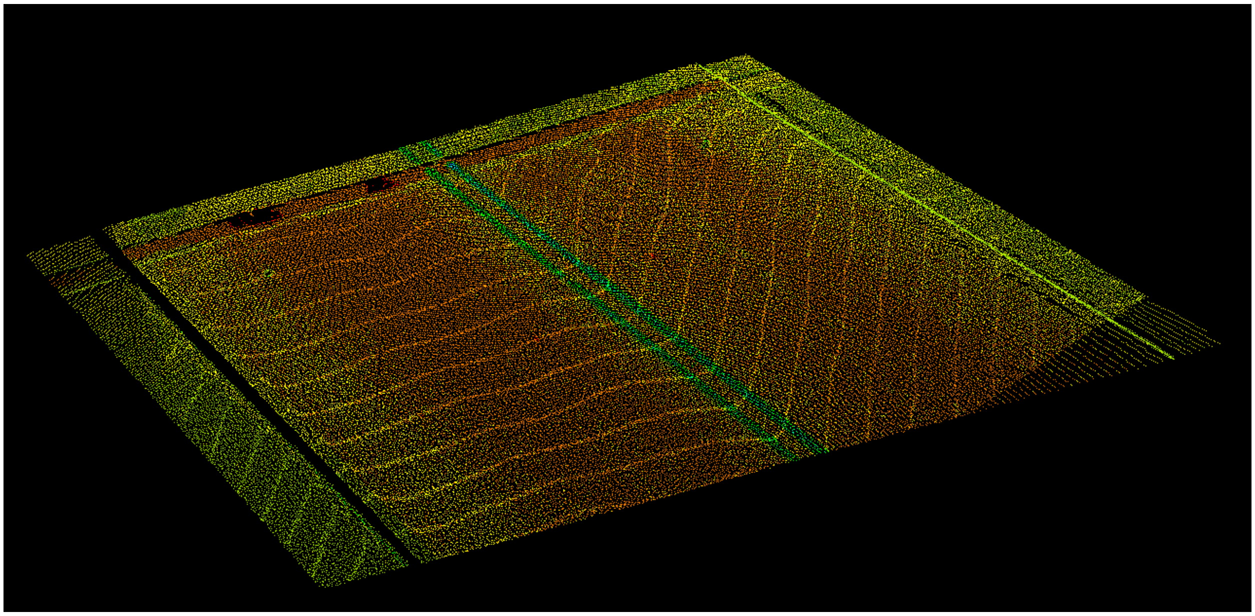

Northbound
Chicot Rd
Southbound
2000 —
2008 —
DIP
BUMP
0.05
0.15
BUMP
DIP
0.06
0.16
0.04
0.14
0.04

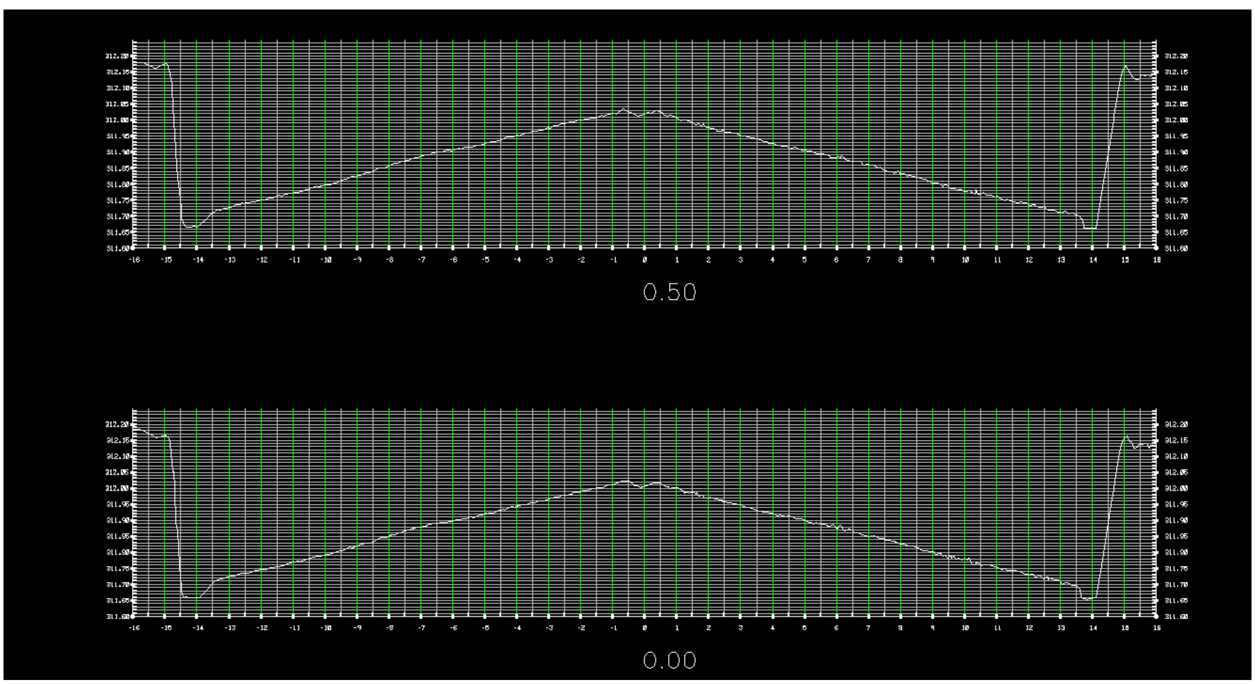

Flowable Fill Approach Embankment



Appendix 9.2

3D Laser Scan of Chicot Road





3D Laser Scan of Raymar Road