Practical Construction Details Used to Build an Instrumented Flexible Pavement with Geosynthetics

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ABSTRACT

A flexible pavement has been constructed over poor subgrade soil consisting primarily of highly plastic clay in northeast Arkansas (the CBR strength ranged from approximately 1-2). Seventeen instrumented test sections (each 15 m in length) have been constructed on this low volume road. In addition to the controls, test sections were reinforced with four different geotextiles, two different geogrids, and one geotextile-geogrid combination at the interface of the subgrade and crushed limestone base. The test sections were heavily instrumented with structural and environmental sensors. Dynamic stresses and strains are being measured using structural sensors located in the outer wheel path of the frontage road, and the environmental instrumentation are obtaining static measurements of pore pressure, moisture content, and temperature outside of the immediate loading area. While other papers address the details of the instrumentation and test configuration in more depth, the focus of this paper is to outline issues related specifically to sensor installation, pavement construction, and cable management and protection. This paper will be a valuable tool to anyone interested in planning and constructing a full-scale, instrumented pavement test.

INTRODUCTION

Flexible pavements constructed over highly plastic soils often perform poorly for a variety of reasons. Subgrade materials serve as the foundation to a pavement structure but have inadequate material strength under wet conditions, causing the base course and subgrade materials to mix, which decreases the design thicknesses of the structural layers. The use of geogrids and geotextiles is an innovative technique gaining favor in the Civil Engineering community to improve performance under the aforementioned conditions. Full-scale tests performed to assess the possible benefits of geosynthetic inclusion have been performed in Virginia (Al-Qadi and Appel, 2003; Al-Qadi and Bhutta, 1999; Brandon et al., 1996), Wisconsin (Tuncer et al., 2002), Montana (Yarger et al., 1991), South Carolina (Sprague and Cioff, 1993), Maine (Fetten and Humphrey, 1998), and New York (Suits and Koerner, 2001).

Data obtained from large full-scale field studies is available in the literature, but it is more difficult to obtain the practical details regarding the construction and installation procedures used in the field to ensure excellent quality control when a significant amount of instrumentation is involved. These types of details are invaluable during the planning,
budgeting, and scheduling phases of a new field study. The objective of this paper is to provide practical insight regarding the construction and the protection of all instrumentation and cabling to ensure maximum survivability. This test section is 260 m in length (divided evenly into seventeen sections) and 130 sensors were installed.

The instrumentation installation was carefully planned for three specific areas on site: 1) the roadway and paved shoulder; 2) the pipe network; and 3) the transition between the paved shoulder and pipe network. The procedures necessary to protect and waterproof the instrumentation and cabling in each of these areas was critical to ensure maximum survivability. While phases 1 and 2 were planned successfully prior to the field installation, much of phase 3 planning and protection occurred during the construction process as a result of issues that can only be addressed in the field (trench geometry, construction schedule, contractor equipment, etc). A large-scale project requires attention to numerous details, the magnitude of which do not become apparent until construction begins. To successfully install this amount of instrumentation, the research team must be actively involved in all aspects of the project and be on-site to ensure sensor, cabling, and the quality of the pavement structure remains uncompromised.

TEST CONFIGURATION

Figure 1 displays the plan view of all control and reinforced test sections, the orientation of the pipe network used to protect the sensor cables, and the data acquisition enclosure. The compacted subgrade is primarily a highly plastic clay (CH) with a CBR ranging between 1-2, but some sandy material is intermixed at various locations. Sections 1-6 have a 25.4 cm thick crushed limestone base, sections 8-13 have a 15.2 cm thick crushed limestone base, and section 7 serves as a transition between the two sets of eight test sections. A 50 mm thick asphalt surface course was placed on this low volume frontage road. The site was equipped with high speed internet access and AC power to allow the data acquisition to be continuously powered and remotely accessed.

CONSTRUCTION

Standard practices (without special provisions to the contractor) were utilized during the construction of the subgrade. Hand tools were used to excavate all holes and trenches necessary for subgrade sensor and cable placement. All geosynthetic materials were placed on the surface of the subgrade and a geosynthetic tensioning procedure was developed for this application to ensure all instrumentation was located correctly, and all geosynthetics were consistently tensioned.

In order to protect the geosynthetics during base course construction, crushed stone was initially delivered to the non-instrumented lane to a depth sufficient to cover both lanes with 15.0 cm of compacted material. The stone was then carefully bladed laterally onto the geosynthetics using a motor grader. Once all lifts were compacted and cut to grade, hand tools were used to install the instrumentation and cabling, mid-depth in the base course.
Asphalt was placed on the opposite lane of the frontage road first. Paving proceeded as normal on the instrumented lane until the paving train came within a few meters of the first test section. Paving ceased until enough asphalt dump trucks were on-site to pave all seventeen test sections without interruption. After the dump trucks lined up behind the paving train, each dump truck was instructed to drive around the paving train on the non-instrumented lane, back up to the Shuttle Buggy® to transfer the asphalt, and exit using the non-instrumented lane. The Shuttle Buggy® was oriented so that both sets of tires were located to the outside of the instrumentation. The tracked paver was oriented so that it just barely straddled the instrumentation. The breakdown roller made an initial static pass to stabilize that asphalt to prevent excessive lateral movement of the gages during compaction. All compaction procedures, thereafter, were standard.

Special provisions were taken to safely re-dress the unpaved shoulder, slope, and drainage ditch containing a significant amount of cabling and PVC pipe. The pipe network had to be re-located in the bottom of the ditch to ensure that the final cut did not damage any pipes and left sufficient cover over them. When the crushed stone was dressed to the asphalt shoulder, any sensitive areas where the sensor cables exited the roadway were passed over only by the motor grader and subsequently dressed by hand.

**General Sensor Installation Procedures**

Sensors utilized to measure the dynamic structural response (foil strain gages, earth pressure cells, and H-type asphalt strain gages) were installed in the outer wheel path of all test sections except the transition section (Section 7 in Figure 1). The initial location for the structural sensors was determined while installing the first earth pressure cell. A string line was
pulled between center line stakes and a Carpenters Square was used to align the measuring tape perpendicular to the string line. Once installed, the center location of each earth pressure cell was surveyed to identify a coordinate that could be relocated to ensure precise vertical alignment of all structural sensors above that point in the remaining pavement layers.

Foil strain gages were installed and waterproofed on all geosynthetics in a controlled laboratory environment, prior to construction. Following geosynthetic placement, the geotextile gages were protected from the rock using neoprene pads and the geogrid gages were protected from the rock using an inverted core of standard strip drain. Total earth pressure cells were installed in the subgrade and base course by hand excavating a hole slightly deeper than the desired depth, inserting a thin layer of fine sand as a protective cushion, leveling the cell in the hole (active face pointing up), checking the location of the cell using survey equipment, covering the cell with fine sand for protection, and tamping the area to ensure adequate compaction. Each active asphalt gage was positioned over a survey nail and a second back-up gage was placed next to it. Less than one hour prior to paving, two pre-heated pans of –No 4 Superpave asphalt were removed from ovens powered by gas generators on-site. The first pan contained enough mix to provide a 3-4 mm thick asphalt pad below each set of sensors, and the second pan provided enough material to surround and just barely cover the sensors, prior to paving. Compaction of the asphalt mix was accomplished by standing on a 30 cm square metal plate and hitting the pre-made asphalt with a mallet. Trenches were created for all sensors to bury the cabling, and sand was used to protect the cables from sharp rocks.

Static environmental responses are being monitored by piezometers, T-type thermocouples, and moisture content probes, installed in the transition section only. Subgrade and base course piezometers were placed in a pre-sewn, non-woven, geotextile bag filled with clean sand. The piezometer filter was pointed slightly upward to allow easy water access, and the cable trench created for each piezometer was plugged with bentonite. Subgrade and base course T-type thermocouples were installed vertically in pre-excavated holes. The asphalt thermocouples were placed horizontally (parallel to traffic) on the surface of the base course and surrounded in a pre-made asphalt mix, identical to the procedure used for the asphalt strain gages. Subgrade moisture content probes were installed vertically by driving a steel bar slightly larger than the probe into the subgrade, removing the bar, and placing the probe into the void created. The void was forced to close by driving a shovel in the material adjacent to the probe and gently pressing toward the sensor. This method proved unsuccessful in the base course due to the lack of cohesion so a hole was hand excavated and the sensor was placed in the hole at a slight angle.

Sensor Cables

Cable placement was one of the most time consuming, cumbersome, and labor intensive portions of the construction due to the length and bundle weights of the cables. All sensors were purchased with 6.1 m lead lengths to ensure the cable would extend past the shoulder into the pipe network trenches. After installation was complete, all leads were trimmed to a convenient length for consistency and splicing efficiency. Trench cables (extending from the lead to the enclosure) were then pre-cut for each active sensor and subsequently spliced to each lead. The leads for each back-up sensor were available for future repairs. The following discussion
summarizes the cumbersome procedures used to splice, protect, identify, and repair more than 5,000 m of sensor cable utilized in the current project.

**Splicing:**

A 20.3 cm long piece of Raychem heat shrink tube (adhesive-lined) was positioned over one of the cables to be spliced for outer protection. The outer protective sheathing on the cable was stripped approximately 10.2 cm in length on each cable and any wrapped foil or tape was cut off. If the cable had a shield wire, it was preserved and spliced separately to control noise. If the shield wire was a braid, the conductors were carefully removed from inside of the braid without compromising the integrity of the conductors or the braid. The conductors were trimmed to length, a 1.9 cm long piece of clear Alpha heat shrink tubing was placed on each conductor of one of the cables, and the ends of all conductor wires were stripped. The stripped ends of the conductor wires were subsequently tied together, soldered, and protected by heat shrink tubing. Each inner conductor and shield wire splice was then wrapped with Scotch 33 electrical tape. The outer Raychem heat shrink tubing was positioned over the entire splice and sealed with heat. The ends of the outer heat shrink material were wrapped with Aqua Seal and the entire splice was tightly wrapped with electrical tape to ensure a waterproof splice.

**Pipe network:**

Standard 10.2 cm sewer and drain (S/D) pipe was used to house and protect the cable underground. Approximately 370 m of pipe were necessary to complete the pipe network, which consists of seventeen lateral sections (running perpendicular to the roadway from the instrumented location in each test section) and a single header pipe (running parallel to the roadway along the length of the seventeen test sections, intersecting each lateral section). A 0.6 m square trench was excavated using a backhoe to bury the pipe in the lateral and header sections. Generally speaking, the pipe network was constructed using normal S/D pipe fittings in conjunction with straight pipe, but access points were constructed at select locations to ensure easy access to the cables for repair when necessary. An access point was constructed using a T-fitting (perpendicular stem facing up for access). The access stem was sealed by gluing a 15.2 cm long connector pipe to the stem and covering the connector pipe with a rubber flexible cap, tightened with a hose clamp. Flexible caps (rather than rigid caps) were utilized for easy accessibility.

In order to safely extend the cables from the roadway elevation to the bottom of the trench in the lateral section, cables were fed through a pre-drilled hole of a rigid cap (the cap was oriented downward), connected to a 15.2 cm long connector pipe and a 45° elbow, which was able to re-orient the pipe along the lateral trench. Access points were installed at the top of the lateral section (just beyond the 45° elbow) and at the bottom of the lateral section (just before the header junction). Otherwise, the lateral consisted of straight S/D pipe. The header junction located at the bottom of each lateral section was constructed using a T-fitting (perpendicular stem facing into the lateral section). There were two additional access points for each test section along the header pipe (one on each side of the header junction). In summary, there are three access points at each header junction (one on each leg of the junction) and one access point just above the splice in each lateral section near the roadway.
In order to construct the pipe network, the spliced cable leads for each test section were strung out in bundles beside the trench, situated so that the cable bundle for the test section farthest from the enclosure was also the bundle farthest from the trench and so forth. Before construction of the pipe network was initiated, the rigid caps were positioned on each cable bundle and waterproofed (details of this procedure are discussed in the next section).

After the waterproofing silicone was dry, the fittings necessary to construct the farthest lateral section (Section 13b or 1b in Figure 1) were strung down the appropriate cable bundle in order to begin building the pipe network. As soon as all components of the lateral were in place, the lateral section was glued and the next closest lateral section was built the same way. When two lateral sections were completed, construction of the header pipe between the lateral sections was initiated. Straight S/D pipe followed by the access point just before the junction was slid down the first of the two cable bundles. The T-fitting for the header junction was then carefully slid down both cable bundles to incorporate the intersection of these bundles at this junction point. For example, the cable bundle from Section 1b was fed through the parallel stem of the T-fitting while the cable bundle from Section 1a was fed through the perpendicular stem of the same T-fitting. The two bundles exit the fitting together and become a combined cable bundle thereafter. The access point on the other side of the header junction was slid down the combined cable bundle, and all components were glued, completing the construction of one full section. This process was repeated until the enclosure was reached on each side.

Waterproofing:

Waterproofing the cable entrance into the pipe network was performed with great care. Before beginning, the rigid cap was positioned at the head of the cables (near the roadway) to keep it out of the way. First, the cables needed waterproofing to prevent moisture from migrating between cables at the entrance to the pipe network. The location where each cable bundle would enter the rigid cap was identified and the bundle was taped approximately 10.0 cm above and below this location. Silicone was squeezed between the cables inside this 20.0 cm length to prevent water from migrating through the void spaces between the cables. A 10.0 cm long section of vinyl tube (32 cm inner diameter) was centered between the taped ends and filled with silicone. Hose clamps were utilized to tighten the ends of the vinyl tubing to ensure all void spaces inside the vinyl tubing were eliminated. The silicone was permitted to cure for approximately 24 hours before proceeding to the next step of the waterproofing procedure.

After waterproofing the cables inside the vinyl tubing to prevent water entry through the cables, the vinyl tubing was positioned inside the pre-drilled hole of the rigid cap and the void space between the cap and the tubing had to be sealed. The bottom hose clamp positioned on the vinyl tubing in the first step was tightened to ensure a water proof seal inside the vinyl tubing after the silicone cured. The top hose clamp was temporarily removed, a thin strip of Aqua Seal was wrapped around the vinyl tubing just above the bottom hose clamp, and the rigid cap was positioned over the Aqua Seal and forced flush with the bottom hose clamp. A flat-head screw driver was used to force the Aqua Seal through the hole to seal the void space between the tubing and the cap. The top clamp was repositioned on the top of the rigid cap, tightly against the surface. The two hose clamps serve as locking nuts on each side of the rigid cap. Additional Aqua Seal was wrapped around the tube on the inside and outside of the rigid cap, and a
significant amount of silicone was also added to both sides to provide a water proof barrier. The silicone cured for an additional 24 hours before proceeding with the construction of the pipe network.

Identification and repair:

All cable leads and spliced cable ends were identified with a laser printed label protected by clear heat shrink tubing. Each label incorporated the sensor type, test section number, pavement layer, active or backup status, and location within the data acquisition system (chassis, module, and terminal block identification). To more easily identify the sensor cables at the access point nearest the roadway, a color coding scheme was developed and colored electrical tape wrapped around each cable 0.6 – 1.2 m past the access point.

In order to easily repair cables, additional access points were added at key locations along the lateral and header pipes. Each lateral section contained an access point near the roadway and near the header junction, which was critical since every splice was located within this section of pipe. There is also an access point on both sides of the junction on the header pipe to create space that will allow someone to untangle or pull cables where bends in the pipe network exist. Approximately 1 m of cable slack was created in the lateral to ensure there was enough extra cable to splice when repairs were necessary. Cable slack was pulled from the bottom access point in the lateral during the pipe network construction and pushed back in when it was complete. If a repair is necessary, splices can be easily cut and re-spliced to the existing cable or re-attached to a backup gage. Flexible caps were utilized so that they could easily be removed using only a screwdriver.

In order to relocate the access points after the pipes are buried, a sign post was driven approximately 1.0 m behind the header pipe at each junction to mark the lateral pipe section locations, and a bolt was fastened to the sign post. A string line was pulled from that bolt to a concrete nail driven into the paved shoulder at the top of the lateral pipe section. The location of each access point with respect to the string line was mapped out for future reference.

Transitioning from the road to the pipe network:

The trenches (and therefore, the pipe network) were positioned only a few centimeters into the unpaved shoulder (approximately 1.2 m wide) and the rigid cap (where the cables enter the pipe network) sits below the roadway elevation. As a result, there was a significant gap in cable protection between the edge of the paved shoulder and the pipe network. While the geosynthetic and subgrade sensors were deep enough to be protected in the unpaved shoulder within a few centimeters of the pipe network entrance, shallow sensors in the base course and asphalt concrete were more susceptible to damage from construction equipment. As a result, an area approximately 5.0 cm wide and 10.0 cm deep was excavated from the edge of the paved shoulder to the pre-excavated trench. Vinyl tubing was used to protect these cables along this distance and neoprene was used to further protect the cables from sharp objects at all levels near the entrance to the pipe network.
SUMMARY

Practical details of the construction of a full scale instrumented test section containing geosynthetics have been provided. The construction of the test section was successful with preliminary evaluations indicating very good sensor survivability. The overall construction process has been summarized, sensor installation procedures outlined, and a variety of details provided regarding sensor cable protection and management.

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REFERENCES


