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Marquette Interchange Installation Report

Marquette University, Transportation Research Center

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Marquette Interchange Perpetual Pavement Instrumentation Project: Installation Report

Presented To:

Wisconsin Highway Research Program

Submitted By:

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Report Organization

Task three of the Perpetual Pavement Instrumentation Plan for the Marquette Interchange Project called for the installation of the various pavement sensors, data acquisition system, and various other components of the system outlined in the project proposal. The MU-TRC research team has successfully completed the installation of these various components of the system. This report fulfills the requirement of the installation report from task three in the project plan. This report is organized to describe in detail each specific component of the system. Most, but not all, of these details are written in the order they were completed.

Not every activity described in this report is associated with the installation of a particular component but have been included because they are thought to have a significant impact on the methodologies and procedures used. This report is intended to describe the installation processes in as much detail as possible. To help accomplish this, many figures, pictures, data, and video were acquired / developed; many of which have obviously been filtered out and only the most pertinent included. All of this material will be compiled into a single archive and will be submitted to WHRP.

This report was also written to explain and document any blunders, failures, and/or deviations from any proposed designs regarding this particular project or the Marquette Interchange project itself. These types of details are given so future research can learn from these experiences and make improvements upon them.

Communication/Planning/Coordination

The re-construction of the Marquette Interchange is a large undertaking for any contractor and the amount of communication and planning is great, even for the smallest task. A project of this size requires all parties to be deeply involved and giving their fullest attention to allow things to go smoothly and on time. This research project was particularly involved with the Northleg contract portion of the project as it contained the proposed pavement test section. The exact location of the test section chosen is located on Interstate 43 between stations 385+00 and 385+50 in the rightmost lane of the northbound direction, illustrated in Figure 1-1.

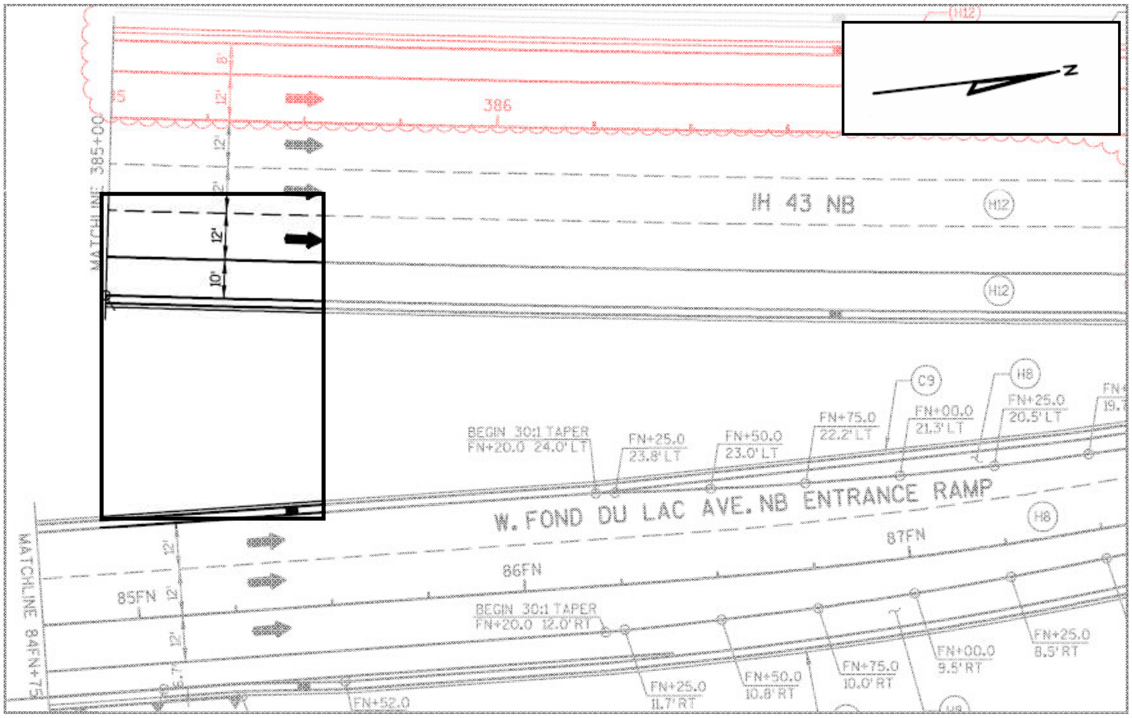

Figure 1-1 - The highlighted area was the proposed location for instrumentation test section.

The research team attended all possible weekly construction meetings to have up-to-date information regarding construction progress as well as having a voice and presence within the project planning. Meeting minutes and weekly schedules for the attended sessions have been filed and archived at Marquette. When work in the field began, it was not always possible to attend meetings, but every effort was made to be in constant contact with all the contractors.

It is the belief of the team that their tasks were conducted with very little interference to the other contractors. The most affected would be the paving contractor and electrical contractor, as many of the work activities were intertwined with their trades. The best efforts were made to minimize the amount of time these contractors had to spend dealing with these rather unusual intrusions into the construction project.

Chapter 2 - Sensor Installations

This chapter is dedicated to explaining step-by-step how the specific instruments were installed into their final locations. For instruments such as the WIM system, the installation procedures have already been set forth by the manufacturer with strict procedures, whereas other instruments have much less strict requirements. In all cases the procedures used follow the manufacturer recommended procedures when available.

Sub-Grade Instruments

The equipment that was installed during this operation was the following: soil moisture probes, soil temperature probes, and sub-grade earth pressure cells. The steps needed to complete this step included excavating soil for installation of the native soil instruments, taking density measurements and soil samples of the native soil layers, and finally installation of the native soil instruments.

The native soil pressure plates, moisture probes, and temperature probes were prepared and calibrated well before their scheduled installation target date. However, the installation of these instruments could only be completed after the underdrain for the main line was placed. This eliminated the risk of damaging conduits and wiring from the excavation needed for the underdrain. The underdrain was installed on June 26th and was adjusted days later on June 30th (adjustment was necessary because the drain was installed at improper elevations with areas where the drain was at or near the surface of the select crushed layer). The dense graded aggregate layer was placed around the same time as the underdrain installation.

On July 13th, the sub-grade pressure plates, moisture probes, and soil temperature probes were installed. Two holes were excavated through the dense-graded aggregate and select crushed material at stations 385+16 and 385+26 for the two sensor groups. Upon excavation, it was noticed that there was a slight deviation from the planned pavement cross-section design. When the mainline was being stripped of the existing pavement structure, some cutting below the finish elevation of the native soils was done primarily to remove areas containing some very poor soils. (It was also noticed that there were areas of very damp soil throughout the pavement structure during construction. Very weak sections of the select material could be easily deformed with pressure exerted by a person's foot. Spots that appeared weak, later exhibited signs of pumping of the clay soils up through the select material. These areas were clearly evident as relatively small portions of clay within the select material had worked up to the surface of the select material. They could have been easily mistaken as soil that spilled off a truck or loader as it passed, but closer inspection showed that the material came from the soil layers below.) Due to this over-cutting, the layer of select material was slightly thicker in some areas. This was recognized as a standard construction practice and the variation was merely documented for the purpose of the research. No action was taken to try to correct the issue.

The excavation was cleaned of loose material and further excavated by hand to reach the proper elevations. Nuclear density readings along with soil samples using Shelby-Tubes were taken at the bottom of the excavations. Previously installed conduits were located, cleaned, and trimmed to the desired location. The conduits had been installed by the contracted electricians, Outdoor Lighting.

All of the instruments to be installed were unpacked, cables unwound, and prepared for installation. The bare ends of the wire were protected and pulled into the conduits to the first pull box. The first and deepest instruments to be installed were the Decagon EC-5 soil moisture probes (see inset Figure 2-1) and Romus Inc. soil temperature probes. Where stiff soil was encountered, a Phillips screwdriver was used to create a void that the temperature probes could be inserted. The moisture probes were designed to be pushed into the soil and require this to function properly. A few probes experienced some extra resistance to insertion and required a little more effort to push into the soil.

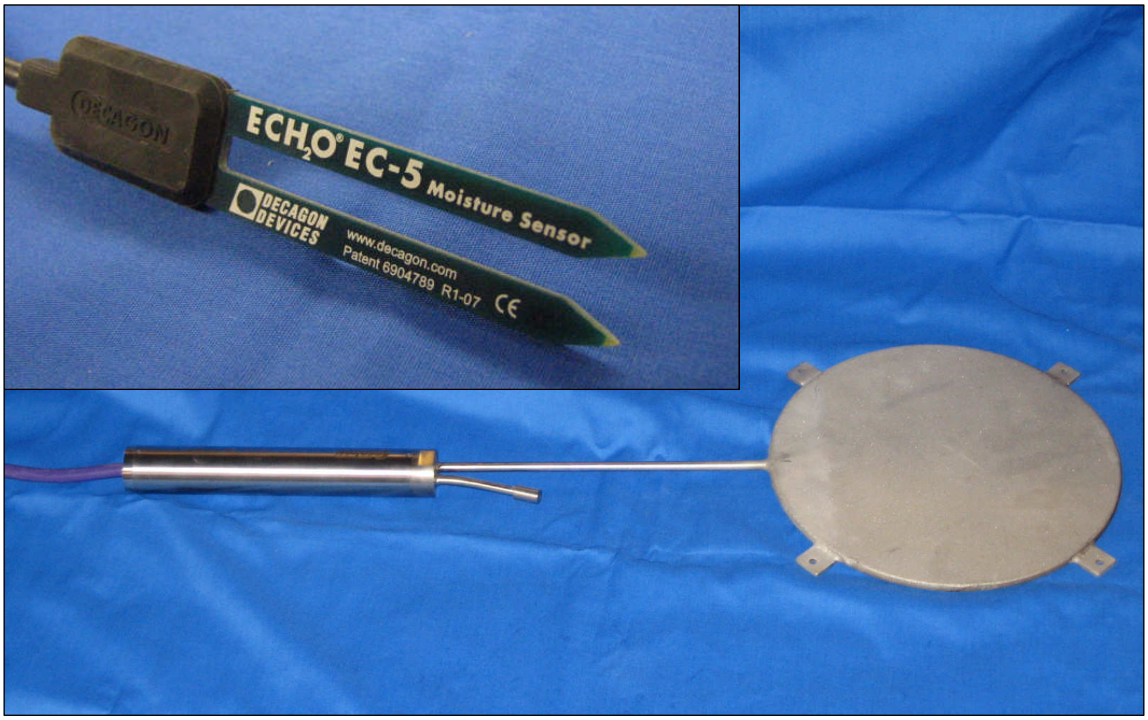

Figure 2-1 - Geokon Model 3500 Earth Pressure cell with protective foam removed from transducer. Inset: Decagon moisture sensor.

After each set of temperature and moisture probe was installed (moisture probes were installed with the pointed end of the prongs pointed east and the temperature probes were installed with the end pointing south), the excavation was filled in lifts with the previously excavated material and re-compacted by hand up to the level of the next sensor set. Care was taken to route and cover the vulnerable senor leads to prevent damage to the wires. This involved creating some strain relief in the leads and packing fine soil without rocks around leads. The next temperature/moisture probe set was installed in a similar fashion and soil level brought up to the next level and so on until all temperature/moisture sensors were installed as shown below in Figure 2-2.

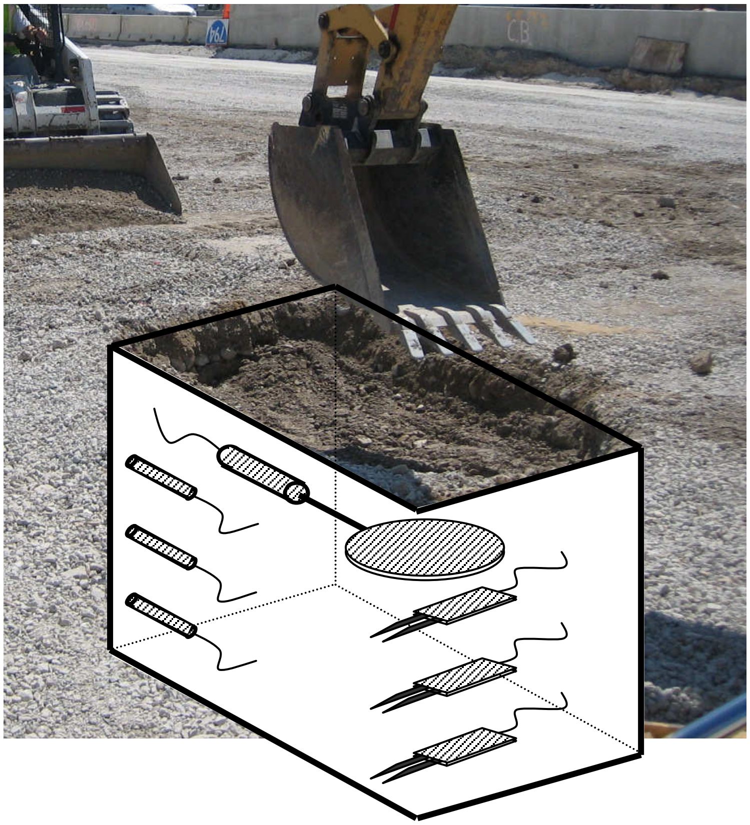

Figure 2-2 - The final arrangement of the sensors after installation. The EPC is aligned so that the sensor leads point into the direction of traffic. All moisture sensors have the pronged end facing east and all temperature sensors have their leads facing north.

All six temperature probes and six moisture probes were installed successfully with target elevations of 3”, 12”, and 24” inches below the top of the native soils. The soil level was brought up higher to the proper elevation for installation of the Geokon

Model 3500 Earth Pressure Cell (see Figure 2-1). About a two to four inch thick cushion of densified fine sand was placed over the re-compacted native soils. The sand was then checked for sufficient area, thickness, flatness, and levelness. The pressure cell was then carefully placed and supported on the bed of sand. A level was placed directly on the plate and the supporting sand was reworked until the plate was level in all directions. The location of the center of the plate was measured and recorded with the help of a GPS based surveying locator as shown in Figure 2-3. Once the location was satisfactory, another layer (about two to four inches) of fine sand was placed over the pressure cell and its leads. The sand was densified in layers using the palm of a hand. Once the fine sand was placed, slightly coarser sand from the site was placed and densified (about six inches, see Figure 2-3). It is extremely important to keep large rocks or other large objects away from the instrument. Not only can they damage the instrument, but large objects can disrupt the natural stress field around the instrument. The final orientations of the sensors are similar to that found in Figure 2-2; the final locations of the sensors are listed below in Table 2-1.

Table 2-1- Final locations of moisture and temperature sensors and earth pressure cells.

Sensor	Station, ft	Offset, ft	Elevation, ft	Sensor	Station, ft	Offset, ft	Elevation, ft
Moisture_A0	385+16	33.55 RT	655.0	Moisture_B0	385+24	33.90 RT	654.9
Moisture_A1	385+16	33.55 RT	655.9	Moisture_B1	385+24	33.90 RT	655.7
Moisture_A2	385+16	33.55 RT	656.2	Moisture_B2	385+24	33.90 RT	656.2
Temperature_A0	385+16	33.55 RT	655.0	Temperature_B0	385+24	33.90 RT	654.9
Temperature_A1	385+16	33.55 RT	655.9	Temperature_B1	385+24	33.90 RT	655.7
Temperature_A2	385+16	33.55 RT	656.2	Temperature_B2	385+24	33.90 RT	656.2
Earth Pressure_A0	385+16	33.40 RT	656.6	Earth Pressure_B0	385+24	33.30 RT	656.5

The excavated native soils were replaced followed by the select and dense graded materials, all compacted in lifts. The energy used to densify the materials increased significantly as the distance between the surface level and the instruments grew. The particle size of the select crushed material is on the order of 6-12 inches in diameter, so compaction essentially consisted of placing the first few inches by hand in a dense state. Following this, the rest of the materials were placed in lifts and compacted by dynamic force from the bucket of a backhoe being dropped repeatedly. The possibility of damage to the instruments after the fine sand layers were placed became minimal.

Figure 2-3 –Top: Placing EPC in a bed of fine sand and routing sensor cable carefully. Bottom left: Measuring and recording the final location of the EPC with a GPS based measuring device. Bottom right: Backfilling against the EPC with sand.

Measuring the electrical resistance of the instruments is a quick and easy way to verify the sensor's operability. This can readily indicate whether or not a sensor has survived the installation process (installation carries most of the risk of failure - broken leads being the most common problem). After installation was complete, resistance checks with a general purpose multi-meter were made and indicated that all the installed sensors were functioning properly (i.e. the resistance showed that the circuit was not open). Subsequent field monitoring showed that all sensors were in good working condition and provided logical data.

Base Layer Earth Pressure Cell

The installation base layer earth pressure cells (EPCs) had been delayed until just prior to paving of the first asphalt layer. This was done to reduce the probability of the equipment being damaged due to passing traffic and other construction operations. The final location of the base layer EPCs was just inches below the surface. Because of this decision, the EPCs were installed the same day as the asphalt strain gauges in two separate operations which took place on August 7th 2006.

The dense graded base layer earth pressure cells were installed in a manner quite similar to the plates installed in the native soils. The conduits placed prior were found using the GPS surveying locator device. The open graded, and some of the dense graded, base layers were then removed, exposing the conduits. An area large enough to contain the EPCs were cleaned out and the approximate proposed elevation was brought up with fine sand. The plates were placed on the sand and the elevation to the center of the plate was checked. Adjustments were made to the bed of fine sand until the elevation of the plate was suitable and the plate itself was level in all directions.

After the checks, another layer of fine sand was placed on top of the plate and carefully densified using the palm of a hand. The dense and open graded base layers were replaced and re-compacted using a hand operated tamper. All procedures for installing the plates followed the manufacturer's instructions provided with the instruments. A few important steps for installing the pressure cells are shown pictorially in Figure 2-4.

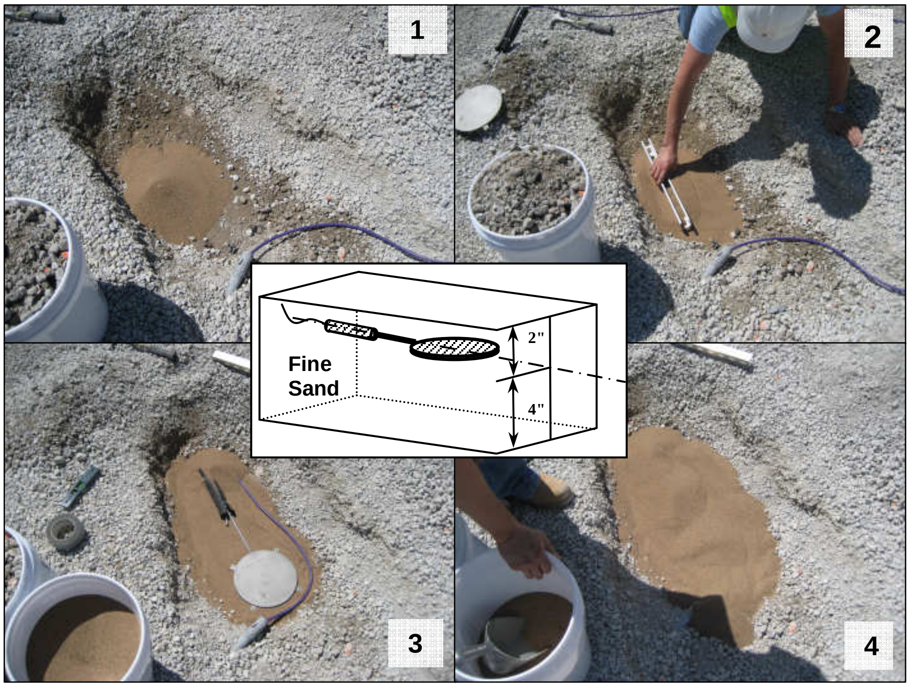

Figure 2-4 - Steps in installing EPC. 1) Filling the cleaned excavation with a bed of fine sand. 2) Leveling the sand out and preparing for EPC placement. 3) Leveling the cell and routing the sensor lead in a safe direction. 4) Backfill against the cell with more sand which would then be followed by the pre-existing base material, compacting each layer by hand. The inset sketch shows the layout of the sensor schematically.

Asphalt Strain Gauges

As stated before in the previous section, the asphalt strain gauges were installed the same day as the earth pressure cells. The first layer of asphalt was scheduled for placement in the test section during the late afternoon of August 7th 2006. During paving strain and pressure data would be recorded throughout various paving operations such as asphalt placement and compaction.

Through meetings with the paving contractor, the paving crews would be crossing the test section during the mid to late-afternoon hours. The median-shoulder and passing lanes would be paved first followed by the shoulder and the lane adjacent to it. Paving started at the Fond du Lac overpass and extended to North Avenue. The placement of the asphalt would follow standard procedures which included dump-trucks backing up to the asphalt pavers and dumping their load while the paver progressed. This presented a problem for installation of the asphalt strain gauges since the gauges could not be driven over by dump trucks supplying the paver with material. Luckily a transfer vehicle was available from the paving contractor which allowed paving to continue without having to drive over the test section (and the sensors). This change allotted more time to arrange and prepare the gauges and is likely a necessity for these types of instruments.

The first step for installation of the ASGs involved finding the previously installed conduits and exposing them. The proposed locations and spacing (see Figure 2-5 and Figure 2-6 below) of each strain gauge was marked on the open graded base layer with paint. The leads on the ASGs were unwound and readied for pulling into the conduits. One team would work on pulling the leads to the bottom pull-box and screwing them into the terminals on the data acquisition system while another worked on preparing the gauges for placement into the asphalt layer.

The cabinet for the project had not been placed at this time, so after the operation was done the wiring for the sensors was left inside the lower pull-box. It was protected from the elements as best as possible. A permanent power supply had not been installed yet either, so a gas powered generator was used in conjunction with proper surge protection to power the computer systems needed for data recordation during the installation.

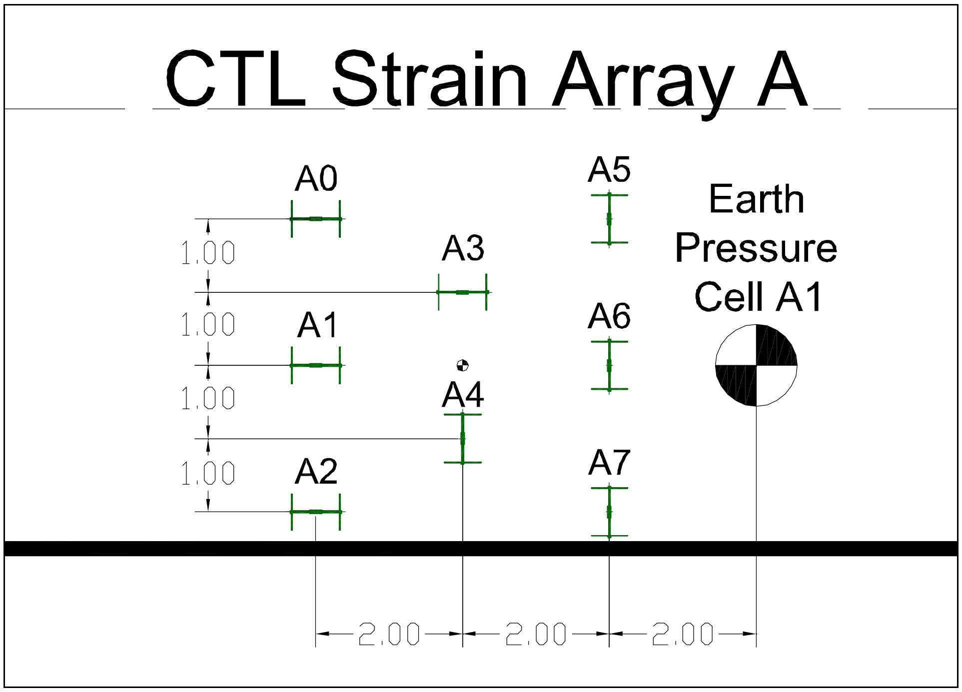

Figure 2-5 - Spacing of the strain gauges and earth pressure cells are shown above. All units are in feet. Note that the orientation of the two gauges in the middle of the array alternate rotation angles (transverse vs. longitudinal) for the two CTL arrays as shown in Figure 2-6.

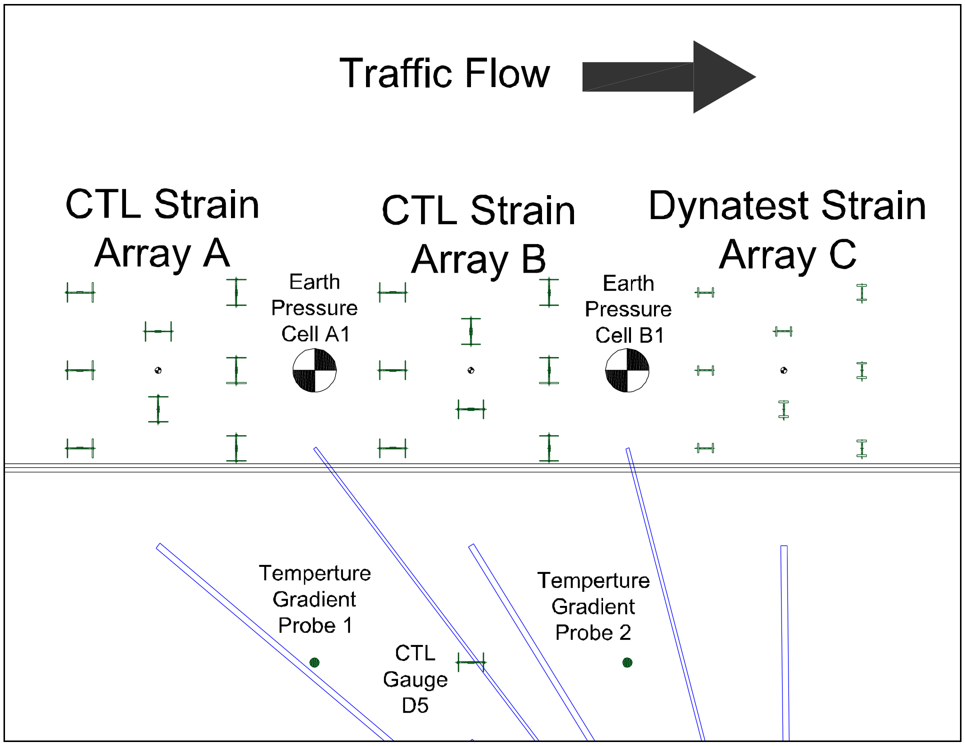

Figure 2-6 - Final configuration of strain gauges, earth pressure cells, and pavement temperature gradient probes.

The locations of the ASGs were checked again and re-marked as necessary. A pre-mixed matrix of sand and binder (the same binder used in the lower asphalt layer mix) was re-heated and brought from the lab into the field. This was placed in a ½ inch thickness on the open graded base layer in the location of each sensor and served as the base pad that the ASGs would sit on. The ASGs were then placed on their respective base pads the leads were organized and buried into the open graded base layer shown in Figure 2-7. The cable armor installed on the exposed length of the leads protected the wiring from puncture from the sharp stone edges during placement of the asphalt. The ASGs were placed so that the leads exiting the protected portion of the gauge did so against the direction of paving; otherwise forces and motions generated by the paving equipment may have a tendency to pull the sensor leads away from the strain gauge, destroying the gauge. Strain relief was provided multiple times, but survival of the gauges was a priority and every precaution was taken to prevent foreseeable damage.

Figure 2-7 - Left: Marking the proposed locations of the gauges. Right: Placing sand/binder pad and fitting gauges.

At this time it was noticed that some of the Dynatest strain sensors had curled from their original shape. The curled shape was that of a frown, i.e. the center portion of the H-shape was lifted off the asphalt pad. A note was made of the observation along with some small repositioning. Curling of the gauges may have been due to the gauges multi-layered construction along with the heat from the asphalt material underneath the gauge. This may have caused some temperature differential causing a curling effect similar to that of a concrete slab. The coefficient of thermal expansion for epoxy resins is significantly higher than steel, so this conclusion is reasonable.

Just before the paver was about to arrive at the gauges, asphalt material from the paver hopper was screened off on the 3/8” sieve and placed on the gauges, roughly 1 inch thick. The material was compacted using mild compaction force using a hand tamper. Once all of the gauges were covered with screened asphalt, the gauges were checked once more for sensor leads that were misplaced. A layer of unscreened asphalt (about 2 inches thick), was placed on top of the gauge arrays and compacted using a gas powered plate tamper shown below in Figure 2-8.

Figure 2-8 - Left: Placing screened asphalt on top of gauges and carefully compacting. Right: Compacting the unscreened asphalt over the gauge arrays with the paving crew approaching.

After this was complete the paver laying the shoulder passed over the strain gauge located in the shoulder of the roadway. It was noticed that the left track of the paver traveled over the edge of the covered strain array, but did not run over any gauges. Due to the highway geometry, the lane-shoulder construction joint fell on the right side of the ASG arrays. Since the shoulder and the adjacent lane were paved at the same time, it should have no effect on the functioning of the gauges. The adjacent lane placement occurred seconds after the shoulder placement and covered all the strain arrays completely. The right track and tire of this paver traveled just right of the center of the arrays. It is likely that this put the gauges under a fairly high amount of stress and demonstrates a difference between instrumenting real-world pavements and typical closed circuit test tracks.

The strain gauges were monitored during paving and rolling. Nuclear density measurements of the pavement at two different locations were taken after final rolling. It was noticed during testing that a few of the gauges were not reading properly. Initially it was not known if it was due to damage to the gauges themselves or because the anticipated values of strain were too large for the software setup created for the data acquisition system. It was expected that some large values of strain would be measured since the gauges would be exposed to not only large stresses, but also extreme temperatures which affect the material properties of the gauges and the output of the sensors. Over the progressive paving operations various testing procedures were carried out and any non-functional or poorly functioning gauges would be discovered during those tests. The initial appearance of the data taken shows that all of the gauges were functioning with the exception of a one Dynatest strain gauge (Gauge ID – C6).

Inductance Loop Detector

Soon after the first asphalt layer (C2 mix; four inch total thickness) was placed, the second layer (E30 mix; seven inch total thickness) was constructed in two lifts (four inch lift followed by a three inch lift). The loop detector for the weigh-in-motion system was installed between the two E30 lifts; the placement of the sensors can be seen in Figure 2-9. Some testing and checking of all sensors was completed beforehand.

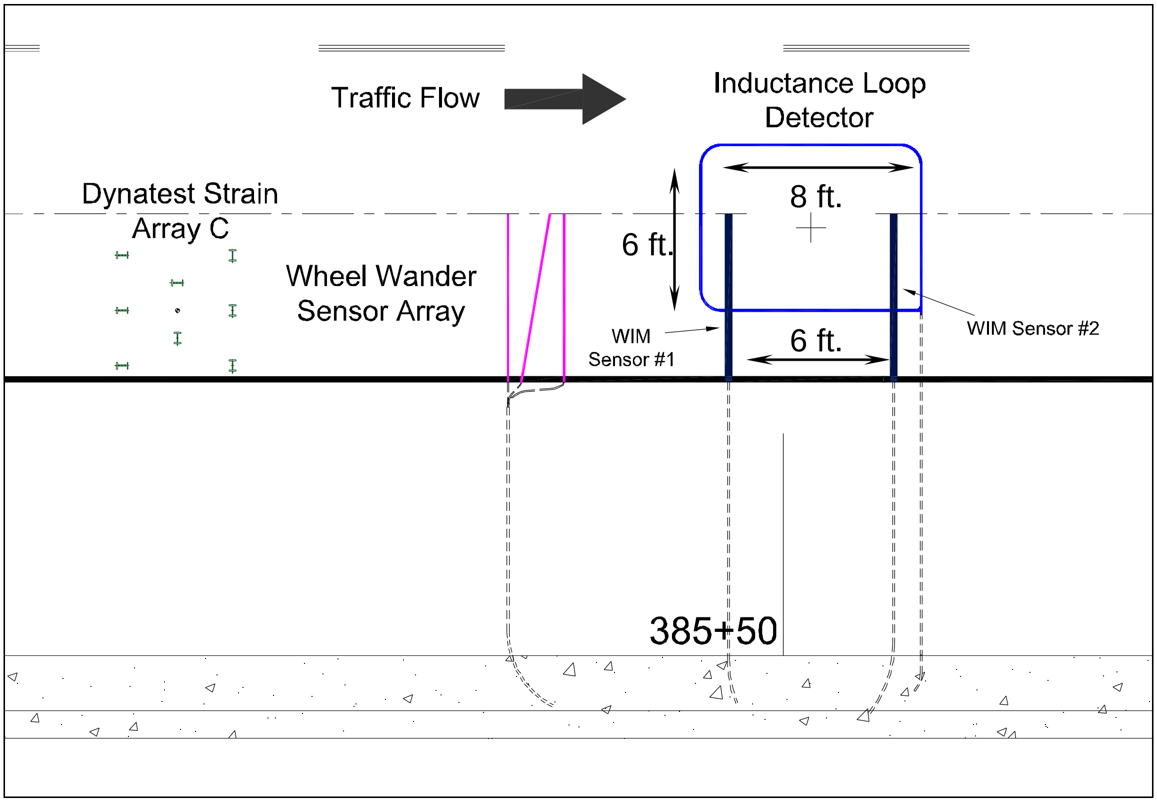

Figure 2-9 - Layout of the WIM sensors (loop detector and two quartz piezo strips) and the wheel wander sensors. The conduits installed into the pavement are also shown as hidden lines extending from the instruments to the curb.

The second lift of E30 was scheduled for placement on August 9th 2006, however due to inclement weather it was pushed back until the following day. Paving started on the inside lanes first and worked towards the outer lanes similar to the pattern used during the first layer. Two lanes were paved simultaneously with two different pieces of paving equipment.

The inductance loop detector was positioned and readied for paving. Instead of using a traditional inductance loop detector, a Never Fail Loop Systems Inc. loop was used instead. This was done because as the name implies, it has a very low risk of being damage and comes with a 10 year warranty. The loop wiring is encased in rigid conduit sections and filled with bitumen, thus protecting the inside and maintaining its shape. The leads running from the loop to the roadside conduit are also protected in a rigid cable sleeve. This level of protection means that it can be driven over by construction equipment reducing construction interference. Further more, since it is being paved over and into the pavement structure, there is no need to come back and saw-cut the new pavement to install the sensor. The loop is pre-assembled as a single unit; installation required nothing more than laying the unit out on the pavement, pulling wires, and securing it in place - the loop installation required no extra specialized help or tools to install.

The inductance loop was secured to the pavement using a fiberglass adhesive-backed tape (known as “Gorilla Tape” manufactured by the Gorilla Glue Company) shown in Figure 2-10. The tape is similar in appearance to standard duct tape, but much stronger and has much more adhesive strength (it should noted that metal should not be used in close proximity to the loop detector as it may deteriorate its sensitivity). Sections of the loop were secured in multiple locations and the wires were pulled to the conduits and secured. A simple resistance and continuity check of the loop after placement showed that the wires had not been broken and the sensor should be operational.

Once the loop was secured in its proper location, the paving crews simply needed to pave over the loop. However, on most pavers it is important to note the scraper that is located in front of the tracks/tires. Its purpose is to scrape any spilled asphalt out of the track/wheel path to promote smooth advancement of the paver. However, it must be raised out of the way when dealing with any instrument leads crossing the path of this scraper. Failure to do so will result in damage to the instruments.

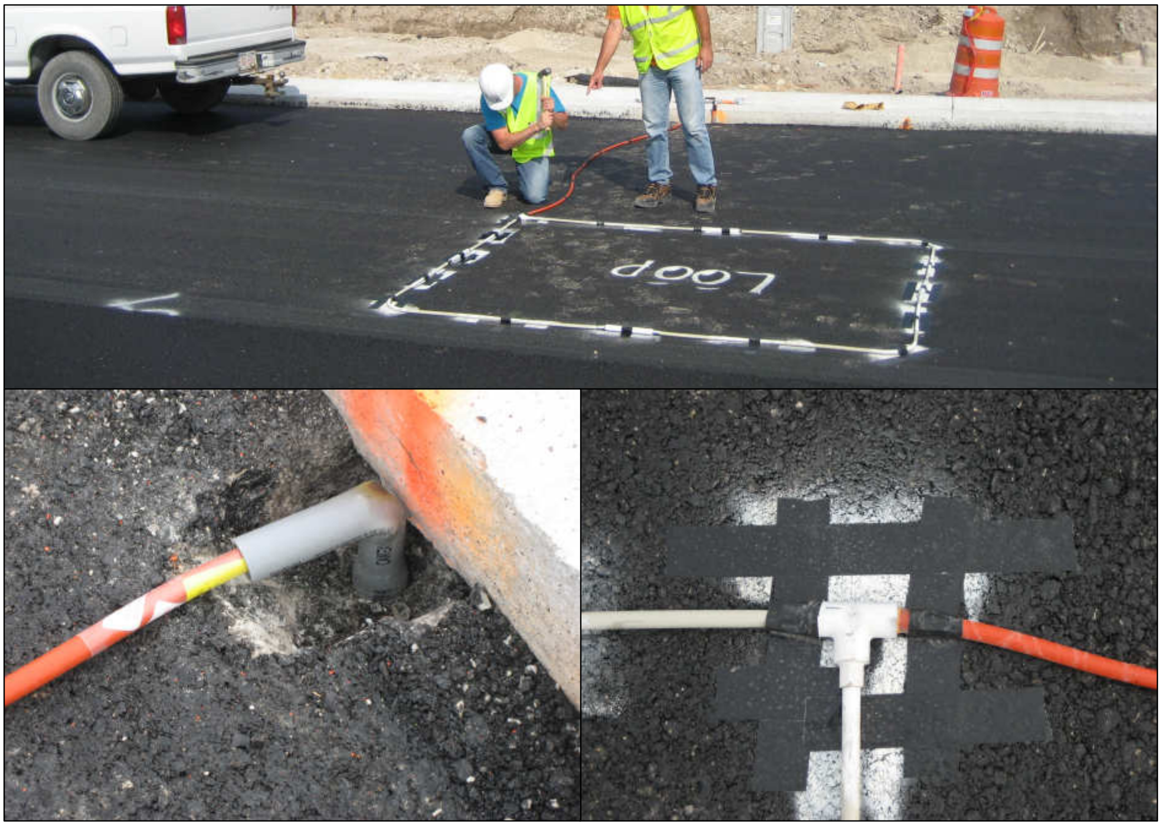

Figure 2-10 - Pictures showing various parts of the loop detector installation. Top: The fiberglass tape was hammered lightly to create a good bond to pavement. Bottom left: The asphalt around the conduit was removed with a cold chisel and hammer to expose enough conduit to install a "homemade" 90° elbow. The rather thick looking orange cable actually ends just inside this elbow and only two small wires actually pass through the elbow. Bottom right: A close up showing how the corner was adhered to the pavement and also the construction of the Never Fail Loop.

The paving train approached and construction proceeded as normal. A quality control technician of the paving company was there taking density measurements of the freshly rolled asphalt. Two separate nuclear density measurements were made at two different elevations. These values were recorded for future research purposes.

Equipment Cabinet

The roadside cabinet had been installed on its concrete pad (Figure 2-11 shows the project cabinet in place) by Outdoor Lighting and since the system was close to being complete, most of the equipment was prepared to be installed into the cabinet. This work was done while waiting for the paving crews to reach the test section with the final SMA surface layer so the temperature probes could be installed. Many of the sensor leads (including moisture probes, temperature probes, strain gauges, etc) needed to be extended to reach the inside the cabinet (a “comfortable” distance from the lower pull-box into the cabinet is about 20 feet). The data acquisition system, din-rails, power supplies, wireless radio, weather/antenna mast, and pavement temperature/camera mast were installed during this time period.

Once all of the wires were pulled into the cabinet they were connected to their appropriate terminals on the data acquisition system. One component of the system which was not installed was the controllers for the WIM system. The WIM controller would be installed with the WIM sensors which required factory certified installers.

The mast containing the environmental sensors (air temperature, anemometer, and pyranometers) and wireless antenna was fitted to the cabinet first and then brought back to the shop at Marquette and properly outfitted with the instruments. The bottom of the mast is supported by a “street” elbow which connects the hollow mast tube to the inside of cabinet. The wiring for the mounted equipment enters into the mast via ports and through the elbow into the cabinet. The mast was sealed as best as possible to prevent moisture from entering the cabinet.

The mast supporting the camera and infrared thermometer is made up of PVC conduit attached to the column supporting the sign structure. A ball-and-socket joint was constructed for the infrared temperature probe and the camera came outfitted with its joint; both instruments have a wide range of adjustment range.

The leads for these two instruments take a non-direct path to the instrument cabinet. The wiring runs into a stainless steel box mounted to the east side of the column. This box has its own access panel and was originally intended for the sign-bridge equipment. The instrument leads have a splice inside this box allowing them to be easily disconnected. From this box, the leads travel to the WisDOT ITS cabinet and finally into the project cabinet. This seemingly complicated wire routing is due to a deviation from the original plans.

Figure 2-11 - The highlighted cabinet is occupied by the equipment for this project. The mast connected to the cabinet holds environmental sensors as well as the wireless communications antenna. The cabinet in the background houses various traffic control devices for WisDOT. The two cabinets are connected by a limited number of conduits.

Wireless Antenna

The wireless antenna system is comprised of antennas at the roadside cabinet and on the roof of Carpenter Tower Hall at MU. The antenna at the roadside cabinet had already been installed, but the wiring in Carpenter Tower Hall required much more work to complete. The antenna is located on the northwest corner of the roof, as shown in Figure 2-12, with the wiring running from the antenna into an access hole on the upper level of the roof. The wire was then strung through the floor and into the corner of the room below adjacent to the data drop provided by Marquette's IT staff. A shelf was provided for the wireless modem at that location.

The coaxial cable that the antennas used for signal transmission required that special connector be installed. Service personnel from TAPCO Inc. installed the terminals on the cables on September 21 and the cable modems were powered up and checked for connectivity. The results showed that the connection was excellent even though the line of sight from Carpenter Tower Hall to the test section is blocked by grain elevators from the now defunct Pabst Breweries. The line of sight is visually shown in the right photograph in Figure 2-12.

Figure 2-12 - Left: The wireless antenna mounted on the corner of Carpenter Tower Hall at Marquette. Right: View from the antenna location at Carpenter Tower. The test section is located just behind the grain elevators in the highlighted area.

Pavement Temperature Gradient Probe

The original schedule for the installation of the temperature probes was the night of September 8th 2006 and into the following morning – most of the cabinet equipment was installed during this time as explained above. However due to unknown reasons, paving stopped during the night and the temperature probes were not installed.

The project contractor needed to open the highway to traffic on the morning of the 15th to avoid penalties and final paving of the final wearing course in the test section occurred in the early morning of September 14th. Installation of the two pavement temperature gradient probes proceeded as expected.

The installation of the probes consisted of a few, but relatively easy steps. The first step was to locate and expose the previously installed conduits. The second step is to determine the location of the probes and drill the appropriate sized holes that the probes would be inserted into. It was very important to drill only to the required depth so the probe didn't settle below the desired elevation. The probes used here actually protrude from the surface of the existing pavement about one inch so that the upper portion of the probe is embedded within the two inch thick SMA layer. The holes and channels for the sensors were cleaned and the sensors were dry-fitted into final locations, making adjustments as necessary.

The sensor leads were pulled almost all of the way into the conduit. Since the conduit opening was close to the curb, the sensors were pulled off to the side of the roadway until the time approached to pave over the sensors. When paving crews approached, the temperature probes were pushed in the drilled hole until they bottomed out. The protruding end of the probe was re-measured to ensure that the probed would not be higher than the final pavement elevation and actually was designed to be one-half to one inch below the surface of the SMA as shown in Figure 2-13. After this check the sensor leads were fitted into the channels and the excess wire was pulled into the pull box. Sealant was then placed in the channel to secure the wire into the channel and also protecting it from the approaching paving equipment.

Figure 2-13 - The photograph on the left shows almost the entire length of the temperature probe. The photograph on the right shows the temperature probe fully inserted to its final position. Note that the sensor lead is fitted into its channel, but has not been sealed yet.

The next step consisted of watching the paving equipment pass over the sensor. Because of the location of the sensor on the pavement and the procedure used to place the SMA, the protruding temperature probes fell within the wheel base of the trucks charging the paving equipment. Again, it is warned to pay close attention to the scrapers in front of the paver's wheel path (see Figure 2-14) because it has the potential to destroy the sensor leads. They can be (typically) easily lifted up and secured with chains (usually welded right to the paver).

Figure 2-14 – The scraper in the wheel paths of the pavers should be lifted off the pavement surface to avoid destroying sensors and their wiring. The inset picture is a close-up of the scraper which is in the down position, resting on the pavement surface.

After the material was placed and rolled the pavement surrounding the probes was inspected and appeared unaffected by the protruding probes. The installation of the temperature gradient probes was successful up to this point, but the sensors still needed to be checked to see if they were operable. During the installation the sensors were connected to the data acquisition system and seemed to produce logical values, however one probe was producing erratic data and it was determined that it was due to a shortage of power and would simply require another power supply.

Wheel Wander and Weigh-in-Motion System

The wheel wander piezo strips and the weigh-in-motion (WIM) sensors were installed at roughly the same time. These sensors are both installed into the SMA surface layer and required the use of two nighttime lane closures to complete the installation of both. The first few steps in installing the sensors are quite similar.

The first night of work included laying out the exact locations of the sensors, saw-cutting and chipping out the channels. Layout of the sensors was done by two separate methods. The first was done by using a series of reference points on the curb line to triangulate the ends of the conduits located within the asphalt. The other method used involved using the GPS location tool to find the ends of the conduits. Both of the methods produced locations that were very similar and proved to be accurate when actually removing the asphalt.

Once the ends of the conduits were located and marked, the layout of the proposed sensor locations were done so that the sensors were perpendicular to the edge stripe painted on the pavement as well as the curb. No drastic difference in these two layout references was found. It was very important that the layout dimensions be as close as possible to that proposed in the original plans, but slight deviations were inevitable. The final locations of the sensors were measured and recorded so that any adjustments or calibrations to the system could be made.

Once the layouts were finished, the channels were cut with a wet-cut diamond blade. It was very important that the cuts were made precisely due the limited volume of grout available for each sensor. Once the saw-cutting had been finished, an electric Hilti chipping hammer was used to the cut out the asphalt. For the WIM slots, the entire SMA layer was removed down to the layer below, which made chipping very easy. The wheel-wander piezo sensors only needed a slot depth of one inch. Both slots were chipped out with relative ease with little refinement needed after the first inspection.

For access to the previously installed conduits, a four inch diameter core was cut at the end of the channels to a depth just below the elevation of the conduits. The conduits for the WIM slots were located just slightly deeper in the pavement than the wheel-wander strips. All of the conduits were located exactly under the layout marks.

Wheel Wander Sensors

The wheel-wander sensors consist of three PK piezo sensors manufactured by Electronique Controle Mesure of France (ECM) arranged in a “Z” or “N” grid on the pavement. Once the asphalt was removed from the channels for the wheel wander sensors, the void was cleaned thoroughly with compressed air and water. After this, the slots were dried completely with a propane brush burner and re-inspected to make absolutely sure the slots were dry. This is important because it allows the grout used to anchor the sensors have a good bond to the surrounding asphalt.

The sensors came with clips that held the sensor in the pavement slot at the proper elevation as shown in Figure 2-15. The clips were attached and the sensors were dry fitted into their appropriate slots. Once satisfactory, the sensors were removed and set aside. Tape was placed on the pavement along the edge of the slot. This would keep grout from getting onto the pavement and acted as an area for excess grout to be wiped off.   The wheel-wander sensors were installed one at a time.

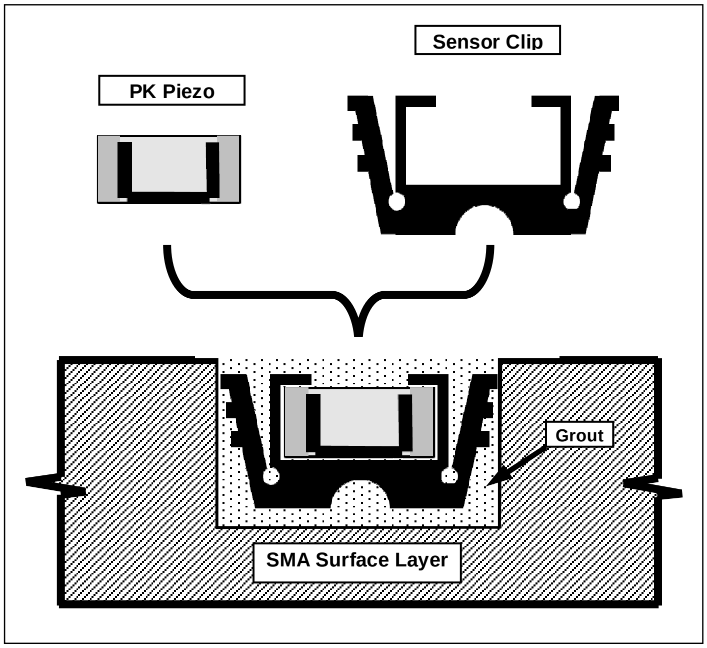

Figure 2-15 – Cross section of the PK piezo strip used for the wheel wander grid showing how it is assembled in the pavement.

One bag of grout was thoroughly mixed using a cordless drill and mixing paddle. The hardener was introduced and the grout was mixed again for three to five minutes. The slot was filled about half full with grout. The sensor was carefully lowered into grout being cautious that no voids would form between the sensor and grout. A supplied depth tool was used to further set the sensor to the proper depth within the slot. More grout was added as needed to fill the slot. Any excess grout was struck off with a trowel, finished flush with the surrounding pavement, and the grout was allowed to set and harden as shown on the left in Figure 2-16.

Figure 2-16 - Left: All three wheel-wander sensors have been installed and the grout on the final sensor is being leveled with the pavement surface before hardening. Right: All three sensors installed with the tape removed.

While the grout was hardening, the other wheel-wander strips were installed using the same process. The grout on the sensors required constant attention during curing because the grout had the tendency to flow into any cavity, such as over-cuts, due to its rather low viscosity. After the grout had hardened (about fifteen to twenty minutes for the air temperature at the time of installation) the tape was removed and the pavement cleaned and any grout that may have spilled over. The finished sensors can be seen in the right photograph in Figure 2-16. According to the manufacturer, the sensors could be opened to traffic in about forty-five to sixty minutes leaving plenty of time for the length of the lane closure window. In the meantime the coaxial cables for the sensors were pulled into the conduits and into the lower pull-box. The coaxial cables were not quite long enough to reach into the cabinet and needed to be extended as well as have BNC style connector bodies installed.

The wheel-wander cable ended up being fifteen to twenty feet short of reaching into the cabinet. The BNC style connectors were crimped onto the wires located into the lower pull-box. Extension cables were made in the lab that were twenty feet long and each end of the cable received BNC connectors (it should be noted that the WIM and the wheel-wander sensors do not used the same style BNC connectors). The wheel-wander and extension cables were then connected using a coaxial “barrel” (essentially a double-ended male section that joins the two female connectors on the cables).

The connection was then coated in a layer of electrical tape followed by a paint-on seal coat and another layer of tape. The cables were then pulled into the cabinet and the spliced portion of the cable was pushed into the conduit adding extra protection from the environment.

Weigh-In-Motion Sensors

The WIM sensors consist of four Kister Quartz piezo WIM sensors which were pre-assembled in the lab beforehand. The pre-assembly consisted of mechanically joining two sensors end-to-end into one unit, turning four individual sensors into two units. All that was left to do in the field was to uncoil leads, make electrical property checks, tighten leveling bars, and install into the pavement. The electrical property checks included measurements of the sensors resistance and impedance and were measured using specialized tools on loan from the manufacturer. The identification, serial number, location, and orientation along with the measured electrical properties and temperature data were all documented in the Kistler Warranty Protocol. Copies of these of documents were forwarded to the manufacturer as needed for the warranty.

After the channels had been chipped out, they needed to be cleaned and dried. The slots for the WIM quartz piezo sensors require extra care when preparing for installation. The pavement is required to be at a specified temperature before installation can begin in order to satisfy the warranty requirements set forth by the manufacturer. All of the channels were blown out with compressed air and dried with heat provided by a propane brush burner. A small amount of moisture was observed leaching out of the SMA layer, potentially causing a problem for installation of the sensors. It was reasoned that the recent wet weather and the porous nature of the SMA was to blame and the installation of the sensors was delayed until the following evening.

A special heating assembly was placed over the strips to initiate the heating process which is depicted in Figure 2-17. The heating assembly consisted of a series of HVAC ducting and a kerosene force air heater. Round sections of standard ducting from a home improvement store were bent to form a half circle and connected with other pieces of ducting that all came together at one junction. The forced air heater was then placed at this junction and blew hot air through ducting and over the slots in the pavement.

Figure 2-17 - The heating assembly was placed over the two slots cut for the WIM sensors. Heat was supplied by a forced-air kerosene fueled heater (not pictured). The sections of the assembly were sealed with aluminum ducting tape to minimize heat loss. Multiple temperature probes were in place to accurately measure pavement temperatures.

Three holes were drilled near the proximity of each sensor channel as dictated by the manufacturer's warranty protocol. Temperature probes were inserted into the holes and were monitored during initial heating and throughout the majority of the installation process. The hoods for the heaters were placed over the channels and the heat was turned on.

It would take almost three hours for the pavement to reach its required temperature of 68° F (20° C). Once the pavement had reached the required temperature for installation the temperature probes were removed and the data acquisition halted. The sensors were installed one at a time and the heating hoods where left running as long as possible and removed only to install and grind the sensors. The key was to get the pavement warm enough along with the ambient air temperature near the sensor to speed up the cure time of the grout. There is a recommended maximum temperature, but for the weather conditions during the operation, it was unlikely to ever exceed it as exhaust temperatures never rose above 100° F.

Once the heating hoods were moved out of the way, the sensors were dry-fitted into the channels. No adjustments to the channels were needed as the width of the channel was meticulously cut and the depth was the same as the pavement layer thickness, making for easy removal of material. Duct tape was placed around the perimeter of the channel to keep grout from getting on the pavement, thus making for easy cleanup and final grinding. At the end of the channel where the coaxial cable exited the sensor, pieces of foam were placed to prevent the grout spilling into the conduits. It was important to not have too much extra volume around the sensor itself because of the limited amount of grout available for each sensor.

When the sensor was dry fitted and half of the foam inserted into the end, the grout for the sensors was prepared. It is important that the grout be at a warm temperature due to its thick consistency, otherwise it can be difficult to mix. In this instance, the grout material, which is a mixture of a two-part epoxy and fine sand, was stored in a vehicle with the heat turned on. To mix the grout, the manufacturer recommends mixing the resin and sand first, blending well and then adding the hardener last. The pot life of the grout at room temperatures is only about fifteen minutes so it is important that the installations operations are done in a timely manner. To save time, the sand and resin can be pre-mixed several minutes before the introduction of the hardener component.

Once the hardener and resin had been combined, the grout was mixed for about five minutes or until well mixed. Half of the grout was poured into the channel and was spread around evenly using disposable plastic trowels depicted in Figure 2-18. Some of the grout was pushed up against the walls of the pavement channel making a “V” shape which helps the grout get around the sensor body and also works the grout into the pores of the asphalt surface. The sensor was then carefully lowered into the pavement until the leveling beams sat on the pavement surface. Immediately following, heavy pieces of steel were placed on the leveling beams to keep the sensors from floating out of the grout until it had cured. Plastic trowels were used to smooth out the surface of the grout left between the pavement and the top of the sensor. Because of the cohesive consistency of the grout getting a nice flat finish was difficult, especially after it began setting up. Some parts of the grout were left high and would be knocked down flat with the pavement during grinding.

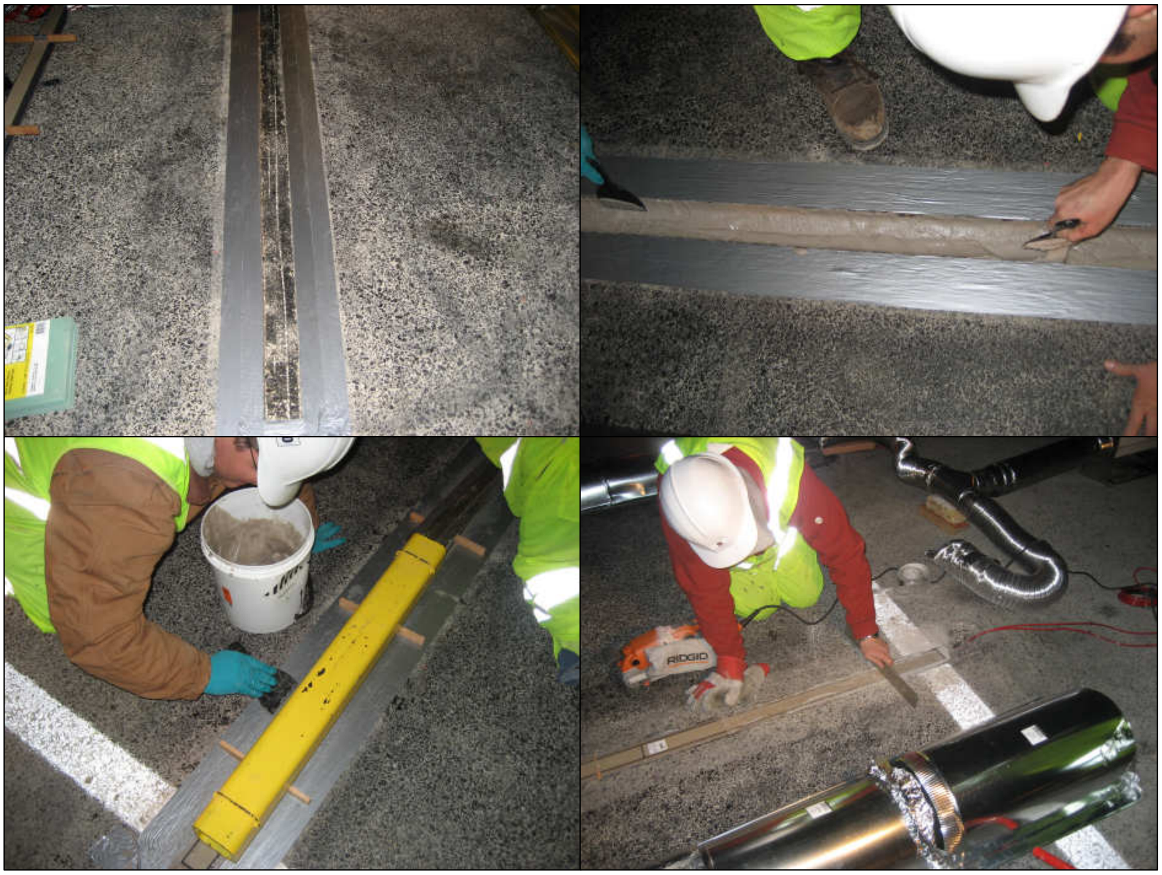

Figure 2-18 - Upper left: Channel for the WIM sensor ready for installation. Upper right: Grout for the sensor being distributed into the channel. Lower left: Sensor in place with pieces of steel placed across the leveling beams to keep sensor from floating out of the grout. Touch up work to the grout was done before its initial set. Lower right: The sensors were ground flush with the surrounding pavement and checked using an 18-inch long straight edge.

Once the first sensor was installed and curing, heat was reapplied. The second sensor was then prepared and the same process for installation was repeated. Total installation time from removal of heating hoods to the reapplication of heat was about one hour total for both sensors. Heating continued for both as long as possible to achieve the full strength of the grout. However, enough time had to be left to allow grinding the sensors flat, filling the conduits voids with quick setting grout, and cleaning up. Heating continued for one-and-a-half hours at which point the grout should have been very near full strength based on a time-temperature maturity relationship provided by the manufacturer.

Grinding consisted of using a belt sander fitted with an alumina zirconia belt and an angle grinder with a general purpose grinding wheel to abrade away excess grout. The angle grinder was used for large amounts of grout needing removal, while the belt sander was used for the finish grinding. To check for flatness, an eighteen inch aluminum straight-edge was placed across the sensor (in the direction of traffic) at different locations. The pavement has to be perfectly smooth across the sensor or else they will not produce consistent measurements, thus degrading the accuracy of the WIM system.

During grinding, the ends of the sensor cable were protected and pulled through the conduits and up into the cabinet. The ends of the sensor cable were protected because it is very important that the sensor cable is not exposed to moisture or other contaminants that can cause signal loss. The sensor cables needed to have new BNC style connectors installed but this task was completed at a later time as the cut-off time for work was approaching.

Once the grinding had been completed, holes in the pavement exposing the conduits needed to be filled. Sealant was placed around the wire leads to prevent grout from entering the conduit and the foam placed at the ends of the sensors was also removed. Fast setting grout (leftover grout used for the wheel-wander sensors) was then poured into the holes up to the level of the pavement surface. Voids left in the pavement by over-cutting were also filled. Once the grout was nearing its full strength, the pavement was cleaned up and the highway was reopened to traffic. The finished products (including the wheel wander grid) are shown below in Figure 2-19

Figure 2-19 – Test section opened to traffic with the wheel-wander and WIM sensors installed (circled areas).

The WIM sensor cables were long enough to reach into the cabinet but required new BNC connectors. The cables came with BNC connectors pre-installed, but it was not possible to pull the cables through the conduits with the connectors on so they had to be removed. The tools required to install the BNC connectors onto the WIM sensor cable were provided in the tool kit on loan from Kistler Instruments.

The charge amplifier for the WIM sensors was installed inside the cabinet using a plastic spacer block and bolted the chassis of the cabinet. Each WIM sensor strip is actually composed of two individual sensors with two separate leads, the cables “tee” into each other just before the charge amplifier. The plastic spacer block brings the charge amplifier away from the cabinet chassis so the cable connections can fit nicely with no interference and also making it easier to remove the cables if needed.

The WIM system is independent of the data acquisition system and data generated from the WIM system is exported to the database and is combined with the rest of the data. However the WIM system still functions like it would if it were a stand alone unit. Users can access the WIM controls and monitor vehicles as they pass over the system and modify the configuration settings. One very important step in setting up the WIM system is to calibrate the system using a test vehicle.

Setting up the WIM system is actually quite simple after the sensors are installed. Once the controller rack is placed into the cabinet a handful of sensor leads need to be connected. There are two wires for the loop detector that have two designated screw terminals and a BNC connection for the charge amplifier must be plugged in. The unit must also be plugged into an electrical receptacle for power. Beyond this, a connection to the controller must be made with a serial cable into a computer. Software provided with the equipment allows users to view data being generated by traffic and also change settings.

To calibrate the WIM a flat bed truck was used with a large weight placed in the back as shown in Figure 2-20. The total truck weights were obtained by driving the entire truck onto a static scale and recording the weight and then advancing the truck forward so that only the rear axle was measured. The scale platform was very flat, so this method should be accurate. To obtain individual wheel loads the axle weights were divided in two.

There are already plans to use portable scales provided by the Wisconsin State DOT to measure individual wheel loads. The truck used is owned by Marquette University and the large weight is easily loaded with a forklift. A standard positioning of the weight has been created so in the future, weighing out the wheel loads will not be necessary. Furthermore, when the wheel loads are measured, it is proposed to position the loaded truck so that it is on a similar cross-slope and grade as the test section to catch any weight bias between wheels.

Figure 2-20 - Vehicle used to calibrate the WIM system. Note the concrete slab placed in the bed of the truck over the rear axle.

To calibrate the system, the truck was driven over the WIM sensors while a user connected to the WIM system watched the response generated. To correct for speed adjustments the distance between the quartz piezo strips is modified in the software setup. If an accurate measurement of the spacing between the sensors has been made and entered into the software setup, it is unlikely that this will need to be modified.

To adjust the system for weight corrections, there is simply one correction factor that needs to be modified. There is actually a slider bar that can be clicked and changed, or the user can enter a factor by entering the number in the text box. These operations should only be done by a trained individual as there are many steps needed to get to these points. A detailed explanation is beyond the scope of this report.

Chapter 3 - Testing Procedures

This chapter highlights the tests and data collections conducted on various sensors and materials. The test done on the sensors were done so to confirm that the specific sensor had survived installation or not. In terms of materials testing, information was collected and archived for future research purposes.

Strain Data Collection During Paving

During the strain gauge installation, data was collected which included responses from the earth pressure cells as well as the strain gauges. Initially it appeared that one of the Dynatest gauges had not survived the installation (Dynatest C6). The data was downloaded and analyzed after paving. It should be noted that the heat generated from the asphalt material creates large fluctuations in the strain gauges due to the circuitry on board the gauges. Many of the signals had drifted out of the range of measurement, but did not necessarily mean the gauges were destroyed.

The following plots were generated from the rolling operations. Figure 3-1 and Figure 3-2 are examples of gauges that are functioning properly. They both show significant induced strain values, with two peaks indicating the time at which the steel wheel roller passed over the gauges. Figure 3-3 shows the output from the Dynatest C7 gauge which was showing a substantial amount of signal noise.

These plots confirmed that the gauges were function properly immediately after paving. More in-depth tests were carried out on the gauges the day following the paving and presented in the following section.

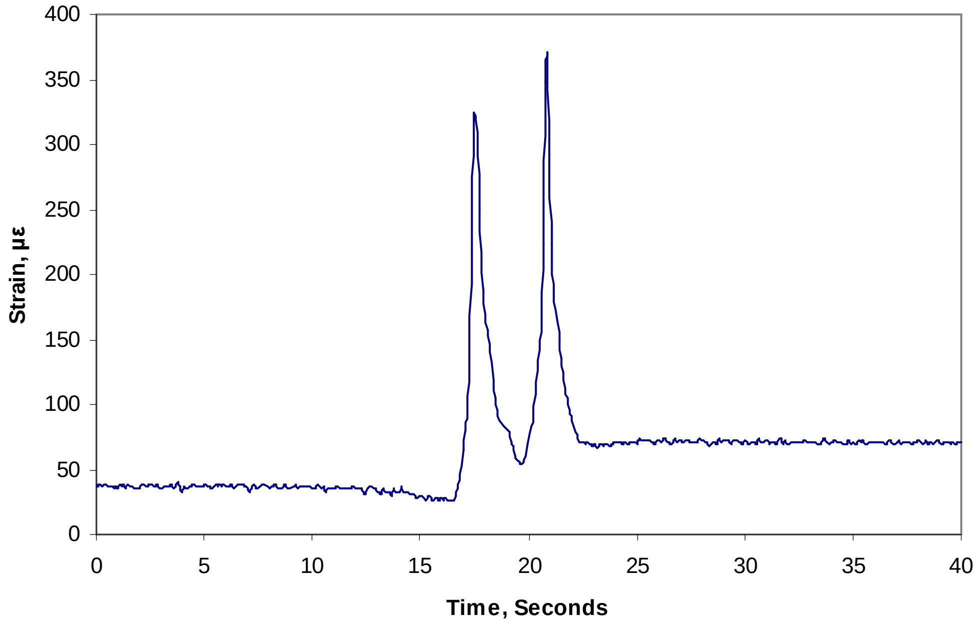

Figure 3-1 - Dynatest PAST II - AC gauge C4 response to roller pass.

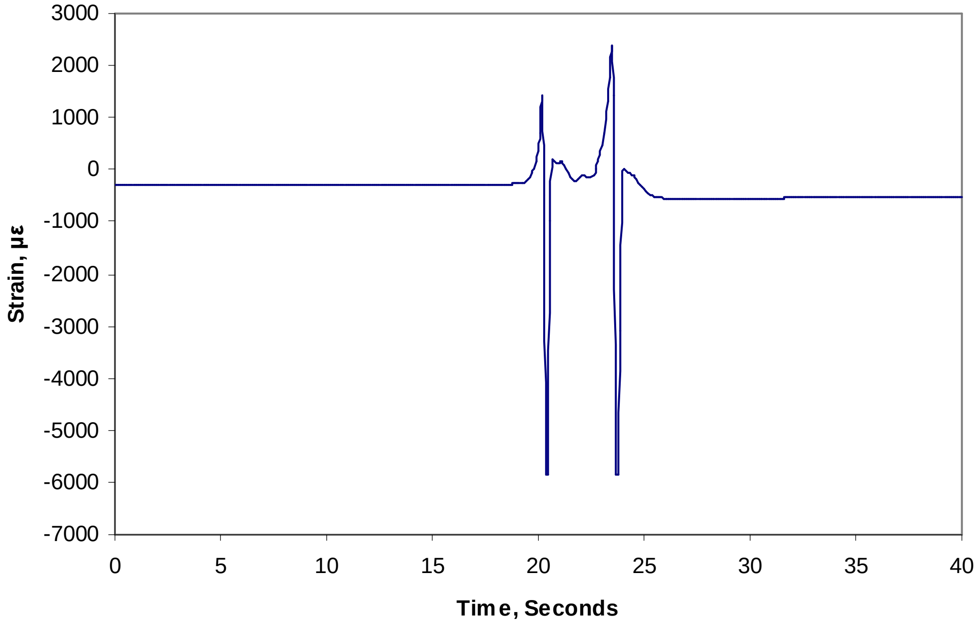

Figure 3-2 – CTL ASG gauge B0 response to roller pass.

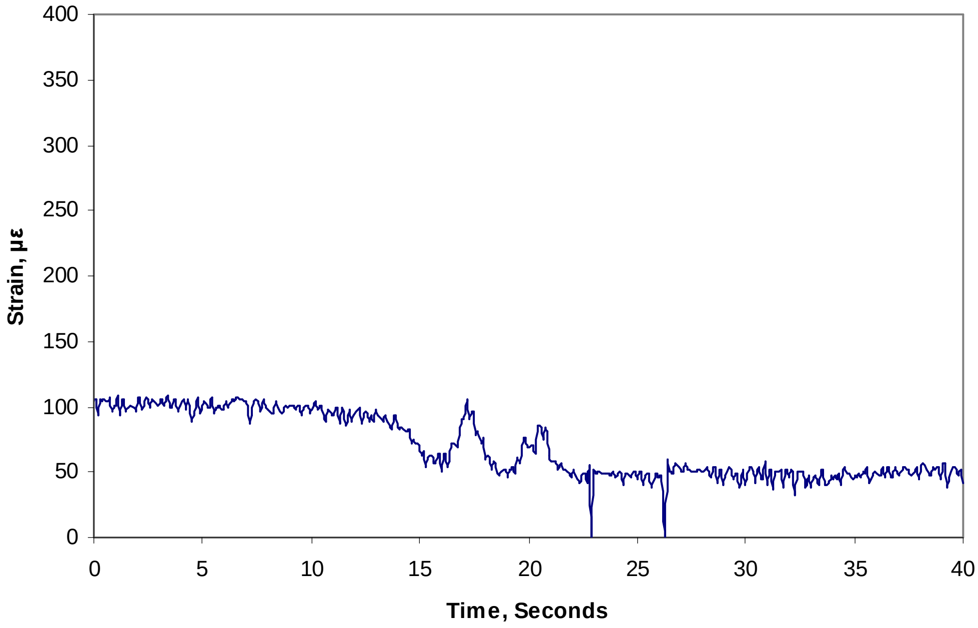

Figure 3-3 –Dynatest PAST II – AC gauge C7 output. Although not explicitly clear, this sensor has a substantial amount of signal noise compared to similar gauges.

Marshall Hammer Testing

This testing was conducted the day after the strain gauges were installed and was done so to check the functionality of the strain gauges. Each strain gauge was located using the GPS based location device and its position marked with paint directly on the pavement. The data acquisition systems were set up and all of the sensor leads connected. (Some sensors such as a few of the moisture and temperature probes were not measured or connected due insufficient lead lengths that needed to be lengthened. Low speed samples were taken using a low speed data acquisition device set up for the purpose of measuring sensors during construction. The system purchased for the project was being set-up for taking high speed strain and pressure measurements.)

Once everything was connected and running, a series of tests were run to check that the sensors were alive and functioning. A Marshall hammer with a rubber pad on the foot was used to stimulate the ASG sensors with four drops in succession. The data acquisition system was started and stopped for each of the series of drops. The series of drops was conducted directly above each ASG sensors.

The data was downloaded and analyzed for functionality of the gauges. Upon inspection, one DynaTest strain gauge (Gauge ID - C6) was unresponsive to the Marshall Hammer drops. A subsequent resistance check of the gauge showed that the resistance was much higher than its gauge resistance of 120 ohms, indicating that the gauge (ID C6 in layout) was damaged and no longer functional (see Table 3-1 for the correct resistance values for the two types of strain gauges). Unfortunately, an adjacent strain gauge (DynaTest ID C7) appeared to have an unusual amount of signal noise. This was an indication that the gauge may have been damaged during paving. All of the CTL ASGs appeared to be in proper working order, as well as the earth pressure cells (although the pressure cells did not respond to the Marshall Hammer drops, passing vehicles did cause observed responses.)

Table 3-1 - Correct resistance values for the two different types of strain sensors. A resistance that is extremely high implies an open circuit. Resistance values lower than the correct value indicates that the sensor is shorting out.

Sensor	Sensor Lead 1	Sensor Lead 2	Correct Resistance Across Lead1 / Lead2, Ohms
CTL Asphalt Strain Gauge	Black	Red	350
	White	Green	350
Dynatest PAST II - AC	Black or Yellow	Blue or Brown	120

Figure 3-4 is a plot of the data generated from the tests using the Marshall Hammer on CTL gauge A0. The plot shows four significant increases in strain that seem to accumulate and slowly return to its previous state. The shape and behavior of these strain impulses were not of much interest at the time, but may be for future research. The point of conducting the test was to stimulate the sensors and get an indication of their functionality. Other gauges produced very similar results to this, with the exception of the damaged gauges.

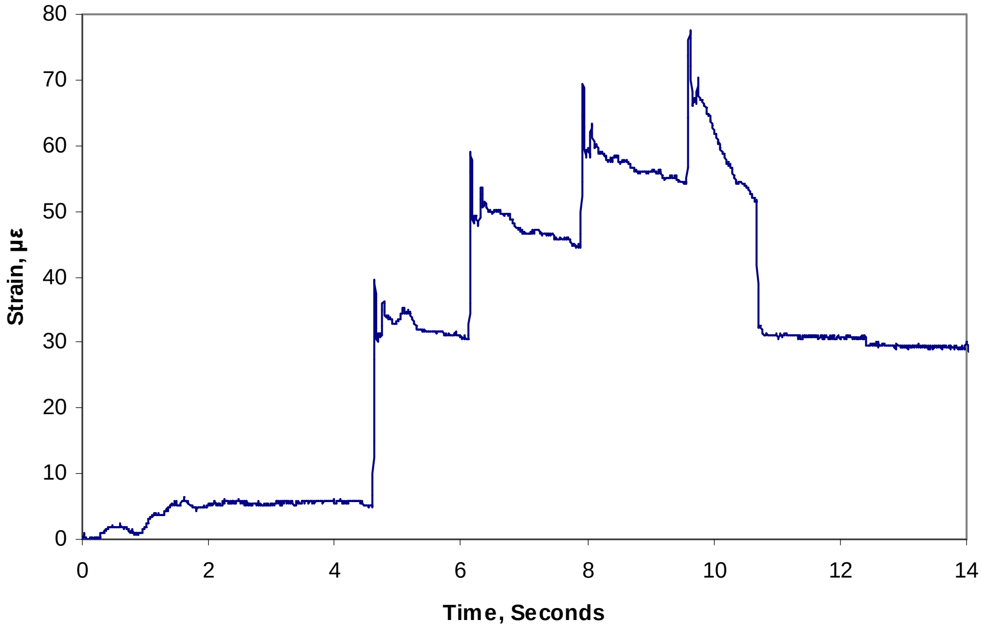

Figure 3-4 – CTL gauge A0 strain in response to a series of four Marshall Hammer drops in succession.

FWD Testing

The final lift of asphalt (SMA wearing surface) in the test section was scheduled for paving in the test section on the night of September seventh and finishing the next morning. Falling Weight Deflectometer (FWD) testing was done beforehand for two reasons. The first was to provide loading to the sensor arrays and record sensor data. The second reason was to record FWD data to gain some insight into the material properties of the pavement. Although FWD testing would be done after the pavement structure was complete, the data was collected as part of an effort to obtain as much information as possible about the pavement.

The FWD was used to create a heavy impulse loading on the pavement while simultaneously recording strain data. Although no detailed analyses of the data have been carried out as of right now, future research may find the data valuable.

FWD tests were done is a series of three tests, each with four drops. Figure 3-5 is a plot of strain response of gauge B1 due to the impulse loading of the FWD. Similar to the Marshall Hammer tests, we see the four distinct drops from the FWD and that the strains seem to accumulate with each drop. There is also a small recovery in between each drop, and over a longer period of time, there is almost a full recovery of strain to it pre-loaded state (this full recovery is not visible in Figure 3-5).

Another set of FWD was acquired on the completed pavement structure at a much later time. Since there was a very narrow window between the final SMA paving and the highway opening, FWD was not conducted during construction. However, a highway shutdown was used (night of October 25th into the following morning) to set a sign bridge structure and FWD testing was conducted on the finish pavement at that time.

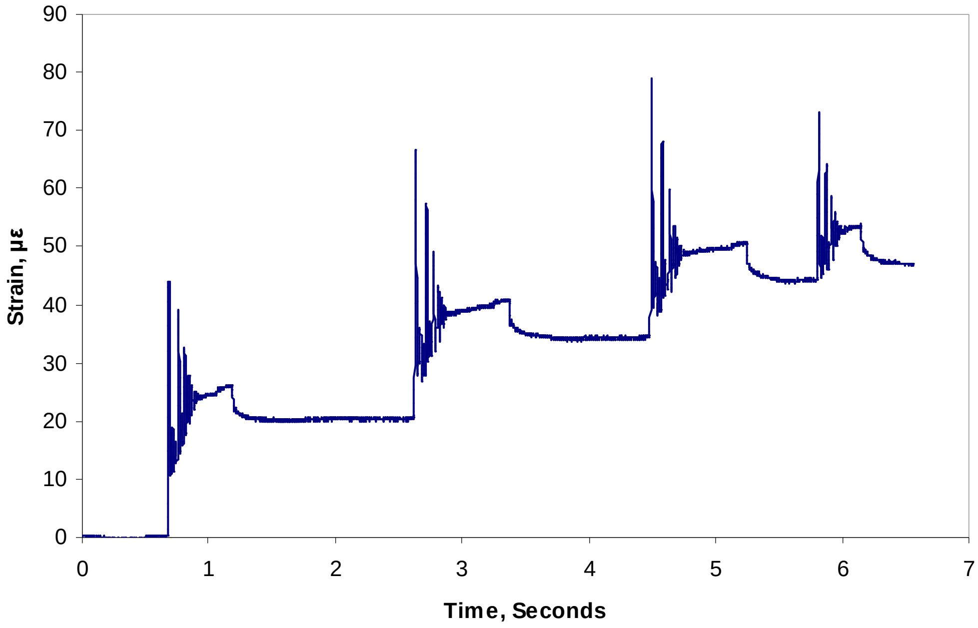

Figure 3-5 – CTL gauge B1 strain response to an impulse loads generated from and FWD.

Chapter 4 – Infrastructure

Some of the critical components of the project are merely incidental items, but took a considerable amount of time to install. These infrastructure components outline the basic framework and provide the necessary means to allow the system to exist. The designs used here were done so in the most simplistic and logical form.

Pull-boxes and Conduit Network

After the majority of the excavation of the Fond Du Lac (FDL) on-ramp concrete pads were cast which would be the future home of cabinets for both the ITS controllers and the equipment for this project. Along with these, pull-boxes were placed, along with conduits running between them. All of the electrical components were installed by Outdoor Lighting according to WisDOT specifications. Two pull-boxes were placed along side the mainline at stations corresponding to the center of the strain arrays and center of the weigh-in-motion/wheel wander systems. A third pull-box exists at an elevation below the roadside cabinet which serves as a drain for the entire conduit system. Open graded stone was used to backfill all of the pull-boxes to drain water. In the case of the pull-box located below the elevation of the cabinet, the backfill material extended, partially, into the select crushed layer and the dense and open graded base layers in the FDL on-ramp. This network is illustrated below in Figure 4-1.

A link between the two different cabinets does exist in the form of two two-inch conduits. One of the conduits is dedicated to supplying the project cabinet with power. Currently the other two-inch conduit is used being used by cables for the sensors mounted to the mast alongside the roadways (infrared thermometer and camera).

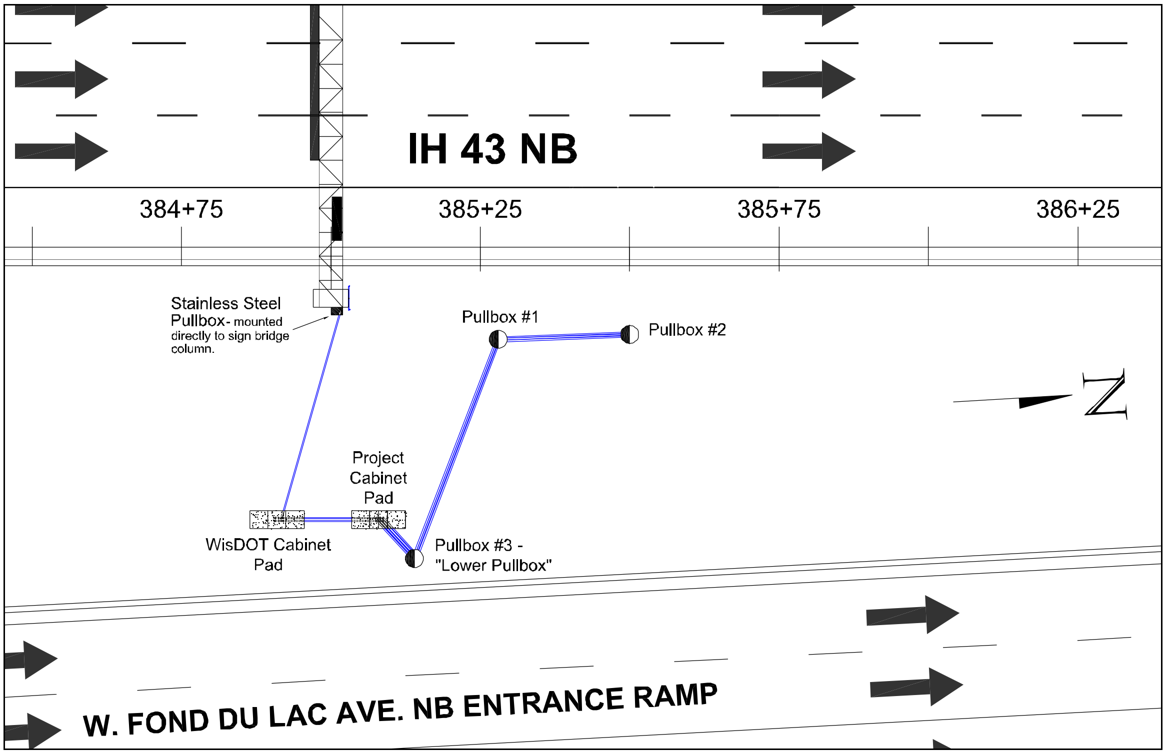

Figure 4-1 - Pullbox locations and the network of conduits connecting them.

Figure 4-1 above shows a conduit running from the column of the sign bridge running to the WisDOT ITS cabinet. The conduits at the sign bridge end are housed in a stainless-steel box. A weatherproof port and flexible conduit mounted into the side of the box allows access for the leads to the instrument mast.

Sensor Conduits - Part I

A week after the installation of the sub-grade sensor arrays and before slip-forming of the concrete curb, conduits were installed which would house wiring for the following equipment: strain gauge arrays, dense graded aggregate layer EPCs, temperature gradient probes, loop detector, wheel wander piezo strips, and weigh-in-motion quartz piezo strips. The layouts of these conduits are identified in Figure 4-2 within the clouded section.

At the time of installation of the conduits, the open graded base layer was being prepared for placement. In part of the test section it had already been placed and stockpiles of the material were left in various locations waiting to be cut to its finish grade. A large area was opened in the open graded aggregate layer along with some of the dense graded aggregate base layers to accommodate the installation of the numerous conduits. The conduits were installed into the lower layer of the dense graded base layer.

It was pre-determined to use a two inch diameter conduit for each strain sensor array and one inch diameter conduits for all others. The ends of the conduits for the earth pressure cells, strain arrays, and temperature gradient probes were placed so that they were as close as possible to the edge of the proposed sensor locations, minimizing the amount exposed wires (this was difficult for the strain sensors, since eight sensors would use one conduit; adding cable armor to the leads took care of this). The ends of the conduits for the weigh-in-motion system, loop detector, and wheel wander strips, were terminated at the proposed face of the curb gutter and were later extended vertically to accommodate the higher elevations of the instruments. All of the placements of the conduits were made using the help of a GPS surveying locator tool.

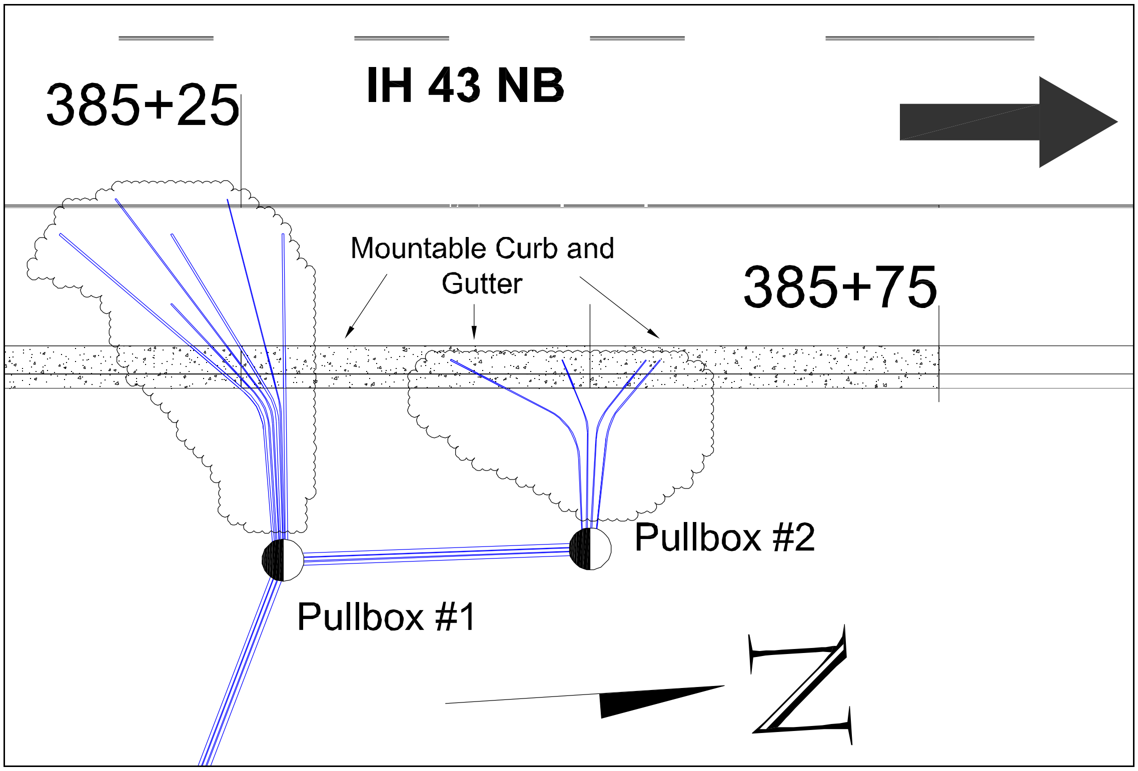

Figure 4-2 – The conduits within the cloud are those installed for the strain sensors, base EPCs, WIM and Wander components.

Since the proposed location of the weigh-in-motion system and wheel wander strips were farther north than the strain sensor arrays, the conduits were run to the northern pull-box which connects to the pull-box housing the strain arrays, pressure cells, etc. and finally into the lower pull-box and up into the cabinet.

After the proposed conduit termination locations were marked, the conduits were laid out, trimmed and inserted into the steel pull-box via ports cut with a hole-saw. The open ends of the conduits were covered with duct tape to prevent foreign material from entering. Before the conduits were backfilled, the exact locations of the ends of the conduits were measured and recorded so that they could be found later and are listed in Table 4-1. The dense graded base layer was replaced and compacted followed by the open graded base layer. Care was taken to keep the layers separate, but some mixing of the layers was inevitable. The open graded base layer was re-worked and re-graded just prior to paving to remove any deficiencies.

Table 4-1 – Location of the conduit ends within the pavement structure. Conduits with an offset of 45.0 feet were terminated at the proposed curb face – in these cases, the locations below are not final and where later modified after paving.

Conduit Description	Conduit Diameter, in.	Station, ft	Offset (RT Of Mainline R/L), ft	Elevation, ft
Strain Array "A"	2	385+12	36.0	659.0
Strain Array "B"	2	385+20	36.0	659.0
Strain Array "C"	2	385+25	36.0	659.0
Base Earth Pressure Cell A1	1	385+16	33.5	659.0
Base Earth Pressure Cell B1	1	385+24	33.5	659.0
Shoulder Strain Gauge	1	385+20	41.0	659.0
Temperature Gradient Probes	1	385+20	45.0	659.6
Wheel Wander	1	385+36	45.0	659.6
WIM #1	1	385+48	45.0	659.6
WIM #2	1	385+54	45.0	659.6
WIM - Inductance Loop Detector	1	385+55	45.0	659.6

Sensor Conduits - Part II

At the time of installation of the base layer earth pressure cells the conduits for the WIM and wheel wander systems (WIM system includes the loop detector) needed to be extended appropriately. This was not done before during the previous conduit work because the concrete mountable curb had not been slip-formed yet. After the curb was placed the conduits were located, excavated, and cut back accordingly to accept 90º elbows so the conduit would run vertically along the face of the flange. These would have to be repositioned once more after the upper layers of asphalt were placed.

Just before the SMA layer was scheduled to be paved, the conduits for the WIM sensors, wheel-wander sensors, and pavement temperature gradient probes were installed. The proposed locations for the sensors were marked on the pavement surface with paint. It was decided to use one one-inch diameter conduits for each WIM strip (two coaxial cables per conduit), one one-inch conduit for all three wheel-wander sensors (three coaxial cables per conduit) and one one-inch conduits to house both pavement temperature gradient sensors (two 16 conductor wires).

Most of the conduit runs for these components had already been complete prior to the placement of the concrete curb and were extended upwards against the face of the curb after it had been placed. Conduits needed to be installed into the pavement layer (the surface of the 7-inch E30 layer) that extended from the conduits at the curb to the edge of the proposed sensor location. Since the WIM and wheel-wander sensors needed to be installed into the surface of the SMA layer, it was proposed to install conduits so that only a small hole was needed to run the sensor cables to the cabinet, thus eliminating cutting unnecessary groves into the new pavement surface. However this was not needed for the pavement temperature sensors, as they would be installed during paving of the SMA layer.

For the two temperature sensors, grooves were cut from the stubbed up conduit at the curb line to the proposed sensor locations. The grooves were cut with a gas powered saw with an abrasive bladed mounted (Figure 4-3 - top left). The grooves were about ¾ inch wide and about ¾ inch deep, just large enough to accommodate the large diameter sensor leads that would be installed into it plus extra room for sealant to be used to secure the wire. One conduit would house both sensor leads. The holes for the temperature probes were not drilled until they were ready to be installed.

For the WIM and wheel-wander sensors, a much larger groove was needed to house the one-inch diameter conduits. A two-inch wide milling wheel mounted on a skid-loader was used to cut the pavement from the conduits to a location just short of the proposed sensor locations (Figure 4-3 - top right). The pavement around the conduits had been cut open and exposed by hand, making it possible to install elbows onto the previously installed conduit stubs.

After the grooves for the WIM sensors were cut, the conduits were placed in the groove. The conduit for the wheel-wander had three extra cuts made that would accommodate the three sensor leads. Pieces of armor cable were used to create smaller access channels for the sensor leads that extended from the base of the proposed wheel-wander sensor locations and inserted into the conduit (though this made it possible to push the wires in only one direction). It is important to note that sharp edges exist on the armor cable when freshly cut and were covered with electrical tape to prevent damage to the sensor leads. In the future it is advised to use flexible tubing that has a smooth interior wall as pushing wire through the armor cable proved to be quite difficult. It is also important that all conduits are sealed tightly just prior to being buried or debris, especially fine material, can be carried into the conduits creating blockages.

Figure 4-3 - Installation of the WIM, wheel wander, and temperature sensor conduits. Top left: Grooves were cut with a saw for the sensor leads for the pavement temperature gradient probes. Top right and bottom left: Groove cut with conduit in place for a WIM sensor. Bottom right: Asphalt being re-compacted into groove cut for the wheel-wander sensors. The plate tamper had a bolt-on bar (circled) mounted on the bottom to fit into the cut to increase compaction efficiency.

After all of the conduits were placed in their proper locations, the exact location of the ends the conduits were measured with the GPS locator and also by using a set of triangulation points. The triangulation points were based off of three nails that were installed into the concrete curb, all of which were located near saw-cut construction joints towards the back of the curb.

Fresh asphalt was then replaced into the grooves in the pavement as seen in the bottom photographs in Figure 4-3 above. Some areas were compacted by hand using a hand tamper, while most the longitudinal portions of the groove were compacted with a gas powered plate-tamper. The day after the conduits were placed, the bucket of a skid-loader was used to trim the re-compacted asphalt flat with the surrounding pavement.

Chapter 5 - Miscellaneous Project Activities

A handful of other tasks were carried out that were important but were not involved with the installation of any equipment. Some of these tasks were important because they dealt with gathering information for future research while others were just observations, but considered noteworthy.

Site Survey and Soil Sampling

As most typical construction projects go, progress takes place in multiple stages. The first steps taken in accomplishing the goal of this project were to take a couple of site surveys where general information was gathered about the chosen location. The initial visits were made before any demolition of the existing pavement and occurred in late April. The first task in the project which consisted of collecting soil samples didn't take place until mid-June.

The project detailed a change in the design of the Fond du Lac (FDL) on-ramp, adjacent to the test section. The existing ramp had a pavement elevation slightly higher than the mainline elevation. The proposed ramp would be many feet below the previous design, thus calling for major work in constructing a secant-pile retaining wall and removal of large amount of soil. Excavation of the ramp at the test location would have to wait until the retaining wall was complete so that excavation of the entire section could begin.

As soon as the mainline excavation was finishing up, select crushed material was placed and graded. Shortly thereafter, excavation began for a sign bridge structure, which included a series of piles for the foundation (it was noted that a large deposit of very gravelly material existed in the excavation for the piles, most likely due some pre-existing construction. It was also noticed that the soil was very wet and the excavation for the piles had to be constantly pumped out. Soils in the excavation were mostly clays). As the structure was being constructed samples of the sub-grade soils were taken at the proposed mainline elevations of the sub-grade (or native materials) from earth slope between the mainline and the FDL on ramp as shown in Figure 5-1.

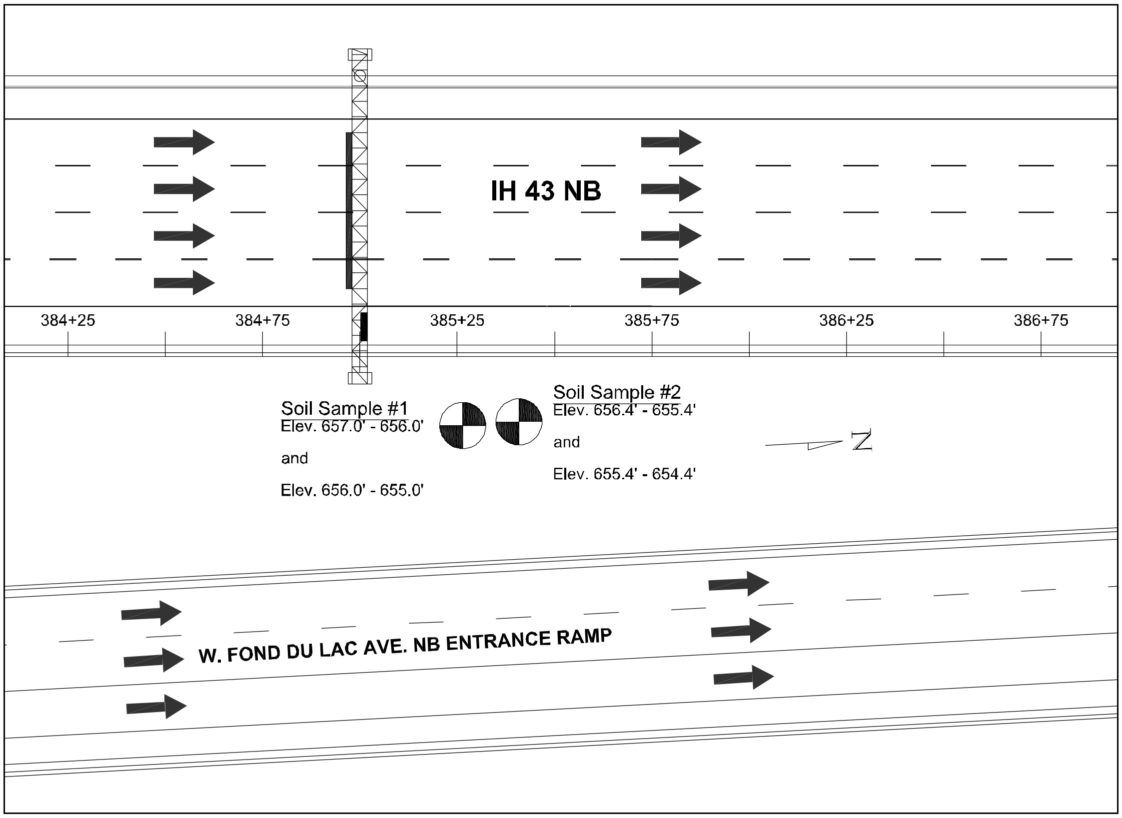

Figure 5-1 - Location of soil samples taken for the project.

The types of soils taken from these locations varied significantly in the small amount of distance that separated them. The soils taken from location #1 in Figure 5-1 were generally very clayey with some gravel throughout. The samples from the location #2 in Figure 5-1 could be better characterized as silty-clays. It was somewhat unknown what the states of the materials were in regards to the previous construction of the highway many years ago. During construction it was noticed that several locations had seams of very gravelly material which, upon further inspection, appeared to be locations of an old system of sewers or other ducts. When installation took place, the soils in the location of the test section appeared to be in an undisturbed state and are assumed to be such.

Pavement Coring

Permission was granted from the guarantor of the pavement to take four four-inch-diameter cores samples, just prior to final of the SMA layer, for future testing and other uses (see Figure 5-2 below). They were taken a substantial distance away from the test section; two taken south of the test section and another two north of the section. Upon removal of one core, the upper pavement layer (upper lift of E30 mix, the SMA layer had yet to be paved) fell away from the rest of the layers. The bond between layers has not been investigated, so the only action taken was to take note of the observation. The core samples were taken back to the lab at Marquette University, preserved by packaging them appropriately, and are currently in storage.

The voids left by the coring were re-compacted in the proper lifts using the properly matched material. A Marshall Hammer was used to compact the asphalt and were finished as flush as possible to the pavement adjacent to it.

Figure 5-2 – Left: Core sample removed from the pavement. Right: The core-drill was secured against the weight of a vehicle to produce samples with very smooth side walls for possible future testing.

Sign Bridge Lift

Poor weather conditions had pushed some of final construction activities behind schedule. It was due to these delays that the wheel-wander and WIM sensors were installed using nightly lane closures, whereas the original plans called for installing them before the highway opened. One aspect of construction that was pushed behind schedule was the erection of large sign bridge structure near station 385+00, just south of the test section.

The sign bridge structure was supposed to be erected before SMA paving, but unknown issues prevented it from being installed. Lagging was set up along roadside in the areas of the project pull-boxes, and the sign structure was lifted and placed on it. The structure remained there until after SMA paving and barrier walls were erected just before the highway opening.

Installation of the sign bridge was scheduled for October 25th and 26th during a night-time full highway closure. The entire highway had to be closed because a heavy-lift crane was brought in to lift the sign structure as one unit over all lanes of traffic as shown in Figure 5-3**Error! Reference source not found.**. The physical positioning of the crane and its outriggers on the pavement was unknown, but it was understood that this could potentially damage the surface mounted instruments. The operation was monitored throughout equipment set-up and lifting. The crews were notified of the sensitive pavement and were very cooperative with avoiding the area.

The closure time was also used as a window to conduct FWD testing on the finished pavement structure. The testing was done in multiple locations while the construction crews were awaiting the arrival of their equipment.

Figure 5-3 - Heavy lift crane lowering the sign bridge into its final resting position. Note that the outriggers for the crane came close to the sensor locations.