

2. EQUIPMENT INSTALLATION

2.1 EVALUATION SITE

The objective of this project is to determine various accuracy parameters of classifying equipment under as nearly ideal conditions as practical. An evaluation site was needed that would accommodate installation of the test devices and equipment cabinets, a mobile office for test personnel, and test instrumentation. The site should also have minimal impact on the accuracy of the equipment under test. The GaDOT provided GTRI with a number of candidate sites for testing with characteristics that meet the specifications listed below, and a final selection was made by a consensus of GaDOT, GTRI, and the FHWA.

2.1.1 Evaluation Site Specifications

The specifications for the evaluation site are listed below.

- A. Horizontal curvature of the roadway lane for 150 feet in advance of and beyond the sensors shall have a radius of not less than 5,700 feet measured along the centerline of the lane;
- B. A longitudinal gradient of the road surface for 150 feet in advance of and beyond the system sensors shall not exceed 2 percent;
- C. The cross-slope (lateral slope) of the road surface for 150 feet in advance of and beyond the system sensors shall not exceed 2 percent;
- D. The width of the roadway lane or lanes being monitored shall be between 10 and 12 feet;
- E. The pavement surface will be relatively smooth and free of rutting and cracking; and
- F. The traffic normally operates in a free flow condition of greater than 30 miles per hour and no more than 65 miles per hour.

2.1.2 Site Location and description

The selected site is located on the westbound side of I-20 east of Covington, Georgia (30 miles east of Atlanta). There are two westbound lanes, but the testing is to be conducted only in the outside lane. The roadway is straight; the grade is less than 1% (westbound is uphill); the cross slope is negligible, and the lane width is 11 feet. The speed limit is 65 MPH, and traffic backups rarely occur.

The evaluation site has traffic that includes all 13 of the FHWA classifications except triple trailer units which are illegal in Georgia. The site is also acceptable for conducting the "Extended Pneumatic Tube Testing" called for in Task F of the statement of work.

The expressway was constructed in 1965 and was improved with an overlay in 1986. The pavement condition is fair with no cracking, dips or uneven areas; however, there is some rutting present. The rutting is most severe at the beginning of the test area (the east end of the site) at approximately 1/2 inch and decreases to approximately 1/4 inch at the end of the test area. It was decided that this amount of rutting is fairly typical and should not be a problem.

2.1.3 Test Facilities and Instrumentation

A mobile field office was placed on the site to house personnel and equipment during the tests. Power poles were installed, wires were run, and breaker boxes installed by the local power company. Instrumentation required for the test included a video camera for classification of vehicles (with lights for videotaping at night), a video camera to record lane changes within the test area, air and pavement temperature recording equipment, and a rainfall quantity sensor. The test instrumentation concept is shown in Figure 1.

The classification camera was mounted near the mobile office on a pole which was 69 feet from the outside edge of the test lane. The camera, in its fan-cooled environmental enclosure, was mounted 40' 4" above the level of the highway surface resulting in a pointing angle of 30 degrees down from horizontal. This mounting gave a sufficient angle of view to determine the position of the vehicle within the test lane. The road was marked with reflective tape at ten foot intervals to allow for vehicle length measurement. Two 1 kilowatt metal halide lights were mounted on the same pole approximately 10 feet below the camera for videotaping at night. A VHS video cassette recorder was located in the mobile office. The video was time stamped for correlation with the classifier data and the lane change video.

The lane change camera was enclosed in a traffic control cabinet mounted on the overpass for State Road 81, and the video cassette recorder was located in another cabinet near the overpass. The camera was mounted such that it was directly over the center line of the westbound lanes and viewed the entire test area. The lane change video was also time stamped for correlation with the classification video.

Temperature and rainfall measuring equipment were set up for each test instead of being permanently installed. Temperatures were measured with thermocouple thermometers, and rain was measured with a digital tilt-pan rain gauge.

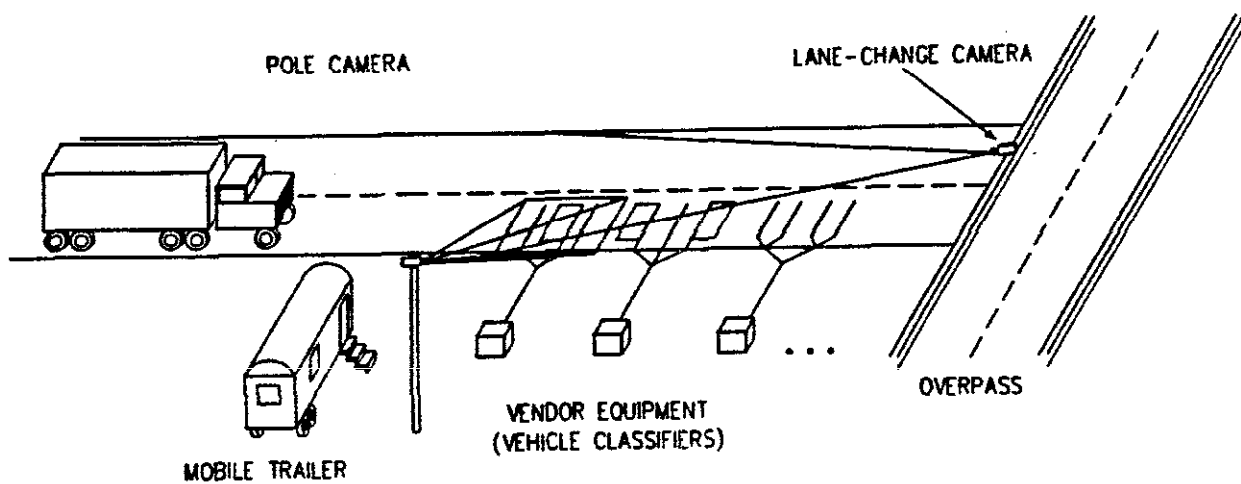


Figure 1. Test Instrumentation Conceptual Drawing

2.2 GENERAL INSTALLATION PROCEDURES

All vendor sensor configurations included in-pavement axle sensors and, in most cases, in-pavement loops. The GaDOT was responsible for providing the equipment, tools, and labor for installing the equipment and was also responsible for traffic control. GTRI monitored and documented the installation process with videotape and written records. The sensors and equipment were installed in strict accordance with the procedures recommended by the vendor, and each vendor sent a representative to supervise the installation. The general procedures presented below were typically followed by each vendor; any exceptions for specific vendors are noted in Section IV.

It was desirable to install the vendor configurations as close together as possible to minimize the overall length of the test area. However, a concern was raised by several vendors about possible electromagnetic crosstalk between their loops the loops of other vendors. Without sufficient separation, a long truck may occupy two vendor's loops simultaneously and induce crosstalk through the truck body. To avoid any potential problems, the spacing between different vendor's loops was maintained at 60 feet or more.

Individual locking equipment cabinets were pole mounted a minimum of thirty feet off the roadway to house each vendor's equipment and protect it from tampering and vandalism. Ground rods were installed at each cabinet, and ground wires were routed into the cabinets for the vendor's use. Cable trenches were dug for the sensor leads. Conduit was supplied for the sensor leads for each vendor who requested it. Some cabinets were supplied with ac power for the classification equipment and for portable computers used for data collection.

The installations were performed mostly during the winter months. Although cold weather installations are not generally desirable, contractual schedule requirements dictated winter installation for this evaluation. Fortunately, Georgia winters are not too severe; the lowest temperature installation was at 38° F, and most were at 50° F or above. The installation procedures included provisions for curing epoxy at low temperatures.

2.2.1 Axle Sensor Installation

The following steps represent a typical installation of an in-pavement axle sensor. These procedures were followed by each vendor except where noted in the detailed installation descriptions of Section IV.

1. Decide on the approximate installation location (leading edge of loop to be situated 60 feet west of the trailing edge of the last vendors loop). Measure the rutting, and adjust the location slightly if necessary.

2. Using a straight edge (10 foot aluminum bar in this case), lay out the sensor configuration and paint guide lines on the pavement. Ensure visually or by measurement that the sensors are perpendicular to the road.
3. Cut each outside edge of the slot with the saw adjusted to the vendor specified depth. Make three or four more cuts inside the previous cuts leaving thin sections of pavement to be removed. Cut a 1/4 slot to the edge of the pavement for the coax cable. To protect the coax from future damage, make the cut deeper near the edge so that the coax will exit the pavement well under ground level.
4. Chip out the excess material using a pneumatic chisel or a hammer and chisel. Use a plywood jig or a ruler to check the depth of the slot. Test fit the sensor to be sure of a proper fit.
5. Wash the slot thoroughly, and blow out any debris using compressed air.
6. Blow out the slot for a few minutes with compressed air to remove any remaining water. Allow the slot to dry thoroughly. Propane torches or torpedo heaters (forced-air, kerosine heaters typically 100,000 BTU) may be necessary depending on conditions. If propane torches are used, do not overheat or melt the asphalt. Torpedo heaters can be utilized more effectively if the hot air is channeled over the slots through tunnels made of cardboard or aluminum sign blanks. In cold conditions, torpedo heaters can also assist in curing of the epoxy by preheating the slot.
7. After the slots are dry, brush all sides with a wire brush to dislodge any dust or dirt that may reduce epoxy adhesion. Blow the slots out a final time with compressed air.
8. Prepare the sensors by attaching leveling bars (typically steel bar stock) to hold it at the right height relative to the pavement surface. The bars are attached using wire or plastic tie-wraps.
9. Form a dam at the coax end of the slot using plumber's putty to prevent the epoxy from flowing out of the sensor slot. Place duct tape along the top of the slot on each side to prevent excess epoxy from adhering to the pavement. Multiple layers of tape can be used to raise the sensor slightly above the road surface by holding the leveling plates slightly higher.
10. Mix the epoxy following the manufacturer's directions. Use a pneumatic or a heavy duty electric drill with a mixing paddle attached. Large paddles of the type used for drywall sealer work very well.

11. Pour the epoxy, and install the sensor. Press the sensor in place, and use a putty knife to remove the excess epoxy or to apply more epoxy to fill any voids around the sensor. Smooth the surface of the epoxy even with the pavement.
12. Place weights on the leveling plates as required to hold the sensor in place.
13. Allow the epoxy to cure in accordance with the manufactures directions. Depending on conditions, torpedo heaters may be necessary to cure the epoxy in the time allowed before the traffic lane must be opened. The same cardboard tunnel arrangement used for drying and preheating can be used for curing.
14. After the epoxy has cured sufficiently, remove the weights and clip the wires or plastic ties holding the leveling plates. Remove the plates by tapping with a hammer. Clip the wires or ties again flush with the epoxy.
15. Route the coax through the coax slot and fill the slot with 3M Loop Sealer. Install the coax in conduit (if used) and route it to the equipment cabinet.
16. Test each sensor using an oscilloscope or by connecting to the classifier.

2.2.2 Loop Installation

The following steps represent a typical installation of an in-pavement loop sensor. These procedures were followed by each vendor with no significant differences except the number of turns of wire as noted in the detailed installation descriptions of Section IV.

1. Locate and mark the loop as in the axle sensor procedure (typically the loop and axle sensor cut lines are all marked at the same time). Chamfer cuts are marked at the corners of each loop to facilitate installing the wire.
2. Make a single cut along each mark using a 1/8 inch saw blade. The cuts should be one inch deep. Cut a slot to the edge of pavement for the lead wires. As for the coax cable, make the cut deeper near the edge so that the wires will exit the pavement well under ground level.
3. Use compressed air to blow out the water and any debris in the cut. It is not necessary to dry the cuts.
4. Starting at the equipment cabinet, route the loop wire (14 AWG type MTW or THHN, oil and gasoline resistant) along the trench to the edge of

the pavement and through the slot cut in the paved shoulder. Place the wire into the loop cuts pressing the wire to the bottom of the cut. The GaDOT installation crew used a pavement saw blade mounted to a handle that allowed it to roll freely to roll the wire into the cut. Install the required number of turns then route the wire back to the equipment cabinet. Leave an extra few feet of wire at the cabinet to allow for twisting and routing.

5. Twist the leads by stretching the wire out straight and placing the ends into the chuck of a drill. Operate the drill until the wire has approximately three turns per foot. Route the wires through the conduit (if used) to the box. Whether conduit is used in the trench or not, conduit is always run from the trench up to the equipment box.
6. Fill the cuts with 3M Loop Seal. The sealer can be applied under wet condition without any apparent problems. Cover the top of the cuts with sand or glass beads. Clean up any excess loop sealer or debris.
7. Test each loop using the digital test instrument supplied by the GaDot. The tester measures the inductance of the loop and indicates the loop frequency stability.

2.2.3 System Testing

After the sensors are installed, the equipment is installed in the cabinet and connected to the sensors. When the lane has been opened and the traffic is travelling over the sensors, the classifier is adjusted if necessary and is checked for normal operation. The vendor makes the determination as to whether the classifier is ready for the evaluation.

2.3 AVC SYSTEM INSTALLATIONS

A summary of each vendor's installation configuration and specific installation procedures, where they differ from the general installation procedures of Section III, are presented below. Any problems that occurred with the installation or with the initial system checkout are discussed. An overall view of the installation layout is shown in Figure 2. The station numbers show that the test area extends from approximately station 183 to station 865 for a total length of 682 feet.

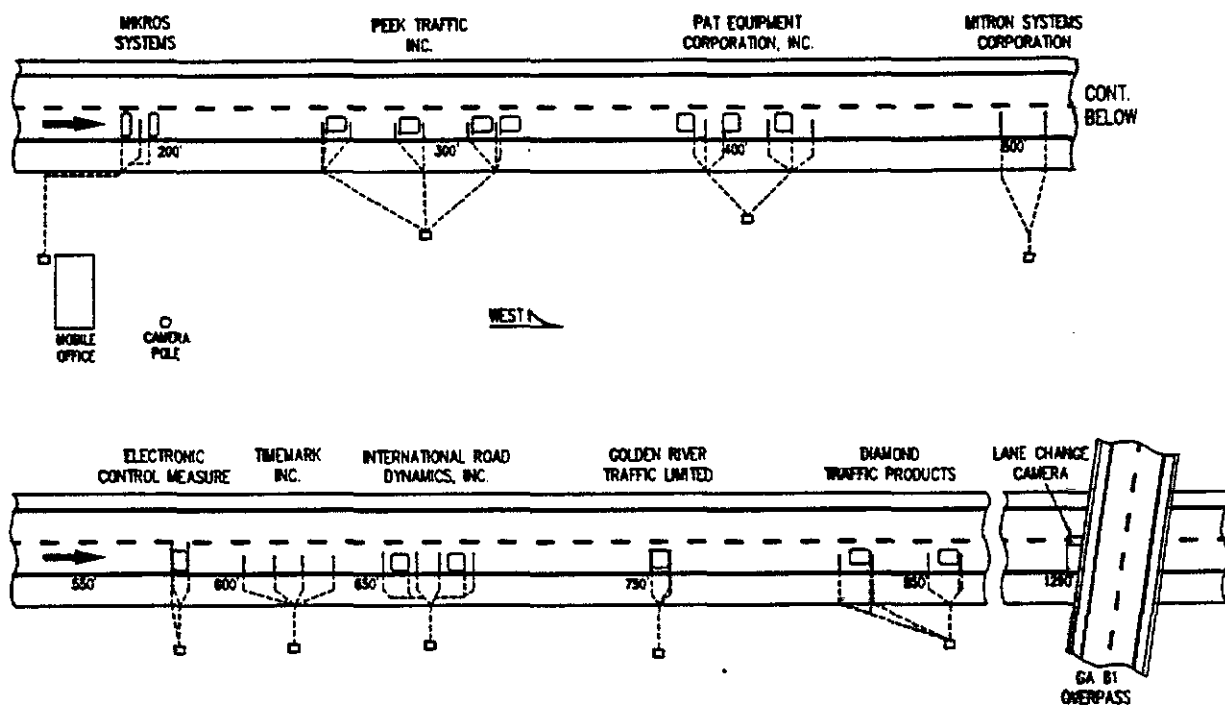


Figure 2. Overall Layout of Evaluation Site

2.3.1 Mikros Systems

Mikros installed a model TEL-2CM classifier with two, three-turn loops and one Philips axle sensor. The sensor layout is shown in Figure 3. The rutting at the location of the axle sensor was 5/32 inch. The installation was performed on 12/3/92. The weather was clear, and the air temperature was 57° F.

The general axle sensor and loop installation procedures were followed. The slots were dried with compressed air, and the epoxy was cured under ambient conditions (no heaters were used). Two layers of duct tape were used along the top of the slot. A strip of duct tape was also used on the top of sensor; it was peeled off after the epoxy cured resulting in a clean sensor surface. The aluminum channel of the sensor was cleaned with solvent prior to installation to insure proper bonding with the epoxy. The epoxy used was Traffic Coil (manufactured by Astor-STAG). The axle sensor was installed using 4 leveling plates.

After the installation was complete, the sensor height profile relative to the pavement surface was measured to determine how well the sensor conforms to the road surface. The measurements were performed by placing a special jig over the sensor with supports resting on the pavement on either side and measuring the height of the sensor surface with a dial caliper. The sensor profile is shown in Figure 4. A sensor height of zero indicates the sensor is flush with the surrounding pavement; negative heights indicate sensor surfaces below pavement level. The rutted area of the road extended from approximately 1.5 feet to 2.5 feet. The plot shows that the sensor was as much as 0.1 inches above the road surface level in the rutted wheel path and was as much as 0.18 inches below the surface at around 3.5 feet.

Initial tests of the axle sensor with oscilloscope verified that it was operational; however, the output levels vary with the position of the vehicle's wheel across the length of the sensor. The sensor performance was determined to be adequate by the vendor. Testing of the loops indicated 89.6 microhenries for loop 1 and 91.2 microhenries for loop 2 with stable frequency readings.

Classifier installation, checkout and training were performed on 12/17/92. The vendor indicated that the classifier was functioning properly and was ready for testing.

The coax and loop leads were broken on 1/28/93 by the power pole installation vehicle. On 1/29/93, the leads were spliced (soldered) and encapsulated inside a six inch section of PVC pipe filled with silicone caulk. The new leads were run in a deeper trench routed away from traffic in the mobile office area. System retests by the vendor indicated that the sensors and classifier were functioning properly.

MIKROS SYSTEMS

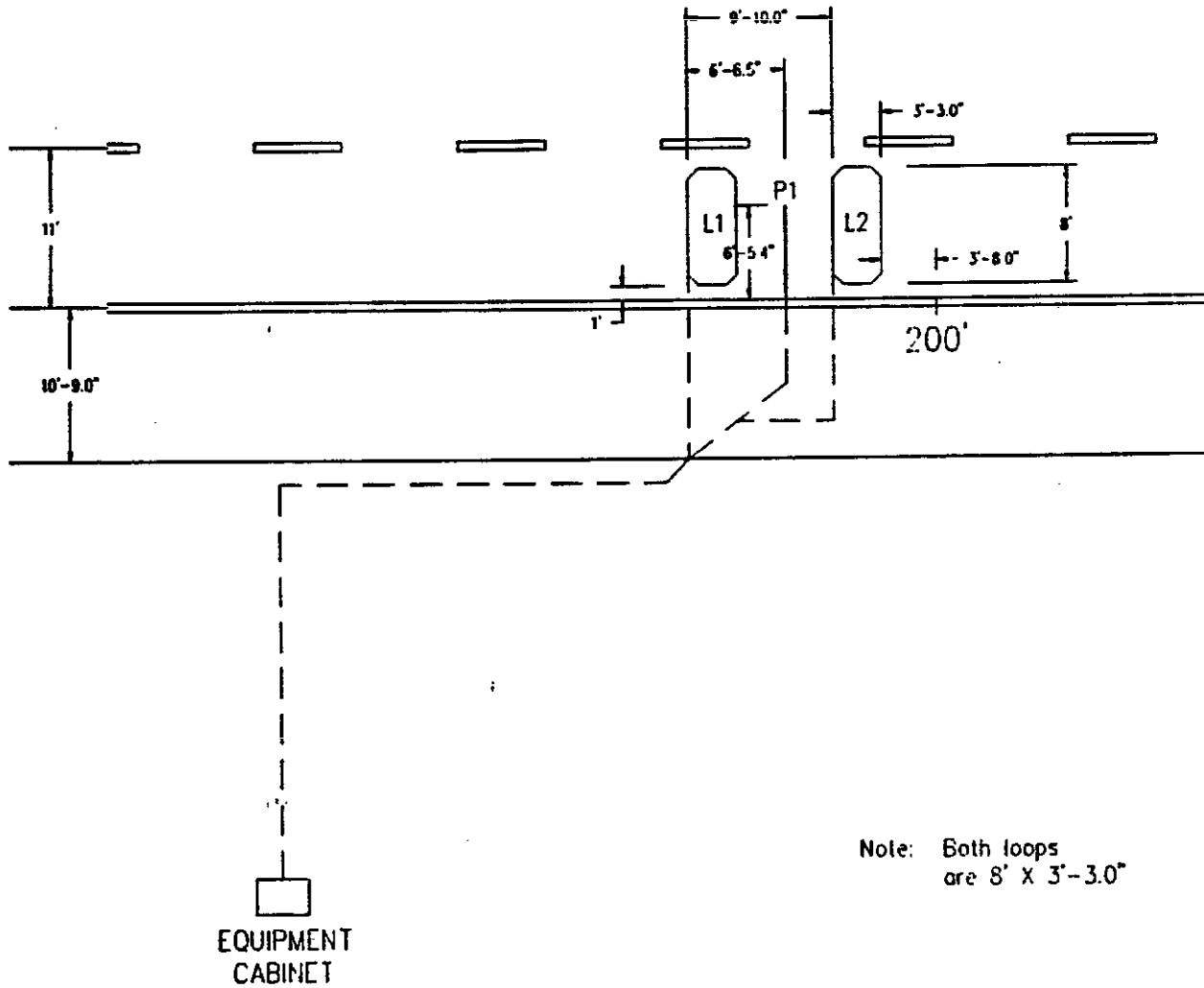


Figure 3. Mikros Installation Configuration Drawing

MIKROS SYSTEMS

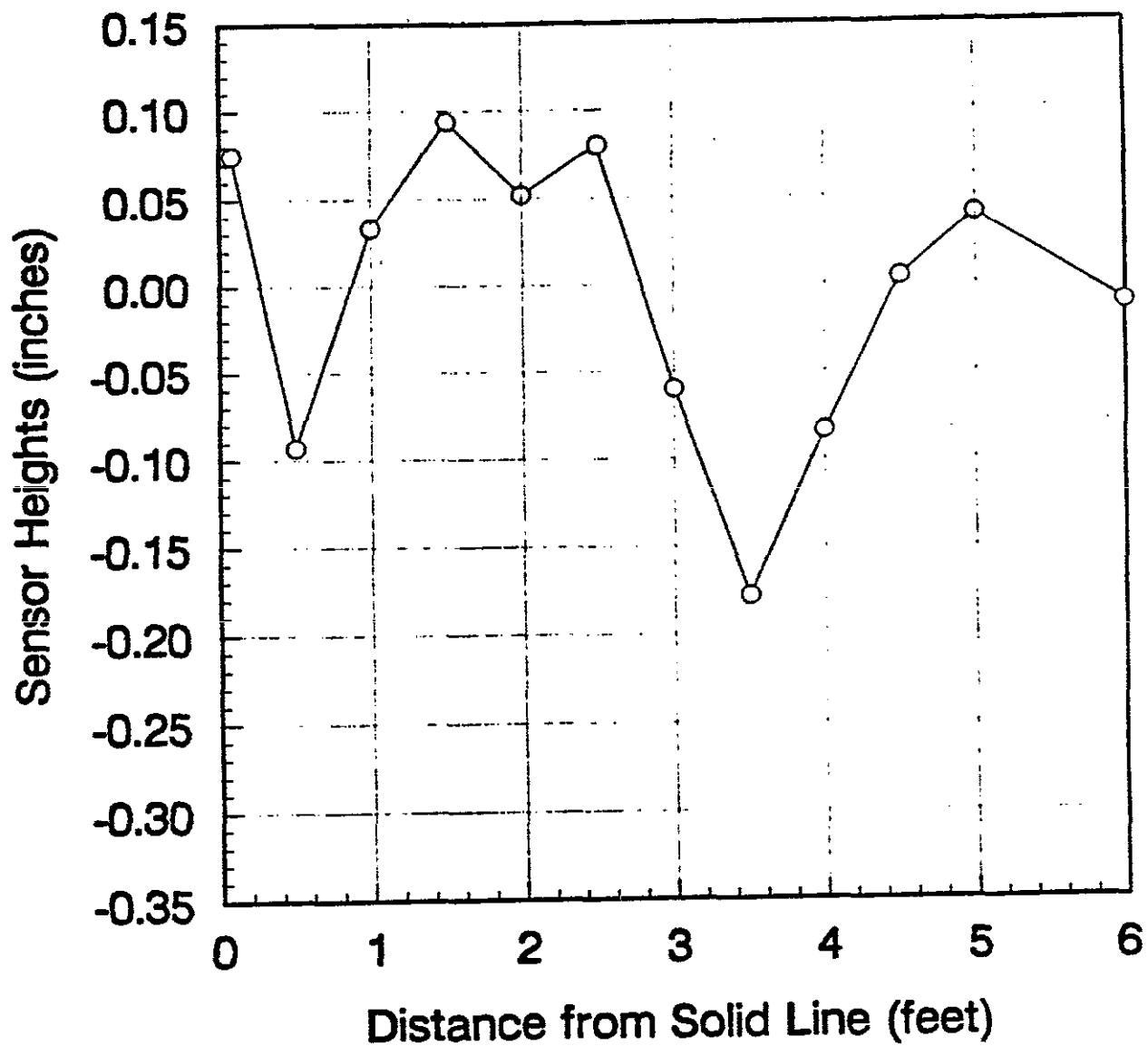


Figure 4. Mikros Axle Sensor Profile

2.3.2 Peek Traffic Inc.

Peek installed a model 241 TrafficComp III classifier with one set of sensors and a model GK 6000 classifier with two sets of sensors configured as two lanes. The sensor layout is shown in Figure 5. The TrafficComp uses two philips piezoelectric axle sensors and one three-turn loop. The GK 6000 uses two philips piezoelectric axle sensors for each configuration (loops were installed for the GK 6000, but were not used during the tests). The rutting at the location of axle sensors 1 through 6 was 14/32, 15/32, 13/32, 14/32, 13/32, 12/32, respectively. The installation was performed on 11/23/92 (axle sensors 1-4 and loops 1-2) and 11/30/92 (axle sensors 5-6 and loops 3-4). The weather was partly cloudy and 59° F on the 23rd, mostly sunny and 55° F on the 30th.

The general axle sensor and loop installation procedures were followed. The slots were dried with compressed air, and the epoxy was cured under ambient conditions (no heaters were used). Three layers of duct tape were used along the top of the slot. A strip of duct tape was also used on the top of sensor; it was peeled off after the epoxy cured resulting in a clean sensor surface. The epoxy used was Traffic Coil. The axle sensors were pre-bent slightly to conform to the local rutting, and were installed using 4 leveling plates. The resulting sensor profiles in Figure 6 show that all of the sensors were close to, or above, the pavement surface level over most of their length. The worst case height variation for any sensor is 0.2 inches (sensor 4).

The axle sensors were tested with an oscilloscope and were all working properly. The loop used for the TrafficComp III (loop 3) measured 140 microhenries and demonstrated good frequency stability. The other loops were functioning properly as well, but were not used during the evaluations.

Classifier installation, checkout and training were performed on 3/24/93. The vendor indicated that both classifiers were functioning properly and were ready for testing. During a subsequent checkout of the TrafficComp III, the processor board latched up several times requiring an internal reset. The vendor supplied a replacement processor board.

PEEK TRAFFIC INC.

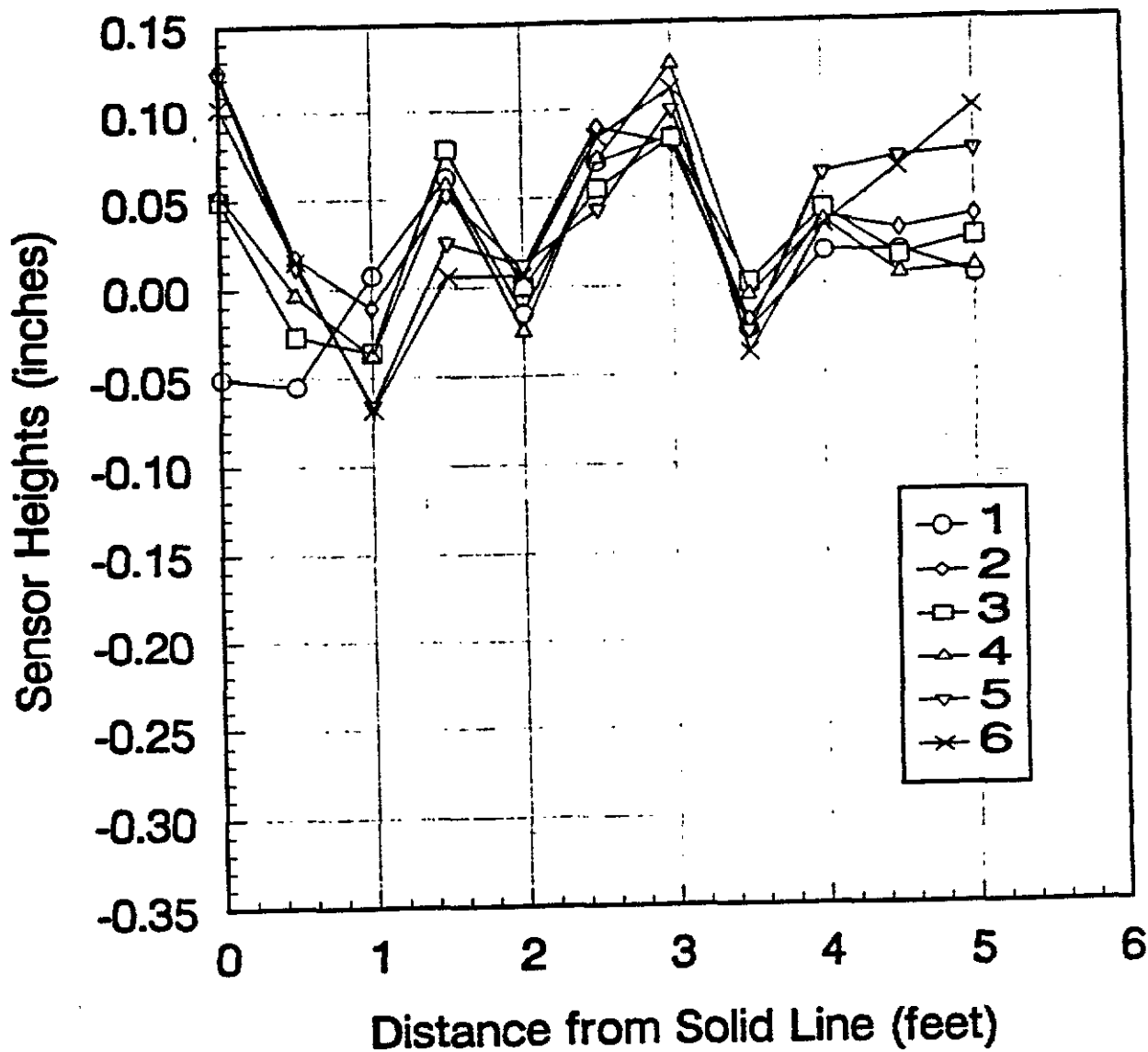


Figure 6. Peak Axle Sensor Profiles

2.3.3 PAT Equipment Corporation

PAT installed two AVC-100 classifiers each with one set of sensors. The sensor layout is shown in Figure 7. The first unit uses one Philips piezoelectric axle sensor and two four-turn loops. The second unit uses two Atochem piezoelectric axle sensors and one four-turn loop. The rutting at the location of axle sensors 1 through 3 was 11/32, 12/32, 11/32, respectively. The installation was performed on 12/9/92. The sky was overcast, and the air temperature was 38° F.

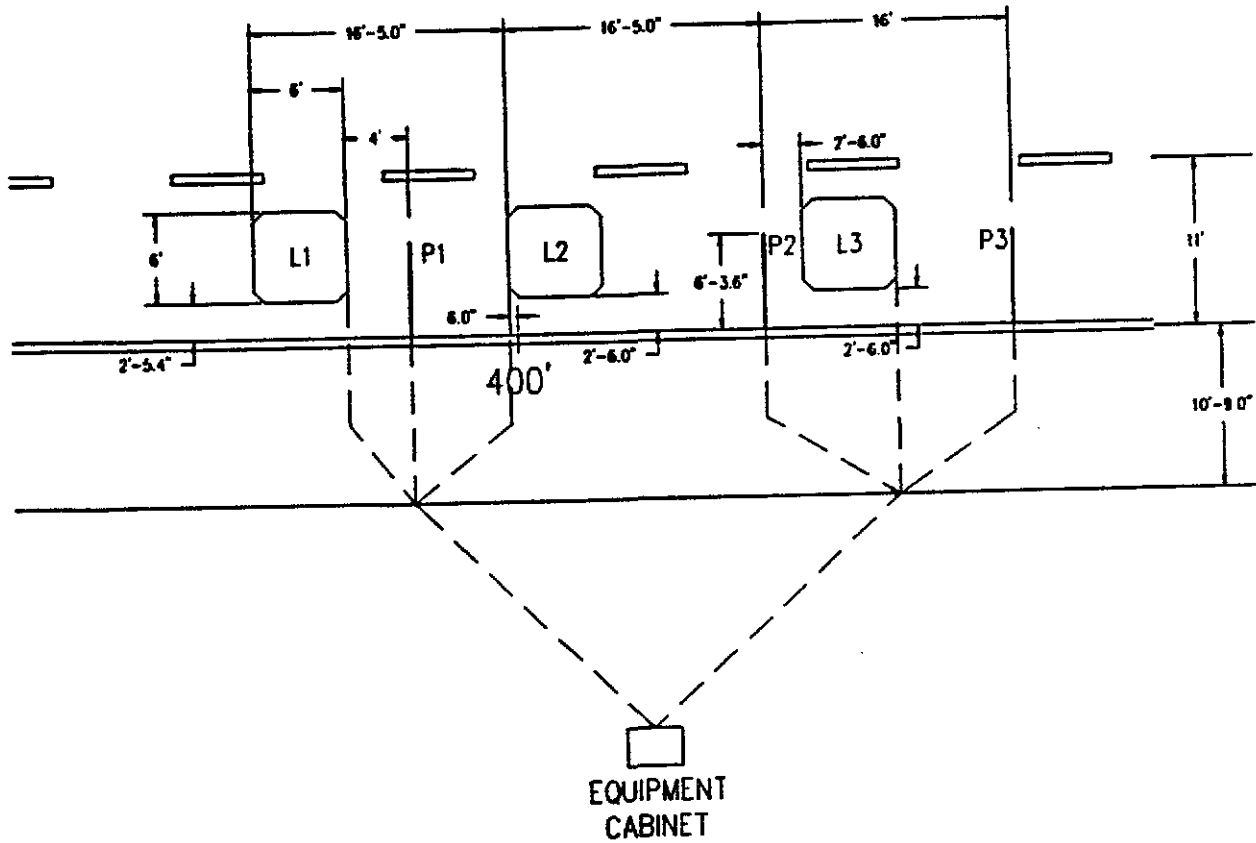
The general axle sensor and loop installation procedures were followed. The slots were dried and preheated using kerosine "torpedo" heaters. No duct tape was used along the top of the slot or on the sensor. Care was taken to scrape off any epoxy on the pavement surface, and epoxy on top of the sensors was smoothed off flush with the road surface. The epoxy used was E-Bond G-100. The Atochem axle sensors were pre-bent slightly to conform to the local rutting, and were installed using only two leveling plates. The philips sensor was not pre-bent; it was installed to be flush in the rut, and the low spots were covered with epoxy. Since the ambient temperature (38° F) was too low for efficient curing of the epoxy, all three sensors were cured using torpedo heaters.

The sensor profile in Figure 8 shows that the number one sensor is flush with the pavement in the wheelpath as intended, and is below the pavement everywhere else. The number two sensor is very low (-0.3 inches) near the solid line, but is near or only slightly below the pavement in the wheelpath and beyond. The number three sensor is at -0.05 to -0.13 inches from the solid line out to well beyond the wheelpath.

Axle sensors were tested with an oscilloscope and were all working properly. Loops 1 through three measured 143, 146, and 145 microhenries, respectively, and demonstrated good frequency stability.

The classifiers were installed in the cabinets and were tested. The vendor indicated that one classifier was not working and that the other classifier was functional but missed too many axles. The vendor returned on 5/5/93, repaired the classifier, and added an enhanced printed circuit card. The axle sensor signals were too low and variable. In order to get acceptable signals, strips of bituthane tape approximately one inch wide were placed over the low areas of each sensor to build them up to pavement level. Both classifiers were then approved by the vendor for testing.

PAT EQUIPMENT CORPORATION, INC.



Note: All loops
are 6' X 6',
and all sensors
are 6'-3.6" long

Figure 7. PAT Installation Configuration Drawing

PAT EQUIPMENT CORPORATION, INC.

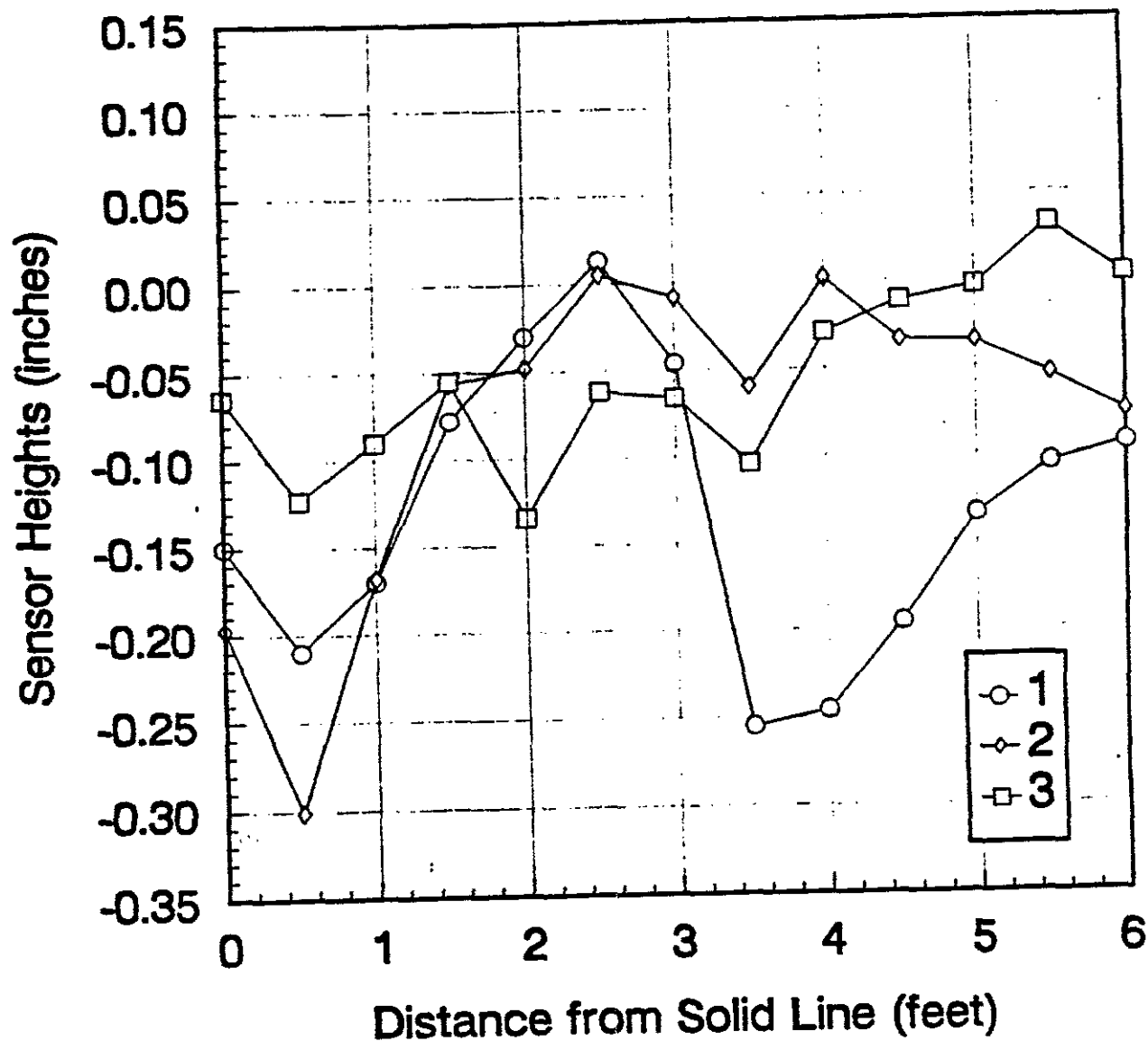


Figure 8. PAT Axle Sensor Profiles

2.3.4 MITRON Systems Corporation

Mitron installed a model MSC 3000, single lane classifier with two Autologger-Gates piezo cable Mini Replaceable axle sensors. These sensors consist of a channel which is epoxied into the road and a replaceable sensor element. The channel has a short section of copper conduit on one end to which 3/4" plastic tubing is attached to form a conduit from the channel to the edge of pavement for the coax cable. The sensor layout is shown in Figure 9. The rutting at the location of both axle sensors was 9/32 inch. The installation was performed on 12/7-8/92. The weather conditions were: overcast, light rain (in the morning), and 42° F on the 7th; partly cloudy and 43° F on the 8th.

The channel was installed much like a typical piezoelectric sensor, and the general axle sensor installation procedures were followed. In order to get the maximum cure time, the slots were cut one day then filled with sand. The next morning the slots were cleaned then dried and preheated with torpedo heaters. Two layers of duct tape was used along the top of the slot. A strip of duct tape was also used on the top of channel to keep epoxy out. The epoxy used was E-Bond G-100. The channels were installed using 16 leveling plates, and since the channels were slightly flexible, good conformity to the rutting profile was achieved. Epoxy was poured to fill the slot approximately half full. The channel was placed in the slot and seated so that the leveling plates were in contact with the pavement. A new empty caulk tube was filled with epoxy, and using a manual caulk gun, the voids along the sides of the channel were filled. The epoxy was then smoothed with a putty knife. Since the ambient temperature (43° F) was too low for efficient curing of the epoxy, the sensor channels were cured using torpedo heaters.

The next day, the sensor element was installed in the channel. The protective tape is removed and the channel is thoroughly cleaned of any debris. The sensor element is laid out along the channel, and the coax is fed through the conduit. Each end and the middle of the sensor element is initially seated in the channel then the element is hammered in place with a rubber mallet. The sensor is very tight in the channel, but several screws are used to ensure the element is held in place. The screws are countersunk in the channel and the heads are covered with caulk.

Initial tests of the axle sensor with oscilloscope indicated outputs slightly lower than desired by the vendor. The first set of elements were damaged by snow plows as well, and were replaced on 2/11/93. The replacement procedure involved removing the screws and pulling up the sensor element then installing a new one as before. The coax on one of the replacements was very difficult to feed through the conduit, which probably should have been a little larger.

Classifier installation, checkout and training were completed on 2/11/93. The vendor indicated that the classifier was functioning properly but the new sensor output levels were still too low for accurate operation. Thin shims were placed under both sensors to raise them higher above the road surface. The vendor verified that the system was ready for

evaluation. The installed sensor element profile in Figure 10 shows that the elements protrude above the channel slightly (+0.05 to +0.14 inches) and conform fairly well to the road surface.

MITRON SYSTEMS CORPORATION

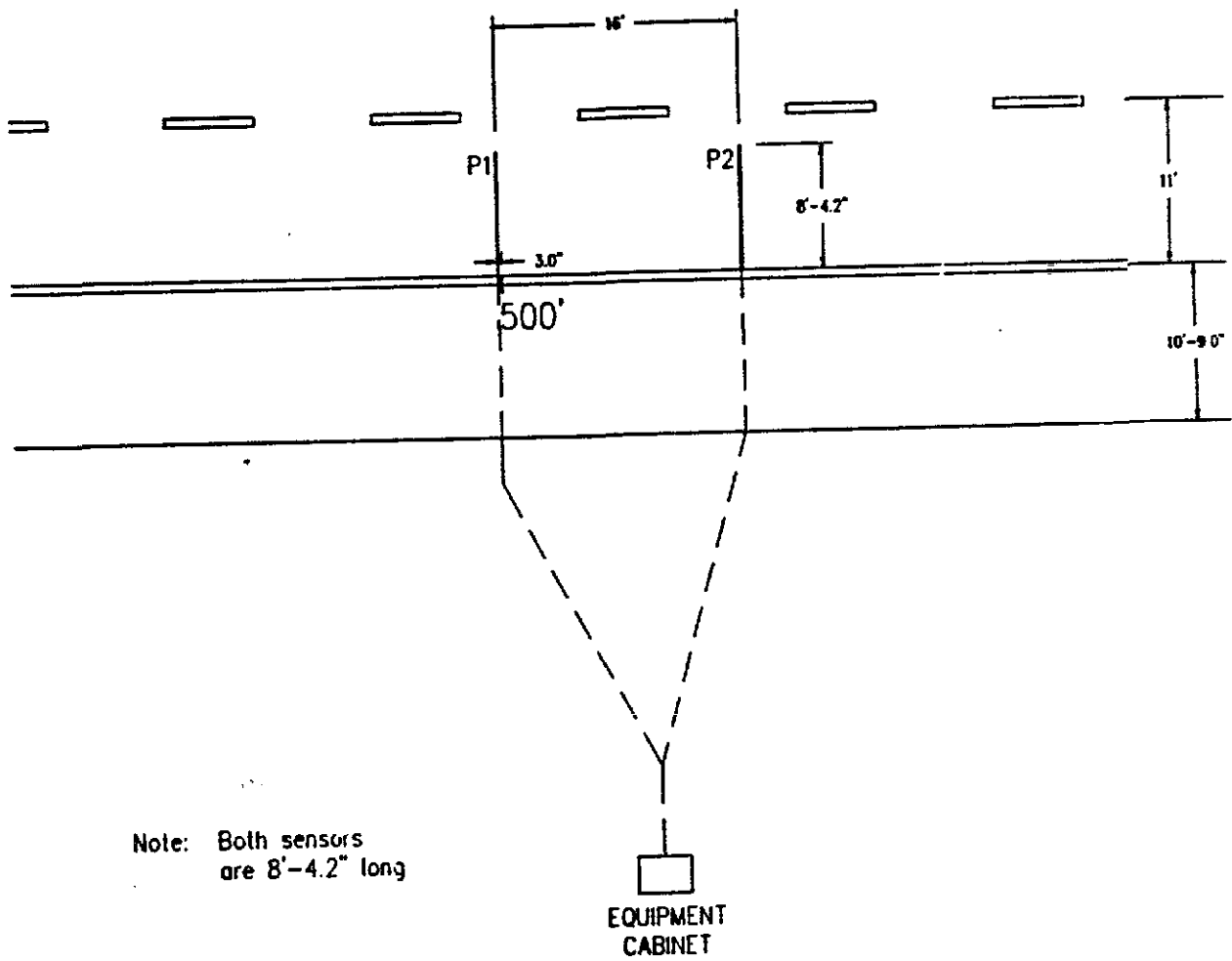


Figure 9. Mitron Installation Configuration Drawing

MITRON SYSTEMS CORPORATION

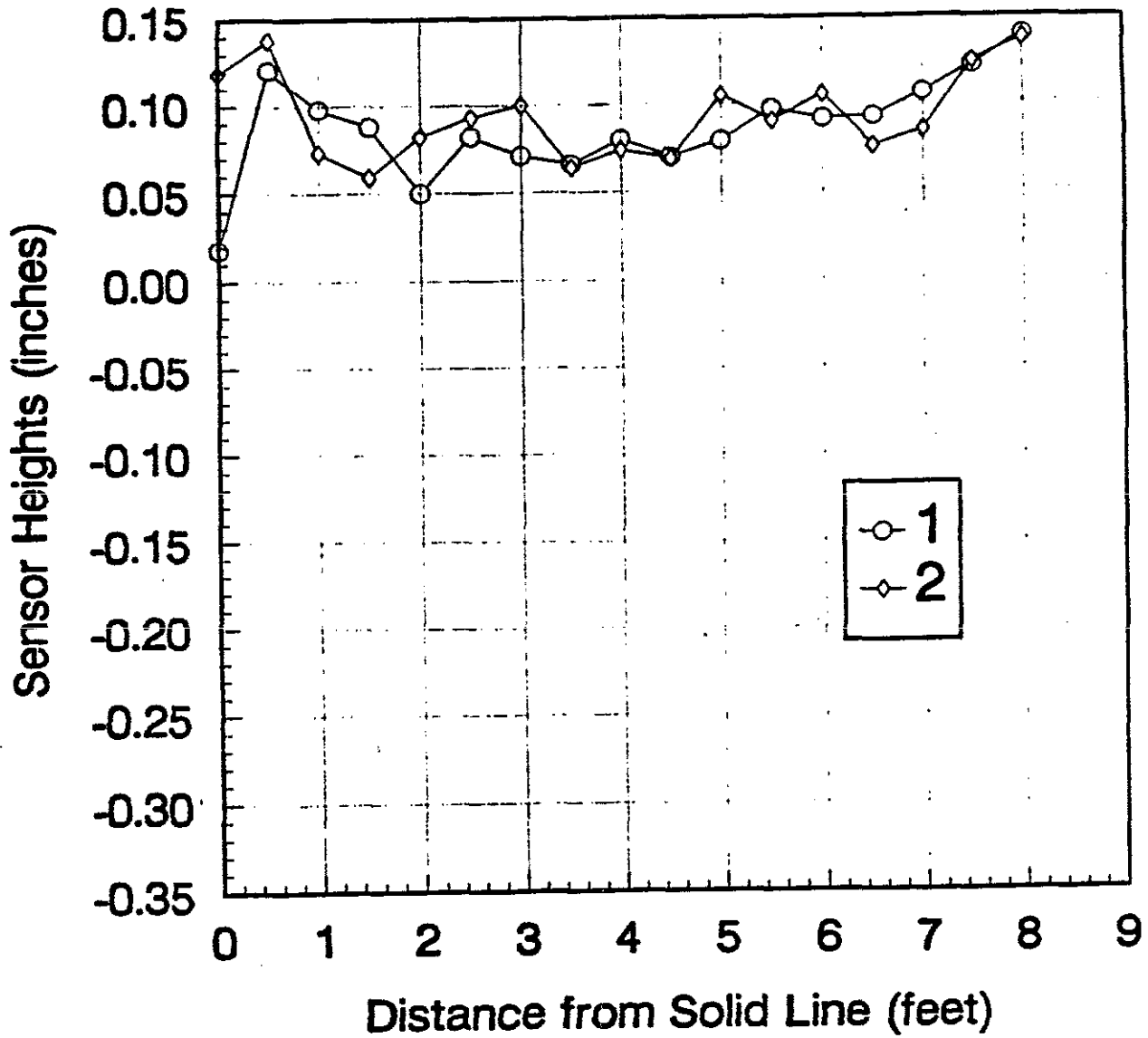


Figure 10. Mitron Axle Sensor Profiles

2.3.5 Electronic Control Measure

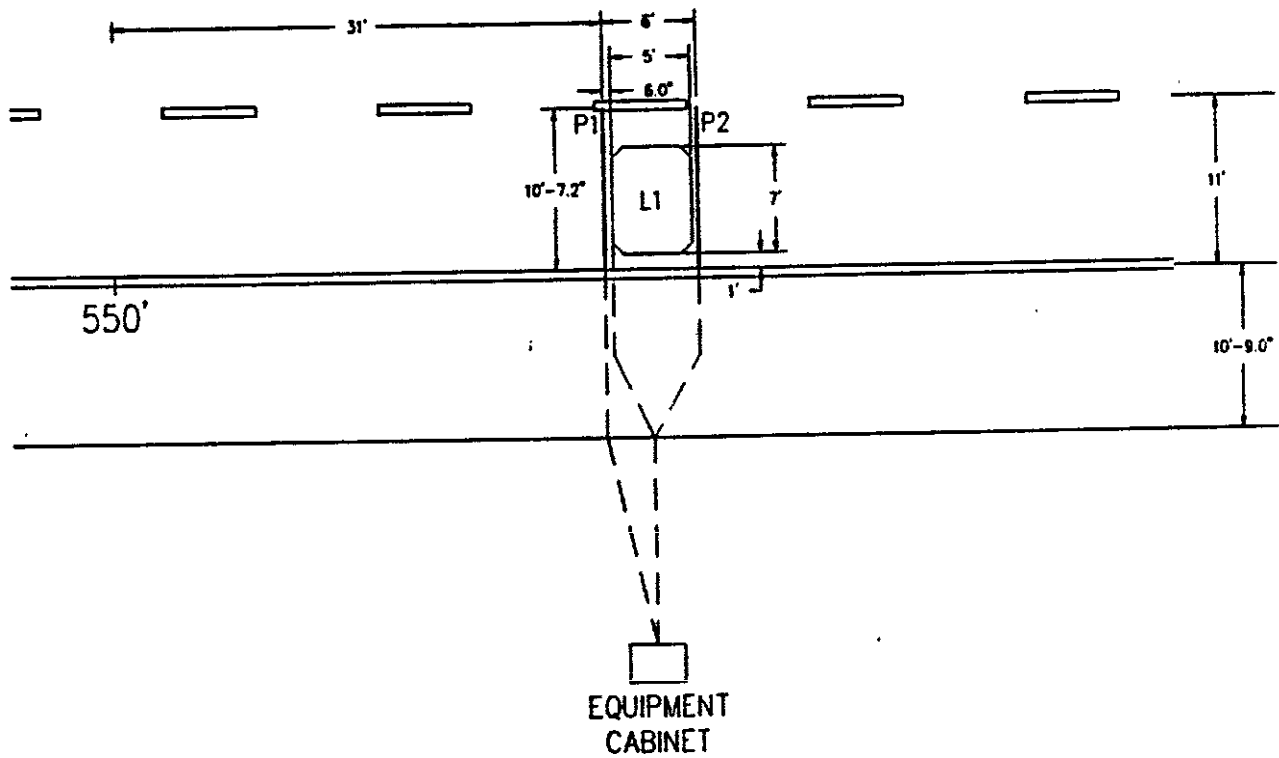
ECM installed a model HESTIA classifier with ECM piezoelectric axle sensors (part number PB2N33/25). The sensor layout is shown in Figure 11. The rutting at the location of both axle sensors was 6/32 inch. The installation was performed on 12/10-11/92. It was lightly raining and 47° F on the morning of the 10th; the asphalt cutting was done that afternoon after the rain stopped. On the 11th, when the sensor was installed, it was partly cloudy, 47° F, and windy.

The general axle sensor installation procedures were followed. The slots were cut one day, but because of the rain, the installation could not be completed. The slots were filled with sand and one turn of loop wire was installed in the loop cuts to protect them. The next day the loop wire was pulled from the cuts to clean out any debris, and the sand was cleaned out of the sensor slots. The slots were washed out, dried and preheated with torpedo heaters. Two layers of duct tape was used along the top of the slot. The epoxy used was ECM proprietary. The sensors were installed using 11 leveling plates, and since the sensors were flexible, good conformity to the rutting profile was achieved. Because of their flexibility, the sensors are always kept in an aluminum channel to protect them from bending and possible damage until they are installed. Sufficient epoxy was poured such that when the sensor was placed in the slot, epoxy was forced out. The epoxy was then smoothed with a putty knife. Weights were placed on the plates to hold the sensor in place until the epoxy starts to harden. The plates were then removed, and the epoxy was heated using torpedo heaters and a full length cardboard tunnel until completely cured. The installed sensor element profiles in Figure 12 show that these sensors are nearly level with the pavement and conform very well to the rutting.

Loop measurements indicated 139 microhenries and good stability. Initial tests of the axle sensors with an oscilloscope indicated outputs slightly lower than desired by the vendor and somewhat erratic for one sensor. The number one sensor frequently gave negative output voltages, low voltages, and occasionally missed axles completely. The number two sensor output was low but fairly consistent. Sensor number one was later replaced. The replacement procedure involved cutting the old sensor out with multiple passes of the asphalt saw. All of the sensor was removed and most of the old epoxy. The same installation procedure was used for the new sensor. The new sensor was slightly different in that it was manufactured with molded-in metallic strips to limit the flexibility and protect the sensor from bending damage.

After the sensor replacement, the classifier was functional but missed too many vehicle axles due to low sensor output levels. In order to get acceptable signals, strips of bituthane tape approximately one inch wide were placed over the entire length of both sensors. The classifier was then approved by the vendor for testing.

ELECTRONIC CONTROL MEASURE



Note: Both sensors
are 10'-7.2" long

Figure 11. ECM Installation Configuration Drawing

ELECTRONIC CONTROL MEASURE

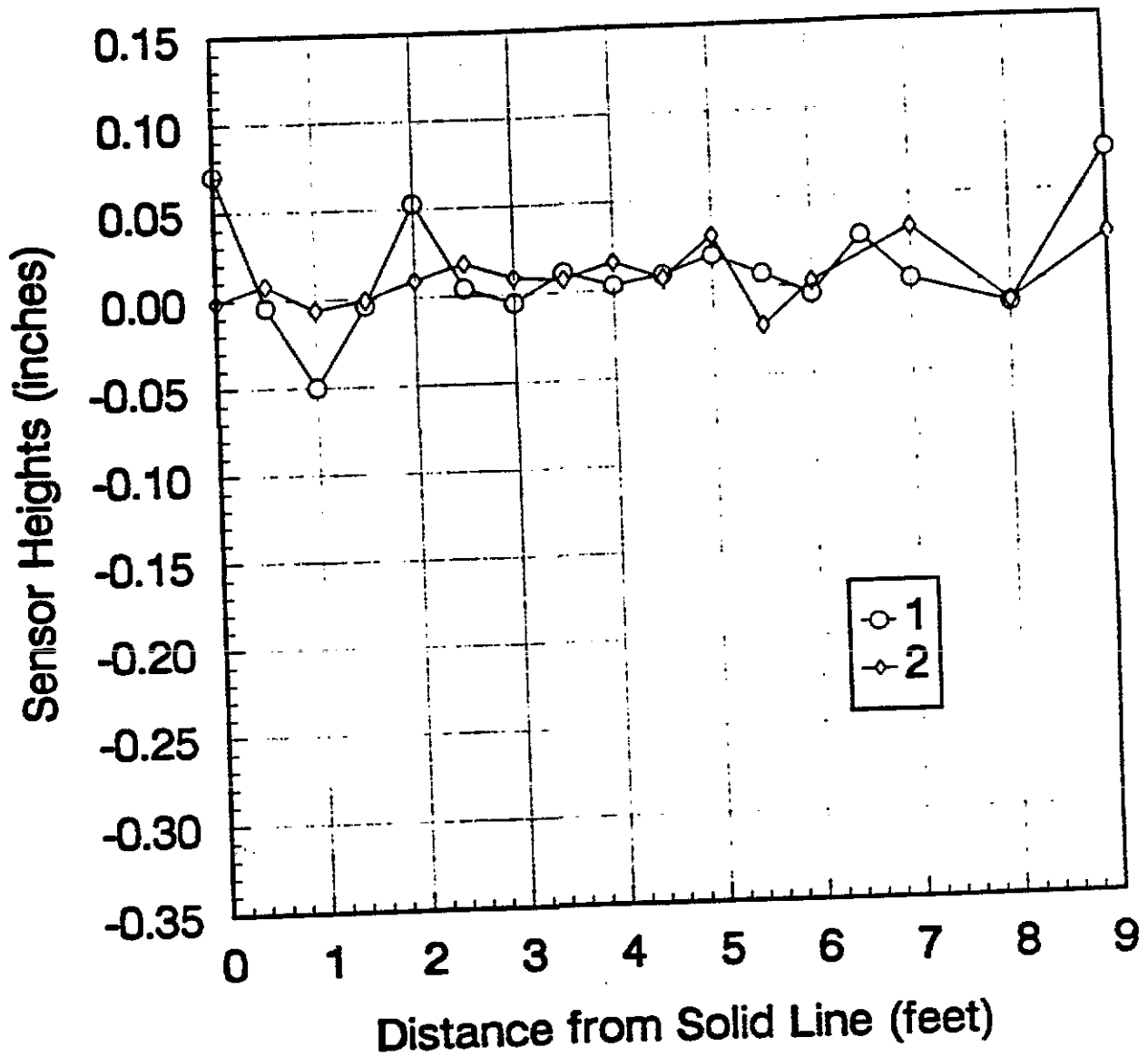


Figure 12. ECM Axle Sensor Profiles

2.3.6 TimeMark

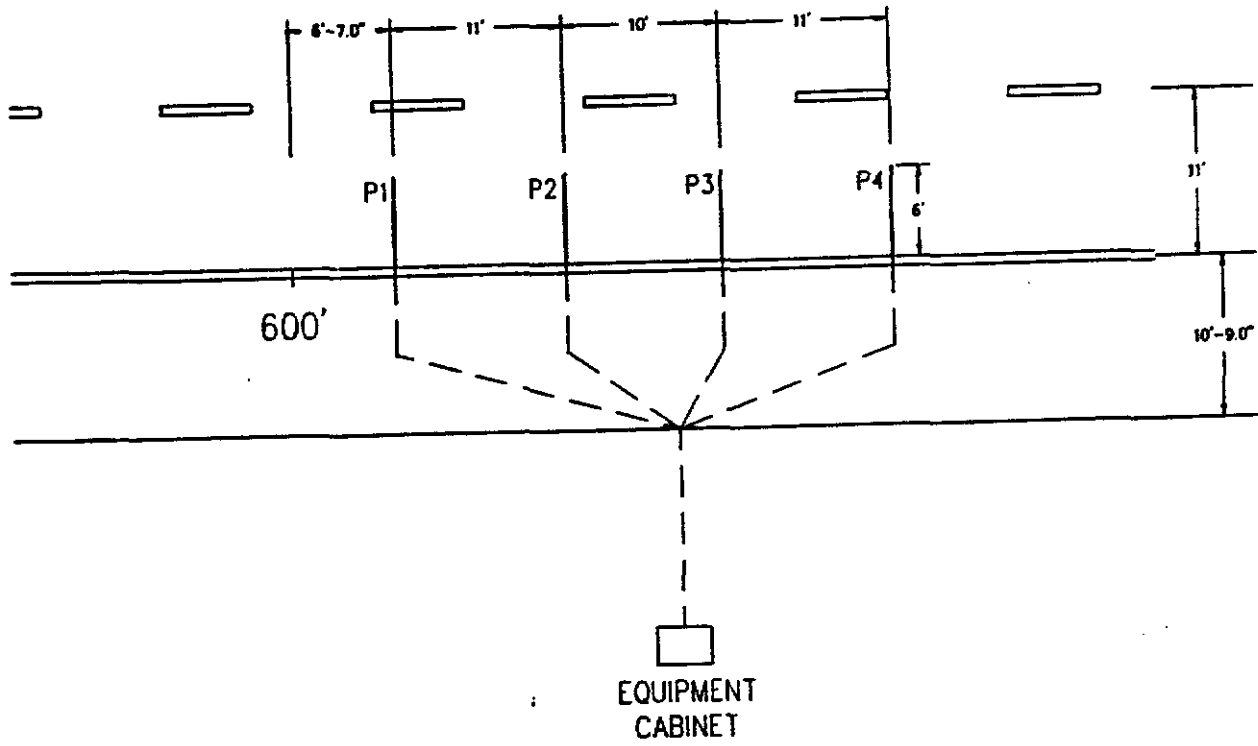
TimeMark installed two classifiers (DELTA I and DELTA II) each with one set of two Philips piezoelectric axle sensors. The sensor layout is shown in Figure 13. The rutting at the location of axle sensors 1 through 4 was 6/32, 5/32, 6/32, and 6/32 inch, respectively. The installation was performed on 12/14/92. The weather was mostly cloudy with an air temperature of 50° F.

The general axle sensor installation procedures were followed. The sensor slots were dried using hand held propane torch being careful not to overheat the pavement. Two layers of duct tape were used along the top of the slot. The epoxy used was Schul International Ready-Set pavement grout (a technical bulletin is included in Appendix A). Schul had a technical representative on site for the installation. The sensors were installed using four leveling plates. Some difficulty was encountered in mixing the epoxy. One batch cured too fast and did not allow time to completely fill the slot and smooth the epoxy, and another batch cured in the bucket before adding the sand and had to be discarded. The last batch was mixed for a shorter time before adding sand. This batch had a better working time allowing for a smooth installation, and was used to top off and smooth the other sensors. However, it also took much longer to cure, and about 2 hours before the lane opened, a torpedo heater was placed on the sensor to speed curing. When the lane had to be opened, that epoxy was still slightly soft. The sensor profiles in Figure 14 show that in the wheelpath the sensors were all slightly high (up to +0.1 inches) and outside the wheelpath they were all slightly low (up to -0.07 inches).

The axle sensors were tested with an oscilloscope. The outputs from sensors 2 and 3 were acceptable, but the output from sensors 1 and 4 were very low. After failing to get sufficient output levels from sensors 1 and 4, it was decided by the vendor to abandon them and only use sensors 2 and 3. The Delta I was withdrawn from the evaluation, and the Delta II was connected to sensors 2 and 3.

The Delta II experienced an oscillation problem (continuous axle counts with no vehicles present) and was repaired at the vendors facility. In order to get more consistent signals for vehicles outside the wheelpath, bituthane tape was placed over the low spots on both sensors. The classifier was then approved by the vendor for evaluation.

TIMEMARK INC.



Note: All sensors
are 6' long

Figure 13. TimeMark Installation Configuration Drawing

TIMEMARK INC.

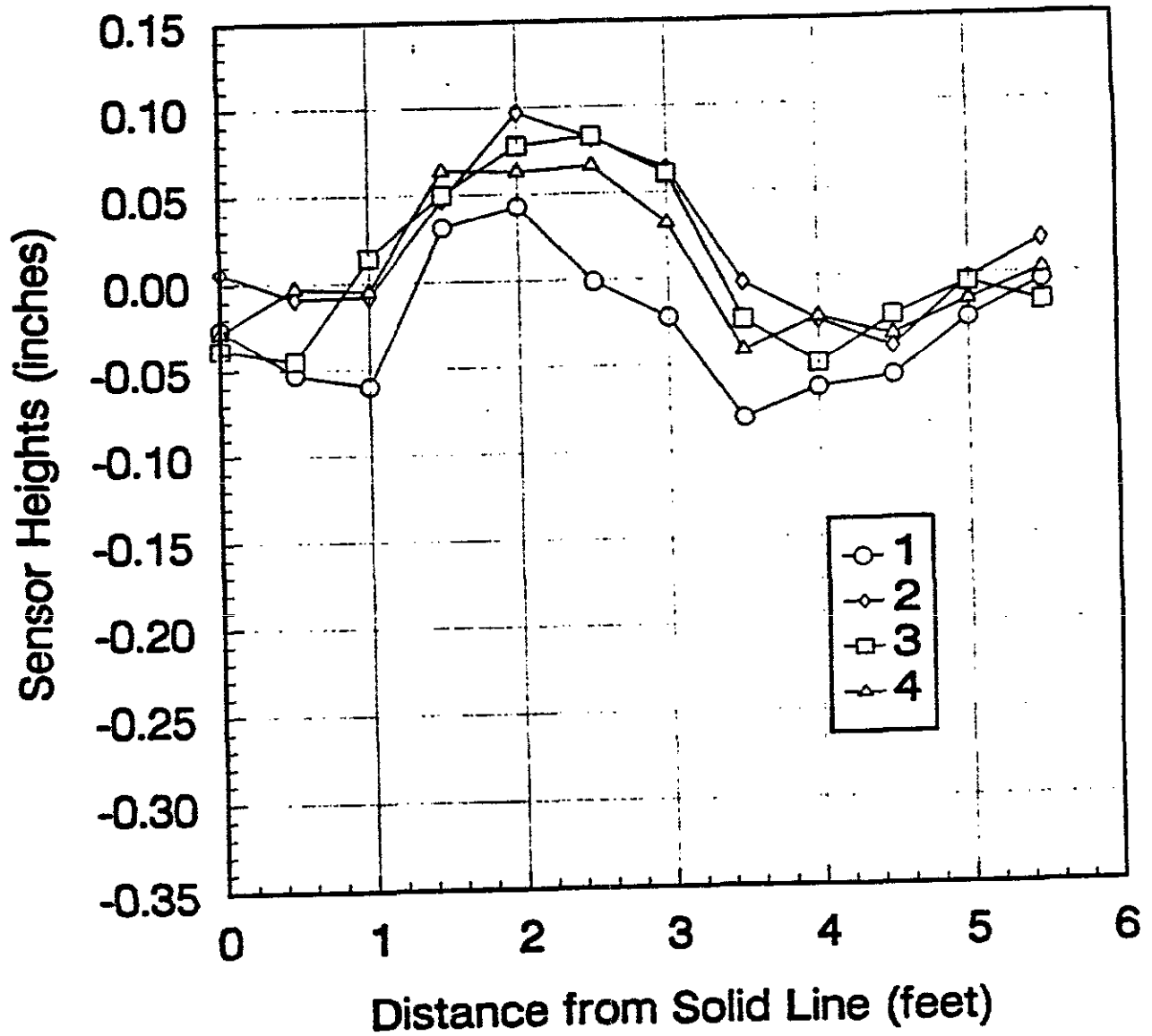


Figure 14. TimeMark Axle Sensor Profiles

2.3.7 International Road Dynamics

IRD installed a model TC/C 530 classifier with two sets of sensors configured as two lanes. The sensor layout is shown in Figure 15. The first sensor configuration uses two IRD DYNAX AS400 resistive axle sensors and one four-turn loop. The second sensor configuration uses two Philips piezoelectric axle sensors one four-turn loop. The rutting at the location of axle sensors 1 through 4 was 6/32, 5/32, 5/32, and 4/32, respectively. The installation was performed on 12/17-18/92. The weather conditions were: cloudy, rain (in the morning), and 59° F on the 17th; clear and 58° F on the 18th.

The general axle sensor and loop installation procedures were followed. The slots were cut on the afternoon of the 12/17/93, but because of the rain delay in the morning, there was not sufficient time to completed the installation. Before opening the lane, the slots were filled with sand to protect them from damage by vehicles. The next day the sand was cleaned out of the sensor slots using compressed air and the slots were dried with hand held propane torch being careful not to overheat the asphalt. Two layers of duct tape were used along the top of the slot. The epoxy used was IRD System 400 for the Philips sensor and Dural International Corporation 331 LV epoxy for the DYNAX sensors. The DYNAX sensors were flexible and conformed well to the local rutting, and were installed using 5 special leveling plates. The plates have a slight hump in the center to allow the raised surface of the DYNAX sensor to come up over the road surface slightly (approx 1/32). The Philips sensors were installed using 7 special leveling plates that were drilled and tapped in the center for a 1/4 inch bolt. The bolt is adjusted and the plate is tie wrapped to the sensor such that the sensor is held down 3/16 inch below the road surface.

The DYNAX sensor procedure is to pour enough epoxy such that excess material extrudes around the sensor. The excess is troweled off and smoothed using a putty knife. Weights are placed on the leveling plates and the epoxy is allowed to cure under ambient conditions.

The Philips sensor procedure is to pour 1/2 the required epoxy, place the sensor in the slot and apply weights to hold it in place, let the epoxy partially set up then remove the weights. After both sensors were installed, another batch of epoxy was mixed to top off the slots flush with road surface. The epoxy is smoothed with a putty knife and allowed to cure under ambient conditions. Sensor 3 had voids underneath due to insufficient epoxy on the first pour and had to be pulled up so more epoxy could be poured in the slot. The epoxy had started to harden and the sensor could not be pressed down fully below the road surface.

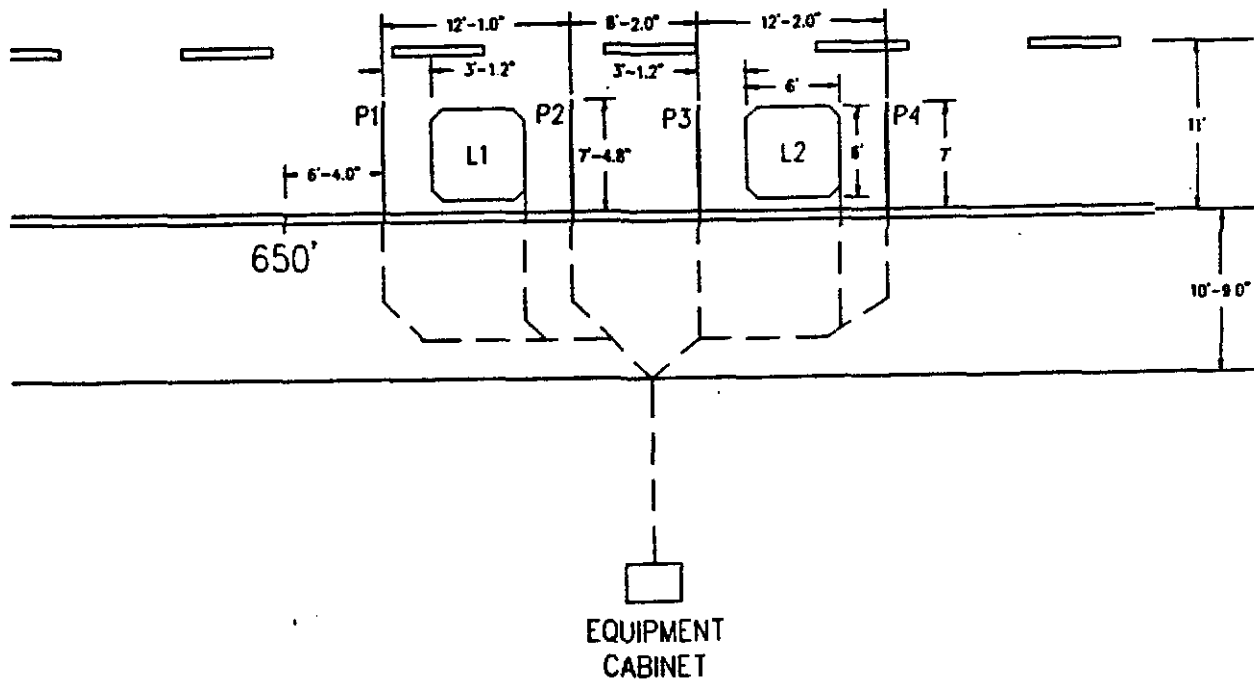
The DYNAX resistive sensor operation was verified using an ohmmeter. The Philips sensors were tested with an oscilloscope and were both working properly. The loops measured 152 microhenries for the Dynax configuration and 154 microhenries for the Philips configuration; both loops demonstrated good frequency stability. The sensor profile in

Figure 16 shows fairly good conformity to the road surface with the highest point at 0.09 inches and the lowest at -0.05 inches.

On initial system installation and checkout on 1/18/93, the classifier would not recognize the DYNAX sensors. The IRD representative found a loose connector inside the classifier, and after repairing it, the classifier worked well with the Dynax sensors. As a normal part of setting up a new installation, the sensitivity of the piezoelectric sensor circuits were adjusted internally for optimum detection.

Sensor number three started to break out of pavement after approximately one month. The epoxy was chipping away at the end of the sensor and in the wheel path. IRD patched the sensor by making saw cuts along the chipping areas, removing the loose epoxy, and applying more epoxy of the same type. The epoxy failure may have been because of the difficulty encountered with its installation as discussed above. After the repair of the sensor, the system was rechecked and readjusted for optimum performance. The classifier was then approved by the vendor for testing.

INTERNATIONAL ROAD DYNAMICS, INC.



Note: The first two sensors have lengths of 7'-4.8", and the last two sensors have lengths of 7'

Figure 15. IRD Installation Configuration Drawing

INTERNATIONAL ROAD DYNAMICS, INC.

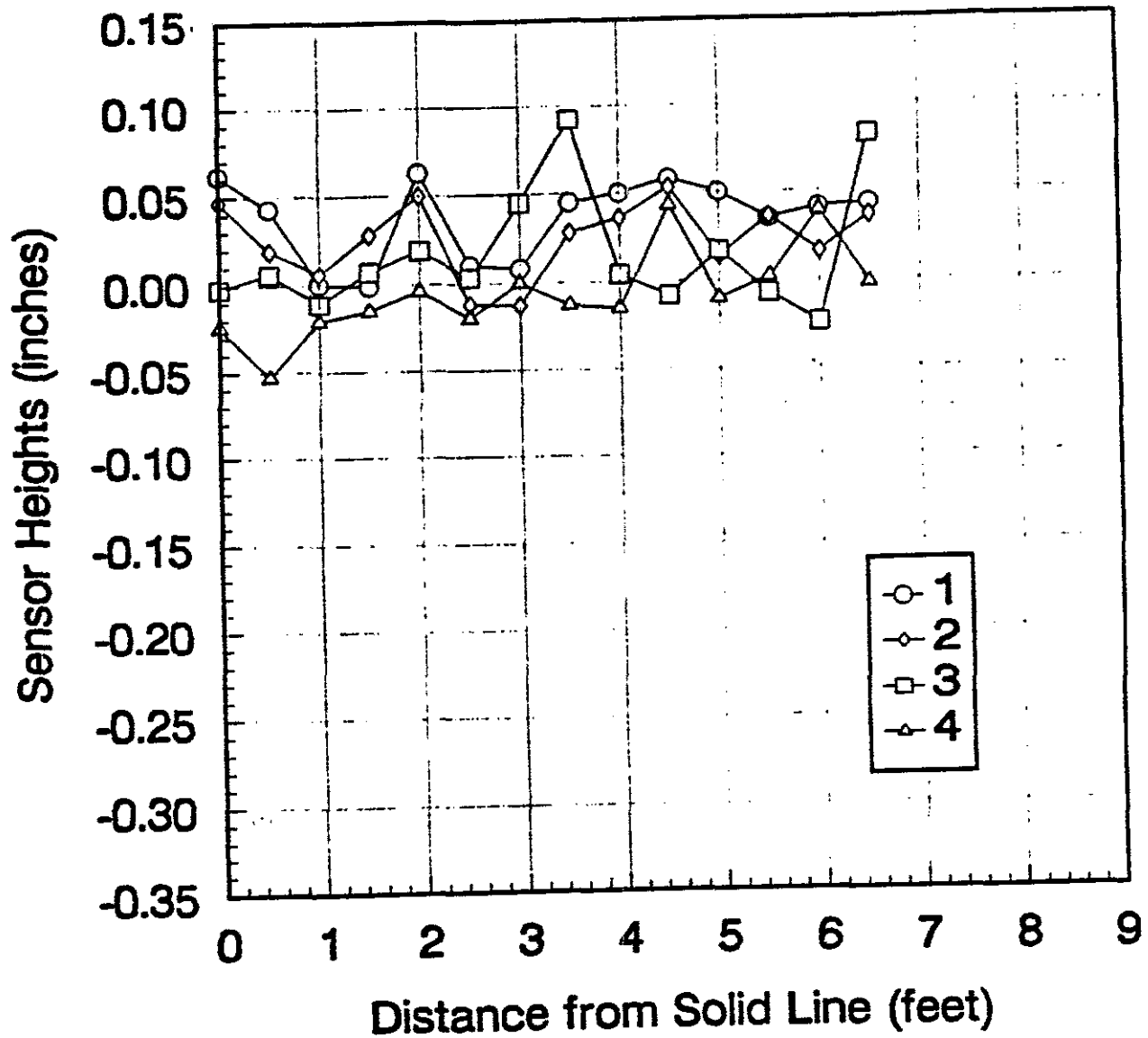


Figure 16. IRD Axle Sensor Profiles

2.3.8 Golden River Limited

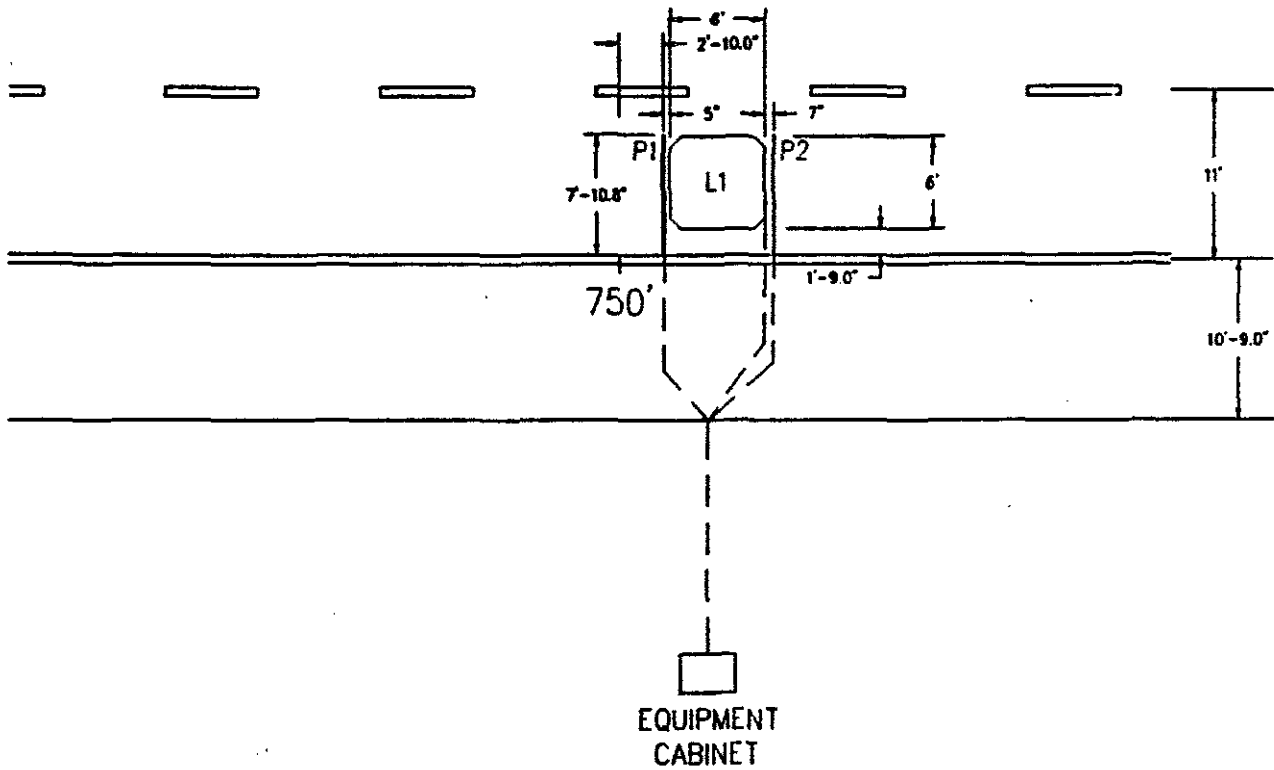
GRI installed a Marksman 660 classifier with Traffic 2000 (14 mm width version) piezoelectric axle sensors and one four-turn loop. The axle sensors are a domed type that extends slightly above the road surface. The sensor layout is shown in Figure 17. The rutting was 5/32 inch at the location of sensors 1 and 6/32 at the location of sensor 2. The installation was performed on 1/13-14/93. The weather was partly cloudy and 58° F on the 13th, partly cloudy and 47° F on the 14th.

The general axle sensor installation procedures were followed. The sensor slot was cut for snug fit (1mm clearance on each side of the sensor) using ganged blades on the asphalt saw. Each end of the cut was made a little wider and deeper to protect the ends of the installed sensor. The slots were cleaned then dried and preheated with torpedo heaters. One layer of duct tape was placed along the top of the slot leaving approximately 1/4 inch of pavement next to the slot uncovered because of the domed sensor construction. The epoxy used was Traffic Coil which was poured in sufficient quantity such that excess material extrudes around the sensor. The excess is trowelled off, and the sensor surface is cleaned with acetone. No weights are required for this type of sensor, it is simply pressed down until the domed portion is touching the pavement. The epoxy had been preheated in a heated truck cab for two hours before mixing, and cured very quickly under ambient conditions. The vendor replaced the leading sensor the next day because it was decided that better performance would be achieved with the axle sensor much nearer to the loop than first installed.

The installed sensor element profile shown in Figure 18 shows that the domed portion of the sensor extended above the road surface approximately 0.12 inches. Since the sensors were flexible, good conformity to the rutting profile was achieved.

Loop measurements indicated 136 microhenries and good stability. Initial tests of the axle sensor with oscilloscope indicated outputs slightly lower than desired by the vendor and somewhat erratic. Both sensors were replaced on 3/11/93 (55° F and partly cloudy) using the same installation procedures. The sensor output was better, but the classifier was not giving consistent results. The equipment was returned for checkout and repair, but was not working properly in time for the first evaluation. The equipment was then returned to GRI in Great Britain for checkout and repair, and was functioning properly for the second evaluation.

GOLDEN RIVER TRAFFIC LIMITED



Note: Both sensors
are 7'-10.8" long

Figure 17. GRI Installation Configuration Drawing

GOLDEN RIVER TRAFFIC LIMITED

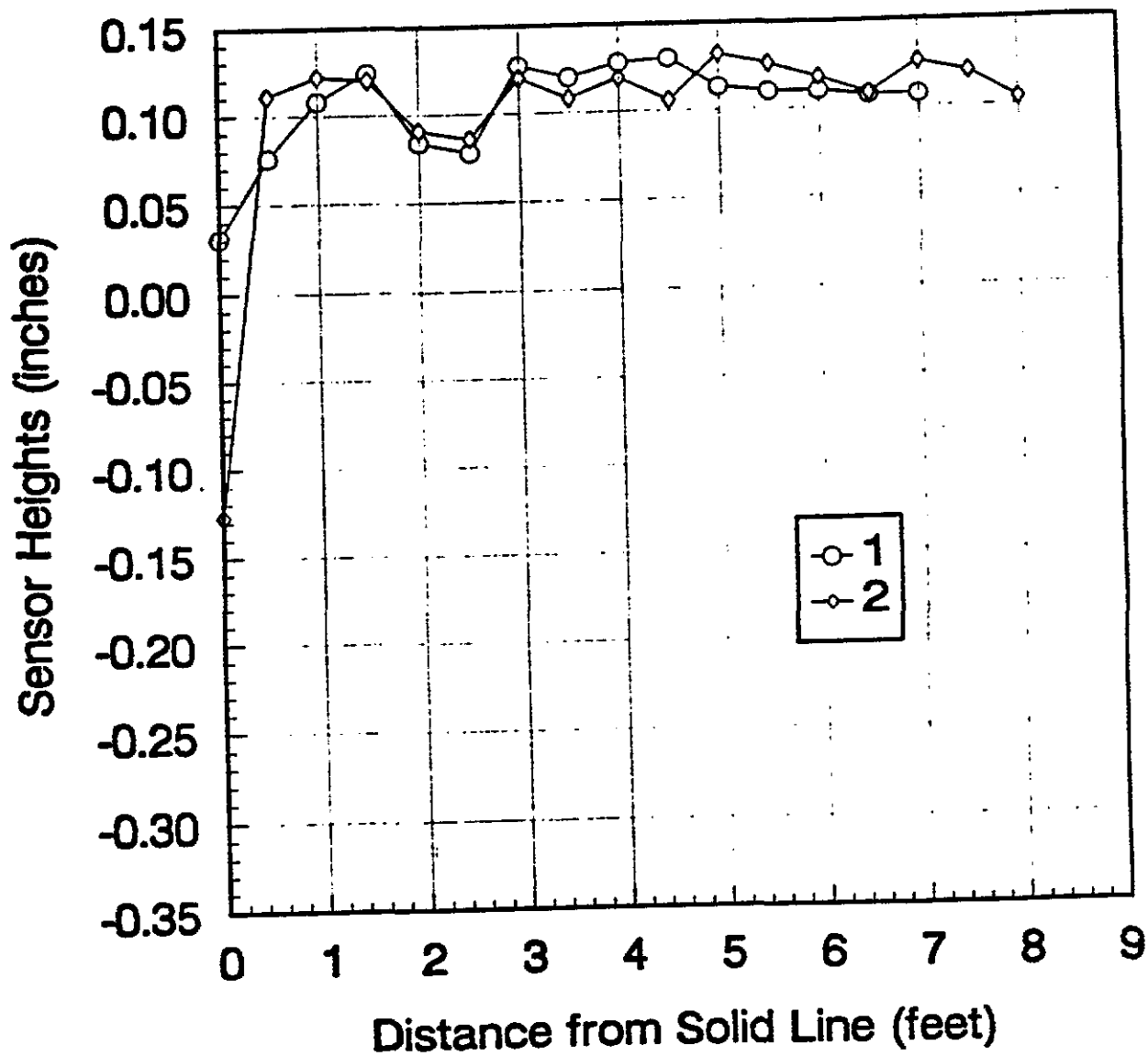


Figure 18. GRI Axle Sensor Profiles

2.3.9 Diamond Traffic Products

Diamond installed a model 2001 multi-lane classification unit with two sets of sensors configured as two lanes. The sensor layout is shown in Figure 19. The first sensor configuration uses two Autologger-Gates, piezo cable, class 2, Maxi replaceable flush fitting design axle sensors and one three-turn loop. The axle sensors consist of channels which are epoxied into the road and replaceable sensor elements. The channel has 3/4" plastic tubing is attached to form a conduit from the channel to the edge of pavement for the coax cable. The second sensor configuration uses two Philips piezoelectric axle sensors one three-turn loop. The rutting at the location of axle sensors 1 through 4 was 4/32, 5/32, 5/32, and 6/32, respectively. Installation began on 1/19/93 and was finished on 1/29/93.

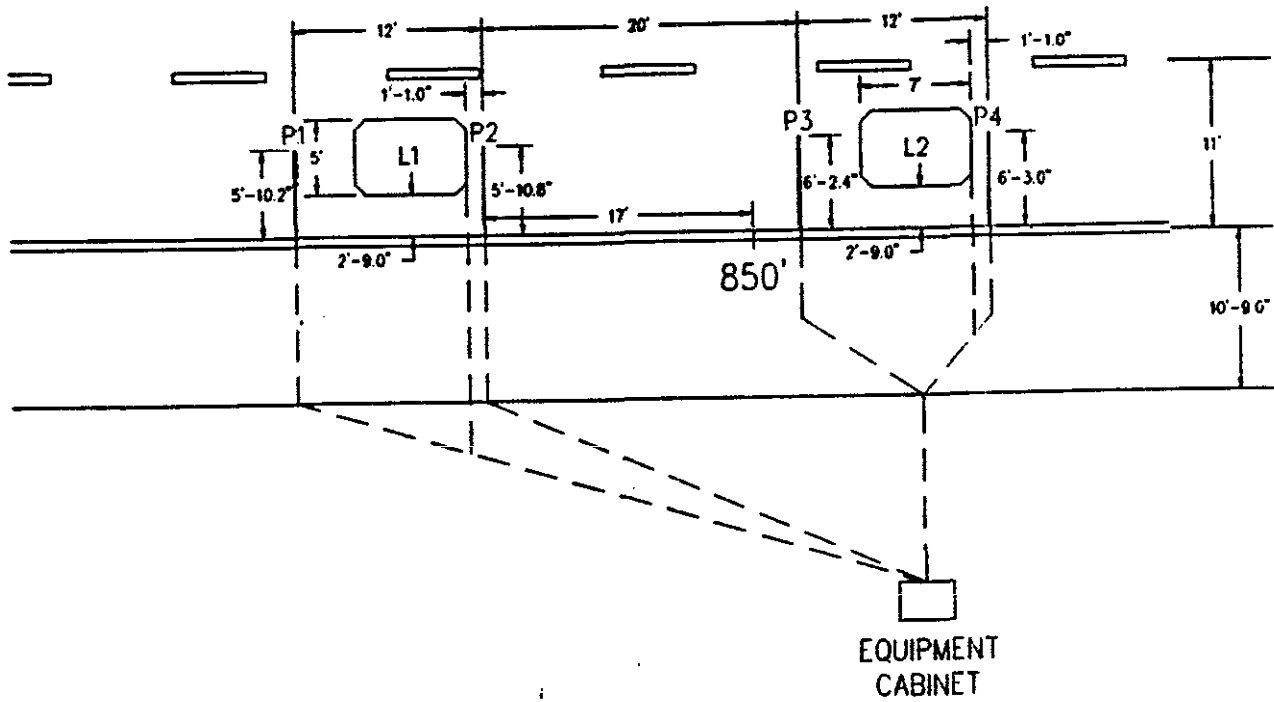
The slots for the Philips were cut on the morning of 1/19/93, but because of rain that began around noon, the installation could not be completed. The slots were filled with sand until the weather cleared and the installation crew could be rescheduled. On 1/26/93 (49° F and partly cloudy) the slots were cleaned then dried and preheated with torpedo heaters. There was no pavement cracking or other noticeable effects on the slot after the seven day delay. Two layers of duct tape were used along the top of the slot. The sensor had five leveling plates installed with tie wraps. The epoxy used was E-Bond G-100. Enough epoxy was poured such that excess material extrudes around the sensor then the excess was trowelled off and smoothed using a putty knife. Weights were placed on the leveling plates and the epoxy was cured using the torpedo heaters.

The Autologger channel was installed much like a typical piezoelectric sensor, and the general axle sensor installation procedures were followed with some extra steps. On 1/27/93 (58° F and clear), the slots were cut and cleaned then dried and preheated with torpedo heaters. Two layers of duct tape was used along the top of the slot. A strip of duct tape was also used on the top of channel to keep epoxy out. The epoxy used was E-Bond G-100. The channels were installed using eight tie-wrapped leveling plates, and since the channels were slightly flexible, good conformity to the rutting profile was achieved. Before installation, the channels were thoroughly cleaned with acetone for better epoxy adhesion. Sufficient epoxy was poured in the slot such that it extruded out when the channel was placed in the slot and seated. The excess epoxy was removed and the surface was then smoothed with a putty knife. The epoxy was allowed to cure under ambient conditions. On 1/29/93 (61° F and partly cloudy), the protective tape was removed, the channel was thoroughly cleaned of any debris, and the sensor element was installed using the same procedure as for the mini-replaceable (Section 3.3, MITRON).

All axle sensors were tested with an oscilloscope and were working properly. The loops measured 152 microhenries for the Autologger configuration and 154 microhenries for the Philips configuration; both loops demonstrated good frequency stability. The sensor profile in Figure 20 shows that all four sensors conform well to the road surface with the maximum height variation of 0.1 inches. The lowest point is -0.08 inches.

The classifier was installed in the cabinet and the sensors were connected. After making the normal internal adjustment of sensor threshold for a new installation, the system was working properly and was approved for evaluation. On a later visit, the vendor replaced the EPROM with updated version and readjusted the sensor threshold.

DIAMOND TRAFFIC PRODUCTS



Note: Both loops
are 5' X 7'

Figure 19. Diamond Installation Configuration Drawing

DIAMOND TRAFFIC PRODUCTS

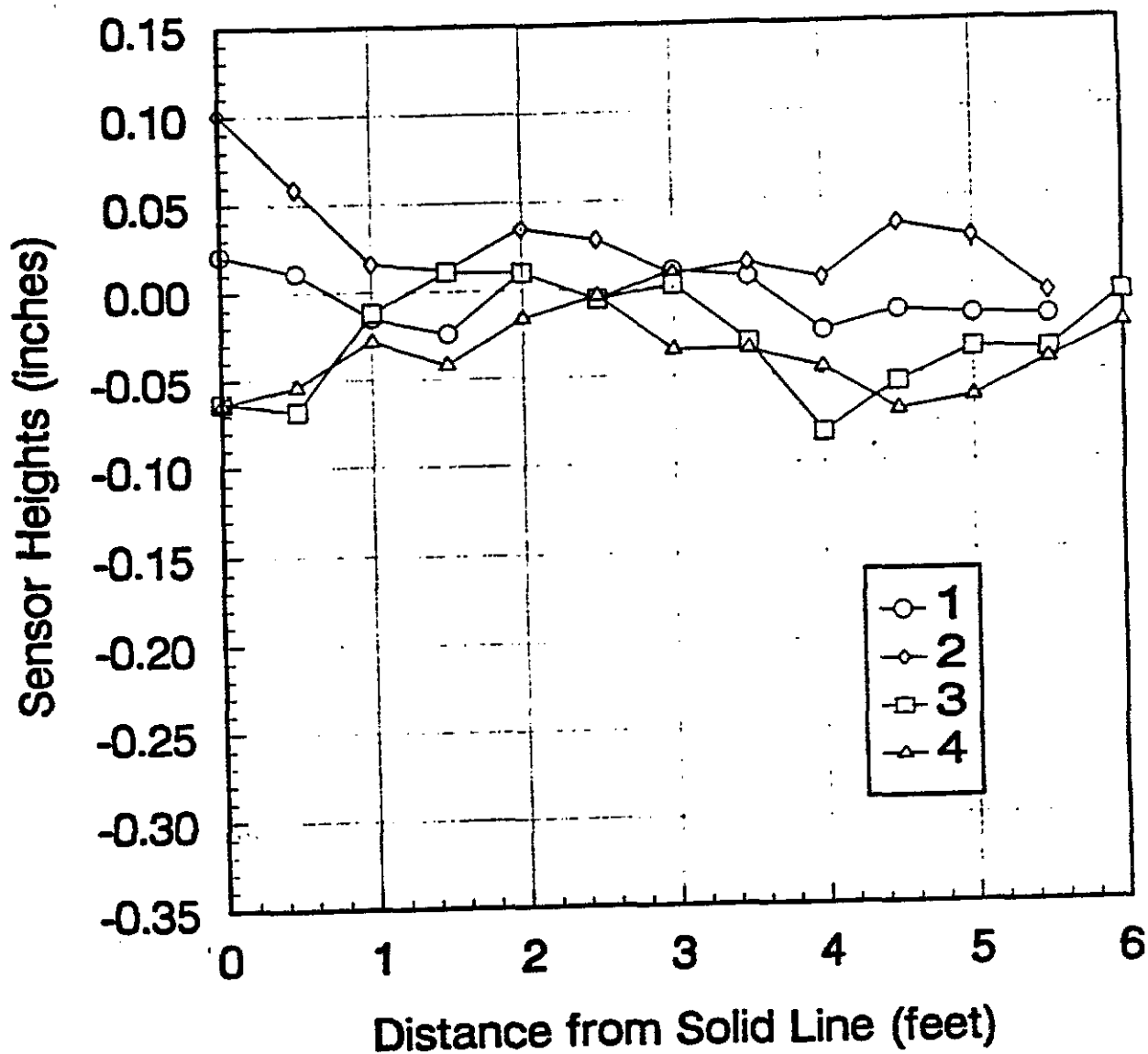


Figure 20. Diamond Axle Sensor Profiles

2.4 INSTALLATION SUMMARY AND CONCLUSIONS

Over the period of November 1992 to March 1993 eleven classifiers from nine vendors were installed using fifteen test sensor configurations. Fifteen loops and twenty-eight axle sensors were originally installed. Six axle sensors were replaced and two were abandoned for a total of thirty-four installed and twenty-six functioning. Six different types of axle sensors were installed using five different types of epoxy. The procedures used by each vendor for sensor installations were the same except for a few minor details. The only significant difference in installation procedures was for the Autologger replaceable type which required some special procedures.

There were no problems encountered with any loop installations; however, there were quite a few problems encountered with the axle sensors. The biggest problem was low output levels and large differences in output levels across the length of the sensor. Some of the variation could be caused by manufacturing variations, but most is caused by the height profile of the installed sensor. Areas of the sensor below pavement level have a lower output voltage causing classifier sensitivity problems; areas above pavement level have a higher output level but subject the sensor to possible damage.

When larger signals are presented to the classifier, overshoot and undershoot of the signal will cause extra axle counts if the detection threshold level is set too low. The threshold level must be set low enough to detect small cars but high enough to avoid extra axle counts. Variation of the output level along the length of the sensor, due to installation or manufacturing, make this setting more difficult. The field repair for the sensor profile problem, bituthane tape over the low spots, had to be employed for thirteen of the twenty-six functioning sensors to achieve good classifier performance. Most of the difficulty with sensor profile can be attributed to the rutting present at the site. Even though the rutting was not too severe, the rigid sensors could not be made to conform well to it.

Other problems encountered with axle sensors included snow plow damage of the Autologger mini-replaceable (which extended over the pavement level), cracking and chipping of epoxy on one of the IRD Philips sensors requiring repair, and poor coax connections to classifiers. The one epoxy failure was probably due to a premature epoxy cure not allowing the sensor to be installed below the road surface as designed.

The axle sensor replacements included, two of MITRON's Autologger Mini replaceable sensors (for low output levels), three of GRI's Traffic 2000 sensors (one to relocate closer to the loop and two for low output), and one ECM sensor (for low and erratic output). The abandoned sensors were two of TimeMark's Philips sensors.

In addition to the axle sensor problems, several problems were encountered with initial setup of the classifiers. Some problems were actually sensor related (such as difficulty in compensating for low or variable axle sensor output) and some were faulty electronics or

bad internal wiring connections. Of the eleven classifiers installed, five were malfunctioning; three were repaired on-site and two were returned to the vendor facility for repair.

The overall conclusion, based on these installations, is that generally a classifier will require some internal adjustment, repair, or sensor compensation when first installed. The problems are usually minor and can be easily corrected by a technically qualified installer. Each system installed for this evaluation was in accordance with the vendor's specification. Before the first evaluation was performed, proper operation of each classifier was achieved and was verified by each vendor.