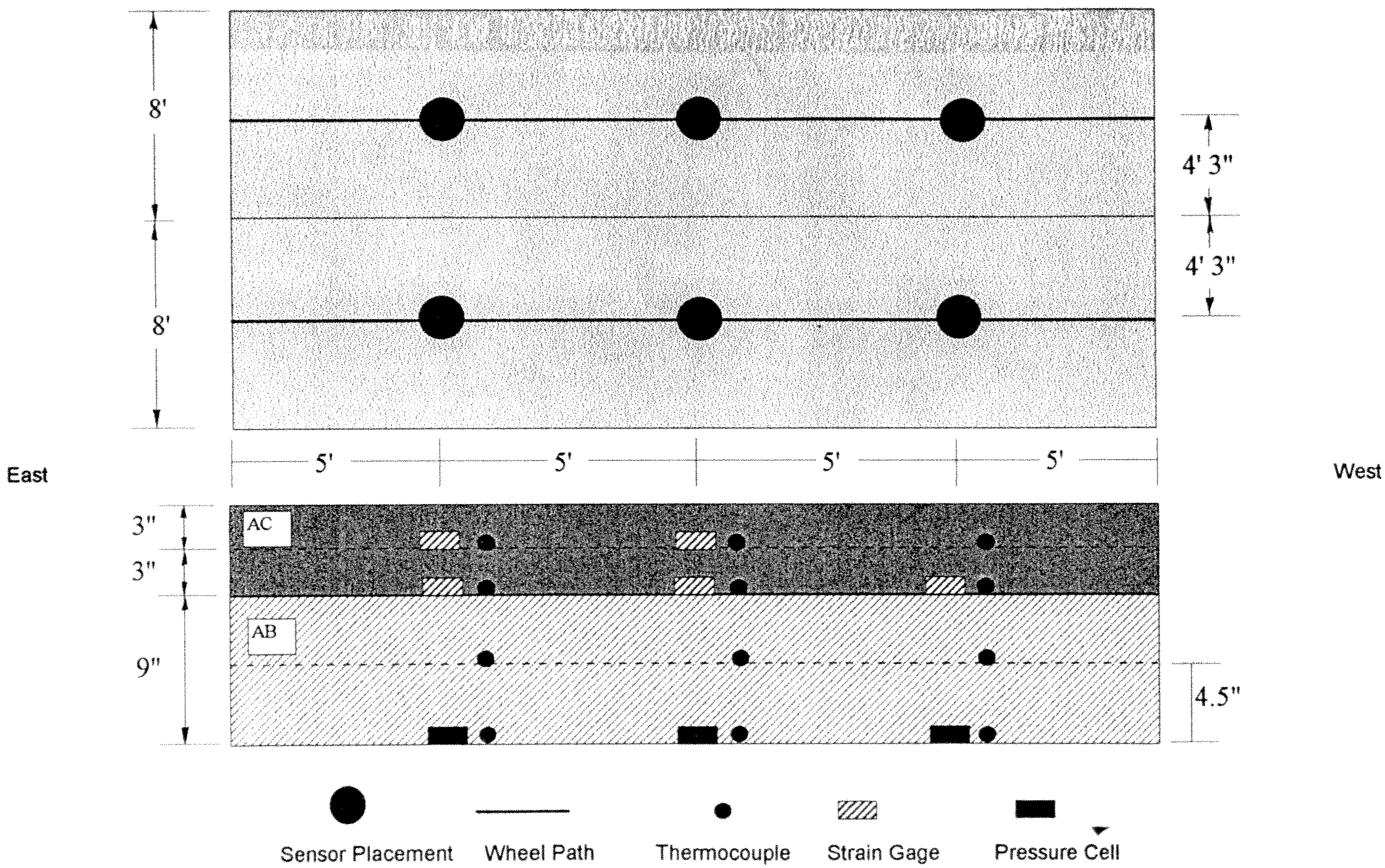


Note: The strain gages 3" below the surface in the AC are only on the North Side.

Figure 4.6 Location of Sensors on Plan and Through Section Depth

The only instrumentation that was placed in the *control sections* is two sets of thermocouples–three sensors in each set–placed at the centerline of Mix 2 (south half) of the north pit. The first set (three) was placed below the pavement, on top of the subbase, and the other set (also three) at mid-thickness of the pavement. The layout and depth of these thermocouples are similar to those of the test sections (see Figure 4.4) except that only the south lane had temperature sensors. These were used in monitoring heat application and temperature gradient, as explained in Section 4.3.

4.4.1.1 Soil Pressure Cells

Six soil pressure cells, Model 3500 Dynamic Series with Ashkroft K1 Transducers (from Geokon), were placed as indicated in Figure 4.6. On the plan, this is along the centerline of each wheel (pair of tires), at the quarter-span points. The centerline of the wheel paths for the north and south lanes are symmetrically located at 1280 mm (51 in.) from the middle of the pit. Three pressure cells were therefore placed on each wheel path, at about 1.5 m (5 ft) from the east and west ends.

The Geokon pressure cells are constructed from two circular flat plates of 230 mm (9 in.)-diameter welded together around their periphery. The plates are separated by a thin film of liquid which is connected through a tube to the pressure transducer. The transducer is connected to the data acquisition system by a conductor cable

Figure 4.7 Geokon Pressure Cell with Pressure Transducer and Conductor Cable

that is sealed into the transducer housing. It utilizes a bonded foil resistance strain gaged diaphragm that converts changes in pressure in a hydraulic flat-jack into a usable electrical signal. One of the cells used is pictured in Figure 4.7.
The pressure cells were installed according to the manufacturer's guidelines and following the procedures recommended by the MnRoad research program. They were placed on top of the compacted subgrade soil, below the AB-3 aggregate base layer. This corresponds to about 390 mm (15 in.) below the surface of the pavement. The connecting cables were placed in PVC pipes for protection during the following base construction and compaction. The location of the installed pressure cells is depicted in Figure 4.8.

Figure 4.8 Location of Installed Pressure Cells

4.4.1.2 Strain Gauges

Eight strain gauges (Dynatest Model PAST-2AC) were placed as indicated in Figure 4.6, along the centerline of the wheel paths. This line is the same line along which the pressure cells were placed. Three gauges were installed at the bottom of the asphalt concrete layer below each of the two test sections, right on top of the AB-3 base. A small amount of cold asphalt mix patching material was placed on top of these gages to protect them during hot asphalt paving. This is shown in Figure 4.9. Two additional strain gauges were installed at about mid-depth; i.e., at the interface between the two asphalt lifts, in the north section only (see Figure 4.10).

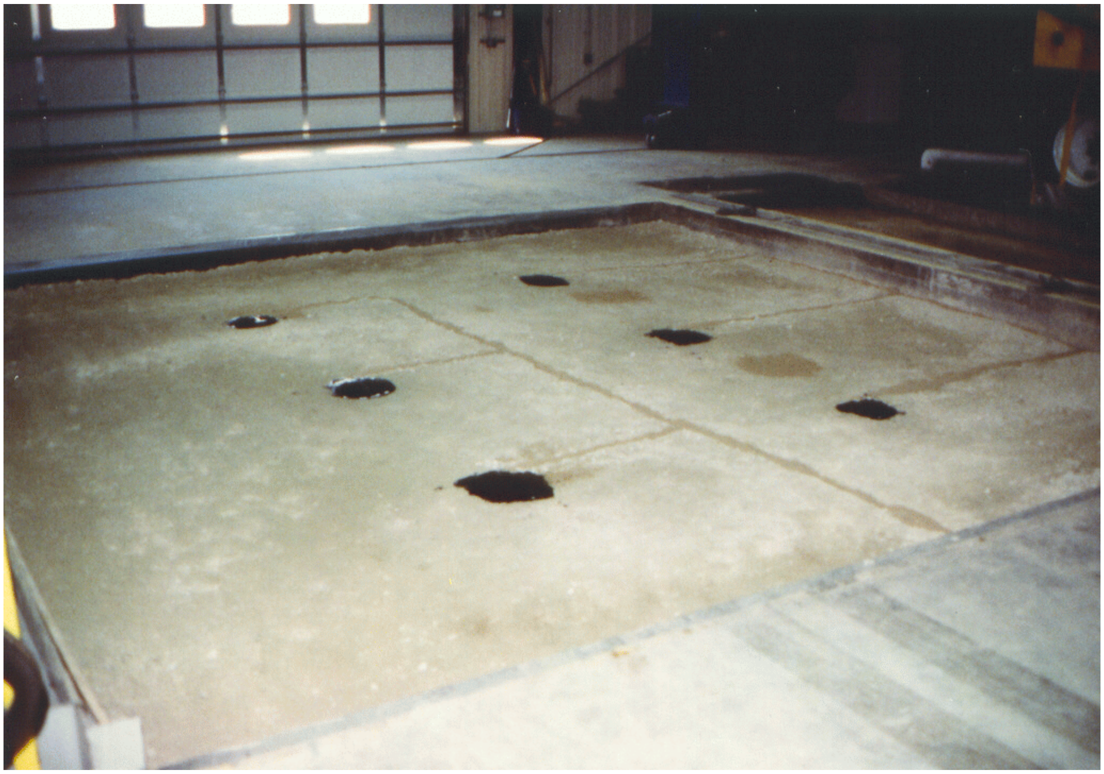


Figure 4.9 An Asphalt Mix Cover Was Used for Protection of Gages

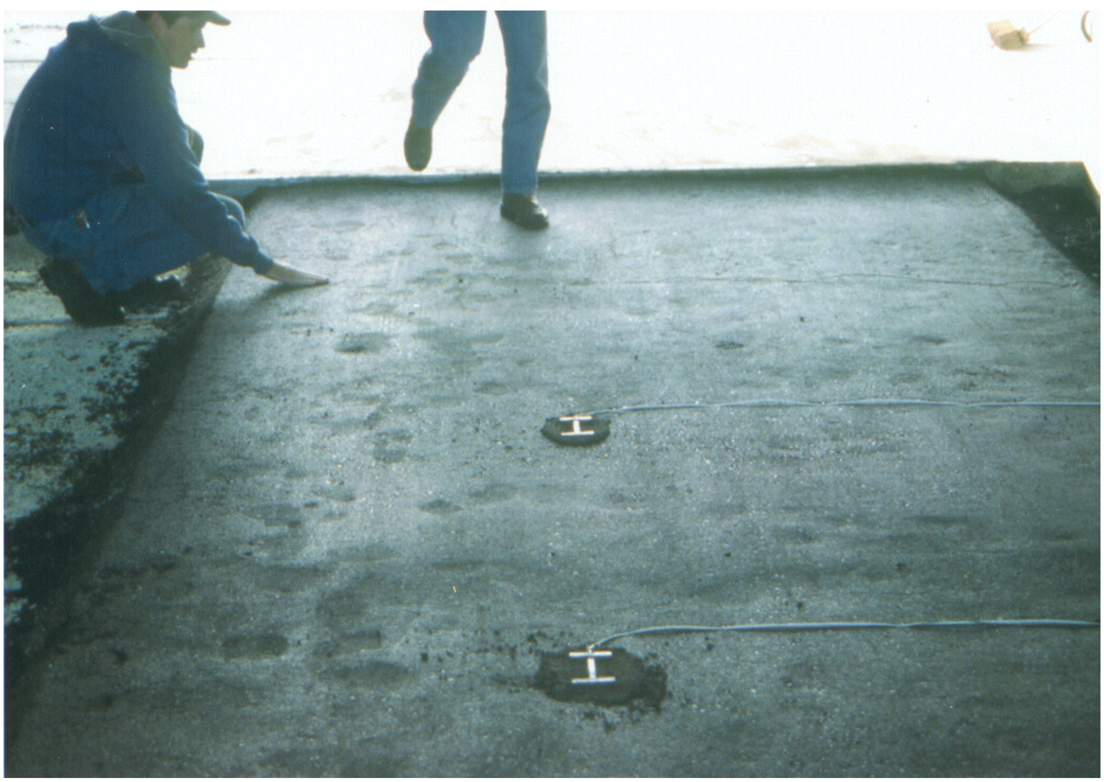


Figure 4.10 Installed Strain Gages at Mid-Depth of Slab

The gauges (often designated as H-gauges) consist of electrical resistors embedded within a strip of glass-fiber reinforced epoxy supported at each end of the strip on transverse stainless steel anchors forming an H-shape. The gauges are installed to measure horizontal tensile strain measurements under the wheel passage. The orientation of the gauges was parallel to the direction of traffic and thus only longitudinal strains were measured. Horizontal strains in asphalt pavement provide the means for comparing the in-situ results to those of analytical models. The data are often useful to study the current failure criteria used in mechanistic-empirical pavement design procedures.

Due to manufacturing complexity, the resistance of these strain gauges is not constant, but rather varies from one gauge to the other between 120 and 127 Ohms. For this reason, commercial ready-to-use strain indicators could not be used for signal conditioning. Special provisions had to be made for electric circuit bridge completion and signal amplification.

4.4.1.3 Thermocouples

Thermocouples are temperature sensors embedded between the pavement layers. They were placed in the two test sections in the middle pit in four vertical layers corresponding to four different vertical depths through the pavement structure and base. Six sensors were installed in each layer corresponding to the horizontal location of the strain and pressure sensors. The top layer is the mid-depth of the asphalt layer. The second layer down was at the interface between the asphalt layer and the base layer. The next two layers are at mid-depth and at the bottom of the base, respectively. A total of 24 thermocouples were installed. The location of these thermocouples is depicted in Figure 4.6.

This arrangement specifically permits having one thermocouple placed in the vicinity of each of the strain gauges. These sensors read the temperature in the neighborhood of the strain gages embedded in the pavement layer. From past experience, these might be needed if temperature compensation is necessary. Even though the strain gauges are supposed to have a self temperature compensation feature, it was thought that these thermocouples would be handy in case of abnormal instability or unexpected malfunction that might be attributed to excessive temperature sensitivity (manufacturer’s recommendation).

All thermocouples were read and recorded periodically. The top layer of thermocouples was particularly observed to ensure that the necessary temperature gradient between the surface of the pavement and the pavement mid-depth was within the specified range as outlined in Section 4.3.2. This gradient had to be maintained during the wheel load applications.

4.4.2 Data Acquisition System

Data were collected using the existing data acquisition system developed at the K-ATL through previous research contracts. The hardware consists of several terminal blocks on a number of corresponding SCXII modules mounted on instrumentation chassis. Data acquisition boards are installed in PC computers with Pentium processors. The software consist of the LabView package of which the Department of Civil Engineering at KSU maintains a current license for 10 users. All these hardware and software are products of National Instruments, Inc.

Additional boards, software updates, and computer upgrades are regularly acquired to enhance the data acquisition system. In order to read and record strain, pressure, and temperature data simultaneously, two separate subsystems, each connected to a different computer, were necessary. Modifications to the previously developed computer programs (or VI's, standing for Virtual Instruments) were made as part of both this and the K-TRAN project.

A brief summary of the data acquisition hardware and software configuration for the strain and pressure data acquisition is given in Bhuvanagiri *et al.* [4]. A detailed description of the strain data acquisition system and its development procedure are given by Melhem [10]. The other systems follow the same format and procedure with minor modifications. The final results are given in this report in Appendix C.

For each of the (a) pressure, (b) strain, and (c) temperature data acquisition systems, Appendix C gives the following:

1. A schematic representation the data acquisition hardware setup,
2. The graphical source code of the corresponding software (VI), and
3. The corresponding Graphical User Interface.

4.5 Performance Monitoring Plan

The instrumentation and data acquisition described above (in Section 4) were mainly intended to collect data that can be used elsewhere to perform a detailed analysis of the pavement behavior under the successive axle load repetitions. Data collection was done only for the two test sections (Mixes 3 and 4).

The purpose of the activity described in this section was to monitor the performance of the pavement sections being tested. This was conducted on the test sections as well as the control sections. The performance monitoring consists of the following tasks:

1. Nuclear Density Measurements on Asphalt Surface
2. Transverse Profile Measurements with Face Dipstick
3. Transverse Profile Measurements with Transverse Rut Measuring Device

4. Longitudinal Profile Measurements with Face Dipstick
5. Deflection measurements by FWD

Except for Task 5 (deflection measurements by FWD) all the other tasks listed above were performed at the beginning and after every 10,000 load applications, for both the test sections and control sections. Task 3 was necessary to obtain a more precise transverse profile of the surface rutting. A detailed description of Tasks 1 through 5 is presented below.

4.5.1 Nuclear Density Measurements

Density measurements were taken periodically after each 10,000 repetitions using a nuclear density gage. Measurements were made at 1.52 m, 3.05 m, and 4.57 m (5 ft, 10 ft, and 15 ft) along the external wheel paths of the dual tandem axle. Each of the test sections and control sections therefore has three locations along the line corresponding to the external tire of the pair rolling on it. Three one-minute readings were taken at each location. Variation of density values versus the number load applications can give an indication of the compaction or distress due to wheel traffic.

4.5.2 Transverse Profile Measurements with Face Dipstick

Profile measurements were taken periodically after each 10,000 repetitions using the Face Dipstick apparatus. Transverse profile curves were computed and plotted at every 1.52 m (5 ft) across the wheel paths. Therefore, each of the test sections and control sections has transverse profiles at three locations along the slabs: one location at mid-span, and two locations at the quarter points.

From past experience, transverse profiles generated this way do not show a good description of the rut since readings are taken every 30 cm (12 in.) and much of the details of the deformation shape are missed. However, this will be done at the request of the K-TRAN project [3].

4.5.3 Transverse Profile Measurements with Rut Measuring Device

When studying rutting of asphalt pavement, in order to obtain accurate transverse profiles, a better device needs to be used rather than relying on the Face dipstick apparatus. The dipstick gives readings every 30 cm (12 in.), and unless several passes are made, many of the heaves and valleys will be missed. Readings at much smaller intervals along the width of the pavement section are needed, such as every 13 mm (1/2 in.) or 6.5 mm (1/4 in.). For this purpose, a special surface rut measuring device was developed.

<u>Transverse Rut Measuring Device</u>

The mechanical parts of this device were fabricated in-house at the K-ATL. They consist of a 3.66 m (12 ft)-long aluminum square tube mounted on two end-brackets with 4 screws each for level adjustment. A sliding mechanism, to which a digital transducer is attached, traverses the tube to measure surface variation, rutting and to obtain accurate and correct measurements of the surface profile. Recording digital data electronically helps eliminate human error. For this reason a Logic-Basic (Model BG4820) electronic digital indicator and associated laptop computer were acquired with funds from this project. The indicator interfaces directly with the computer and serial port through a RS232 connecting cable. It has a 101.6 mm (4.0") measuring range and 0.01 mm (0.0005") accuracy.

Transverse profile measurements were taken periodically after each 10,000 repetitions using the developed rut measuring device. Data was collected and stored electronically so that elevations could be recorded every 13 mm (½ in.). This ensured that all heaves and depressions are recorded and a more accurate surface profile could be constructed. Transverse profile locations are the same as those measured with the dipstick (Section 4.5.2).

4.5.4 Longitudinal Profile Measurements with Face Dipstick

Measurements were taken along the external wheel paths of the dual tandem axle. As the load repetitions are incrementally applied, surface profiles along the line corresponding to the external tire of the pair rolling were constructed. This was done for each of the test sections and control sections. Taking measurements on the wheel path (rather than on the centerline of the lane) will give a better indication of the change in the profile, if any, due to the application of the load cycles. Moreover, measuring the surface elevation under any of the tire lines is more significant than at the center line of the wheel (pair of tires). This could be done on either tire path. The selection of the external tire in particular was done mainly for consistency.

Attempts were made to compute the International Roughness Index (IRI) values using the computer software RoadRuf, made available by the University of Michigan. The software uses recorded values for the longitudinal profiles to compute the IRI. However, the procedure used in the software is based on an extensive length of the profile measurements and is not appropriate for data collected over a 6.1 m (20 ft)-long travel.

4.5.5 Deflection Measurements by FWD

Falling Weight Deflectometer (FWD) tests were conducted on all sections (test sections and control sections) but only at three intervals during the experiment. These were as follows:

a. At the start, before any load cycles are applied,

b. At midway, or after about 40,000 cycles have been applied, and
c. At the end of the test, or at about 80,000 cycles

FWD tests were performed by the KDOT crew with a Dynatest 8000 FWD in both traffic directions (East to West, and West to East). A comparison of the responses computed from the FWD back-calculated layer moduli and the measured responses has been reported by Bhuvanagiri *et al.* [4].

4.6 Other Tasks and Responsibilities

The other tasks performed in this project are:

1. Test sections and scheduling (placement by Shilling Construction under KDOT supervision.)
2. Scheduling of coring and FWD tests (coring and tests done by KDOT personnel)
3. Bulk sample collection
4. Trenching transverse cuts at the maximum rut locations (two test sections only)
5. Saw cutting materials-lab fatigue-test bulk samples

These tasks and the monitoring plan described in Section 4.5 were performed as delineated in Table 4.1.

Table 4.1 Task Distribution and Responsibilities

Activity	Responsibility Distribution		
	K-TRAN: KSU 98-2	FHWA-KS-99-7	KDOT
1. Literature Search	°		
2. Instrument order and installation	°		
3. LabView and strain module interface buildup	°		
4. Response monitoring reading (gages)	°		
5. Pavement section design	input		° [1]
6. Superpave mixture design	input		° [1]
7. Construction of the test sections and scheduling	input	°	super-vision
8. Quality control including in-situ Nuclear density tests for the as-built sections and subsequent coring	input	°	° [1]
9. Bulk sample collection		°	
10. Load applications and performance monitoring scheduling		°	
11. FWD tests			° [2]
12. Transverse profile measurements & reporting		°	
13. Longitudinal profile measurements, IRI computation & reporting		°	
14. Fabrication of laboratory fatigue test samples (from bulk samples)	°		help
15. Saw cutting laboratory fatigue test samples (from one test section)		°	
16. Analytical and numerical studies	°		input
17. Reporting of the *KSU 98-2* project	°		review

[1]Glenn Fager
[2]Albert Oyerly

5.0 TEST RESULTS AND PAVEMENT PERFORMANCE

This chapter presents a summary of the test results, pavement performance, and conclusions of this experiment. Load and heat application followed the procedure described in Sections 4.2 and 4.3. The data were collected from the embedded instrumentation using the electronic data acquisition system as outlined in Section 4.4. The performance monitoring plan presented in Section 4.5 has been executed as planned.

The summary of the testing activity and experiment monitoring is shown in Tables 5.1 and 5.2. Table 5.1 pertains to the North pit with the control sections (Mixes 1 and 2). Table 5.2 pertains to the South pit (middle pit of the Lab) with the test sections (Mixes 3 and 4) which had the instrumentation embedded. The dates shown in these tables are the days when the corresponding number of load applications (2^{nd} column) have been achieved and, for the rest of the columns, the days when the respective activities have been performed.

As mentioned earlier (Section 4.2), each pair of the control sections and test sections were loaded in turn, 20,000 repetitions at a time, starting with the control sections. This required moving the testing machine and radiant heaters back and forth from one pit to the other. Except for deflection measurements by FWD all other sensor readings and monitoring task were performed at the beginning of the experiment and after every 10,000 load applications.

It can be noted that Table 5.2 has an additional column (3^{rd} column) which shows the sensor data collection that does not exist in Table 5.1; the control pit was not instrumented. Sensor data include measurements of strain gauges, pressure cells, and temperatures (thermocouples). It can also be noted that sensor data were recorded towards the completion of each set of 10,000 load repetitions. These were measured under the rolling wheel loads while the last few hundred cycles in the corresponding set of loads are applied. This was normally done the same day the specified number of repetitions was achieved; however, surface profiles and nuclear density measurements were performed after load cycles were completed, with no loading or heating being applied. These were performed the same day or sometimes one or two days later.

Table 5.1 Executed Monitoring Plan for North (Control) Section

Date Completed	Number of Repetitions	Transverse Profile	Longitudinal Profile	Static Profile	Nuclear Density	FWD
	0	11/18/98	11/18/98	11/20/98	11/18/98	11/10/98
12/3/98	10k	12/4/98	12/4/98	12/4/98	12/4/98	
12/9/98	20k	12/10/98	12/9/98	12/18/98	12/16/98	
1/6/99	30k	1/6/99	1/6/99	1/6/99	1/6/99	
1/11/99	40k	1/12/99	1/12/99	1/12/99	1/12/99	1/28/99
2/2/99	50k	2/2/99	2/2/99	2/3/99	2/3/99	
2/8/99	60k	2/9/99	2/9/99	2/8/99	2/10/99	
2/23/99	70k	2/23/99	2/23/99	2/23/99	2/23/99	
2/26/99	80k	2/26/99	2/26/99	2/26/99	3/1/99	3/29/99

Table 5.2 Executed Monitoring Plan for Test Sections (South Pit)

Date Completed	Number of Repetitions	Sensor Data	Transverse Profile	Longitudinal Profile	Static Profile	Nuclear Density	FWD
	0	11/12/98	11/18/98	11/18/98	12/19/98	11/18/98	11/10/98
12/16/98	10k	12/16/98	12/16/98	12/16/98	12/17/98	12/16/98	
12/18/98	Task 6	12/18/98					
12/23/98	20k	12/23/98	1/5/99	1/5/99	1/5/99	1/6/99	
1/15/99	30k	1/15/99	1/19/99	1/19/99	1/19/99	1/19/99	
1/22/99	40k	1/22/99	1/22/99	1/22/99	1/22/99	1/22/99	1/28/99
2/12/99	50k	2/12/99	2/15/99	2/15/99	2/15/99	2/15/99	
2/18/99	60k	2/18/99	2/18/99	2/18/99	2/19/99	2/18/99	
3/3/99	70k	3/3/99	3/4/99	3/4/99	3/4/99	3/4/99	
3/9/99	80k	3/9/99	3/9/99	3/9/99	3/10/99	3/10/99	3/29/99

5.1 Vertical Soil Pressure

As discussed in Section 4.4.1.1, six pressure transducers were placed on top of the compacted subgrade soil, below the AB-3 aggregate base layer, at about 390 mm (15 in.) below the surface of the pavement. These are identified in Figure 5.1 as cell p1 through p6, along with the corresponding transducer serial number (PT-464xx) and channel number (Ch.x) used in the NIDAQ data acquisition system.

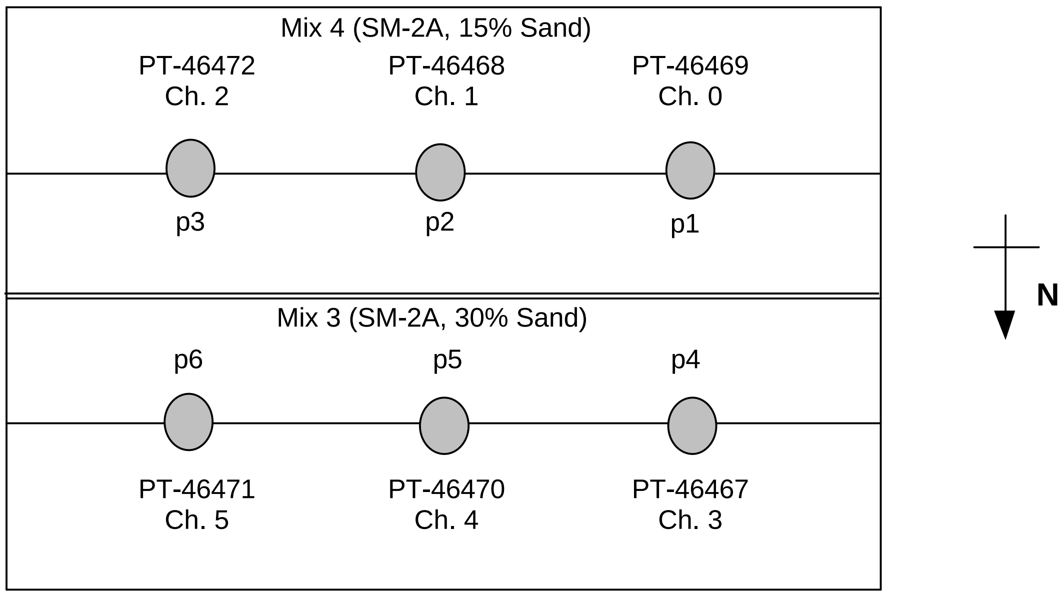


Figure 5.1 Pressure Cells Numbering and Location

Soil pressure traces induced by the passage of the truck tandem axle were digitally recorded. These traces, also seen on the computer screen as signals from the sensors, were transmitted to the data acquisition system. As discussed earlier and indicated in Table 5.2, these measurements were made towards the end of the application of each 10,000 load repetitions while the wheel axles were kept rolling. After the data acquisition system had warmed up, pressure signals would stabilize, noises would be eliminated, and displayed pressure traces from all six gauges would appear more regular and more consistent. At this time 25 complete cycles are recorded consecutively for each gauge, one gauge at a time. Recording starts for the first cycle when the wheel carriage is heading from east to west (west bound), followed by the reversed rolling direction of this cycle (east bound). Subsequent cycles are recorded in the same fashion immediately afterward. This procedure and sequence was used at all times for all recorded pressure and strain sensor data.

Representative traces for the first of such group of cycles (i.e., two wheel passes) is shown in Figure 5.2. These are depicted for the pressure transducers placed at midspan of each specimen (sensor p2 in Mix 4, SM-2A with 15% sand; and sensor p5 in Mix 3, SM-2A with 30% sand). Even though, measurements were recorded every 10,000 load repetitions, for the sake of demonstration, traces are shown at every 20,000 repetitions. Also only the first of each 25 consecutive cycles is plotted.

It can be noted that each truck pass produces two consecutive peaks corresponding to the passage of each of the two axles of the tandem. For any particular curve, the two passes are separated by about 3.5 seconds of zero stress which correspond to the time between two consecutive truck passes. The graphs show the first peak which would be due to the front axle (heading west), immediately followed by the second axle, then after about 3.5 seconds a third peak from the second axle on its way back (heading east), and finally a forth peak from the front axle return. The time period between consecutive peaks of the front axle (first and forth peaks) is about 6.5 seconds. This is half of a complete two-way cycle that takes between 12 and 13 seconds.

The four peak values of each first cycle (such as those shown in Figure 5.2) were averaged at increments of 10,000 load repetitions. Referring to Figure 5.1, each of the south and north lanes has three pressure cells designated p1, p2, p3, and p4, p5, p6, respectively. The variation of the peak pressure with the number of load repetitions is displayed in Figure 5.3 for (a) Mix 4, SM-2A with 15% river sand (south lane), and (b) Mix 3, SM-2A with 30% river sand (north lane). Once again, these values are based on the first of the 25 consecutive cycles recorded at any particular stage for a certain transducer.

(a) Sensor p2 in Mix 4

(b) Sensor p5 in Mix 3

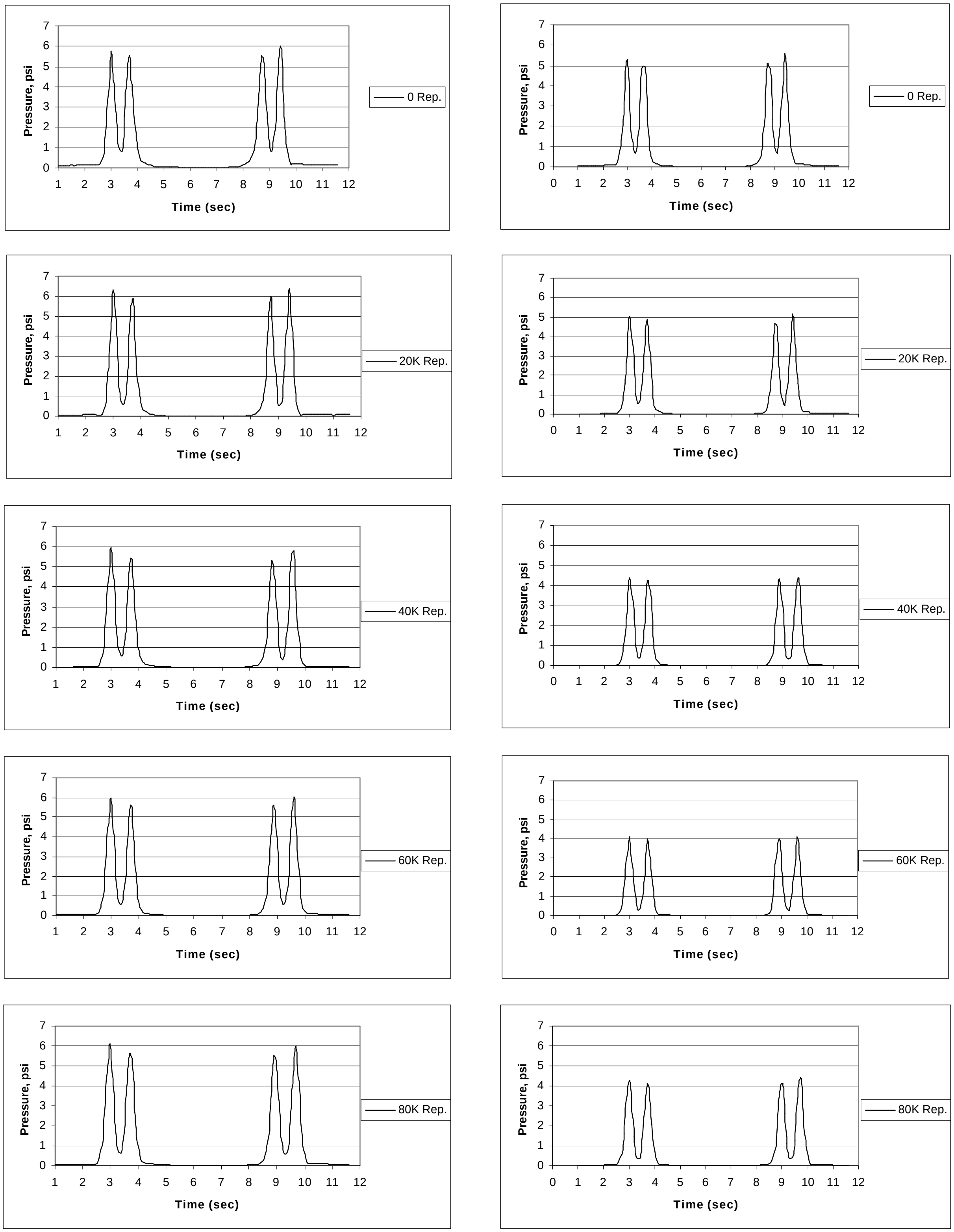
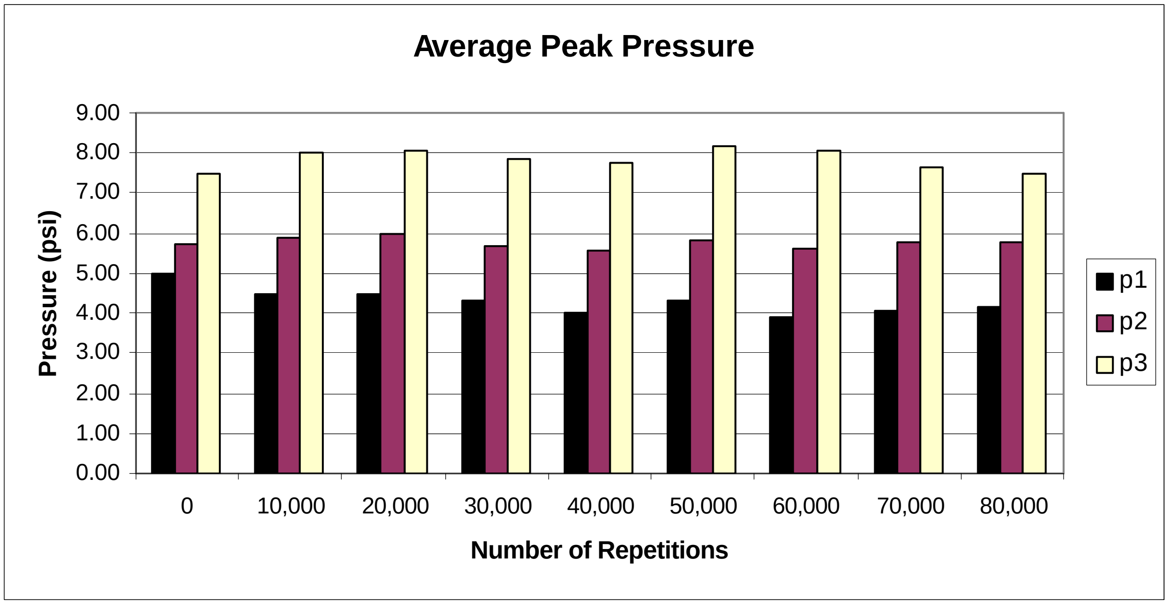
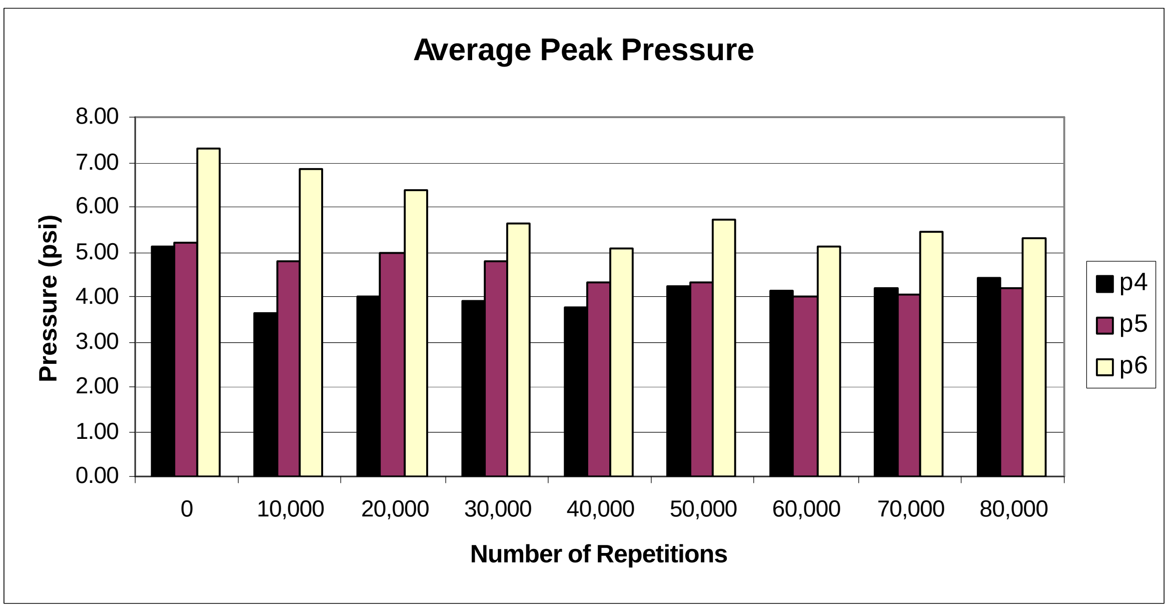


Figure 5.2 Representative Pressure Traces from Cells Located at Mid-span



(a) Mix 4 (SM-2A, 15% Sand)



(b) Mix 3 (SM-2A, 30% Sand)

Figure 5.3 Variation of Peak Pressure with Number of Load Repetitions

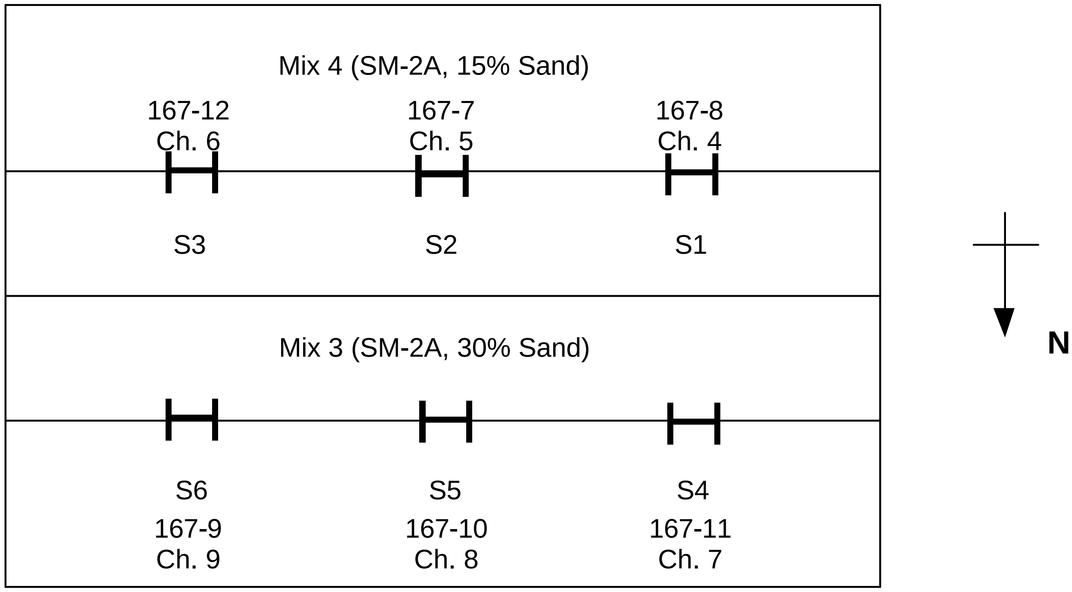
5.2 Horizontal Tensile Strains

As in the case of pressure cells, strain traces were digitally recorded under the passage of the truck tandem axle. A different computer connected to a second National Instrument data acquisition (NIDAQ) system was used to record strains. The two computers and respective NIDAQ's were run simultaneously such that at each location strain and stresses would be recorded under the same truck passage. The strain traces were displayed on the computer screen as signals from the gauges were transmitted to the data acquisition system. Signals from the strain gauges had significantly more noise than those from all six pressure cells.

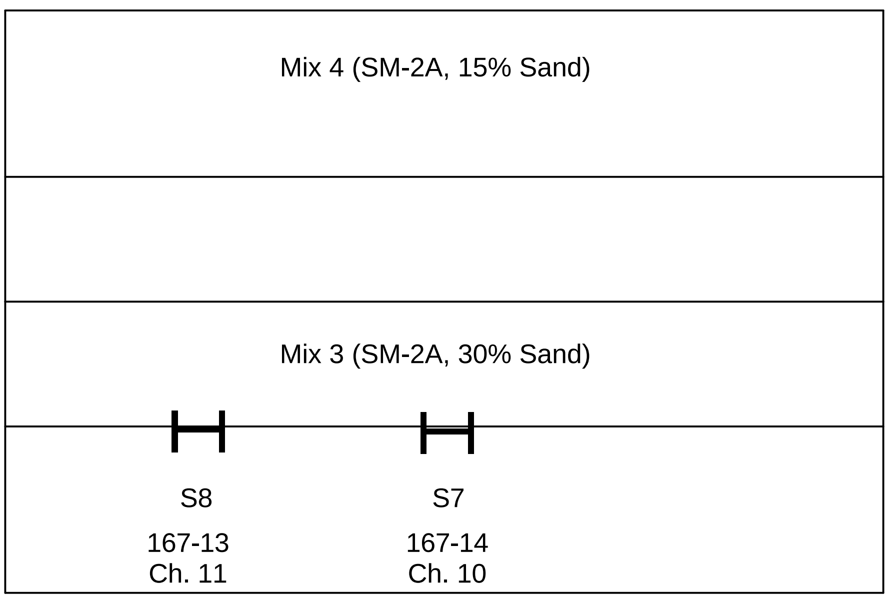
The location of the eight strain gauges was discussed in Section 4.4.1.2. These are identified in Figure 5.4 as gauges s1 through s8, along with the corresponding transducer serial number (167-xx) and channel number (Ch.x) used in the NIDAQ data acquisition system. Note that s1 through s6 were placed below the Asphalt Concrete (AC) layer (Figure 5.4 (a)) while s7 and s8 were placed at mid-depth of the AC in the north lane only (Figure 5.4 (b)). Referring to both Figures 5.1 and 5.4, it should be noted that pressure cells p5 and p6 were each recorded twice, once with strain gauges s5 and s6**,** and again with gauges s7 and s8**.** The reason for this was to obtain simultaneous strain and pressure measurements under the same truck passage at each of the designated locations (referring to Figure 4.8, it can be seen that p5, s5, s7, and p6, s6, s8 correspond to the same location in the plan).

As described in Section 5.1 for the case of the pressure cells, 25 complete cycles were recorded consecutively for each strain gauge, one gauge at a time (recording started for the first cycle when the wheel carriage is heading from east to west). Representative traces for the first of such cycles (i.e., two wheel passes) is shown in Figure 5.5. These are depicted for the strain gauges placed at midspan of each specimen (sensor s2 in Mix 4, SM-2A with 15% sand; and sensor s5 in Mix 3, SM-2A with 30% sand). Once again, even though measurements were recorded every 10,000 load repetitions, for the sake of demonstration traces are shown at every 20,000 repetitions.

The number of peaks due to the tandem axle, the time interval between consecutive truck passes, and period of zero strain between passes are the same as in the case of the soil pressure. Here, however, a small negative strain (compression) is detected slightly before the front axle of the tandem produces the peak tensile wave, and after the back axle produces the second peak tensile wave. Between the two tensile peaks, a more pronounced compression dip is noted. These phenomena are similar to others' results reported in the literature (as discussed in Chapter 1 and 4) and were consistent at all sensor locations. This stress reversal is normally attributed to the rebound of the pavement slabs due to the truck passage. Lower fibers of the slabs experience tensile strains under the wheel load due to the bending of the slab. In contrast, pressure is always negative (compression) under the slab and no tension is developed due to a truck (or wheel) passage.



(a) At Top of AB-3, 6" Below Surface of Pavement



(b) At Mid-depth of AC, 3" Below Surface of Pavement

Figure 5.4 Strain Gages Numbering and Location

Gage S2 in Mix 4

Gage S5 in Mix 3

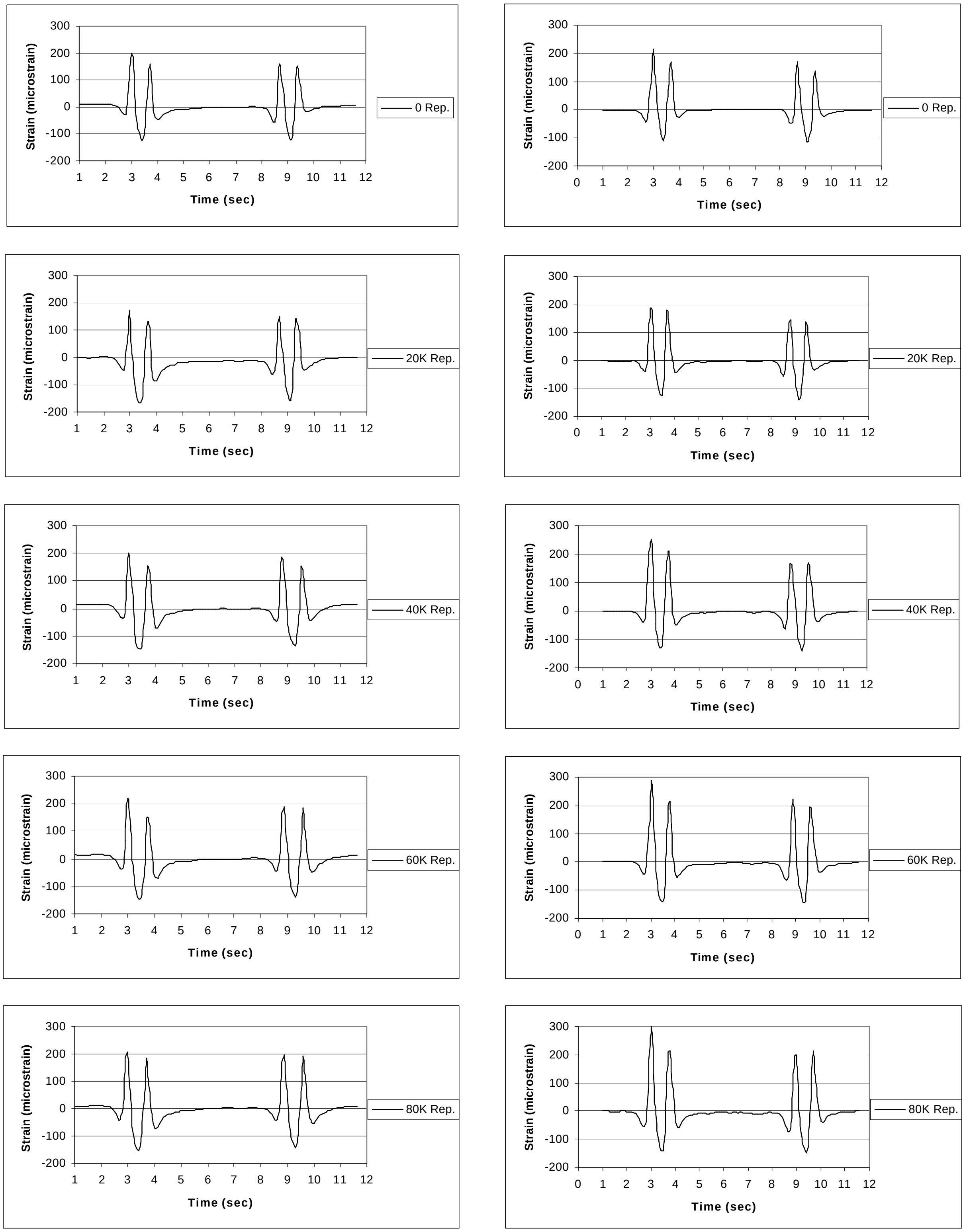


Figure 5.5 Representative Strain Traces from Gages Located at Mid-Span

The four peaks of the first recorded cycle were averaged at increments of 20,000 load repetitions. Referring to Figure 5.4(a), each of the south and north lanes has three strain gauges designated s1, s2, s3, and s4, s5, s6, respectively. The variation of the peak strain with the applied number of load repetitions is displayed in Figure 5.6 for (a) Mix 4, SM-2A with 15% river sand (south lane), and (b) Mix 3, SM-2A with 30% river sand (north lane).

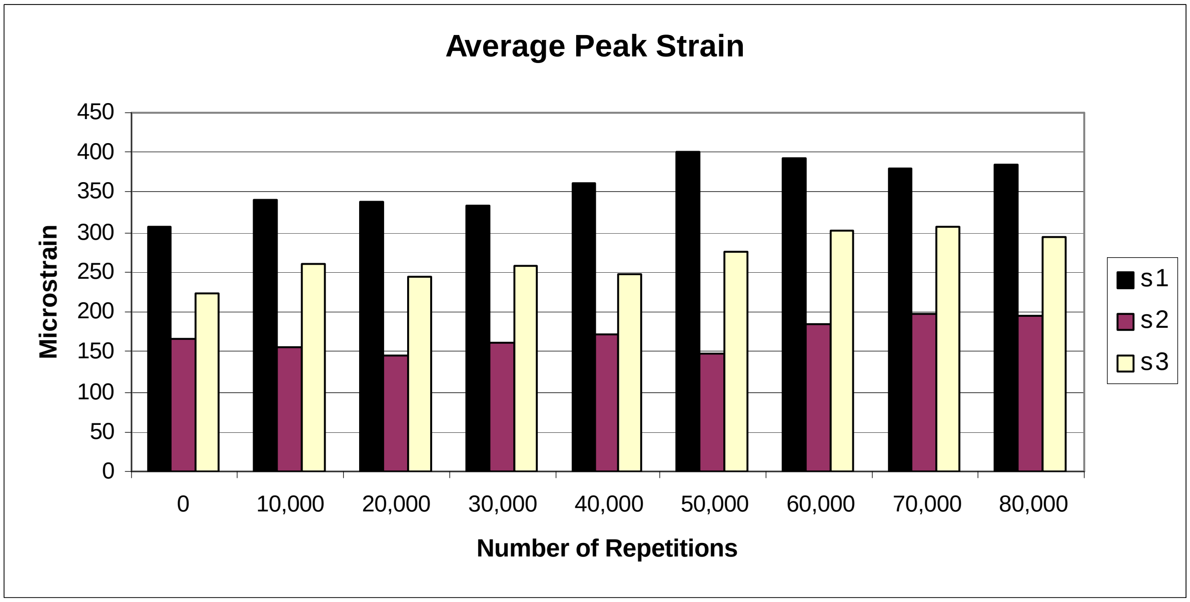
5.3 Pavement Temperature

Temperatures were recorded during the application of the wheel load cycles. These were used to verify the heat application procedure and the heating/loading combination discussed in Sections 4.3.1 and 4.3.2. Temperature logs were electronically maintained each testing day during working hours, including the times when the testing machine was run or when strain and pressure readings were being recorded. All 24 thermocouples, at the different depth and locations (see Figure 4.8), were recorded every 30 minutes, on the average.

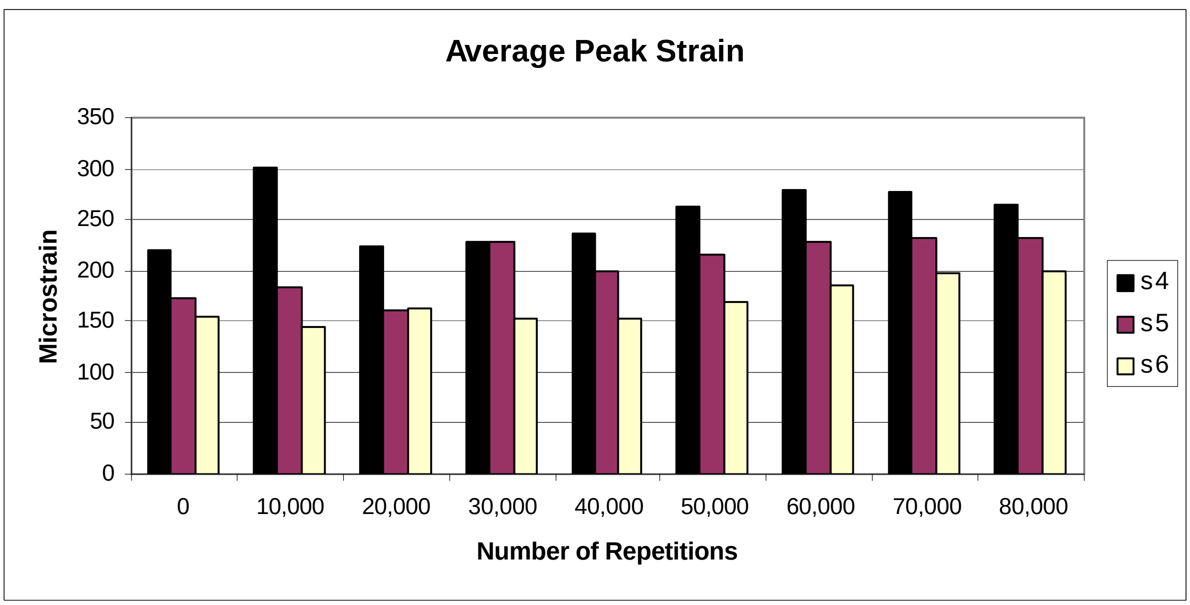
5.4 Asphalt Concrete Density

The (wet) density of the asphalt concrete was measured at the beginning of the test and every 10,000 repetitions thereafter, up to 80,000 for all four slabs. Recalling Figure 4.1, Mixes 1 and 2 were in the north pit (control sections), while Mixes 3 and 4 were in the south pit (test sections). For each of the two pits, measurements were made at three locations on each of the south and north slabs, designated 1, 2, 3 and 4, 5, 6, respectively. These locations were selected at the quarter-span points along the north track of each pair of wheel paths. For the test sections, they correspond longitudinally to the location of the strain gauges embedded under the pavement.

At each location, three one-minute readings of the nuclear gauge were taken and averaged. The variation of the asphalt concrete density with the number of load repetitions applied to the pavement sections is depicted in Figure 5.7. It can be observed that the values do not change significantly except from the initial conditions before any load was applied.



(a) Mix 4 (SM-2A, 15% Sand)



(b) Mix 3 (SM-2A, 30% Sand)

Figure 5.6 Variation of Peak Strains with Number of Load Repetitions

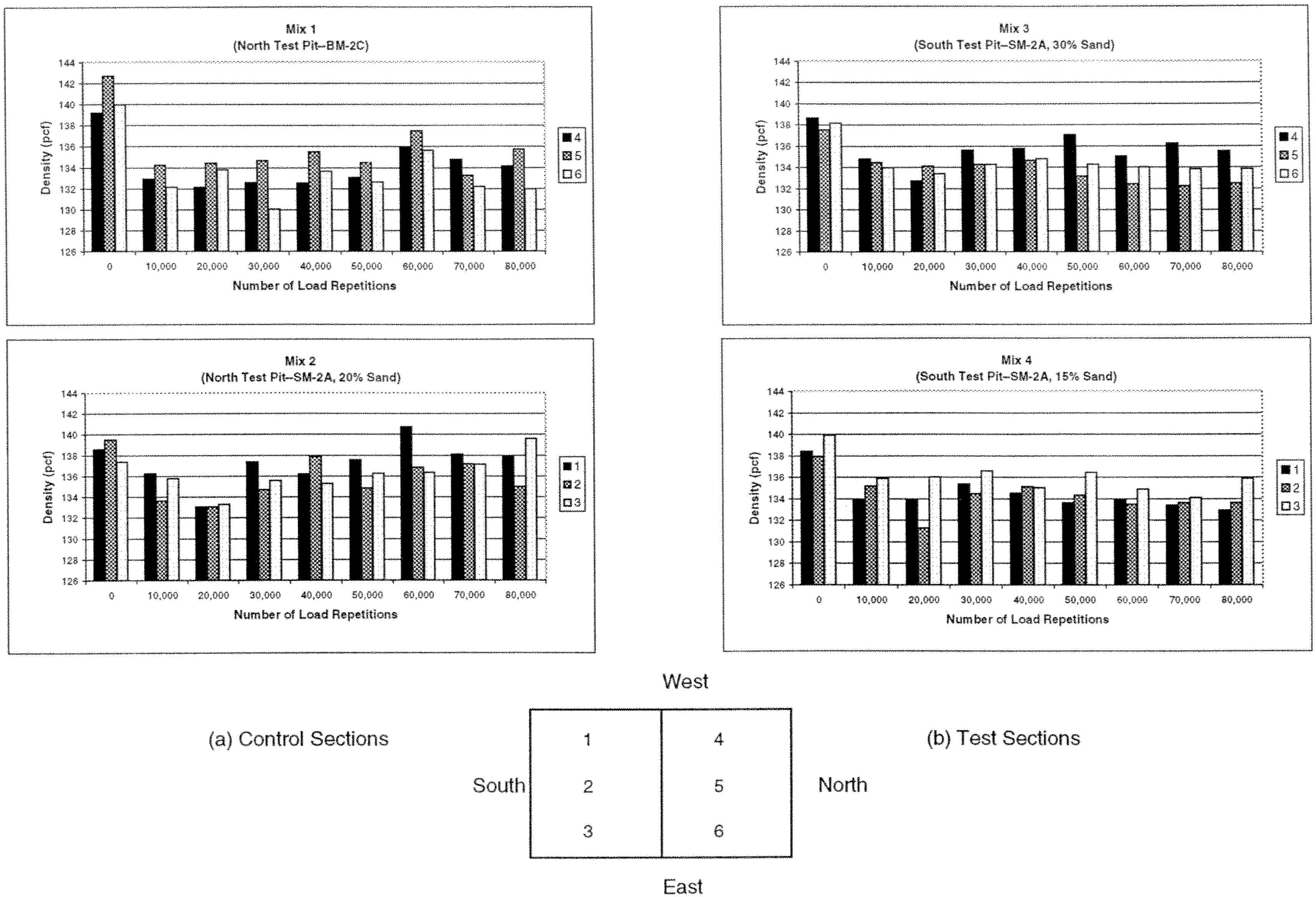


Figure 5.7 Variation of Asphalt Concrete Density with Number of Load Repetitions

5.5 Pavement Surface Rutting

Surface rutting was measured using both a Face Dipstick device and the Transverse Rut Measuring Device developed at the K-ATL and described in Section 4.5.3. Using the Face Dipstick, surface elevations of the pavement are measured at 305 mm (12 in.)-intervals, corresponding to the swiveling feet of the apparatus. Readings were recorded manually as the device was moved along a straight path. A two-way passage on any given path allows corrections to be made such that the elevation of the ending point would correspond to that of the initial point and ensure that the loop is closed correctly. This was most useful to construct the longitudinal profiles.

With the Transverse Rut Measuring Device, a more accurate reading elevation could be measured and electronically recorded every 13 mm (1/2 in.). This allowed plotting of a more precise and more accurate surface profile that depicts the progression of asphalt rutting under the fixed wheel paths.

5.5.1 Longitudinal Profiles

Longitudinal profiles were constructed using readings from the Face Dipstick device. As indicated in Tables 5.1 and 5.2, longitudinal profiles were constructed (for both the control sections and test sections) at the beginning of the tests and after each 10,000 load applications, as well as at the end of the tests. These were measured along a line spanning the entire length of the slabs (6.1 m or 20 ft). Measurements started always at the East heading West and back to the starting point. Longitudinal profiles followed chalk-lines traced at the center of the outer track of any dual's path; for a north lane, that would be the north track, and for a south lane the south track.

The changes in the longitudinal profiles are shown in Figures 5.8 through 5.11, for Mixes 1 through 4, respectively. It should be noted that the first and last 610 mm (2 ft) of the tracks (towards the east and west edges of the pavement sections) are where the wheel carriage gets on and off the pavement slabs onto the lab floor. During testing these regions are subject to the worst impact from the carriage which causes dipping in the longitudinal tracks at the beginning and the end of the path. These were periodically filled with additional asphalt repair material to level up the ramp on and off the lab floor. The profiles measurements could have been taken before or after these ramps were formed, and therefore the variation in the first and last two feet of the longitudinal profile can be disregarded.

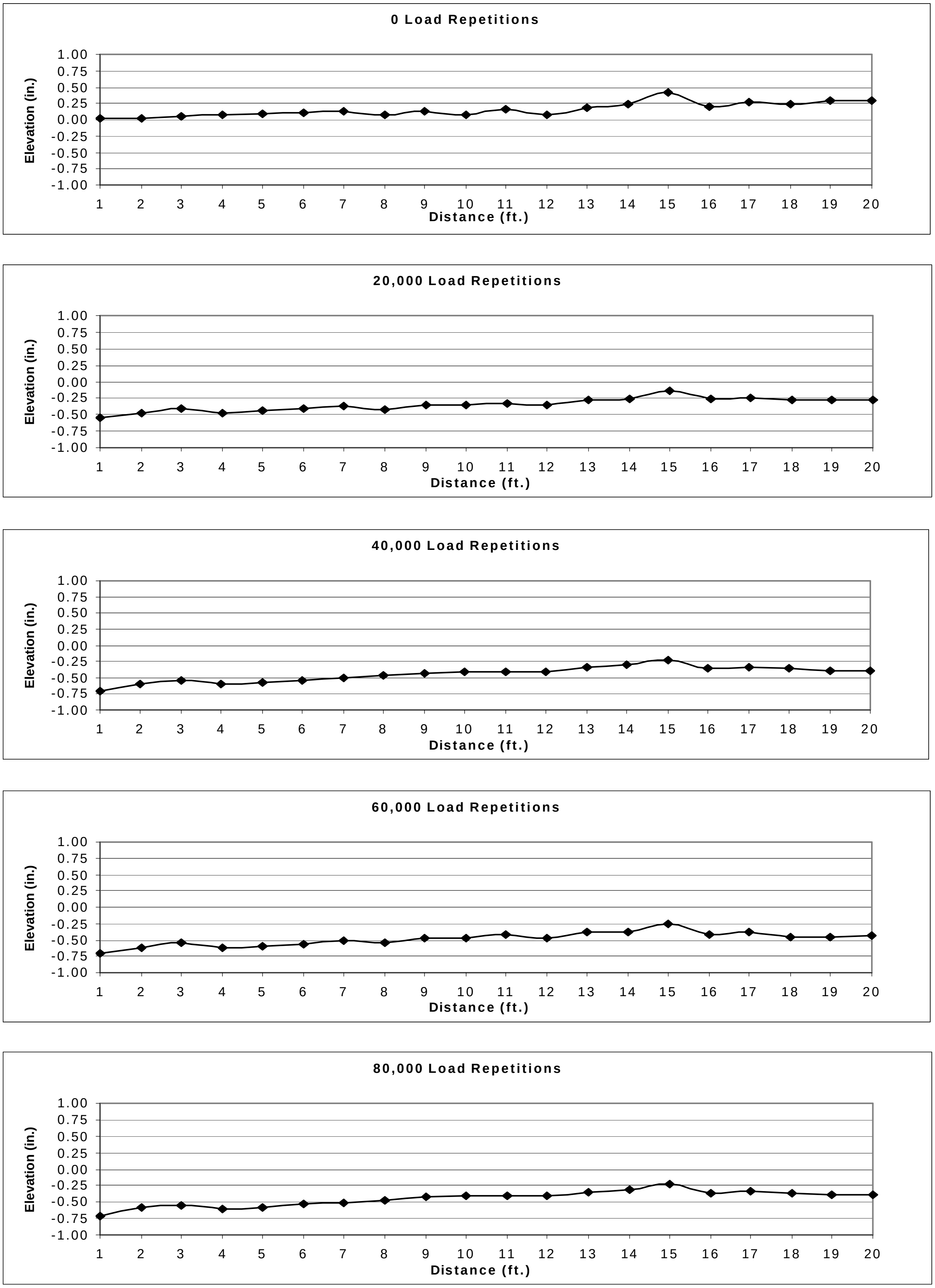


Figure 5.8 Change in Longitudinal Profile with Loading for Mix 1

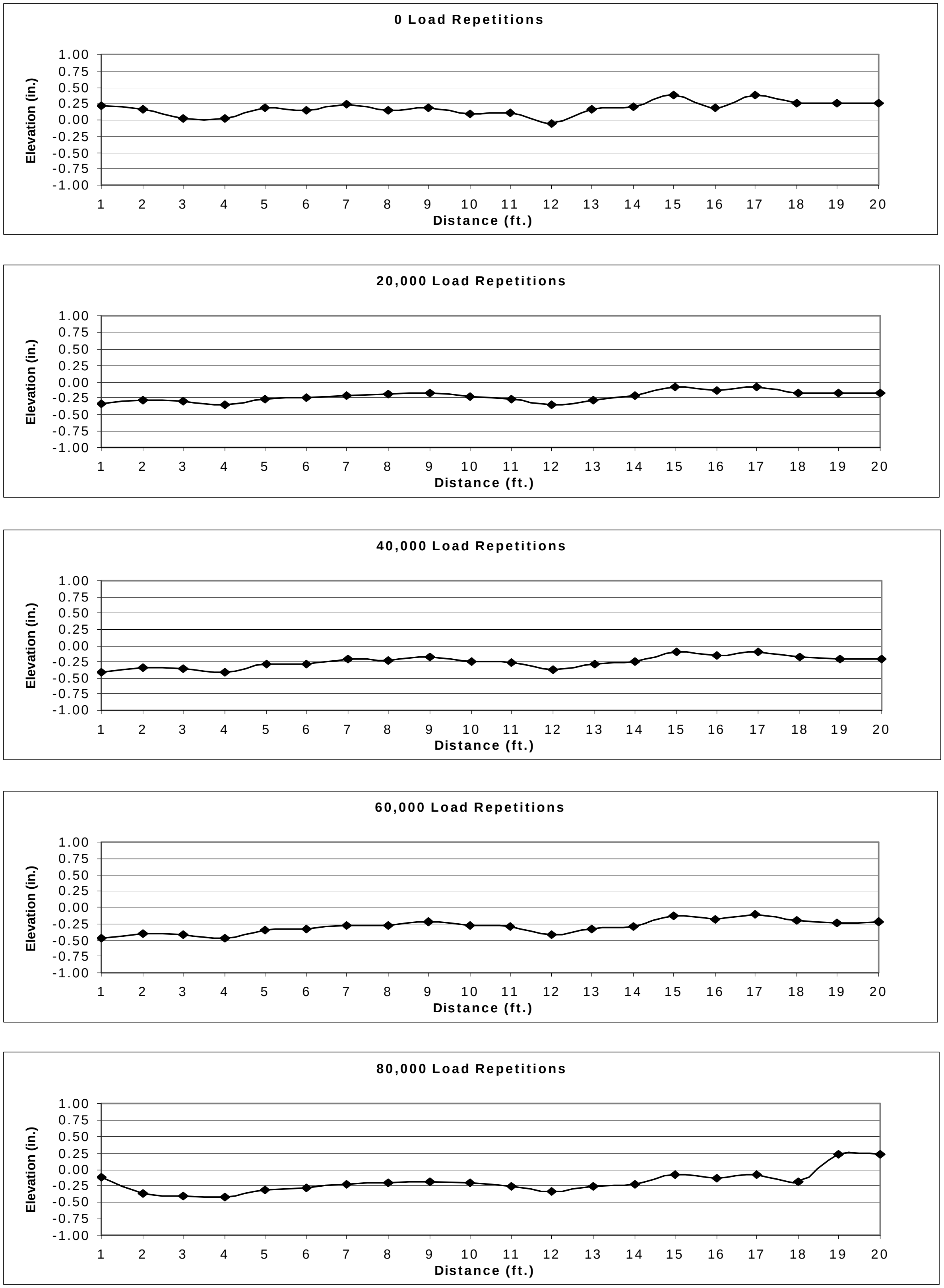


Figure 5.9 Change in Longitudinal Profile with Loading for Mix 2

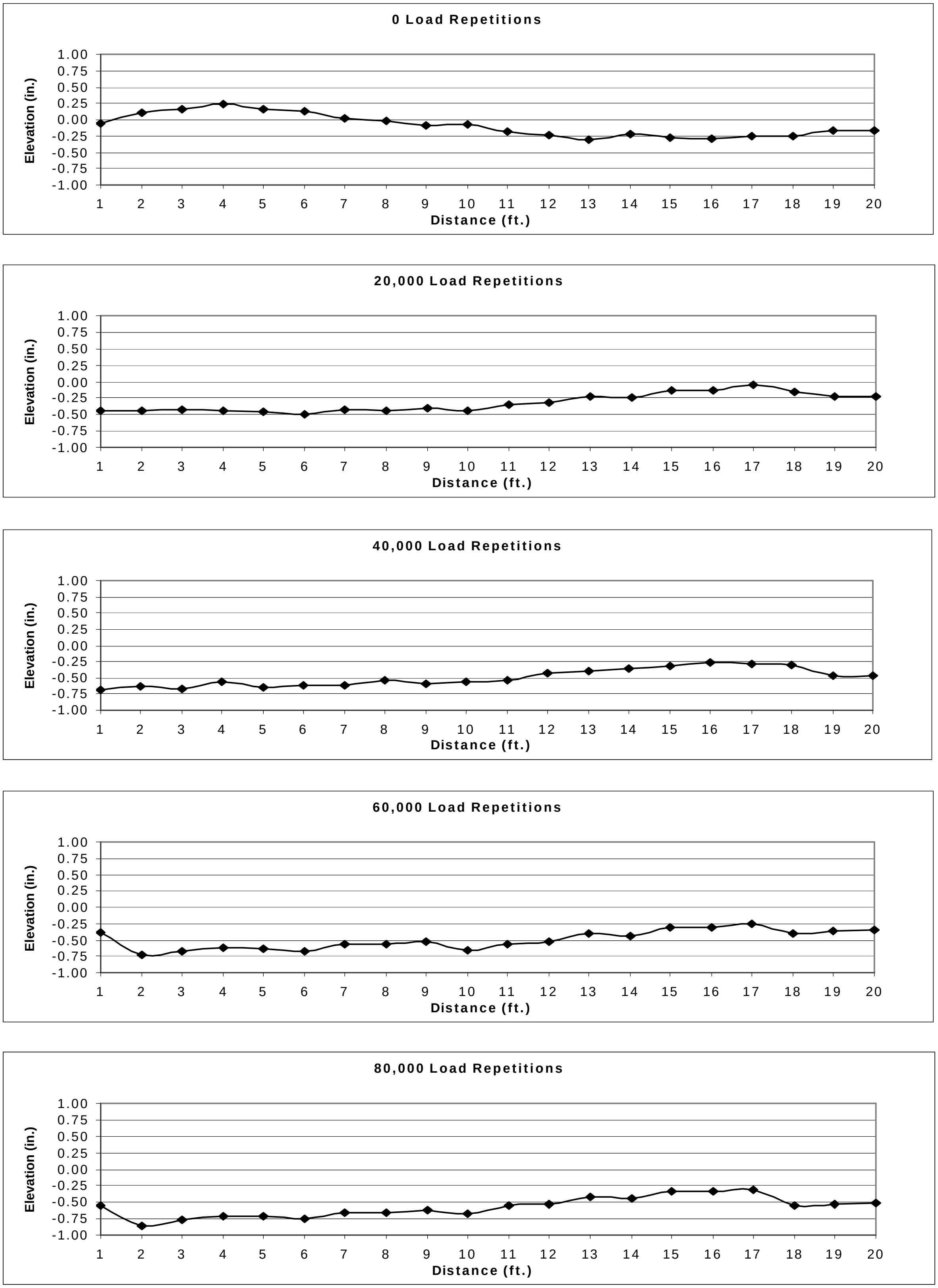


Figure 5.10 Change in Longitudinal Profile with Loading for Mix 3

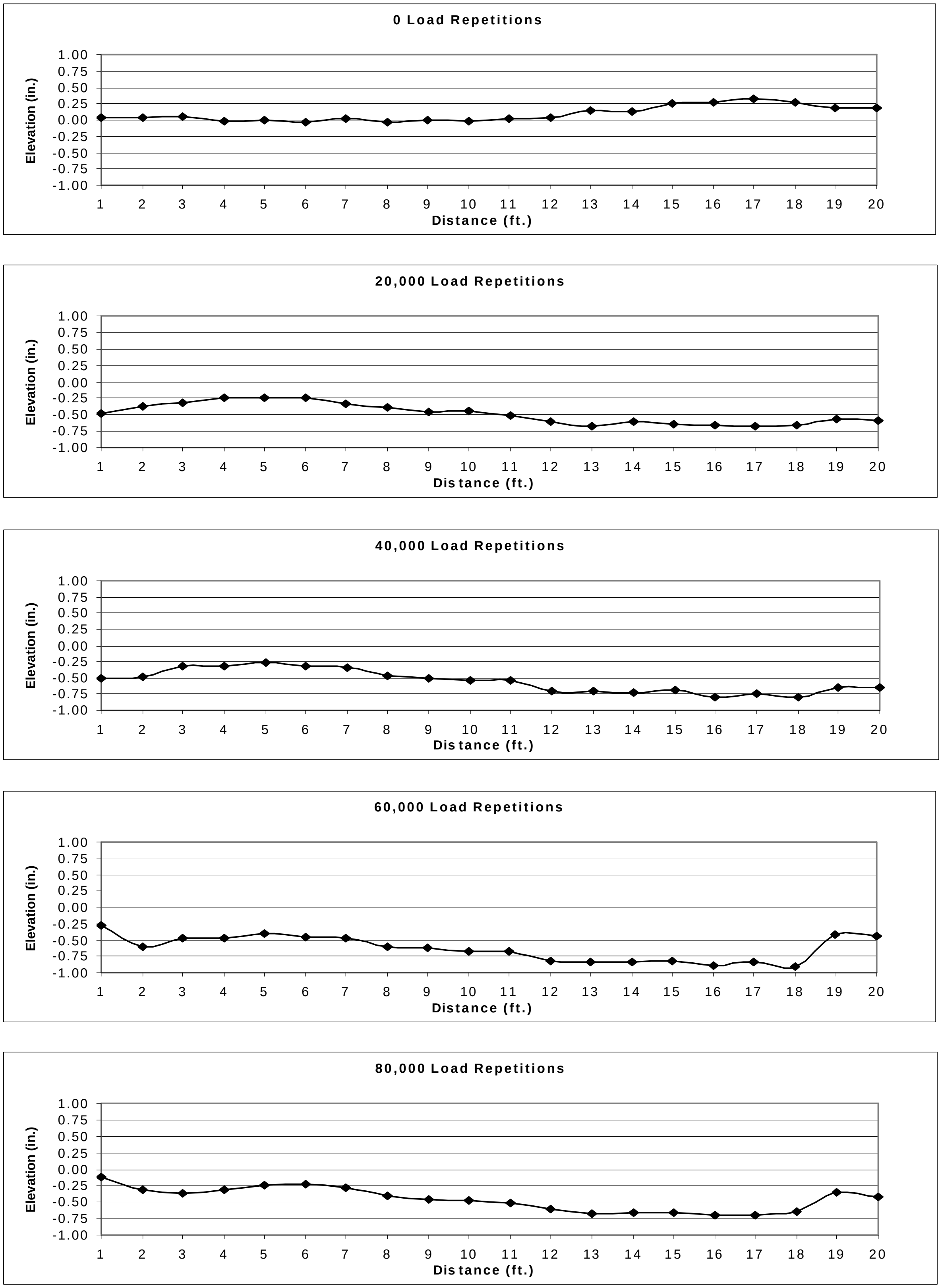


Figure 5.11 Change in Longitudinal Profile with Loading for Mix 4

5.5.2 Transverse Profiles

As indicated in Tables 5.1 and 5.2 transverse profiles were also constructed (for both the control sections and test sections) at the beginning of the tests and after each 10,000 load applications, as well as at the end of the tests. The change in elevation between the different loading stages indicates the progression of rutting, and comparison with the initial profile gives an indication of the total rut depth.

The physical definition of rutting is the longitudinal depressions in the wheel paths accompanied by upheavals to the sides [11]. The K-ATL single or tandem axles have two wheels per axle, and each wheel has a pair of tires. When asphalt concrete material is displaced (by plastic deformation) from under the wheels to the sides of the wheel tracks the deepest valleys are at the centerline of the tire tracks and heaves would form outside and between the dual tracks of any given wheel. As shown in Figures 5.12 through 5.15 the highest heave is between the two tire tracks.

Evaluation of Rutting

In this experiment, rutting is taken as the difference between the lowest point on a profile (usually at, or close to, the centerline of an individual tire track) and an imaginary straight edge resting on the test lane surface and spanning an individual tire track. This method of rut measurement is similar to the one used by White and Hua [5]. There are certainly other ways of quantifying ruts, but this one is followed here and throughout this study for comparison purpose. Rutting defined by different methods can be easily obtained by measuring directly off the constructed profile curves.

As indicated earlier, two apparatuses were used to measure the pavement surface elevation every 10,000 load repetitions for all four sections. Rutting computations were based on the profiles constructed using the Transverse Rutting Measurement Device. The device length is 3.66 m (12 ft; measuring range is 267 cm or 105 inches), therefore, covering the width of both wheel paths of the tandem axle. Therefore each two adjacent sections were measured at once: Mixes 1 and 2 (control sections) side-by-side in the north pit, and Mixes 3 and 4 (test sections) side-by-side in the south pit. The covered width is beyond most of the heaves that are formed along the outside edges of the wheel paths.

Measuring always started on the south side of the south lane, going North across a pair of adjacent pavement section, to the north side of the north lane. Anchor screws were fixed in the pavement to ensure that the rutting measurement device base plates were always installed at the same location every time measurements are taken. These screws, and consequently the resulting profiles, were positioned at mid-span of the slabs (labeled “Middle Profiles”) and 1.52 m (5 ft) from the east and west ends (labeled “East Profiles” and “West Profiles,” respectively).

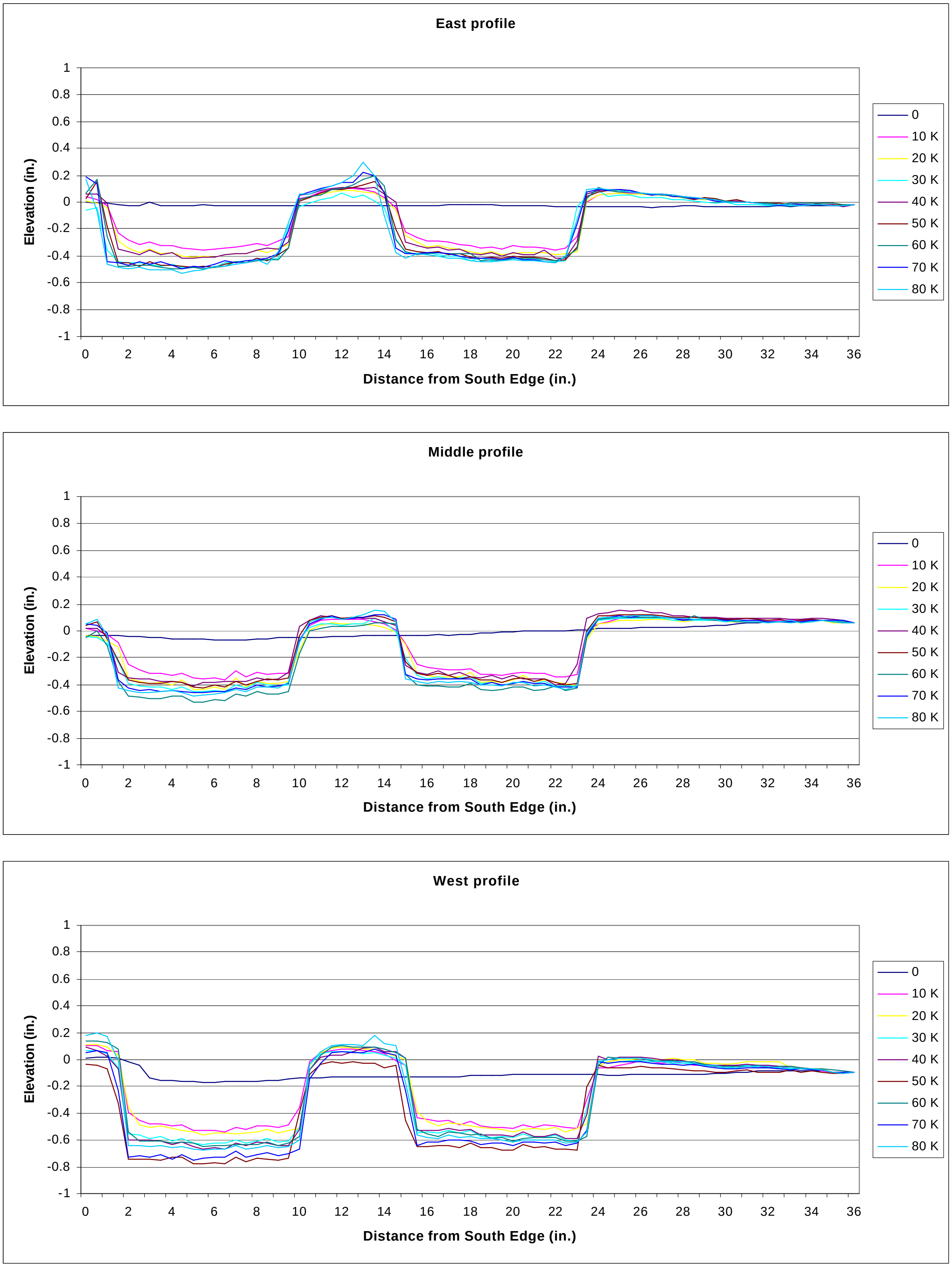
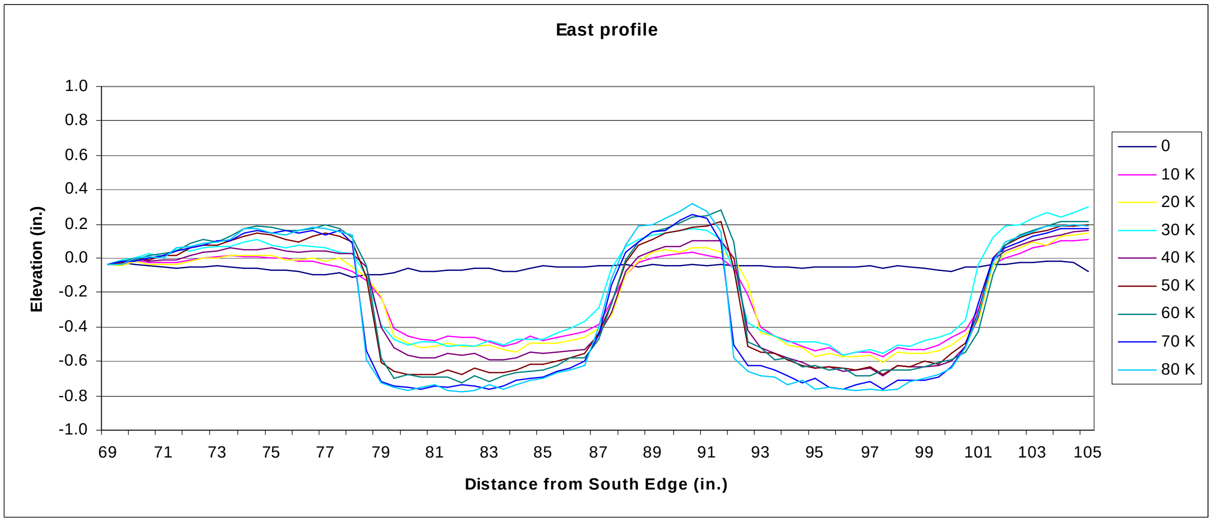
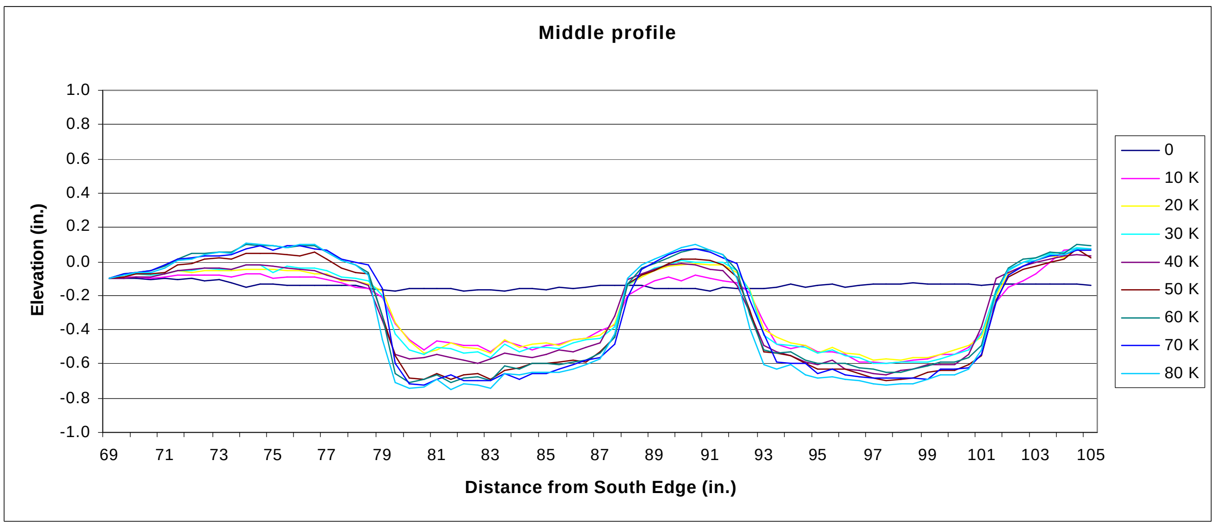


Figure 5.12 Transverse Profile and Progression of Rutting for Mix 2





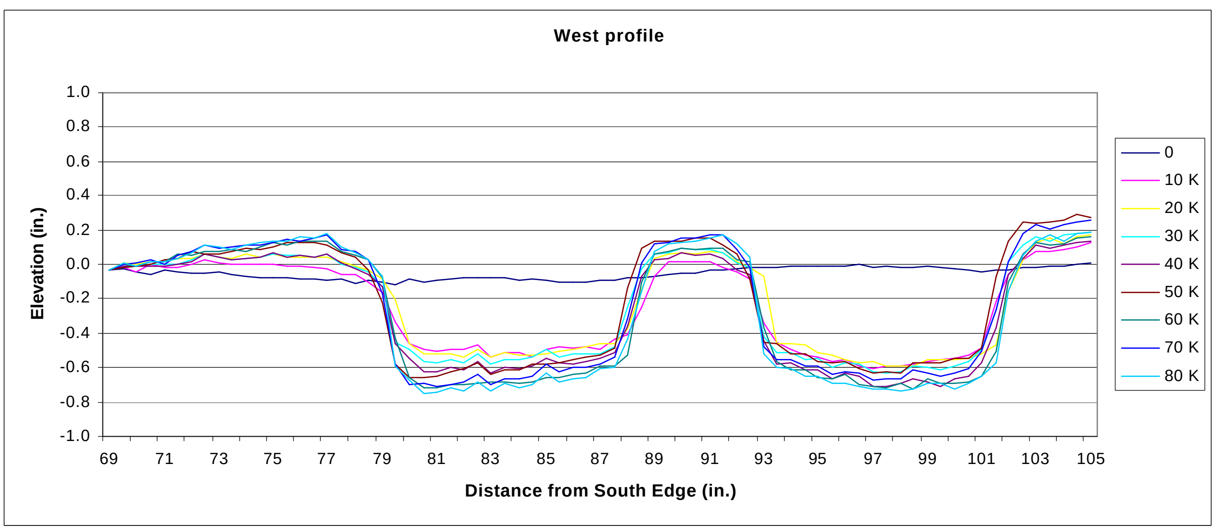


Figure 5.13 Transverse Profile and Progression of Rutting for Mix 1

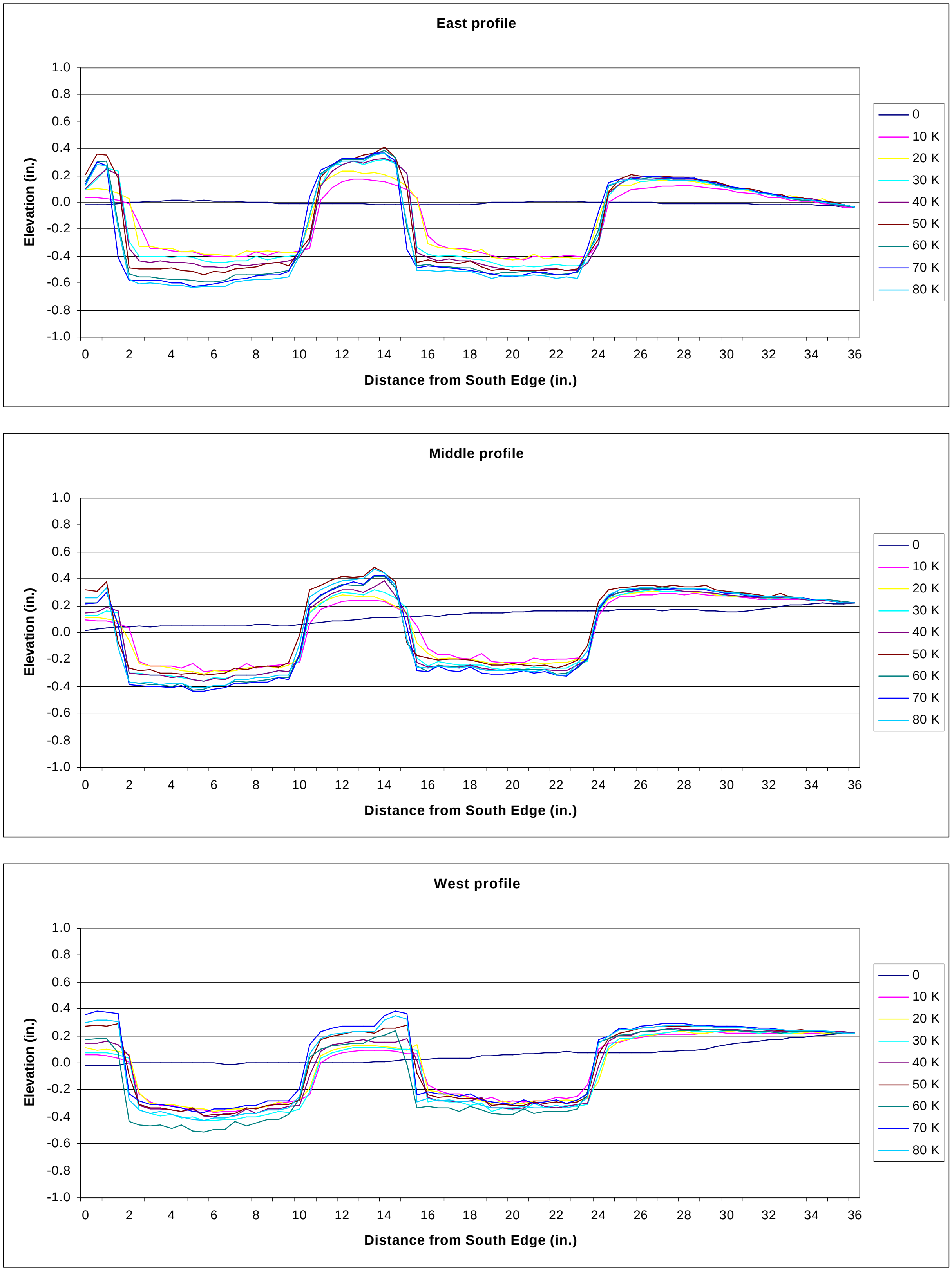
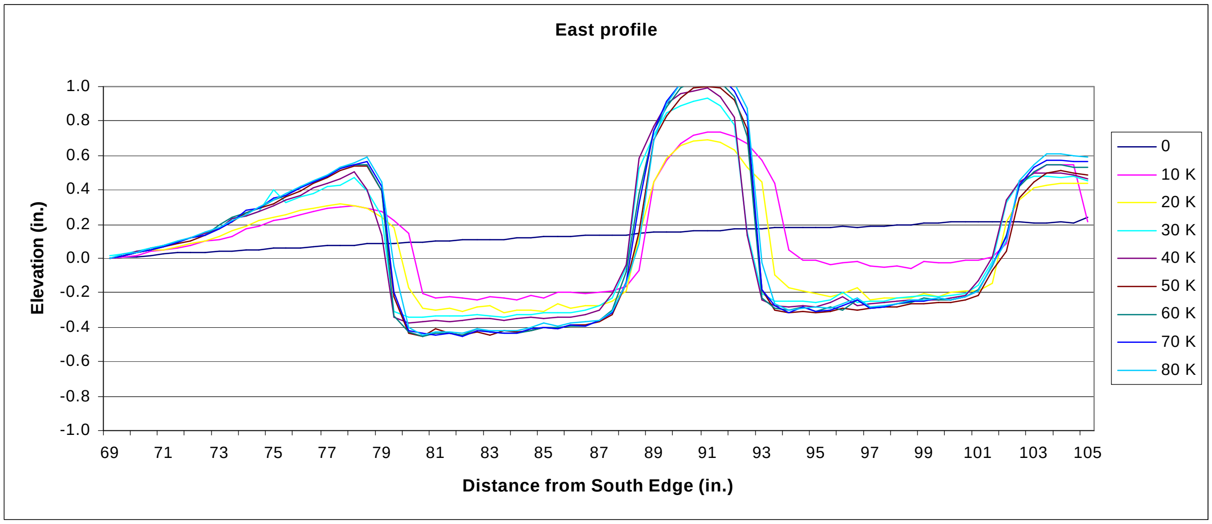
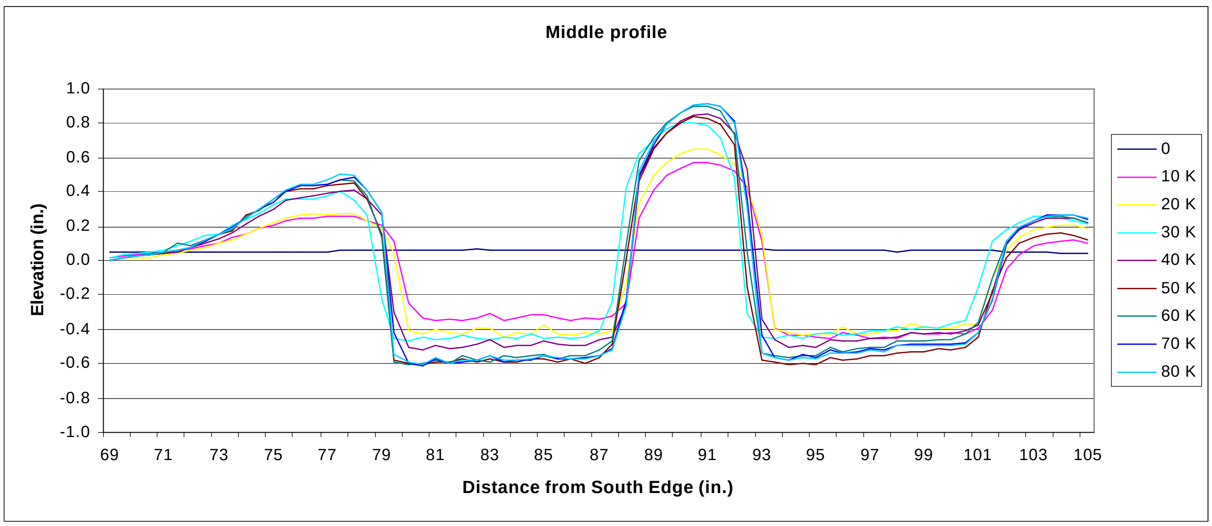


Figure 5.14 Transverse Profile and Progression of Rutting for Mix 4





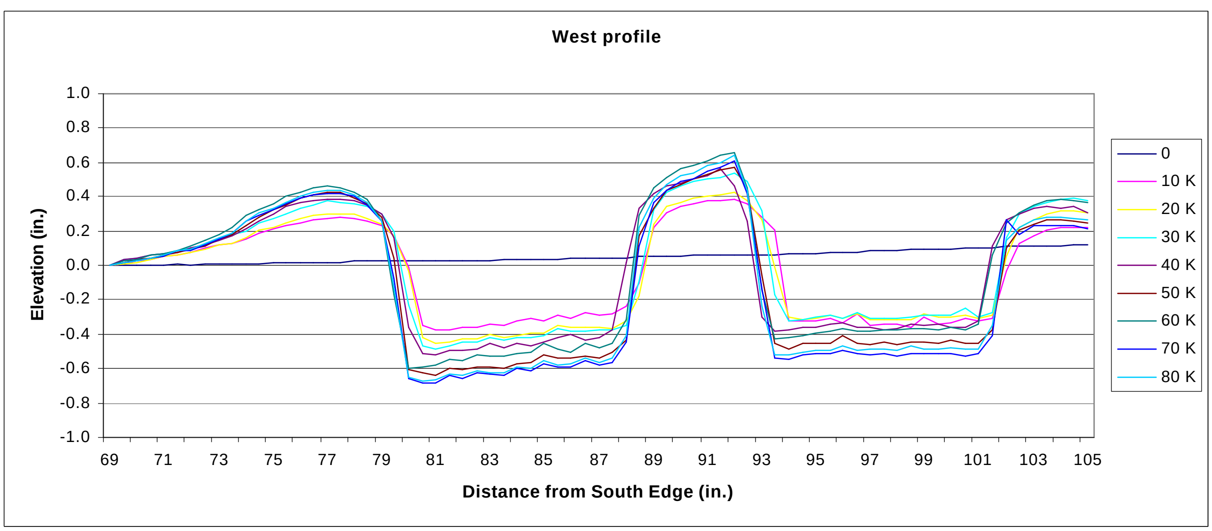


Figure 5.15 Transverse Profile and Progression of Rutting for Mix 3

The surface profiles constructed at the start of the experiment and after each 10,000 load applications are shown in Figures 5.12 through 5.15 for the four sections tested in this experiment. This gives an indication of the progression of rutting in each section relative to the number of load passes applied. In each figure, three graphs are presented showing the east, middle, and west profiles, respectively. Since the passage of the truck normally does not have much affect on the portions away from the wheel path, detailed profile curves were constructed only for the main portion of the wheel path. This gives a width coverage of 91 cm (36 in.) for each wheel. Noting that Mixes 1 and 2, and 3 and 4 were tested in pairs, so too were the measurement of their surface profiles, as graphed in Figures 5.12 and 5.13. This is why Mix 2 is reported before Mix 1, since Mix 2 was in the south lane and Mix 1 was in the north lane and measuring started from the south edge. For this reason the distance from the south edge is shown as 25 mm to 915 mm (1 to 36 in.) in Figure 5.12 and 1.75 m to 2.67 m (69 to 105 in.) in Figure 5.13. This is also the case for Mixes 4 and 3 in Figures 5.14 and 5.15.

The magnitude of the rut depths (as defined above) in each of the east, middle and west profiles for Mixes 1 though 4 are presented in Tables 5.3 through 5.6, respectively. The rut marks along the wheel paths for the test sections (middle pit) can be seen in Figure 5.16, with Mix 3 on the left of the picture and Mix 4 on the right.

Figure 5.16 Wheel Marks on the Test Sections at the end of 80,000 Load Applications of the ATL 36 Kip-Tandem Axle.

Table 5.3 Rutting Depths (in.) for North Pit, North Wheel Path (BM-2C)--Mix 1

No. of Reps.	East Profile			Middle Profile			West Profile		
	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10,000	0.52	0.63	0.58	0.41	0.58	0.50	0.55	0.67	0.61
20,000	0.56	0.69	0.63	0.51	0.59	0.55	0.58	0.70	0.64
30,000	0.64	0.76	0.70	0.54	0.64	0.59	0.64	0.78	0.71
40,000	0.67	0.80	0.74	0.59	0.64	0.62	0.69	0.81	0.75
50,000	0.86	0.87	0.87	0.68	0.73	0.71	0.78	0.85	0.82
60,000	0.96	0.94	0.95	0.78	0.74	0.76	0.84	0.85	0.85
70,000	0.98	0.98	0.98	0.80	0.76	0.78	0.85	0.88	0.87
80,000	1.02	1.02	1.02	0.84	0.81	0.83	0.91	0.91	0.91

Table 5.4 Rutting Depths (in.) for North Pit, South Wheel Path (SM-2A, 20% Sand)--Mix 2

No. of Reps.	East Profile			Middle Profile			West Profile		
	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10,000	0.42	0.43	0.43	0.41	0.43	0.42	0.61	0.55	0.58
20,000	0.45	0.48	0.47	0.44	0.48	0.46	0.64	0.60	0.62
30,000	0.50	0.50	0.50	0.48	0.51	0.50	0.68	0.64	0.66
40,000	0.50	0.50	0.50	0.48	0.52	0.50	0.75	0.65	0.70
50,000	0.64	0.54	0.59	0.51	0.54	0.53	0.76	0.65	0.71
60,000	0.68	0.58	0.63	0.55	0.55	0.55	0.77	0.66	0.72
70,000	0.70	0.60	0.65	0.55	0.55	0.55	0.82	0.68	0.75
80,000	0.74	0.64	0.69	0.61	0.58	0.60	0.83	0.73	0.78

Table 5.5 Rutting Depths (in.) for Middle Pit, North Wheel Path (SM-2A, 30% Sand)--Mix 3

No. of Reps.	East Profile			Middle Profile			West Profile		
	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10,000	0.72	0.74	0.73	0.78	0.78	0.78	0.70	0.68	0.69
20,000	0.80	0.82	0.81	0.92	0.88	0.90	0.81	0.70	0.76
30,000	1.00	0.95	0.98	1.07	0.98	1.03	0.93	0.76	0.85
40,000	1.08	1.02	1.05	1.10	1.10	1.10	0.99	0.83	0.91
50,000	1.16	1.08	1.12	1.24	1.15	1.20	1.12	0.92	1.02
60,000	1.18	1.10	1.14	1.29	1.18	1.24	1.15	0.96	1.06
70,000	1.22	1.13	1.18	1.31	1.21	1.26	1.18	1.00	1.09
80,000	1.24	1.21	1.23	1.32	1.22	1.27	1.21	1.06	1.14

Table 5.6 Rutting Depths (in.) for Middle Pit, South Wheel Path (SM-2A, 15% Sand)--Mix 4

No. of Reps.	East Profile			Middle Profile			West Profile		
	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.	South Tire	North Tire	Avg.
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10,000	0.50	0.58	0.54	0.43	0.48	0.46	0.44	0.41	0.43
20,000	0.56	0.64	0.60	0.49	0.52	0.51	0.49	0.46	0.48
30,000	0.71	0.73	0.72	0.62	0.59	0.61	0.51	0.51	0.51
40,000	0.76	0.77	0.77	0.62	0.64	0.63	0.57	0.55	0.56
50,000	0.90	0.83	0.87	0.72	0.69	0.71	0.70	0.60	0.65
60,000	0.93	0.85	0.89	0.77	0.69	0.73	0.70	0.63	0.67
70,000	0.96	0.88	0.92	0.79	0.71	0.75	0.76	0.63	0.70
80,000	0.97	0.88	0.93	0.90	0.74	0.82	0.78	0.69	0.74

5.6 Cores and Trenches

A number of cores were drilled in the wheel path and away from the wheel path at the end of the experiment. Coring was performed by KDOT personnel. The diameter of the cores were 102 mm (4 in.) and were drilled through the full depth of the pavement. The cores taken from the test sections, as well as a number of beam specimens for fatigue tests, were cut from these pavement sections, and given to the principal investigators of the K-TRAN Project for further experimental and analytical studies. Cores taken from the control sections were given to KDOT engineers for further analysis.

A full-depth transverse trench was saw-cut through the width of the test sections in the middle pit to have a visual observation of the asphalt concrete layer. About 51 mm (2 in.) of the aggregate base material was also removed to expose the separation line between the bottom of the pavement layer and the top of the AB-3 base. A close-up view of SM-2A sections is shown in Figure 5.17 for Mix 4 (15% sand) and in Figure 5.18 for Mix 3 (30% sand). No evident indication was found of any consolidation or compaction of the subgrade soil or aggregate base layer below the pavement.

Figure 5.17 Side Wall of Cut Trench in SM-2A Test Section with 15% Sand