PAVEMENT SUBGRADE PERFORMANCE STUDY

Test Section 710

Subgrade AASHTO soil borderline between
types A-6 and A-7-6 at wet of optimum (21%)

By

Edel R. Cortez (1)
Vincent C. Janoo (1)

Subgrade Moisture Content	AASHTO Soil Type			
	A-2-4	A-4	A-6	A-7-5
M1	Optimum 10 % TS 701	Optimum 17 % TS 702	Optimum 16 % TS 709	Optimum 20.4% TS 712
M2	12 % TS 707	19 % TS 704	**19 % TS 708**	**21% TS 710**
M3	15 % TS 703	23 % TS 705	22% TS 706	25% TS 711

1. U.S. Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road,
Hanover, New Hampshire 03755, United States

EXECUTIVE SUMMARY

This report is one of a series of reports on the pooled-fund research project titled Subgrade Performance Study (SPR-208). The hypothesis for this study is that the failure criterion depends on the subgrade soil type and the in-situ moisture content. Many of the current mechanistic design procedures incorporate the results from AASHO Road Tests conducted in the late nineteen fifties. However, the AASHO Road Tests were all conducted on only one soil type (AASHTO type A-6). The tests results reflect the combined effect of traffic loads and seasonal variations. Applying failure criteria based on the AASHO Road Tests to other soil types, at different moisture contents and different climate creates much uncertainty.

In recent decades much progress has been achieved in computer technology, and new sensors allow reliable in-situ stress and strain measurements. The authors recognized the new opportunities brought by these technological advances to be able to develop more reliable pavement failure criteria that consider the effects of subgrade soil type and moisture condition.

Transportations agencies from several US states are contributing to a research initiative that will develop the bases for new pavement failure criteria that is adequate for the most common subgrade soil types found in the United State at various soil moisture contents. As part of the research program, four subgrade soils were selected for testing in the Frost Effects Research Facility (FERF). Each subgrade soil was to be constructed at three moisture contents, with one at or near optimum density and moisture content. The test sections consisted of 75 mm of asphalt concrete, 229 mm of crushed base and 3 m of the test subgrade soil type at pre-determined moisture content. The current test section was named Test Section 710. It was intended to represents the case of a subgrade soil AASHTO type A-7-6, but a discrepancy was found between Atterberg limit test results from the limited field samples and those from the actual soil delivered at the FERF. The actual soil classification for this subgrade soil was a borderline between A-6 and A-7-6. A new source of soil classified as AASHTO A-7-5 was later identified and used for Test Sections 711 and 712.
For this soil, the optimum moisture content was 17 percent. According to the Unified Soil Classification System, the subgrade soil was type CL (low liquid limit, clay).

Accelerated traffic was applied by means of a Heavy Vehicle Simulator (HVS). Each test window was subjected to one of various load levels. The traffic load was varied for each test window, ranging from 20 to 40 kN (4.5 to 9 kips). The load was applied through a dual truck tire assembly representing a half axle of a standard truck. Therefore, a 40-kN (9-kip) load is equivalent to an 80 kN (18-kip) load applied with a complete truck axle. The tire pressures were kept at 689 kPa (100 psi).

The test section was built inside the FERF testing facility, therefore the moisture and temperature conditions were controlled. The test section contained six test windows. Each test window was approximately 6.0 m long and 1 m wide. Loading was applied unidirectionally at an average speed of 12 km/hr. The test windows were subjected to about 600 load repetitions per hour. The HVS applied traffic 23 hours per day. The remaining hour was used for maintenance.

Stress, strain, and surface rut measurements were taken periodically. Stress and strain sensors were located at various depths in the base course and the subgrade. Permanent strain (while no traffic was occurring) and dynamic strain (during the passing of the tire assembly)

were measured at continuous layers from the asphalt surface down to a depth of 1.52 m. This configuration provided a distribution and a summation of deformations that enabled calibration of the deformation measurements with the surface rutting measured with a laser profilometer.

This report contains a description of the test section, construction, instrumentation, and pavement response to accelerated traffic.

CONTENTS

INTRODUCTION

As part of an international study on pavement subgrade performance, several full-scale test sections were constructed in the Frost Effects Research Facility (FERF) at the U.S. Army Cold Regions Research & Engineering Laboratory (CRREL) in Hanover, New Hampshire. CRREL is a component of the US Army Corps of Engineers Research and Engineering Center. The tests were conducted indoors at approximately 20 °C (68 °F). They were instrumented with stress cells, strain gages, moisture gages, and temperature sensors. The test sections were subjected to accelerated loading using CRREL's Heavy Vehicle Simulator (HVS). Pavement failure was defined at 12.5 mm (0.5 in.) surface rut depth, or the development of asphalt cracks 9.5 mm (3/8 in.) wide. Surface rut depth measurements were taken periodically during the accelerated load tests. At the same time, subsurface stress and strain measurements were also taken. A detailed overview of the project can be found in Janoo et al (2001). The test sections consisted of a 76-mm (3 in.) asphalt concrete (AC) layer, a 229-mm (9 in.) crushed gravel base and 3 m (10 ft) of subgrade soil. All the test sections in this research project were alike in geometry, instrumentation, and materials, except for the subgrade soil type and moisture content. The test sections were constructed using several subgrade soil types conditioned at various moisture contents. For each test section, provisions were made to maintain the temperature and moisture content as constant as possible. The test matrix for this study is shown in the table below.

Table 1. Experimental test matrix.

Subgrade Moisture Content	AASHTO Soil Type			
	A-2-4	A-4	A-6	A-7-5
M1	Optimum 10 % TS 701	Optimum 17 % TS 702	Optimum 16 % TS 709	Optimum 20.4% TS 712
M2	12 % TS 707	19 % TS 704	**19 %** **TS 708**	**21%** **TS 710** **Borderline soil** **A-6 and A-7-6**
M3	15 % TS 703	23 % TS 705	22% TS 706	25% TS 711

This reports deals with the construction, accelerated traffic testing, and pavement response of Test Section 710. As shown in Table 1, the subgrade soil in this test section was classified as AASHTO borderline between soil types A-6 and A-7-6 conditioned to 21 percent gravimetric moisture content.

DESCRIPTION OF THE TEST SECTION

The test section consists of a 76-mm (3-in) hot mixed asphalt (HMA) layer, a 229-mm (9-in) crushed gravel base course, and 3 m of subgrade soil. The subgrade soil was classified as borderline between AASHTO soil types A-6 and A-7-6. This soil was conditioned to 21 percent gravimetric moisture content. According to the modified Proctor test results, the optimum moisture content for this soil was 17 percent. The laboratory CBR test results indicate that at 21 percent moisture content, this soil had a CBR of 2.3 percent, i.e., a soft soil.

The test section was divided into six test windows. A test window is the area where traffic is applied. An effective test window was 0.91 m (3 ft) wide by 6.08 m (20 ft.) long, excluding acceleration and deceleration areas. The thickness and material properties for all test windows were intended to be constant, but the traffic load was set to one of several values for each of the test windows.

Each test window was instrumented with embedded sensors to measure in-situ stress, strain, moisture and temperature at various locations within the pavement structure. Dynatest® stress cells were used to measure stress in the subgrade soil. Geokon® stress cells were embedded in the unbound base course. εmu coils were installed in stacks able to measure displacement between coil pairs in vertical, longitudinal and transverse directions. Vertical displacements were measured in ten layers to a depth of approximately 1.52 m (5 feet). Strains were deducted from the displacement measurements. Vitel Hydra® sensors were used to record volumetric soil moisture content and temperature in the base course and subgrade during the accelerated traffic tests. Additionally, strings of thermocouples were used to record subgrade, base, asphalt and air temperatures.

The test section was built indoors where the temperature and soil moisture were controlled. The test basin where the test section was built consisted of 3 concrete walls, a concrete floor and an access ramp also made of concrete.

Typical construction equipment was used to build the test sections, but the quality control testing was more rigorous than is common in regular construction.

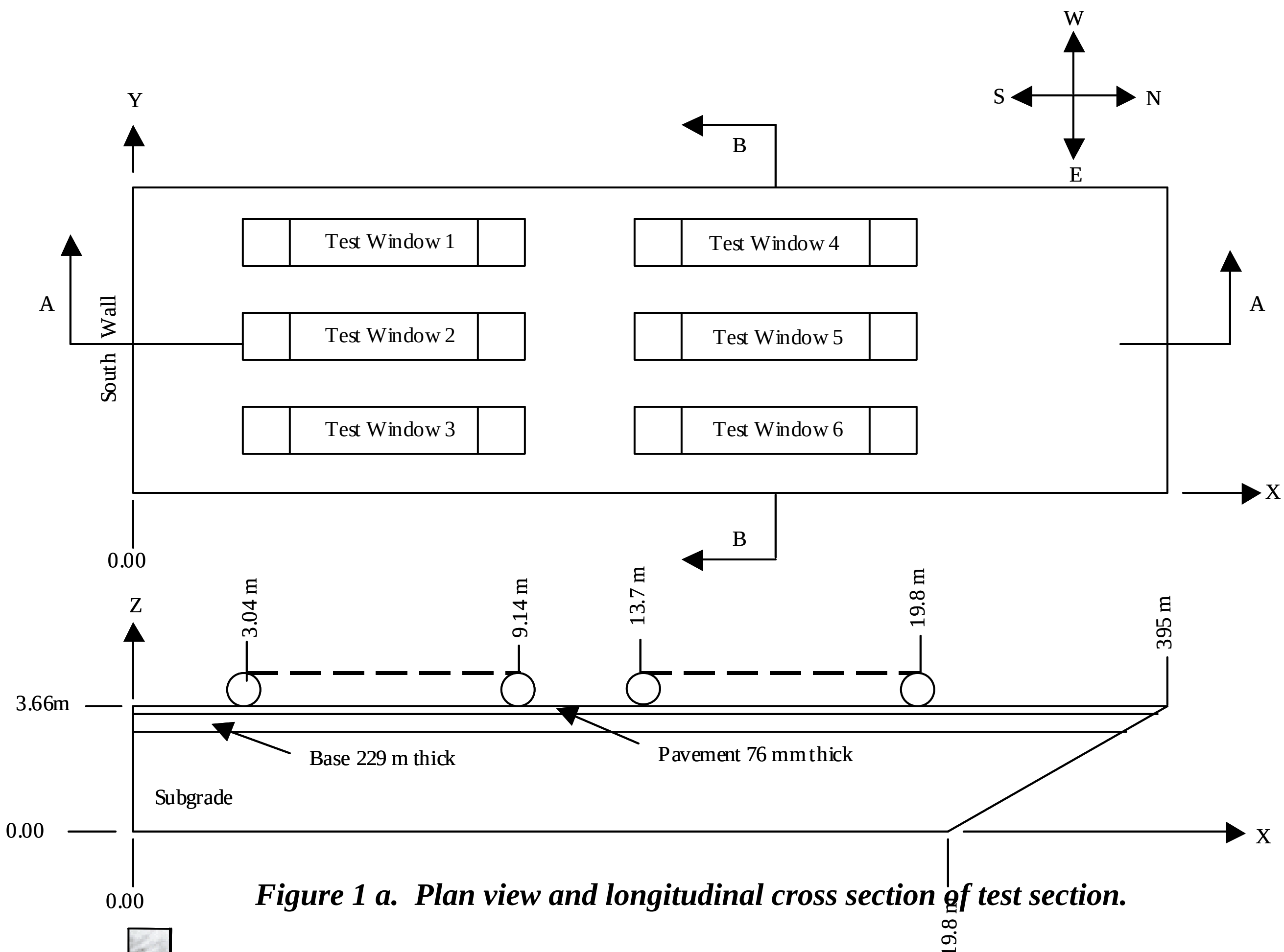

Figure 1 a. Plan view and longitudinal cross section of test section.

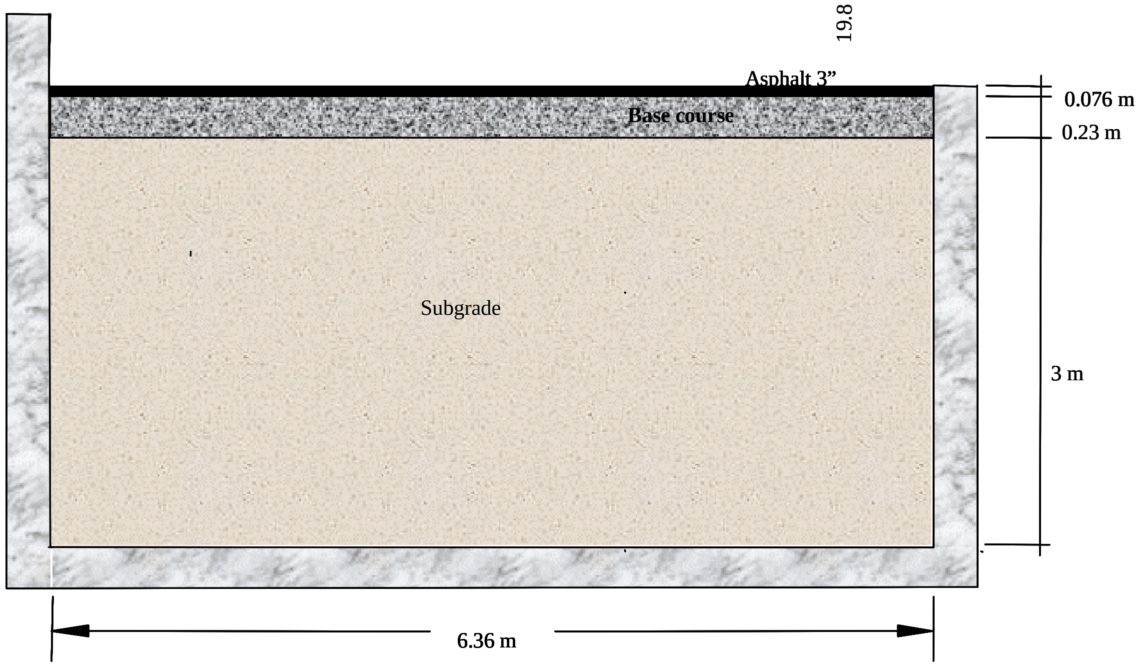

Figure 1 b. Transversal cross section.

MATERIAL PROPERTIES

Laboratory tests were conducted on representative samples of the subgrade soil and the base course soil. The battery of tests included modified proctor, grain size distribution, specific gravity, liquid and plastic limits, and hydrometer tests.

Figure 1 shows grain size distributions for the subgrade soil and for the base course soil. The subgrade soil has approximately 99 % passing the 0.074-mm sieve. The average liquid limit (LL) and plasticity index (PI) of the soil was 40.2 % and 21 % respectively. The average specific gravity of the subgrade soil was 2.72. According to the American Association of Highway & Transportation Officials (AASHTO) soil classification system, the subgrade soil was borderline between soil types A-6 and A-7-6. According to the Unified Soil Classification System, the subgrade soil was type CL (low liquid limit clay).

The base course material was made of unbound crushed stone. It was classified as an AASHTO type A-1 soil. According to the Unified Soil Classification System, the base course soil was type GP-GM (mix of poorly graded gravel and silty gravel). About 11 percent by weight of the base course soil particles passed through the sieve 0.074-mm (#200) sieve. The fines were classified as non-plastic.

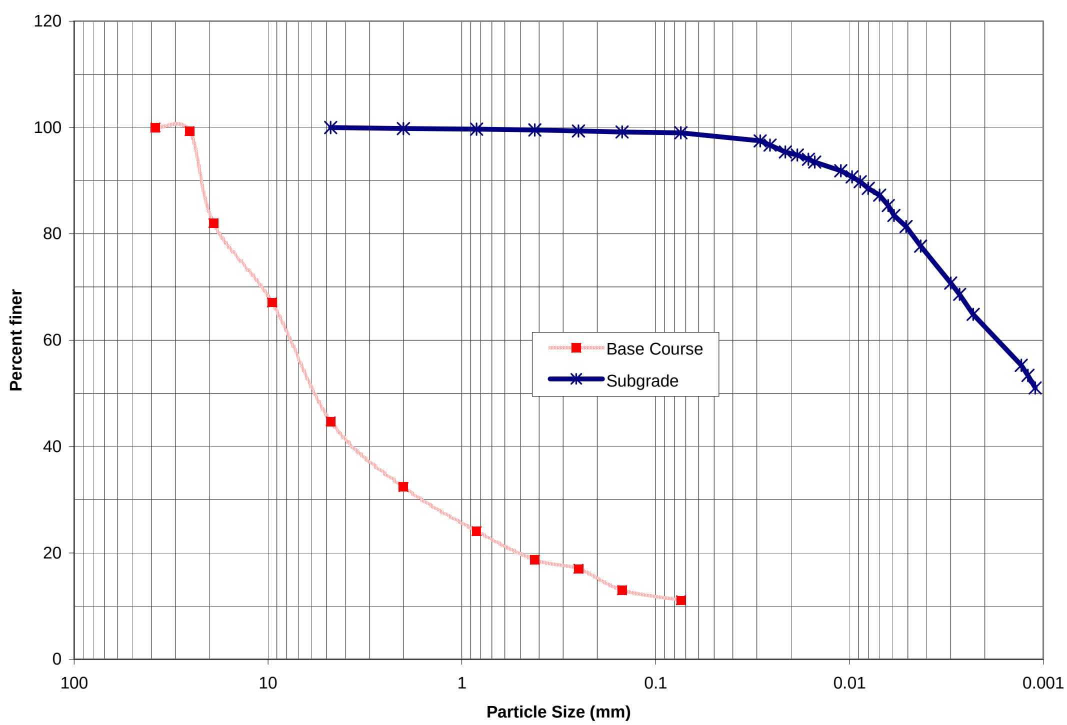

Figure 2. Grain size distribution for the subgrade soil and base course soils.

Samples were collected from various parts of the stockpiles. Laboratory tests were conducted to determine the optimum moisture content and maximum density for the base course and subgrade soils using the AASHTO test procedure, "*The Moisture-Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer and a 12 in. (305 mm) Drop* (T 99-90)". California Bearing Ratio (CBR) test were also conducted on representative samples of the subgrade soil. The optimum density and moisture content of the subgrade soil was 1800 kg/m^3 (112.5 pcf) and 17 % respectively. The subgrade was conditioned to an average of 20.7 percent gravimetric moisture content during construction. The laboratory CBR for this moisture content was 2.3 percent. The subgrade moisture content measured during the forensic evaluation after the traffic tests was on average 19.5 percent which would correspond to a CBR value of 4 percent.

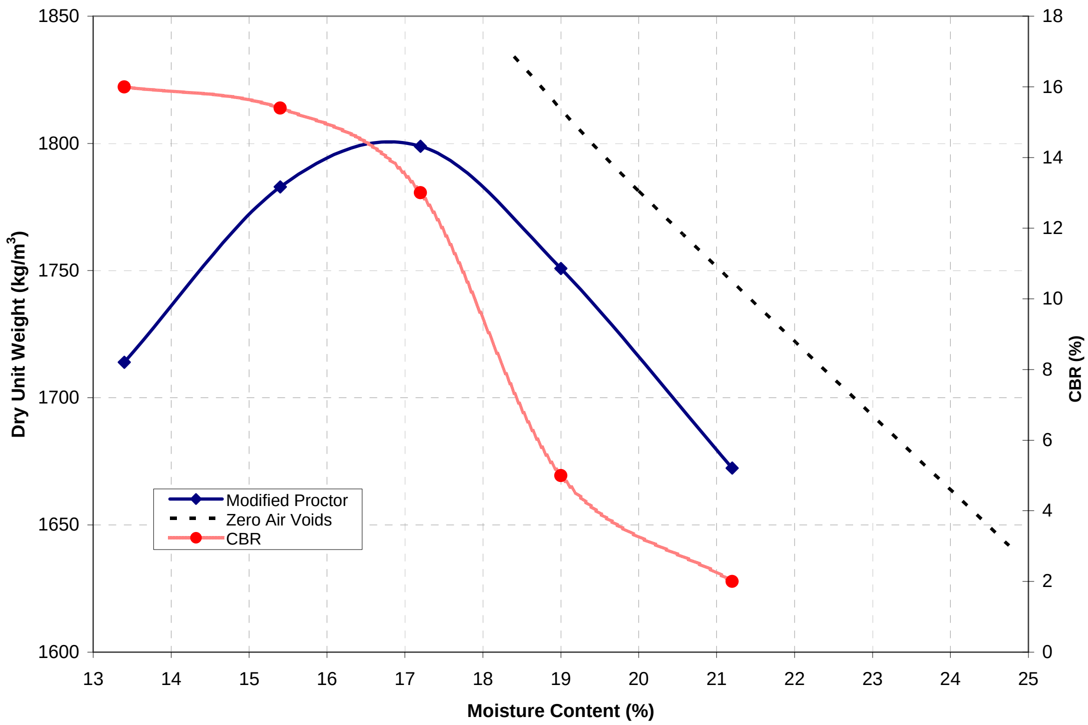

Figure 3. Modified Proctor and CBR test results for the subgrade soil

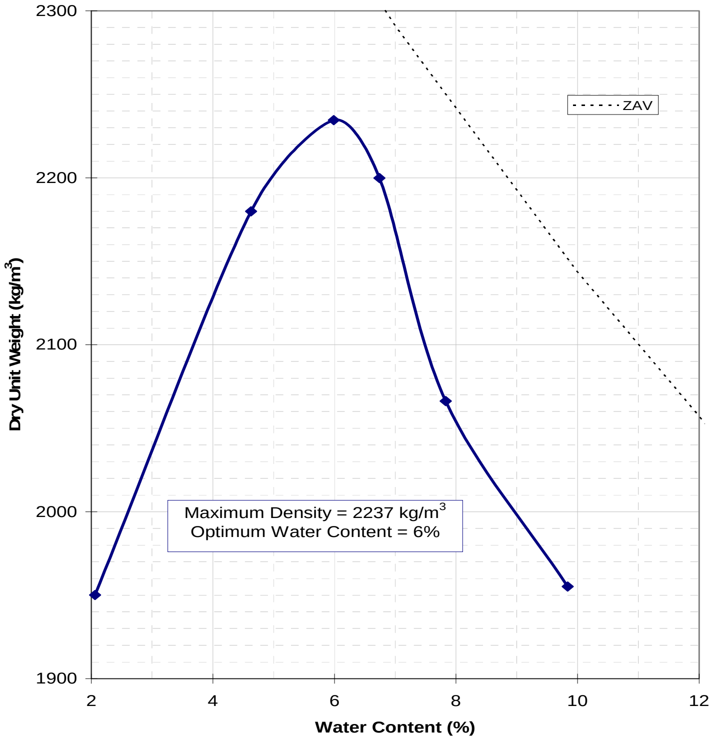

Figure 4. Base course modified Proctor test result.

The modified Proctor test results shown in Figure 4 indicate that the optimum gravimetric moisture content of the base course material was 6 percent and the maximum density was 2237 kg/m^3 (139.5 pcf). Obtaining this moisture content with high hydraulic conductivity materials is difficult in practice. The average moisture content of the base course material during construction was 4.6 percent. The average moisture content of the base course material during the forensic evaluation was 2.3 percent. Apparently, the moisture content in the base course diminished gradually during the period of traffic testing.

Table 2. Summary of properties of the subgrade soil used in Test Section 710.

AASHTO	Borderline A-6/A-7-6
USCS	CL
Spec. Gravity	2.72
LL (%)	40.2
PI	21
Optimum moisture content (%)	17
Maximum Density (kg/m^3)	1800
% passing #10	99
% passing #200	99

The asphalt concrete material of the binder course conformed to the Vermont Type II standard, with 19-mm maximum aggregate particle size and 4.5% of asphalt binder PG-58-34. The asphalt concrete material of the wearing course conformed to the Vermont Type III standard, with 13-mm maximum aggregate particle size and 5.3% of asphalt binder PG-58-34. The nominal thickness of the binder course was 51 mm. The nominal thickness of the wearing course was 25 mm.

CONSTRUCTION OF THE TEST SECTION

The subgrade was built in layers 150 mm (6 inches) thick. The soil was first placed at a moisture condition lower than the target moisture content. The soil was rototilled and moisture was gradually added until reaching the target. Then, the soil was compacted with four passes of a 10-Ton (9,072-kg) steel roller in static mode. Moisture and density quality control measurements were taken using a nuclear gauge. Additional roller compacting was applied until the density was at least 95 percent of the modified proctor density for the given moisture content.

The base course was placed in 2 layers 114.3 mm (4.5 inches) thick for a total of 228.6 mm (9 inches). Finally, the AC layer was placed in two lifts for a total of 76 mm (3 inches).

CONSTRUCTION QUALITY CONTROL

During the construction of the subgrade, a series of tests were conducted on each of the compacted layers. Measurements included layer thickness taken with a survey level, and moisture/density measurements taken with a nuclear gauge. Falling weight deflectometer (FWD) tests were conducted on top of the asphalt concrete prior to traffic testing.

The mean moisture content of the test subgrade was 20.7 percent with a COV of 4.0 percent. The average moisture content of the base was 4.6 percent with a COV of 10.3 percent

The mean dry density of the subgrade was 1697 kg/m^3 (105.9 pcf) with a COV of 1.5 percent. The mean dry density of the base course was 2284 kg/m ^{3} (142.6 pcf) with a COV of 1.35 percent. The mean density of the AC was 2304 kg/m^3 (143.8 pcf) with a COV of 2.2 percent.

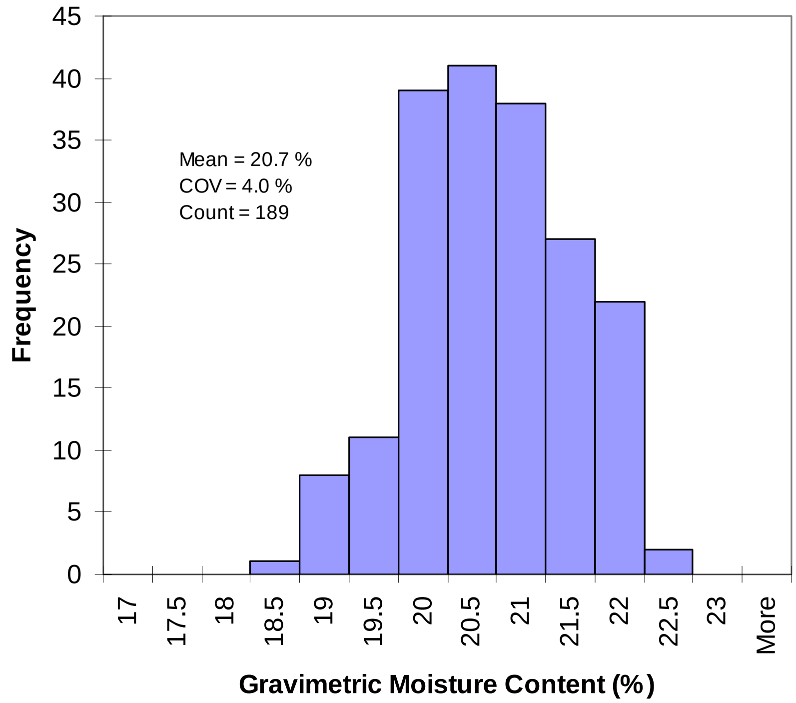

Figure 5. Subgrade moisture content.

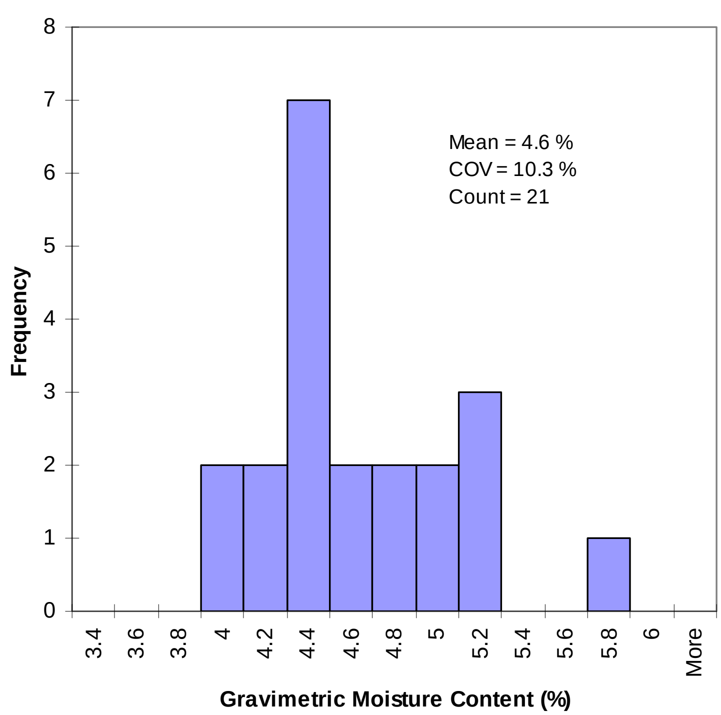

Figure 6. Base course moisture content.

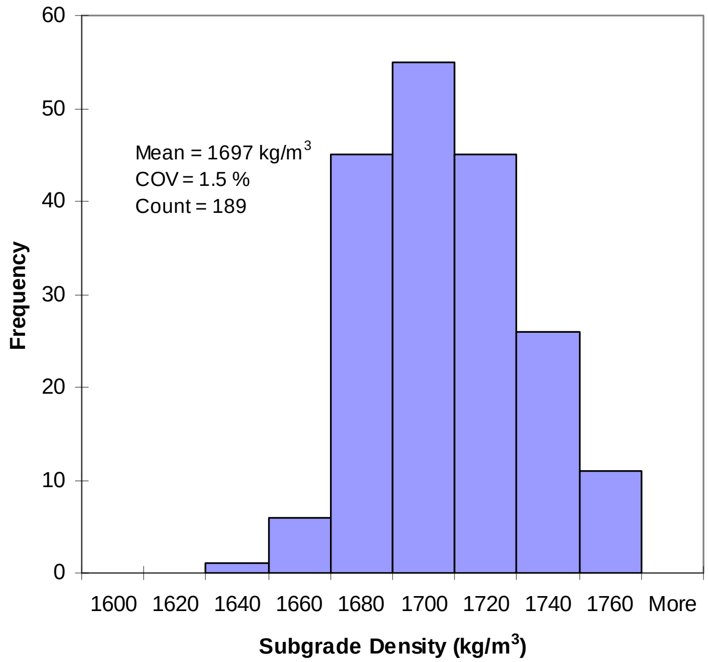

Figure 7. Subgrade density.

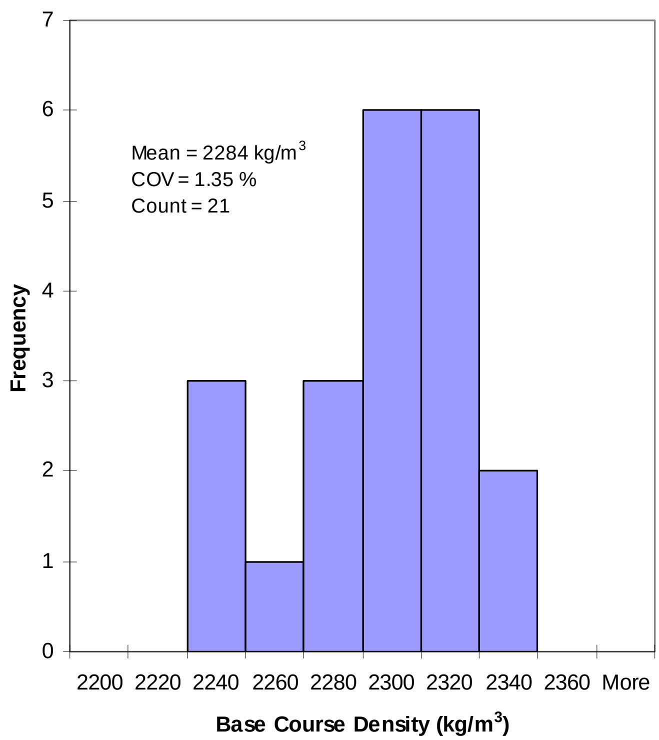

Figure 8. Base Course density.

INSTRUMENTATION

Instrumentation for measuring stress, strain, temperature, and moisture content were installed in the pavement structure during construction of the test section. More details about the instrumentation can be found in Janoo et al., 2002. The locations of the gages in the test section were similar to those in previous test sections.

Displacement measurements were made in the base and subgrade by means of εmu coils. Strain can be deducted from displacement measurements between coil pairs in either coaxial or co-planar arrangements. The sensors were placed 150 mm center to center. Displacements were measured in the longitudinal (x), transverse (y), and vertical (z) direction of loading. Displacements in the vertical direction were measured to a depth of 1.52 m.

Figure 9. Emu coils in a co-planar arrangement to measure longitudinal and transverse displacements. ***A US 25-cent coin is included for scale reference.***

A triaxial Dynatest® stress cell set was installed at a depth of 76 mm (3 in.) below the top of the subgrade in all test windows. In Test Windows 2 and 5 an additional triaxial stress cell set was installed at a depth of 381 mm (15 in.) below the top of the subgrade. The diameter of the Dynatest® stress cells was 76 mm (3 in.).

Geokon® stress cells were installed in the middle thickness of the base course in each of Test Windows 2 and 5 in triaxial sets. In Test Window 6 Geokon stress cells were installed to measure only vertical stress at depths 51 mm (2 in.) below the bottom of the asphalt, at 25.4 mm (1 in.) above the base course-subgrade interface, and 127 mm (5 in.) below the top of the subgrade.

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

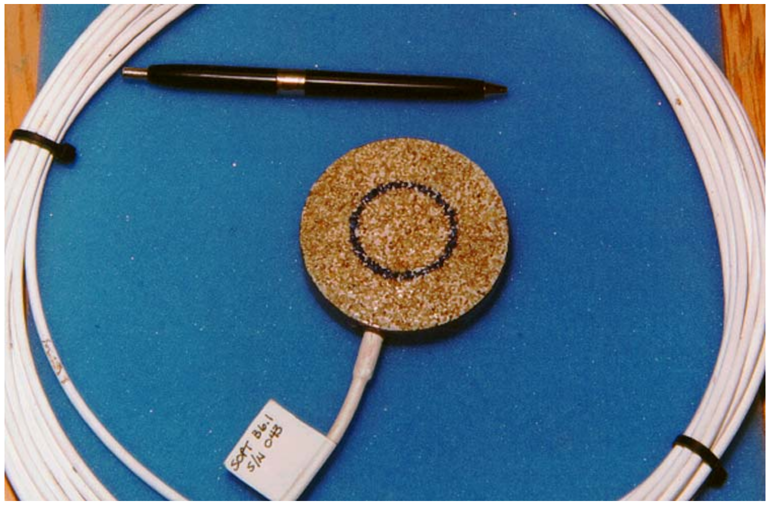

Figure 10. Dynatest® stress cell used in the subgrade.

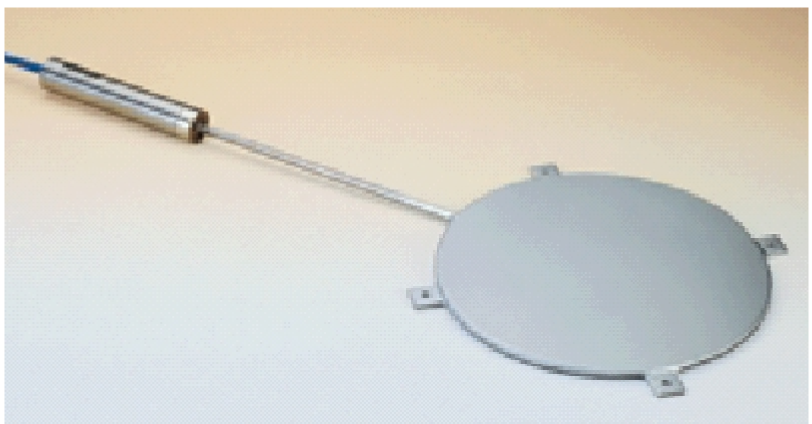

Figure 11. Geokon® stress cell used in the base course and subgrade.

Vitel Hydra® soil moisture probes were used to measure the moisture content in the base and subgrade during the traffic tests. The outputs from the sensors were calibrated in-situ by means of direct sampling and oven dry tests conducted during construction and forensic evaluation. Moisture sensors were located at three depths at each of three horizontal locations. The moisture sensors were located in the base course at depths 76 mm (3 in.) below the top of the base course, 305 mm (12 in.) and 508 mm (20 in.) below the top of the subgrade. The Vitel Hydra® soil moisture probes measure soil moisture indirectly through measuring the dielectric constant of the materials between its sensing rods and converting four electronic signals into volumetric moisture content according to laboratory calibrations. Volumetric moisture content is then converted into gravimetric moisture content by means of the specific gravity of the soil. The laboratory calibrations were later corrected to ensure agreement with the more reliable oven dry measurements conducted during construction and during the forensic evaluation.

Figure 12. Vitel Hydra moisture sensor.

Subsurface temperatures were taken using thermocouple sensors. The thermocouples have an accuracy of ± 0.5°C. The subsurface temperature sensors were installed at three locations within the test section.

TRAFFIC TESTING

The test windows were subjected to accelerated traffic loads using CRREL's Heavy Vehicle Simulator (HVS).

The following tests were conducted:

1. Prior to the accelerated load tests, FWD measurements were conducted on the surface of the AC layer at locations in a representative grid arrangement.
2. Initial transverse profiles of each test window were measured using a laser profilometer. The laser source and sensor were located 45 cm (1.5 ft.) above the pavement surface. Each cross section was composed of 256 measurements spaced at 9-mm (3/8-in.) intervals. Twenty profilometer transverse cross section measurements at 0.3-m (1-ft.) intervals were taken at each window. Surface profile measurements were made at each traffic stop to define the progression of surface rutting throughout the traffic tests. Rut depth was defined as the difference between the surface depth at a given number of passes and the corresponding depth measured at zero passes. A typical surface rut measurement and the definition of maximum rut depth are shown in Figure

15. Traffic testing was terminated when the average maximum surface rut depth of 12.5 mm was reached or exceeded.

3. In addition to the profilometer measurements, elevation measurements were conducted with a rod and level prior to the start and at the end of the traffic tests for each test window. Elevations were monitored at locations were the profilometer legs were placed during profilometer measurements to detect any potential change in elevation that would affect the profile measurements. In addition, the elevation of the projection of vertical εmu stack on the asphalt surface was also monitored with a rod and level system. The results from the level surveys indicated that the profilometer leg points were stationary throughout the test.

Figure 13. Laser profilometer.

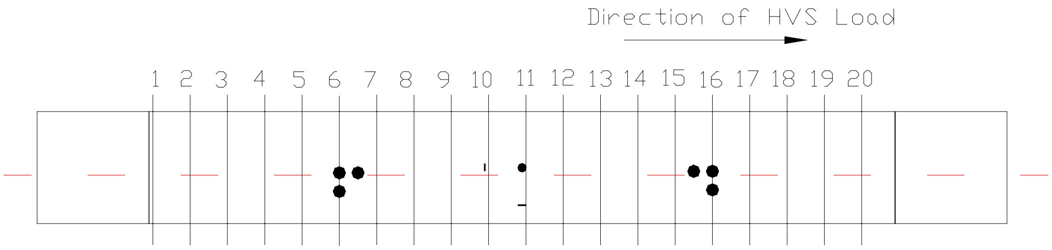

Figure 14. Locations for profile measurements in a test window.

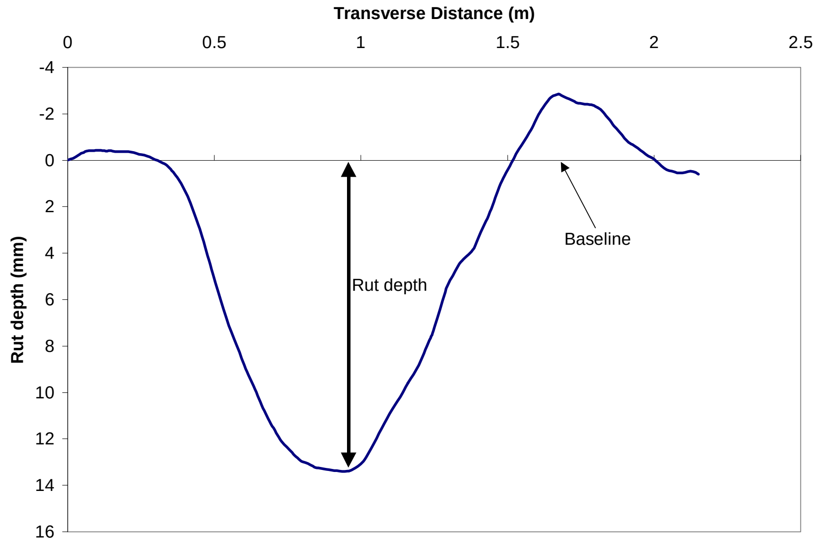

Figure 15. Definition of rut depth

4. Subsurface stress and displacement measurements conducted in the vertical, longitudinal, and transverse directions relative to the direction of traffic. The measurements were conducted at various pass levels to define their progression throughout the traffic tests. The displacement measurements were conducted dynamically upon the passing of tire traffic, and also statically when no traffic was occurring. The dynamic measurements were intended to measure resilient deformation traffic load applications. The static measurements were intended to measure permanent deformation.
5. In addition to the εmu coils embedded in the pavement, a mobile coil was placed on top of the asphalt over the vertical stack of embedded εmu coils as shown in Figure 16. This provided a means to measure the vertical permanent deformation in the asphalt layer.

Figure 16. Measuring displacement between the AC surface and the top of the base course.

TRAFFIC LOADING

Traffic loading was applied by means of CRREL's Heavy Vehicle Simulator (HVS). The tire assembly was a dual-tire standard truck half axle. The traffic speed was 12 km/hr. The traffic was allowed to wander across a width of 0.91 m (3 ft.). The mean applied loads are summarized in Table 3. The tire pressure was set to 690-kPa (100 psi).

Table 3. Mean semi-axial loads on test windows

	Applied Loads	
Test Window	kips	kN
708C1	6.0	27.0
708C2	9.0	40.0
708C3	4.6	20.5
708C4	9.0	40.0
708C5	4.5	20.0
708C6	7.5	33.4

Table 4. Sequence of HVS tests on test windows

Window	Start	End
710C1	12-Jan-2004	22-Jan-2004
710C2	11-Feb-2004	13-Feb-2004
710C3	05-Feb-2004	09-Feb-2004
710C4	26-Jan-2004	27-Jan-2004
710C5	28-Jan-2004	02-Feb-2004
710C6	18-Feb-2004	04-Mar-2004

TEMPERATURE AND MOISTURE DURING TRAFFIC

The mean air temperatures and the coefficient of variation (COV) in the test sections during the time of HVS testing are presented in Table 5. The subsurface temperatures during the traffic tests were approximately constant at 18.0°C.

Table 5. Mean air temperatures during traffic testing of the test windows.

Window	Temperature (°C)	COV (%)
710C1	17.13	1.57
710C2	17.60	1.13
710C3	17.44	1.05
710C4	17.73	1.22
710C5	17.25	0.98
710C6	16.96	1.61

Vitel® moisture sensors were installed in the base course and in the subgrade in this test section. The Vitel® moisture sensors generate four voltages of which the first three are used to determine the dielectric constant of the moist soil inside the probe zone. The manufacturer of the sensors provides a function based on laboratory correlations to convert dielectric constant to volumetric moisture content. The fourth voltage is used to determine the temperature needed to correct for the effect of temperature on the apparent dielectric measurements. In these tests, it was found that the 4th voltage measurements were erroneous, and the mean temperatures from thermocouple measurements were used instead. The volumetric moisture contents were converted into gravimetric moisture contents by dividing the volumetric moisture contents by 2.70 for the specific gravity of the base or by 2.72 for the subgrade. The measurements obtained from these sensors in the base course were consistent with those obtained by the oven-dry method during construction and during the forensic evaluation. The moisture measurements obtained from these sensors in the subgrade were higher than those obtained from oven dry measurements during the construction and forensic exploration stages. A comparison of the oven dry moisture contents between the construction and the forensics exploration reveals that the moisture condition of the subgrade remained practically constant. The signals obtained from the Vitel sensors were also almost constant throughout the traffic tests but showed significant bias. Because of uncertainty on the proper scale of the Vitel measurements, we will rely on the oven dry and nuclear gauge measurements conducted during the construction and the forensic stages to define the moisture content of the subgrade during the traffic tests. Because the Vitel business was purchase by another company, and now technical support is very limited, we plan to discontinue the use of Vitel sensors for future test sections and replace them with alternative sensors. Table 6 presents the moisture content during the traffic tests deducted from the average of the values measured during the construction (before traffic) and during the forensic evaluation (after traffic). The moisture measurements obtained with Vitel sensors embedded in the base course did agree with those obtained by the oven dry method. Table 7 shows the average moisture content for the base course during traffic testing.

Table 6. Average moisture content in the subgradesubgrade during HVS testing.

Depth (mm)	457	762	457	762	457	762
Test Window	Moisture Content (%)					
710C1	21.4	21.0	20.8	21.4	21.1	20.8
710C2	20.8	21.2	20.4	21.6	21.2	21.0
710C3	21.6	20.6	21.0	21.4	21.2	20.6
710C4	21.2	20.8	21.2	20.8	21.2	20.4
710C5	20.6	20.4	20.8	21.4	21.4	21.2
710C6	20.4	21.0	20.6	20.8	21.2	21.4

Table 7. Moisture content in base course during HVS testing 76 mm (3 in) below bottom of asphalt.

Test Window	Moisture Content (%)
710C1	3.4
710C2	3.6
710C3	3.5
710C4	3.8
710C5	3.8
710C6	3.9

SUMMARY OF RESULTS

SURFACE RUTTING

Transverse surface profile measurements were taken periodically during testing. . The rut depth was calculated as the difference between the profile measurements taken at the pass level and the profile measurements taken prior to testing. Profile measurements were taken every 305-mm starting from one end of the test window (within the constant speed zone) for a total of 20 locations.

The maximum rut depths from transverse profile measurements were used to develop the longitudinal profile. The longitudinal rut depth in various test windows as a function of load repetitions are presented in Figures 17 to 22. It can be seen that it did not take many passes to exceed a surface rut of 12.5 mm (1/2 inch). According to laboratory CBR and in-situ moisture tests, the subgrade had a CBR of 2.3 percent.

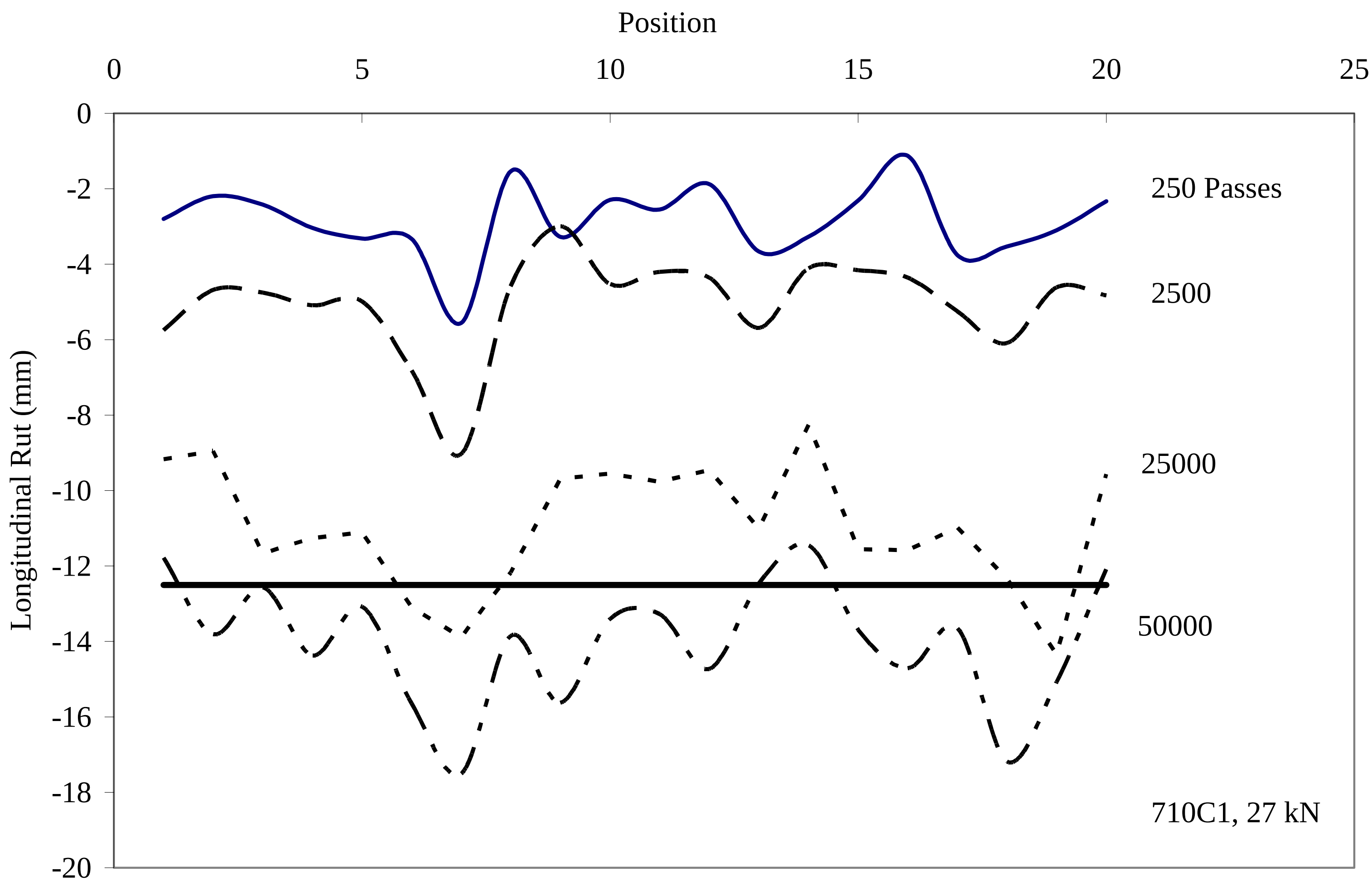

Figure 17. Longitudinal progression of surface rutting in Test Window C1.

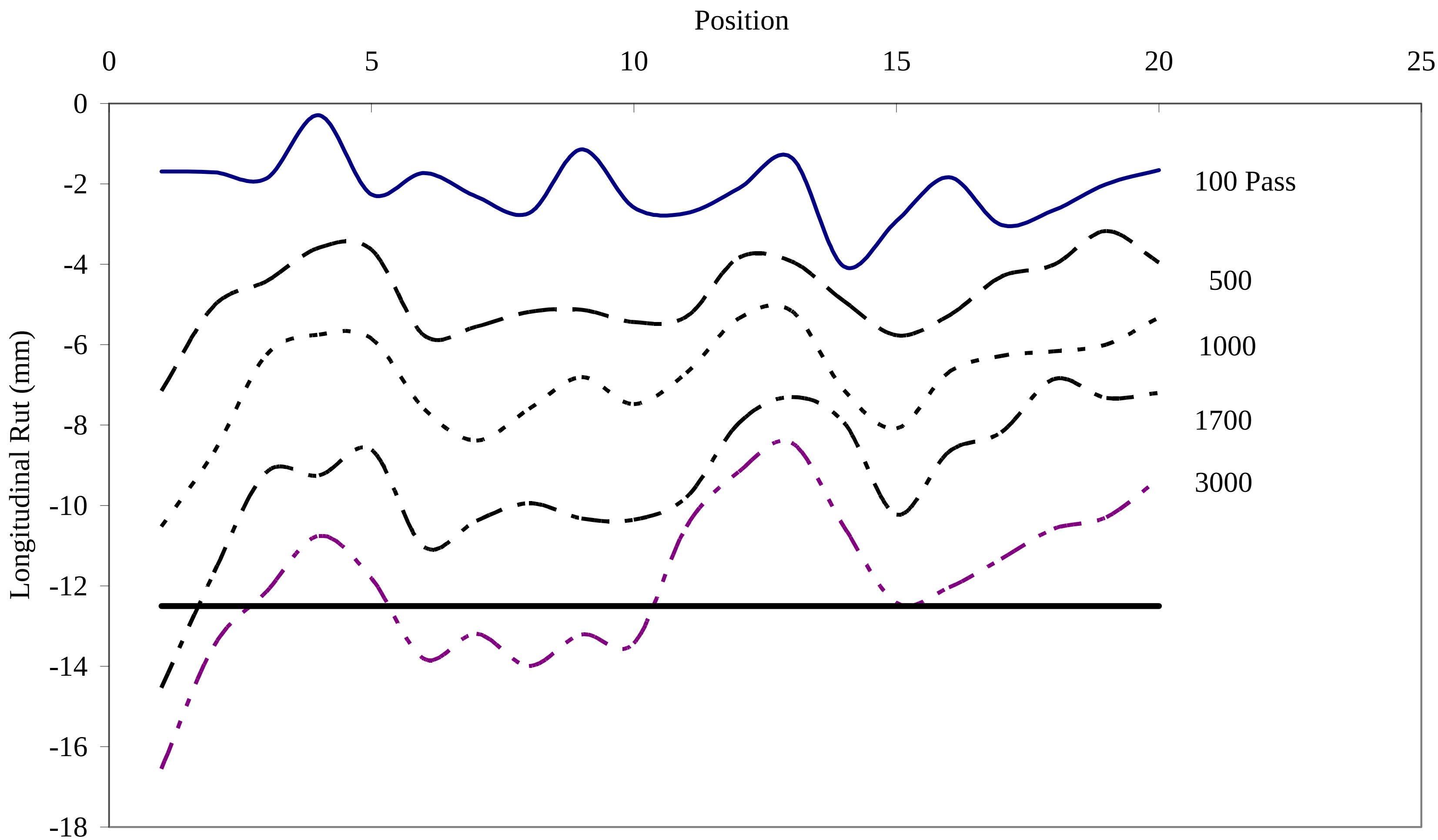

Figure 18. Longitudinal progression of surface rutting in Test Window C2.

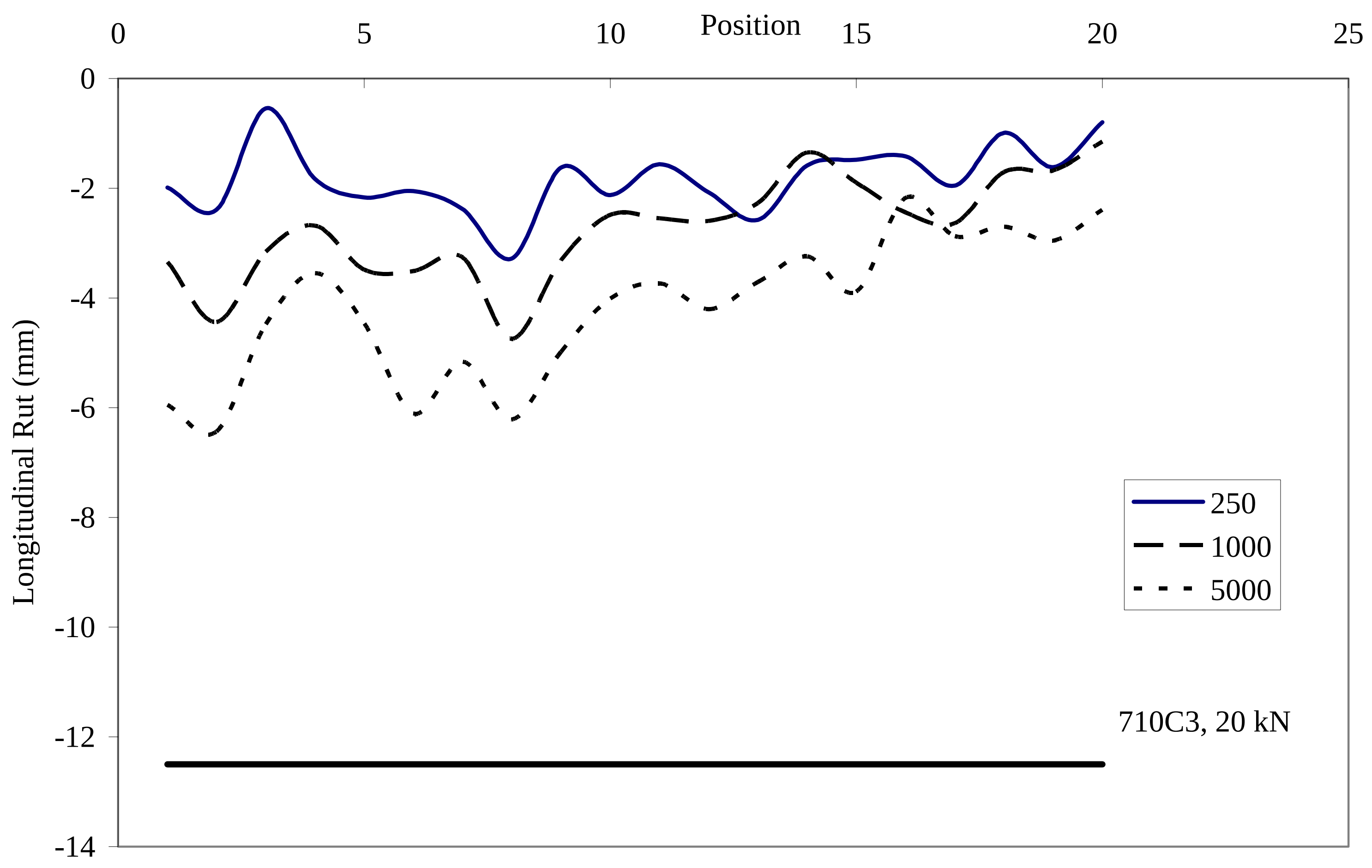

Figure 19. Longitudinal progression of surface rutting in Test Window C3.

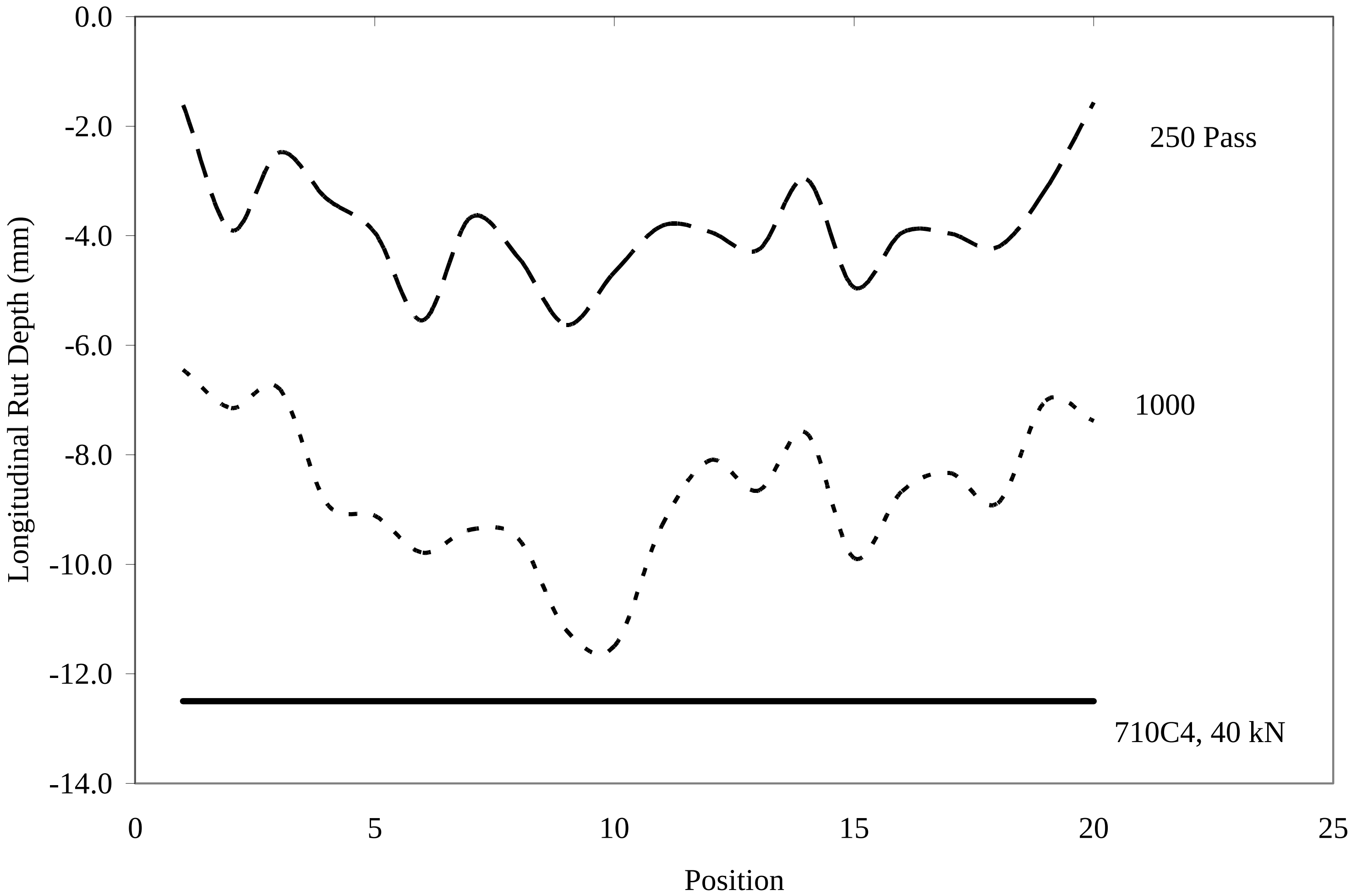

Figure 20. Longitudinal progression of surface rutting in Test Window C4.

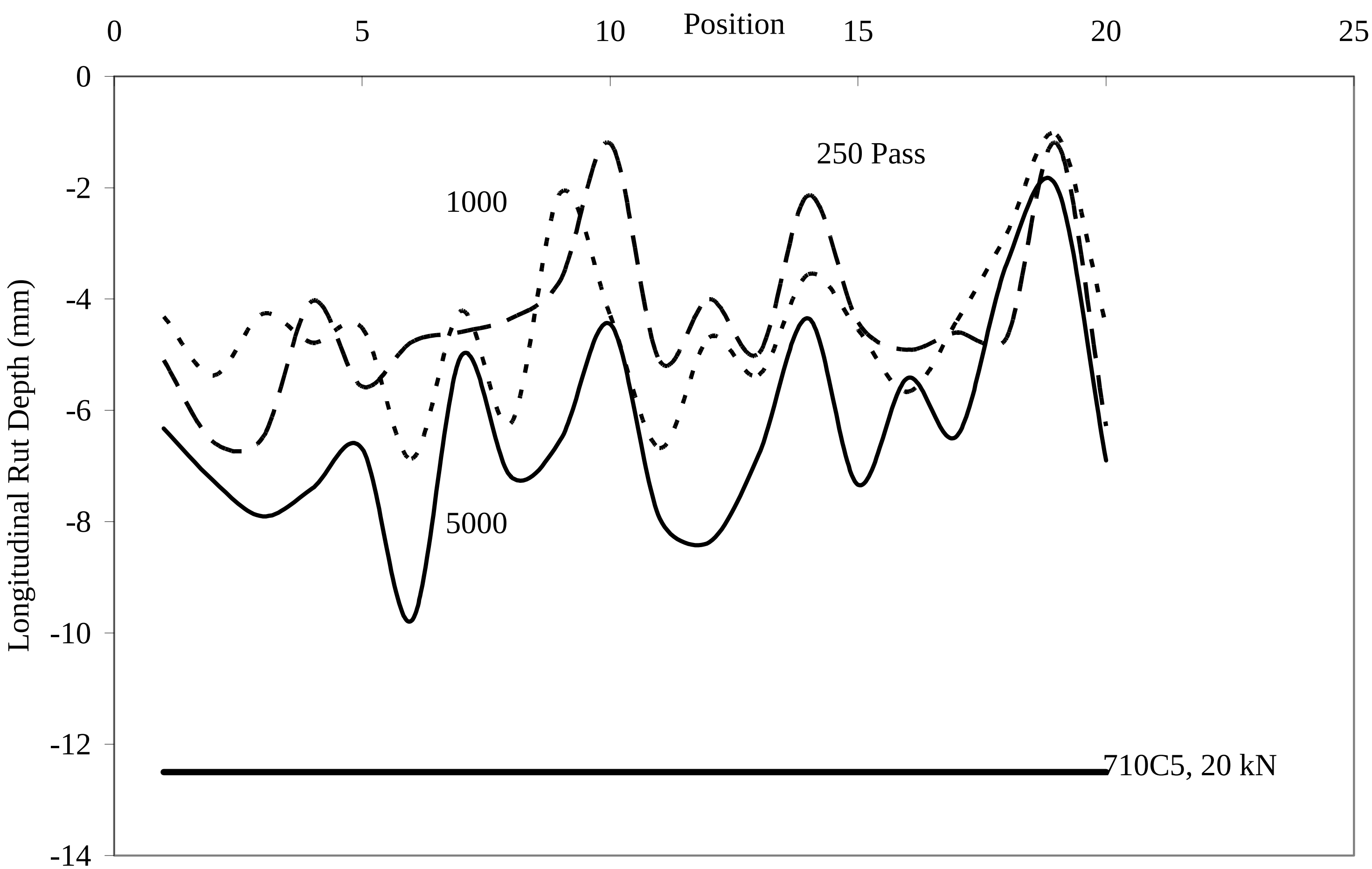

Figure 21. Longitudinal progression of surface rutting in Test Window C5.

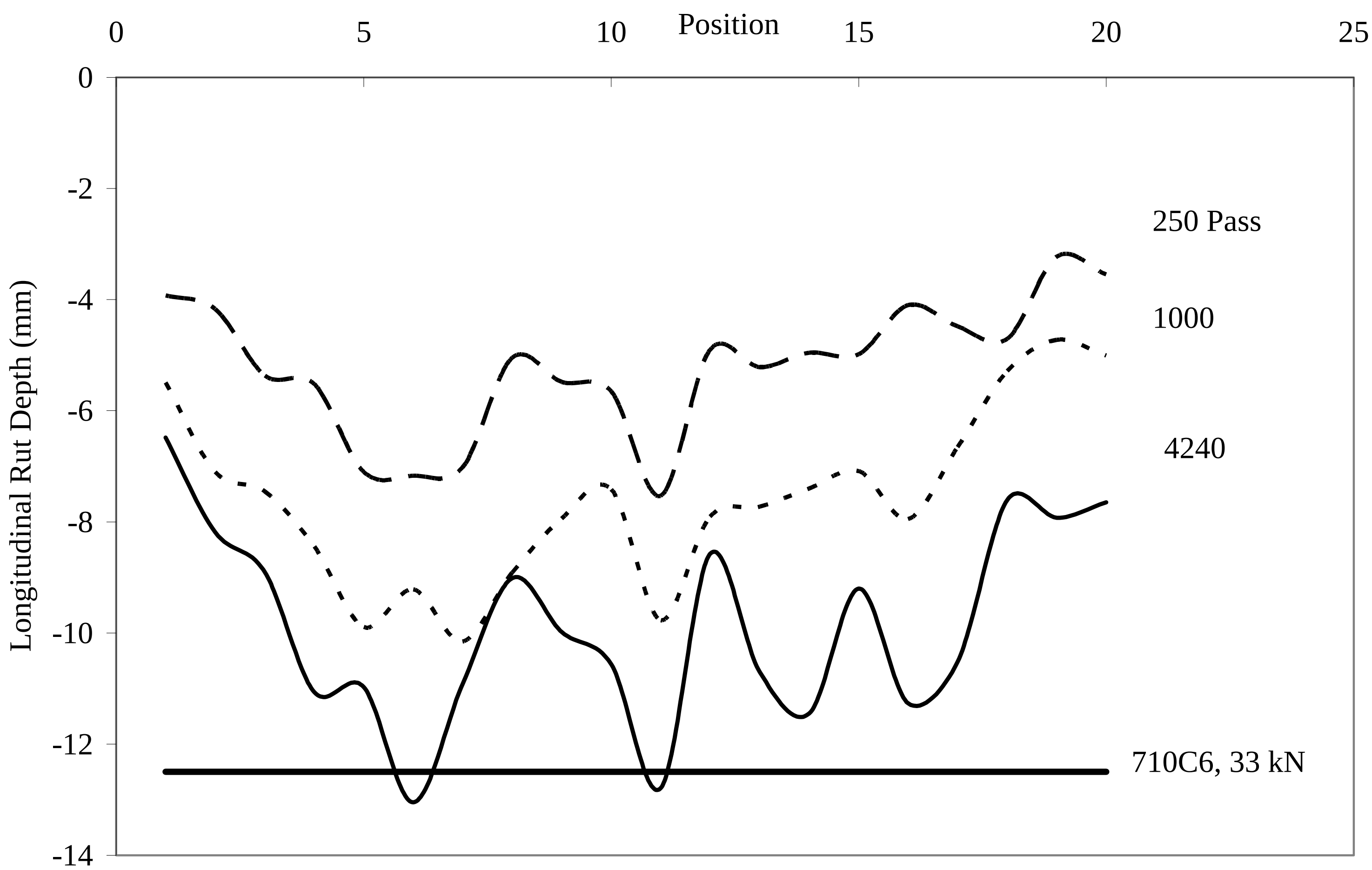

Figure 22. Longitudinal progression of surface rutting in Test Window C6.

The progressions of rut depths as a function of load repetitions in the various windows are presented in Figure 23. In general, as the applied load increased so did the rate of rut depth with the exception of 710C6 where under 33 kN loading the rut developed were similar to that created by 40 kN load. One possible explanation for this behavior is that when the applied load exceeded 33 kN the subgrade failed and any additional load will not create any more rutting. The average rut depth as a function of applied load was used to determine the number of load repetitions to reach the failure rut depth of 12.7 mm.

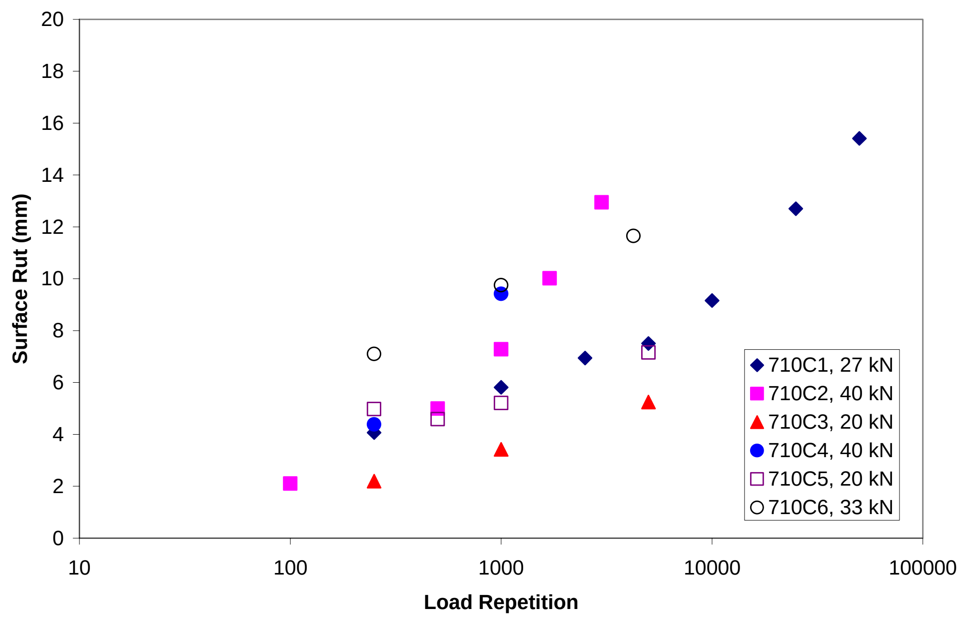

Figure 23. Rut depth progressions as function of load repetitions.

The estimated load repetitions were then used with the appropriate power equations to estimate the failure stresses and strains shown in Table 8.

Table 8. Load Repetitions to reach failure of 12.7 mm

Load (kN)	A	b	R^2	$N_{failure}$
20	0.2698	5.323	0.89	186,257
27	1.059	4.007	0.98	26,316
40	25.418	1.820	0.99	2,521

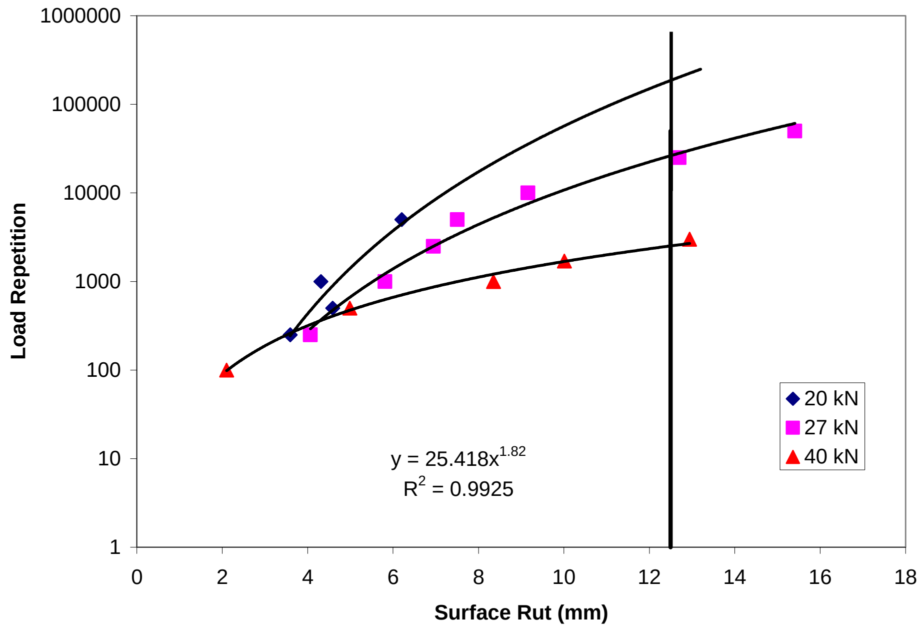

Figure 24 Load repetitions as a function of rut depth.

DEFORMATIONS AND STRAINS

a) Permanent Deformations and Strains

Permanent deformation measurements were collected in the base and subgrade. During the test, a mobile surface εmu coil was paired with a coil embedded just below the bottom of the asphalt concrete (AC) to measure the vertical deformation that occurred in the asphalt layer with increasing load repetitions. Stacks of εmu coils in triaxial arrangements were embedded in the base and subgrade to a sufficient depth to define the permanent and resilient deformations that occurred with traffic. Strain was inferred from the deformation measurements between pairs of εmu coils. Extensive measurements of permanent and resilient deformations in the base course and in the subgrade are shown in the tables in Appendix B.

The vertical permanent deformations on the top of the subgrade as a function of load repetitions are shown in Figure 25. The deformations were compressive and there appears to be correlation between applied load and permanent deformation. It should also be noted that there is a significant difference between the measured sum of deformations from the coil measurements and the surface rut measurements. In all the test windows in Test Section 710, the sum of coil deformations was smaller than the surface rut measurements. In previous tests, the differences were smaller than those of this test section.

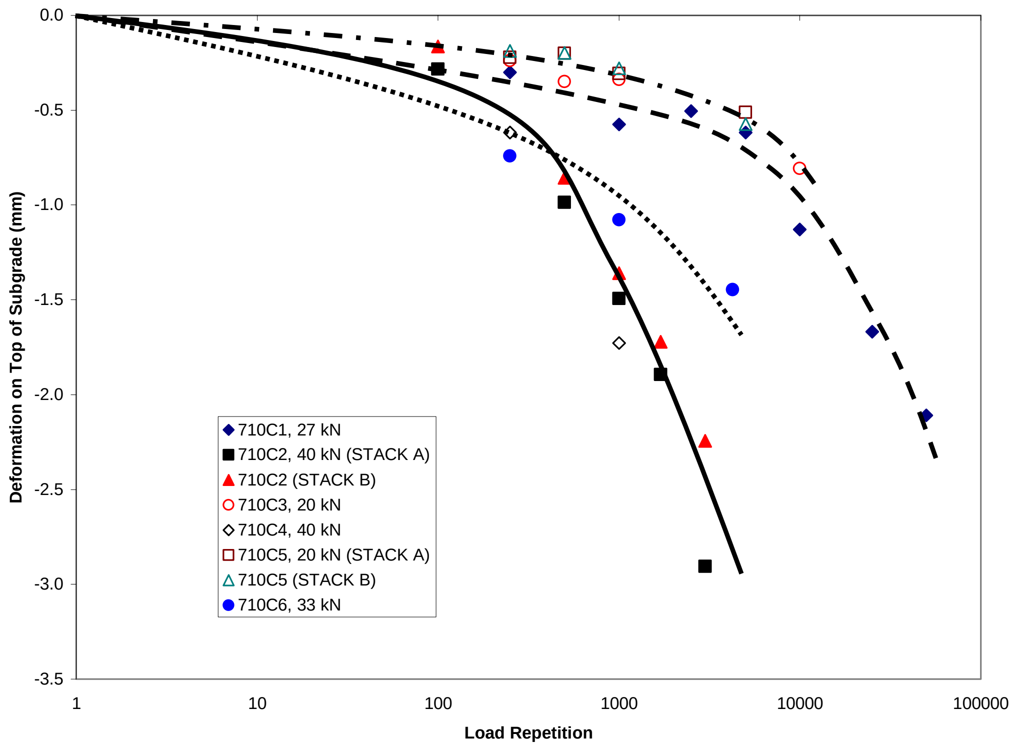

Figure 25. Permanent deformation at 76 mm below the top of subgrade layer

b) Dynamic Deformations and Strains

As with previous test sections, triaxial dynamic displacements were measured with the εmu coil gages in the base and subgrade. The vertical displacements were compressive, whereas the peak longitudinal and transverse displacements were tensile. In general, the greater the load, the greater was the displacement. The change in dynamic vertical strain as a function of load repetition is presented in Figure 26. Power curves were fitted to the data and the coefficients are presented in Table 9.

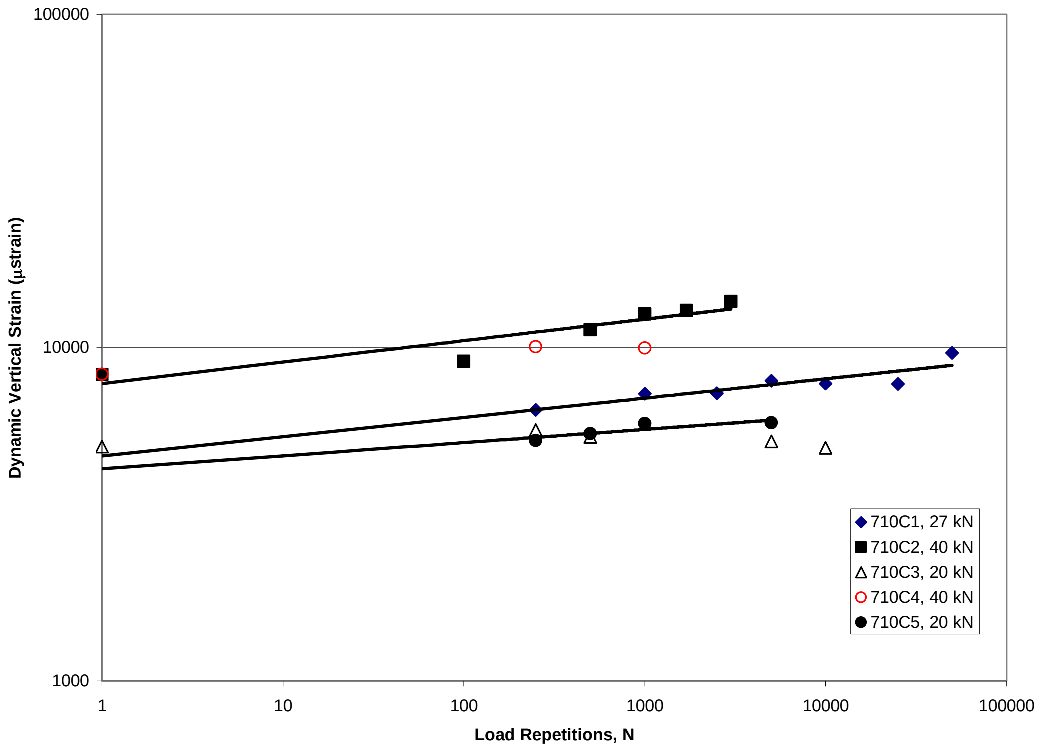

Figure 26. Peak dynamic vertical strains of subgrade as function of load repetitions

Table 9. Power curve coefficients for the dynamic vertical strains

Test Windows	Load (kN)	A	n	R^2
C1	27	4728	0.0579	0.79
C2,C4	40	7804	0.0643	0.86
C3, C5	20	4323	0.0396	0.76

FORENSIC EVALUATION

A forensic evaluation was conducted to establish the condition of the pavement structure at the end of the traffic tests. Two trenches were cut across the test windows. One trench was excavated across test windows 1, 2, and 3 on the south region of the test section. This trench will be referred to as the “South Trench”. Another trench was excavated in the north region of the test section. This trench cut across test windows 4, 5, and 6. The trenches had to be carefully located to avoid damaging the embedded sensors and wires.

The areas of the trenches were marked with paint over the asphalt pavement. A dry saw was used to neatly cut the asphalt concrete layers so that reliable layer thickness measurements could be made. Rod and level elevation measurements were taken at 0.20-m (8-in) spacing along the edge of the trenches.

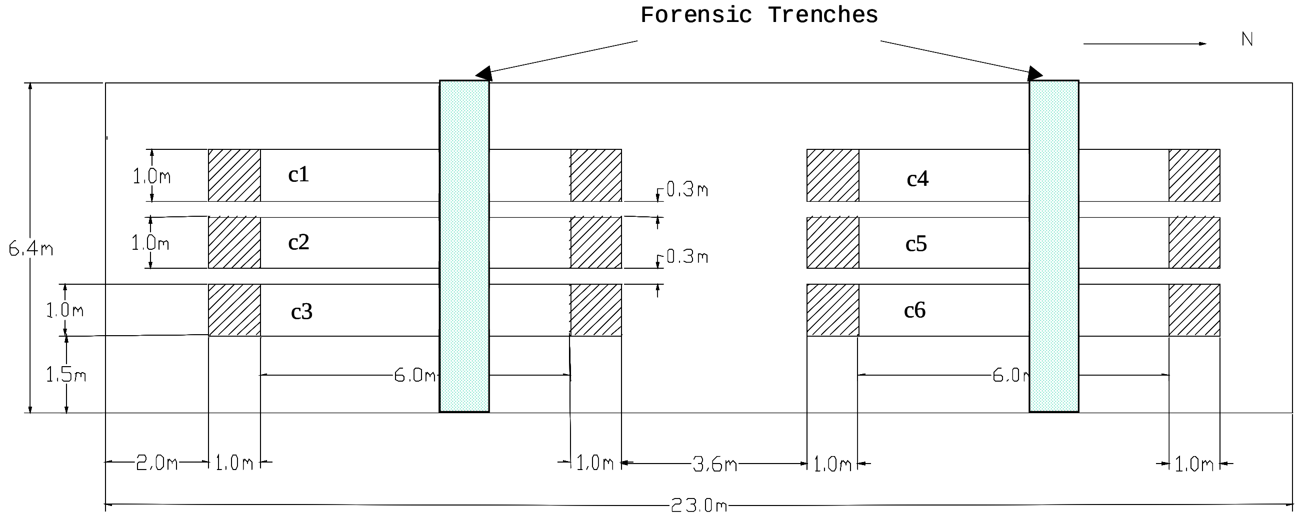

Figure 27. Location of the forensic trenches in Test Section 710

Figure 28. Forensic trenches..

As soon as the asphalt layer was removed from the trenches, base course samples were collected to determine moisture content by the oven-dry method.

Moisture and density measurements were conducted in the base course and in the upper subgrade in the trenches down to a depth of 0.61 m (2 ft.) below the top of the subgrade. Vane shear and dynamic cone penetrometer measurements were conducted at each soil layer in the forensic trenches including each of the test windows. Layer thickness measurements were conducted on the sides of the trenches.

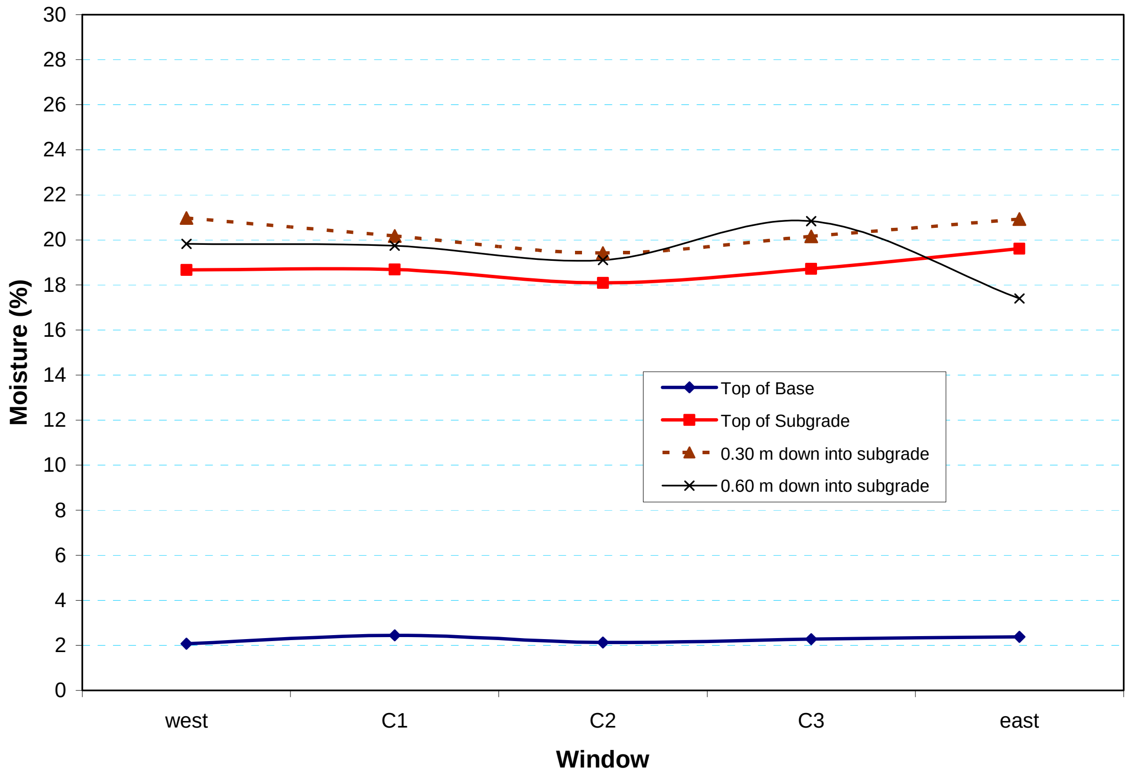

Figure 29. Moisture content in the base and upper subgrade in the south trench.

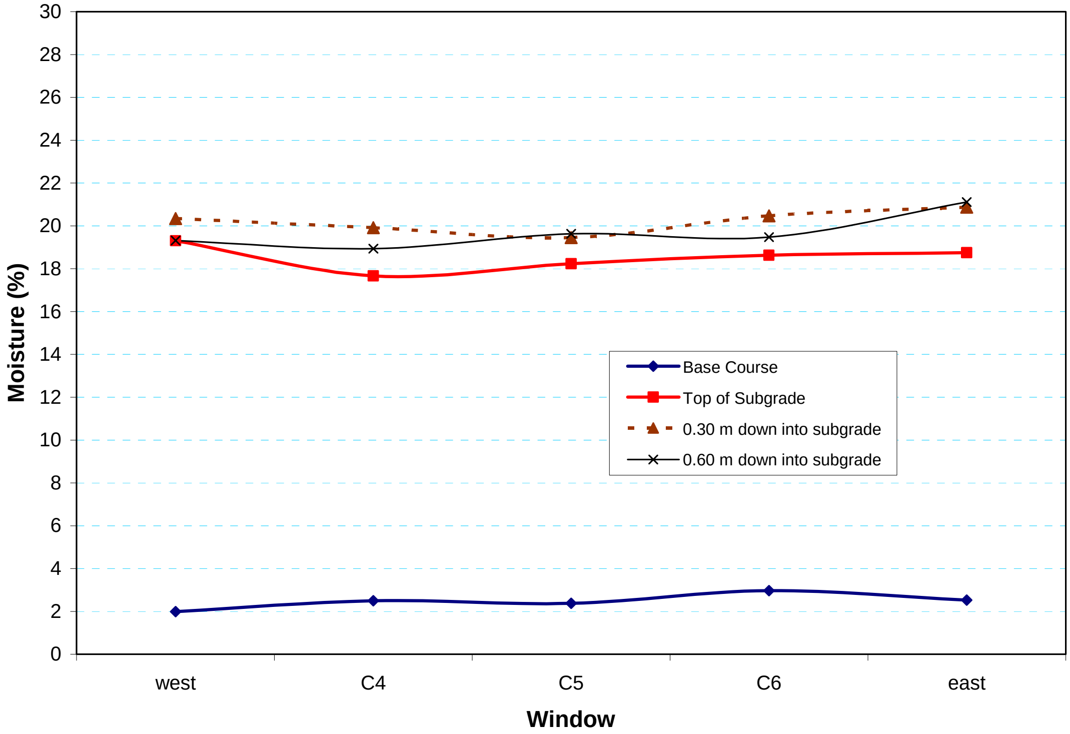

Figure 30. Moisture content in the base and upper subgrade in the north trench.

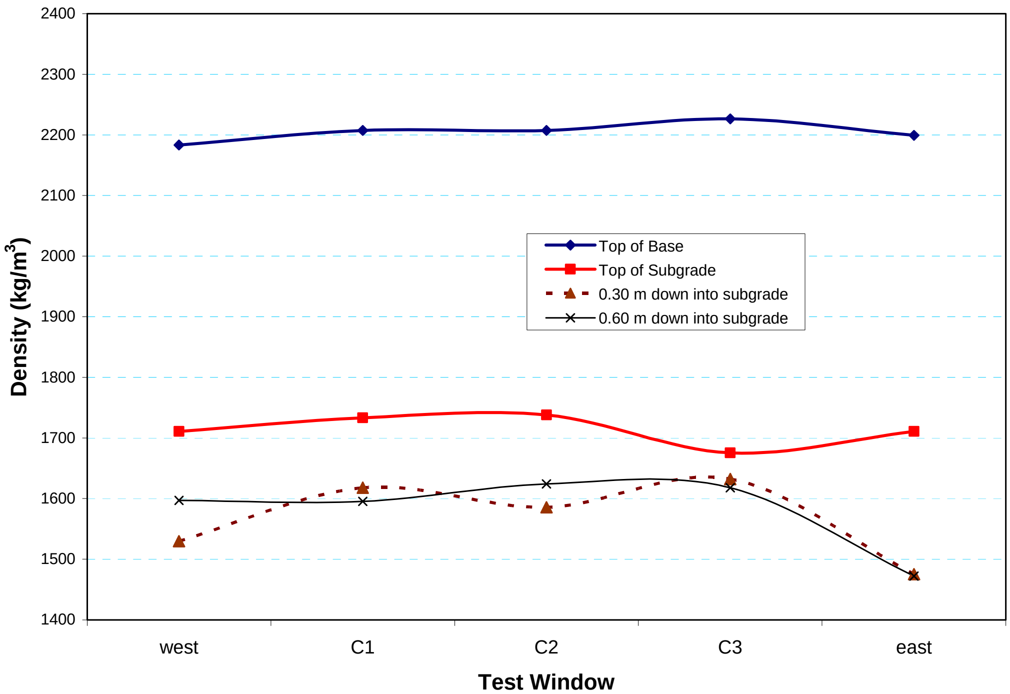

Figure 31. Density measurements in the base and upper subgrade in the south trench.

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

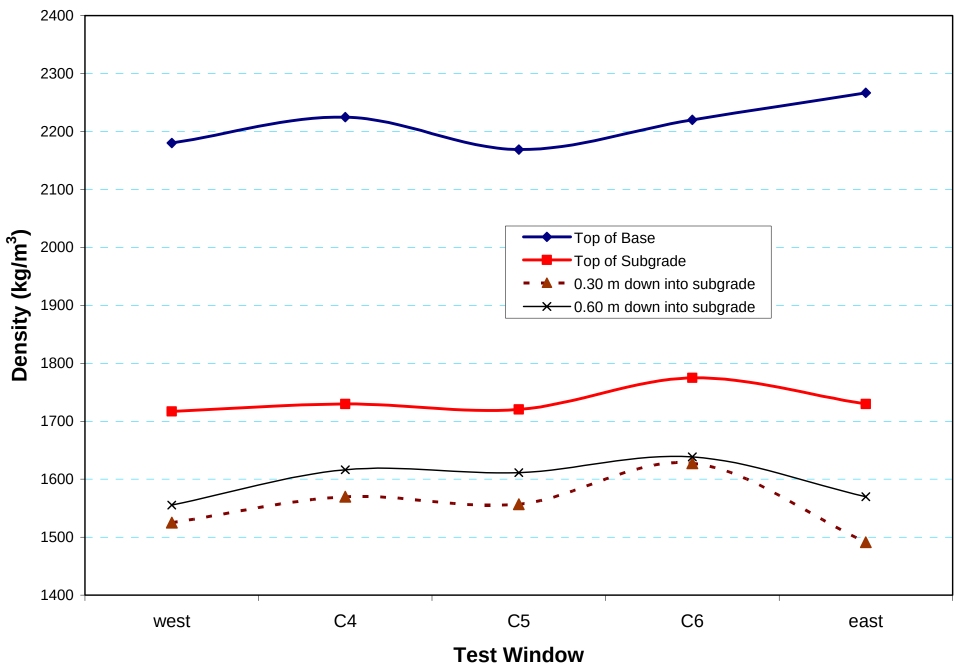

Figure 32. Density measurements in the base and upper subgrade in the north trench.

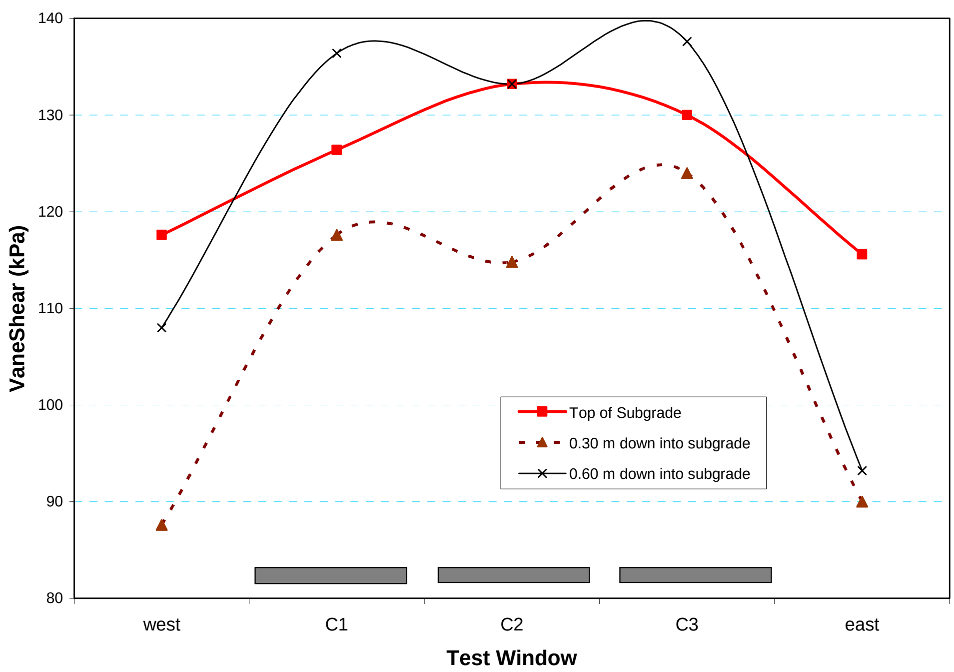

Figure 33. Vane shear measurements in the upper subgrade in the south trench.

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

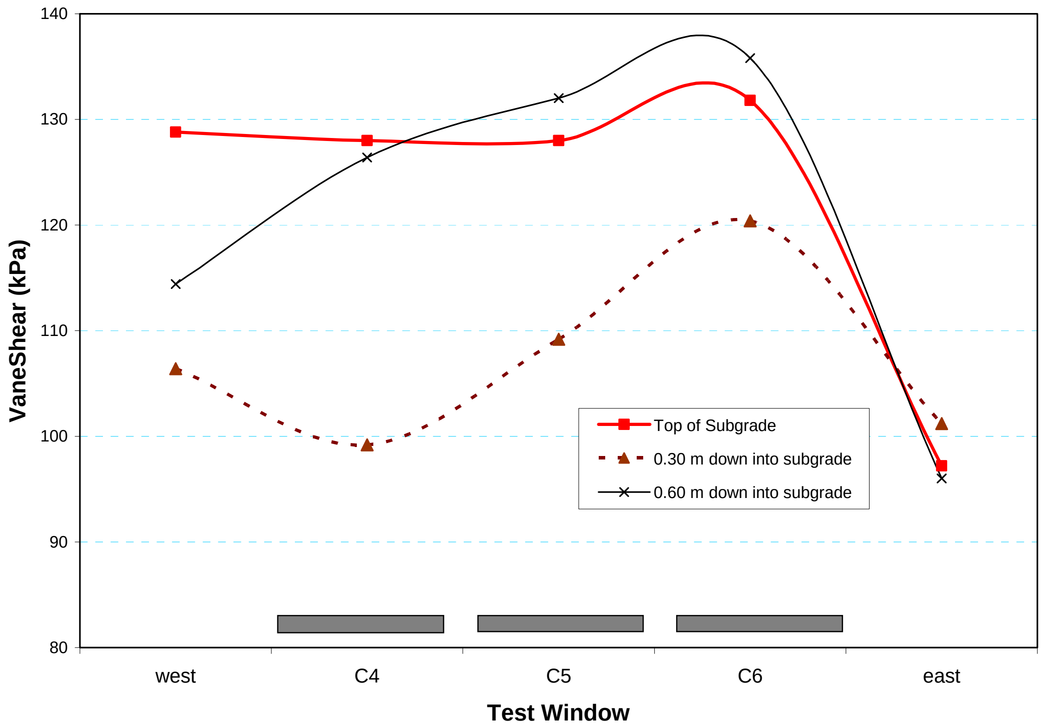

Figure 34. Vane shear measurements in the upper subgrade in the north trench.

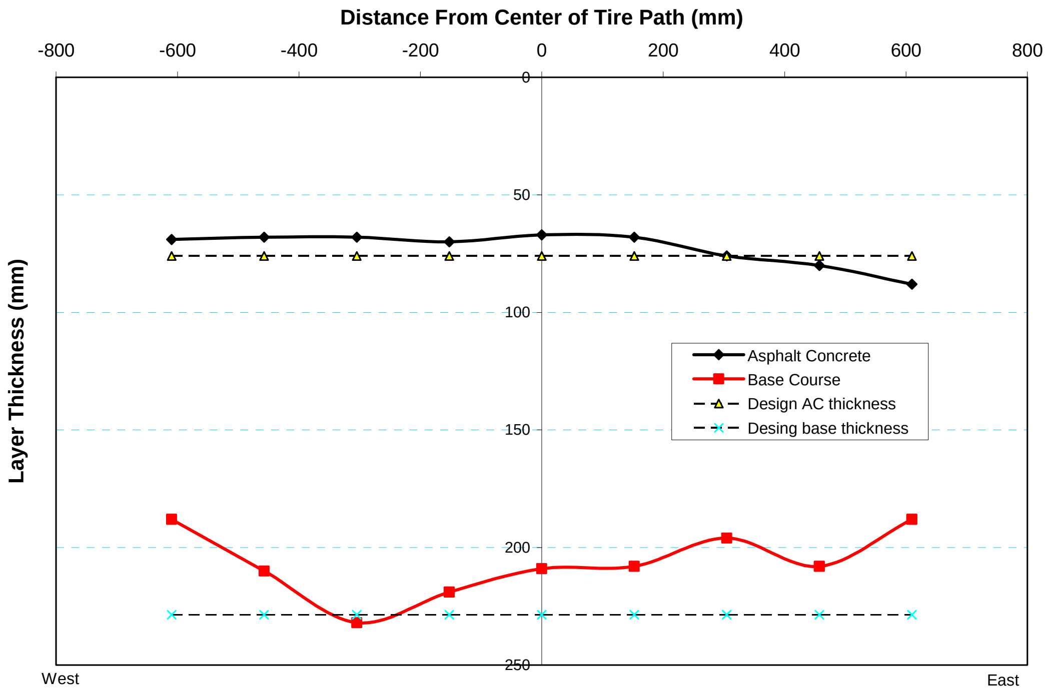

Figure 35. Layer thickness measurements across Test Window C1.

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

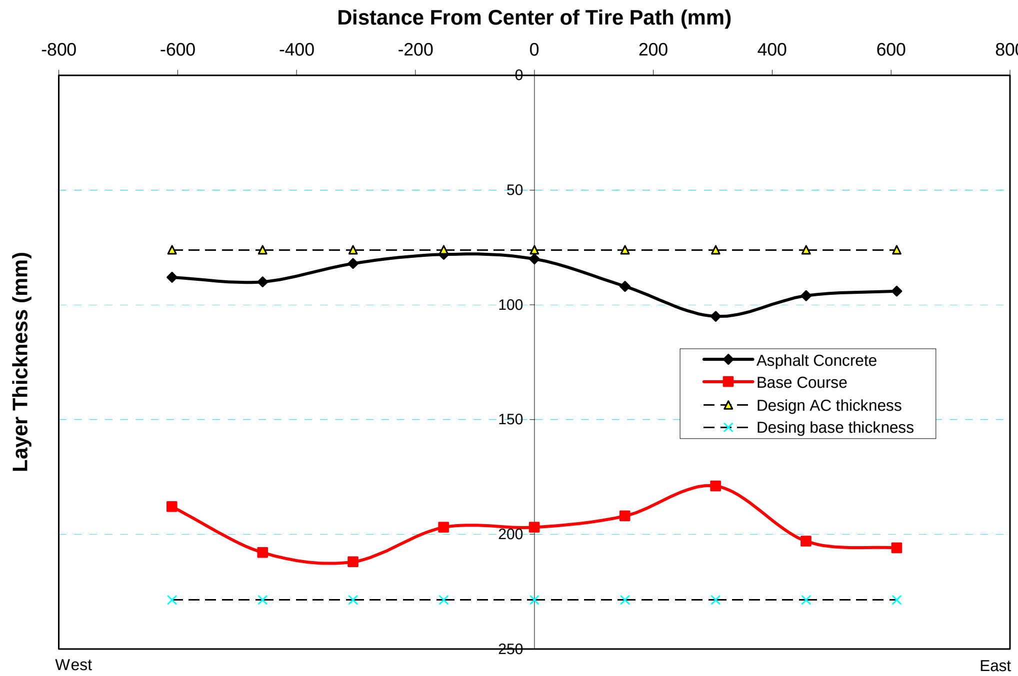

Figure 36. Layer thickness measurements across Test Window C2.

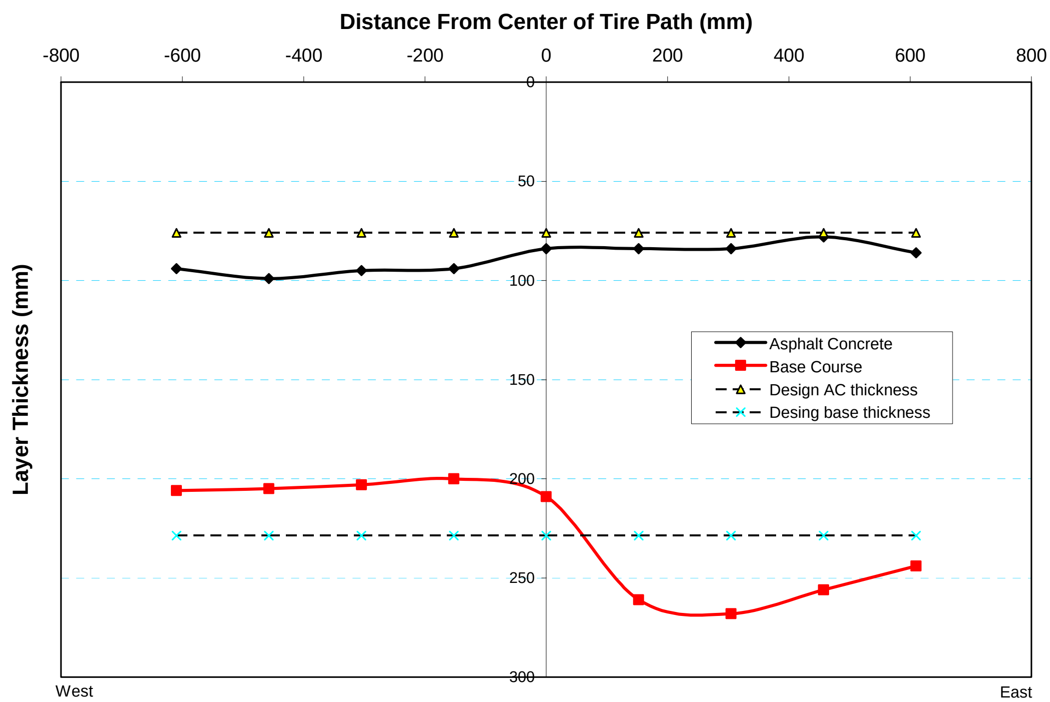

Figure 37. Layer thickness measurements across Test Window C3.

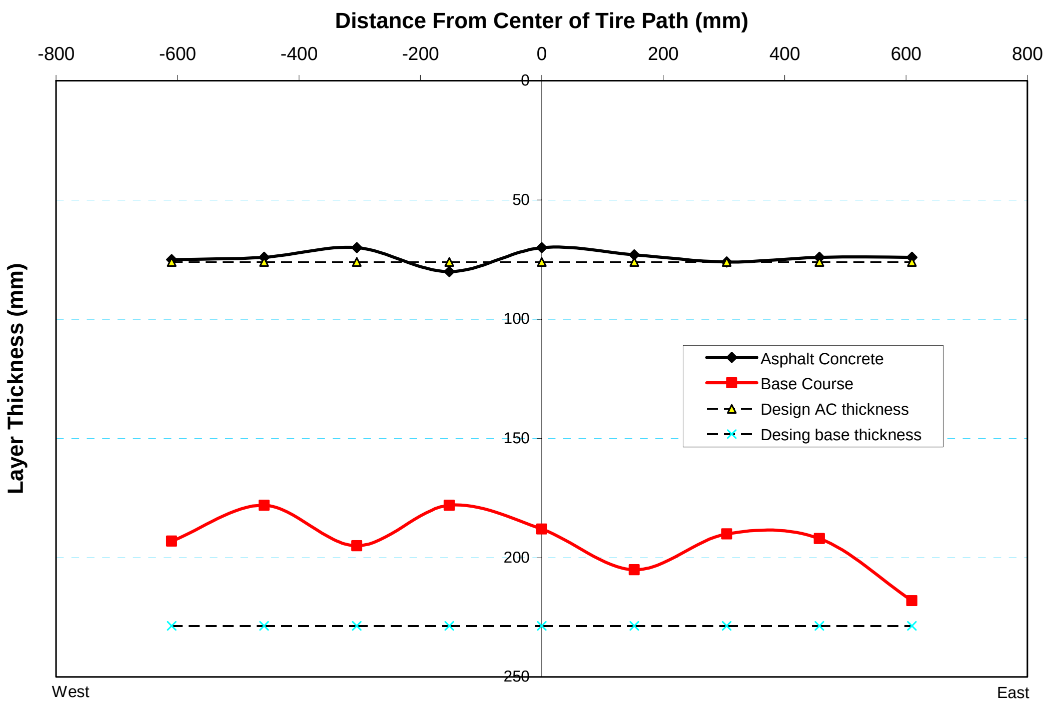

Figure 38. Layer thickness measurements across Test Window C4.

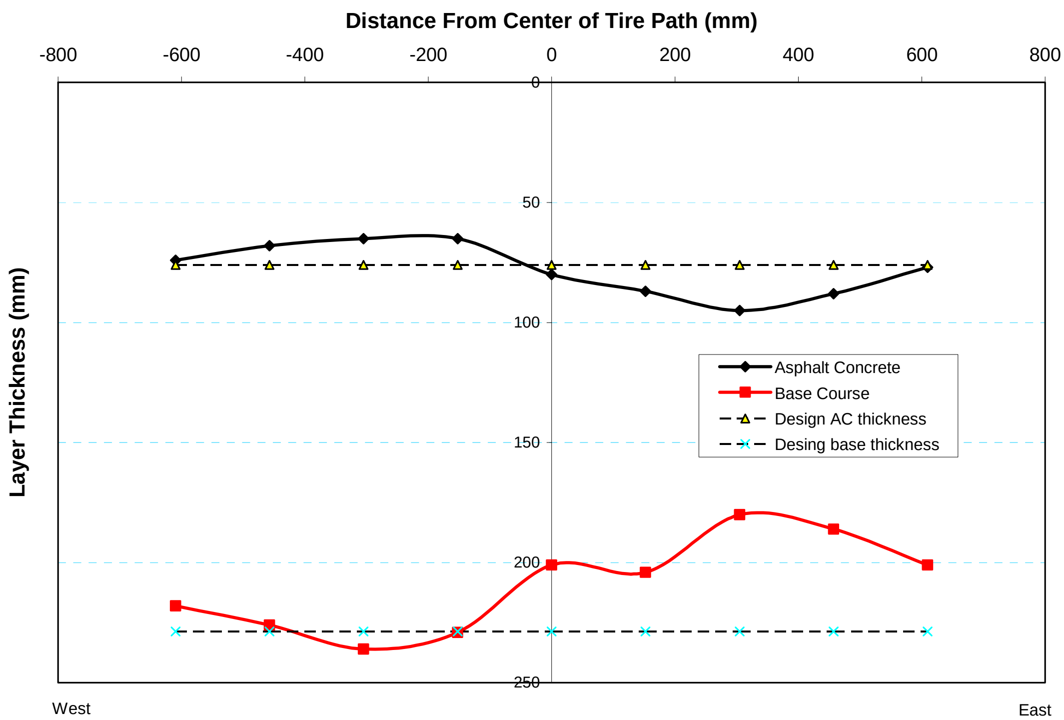

Figure 39. Layer thickness measurements across Test Window C5.

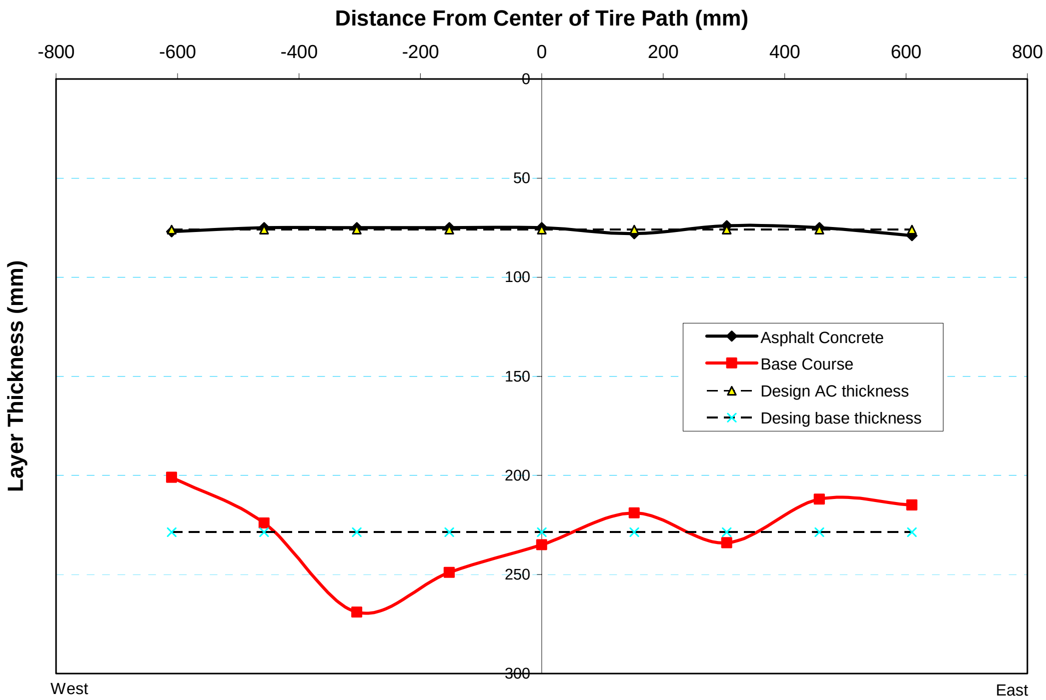

Figure 40. Layer thickness measurements across Test Window C6.

Nuclear moisture and density measurements were taken in the trenches at each layer. The measurements were conducted in the direct mode, i.e., the probe was inserted 0.15 m (6 in.) into the soil. The measurement represents the region of soil between the inserted nuclear source and the receiver in the box of the apparatus. Drive cylinder tests samples were taken in the same volume where the nuclear gauge measurements were taken.

Forensic Observations

Surface rutting at the end of traffic testing in Test Window 710c1 was as expected. No visible crack was observed.

By the end of traffic testing Test Window 710c2 a transverse crack 10-mm (3/8-in.) wide and covering the entire width of the test window had developed near the acceleration zone at the south end of the test window. The surface course of the asphalt had apparently delaminated from the lower asphalt course and shoving was evidenced by distortion of the paint lined marking the end of the effective test window. It appears that the crack had originated in the neighboring Test Window 710c3 that had been traffic tested earlier, and it grew into Test Window 710c2 during trafficking.

During the forensic exploration, it was observed that the bond between the two asphalt layers was weak at most locations, and the layers were separated in the region where large cracks and shoving had been observed during trafficking. Test Window 710c3 had significant asphalt delamination.

A transverse crack 11-mm (7/16-in.) wide developed across Test Window 710c4. There was also some delamination of the asphalt layers at Test Windows 710c5.
Test Window 710c6 also developed shoving that began with apparent shear failures in the asphalt at the lateral boundaries for a length about 0.91 m (3 ft).

The moisture content measurements obtained during the forensic exploration indicate that there was no measurable loss of moisture in the subgrade during the traffic loading period. However, the moisture content near the top of the base course decreased significantly during this period.

The asphalt thickness measurements taken on one side of the trenches show no difference between the traffic areas and the areas outside the test windows, but weak bond between the asphalt layers was evidenced by some shoving and cracking at several locations.

The thickness of the base course had some significant deviation from the design thickness of 230 mm (9 in.). Except for Test Windows 710c3, 710c6, the base course was thinner than specified.

The Vane shear tests suggest slightly lower shear strength at the sides of the test windows.

SUMMARY AND CONCLUSIONS

Accelerated pavement testing (APT) was conducted on a test section with a subgrade soil that was classified as borderline between AASHTO types A-6 and A-7-6. The subgrade was built at 21 percent moisture content for a soil with optimum moisture content of 17 percent via modified Proctor tests. At this moisture condition, the laboratory CBR was found to be 4 percent. This is a weak subgrade soil.

The subgrade layer was instrumented with stress, strain, temperature and moisture sensors.

The test section was divided into 6 test windows. Accelerated pavement testing was conducted over a period of 2.5 months. During the accelerated pavement testing, dynamic stresses, dynamic and permanent strains, and surface rut depth measurements were collected at given loading intervals. Stress measurements were collected in all of the six test windows. However, the data from the subgrade was poor and not used in the analysis. Strain measurements were collected in all six windows to a depth of 1.2-m into the subgrade. Stress and strain measurements were made in the vertical, longitudinal and transverse directions of loading. Temperature and moisture measurements were made every 4 hours during the tests. The test loads varied between 20 to 40-kN (4.5 to 9 kips). The average tire pressure was 690-kPa (100 psi). The load was applied by means of a standard dual truck tire assembly that constituted half of a truck axle. Therefore, for example, 40 kN (9 kips) is equivalent to a full axial load of 80 kN (18 kips).

The dynamic strains at failure are compared with the current Asphalt Institute and Shell subgrade failure criterions. In addition to the strain measurements from this test sections, Figure 41 shows those from other test sections in this research project and compares them to the Shell and Asphalt Institute failure criteria. Note that these results were measured at 12 km/hr. To be able to compare with the results from the AASHO Road tests, where the test speed was 48 km/hr, a correction factor was applied to the strain data. The correction factors were developed based on results from MnRoad (Dai and Van Deusen, 1998, Janoo, et al, 2002). The test results were multiplied by factors of 0.63 and 0.48 for speeds of 48 km/hour (AASHO Road Test) and 88 km/hour (highway) respectively.

The following equation relates the allowable number of load repetitions N_d to limit rutting on top of the subgrade to the vertical strain modified by two constants.

$$N_d = f_4\left(\varepsilon_v\right)^{-f5} \qquad \textbf{\textit{(Equation 1)}}$$

where the coefficients f_4, f_5 are 0.3224 and -0.4734 for highway speeds.

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

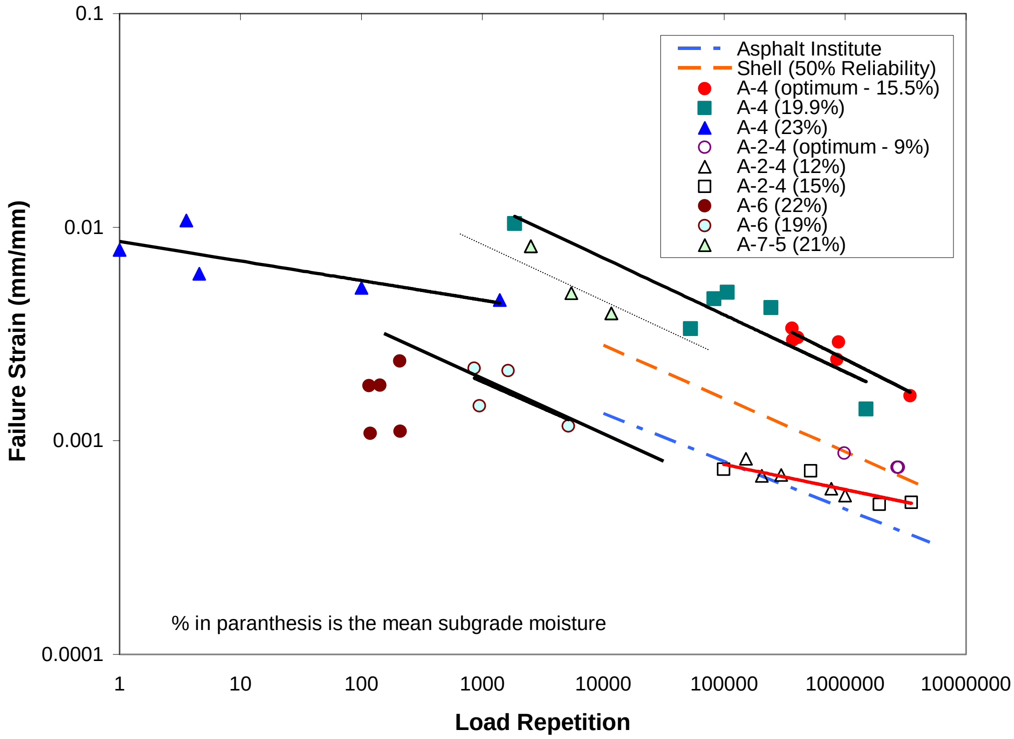

Figure 41. Effect of soil type on the subgrade failure criterion

REFERENCE

Dai, S.T., D.Van Deusen, D.Rettner and G.Cochran. "Investigation of Flexible Pavement Response to Truck Speed and FWD Load Through Instrumented Pavements", Proceedings of the 8th International Conference on Flexible Pavements. Seattle, Washington, pp.141-160. 1997.

Hilderbrand & Irwin, "Theoretical Analysis of Pavement Test Sections in the FERF", Internal Report, 1994.

Janoo, V., L. Irwin, R. Eaton, and R. Haehnel, "Pavement Subgrade Performance Study: Project Overview, ERDC Report TR15, 2002.

APPENDIX A

SURFACE PROFILE TEST RESULTS

Table A1. Surface rut measurements in 710C1

Pos/Pass	250	1000	2500	5000	10000	25000	50000
	Maximum Rut Depth (mm)						
1	-2.802	-0.733	-5.755	-4.031	-5.256	-9.174	-11.782
2	-2.198	-1.638	-4.685	-6.166	-5.916	-8.951	-13.808
3	-2.419	-2.788	-4.749	-5.647	-5.879	-11.671	-12.569
4	-3.039	-4.637	-5.090	-5.733	-7.594	-11.257	-14.374
5	-3.314	-4.455	-4.985	-5.767	-7.108	-11.106	-13.081
6	-3.327	-5.673	-6.812	-6.295	-8.578	-13.099	-15.645
7	-5.555	-7.298	-9.033	-10.444	-11.789	-13.887	-17.504
8	-1.533	-3.475	-4.591	-4.402	-6.995	-12.172	-13.853
9	-3.277	-4.066	-2.997	-4.942	-5.323	-9.689	-15.627
10	-2.293	-3.104	-4.526	-4.559	-4.828	-9.554	-13.408
11	-2.547	-3.392	-4.202	-4.706	-5.075	-9.771	-13.279
12	-1.877	-2.770	-4.355	-5.165	-6.336	-9.454	-14.734
13	-3.663	-4.168	-5.687	-4.801	-5.915	-11.004	-12.459
14	-3.269	-3.881	-4.105	-4.082	-5.348	-8.257	-11.452
15	-2.314	-3.169	-4.159	-5.810	-6.910	-11.559	-13.689
16	-1.127	-3.192	-4.355	-5.869	-7.122	-11.585	-14.709
17	-3.758	-3.701	-5.253	-6.489	-7.314	-10.988	-13.648
18	-3.531	-4.000	-6.093	-7.156	-8.593	-12.340	-17.187
19	-3.098	-3.364	-4.614	-5.895	-6.551	-14.352	-15.076
20	-2.330	-3.506	-4.825	-5.424	-6.351	-9.565	-12.089

Table A 2. Surface rut measurements in 710C2

Pos/Pass	100	500	1000	1700	3000
	Maximum Rut Depth (mm)				
1	-1.694	-7.149	-10.527	-14.538	-16.5521
2	-1.712	-5.036	-8.673	-11.668	-13.4945
3	-1.863	-4.421	-6.257	-9.172	-12.1489
4	-0.294	-3.592	-5.749	-9.252	-10.7585
5	-2.264	-3.637	-5.856	-8.619	-11.8189
6	-1.729	-5.776	-7.603	-11.035	-13.8158
7	-2.317	-5.553	-8.388	-10.384	-13.1915
8	-2.727	-5.188	-7.603	-9.947	-13.994
9	-1.141	-5.134	-6.810	-10.322	-13.2099
10	-2.585	-5.437	-7.478	-10.357	-13.4322
11	-2.727	-5.304	-6.703	-9.796	-10.5266
12	-2.113	-3.841	-5.348	-7.950	-9.16273
13	-1.346	-3.931	-5.161	-7.300	-8.44109
14	-4.055	-4.920	-7.130	-7.942	-10.5266
15	-2.924	-5.767	-8.084	-10.224	-12.4253
16	-1.836	-5.277	-6.685	-8.664	-12.0422
17	-3.022	-4.314	-6.284	-8.183	-11.3288
18	-2.656	-4.011	-6.168	-6.855	-10.5803
19	-2.005	-3.173	-5.998	-7.327	-10.295
20	-1.658	-3.957	-5.330	-7.202	-9.34091

Table A 3. Surface rut measurements in 710C3

Pos/Pass	250	1000	5000	5001	10000
	Maximum Rut Depth (mm)				
1	-1.988	-3.342	-5.945	-5.472	-5.972
2	-2.388	-4.439	-6.435	-4.715	-4.341
3	-0.544	-3.156	-4.483	-2.772	-3.868
4	-1.827	-2.683	-3.547	-3.022	-4.930
5	-2.166	-3.485	-4.465	-4.501	-6.328
6	-2.050	-3.512	-6.106	-4.439	-5.954
7	-2.380	-3.262	-5.161	-4.760	-6.480
8	-3.280	-4.742	-6.212	-2.211	-6.837
9	-1.622	-3.307	-4.983	-3.156	-4.564
10	-2.121	-2.487	-4.011	-2.237	-4.983
11	-1.560	-2.549	-3.735	-2.015	-4.145
12	-2.077	-2.594	-4.207	-2.558	-4.662
13	-2.576	-2.273	-3.708	-2.175	-4.510
14	-1.587	-1.346	-3.245	-1.524	-3.619
15	-1.480	-1.899	-3.886	-1.890	-20.786
16	-1.417	-2.442	-2.175	-2.211	-3.770
17	-1.952	-2.638	-2.870	-1.685	-4.261
18	-0.990	-1.703	-2.701	-1.515	-3.539
19	-1.613	-1.676	-2.959	-1.524	-3.120
20	-0.793	-1.150	-2.398	-1.247	-5.045

Table A4. Surface rut measurements in 710C4

Pos/Pass	250	1000
	Maximum Rut Depth (mm)	
1	-1.616	-6.447
2	-3.900	-7.148
3	-2.478	-6.789
4	-3.325	-8.893
5	-3.942	-9.112
6	-5.547	-9.787
7	-3.668	-9.368
8	-4.403	-9.536
9	-5.626	-11.209
10	-4.672	-11.495
11	-3.819	-9.288
12	-3.935	-8.104
13	-4.259	-8.657
14	-2.969	-7.603
15	-4.944	-9.888
16	-3.947	-8.665
17	-3.960	-8.333
18	-4.205	-8.882
19	-3.152	-7.012
20	-1.565	-7.381

Table A 5. Surface rut measurements in 710C5

Pos/Pass	250	500	1000	5000
	Maximum Rut Depth (mm)			
1	-5.099	-3.958	-4.314	-6.328
2	-6.569	-12.122	-5.375	-7.264
3	-6.489	-6.935	-4.269	-7.906
4	-4.038	-5.045	-4.786	-7.398
5	-5.571	-3.842	-4.519	-6.685
6	-4.778	-6.275	-6.872	-9.778
7	-4.590	-3.637	-4.216	-5.018
8	-4.350	-6.338	-6.230	-7.193
9	-3.654	-4.047	-2.086	-6.525
10	-1.203	-2.585	-4.296	-4.448
11	-5.116	-5.838	-6.676	-7.942
12	-4.002	-4.626	-4.688	-8.370
13	-4.974	-4.287	-5.366	-6.792
14	-2.139	-4.466	-3.556	-4.350
15	-4.421	-5.152	-4.555	-7.336
16	-4.911	-4.278	-5.669	-5.419
17	-4.599	-5.972	-4.385	-6.453
18	-4.697	-4.608	-2.826	-3.369
19	-1.203	-1.533	-1.052	-1.979
20	-6.284	-3.663	-4.474	-6.899

Table A 6. Surface rut measurements in 710C6

Pos/Pass	250	1000	4240
	Maximum Rut Depth (mm)		
1	-3.922	-5.491	-6.480
2	-4.171	-7.104	-8.182
3	-5.366	-7.452	-8.904
4	-5.517	-8.441	-11.061
5	-7.104	-9.894	-10.972
6	-7.166	-9.216	-13.049
7	-7.024	-10.152	-10.919
8	-5.045	-8.914	-9.012
9	-5.482	-7.942	-9.983
10	-5.651	-7.416	-10.562
11	-7.532	-9.769	-12.791
12	-4.902	-7.906	-8.575
13	-5.214	-7.728	-10.705
14	-4.956	-7.399	-11.445
15	-4.983	-7.086	-9.199
16	-4.100	-7.951	-11.266
17	-4.484	-6.659	-10.518
18	-4.706	-5.285	-7.603
19	-3.227	-4.724	-7.924
20	-3.547	-5.009	-7.647

Test Section 710 AASHTO A-6/A-7-6 subgrade soil at 21 % gravimetric moisture content

APPENDIX B

PERMANENT DEFORMATION & STRAIN TEST RESULTS

Table B 1. Permanent deformation (mm) in 710C1

710C1		Load = 27 kN						
		VERTICAL DISPLACEMENT (mm)						
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
Surface	0	-0.1411	-0.3514	-0.7677	-0.9051	-1.1101	-1.9160	-2.3107
135	0	-0.1166	-0.3405	-0.6105	-0.8216	-1.0745	-1.8638	-2.3944
250	0	-0.1024	-0.3511	-0.6481	-0.8628	-1.1930	-2.1522	-2.7355
380	0	-0.3007	-0.5757	-0.5053	-0.6186	-1.1288	-1.6688	-2.1088
535	0	-0.0004	-0.4388	-0.5236	-0.2363	-0.5450	-0.7910	0.3659
685	0	0.0248	0.5973	0.5858	0.6299	0.5332	0.5396	-3.6387
840	0	0.0532	0.0608	0.0900	0.1664	0.1478	0.0133	-0.0011
990	0	0.0165	0.1598	-0.2382	0.1812	0.2897	0.0518	0.0430
1145	0	0.0120	0.1474	-0.1891	0.1821	0.2621	0.0145	0.0092
1295	0	0.0308	0.1323	-0.0169	0.1404	0.2017	0.0379	0.0466
1450	0	0.0391	0.2635	0.1946	0.1869	0.3507	0.0669	0.0652
		LONGITUDINAL DISPLACEMENT (mm)						
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	0	-0.0307	-0.0130	-0.0480	-0.1455	-0.1433	-0.4161	-0.5222
191	0	0.0158	0.0711	0.0782	0.0091	-0.0140	-0.3225	-0.4372
305	0	0.0091	0.1097	0.0922	0.0853	0.1028	-0.1926	-0.2577
457	0	-0.0015	0.1086	0.1023	0.1043	0.1508	-0.0022	0.0116
610	0	0.0200	0.5973	0.6185	0.5564	0.5699	0.5676	-2.6909
762	0	0.0363	0.1279	0.1874	0.1116	0.1762	0.0232	0.0377
914	0	0.0101	0.1145	0.1157	0.1350	0.1948	0.0435	0.0377
		TRANSVERSE DISPLACEMENT (mm)						
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	0	0.1185	0.4825	0.7401	0.9683	1.2509	1.6209	1.8667
191	0	0.0674	0.3202	0.5160	0.6425	0.8629	1.1490	1.3686
305	0	0.0004	0.1038	0.1548	0.2206	0.2793	0.1997	0.2287
457	0	-0.0080	0.0859	0.1042	0.1846	0.2328	0.2017	0.2364
610	0	0.0002	0.4975	0.5157	0.5233	0.4987	0.5396	-2.5391
762	0	0.0187	0.0777	0.0891	0.1125	0.1378	0.0230	0.0182
914	0	0.0104	0.0828	0.1398	0.0832	0.1347	0.0259	0.0381

Table B 2. Permanent deformation (mm) in 710C2 (STACK A)

710C2		Load = 40 kN				
		VERTICAL DISPLACEMENT (mm)				
Depth (mm)	0	100	500	1000	1700	3000
Surface	0	-0.1589	-0.6308	0.0000	0.3204	-0.1589
134	0	-0.2807	-1.0497	-1.5297	-1.8149	-2.2451
248	0	-0.3061	-1.2658	-1.8613	-2.2593	-3.1085
381	0	-0.2827	-0.9874	-1.4927	-1.8928	-2.9056
534	0	-0.1298	-0.5436	-0.8526	-1.0884	-1.8128
686	0	-0.0376	-0.1822	-0.1994	-0.2792	-0.5798
838	0	-0.0015	-0.0538	-0.0843	-0.0800	-0.2356
991	0	0.0412	0.0048	0.0115	0.0077	-0.0299
1143	0	0.0554	0.0196	0.0092	0.0234	-0.0060
1296	0	-0.0133	-0.0495	-0.0565	-0.0449	-0.0830
1448	0	0.0189	-0.0333	-0.0246	-0.0351	-0.0644
		LONGITUDINAL DISPLACEMENT (mm)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	-0.0630	-0.1303	-0.1646	-0.1330	-0.1310
191	0	-0.0236	-0.0625	-0.0300	-0.0219	-0.0512
305	0	-0.0137	0.0469	0.1280	0.2057	0.2543
457	0	-0.0120	0.0128	0.0234	0.0451	0.0740
610	0	-0.0056	-0.0716	-0.0696	-0.0714	-0.0318
762	0	0.0088	-0.0279	-0.0333	-0.0282	-0.0435
914	0	-0.0054	-0.0464	-0.0384	-0.0361	-0.0406
		TRANSVERSE DISPLACEMENT (mm)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	0.2010	0.5186	0.6647	0.8350	1.1104
191	0	0.2194	0.6111	0.8507	0.9704	1.3261
305	0	0.0803	0.2787	0.4942	0.6364	1.0612
457	0	0.0385	0.1739	0.2677	0.3340	0.6314
610	0	0.0192	-0.0153	0.0033	0.0021	0.0951
762	0	0.0361	0.0187	0.0187	0.0341	0.0694
914	0	0.0286	0.0024	0.0057	0.0025	0.0106

Table B2b. Permanent deformation (mm) in 710C2 (STACK B)

710C2		Load = 40 kN				
		VERTICAL DISPLACEMENT (mm)				
		Load Repetitions				
Depth (mm)	0	100	500	1000	1700	3000
Surface	0	-0.1379	-0.5472	-1.0832	-1.2594	-1.4780
134	0	20.5111	29.8771	12.2810	32.2661	30.6423
248	0	-0.2022	-0.9217	-1.3401	-1.6331	-2.0458
381	0	-0.1635	-0.8562	-1.3592	-1.7210	-2.2423
534	0	-0.2729	-1.1103	-1.5215	-1.7560	-2.1336
		LONGITUDINAL DISPLACEMENT (mm)				
		Load Repetitions				
Depth (mm)	0	100	500	1000	1700	3000
76	0	0.1137	0.2063	0.1921	-0.1425	0.4011
191	0	1.1275	5.7765	8.3610	10.1512	9.8731
305	0	0.4500	2.7426	4.5995	6.0093	8.0862
457	0	0.0875	0.3068	0.3957	0.4393	0.5849
610	0	0.0112	-0.1046	-0.2392	-0.2302	-0.2355
		TRANSVERSE DISPLACEMENT (mm)				
		Load Repetitions				
Depth (mm)	0	100	500	1000	1700	3000
76	0	-0.7458	-1.1306	-0.4323	-0.9780	-0.9189
191	0	-5.5027	-21.2774	-30.0855	-35.0861	-40.8596
305	0	0.6626	3.3716	5.6614	7.2805	9.5378
457	0	0.2632	0.8295	1.1275	1.2663	1.5769
610	0	0.1212	0.1394	0.1239	0.1805	0.2772

Table B3. Permanent deformation (mm) in 710C3

710C3		Load = 20 kN				
		VERTICAL DISPLACEMENT (mm)				
Depth (mm)	0	250	500	1000	5000	10000
Surface	0	-0.2751	-1.0865	-1.2640	-1.2640	-1.6160
133	0	-0.3908	-0.6057	-0.8287	-1.4468	-1.6771
248	0	-0.1945	-0.3157	-0.4393	-0.9010	-1.4819
381	0	-0.2384	-0.3500	-0.3377	12.2199	-0.8075
533	0	-0.0571	-0.0575	-0.0763	-0.0615	-0.1105
686	0	-0.0665	-0.0775	-0.1214	-0.0773	-0.1731
838	0	0.0051	-0.0354	0.0060	0.0854	0.0368
991	0	-0.0153	-0.0166	0.0017	0.0894	0.3744
1143	0	-0.0060	-0.0144	0.0007	0.0895	0.1942
1295	0	0.0020	0.0018	0.0079	0.0889	0.1743
1448	0	-0.0084	-0.0080	-0.0142	0.0871	0.3279
		LONGITUDINAL DISPLACEMENT (mm)				
Depth (mm)	0	250	500	1000	5000	10000
76	0	-0.0302	-0.0519	-0.0439	-0.0514	-0.0461
191	0	-0.0394	-0.0368	-0.0061	0.0444	-0.0530
305	0	-0.0329	-0.0498	-0.0615	-0.0179	0.0440
457	0	-0.1149	-0.2158	-0.1151	-0.1206	-0.1297
610	0	-0.0269	-0.0230	-0.0250	0.0418	0.0352
762	0	-0.0051	-0.0189	0.0043	0.0593	0.0527
914	0	-0.0440	-0.0578	-0.0476	0.0273	-0.0113
		TRANSVERSE DISPLACEMENT (mm)				
Depth (mm)	0	250	500	1000	5000	10000
76	0	0.3596	0.4338	0.5989	1.0260	1.1907
191	0	0.1309	0.1661	0.2674	0.5222	0.5787
305	0	0.0303	0.0147	0.0349	0.1714	0.1583
457	0	-0.1655	-0.4614	-0.1873	-0.2692	-0.3585
610	0	0.0005	-0.0129	-0.0061	0.0483	0.0294
762	0	0.0172	-0.0134	0.0094	0.0423	0.0000
914	0	0.0009	-0.0018	-0.0010	0.0036	0.0013

Table B4. Permanent deformation (mm) in 710C4

710C4		Load = 40 kN	
		VERTICAL DISPLACEMENT (mm)	
Depth (mm)	0	250	1000
Surface	0	-0.1298	-0.2590
133	0	0.6392	GF
248	0	-0.7353	-1.6079
381	0	-0.6173	-1.7282
533	0	-0.9746	-2.0801
686	0	0.0438	-0.1991
838	0	0.1129	0.0192
991	0	0.1698	0.1681
1143	0	0.1683	0.0550
1295	0	0.1536	0.0586
1448	0	0.1843	0.1499
		LONGITUDINAL DISPLACEMENT (mm)	
Depth (mm)	0	250	1000
76	0	-5.9508	GF
191	0	-7.9014	-8.1772
305	0	-0.0192	-0.2683
457	0	1.5050	1.3857
610	0	1.9786	1.9374
762	0	5.0422	4.9860
914	0	5.5575	5.5291
		TRANSVERSE DISPLACEMENT (mm)	
Depth (mm)	0	250	1000
76	0	1.6162	GF*
191	0	7.9706	8.3956
305	0	0.5193	0.8851
457	0	-6.0160	-5.8752
610	0	-1.6878	-1.6435
762	0	-0.0125	-0.0571
914	0	-0.4494	-0.5307

*GF – Gage Failure

Table B5. Permanent deformation (mm) in 710C5 (STACK A)

710C5		Load = 20 kN			
		VERTICAL DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
Surface	0	-0.0843	-0.5027	-0.5027	-0.8333
134	0	-0.2684	-0.3265	-0.4536	-0.8197
248	0	-0.2090	-0.2434	-0.3269	-0.5935
381	0	-0.2225	-0.2008	-0.3066	-0.5106
534	0	-0.1333	-0.0988	-0.1122	-0.1499
686	0	-0.2407	-0.2159	-0.2401	-0.2392
838	0	-0.2193	-0.2000	-0.2222	-0.2005
991	0	-0.0507	-0.0618	-0.0508	-0.0267
1143	0	-0.1027	-0.0943	-0.0961	-0.0850
1296	0	-0.1135	-0.0805	-0.1236	-0.0894
1448	0	-0.2667	-0.2466	-0.2616	-0.2566
		LONGITUDINAL DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
76	0	-0.1927	-0.1787	-0.2076	-0.1807
191	0	-0.0716	-0.0988	-0.1433	-0.1320
305	0	-0.0713	-0.0637	-0.0963	-0.0504
457	0	-0.0807	-0.0559	-0.0548	-0.0416
610	0	-0.0579	-0.0512	-0.0695	-0.0470
762	0	-0.1648	-0.1534	-0.1754	-0.1511
914	0	-0.0503	-0.0570	-0.0564	-0.0338
		TRANSVERSE DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
76	0	-0.0474	0.0098	0.0845	0.3803
191	0	0.0068	-0.0118	-0.0260	0.0814
305	0	-0.0026	0.0037	-0.0116	0.1391
457	0	-0.0538	-0.0423	-0.0423	-0.0469
610	0	-0.1495	-0.1472	-0.1655	-0.1623
762	0	-0.0152	-0.0287	-0.0277	-0.0118
914	0	-0.1616	-0.1560	-0.1666	-0.1536

Table Bb. Permanent deformation (mm) in 710C5 (STACK B)

710C5		Load = 20 kN			
		VERTICAL DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
Surface	0	-0.0843	-0.3360	-0.4195	-0.6684
134	0	-20.0000	-13.7023	-11.9595	-16.6020
248	0	-0.2251	-0.2593	-0.3592	-0.6807
381	0	-0.1866	-0.1978	-0.2791	-0.5738
534	0	-0.2544	-0.2434	-0.3004	-0.4456
		LONGITUDINAL DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
76	0	-3.4810	-3.7884	-3.8403	-3.8441
191	0	-0.1172	1.1216	2.8368	13.2745
305	0	-1.8859	-1.4379	-1.2122	0.7767
457	0	0.5979	0.3730	0.2147	-0.3135
610	0	-0.5897	-0.5333	-0.6114	-0.6415
		TRANSVERSE DISPLACEMENT (mm)			
Depth (mm)	0	250	500	1000	5000
76	0	11.2163	10.5155	9.2260	10.4356
191	0	-1.7261	0.4088	2.8633	22.0016
305	0	-3.0982	-2.5570	-2.0210	1.0425
457	0	0.4777	0.3971	0.3129	0.3155
610	0	-1.2750	-1.1425	-1.1953	-1.1117

Table B6. Permanent deformation (mm) in 710C6

710C6		Load = 33 kN		
		VERTICAL DISPLACEMENT (mm)		
Depth (mm)	0	250	1000	4240
Surface	0	-0.2749	-0.4114	-0.4794
133	0	-0.6513	-1.4056	-2.2133
248	0	-0.9316	-1.5794	-2.4825
381	0	-0.7416	-1.0781	-1.4467
533	0	-0.1513	-0.0950	-0.1350
686	0	-0.1015	-0.0027	-0.0254
838	0	-0.1223	-0.0191	-0.0725
991	0	-0.0268	0.1148	0.1827
1143	0	-0.0256	0.1124	0.2029
1295	0	-0.0232	0.1147	0.1672
1448	0	-0.0372	0.0764	0.1294
		LONGITUDINAL DISPLACEMENT (mm)		
Depth (mm)	0	250	1000	4240
76	0	-0.0721	-0.1057	-0.3761
191	0	-0.0008	0.0474	-0.0442
305	0	-0.0443	-0.0218	-0.1296
457	0	-0.0244	0.0897	0.1710
610	0	-0.0287	0.0743	0.1141
762	0	-0.0447	0.0370	0.0563
914	0	-0.0077	0.0880	0.1240
		TRANSVERSE DISPLACEMENT (mm)		
Depth (mm)	0	250	1000	4240
76	0	0.6419	1.2410	1.9928
191	0	0.6070	0.9334	1.3387
305	0	0.4872	0.7583	1.0135
457	0	0.0676	0.1559	0.1922
610	0	0.0024	0.0554	0.0775
762	0	-0.0179	0.0421	0.0467
914	0	0.0000	0.0048	0.0052

.

Table B7. Permanent strains in 710C1

710C1 Load = 27 kN

		VERTICAL STRAIN (%)						
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
Surface	0	-0.135	-0.337	-0.737	-0.869	-1.066	-1.839	-2.218
135	0	-0.114	-0.332	-0.595	-0.801	-1.047	-1.816	-2.334
250	0	-0.105	-0.361	-0.667	-0.888	-1.228	-2.215	-2.815
380	0	-0.215	-0.412	-0.362	-0.443	-0.809	-1.195	-1.510
535	0	0.000	-0.281	-0.336	-0.151	-0.349	-0.507	0.235
685	0	0.017	0.409	0.401	0.431	0.365	0.369	-2.490
840	0	0.035	0.040	0.060	0.110	0.098	0.009	-0.001
990	0	0.011	0.108	-0.161	0.122	0.195	0.035	0.029
1145	0	0.008	0.095	-0.122	0.118	0.170	0.009	0.006
1295	0	0.023	0.097	-0.012	0.103	0.149	0.028	0.034
1450	0	0.026	0.173	0.127	0.122	0.230	0.044	0.043
				LONGITUDINAL STRAIN (%)				
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	0	-0.020	-0.008	-0.031	-0.094	-0.092	-0.268	-0.337
191	0	0.010	0.046	0.051	0.006	-0.009	-0.211	-0.286
305	0	0.006	0.071	0.060	0.055	0.066	-0.125	-0.167
457	0	-0.001	0.070	0.066	0.068	0.098	-0.001	0.008
610	0	0.013	0.382	0.395	0.355	0.364	0.363	-1.719
762	0	0.023	0.081	0.118	0.070	0.111	0.015	0.024
914	0	0.006	0.072	0.073	0.085	0.122	0.027	0.024
				TRANSVERSE STRAIN (%)				
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	0	0.073	0.299	0.459	0.600	0.775	1.004	1.157
191	0	0.044	0.210	0.338	0.421	0.566	0.753	0.897
305	0	0.000	0.067	0.101	0.143	0.182	0.130	0.149
457	0	-0.005	0.056	0.068	0.120	0.151	0.131	0.154
610	0	0.000	0.323	0.335	0.340	0.324	0.351	-1.650
762	0	0.012	0.049	0.056	0.070	0.086	0.014	0.011
914	0	0.006	0.047	0.079	0.047	0.077	0.015	0.022

.

Table B8. Permanent strains in 710C2 (STACK A)

710C2		Load = 40 kN				
		VERTICAL STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
Surface	0	-0.1475	-0.5853	0.0000	0.2972	-0.1475
134	0	-0.2525	-0.9442	-1.3759	-1.6324	-2.0194
248	0	-0.2727	-1.1279	-1.6586	-2.0132	-2.7698
381	0	-0.1805	-0.6306	-0.9534	-1.2090	-1.8558
534	0	-0.0860	-0.3602	-0.5649	-0.7212	-1.2012
686	0	-0.0226	-0.1095	-0.1199	-0.1678	-0.3485
838	0	-0.0011	-0.0407	-0.0638	-0.0605	-0.1783
991	0	0.0287	0.0033	0.0080	0.0053	-0.0209
1143	0	0.0363	0.0128	0.0060	0.0153	-0.0039
1296	0	-0.0098	-0.0365	-0.0417	-0.0331	-0.0612
1448	0	0.0121	-0.0213	-0.0157	-0.0225	-0.0412
		LONGITUDINAL STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	-0.0410	-0.0848	-0.1071	-0.0866	-0.0853
191	0	-0.0144	-0.0380	-0.0183	-0.0134	-0.0312
305	0	-0.0084	0.0289	0.0790	0.1269	0.1569
457	0	-0.0075	0.0080	0.0147	0.0283	0.0464
610	0	-0.0034	-0.0441	-0.0428	-0.0439	-0.0196
762	0	0.0058	-0.0184	-0.0220	-0.0186	-0.0288
914	0	-0.0036	-0.0310	-0.0256	-0.0241	-0.0271
		TRANSVERSE STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	0.1261	0.3253	0.4169	0.5237	0.6965
191	0	0.1430	0.3982	0.5543	0.6323	0.8640
305	0	0.0529	0.1835	0.3253	0.4190	0.6986
457	0	0.0251	0.1133	0.1745	0.2177	0.4116
610	0	0.0124	-0.0099	0.0021	0.0013	0.0614
762	0	0.0230	0.0119	0.0119	0.0217	0.0442
914	0	0.0194	0.0016	0.0039	0.0017	0.0072

Table B9b. Permanent strains in 710C2 (STACK B)

710C2		Load = 40 kN				
		VERTICAL STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
Surface	0	-0.1495	-0.5933	-1.1744	-1.3655	-1.6025
134	0	1.8197	2.6507	1.0896	2.8626	2.7185
248	0	-0.1791	-0.8166	-1.1873	-1.4469	-1.8124
381	0	-0.1392	-0.7289	-1.1571	-1.4650	-1.9088
534	0	-0.1907	-0.7760	-1.0634	-1.2272	-1.4912
		LONGITUDINAL STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	0.0323	0.0585	0.0545	-0.0404	0.1138
191	0	0.3818	1.9560	2.8311	3.4373	3.3432
305	0	0.1441	0.8785	1.4734	1.9250	2.5902
457	0	0.0396	0.1388	0.1791	0.1988	0.2647
610	0	0.0045	-0.0425	-0.0972	-0.0936	-0.0957
		TRANSVERSE STRAIN (%)				
Depth (mm)	0	100	500	1000	1700	3000
76	0	-0.1677	-0.2542	-0.0972	-0.2199	-0.2066
191	0	-1.3984	-5.4072	-7.6456	-8.9163	-10.3836
305	0	0.2166	1.1023	1.8510	2.3803	3.1183
457	0	0.1050	0.3309	0.4498	0.5052	0.6291
610	0	0.0459	0.0528	0.0469	0.0684	0.1050

Table B10. Permanent strain in 710C3

710C3		Load = 20 kN				
		VERTICAL STRAIN (%)				
Depth (mm)	0	250	500	1000	5000	10000
Surface	0	-0.2449	-0.9673	-1.1254	-1.1254	-1.4388
133	0	-0.3733	-0.5786	-0.7917	-1.3823	-1.6022
248	0	-0.1671	-0.2711	-0.3772	-0.7737	-1.2726
381	0	-0.1561	-0.2292	-0.2211	8.0023	-0.5288
533	0	-0.0401	-0.0404	-0.0536	-0.0432	-0.0777
686	0	-0.0419	-0.0489	-0.0766	-0.0488	-0.1092
838	0	0.0031	-0.0217	0.0037	0.0524	0.0226
991	0	-0.0104	-0.0113	0.0012	0.0608	0.2547
1143	0	-0.0040	-0.0096	0.0004	0.0594	0.1289
1295	0	0.0015	0.0013	0.0057	0.0638	0.1251
1448	0	-0.0054	-0.0051	-0.0091	0.0560	0.2108
		LONGITUDINAL STRAIN (%)				
Depth (mm)	0	250	500	1000	5000	10000
76	0	-0.0188	-0.0324	-0.0274	-0.0321	-0.0288
191	0	-0.0252	-0.0235	-0.0039	0.0284	-0.0339
305	0	-0.0212	-0.0320	-0.0395	-0.0115	0.0283
457	0	-0.0758	-0.1423	-0.0759	-0.0796	-0.0855
610	0	-0.0175	-0.0150	-0.0163	0.0272	0.0229
762	0	-0.0032	-0.0121	0.0027	0.0378	0.0336
914	0	-0.0281	-0.0369	-0.0303	0.0174	-0.0072
		TRANSVERSE STRAIN (%)				
Depth (mm)	0	250	500	1000	5000	10000
76	0	0.2314	0.2792	0.3855	0.6603	0.7663
191	0	0.0830	0.1053	0.1695	0.3310	0.3668
305	0	0.0189	0.0092	0.0218	0.1068	0.0986
457	0	-0.1074	-0.2993	-0.1215	-0.1746	-0.2325
610	0	0.0004	-0.0084	-0.0039	0.0313	0.0190
762	0	0.0118	-0.0092	0.0065	0.0291	0.0000
914	0	0.0006	-0.0013	-0.0007	0.0026	0.0009

Table B11. Permanent strain in 710C4

710C4		Load = 40 kN	
		VERTICAL STRAIN (%)	
Depth (mm)	0	250	1000
Surface	0	-0.1276	-0.2546
133	0	0.6159	GF
248	0	-0.6198	-1.3555
381	0	-0.3925	-1.0989
533	0	-0.6326	-1.3502
686	0	0.0282	-0.1283
838	0	0.0750	0.0128
991	0	0.1146	0.1135
1143	0	0.1100	0.0359
1295	0	0.1128	0.0431
1448	0	0.1176	0.0956
		LONGITUDINAL STRAIN (%)	
Depth (mm)	0	250	1000
76	0	-3.7129	GF
191	0	-4.8674	-5.0373
305	0	-0.0123	-0.1719
457	0	0.9519	0.8764
610	0	1.3410	1.3130
762	0	3.2773	3.2408
914	0	3.7200	3.7010
		TRANSVERSE STRAIN (%)	
Depth (mm)	0	250	1000
76	0	1.0293	GF
191	0	5.2074	5.4851
305	0	0.3308	0.5638
457	0	-3.7401	-3.6526
610	0	-1.1219	-1.0925
762	0	-0.0083	-0.0378
914	0	-0.2961	-0.3497

GF – Gage Failure

Table B12. Permanent strain in 710C5 (STACK A)

710C5		Load = 20 kN			
		VERTICAL STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
Surface	0	-0.0770	-0.4587	-0.4587	-0.7605
134	0	-0.2566	-0.3121	-0.4336	-0.7837
248	0	-0.1695	-0.1975	-0.2652	-0.4815
381	0	-0.1455	-0.1314	-0.2005	-0.3339
534	0	-0.0847	-0.0628	-0.0713	-0.0952
686	0	-0.1502	-0.1347	-0.1498	-0.1492
838	0	-0.1510	-0.1377	-0.1530	-0.1380
991	0	-0.0326	-0.0398	-0.0327	-0.0172
1143	0	-0.0653	-0.0600	-0.0611	-0.0541
1296	0	-0.0762	-0.0541	-0.0830	-0.0600
1448	0	-0.1797	-0.1662	-0.1763	-0.1730
		LONGITUDINAL STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
76	0	-0.1199	-0.1113	-0.1292	-0.1125
191	0	-0.0463	-0.0639	-0.0926	-0.0853
305	0	-0.0460	-0.0411	-0.0621	-0.0325
457	0	-0.0497	-0.0345	-0.0338	-0.0256
610	0	-0.0369	-0.0327	-0.0443	-0.0300
762	0	-0.1059	-0.0986	-0.1126	-0.0971
914	0	-0.0319	-0.0361	-0.0357	-0.0214
		TRANSVERSE STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
76	0	-0.0291	0.0060	0.0519	0.2336
191	0	0.0044	-0.0077	-0.0170	0.0533
305	0	-0.0017	0.0024	-0.0076	0.0907
457	0	-0.0365	-0.0287	-0.0287	-0.0319
610	0	-0.0986	-0.0971	-0.1091	-0.1070
762	0	-0.0098	-0.0185	-0.0179	-0.0076
914	0	-0.1028	-0.0992	-0.1060	-0.0977

Table B13b. Permanent strain in 710C5 (STACK B)

710C5		Load = 20 kN			
		VERTICAL STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
Surface	0	-0.0770	-0.3066	-0.3828	-0.6100
134	0	-2.2151	-1.5176	-1.3246	-1.8388
248	0	-0.2161	-0.2489	-0.3447	-0.6533
381	0	-0.1721	-0.1824	-0.2574	-0.5292
534	0	-0.1611	-0.1541	-0.1901	-0.2821
		LONGITUDINAL STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
76	0	-0.9662	-1.0515	-1.0659	-1.0670
191	0	-0.0336	0.3221	0.8146	3.8118
305	0	-0.5551	-0.4232	-0.3568	0.2286
457	0	0.2131	0.1329	0.0765	-0.1117
610	0	-0.2460	-0.2225	-0.2551	-0.2676
		TRANSVERSE STRAIN (%)			
Depth (mm)	0	250	500	1000	5000
76	0	2.5380	2.3794	2.0876	2.3613
191	0	-0.4319	0.1023	0.7164	5.5050
305	0	-0.8764	-0.7233	-0.5717	0.2949
457	0	0.1976	0.1643	0.1294	0.1305
610	0	-0.4603	-0.4125	-0.4315	-0.4013

Table B14. Permanent strain in 710C6

710C6		Load = 33 kN		
		VERTICAL STRAIN (%)		
Depth (mm)	0	250	1000	4240
Surface	0	-0.2657	-0.3976	-0.4633
133	0	-0.6057	-1.3071	-2.0582
248	0	-0.8156	-1.3828	-2.1733
381	0	-0.4796	-0.6972	-0.9356
533	0	-0.0937	-0.0588	-0.0836
686	0	-0.0643	-0.0017	-0.0161
838	0	-0.0813	-0.0127	-0.0482
991	0	-0.0184	0.0790	0.1256
1143	0	-0.0164	0.0717	0.1294
1295	0	-0.0155	0.0767	0.1118
1448	0	-0.0243	0.0500	0.0846
		LONGITUDINAL STRAIN (%)		
Depth (mm)	0	250	1000	4240
76	0	-0.0468	-0.0685	-0.2438
191	0	-0.0005	0.0308	-0.0287
305	0	-0.0279	-0.0138	-0.0816
457	0	-0.0152	0.0557	0.1063
610	0	-0.0192	0.0498	0.0765
762	0	-0.0281	0.0233	0.0354
914	0	-0.0051	0.0581	0.0819
		TRANSVERSE STRAIN (%)		
Depth (mm)	0	250	1000	4240
76	0	0.4153	0.8029	1.2893
191	0	0.3896	0.5992	0.8594
305	0	0.3156	0.4911	0.6564
457	0	0.0438	0.1009	0.1245
610	0	0.0016	0.0364	0.0509
762	0	-0.0120	0.0283	0.0314
914	0	0.0000	0.0034	0.0037

APPENDIX C

DYNAMIC DISPLACEMENT AND STRAIN TEST RESULTS

Table C 1. Maximum peak vertical strains in base & subgrade (TS710C1)

710C1 Load = 27 kN

	VERTICAL STRAIN (μstrain)							
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
135	-2796	-2826	-2736	-2647	-2680	-2610	-2043	-2900
250	-3557	-3313	-3377	-3406	-3546	-3493	-3606	-4359
380	-8129	-6499	-7270	-7298	-7962	-7801	-7773	-9639
535	-2701	-2720	-2874	-2912	-3292	-3027	-2993	-3703
685	-1853	-1623	-1895	-1703	-1804	-1602	-1675	-8636
840	-751	-764	-840	-757	-755	-732	-783	-890
990	-506	-431	-421	-389	-339	-396	-444	-357
1145	-287	-186	-235	-228	-319	-247	-155	-279
1295	-208	-276	-285	-258	-267	-249	-220	-283
1450	-322	-297	-421	-318	-225	-293	-308	-327

Table C 2. Maximum peak transverse strains in base & subgrade (TS710C1)

710C1 Load = 27 kN

	TRANSVERSE STRAIN (μstrain)							
Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	2356	2450	2604	2557	2668	2742	1711	2713
191	951	843	1061	1069	1233	1304	1277	1479
305	1514	1256	1420	1543	1427	1523	1550	1925
457	615	641	668	743	686	833	766	895
610	236	378	296	402	385	481	338	2394
762	372	373	359	418	439	437	332	371
914	133	130	133	125	109	123	109	123

Table C 3. Maximum peak longitudinal strains in base & subgrade (TS710C1)

710C1 Load = 27 kN

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	-441	-747	-672	-759	-679	-713	-721	-831
191	-518	-589	-553	-621	-575	-624	-699	-1015
305	-831	-727	-826	-787	-978	-1014	-1043	-1456
457	-188	-166	-205	-160	-302	-149	-205	-348
610	-307	-149	-213	-143	-161	-111	-163	-4339
762	-64	-49	-63	-47	-57	-51	-77	-57
914	-49	-52	-49	-55	-56	-53	-58	-58

(B)

Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	1631	1802	2089	2162	2475	2534	1914	3716
191	2214	2050	2531	2715	3169	3207	3358	4757
305	2904	2600	3036	3169	3251	3290	3369	4592
457	708	785	814	888	861	998	957	1200
610	350	541	472	576	585	682	522	2347
762	353	340	328	392	418	420	311	365
914	130	124	133	131	133	134	110	125

(C)

Depth (mm)	0	250	1000	2500	5000	10000	25000	50000
76	-350	-286	-274	-228	-292	-199	-341	-312
191	-307	-428	-412	-477	-451	-421	-479	-705
305	-289	-545	-568	-551	-804	-677	-748	-846
457	-195	-219	-225	-218	-333	-163	-221	-299
610	-316	-173	-261	-156	-225	-169	-244	-4540
762	-44	-61	-63	-60	-61	-82	-76	-72
914	-55	-71	-68	-71	-71	-73	-77	-79

Table C 4. Maximum peak vertical strains in base & subgrade (TS710C2)

710C2 Load = 40 kN

STACK A

VERTICAL STRAIN (μstrain)

Depth (mm)	0	100	500	1000	1700	3000
135	-3016.6	-3241.3	-3528.2	-3399.5	-3108	-4114.5
250	-4135.8	-4469.9	-5042.3	-5425.8	-5138.3	-5403.9
380	-8289.7	-9097.3	-11306	-12605	-12923	-13727
535	-4076.5	-4573.4	-5659.3	-6081.8	-6018	-6497.4
685	-2331.5	-2504.8	-3122.5	-3594.2	-3625.4	-3866.4
840	-1596.8	-1774	-1874.3	-2185.1	-2197.3	-2372.6
990	-580.36	-627.28	-778.74	-885.03	-763.11	-880.46
1145	-488.08	-530.89	-598.91	-619.25	-627.49	-649.76
1295	-362.22	-356.6	-411.96	-427.05	-422.99	-444.92
1450	-399.68	-378.86	-473.43	-617.69	-470.07	-501.97

STACK B

Depth (mm)	0	100	500	1000	1700	3000
135	-46921	-30168	-28578	-19170	-37478	-25621
250	-2680	-2879	-2809	-2936	-2945	-2846
380	-3649	-4069	-4767	-5471	-5332	-5467
535	-5426	-5795	-6552	-7088	-7222	-7394

Table C 5. Maximum peak transverse strains in base & subgrade (TS710C2)

710C2 Load = 40 kN

STACK A

TRANSVERSE STRAIN (μstrain)

Depth (mm)	0	100	500	1000	1700	3000
76	2049	2218	1784	2222	1654	2357
191	1243	1233	1403	1241	1278	1664
305	1659	1731	2100	2091	2079	2301
457	775	860	1003	1074	1120	1067
610	463	580	745	753	779	838
762	233	224	378	362	361	393
914	154	150	172	169	198	201

STACK B

Depth (mm)	0	100	500	1000	1700	3000
76	5269	4380	3362	3514	6601	6020
191	1038	972	1143	1076	1112	976
305	504	735	875	1293	906	909
457	342	273	338	273	430	335
610	404	416	335	483	344	584

Table C 6. Maximum peak longitudinal strains in base & subgrade (TS710C2)

710C2 Load = 40 kN
STACK A

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	100	500	1000	1700	3000
76	-246	-286	-370	-413	-283	-429
191	-566	-622	-746	-978	-822	-993
305	-656	-789	-1247	-1517	-1632	-1986
457	-189	-236	-450	-444	-524	-623
610	-145	-154	-159	-257	-357	-338
762	-76	-80	-98	-106	-106	-119
914	-49	-91	-116	-89	-64	-65

(B)

Depth (mm)	0	100	500	1000	1700	3000
76	1544	1889	1906	2313	2419	2963
191	2094	2337	3390	3841	4070	4983
305	3169	3651	4812	5441	5546	6281
457	1196	1313	1589	1833	1906	2015
610	667	816	1050	1154	1200	1406
762	233	258	324	356	369	405
914	142	170	182	141	217	201

(C)

Depth (mm)	0	100	500	1000	1700	3000
76	-519	-625	-315	-216	-213	-451
191	-344	-410	-483	-664	-493	-633
305	-534	-658	-884	-1008	-1035	-1132
457	-167	-328	-414	-428	-417	-491
610	-207	-264	-305	-383	-409	-376
762	-69	-84	-91	-103	-109	-117
914	-71	-178	-145	-142	-128	-174

Table C6. Maximum peak longitudinal strains in base & subgrade (TS710C2) – cont.

STACK B

(A)

Depth (mm)	0	100	500	1000	1700	3000
76	-984	-614	-832	-738	-1275	-1006
191	-242	-347	-386	-411	-592	-573
305	-523	-670	-696	-547	-946	-907
457	-146	-189	-268	-313	-271	-205
610	-223	-227	-457	-282	-245	-151

(B)

Depth (mm)	0	100	500	1000	1700	3000
76	2005	1929	2587	2512	1966	2045
191	6862	7962	10539	12436	12008	13205
305	10081	11825	15380	19237	19217	20295
457	3446	3771	4483	5041	5226	5403
610	2144	2409	2448	3048	2748	2997

(C)

Depth (mm)	0	100	500	1000	1700	3000
76	-2254	-1830	-2286	-1686	-2275	-2020
191	-684	-734	-1096	-1186	-1297	-1340
305	-2081	-1882	-2630	-2083	-3144	-3232
457	-1543	-1738	-2073	-2323	-2284	-2412
610	-741	-847	-1294	-1123	-1401	-1264

Table C7. Maximum peak vertical strains in base & subgrade (TS710C3)

710C3 Load = 20 kN

	VERTICAL STRAIN (μstrain)					
Depth (mm)	0	250	500	1000	5000	10000
135	-2690	-2559	-2478	-2660	-2583	-80
250	-1867	-1994	-2063	-2084	-2068	-2009
380	-5043	-5651	-5403	-2718	-5238	-5003
535	-1624	-1930	-2169	-1740	-1341	-168
685	-1278	-1600	-1666	-1586	-1481	-1429
840	-469	-721	-749	-706	-542	-605
990	-294	-326	-313	-333	-306	-304
1145	-204	-258	-238	-228	-249	-235
1295	-165	-193	-187	-185	-151	-167
1450	-221	-389	-392	-341	-214	-245

Table C8. Maximum peak transverse strains in base & subgrade (TS710C3)

710C3 Load = 20 kN

	TRANSVERSE STRAIN (μstrain)					
Depth (mm)	0	250	500	1000	5000	10000
76	1881	1596	1310	1834	1932	1982
191	495	636	572	702	692	773
305	515	918	948	856	852	940
457	182	335	261	77	119	123
610	163	215	256	236	193	180
762	162	106	142	109	170	133
914	7	8	16	9	7	10

Table C9. Maximum peak longitudinal strains in base & subgrade (TS710C3)

710C3 Load = 20 kN

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	500	1000	5000	10000
76	-197	-128	-144	-142	-139	-118
191	-303	-229	-268	-243	-319	-311
305	-466	-445	-481	-513	-485	-490
457	-93	-114	-136	-381	-518	-1189
610	-128	-136	-135	-137	-149	-186
762	-27	-99	-156	-73	-31	-63
914	-42	-154	-81	-86	-29	-29

(B)

Depth (mm)	0	250	500	1000	5000	10000
76	1583	1273	1179	1524	1781	1900
191	916	1172	1247	1383	1358	1545
305	1010	1650	1816	1837	1881	1935
457	230	525	473	50	124	101
610	275	370	441	418	389	400
762	148	107	154	91	157	112
914	77	105	184	108	74	117

(C)

Depth (mm)	0	250	500	1000	5000	10000
76	-721	-426	-261	-543	-745	-778
191	-173	-201	-232	-275	-330	-294
305	-482	-506	-522	-595	-573	-533
457	-236	-139	-257	-841	-798	-1118
610	-127	-202	-187	-151	-155	-220
762	-45	-181	-179	-197	-92	-151
914	-72	-173	-101	-146	-59	-40

Table C2. Maximum peak vertical strains in base & subgrade (TS710C4)

710C4 Load = 40 kN

VERTICAL STRAIN (μstrain)

Depth (mm)	0	250	1000
135	-4590	GF	GF
250	-7982	-9073	-10401
380	-8328	-10068	-9966
535	-5194	-5602	-5909
685	-2544	-3076	-3227
840	-1147	-1296	-1348
990	-763	-887	-1030
1145	-760	-878	-890
1295	-432	-496	-502
1450	-293	-466	-391

Table C3. Maximum peak transverse strains in base & subgrade (TS710C4)

710C4 Load = 40 kN

TRANSVERSE STRAIN (μstrain)

Depth (mm)	0	250	1000
76	3038	2956	GF
191	4046	1622	1761
305	5301	2494	2402
457	1606	970	942
610	672	709	858
762	199	369	397
914	214	197	194

Table C4. Maximum peak longitudinal strains in base & subgrade (TS710C4)

710C4 Load = 40 kN

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	1000
76	-131	-641	GF
191	-34	-919	-1184
305	-42	-1228	-1349
457	-71	-490	-646
610	-78	-338	-323
762	-94	-124	-165
914	-57	-127	-132

(B)

Depth (mm)	0	250	500
76	2386	3021	GF
191	1223	5573	6695
305	1812	5984	6910
457	796	1638	1861
610	498	779	940
762	187	300	329
914	121	283	228

(C)

Depth (mm)	0	250	500
76	-152	-47	GF
191	-42	-389	-564
305	-115	-640	-791
457	-57	-265	-360
610	-71	-218	-286
762	-95	-119	-174
914	-68	-122	-146

Table C13. Maximum peak vertical strains in base & subgrade (TS710C5)

710C5 Load = 20 kN

STACK A

VERTICAL STRAIN (μstrain)

Depth (mm)	0	250	500	1000	5000
135	-1835	-1836	-1766	-1583	-1856
250	-2363	-2293	-2325	-2380	-2448
380	-5305	-5270	-5521	-5918	-5947
535	-1518	-1368	-1488	-1717	-1673
685	-915	-890	-959	-996	-980
840	-536	-495	-541	-548	-555
990	-306	-357	-360	-342	-396
1145	-267	-276	-226	-276	-304
1295	-256	-319	-244	-299	-266
1450	-196	-249	-238	-248	-240

STACK B

Depth (mm)	0	250	500	1000	5000
135	-12328	-12895	-10358	-11078	-10945
250	-1755	-1759	-1816	-1811	-1898
380	-2073	-1964	-2049	-2133	-2250
535	-3237	-3308	-3503	-3791	-4016

Table C14. Maximum peak transverse strains in base & subgrade (TS710C5)

710C5 Load = 20 kN

STACK A

TRANSVERSE STRAIN (μstrain)

Depth (mm)	0	250	500	1000	5000
76	1543	1667	1600	1590	1787
191	509	573	633	681	770
305	759	785	917	1019	1086
457	224	330	326	283	345
610	179	179	193	229	255
762	56	173	121	135	125
914	86	80	90	90	80

STACK B

Depth (mm)	0	250	500	1000	5000
76	3277	2792	2767	2472	3273
191	2890	2717	2930	2629	3336
305	1124	1094	935	1069	1311
457	393	203	366	369	538
610	515	619	558	470	603

Table C15. Maximum peak longitudinal strains in base & subgrade (TS710C5)

710C5 Load = 20 kN

STACK A

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	500	1000	5000
76	-108	-126	-123	-122	-268
191	-196	-252	-246	-220	-292
305	-518	-554	-531	-640	-654
457	-153	-56	-108	-163	-108
610	-93	-112	-140	-115	-58
762	-53	-48	-59	-60	-54
914	-61	-68	-75	-71	-82

(B)

Depth (mm)	0	250	500	1000	5000
76	990	1079	1125	1153	1435
191	1016	1111	1244	1381	1554
305	1544	1573	1729	1870	1964
457	355	489	487	459	589
610	194	231	217	246	318
762	96	102	111	102	114
914	100	82	85	92	66

(C)

Depth (mm)	0	250	500	1000	5000
76	-140	-243	-212	-179	-399
191	-147	-128	-129	-118	-161
305	-378	-366	-370	-412	-411
457	-191	-66	-122	-175	-132
610	-111	-137	-139	-131	-114
762	-54	-55	-56	-54	-59
914	-92	-123	-75	-78	-69

Table C15. Maximum peak longitudinal strains in base & subgrade (TS710C5) – cont.

710C5 Load = 20 kN
STACK B

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	500	1000	5000
76	-1436	-933	-878	-831	-1114
191	-849	-1416	-844	-1169	-980
305	-784	-1017	-913	-1274	-501
457	-527	-528	-404	-478	-253
610	-195	-141	-191	-163	-215

(B)

Depth (mm)	0	250	500	1000	5000
76	2424	2360	2703	2797	2955
191	4096	4494	4790	4384	5149
305	7937	7707	8322	9009	10258
457	3996	3851	4212	4288	4142
610	1241	1337	1309	1297	1129

(C)

Depth (mm)	0	250	500	1000	5000
76	-897	-1646	-571	-1110	-1531
191	-4520	-5270	-5548	-4317	-6079
305	-2071	-2246	-2196	-2385	-2339
457	-1673	-2002	-1979	-2123	-1976
610	-590	-491	-666	-684	-829

Table C16. Maximum peak vertical strains in base & subgrade (TS710C6)

710C6 Load = 33 kN

VERTICAL STRAIN (μstrain)

Depth (mm)	0	250	1000	4240
135	-3780	-3705	-3259	-3401
250	-4157	-3576	-3015	-2943
380	-11988	-12085	-10023	-10120
535	-4018	-3948	-3086	-3247
685	-2448	-2382	-1841	-2024
840	-1581	-1660	-1324	-1272
990	-766	-727	-547	-702
1145	-568	-526	-415	-493
1295	-425	-363	-370	-404
1450	-539	-534	-409	-388

Table C17. Maximum peak transverse strains in base & subgrade (TS710C6)

710C6 Load = 33 kN

TRANSVERSE STRAIN (μstrain)

Depth (mm)	0	250	1000	4240
76	2117	2142	2198	2130
191	1353	1366	1175	1285
305	2158	2111	1673	1845
457	978	1064	822	830
610	547	557	453	390
762	366	318	259	281
914	16	14	10	10

Table C18. Maximum peak longitudinal strains in base & subgrade (TS710C6)

710C6 Load = 33 kN

LONGITUDINAL STRAIN (μstrain)

(A)

Depth (mm)	0	250	1000	4240
76	-123	-126	-136	-166
191	-638	-742	-600	-608
305	-1740	-1723	-1360	-1396
457	-355	-286	-220	-310
610	-174	-186	-134	-164
762	-97	-111	-105	-86
914	-36	-34	-36	-45

(B)

Depth (mm)	0	250	1000	4240
76	1918	2416	2342	2450
191	2748	3316	2833	2834
305	4805	4988	4059	4130
457	1167	1307	981	1114
610	586	591	434	466
762	326	282	246	271
914	127	124	96	90

(C)

Depth (mm)	0	250	1000	4240
76	-178	-192	-475	-540
191	-282	-390	-376	-381
305	-787	-914	-785	-910
457	-258	-188	-217	-261
610	-208	-237	-195	-225
762	-162	-204	-178	-116
914	-64	-61	-51	-69