SEASONAL AND LOAD RESPONSE INSTRUMENTATION OF THE WAY-30 PERPETUAL PAVEMENTS

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ABSTRACT

A perpetual asphalt concrete pavement test section was completed along US-30 in Wayne County, OH, as part of the Wooster by-pass, in the fall of 2005. This project represents a collaborative effort between the Ohio Department of Transportation (ODOT) and the asphalt concrete paving industry with the purpose of evaluating the performance of these novel pavements. Perpetual asphalt concrete pavements are designed to last more than 50 years without major structural rehabilitation or reconstruction, and needing only periodic surface renewal to remediate distresses confined to the top pavement layer. Seasonal and load response data collection along the perpetual pavement will be useful in validating design assumptions used to determine the pavement buildups and in calibrating mechanistic/empirical analysis codes.

This paper describes the development and installation of a comprehensive instrumentation plan to monitor seasonal (environmental) parameters within the pavement structure, prevalent weather conditions and pavement response when subjected to dynamic loads applied by traffic or during Non-Destructive Testing. The seasonal instrumentation is intended to

monitor temperature, volumetric moisture content, frost penetration and ground water level, while the load response instrumentation is planned to gather data that include displacements, strains and pressures at critical locations within the pavement profile during dynamic load application. An automated weather station is designed to monitor air temperature, precipitation (rain and snow), wind speed and direction, relative humidity, and incoming solar radiation on an hourly basis.

Preliminary summaries of seasonal and load response data collected during the fall of 2005 are presented. A series Controlled Load Vehicle tests were conducted along the completed roadway, to obtain the mechanical response of the pavement under varying types of loads and speeds, to determine their influence on the measured parameters.

INTRODUCTION

A perpetual pavement was completed on US 30 in Ohio's Wayne County in the fall of 2005, as part of a demonstration project devised by the Ohio Department of Transportation (ODOT) to monitor the performance of a long life hot mix asphalt pavement. The pavement was built along the two westbound lanes of the 4-lane project. ODOT and Ohio University are working together to evaluate the pavement under three separate research projects aimed at determining the mechanical properties of materials, instrumenting the pavement sections and finally, validating current pavement design and analysis procedures to encourage continued use in the future.

The research described in this paper follows the successful collaboration between ODOT and Ohio University in the instrumentation of the Ohio SHRP Test Road on US-23 in Delaware County, Ohio and a small perpetual pavement test section on I-77 near Akron, Ohio.

The project bypasses a portion of Route 30 known as East Lincoln Way, relieving a congested two-lane arterial with a current ADT of 17720. The new four-lane divided highway section, classified as a rural freeway, begins on the East side of Wooster, at an interchange with State Route 83, and runs eastward for approximately 12.87 km (8 miles). Test sections were constructed in two locations along the project mainline. Two adjacent AC test sections were constructed at Station 876+60, and are designated as 876A and 876B (or AC1 - 390181). The remaining AC test site is located at Station 664+00 and is designated as 664 (or AC2 - 390182). Preliminary test results were obtained in December 2005, prior to opening the road to traffic. Results from the initial controlled load vehicle testing performed on the perpetual asphalt pavement test sections in the Fall of 2005, as well as seasonal data are presented.

PERPETUAL PAVEMENT DESIGN

A task force comprised of representatives from ODOT, the Federal Highway Administration, the asphalt industry and academia developed the specifications and design of the perpetual pavement. The task force used the legal load plus 20%, and determined that an overall thickness of 413 mm (16.25 inches) would limit the maximum tensile strain at the bottom of the AC layer to less than 70 microstrains. Researchers currently specify 70 microstrains as the endurance limit that will prevent bottom up fatigue cracking from developing. The dimensions and specifications for each layer (from bottom to top) are listed below, as presented by Ursich (2005), while the subgrade soil exhibited a CBR range of 4 to 6%. Following are specific layer configurations:

- A 152.4 mm (6 inch) building platform: ODOT Item 304, a highly crushed densely graded granular base, with under drains.
- A 101.6 mm (4 inch) bottom — fatigue resistant layer: ODOT's large stone base mix, Item 302, made binder rich by designing it for 3% air voids and 94 to 97% constructed density.
- A 228.6 mm (9 inch) middle — high modulus layer: ODOT's large stone mix, Item 302, using a PG 64-22 asphalt binder; with a target density of 93 to 96%.
- An 82.55 mm (3.25 inch) top — sacrificial layer composed of:
  - A 44.45 mm (1.75 inch) intermediate course: ODOT 19-mm Superpave, Type A, with PG 76-22M polymer modified binder; with a target density of 93 to 97%.
  - A 38.1 mm (1.5 inch) wearing course: ODOT 12.5-mm stone mastic asphalt with a PG 76-22M polymer modified binder; with a target density of 93 to 97%.

INSTRUMENTATION OVERVIEW

Comprehensive instrumentation plans were developed to monitor the effects of environmental conditions and the structural response of the pavement when subjected to dynamic loading. Seasonal (environmental) data collected included temperature, moisture content, frost depth, and ground water table levels. Pavement response data was collected by sensors recording deflections, pressure, and strain in varying pavement layers. An automated weather station also continuously monitors air temperature, precipitation (rain and snow), wind speed and direction, relative humidity, and incoming solar radiation. A summary of the instruments used to monitor the load response and environmental factors is shown in Tables 1 and 2.

TABLE 1 Load Response Instrumentation Detail

Measurement	Parameters	Manufacturer	Sensor
Displacement	Load & Seasonal Response	Macro Sensors	HSD 750-500
Strain	Load Response	Dynatest Consulting Inc.	Dynatest PAST II - AC SG
Pressure	Load Response	Geokon Inc.	Geokon 3500 PC

TABLE 2 Seasonal Instrumentation Detail

Measurement	Layers	Manufacturer	Sensor
Temperature	Pavement, Base, and Subgrade	Measurement Research Corporation	MRC Thermistor
Moisture	Base and Subgrade	Campbell Scientific, Inc.	CS - TDR Probe
Groundwater Table	Base and Subgrade	------	Open Wells

Structural Response Sensors

As shown in Table 1, asphalt concrete strains were measured with gages specifically manufactured to measure strains within hot-mix asphalt pavement layers. This gages have an 'H'-shape that provides versatility in measuring either longitudinal (tensile) or transverse strains, depending on the orientation of the gage. Only the longitudinal strain was measured at the bottom of the fatigue resistant layer (FRL) layer, while both longitudinal and transverse strains were measured in the intermediate and surface layers. Strain gages at the bottom FRL layer monitor fatigue resistance while gages in the intermediate layer check the potential for cracking resulting from the use of the flexible material in the bottom layer. Strain gages within the top layer complete the distribution of strain throughout the pavement layer. A minimum of four gages was used per test section in the FRL and intermediate layers.

Two earth pressure cells were placed on top of the subgrade to measure vertical pressure induced from dynamic loading, which will be indicative of the potential for rutting in the subgrade. The pressure cells were aligned under the wheel path and bedded on a thin layer of sand to insure a level and uniform surface.

Vertical pavement deflection was measured with Linear Variable Displacement Transducers (LVDTs). Shallow referenced LVDTs examine displacement above the subgrade, while deep referenced LVDTs monitor total displacement in the pavement system. The difference between the two measurements gives the displacement of the subgrade alone. This value is crucial when evaluating the potential for rutting in the subgrade. Custom housing units were fabricated for these LVDTs. Figures 1 and 2 show the structural response instrumentation plans for the perpetual pavement test sections.

Seasonal Parameter Sensors

Instrumentation to monitor seasonal parameters was identical at sections 876 (AC1 - 390181) and 664 (AC2 - 390182). Instrumentation details were implemented following guidelines previously developed in a similar instrumentation and monitoring project at the Ohio SHRP Test Road, along US23 in Delaware County, OH, as part of the Long Term Pavement Performance Seasonal Monitoring Program (LTPP-SMP). Seasonal monitoring will provide important inputs to an existing database that includes information from several other ODOT projects. Variations in pavement load response and material properties can result from changes in seasonal parameters.

Time-domain reflectometry (TDR) probes were installed to measure volumetric moisture content within the subgrade and the base. Ten TDR probes were spaced with depth at intervals of 152.4 mm (6 inches) near the surface to 304.8 mm (1 foot) for the deeper sensors. The first probe was installed at mid-depth of the aggregate base layer, with the remaining ones extending to 1.83 m (6 feet) below the top of the subgrade. MRC thermistor probes were used to measure temperature variation in each section. The probes, encased in a 1.83 m (6-foot) long acrylic rod are intended to measure temperature gradients throughout the subgrade, base, and pavement layers. PVC-encased and freely flowing wells were installed at both locations to measure water table variations.

CONTROLLED LOAD VEHICLE TESTING

Controlled load vehicle (CLV) testing was used to monitor the dynamic response to load of the pavement under traffic conditions, using conventional ODOT single axle and tandem axle trucks designated for snow/ice removal and salt and deicing agent spreading. Tests were performed at speeds of 8, 48, 72, and 96 km/h (5, 30, 45, and 60 mph) using 3 test runs per speed, per truck. Data was collected at a rate of 400 points per second per sensor. The data acquisition systems used included CR7 and CR10 systems manufactured by Campbell Scientific and MEGADAC 510AC systems manufactured by Optim Electronics.

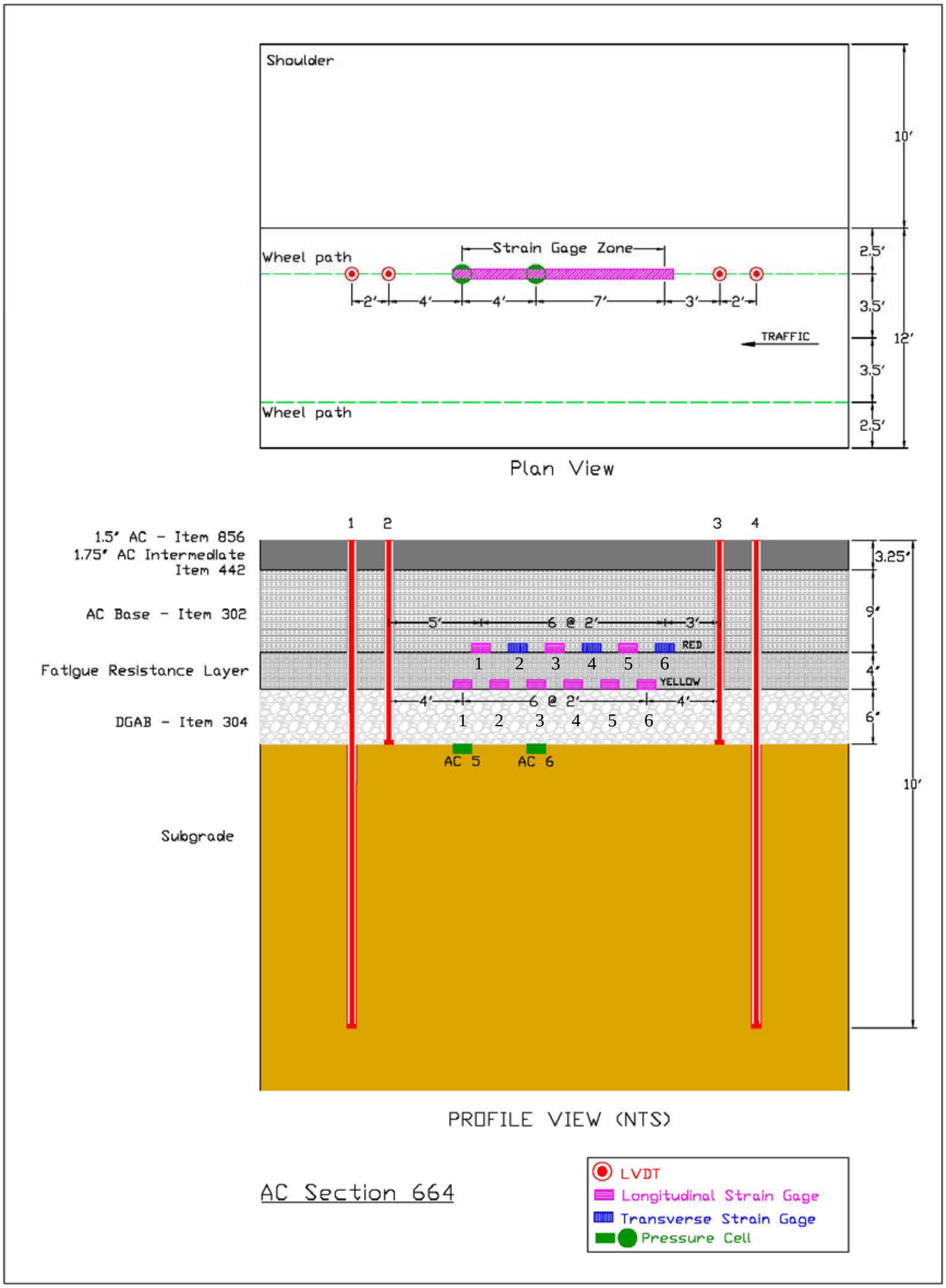

FIGURE 1 Structural Response Instrumentation: AC Section 664 (AC2 - 390182)

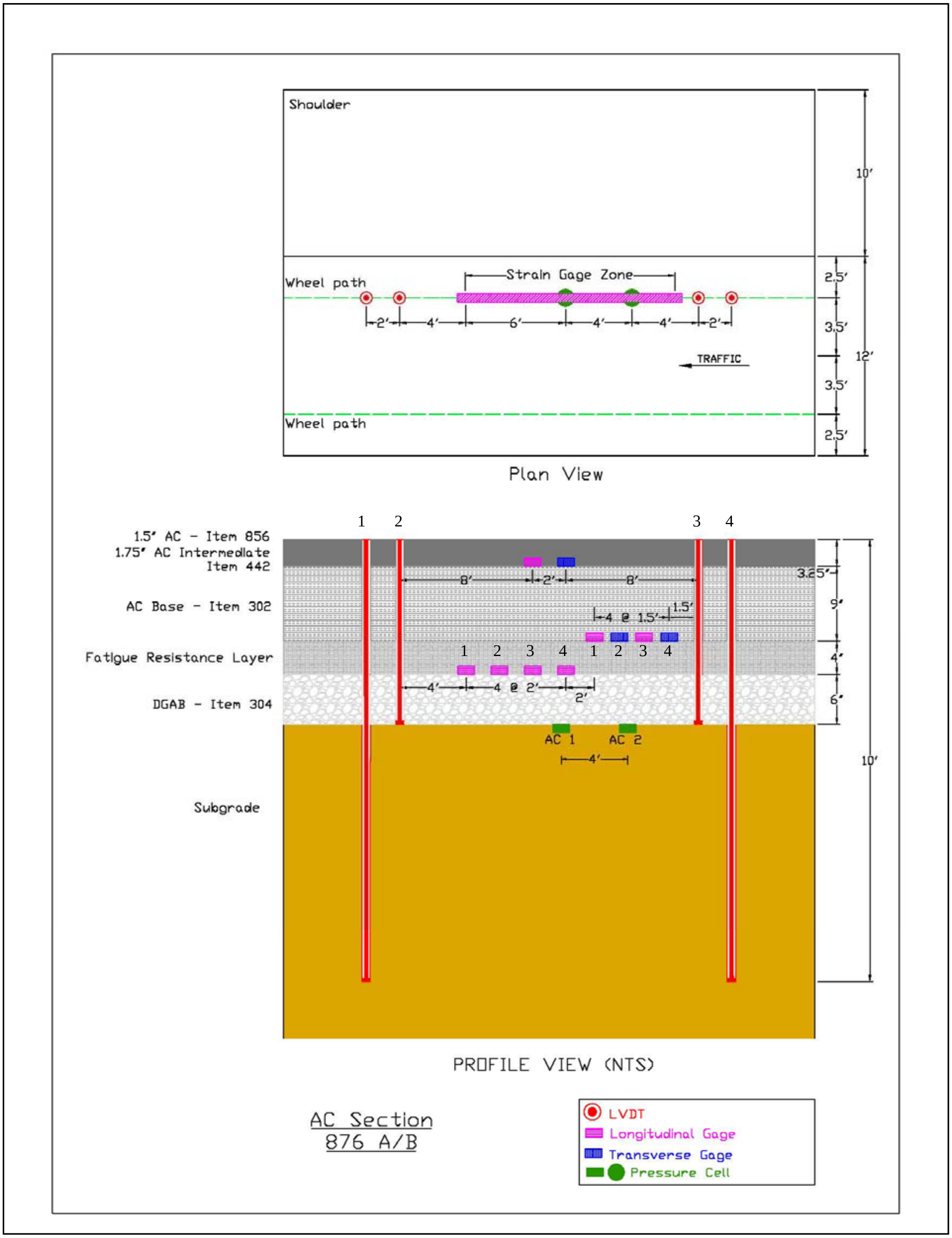

FIGURE 2 Structural Response Instrumentation: AC Section 876 A/B (AC1 - 390181)

Load Response Results

The CLV testing was conducted in December of 2005 and test sections were subjected to single axle loads of 77.84 and 124.54 kN (17.5 and 28 kips), and tandem axle loads of 126.77 and 177.92 kN (28.5 and 40 kips). Test section 664 (AC2 - 390182) was subjected to the higher axle loads only, while test section 876 (AC1 - 390181) was subjected to both the high and low axle loads. Air temperatures during testing were below freezing, with pavement temperatures ranging from -1.11 to 1.67 ^{o}C (30-35^{o}F). The second round of CLV testing will be conducted during the summer of 2006, providing an excellent opportunity to compare results between contrasting weather conditions. A summary of the preliminary results obtained during the first controlled load vehicle testing is presented in the next few sections with a variety of figures showing typical results.

Limiting the maximum tensile strain to less than 70 microstrains (design limit of the perpetual pavement) in the fatigue resistant layer is the main focus when analyzing the test results. For each test run, the peak strain occurrence for each gage is taken from the results and placed into the numerical analysis. For each test run speed, the average peak tensile strain occurrence from the set of strain gages is reported as the average strain, while the highest tensile strain occurrence for the set of gages is reported as the maximum strain. This method is also used on peak strains in the intermediate layer and pressure in the subgrade. The highest tensile strain experienced during any one run was 32.6 microstrains, which occurred at test section 664 (AC2 - 390182) under the 126.77 kN (28.5kip) single axle truck traveling at 8 km/h (5mph). Tables 3 to 5 show the results of the maximum tensile strains recorded in the fatigue resistant layer for test sections 664 (AC2 - 390182) and 876A (AC1 - 390181). Figure 3 graphically shows the decrease in strain when axle loads were reduced for section 876A (AC1 - 390181).

The average maximum tensile strains recorded at the bottom of the intermediate layer in each test section showed a significant decrease from strains at the bottom of the fatigue resistant layer. For the test run speed of 8 km/h (5mph), the percent reduction ranged from 36% to 46% in all test sections. The maximum and average maximum tensile and transverse strains recorded for the 5mph test runs are shown in Tables 6 and 7.

TABLE 3: Maximum Tensile Strains in Fatigue Resistant Layer: Test Section 664 (AC2 - 390182)

	Maximum Tensile Strain, ue			
Speed (mph)	28.5k Single Axle		40k Tandem Axle	
	Maximum	Average	Maximum	Average
5	32.6	29.0	19.5	17.1
30	27.2	23.9	19.6	17.7
45	27.4	25.1	21.5	17.4
60	27.7	24.9	19.9	18.3

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

TABLE 4: Maximum Tensile Strains in Fatigue Resistant Layer: Test Section 876A (AC1 - 390181)

Speed (mph)	Maximum Tensile Strain, ue			
	28k Single Axle		40k Tandem Axle	
	Maximum	Average	Maximum	Average
5	23.1	20.5	15.3	13.9
30	18.8	16.8	14.9	13.0
45	18.6	15.5	15.4	14.3
60	18.5	16.8	15.0	12.0

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

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TABLE 5: Maximum Tensile Strains in Fatigue Resistant Layer: Test Section 876A (AC1 - 390181)

Speed (mph)	Maximum Tensile Strain, ue			
	17.5k Single Axle		28.5k Tandem Axle	
	Maximum	Average	Maximum	Average
5	14.9	12.8	12.7	11.4
30	12.9	11.4	11.1	10.2
45	11.5	10.8	10.2	9.0
60	11.8	10.2	10.3	9.7

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

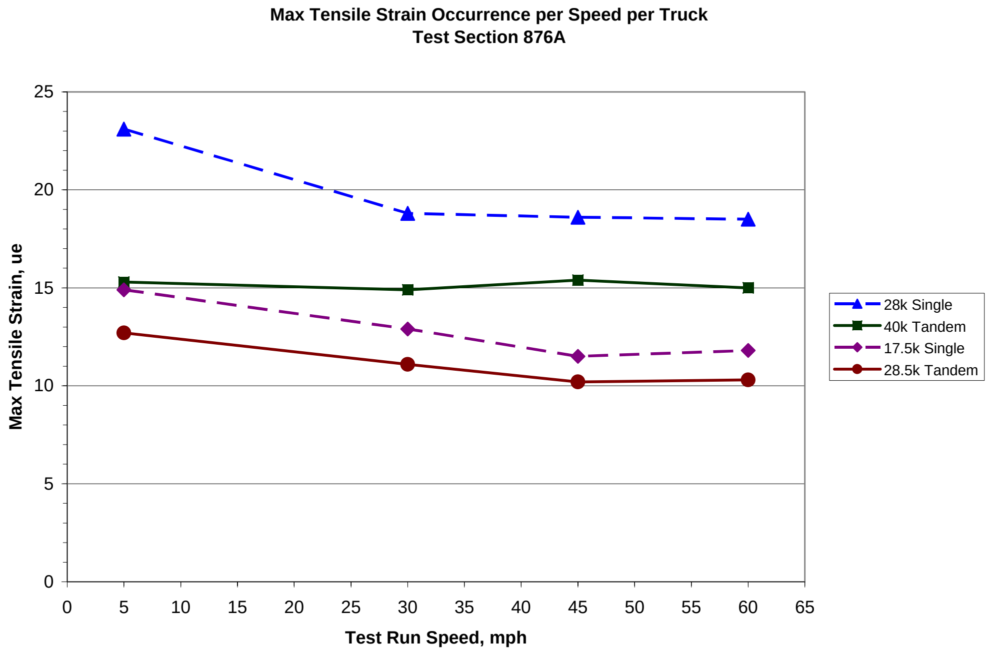

FIGURE 3: Maximum Tensile Strain Variation vs. Speed and Axle Type: Section 876A (AC1 - 390181)

Figures 4 and 5 are typical time series of strains measured by longitudinal strain sensors located at the bottom of the FRL layer under single and tandem axle loads respectively. Each of these graphs clearly shows the strain developed by the truck's front axle starting from an initial rest period to tension, followed by compression, until the influence of the heavier rear axle reverses the strain back to tension, followed by compression and the final rest period, as the truck moves away from the gage location. The curves are consecutive, as the sensors are located one after the other separated by a spacing of 0.605 m (2 feet), as shown in Figure 2. Pavement response due to tandem axle loads is clearly shown in Figure 5, where the double peak corresponding to this axle is evident. Compressive strain does not develop after the passage of the first tandem wheel, because of the close spacing of the two wheels.

TABLE 6: Maximum Tensile Strain in the Intermediate Layer – 8 km/h (5 mph)

	Maximum Tensile Strain, ue			
Test Section	28.5k Single Axle		40k Tandem Axle	
	Max	Average	Max	Average
664	19.9	17.8	12.1	10.9
876A	12.9	11.8	8.2	7.7

Note: 1 kip = 4.448 kN

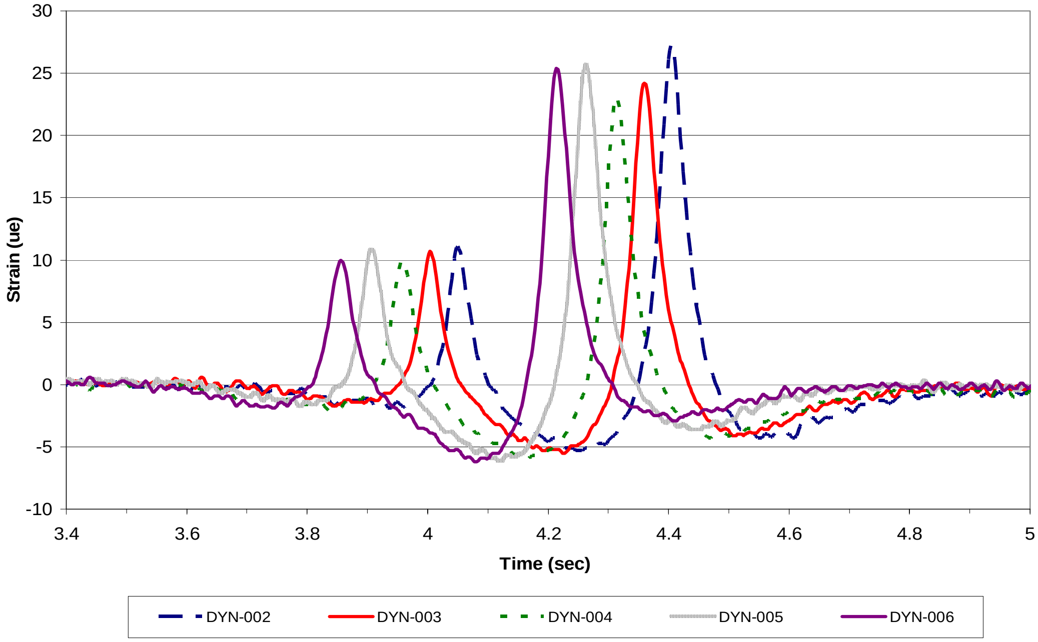

FIGURE 4. Longitudinal Strain: Section 664 (AC2 - 390182) – FRL Layer – 124.54 kN (28k) Single Axle, 48km/h (30 mph)

Two pressure cells were placed on top of the subgrade under the wheel path in each section. The highest pressure recorded was 44.81 kPa (6.5 psi) during the 72 km/h (45mph) under the 177.92 kN (40k) tandem axle on section 664 (AC2 - 390182). In Section 664 (AC2 -

390182), peak pressure readings for all test runs ranged from 32.4 to 37.92 kPa (4.7 to 5.5 psi) for the 126.77 kN (28.5k) SAL and 33.09 to 44.81 kPa (4.8 to 6.5 psi) for the 177.92 kN (40k) TAL. For Section 876 (AC1 - 390181), peak pressure readings ranged from 22.75 to 35.16 kPa (3.3 to 5.1 psi) for the SAL and 24.82 to 39.29 kPa (3.6 to 5.7 psi) for the 177.92 kN (40k) TAL. Figure 6 shows the time series for pressure readings taken during the 28k Single Axle CLV tests, conducted at 45 mph. The influence of the two axle loads on the recorded pressure is evident as in the strain gage plot shown in Figure 4.

TABLE 7: Maximum Transverse Strain in the Intermediate Layer – 8 km/h (5 mph)

	Maximum Transverse Strain, ue			
Test Section	28.5k Single Axle		40k Tandem Axle	
	Max	Average	Max	Average
664	14.2	12.4	11.4	10.9
876A	8.8	8.3	7.7	7.3

Note: 1 kip = 4.448 kN

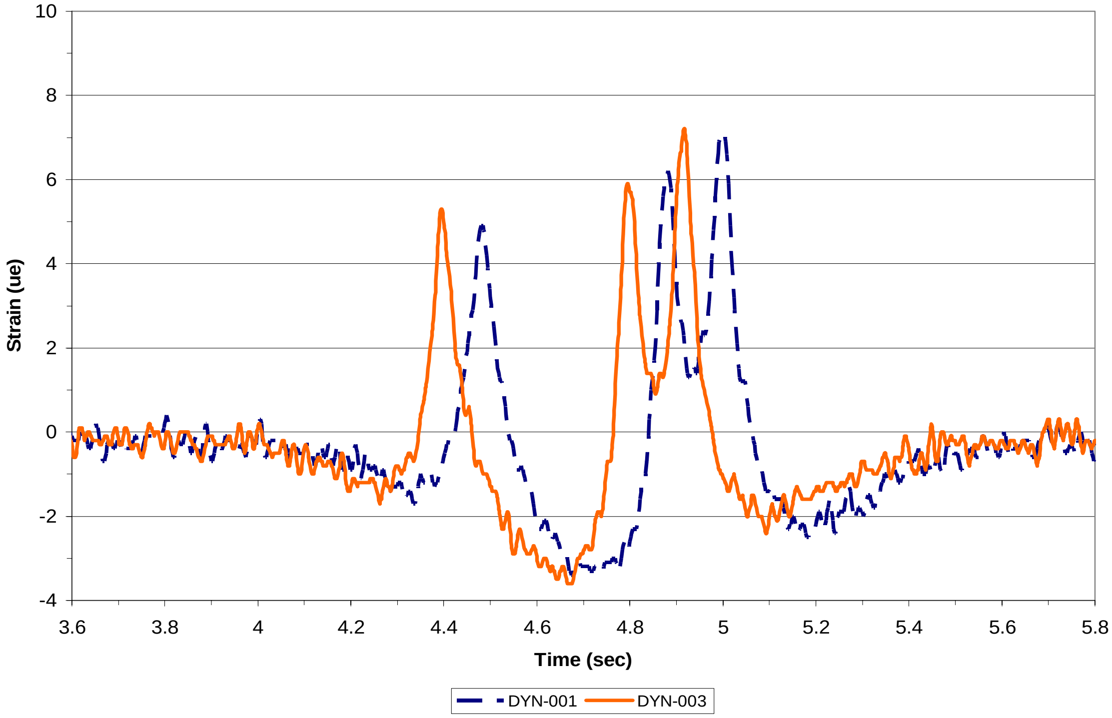

FIGURE 5. Longitudinal Strain: Section 876A (AC1 - 390181) – FRL Layer – 177.91 kN (40k) TAL, 48km/h (30 mph)

Pavement deflection was recorded during the same series of CLV tests for each test section. Total displacement in the pavement and displacement above the subgrade was distinguished by deep and shallow LVDT reference points. The maximum total displacement measured on any one test run occurred during the first 5mph single axle test run on section 664 (AC2 - 390182), yielding a value of 0.15mm (5.83 mils). This maximum deflection reading was measured during the same CLV test which yielded the maximum tensile strain. The maximum differential displacement (displacement of subgrade) was recorded on the same run with a magnitude of 0.116mm (4.58 mils). A typical time series of displacement is shown on Figure 7 for the 177.91 kN (40k) Tandem Axle CLV test at 48km/h (30 mph), conducted along Section 664 (AC2 - 390182). The signature of the tandem axle is not as evident as in the strain gage measurements, because of the slower LVDT reaction time.

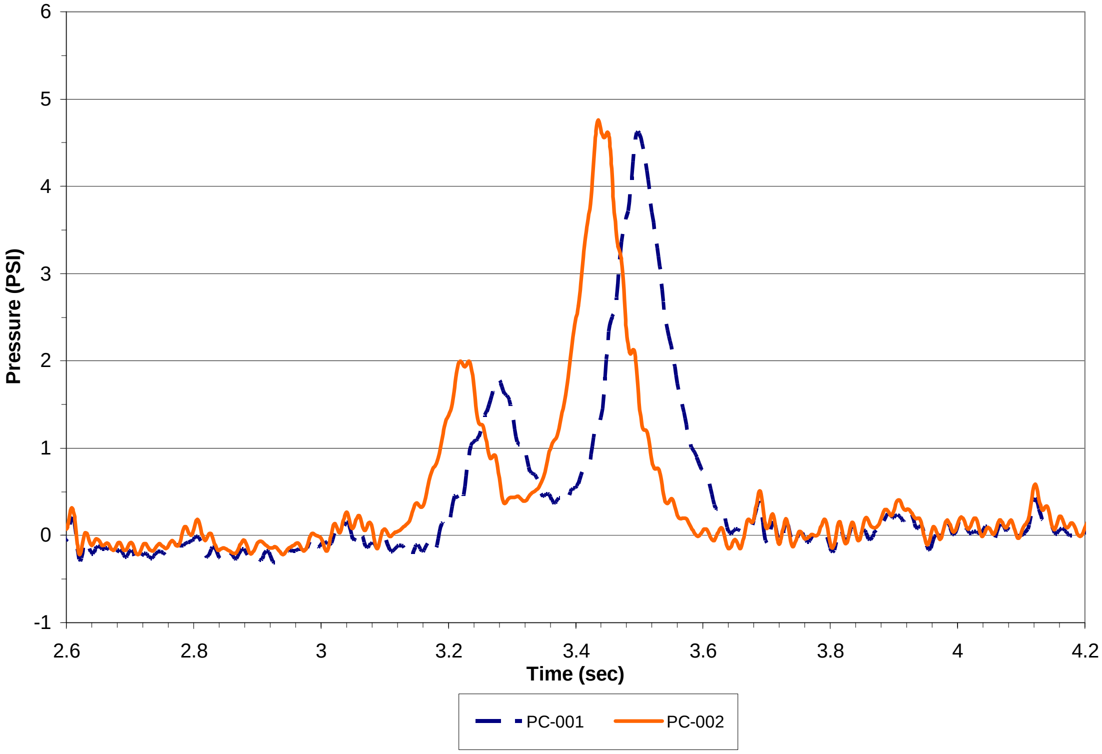

FIGURE 6. Pressure Readings: Section 664 (AC2 - 390182) – 124.54 kN (28k) SAL, 72km/h (45 mph)

SEASONAL INSTRUMENTATION RESULTS

The recent installation of seasonal instrumentation has not allowed the collection of sufficient data to identify any significant trends in the variation of the volumetric moisture content (VMC) within the subgrade soil. The perpetual pavement section has been instrumented at two locations with TDR sensors capable of recording the volumetric moisture content. These sensors were installed on June 6, 2005 in section 876 (AC1 - 390181) and on October 13, 2005 in section 664 (AC2 - 390182).

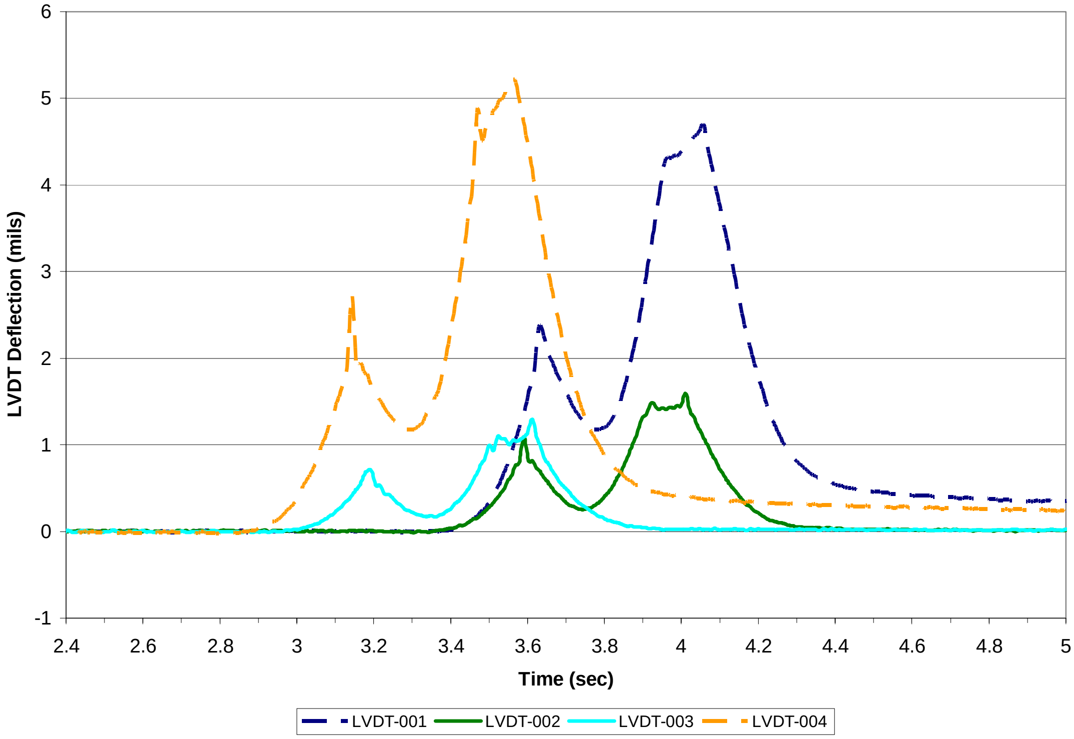

FIGURE 7. LVDT Deflections: Section 664 (AC2 - 390182) – 40k Tandem Axle, 30 mph

Figure 8 shows the variation of the volumetric moisture content measured by TDR sensors M1 (surface) to M10 (deepest) in section 876 (AC1 - 390181) since their installation.

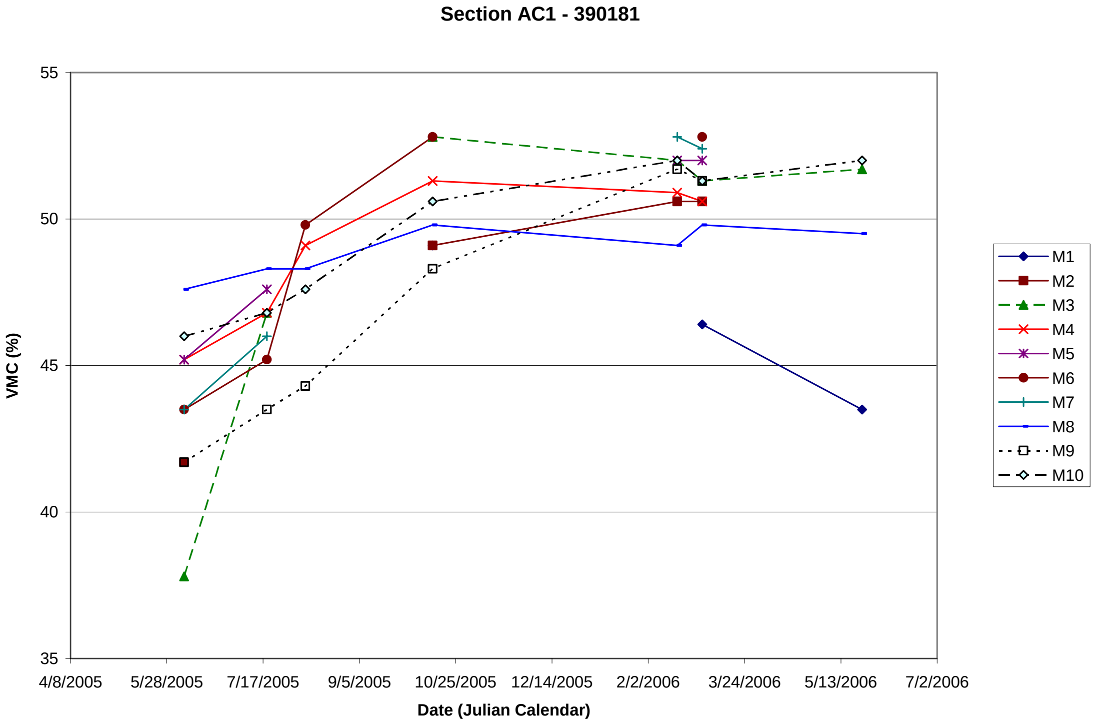

FIGURE 8. VMC Variation – Section 876 (AC1 – 390181) (10 TDR Sensors)

This plot indicates that the VMC beneath the pavement tends to increase and stabilize to values above the initial reading, (and in some instances nearing saturation) as measured by all sensors within the subgrade. A similar trend has been observed in other projects, including the majority of Hot Mix Asphalt (HMA) and Portland Cement Concrete (PCC) sections at the Ohio SHRP Test Road (Figueroa, et al. 2006). The implications of this recently observed fact are that, in most cases, the subgrade moisture content tends to stabilize at a value higher than that observed during the construction season. This behavior could be the result of site-specific conditions in combination with the presence of the pavement structure. If these findings are proven conclusive, pavement designers need to be aware of unfavorable support conditions expected during the projected life of the pavement. The VMC of section 664 (AC2 - 390182 has not been monitored for a sufficiently long period of time to draw any meaningful observations.

SUMMARY AND CONCLUSIONS

A perpetual asphalt concrete pavement test section was recently completed along US-30 in Wayne County, OH, as part of the Wooster by-pass, in the fall of 2005. Two perpetual asphalt concrete pavement sections: 876 (AC1 - 390181) and 664 (AC2 -390182) were instrumented with pressure, strain and deflection gages to measure pavement response to traffic loading. Time Domain Reflectometry (TDR) gages were also installed at each of these two locations to monitor the variation of the volumetric moisture content (VMC) and thereby the stiffness of the predominantly fine-grained subgrade soil. Each gage and the methodology used in the individual installation is described in detail, following pioneering techniques, previously developed during a similar instrumentation program at the Ohio SHRP Test Road (Sargand, 1994)

Preliminary results of load response data, collected during the fall of 2005, through series of Controlled Load Vehicle (CLV) tests on the two sections of the completed roadway, indicate that the design value of 70 microstrains at the bottom of the HMA layer was easily achieved even at the lowest testing speed of 8 km/h (5 mph). It is expected that a much closer value to the design tensile strain will be measured when the CLV tests are conducted in the summer of 2006, as the HMA will be substantially less stiff. The strain at the bottom of the HMA decreased as the vehicle speed increased from 8 to 96 km/h (5 to 60 mph). As expected the strain within the HMA layer decreased as the gage was position closer to the neutral axis of the layer. The strain developed under single axle loads was always higher than the strain under tandem axle loads: 126.77 kN SAL vs. 177.92 kN TAL (28.5 kip SAL vs. 40 kip TAL) and 77.84 kN SAL vs. 126.77 kN TAL (17.5 kip SAL vs. 28.5 kip TAL).

Peak pressure values measured by pressure cells located on top of the subgrade and beneath the pavement did not show a consistent trend, with a maximum value of 44.81 kPa (6.5 psi) measured during the 72 km/h (45mph) under the 177.92 kN (40k) tandem axle load on section 664 (AC2 - 390182). It is expected that more consistent and higher pressures may be obtained during the scheduled summer testing as the HMA will be softer.

Maximum pavement deflections were measured, as expected, during the same CLV test yielding the maximum tensile strain at the bottom of the HMA layer. Similarly pavement deflection also decreased as the vehicle speed increased. The time series of pressure and deflection clearly identify the influence of the front and rear axles on the pavement response. However, the influence of the individual tandem axle wheels is not as marked as in the measured strains, possible due to the slower reaction time of pressure cells and LVDTs, as compared to that of strain gages.

The load response data collected during the CLV tests were consistently and noticeably higher in Test Section 664 (AC2 - 390182) than in Test Section 876 (AC1 - 390181). This is attributed to the fact that core samples revealed a slightly thicker pavement in Section 876 (AC1 - 390181) than in Section 664 (AC2 - 390182), because of the need to adjust the grade to match the elevation of the Weight in Motion pad.

Measuring of pavement response parameters during carefully controlled CLV tests leads to the development of data that researchers can readily use in the validation of perpetual pavement analysis methods, with the eventual aim of developing mechanistic-based pavement design procedures

Initial observations of seasonal data, obtained by TDR probes indicate that the VMC beneath the pavement tends to increase and stabilize to values above the initial reading, (and in some instances nearing saturation) as measured by all sensors within the subgrade. This trend coincides with observations obtained in other projects, including the majority of Hot Mix Asphalt (HMA) and Portland Cement Concrete (PCC) sections at the Ohio SHRP Test Road.

Acknowledgments

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policies of the Federal Highway Administration, the Ohio Department of Transportation, nor do the contents constitute a standard, specification, or regulation. The authors are grateful to the Federal Highway Administration / Ohio Department of Transportation/Joint Transportation Research Program for supporting this research. They are especially indebted to Mr. Roger Green from the Pavement Research Division, Office of Pavement Engineering.

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