NCAT Report 04-03

DYNAMIC PAVEMENT RESPONSE DATA COLLECTION AND PROCESSING AT THE NCAT TEST TRACK

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June 2004

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DISCLAIMER

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INTRODUCTION

In the 2003 test cycle at the NCAT Test Track, a structural experiment was included to investigate dynamic pavement responses under live truck loading. Instrumentation was installed in different layers of the pavement structures in sections N1 through N8. Full details regarding the construction and instrumentation of these sections can be found in (Powell, 2004 and Timm et al., 2004). Data from the instruments are collected in two ways: a data logger records at a low sampling frequency (i.e., one reading per minute) and aggregates the data into an hourly basis, 24 hours a day, and a high frequency data acquisition system is used to collect dynamic data of specific truck passes. The objective of this report is to provide an explanation of the high frequency data collection and processing procedure currently used at the Test Track. Future reports will provide much deeper and comprehensive analyses of the relevant pavement response data. The figures included in this report are from data collected on November 7, 2003. Data were collected on a sunny morning, and pavement surface temperatures increased from 85 to 102°F during the testing period.

FIELD DATA COLLECTION

The high frequency data acquisition system used at the NCAT Test Track is a DATAQ portable system that is connected to the junction box of each section to record the dynamic pavement response resulting from a truck pass. It is the current practice to collect high frequency data at least once a month. As the pavement begins to show distress failure, data collection efforts will increase. At each test section, three passes of the truck are recorded at 2,000 samples per second per channel and inspected in the field to ensure that all three passes were successfully recorded in their entirety. Figure 1 shows the output of the DATAQ acquisition system that can be viewed in real time or reviewed after the data are recorded. The voltage outputs of the gauges are recorded in the field, and the conversions to psi and microstrain are later applied to the data. Each truck pass shown in Figure 1 indicates approximately 2 seconds of data collection. The surface temperature of the pavement is also recorded at each section just prior to testing using a handheld infrared temperature gun.

Recording three passes was an initial decision based upon a balance between having a representative distribution of pavement responses that included wheel wander and other random effects with the need to conduct testing in a relatively short amount of time. The time factor was important from a safety perspective (i.e., minimize the time spent on the track with live traffic) and a need to hold the environmental conditions relatively constant during testing between sections. Using three passes on each results in completing all eight sections in approximately 2 hours.

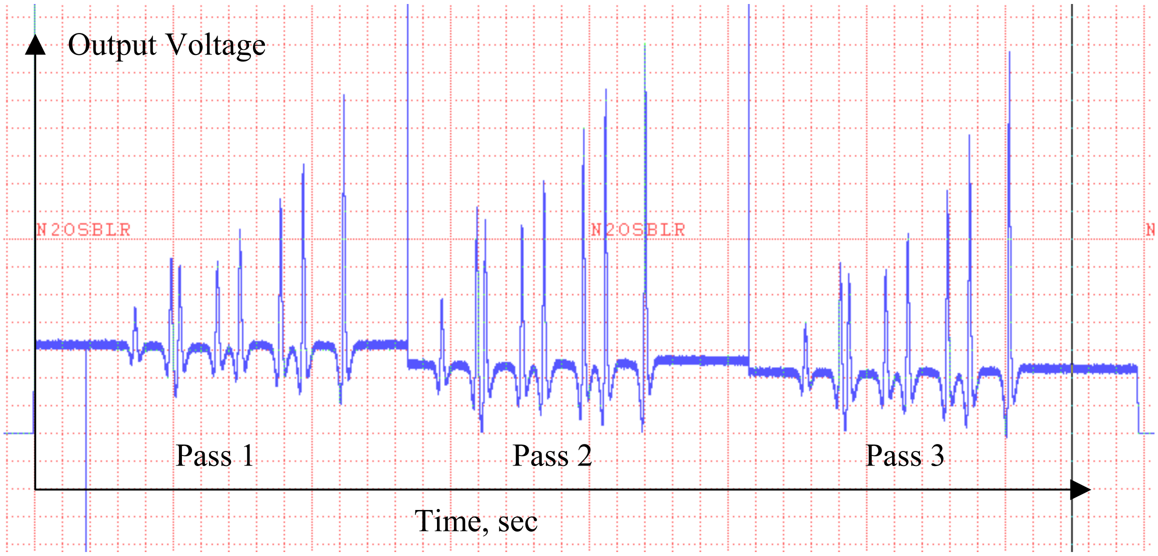


Figure 1. DATAQ Output for a Longitudinal Asphalt Strain Gauge.

The testing on November 7, 2004 began during the 10 am hour and concluded during the 12 pm hour. To evaluate the environmental effects of testing over this period, temperature increases at a depth of 2 in. for each test section are plotted in Figure 2. The data indicate that each section experienced approximately the same warming trend over the two-hour period, with a maximum increase of less than 10°F. While a change of 0°F would be ideal, the plot highlights the challenge of testing in a real-world setting where environmental conditions can not be controlled, only accounted for and minimized. Figure 2 also illustrates the average temperature over the testing period. The averages were remarkably consistent between sections, differing by a maximum of 1.5°F. From these data it was concluded that a testing duration of two hours, though not completely eliminating changes in the environment, does help in establishing a practical limit in temperature change of 10°F. A shorter testing period could be achieved, however it would sacrifice the ability to capture wheel wander, as will be discussed below, by collecting multiple passes on the same test section.

DATA PROCESSING

The data recorded by the DATAQ system for each truck pass at each sensor in all eight test sections are then processed to clean the signal and compute strain and pressure values. Cleaning is required because of residual noise that is inherent in making measurements with electrical signals. The noise is not caused by pavement deformation but is simply present within the electrical circuitry and must be accounted for during processing. DADiSP 2002 and Microsoft Excel software programs are used to process the data and display the results. Each are discussed below.

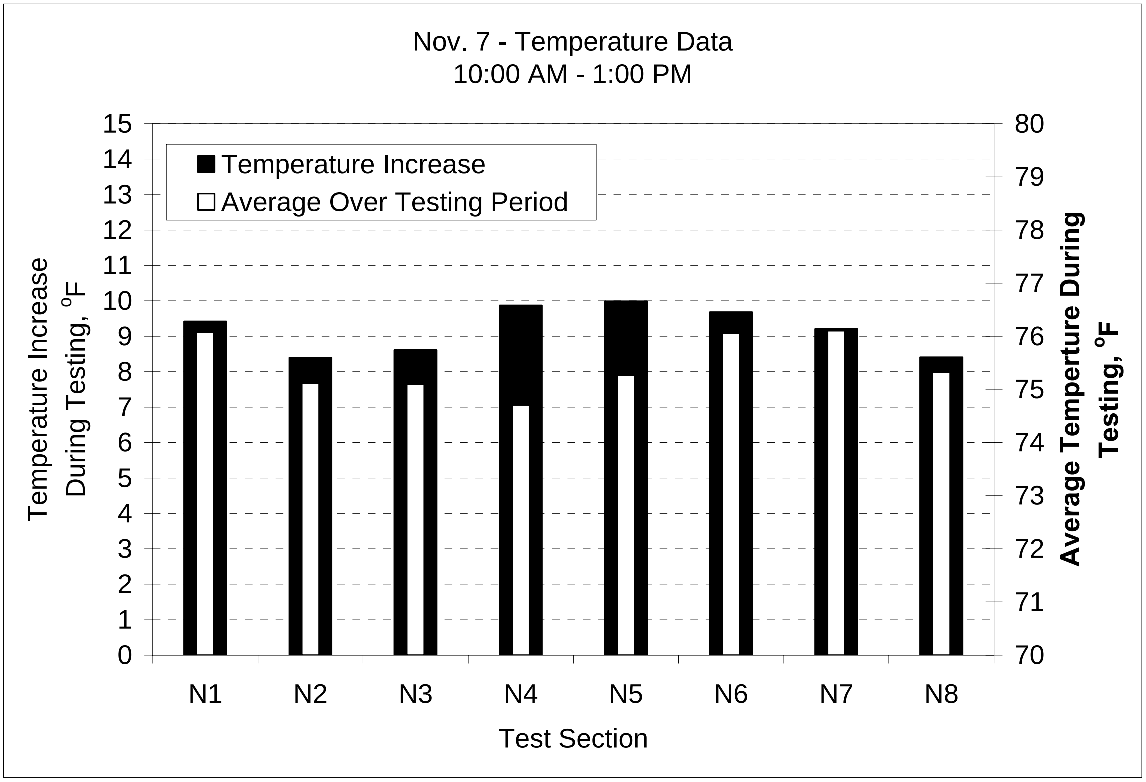
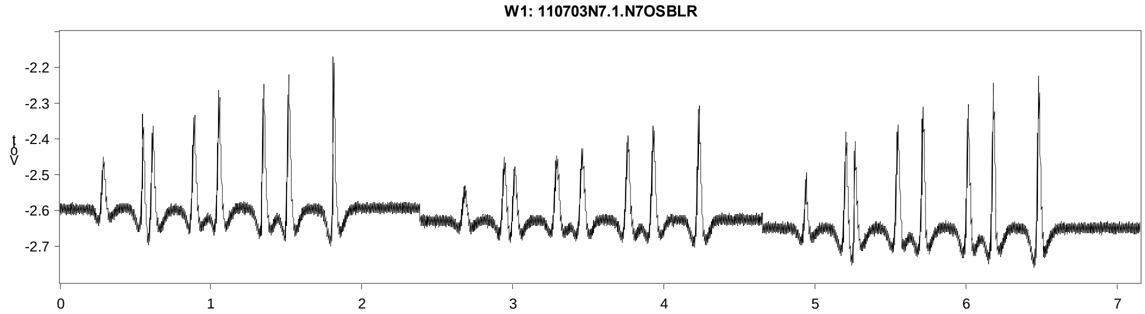


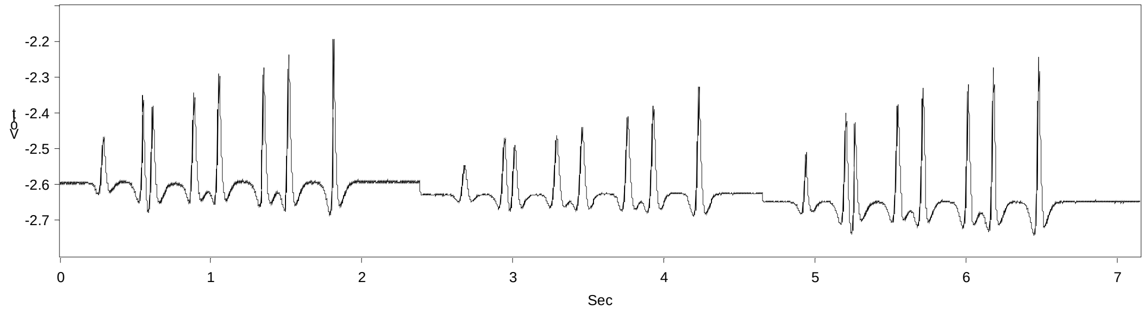
Figure 2. Temperature Increase During Testing.

DADiSP Signal Processing

DADiSP is a powerful software program that compliments the DATAQ data acquisition system. Data from an individual section can be read from the DATAQ file and displayed in DADiSP where different functions can then be applied to the signal (i.e., moving average, Fourier Transform, etc.). The first step in the procedure is to clean each signal to process it more efficiently. A moving average is taken of each signal using a DADiSP function that pads the end points of the data set and allows the user to specify the number of points to use in the moving average calculation. It was determined through inspection that ten data points was normally sufficient to clean the signal without compromising the data. Taking too large a moving average would result in eliminating actual strain measurements in addition to the electrical noise. Some signals were especially noisy, and the number of averaging points had to be increased to have a sufficiently clean signal. Figure 3 shows the contrast between a signal from a strain gauge a) directly from DATAQ and b) after the moving average was taken. Figure 4 is a closer view of same gauge with the signal before and after processing plotted together.



3a) Longitudinal Asphalt Strain Gauge Before Signal Processing.



3b) Longitudinal Asphalt Strain Gauge After Processing.

Figure 3. Strain Gauge Signal Processing.

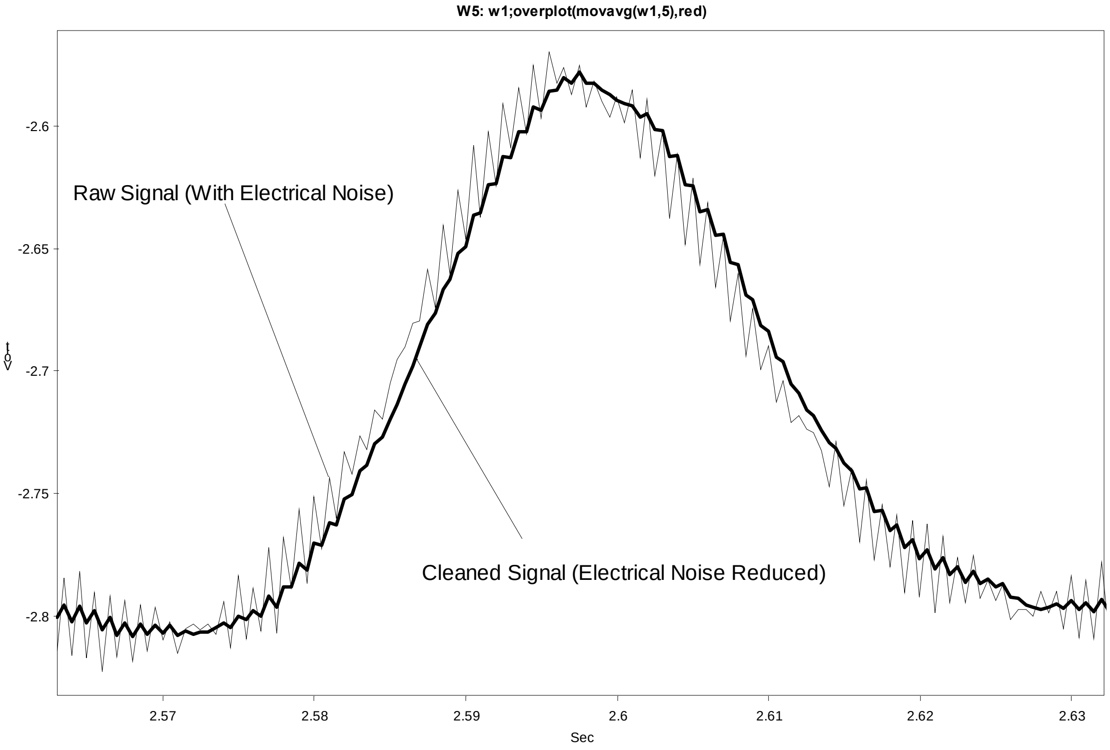


Figure 4. Expanded View of Strain Gauge Trace Before and After Moving Average.

The amount of data points that are recorded in one data collection day is massive, over 1.5 million, considering that there are eight test sections that include over 133 total gauges and three passes are recorded at 2,000 samples per second per channel. The large amount of data are necessary to get an accurate dynamic picture of the pavement response, but the next challenge is filtering and gathering the important points of the signal quantify the results. The current procedure involves visually selecting the baseline and local maximum and minimum points (inflection points) of the signal with the cursor in DADiSP and copying them into an Excel workbook. The voltage and time of the selected point are recorded and organized by date, section, gauge, truck pass, and axle. This process is lengthy and laborious, but a computer algorithm is being developed to record the needed points more efficiently. Future reports will detail the algorithm. Once the data are simplified into an Excel spreadsheet they can be analyzed with greater ease.

Excel Data Processing

Figure 5 shows the signal from a longitudinal strain gauge located in test section N7, and it will be used to illustrate the process used to quantify the measured strain. Also indicated in Figure 5 are the axles responsible for each of the pavement responses during the truck pass. The signal is still in the original output units of voltage and seconds, but the relative strain trace can be investigated. Notice that each axle is easy to identify: the steer, tandem, and four single axles. It is also important to notice that prior to the tensile spikes, there is a compression wave recorded from the initial approach of the tire.

It was decided that the measured voltage difference used to compute the strain would be between two successive inflection points, not the difference between the peak and the baseline. This is an important distinction that will yield unique results. For instance, the first recorded strain for the steer axle is the compressive strain taken from the baseline to the compressive valley (point 1 to point 2). Then, the first tensile strain of the steer axle was measured from that valley (prior inflection point) to the tensile peak (point 2 to point 3). It is important to include the response from the valley to the original baseline because it is caused by the load of the tire, and it is not simply an unloading of the initial compressive force. Then the compression caused by the tire leaving the gauge area was recorded (point 3 to point 4). The change from point 4 to point 5 was recorded as a tensile response as the load left the area.

It is also important to note that recording inflection points allows for maximum flexibility in future data analysis. For the purposes of examining repeatability of measurements, the differences between consecutive inflection points are calculated as described above. However, other analyses can also be performed with the same set of inflection points. For example, one could easily calculate the strain magnitude as referenced to the baseline value rather than the previous inflection point. In either case, the analysis would rely upon the same set of inflection points.

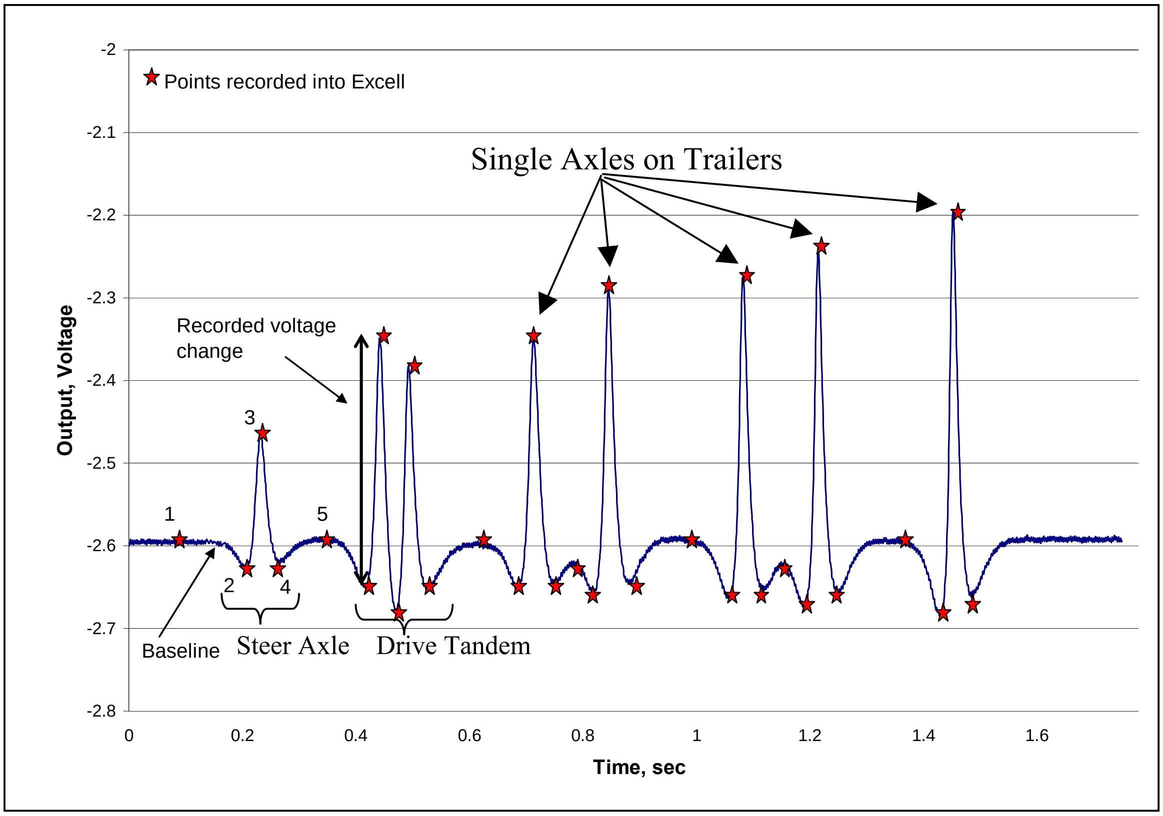


Figure 5. Selection of Inflection Points from Asphalt Strain Gauge Trace.

To process the data, the inflection points shown as stars in Figure 5 are first transferred from DADiSP into an Excel spreadsheet. Then, the change in voltage between the recorded points was calculated and converted to either units of microstrain or psi by:

$$output = \Delta V * multiplier \tag{1}$$

where:

output = either strain (με) or pressure (psi)

ΔV = change in output voltage = voltage difference between consecutive inflection points

multiplier = gauge factor

Each asphalt strain gauge has its own multiplier that was calculated from the calibration information supplied by the manufacturer. Equation (2) was used to calculate the conversion multiplier to get microstrain from output voltage:

$$multiplier = \frac{V_{EXcal}}{V_{EXdataq}} * CalibrationFactor * \frac{30mV}{5V} \tag{2}$$

where:
V_{EXcal} = Calibration excitation voltage used by manufacturer (approx. 5V)
$V_{EXdataq}$ = Excitation voltage of data acquisition system (10V)
$CalibrationFactor$ = factor supplied by manufacturer

The 30mV/5V term accounts for the signal output amplification that the DATAQ system performs on the signal. More specifically, the maximum output voltage of the asphalt strain gauge is ±30mV, but once it passes through the signal conditioning card in DATAQ, the maximum output voltage changes to ±5V in order to make it easier to read and more sensitive to change. The pressure cells do not have individual calibration factors nor do they undergo signal amplification. Therefore, the multiplier to calculate the pressure is:

$$multiplier = \frac{P_{fullscale}}{V_{fullscale}} \tag{3}$$

where:
$P_{fullscale}$ = full scale pressure of the gauge, psi
$V_{fullscale}$ = full scale output (5V)

The full scale voltage is 5 volts and the full scale pressure for the pressure cells installed in the subgrade is 14.5 psi and the cells installed in the granular base is 36.3 psi.

Once the strains and pressures were computed using the above procedure, an analysis procedure was developed to determine if the random effects of wheel wander were being captured with three passes of the test vehicle. The passes were compared first in order to determine if three passes per section per data collection day was sufficient. As stated previously, three passes were initially decided upon to balance having a representative distribution of pavement responses that included wheel wander and other random effects, with the need to conduct testing in a relatively short amount of time.

A percentile statistical analysis (i.e., cumulative distribution function) was performed on the calculated strains. Figure 6 is an example of this analysis from the longitudinal gauge in test section N1 while Figure 7 is an example of the corresponding transverse gauge. The figures depict the range and frequency of various strain readings for the three passes of the test vehicle. Each curve in Figures 6 and 7 represent an increased sample size. The “1 Pass” series corresponds to the first pass of the test vehicle. The “2 Passes” and “3 Passes” series were determined from the first two and all three passes, respectively. Theoretically, with a sufficiently large number of truck passes, the cumulative distribution curve would remain unchanged as more truck passes are included in the analysis. However, it appears that even with only three passes the cumulative distributions are relatively stable (i.e., the shape and magnitude of the strains are reasonably consistent) when considering one, two or all three passes together. Certainly, the most representative distribution comes from the “3 Passes” series since it includes strain measurements from all three passes of the test vehicle.

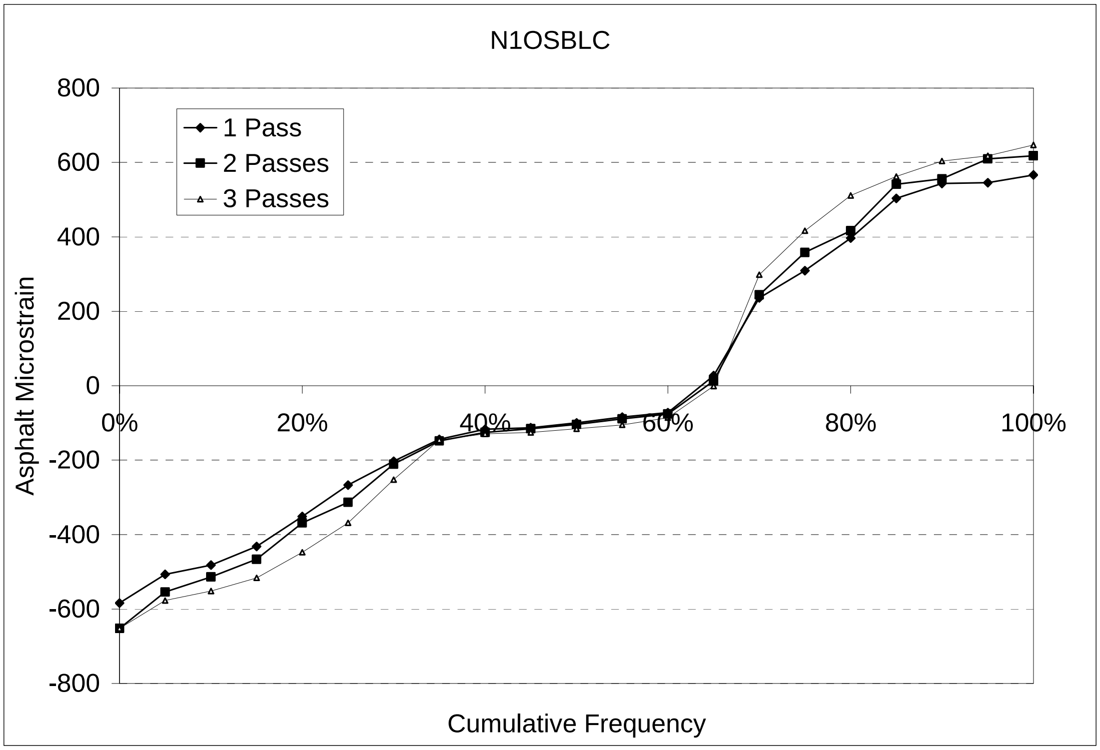


Figure 6. Distribution of Strain Measurements of a Longitudinal Asphalt Strain Gauge for Three Truck Passes in N1.

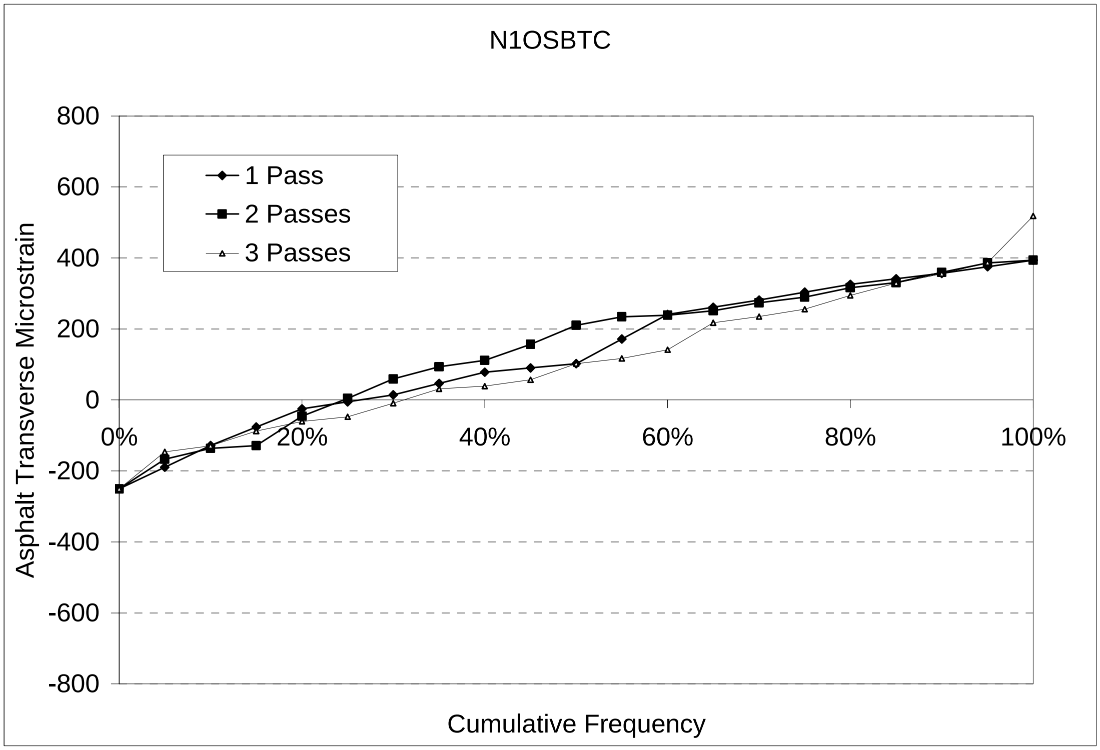


Figure 7. Distribution of Strain Measurements of a Transverse Asphalt Strain Gauge for Three Truck Passes in N7.

Figure 6 indicates the maximum tensile strain (+ = tension) increased from 566 με in Pass 1 to 618 με in Pass 2 and finally, a maximum strain between all three passes was recorded during the third pass and equaled 646 με. The various strain readings are indicative of the natural wheel wander (i.e., the truck passing nearer or further from the gauge), and indicate that three passes may be sufficient given the other constraints of testing.

Graphs such as those depicted in Figures 6 and 7 were created for each test section, and resulted in similar trends. To summarize the data, the maximum responses in compression and tension are tabulated for all eight sections in Appendix A.

The use of cumulative distribution functions is a powerful analysis tool when comparing between gauges and sections. Since only a limited amount of data are collected (i.e., 3 passes), it makes sense to use a probability function to characterize the response since the three passes represent only a statistical sample of the population of responses. In this way, the spectrum of pavement response can be characterized, not simply the minimum, maximum or average. Also, there are many statistical tests (e.g., Kolmogorov-Smirnov) that can be performed, and will be in the future, to detect differences between cumulative distribution functions like those depicted in Figures 6 and 7.

SUMMARY AND CONCLUSIONS

This report documented the data collection and processing procedures for the high frequency instrumentation at the NCAT test track. Based on the data collected on November 7, 2003, it appears that the sampling rate (2,000 samples/sec/sensor) and number of truck passes (3/test section) are sufficient to balance between collecting the data over a short time period and characterizing the natural wheel wander of the test vehicle. Therefore, the fundamentals of these procedures will remain in place for the duration of the 2003 Test Track research cycle.

It was found that selecting inflection points from the dynamic data, as was described in this report, was very time consuming and laborious. To address this difficulty, an automated algorithm to process the data much more quickly is under development and nearing completion. Future data processing and analyses will use the new algorithm.

This report was meant to only focus on the data collection and processing procedures and intentionally did not provide much analysis of the various gauges and test sections. Future studies and reports will be written to specifically address the objectives of the structural experiment.

REFERENCES

1. Powell, R. Buzz, "As-Built Properties of Experimental Sections on the 2003 NCAT Pavement Test Track," National Center for Asphalt Technology, 2004.

2. Timm, D.H., Priest, A.L. and McEwen, T.V., "Design and Instrumentation of the Structural Experiment at the NCAT Test Track," National Center for Asphalt Technology, 2004.

Appendix A:

Summary of Maximum Pavement Responses

Note: Refer to (Timm et al., 2004) for further gauge identification information.

Table A.1 Maximum Responses for Cell N1.

Cell:	N1
Date:	7-Nov-03
Pavement Temp:	101 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N1OSBLR	733.86	-692.94	
N1OSBTR	INACTIVE	INACTIVE	
N1OSBLC	646.99	-651.97	
N1OSBTC	518.33	-162.89	
N1OSBLL	INACTIVE	INACTIVE	
N1OSBTL	111.15	-123.00	
N1OSALR	617.23	-542.18	
N1OSATR	INACTIVE	INACTIVE	
N1OSALC	629.11	-636.12	
N1OSATC	498.63	-227.94	
N1OSALL	INACTIVE	INACTIVE	
N1OSATL	INACTIVE	INACTIVE	
N1OPASC			10.87
N1OPBBC			20.04

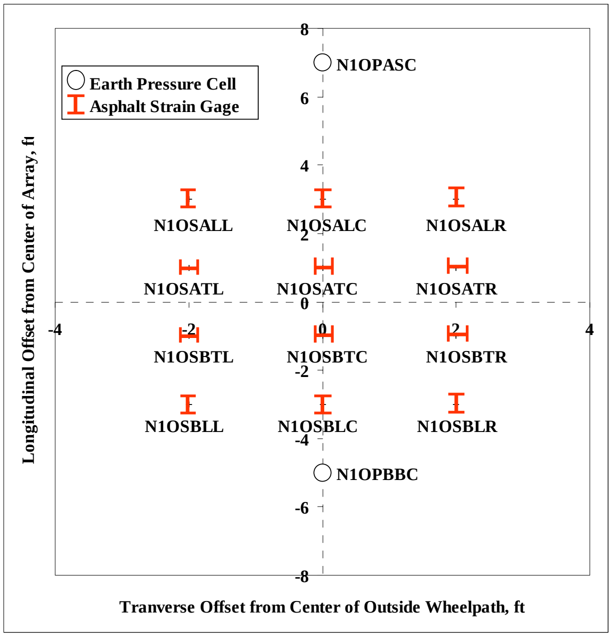


Figure A.1 Section N1 Gauge Arrangement.

Table A.2 Maximum Responses for Cell N2.

Cell: N2
Date: 7-Nov-03
Pavement Temp: 102 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N2OSBLR	501.74	-454.65	[redacted]
N2OSBTR	360.83	-144.35	[redacted]
N2OSBLC	420.77	-294.77	[redacted]
N2OSBTC	INACTIVE	INACTIVE	[redacted]
N2OSBLL	39.19	-39.35	[redacted]
N2OSBTL	INACTIVE	INACTIVE	[redacted]
N2OSALR	479.72	-448.22	[redacted]
N2OSATR	342.79	-78.17	[redacted]
N2OSALC	566.30	-568.85	[redacted]
N2OSATC	407.20	-278.21	[redacted]
N2OSALL	58.02	-48.05	[redacted]
N2OSATL	88.34	-95.61	[redacted]
N2OPASC	[redacted]	[redacted]	11.10
N2OPBBC	[redacted]	[redacted]	16.40

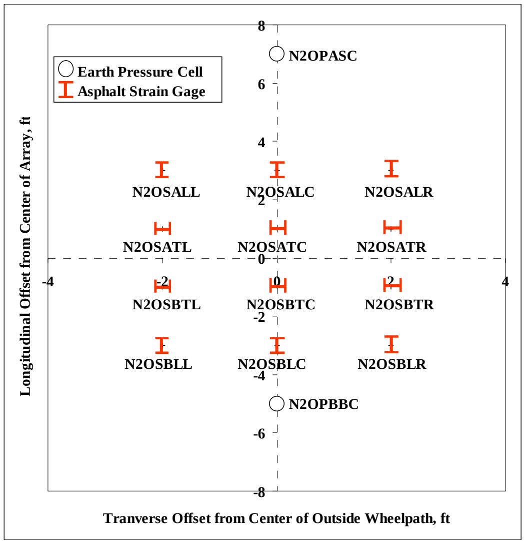


Figure A.2 Section N2 Gauge Arrangement.

Table A.3 Maximum Responses for Cell N3.

Cell: N3
Date: 7-Nov-03
Pavement Temp: 102 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N3OSBLR	243.17	-230.55	
N3OSBTR	INACTIVE	INACTIVE	
N3OSBLC	178.37	-160.66	
N3OSBTC	INACTIVE	INACTIVE	
N3OSBLL	INACTIVE	INACTIVE	
N3OSBTL	38.91	-40.67	
N3OSALR	INACTIVE	INACTIVE	
N3OSATR	INACTIVE	INACTIVE	
N3OSALC	INACTIVE	INACTIVE	
N3OSATC	INACTIVE	INACTIVE	
N3OSALL	63.22	-65.81	
N3OSATL	INACTIVE	INACTIVE	
N3OPASC			4.55
N3OPBBC			6.32

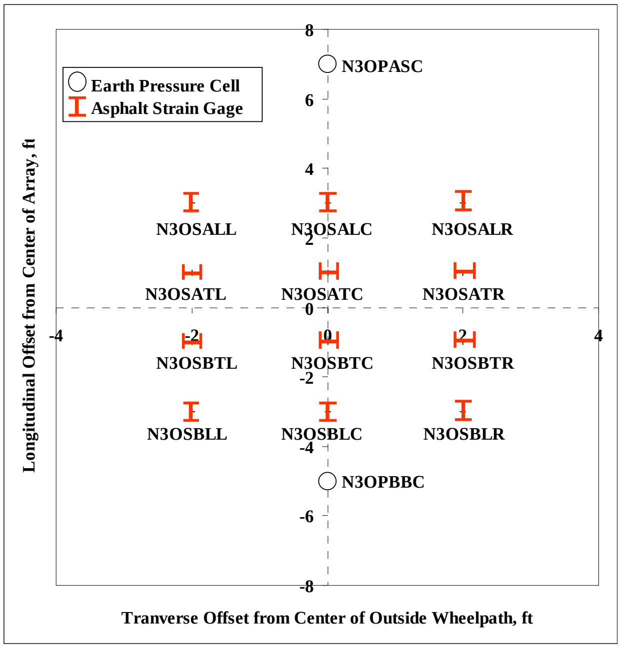


Figure A.3 Section N3 Gauge Arrangement.

Table A.4 Maximum Responses for Cell N4.

Cell: N4
Date: 7-Nov-03
Pavement Temp: 95 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N4OSBLR	208.06	-198.96	
N4OSBTR	135.64	-49.66	
N4OSBLC	172.37	-167.52	
N4OSBTC	125.76	-115.33	
N4OSBLL	INACTIVE	INACTIVE	
N4OSBTL	INACTIVE	INACTIVE	
N4OSALR	232.24	-215.92	
N4OSATR	128.44	-115.60	
N4OSALC	INACTIVE	INACTIVE	
N4OSATC	INACTIVE	INACTIVE	
N4OSALL	96.66	-97.09	
N4OSATL	INACTIVE	INACTIVE	
N4OPASC			5.78
N4OPBBC			8.41

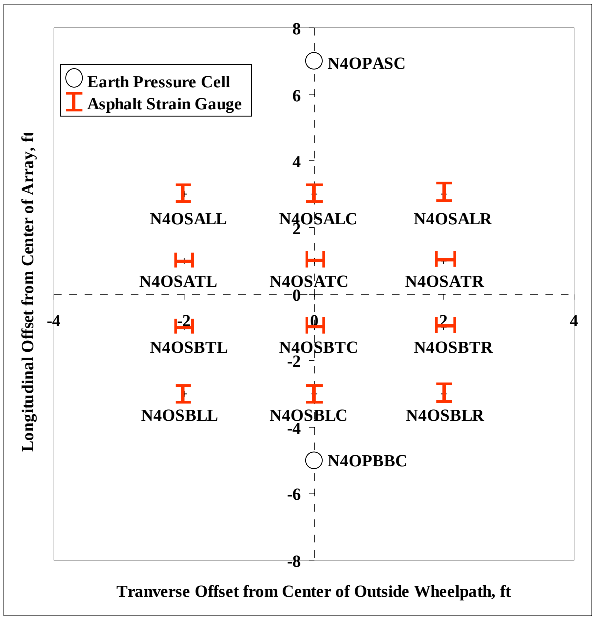


Figure A.4 Section N4 Gauge Arrangement.

Table A.5 Maximum Responses for Cell N5.

Cell:	N5
Date:	7-Nov-03
Pavement Temp:	94 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N5OSBLR	INACTIVE	INACTIVE	
N5OSBTR	INACTIVE	INACTIVE	
N5OSBLC	231.93	-221.45	
N5OSBTC	INACTIVE	INACTIVE	
N5OSBLL	82.23	-84.93	
N5OSBTL	11.77	-58.93	
N5OSALR	276.61	-251.34	
N5OSATR	INACTIVE	INACTIVE	
N5OSALC	INACTIVE	INACTIVE	
N5OSATC	INACTIVE	INACTIVE	
N5OSALL	856.95	-898.51	
N5OSATL	63.97	-63.91	
N5OPASC			6.35
N5OPBBC			7.74

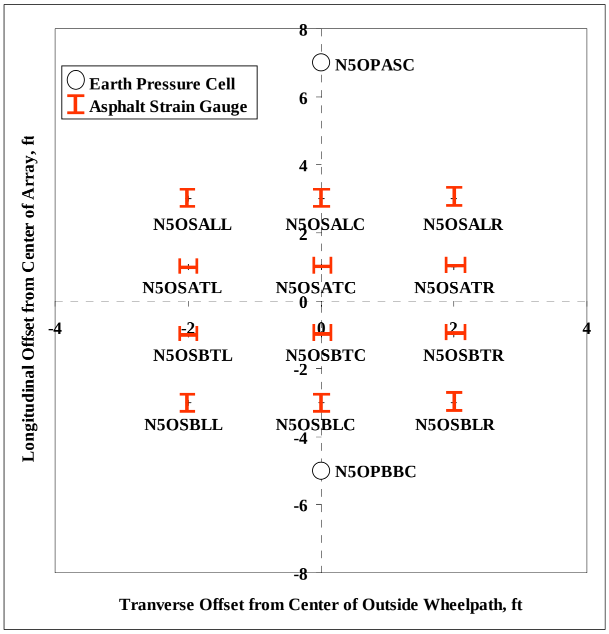


Figure A.5 Section N5 Gauge Arrangement.

Table A.6 Maximum Responses for Cell N6.

Cell:	N6
Date:	7-Nov-03
Pavement Temp:	94 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N6OSBLR	374.04	-306.96	
N6OSBTR	219.42	-103.99	
N6OSBLC	170.25	-169.88	
N6OSBTC	INACTIVE	INACTIVE	
N6OSBLL	57.84	-60.48	
N6OSBTL	INACTIVE	INACTIVE	
N6OSALR	229.27	-214.66	
N6OSATR	133.41	-55.35	
N6OSALC	198.99	-184.61	
N6OSATC	63.79	-50.92	
N6OSALL	INACTIVE	INACTIVE	
N6OSATL	18.37	-51.76	
N6OPASC			5.13
N6OPBBC			5.19
BUTTON			

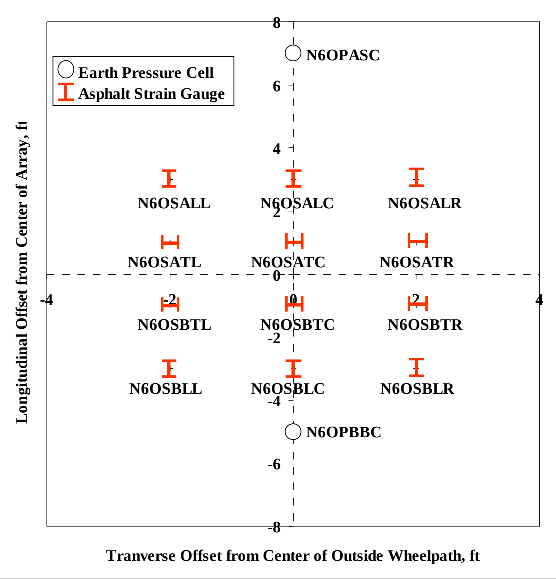


Figure A.6 Section N6 Gauge Arrangement.

Table A.7 Maximum Responses for Cell N7.

Cell: N7
Date: 7-Nov-03
Pavement Temp: 94 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N7OSBLR	149.58	-142.81	
N7OSBTR	160.26	-50.10	
N7OSBLC	189.79	-183.74	
N7OSBTC	112.15	-51.45	
N7OSBLL	50.21	-52.91	
N7OSBTL	12.72	-56.53	
N7OSALR	246.88	-227.39	
N7OSATR	175.43	-25.62	
N7OSALC	217.16	-197.76	
N7OSATC	102.33	-35.78	
N7OSALL	63.34	-63.81	
N7OSATL	INACTIVE	INACTIVE	
N7OPASC			6.65
N7OPBBC			8.89
N7IPASC			5.56
N7IPBBC			7.43
N7OSBLC2	INACTIVE	INACTIVE	
N7OSBTC2	70.64	-34.89	
N7OSATC2	INACTIVE	INACTIVE	
N7OSALC2	254.51	-231.92	

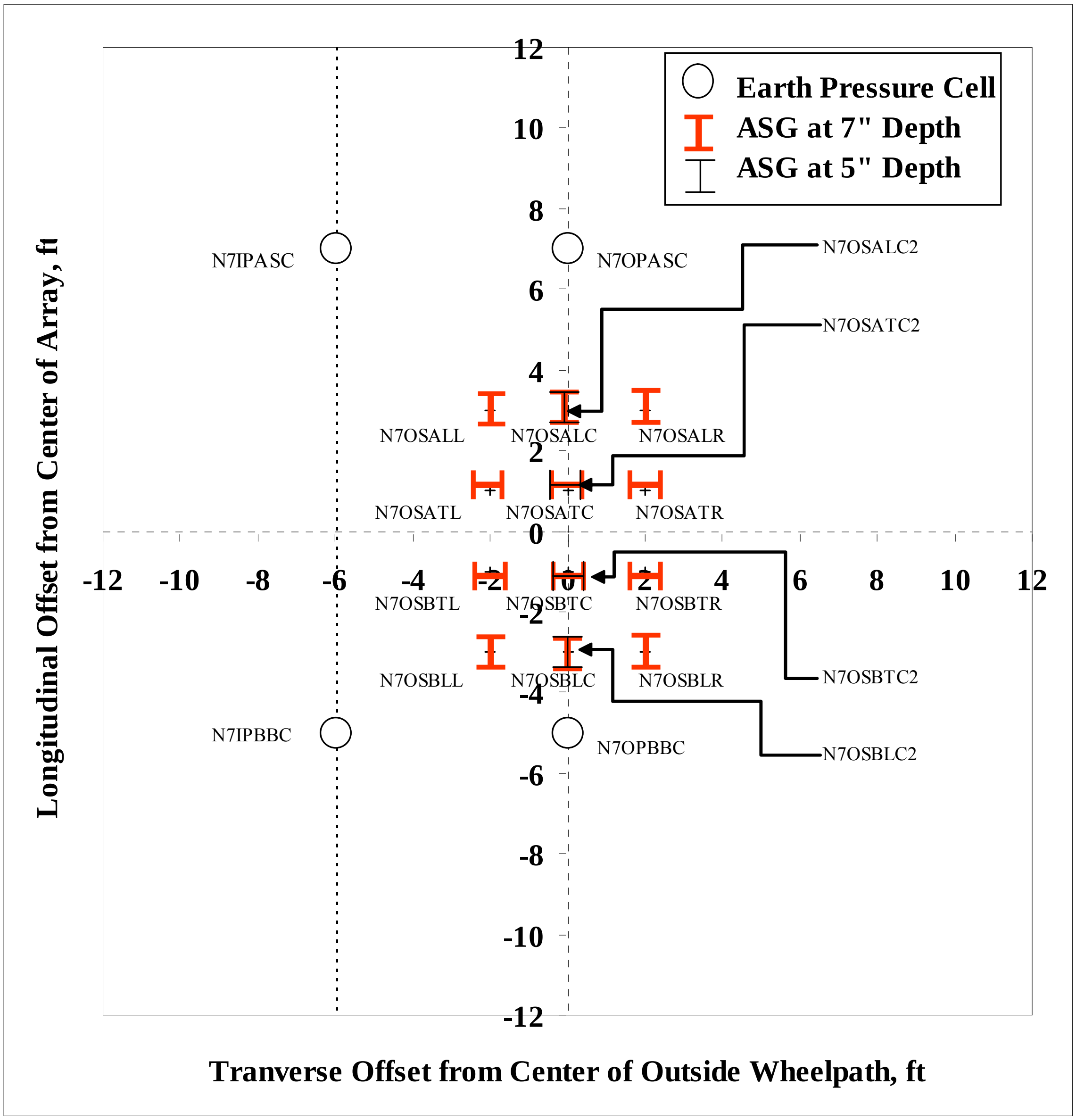


Figure A.7 Section N7 Gauge Arrangement.

Table A.8 Maximum Responses for Cell N8.

Cell:	N8
Date:	7-Nov-03
Pavement Temp:	85 ^{0}F

GAUGE	MAXIMUM TENSILE STRAIN (με)	MAXIMUM COMPRESSIVE STRAIN (με)	MAXIMUM VERTICAL PRESSURE (PSI)
N8OSBLR	0.66	-0.61	
N8OSBTR	136.47	-46.33	
N8OSBLC	190.33	-184.96	
N8OSBTC	INACTIVE	INACTIVE	
N8OSBLL	INACTIVE	INACTIVE	
N8OSBTL	10.90	-64.84	
N8OSALR	278.62	-257.78	
N8OSATR	INACTIVE	INACTIVE	
N8OSALC	240.27	-224.36	
N8OSATC	INACTIVE	INACTIVE	
N8OSALL	INACTIVE	INACTIVE	
N8OSATL	INACTIVE	INACTIVE	
N8OPASC			5.30
N8OPBBC			7.41
N8OSBLC2	145.25	-145.28	
N8OSBTC2	95.98	-51.13	
N8ISBLC2	92.25	-86.81	
N8ISBTC2	55.47	-31.11	
N8ISBLC	205.02	-190.01	
N8ISBTC	111.35	-21.92	
N8ISBLL	INACTIVE	INACTIVE	
N8ISBTL	INACTIVE	INACTIVE	
N9ISALC	165.53	-160.82	
N8ISATC	98.09	-15.00	
N8ISALL	52.61	-47.52	
N8ISATL	15.60	-37.30	

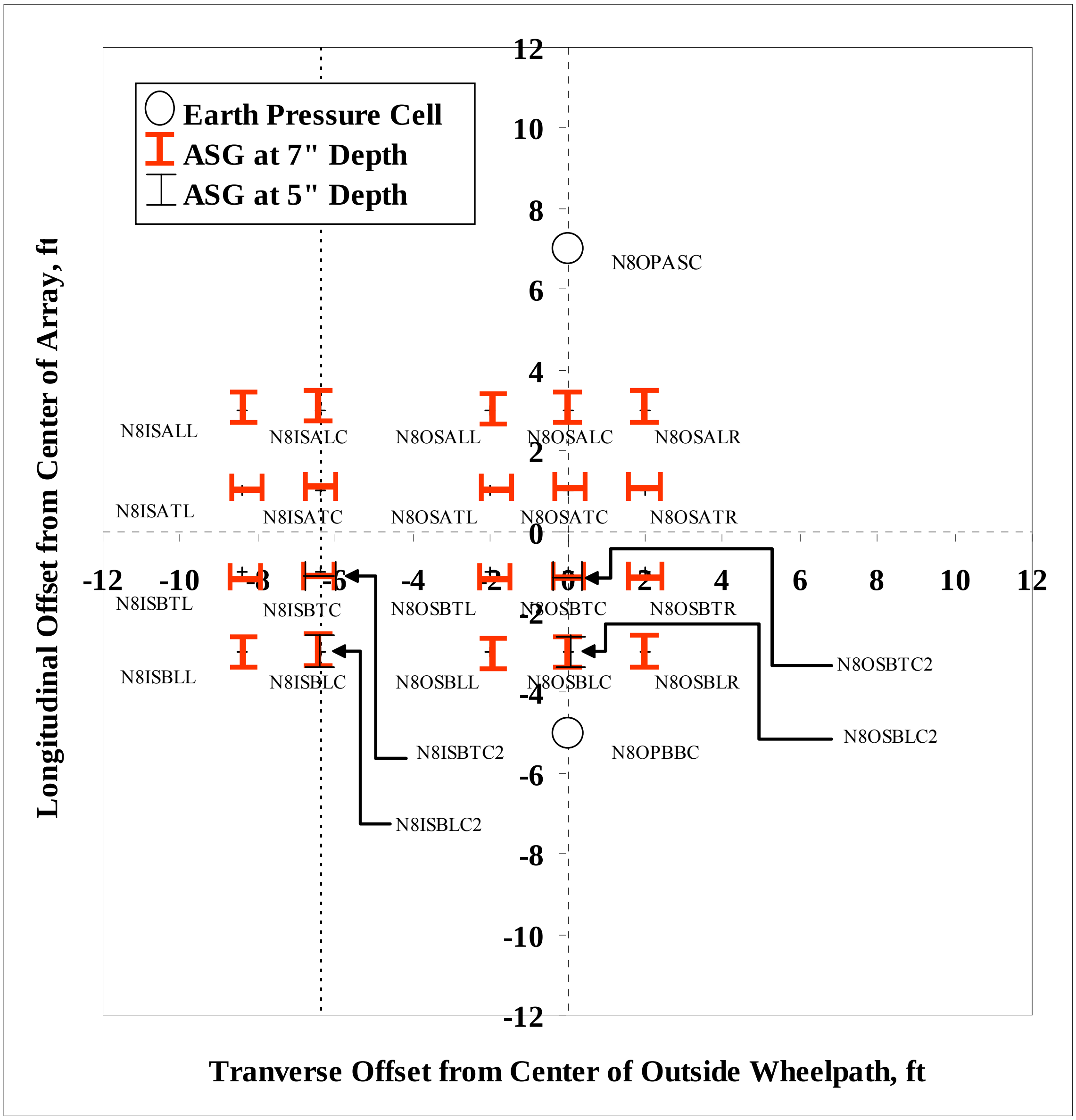


Figure A.8 Section N8 Gauge Arrangement.