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Transportation Research Division

Technical Report 99-8

Experimental Use of Geogrids as an Alternative to Gravel Placement

Fourth Year Interim and Final Report, October 2006

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Introduction

With the ongoing demand for improved infrastructure, the Maine Department of Transportation (MaineDOT) continues to identify and evaluate new and innovative construction methods and materials. The Department's Collector Highway Improvement Program (CHIP) attempts to reduce construction costs by utilizing existing roadway base and pavement materials. In the fall of 1998, MaineDOT began construction of a project that incorporated this philosophy and an experimental feature of geogrids to minimize the need for additional base gravel materials.

Project Location/Description

The project is located on Routes 6 and 15 in Big Moose Township (formerly Big Squaw Township), Piscataquis County. A location map is displayed in Figure 1. This 5.94 kilometer (3.69 mile) section of roadway was originally identified to receive a standard 16 mm (0.63 in) maintenance mulch overlay. After further review and several discussions concerning the significant distortion (crown) of the existing roadway and the high volume of heavy truck traffic, it was determined that this section was an excellent candidate for the CHIP process.

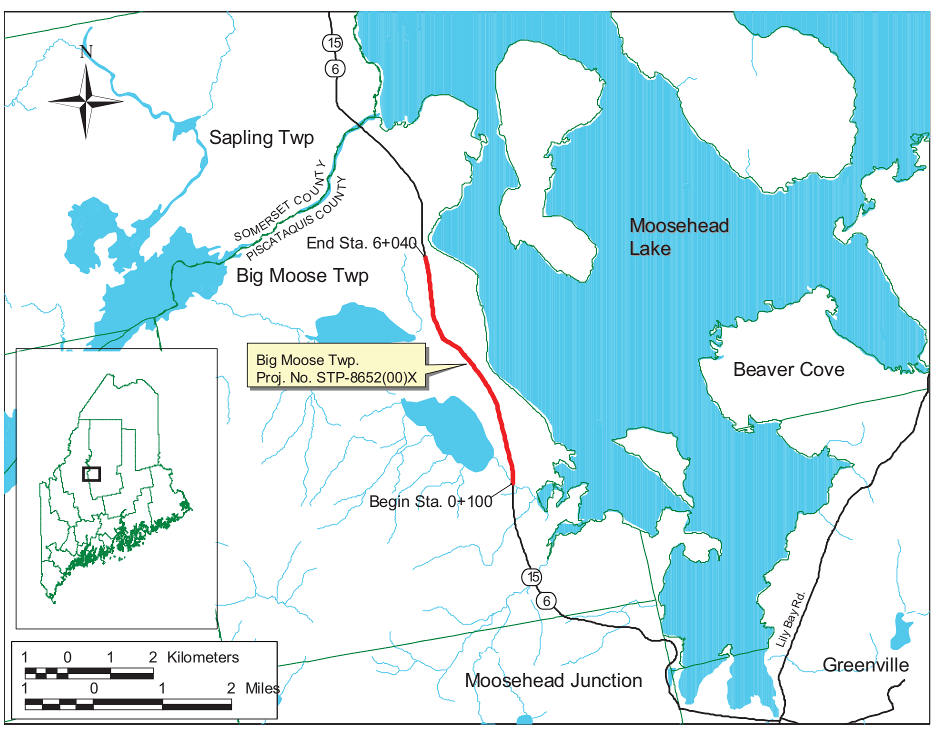


Figure 1: Project Location Map

The experimental feature of this project consists of 11 sections of varying length encompassing the entire project length. The primary focus of this research was to determine if placement of a Geogrid product could minimize the need for additional base gravel materials.

As this research evolved, it became apparent that not only could MaineDOT evaluate the effectiveness of Geogrids, but also conduct an analysis on each of the construction procedures utilized within this project.

MaineDOT's Geotechnical group played a significant role in selecting the Geogrid product used in the research portion of this project and in establishing the overall research strategy. The Geogrid product is Biaxial Geogrid BX1200 (SS-2), manufactured by The Tensar Corporation of Morrow, Georgia.

Construction

Preliminary Falling Weight Deflectometer (FWD) data was collected in June 1998 for design considerations. Roadway evaluation included FWD testing at 150 meter (500 ft) intervals and 25 pavement, base, and subgrade explorations using power augers randomly located along the project. The data was then combined with traffic information and analyzed using DARWin 3.01 software to develop necessary gravel and pavement thickness for the project's construction. A 15-year design life was used to develop each layer thickness.

With the exception of the two undercut sections, pavement was reclaimed the entire project length using a Wirtgen Pavement Reclaimer. This reclamation process consisted of full depth reclaiming of the existing pavement layer, plus approximately 25 mm (1 in) of the existing gravel base. Pavement depths varied from 60 to 125 mm (2.36 to 4.92 in).

During the milling process, it was noted that the reclaimed material was of poor quality and became muddied with rainfall. Quality of this material was improved by applying 75 to 100 mm (3 to 4 in) of gravel to the existing pavement before reclaiming.

Construction began in mid-September 1998. This late season start did not allow sufficient time to complete the entire project. However, all of the pavement reclamation and base material work was completed, and a 65 mm (2.56 in) layer of 19 mm (0.75 in) Superpave binder coarse was applied and left exposed for the winter season of 1998-1999.

In late January 1999, maintenance personnel identified two areas of pavement failure within the project and a decision was made to restrict heavy loads from traveling along the constructed section. This "posting" was implemented using MaineDOT's standard posting procedure which limits gross vehicle weights to 10.4 kilograms (23,000 pounds) except when air temperatures fall below 0 degrees Celsius (32 degrees Fahrenheit) and water is not present at roadway cracks. This posting minimized any additional failures and overall, the project performed adequately.

In early spring, 1999, additional FWD testing was performed on the binder coarse to determine if the total pavement depth of 105 millimeters (4.13 inches) would sufficiently support future traffic weight and volume. Several areas of minor deficiency were identified and treated with additional pavement at the time of wearing surface placement.

Final pavement depths for the project consisted of 65 mm (2.56 in) of 19 mm (0.75 in) Superpave binder course topped with 12.5 mm (0.50 in) Superpave surface course at depths ranging from 30 to 100 mm (1 to 4 in).

A summary of the length, location, and final average gravel and pavement depths for each section are presented in Table 1 followed by a summary of each construction procedure.

Table 1: Section Limits with Layer Depths

Section Number	Station Limits	Treatment	Average Layer Depth (mm)	
			Gravel	Pavement
1	0+100 - 0+220	Undercut	650	110
2	0+220 - 0+600	Geogrid	685	115
3	0+600 - 0+700	Control	750	115
4	0+700 - 2+770	Reclaim	685	115
5	2+770 - 3+270	Geogrid	700	95
6	3+270 - 3+390	Control	640	110
7	3+390 - 3+520	Geogrid	540	115
8	3+520 - 5+120	Reclaim	590	110
9	5+120 - 5+320	Geogrid	680	120
10	5+320 - 5+400	Undercut	420	165
11	5+400 - 6+040	Reclaim	650	115

Undercut Sections

Undercut Section 1 and 10 had existing HMA and roadway subbase materials excavated at varying depths between 300 and 600 mm (12 and 24 in). As anticipated, ledge was encountered in several areas of Section 1. Gravel and pavement materials were reintroduced to a depth of between 760 and 800 mm (30 and 32 in) in Section 1, and a depth of between 550 and 585 mm (22 and 23 in) in Section 10. As stated above, FWD testing in the spring of 1999 identified deficient loading capacities in several areas of Section 10. To correct this deficiency, an additional 50 mm (2 in) of wearing surface was placed. A Typical Cross Section Detail is illustrated in Figure 2.

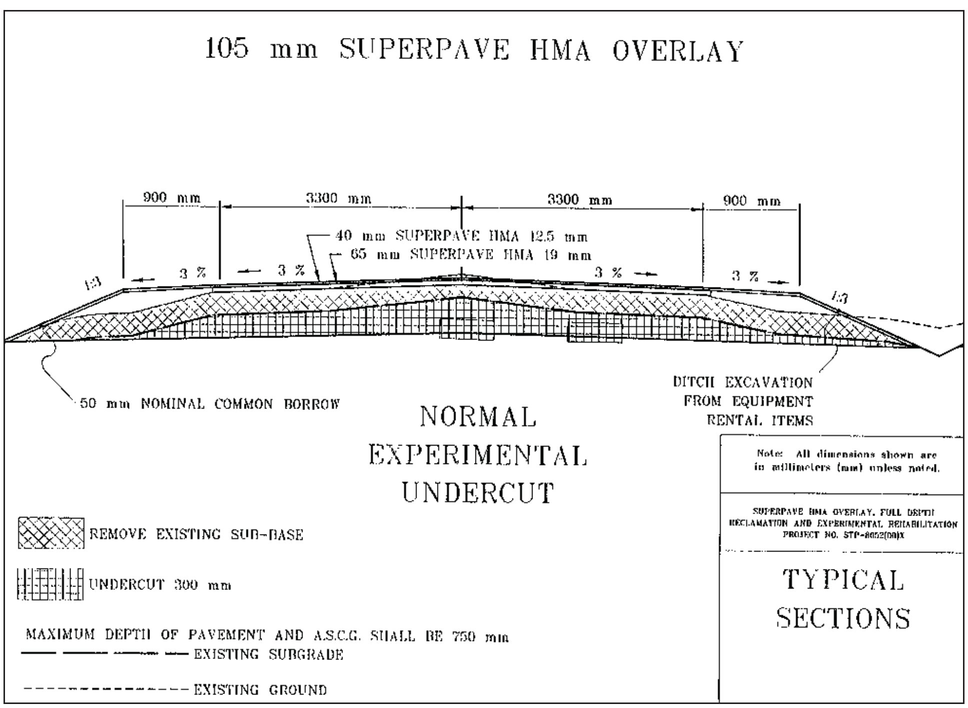


Figure 2: Typical Undercut Cross Section

Geogrid Sections

In the four Geogrid Sections (2, 5, 7 and 9), existing pavement material and 25 mm (1 in) of gravel base material were milled in-place and shaped to eliminate excessive crown. Figure 3 contains a typical cross section. Two rolls of Geogrid product, each measuring 4 m (13 ft) in width and approximately 50 m (164 ft) in length were then placed on top of the reclaimed material at full roadway width as displayed in Photo 1.

The Geogrid product was overlapped 0.6 m (2 ft) at centerline and each end then tied together utilizing "tie connectors". After initial application, it was determined that a single tie did not supply adequate strength and two tie connectors were used at each tie location.

Both lanes of traffic were stopped during this process, until a single lane width layer of variable depth gravel were placed over the longitudinal seam at centerline as displayed in Photo 2. Once single lane traffic flow was reestablished, the left and right side of the Geogrid was covered to a total width of 7.3 m (24 ft).

Some "pushing" or "waving" of the Geogrid product was observed during gravel application and can be seen in Photo 3. This movement was not considered critical but it did create concern with respect to ease of application. Construction of each Geogrid section was completed using this 50 m (164 ft) application interval to minimize traffic interruptions.

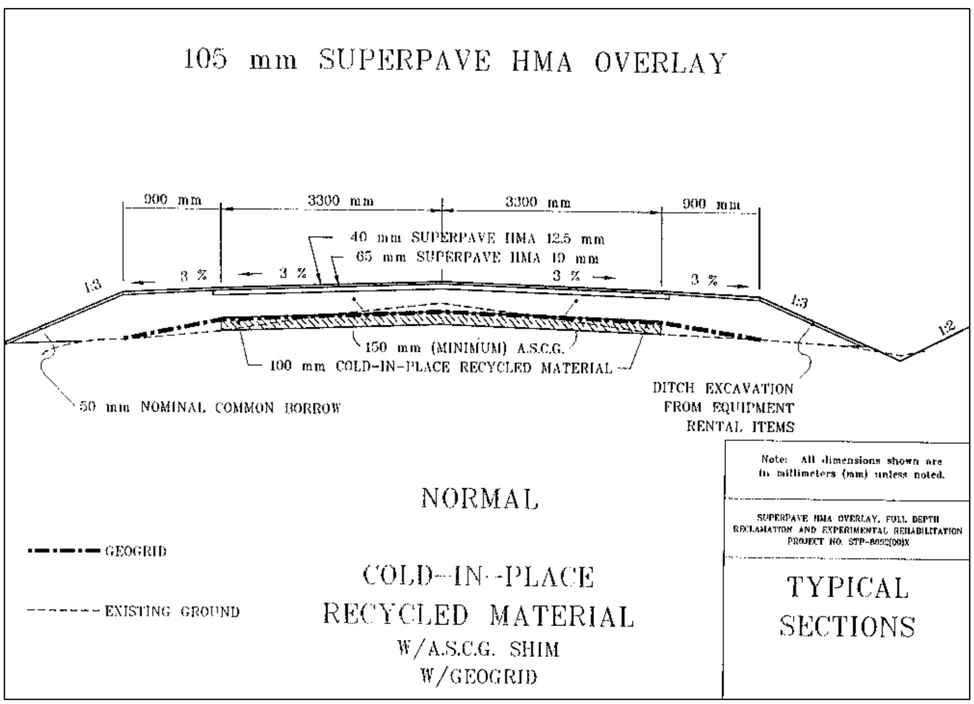


Figure 3: Typical Geogrid Cross Section

Control Section

The two Control Sections (3 and 6) were constructed in the same manner as the Geogrid Sections excluding the Geogrid product and its associated procedures.

Photo 1: Geogrid Placement.

Photo 2: Gravel Placement

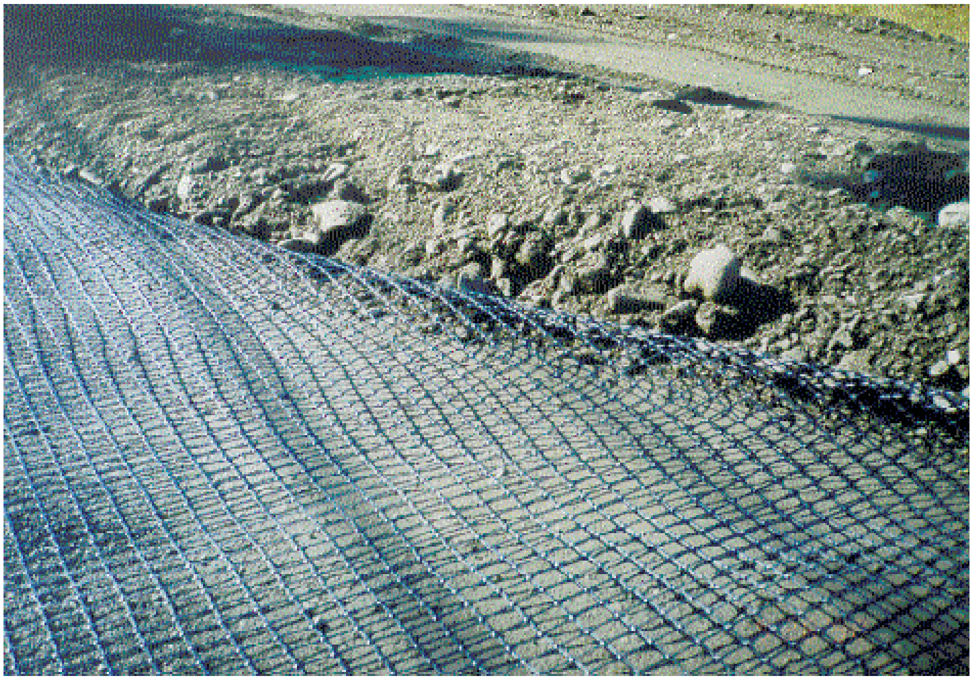


Photo 3: Geogrid Shoving

Reclaim Sections

Construction of the three Reclaimed Sections (4, 8 and 11) included reclamation of the existing pavement layer plus 25 mm (1 in) of the existing gravel base material. Gravel was added at depths of 75 to 100 mm (3 to 4 in) where necessary as stated earlier. There was concern on the project that these sections would fail prematurely. Therefore these sections were further built up by adding a minimum of 500 mm (20 in) of ASCG then leveled to grade and sealed with HMA. They are actually constructed the same as the Control Sections. Figure 4 contains a Typical Cross Section.

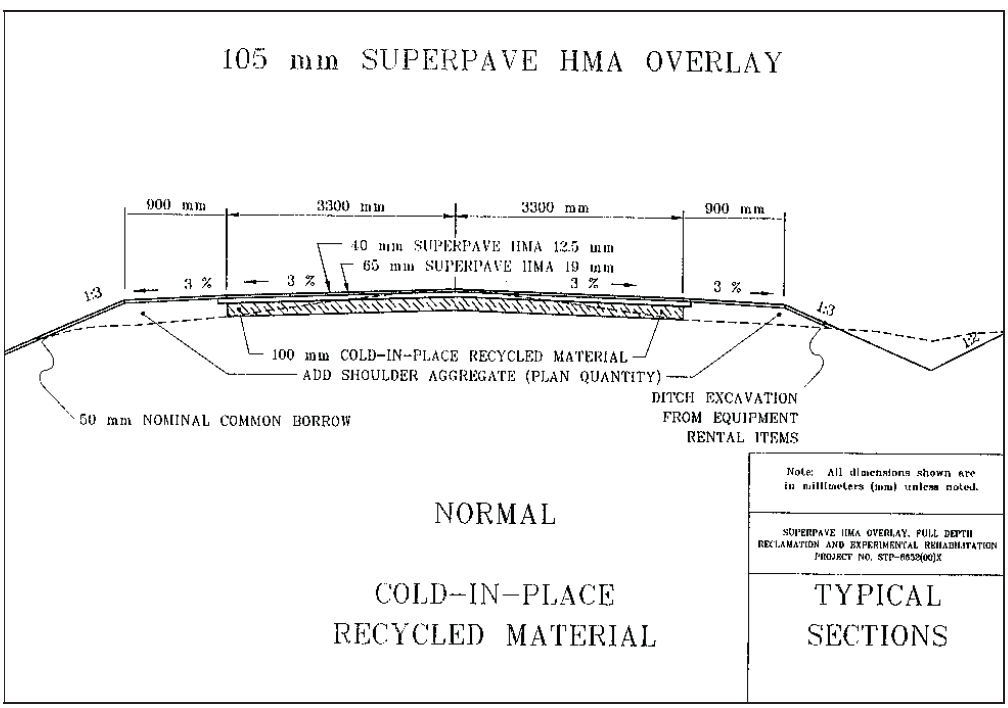


Figure 4: Typical Reclaim Cross Section

Cost Summary

A cost summary for each section is displayed in Table 2. The right column contains a cost per square meter for a 6.6 meter (22 foot) wide travel way in each section.

Undercut Section 10 has the greatest cost per square meter at $32.31 ($27.02 yd^2). Costs are high due to excavation costs plus the additional 50 mm (2 in) of HMA surface mix that was requested for section 10 after FWD readings collected in the spring revealed that the planned thickness of 115 mm (4.5 in) of surface mix was inadequate to support projected traffic.

Geogrid Sections 9, 2, 5, and 7 have costs ranging from a high of $28.25 to a low of $25.65 per square meter ($23.62 to $21.45 yd^2). Costs vary due to the quantity of ASCG and HMA used in each section.

Undercut Section 1 has a cost per square meter of $27.11 ($22.67 yd^2) mainly due to excavation costs.

Control sections 3 and 6 have costs of $24.50 and $22.35 per square meter ($20.49 and $18.69 yd^2) respectively. Costs vary due to HMA and ASCG layer thickness within each section.

Reclaim Sections 4, 11, and 8 have costs of $23.53, $23.00, and $21.60 per square meter ($19.67, $19.23, and $18.06 yd^2) respectively. Section 8 has a lower cost due to thinner HMA surface mix.

Table 2: Section Cost Summary

	Cost per Section							
Section / Treatment	Excavation ($9.40 / m^3)	CIP ($1.88 / m^2)	Geogrid ($4.30 / m^2)	ASCG ($15.00 / m^3)	HMA Base ($39.90 / Mg)	HMA Surface ($40.75 / Mg)	Total	Cost / m^2 Travel Way Only
1 / Undercut	$5,136.91	$0.00	$0.00	$7,722.00	$5,044.75	$3,566.92	$21,470.59	$27.11
2 / Geogrid	$0.00	$4,715.04	$10,784.40	$25,769.70	$15,975.05	$12,550.28	$69,794.47	$27.83
3 / Control	$0.00	$1,240.80	$0.00	$7,425.00	$4,203.96	$3,302.71	$16,172.47	$24.50
4 / Reclaim	$0.00	$25,684.56	$0.00	$140,377.05	$87,021.97	$68,366.01	$321,449.59	$23.53
5 / Geogrid	$0.00	$6,204.00	$14,190.00	$34,650.00	$21,019.80	$9,908.12	$85,971.92	$26.05
6 / Control	$0.00	$1,488.96	$0.00	$7,603.20	$5,044.75	$3,566.92	$17,703.83	$22.35
7 / Geogrid	$0.00	$1,613.04	$3,689.40	$6,949.80	$5,465.15	$4,293.52	$22,010.91	$25.65
8 / Reclaim	$0.00	$19,852.80	$0.00	$93,456.00	$67,263.36	$47,558.97	$228,131.12	$21.60
9 / Geogrid	$0.00	$2,481.60	$5,676.00	$13,464.00	$8,407.92	$7,265.95	$37,295.47	$28.25
10 / Undercut	$5,087.28	$0.00	$0.00	$3,326.40	$3,363.17	$5,284.33	$17,061.18	$32.31
11 / Reclaim	$0.00	$7,941.12	$0.00	$41,184.00	$26,905.34	$21,137.32	$97,167.78	$23.00

Project Evaluation

The project was evaluated by utilizing the Falling Weight Deflectometer (FWD) and Automatic Road Analyzer (ARAN) test vehicles and a visual inspection. The FWD records pavement deflections that are processed to measure Subgrade Modulus, Pavement Modulus, and Structural Number. The ARAN measures wheel rut depths and smoothness reported as International Roughness Index.

Visual Inspection

A visual inspection of the experimental project was completed on October 17, 2003 and October 26, 2004. The overall condition of the roadway is good after five years exposure to traffic. Types of cracking surveyed include centerline, transverse, longitudinal, and load cracking. To equally represent the amount of cracking in each section, centerline and longitudinal cracking is measured as a percentage of the section length, transverse cracking is represented as the number of full width cracks per 100 meters (328 feet), and load cracking is calculated as a percentage of the section area.

Centerline Cracking

In 2003 all but Geogrid Section 9 exhibited centerline cracking and many sections had significant increases from 2002. Length of cracking ranged from 0.0 to 44.0 percent of section length. In 2004 the amount of centerline cracking nearly doubled for all sections. Quantities ranged from 15.5 to 97.5 percent.

Severity of cracking for each section is detailed in the following list:

- Undercut Section 1 increased 16.7 percent in 2003 to 25 percent then increased 25 percent in 2004 to a total of 50 percent.
- Geogrid Section 2 first showed signs of cracking in 2003 with 0.5 percent then increased 15 percent in 2004 to a total of 15.5 percent. This section has the lowest amount of centerline cracks.
- Control Section 3 had no centerline cracking in 2002 then increased 44 percent in 2003. Cracking increased another 40 percent in 2004 to a total of 84 percent, the second highest amount of centerline cracking.
- Reclaim Section 4 increased 6.7 percent in 2003 and 14.5 percent in 2004 to a total of 29.2 percent.
- Geogrid Section 5 increased 7.2 percent in 2003 and 16.8 percent in 2004 to a total of 26.6 percent the third lowest amount of centerline cracking.
- Control Section 6 increased 33.3 percent in 2003, the second greatest amount, and then increased 19.2 percent in 2004, the third greatest amount.
- Geogrid Section 7 increased 10.7 percent in 2003 and 26.2 percent in 2004 to a total of 44.6 percent, the greatest amount of centerline cracking among the four Geogrid Sections.
- Reclaim Section 8 increased 7.1 percent to 16.4 in 2003 then increased 41.1 percent in 2004 to 57.4 percent total.
- Geogrid Section 9 had no cracks in 2003 then increased to 18.5 percent in 2004, the second lowest amount.
- Undercut Section 10 had a small increase from 0 to 7.5 percent in 2003 then a dramatic increase of 90 percent in 2004 to end with the highest amount of centerline cracking at 97.5 percent.
- Reclaim Section 11 increased 10.9 percent in 2003 then 21.4 percent in 2004 to a total of 32.3 percent.

Three of the four Geogrid Sections (2, 9, and 5) have the lowest amount of centerline cracking. Figure 5 contains a graphical representation of centerline cracking from year 2000 to 2004. Average subbase gravel depth, average combined HMA and subbase gravel depth, and 2004 Subgrade Resilient Modulus test results are also included in Figure 5.

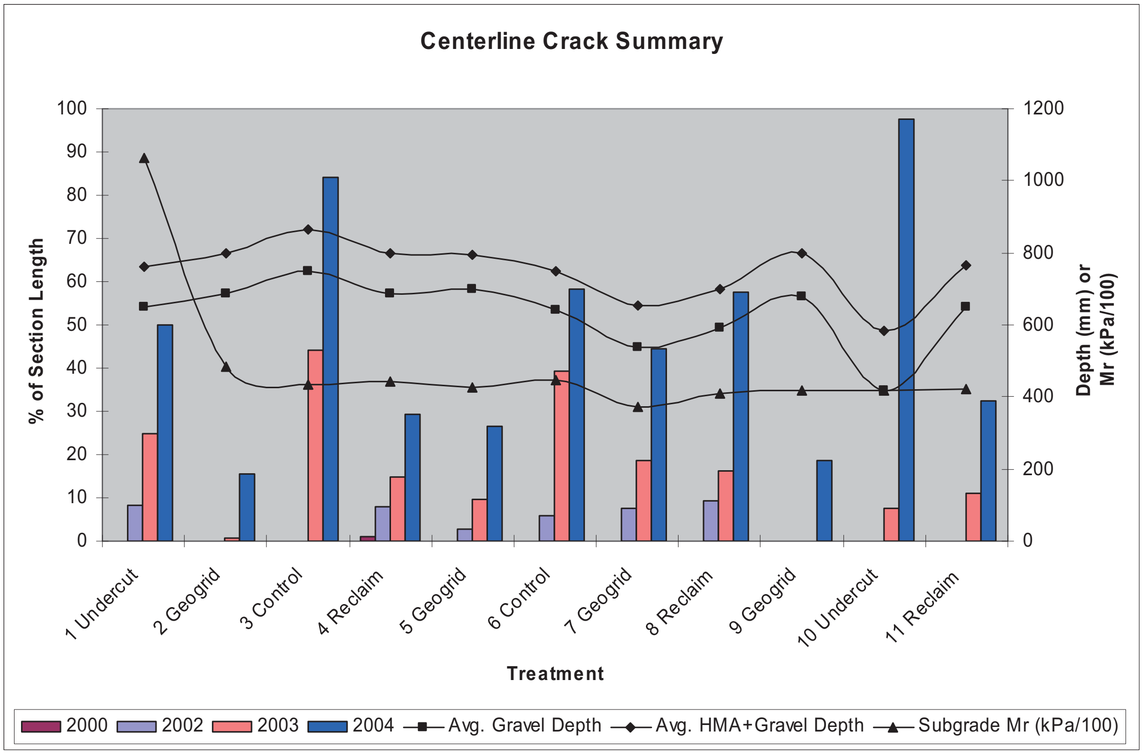


Figure 5: Centerline Crack Summary

Transverse Cracking

Transverse cracking ranged from a low of 0.0 to a high of 2.9 full width cracks per 100 meters (328 ft) in 2003 and a low of 1.3 to a high of 5.8 in 2004.

A summary of the extent of transverse cracking for each section is as follows:

- Undercut Section 1 increased from 2.1 in 2002 to the greatest amount of transverse cracking at 2.9 in 2003. In 2004 cracking increased to 4.2 cracks per 100 m (328 ft) in 2004.
- Geogrid Section 2 went from 0.0 in 2002 to 1.4 in 2003 and 4.9 in 2004, the third highest amount.
- Control Section 3 increased from 0.0 to 1.0 in 2003 then to 2.5 in 2004. This is the third lowest amount of transverse cracking.
- Reclaim Section 4 increased from 0.4 to 1.8 in 2003 then increased to the second greatest amount at 5.0 in 2004.
- Geogrid Section 5 increased from 0.0 to 0.4 in 2003 and 3.3 in 2004.
- Control Section 6 had no transverse cracks in 2003 then increased dramatically to one of the highest amounts at 5.8 in 2004.
- Transverse cracking in Geogrid Section 7 increased from 0.8 in 2002 to 1.9 in 2003 and 3.8 in 2004.
- Reclaim Section 8 increased from 0.3 in 2002 to 1.1 in 2003 then increased to 3.0 in 2004. This Section has the fourth lowest amount of transverse cracking.
- Geogrid Section 9 increased from 0.0 to 0.8 in 2003 then to the second lowest amount at 1.8 cracks per 100 m (328 ft) in 2004.
- Undercut Section 10 had no transverse cracks in 2002 then increased to 1.3 in 2003 and remained the same in 2004. This section has the lowest number of transverse cracks. Perhaps the additional HMA is reducing or delaying the formation of transverse cracks.

- Reclaim Section 11 went from 0.5 to 1.0 in 2003 then jumped to one of the greatest amounts of transverse cracking at 5.8 per 100 m (328 ft) in 2004.

All treatments have high and low amounts of transverse cracking. It doesn't appear that one treatment reduces transverse cracking better than another. Figure 6 contains a summary of transverse cracking from year 2000 to 2004.

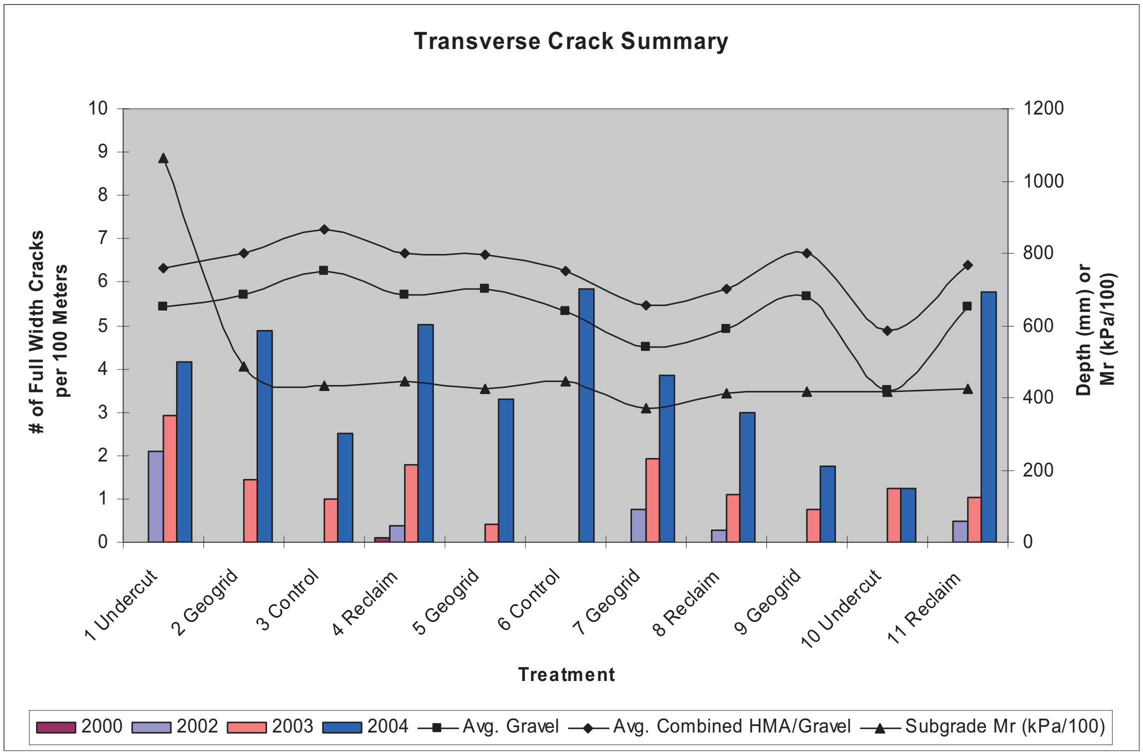


Figure 6: Transverse Crack Summary

Longitudinal Cracking

Longitudinal cracking is a good indicator of roadway durability. Amounts range from 0.0 to 9.0 percent of section length in 2003 and 0.0 to 11.0 percent in 2004. Geogrid Sections 5 and 7 plus Control Section 6 and Undercut Section 10 had no longitudinal cracking in 2003. Geogrid Section 7 was the only Section that had no longitudinal cracking in 2004. Sections 5 and 7 with Geogrid and Control Section 6 had less than 1 percent longitudinal cracking. Seven Sections had longitudinal cracking between 3.0 and 6.6 percent. Control Section 3 had the greatest amount at 11.0 percent. A summary of longitudinal cracking is displayed in Figure 7.

- Undercut Section 1 increased from 0.0 to 3.3 percent in 2003 then increased another 1.7 percent to a total of 5.0 in 2004.
- Geogrid Section 2 increased 2.1 percent in 2003 and 1.6 percent in 2004 to a total of 4.5 percent.
- Control Section 3 had the greatest amount at 9.0 in 2003 and continues to have the most in 2004 at 11.0 percent.
- Reclaim Section 4 had the second greatest amount of cracking in both 2003 and 2004 at 3.8 and 6.6 percent respectively.
- Geogrid Section 5 had no longitudinal cracking in 2003 and has the one of the lowest amounts in 2004 at 0.4 percent.
- Control Section 6 also has one of the lowest amounts of cracking with 0.0 in 2003 and 0.8 percent in 2004.

- Geogrid Section 7 is fairing very well with no longitudinal cracking in both 2003 and 2004. This is very good considering this section has the lowest subgrade resilient modulus and the least amount of subbase gravel and HMA of all the Geogrid sections.
- Reclaim Section 8 has one of the higher amounts of cracking at 1.7 percent in 2003 and 5.4 percent in 2004.
- Geogrid Section 9 is doing well with 1.0 percent in 2003 and 3.0 percent in 2004.
- Undercut Section 10 is also doing well with 0.0 in 2003 then increased to 3.8 percent in 2004. Longitudinal cracking may have been delayed due to the additional HMA in this section.
- Reclaim Section 11 had 0.9 percent in 2003 then jumped to 4.5 percent in 2004.

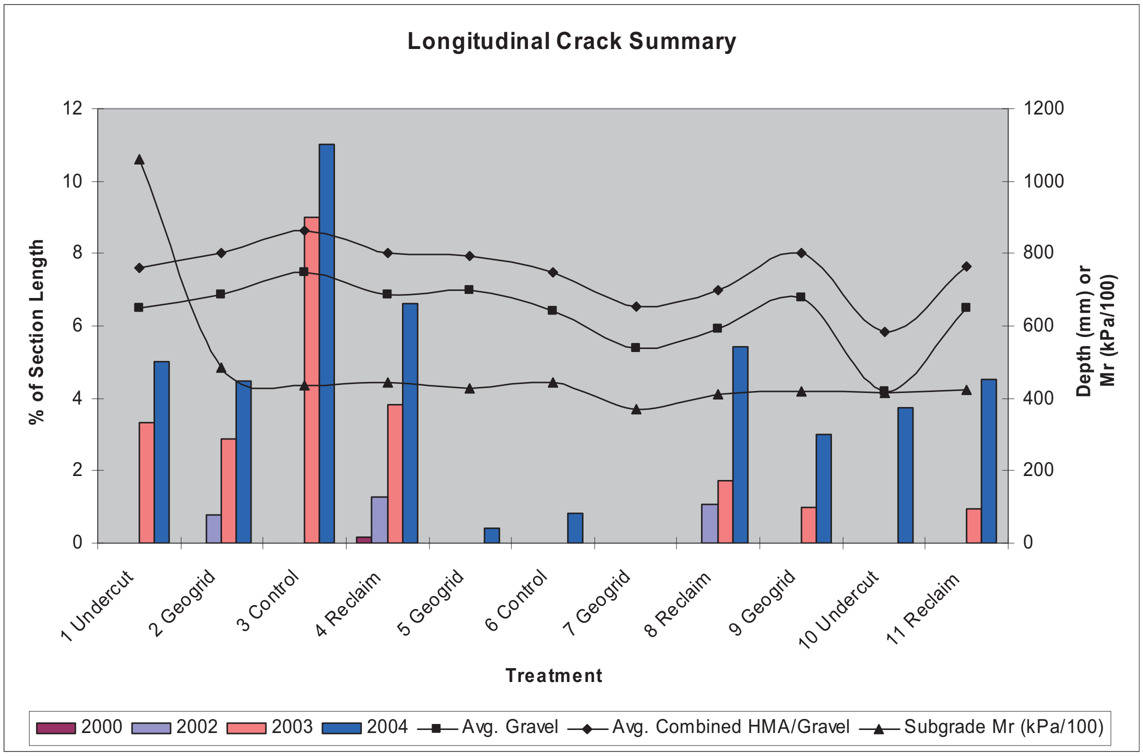


Figure 7: Longitudinal Crack Summary

Load Cracking

Load Cracking is one of the best visual indicators of roadway deficiencies. Load cracking occurs mainly in the wheel path and has been separated into three categories, initial, moderate, and severe. Initial cracking are one or more cracks that are parallel to the shoulder. Moderate cracking is initial cracking with perpendicular cracks joining or beginning to joint the perpendicular cracks. Severe cracking is moderate cracking with loose or missing pieces of HMA and/or evidence of water pumping to the surface. Only initial and moderate load cracking was evident on the project. Load cracking is measured in square meters and reported in Figures 8 and 9 as a percentage of the total area of the section.

The following list outlines the amount and severity of load cracking in each section:

- Undercut Section 1 had no load cracking until 2004 with 2.9 percent initial and 0.9 percent moderate. This section has ledge in many areas and it is evident with a Subgrade Resilient Modulus reading of 106204 kPa, more than twice the other sections. This may be contributing to the low amount of load cracking.

- Geogrid Section 2 had 0.5 percent initial load in 2003 and 1.1 percent in 2004. There was also a small amount of moderate load cracking in 2004 at 0.3 percent. This is the only Geogrid Section that has moderate load cracking.
- Control Section 3 had 1.8 percent initial load cracking in 2003. Initial and moderate load cracking increased to the highest levels of all sections at 9.8 and 0.9 percent in 2004.
- Reclaim Section 4 had the greatest amount of initial load cracking in 2003 at 3.6 percent and was one of only two sections that had moderate load cracking at 0.3 percent. In 2004, initial and moderate load cracks were second highest at 6.9 and 0.6 percent respectively.
- Geogrid Section 5 has the highest amount of initial load cracking of all the Geogrid Sections. In 2003 there was 1.2 percent with no moderate cracking and in 2004 there was 2.9 percent with no moderate cracks.
- Control Section 6 has the second best performance with no initial or moderate load cracking in 2003 and only 0.4 percent initial load cracking in 2004.
- Geogrid Section 7 has very little load cracking with no initial or moderate cracking in 2003 and 0.5 percent initial in 2004.
- Reclaim Section 8 is the second of two sections that had moderate cracking in 2003. This section had 0.5 percent initial and 0.4 percent moderate in 2003 followed by 1.2 percent initial and 0.5 percent moderate in 2004.
- Geogrid Section 9 has one of the lowest amounts of cracking with 0.1 percent initial in 2003 and 0.8 percent initial in 2004 with no moderate cracking.
- Undercut Section 10 is performing very well with no load cracking over the five year period. This could be attributed to the additional HMA.
- Reclaim Section 11 is doing well with no load cracking in 2003 and only 1.5 percent initial cracking in 2004.

Reclaim Sections 4 and 8 were the only two sections that had moderate cracking in 2003. Geogrid Section 7, with 140 mm (5.5 in) less subbase gravel than the remaining Geogrid Sections, is performing very well. Undercut Section 10, with the greatest amount of HMA at 165 mm (6.5 in) and least amount of subbase gravel at 420 mm (16.5 in) is performing better than the remaining sections.

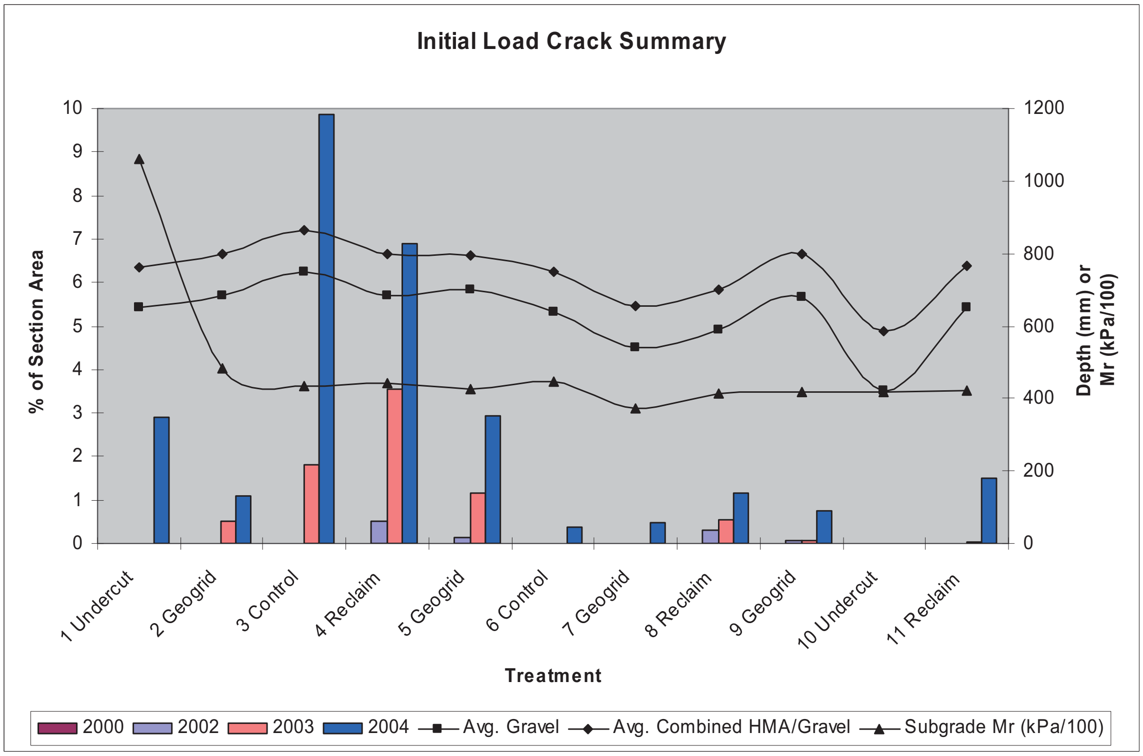


Figure 8: Initial Load Crack Summary

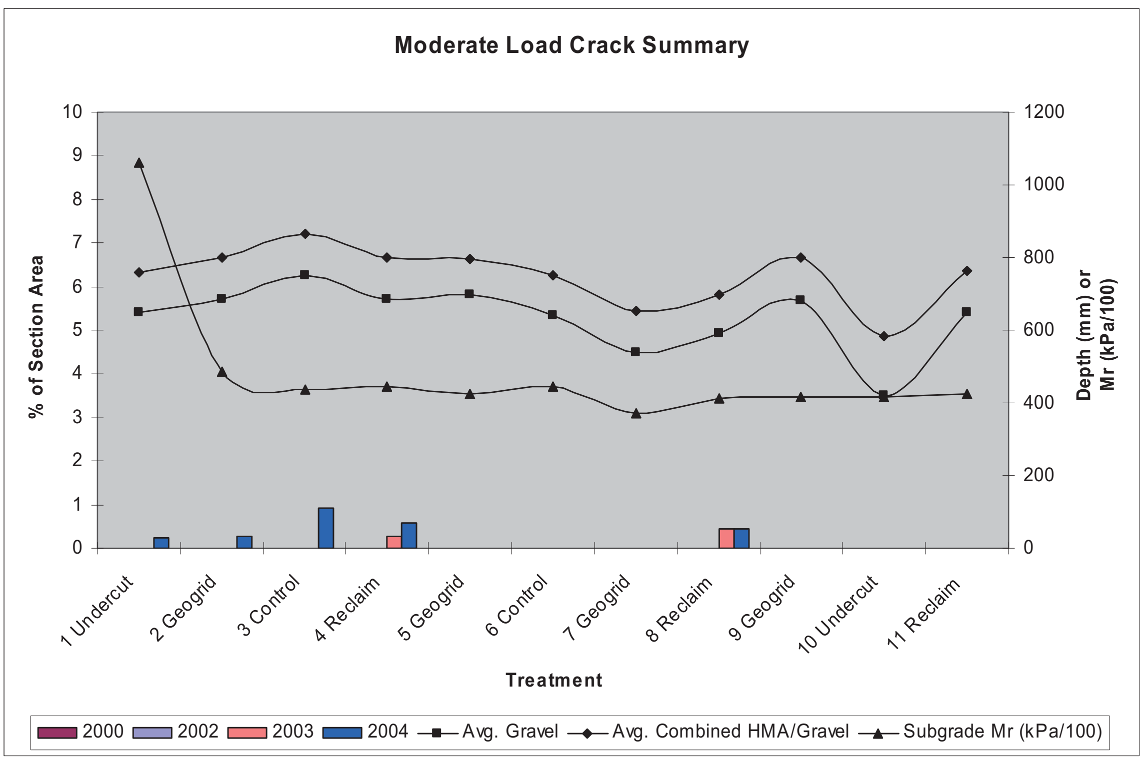


Figure 9: Moderate Load Crack Summary

Falling Weight Deflectometer

The Falling Weight Deflectometer measures pavement deflections by dropping the equivalent weight of 40 kN (9000 lb) onto a platform that is lowered to the pavement. Pavement deflections are recorded by seven sensors extending away from the platform. Pavement deflections indicate the structural stability of the roadway to a depth of 1.5 m (5 ft). FWD data is processed using DARWin Pavement Design Analysis System. DARWin utilizes FWD deflections plus pavement and gravel depths to determine Subgrade Resilient Modulus, Existing Pavement Modulus, Effective Existing Pavement Structural Number, and Structural Number for Future Traffic.

The Effective Existing Pavement Structural Number measures the structural ability of a roadway to carry traffic loads and will be used to compare structural differences between sections. Data is collected at predefined stations in the north and south bound lanes. Deflections were recorded on the same stations in the spring and fall of each year when the roadway is at its weakest and strongest state. Fall data will be compared to determine which section has the greater load bearing capacity. Spring data will be compared to determine which section has greater load bearing capacity when the roadway is at its weakest state. Spring and fall data will be compared to determine the strength of each section at its weakest condition and the strength differential between spring and fall conditions.

FWD deflections from the number one sensor, located at the force platform, will be used to determine Section Uniformity which will be explained later in the report.

Fall Data Comparison

Deflections were collected in August of 2003 and September of 2004. A summary of average fall Structural Numbers from 2000 to 2004 are displayed in Figure 10.

A multiple comparison test was performed on 2004 Structural Numbers in each section. Results are presented in Appendix A.

The following list summarizes Structural Numbers for each Section:

- Undercut Section 1 has had a relatively high SN all five years ranging from a low of 147 in year 2002 and 2003 to a high of 157 in year 2000. Statistical analysis reveals that this section is significantly stronger than Reclaim Sections 11 and 8, Undercut Section 10, and Geogrid Section 7. Ledge discovered under the roadway during construction may be contributing to the high SN readings.
- Geogrid Section 2 also has high Structural Numbers ranging from a low of 147 in 2002 to a high of 157 in 2000. Structural Numbers are significantly higher than Geogrid Sections 5 and 7, Reclaim Sections 4, 11, and 8, Control Section 6, and Undercut Section 10. The combined HMA/Gravel depth of 800 mm (31.5 in) plus Geogrid may be contributing to the high numbers.
- Control Section 3 has the greatest amount of HMA/Gravel depth at 865 mm (34 in). Structural Numbers ranged from a high of 159 in 2000 to a low of 147 in 2002. This Section is significantly stronger than Undercut Section 10, Reclaim Section 8, and Geogrid Section 7 most likely due to the additional gravel.
- Reclaim Section 4 had relatively high SN's in the first two years at 159 and 158 then dropped and settled to 138 in 2002 and 2003 and 140 in 2004. This Section has 95 mm (3.7 in) more gravel and 5 mm (0.2 in) more HMA than its counterpart, Reclaim Section 8. This section has significantly lower Structural Numbers than Geogrid Section 2 and significantly higher Structural Numbers than Undercut Section 10, Reclaim Section 8, and Geogrid Section 7.
- Geogrid Section 5 has Structural Numbers ranging from a high of 149 in 2001 to a low of 138 in 2003. Of all Geogrid Sections, Section 5 has the greatest amount of gravel at 700 mm (27.5 in) and the lowest amount of HMA at 95 mm (3.7 in). This Section is significantly weaker than

Geogrid Section 2 but stronger than Undercut Section 10, Reclaim Section 8, and Geogrid Section 7.

- Control Section 6 is similar in strength to Geogrid Section 5. Structural Numbers range from a high of 147 in 2001 to a low of 134 in 2003. This control section has less HMA and gravel then Control Section 3 and less stability. This section is significantly weaker than Geogrid Section 2 but similar in strength to the remaining sections.
- Geogrid Section 7 has the least amount of gravel and lowest Structural Numbers of all Geogrid Sections. Readings range from a high of 128 in years 2000 and 2001 to a low of 118 in 2003. Structurally this section is significantly weaker than Geogrid Sections 2, 9, and 5, Undercut Section 1, Control Section 3, and Reclaim Section 4.
- Reclaim Section 8 also has low Structural Numbers. Data ranges from a high of 136 in 2001 to a low of 122 in 2003. This section is significantly weaker than Geogrid Sections 2, 9, and 5, Undercut Section 1, Control Section 3, and Reclaim Section 4. This section has one of the lowest average gravel depths at 590 mm (23.2 in) which could account for the low Structural Numbers.
- Geogrid Section 9 has Structural Numbers ranging from a high of 161 in 2003 to a low of 143 in 2003. This section has similar average layer depths to Geogrid Section 2 with slightly less gravel. Analysis reveals this section is significantly stronger than Reclaim Sections 11 and 8, Undercut Section 10, and Geogrid Section 7.
- Undercut Section 10 has some of the lowest Structural Numbers with a high of 137 in 2001 to a low of 114 in 2003. Average gravel depths are the lowest of all sections at 420 mm (16.5 in) and average HMA depths are the highest at 165 mm (6.5 in). Statistically this section is structurally weaker than Geogrid Sections 2, 9, and 5, Undercut Section 1, Control Section 3, and Reclaim Section 4.
- Reclaim Section 11 has Structural Numbers ranging from a high of 154 in 2003 to a low of 132 in years 2002 and 2003. Analysis shows this section is structurally weaker than Geogrid Sections 2 and 9, and Undercut Section 1.

Figure 10 displays a correlation between average Structural Numbers and the average layer depth of gravel and HMA for the first two years. The pattern continued for the next three years with the exception of Control Section 3. It appears that the Structural Number decreased more in Section 3 than the remaining sections although this section has the greatest amount of gravel.

Geogrid Section 7, Reclaim Section 8, and Undercut Section 10 have the least amount of combined gravel and HMA. All three sections have similarly low Structural Numbers. Section 7 has relatively similar Structural Numbers over the five year period possibly due to the Geogrid adding stability to the gravel base. Section 8 with reclaim has slightly more gravel and higher Structural Numbers than sections 7 and 10. Section 10 has fluctuating Structural Numbers, beginning modestly in year one then spiking high the second year then dropping low for the next two years then settling to a level even with the first years reading. This could be attributed to the small amount of gravel supporting the roadway possibly allowing water saturation.

Spring Data Comparison

FWD deflections were collected in April 2000, May 2003, and April 2004. A graphical display of results is presented in Figure 11.

Data reveals that all Geogrid Sections have higher Structural Numbers than sections with similar or slightly heavier ASCG and HMA layer thicknesses.

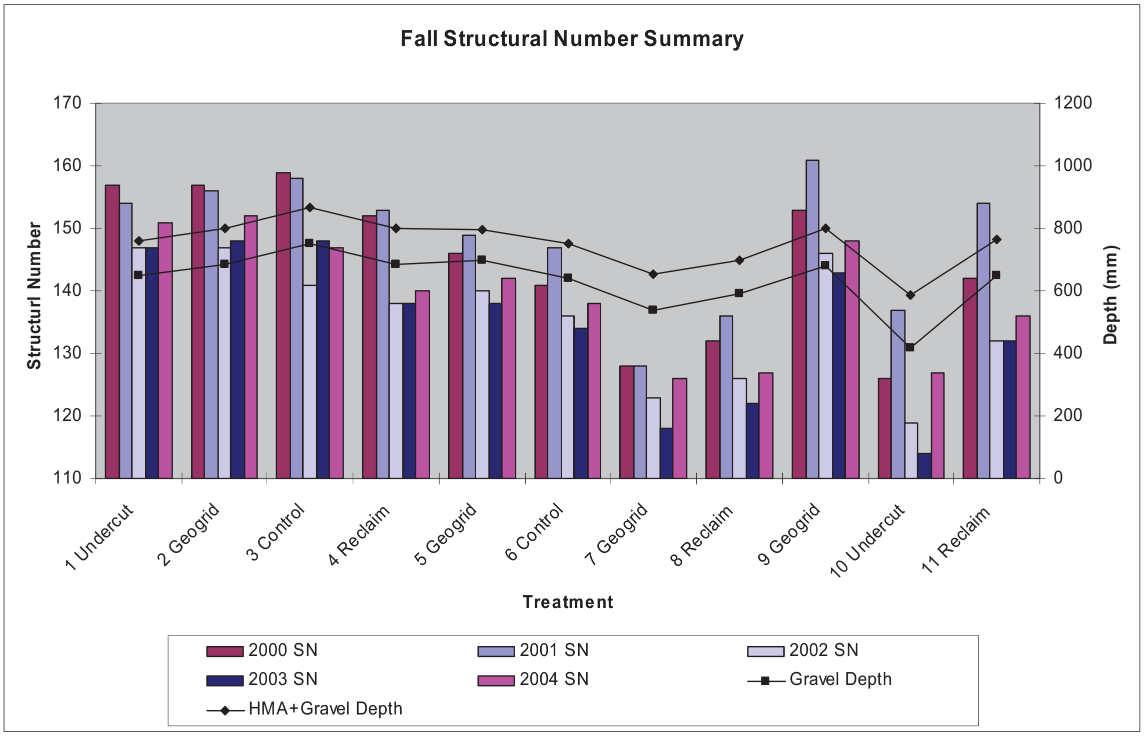


Figure 10: Mean Fall Structural Number Summary

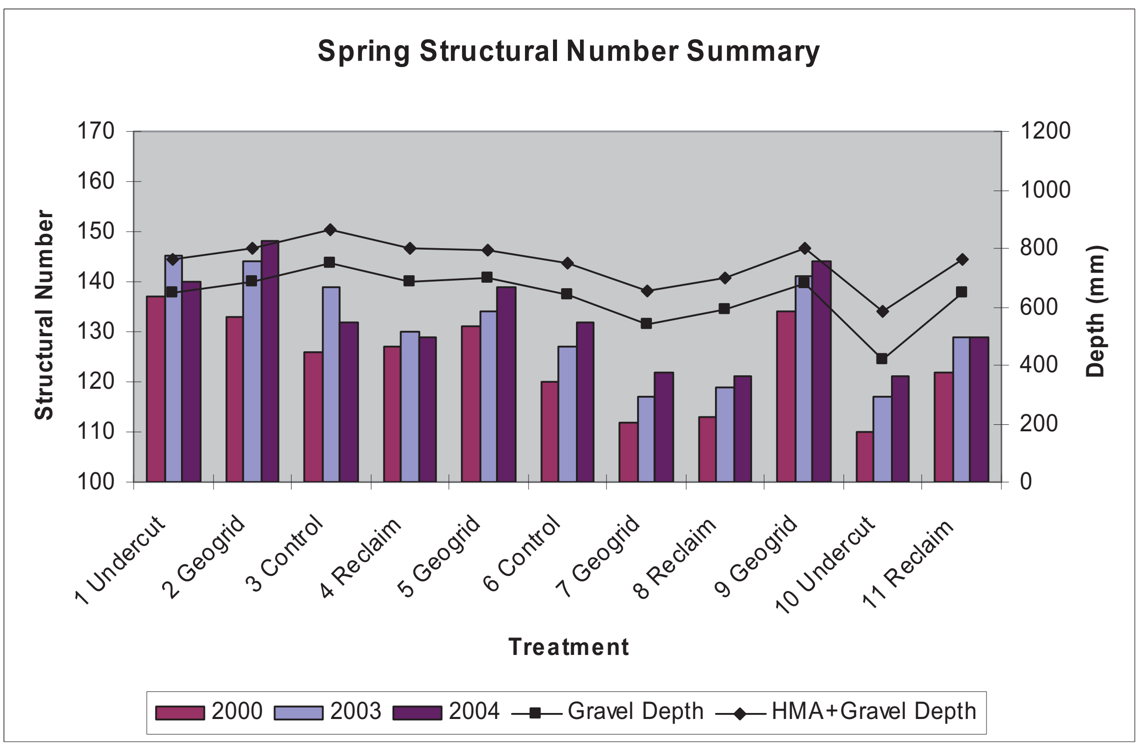


Figure 11: Mean Spring Structural Number Summary

Spring and Fall Data Comparison

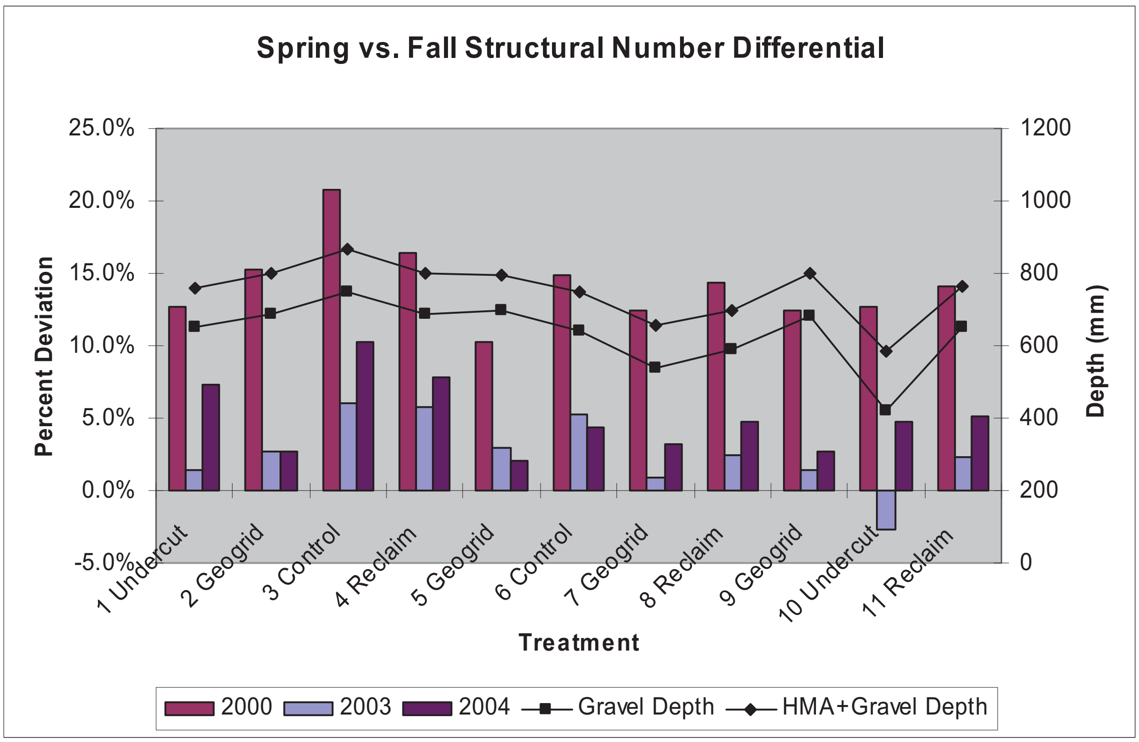
Average Structural Numbers collected in the spring season are compared to average readings in the fall season of the same year to determine how structurally sound a section or treatment is at its weakest condition. FWD data was collected in May of 2003 and April of 2004. Figure 12 contains a summary of test results. Unfortunately deflection data was not collected in the spring of years 2001 and 2002. Deflections in the spring of 2003 were collected too late in the season to be regarded as valid comparison data.

Geogrid Sections 5, 2, 9, and 7 have the lowest Structural Number differential in 2004 at 2.1, 2.6, 2.7, and 3.2 percent respectively. It appears that Geogrid may be increasing stability of the subbase gravel during spring conditions.

Control Section 3 has the highest differential at 10.7 percent followed by Reclaim Section 4 at 7.9, Undercut section 1 at 7.3, Reclaim Section 11 at 5.1, Reclaim Section 8 and Undercut Section 10 at 4.7, and Control Section 6 at 4.3 percent.
Figure 12: Spring vs. Fall Mean Structural Number Differential Summary

Section Uniformity

Section Uniformity is a pavement performance measurement utilizing FWD data to determine the



"uniformity" of a section. This procedure was developed by William Phang using LTPP pavement data collected on sections of roadways in North America. The results of Mr. Phangs initial efforts can be reviewed in the FHWA report titled "LTPP Data Insight – Section Uniformity Using FWD", Report No. FHWA-LTPP-NAR-96-01. The report states that the more uniform a section is, relative to its pavement deflection, the longer it will last. If a pavement is non-uniform the pavement response to load leads to larger tensile and shear stress in the adjacent elements in pavement layers resulting in particle rotation and volume expansion in unbound or loosely bound materials.

Section Uniformity is determined from pavement deflections recorded from the number one sensor located at the falling weight. The deflections are "normalized" to a force of 40 kN (9000 lbs) then temperature corrected to 20° C (68° F). An average and standard deviation are then calculated for each pavement section and the standard deviation is divided by the average to get a Coefficient of Variation (COV) as a percent. COV results are displayed in Table 3.

Coefficient of Variation is classified as follows:

COV < 10 %	Excellent
COV ≥ 10 % and < 15 %	Good
COV ≥ 15 % and < 20 %	Fair
COV ≥ 20 % and < 25 %	Fair – Poor
COV ≥ 25 %	Poor

Table 3: Section Uniformity

Section	Number of Tests	Mean #1 Deflection	Standard Deviation	C O V	Classification
1 Undercut	11	12.43	2.84	22.8%	FAIR-POOR
2 Geogrid	22	13.03	1.89	14.5%	GOOD
3 Control	10	16.13	2.22	13.8%	GOOD
4 Reclaim	24	15.38	2.87	18.7%	FAIR
5 Geogrid	23	14.58	2.07	14.2%	GOOD
6 Control	10	13.40	1.55	11.6%	GOOD
7 Geogrid	16	12.93	0.94	7.3%	EXCELLENT
8 Reclaim	21	14.32	2.40	16.8%	FAIR
9 Geogrid	19	13.06	2.13	16.3%	FAIR
10 Undercut	9	10.07	0.59	5.9%	EXCELLENT
11 Reclaim	21	14.14	2.08	14.7%	GOOD

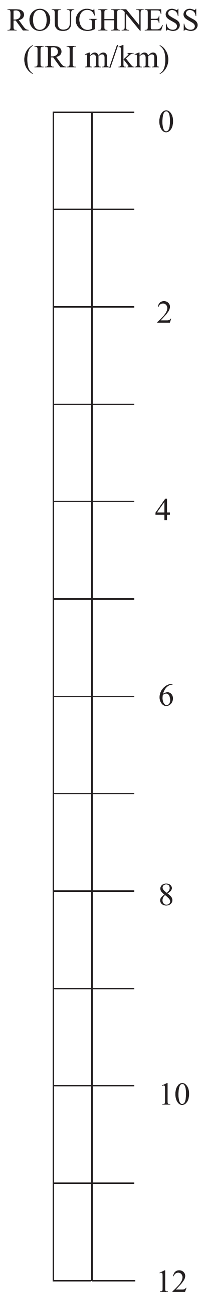
Results show that:

- Undercut section 10 and Geogrid Section 7 have one of the lowest number one sensor deflections and lowest standard deviations resulting in excellent COV ratings. It’s interesting that section 10 and 7 also have the lowest Fall Structural Number values and the least amount of load cracking. This suggests that even though the sections are structurally weaker they may last longer.
- Geogrid Sections 2 and 5, Control Sections 3 and 6, and Reclaim Section 11 are classified as good. These sections have higher mean deflections than most of the remaining sections but the standard deviation is low.
- Geogrid Section 9 and Reclaim Sections 8 and 4 have COV classifications of fair. All three sections exhibited signs of initial load cracking beginning in 2002.
- Undercut Section 1 has the highest COV at 22.8 percent most probably due to ledge under the roadway producing differential number one sensor deflections.

ARAN International Ride Index

Smoothness measurements were collected utilizing the departments Automatic Road Analyzer (ARAN). This is an ASTM Class I profile-measuring device that is capable of accurately measuring roadway smoothness. The ARAN utilizes lasers and accelerometers to measure the lateral profile of each wheel path at 12.5 mm (0.5 in) intervals then calculates and reports the profile as International Roughness Index (IRI) units at 20 meter (66 ft) intervals. Data was collected in 2000, 2001, 2002, 2003, and 2005. The ARAN was not available to collect data in 2004.

The IRI scale starts at zero for a roadway that is smooth and increases with positive numbers as roughness increases. Figure 13 displays typical IRI values with descriptions, referenced from Sayers, M.W., Gillespie, T.D., Paterson, W.D.O., “Guidelines for Conducting and Calibrating Road Roughness Measurements”, World Bank Technical Paper Number 46, 1986.



Ride comfortable over 120 km/h (75 mph). Undulation barely perceptible at 80 km/h (50 mph) in range 1.3 to 1.8. No depressions, potholes, or corrugations are noticeable; depressions < 2 mm/3 m (0.08 in / 10 ft). Typical high quality asphalt 1.4 to 2.3, high quality surface treatment 2.0 to 3.0.

Ride comfortable up to 100 - 120 km/h (60 -75 mph). At 80 km/h (50 mph), moderately perceptible movements or large undulations may be felt. Defective surface; occasional depressions, patches or potholes (e.g. 5 - 15 mm/3m (0.2 – 0.6 in/10 ft) or 10 - 20 mm/5m (0.4 – 0.8 in/16 ft) with frequency 2 - 1 per 50 m (164 ft)), or many shallow potholes (e.g. on surface treatment showing extensive raveling). Surface without defects; moderate corrugations or large undulations.

Ride comfortable up to 70 - 90 km/h (45 - 55 mph), strongly perceptible movements and swaying. Usually associated with defects; frequent moderate and uneven depressions or patches (e.g. 15 - 20 mm/3m (0.6 – 0.8 in/10 ft) or 20 - 40 mm/5m (0.8 – 1.6 in/16 ft) with frequency 5 - 3 per 50 m (164 ft)), or occasional potholes (e.g. 3 - 1 per 50 m (164 ft)). Surface without defects: strong undulations or corrugations.

Ride comfortable up to 50 - 60 km/h (30 – 35 mph), frequent sharp movements or swaying. Associated with severe defects: frequent deep and uneven depressions and patches (e.g. 20 - 40 mm/3m (0.8 – 1.6 in/10 ft) or 40 - 80 mm/5m (1.6 – 3.1 in/16 ft) with frequency 5 - 3 per 5 m (16 ft)), or frequent potholes (e.g. 4 - 6 per 50 m (164 ft)).

Necessary to reduce velocity below 50 km/h (30 mph). Many deep depressions, potholes and severe disintegration (e.g. 40 – 80 mm (1.6 – 3.1 in) deep with frequency 8 – 16 per 50 m (164 ft)).

Figure 13: Road Roughness Estimation Scale for Roads Paved with HMA

A summary of International Ride Index (IRI) readings for each section is displayed in Figure 14. A comparison of each section using 2005 IRI data and Tukey's Studentized Range was performed to determine if a section has significantly different IRI values. Results are displayed in Appendix B.

The majority of average IRI values in 2003 and all values in 2005 have increased. All readings are well within the range of comfortable ride at a speed of between 100 and 120 km/h (60 and 75 mph).

Roughness data reveals that:

- Undercut Section1 had the second highest IRI at 1.62 in 2003, a decrease of 9.5 percent from 2002. In 2005 the IRI increased 69.8 percent to 2.75, the greatest increase and highest reading of all sections. Roughness may have increased due to areas of ledge influencing frost movement within the section. This section is significantly rougher than Geogrid Sections 5, 2, and 9, and Undercut Section 10.
- Geogrid Section 2 had the lowest IRI in 2003 and second lowest in 2005. IRI readings have been consistently low and uniform throughout the study. This section is significantly smoother than Undercut Section 1 and Reclaim Sections 4, 11, and 8.
- Control Section 3 increased 3.1 percent in 2003 and 70.1 percent in 2005 to an IRI of 2.28. The increase in 2005 was the greatest increase of all sections. Statistical comparison shows no significant difference between sections.
- Reclaim Section 4 had a 9.4 percent increase in 2003 to 1.52 and a 61.8 percent increase in 2005 to an IRI of 2.46, the second highest. This section is significantly rougher than Reclaim Section 8 and Geogrid Sections 5, 9, and 2.
- Roughness increased 2.4 percent in 2003 and 32.0 percent in 2005 to an IRI of 1.69 in Geogrid Section 5. IRI values have been relatively uniform the first four years very similar to Geogrid Section 2. This section is significantly smoother than Undercut Section 1 and Reclaim Section 4.
- IRI numbers in Control Section 6 increased 11.8 percent in 2003 and 35.2 percent in 2005 to 1.92. There is no significant difference when comparing sections.
- Geogrid Section 7 has the least amount of gravel and highest IRI of all Geogrid Sections. IRI values increased 16 percent in 2003 and 26.0 percent in 2005 to an IRI of 2.28. The reduced gravel appears to contribute to the high IRI readings. There is no significant difference when comparing sections. IRI values in Reclaim Section 8 have been steadily increasing. Readings increased 7.1 percent in 2003 and 41.3 percent in 2005 to an IRI of 2.12. This section is significantly smoother than Reclaim Section 4 and rougher than Geogrid Section 2.
- Geogrid Section 9 is performing similar to Geogrid Sections 2 and 5. The IRI increased 4.8 percent in 2003 and 22.1 percent in 2005 to a value of 1.60. This section is significantly smoother than Undercut Section 1 and Reclaim Section 4.
- Undercut Section 10 has had consistently low IRI values. Readings decreased 1.5 percent in 2003 then increased the smallest amount of all sections at 14.6 percent in 2005 to the lowest value of 1.49. The extra 50 mm (2 in) of HMA surface could be contributing to the low IRI values. This section is significantly smoother than Undercut Section 1.
- Reclaim Section 11 IRI readings increased 6.5 percent in 2003 and 50.0 percent in 2005 to an IRI of 2.22. Smoothness has been very uniform the first three years. This section is significantly rougher than Geogrid Section 2.

Undercut Sections 1 and 10 are performing quite different. Section 1 has the highest IRI while Section 10 has the lowest. As mentioned earlier, ledge under the roadway of Section 1 may be contributing to the high IRI numbers and the increased amount of HMA in Section 10 may be responsible for low IRI values.

Three of the four Geogrid sections have similar IRI values. High IRI values in Section 7 may be linked to the small amount of ASCG.

Control Section 6 with less gravel and HMA has a smoother ride than Control Section 3.

Reclaim Section 8 has a smoother ride than Reclaim Sections 4 and 11 and has less gravel and HMA.

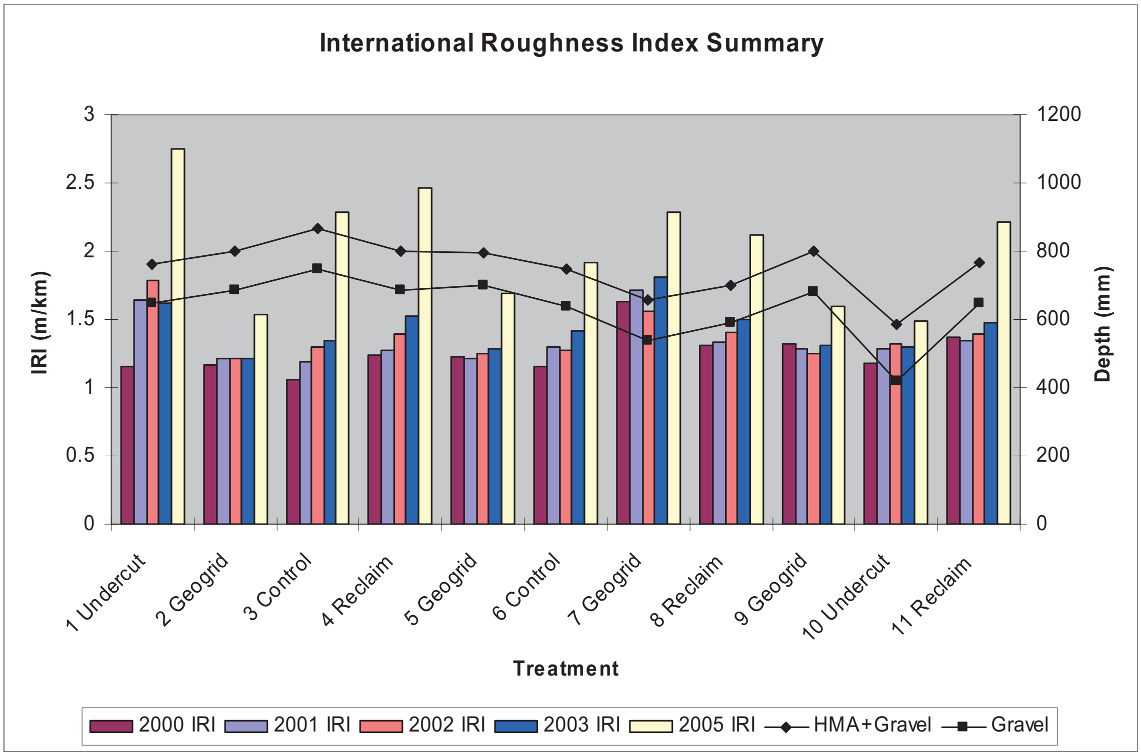


Figure 14: International Roughness Index Summary

ARAN Rut Depth

The ARAN test vehicle was utilized to measure rut depths. Measurements are recorded at each 20 m station to an accuracy of 1.5 mm (0.06 in).

Average rut depths for each section are displayed in Figure 15 and a statistical comparison of each section using Tukey's Studentized Range Test is included in Appendix C.

It appears that 2002 rut depth data is abnormally high in all sections and the reason for this is unknown. Because of this, 2002 rut data will be disregarded.

Rut depths in 2003 range from a low of 2.90 to a high of 4.05 mm (0.11 to 0.16 in). All sections with the exception of Control Section 3 had an increase in rut depth as compared to year 2001.

Year 2005 rutting ranged from a low of 2.90 to a high of 7.00 mm (0.11 to 0.28 in). All sections with the exception of Geogrid Sections 7 and 9 experienced an increase in rut depths compared to year 2003.

The following observations were made:

- Average rutting in Undercut Section 1 is very nominal. After the initial rut depth of 3.38 mm (0.13 in) in year 2000 the depth has increased very little with a low of 3.08 mm (0.12 in) in 2001 to a high of 3.50 mm (0.14 in) in 2005. Undercut Section 10 has minimal rutting also. Low rutting may be attributed to the removal and replacement of sub-standard aggregate base soils resulting in an aggregate base that has improved load bearing capacity. Statistical analysis reveals no significant difference between sections.
- Geogrid Section 2 has minimal rutting over the five year period. Rut depths range from a low of 2.93 mm (0.12 mm) in 2001 to a high of 3.58 mm (0.14 in) in 2000. Geogrid stabilized base

aggregate may be contributing to the reduced amount of rutting. Statistically, this section has significantly less rutting than Control Section 3 and Reclaim Section 4.

- Control Section 3 had mean rut depths of 2.90 mm (0.11 in) in 2003 and 7.00 mm (0.28 in) in 2005 an increase of 141.4 percent and the greatest increase of all sections. This is unusual considering the average depth of gravel is 750 mm (30 in). Section 3 has significantly deeper ruts than Geogrid Section 2 and Geogrid Section 9.
- Section 4 with Reclaim has the second highest average ruts at 5.35 mm (0.21 in) in 2005 and 3.87 mm (0.15 in) in 2003, an increase of 38.2 percent. Even though Geogrid Section 2 has the same amount of gravel and HMA, the average rut depth is 35 percent less. Section 4 has significantly higher rutting than Geogrid Section 9 and 2, and Reclaim Section 8.
- Geogrid Section 5 has the highest rut depth of all Geogrid sections at 3.94 mm (0.16 in), an increase of 21.8 percent from 2003. This section has the second greatest amount of gravel at 700 mm (27.5 in) and the least amount of HMA at a depth at 95 mm (3.75 in). The thin HMA layer depth may be attributing to the increased rutting. There is no significant difference between Section 5 and the remaining sections.
- The average rut depth in Control Section 6 increased 26.3 percent to a depth of 4.21 mm (0.17 in) in 2005. This is the fourth highest rut depth on the project. There is no significant difference between Section 6 and the remaining sections.
- Geogrid Section 7 has one of the lowest rut depths at 3.46 mm (0.14 in) in 2005, a decrease of 7.6 percent from year 2003. This section has one of the thinnest layers of ASCG at 540 mm (21.25 in) and it appears that Geogrid may be reducing the progression of rutting. There is no significant difference between Section 7 and the remaining sections.
- Reclaim Section 8 has the fifth highest amount of rutting at 4.00 mm (0.16 in), an increase of 4.8 percent from 2003. Statistically, Section 8 has significantly lower rutting than Reclaim Section 4.
- Geogrid Section 9 has the least amount of rutting at 2.90 mm (0.11 in) a decrease of 11.5 percent. This section has one of the heavier layers of ASCG base and HMA which, combined with Geogrid, may be distributing traffic loads more effectively thereby reducing the amount of rutting. Section 9 has significantly less rutting than Control Section 3 and Reclaim Section 4.
- Undercut Section 10 has the second lowest amount of rutting at 3.19 mm (0.13 in) an increase of 6.3 percent. This undercut section has been performing better than Undercut Section 1 possibly due to the heavy layer of HMA at 165 mm (6.50 in). Section 10 is not significantly different than the other sections.
- Reclaim Section 11 has 4.50 mm (0.18 in) of average rut depth. This is the third greatest amount of rutting. Section 11 is not significantly different than the other sections.

Geogrid and Undercut Sections have less rutting than the Control and Reclaim Sections. The replacement of sub-standard base material in the Undercut sections and the use of Geogrid may be contributing to the reduction of wheel ruts.

Geogrid Section 2 has 35 percent less rutting than Reclaim Section 4 although both sections have equal average layer depths of ASCG and HMA (685 and 115 mm respectively).

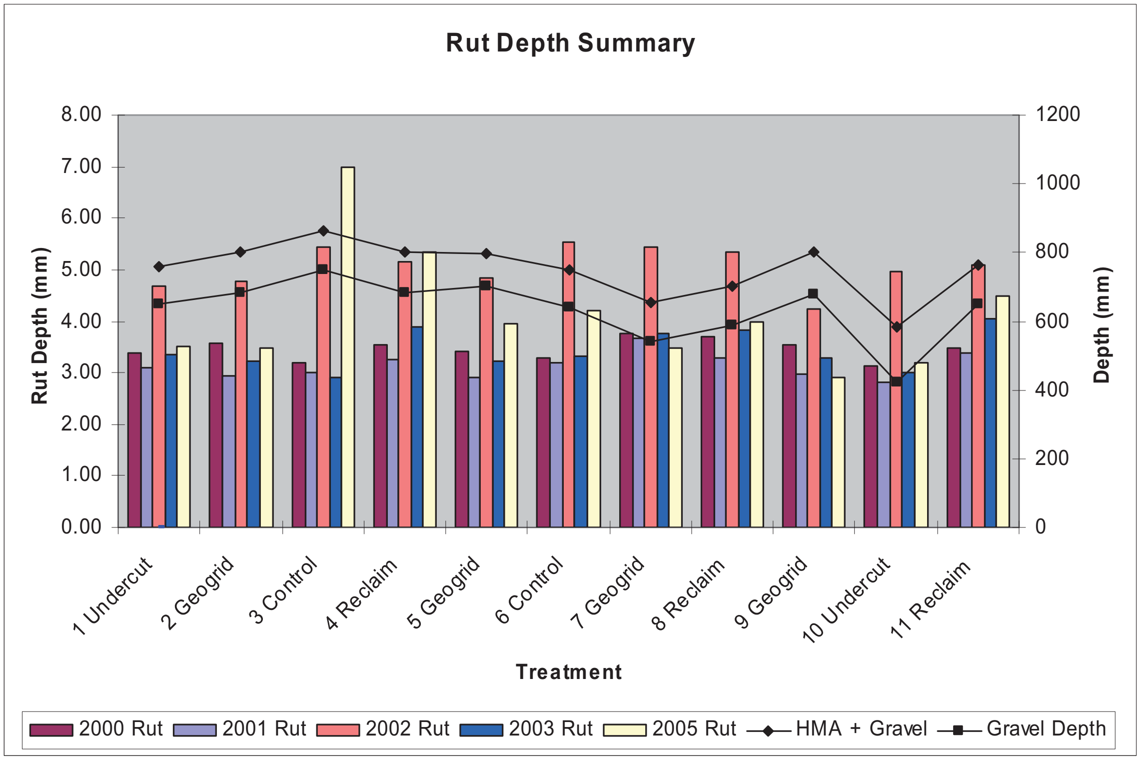


Figure 15: Rut Depth Summary

Cross Pipe Evaluation

A Rolling Dipstick (Photo 5) was utilized in an effort to monitor vertical movement of eight cross pipes.

Photo 5: Rolling Dipstick

Data was collected in April of 2003 and 2004 and again in October of 2003 and 2004 as part of the annual evaluation process. Three measurements were recorded in the right wheel path of each lane for a total of six profiles per cross pipe. Each profile is 20 meters (66 feet) in length centered over the cross pipe. Profiles are displayed as International Roughness Index values. Cross pipe locations and material layer depths are displayed in Table 4.

There will be two summaries of IRI readings, one to compare fall IRI readings to monitor overall cross pipe smoothness from 2000 to 2004, and another to compare spring and fall IRI readings within each year from 2000 to 2004 to monitor the amount of spring thaw displacement. Pipe displacement is displayed as the difference between the spring and fall IRI readings.

Fall IRI Comparison

Cross pipe IRI readings are summarized in Figure 16. Values in 2003 increased for all cross pipes with the exception of pipe numbers 3 and 4 located in Geogrid sections. IRI readings in 2004 increased for all cross pipes with the exception of pipe numbers 6, 7, and 8 located in Geogrid, Control, and Reclaim sections respectively. All IRI values are in the range of Comfortable Ride at 100 to 120 km/hr (60 to 75 mph).

Table 4: Cross Pipe Locations

			Material Layer Depth (mm)		
Number	Station	Treatment	HMA	Gravel	Total
1	2+314	Reclaim	115	685	800
2	2+957	Geogrid	95	700	795
3	3+110	Geogrid	95	700	795
4	3+432	Geogrid	115	540	655
5	4+221	Reclaim	110	590	700
6	5+162	Geogrid	120	680	800
7	5+349	Control	165	420	585
8	5+459	Reclaim	115	650	765

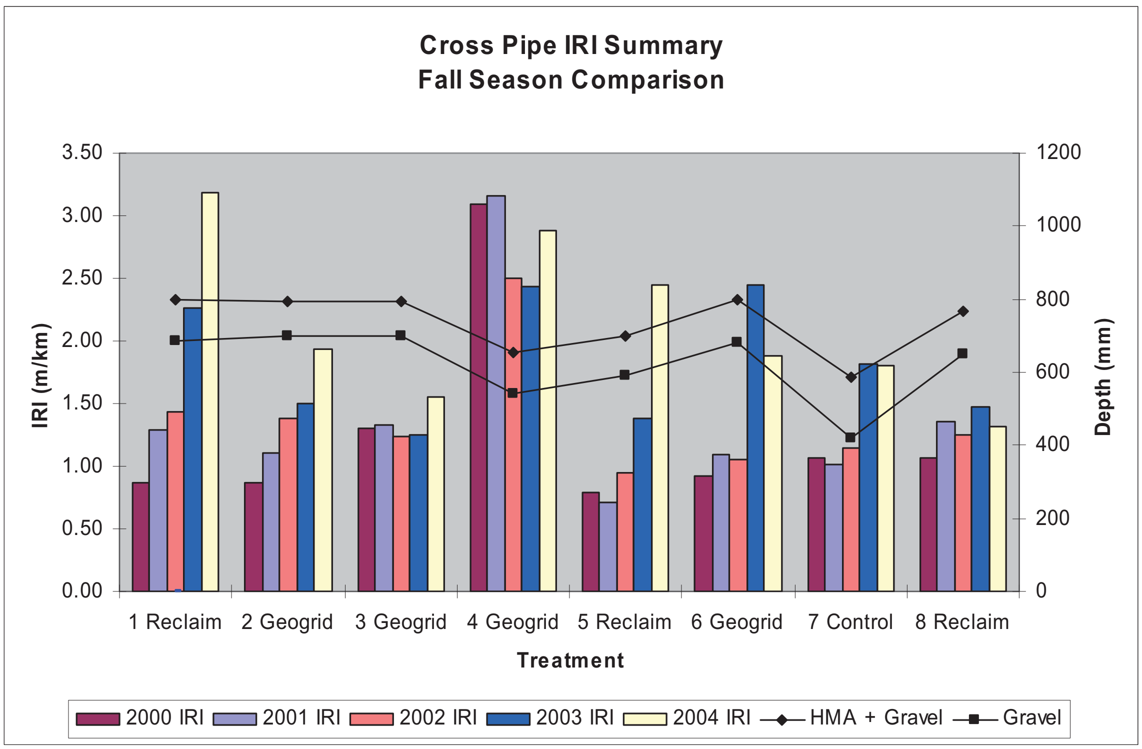


Figure 16: Fall Cross Pipe IRI Summary

The following observations were made:

- IRI values for Cross Pipe 1 have steadily increased each year. Two Transverse cracks with interconnecting cracks were observed at this location. This cross pipe has the roughest ride of all the pipe locations.
- Cross pipe 2, in a Geogrid section, also has steadily increasing IRI values although the rate of increase is markedly reduced compared to Cross Pipe 1. This pipe area has 15 mm (0.6 in) more gravel and 20 mm (0.8 in) less HMA than pipe number 1 and has no visible cracks. It appears that the Geogrid may be compensating for the reduced HMA layer thickness by distributing traffic loads more efficiently.

- Smoothness readings on cross pipe 3 are stable with IRI values between 1.24 and 1.33 m/km (78.57 and 84.27 in/mi) for the first four years then increasing 24 percent to an IRI of 1.55 m/km (98.21 in/mi) in 2004, the second lowest value of all cross pipes. This cross pipe has the same material layer thickness as pipe number 2 with no visible cracks. Geogrid may be reducing the amount of pipe movement.
- Pipe number 4 has the highest IRI readings for the first four years and has the second highest reading in year 2004. This cross pipe has one of the lowest amounts of gravel which could be contributing to the initial high IRI readings and sporadic readings thru the five year period. This cross pipe also has the greatest amount of transverse cracking as displayed in Photo 5.
- Cross pipe 5, in a reclaim section, was very stable and had the lowest IRI values for the first three years. Measurements increased 45 percent in 2003 to an IRI of 1.38 m/km (87.44 in/mi) then increased 77 percent in 2004 to the third highest IRI at 2.45 m/km (155.23 in/mi). There is one transverse crack centered over the pipe that is 12 mm (0.5 in) wide. This site has one of the lowest amounts of gravel which could be contributing the dramatic increase in IRI.
- Cross pipe 6 is placed in a Geogrid section with one of the heavier HMA and gravel layers. There is one closed transverse crack at this location. IRI readings were the third lowest for the first three years then increased 133 percent in 2003 to the highest IRI at 2.45 m/km (. In 2004 the IRI decreased 23 percent to the fourth lowest reading at 1.88. Perhaps over time the Geogrid will help reduce the effects of frost on this cross pipe.
- Cross pipe 7 has the heaviest layer of HMA over the thinnest layer of gravel. This pipe area has one transverse crack. IRI values were the third lowest the first three years then increased 57 percent in 2003 to an IRI of 1.81. The IRI remained about the same in 2004 at 1.80. The additional amount of HMA is most likely contributing the smoother ride numbers.
- Cross pipe 8 was placed in a Reclaim Section with 115 mm (4.5 in) of HMA over 650 mm (26 in) of gravel. One transverse crack that has opened to a width of 12 mm (0.5 in) was observed. IRI values are very stable with a low of 1.06 in 2000 to a high of 1.48 in 2003. The cross pipe is located in an area of the project with very good drainage which could be the reason for low IRI values.

Photo 5: Cross Pipe 4 Transverse Cracking

Spring vs. Fall IRI Comparison

Figure 17 displays the difference between IRI readings collected in the same year during the spring season when the roadway has the most movement and the fall season after the roadway has stabilized.

Data was collected between 2000 and 2004. Spring data in 2004 was collected after the frost had left the roadway resulting in unusually low IRI values. Because of this, IRI measurements for 2004 will be disregarded.

The following observations were made:

- Cross pipe 1 had the greatest amount of movement in 2000 then settled to a difference of about 1.00 from 2001 to 2003. This pipe was installed over an area of ledge which could be contributing to the pipe movement.

- Cross pipe 2 was installed in a Geogrid section. Differential movement was uniform in 2000, 2002, and 2003 at a difference of about 1.00 m/km. IRI readings in 2001 were collected near the end of April when the frost may have been partially out resulting in a small difference in IRI readings. This pipe has no visible cracks indicating that the Geogrid appears to reduce the amount of movement and cracking associated with spring thaw.

- Pipe 3 is also located in a Geogrid section with identical pavement and gravel depths as cross pipe 2. Pipe 3 has roughly 0.50 m/km greater differential movement than pipe 2. As with pipe 2 displacement is consistent for each year with the exception of 2001. No transverse cracks were observed.

- Cross pipe 4 is located in a Geogrid Section with one of the lowest amounts of gravel. This pipe has the greatest amount of differential movement and transverse cracking. It appears that Geogrid with a reduced gravel layer thickness does not reduce pipe movement.

- Cross pipe 5 in a Reclaim Section has the lowest amount of differential movement. There is one transverse crack that has opened to a width of 12 mm (0.5 in).

- Pipe number 6 in a Geogrid Section had the second largest differential movement in 2000 then a consistent movement of 0.5 m/km in the following years. There is one thin transverse crack at this location.

- Cross pipe 7 in a Control Section has a little more movement than pipe number 6. The first year yielded the third greatest difference of movement at 1.91 m/km then a difference of about 0.50 m/km the following years. One transverse crack with an average width of 6 mm (0.25 in) was observed. The heavy HMA layer thickness may be contributing to the reduced movement.

- Cross pipe 8 has the second greatest amount of movement. Years 2000, 2002, and 2003 had a difference of between 1.66 and 1.79 m/km. One 12 mm (0.5 in) transverse crack was observed.

Cross pipes 2, 3, and 6 in Geogrid Sections have no transverse cracks. This may be attributed to the Geogrid displacing frost movement thereby relieving pressure on the HMA. Cross pipe 4 in a Geogrid Section has the greatest amount of transverse cracking and the least amount of gravel subbase. It appears that the Geogrid doesn’t displace movement as well without the added thickness of gravel.

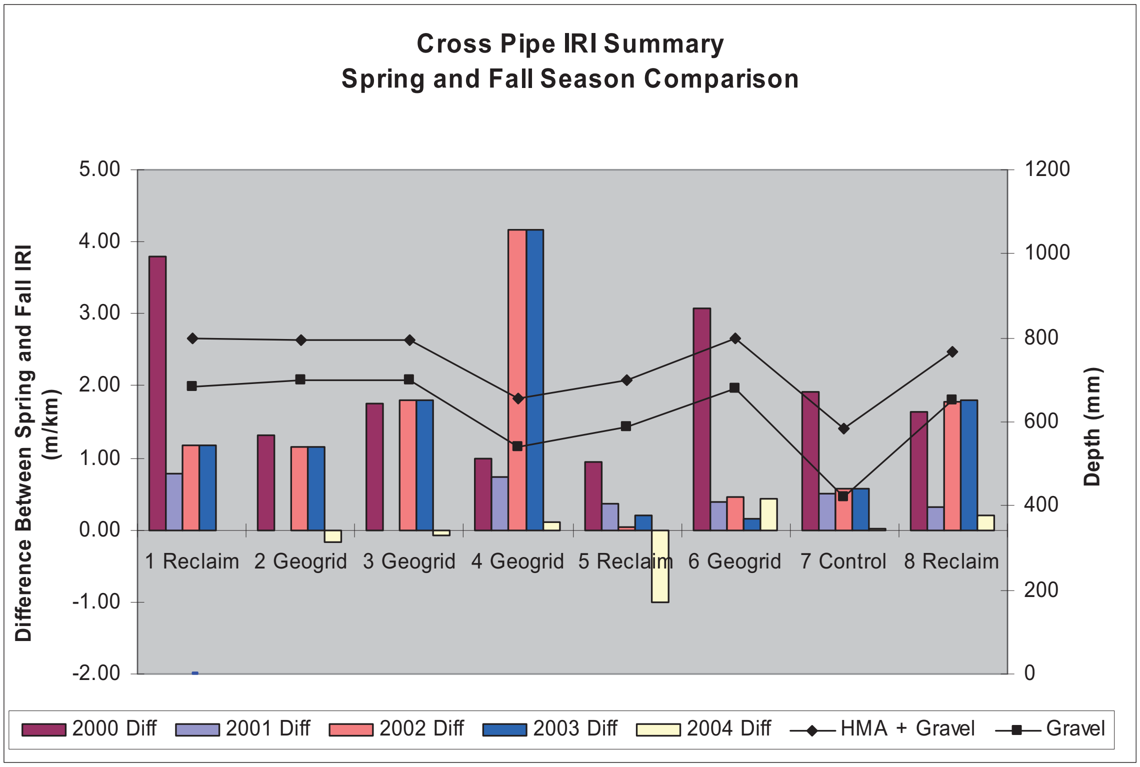


Figure 17: Spring vs. Fall Cross Pipe IRI Summary

Conclusion

Material layer depths influence rutting, cracking, and structural properties of the roadway. Each section, with the exception of Geogrid Section 2 and Reclaim Section 4, has variable depths of HMA and ASCG making it very difficult to evaluate the project. Future evaluations of projects such as this should be constructed with equal amounts of material layer depths to clearly evaluate test results.

All Geogrid Sections have less longitudinal and load associated cracking than Control and Reclaim Sections. Undercut Sections have similar amounts of cracking possibly due to removal of a portion of subgrade material and replacing with ASCG which has greater stability.

When comparing Structural Numbers of sections with similar HMA and subbase gravel depths, Geogrid sections have higher Structural Numbers that displace traffic loads more efficiently which in turn should extend roadway life.

Geogrid sections with suitable quantities of gravel have stabilized the roadway better than the remaining experimental sections. Geogrid manufactures claim the use of their products can reduce the amount of gravel necessary to stabilize the road. Geogrid Section 7, which has one of the thinnest layers of gravel, has low Structural Numbers but also has fewer longitudinal and load cracking. It appears that Geogrid may be distributing loads better thereby slowing roadway deterioration.

All Reclaim sections have more longitudinal and load cracking than the Geogrid and Undercut Sections. Reclaim does not appear to support the roadway as well and is not considered a viable material unless the reclaim is stabilized with another product or additional ASCG or HMA is used.

This project was constructed over an area that has been historically inadequate at supporting daily truck traffic due to poor drainage combined with poor soils under the roadway. During the five year evaluation period, the roadway has performed better than expected. Sections with Geogrid have reduced cracking, rutting, roughness and increased stability. The cost of utilizing Geogrid amounts to approximately $4.00 per square meter. Based on cost and performance, the use of Geogrid is recommended to give additional support to roadways that are susceptible to deformation. This is especially true during spring season when the roadway is at its weakest state.

Cross pipe areas with Geogrid and adequate ASCG have reduced cracking. Fall IRI data does not establish a significant advantage to using Geogrid, but Spring and Fall IRI differences do show that there is less cross pipe movement in the Geogrid sections. Based on the spring and fall comparison data it is recommended that Geogrid be used to reduce cross pipe movement on roadways that are susceptible to frost deformation.

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Dale Peabody
Director, Transportation Research Division

Other Available Documents:

Construction Report, December 1999
Interim Report - First Year, February 2001
Interim Report – Second Year, August 2002
Interim Report – Third Year, July 2004

Appendix A

Statistical Analysis of Structural Numbers
The SAS system using the GLM Procedure

Class Level Information

Class	Levels	Values
Section	11	10U 11R 1U 2G 3C 4R 5G 6C 7G 8R 9G

Number of observations 186

Dependent Variable: SN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	13963.18485	1396.31849	16.97	<.0001
Error	175	14398.40655	82.27661		
Corrected Total	185	28361.59140			

R-Square	Coeff Var	Root MSE	SN Mean
0.492327	6.514557	9.070645	139.2366

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Section	10	13963.18485	1396.31849	16.97	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Section	10	13963.18485	1396.31849	16.97	<.0001

Tukey's Studentized Range (HSD) Test for SN

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	175
Error Mean Square	82.27661
Critical Value of Studentized Range	4.61291

Comparisons significant at the 0.05 level are indicated by ***.

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
2G - 1U	2.682	-8.244	13.607	
2G - 9G	3.959	-5.307	13.226	
2G - 3C	5.091	-6.193	16.375	
2G - 5G	10.200	1.376	19.023	***
2G - 4R	11.716	2.983	20.449	***
2G - 6C	14.191	2.907	25.475	***
2G - 11R	16.162	7.136	25.189	***
2G - 10U	24.146	12.439	35.853	***
2G - 8R	24.543	15.517	33.570	***
2G - 7G	25.778	16.057	35.500	***
1U - 2G	-2.682	-13.607	8.244	
1U - 9G	1.278	-9.932	12.487	
1U - 3C	2.409	-10.518	15.336	
1U - 5G	7.518	-3.328	18.364	
1U - 4R	9.034	-1.739	19.807	
1U - 6C	11.509	-1.418	24.436	
1U - 11R	13.481	2.468	24.493	***
1U - 10U	21.465	8.166	34.763	***
1U - 8R	21.861	10.849	32.873	***
1U - 7G	23.097	11.508	34.685	***

Tukey's Studentized Range (HSD) Test for SN (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
9G - 2G	-3.959	-13.226	5.307	
9G - 1U	-1.278	-12.487	9.932	
9G - 3C	1.132	-10.427	12.691	
9G - 5G	6.240	-2.932	15.413	
9G - 4R	7.757	-1.329	16.842	
9G - 6C	10.232	-1.327	21.791	
9G - 11R	12.203	2.835	21.571	***
9G - 10U	20.187	8.215	32.159	***
9G - 8R	20.584	11.216	29.952	***
9G - 7G	21.819	11.780	31.858	***
3C - 2G	-5.091	-16.375	6.193	
3C - 1U	-2.409	-15.336	10.518	
3C - 9G	-1.132	-12.691	10.427	
3C - 5G	5.109	-6.098	16.316	
3C - 4R	6.625	-4.511	17.761	
3C - 6C	9.100	-4.132	22.332	
3C - 11R	11.071	-0.296	22.439	
3C - 10U	19.056	5.461	32.650	***
3C - 8R	19.452	8.085	30.820	***
3C - 7G	20.688	8.761	32.614	***
5G - 2G	-10.200	-19.023	-1.376	***
5G - 1U	-7.518	-18.364	3.328	
5G - 9G	-6.240	-15.413	2.932	
5G - 3C	-5.109	-16.316	6.098	
5G - 4R	1.516	-7.117	10.150	
5G - 6C	3.991	-7.216	15.198	
5G - 11R	5.963	-2.967	14.893	
5G - 10U	13.947	2.314	25.580	***
5G - 8R	14.344	5.414	23.274	***
5G - 7G	15.579	5.947	25.211	***
4R - 2G	-11.716	-20.449	-2.983	***
4R - 1U	-9.034	-19.807	1.739	
4R - 9G	-7.757	-16.842	1.329	
4R - 3C	-6.625	-17.761	4.511	
4R - 5G	-1.516	-10.150	7.117	
4R - 6C	2.475	-8.661	13.611	
4R - 11R	4.446	-4.394	13.287	
4R - 10U	12.431	0.866	23.995	***
4R - 8R	12.827	3.987	21.668	***
4R - 7G	14.063	4.513	23.612	***
6C - 2G	-14.191	-25.475	-2.907	***
6C - 1U	-11.509	-24.436	1.418	
6C - 9G	-10.232	-21.791	1.327	
6C - 3C	-9.100	-22.332	4.132	
6C - 5G	-3.991	-15.198	7.216	
6C - 4R	-2.475	-13.611	8.661	
6C - 11R	1.971	-9.396	13.339	
6C - 10U	9.956	-3.639	23.550	
6C - 8R	10.352	-1.015	21.720	
6C - 7G	11.588	-0.339	23.514	

Tukey's Studentized Range (HSD) Test for SN (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
11R - 2G	-16.162	-25.189	-7.136	***
11R - 1U	-13.481	-24.493	-2.468	***
11R - 9G	-12.203	-21.571	-2.835	***
11R - 3C	-11.071	-22.439	0.296	
11R - 5G	-5.963	-14.893	2.967	
11R - 4R	-4.446	-13.287	4.394	
11R - 6C	-1.971	-13.339	9.396	
11R - 10U	7.984	-3.804	19.772	
11R - 8R	8.381	-0.750	17.512	
11R - 7G	9.616	-0.202	19.434	
10U - 2G	-24.146	-35.853	-12.439	***
10U - 1U	-21.465	-34.763	-8.166	***
10U - 9G	-20.187	-32.159	-8.215	***
10U - 3C	-19.056	-32.650	-5.461	***
10U - 5G	-13.947	-25.580	-2.314	***
10U - 4R	-12.431	-23.995	-0.866	***
10U - 6C	-9.956	-23.550	3.639	
10U - 11R	-7.984	-19.772	3.804	
10U - 8R	0.397	-11.391	12.184	
10U - 7G	1.632	-10.696	13.960	
8R - 2G	-24.543	-33.570	-15.517	***
8R - 1U	-21.861	-32.873	-10.849	***
8R - 9G	-20.584	-29.952	-11.216	***
8R - 3C	-19.452	-30.820	-8.085	***
8R - 5G	-14.344	-23.274	-5.414	***
8R - 4R	-12.827	-21.668	-3.987	***
8R - 6C	-10.352	-21.720	1.015	
8R - 11R	-8.381	-17.512	0.750	
8R - 10U	-0.397	-12.184	11.391	
8R - 7G	1.235	-8.583	11.053	
7G - 2G	-25.778	-35.500	-16.057	***
7G - 1U	-23.097	-34.685	-11.508	***
7G - 9G	-21.819	-31.858	-11.780	***
7G - 3C	-20.688	-32.614	-8.761	***
7G - 5G	-15.579	-25.211	-5.947	***
7G - 4R	-14.063	-23.612	-4.513	***
7G - 6C	-11.588	-23.514	0.339	
7G - 11R	-9.616	-19.434	0.202	
7G - 10U	-1.632	-13.960	10.696	
7G - 8R	-1.235	-11.053	8.583	

Appendix B

Statistical Analysis of IRI
The SAS system using the GLM Procedure

Class Level Information

Class	Levels	Values
Treatment	11	10U 11R 1U 2G 3C 4R 5G 6C 7G 8R 9G

Number of observations 594

Dependent Variable: IRI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	60.4269911	6.0426991	8.40	<.0001
Error	583	419.2380210	0.7191047		
Corrected Total	593	479.6650121			

R-Square	Coeff Var	Root MSE	IRI Mean
0.125977	39.09292	0.848000	2.169192

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	10	60.42699108	6.04269911	8.40	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	10	60.42699108	6.04269911	8.40	<.0001

Tukey's Studentized Range (HSD) Test for IRI

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	583
Error Mean Square	0.719105
Critical Value of Studentized Range	4.57012

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1U - 4R	0.28007	-0.53340	1.09354	
1U - 7G	0.46115	-0.63587	1.55818	
1U - 3C	0.46900	-0.70435	1.64235	
1U - 11R	0.53000	-0.33205	1.39205	
1U - 8R	0.62050	-0.19970	1.44070	
1U - 6C	0.82833	-0.29042	1.94708	
1U - 5G	1.05250	0.16805	1.93695	***
1U - 9G	1.14100	0.14036	2.14164	***
1U - 2G	1.21842	0.31100	2.12585	***
1U - 10U	1.25375	0.00295	2.50455	***

Tukey's Studentized Range (HSD) Test for IRI (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
4R - 1U	-0.28007	-1.09354	0.53340	
4R - 7G	0.18108	-0.60224	0.96440	
4R - 3C	0.18893	-0.69814	1.07600	
4R - 11R	0.24993	-0.14157	0.64142	
4R - 8R	0.34043	0.05256	0.62829	***
4R - 6C	0.54826	-0.26521	1.36173	
4R - 5G	0.77243	0.33382	1.21104	***
4R - 9G	0.86093	0.21951	1.50234	***
4R - 2G	0.93835	0.45508	1.42162	***
4R - 10U	0.97368	-0.01356	1.96091	
7G - 1U	-0.46115	-1.55818	0.63587	
7G - 4R	-0.18108	-0.96440	0.60224	
7G - 3C	0.00785	-1.14481	1.16050	
7G - 11R	0.06885	-0.76482	0.90251	
7G - 8R	0.15935	-0.63097	0.94966	
7G - 6C	0.36718	-0.72984	1.46420	
7G - 5G	0.59135	-0.26546	1.44815	
7G - 9G	0.67985	-0.29644	1.65614	
7G - 2G	0.75727	-0.12323	1.63777	
7G - 10U	0.79260	-0.43881	2.02400	
3C - 1U	-0.46900	-1.64235	0.70435	
3C - 4R	-0.18893	-1.07600	0.69814	
3C - 7G	-0.00785	-1.16050	1.14481	
3C - 11R	0.06100	-0.87083	0.99283	
3C - 8R	0.15150	-0.74175	1.04475	
3C - 6C	0.35933	-0.81402	1.53269	
3C - 5G	0.58350	-0.36908	1.53608	
3C - 9G	0.67200	-0.38934	1.73334	
3C - 2G	0.74942	-0.22453	1.72337	
3C - 10U	0.78475	-0.51512	2.08462	
11R - 1U	-0.53000	-1.39205	0.33205	
11R - 4R	-0.24993	-0.64142	0.14157	
11R - 7G	-0.06885	-0.90251	0.76482	
11R - 3C	-0.06100	-0.99283	0.87083	
11R - 8R	0.09050	-0.31481	0.49581	
11R - 6C	0.29833	-0.56372	1.16039	
11R - 5G	0.52250	-0.00075	1.04575	
11R - 9G	0.61100	-0.09101	1.31301	
11R - 2G	0.68842	0.12721	1.24963	***
11R - 10U	0.72375	-0.30389	1.75139	
8R - 1U	-0.62050	-1.44070	0.19970	
8R - 4R	-0.34043	-0.62829	-0.05256	***
8R - 7G	-0.15935	-0.94966	0.63097	
8R - 3C	-0.15150	-1.04475	0.74175	
8R - 11R	-0.09050	-0.49581	0.31481	
8R - 6C	0.20783	-0.61237	1.02804	
8R - 5G	0.43200	-0.01898	0.88298	
8R - 9G	0.52050	-0.12943	1.17043	
8R - 2G	0.59792	0.10339	1.09245	***
8R - 10U	0.63325	-0.35954	1.62604	

Tukey's Studentized Range (HSD) Test for IRI (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
6C - 1U	-0.82833	-1.94708	0.29042	
6C - 4R	-0.54826	-1.36173	0.26521	
6C - 7G	-0.36718	-1.46420	0.72984	
6C - 3C	-0.35933	-1.53269	0.81402	
6C - 11R	-0.29833	-1.16039	0.56372	
6C - 8R	-0.20783	-1.02804	0.61237	
6C - 5G	0.22417	-0.66028	1.10862	
6C - 9G	0.31267	-0.68797	1.31331	
6C - 2G	0.39009	-0.51734	1.29751	
6C - 10U	0.42542	-0.82538	1.67622	
5G - 1U	-1.05250	-1.93695	-0.16805	***
5G - 4R	-0.77243	-1.21104	-0.33382	***
5G - 7G	-0.59135	-1.44815	0.26546	
5G - 3C	-0.58350	-1.53608	0.36908	
5G - 11R	-0.52250	-1.04575	0.00075	
5G - 8R	-0.43200	-0.88298	0.01898	
5G - 6C	-0.22417	-1.10862	0.66028	
5G - 9G	0.08850	-0.64084	0.81784	
5G - 2G	0.16592	-0.42912	0.76096	
5G - 10U	0.20125	-0.84524	1.24774	
9G - 1U	-1.14100	-2.14164	-0.14036	***
9G - 4R	-0.86093	-1.50234	-0.21951	***
9G - 7G	-0.67985	-1.65614	0.29644	
9G - 3C	-0.67200	-1.73334	0.38934	
9G - 11R	-0.61100	-1.31301	0.09101	
9G - 8R	-0.52050	-1.17043	0.12943	
9G - 6C	-0.31267	-1.31331	0.68797	
9G - 5G	-0.08850	-0.81784	0.64084	
9G - 2G	0.07742	-0.67961	0.83446	
9G - 10U	0.11275	-1.03363	1.25913	
2G - 1U	-1.21842	-2.12585	-0.31100	***
2G - 4R	-0.93835	-1.42162	-0.45508	***
2G - 7G	-0.75727	-1.63777	0.12323	
2G - 3C	-0.74942	-1.72337	0.22453	
2G - 11R	-0.68842	-1.24963	-0.12721	***
2G - 8R	-0.59792	-1.09245	-0.10339	***
2G - 6C	-0.39009	-1.29751	0.51734	
2G - 5G	-0.16592	-0.76096	0.42912	
2G - 9G	-0.07742	-0.83446	0.67961	
2G - 10U	0.03533	-1.03065	1.10131	
10U - 1U	-1.25375	-2.50455	-0.00295	***
10U - 4R	-0.97368	-1.96091	0.01356	
10U - 7G	-0.79260	-2.02400	0.43881	
10U - 3C	-0.78475	-2.08462	0.51512	
10U - 11R	-0.72375	-1.75139	0.30389	
10U - 8R	-0.63325	-1.62604	0.35954	
10U - 6C	-0.42542	-1.67622	0.82538	
10U - 5G	-0.20125	-1.24774	0.84524	
10U - 9G	-0.11275	-1.25913	1.03363	
10U - 2G	-0.03533	-1.10131	1.03065	

Appendix C

Statistical Analysis of Rut Depths
The SAS system using the GLM Procedure

Class Level Information

Class	Levels	Values
Treatment	11	10U 11R 1U 2G 3C 4R 5G 6C 7G 8R 9G

Number of observations 594

Dependent Variable: RutDepth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	401.489007	40.148901	4.49	<.0001
Error	583	5208.403249	8.933796		
Corrected Total	593	5609.892256			

R-Square	Coeff Var	Root MSE	RutDepth Mean
0.071568	66.89652	2.988946	4.468013

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	10	401.4890067	40.1489007	4.49	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	10	401.4890067	40.1489007	4.49	<.0001

Tukey's Studentized Range (HSD) Test for RutDepth

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	583
Error Mean Square	8.933796
Critical Value of Studentized Range	4.57012

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
3C - 4R	1.6456	-1.4821	4.7733	
3C - 11R	2.5000	-0.7844	5.7844	
3C - 6C	2.7917	-1.3441	6.9274	
3C - 8R	3.0031	-0.1453	6.1516	
3C - 5G	3.0600	-0.2860	6.4060	
3C - 1U	3.5000	-0.6357	7.6357	
3C - 2G	3.5263	0.0934	6.9592	***
3C - 7G	3.5357	-0.4635	7.5349	
3C - 10U	3.8125	-0.7691	8.3941	
3C - 9G	4.1000	0.3591	7.8409	***

Tukey's Studentized Range (HSD) Test for RutDepth (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
4R - 3C	-1.6456	-4.7733	1.4821	
4R - 11R	0.8544	-0.5279	2.2366	
4R - 6C	1.1460	-1.7223	4.0144	
4R - 8R	1.3575	0.3397	2.3753	***
4R - 5G	1.4144	-0.1084	2.9371	
4R - 1U	1.8544	-1.0140	4.7227	
4R - 2G	1.8807	0.1754	3.5860	***
4R - 7G	1.8901	-0.7777	4.5578	
4R - 10U	2.1669	-1.3138	5.6475	
4R - 9G	2.4544	0.1921	4.7166	***
11R - 3C	-2.5000	-5.7844	0.7844	
11R - 4R	-0.8544	-2.2366	0.5279	
11R - 6C	0.2917	-2.7468	3.3301	
11R - 8R	0.5031	-0.9255	1.9317	
11R - 5G	0.5600	-1.2631	2.3831	
11R - 1U	1.0000	-2.0385	4.0385	
11R - 2G	1.0263	-0.9518	3.0044	
11R - 7G	1.0357	-1.8141	3.8856	
11R - 10U	1.3125	-2.3096	4.9346	
11R - 9G	1.6000	-0.8744	4.0744	
6C - 3C	-2.7917	-6.9274	1.3441	
6C - 4R	-1.1460	-4.0144	1.7223	
6C - 11R	-0.2917	-3.3301	2.7468	
6C - 8R	0.2115	-2.6795	3.1024	
6C - 5G	0.2683	-2.8366	3.3733	
6C - 1U	0.7083	-3.2349	4.6516	
6C - 2G	0.7346	-2.4638	3.9331	
6C - 7G	0.7440	-3.0558	4.5439	
6C - 10U	1.0208	-3.3879	5.4295	
6C - 9G	1.3083	-2.2186	4.8353	
8R - 3C	-3.0031	-6.1516	0.1453	
8R - 4R	-1.3575	-2.3753	-0.3397	***
8R - 11R	-0.5031	-1.9317	0.9255	
8R - 6C	-0.2115	-3.1024	2.6795	
8R - 5G	0.0569	-1.5081	1.6218	
8R - 1U	0.4969	-2.3941	3.3878	
8R - 2G	0.5232	-1.2199	2.2662	
8R - 7G	0.5326	-2.1594	3.2246	
8R - 10U	0.8094	-2.6899	4.3087	
8R - 9G	1.0969	-1.1939	3.3877	
5G - 3C	-3.0600	-6.4060	0.2860	
5G - 4R	-1.4144	-2.9371	0.1084	
5G - 11R	-0.5600	-2.3831	1.2631	
5G - 6C	-0.2683	-3.3733	2.8366	
5G - 8R	-0.0569	-1.6218	1.5081	
5G - 1U	0.4400	-2.6649	3.5449	
5G - 2G	0.4663	-1.6124	2.5450	
5G - 7G	0.4757	-2.4449	3.3963	
5G - 10U	0.7525	-2.9255	4.4305	
5G - 9G	1.0400	-1.5155	3.5955	

Tukey's Studentized Range (HSD) Test for RutDepth (continued)

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1U - 3C	-3.5000	-7.6357	0.6357	
1U - 4R	-1.8544	-4.7227	1.0140	
1U - 11R	-1.0000	-4.0385	2.0385	
1U - 6C	-0.7083	-4.6516	3.2349	
1U - 8R	-0.4969	-3.3878	2.3941	
1U - 5G	-0.4400	-3.5449	2.6649	
1U - 2G	0.0263	-3.1721	3.2247	
1U - 7G	0.0357	-3.7641	3.8355	
1U - 10U	0.3125	-4.0962	4.7212	
1U - 9G	0.6000	-2.9270	4.1270	
2G - 3C	-3.5263	-6.9592	-0.0934	***
2G - 4R	-1.8807	-3.5860	-0.1754	***
2G - 11R	-1.0263	-3.0044	0.9518	
2G - 6C	-0.7346	-3.9331	2.4638	
2G - 8R	-0.5232	-2.2662	1.2199	
2G - 5G	-0.4663	-2.5450	1.6124	
2G - 1U	-0.0263	-3.2247	3.1721	
2G - 7G	0.0094	-3.0104	3.0292	
2G - 10U	0.2862	-3.4711	4.0435	
2G - 9G	0.5737	-2.0946	3.2420	
7G - 3C	-3.5357	-7.5349	0.4635	
7G - 4R	-1.8901	-4.5578	0.7777	
7G - 11R	-1.0357	-3.8856	1.8141	
7G - 6C	-0.7440	-4.5439	3.0558	
7G - 8R	-0.5326	-3.2246	2.1594	
7G - 5G	-0.4757	-3.3963	2.4449	
7G - 1U	-0.0357	-3.8355	3.7641	
7G - 2G	-0.0094	-3.0292	3.0104	
7G - 10U	0.2768	-4.0041	4.5577	
7G - 9G	0.5643	-2.8015	3.9301	
10U - 3C	-3.8125	-8.3941	0.7691	
10U - 4R	-2.1669	-5.6475	1.3138	
10U - 11R	-1.3125	-4.9346	2.3096	
10U - 6C	-1.0208	-5.4295	3.3879	
10U - 8R	-0.8094	-4.3087	2.6899	
10U - 5G	-0.7525	-4.4305	2.9255	
10U - 1U	-0.3125	-4.7212	4.0962	
10U - 2G	-0.2862	-4.0435	3.4711	
10U - 7G	-0.2768	-4.5577	4.0041	
10U - 9G	0.2875	-3.7531	4.3281	
9G - 3C	-4.1000	-7.8409	-0.3591	***
9G - 4R	-2.4544	-4.7166	-0.1921	***
9G - 11R	-1.6000	-4.0744	0.8744	
9G - 6C	-1.3083	-4.8353	2.2186	
9G - 8R	-1.0969	-3.3877	1.1939	
9G - 5G	-1.0400	-3.5955	1.5155	
9G - 1U	-0.6000	-4.1270	2.9270	
9G - 2G	-0.5737	-3.2420	2.0946	
9G - 7G	-0.5643	-3.9301	2.8015	
9G - 10U	-0.2875	-4.3281	3.7531	