Application of Flax Straw in Subgrade Strengthening

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Abstract

Due to the recent developments affecting the transportation systems in Saskatchewan such as rationalization of the grain handling facilities, economic diversification, increased value-added production, abolishment of the Crow Rate, consolidation of railway branch lines and introduction of bigger truck configurations, Saskatchewan Department of Highways and Transportation (DHT) has been struggling to provide a desirable level of service on its thin membrane structure (TMS) road network. This has occasionally resulted in less than acceptable and unsafe road surface conditions.

In order to address some of these problems, DHT began researching innovative TMS strengthening techniques. One such technique involves rotomixing the existing asphalt oil surface and incorporating mulched flax straw to increase the subgrade tensile strength. Flax straw was chosen primarily because of its tough fiber properties and slow biodegradability caused by the fiber oils that act as decomposition inhibiting agents. In the summer of 2000, DHT installed three test sections using flax straw as a primary subgrade strengthening material on a section of the provincial Highway 19 near Strongfield, approximately 100 kilometers south of Saskatoon.

The main purpose of this paper is to describe the construction procedures used in incorporating flax straw into the subgrade on Highway 19 and share DHT experience in using this agricultural waste by-product as a subgrade strengthening material. The field test results and performance findings are also discussed. The research methodology used considers three main elements: 1. pre-construction investigation including road surface conditions, preliminary field and lab tests; 2. construction procedures used in installing the flax straw test sections; and 3. discussion of post-construction field and lab test results.

Key terms: thin membrane structure (TMS), desirable level of service, rotomixing, flax straw, subgrade strengthening, construction procedures, field and lab tests, performance findings.

1.0 Introduction

Saskatchewan Department of Highways and Transportation (DHT) is currently responsible for 26,267 kilometers of year-round provincial highways and 131 kilometers of seasonal ice roads (DHT 2003). Of those, 13,696 kilometers are classified as structural pavements that are further subdivided into granular structures with sealed surface (4,764 km) and asphalt concrete pavement structures (8,932 km). There are also 12,440 kilometers of non-structural roads in the province, mainly 6,763 kilometers of dust-free thin membrane structure roads (TMS) and 5,677 kilometers of gravel surface roads.

Majority of the TMS road network was built in the late 1960's and early 1970's when asphalt prices were relatively low. TMS roads were designed to provide a dust free surface in rural Saskatchewan and support light vehicles and smaller farm trucks at that time. In addition, DHT had also adopted road maintenance strategies that were relatively successful in providing an adequate level of service to the traveling public on the TMS road network. However, due to the recent developments affecting the transportation systems in Saskatchewan such as rationalization of the grain handling facilities, economic diversification, increased value-added production, abolishment of the Crow Rate, consolidation of railway branch lines and introduction of bigger truck configurations, DHT has been struggling to provide a desirable level of service on its TMS road network. This has occasionally resulted in less than acceptable and unsafe road surface conditions as illustrated in Figure 1.

As the pressures on the TMS road system increased DHT began doing more conventional structural overlays on some of the roads that warranted those improvements. Conventional overlays consist of building the structure up by laying down and compacting subbase, base and surface aggregate seal or asphalt concrete mat. This type of treatment has been proven adequate in addressing road structural issues. Engineering principles behind structural strengthening are also well understood and engineering design procedures well developed. Figure 2 (Stack 2000) illustrates the difference between a TMS non-structural road and a fully structural road.

Conventional strengthening construction practices employed by the Saskatchewan Road Builders and the DHT maintenance crews usually hold good and reliable results. However, increased costs of the treatment has become an issue in a tight budget. Furthermore, road widening is often required when this type of treatment is applied because the road structure is raised up, thus resulting in a narrower top surface. Conventional construction methods also highly depend on adequate supply of crushed aggregate material used in road construction (subbase, base and seal or asphalt concrete mix). Aggregate materials are a non-renewable natural resource with finite supply. This is especially becoming evident in aggregate scarce areas where the long aggregate hauls increase the costs of preserving the road network in a desired condition.

Therefore, in order to address some of these problems, DHT began researching innovative TMS strengthening techniques. As a result of its continuous search for more cost effective construction methods DHT has considered various preservation and upgrading techniques such as different cement products, lime, flyash, geotextiles, geogrids, natural fibers such as flax straw, emulsified bitumen, and tall oil (Berthelot and Gerbrandt 2003). Most of the above treatments presume a structural “build down” approach or a combination of build down and conventional build up approaches. Consequently, Highway 19 between Highways 44 and 15 was used to construct over 30 field test sections to compare the conventional and non-conventional construction methods. The Highway 19 test sections layout is illustrated in Figure 3 (Stack 2000) with detailed description provided in Table 1.

As part of this research one such technique evaluated was the rotomixing of the existing asphalt oil surface and incorporation of mulched flax straw to increase the subgrade tensile strength. The main purpose of this paper is to describe the construction procedures used in incorporating flax straw into the subgrade on the provincial Highway 19 and share DHT experience in using this agricultural waste by-product as a subgrade strengthening material.

2.0 Flax Straw as a Strengthening Material

Flax is usually grown for its oil seeds used in the production of various edible and non-edible products such as linseed oil. This oil serves as an ingredient in the production of paints and low quality paper. Flax straw left in the fields after harvest, on the other hand, have found a very limited application. It is usually burnt in the field because of its too tough a fiber for agricultural activities to easily handle it. Therefore, no wonder farmers in Western Canada are almost willing to give away flax straw to anybody interested in taking it (Saskatchewan Flax Development Commission). Furthermore, many factors such as the amount of litter and weed in the straw as well as height, fiber content and dimensions of the straw pieces impact the quality and potential application of the straw (Government of Saskatchewan – Department of Agriculture).

Despite of some of these apparent problems with flax straw attempts have been made to apply it in road strengthening. Charleson and Widger (1989), for example, describe a study on the provincial Highway 307 in west central Saskatchewan where a geocomposite consisting of mulched flax straw and sand was used to stabilize and reinforce the shoulders of a sand subgrade. In addition, some attempts have also been made to use flax pulp mill liquor as a lignosulfonate component in road construction stabilizers (Environmental Management Centre).

For the purpose of this project, flax straw was chosen as a subgrade strengthening material primarily because of its tough fiber properties and slow biodegradability caused by the fiber oils that act as decomposition inhibiting agents. In the summer of 2000, DHT installed three test sections using flax straw as a primary subgrade strengthening material on a section of provincial Highway 19 near Strongfield, approximately 100 kilometers south of Saskatoon. The test sections varied in percent of the flax straw incorporated in the soil and the thickness of the overlaying crushed base aggregate layer.

3.0 Pre-construction Site Investigation

Road surface condition data were collected in the fall of 1999 as part of the DHT annual asset management data collection process. The following surface distresses were observed on Highway 19-06 from kilometer 22.5 to kilometer 27.1 prior to the construction: 1.) rutting – good (overall score slight - S). Over 90% of manual rutting measurements (using a straight edge bar and a calibrated wedge) were between 5 and 10 mm which is identified as slight in the DHT asset management rating protocol. The remaining 10% were measured as less than 5 mm which is classified as non-existent rutting; 2.) International Roughness Index (IRI) – poor (4 mm / m). This is considered as very rough in DHT asset management; 3.) Cracking – poor (overall score Extreme - X). Figure 4 illustrates typical road surface conditions on Highway 19-06 before construction.

Grain size distribution of core soil samples taken from the subgrade and mat from various locations throughout the test sites on Highway 19-06 is illustrated in Figure 5 (Stack 2000). Course grain size points are obtained from sieve analysis of the collected soil samples and finer grain size points come from hydrometer lab analysis. Standard Proctor moisture-density tests performed on the Highway 19-06 subgrade reveal optimum moisture content from 16.2% to 16.6% and optimum density of 1,765 to 1,865 kg/m^3. In addition, it was observed from Atterburg limit soil characterization that the subgrade is mainly composed of clay and is highly plastic.

4.0 Construction of Test Sections

This paper will look at the construction and performance of five different segments constructed on Highway 19 as illustrated in Table 2.

Three of the those segments were constructed using flax straw as a primary subgrade strengthening material. The other two segments were constructed using DHT conventional base overlay strengthening methods. These five segments provide a basis for further performance evaluation of the flax straw test sections and comparison with the conventional strengthening method.

Test sections were constructed using a typical cold in-place recycling methodology. Equipment used for rotomixing in this project consisted of road reclaimer, packers (vibratory pad and sheepsfoot), motor grader and water truck. In addition, agricultural tap grinder, tractor and tractor with bale lift fork were used for mulching flax straw bales. During base aggregate overlay, tandem trucks, water trucks, motor graders and packers were utilized.

4.1 Flax Straw Test Sections

The flax straw test segment #92 was constructed by first processing the flax straw bales through the tap grinder into smaller stem pieces (5 to 10 cm long) as seen in Figure 6 and then spreading it across the entire road width as illustrated in Figure 7. This procedure resulted in the flax straw fibers being somewhat unevenly spread. For this test segment the amount of flax straw added was based on 0.5% of soil weight. The flax straw was then rotomilled into 150 mm of subgrade with the road reclaimer as shown in Figure 8. The result was a geocomposite consisting of randomly oriented flax straw fibers, subgrade soil material and old asphalt mat. Figure 9 illustrates this mix. Rotomixed material was then bladed off using the motor graders, water was sprayed down on the road, material was put back and compacted until no further settlement was apparent and the particles were well keyed into place. Figures 10, 11 and 12 illustrate those construction procedures. The segment was left like this for few weeks to be further compacted under traffic. The final step in the construction was to lay down 100 mm of base aggregate material and compact it as presented in Figure 13. High float emulsion (HF-250) was sprayed on top of the compacted base layer and graded aggregate seal (total thickness of 25 mm) was added as a final surface as seen in Figure 14.

The flax straw test segment #94 was constructed in the same way as segment #92. The only difference was in the amount of flax straw rotomixed into the subgrade (0.3% of soil weight).

The third flax straw test segment #95 was first pre-milled to the depth of 150 mm and than lightly compacted. After that the same procedure was followed as for the construction of the segment #94 with the exception of laying down 150 mm of base aggregate material.

4.2 Conventional Base Overlay Sections

Segments #33 and #93 were constructed for the comparison purposes. Segment #33 was simply overlaid with 100 mm of base aggregate material and 25 mm graded aggregate seal installed as a top wearing course. On the other hand, segment #93 was first rotomixed to a depth of 150 mm and then tightly compacted. No subgrade strengthening material was added during this process. Once properly compacted it was then overlaid with 100 mm of base aggregate material with 25 mm graded aggregate seal installed as a final surface wearing course.

5.0 Test Sections Performance Evaluation

5.1 Traffic Data

Highway 19 is considered a low volume highway according to the DHT functional classification system. Table 3 shows the Average Annual Daily Traffic collected for this highway from 1999 to 2003. It is generally estimated that truck traffic is about 11% of the total traffic. Traffic trends do not significantly change over the years.

5.2 Road Surface Distresses

Every year in the fall, after all planned construction and preservation work has been completed or is near completion, DHT evaluates its road network conditions by collecting current road surface condition data. The condition rating is done according to the surface condition rating manuals that ensure the collection of high quality data and measurement procedures (DHT 2000). The following distresses are used to evaluate the field performance of the constructed test sections: International Roughness Index (IRI), cracking and rutting.

DHT has just recently moved to a fully automated data collection system. This system consists of the three major functional components used for measuring cracking, rutting and IRI. These major components and their accompanying hardware and software are described in Lazic (2003). This switch has resulted in different measurement methods and units of measurements compared to the old manual (rutting and cracking) and automated (IRI) distress scores. Because of that it may not be possible to follow the performance of the installed test sections on a temporary basis. However, direct comparison of the performance of different test sections is possible in the same year. Table 4 presents measured surface condition data from 1999 to 2003.

5.3 Benklemen Beam Test

In addition to the road surface conditions, DHT staff also regularly collect Benklemen Beam data on Highway 19 that show the deflection of the road structure under static loading of 80 kN on the rear dual axle of a single axle truck. Once the truck moves away a 3.65 m long beam measures the rebound of the road structure. Measurements are taken every 50 meters and then, average values are calculated for each segment as presented in Table 5. No data are available for 1999 and 2000 for the project limits from 23.39 km to 25.04 km. The performance of the road structure is estimated based on the deflection numbers. Essentially, it can be approximated that the smaller the deflection the more structurally sound the road. However, when the comparison is made over a few year span environmental conditions should also be considered especially the amount of precipitation in a given year.

5.4 Ground Penetrating Radar (GPR) Measurements

Furthermore, to help fully appreciate and understand different strengthening strategies implemented on Highway 19-06, DHT contracts out data collection of dielectric permittivity and surface deflections under dynamic loading to Pavement Scientific International (PSI). Ground Penetrating Radar (GPR) is used to measure surface and subgrade dielectric permittivities as well as layer mean thickness. In addition, Falling Weight Deflectometer (FWD) measures peak surface deflections and is also collected by PSI.

An air coupled GPR emits and receives pulses of electromagnetic energy through a medium such as road structure and subgrade at highway speeds. As the radar signal reflects off materials the antennas ‘echo locate' materials under ground based on different electromagnetic conductivity and dielectric permittivity of each layer within a soil matrix. This reflection is then processed and displayed along a horizontal line with the reflection time related to the depth of a soil layer. GPR penetrates to a depth of 0.5 to 1 meter. Table 6 (PSI 2003) shows mean surface and subgrade dielectric permittivity collected in 2001 and 2002.

5.5 Falling Weight Deflectometer (FWD) Results

The FWD is used for non-destructive testing of the pavement strength. It operates on a principal of loading the pavement in a controlled manner such that the load pulse resembles that from moving traffic. A dynamic load is generated by dropping a mass from a variable height onto a loading plate. The magnitude of the load and the pavement deflection are measured by a load cell and geophones equally spaced away from the loading point. The recorded shape of the surface is often called the "Deflection Bowl". The magnitude of the applied load is also recorded. Table 7 (PSI 2003) captures mean peak surface deflections collected on the test sections.

5.6 Dynamic Cone Penetrometer (DCP)

DCP data were collected in 2000 immediately after the construction. The DCP test consists of dropping an 8 kg hammer on a cone attached to a 16 mm diameter metal rod from a 575 mm height. The depth of penetration in millimeters is recorder after each hammer drop. Figures 15 – 19 show the penetration plotted against the hammer drops (Morrison 2001). This is a quick field test used to measure the relevant strength of the upper road layers.

6.0 Discussion of the Field Results and Test Segments Performance

From the surface data collected over a five year period it can be argued that the flax straw segments have slightly outperformed the other two conventionally strengthened segments. This is specially evident in the case of segment #95. However, the evidence is not strong enough to conclusively suggest that the flax straw added to the subgrade had indeed contributed to the increase in the tensile strength of the test segments.

The results from Benklemen beam testing reveal that the flax straw test segments exhibit somewhat lower deflection under static loading. Even though this phenomenon is pretty consistent over a three year period of data collection it is, however, not significant enough to be considered conclusive.

GPR mean surface and subgrade dielectric permittivity data show that the flax straw segments #94 and #95 perform slightly better than the two conventional segments. The conventional segment #33 consistently has the worst values of the five test segments.

Deflection measurements collected in 2002 although fairly close across all five segments show that the two conventional segment marginally outperformed the flax straw test sections.

Similarly, the conventional segments, especially segment #33, perform somewhat better structurally compared to the flax straw segments.

7.0 Summary

Flax straw provides a source of natural fibers suitable for the application in road strengthening. This is mainly contributed to the tough properties of the fibers and slow biodegradability. During the construction procedure the flax straw is mulched into smaller stem pieces and rotomixed with in situ materials such as the existing asphalt mat and subgrade material. This creates a geocomposite consisting of the in situ material and randomly oriented natural flax straw fibers.

Despite data available from the various data collection methods the results are inconclusive as to the real performance of the flax straw test segments compared to the conventionally strengthened test sections. At best, there might be only some marginal advantages of having the natural fibers mixed into the subgrade. On the other hand, if a road agency is already rotomixing its existing road, then adding mulched flax straw can only be a benefit because it can be essentially obtained from the farming community at almost no extra cost.

Saskatchewan Department of Highways and Transportation continues to monitor all installed test sections. It is expected that more insight into the performance of the flax straw test sections will be gained as more information becomes available in the future.

8.0 References

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9.0 Internet sources

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Government of Saskatchewan – Department of Agriculture: www.agr.gov.sk.ca

Environmental Management Centre: www.emcentre.com

Figures

Figure 1 – Surface Failures on TMS Highway 19

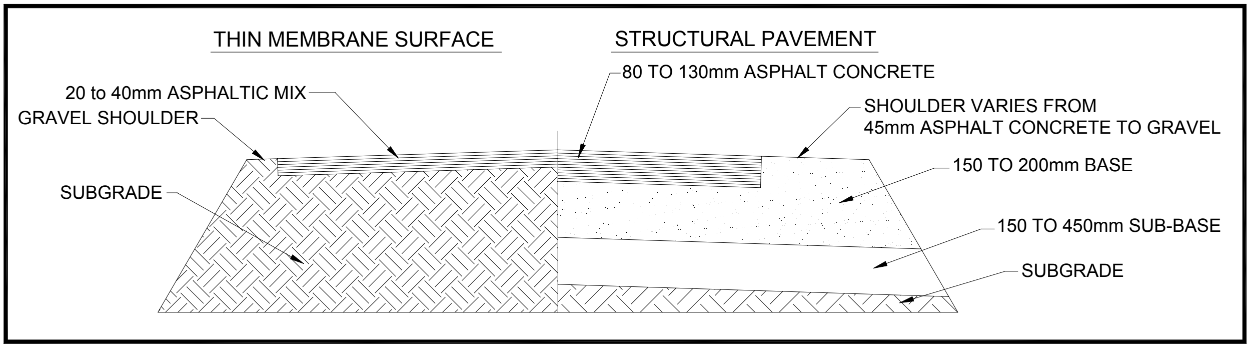

Figure 2 - Comparison of a Typical Thin Membrane Surfaced Cross-Section with a Structural Pavement

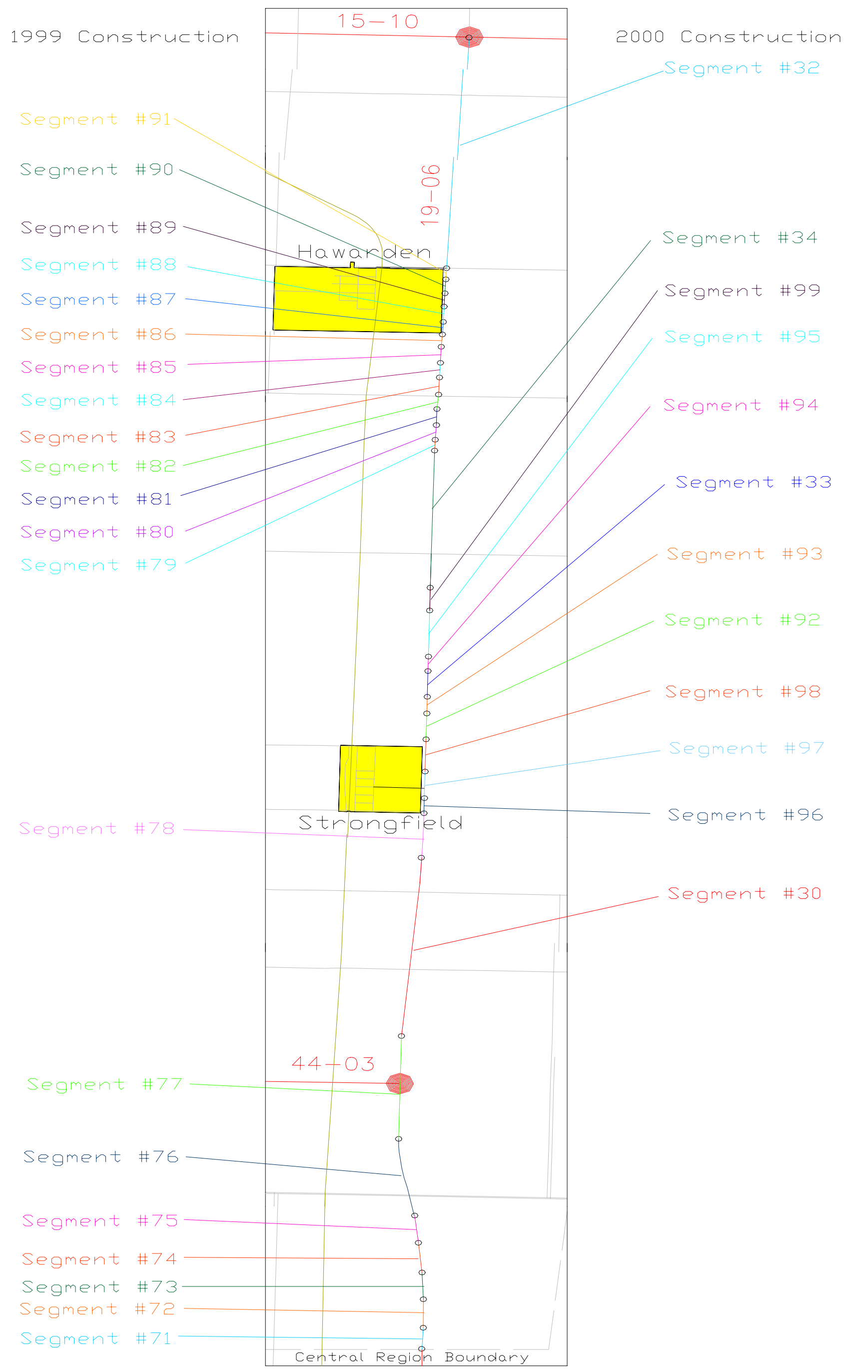

Figure 3 – Highway 19 Test Sections Layout

Figure 4 – Pre-construction Road Condition on Highway 19

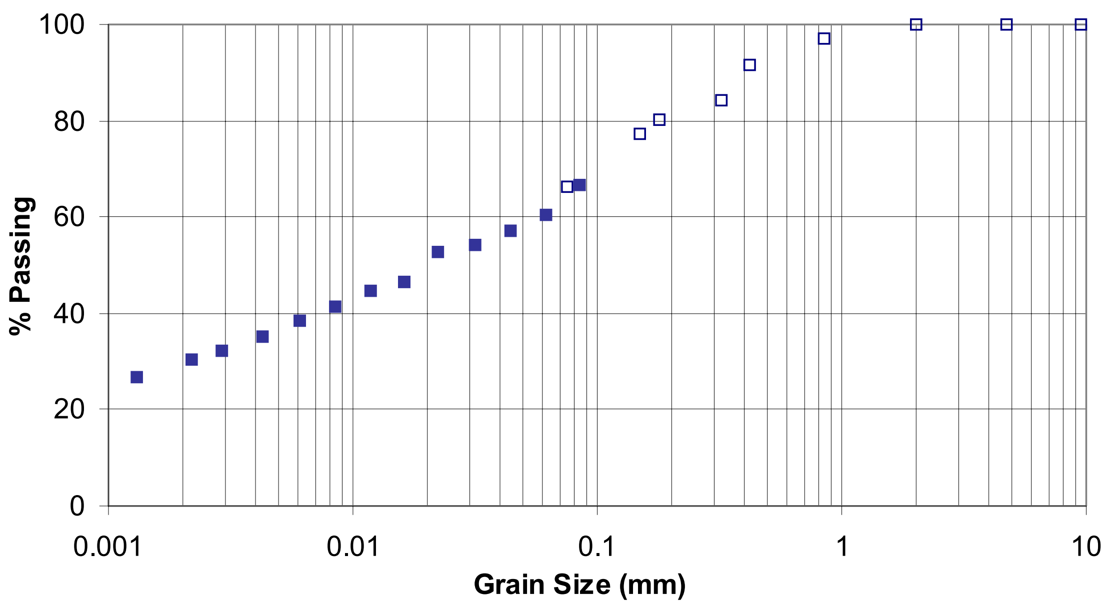

Figure 5 – Grain Size Distribution of Subgrade Material on Highway 19

Figure 6 – Mulching of Flax Straw

Figure 7 – Spreading of the Flax Straw Pieces

Figure 8 – Rotomixing Flax Straw Into Subgrade

Figure 9 – Geocomposite of Flax Straw and In Situ Material

Figure 10 – Blading Off Geocomposite

Figure 11 – Blading, Water Spraying and Compaction Procedure

Figure 12 – Road Compaction Procedure

Figure 13 – Base Aggregate Overlay

Figure 14 – Sealing Operation

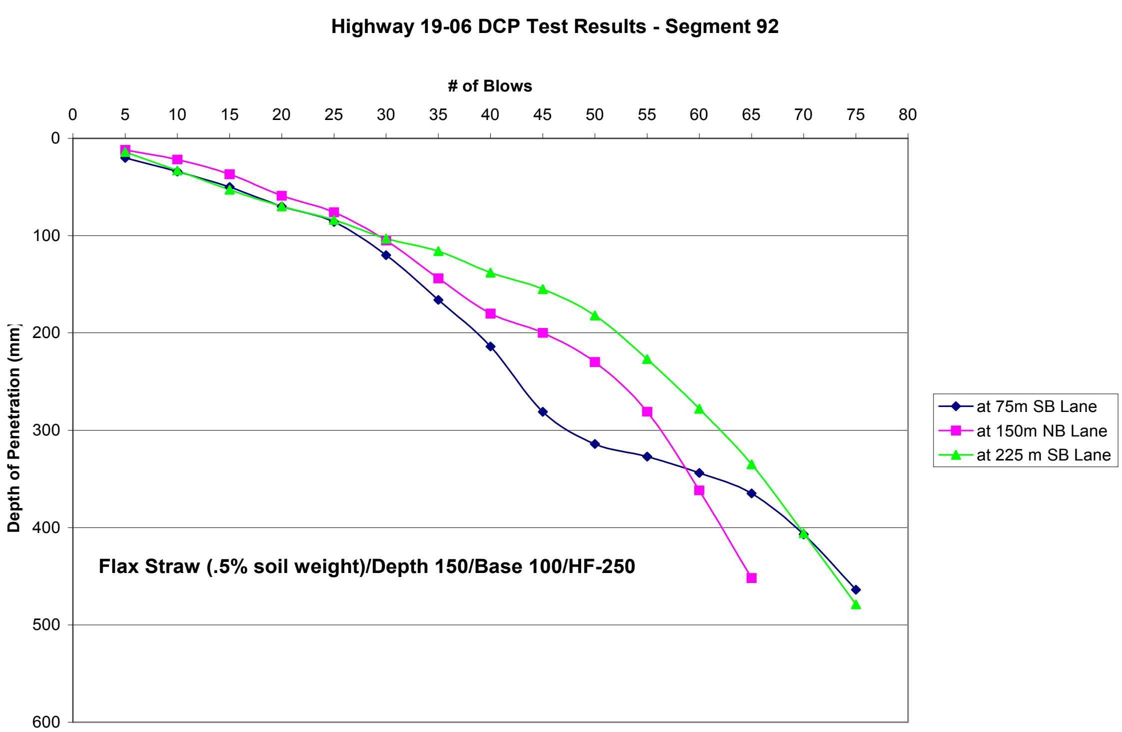

Figure 15 – DCP Results for Segment #92

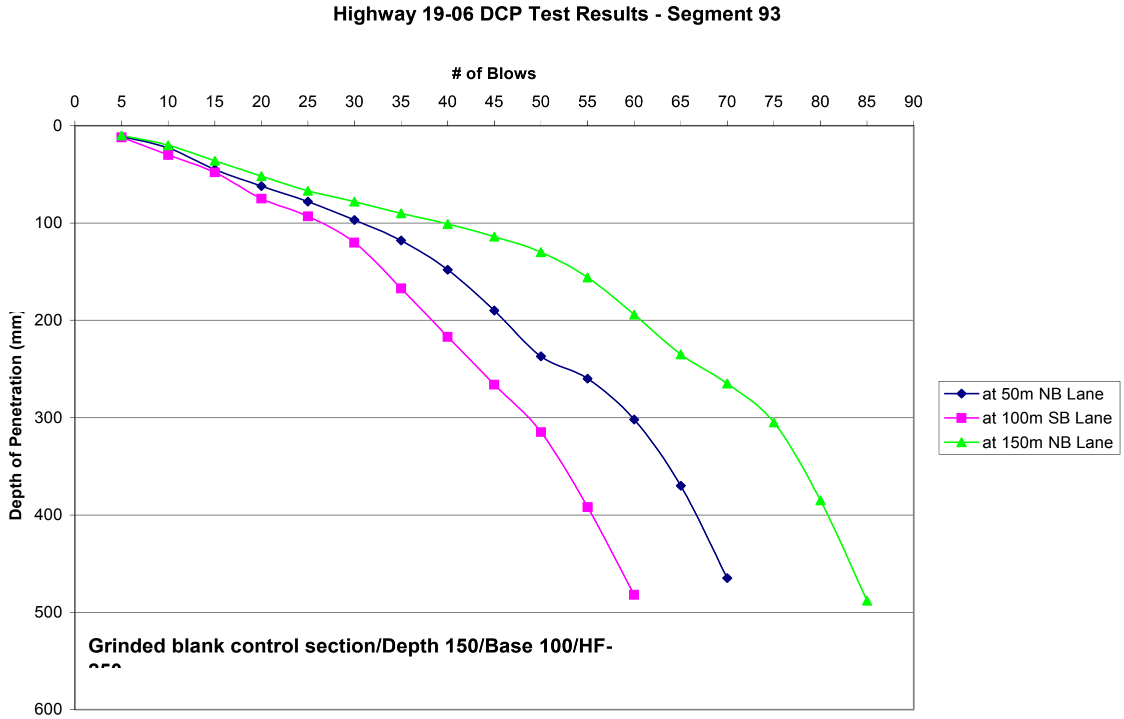

Figure 16 – DCP Results Segment #93

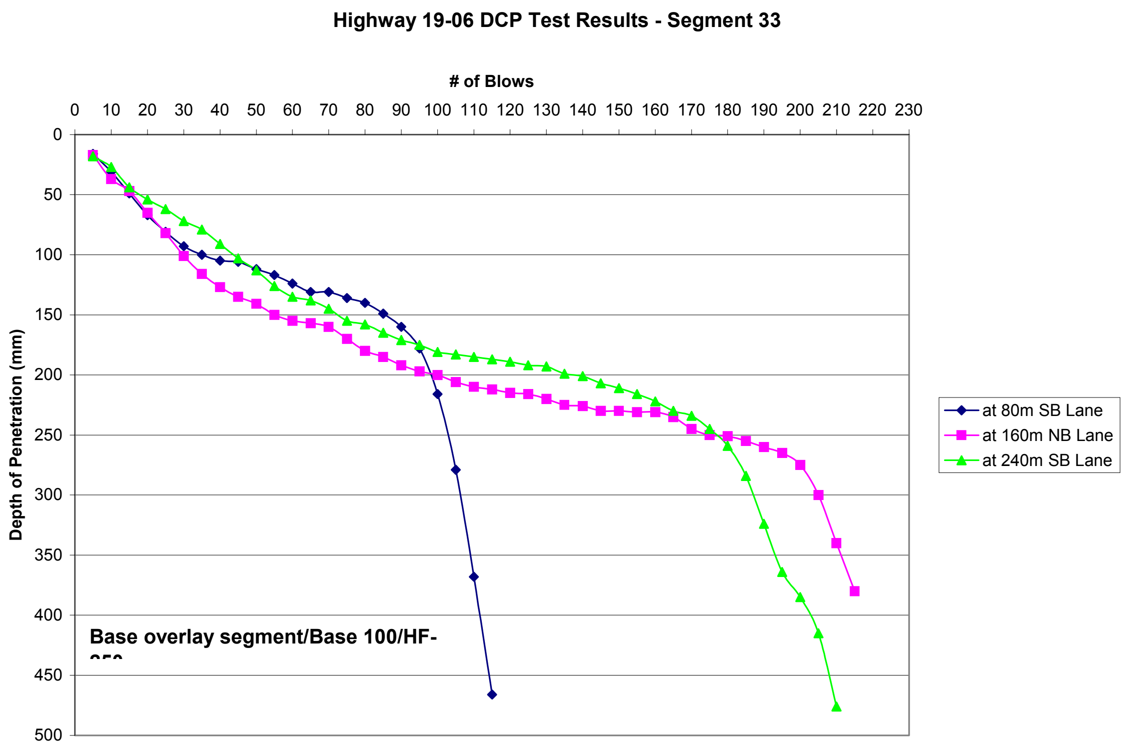

Figure 17 – DCP Results Segment #33

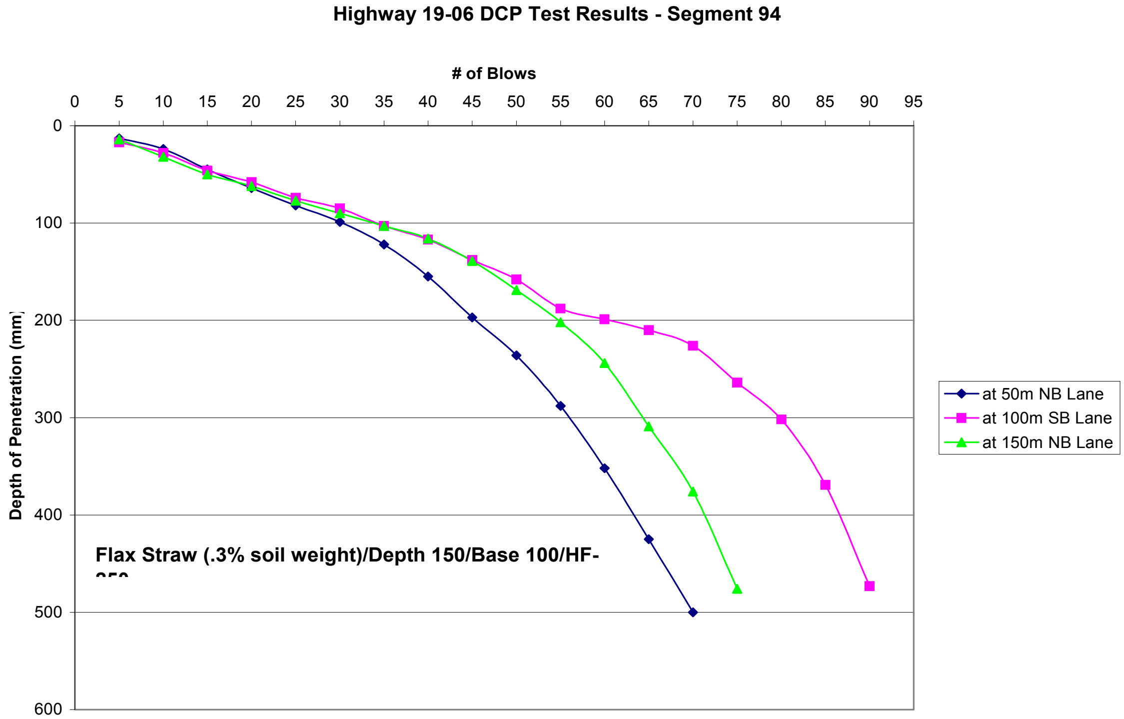

Figure 18 – DCP Results Segment #94

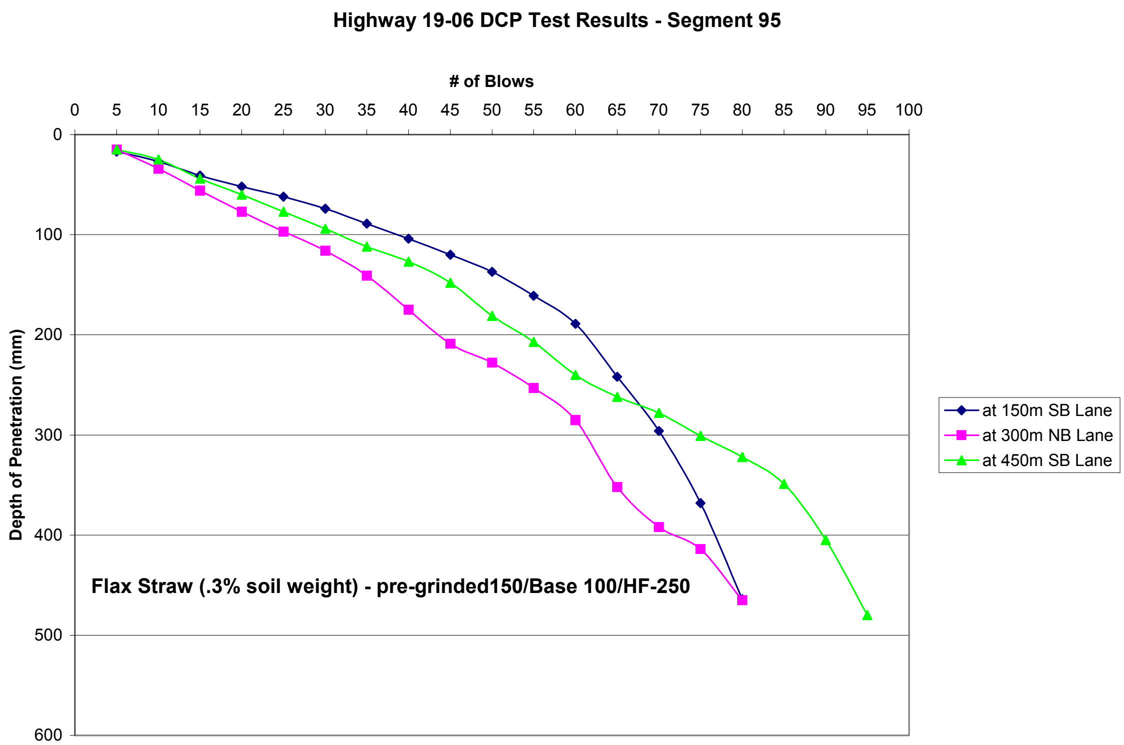

Figure 19 – DCP Results Segment #95

Tables

Table 1 – Highway 19-06 Test Sections

Segment #	From km	To km	Section Description
71	13	13.5	LFA150/Depth150/Base150/HF-250
72	13.5	14	LFA150/Depth150/Base150HF-250P
73	14	14.5	NoStb/Depth150/Base100/HF-250
74	14.5	15	CBR150/Depth150/Base100/HF-250
75	15	15.5	CBR150/Depth150/Base150/HF-250P
76	15.5	17	NoStb/Depth0/Base150/HF-250 and 250P
77	17	19	NoStb/Depth150/Base150/HF-250 and 250P
30	19	21.3	CKD 250/Depth 250/Base 100/HF-250
78	21.3	22.5	NoStb/AddBase75/Depth150/Base150/HF-250
96	22.5	22.8	Geo-grid BXGI/Base150/HF-250
97	22.8	23.07	Geo-textile HS1100/Base150/HF-250
98	23.07	23.39	Geo-textile GMF 245/Base100/HF-250
92	23.39	23.7	Flax Straw (.5% soil weight)/Depth150/Base100/HF-250
93	23.7	23.9	Grinded blank control section/Depth150/Base100/HF-250
33	23.9	24.23	Base overlay segment/Base100/HF-250
94	24.23	24.43	Flax Straw (.3% soil weight)/Depth150/Base100/HF-250
95	24.43	25.04	Flax Straw (.3% soil weight) - pre-grinded150/Base150/HF-250
99	25.04	25.35	Geo-textile GMF 245/Base150/HF-250
34	25.35	27.1	2001: Subbase150/Base150/HF-250
79	27.1	27.5	CBR300/Depth300/Base0/HF-250/Section failed so 200mm were milled and compacted again in 2000;100mm base added and sealed.
80	27.5	27.9	CBR150/Depth150/Base0/HF-250/Section failed so 200mm were milled and compacted again in 2000;100mm base added and sealed.
81	27.9	28.3	CBR150/Depth150/Base150/HF-250
82	28.3	28.7	CBR150/Depth150/Base100/HF-250
83	28.7	29.1	NoStb/Depth150/Base0/HF-250
84	29.1	29.5	LFA300/Depth300/Base0/HF-250
85	29.5	29.9	LFA150/Depth150/Base0/HF-250
86	29.9	30.3	LFA150/Depth150/Base150/HF-250
87	30.3	30.7	LFA150/Depth150/Base100/HF-250
88	30.7	31.1	CKD300/Depth300/Base0/HF-250
89	31.1	31.5	CKD150/Depth150/Base0/HF-250
90	31.5	31.9	CKD150/Depth150/Base150/HF-250
91	31.9	32.3	CKD150/Depth150/Base100/HF-250
32	32.3	42.16	CKD150/Depth150/Base150/HF-250

Table 2 – Flax Straw Test Segments

Segment #	From Km	To Km	Segment Description
92	23.39	23.7	Flax Straw (.5% soil weight)/Depth150/Base100/HF-250
93	23.7	23.9	Grinded blank control section/Depth150/Base100/HF-250
33	23.9	24.23	Base overlay segment/Base100/HF-250
94	24.23	24.43	Flax Straw (.3% soil weight)/Depth150/Base100/HF-250
95	24.43	25.04	Flax Straw (.3% soil weight) - pre-grinded150/Base150/HF-250

Table 3 – Annual Average Daily Traffic 1999-2003

1999	2000	2001	2002	2003
357	314	325	246	314

Table 4 – Road Surface Conditions 1999 - 2003

	Segment #92	Segment #93	Segment #33	Segment #94	Segment #95
IRI 99	4	4	4	4	4
IRI 00	2.8	2.8	2.8	2.8	2.8
IRI 01	2.5	2	2.6	2	2
IRI 02	2.38	2.54	2.3	1.92	1.64
IRI 03	2.74	2.69	2.66	2.06	1.76
Rut 99	Slight	Slight	Slight	Slight	Slight
Rut 00	None	None	None	None	None
Rut 01	Slight	Slight	Slight	None	Slight
Rut 02	5.94 mm	4.2 mm	3.89 mm	3.38 mm	3.86 mm
Rut 03	5.7 mm	4.6 mm	4.35 mm	4.38 mm	4.84 mm
Cracking 99	Extreme	Extreme	Extreme	Extreme	Extreme
Cracking 00	None	None	None	None	None
Cracking 01	None	None	None	None	None
Cracking 02	None	None	None	None	None
Cracking 03	782 lineal m/km	609 lineal m/km	1,014 lineal m/km	749 lineal m/km	704 lineal m/km

Table 5 – Benklemen Beam Data 2001 - 2003

	Deflection 2001 (mm)	Deflection 2002 (mm)	Deflection 2003 (mm)
Segment #92	1.68	1.65	1.89
Segment #93	1.76	1.86	1.87
Segment #33	2.02	1.83	1.84
Segment #94	1.7	1.6	1.69
Segment #95	1.71	1.52	1.65

Table 6 – GPR Dielectric Permittivity

	Mean Surface Dielectric Permittivity		**Mean Subgrade Dielectric Permittivity**	
	2001	2002	2001	2002
Segment #92	7	6.7	9.2	8
Segment #93	6.3	6.4	9.1	7.6
Segment #33	6.8	6.8	10.6	8.2
Segment #94	6.3	6.2	9	7.4
Segment #95	6.3	6.4	9	7.9

Table 7 – FWD 40 kN Mean Peak Surface Deflections

	Deflection 2001 (mm)	Deflection 2002 (mm)
Segment #92	N/A	1.69
Segment #93	2.47	1.46
Segment #33	N/A	1.19
Segment #94	2.38	1.5
Segment #95	1.59	1.36