RECYCLED AGGREGATE AND GEOSYNTHETIC STUDY
CITY OF EDMONTON

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1. ABSTRACT

In 2002 the City of Edmonton (City) in conjunction with Alberta Environment through their Construction, Renovation and Demolition (CRD) Waste Reduction Advisory Committee (WRAC) undertook a study to evaluate the performance of recycled aggregates as a base course material for their pavements and sidewalks. The need for this study was necessitated as a result of a January 2001 report prepared by Thurber Engineering Ltd. for Alberta Environment entitled ""Market Development Study for Recycled Aggregate Products", this report concluded that recycled aggregates were being used very successfully by the City as a base course material for their pavements and sidewalks. The report also concluded, however, that there was little hard data quantifying the performance of these pavements.

It was subsequently agreed that the City would construct a series of pavement test sections to compare the performance of pavements built with and without recycled aggregates with comparable sub-grade conditions. The City of Edmonton also took this opportunity to evaluate the use of two types of Geosynthetics, currently specified in their contracts, a Biaxial Geogrid and a Non-woven geotextile. The City conducted inspection of the construction, appropriate testing to characterize the sub-grade conditions at the time of construction, as well as the performance measurements of the different pavement test sections during and after construction.

This paper presents a description of the test sections and the results of 8 years of performance monitoring of the constructed pavement sections.

2. BACKGROUND

Since the early 1980's in the Edmonton area, most roadways are constructed using either 20 mm or 25 mm crushed gravel in the base course or a 20mm cement treated Granular base. The gravel available to the City for construction use has diminished in quantity and quality over the last thirty years while the cost of gravel has increased. As a consequence, in the early 1980's, the City began to experiment with alternate aggregate sources and with the use of geosynthetics in their road base construction.

2.1 RECYCLED AGGREGATE

In the early 1980's, based on ever increasing aggregate costs, the City determined that old asphalt, concrete and granular materials being removed from capital construction projects were too valuable a commodity to be landfilled. As a result of this determination the City used its gravel crushing expertise to create an aggregate recycling section within the Transportation Department. Instead of trucking the concrete and asphalt rubble from demolition projects to the landfill, the material was diverted to one of several City recycling sites, where the materials were processed to create an alternative aggregate material. Sources of concrete and asphalt rubble included asphalt street rehabilitation projects, concrete sidewalk replacement programs, asphalt and concrete roadways, excavations from building demolition, as well as material from private contractors such as parking lot reconstruction, etc. This practice has proven to be extremely successful and is now used extensively throughout the City of Edmonton by both City and private construction forces.

The City crushes the concrete and asphalt rubble into a 3-63 mm aggregate size (termed "3-63 mm reclaim"). The typical composition of the 3-63 reclaim is 60% concrete, 25% asphalt and 15% other materials such as cement treated Granular base (soil cement), brick, granular and miscellaneous recyclable material.

The 3-63 mm reclaim has been used in many of the City projects for the past 30 years in lieu of the 3-20 mm crushed gravel and/or soil cement. Over that period, the City has placed over 4,500, 000 tonnes of recycled aggregate or about 150,000 tonnes of reclaim aggregate per year (annual amounts can vary depending on the amount of feed stock available). Example projects within the City which have used this 3-63 mm reclaim aggregate, include:

- Yellowhead Trail and 50th Street Interchange (1996) – 42,000 tonnes
- Anthony Henday from Whitemud Drive to Stony Plain Road (1998) – 207,000 tonnes
- Whitemud Drive East from 34 Street to Highway 14 (1998) 65,000 tonnes
- 99 Street Rehabilitation from 67th to 82nd Avenue (2000) 27,000 tonnes

2.2 GEOSYNTHETICS

The subsoil conditions encountered within the City of Edmonton boundries consist of soft and wet high plastic clay for the majority of the City to saturated sensitive silts and peat bogs towards the west side of the City. As a result of these uniques soil conditions the City has had to utilizes various methods for construction of subgrade soils and embankments for roadways. The use of geosynthetics as a means to stabilize some of these problimatic subgrade soils has been evaluated on several projects since the early 1980's.

Geosynthetics is the term used to describe a range of generally polymeric products used to solve civil engineering problems. Generally two geosynthetics materials are commonly used on City projects, geotextiles and geogrids.

Geotextiles make up one of the two largest groups of geosynthetics and are textiles in the traditional sense. They consist of polymer based synthetic fibers rather than natural fibers. As a result of the synthetic fibers biological degradation and resulting reduction of service life is not a problem. The synthetic fibers are made into flexible, porous fabrics by standard weaving machinery or they are matted together in a random nonwoven manner, some are also knitted. The major point is that geotextiles are porous and allow liquid to flow through the fabric, but to a widely varying degree. Geotextiles have been used in varying construction activities but generally always perform at least one of four functions; separation, reinforcement, filtration and/or drainage. ASTM defines a geotextile as "any permeable textile material used with foundation soil, rock, earth, or any other geotechnical engineering-related material, as an integral part of a man-made project, structure or system". Figure 1 shows a non-woven and woven geotextile.

Geogrids are one of the most rapidly growing segment within geosynthetics family. Rather than being woven or non-woven textiles, geogrids are polymers formed into a very open, gridlike configuration, i.e., they have large openings between individual ribs in the longitudinal and transverse directions. Geogrids are either tensioned in one or two directions for improved physical properties. These products are known as uniaxial if tensioned in one direction and biaxial if tensioned in two directions. There are many specific application areas, however, they function almost exclusively as reinforcement materials. Geogrids are used in layers with mineral aggregate fills or other suitable soil to create a stiff mechanically stabilised layers within the soil and thus improve its load caarrying capacity The openings of the grid hold or confine the aggregate or soil particles, preventing the lateral shear created by vertical loading. The City has generally used biaxial geogrids in its projects. Figure 2 shows a biaxial geogrid.

The two geosynthetics chosen for these trials were a non-woven Geotextile Layfield Plastics LP6 and a biaxial Geogrid Tensar BX1200.

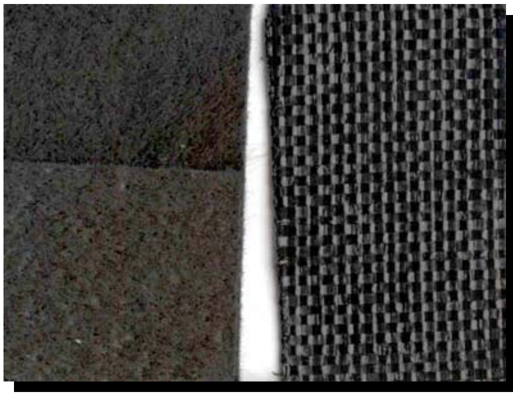

Figure 1 - Non-Woven & Woven Geotextile

Figure 2 - Biaxial Geogrid

3. FIELD PROGRAM

It was agreed that the field program would consist of the construction of a total of five test sections each designed to evaluate a different material or combination of materials. The City provided geotechnical evaluation, survey, materials testing, construction inspection and project management for the construction of the trial sections. A construction and testing protocol was created for the program to ensure uniformity of construction and evaluation. This protocol is discussed in the following section

3.1 TEST PROGRAM

The selected site for the pavement test sections is located in the west end of the City in the White Industrial neighbourhood. The roadway chosen was 111 Avenue between 186 Street and Anthony Henday Drive. This roadway is an arterial section connecting the White industrial neighbourhood with Anthony Henday Drive. The test section is a total length of approximately 1600 meters (see Figure 3). The test sections were constructed between July 2002 and September 2002. The contractor responsible for construction of the test sections was Standard General Inc. of Edmonton.

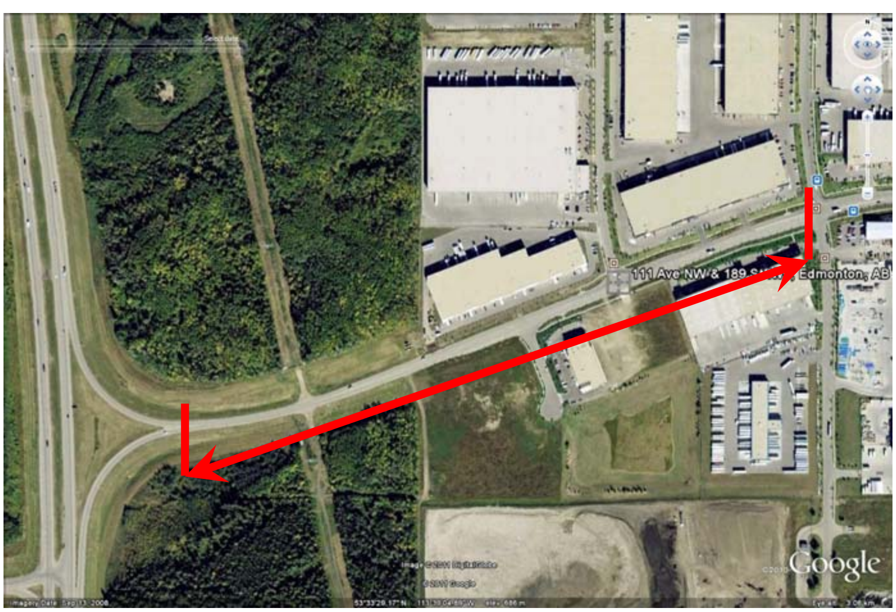

Figure 3– Test Section Location
111 Avenue, 186 Street to Anthony Henday Drive

The test program protocol developed and followed during construction, consisted of the following:

1. Five test sections were constructed and each section was 150 meters long and the terminus of any section was designed to be at least 50 meters from a major intersection (i.e. 184 Street to the East and Anthony Henday Drive to the West). Section lengths of 150 meters were chosen in an attempt to decrease the effect of any anomalies. 10 meter transition sections were also constructed between the test sections.

2. Subgrade material along each section were characterized by the City using the following laboratory tests
   - Soil classification,
   - Atterberg limits,
   - California Bearing Ratio (CBR),
   - Moisture content.

3. The contractor then performed subgrade preparation on the test sections. Subgrade preparation consisted of cement stabilization of the subgrade soils to a depth of 150mm with a cement application of $10Kg/m^3$. Cement stabilization is a routine construction practice for the City and is carried out to reduce the swelling potential of clay subgrade soils and in some cases assist in drying of wet subgrade soils. Upon completion of subgrade preparation, the City undertook deflection based structural testing, using the Dynaflect. A further discussion of the Dynaflect equipment can be found in Section 4.4 Dynaflect (Deflection) Testing. Dynaflect testing was arranged with Al Cepas of the City's Pavement Management Group 48 hours prior to task completion. Dynaflect testing was carried out at 10 meter intervals in both lanes. One of the requirements for dynaflect testing was that the subgrade surface must be dry enough so that material would not adhere to vehicle tires. Dynaflect testing was completed in approximately three hours per section. In addition, a minimum of three compaction tests were carried out by the City in each section.

4. The contractor placed and compacted City of Edmonton (COE) Designation 3, Class 20 crushed natural gravel in section one; Designation 3, Class 63 crushed natural gravel in section two; Recycled Designation 3, Class 63 over a non-woven geotextile in the third section; Recycled Designation 3, Class 63 in the fourth section and Recycled Designation 3, Class 63 (reduced thickness) over a bi-axial geogrid in the fifth section. The granular material was placed and compacted to 100% of Standard Proctor maximum dry density. Laboratory testing for the granular materials consisted of sieve analysis, Standard Proctors and crushed face counts. Steps were taken to ensure that material types are not mixed between sections.

5. Upon completion of the granular base compaction, the contractor provided another opportunity for Dynaflect testing under the same conditions as Item #3. Again a minimum of three compaction tests were carried out by the City in each of the test sections.

6. The contractor then placed two lifts of hot mix asphalt concrete with the first lift being a 25mm Asphalt Concrete Base (ACB) mix and the second lift being a 12.5mm Asphalt Concrete Overlay (ACO) mix. The Quality assurance testing was conducted by the City and consisted of full Marshall testing of each mix followed by Dynaflect testing at the same spacing as described in #3 after each lift had been placed.

7. Upon completion of construction, a schedule for Dynaflect testing twice annually was set up to monitor the long term performance of the test sections.

3.2 Pavement Structures

A summary of the five different pavement structures built within the test section is provided in Table 1.

TABLE 1
SUMMARY OF FIVE PAVEMENT SECTIONS

Section 1 Sta 1+380 to 1+530	50 mm ACO (FAC future overlay) 50 mm ACO 60 mm ACB *325 mm - 3-20 Natural Gravel* *150 mm Cement stabilized subgrade at 10 kg/m^3 cement*
Section 2 Sta 1+220 to 1+370	50 mm ACO (FAC future overlay) 50 mm ACO 60 mm ACB *325 mm - 3-63 Natural Crushed Natural Gravel (Cameron Pit)* *150 mm Cement stabilized subgrade at 10 kg/m^3 cement*
Section 3 Sta 1+035 to 1+160	50 mm ACO (FAC future overlay) 50 mm ACO 60 mm ACB 325 mm - 3-63 Reclaimed Crushed Gravel *Non-woven geotextile (Layfield Plastics LP6)* *300 mm Cement stabilized subgrade at 20 kg/m^3 cement*
Section 4 Sta 0+875 to 1+025	50 mm ACO (FAC future overlay) 50 mm ACO 60 mm ACB *325 mm - 3-63 Reclaimed Crushed Gravel* *150 mm Cement stabilized subgrade at 10 kg/m^3 cement*
Section 5 Sta 0+700 to 0+850	50 mm ACO (FAC future overlay) 50 mm ACO 60 mm ACB 150 mm - 3-63 Reclaimed Crushed Gravel *Biaxial Geogrid (Tensar BX1200)* *150 mm Cement stabilized subgrade at 10 kg/m^3 cement*

Notes: ACO = Asphalt Concrete Overlay – 12.5mm City of Edmonton 75 Blow Marshall Mix
ACB = Asphalt Concrete Base – 25mm City of Edmonton 75 Blow Marshall Mix

As noted in the above table, the total thickness of asphalt for each section is the same (160 mm, including a FAC future overlay) with differences in the type and thickness of granular base course in each section. The granular base course materials consisted of 3-20 mm crushed natural gravel, 3-63 mm crushed natural gravel and 3-63 mm reclaim gravel. Sections 1 to 4 had a total base course thickness of 325 mm while Section 5 had a total base course thickness of 150 mm.

3.3 Observations and Comments during Construction

Observations and comments from field personnel are summarized below:

- The 3-63 mm reclaim aggregate packed well and was easy to work with.

- Although the 3-63 mm reclaim aggregate looks coarse (i.e., lacking in fines), they were able to pave over top of the 3-63 mm reclaim aggregate without having to place a lift of smaller aggregate material (i.e., 3-20 mm crushed gravel). The contractor indicated that this material has a relatively smooth and tight surface after compacting.

- The surface of the 3-63 mm reclaim “tightens up” after packing allowing it to shed water. The contractor’s personnel indicated that they have never lost a subgrade due to rain over the nine to ten year period they have been using this material provided the 3-63 mm reclaim aggregate has been compacted.

- For the same thickness, the 3-63 mm reclaim aggregate bridges soft subgrade better than the natural 3-63 mm aggregate. The contractor’s opinion is the better bridging ability comes from the 100 percent fractured faces of the material and possibly the presence of residual cement fines in the reclaim aggregate which may be still hydrating.

- The geotextile and geogrid sections were fairly easy to construct but care needed to be taken to ensure that the overlap of the geosynthetic materials was maintained and that there was no damage to the geosynthetic materials during granular material placement.

- Over the City’s 20 year history using this material, it has been shown that the 3-63 mm reclaim has been very effective bridging soft subgrade. This has been reflected in comments from contractors who have used this material and have started to produce and create their own reclaim aggregate stockpiles.

4. DATA COLLECTION

4.1 Geotechnical Information

The subsurface soil conditions at the test site consisted of medium plastic silty clay. A summary of the laboratory testing conducted is summarized in Table 2.

TABLE 2
SUMMARY OF GEOTECHNICAL LABORATORY TESTING

SECTION	MOISTURE (%)	ATTERBERG LIMITS			GRADATION (%)			CBR (%)		
		L.L.	P.L.	P.I.	SAND	SILT	CLAY	M.C.	UNSOAKED	SOAKED
1-1	25.8	63	29	34	6	46	48			
1-2	26.5	46	26	21	3	49	48			
1-3	26.0	60	28	31	6	49	45			
1-3								26	9.2	6.0
2-1								20	13.0	4.0
2-1	20.4	51	24	27	5	57	38			
2-3								25	4.5	6.0
2-3		54	28	26	6	50	44			
3-1								22	3.7	7.9
3-1		48	18	30	6	58	36			
3-2		37	23	14	10	61	29			
3-3	22.4							22.4	6.0	5.5
3-3		43	24	19	11	53	36			
4-2								22.2	4.2	6.1
4-2		53	29	24	2	52	46			
4-3								20	12.5	3.0
4-3		54	28	26	3	47	50			

Notes: L.L. = Liquid Limit, P.L. = Plastic Limit, P.I. = Plastic Index, M.C. = Moisture Content
CBR = California Bearing Ratio

4.2 Field Materials Testing

During construction, the City conducted field quality assurance testing consisting of Standard Proctors, material gradation, and compaction testing.

Samples of material for Standard Proctor analysis were obtained from the cement stabilized clay and the various gravels (i.e., 3-20 mm crushed natural 3-63 mm crushed natural and 3-63 mm reclaim Aggregate). Results of Standard Proctors conducted on the subgrade and granular materials are summarized in Table 3.

TABLE 3
SUMMARY OF STANDARD PROCTORS

LOCATION	SOIL TYPE	OPTIMUM MOISTURE CONTENT (%)	MAXIMUM DRY DENSITY (kg/m^3)
Section 1			
Sta. 1+461 @ grade	Cement stabilized clay	24	1586
Sta. 1+510 @ grade	Cement stabilized clay	24	1581
Sta. 1+410 @ grade	Cement stabilized clay	24	1563
Sta. 1+410 @ grade	20 mm crushed gravel	7	2149
Section 2			
Sta. 1+288 @ grade	Cement stabilized clay	24	1598
Sta. 1+236 @ grade	Cement stabilized clay	23	1625
Sta. 1+288 @ grade	3-63 mm crushed gravel	10	2060
Section 3			
Sta. 1+165 @ grade	Cement stabilized clay	22	1641
Sta. 1+080 @ grade	Cement stabilized clay	22	1649
Sta. 1+190 @ grade	3-63 mm recycled aggregate	10	1955
Section 4			
Sta. 0+938 @ grade	Cement stabilized clay	26	1513
Sta. 0+884 @ grade	Cement stabilized clay	26	1510
Sta. 0+972 @ grade	3-63 mm recycled aggregate	10	1955
Sta. 1+020 @ grade	Cement stabilized clay	26	1536
Section 5			
Sta. 0+763 @ grade	Cement stabilized clay	25	1577
Sta. 0+720 @ grade	Cement stabilized clay	22	1600
Sta. 0+762 @ grade	3-63 mm recycled aggregate	10	1955

The City of Edmonton project specifications call for a required compaction of 100 percent of Standard Proctor Maximum Dry Density (SPMDD) for both the clay subgrade and the granular base course. Table 4 details the results of compaction testing carried out by the City. Based on the results of compaction testing the compaction requirements were met.

TABLE 4
SUMMARY OF FIELD DENSITY TESTS

LOCATION	SOIL TYPE	FIELD MOISTURE CONTENT (%)	DRY DENSITY (kg/m^3)	% COMPACTION
Section 1				
Sta. 1+461 @ top of clay	Cement stabilized clay	23.6	1582	99.7
Sta. 1+510 @ top of clay	Cement stabilized clay	22.6	1586	100.3
Sta. 1+410 @ top of clay	Cement stabilized clay	22.0	1571	100.5
Sta. 1+410 @ top of 20mm	3-20 mm crushed gravel	5.2	2145	99.8
Sta. 1+510 @ top of 20mm	3-20 mm crushed gravel	5.8	2179	101.4
Section 2				
Sta. 1+335 @ top of clay	Cement stabilized clay	23.6	1559	99.6
Sta. 1+288 @ top of clay	Cement stabilized clay	18.6	1614	101.0
Sta. 1+281 @ top of clay	Cement stabilized clay	19.0	1608	100.6
Sta. 1+236 @ top of clay	Cement stabilized clay	20.0	1615	99.4
Sta. 1+288 @ top of clay	3-63mm natural gravel	3.7	2086	101.3
Sta. 1+281 @ top of 63mm	3-63mm natural gravel	4.4	2097	101.8
Sta. 1+236 @ top of 63mm	3-63mm natural gravel	6.3	2105	102.2
Section 3				
Sta. 1+165 @ top of clay	Cement stabilized clay	17.5	1647	100.4
Sta. 1+080 @ top of clay	Cement stabilized clay	17.1	1656	100.4
Sta. 1+190 @ top of 63mm	3-63 mm recycled gravel	7.1	1992	101.9
Sta. 1+120 @ top of 63mm	3-63 mm recycled gravel	5.2	1957	100.1
Sta. 1+060 @ top of 63mm	3-63 mm recycled gravel	6.1	1961	100.3
Section 4				
Sta. 0+972 @ top of clay	Cement stabilized clay	23.6	1545	101.0
Sta. 0+938 @ top of clay	Cement stabilized clay	25.3	1518	100.3
Sta. 0+884 @ top of clay	Cement stabilized clay	23.5	1538	101.9
Sta. 0+972 @ top of 63mm	3-63 mm recycled gravel	8.4	1984	101.5
Sta. 0+938 @ top of 63mm	3-63 mm recycled gravel	6.2	1947	99.6
Sta. 0+883 @ top of 63mm	3-63 mm recycled gravel	7.1	1943	99.4
Section 5				
Sta. 0+763 @ top of clay	Cement stabilized clay	23.0	1571	99.8
Sta. 0+720 @ top of clay	Cement stabilized clay	20.1	1627	101.7
Sta. 0+762 @ top of 63mm	3-63 mm recycled gravel	5.2	1951	99.8
Sta. 0+720 @ top of 63mm	3-63 mm recycled gravel	7.2	1960	100.3

City of Edmonton gradation limits for the 3-20 mm crushed gravel, 3-63 mm crushed gravel and the 3-63 mm reclaimed gravel are shown in Table 5.

TABLE 5
CITY OF EDMONTON GRADATION LIMITS

SIEVE SIZE	DES. 3 CLASS 20 (20 mm CRUSH)	DES. 3 CLASS 63 (3-63 mm NATURAL & RECLAIM)
80 mm		
3-63 mm		100
25 mm		55-75
20 mm	100	
12.5 mm	60-92	40-60
5 mm	37-62	20-45
2 mm	26-44	
1.25 mm		14-33
400 μm	12-27	
315 μm		7-22
160 μm	7-18	
80 μm	2-10	0-10
Min. Percent Crush Faces	60 (2 face)	75 (2 face)

Gradation analyses conducted on each of the aggregate types as delivered to site indicated that the supplied aggregate samples met the required gradation limits.

4.3 Geosynthetic Materials Specification Requirements

Table 6 details the specified criteria for the Geotextile and Table 7 details the specified criteria for the Geogrid used in the test sections:

Table 7
NON-WOVEN GEOTEXTILE REQUIREMENTS

	Non-Woven Needle-Punched Geotextile Metric Values	
	ASTM Designation	**LP6**
Grab Tensile (N)	**D4632**	**711**
Elongation (%)	**D4632**	**50**
Tear (N)	**D4533**	**267**
CBR Punc (N)	**D6241**	**1820**
AOS (microns)	**D4751**	**212**
Permittivity (sec-1)	**D4491**	**1.5**
Water Flow (l/min/m^2)	**D4491**	**4,480**
Weight[1](g/m^2) Typical	**D5261**	**203**
Thickness[1] (mm) Nominal	**D5199**	**1.7**
UV (500 hrs)	**D4355**	**70%**
Roll Size (m)		**4.57 x91.4**
Roll Weight[1](kg)		**92**

Note[1]: Typical values. All other values are minimum average roll values (MARV).

Table 8
GEOGRID REQUIREMENTS

	Biaxial Geogrid BX1200 Metric Values
Index Properties	
Aperture Dimensions[2] (mm)	25
Minimum Rib Thickness[2] (mm)	0.76
Tensile Strength @ 2% Strain[3] (kN/m)	4.1
Tensile Strength @ 5% Strain[3] (kN/m)	8.5
Ultimate Tensile Strength[3] (kN/m)	12.4
Carbon Black Content %	2
Structural Integrity	
Junction Efficiency[4] %	93
Flexural Stiffness[5] mg-cm	250,000
Aperture Stability[6] m-N/deg	0.32
Durability	
Resistance to Installation Damage[7] %	95/93/90
Resistance to Long Term Degradation[8] %	100
Resistance to UV Degradation[9] %	100
Dimensions and Delivery	The biaxial geogrid shall be delivered to the jobsite in roll form with each roll individually identified and nominally measuring 3.0 meters or 4.0 meters in width and 50.0 meters in length. A typical truckload quantity is 160 to 210 rolls

Notes

1. Unless indicated otherwise, values shown are minimum average roll values determined in accordance with ASTM D4759-02. Brief descriptions of test procedures are given in the following notes.
2. Nominal dimensions.
3. True resistance to elongation when initially subjected to a load determined in accordance with ASTM D6637-01 without deforming test materials under load before measuring such resistance or employing "secant" or "offset" tangent methods of measurement so as to overstate tensile properties.
4. Load transfer capability determined in accordance with GRI-GG2-05 and expressed as a percentage of ultimate tensile strength.
5. Resistance to bending force determined in accordance with ASTM D5732-01, using specimens of width two ribs wide, with transverse ribs cut flush with exterior edges of longitudinal ribs (as a “ladder”), and of length sufficiently long to enable measurement of the overhang dimension. The overall Flexural Stiffness is calculated as the square root of the product of MD and XMD Flexural Stiffness values.
6. Resistance to in-plane rotational movement measured by applying a 20 kg-cm (2 m-N) moment to the central junction of a 9 inch x 9 inch specimen restrained at its perimeter in accordance with U.S. Army Corps of Engineers Methodology for measurement of Tensional Rigidity.
7. Resistance to loss of load capacity or structural integrity when subjected to mechanical installation stress in clayey sand (SC), well graded sand (SW), and crushed stone classified as poorly graded gravel (GP). The geogrid shall be sampled in accordance with ASTM D5818-06 and load capacity shall be determined in accordance with ASTM D6637-01.

8. **Resistance to loss of load capacity or structural integrity when subjected to chemically aggressive environments in accordance with EPA 9090 immersion testing.**
9. **Resistance to loss of load capacity or structural integrity when subjected to 500 hours of ultraviolet light and aggressive weathering in accordance with ASTM D4355-05.**

4.4 Dynaflect (Deflection) Testing

Deflection measurements of pavement structures are an important aid to proper design, maintenance and performance studies of such structures. Up until the last 15 years or so, deflection measurements have been made through use of the “California Bearing Raito (CBR)” for soils, the "Plate Bearing Test" for soils and pavements and the "Benkelman Beam" for pavements. The Plate Bearing Test, CBR and Benkelman Beam systems are very slow and require large crews and costly special equipment to perform the deflection operations. More recently the “Resilient Modulus” has been used for soils and the “Dynaflect” and “Falling Weight Deflectometer (FWD)” have been used for the evaluation of soils and pavements.

The City using their Dynaflect unit undertook deflection based strength testing of the constructed pavement structure after construction of the subgrade, granular base course, asphalt base course and asphalt surface course. The Dynaflect is a steady state vibratory device that is instrumented to measure peak-to-peak dynamic deflection of the pavement surface. It is an electromechanical device which is used for measuring highway and airfields pavement deflection. The Dynaflect apparatus consists of a dynamic cyclic force generator mounted on a two-wheel trailer, a remote control unit, a sensor assembly and a sensor (geophone) calibration unit. The Dynaflect unit has five sensors (geophones) equally spaced at 300 mm intervals away from the dynamic force generator. The reading obtained from Sensor 1 is utilized in design calculations and was therefore the reading used in this study. A photograph of the Dynaflect unit can be seen below in figure 4. This apparatus is used by the City to obtain pavement deflection readings for input into their pavement management system. The City’s target deflection value for acceptable pavement structures is 0.025 mm (1mil) after the final lift of asphalt has been placed.

Figure 4 - Dynaflect Apparatus

The averaged dynaflect test results from each stage of construction are summarized in the following table and also in Figures 5.

TABLE 9
SUMMARY OF AVERAGED SENSOR 1 INITIAL DYNAFLECT TEST RESULTS

	Section 1 20 mm Crush (mm)		Section 2 3-63 mm Natural (mm)		Section 3 63mm Reclaim on non-woven geotextile (mm)		Section 4 3-63 mm Reclaim (mm)		Section 5 63mm Reclaim on Geogrid (mm)	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Subgrade	0.0555	0.0538	0.0673	0.0608	0.0535	0.0538	0.0588	0.0590	0.0503	0.0548
Base Course	0.0440	0.0440	0.0445	0.0400	0.0475	0.0433	0.0373	0.0383	0.0430	0.0513
First Lift ACB	0.0410	0.0398	0.0290	0.0303	0.0290	0.0298	0.0262	0.0260	0.0345	0.0308
Second Lift ACO	0.0295	0.0295	0.0245	0.0230	0.0245	0.0238	0.0215	0.0223	0.0248	0.0233

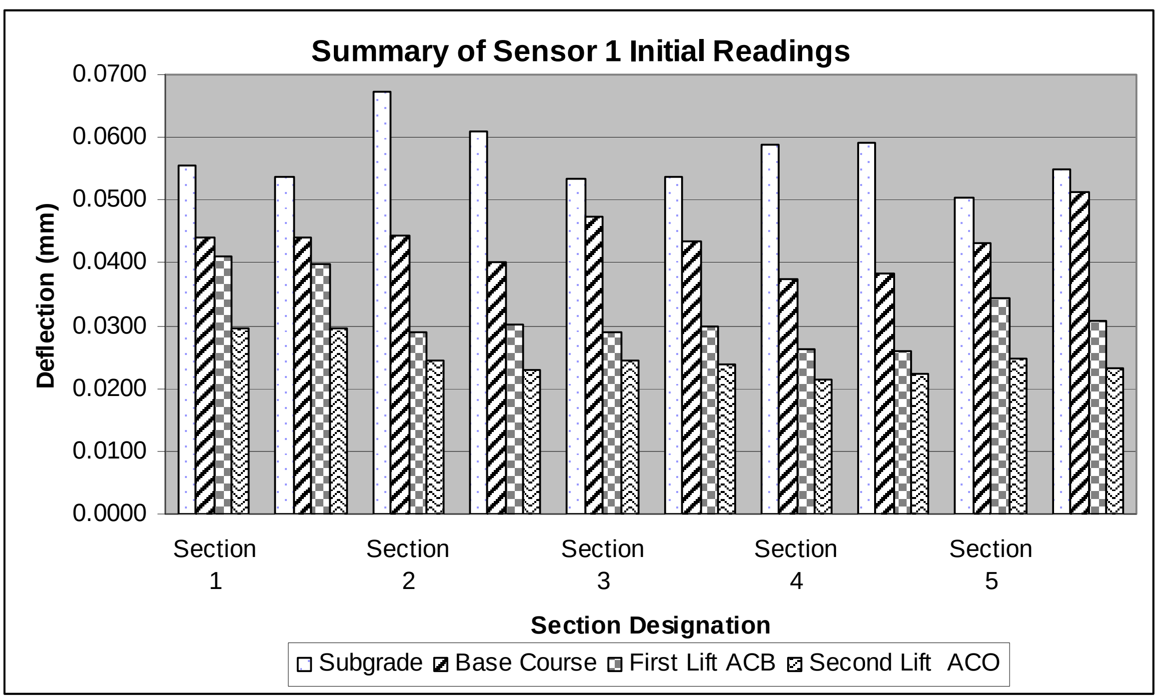

Figure 5 – Sensor 1 Initial Dynaflect Readings

4.4.1 Dynaflect Results

4.4.1.1 Subgrade Dynaflect Results

The results of the subgrade testing for both lanes indicate average deflections of 0.0561 mm in Section 1 (crushed natural 3-20mm aggregate), 0.0640 mm in Section 2 (crushed natural 3-63 mm aggregate), 0.0537 mm in Section 3 (reclaim 63mm aggregate with geotextile), 0.0590 mm in Section 4 (reclaim 3-63 mm aggregate) and 0.0527 mm in Section 5 (reclaim 3-63mm aggregate with Geogrid). The range in the deflections was likely due to the variability of the subgrade soils.

4.4.1.2 Granular Base Course Dynaflect Results

The average deflections in the granular base course were 0.0440 mm in Section 1, 0.0423 mm in Section 2, 0.0454 mm in section 3, 0.0378 mm in Section 4 and 0.0472 mm in Section 5.

The deflections obtained in Section 4 (containing the 3-63 mm reclaim gravel) were 17% lower than Section 1 (3-20 mm crushed gravel), 11% lower than Section 2 (3-63 mm natural aggregate), 20 lower than Section 3 (3-63 mm reclaim with geotextile) and 25% lower than Section 5 (3-63 mm reclaim with geogrid).

4.4.1.3 Asphalt Concrete Dynaflect Results

The initial results of the Dynaflect testing from the first and second lifts of asphalt show the 3-63 mm reclaim aggregate with significantly lower deflections than either the 3-63 mm natural or the 3-20 mm crushed gravel. The two sections with geosynthetics were in the range of the 3-63 mm natural section.

It should be noted that Dynaflect testing was conducted within one to two days following the paving for each lift.

As shown in Table 9 the following observations with respect to the dynaflect testing are noted:

- **Observations Following First Lift of ACP**

- Section 4 (3-63 mm reclaim) shows 35% lower deflection than Section 1 (20 mm crush);
- Section 4 (3-63 mm reclaim) shows 12% lower deflection than Section 2 (3-63 mm natural);
- Section 4 (3-63 mm reclaim) shows 11% lower deflection than Section 3 (3-63 mm reclaim with geotextile);
- Section 4 (3-63 mm reclaim) shows 12% lower deflection than Section 5 (3-63 mm reclaim with geogrid).

- **Observations Following Second Lift of ACP**

- Section 4 (3-63 mm reclaim) shows 25% lower deflection than Section 1 (20 mm crush).
- Section 4 (3-63 mm reclaim) shows 7% lower deflection than Section 2 (3-63 mm natural).
- Section 4 (3-63 mm reclaim) shows 9% lower deflection than Section 3 (3-63 mm reclaim with geotextile);
- Section 4 (3-63 mm reclaim) shows 9% lower deflection than Section 5 (3-63 mm reclaim with geogrid).

TABLE 10
RANKING BASED ON INITIAL DYNAFLECT RESULTS

	Section 1 20 mm Crush		Section 2 3-63 mm Natural		Section 3 63mm Reclaim on non-woven geotextile		Section 4 3-63 mm Reclaim		Section 5 63mm Reclaim on Geogrid	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Subgrade	1	3	4	5	1	2	3	4	2	1
Base Course	3	4	4	2	5	3	1	1	2	5
First Lift ACB	5	5	3	4	3	3	1	1	2	4
Second Lift ACO	5	5	3	2	3	4	1	1	4	3
Average Ranking	3.5	4.25	3.5	3.25	3	3	1.25	1.75	2.5	3.25
Combined Section Average	3.88		3.38		3.000		0.75		1.44	
Overall Ranking	5		4		3		1		2	

4.4.2 Extended Monitoring

The City continues to monitor the five test sections through deflection testing of each section twice annually typically in late June and late September. The following Table 11 presents the average Sensor 1 result for each of the test sections. Figure 6 graphically presents this data.

Table 11
Average Sensor 1 Reading - Annual Spring Results

Year	Section 1 3-20mm (mm)	Section 2 3-63mm Natural (mm)	Section 3 3-63mm With Geotextile (mm)	Section 4 3-63mm Reclaim (mm)	Section 5 3-63mm With Geogrid (mm)
2002	0.0295	0.0245	0.0245	0.0215	0.0248
2003	0.0381	0.0440	0.0299	0.0270	0.0297
2004	0.0397	0.0461	0.0278	0.0267	0.0267
2005 *	0.0339	0.0376	0.0256	0.0231	0.0240
2006	0.0349	0.0360	0.0241	0.0234	0.0244
2007	0.0382	0.0395	0.0270	0.0252	0.0252
2008	0.0390	0.0410	0.0288	0.0263	0.0276
2009	0.0402	0.0429	0.0298	0.0269	0.0289
2010	0.0415	0.0451	0.0306	0.0278	0.0299

*Note: a 50mm FAC Overlay of ACO was placed on 111 Avenue in late 2004 resulting in a drop in the spring deflection readings.

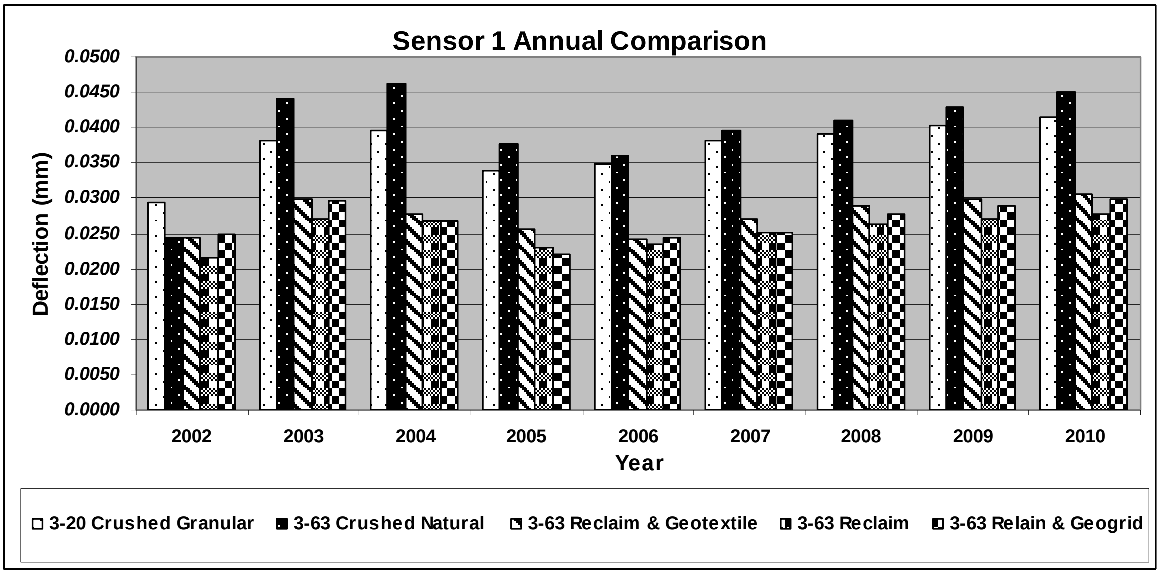

Figure 6 - Average Sensor 1 Reading - Annual Spring Results

5. EVALUATION

The City uses the "1993 AASHTO Guide for Design of Pavement Structures" for the design of new roadways and the Asphalt Institute Manual Series No.17 (MS-17) "Asphalt Overlays for Highway and Street Rehabilitation" for our rehabilitation designs. The Asphalt Institute procedure used deflection based testing and evaluation for the determination of existing pavement life as well as estimating remaining pavement life to determine the required structural overlay requirements for a roadway section. As a result of our deflection based evaluation of the pavement sections we have chosen the Asphalt Institute method for comparison purposes.

The average deflections were plotted on a chart prepared by the Asphalt Institute (Manual Series 17) titled, *Design Rebound Deflection Chart, June 1983*. This chart provides an indication of total Equivalent Single Axle Loads (ESAL's) a pavement structure is capable of supporting based on a deflection value. The information obtained from the chart can be used by pavement engineers to estimate remaining pavement life. The total ESAL's obtained from this chart and the individual section rankings are summarized in Table 12.

TABLE 12
TOTAL ESALS FROM INITIAL DESIGN REBOUND DEFLECTIONS

Section No. - Material	Design* Rebound Deflection (mm)	Total ESAL's	Rank
1 – 3-20 mm Crush	0.80	1,600,000	4
2 – 3- 3-63 mm Natural	0.64	3,500,000	2
3 – 3- 3-63 mm Reclaim with Geotextile	0.64	3,500,000	2
4 – 3- 3-63 mm Reclaim	0.55	6,000,000	1
5 – 3- 3-63 mm Reclaim (150mm Thickness) with Geogrid	0.65	3,000,000	3

*Note: Design Rebound Deflection values were obtained by converting the deflection values obtained from dynaflect testing to equivalent Benkelman Beam readings. The formula used for this conversion was developed by Tom Christenson of the Alberta Research Council in conjunction with Alberta Transportation.

The information obtained from this chart based in the initial testing carried out after construction completion in 2002 shows that the pavement section constructed with 3-63 mm reclaim (Section 4) would be capable of supporting up to 7 million ESAL's versus 3.5 million for the 3-63 mm natural aggregate and 1,600,000 ESAL's for the 3-20 mm crush, while the geotextile section is capable of carrying 3.5 million ESAL's and the geogrid Section is capable of carrying 3.0 million. For comparative purposes, the City design for this roadway section using a 20 year design life would be 1.8 million ESAL's.

Based on this initial deflection testing Section 4 is ranked the highest based on total allowable ESAL counts, with sections 2 and 3 ranking second, section 5 ranking third and section 1 ranking last.

In the fall of 2004 a 50 mm, Final Acceptance Completion (FAC), overlay of ACO was placed on 111 Avenue. As a result of this FAC overlay the deflection readings in the spring of 2005 were noted to be lower than those taken in the fall of 2004. Due to the lower readings it was decided to use the 2005 readings as a starting point for long term evaluation of the sections. The average deflections from 2005 and 2010 were plotted on the same chart prepared by the Asphalt Institute (Manual Series 17). This information was used to estimate remaining pavement life for each the 2005 and the 2010 readings to compare the remaining pavement life.

Table 13 below details the results of the back evaluation of the ESAL's from the sensor 1 deflection readings converted to Defection Rebound Numbers for both 2005 and 2010 readings.

Table 13

TOTAL ESALS FROM 2005 and 2010 DESIGN REBOUND DEFLECTIONS

Section No. - Material	2005 Design * Rebound Deflection (mm)	Total ESAL's	Rank	2010 Design * Rebound Deflection (mm)	Total ESAL's	Rank
1 - 3-20 mm Crush	0.96	750,000	4	1.14	320,000	4
2 - 3-63 mm Natural	1.03	500,000	5	1.24	180,000	5
3 – 3-63 mm Reclaim with Geotextile	0.70	2,700,000	3	0.81	925,000	3
4 - 3-63 mm Reclaim	0.59	6,100,000	1	0.73	2,100,000	1
5 – 3-63 mm Reclaim (150mm Thickness) with Geogrid	0.62	4,900,000	2	0.80	1,500,000	2

*Note: Design Rebound Deflection values were obtained by converting the deflection values obtained from dynaflect testing to equivalent Benkelman Beam readings. The formula used for this conversion was developed by Tom Christenson of the Alberta Research Council in conjunction with Alberta Transportation.

The information obtained from the chart shows that the pavement section constructed with 3-63 mm reclaim (Section 4) was capable of supporting up to 6.1 million ESAL's in 2005 and has 2.1 million ESAL's remaining life in 2010. Section 5 was capable of carrying up to 4.9 million ESAL's in 2005 and has 1.5 million ESAL's remaining life in 2010. As of 2010 the roadway has been in service for 8 years which would relate to approximately 40% of its total design life.

Based on the 2005 to 2010 deflection testing Section 4 is ranked the highest based on total Allowable ESAL counts, with sections 5 ranking second, section 3 ranking third, section 1 ranking forth and section 1 ranking last.

It should be noted that deflection readings tend to increase, thus resulting in a loss of service life as the pavement ages and that the total ESAL's shown in Table 11 and 12 only provide an indication of the remaining capacity of the road sections. Other factors may affect the capacity of the road section such as maintenance history, quality of construction, and increase in traffic volume, etc.

6. OBSERVATIONS

Based on the information obtained, our observations from this study are as follows:

- The 3-63 mm reclaim has better load carrying ability than the equivalent thickness of 3-20 mm crushed gravel or 3-63 mm natural gravel. This may be explained as the 3-63 mm reclaim aggregate material is almost 100 percent angular. In addition, due to the angularity of the material, the friction angle (or aggregate interlock) of the 3-63 mm reclaim is estimated to be about 45° (similar to railway ballast) whereas the friction angle of the 3-63 mm natural aggregate is estimated to be around 38° and the 3-20 mm material is estimated to be 35^{o}.

- The initial deflection values measured by Dynaflect for the 3-20 mm natural crushed gravel section were higher than all other sections. However when we look at the long term monitoring the 20mm does seem to outperform the natural 3-63mm granular, however only marginally. It should be noted that 3-20 mm crushed gravel was historically considered a better aggregate product than both the natural 3-63 mm aggregate and the reclaim 3-63 mm aggregate.
- The roadway sections containing the 3-63 mm reclaim aggregate performed better both initially and in the long term than the other roadway sections (as measured by Dynaflect testing). When looking at the long term data the test sections containing the geosynthetics are performing in a comparable manner to the 3-63mm reclaim only section
- The City considers a value of 0.0250 mm (1 mil) to be an acceptable post construction deflection for asphalt pavements. The initial measured average deflection from the 3-20 mm crushed gravel section was 0.0295 mm, 0.0245 mm for the natural 3-63 mm section and 0.0215 mm for the reclaim 3-63 mm section with 0.0245 mm for the geotextile section and 0.248 for the geogrid section. Expressing this in percentage terms, Section 4 containing the 3-63 mm reclaim aggregate section has a 25% lower deflection than Section 1 (20 mm crush), 7% lower deflection than Section 2 (3-63 mm natural aggregate), 7% lower than Section 3 (3-63 mm reclaim with geotextile) and 13% lower than section 5 (3-63 mm reclaim with geogrid). This indicates that the pavement structure containing the reclaim 3-63 mm aggregate is more capable of handling heavier loads than the pavement structure constructed with either 3-63 mm natural aggregate or 3-20 mm crushed gravel in the base course.

7. CONCLUSIONS

- The results of this study indicate that the roadway sections constructed using the 3- 3-63 mm reclaim aggregate performed better than the roadway sections constructed with the 3- 3-63 mm natural and the 3-20 mm natural aggregate.
- The use of geotextile while worthwhile when soil conditions are less than suitable, provide little benefit if the soil conditions are considered relatively good. The use of geotextile, while not as effective as the geogrid provides an added factor of safety to the overall pavement section.

- The use of a geogrid can be an effective way of reducing a granular section while still providing the long term load carrying capacity of a pavement section.
- The use of a geogrid can allow a reduction in granular base thickness of as much as 50%, given suitable subgrade support.
- Without the reduction in granular base thickness, the use of a geogrid in a pavement structure can give an added factor of safety to the overall load carrying capacity of a pavement section, again given suitable subgrade support
- The use of locally available 3-20 mm and 3-63 mm crushed granular materials is substantially less effective in providing load carrying capacity.
- Prior to this study the City allowed the following equivalencies in pavement designs:
  - 1mm Asphalt = 2mm of 3-20 mm crush
  - 1mm Asphalt = 2mm of 3-63 mm reclaim
- In 2004 as a result of the initial results from this study the City revised its equivalencies and now uses the following equivalencies in pavement designs:
  - 1mm Asphalt = 1.8mm of 3-20 mm crush
  - 1mm Asphalt = 2mm of 3-63 mm reclaim
- Based on the results of this study, the City will continue to utilize the 3-63 recycled materials for granular base course on our Capital construction projects and continue to promote the use of the geosynthetics in our pavement structures.

8. REFERENCES

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