Performance of a Trial Section Reconstructed Using Cellular Concrete in the City of Edmonton

Hugh Donovan, P.Eng., General Supervisor Research & Development,
Integrated Infrastructure Services, City of Edmonton

Faizal Kanji, P.Eng., Senior Research Engineer,
Integrated Infrastructure Services, City of Edmonton

Brad Dolton, P.Eng., Manager – Geotechnical Engineering,
CEMATRIX (Canada) Inc.

Paper prepared for presentation at the
SES - Innovation in Geotechnical and Materials Engineering Session
of the 2018 Conference of the
Transportation Association of Canada
Saskatoon, SK

Abstract

Over the past two decades, roadways in several residential neighborhoods within northeast Edmonton have experienced significant early structural failures. Failures were so severe in some cases that heavy vehicles (i.e. garbage and fire trucks) were not able to access some affected streets. These failures occurred as a result of the presence of subgrade soils that are susceptible to water softening, poor subgrade drainage, and additional water drainage from private sump pumps. As a consequence, The City of Edmonton has established an extensive roads program that conducts annual replacement of roadways in northeast Edmonton.

As part of the above-noted roads replacement program, two trial sections were selected by The City of Edmonton to be reconstructed in 2009. These sections were located in adjacent cul-de-sacs to provide for comparison of performance between two constructions methods. One section was constructed using a traditional granular section, and the other used lightweight cellular concrete (LCC) as a subbase material. LCC is a construction material formed by mixing a cement and water slurry with a pre-formed foam, similar in consistency to shaving cream. The material is produced onsite and pumped into place using proprietary pumping equipment that may be setup several hundred meters from the pour area. The LCC supplied for the above-noted projects had a wet (cast) density of 475 kg/m^3, which is approximately one-fifth the density of typical granular subbase. As a result of the high percentage of air bubbles (approximately 72% by volume), the material also has insulating qualities that, depending on the applied thickness, can reduce or prevent frost heave and subsequent thaw weakening of subgrade soils.

Load-deflection data was gathered on the trial sections for both pre and post construction conditions using The City of Edmonton's Dynaflect system. The City performed additional testing in 2016 using both its Dynaflect and Falling Weight Deflectometer systems. The results of this testing are presented in this paper. Since reconstruction, no maintenance activities have been required for either the granular or cellular concrete trial sections.

Introduction

When roadways in the Ozerna Neighborhood located in the Northeast quadrant of the City of Edmonton started to show signs of significant structural failures, a study was carried out by the City of Edmonton, Engineering Services Section in an attempt to identify the extent of the issue. Based on the results of the original study, Golder Associates was engaged in 2005 to carry out a more detailed Hydrological investigation into the observed failures. As a result of both studies and past experience, a rehabilitation procedure was developed by the City which included removal and replacement of the soft subgrade soils, installation of sub-drains connected to the storm sewer system and installation of a specifically designed road section. This procedure is still being utilized today in the ongoing rehabilitation of the affected roadways. To address the problem the City of Edmonton created the North East Roads Program (NERP) to proactively deal with the ongoing issue. This program has been found to be successful and it has now been in place for ten years. As part of ongoing improvements, the City of Edmonton has also taken this opportunity to trial several products as part of the rehabilitation process. This paper details the City of Edmonton's use of cellular concrete as a trial product for the rehabilitation process.

Background

During the 1999 spring roadway cleanup campaign, roadways in the Ozerna Neighborhood located in the Northeast quadrant of the City of Edmonton started to show signs of significant structural failures. As a result of a street sweeper breaking through the pavement at a number of locations and continued deterioration, the City of Edmonton Engineering Services Section, in 2002, undertook a study to determine the cause/causes for these earlier than expected structural failures. The roadways in question ranged from 6 to 8 years in age. In August 2003 City Council, during an inquiry into the issues in the northeast, requested details pertaining to the issues. Council's inquiries included: Were the poor conditions present at the time of development, is there evidence that the water table has changed since development, what is the extent of the issue and who will pay for the rehabilitation costs? After presentation of the results of the Engineering Services Study to City Council a request was made for further information and Golder Associates was retained to complete a hydrological study of the area to provide additional information.

Geotechnical / Hydrogeological Study

The study completed by Golder reviewed reports of the pre-development conditions, aerial photos and sump pump discharge details. From the information that was collected and analyzed, a drilling and testing program was developed to review the existing conditions. The pre-development boreholes show the groundwater elevation was 1 to 3 m below the surface. The pre-development aerial photos of the study area show that the area was observed to be generally flat with a number of sloughs and swamps as well as seasonally waterlogged areas. The testing conducted through the drilling program included water content, plasticity index and grain size distribution. Golder performed a hydrological analysis of the potential movement of groundwater within the study area. This analysis indicated a downward movement of the groundwater indicating that the observed softening was as a result of surficial water moving downward into the subsoils rather than groundwater moving upwards into the subsoils. The findings in the Golder report concluded that the softening of the subgrade soil is directly related to the available water from the roof leaders and sump discharge penetrating into the subgrade soils under the roadway and through time weakening these soils to a point where they no longer provide support for the road structure and traffic loading. Figure 1 shows the location of the Study area in the Northeast portion of the City of Edmonton.

The water softening of soils is defined as the reduction in strength due to an increase of water content. To have water softening of soils three physical conditions must exist. The confining stress must be sufficiently low to allow the soils to swell, the mineralogy of the soils must be susceptible to water and water must be present. The study found that there were four contributing factors to the softening of the subgrade in these areas. These are the presence of softening susceptible soils, the age of the development, sump pump discharge from homes to the surface and poor drainage of the subgrade.

The recommendations from the report were to install edge drains beneath the reconstructed roads, installation of interceptor drains to avoid overland water flow into the subgrade, connection of adjacent sump pumps to the drainage system or a combination of these recommendations (Golder 2005).

Figure 1 – Northeast Roadway Study Area

Condition Ratings

The City of Edmonton utilizes the Municipal Pavement Management Application (MPMA) to collect data from the roadway network to produce a condition rating of an individual roadway within our network. This rating system is known as the Pavement Quality Index (PQI). The PQI index is made up of various components including but not limited to the Structural Adequacy Index (SAI), Visual Condition Index (VCI) and Riding Comfort Index (RCI). This index is calculated and is measured on a scale of 1 through 10 with 10 being “Excellent” and 1 being “Poor”. An example of the use of the PQI is in the arterial road network where a roadway with a PQI value of less than 4 is considered in need of rehabilitation. In neighbourhood and local roadways the VCI is utilized in the determination of whether a roadway needs to be rehabilitated. A VCI of less than 4 out of 10 is the trigger value that a neighbourhood/local roadway is in need of rehabilitation.

The roadways within the study area had VCI values ranging from a high of 4 to a low of 1.9, averaging 2.3. Typically, deflection testing of local roadways is not done as a standard practice. In the case of the roadways within the north east study area it was decided in 2002, due to the poor VCI values, to perform deflection testing of the roadway utilizing the City's Dynaflect testing system. Typical deflection values for a well performing residential roadway would be in the range of 0.025 to 0.05 mm. Upon completion of deflection testing of the four north east neighborhoods deflection values ranging from 0.1 to 0.3 mm were found which indicated a very weak pavement structure. In back calculating the subgrade modulus from this deflection testing a value as low as 1.3 MPa was obtained. California Bearing Ratio could not be estimated, but was less than 0.5%. Normal subgrade modulus values obtained from back calculation methods for good performing pavements would be in the range of 5-7 MPa.

Rehabilitation Process

As a result of the two studies carried out it was determined that the rehabilitation of the affected roadways would consist of: installation of 200 mm diameter sub-drains connected to the stormwater system along the periphery of the roadway on both sides; removal of the softened subgrade soils to a depth of approximately 800 mm (determined in the field); placement of nonwoven geotextile; 3-63 granular sub-base layer of varying depths with a layer of geogrid at approximately 300 mm up from the bottom of the fill; and a 150 mm layer of 3-20 granular base followed by 100 mm of 10mm-LT asphalt (local roadways) and 50 mm of 10mm-HT asphalt and 100 mm of 20mm-B asphalt (for collector roadways). Typical cross sections for residential and collector roadways were developed. These cross sections are shown in Figure 2 and Figure 3.

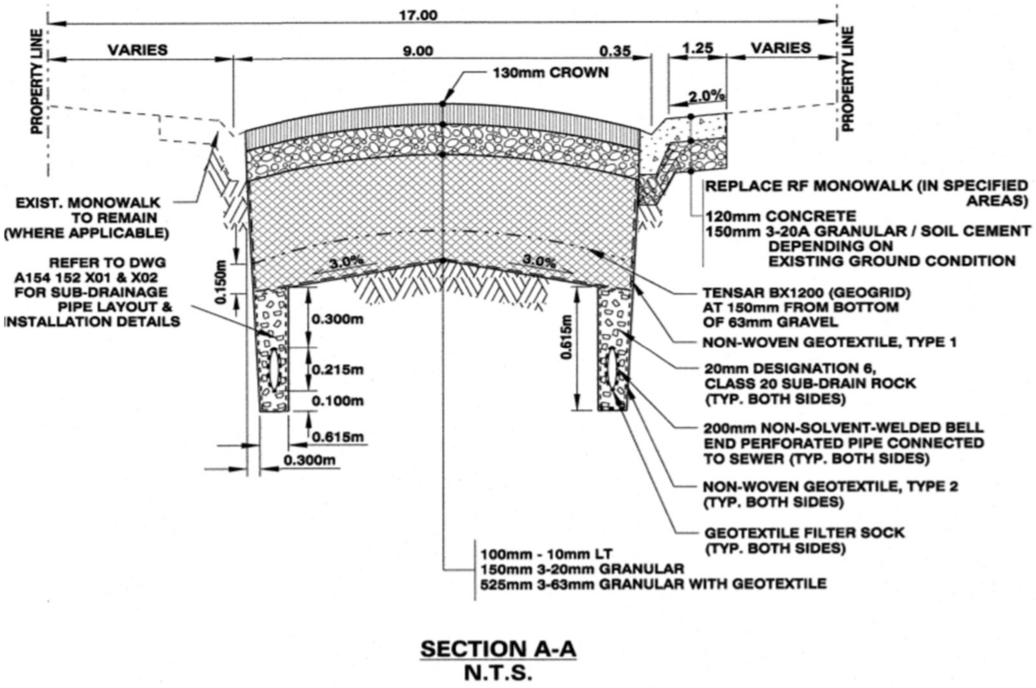

Figure 2 - Typical Residential Cross Section

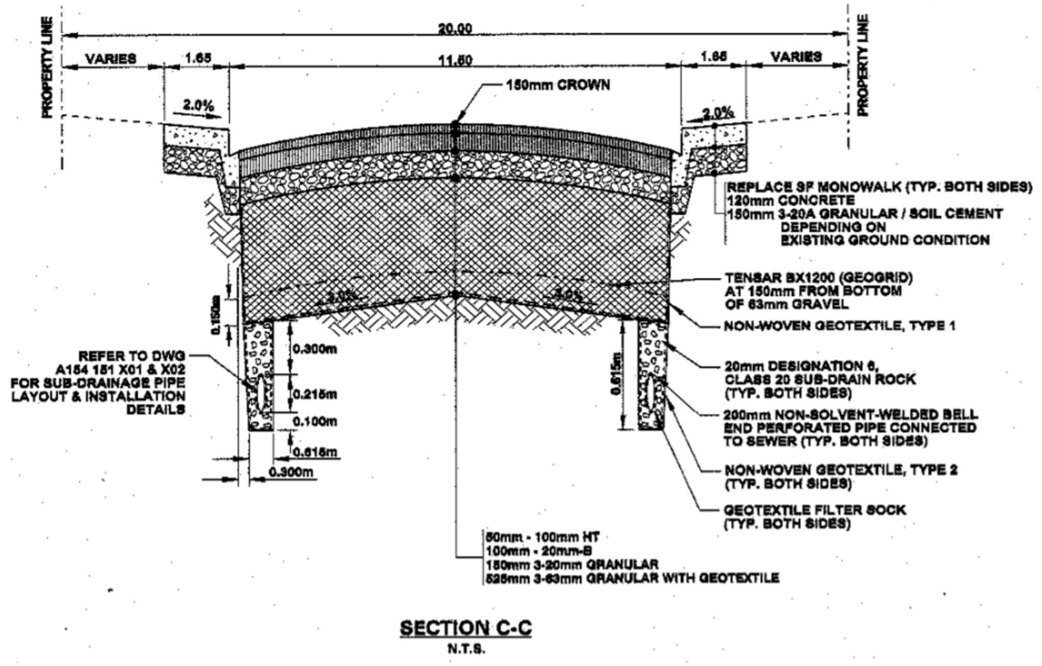

Figure 3 – Typical Collector Cross section

The time and cost associated with the construction of the detailed sections has always been questioned and as a result the use of cellular concrete was trialed in 2003 and 2009.

Lightweight Cellular Concrete

Lightweight cellular concrete (LCC), sometimes referred to as foamed concrete (CROW, 2003), is a lightweight construction material consisting of Portland cement or Portland Limestone Cement, water, specialized pre-formed foaming agent, and compressed air. Fly ash and/or slag are often added to the mix to customize compressive and flexural strengths. Cellular concrete usually contains no sand or aggregate. Fresh LCC is highly flowable and can be pumped into place over large distances (up to 1,000m) through flexible hoses. In the vast majority of cases, cellular concrete is cast-in-place.

By trapping air bubbles within the concrete, a lightweight, insulating material is formed. It has fireproofing, insulation, sound attenuation and energy absorbing characteristics.

LCC can have wet densities from 250 to 1600 kg/m^3; however, most below-ground applications are placed at wet densities of 400 to 600 kg/m^3.

LCC may be produced using either “wet” or “dry” mix processes. “Wet” mix processes use a cement and water slurry batched by a ready mix supply company. Once onsite, the temperature, density and viscosity of the slurry is measured to confirm compliance with the requirements to make LCC. After quality is verified, the slurry is delivered into the LCC equipment, which then injects foam into the slurry and pumps the LCC into place. “Dry” mix processes are commonly used to produce LCC for high volume and/or high production rate (approximately 100m^3 per hour) projects. “Dry” mix refers to the process whereby all of the constituents of the LCC are blended onsite, first by mixing the cement and water into a slurry, followed by injecting the foam and pumping the LCC into place. Cement is delivered to site using bulkers. Photographs of “dry” and “wet” mix units are shown in Figures 4 and 5, respectively.

Figure 4 – Lightweight Cellular Concrete Dry Mix Equipment

Figure 5 - Lightweight Cellular Concrete Wet Mix Equipment

Lightweight Cellular Concrete Trials

During construction carried out in 2003 in the Ozerna Neighbourhood, the use of lightweight cellular concrete (LCC) was first evaluated. In an attempt to reduce the amount of excavation and granular fill required to reconstruct the roadways, LCC was proposed to be used as a structural sub-base material. It was also intended that the LCC would serve as an insulation material from frost heave and spring weakening of the existing wet subgrade soils. The LCC was specified to have a wet (cast) density of 475kg/m^3, and a minimum 28-day compressive strength of 500kPa. Note that the typical average compressive strength of this material is 1 MPa. The proposed remediation involved the excavation of the existing materials and replacement with structures as indicated in Table 1. Differing residential and collector structures were proposed based on the appropriate traffic volumes. The collector structure had an additional 60 mm of asphalt and an additional 50mm of 3-20 recycled granular base. Wick drains were proposed to be placed under the cellular concrete at the periphery adjacent to the curb and gutter but were actually placed on top of the cellular concrete. Figure 6 shows the 2003 cellular concrete sub-base installed.

Table 1 - 2003 CEMATRIX Trial

Material	Residential Road (mm)	Collector Road (mm)
ACO	65	50
ACB	-	75
3-20 Granular Base	100	150
CMI - 475 Cellular Concrete	150	150
Total	415	425

Figure 6 - Cellular concrete after placement along 67A Street NW, Edmonton, Alberta

In 2009 the City of Edmonton was contacted by CEMATRIX to carry out another trial of the cellular concrete product in its 2009 NERP rehabilitation program. The selected location was a cul-de-sac immediately south of the intersection of 62 Street and 162 Avenue NW. The structure utilized in 2009 construction is listed in Table 2.

Table 2 - 2009 CEMATRIX Trial

Material	**Residential Road (mm)**	**Standard Granular Structure (mm)**
10mm - LT	100	100
3-20 Granular Base	150	150
CMI-475 Cellular Concrete	250	-
3-63 Granular Base	-	525
Total	500	775

The typical cross section for the 62 Avenue Work is detailed in Figure 7. During the installation of the test section, as a result of the soft subgrade soils present, it was recommended that a woven geotextile fabric (Tencate Mirafi HP370) be placed to establish a working platform on the soft soils. The geogrid noted in the cross section in Figure 8 within the LCC section was deleted and not installed.

A total of 150 m^3 of LCC was placed by CEMATRIX on July 31, 2009. Figures 8 and 9 illustrate the CEMATRIX material during placement on top of the Tencate Mirafi HP370 Fabric at the 62 Street trials in 2009. Following the placement of the cellular concrete, 150mm of a 3-20 Granular Base material was placed and compacted to 100% of Standard Proctor Density by the contractor. This was followed by the placement of the 100mm of the 10mm-LT Asphaltic concrete surface course.

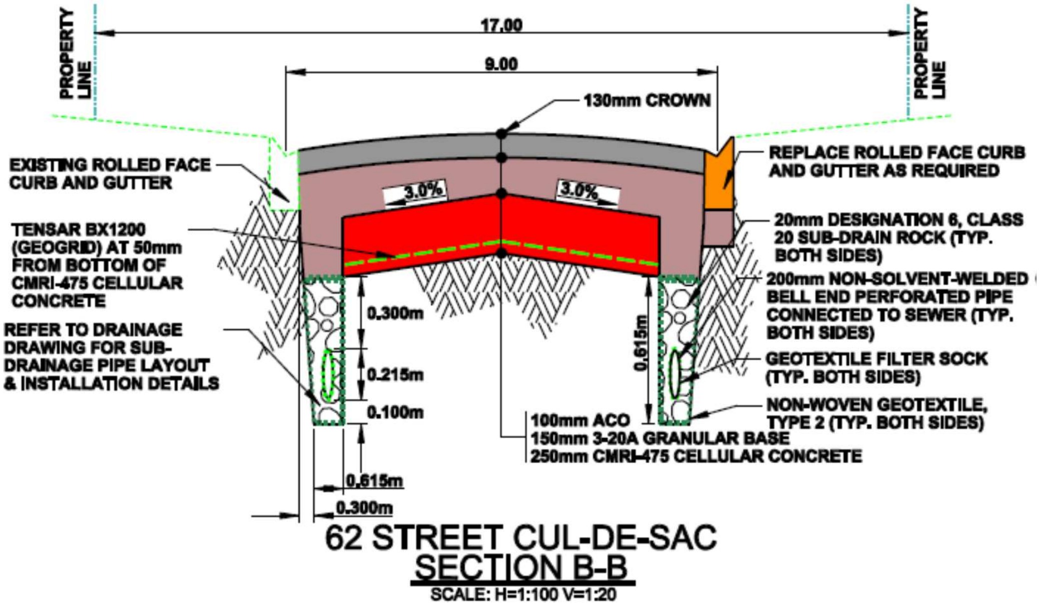

Figure 7 – 62 Avenue Cellular Concrete Test Section Cross Section

Figure 8 - Placement of Lightweight Cellular Concrete on 62 Street NW, Edmonton, Alberta

Figure 9 - Placement of Lightweight Cellular Concrete on 62 Street NW, Edmonton, Alberta

Figure 10 - Completed Lightweight Cellular Concrete on 62 Street NW, Edmonton, Alberta

Figure 11 - Completed Granular Layer on the Lightweight Concrete Layer on 62 Street NW, Edmonton, Alberta

Figure 12 - Placement of the Asphalt on the Granular on 62 Street NW, Edmonton, Alberta

Load Deflection Data

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 Ratio (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 prior to and after construction. 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 in figure 11. This apparatus is used by the City to obtain pavement deflection readings for neighborhood rehabilitation and pavement design consideration in residential neighborhoods. The City’s target deflection value for acceptable pavement structures is 0.05 mm after the final completion of rehabilitation/reconstruction. Deflection testing was carried out by the City of Edmonton on the 62 Street CEMATRIX trial section as well as the 61 Street Cul-de-sac at 162 Avenue NW which was constructed utilizing our standard granular section for comparative purposes. Table 3 details the results of Dynaflect Deflection testing pre and post reconstruction as well as testing carried out in August 2016 for the 62 Street CEMATRIX trial section and the adjacent 61 Street cul-de-sac. Figure 12 shows a graphical representation of the results of all the deflection test results.

Falling Weight Deflectometer (FWD) Testing was carried out by the City of Edmonton in 2016 utilizing their Dynatest 8000 Falling Weight Deflectometer. The FWD applies a 40 KN dynamic load that simulates the loading of a moving wheel. The pavement response is analyzed with Dynatest's ELMOD (Evaluation of Layer Moduli and Overlay Design) software to determine the elastic moduli, stresses and strains of each modeled layer. The results of the August 2016 FWD testing can be found detailed in table 4.

Figure 13 - Dynaflect Deflection Apparatus

Figure 14 - FWD Deflection Apparatus

Table 3 – Dynaflect Deflection Test Results

Station	Dynaflect Deflection Readings (mm)					
	CEMATRIX Section			Granular Section		
	Preconstruction	Post Construction	2016	Preconstruction	Post Construction	2016
0	0.029	0.037	.031	0.089	0.023	.027
10	0.175	-		0.065	-	
15	-	0.059	.056	-	0.038	.038
20	0.121	-		0.126		
30	0.180	0.054	.050	0.108	0.032	.031
40	0.210	-		0.109	-	
45	-	0.052	.054	-	0.046	.041
50	0.150	-		0.164	-	

Station	Dynaflect Deflection Readings (mm)					
	CEMATRIX Section			Granular Section		
	Preconstruction	Post Construction	2016	Preconstruction	Post Construction	2016
60	0.190	0.047	.048	0.096	0.031	.028
70	0.124	-		0.092	-	
75	-	0.041	.043	-	0.031	.030
80	0.185	-		0.178	-	
90	0.220	0.061	.054	-	0.042	.031
95	-	0.058		-	0.043	

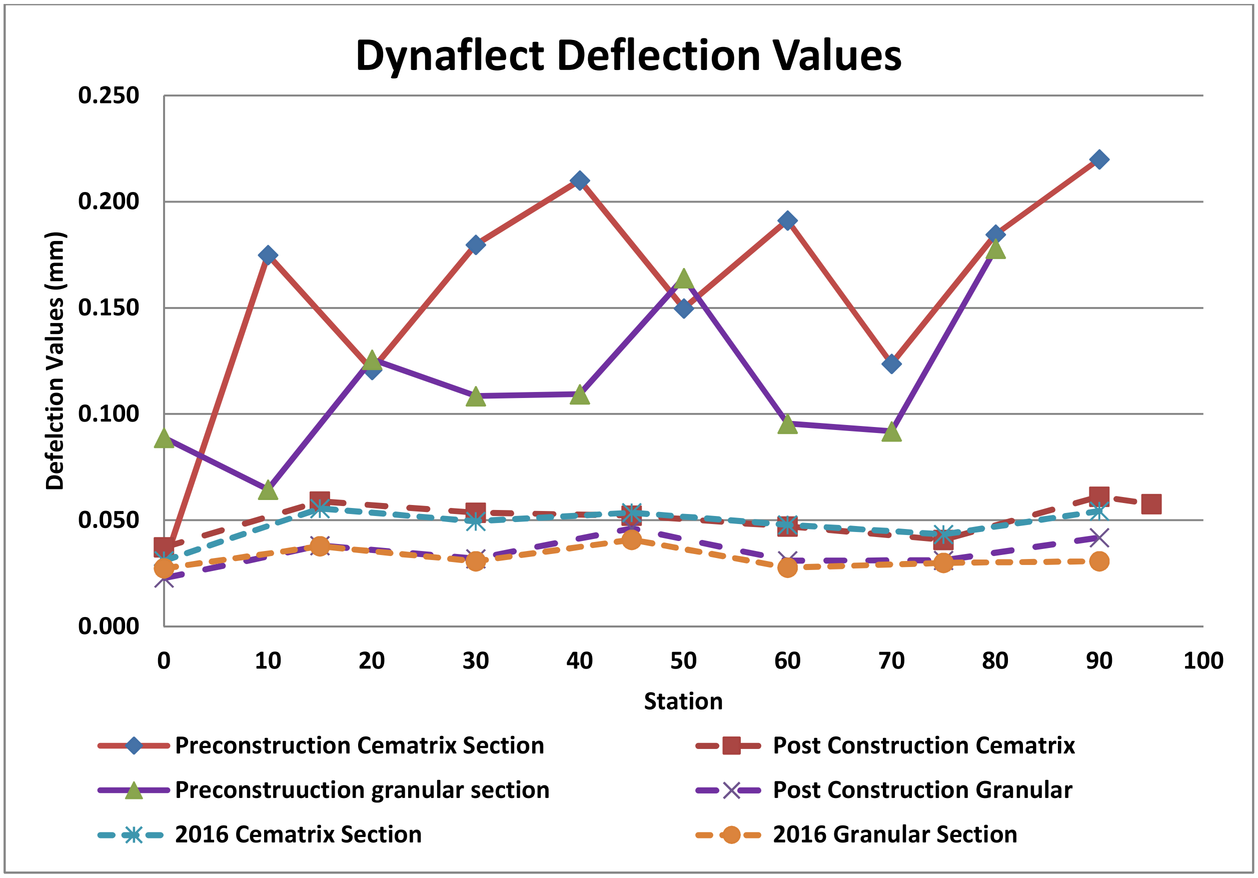

Figure 15 – Deflection Test Result pre and Post Construction for 62 Avenue Trial Section

Table 4 – FWD Deflection Test Results

	FWD Results	
Station	**2016 CEMATRIX Section (mm)**	**2016 Granular Section (mm)**
0	.456	.155
15	.416	.347
30	.397	.456
45	.511	.332
60	.451	.278
75	.375	.326
90	.534	.349

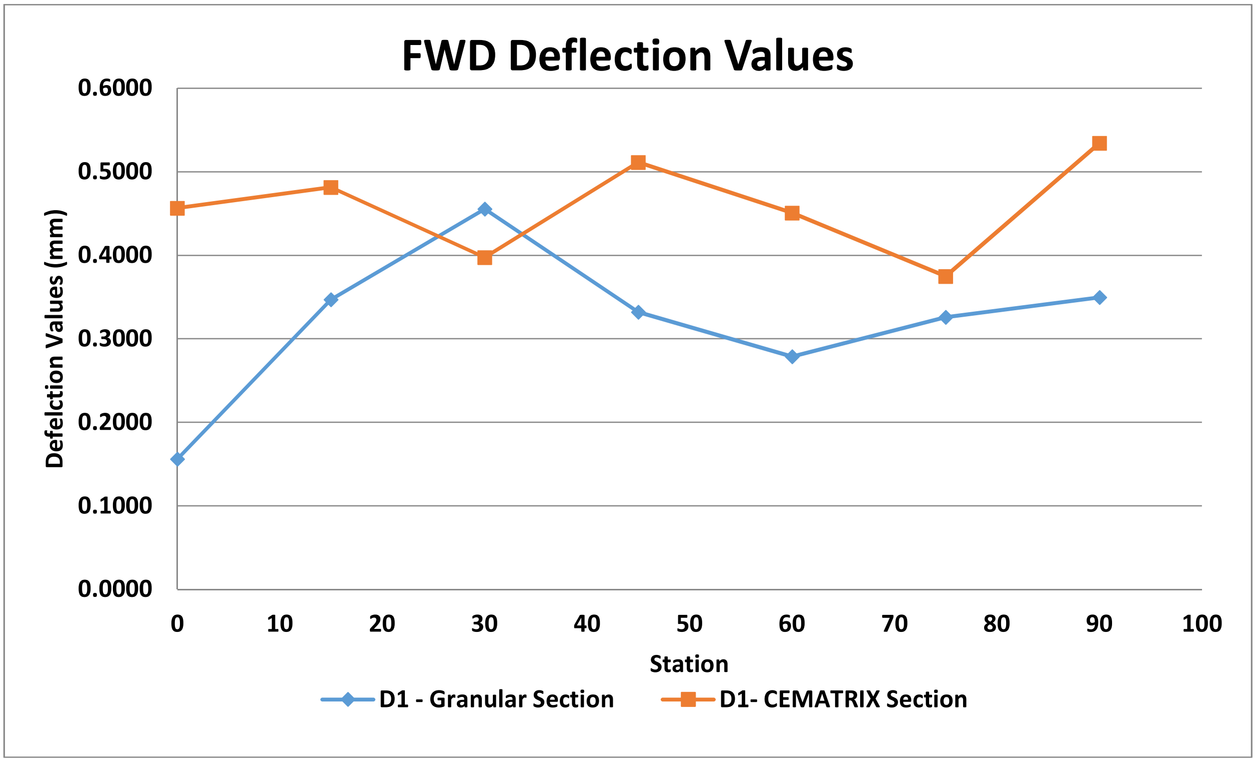

Figure 16 – FWD Deflection Test Result August, 2016 Granular and CEMATRIX Sections

Discussion

Results of Dynaflect deflection testing of both cul-de-sacs indicated that the 62 St. cul-de-sac where CEMATRIX was placed was experiencing slightly more deflection than the standard granular NERP section. The adjacent 61 Street Cul-de-sac on the South end of 162 Avenue was used as a control section. The average deflection for each of the two sections within each of the 5 depths was calculated and the standard error between the two averages was determined. In comparing the adjacent cul-de-sac (61 St. and 162 Ave.) approximately 30% more deflection was observed within the CEMATRIX test section cul-de-sac. However, in looking at the pre-construction deflection testing carried out prior to the work taking place when the same criteria was utilized, the CEMATRIX 62 Avenue Cul-de-sac was found to have approximately 30 % more deflection when compared to the granular 61 Avenue cul-de-sac. It was also noted that post construction testing resulted in deflections that were deemed comparatively even throughout the structure in both cases.

On July 6, 2011 a visual inspection of the test sections was made and no visible differences between the two sections were observed.

Additional Dynaflect Deflection testing carried out in August of 2016 indicated that the deflection results were slightly better than those obtained post construction, but that the 30% difference in deflection is still being observed 7 years after completion of the construction.

In comparing the pavement structural design utilizing AASHTO 1993 the following was noted. In the original design, CEMATRIX personnel used a total Structural Number (SN) of 124 and an a-value of the CEMATRIX cellular concrete was assumed to be a=0.25. Assuming a=0.4 for the Asphaltic Concrete and a=0.14 for the granular materials the NERP design installed on the adjacent cul-de-sac and throughout the neighbourhood has a Structural number of 144.5. In order for the CEMATRIX design to obtain an equivalent SN, the amount of CEMATRIX used would have to be increased from a depth of 250 mm to a depth of 334 mm, or the CEMATRIX would need a structural a value of 0.33.

In an attempt to quantify the modulus of the CEMATRIX materials the City of Edmonton utilized its Dynatest 8000 Falling Weight Deflectometer to obtain deflection values, and then utilized the ELMOD software to determine the elastic moduli of the individual layers in the pavement structure. The results of the analysis are presented in Table 5. The results of this testing indicates that the combined granular/CEMATRIX modulus is actually higher than that obtained from the straight granular section. It also shows the subgrade modulus in the CEMATRIX section is approximately 35% lower than the subgrade modulus in the Granular section.

Table 5 – FWD Backcalculated Modulus Values

Material	Modulus Values 2016 CEMATRIX Section (MPa)	2016 Granular Section (MPa)
Asphalt	6784	10305
Granular	214	240
CEMATRIX	304	-
Subgrade	48	74

Based on the results of our study, it is our opinion that the main reason for the greater deflection levels is that the depth of the overall pavement structure has resulted in the CEMATRIX pavement structure (62 St. Cul-de-sac) being founded in shallower, softer soils. Extrapolating from the data obtained from borehole data for testing in the area geotechnical investigation, the unconfined compressive strengths (q_u) at the founding depths are compared below in Table 6.

Table 6 - Unconfined Compressive Strength at Founding Depths

Design	Base Depth	Approximate q_u at that depth
CEMATRIX Section	500 mm	45 kPa
Typical NERP Granular Section	800 mm	53 kPa

The weaker performance of the CEMATRIX we believe to be a result of the bias that the CEMATRIX is founded on the upper soils, which are weaker than the soils that the granular section is founded upon (the q_u increases with depth).

In order to for the CEMATRIX pavement structure to match the existing NERP gravel structure using pure structural equivalencies, an increase of the CEMATRIX thickness would be required.

This however does not take into account the placement of the woven geotextile that was used as a working platform for the CEMATRIX section. This product would contribute somewhat to the structural capacity of the section. In looking at the cost of Construction in 2009, the cost for the original CEMATRIX design resulted in a total cost for the 62 Avenue Cul-de-sac of $63,000.00. The cost for the 61 Avenue cul-de-sac using the standard Granular structure resulted in a total cost of $43,000.00. It should be pointed out that both Cul-de-sacs were approximately the same size.

Conclusions

Based on the performance of the CEMATRIX materials in this trial, the use of CEMATRIX cellular concrete to increase roadway subgrade support in areas consisting of soft, high plastic, problematic soils is a viable option. Since cellular concrete has both insulating and structural qualities, additional benefits could be realized in areas with frost heave susceptible subgrades. The costs detailed in this paper would need to be reviewed and are only based on a small test section, which may skew the actual costs. For example, this project used a wet mix process to produce cellular concrete, which requires slurry to be delivered by a ready mix company. Using dry mix cellular concrete units on higher volume projects typically results in substantial cost savings.

References

Golder Associates Ltd. 2005. Final Report Northeast Edmonton Hydrogeological Program

American Concrete Institute, ACI523.1R-06, 2006. Guide for Cast-in-Place Low-Density Cellular Concrete

CROW 2003. Roads and car parks on foam concrete. CROW, Ede, Gelderland, The Netherlands