New Advances in Novel Polymeric Alloy Geocell-Reinforced Base Course for Paved Roads

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ABSTRACT

Seventh Street in Nisku industrial hub of Alberta was in very poor serviceability condition for the heavy traffic of the industrial area. In 2012, the County of Leduc decided to rehabilitate the road structure with asphalt pavement on cement treated base (CTB). Typical to most of the roads in cold climatic regions the conventionally designed CTB work satisfactorily at the beginning but start to show signs of failure as soon as the first freeze-thaw cycle completes with block cracks and other forms of pavement distress. To find a reliable solution to the problem the County decided to install a trial section with a Nano Polymeric Alloy (NPA) geocell-reinforced granular base and compare the performance over time with the conventional practice of CTB. Commercially available higher strength geocells made from NPA material were used to reinforce the base course. Two test sections were constructed over a total stretch of 1000m of the road, 500m each of the CTB and NPA geocell-reinforced granular base on either side of the railway track. The University of Alberta conducted initial research and monitoring on the test sections. During the following years, non-destructive testing and monitoring of both the sections was carried out by the Leduc County employing independent organizations. Monitoring of the tests sections conducted after consecutive freeze-thaw season have demonstrated the increasing benefit of using NPA geocells over CTB. This paper discusses the construction, immediate tests and monitoring done over three years on the road and compares the performance based on the findings.

INTRODUCTION

Roads form the backbone of any industrial development. The industrial roads need to be strong enough to hold the heavy traffic for the design period and at the same time be economical in operation and recurring maintenance. Road closures for any reasons impact the supply and production chain of the industry in any particular corridor. In 2012 the Seventh Street in Nisku industrial hub of Alberta was in extremely poor serviceability condition. There was an immediate need to maintain the road to facilitate the smooth heavy industrial traffic operation. The County of Leduc which boasts on promoting the industries in the heartland of Alberta, had decided to rehabilitate the road structure with asphalt pavement on cement treated base (CTB). Typical to most of the roads in cold regions the conventionally designed cement treated bases work satisfactorily at the beginning but start to show signs of failure as soon as the first freeze-thaw cycle is completed with block cracks and other forms of pavement distress develop. To find a sustainable solution to the problem the County decided to install a trial section with an innovative high strength Nano Polymeric Alloy (NPA) geocell reinforced base course.

NPA geocells have been used worldwide to reinforce the base and subbase courses of paved roads. These geocells that can use inferior aggregate material to give a superior strength have proved to be a sustainable option. NPA geocells have been utilized in several projects constructed in Canada especially, Saskatchewan, Alberta and British Columbia. The projects range from paved and unpaved roads, causeway, oil pads, tank foundations, logging yards and slope and erosion control and channel protection (Pokharel et al., 2013, 2015, 2016, and Norouzi et al., 2017). Other than the savings in initial cost and recurring operation maintenance cost, Pokharel et al. (2016) and Norouzi et al. (2017) have highlighted the sustainability issues with carbon emission saving caused by utilizing NPA geocell in road construction. As the infrastructure and construction industry are aiming for a sustainable construction model for the future generations NPA geocells have provided a promising future for them.

This project was a tripartite effort among the County of Leduc as client and responsible for construction, the university of Alberta as an independent party for initial project monitoring and reporting and the Paradox Access Solutions Inc. as the NPA geocell supply and installer. Paradox Access Solutions Inc. sought help from Stratum Logics Inc. for the design of NPA geocell reinforced base course and the future monitoring work. A section of 500m length was designed and constructed with commercially available higher strength NPA geocell-reinforced granular base to compare the performance over time with the conventional practice of CTB. Two test sections were constructed over a total 1000m stretch of the road; 500m each of CTB and NPA geocells-reinforced granular base. The University of Alberta conducted initial research on the test sections. During the following years, non-destructive testing and monitoring of both the sections was carried out by an independent organization. Observations made after consecutive thawing season have demonstrated the increasing benefit of using NPA geocells over CTB. This paper discusses the construction, immediate tests and monitoring done over three years on the road and compares the performance based on the findings.

BASE COURSE IMPROVEMENT FOR ROADS

Use of granular base course (GBC) for pavement construction has been a standard practice over the years. However, availability of high quality granular aggregate and higher cost associated with mining, hauling and handling of the material pose a huge challenge to the road construction industry. CTB concept is a measure to achieve the strength required for the base course by mixing cement with the soil. Discussing the use of engineered soils in Canada Smith et al. (2014) reported that cement treated soils result in stiffer foundation for asphalt pavement and mentioned that CTB will reduce required thickness of pavement structure, improve performance in rutting and fatigue cracking and reduce moisture susceptibility. While introducing the benefits of CTB Smith et al. (2014) also reported that using CTB can potentially lead to propagation of reflective cracking in the pavement if not installed properly. Alberta Transportation uses a pavement design method which follows AASHTO (1993) design procedure. This design method recommends using a layer coefficient of 0.14 for granular base course and a layer coefficient of 0.23 for cement stabilized base courses. This means cement treated base is expected to provide more support for the pavement structure after construction. Alberta Transportation (1997) had indicated that in recent years the application of cement treatment for base course has been limited due to lower than expected performance and also the cost of cement treated construction.

Cracking in CTB is a severe problem in cold climatic region with daily and seasonal variation in the Temperature. Over the years a lot of research work has been performed regarding cracking in cement-treated road base. There are the shrinkage cracks which eventually reflect through the pavement surfacing. Initially the shrinkage cracks were thought to be cosmetic in nature however, as these cracks allow water into the pavement it accelerates the rate of pavement deterioration. Faced with both negative public perception due to the cracking and the risk of early pavement distress, agencies and researchers alike continue their quest for solutions to the shrinkage cracking problem to this day (Sebesta and Scullion, 2004). While numerous approaches to minimize shrinkage cracking exist Sebesta and Scullion (2004) focused on field test sites for evaluating the microcracking technique for minimizing shrinkage cracking problems in CTB. Sebesta (2005) reported that the Texas Department of Transportation estimated savings of between $3.3 million and $8.6 million in annual net present value maintenance costs, if shrinkage cracking could be prevented on projects where CTB layers are placed.

Citing the issues discussed above and the need for strengthening the base course, geosynthetic reinforcement of the GBC seems to be a very promising option. Therefore, use of NPA geocell reinforcement that provides confinement to the granular infill and imparts modulus and bearing capacity improvements to the reinforced composite is exponentially increasing in the recent years.

Explanations of the reinforcement mechanism and benefits of the NPA geocells are given in the following sections.

THE PROJECT DESCRIPTION

The industrial area of Nisku in the County of Leduc experiences heavy truck loads which exposes pavement structure to excessive damage. The need for sustainable roads in this industrial area seemed evident after assessing the damage caused over the past few years and an expected exponential growth of similar traffic in coming years. The County needed stronger pavement structure with longer life span. As the CTB is the strengthening method that the County of Leduc has used in the past the County had already decided to use a CTB in on the entire 1000m length of this road. However, as a proponent to the innovative and sustainable technology the County of Leduc decided to construct a portion of the road with NPA geocell as base reinforcement. The NPA geocell-reinforced portion of the road is located between 15th Avenue and the railway crossing located 500m south on 7th Street in Nisku, Leduc County. This two-lane road serves as the access road to several industrial businesses along this section of the 7th Street. The location of the test sections are shown in Figure 1. Paradox Access Solutions Inc. provided technical support and installed the NPA geocell for this project.

Although the entire length of the 7th street experiences very heavy traffic, the road on the north of the railway line where the granular base was reinforced with NPA geocell is exposed to some additional traffic load especially because of the traffic to a pipe yard and the County's water filling area. Figure 2 shows the condition of the road before the new pavement construction in 2012.

Construction of this project took place in July and August of 2012. The existing road was in very poor serviceability condition. The subgrade of the existing road was scarified and used as the subgrade of the rehabilitated road structure. NPA geocell was placed and infilled with new granular material to construct a reinforced base layer. A layer of woven geotextile was used under the NPA geocell as a separator between the base and subgrade. The GBC was 200mm thick and was reinforced with 150mm high NPA geocell. In the CTB side a minimum 16kg of Portland cement per square meter of the surface area was used to mix with soil to build the stabilized base course. In both the sections a 100mm thick asphalt concrete layer was recommended but the County decided to pave with 65 mm of asphalt concrete as the first paving stage and overlay the remaining in the future. The design recommendation was based on AASHTO (1993) method with a modulus improvement factor of 3.5 for the NPA geocell reinforced base course compared to the unreinforced granular base. Figures 3 shows the pavement cross sections of CTB and NPA geocell-reinforce GBC of the road and the photographs in Figures 4 shows the road at different stages of the construction that includes the stretching of NPA geocell, infilling of GBC material and compacted base course surface.

The CTB section was constructed by the County of Leduc as per their conventional construction practice. On the Geocell reinforced section the subgrade was rolled and graded before placing the woven geotextile separation. NPA geocell was then stretched on top of the separation layer and infilled with the granular material. The granular fill was compacted to 98% of the standard Proctor maximum dry density (SPMDD) within +/-2% of the optimum moisture content.

GEOCELL AND GRAVEL MATERIAL USED FOR THE TEST

In the 1970s intended use of geosynthetic cellular confinement system known as geocells was mainly to stabilize the beach sand (Webster, 1979) however, the geocells have been successfully used for over 40 years in different geotechnical applications since then. In this period geocell made from paper, cardboard, bodkin bars, and aluminum were used and tested before the high density polyethylene cells came into the picture. Nano-composite alloy of polyester/polyamide nano-fibers, dispersed in a polyethylene matrix based NPA Geocell are the latest development in this series.

Granular material is usually unbound, meaning, it lacks the ability to withstand tensile stresses. Soil stabilization adds the ability to withstand tensile stresses by apparent cohesion which transforms the unbound granular material to a bound one. After conducting a series of static and repeated plate loading and moving wheel tests, Pokharel et al. (2009, 2010a,b,c and 2011) and Han et al. (2011a and 2011b) summarized the key geocell reinforcement mechanisms as lateral and vertical confinement, beam effect and wider stress distribution. When granular material is reinforced with the cellular confinement these mechanisms in combination improve the soil bearing capacity and modulus. Pokharel (2010) had reported that NPA geocell-reinforcement can improve the modulus by up to 7.5 times. A detailed summary of these benefits have been summarized by Kief et al. (2014) that includes all the major research work conducted on NPA geocells.

NPA geocell used in this project is characterized by flexibility at low temperatures similar to HDPE and elastic behavior similar to engineering thermoplastic. As per Kief et al. (2014) the NPA geocell is characterized by long-term plastic deformation measured by accelerated stepped isothermal method (SIM test) as: ≤0.5 % at 44^{o}C; ≤0.6 % at 51^{o}C, ≤0.7 % at 58^{o}C (at 6.6 kN/m, ASTM D-6992 modified, according to the manufacturer's specifications). The NPA geocell used in this project had tensile strength of 21.5kN/m and the elastic modulus at 2% strain was 620MPa. The NPA geocell was non-perforated and had the height and thickness of 150mm and 1.1mm, respectively. The properties of the NPA geocell used to reinforce the granular base course at the test section of this project are given in Table 1.

Table 1: Details of NPA Geocell

Description	Value
Material	Neloy polymeric nano-Composite alloy
Material strength at yield	24 MPa
Strength at yield (wide-width)	29 kN/m
Long term resistance to plastic deformation, allowable strength for design (5 years)	19.8 kN/m
Creep reduction factor (5 years)	1.2
Coefficient of thermal expansion	80 ppm/^{0}C
Coefficient soil-cell friction efficiency	0.95
Distance between weld seams	330mm
Cell height	150mm
Cell dimension	245mm x 210mm (+/- 3%)

A layer of 800N woven geotextile was used for separation at the bottom of the NPA Geocell. The fill material in the geocell was 20mm maximum size (Alberta Transportation specification Designation 2 Class 16) crushed gravel.

TESTING, MONITORING AND PERFORMANCE EVALUATION

Based on project schedule and available resources, Soleymani et al. (2012) conducted laboratory material testing and field testing using Dynamic Cone Penetration (DCP) and Falling Weight Deflectometer (FWD) tests for the evaluation of these two pavement sections. They had recognized that the proposed short term evaluation methods may not be the best evaluation method and recommended to continue to monitor field performance of these pavement sections for several seasons. In this paper the visual monitoring and the FWD tests that were carried every year after construction is discussed in detail.

All the three concerned parties involved in this project discussed about different tests methods and monitoring. Expert opinion on the limitations of FWD while testing the geosynthetic-reinforced structures were apprised to the concerned parties especially, the expert's opinion on this that has been highlighted by Jersey et al. (2012) and later by Giroud and Han (2016). Possibility of other test method particularly repetitive plate loading test was also discussed however, it was decided to go ahead with the FWD and conduct visual monitoring of the site at regular interval after construction. The testing and monitoring during construction was done by University of Alberta (Soleymani et al., 2012). The County conducted two further FWD tests on the section in the following years and the authors monitored the site at regular intervals for visible pavement distress and serviceability condition of both sides of the test section. The authors had been visiting the site at regular interval, documented their observation from visible performance and serviceability issues and reported them with pictures from the site. Although this paper bases its recommendations on observations made on the surface failures as the main indicator of performance on the test sections a short discussion is also made here to show it correlation with the FWD test results.

Soleymani et al. (2012) had conducted FWD tests 18 days after construction and reported structural numbers of 108.2mm for CTB and 103.8mm for the NPA geocell reinforced section from 300mm FWD plate size and structural numbers of 90.7mm for CTB and 83.5mm for the NPA geocell reinforced section from 450mm FWD plate size however, the report considered very thick base course in both the cases 500mm in case of CTB and 700mm in case of NPA-geocell reinforcement. Table 2 summarises the results from Soleymani et al. (2012). It would not have given an accurate comparison so, the authors recalculated the effective structural number based on the FWD data and total pavement structure of 265mm. The values thus obtained are 51mm for CTB section and 40mm for NPA geocell-reinforced section (a total pavement thickness of 565 would have given 97mm and 73mm, respectively).

A year after the construction the County conducted FWD tests on both the section their report showed a minimum effective structural number of 46mm on the CTB side assuming 265mm of total pavement thickness and 63mm on NPA geocell-reinforced. The FWD tests had shown back calculated pavement modulus of 375Mpa on CTB side and 981MPa on the NPA geocell-reinforced section. County had later employed a third party in July 2014 to conduct the FWD test which reported minimum effective structural number of 36mm on the CTB side assuming 200mm CTB thickness and 38mm on NPA geocell reinforced section assuming 200mm granular base course, in both cases 65mm ACP thickness was used. The FWD tests in July 2014 had shown AASHTO pavement modulus of 586 MPa with standard deviation of 398 on CTB side and 270 MPa with standard deviation of 64 in NPA geocell-reinforced section.

Table 2: FWD test result 18 days after CTB construction (reproduced from Soleymani et al. (2012))

Direction	FWD plate size	Average value and (Standard Deviation)		
		Subgrade Modulus, Mr	Pavement Modulus, Ep	Structural Number, SN
	(mm)	(MPa)	(MPa)	(mm)
North Section (NPA geocell-reinforced base)	300	28.8 (2.5)	190.5 (28.2)	103.8 (5.1)
South Section (Cement treated base)		31.9 (3.3)	537.9 (112.6)	108.2 (8.1)
North Section (NPA geocell-reinforced base)	450	13.3 (0.9)	99.4 (17.0)	83.5 (4.9)
South Section (Cement treated base)		15.0 (1.6)	320.6 (77.2)	90.7 (7.6)

Using direct cone penetrometer (DCP) on the base courses of the test section, it was found that the number of drops required to penetrate in the NPA geocell-reinforced granular layer varied from 15 to 20 while for the CTB layer it varied from 30 to 55. The higher variation in DCP results for the CTB layer could be due to many reasons such as the non-uniformity of CTB materials (Soleymani, 2012). Similar variation was observed in the FWD test results as well. However, in both type of the tests the NPA geocell-reinforced base layer was very consistent with small value of standard deviation, which is an indication of uniformity of this layer.

The FWD results from different tests had so much variations that it was not possible to draw a clear conclusion regarding performance of these road sections solely based on these tests. Therefore, the authors decided to regularly monitor the performance of NPA geocell-reinforced section of the road until ACP overlay was done by the County in 2016. There were no signs of rutting or surface distresses on the NPA geocell-reinforced side and it was performing without any problem for first three years of operation until the overlay. Some pictures from the test sections in the Figures 5 through Figure 8 show conditions of these road sections. These pictures are self-explanatory of the road condition before, during construction and after the road was opened to traffic operation for three subsequent years. Figure 5 shows the condition of NPA geocell-reinforced side after construction in August 2012 and a year after in August 2013. The driving surface was smooth and the visual observation showed no sign of any pavement distress in the entire 500m length of this section. A comparison of the CTB and NPA geocell reinforced section one year after the construction in August 2013 either side of the railway track is shown in Figure 6. The pictures clearly show the deteriorated condition with surface distress on the CTB side and no issue on the NPA-Geocell reinforced side. Photographs in Figure 7 and Figure 8 were taken in March 2015. There were longitudinal and transverse cracks and a completely damages pavement section on the CTB side but the NPA geocell reinforced did not have any visible rut or distress and the surface was smooth for driving.

DISCUSSIONS

The monitoring and evaluation of a road projects take years to complete. The performance of a paved road structure depends several factors on the combined strength/performance of the subgrade, base course and the pavement surface layer. Roads initially showing stronger response may not always be the best in long run as it has to go through series of seasonal variations. The seasonal variations create variation in strength properties of the road structure too.

The FWD is a cheaper and quicker test method compared to other available alternative tests method. FWD gives reasonable values in most cases but when testing on geosynthetics reinforced base courses it may not prove to be the appropriate test method. Giroud and Han (2015) mentions that "*for quality assurance, field tests are performed to evaluate whether a geosynthetic-stabilized unpaved road meets the design requirements. FWD, LWD, and static and repetitive plate loading tests may be performed. Static plate loading tests can assess the composite elastic modulus increase of a test section by geosynthetic while repetitive plate loading tests can evaluate the composite resilient modulus increase of a test section by geosynthetic*". Repetitive plate loading tests can induce elastic rebound and permanent deformations; therefore, these tests are effective in evaluating the benefit of geosynthetics in stabilizing base courses over subgrade under repeated loading, which includes increased in section composite resilient modulus (related to the rebound).

Although, as expected, the results from the initial FWD tests showed the CTB section to be stronger than the test section with NPA geocell-reinforced GBC, the rate of deterioration of the pavement surface in the proceeding years was quicker in the CTB section. The pavement distresses in the CTB section had initiated even before completing a full year of service. By the end of the second year, there were a couple areas with severe pavement distresses in the CTB side close to the railway track but nothing like that was observed on the NPA-geocell-reinforced side. CTB is usually expected shows higher stiffness values but the main problem with it is the shrinkage cracking. The failure of pavement on the CTB side that was observed on the CTB side was mainly the reflection of the shrinkage cracking. However, even in that condition after three years of operation the FWD test was showing similar strength values on both the test sections. In the absence of other tests the County, in this case used the results from the FWD tests to decide on overlay requirement. Therefore, in the summer of 2015 the County placed ACP overlay in both of these test sections to meet the originally designed 100mm of ACP thickness. However, the authors based on the several field observations supported by the picture in Figures 6, 7 and 8, believed that the road on the NPA geocell-reinforced side still was in good serviceability condition. As evidenced by the pictures and site observation the CTB side had some surface distress, longitudinal and transverse cracks and even pot holes in a couple of location which needed rehabilitation.

Since the inception of this project almost 5 years ago the authors have been emphasizing that while analysing the benefits of a geosynthetic reinforced granular material the 'elaborated path' should be based on back calculated moduli derived from measured stresses not the displacement as false results can stem from back calculated moduli derived from measured displacement. The same applies to the back calculated layer moduli derived from the measured displacements (FWD) on NPA geocell reinforced granular base. Leading pavement researchers had previously reported that the FWD and light weight deflectometer (LWD) tests are not effective in detecting the improved performance immediately after the construction of test sections incorporating geosynthetics, NPA geocell in this case. The reason identified were the deformations induced by the deflectometer to be too small to mobilize the contribution of geosynthetics however, after the test sections are subjected to wheel loading, geosynthetics can minimize the deterioration of granular bases so that the modulus of the base is retained for a longer performance period (Giroud and Han, 2016). Jersey et al. (2012) demonstrated that the FWD test then can detect the higher retained composite modulus of the test section with geosynthetic compared to the composite modulus of the test section without geosynthetic.

The comparison of the numbers from FWD and the pictures and visual observation made over the duration of the research show that as identified by Giroud and Han (2016) FWD test may not be the appropriate test method for Geosynthetic reinforced structures.

Soleymani et al. (2012) had concluded that the evaluation methods with FWD had limitations and could not provide a full picture of the future performance of the pavement structures because the main mechanism of the NPA geocell in strengthening of the base layer is improving its confining pressure. FWD are not the best test to show the structural improvement of pavement with NPA geocell. That report also concluded that as the testing program was focused on the structural evaluation of these two pavement structures, the functional performance of these two sections, in terms of smoothness and distresses, was not studied and Soleymani et al. (2012) had recommended a full performance evaluation of these pavement sections that should include structural and functional performance evaluation. They had also pointed that it would be necessary to monitor structural and functional performances of these two pavement structures in the coming years after several freeze and thaw cycles especially, given Alberta's climatic conditions as environmental factors could be the main factor in deterioration of pavements.

The choice of base course design whether to reinforce with geosynthetic material or use other treatment depends greatly on the cost and environmental factors also. A better understanding of the sustainability factors using NPA geocells are discussed by Pokharel et al. (2016) and Norouzi et al. (2017). A comprehensive evaluation in this regard would be the scope of future research.

CONCLUSION

NPA Geocell and CTB sections were constructed side by side in Leduc's 7th street to evaluate the performance of the two sections over the years. Initial FWD test results obtained right after construction showed higher effective structural number for CTB section compared to NPA Geocell section. However, as observed by continuous monitoring of pavement performance over the span of three years following construction, NPA Geocell section continued its integrity even after three years of monitoring period and the difference in the pavement condition in the two sections was visibly noticeable at the pavement surface during the first thaw season. The innovative NPA geocell-reinforced GBC designs therefore proved to be a big stride towards the goal of sustainable road construction. It is more so when NPA Geocell-reinforced GBC is compared to the CTB in cold climatic region.

Although CTB has been a widely accepted method in road construction it is well understood that it is prone to thermal cracks that ultimately reflect to the surface and later turn into surface failures.

Three years of monitoring in the 7th street showed that the signs of failure in the CTB section started to show during the first thawing season and before the end of second year the this section was already needing maintenance. As the results from FWD tests on NPA-geocell reinforced section was inconclusive and did not show any correlation with surface distresses in two test sections the FWD tests are not suitable method for quality control and assurance testing in case of geosynthetics-reinforced (especially, geocell-reinforced) pavement structures; this goes in line as reported by Giroud and Han (2016) . Also, Comparing the results of FWD tests both at the initial stage and throughout the monitoring period, authors would like to emphasize on the fact that pavement rehabilitation decisions in case of NPA geocell-reinforced structures should not be made solely by relying on the FWD test results; those decisions should rather be made by taking into account pavement performance indicators such as International Roughness Index, Riding Comfort Index, Visual Condition Index, Pavement Quality Index, etc. Repetitive Plate loading tests instead of the falling weight tests could be another option. Further research is required to fully investigate and compare performance of NPA Geocell reinforcement and CTB. It would be prudent to conduct similar research to compare untreated base courses and/or asphalt emulsion treated base that would cover wide range of alternatives to choose for the pavement designers. It is recommended for future researchers to perform pavement performance measurements in regular intervals to be able to develop performance models for NPA geocells in Canadian Climate Condition.

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REFERENCES

1. Pokharel, S.K., Martin, I., and Breault, M. 2013. "Causeway Design with Neoweb Geocells." *Proc. of Design and Practice of Geosynthetic-Reinforced Soil Structures*, eds. Ling, H., Gottardi, G., Cazzuffi, D, Han, J., and Tatsuoka, F., Bologna, Italy. October 14-16, 2013, pp 351-358.
2. Pokharel, S.K., Martin, I., Norouzi, M. and Breault, M. 2015. "Validation of Geocell Design for Unpaved Roads." In *Geosynthetics 2015*. Portland, OR, USA. Feb 15-18, 2015.
3. Pokharel S.K., Norouzi M., Martin I., and Breault M. 2016. "Sustainable Road Construction for Heavy Traffic Using High Strength Polymeric Geocells." In *Canadian Society of Civil Engineers annual conference on Resilient Infrastructure*, London, ON, Canada. June 1-4, 2016.
4. Norouzi, M., Pokharel, S., Breault, M., and Breault, D., 2017. "Innovative solution for road construction." *In Canadian Society of Civil Engineers annual conference*, Vancouver, May 31 to June 3, 2017.
5. Smith, T., Barnes, C.L., and Zupko, S. 2014. "The use of engineered soils in Canada." In *TAC 2014: 2014 Conference and Exhibition of the Transportation Association of Canada.* Montreal, QC: Transportation Association of Canada.
6. American Association of State Highway and Transportation Officials. 1993. *AASHTO Guide for Design of Pavement Structures.* Washington, D.C., USA.
7. Alberta Transportation, 1997. Pavement design manual, *Alberta Transportation and Utilities*.
8. Sebasta S. and Scullion, T. 2004. "Effectiveness of Minimizing Reflective Cracking in Cement-Treated Bases by Microcracking." Technical Report: # FHWA/TX-05/0-4502-1

9. Sebasta, S. 2005. “Continued Evaluation of Microcracking in Texas.” College Station, TX: Texas Transportation (Report 0-4502-2).
10. Google Maps [Viewed 17 April 2017.] http://maps.google.ca/maps?hl=en&tab=wl
11. Webster, S.L. 1979. “Investigation Of Beach Sand Trafficability Enhancement Using Sand-Grid Confinement and Membrane Reinforcement Concepts.” U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Report GL-79-20 (1).
12. Pokharel S.K., Han J., Parsons R.L., Qian Y., Leshchinsky D. and Halahmi I. 2009. “Experimental study on bearing capacity of geocell-reinforced bases.” *Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways, and Airfields*, Champaign, Illinois, June 29–July 2.
13. Pokharel, S.K. 2010a. ‘‘Experimental study on geocell-reinforced bases under static and dynamic loading,’’ *PhD dissertation*. Civil, environmental, and architectural engineering department, University of Kansas.
14. Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., and Halahmi, I. 2010b. “Investigation of factors influencing behavior of single geocell-reinforced bases under static loading.” *Journal of Geotextile and Geomembrane*. 28 (6), pp 570-57.
15. Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., and Halahmi, I. 2010c. “Investigation of Factors Influencing Behavior of Single Geocell-Reinforced Bases under Static Loading.” *Journal of Geotextile and Geomembrane*, 28 (6), 570-578.
16. Han J, Pokharel SK, Yang X and Thakur J (2011a) ‘‘Unpaved roads: tough cell—geosynthetic reinforcement shows strong promise.’’ *Roads and Bridges*. July, 49 (7), p. 40–43
17. Han J, Pokharel SK, Yang X, Manandhar C, Leshchinsky D, Halahmi I, Parsons R.L. 2011b. “Performance of geocell-reinforced RAP bases over weak subgrade under fullscale moving wheel loads.” In *ASCE Journal Materials in Civil Engineering,* 23(11):1525–1535.
18. Kief, O., Schary, Y., Pokharel, S.K. 2014. “High Modulus Geocells for Sustainable Highway Infrastructure.” *Indian Geotechnical Journal: Special Issue on Transportation Geotechnics*. Vol. 45, Issue 4, pp 389-400.
19. Soleymani, H.R., Qui, T, Mirza, T., Saha, Aniruddha, and Nasir, M.S. 2012. “Construction and structural evaluation of pavement structures with NPA geocell Geocell and cement treated base layers of the 7th street, Nisku, Leduc County, Alberta.” University of Alberta, Department of Civil and Environmental Engineering - unpublished report.
20. Jersey, S.R., Tingle, J.S., Norwood, G.J., Kwon, J., and Wayne, M. 2012. “Full-scale evaluation of geogrid reinforced thin flexible pavements.” *Transportation Research Record: Journal of the Transportation Research Board, No. 2310*, pp. 61-71.
21. Giroud J.P. and Han J. 2016. Part 2: Field evaluation of the performance of unpaved roads incorporating geosynthetics—planning. *Geosynthetics Magazine*, 1 Apr. 2016. Web. 9 Feb. 2017.

Figure 1: Location of the test section showing 7th Street in Nisku (Google Earth, 17 April 2017)

Figure 2: Condition of the seventh street before rehabilitation (picture taken in April 2012)

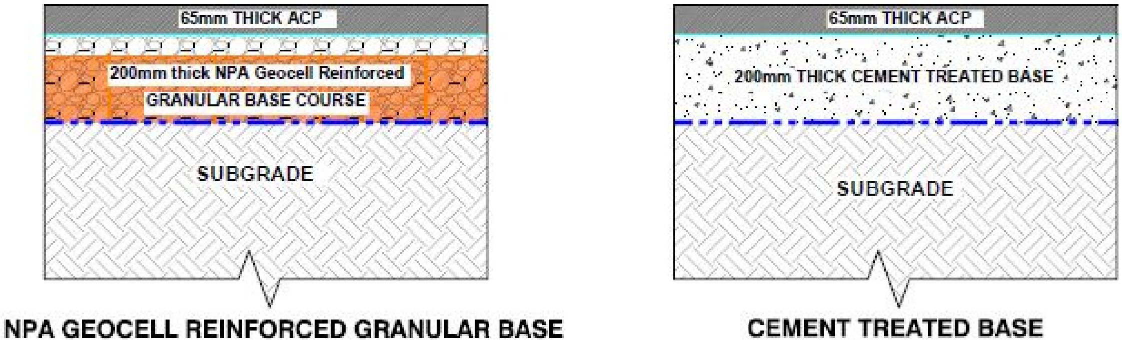

Figure 3: Cross sections of the Test sections

Figure 4: Fully stretched NPA geocell (top) and compacted NPA geocell-reinforced base (bottom) (picture taken in July 2012)

Figure 5: Paved road surface on NPA geocell-reinforced base (August 2012 and August 2013)

Figure 6: CTB section on left and NPA Geocell-reinforced on right side of rail track (Picture taken on August 2013)

Figure 7: Pavement failures on CTB section in March 2015

Figure 8: NPA Geocell-reinforced section in March 2015