Validation of Geocell Design for Unpaved Roads

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ABSTRACT

Based on cyclic plate load and moving wheel tests Pokharel (2010) proposed a design method for unpaved roads using Neoloy based Geocell with a theoretical base from the Giroud and Han (2004) design method for planar reinforcement. To validate it under real time traffic, unpaved haul roads, well pads, and logging yards were designed. To the possible extent locally available cheaper poorly graded but environmentally friendly materials were used as infill. In case of extremely soft subgrades, construction layer of poorly graded sand reinforced with Geocell provided a driving surface for the construction equipment. The performance of the structures was evaluated on the rutting criteria, maintenance requirement, and visual serviceability after one year of service. This paper discusses the design method used in a number of projects in Western Canada including the Oil Sands region that face extreme cold weather conditions. The limitations of the design method are also discussed.

1. INTRODUCTION

Reinforcement of the structural pavement layer for load support applications is a key to overcome weak soil problems, reduce the base layer's thickness and increase the life-span of the project. Conventional ground stabilization solutions (soil replacement, additives, or thicker base layers) either do not provide sufficient long-term stability and strength or entail high costs and environmental impacts. Geosynthetics reinforcements have been in practice to improve the performance of unpaved and paved roads for over 40 years. These reinforcements can be placed above the subgrades to increase the bearing capacity, or within the base course to enhance the load distribution capacity. This results in reduced base course thickness and longer service life.

Geocells are suitable for reinforcement of granular soils to support static and moving wheel loads on roadways, railways and similar applications. Increasing bearing capacity of subgrade and improving modulus of the infill material are not the only benefit of using Geocell in the pavement structure but it will also reduce the initial project cost by reducing the amount of required infill material, reduces the construction time of the project and also minimizes required maintenance and rehabilitation. In addition, road construction will be more environmentally friendly as the Geocell can be filled with locally available inferior infill which eliminates the need for transporting infill material from a long distance to the construction site. This will ultimately result in reduced amount of haul time and trucks which will lead to less fuel consumption, pollution and carbon footprint.

Until a few years ago, most of the commercially available Geocells were made of high-density polyethylene (HDPE) material. There were some inherent issues with HDPE material such as low creep resistance and poor thermal and elastic properties that had rendered use of Geocells ineffective for some load support applications especially, in the cold climate regions in Canada. After extensive research in cellular confinement and polymer technology Neoloy based Geocells are now commercially available for application that goes beyond and above in performance compared to its predecessors. Comprised of exclusive nano-polymeric-alloy (Neoloy), Geocell material composition and performance offers the long term strength, stiffness, creep resistance and durability required by today's highway engineering standards. The discussions, results, and conclusion in this paper are entirely based on the performance of the Neoloy based Geocells that is referred to as Geocells in this paper.

Severe cold winter conditions and subsequent freeze and thaw in Northern Alberta and British Colombia pose a challenging task to build a road that lasts for a long time with minimal maintenance requirement using the traditional methods. In addition to climate, typical subgrade condition in this area is considered poor and does not provide adequate structural support in many cases. On top of these issues, the higher loading demand of oil sand and forestry industries add further to this challenge. Neoloy Geocells have been showing the traits of a reliable solution to build roads that can serve up to industry requirements in the undesirable subgrade and climate conditions. This paper discusses unpaved road designs using the Neoloy Geocells in Northern Alberta and Northern BC and evaluates their performance after being service for various amounts of time. The paper has also attempted to validate a design method for three-dimensional geosynthetic reinforcement using the real time data from the unpaved roads.

2. BACKGROUND

Geocells in the 1970s was mainly intended to stabilize beach sand (Webster, 1979). In the last 40 years, numerous research and applications of these geosynthetic soil confinement cells have led to better understanding of the reinforcement mechanism. In recent time, many researchers have worked with the Neoloy based Geocells. An extensive research that comprised of laboratory cyclic plate loading and moving wheel test with Accelerated Pavement Testing conducted by Pokharel (2010) explained the benefit Neoloy based Geocells and suggested a design methodology by modifying established Giroud and Han (2004) design method for planar geosynthetic reinforcement. Figure 1 shows the benefit of the Geocell reinforcement in terms of permanent deformation of the pavement by comparing the deformation with unreinforced case. As per Pokharel (2010) even though the reinforced section had slightly weaker subgrade compared to the unreinforced section the improvement was huge (10.6 times).

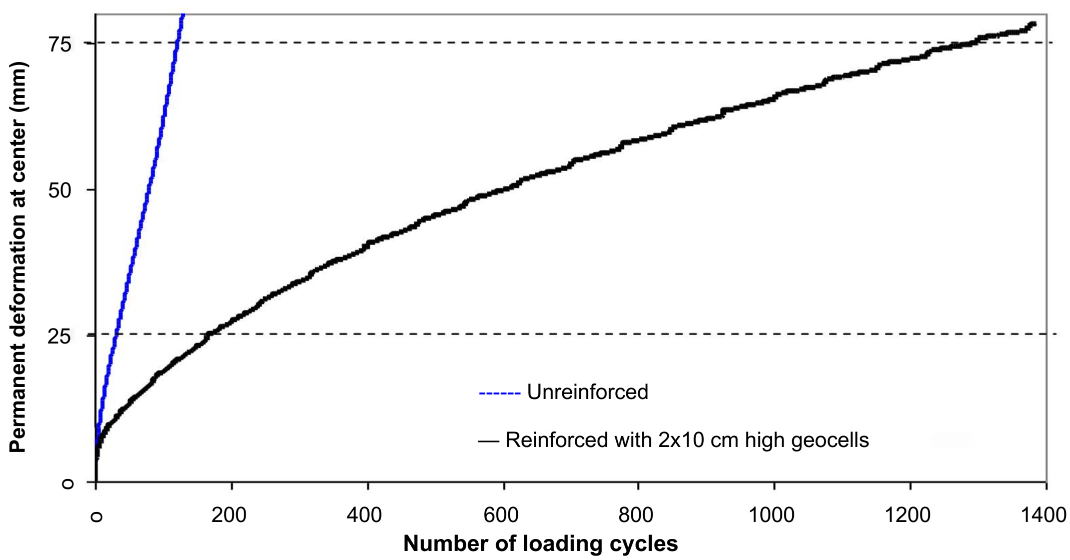

Figure 1. Effect of Geocell reinforcement on pavement permanent deformation (reproduced from Pokharel, 2010).

Kief et al. (2011) found that Geocell can improve modulus of pavement layers by up to three times which results in reduced layer thickness of the reinforced layer. They also showed Geocells can increase service life of the pavement structure with less required maintenance during the service life. Thakur et al. (2012) found that the Geocell reinforcement significantly reduced the permanent deformation of the flexible pavement and increased the pavement life by a factor of 10 and reported that the Geocell confinement increased the stiffness of the base course. Similar observation and potential benefit of Geocell reinforcement was reported by Pokharel et al. (2010) by cyclic plate loading tests and Pokharel et al. (2011) and Han et al. (2011) by conducting full scale accelerated pavement test. Leshchinsky and Ling (2013) tested Geocell for a ballasted railroad substructure and found that even using low quality material the Geocell-reinforced sections reduced the vertical deformations, lateral spreading of the ballast material, allowed uniform subgrade distribution. Following an extensive series of static and dynamic load testing, Han et al, (2013) summarized the research on Neoloy based Geocells and stated that Geocell increased the bearing capacity and stiffness of granular bases and elasticity of Reclaimed Asphalt Pavement (RAP) bases. They also found out that Geocell reinforcement can reduce the creep and permanent deformation.

3. PROPERTIES OF GEOCELL

The Neoloy Geocell used in the projects under consideration is characterized by flexibility at low temperatures similar to HDPE and elastic behavior similar to engineering thermoplastic. It is a composite alloy of polyester/polyamide nano-fibers dispersed in a polyethylene matrix. It had tensile strength of 21.5kN/m and the elastic modulus at 2% strain was 620MPa. The properties of the Geocell are given in Table 1.

Table 1. Properties of Geocell.

Description	Value
Neoloy Material	Polymeric nano-composite alloy
Material strength at yield	24 MPa
Strength at yield	21.5 kN/m (wide-width)
Cell height of Geocell	150mm
Distance between weld seams	330mm
Coefficient of soil-cell friction efficiency	0.95
Coefficient of thermal expansion	<115 ppm/°C
Brittle temperature	<minus 70°C
Long term plastic deformation at 65°C (load 6.6kN/m)	<1.3% deformation

4. DESIGN METHODOLOGY

Pokharel (2010) modified the Giroud and Han (2004) design methodology for geosynthetic reinforcement for unpaved roads by changing planar geosynthetic reinforcement dependent parameters (such as aperture modulus) to Geocell dependent parameters. These parameters were calibrated by the laboratory cyclic plate loading tests and full-scale moving wheel tests on Neoloy based Geocell-reinforced granular bases over weak subgrade. In the design methodology a maximum allowable rutting is set (together with all other parameters), and the pavement thickness is determined by,

$$h = \frac{\left(0.868 + 0.52\left[\frac{r}{h}\right]^{1.5}\log N\right)}{\{1 + 0.204(R_E - 1)\}} \times \left(\sqrt{\frac{P}{\pi r^2 m\,5.14\, c_u}} - 1\right) r \qquad [1]$$

Where, h = required base course thickness (m)

r= radius of tire contact area (m)

N= number of wheel passes or equivalent single axle load (ESAL)

P = wheel load (kN)

c_u = undrained cohesion of the subgrade soil (kPa)

R_E = modulus ratio of base course to subgrade soil

m = bearing capacity mobilization factor

In this design formula the thickness of the base course is calculated based on the subgrade and base course California Bearing Ratio (CBR), the traffic ESAL, equivalent radius the loading traffic and improvement factor provided by the Neoloy Geocells.

5. PROJECTS DESIGNED WITH THE METHOD

Following projects were designed with the design formula in Eq. 1 and discussed in section 4 of this paper. Project monitoring, rut measurement and serviceability criteria based on driving condition are used as the basis to check the design after some time of operation. The were no actual traffic count records maintained to check the design but the ESAL was estimated based on the average daily traffic counts reported by the owners of the road at the time rut measurement. The proceeding sub sections discuss the project features in brief. Section 6 discusses the designed and actual measurements at the site. Performance evaluation of the each road includes measurements, visual observation, road owner's comments, and driving conditions.

5.1. MEG Energy - Temporary Access Road - P3 Connector

This temporary access road was constructed in the summer of 2012 in the Christina Lake region, Alberta, Canada for MEG Energy Corporation as an access to their drilling area that was to be developed as the Central Processing Facility for Phase 3B development at a later date. This 3.2km long and 8m wide access road was expected to carry heavy loads such as 777 Rock Truck, 1200 Track Hoe and CL-800 Trucks. At the time of construction only 11m wide right of way was available that required constructing steep (1V:1.5H) side slope as the majority of the road had to pass through Muskeg zone which is spongy highly organic ground with very high moisture content. The project had a tight timeline; 6 weeks for 3.2 km length. The road had two separate structures for Muskeg and non-Muskeg area. The Muskeg area was constructed in two layers; a construction layer and a top layer and non-Muskeg area just had one layer of Neoloy Geocell filled with locally available sand. The wearing course was constructed with 175mm thick 40mm minus crushed gravel.

This road was designed for 250,000 ESAL and rut of 62mm. There were no sign of failure at the road after three months and the rut measurement was less than 25mm in average after a full year in service. During this time no additional gravel material was added on the road. Currently, after two years of operation the road is in excellent driving condition, no material has been added, but as it was graded during this period rut measurement was not made after the first year of operation. This road has been in service and subject to numerous heavy loads for two years now. Structural and serviceability evaluation of the road demonstrate an outstanding performance. Client satisfaction is reflected by their willingness to expand this road with this design and constructing main access road (explained in section 5.2) with Neoloy Geocell reinforcement. Figure 2 shows the road during construction and condition after three months of operation. As seen in the picture road structure has stood firm during the first few month of heavy construction traffic and is continuing to perform exceptionally well after two years of operation.

Figure 2. P-3 connector during construction and during the heavy traffic period

5.2. MEG Energy - Main Access Road (C-Road)

This project started after the success of the P-3 connector. This project was designed to improve the condition of the seasonal road to all weather and widen the existing 8m width to a 10m using Neoloy Geocells and constructed in the winter of 2012/2013. In total this road is about 7km long. It was designed for 500,000 ESAL and 62mm of rut. The existing seasonal clay road was used as the subgrade and 300mm thick 40mm minus gravel reinforced with a single layer of Neoloy Geocell was designed as the base course and driving surface. The widened side of the road was designed with an additional layer of Geocell in-filled with locally available sand. Visual observations on this road have been an ongoing process and rut measurements were made once after 6 months of full operation. As the road has been graded at least once no rut measurement has been done after that. The road needed almost no maintenance but graded a few times which as per the clients road maintenance department is too little compared to what is done for their other unpaved assess roads.

Rut measurement after estimated 20,000 ESALs was less than 10mm and after 100,000 ESAL was less than 30mm in an average. Figure 3 shows the condition of the road before and after construction. The road structure has stood firm and there is no sign of structure failure in road surface after two severe winters and undergoing heavy loading.

5.3. MEG Energy - J-Hook Road at the Main Access (C-Road)

There was about 700m long temporary curved section of the road that was to be constructed before a small straight stretch of the C-road could be constructed pending the environmental permits. The road was designed for only three months of operation and 16,000 ESAL with 75mm high Geocell. Heavy construction and logging operation in the area lead to heavy traffic in the first month of operation with an estimated traffic of 25,000 ESAL in the first months. The rut after the first month of operation was higher than 75mm and the failure was obvious with broken and exposed Geocell sections at some locations.

Figure 3. Driving condition on C-road before and after installation of Neoloy Geocell reinforcement

Figure 4. Failure after exceeding the design traffic at the J-Hook road

5.4. CANFOR - Access Road to the Logging Yard

Canadian Forest Service (CANFOR) needed to improve their access road leading to their logging yard in Ft. St. John, BC, Canada. This road is the main access road for the facility and is subjected to approximately 100 fully loaded double trailer truck loads every day. This road was designed and constructed with 300mm thick 40mm minus well graded gravel reinforced with a single layer of 150mm high Neoloy Geocell. It was designed for 500,000 ESAL and a rut of 62mm.

This road has been in service for 18 months now and has already experienced more than 400,000 ESAL. It has not been graded and no material has been added during this time. The average rutting measured in this road is 25mm. Figure 5 shows as constructed and current condition of the road. As seen in the picture road structure has stood firm and there is no sign of structure failure in road surface after two severe winters and undergoing heavy loading.

5.5. CANFOR - Access within the Logging Yard

These logging yards experience about 20 passes of CAT988H loaders running per hour and within the yard these equipment in some area follow defined track. Rut measurement was made at few locations along the defined track to measure the rut and compare with the design value after 8 months of operation. The estimated ESAL for this period was 307,200 and measured rut was an average of 50mm (with a maximum of 80mm at two locations).

This road was designed and constructed with 600mm thick 75mm minus gravel reinforced with two layers of 150mm high Neoloy Geocell on soft subgrade. It was designed for 500,000 ESAL and a rut of 75mm. This Traffic count is based on daily average traffic reported by the client. Figure 6 shows the current condition of this track with in the logging yard.

Figure 5. Condition of Access Road at CANFOR

Figure 6. Access inside the CANFOR logging yard

5.6. County Road - Lac St Anne

The County of Lac St Anne had been having difficulty maintaining both approaches to a bridge in Alberta Range Road 540 especially during spring thaw. They had been dumping gravel and grading the road almost every week during the spring thaw. The road was designed with 300mm of 40mm minus crushed gravel reinforced with 150mm high Neoloy Geocells and constructed in November 2011. The new design has shown excellent performance, they have not added any new gravel and had graded only twice in the first year compared to a minimum of one grading per week with additional material before. There were no visible ruts on the surface but as the road was already graded once the design verification was not possible in this case however, the road has shown positive results and the design has worked excellent. Figure 7 shows as constructed and current condition of road.

During Construction **After two years of operation**

Figure 7. Range Road 540 in County of Lac St Anne.

5.7. County Road - Long Run Exploration

A 3km long road in the county of Little Smoky had seasonal problem with road break. This road also serves as the major access to the drilling site for the Long Run Exploration Oil Company. A Geocell reinforced surface was design for the road and constructed in the summer of 2013. The road was designed with 200mm of sand reinforced with 150mm high Neoloy Geocells and wearing course of 40mm minus gravel. It was designed for 250,000ESAL and 62mm of rut. An average of less than 10mm rut was measured after 4 weeks with an estimated traffic of about 8,000ESAL. Further rut measurement or visual observation had no value as the owner graded the road and applied Calcium binder on top after that. Figure 8 shows as constructed and post construction condition of road.

After completion **After one month of operation**

Figure 8. Road in Little Smoky County also used by Long Run Exploration.

5.8. Cause Way Grizzly Oil Sand

The causeway was designed for 100,000 equivalent single axle load (ESAL). It was designed to pass hydraulic Scheuerle trailer with 112 wheels in 14 axles of the trailer and the tire pressure was 862 kPa. The subgrade California Bearing Ratio (CBR) was taken as 3% and the CBR of the base course as 60% for the design purpose. The failure criterion for the road section was set at 75mm of rut. The section was designed as two layers of 150mm high Neoloy-reinforced 75mm minus gravel and a 75mm thick wearing course of 2-40 gravel. Rut measurement was done on this road after three months; it has not been monitored since then. Pokharel et al. (2013) discusses the design of this project in detail. Figure 9 shows as constructed and condition of road after three months of operation.

Figure 9. Cause Way for Grizzly Oil Sands.

6. DISCUSSIONS

There are about one hundred unpaved roads designed with the formula suggested by Pokharel (2010) in the provinces of Alberta, Saskatchewan, and British Columbia in Canada. All of them are in good serviceability conditions but only 8 of those could be included in this paper due to the fact that the owners of the roads grade the road before the road starts showing appreciable rut. The feedback received from all of those projects has one thing in common that is, they have not been adding any additional gravel material since the road was reinforced with Neoloy Geocells. A comparison between estimated and measured rut depth as shown in Table 2 reveals that the roads hold good for the rut design criteria for given number of ESAL. Therefore, the design method works well for unpaved road and has a slight margin of safety factor. But the failure at the MEG J-Hook road showed that the road can fail soon after the design limit is exceeded.

Table 2: Design versus actual measurements.

Project	Design tire pressure (kPa)	Design ESAL (no.)	Design Rut (mm)	Estimated ESAL (no.)	Measured Rut (average) (mm)	Remarks
MEG P-3 connector	[illegible]	250000	[illegible]	150000	[illegible]	After 3 months
MEG C-Road	[illegible]	500000	[illegible]	100000	[illegible]	After 6 months
MEG J-Hook road	832	16000	75	25000	failed	Exceeded design ESAL
CANFOR access road to yard	760	500000	62	400000	25	After 18 months
Wheel track inside CANFOR logging yard	760	500000	75	307200	Average 50 Max 80	After 8 months
Range road 540, Lac St Anne	694	100000	62	Exceeded design	<20	Graded, so design could not be verified
Smoky County road	[illegible]	250000	[illegible]	8000	<10	After 1 month
Grizzly Oil Cause way	[illegible]	100000	[illegible]	23400	10	After 3 months

The measured data shown in Table 2 are at different ESAL values than they were designed for therefore the authors take this values as representative values for comparison rather than the actual. Most of the design in Table 2 seem to be over designed for the ESAL count at the time of rut measurement but the design for MEG J-Hook road and wheel track inside CANFOR logging yard show that the design criteria is just met. The authors have noticed change in the practice of road operation such as use of road by heavier traffic and increase in traffic volume after the roads are constructed with Geocell reinforcement and believe that this fact combined with the uncertainty in the geotechnical data on subgrade prepared by some of the road owners has contributed to design not matching the 100% to the measured data. To some extent the roads seem to perform better than that predicted by the design when a Neoloy Geocell reinforced construction layer was installed above the subgrade. The construction layer in the design is not considered as a structural layer but just a platform to allow the movement of construction equipment when subgrade is too soft (Muskeg area) to drive construction equipment on it.

7. CONCLUSIONS

The eight real time test cases considered for this paper showed that the design formula worked well within and beyond the laboratory and moving wheel test limits set out by Pokharel, 2010. In some cases the design seemed to perform better than that predicted by design. This can be partly attributed to the improvement imparted by the construction layers especially in terms of the CBR value. In all the double layer cases the construction or the bottom layer improved the subgrade so that the subgrade strength used in the design produced design with bigger margin of safety.

In conclusion the design method applied first time in the real application proved valid and reliable. There are however, space for improvement in the design calculations and more accurate monitoring of the structure performance. This design method was originally developed and tested for Neoloy based Geocells and the validation done in this paper is also valid for the same type of Geocell only.

ACKNOWLEDGEMENTS

The authors would like to thank Paradox Access Solutions Inc., the Neoloy Geocell manufacturer PRS-Mediterranean and the owners of the eight projects studied for this research for the opportunity, time, and resources provided.

REFERENCES

Giroud, J.P. and Han, J. (2004a). “Design method for geogrid-reinforced unpaved roads. I: Development of design method.” *J. Geotech. Geoenviron. Eng.,* 130(8), 775-786.

Giroud, J.P. and Han, J. (2004b). “Design method for geogrid-reinforced unpaved roads. II: Calibration and applications.” *J. Geotech. Geoenviron. Eng.,* 130(8), 787-797.

Han, J., Thakur, J. K., Parsons, R.L., Pokharel, S.K., Leschinsky, D., and Yang, X. (2013). A Summary of Research on Geocell-Reinforced Base Courses. *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, 331-340.

Han, J., Pokharel, S.K., Yang, X., Manandhar, C., Leshchinsky, D., Halahmi, I., and Parsons, R.L. (2011). Performance of geocell-reinforced RAP bases over weak subgrade under full-scale moving wheel loads. *Journal of Materials in Civil Engineering,* ASCE, 23(11): 1525-1535.

Kief, O.,Rajagopal, K. Veeraragavan, A. and Chandramouli, S. (2011). Modulus Improvement Factor for PRS-Neoloy-Reinforced Bases. *Goesythetics India.* Chennai, India. September 22-24, 2011.

Leshchinsky, B., & Ling, H. I. (2013). Numerical modeling of behavior of railway ballasted structure with geocell confinement. Journal of *Geotextiles and Geomembranes,* 36, 33-43.

Pokharel, S. K. (2010). Experimental study on geocell-reinforced bases under static and dynamic loading. *Ph.D. Dissertation.* University of Kansas. 349 pages.

Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., and Halahmi, I. (2010). Investigation of factors influencing behavior of single Geocell-reinforced bases under static loading. *Journal of Geotextile and Geomembrane,* 28, 570-578.

Pokharel, S.K., Han, J., Manandhar, C., Yang, X.M., Leshchinsky, D., Halahmi, I., and Parsons, R.L. (2011). Accelerated pavement testing of geocell-reinforced unpaved roads over weak subgrade. *Transportation Research Record: Journal of Transportation Research Board,* No. 2204, Low-Volume Roads, Vol. 2, pp 67-75.

Pokharel, S.K., Martin, I., and Breault, M. (2013). Causeway design with neoloy 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, 351-358.

Thakur, J. K., Han, J., & Parsons, R. L. (2012). Creep Behavior of Geocell-Reinforced Recycled Asphalt Pavement Bases. *Journal of Materials in Civil Engineering,* 25(10), 1533-1542.

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).