RESILIENT INFRASTRUCTURE
June 1–4, 2016

SUSTAINABLE ROAD CONSTRUCTION FOR HEAVY TRAFFIC USING HIGH STRENGTH POLYMERIC GEOCELLS

Sanat K Pokharel, P.Eng.
Principal Engineer, Stratum Logics Inc., Canada

Meisam Norouzi, E.I.T.
Project Engineer, Stratum Logics Inc., Canada

Ian Martin, P.Eng.
Business Manager, Stratum Logics Inc., Canada

Marc Breault
President, Paradox Access Solutions Inc., Canada

ABSTRACT

Construction Sustainability has been the focus of debate ever since the Brundtland commission report 'Our Common Future' defined Sustainable Development. Kyoto Protocol and subsequent climate change conferences leading upto the Paris submit this year has put still more emphasis on this agenda. Construction of heavy traffic unpaved access roads require huge amount of aggregate mining and long haulage in the areas of scarce virgin aggregate. Conventional practices in these road constructions seek structural adequacy but never specifically address the sustainability issue. Innovative technology that can reduce the volume of aggregate material while maintaining the structural integrity is required to address the sustainability issue of these roads construction. This paper discusses the construction of these roads with high strength Geocell (Neoloy) reinforcement giving special reference to Oil Sand region of Alberta. These Geocells improve the modulus and strength of the reinforced composite and durability of the road structure by drastically reducing the required quantity of aggregate material. Operation of these access roads has also demonstrated saving on running cost, maintenance and down time. Neoloy Geocells also make it possible to use recycled and locally available cheaper materials for road construction still exceeding the overall performance of conventional construction. In terms of sustainability the benefit will be more visible when the carbon footprint is analyzed for the virgin material mining and haulage to the construction site. A basic analysis of CO_2 emission reduction and how it is applied to new emission standards in Alberta industry with this innovative method is also discussed.

Keywords: - Neoloy Geocells, Sustainable Construction, Access Roads, CO_2 emission

1. INTRODUCTION

Development that meets the needs of the present without compromising the ability of the future generations to meet their own needs is the sustainable development (WECD, 1987). Sustainable construction aims to achieve the sustainable development objectives through the use of sustainable technology and knowledge however, the construction industry still following the conventional practice leaves behind significant environmental and carbon footprint (Chong et al., 2009). Study conducted by Lippiatt (1999) in the United states had reported that the construction industry consumes 40% of all raw stones, gravel and sand, 25% of all raw timber, 40% of energy, and 16% of the water produced annually in that country; the trend can be expected to be similar in Canada too. Since cost drives most business decisions, the benefits whether tangible or intangible needs to be expressed in economic terms (Chong et al., 2007) as sustainability with emphasis on environmental terms alone without the substantiating the economic value could alienate the business community. The Oil Sand development in Alberta has been a continuous focus of sustainability debate but only a few stakeholders have looked into the economic value of environmental sustainability. This inclination sometimes tends to give falls consideration as other pillars of sustainable development seems to be overlooked. In a development as massive as the development in the oil sand area all three economic, environmental and societal pillars of sustainable development should get reasonable emphasis. The concept carbon tax can be seen as the massive step in quantifying the environment into economic terms.

Access roads leading to oil drilling areas in Canada use huge amount of virgin construction material. The sustainability issue get hard hit right at the gravel mining site starting from quarry, crushing, hauling and placing. This applies to all the construction materials such as asphalt, sand, gravel, rocks and clay. Based on some real projects completed in the Oil Sand region this paper discusses the use of a high strength Geocell made from nano polymeric alloy (Neoloy) for the access road construction. Reinforcing the road structure with Neoloy Geocells drastically reduces the required structural thickness of roads compared the ones designed and constructed conventionally. These Geocells can utilize locally available inferior infill material for road construction that otherwise would just have been a waste. Keeping other tangible and intangible benefits aside the use of locally available material saves time, money and carbon emission. Savings in total quantity and reduced haulage in terms of CO_2 emission are also explained but other benefits that lead to a sustainable development such as the reduced mining and extraction of the virgin construction material, avoided double handling, reduced grading and operation and maintenance requirement, safety, and health issue are discussed qualitatively.

2. HIGH STRENGTH NEOLOY GEOCELL

In early 1970s the US Army Corps of Engineers developed the concept of cellular confinement mainly to stabilize the beach sand (Webster, 1979). The cellular confinement system mimicking a honeycomb structure, commonly known as Geocells, has since been the focus of major research. The earlier versions of the Geocells were made up of paper, metal and HDPE, the latest development in this series is Neoloy that has the desirable reinforcement property to reinforce granular soils even at the coldest Albertan climate for a period of time that extends beyond the economic life of the road.

Neoloy is a polymeric nano-composite alloy of polymer/polyamide nano-fibers dispersed in a polyolefin matrix that possesses the ductility of high density polyethylene and dimensional stability and creep resistance as polyester. Neoloy Geocells are recognized geosynthetic reinforcement to stabilize weak subgrade and strengthen the base course. It has proved to be promising solution for the future of access roads to the drilling area and similar applications. The properties of Neoloy Geocells are given in Table 1 and Figure 1 shows its fully stretched form at the base course ready to be filled with granular infill.

Table 1: Properties of Geocell

Description	Value
Neoloy Material	Polymeric nano-composite alloy
Material strength at yield	24 MPa
Strength at yield (wide-width test)	21.5 kN/m
Cell height of Geocell	150mm
Distance between weld seams	330mm
Cell wall thickness	1.1mm
Coefficient of soil-cell friction efficiency	0.95
Coefficient of thermal expansion	<115 ppm/^{0}C
Brittle temperature	<minus 70^{0}C
Long term plastic deformation at 65^{0}C (load 6.6 kN/m)	<1.3% deformation

Figure 1: Geocells stretched and being infilled

3. SUSTAINABLE ACCESS ROADS

The researches on the Geocell have mainly focused on the structural integrity, modulus and bearing capacity improvement factors and the reinforcement mechanism (Pokharel et al., 2010). Pokharel et al. (2015) validated a design method for Neoloy Geocell reinforced unpaved road while overall sustainability is still overlooked. Kief et al. (2015) discussed benefits of the Neoloy Geocells for highway infrastructure and discussed the sustainability factor however they did not make any comparison between the conventional road building and construction with Neoloy Geocell in terms of overall sustainability. Access to the drilling locations in the Canadian oil exploration and subsequent development is a challenging job as most of these drilling sites need access to pass through very soft and highly organic spongy ground with very high moisture content known as 'Muskeg'. Access to these areas is difficult for traffic carrying heavy drilling equipment and future traffic. Pokharel et al. (2013) had discussed a causeway construction using Neoloy Geocell in such a difficult ground condition in Norther Alberta. The conventional access to this area involves use of wooden mats at the exploration stage and construction of a permanent road during development and production stages. The road construction is usually done either by removing the muskeg and back filling with engineered fill if the muskeg depth is less than a meter or providing high strength geotextile and geogrid to support the embankment fill that is used as preloading fill if the muskeg is deeper. These practices are costly and time consuming and still see frequent failures of the road sections that hamper the access at critical times. Most of the time the operation and maintenance cost exceed the reasonably allocated budget limits. In addition to that these practices leave carbon footprint by excessively utilizing Earth's ever depleting resources. A sustainable solution for these problems is therefore, has become inevitable.

Structural strength of any road to withstand the traffic load for entire design life is basic requirement for any road design but a sustainable road does not only go by the strength, to be sustainable it should have cheaper life cycle cost, be environmental friendly and reduce the negative impact on society. This paper discuses four of several projects the authors have designed and constructed recently giving due consideration to all three pillars of sustainability. The road structure designed with Neoloy Geocells has a validated design method (Pokharel et al., 2015) for unpaved roads and AASHTO-1993 design method for paved road. These design methods confirm the structural strength of the roads for the design traffic and life. Neoloy Geocells provide lateral and vertical confinement to the reinforced layer that controls gravel surface deterioration which provide huge saving in recurring operation and maintenance cost.

The environmental benefits of this innovative design and construction include the saving in the right of way clearance as the design structurally need lower embankment height which in turn reduce the disturbances to the natural habitat of many pristine wildlife and vegetation. The road design with Neoloy Geocell uses less amount of aggregate for similar or better structural performance, that is, it requires mining of less virgin aggregate for construction, locally available inferior or otherwise waste material can be used for construction that provided huge saving in haulage and fuel burnt, ultimately minimizing the CO_2 emission. Reduction in CO_2 emission will carry great value as Alberta is starting Carbon tax at the rate of $20/tonne in 2017, $30/tonne in 2018 and a minimum of 2% increase annually after that. Moving forward this price on carbon can be looked into as the monetary value of environmental damages caused by the emission. In addition this sustainable construction avoids the muskeg removal meaning the natural ground will be left as it is if any future reclamation is needed. The design also has societal benefits such as providing jobs to local community in easy manual Geocell installation work, a year round serviceable road, greatly reduced downtime because of reduced maintenance requirement and, safety and peace of mind for the road users. The better serviceability conditions of the Neoloy Geocell reinforced road structure eliminate all the downtime related to access leading to improved production and service, employee morale, safety and reduced equipment operating and wear and tear costs.

4. REPRESENTATIVE PROJECTS

Four projects constructed after 2012 that represent access roads, haul roads and county roads are taken as representative case to study the sustainability of the roads designed and constructed with Neoloy Geocell reinforcement. The discussion in the proceeding section will be based on the real cost, quantity and haulage distance used for transporting construction material for Neoloy reinforced case and estimated value for conventional method of construction that would have happened if conventional design was followed. The conventional values are based on the typical designs provided by the project owners and the usual practice in the area under consideration communicated by the clients.

4.1 Case 1: MEG Energy Corporation - temporary access road –P3 Connector

This 3.2 km long road was constructed in the summer of 2012 as access for heavy drilling equipment to the proposed Phase 3B central processing facility (CPF) in Christina lake area in Alberta. As the road was aligned to pass through deep muskeg and scheduled to be completed within one and a half month time the only possible option left at that time was to use the wooden mats. The conventional road construction in such situations would have been either to remove the muskeg and backfill it with compacted engineered fill or preload without muskeg removal with embankment. It was not possible to complete these options in given time frame. In addition to that the conventional approaches would have had issues as the available right of way was only 11m for an 8m wide driving surface that would have needed a minimum of 1m high embankment fill with the conventional design. The minimum haul distance for clay was of about 20km and 100km for good gravel while sand was available right at the site. A sustainable Neoloy Geocell reinforced road structure with sand infill was instead proposed and MEG Energy convinced with the merits decided to go ahead with it. The road was designed with two separate structures for muskeg and non-muskeg area. The muskeg area was constructed in two layers of Neoloy Geocells; a construction layer and a top layer and non-muskeg area just had one layer at the top filled with locally available sand. The base course for this road was 200 mm thick sand reinforced with 150mm high Neoloy Geocells and the driving surface was just 175mm thick crushed gravel. The construction using Neoloy Geocell avoided the removal of muskeg and backfill, one layer geogrid, in an average one meter of clay fill and about 270mm thickness of crushed gravel.

Although the road already exceeded the design expectation within a year of operation the road is in excellent driving condition after three years without adding any more gravel. Client satisfaction is reflected by their willingness to expand this road with this design and constructing main access road with Neoloy Geocell reinforcement (Pokharel et al. 2015). Figure 2 shows the road under construction and during operation.

4.2 Case2: MEG Energy - main access road (C - Road)

With the sustainable results of the P-3 connector MEG Energy decided to construct their main access road to Phase 3B CPF using Neoloy Geocell. This project was designed to improve the condition of the 7km long seasonal road to all weather and widen the existing 8m driving surface to 10m using. The entire road was widened on muskeg upto 6m deep. It was designed with 300mm thick gravel reinforced with a single layer of Neoloy Geocell. The widened side of the road was designed with a construction layer of Geocell in-filled with locally available sand. 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 access roads. The road is in excellent operating condition after three years. Using Neoloy Geocell in this road avoided removal of muskeg at the widened part, required engineered backfill, layer of geogrid, and saved 150mm of thick crushed gravel. Figure 3 shows the road condition before and after one year of construction.

Figure 2: P-3 connector a) during construction and b) during the heavy traffic operation

Figure 3: Driving condition on C-road a) before and b) one year after construction

4.3 Case 3: Creek crossing for a major oil producing company north of Ft McMurray

One of the largest oil producers in Fort Hills area 90km north of Ft McMurray needed a heavy haul road crossing a creek which has deep muskeg for 200m length on either side. For environmental reason and also to keep the ground water flow through muskeg at its predevelopment stage they wanted to avoid muskeg removal and back fill with clay. So, locally available highly pervious sand reinforced with perforated Neoloy Geocells and separated by a medium strength non-woven geotextile between the muskeg and sand fill was designed as construction layer. Creek flow channel was maintained by placing two corrugated steel pipes. The driving surface was also designed with 200mm thick crushed gravel reinforced with Neoloy Geocells. The road was 22m wide at the top with 3H:1V side slope. Although the conventional design called for upto 3m high embankment fill of clay subbase, pit run gravel and crushed gravel, the Geocell design reduced the total fill thickness to less than 1m with two layers of Geocell. The construction layer was filled with sand and the top layer and driving surface was graveled. Provision for immediate muskeg settlement was made with allowance of 40% of the Muskeg thickness or 800mm in case of Muskeg depths thicker than 2m.

4.4 Case 4: Township road 762, Long Run Exploration and Municipal District of Smoky River

A 3.2km long stretch of township road 762 between highway 49 and range road 205 in the Municipal District of Smoky River, Alberta had seasonal problem with road break. This road also served as the major access to the production site for the Long Run Exploration Oil Company. To solve the problem the surface road was designed with 200mm of sand reinforced with 150mm high Neoloy Geocells and wearing course of 40mm minus gravel. The road is performing excellent for last three years and has not required any maintenance. Other than the maintenance this design saved almost 150mm of gravel thickness. Figure 5 shows as constructed and post construction condition of road.

Figure 4: Creek Crossing: a) Pre-construction, b) Construction layer, c) Base course and d) in operation

Figure 5: Township road 762 in MD of Smoky River County during a) construction and b) after operation

5. DISCUSSION

As identified in previous sections every road construction faces challenges such as supply, cost and extensive construction effort required. In addition to the traditional challenges, environmental issues have been receiving a great deal of attention in the recent years. Therefore, the necessity of using innovative solutions to avoid such challenges is felt more than ever. Biggest challenges the conventional methods faced in the projects mentioned in the preceding section can be listed as: 1) availability of gravel nearby, 2) high cost of hauling and carbon emission,

3) challenging geotechnical condition with extremely soft subgrade and expensive muskeg removal and backfill, 4) limited right of way, 5) limited construction time line and 6) extremely heavy anticipated traffic.

Neoloy Geocells reinforced sustainable road construction minimizes the environmental impacts and extends project life. Its ability to use locally available inferior quality infill including poorly graded sand still providing better structural strength compared to the traditionally designed roads has multiple sustainability impacts. As the design drastically reduces the need for virgin aggregate, carbon footprint is also reduced as less aggregate screening, crushing, processing and hauling is required. Less material placement and little or no subgrade preparation also mean less earthworks / equipment operations. This adds to reduces fuel consumption, vehicle pollution, airborne dust, sediment runoff and the carbon emission. The economic goal of sustainable construction is met by lower capital costs and lower life-cycle maintenance with fewer disruptions to traffic. The social benefits of the enhanced performance of the road include more reliable and safer transportation, as well as all-weather access to remote and difficult areas plus local work crews can be easily trained on-site to perform the installation jobs.

A comparison of quantifiable sustainability indicators between the roads as constructed using Neoloy Geocells and as would have been constructed based on prevailing conventional practice is shown in Table 2. In calculating the values presented in Table 2 the total quantity of material includes any used/required gravel, sand and clay while total hauling includes haulage of these material to the construction site. The amount of material saving is taken as the representative of the cost saving so a separate cost calculation is not included here. The cost of placing the materials which would have been very high for the conventional designs as they use more material is not included making the comparisons more favourable to conventional design compared to the sustainable Neoloy design. Construction with Neoloy Geocell did not require any muskeg removal so, the required removal in conventional alternative is estimated based on the available geotechnical investigation of the area.

The values presented for CO_2 emission in Table 2 include the CO_2 generated to produce aggregate and Neoloy Geocells and also the CO_2 generated when hauling material to the construction site. It is important to mention that the locally available sand used in the representative projects discussed above required no other preparation than hauling to a short distance. The emission calculation uses, US-EI database (Earthshift, Huntington, VT, the Ecoinvent 3.1 database adjusted for U.S. energy grid inputs), value of 0.197kg CO_2 generated per tonne-km hauling by a transport truck, producing one kg of crushed gravel will generate 0.0104kg of CO_2 and producing one kg of Geocells will generate 1.93 kg of CO_2.

A 25tonne pay load for the gravel trucks has been assumed which results in generating 4.92kg of CO_2 per km of hauling. For the representative Case 1 the round trip gravel haul distance was 198km while it was only 8km for sand and 20km for clay material. For Case 2 gravel haul distance was 192km round trip for sand the round trip was 14km and clay was being hauled from 10km away. For the Case 3 the haul distance for sand and gravel was 30km round trip and it was 82km for Case 4.

Table 2: Comparison of Traditional Methods to Neoloy Geocell Alternative

	Conventional Option				Neoloy Geocell Option			
Rep. Case	Quantity (tonnes)	Total Hauling (km)	Muskeg Removal (m3)	CO_2 Emission (kg)	Quantity (tonnes)	Total Hauling (km)	Muskeg Removal (m3)	CO2 Emission (kg)
Case 1	83,866	274,609	23,040	1,654,191	48,993	153,578	-	1,033,321
Case 2	110,670	398,042	57,600	2,410,457	51,744	219,288	-	1,633,276
Case 3	16,560	19,872	5,200	269,994	10,560	14,272	-	114,210
Case 4	28,152	90,086	-	736,006	18,768	63,159	-	547,466

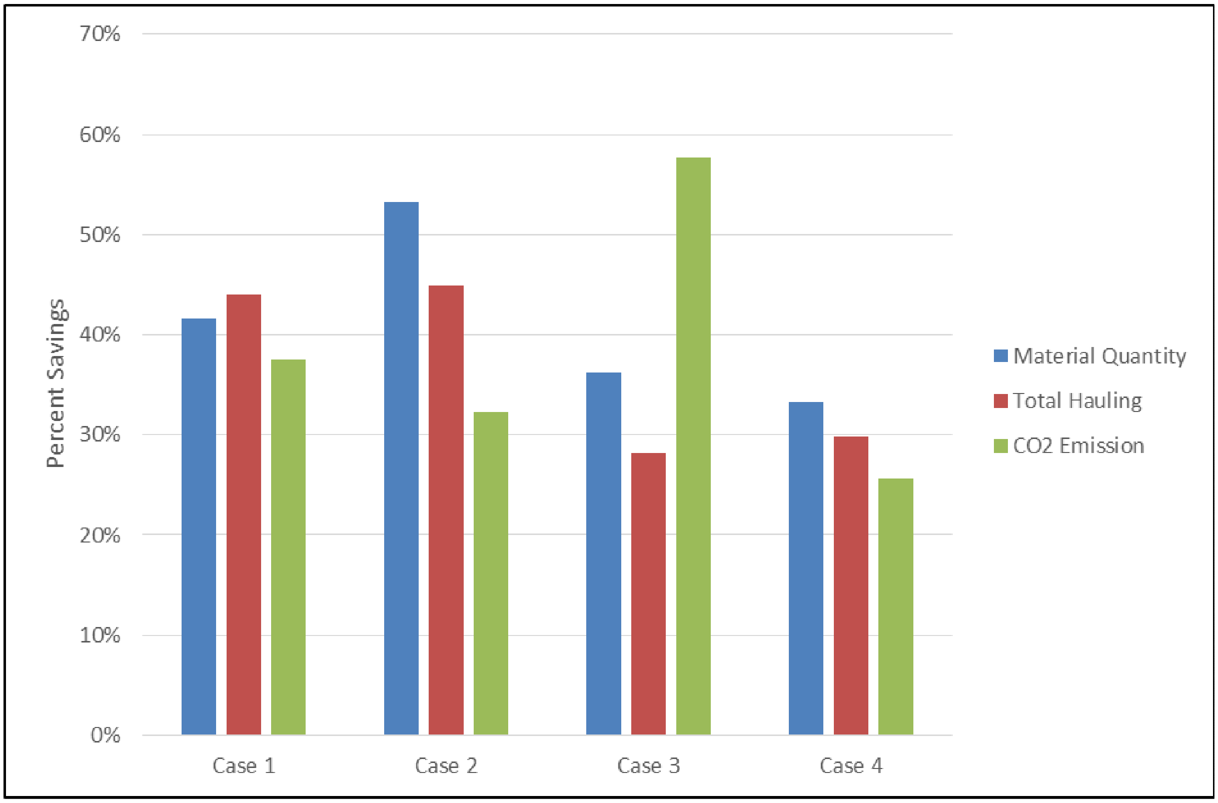

Figure 6: Percentage saving achieved by using Neoloy Geocells in different projects (case)

As seen in Figure 6 the innovative construction method using Neoloy Geocell reduced the total quantity of soil and aggregate, haulage, muskeg removal and CO_2 emission. The aggregate savings was in the range of 30 to 50% that ultimately saved at least 30% in haulage. This reduced hauling is a major contributor to reduction of CO_2 emission. The savings in CO_2 emission vary from 25 to approximately 60% in these four projects based on the respective hauling distance. It is noteworthy that these reductions are contribution of only a portion of the entire life cycle of the road. Regular monitoring has not been done to evaluate the operation and maintenance costs of these roads however, during verbal communication the project officials have informed that their Neoloy Geocell reinforced road structures needed very little maintenance and show no appreciable surface deterioration. So, these roads require non to minimal aggregate addition that could be in the range of 50mm a year for conventional roads. Analyzing the full life cycle of the road will reveal more savings in regards to less maintenance work required and longer service life of the roads using the Neoloy Geocells.

6. CONCLUSION

The analysis of the available data from four representative cases and results discussed in this paper has quantified the contributions by Neoloy Geocells to sustainability wherever possible. The economic, environmental and societal sustainability indicators were discussed and identified qualitatively but the virgin aggregate quantities and CO_2 emission is calculated and quantified. However, while calculating the CO_2 emission it only focused on one part of the overall sustainability, that is, the CO_2 emission reduction during aggregate production and hauling. The calculation did not cover the saving in CO_2 emission made during the placing and preparation at site. This would make utilizing Neoloy Geocell in road construction more attractive. As soon as the carbon tax starts in 2017 this will be a tangible value in economic terms. The sustainability benefits considering carbon footprint alone outweighed the other benefits of high strength Neoloy Geocell reinforced access roads over the conventional construction practice in Alberta. The saving in construction and operation and maintenance costs, time for construction, reduction in down time, virgin material mining, health and safety benefits are other benefits. All these additional benefits will show that the high strength Neoloy Geocell reinforced construction will contribute even more to the sustainable construction targets. Inclusion of this innovative technology by engineers and construction industry to realise the reduction in CO_2 emission and other sustainability benefits and spreading this knowledge base on Neoloy Geocell technology is highly recommended.

7. ACKNOWLEDGEMENTS

The support received from the manufacturer of PRS-Neoweb tough cell ®, PRS-Mediterranean Inc., construction data received from Paradox Access Solutions Inc., and opportunity work on the projects MEG Energy Corporation and Long Run Exploration is highly appreciated.

8. REFERENCES

WECD 1987. *Our Common Future, World Commission on Environment and Development*. Oxford University Press, London.

Lippiatt B., 1999. Selecting cost effective green building products BEES approach. *Journal of construction engineering and management*, 125 (6), pp 448-455.

Chong, W.K., Pokharel, S.K., Haas, C.T., Beheiry, S.M.A, Coplen, L., and Oye, M. 2009. Understanding and Interpreting Baseline Perceptions of Sustainability in Construction among Civil Engineers in the United States. *ASCE Journal of Management in Engineering*, Vol.25, No.3, pp.143-154.

Chong, W. K., Pokharel, S. K., Leyden, C. 2007. A proposed application of using LCCA to measure cost of sustainable design. *CME 25 Conference, construction management and economics: past, present and future*, University of Reading, UK (July 16-18, 2007).

Pokharel, S.K., Martin, I., Norouzi, M. and Breault, M. 2015. Validation of Geocell Design for Unpaved Roads, *Geosynthetics 2015*. Feb 15-18, 2015, Portland, OR, USA.

High Modulus Geocells for Sustainable Highway Infrastructure. Kief, O., Schary, Y., Pokharel, S.K. (2015). *Indian Geotechnical Journal: Special Issue on Transportation Geotechnics*. Vol. 45, Issue 4, pp 389-400.

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 (6), pp 570-57.

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.