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High Strength Geocell and Geogrid Hybrid Reinforcement for Compressor Station Gravel Pad on Very Soft Subgrade

Sanat Pokharel, Ph.D. P.Eng.,[1] Timothy Yii, E.I.T.,[2]
Marc Breault,[3] Meisam Norouzi, MSc., P.Eng.[4]

[1]Stratum Logics Inc., Acheson, AB, Canada; e-mail: sanat.pokharel@stratumlogics.com
[2] Stratum Logics Inc., Acheson, AB, Canada; e-mail: timothy.yii@stratumlogics.com
[3]Paradox Access Solutions Inc., Acheson, AB, Canada; e-mail: marc@paradoxaccess.com
[4]Stratum Logics Inc., Acheson, AB, Canada: meisam.norouzi@stratumlogics.com

ABSTRACT

A gravel pad for a compressor station near Otter Lake in Northern Sunrise County of Alberta was conventionally designed to support heavy operating traffic and a 215 tonne crane. The design included removal of up to 800mm of soft clay and replaced with 1300mm thick multi-layer geogrid and geotextile reinforced structure of high quality crushed gravel. The construction of the pad was planned for winter of 2016-17 when the temperatures could remain below -20°C for an extended period of time. The project stakeholders had concerns with the very soft subgrade that was reported to have a characteristic undrained shear strength value of only 15 kPa. Even in the frozen condition deep ruts were observed on the existing subgrade under construction traffic and was passable only over layers of wooden mats. The project was under a tight timeline to commission the station so, an alternative design option was urgently sought. An alternative design with a layer of biaxial geogrid perched between two layers of high strength novel-polymeric alloy (NPA) geocell reinforcement and geotextile as a separation layer was proposed in lieu of the conventional design. The design did not require any removal of the existing soil and used only 450mm of crushed and 300mm of cheaper pit run gravel that reduced the total gravel thickness by 550mm (42.3%). The construction was completed in February 2017 and the heavy construction equipment and crane were able to operate on the pad from early spring that year. The pad operation has not reported any issue since commissioning. This paper highlights challenges of winter construction and compares the innovative hybrid design utilizing different geosynthetic materials with the conventional design in terms of required strength, ease of construction and savings in construction cost and time.

INTRODUCTION

Infrastructure development in natural resources rich Alberta's Boreal forest region often faces rolling landscapes, glacial till and very soft ground conditions. The infrastructure for natural resources development of the region and transporting it through roads, rails and pipelines faces several construction and sustainability challenges. As the conventional construction practices may not always prove sustainable, especially considering the pristine nature of the region, the developers always look for cost effective and environment friendly innovative options.

Minimizing the use of virgin aggregates in construction is important as they are scarce and expensive in this region. This region situated in the cold northern climate faces short construction period and as soil remains frozen for considerable time outdoor construction activities come to halt during winter. This makes the tight project timelines a difficult task and both cost and time overruns can happen.

The conventional practice in this region for unpaved roads and load bearing soil structures, such as compressor station pads, is to remove the existing soft soil and backfill it with competent imported fill. For good quality gravel haul distance can even be a 100 km. In a similar setting the authors were approached to recommend a cost effective innovative design for compressor station pad near Otter Lake in Northern Sunrise County of Alberta, Canada. The pad to support heavy operating traffic and crane was conventionally designed to remove the soft soil and build a gravel structure with multiple layers of planar geosynthetics reinforcement. An adjacent pad recently built as per the conventional design had met several problems during construction. The experience showed that same type of structure on this pad was going to be expensive and the construction schedule would be overrun. As it had to be completed in time for project commissioning the work with conventional design of removing the soft material and bringing in huge amount of gravel from a long distance did not seem practical. In addition to that, winter construction had to happen to meet the tight construction schedule of the compressor station. In lieu of the conventional design the authors designed a hybrid geogrid and high strength novel-polymeric alloy (NPA) geocell reinforced gravel structure that saved huge amount of crushed gravel resulting in saving in cost and construction time.

This paper discusses design of hybrid geosynthetics reinforcement to support a heavy loaded gravel pad for the compressor station and compares it with the conventional design. A discussion of the design, challenges faced during the construction, benefits introduced and performance of the structure have also been be provided.

GEOSYNTHETIC REINFORCEMENT FOR LOAD SUPPORT

Planar geosynthetics such as geotextile and geogrid have been used as soil reinforcement for many years; the three dimensional geocells are a comparatively recent development. Geocell reinforcement for load support application most of the time utilizes geotextile for separation. Geogrid improves the stiffness of the reinforced soil by interlocking, lateral restraint and tension membrane; it reduces the applied stress on the soft soil and increases the bearing capacity while decreasing settlement (Qian et al., 2013). The performance of geogrid depends on aperture size and shape, material stiffness at junctions, and shape and stiffness of ribs (Giroud and Han, 2016).

Since the US Army Corps of Engineers used geocell for reinforcing beach sand in the 70s (Webster, 1979), numerous research programs, experiments, and monitored applications have been carried out to further understand the geocell reinforcement mechanisms (Han et al., 2013). Vertical and lateral confinement, wider stress distribution and beam/slab effect are identified as the main reinforcement mechanism of geocell. Higher tensile stiffness, strength and creep resistance of geocell material provide the reinforced base with improved bearing capacity, higher modulus and extended design life (Pokharel et al., 2010, Thakur et al., 2013 and Kief et al. 2015). High strength NPA geocell reinforcement also improves the creep resistance of the reinforced structure which is a very important factor in the repetitive loading conditions, as it significantly reduces the initial deformation and rate of creep of the reinforced material (Thakur et al., 2013).

A design method using geocell reinforcement for unpaved roads was developed by modifying the Giroud and Han (2004) method for planar reinforcement for rut criteria (Pokharel, 2010). This method has already been employed to design unpaved roads in various projects and verified by Pokharel et al. (2015). Design using NPA Geocells has been successfully employed in paved and unpaved roads and other geocell-reinforced load bearing earthen structures (Pokharel et al., 2013, 2015 and 2017, and Norouzi et al., 2017).

Researchers and engineers are always looking for innovative design alternatives. The authors have encountered several cases where a hybrid design with geogrid and geocells make the project structurally sound and economically feasible. Sitharam and Hegde (2013) recommended high strength geocell and geogrid hybrid design as an alternative to ground improvement in soft soil that could improve the bearing capacity of the foundation by 4 to 5 times. Kief (2015) reported reduction in maintenance cycles and cost that showed the efficacy of the hybrid geosynthetic solution when a hybrid geosynthetic solution for a new railway track embankment over weak clay involving the use of biaxial geogrid and NPA geocells was used.

THE PROJECT AND HYBRID DESIGN

The compressor station had two pads adjacent to each other, Pad A was constructed earlier in the summer and the pad under consideration is Pad B. Pad A had faced several challenges due to soft soil at the surface. For the construction of Pad A, the Pad B area was used as a construction camp. To prepare the area for the camp the contractors had cleared some peat and the camp site was supported on layers of wooden mats. The mats were still left in place after the contractor had demobilized from site. Construction of Pad B was actually planned to begin in the summer of 2016 but as the existing soil on site was found to be of very poor strength it was delayed. The pad had gone through uneven and differential settlements under the loading from camp site supported on wooden mats and the existing silty clay soil was not found to be suitable for bearing the expected loads of compressor station pad. After removal of the mats the equipment and trucks were stuck on the clay surface; the depressions right under the truck tires were as deep as 900mm. To avoid the difficulties faced earlier, the owner decided to look for alternative solution for Pad B.

The footprint of Pad B under consideration was about 27,000 square meters. Geotechnical investigation supplied by the owner had recommended 15 kPa as the characteristic undrained shear strength (Su) of the soft silty clay subgrade. Seasonal water table was found to be lying close to the existing subgrade in the southern side of the pad. The project needed solutions to support a 215 tonne crane and loads from trailers carrying 140 tonne loads with individual axle loads not exceeding local highway regulations. A 1300 mm thick planar geosynthetics reinforced granular structure was originally designed with three layers of non-woven geotextile (grab tensile strength 712 N) and triaxial geogrid to build the pad. This solution would have required 800mm of existing soft soil excavation and 1300mm of reinforced crushed gravel fill. Once excavated, the material needed to be hauled off-site and replaced with imported material. All these activities would have contributed to huge increase in the project cost as well extraction of a lot of virgin crushed gravel aggregate. In addition to that it would have almost been impossible to meet the project schedule. Thus, an innovative design with hybrid geosynthetics solution was presented that was not only sustainable in terms of cost and environmental indicators but it also enabled winter construction.

The alternative design with a layer of biaxial geogrid perched between two layers of high strength novel-polymeric alloy (NPA) geocell reinforcement and geotextile as a separation layer was proposed in lieu of the conventional design. The design was tested for safety against bearing capacity, rut criteria as mentioned in Pokharel (2010) and the hoop strength of the geocell wall. Another problem was to have a working layer or a construction platform where construction equipment could operate. NPA geocell construction layer was used for dual purpose as construction platform during construction and later as a structural base layer for heavier loads.

A non-woven geotextile was selected to act as a separation layer between the granular fill and the subgrade. A layer of NPA geocell reinforcement installed on top of the non-woven geotextile and was filled with 300mm thick 75mm maximum size pit run gravel. Above this layer 150 mm thick well-graded 40mm maximum size crushed gravel was reinforced with a layer of biaxial geogrid. Finally the top layer of NPA geocell was installed and filled with the 300mm of the same crushed gravel material. A sketch of the full structure is provided side by side with conventional design for better comparison in Figure 1. The properties of the geosynthetic material are shown in Table 1 and Table 2 in the proceeding section.

At the time of design the existing ground was thought to be 500 mm below the final design grade that would have required 250mm of soft soil removal. After the demobilization of camp and removal of wooden mats and debris at the time of construction in January 2017, the subgrade was already found to be 750mm below the final grade so, there was no need for further excavation and removal of the existing soft soil for the installation of the bottom layer of NPA geocell. 700 mm thick gravel reinforced with two layers of NPA geocell and one layer of biaxial geogrid reinforced hybrid design would have been good for the design but as the subgrade was already at 750mm below the finished grade the structure was designed as 750mm thick to exactly match the final grade. The 750mm of structure was checked for all three design criteria and it was found that the structure will transfer 34.7 kPa of stress on the subgrade. A global factor of safety of 3 chosen against the bearing capacity of the subgrade of 113.9 kPa due to the presence of dynamic crane loads was therefore met. The pad had a short stretch of access road that was designed for heavy traffic load going into the pad. The access road was designed only with a two layers of NPA geocell reinforcement for rut as well as bearing capacity criteria.

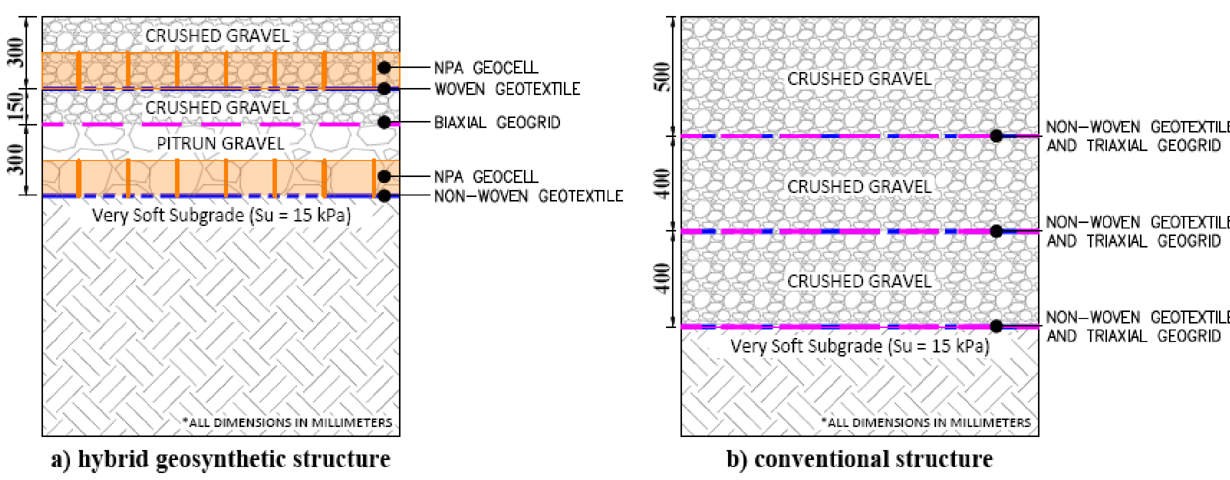

Figure 1: a) Hybrid reinforced structure compared with b) the conventional structure

MATERIAL USED

NPA geocell, biaxial geogrid, and woven and non-woven geotextiles were used. The properties of NPA geocell are shown in Table 1. Table 2 shows the properties of biaxial geogrid. The non-woven geotextile had a grab tensile strength of 1200N and the woven geotextile had a grab tensile strength of 800N. Cheaper pit run gravel was used as infill at the construction (bottom) layer and crushed gravel was used for the upper structural layers. The gravel materials were specified to have less than 12% fines. Maximum particle size for pit run and crushed gravel was specified to be 75mm and 40mm, respectively.

Table 1. Properties of Geocell

Description	Value
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	< -70°C
Long term plastic deformation at 650C (load 6.6kN/m)	<1.3% deformation
Dynamic (elastic stiffness) modulus at +300C	>800 MPa

Table 2. Properties of Biaxial Geogrid

Description		Value
Geogrid Material		Polypropylene
Aperture Dimensions	*Machine Direction*	25mm
	Cross-Machine Direction	33mm
Rib Thickness		1.27mm
Tensile Strength at 2% Strain	*Machine Direction*	6 kN/m
	Cross-Machine Direction	9 kN/m
Aperture Stability		0.65 m-N/°
Flexural Stiffness		750,000 mg-cm

CONSTRUCTION AND PERFORMANCE OF THE PAD

The construction of the hybrid geosynthetic reinforced gravel structure started in January 2017 and was completed before the end of February that year. The non-woven geotextile was first laid on top of the subgrade which was fairly level. The bottom layer NPA geocell was stretched and filled with pit run gravel. A single lift of 300mm was allowed at the construction layer for the compaction so as not to damage to the subgrade and create a safe construction layer for equipment and gravel trucks. The gravel brought in was in non-frozen state with natural moisture about 3% less than the optimum moisture content. Freezing temperatures during construction introduce complications due to the freezing of moisture within soil. As such, contractors are always looking for methods that enable them to work effectively. Compaction of soils in freezing temperatures is very contentious topic however, given the timeline a method had to be devised so that the existing cohesive subgrade was minimally disturbed and the granular reinforced fill was compacted to the required degree. A control volume/weight method was applied to achieve 98% of the standard proctor maximum dry density.

Figure 2 a) shows the subgrade condition and Figure 2 b) shows the NPA geocell stretched on top of the subgrade separated by non-woven geotextile. The gravel was end dumped and pushed by dozer into the geocell pockets. Any frozen soil in lumps and large chunks were deemed unsuitable for construction and were rejected. Figure 3 a) shows the biaxial geogrid layer with 150mm thick crushed gravel and Figure 3 b) shows the top layer NPA geocell being stretched and filled with gravel. Pokharel (2010) emphasized on the importance of compaction in geocell reinforced structures, so to achieve the required strength, achieving the right degree of compaction was always the top priority. In subzero temperatures the nuclear densometer compaction testing did not seem to give accurate results. Therefore, a controlled volume/weight method was employed to guarantee that required degree of compaction was achieved. The pad was divided into separate blocks and the gravel brought into that area by each truck was weighed. For each given area, the required weight of the material for a specified degree of compaction was calculated, and compaction continued until the exact compacted thickness of the fill material was achieved. This was continued for each subsequent layer of gravel fill. This method was utilized to good success and helped ensure adequate compaction was achieved. The crane was brought to the site during spring thaw, where soil conditions are typically expected to be in their poorest state. The structure performed as expected with no visible signs of rutting or bearing capacity failures.

Figure 1: a) Existing soft soil subgrade and b) Partially stretched bottom layer NPA geocell

Figure 3: a) Partially filled geogrid Layer and b) Partially filled top NPA geocell layer

The bottom layer improved the bearing capacity and also served as the construction layer for the construction traffic which otherwise would have needed layers of wooden mats to pass the truck traffic. After installation of the top structural area in some portions of the pad, a pile driving rig was allowed to operate on the pad while installation was completed in other parts. During this time no significant rutting or differential settlement of the pad was observed. The site condition at the compressor station pad B was working out great and the operating 275 tonne crawler crane did not even make a small rut when moving around the site so the hybrid geosynthetic design was working very well (personal communication with contractor's Project Manager, Mr. Cord Roberts, July 26, 2017). Figure 4a) shows the condition of the pad on May 8, 2017 while lifting the compressor and Figure 4b) after two freeze-thaw cycles and one and a half year of service on July 27, 2018, the pad and access road are both performing well without any maintenance requirements (personal communication with contractor's program manager Mr. Mark Bonnell, July 27, 2018).

Figure 4: a) 275 tonne Crane lifting compressor on May 8, 2017 and b) Condition of pad after one and a half year of service on July 27, 2018 (Pictures courtesy Mr. Mark Bonnell, Program Manager, Strike Group)

DISCUSSIONS

The design was successfully implemented to withstand the anticipated loads. Initial concerns had been brought up regarding the weak subgrade shear strength as well as the potential of subgrade and base course softening during the following spring after the pad was constructed. The design had anticipated that the mechanisms of cellular confinement and gravel interlocking would increase the stiffness of the entire structure and thereby reduce stress applied to the subgrade during spring thaw. The pad held firm under the applied loading which validated the designed structure and construction methodology. The structure was basically designed for load support purposes hence possible subgrade settlement was not looked into however, the designers had anticipated no appreciable differential settlement would occur at the pad under the design load. It was also assumed that some of the settlement of the subgrade might already have occurred during the period of loading from the matted camp structure and limited construction activity during that time.

A comparison of costs and quantities was conducted between the hybrid reinforcement design and the 1300mm thick 3 layers of planar geosynthetic reinforced conventional design. This comparison was performed for a pad area of 27,000m^2. The conventional design would have required to remove 550mm of existing subgrade soil, which is equivalent to a total of 14,850 cubic meters of soft clay removal and hauling out. In addition to that it would have required 35,100 cubic meters of crushed gravel. The hybrid design however, completely avoided the excavation; the crushed gravel required was only 12,150 cubic meters and 8,100 cubic meters of cheaper pit run gravel. The average haul distance for the gravel was about 60 km one way. The hybrid design therefore reduced the total gravel quantity by 14,850 cubic meters and haul by 891,000 km-m^3.

The actual costs for supply and install of geotextiles were provided by the contractor. Costs for earthwork and the supply and install of geogrid were taken from unit price averages from the provincial authority (Alberta Transportation). The analysis showed that, by using the hybrid reinforcement structure: 22.8% savings in initial project cost, 100% savings in excavation, 42.3% savings in granular fill volume, and 45.7% savings in granular fill costs was realized. In addition to this, the hybrid geosynthetic reinforced gravel pad structure also contributed to environmental benefits. The reduction in the volume of aggregate, the number of trips to haul material, and construction duration all contribute towards a reduction in CO_2 emissions as suggested by Norouzi et al. (2017).

CONCLUSION

A hybrid geosynthetic structure was designed to support a 215 tonne crane load and regular and construction traffic on a compressor station pad. The design was based on mechanisms of combination of planar geosynthetic (geogrid and geotextile) and three dimensional NPA geocell reinforcement to improve the modulus of the structure, create a slab effect and distribute the loads to wider area to meet bearing capacity requirements of the subgrade and rut criteria at the surface for moving wheel traffic. The hybrid design eliminated the sub-excavation of existing soft subgrade soil, reduced the thickness of the structure by 42.3% and enabled the construction activities to be completed in freezing conditions. Overall, this design saved 22.8% of the project costs and reduced possible maintenance cost during the pad operation. The structure performed well under the design loads and fulfilled its intended design requirements. In conclusion, this design has paved path and directed a future course for combining different geosynthetic material for the design and construction of heavily loaded gravel pad on very soft subgrade soil in a sustainable way.

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