Geocells: Technical aspects under local African soil conditions

D. Alexiew
Consultant Geosynthetics & Geotechnics, Gescher, Germany

ABSTRACT: Development and application of geosynthetic soil reinforcements in geotechnical engineering began some decades ago. Their popularity, product range and applications continue growing due to the associated significant technical, economical and environmental advantages. Geocells belong to the products used for this purpose. They are flexible honeycomb 3D-products with a fill inside. Their most popular application is the creation of bearing layers of high bearing capacity e.g. for roads, railroads and airfields. A specific feature of geocells in such cases is the possibility of using as fill not only gravels (as with geogrids), but also sands. An extrapolation of the successful use of sand leads to the concept of using as a next step finer-grained, partially cohesive soils. This can be of great interest in regions, where even sand is rare, like in many regions in Africa. Beside the lack of gravel and sand, a problem in Africa are often expansive soils. In such cases geocells can help to equalize the deformations caused by subsoil heave. Corresponding to the two points mentioned above, the paper describes shortly some theoretical background and focuses on two corresponding case studies: a railroad on expansive soils and an airfield using partially cohesive fill.

1 INTRODUCTION

Geocells are flexible polymeric honeycomb 3D-products. They are delivered as a flat harmonica to the building site and then stretched and filled creating the final geocell system. Their third dimension - the height of 100 to 200 mm - provides a controlled fill confinement and immobilization. Based on this stringent lateral confinement a bearing layer of increased stiffness and bearing capacity and with a clearly defined thickness can be formed. Due to some bending stiffness this layer is also able to equalize differential settlements or heaving. A specific feature of geocells (based also on the confinement) is the possibility of using as fill not only gravels, but also sands or even finer partially cohesive soils.

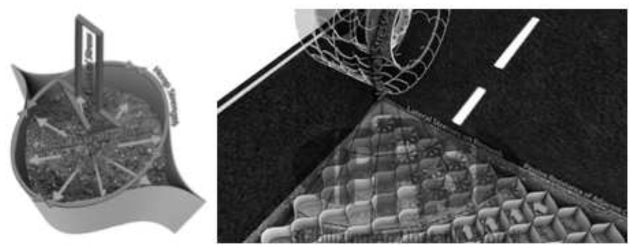

Figure 1. Illustration of geocell bearing mechanisms: single cell, left, and geocell system, right

2 SOME BASICS

The mechanical behaviour of a geocell system as a composite in the sense of both deformability and bearing capacity is defined by the geomechanical parameters of the fill and by the mechanical behaviour and geometry of the geocells. In the meantime, established design procedures are available based on research, testing and measurement programs over the recent 15 years (Emmersleben 2009, Han et al. 2007, 2013, Kief & Rajagopal 2011, Leshchinsky 2008, Pokharel 2010, 2013, Yang 2010). Due to brevity they are not included herein. Only the main factors for design summarised by the author are cited below.

2.1 *Fill*

Main factors are the angle of internal friction φ and the deformation modulus E as common in geotechnical engineering. The unit weight γ is less critical. Note that lower φ and/or E (e.g. sand or marginal fill) can be compensated by cell geometry and cell wall tensile stiffness (Figure. 1).

2.2 *Geocells*

Geometrical factors:
Cell diameter (usually 150 to 250 mm), cell height (usually 100 to 200 mm) and their ratio (Figure. 1).
Mechanical factors:
Cell wall roughness: the higher, the better.

Cell wall (strip) tensile stiffness: of crucial importance, the higher, the better (Figure. 1), both in the short term ("dynamic stiffness") and in the long term, say, low creep of material is extremely important. Note that this is well known also from other geosynthetic reinforcement applications, see e.g. Alexiew et al (2000), EBGEO (2011). According to the state-of-the-art for geocell systems creep strain should be limited to less than 2 % to max 3 % at the end of design life. This corresponds to similar limitations in established georeinforcement Codes (EBGEO 2011, BS 8006 2010-2016).

Cell wall (strip) tensile strength: the higher, the better, as for the stiffness, also in the long term (low creep).

Strength of joints (strip to strip, forming the cell, Figure 1): it has to be high enough to avoid a "week point" reducing the cell efficiency.

2.3 *Optimization and possibilities*

Note that due to the many variable factors the design is a process of performance-costs optimization.

The local foundation soils are a matter of nature/geology and cannot be "chosen", and a "good" fill is often not available. Fortunately, the wide range of geocells available provides a powerful tool to the design engineer to compensate that. This will be demonstrated here with two case studies.

3 SOLVING RAILWAY TRAFFICABILITY PROBLEMS ON SOFT SWELLING SUBSOIL: NAHARIYA RAILWAY LINE

3.1 *Project background*

The Nahariya-Acre Rail line is part of the Israeli Coastal Rail main line. Due to insufficient capacity a new parallel eastern track had to be added to the older western track in 2013. Although rehabilitated some years earlier, the western track deformed again and again significantly causing reduced trafficability and high maintenance costs. It seemed likely that the same problems would arise with the new track. For more details see Kief (2015, 2016).

3.2 *Problem description*

The main reasons for those problems were identified during geotechnical survey and start of execution of the new eastern track. The natural subgrade (subsoil) was characterized as CH (fat expansive clay) at a depth of 2 m to over 6 m in combination with a high groundwater level, say, a high swelling/shrinking potential was combined with low consistency and high deformability. Selected clay parameters can illustrate the problem: liquid limit w_L = 40 to 100 %, plastic limit w_P = 20 to 35 %, w_n/w_P = 0.8 to 2.1, CBR = 2 to 11 %. (Note the significant scattering of parameters leading later to a conservative choice of design parameters). Figure 2 illustrates the problematic subsoil conditions.

Figure 2. Problematic subsoil conditions at the Nahariya-Acre railway.

3.3 *Conventional design*

Assuming a conservative CBR-value of 2 %, the conventional design results in the following bearing layers between rail ballast and native subsoil, from top to bottom:

- Sub-ballast - 750 mm;
- Processed subgrade - 400-600 mm;
- Total thickness up to 1350 mm.

3.4 *Design with geocells and additional geogrid*

Besides the negative experience and problems with a conventional solution for the old western track, a conventional design for the new eastern track would ask for a deep excavation just adjacent to the western track which had to be kept under operation. The consequence would be the necessity of a lateral support by e.g. a sheet pile wall. Thus, two challenges were faced:

- the new bearing system had to perform better in the sense of significantly decreased deformability;
- this new bearing system had to be significantly thinner than the conventional one.

It was decided to develop a solution with geocells. The design philosophy is as follows:

Implement in the upper zone of the bearing system a geocell layer creating a new compound layer with a much higher modulus E than for the unconfined soil.

Now it is possible to reduce the thickness of the layer below (and consequently of the total thickness!). The reduction can be done until the equivalent modulus on top of the new modified system (stiff thin geocell layer plus reduced layer below) becomes the same as for the conventional thicker system without geocells. An option more is to generate on top even a higher modulus than for the conventional case. The latter option was chosen for the Nahariya project looking for a better track performance.

The design was based on the so-called MIF (modulus improvement factor) which is the relation of geocell-confined to unconfined soil modulus. Its value can amount up to 6 for high-class geocells (Han et al. 2007, 2013, Leshchinsky 2008).

The final solution with geocells in the case here is shown in Figure 3. The same conservative CBR = 2 % as for the conventional design was used, and the same geomechanical parameters for the fill material as well. This optimized design reduced the total bearing layer thickness to 950 mm, say by 400 mm, say by 40 % in comparison to the conventional solution. So called NPA (new polymeric alloy) geocells were used with a high tensile stiffness and very low creep tendency resulting in a long term creep strain less than 2 % (see Chapter 2.2).

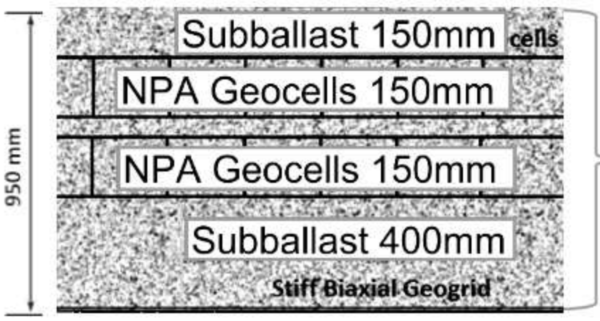

Figure 3. Geocell solution for the Naharya railway (modified from Kief 2016)

Due to the two layers of high-stiffness geocells (with a MIF ~ 4.0) the total equivalent modulus E of the bearing layers amounts to 400 MPa (Fig. 3), and the vertical contact stress on the local subsoil becomes 2.5 times lower thus reducing the settlement due to cyclic loads significantly. The final result is a better trafficability performance.

Additionally, beside the savings of fill and construction time, the reduced thickness allowed to keep the adjacent old western track under operation without any additional supporting measures (Fig. 4).

Figure 4. Due to the shallow excavation for the thinner geocell solution no support is needed for the adjacent track under operation

A specific point is the application of a biaxial geogrid at the bottom of the system. The goal is to provide support for an efficient compaction of the sub-ballast and to provide some additional bending stiffness as well. One could consider the system as a granular beam strengthened by the geocells in the upper zone and by the grid in the bottom zone. Although not quantifiable yet, such a beam-like behavior helps to equalize differential settlements due to irregular subsoil swelling. Such a solution is an object of further optimization and development of more precise deterministic design.

3.5 *Experience until now*

Since 2014 systematic measurements of settlement and deflection of the old (conventionally founded) western track and the new eastern one with the thinner "geocells plus geogrid" solution are conducted. For the old track both settlement and heave of about - / + 10 mm are registered, depending on the season. For the new track these changes are negligible. There are no problems with the trafficability performance, and the maintenance intervals are significantly longer.

4 RUBKONA AIRSTRIP UPGRADE WORKS, SOUTH SUDAN

4.1 *Project background*

The Rubkona Airfield is essential to the transport infrastructure for humanitarian aid efforts. The airstrip provides a primary access which is used when delivering aid for the United Nations Mission in South Sudan (UNMISS). The airstrip had to be upgraded for heavier aircrafts (C130 Hercules) ensuring also long-term permanent trafficability. Road conditions in the region are very poor, thus the possibilities of soil/fill import to the airfield are very limited (PRS Geo-Technologies 2017).

4.2 *Problem description*

The foundation soil directly below the airfield consists of alluvial clay deposits known as “Black Cotton Soil”: expansive clays with a potential for shrinking or swelling, sensitive to water content, say, problematic foundation soils. For construction purposes some sandy silts are available in the vicinity; "good" non-cohesive soil (lateritic gravel called Murram) is available 180 km away. Due to the poor road conditions bringing even a single ton of Murram to site is an expensive and logistically challenging operation. The main soil data are given in Table 1. Note that fortunately the vertical swelling of the Black Cotton Soil is in that case very moderate; the real problem remaining is its softening due to wetting.

Table 1. Main soil data for the Rubkona airfield

Soil	Murram lateritic gravel	White sandy silt	Black cotton soil
Liquid limit, %	30	20	40
Plastic limit, %	15	0	15
Plasticity index, %	15	NP	25
% passing 37.5 mm	100	100	100
% passing 26.5 mm	100	100	100
% passing 4.75 mm	75	100	97
% passing 2.0 mm	51	100	96
% passing 0.425 mm	39	99	95
% passing 0.075 mm	29	46	73
CBR (95 %)	35	14	1
% swell at CBR	N/A	0	1.9

4.3 *Conventional design*

A conventional design was performed applying standard airfield pavement design procedures. The C130 Hercules aircraft loads and geometry were considered and the soil data (Table 1) as well.
The layers resulting are depicted in Figure 5 and the layer moduli assumed in Figure 6.

Layer #	Type	Thickness
1	Murram Gravel Wearing Course	100 mm
2	Murram Gravel Base	300 mm
3	50/50 mix of White Sandy Silt and Murram Sub-base	300 mm
4	White Sandy Silt Selected Layers	300 mm
5	Insitu Black Cotton Soil	-

Figure 5. Layers for the upgrade of the Rubkona airfield from conventional design

Layer #	Type	Design E-Modulus
1	Murram Gravel Wearing Cours	212 MPa
2	Murram Gravel Base	212 MPa
3	50/50 mix of White Sandy Silt and Murram Sub-base	96 MPa
4	White Sandy Silt Selected Layer	52 MPa
5	Insitu Black Cotton Soil	20 MPa

Figure 6. Design E moduli for the layers used

The total thickness of the system is significant. However, not the thickness is the critical problem, but the massive use of Murram gravel: for the 100 mm wearing course (practically unavoidable), and also for the 300 mm base and as 50 % admixture for the 300 mm white sandy silt layer. Thus, the Murram equivalent thickness amounts to 550 mm resulting in a huge volume to be imported from 180 km over very poor roads being often flooded. Consequently, the conventional solution had to be avoided and replaced by another one using significantly less Murram gravel.

4.4 *Design with geocells*

A possible solution with geocells was analyzed based on two of their specific capabilities:

- To reduce the total thickness of a bearing layer system implementing in its upper part a geocell layer with a significantly higher deformation modulus thus enabling a thinner rest-layer below (as it was the case with the Nahariya-Acre Rail line, see Chapter 3).
- To use as fill a soil of lower (shear) strength compensating its lack of bearing capacity and stiffness providing a more stringent confinement by correspondingly designed "stronger" geocells (see design factors in Chapter 2).

As mentioned in Chapter 2.3 there was also the possibility of performance-costs optimization based on the wide range of high-modulus geocells available today.

Multiple detailed designs were performed comparing resulting pavement modulus, surface deflection under the wheels of the aircraft, settlement at the bottom boundary of the system (on the sensitive Black Cotton Clay) and the stress reduction at that level. A design life of 10 years was assumed as required by the owner. NPA geocells were used due to their high tensile stiffness and (mainly) low creep strain. In that case the creep strain was limited to max 1.2 % for 10 years under load (Fig. 7) resulting in high system modulus and low surface settlement despite the marginal fill used, see below. Due to brevity only the final solution is described here (Figs 8 & 9).

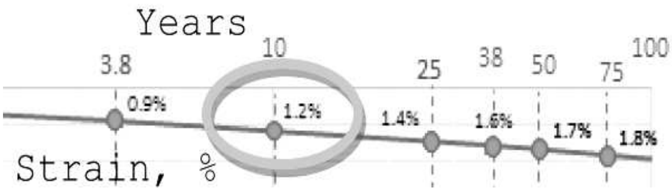

Figure 7. Creep curve and creep strain for the NPA geocells used (modified from PRS 2017)

Two important facts should be noted:

- The solution with geocells is thinner than the conventional design saving excavation and soil replacement time and costs.
- Even more important: only marginal local fill (the sandy silt, white in Figure 9) is used as fill for the geocells, for the intermediate layers and for the sublayer. The Murram gravel (to be imported from 180 km) is reduced to only 100 mm as wearing course.

Layer	Type	Thickness
1	Murram Gravel Wearing Course	100 mm
2	PRS-330-100-C Neoloy Geocell with Selected White Sandy Silt	150 mm
3	PRS-330-100-C Neoloy Geocell with Selected White Sandy Silt	150 mm
-	High-Strength Low-Deformation Separation Layer or equivalent	-
4	White Sandy Silt Selected Layers	200 mm
5	Insitu Black Cotton Soil	-

Figure 8. Marginal local soils used as geocell fill (marked by a dashed line) and as sublayer

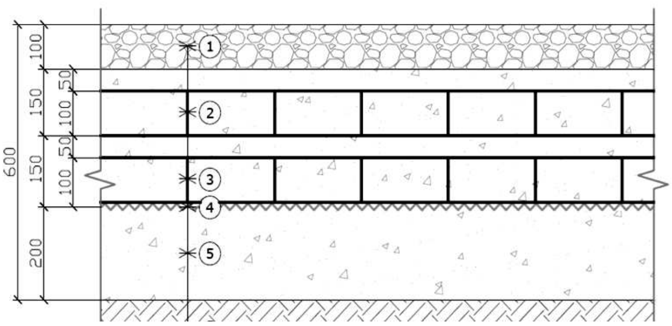

Figure 9. Cross-section of the final optimized solution with geocells for the Rubkona airfield (modified from PRS 2017)

It should be also noted that beside the easier logistics and the shorter construction time the costs for the geocell solution (28 USD/m²) are less than the half of the conventional solution (65 USD/m²).

4.5 *Experience until now*

The airfield was constructed meeting the schedule. In a similar way, access roads in its vicinity were upgraded as well, which is beyond the scope of this publication.

To our best knowledge the upgraded Rubkona airfield is permanently under operation, no trafficability or maintenance problems of any type are known until now.

Figure 10: An aircraft C130 Hercules landing

5 FINAL REMARKS

The use of geocells as soil reinforcing respectively. stabilizing elements can help to reduce significantly the thickness of bearing soil systems (subbase) for roads, railways and airfields, consequently saving costs and construction time and reducing the carbon footprint.

Additionally, they open the door for the use of fills with lower shear resistance and deformation moduli than the normally used gravels. Due to the geocell confinement e.g. sands or even partially cohesive local marginal soils can be used as fill. This is a decisive advantage in regions with a deficit of "good" non-cohesive soils.

Due to some bending stiffness geocells can also help to equalize differential settlements or heaves e.g. on swelling/shrinking subsoil.

Because the latter two situations are often the case in Africa, geocells can be of great interest.

The publication describes shortly two corresponding successful projects:

the first one is a railroad on soft swelling soils in Israel, the second one an airfield in South Sudan on black cotton soils using local marginal fills.

6 ACKNOWLEDGMENTS

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