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Cost effective & sustainable solutions for embankments on soft soils - performance review of geocells in embankment

Solutions rentables et durables pour les remblais sur sols meubles - évaluation des performances des géocellules dans les remblais

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ABSTRACT: Geosynthetic solutions offer sustainable alternatives, delivering long-lasting, stable embankment foundations that are easier and faster to build compared to traditional methods, reducing not only construction time and costs but also contribute to carbon footprint savings. This publication describes cellular foundation mattresses technology called Stratum that consists of 1m high bespoke geocell structure, as described in BS 8006-1: 2010. This solution has been utilised on infrastructure projects such rail and highways, acting as embankments foundations. This paper presents a case study of a highway embankment built in 1990s and is supplemented by recently obtained information on the performance of a road embankment after 30 years from its installation. This example proves the long tracked record of 1m high, bespoke geocell mattresses economical advantage over the alternative traditional solutions. 1m high geocells offer reduction of excavation volumes of unsuitable soils that typically would be replaced with engineered fill, or remove the need for piling works, delivering solutions without compromising on performance.

RÉSUMÉ: Les solutions géosynthétiques offrent des alternatives durables, fournissant des fondations de remblai durables et stables, plus faciles et plus rapides à construire par rapport aux méthodes traditionnelles, réduisant non seulement le temps et les coûts de construction, mais contribuant également à la réduction de l'empreinte carbone. Cette publication décrit la technologie de matelas de fondation cellulaire appelée Stratum qui consiste en une structure géocellulaire sur mesure de 1 m de haut, comme décrit dans la norme BS 8006-1: 2010. Cette solution a été utilisée sur des projets d'infrastructure tels que les chemins de fer et les autoroutes, agissant comme fondations de remblais. Cet article présente une étude de cas d'un remblai routier construit dans les années 1990 et est complété par des informations récemment obtenues sur la performance d'un remblai routier 30 ans après son installation. Cet exemple prouve l'avantage économique des matelas géocellulaires sur mesure de 1 m de haut par rapport aux solutions traditionnelles alternatives. Les géocellules de 1 m de haut permettent de réduire les volumes d'excavation de sols inappropriés qui seraient généralement remplacés par des remblais techniques, ou suppriment le besoin de travaux sur pilotis, offrant ainsi des solutions sans compromettre les performances.

Keywords: Geomattress; embankments; soft soils; monitoring instrumentation.

1 INTRODUCTION

Embankments are a key feature of many infrastructure projects such highways, railways or flood defence schemes. It is vital that these structures are built on firm and stable foundations ensuring minimal maintenance required over their service life. This can be challenging when dealing with weak, variable and saturated subgrade soils. Traditional solution for construction of foundation embankments, involve digging and replacing soft deposits with engineered fill, piling an embankment or to utilising other deep ground improvement methods such as, e.g.: vibro concrete, stone columns, dynamic compaction, deep ground mixing, load transfer platforms etc. These approaches are technically valid, but they are also expensive, time consuming, heavy on carbon footprint and often involve extensive temporary works.

A 1m high, bespoke geocell foundation mattresses, as defined by BS 8006-1 (2010) constructed using uniaxial geogrids (Figure 1), offers a cost-effective solution alternative to the traditional methods.

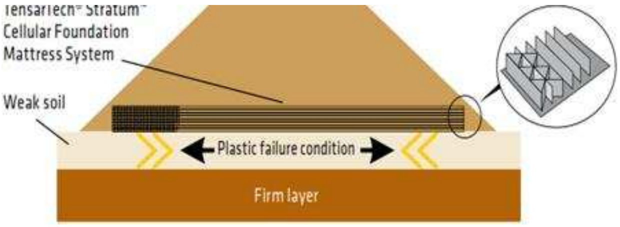

Figure 1. Typical section through embankment constructed on Cellular Foundation Mattress System.

To the Authors's knowledge the technology is still relatively uncommon and underutilised. Kuznietzowa and Doulala-Rigby (2015) and Pyne (1993) present cost comparison between this and alternative technologies that is based on site efficiencies and production costs. This shows already considerable advantage of geosynthetic solution over the alternative methods. However, these do not consider additional savings due to programme time reductions or more importantly carbon footprint reductions that geosynthetic solutions offer (Rimoldi et al. 2021).

Geocell mattress technology involves construction of a three dimensional, typically 1m high, honeycombed structure on site using uniaxial geogrids that form interlocking cells (Figure 1). These get filled with suitable aggregate and form foundation of the embankment (or are used for temporary working platforms construction).

Embankments built on geocell mattresses are characterized by an even distribution of typically heterogeneous settlements (e.g. Pyne 1993, Jenner et al. 2008, Lees et al. 2020). The mattress built into the base of an embankment creates a stiffened platform, which allows an application of higher loads directly on the mattress, and the stresses transmitted by the mattress are distributed over a larger area, reducing unit stresses acting directly on the base. BS 8006-1: 2010 presents an analytical method of calculating the bearing capacity of embankments reinforced with geocell mattresses on cohesive soils.

The method presented in BS 8006-1 (2010) and described in more detail in Jenner et al (1988) is based on the conditions of plastic deformation of the substrate under a wide embankment. The bearing capacity resulting from the slip line analysis should be compared with the additional stresses resulting from the installation of the embankment and its weight in order to estimate the safety factor and check if the equilibrium condition is met.

It should be noted that this method does not apply to geosynthetics of smaller dimensions (so-called geocells 0.15 m to 0.3 m high). The method applies to geomattresses that reach at least 0.5 m in height, but more typically 1 m or 1.2 m height. The method allows to estimate bearing capacity of the mattress, as well as to select the appropriate type of a uniaxial geogrid from which the mattress will be constructed.

Whilst utilisation of cellular foundation mattresses on projects globally is not widespread, there exists a lot of evidence of their performance, in a variety of applications, e.g.: embankments (Jenner et al. 2008), temporary working platforms (Lees et al. 2020) and shallow foundations for steel structure - warehouse (Duffin and Jenner 2000).

2 CASE STUDY: DARTFORD HIGHWAY EMBANKMENT 1992 (UK)

The current records of the project are scarce, however, the site of Dartford Highway Embankment was monitored and information about the historical project details were reported by Payne (1993). In addition, Payne (1993) described the design and construction stages of the embankment built at Dartford, UK, in 1992 (East London).

To summarise, the embankment was built using geocell mattresses technology. In addition, prefabricated vertical drains at 1.5 m intervals (in a triangular grid) were used to accelerate the process of consolidation under the embankment. The embankment was 4.3 m high, the width in the crest was 27 m to accommodate the total of 4 lanes (2 in each direction). The length of the section of the embankment on the weak subsoil was 350 m. The site geology was dominated by alluvial deposits of the Thames River, which flows in the immediate vicinity of the embankment. This also resulted in a high level of groundwater table in the subsoil. The layer of plastic clay was 10 m deep with subsurface interlayer of peat (Figure 2). The subsoil was characterized by an undrained shear strength Su value of 10 kPa, although in some areas this was considered an overestimated assumption and the actual value of Su was in the range 4.5 – 8 kPa (Pyne 1993).

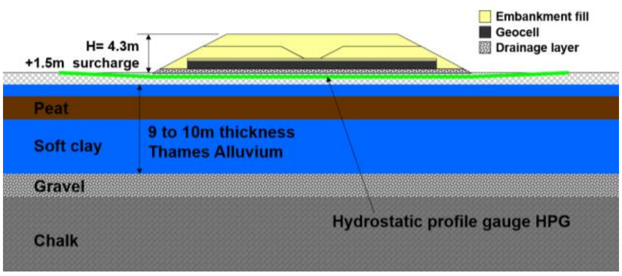

Figure 2. Geological setting of the Dartford road embankment (source Jenner et al. 2008).

The designed solution for this project took advantage of the rigid bespoke 1m high geocell foundation mattresses ensuring even load distribution over weak soils in the sub-base. All four lanes of the roadway were constructed on one mattress.

Embankment deformation was monitored at the level between the mattress and the subsoil. The profile of vertical displacement (Figure 3) showed a very even settlement across the embankment with a mattress providing load distribution and control necessary to achieve the required bearing capacity and stability of the embankment. Figure 3 shows the values of settlement during construction and embankment overload. Settlement over time is clearly visible, with a very even deformation over the entire width of the base of the embankment and very limited differential settlement across the embankment. This is an essential feature considering long term use of the efficient, economical and durable structure. The monitoring confirms the assumptions of the cellular mattress technology, which refer to the creation of a semi rigid foundation structure at the base of the embankment that allows uniform settlements at the base of the embankment.

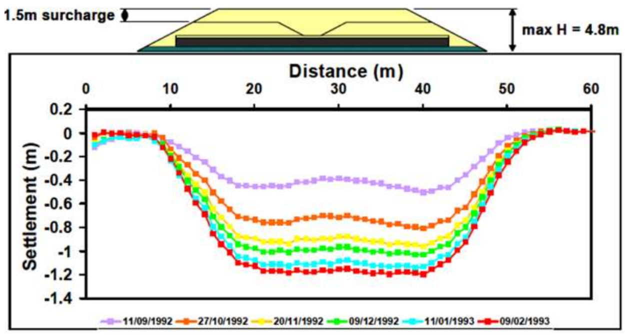

Figure 3. Settlements records under the embankment with time (source Jenner et al. 2008).

3 CURRENT STATE OF THE EMBANKMENT

Up to date quantitative data on the embankment performance are not available, however, the authors of this paper investigated the qualitative in-service performance of the embankment during a recent site visit. The authors interviewed the local road maintenance contractor who has been engaged with resurfacing works on the relevant section of the road by the local County Council. The following remarks and statements were collected from the contractor:

- There has been no major works undertaken on the embankment after its installation,
- The only works undertaken on the section, were the scheduled cyclic resurfacing maintenance works,
- Major resurfacing works took place in late 2000s, there was no need for major restorations to the structure of the embankment,
- No works related to kerbs alignments were needed, as all of them were in place with no noticeable horizontal or vertical displacements,
- No works related to manholes and drains relating to embankment settlement took place.

Moreover, during the site visit by the authors, the examination of the road and photo records (Figure 4 & 5) were collected, as a part of the evidence to support the Contractor's statement. Whilst no quantitative data is available to assess scientifically the performance of the embankment 30 years after its installation, the above statements are satisfying and the site visit with the surface examination confirmed long term performance of geocell mattresses under highway embankments from the user and owner perspective. It is evident that the majority of the settlements of the embankment occurred during the first months after the installation (Figure 3). Following that the embankment remained stable with not recorded differential settlements or stability problems that would cause issues to the asset owner or maintenance contractor.

Figure 4. Current photos of the embankment showing high water table – water ponds in close vicinity of the embankment (on Thames River side).

Figure 5. Current photo of the embankment: Pavement and footpath photo showing smooth, even surface.

The mechanism of the reduction of subsidence (with vs without cellular foundation mattresses), however, is not yet sufficiently well understood to be able to accurately estimate the reduction of subsidence at the design stage. Typically, settlements should be monitored during the project implementation by installing measuring instruments that verify the results and assumptions of the project. Recent publication of a project back analysis using numerical modelling approaches, advance the understanding and predictions made for serviceability limit state where settlements and differential settlements reductions of the cellular mattresses solution can be quantitatively estimated (Lees et al 2020).

4 CONCLUSIONS

Cellular foundation mattresses comprise a cost-effective and carbon footprint saving alternative to more traditional ground improvement technologies. Dartford embankment shows an example where after 30 years from embankment installation on extremely soft grounds, no issues with the solution was recorded. The technology is versatile it can offer the asset owner or contractor multiple benefits:

- Provides significant carbon reductions compared with any other ground deep improvement methods
- Can be installed on most types of weak or heterogeneous soils (as well as in municipal landfills, i.e. Duffin and Jenner (2000),
- Eliminates or limits the need for excavation, as it is a trenchless solution, performed directly on the existing ground. This allows the work to be carried out without damaging the natural structure of the substrate,
- Requires a short time of execution and implementation - proper arrangement of geogrids and filling the cells is not a time-consuming task, an additional advantage is the fact that geocell mattresses are part of the embankment. The construction of the cellular foundation mattresses is therefore a phase in the construction of the embankment, which reduces the time needed to build the entire embankment,
- Does not require specialised workforce - installation of geocells is very simple, there is no need to use special construction machines. Typical earthmoving construction machines are sufficient to properly install a geocells in the ground,
- Can be installed in conjunction with prefabricated vertical drains accelerating the consolidation of the substrate.

Cellular foundation mattresses reduce uneven settlement as well as contribute to the reduction of total settlement. More research and construction of structures with long term monitoring will be beneficial to advance the knowledge on the mechanisms of the cellular foundation mattresses performance.

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