Foundations With Controlled Settlement

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ABSTRACT
The construction of embankments over soft soil often faces a problem of settlement. Both in terms of the range of it and time both for the construction and consolidation. In most cases the settlement itself is not the key problem. Differential, uncontrolled settlement and long time consolidation is the real issue in these cases. The technology of foundations with controlled settlement is based on special cellular mattress. The incorporation of a deep cellular mattress at foundation level provides a relatively stiff platform which enables the efficient construction of the embankment whilst controlling the settlement process, and speeding up the consolidation process. This innovative technology is described and discussed with case examples in rather challenging projects in Europe. Economic and technological benefits are significant in comparison with traditional systems.
Keywords: embankments, foundations, geocell, soft soil.

1. THE CONCEPT

The concept a Geocell Mattress foundation was brought by Jenner et al. (1988) is based on forming of the system of 1m high triangular cells from HDPE geogrid over the platform of a single layer of PP usually biaxial geogrid. Figure 1.

Figure 1. Geocell Mattress

This system forms a relatively stiff plate at the base of the embankment. The stiff plate at the base of the embankment enables the loads from the embankment to be distributed in an even way onto the foundation soils giving even settlement profile. This is in direct contradiction to an unreinforced embankment or an embankment with geotextile reinforcement. In those cases the deformation profile tends to be in the form of a dishing with very much larger settlements at the centre and virtually zero settlement at the embankment toes. These characteristics provide a confinement to the granular fill within the cells which in turn alters the deformation mechanism forcing the potential critical shear surface to be rotated to pass through the mattress and the mattress/foundation interface vertically, or near vertically, Figure 2. As the shear surface is driven deeper the critical foundation failure mechanism is altered to one of plastic squeezing out of the soft soil laterally, i.e. bearing capacity. In the special case when the soft soil layer is relatively thin compared with the width of the cellular mattress the extrusion mechanism (plastic flow) comes more significant and can generate a large increase in bearing capacity, Figure 3. This can result in the embankment being constructed to full height much more quickly than would otherwise be possible.

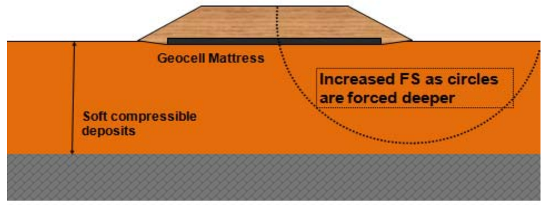

Figure 2. Rotation of slip circle

Figure 3. Plastic flow

The combination of the cellular mattress with the vertical drains is a powerful partnership with the granular mattress not only providing the stiffness and uniform loading to the foundation soils but also being able to be the water collection layer allowing the rapid release of pore pressures.

2. THE DESIGN

The design of is well established, described in and also referenced in BS 8006:1995. The calculation for the bearing capacity/resistance to plastic flow is based on the model of the pressing of metals and the plastic flow of a metal between two stiff rigid platens (Johnson and Mellor 1983). A slip line field can be constructed to determine the limiting load required to cause plastic flow and hence determine whether the foundation soil can support the embankment load being imposed.

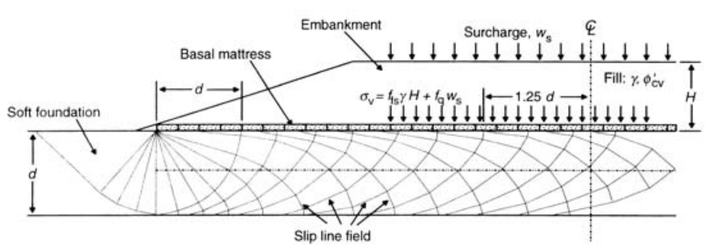

Figure 4. Slip line field

The construction of pressure diagram follows in the design procedure.

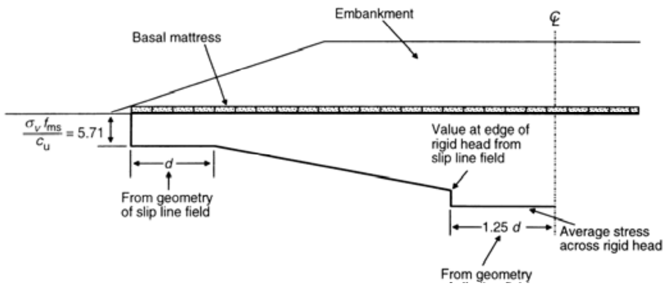

Figure 5. Pressure diagram

Checking the strength of the geocell system in horizontal direction using standard Mohr-Coulomb calculation of horizontal stresses is the final step in the design.

3. APPLICATION CASE EXAMPLES

3.1 Senkvice, Bratislava-Trnava Railway, Slovakia

The modernisation of the railway track between Bratislava and Trnava formed part of the upgrading of one of the major infrastructure corridors following Slovakia's integration into the European Union. An assessment of the track alignment at Senkvice by the railway authorities in the Slovak Republic determined that the track should be taken by a less tortuous route over a length of approximately 3km. This realignment would allow a smooth curve to be achieved, in plan, which would then enable the allowable train speed to be increased to acceptable levels in line with the general track quality. The reasons for the original alignment become apparent when the foundation soil conditions are examined with very soft soils near the existing ground surface and a high water table at 0.5m – 1.5m below the ground surface on the line of the new section of track. The new track alignment also required transitions between embankment construction and bridge abutments as the rail track crossed two river channels.

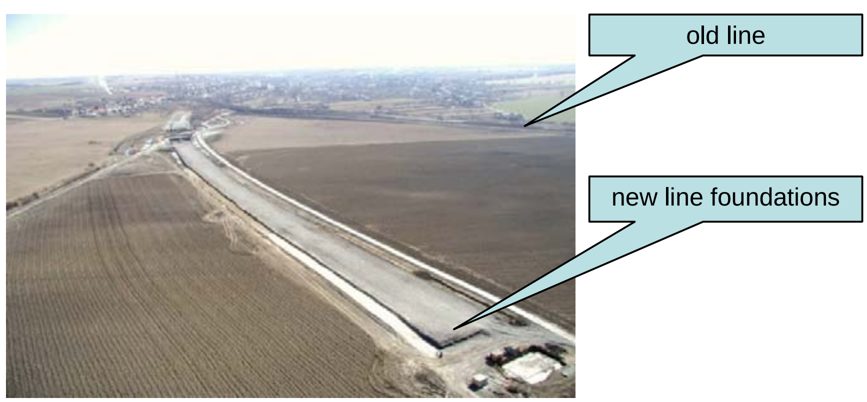

Figure 6. Lines alignment

The Slovak Railway Administration had specific requirements for the new track in addition to the increase in allowable speed from 120km/hr to 160km/hr. This speed condition has inevitable consequences on the limits of differential settlement and therefore any solution chosen was required to give adequate control of both total and differential settlement. The Railway Administration also required the railway to be ready for traffic as soon as the bridge structures were complete. The embankment height was generally 7.0m and therefore the method of construction and the rate of consolidation of the soft foundation soils was critical to the success of the project.

The design of the embankment is described in Matys et al. (2004) and deals with the monitoring of the construction up to a level of approximately 75% of the full design thickness. The combination of vertical drainage punched through the base of the structure, Figure 7., and the 1m deep Geocell Mattress provided a very efficient and economic solution. Other, more intrusive methods of construction such as the construction of the embankment on piles combined with a load transfer mechanism would have been many times more costly with the additional difficulties of heavy construction equipment over very weak soils. The use of geogrid reinforcement in the embankment side slopes allowed a steepening of those slope with an unreinforced toe berm assisting with global stability. The speed of construction was very much more rapid than anticipated with the waiting time between filling operations being shorter than expected by the designer. The intensive pore pressure and settlement monitoring enabled the full advantages of this type of construction to be utilised. The monitoring of the project allowed the construction to proceed very quickly.

Figure 7. The base of the mattress

The observation of the pore pressure development as the construction was being carried out showed that the anticipated large increases in pore pressure did not actually occur, a common result with the Geocell Mattress construction, and therefore the staged construction did not require long waiting periods between stages.

The monitoring regime was adopted with a comprehensive arrangement of pore pressure and settlement monitoring equipment. Figure 8. Previous technical papers, e.g. Matys et al. (2004), described the performance of the construction from commencement up to approximately 75% of the final construction height. Information is now available for the full height construction and the performance in service. The hydrostatic profile gauges provide valuable confirmation of the settlement profile under an embankment on soft soil with a Geocell Mattress at the base. There has been some discussion over the validity of expected even settlement profile versus a dished profile that would be expected from an unreinforced embankment or an embankment with layered basal reinforcement. Field monitoring in this project has definitive showed the development of a very even settlement profile. The comparison up to October 2003 shows the typical situation with measured settlements being only a fraction of the anticipated values. Figure 8.

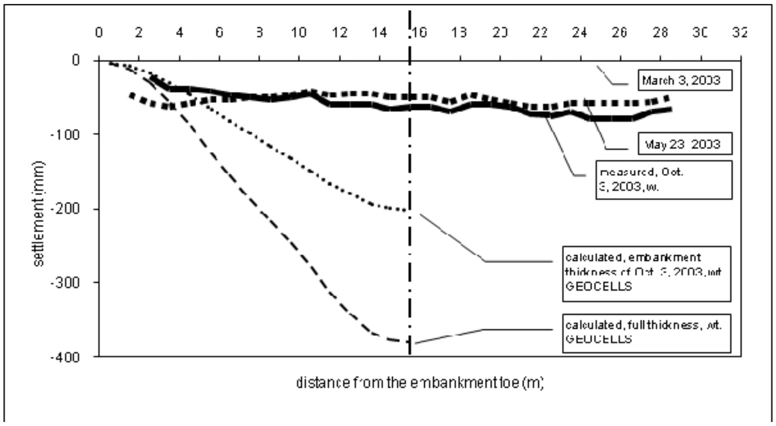

Figure 8. Profile at October 2003

Rail trafficking started in 2005 and monitoring continues with results available up to the end of 2006 with similar settlement performance.

The progression of settlement achieved a maximum of only 35mm over nearly 3 years combined with a very even profile. The 7 months up to November 2006 showed virtually no settlement even though the track was open to traffic.

3.2 Motorway M74, United Kingdom

Motorway embankment was located over infilled quarry with waste deposits and soft silts of variable depth having c_u value around 20kPa, but variable. The goal was to minimize differential settlement. The support for an underpass was a special challenge in this project. The Geocell Mattress has to be built on slope 1:4. Figure 9. Total area of Geocell Mattress foundation was 48.000m^2.

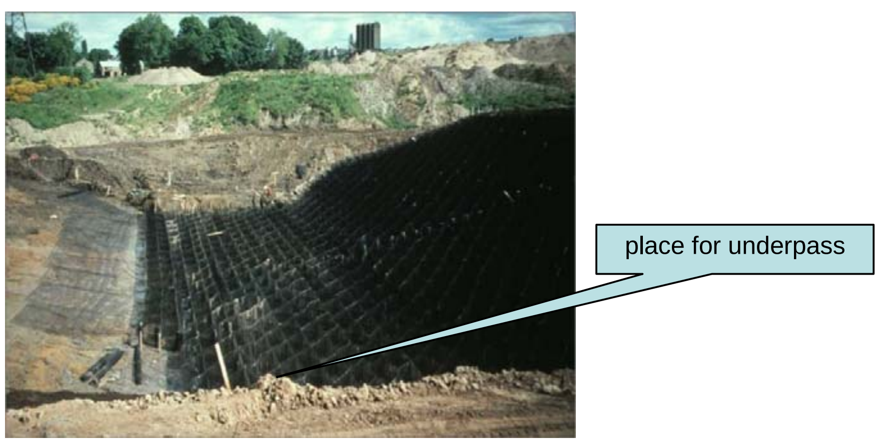

Figure 9. Construction of inclined geocell (M74, UK)

3.3 High Landfill over Tailing Pond, Haushamm, Germany

The goal was to provide a foundation for high landfill situated over old tailing pond filled with very weak and fine waste material. Figure 10. The depth of weak subgrade was around 10m, c_u value around 5kPa or even less. Due to extreme conditions a trial was done before starting real structure. The trial shows sufficient stability and consistency of the mattress. The width of geocell was 150m, total area 40.000m^2. The height of the landfill achieved 30m.

Figure 10. Biaxial geogrids provides working platform over very weak fill

Figure 11. Geocell Mattress over tailing pond

3.4 Structure over Communal Waste, Elstow, United Kingdom

A building of waste transfer station was to be built over communal waste deposit in Elstow, UK. Geocell Mattress was selected as the most appropriate foundation system, Figure 12., ensuring even settlement. Surcharging of geocell by 4m soil fill was applied as the measure to reduce total after construction settlement. Post constructions settlement was very small (60mm) and very even. Re-levelling devices which were installed under all foundation pads to be able to compensate eventual non even settlement were finally not needed.

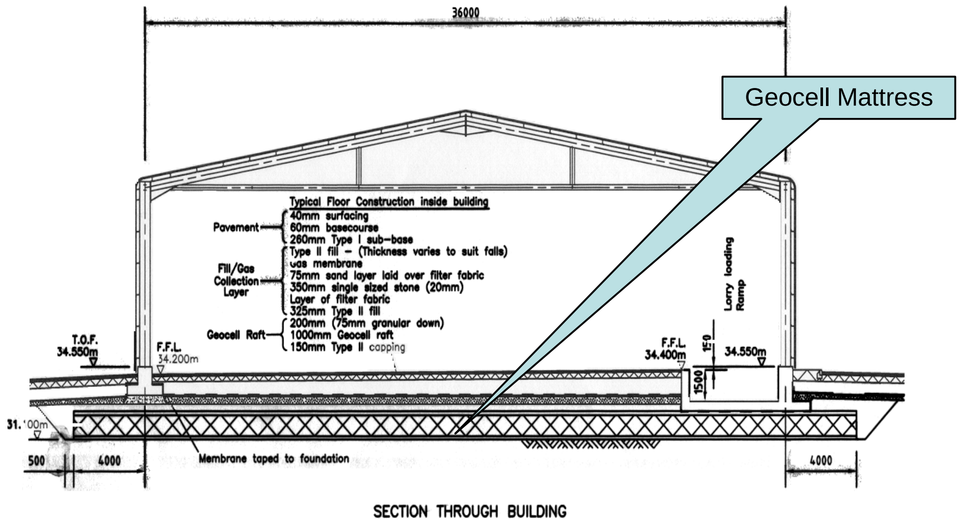

Figure 12. Geocell Mattress forms the foundation under industrial building

Figure 13. Waste transfer station in operation over Geocell Mattress foundations

4. CONCLUSIONS

The use of a Geocell Mattress at the base of an embankment over soft soil can provide a very efficient engineering solution to a difficult problem.

Some settlement will occur in this type of project; these techniques do not eliminate settlement but do enable controls to be exercised over the settlement magnitude and profile.

The economic benefits of this type of solution over other treatments such as piling or ground improvement techniques, if they are applicable, are significant and there are large cost savings to be made if the techniques are combined with sound construction activities.

The construction of a Geocell Mattress provides an additional advantage in that all the construction equipment can travel on top of the filled mattress and is not required to travel on the soft soil. It is only the site personnel constructing the cellular structure that need to pass over the soft soil and hence the existing ground surface remains as undisturbed as possible.

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