Design method for geogrid reinforcement of working platforms: recent UK experience

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ABSTRACT: Working platforms are temporary structures that provide a suitable foundation for heavy construction plant and working machines. They can be greatly improved by including high strength reinforcing geosynthetics. As stated in the new BS 8004:2015 “Code of practice for foundations”, even if temporary these structures have a critical safety role since an overturning large machine, caused by bearing capacity failure, will have very serious consequences for the safety of site personnel. Working platforms are currently designed in the UK following the BRE Report 470 “Working Platform for Tracked Plant”. This is just a guideline, which has been extensively used in the past and still is, although it is not compatible with Eurocode principles.
The BRE 470 design method leads to unnecessarily (and not cost-effective) high platform thickness and only provides guidance for a single layer of reinforcement placed at the platform/subgrade interface, while ignoring the benefit from any other reinforcing layers. The paper will describe an innovative method for designing this type of structure, and include case studies of recent actual applications in the UK.

Keywords: geogrids, piling, stabilization, design method

1 INTRODUCTION

Traditionally the design of granular working platform for heavy construction plant and working machines has not been carried out in a consistent manner across the industry. Historically, the methods have generally considered what might loosely be described as “empirical”, and have been based on previous projects of suitable materials and thickness. Furthermore, the design is frequently only derived from past experience. This has, on occasions, resulted in catastrophic failure and significant incidents.
While, current design approaches proved generally reliable, it is recognized that there is a lack of consistency on how and when they are applied, resulting in different degrees of economy (and sometimes un-economic design).
This paper is not intended to replace current guidance but the intention of the authors is simply to provide an additional support and provide a recommendation for the overall design of working platform.
This paper discusses the development in the UK of an innovative design method for temporary working platform reinforced by geosynthetics.
The described design method is not based on an empirical approach but is based on a theoretical model that is proved to be ideal and reliable for soil decks/platforms on a soft clay subgrade, characterized by the following geotechnical parameters in undrained condition: $\varphi = \varphi_u = 0$ and $c = c_u$.
The successful real experience and case studies will emphasize the effectiveness of the design approach.
Following the proposed design method a transparent calculation output could then be produced and can be readily checked by a third party.
This design method is based on applying the load on a defined rectangular area, based on the load data of construction plant to be used, rather than the different approach based on “area of applied load on the surface of the existing subgrade” and “bearing pressure on the surface of the existing subgrade” (which is supported by the empirical method). The described design method enables the calculation of the tensile forces in each of the reinforcing geogrid layers generated by:
- horizontal thrust due to self-weight of the different soil layers;
- wheel / track load of heavy vehicles;

- membrane effect at the base (or subbase) – subgrade interface.

It is then possible to determine the optimum number and the mechanical characteristics of geogrid layers required for absorbing the horizontal forces generated by the above listed mechanisms.
This approach will allow determination of the additional reinforcement required to stiffen the platform to prevent catastrophic failure.
The successful case histories presented at the end of the paper confirm by practical experience the soundness of the described design method.

2 TRADITIONAL DESIGN APPROACH

As no official standards are available, to date, for soil stabilization applications within the UK, publication of CIRIA SP123 and BRE BR470 introduced analytical design approaches for the design of both un-reinforced and geosynthetics reinforced granular working platforms. BRE BR470 issued back in 2004 is certainly the common reference for design of platforms for tracked plant and widely used.
More recently in the latest issue of BS8004 "Foundations" and BS8006 "Reinforced Soils", both SP123 and BRE BR470 have been mentioned as permitted methods for the geotechnical design of reinforced/stabilized granular working platforms.
In the new BS8004:2015 it is noted that "geosynthetics incorporated into the construction of granular working platforms might provide beneficial effects that enhance the stability of the working platform". As well, it is also noted that when a geosynthetics material is then introduced within the granular platform it will be necessary to use an alternative design method, and it is recommended that this is undertaken with the support of a geosynthetics manufacturer.

2.1 *CIRIA SP123 and BRE BR470*

CIRIA SP123 provides guidance on the use of geosynthetic reinforcement in various soil structures and applications. Considering the working platform in particular, its approach is based on classical bearing capacity methods with an allowance for lateral stresses in the platform material. The method uses partial factor with ULS checks on bearing capacity and geosynthetic reinforcement strength and SLS checks on geosynthetics reinforcement. The complexity of the calculations and the limitation in terms of angle of load spread, partial factors for geosynthetics reinforcement and the choice of a single strata sub-formation design (with no alternative offered for multi-layered subgrades), will push the designer to consider the worst case scenario and lead to unnecessarily (and uneconomically) large platform thickness.
On the other hand, the BRE BR470 is based on classical bearing capacity methods but uses the concept of punching shear capacity within the platform as suggested by the experimental model developed by Meyerhof. Instead of assuming load spread through the platform, it is assumed that punching shear resistance develops within the platform thus partially supporting the applied load and reducing bearing pressures on the formation. Checks on bearing capacity are deemed to satisfy limits on settlement. This is not a limit state method and the factors should not be viewed as partial factors. No strength factors are applied to the formation or fill but a factor of 2 is applied to geosynthetic reinforcement strength, to limit deformation under load to an acceptable amount.
Unlike the SP123 model, in the BRE BR470 geosynthetic reinforcement is not considered to provide lateral restraint. Instead it is considered to provide additional vertical restraint at the punching perimeter, which further reduces the bearing pressure on the formation. Both guidelines give instruction for single layers of reinforcement placed at the formation of working platforms and ignores the benefit from any other reinforcing layers. The BR470 method of analysis is only representative if punching type failure occurs through the platform and in the sub-grade; for most sub-grades this is not considered to be representative of the actual failure mode.
The sensitivity to input parameters, the consideration for a single strata sub-formation and the limited range for cohesive sub-grades (the calculations are only considered valid for un-drained cohesion greater than 20 kPa and less than 80 kPa) plus the considered geosynthetics reinforcement mechanism will again guide the designer to high platform thickness.
As well, in the design of working platforms the design document BR470 states in Appendix A2:
"where c_u < 20kPa the ground will be so soft that special measures will be needed to construct a working platform, and a more sophisticated type of design calculation is appropriate".

3 STATIC METHOD FOR RECTANGULAR LOADED AREA

Referring to previous research (Rodin, 1965; Bender and Barenberg, 1978; Barenberg et al., 1992), the static method which is applicable for designing working platform over soft clay soil, assumes that the bearing capacity of an unreinforced platform on a soft clay sub-grade is:

$$q_u = \pi\, c_u \qquad (1)$$

and assumes that the bearing capacity of a geosynthetics reinforced platform on a soft clay subgrade is defined as:

$$q_u = 2\,\pi\, c_u \qquad (2)$$

where c_u = undrained shear strength.
This approach is based on the distribution of vehicle track pressures throughout a geosynthetic reinforced layer. The design method ensures that the pressure at the top of subgrade is less than the allowable bearing pressure of the subgrade soil, divided by a defined Factor of Safety.
The Static Method assumes that the vertical pressures are distributed through the platform soil layer according to Boussinesq theory (Das, 1990) for uniform load on a rectangular loaded area: hence the width and length of the crawler track will be considered as loaded area, as shown in Figure 1. The Boussinesq equation provides the induced vertical stress at any point below the rectangular loaded area.

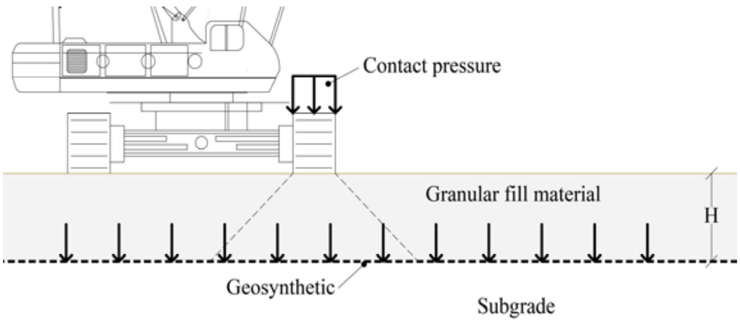

Figure 1. Static Method considers uniform load on a rectangular loaded area

An empirical relation between CBR value and the undrained shear strength can be used if subgrade CBR value is provided:

$$c_u = 30\ \text{CBR}\ \ (\text{kPa}) \qquad (3)$$

The required platform thickness (H) can be plotted versus the undrained cohesion (c_u) of the subgrade for both reinforced and unreinforced soil (Figure 2). If a geogrid is introduced into the system, the thickness of the foundation decreases dramatically.

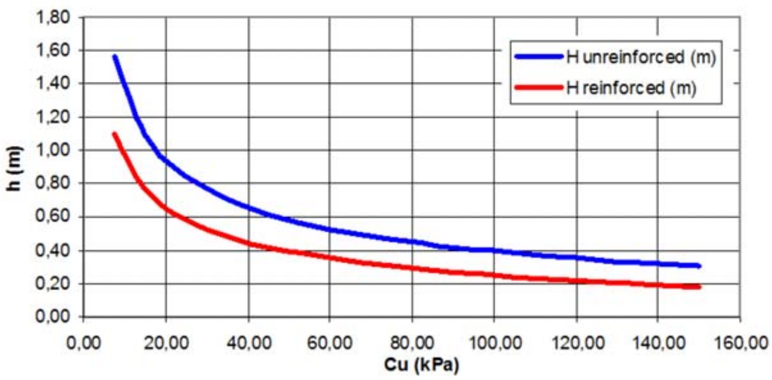

Figure 2. Typical plot of the required platform thickness (H) versus the undrained cohesion c_u of the subgrade considering a reinforced (red line) and unreinforced (blue line) platform.

More details about the method can be found in Rimoldi & Simons (2012) and Rimoldi & Grimod (2015).

4 GEOGRID DESIGN

Geosynthetics have high tensile strength, high tensile modulus and geogrids especially have great soil interlocking capacity. Large scale pull-out testing demonstrated that geogrids retain great soil interlocking capacity when the soil type changes from gravel to sand. Testing and project experience have proven that geogrids are capable of preventing localized shear failure of the soft subgrade. Geogrid prevents local movement of the material through the mechanism of interlocking the fill material in the aperture of the geogrid itself. The use of biaxial geogrids for reinforcing the soil platform results in lower aggregate thickness, faster construction, better compaction and increased capacity of load support.
It has to be noted that the horizontal stresses produced by a tracked vehicle are mainly distributed along the longitudinal and transverse axis of the tracks: hence biaxial geogrids are the optimal reinforcement in such situation, while uniaxial geogrids are not suitable, and multi-axial geogrids are less effective in matching the horizontal stresses distribution.
For a platform constructed on soft subgrade, the geogrids stiffen the aggregate, thereby enabling the layer to distribute the crawler track loads or other loads over a larger area of the subgrade. At the same time geogrids prevent local shear failure in the subgrade soil. Hence the net effect of geogrids is to change the mode of failure in the subgrade from a local bearing failure to a general bearing failure.
The Static Method assumes that the platform is reinforced with geosynthetics, but this geosynthetic reinforcement needs to be designed on the basis of sound engineering principles.
Geogrids provide the following reinforcing mechanisms:
- base course lateral restraint mechanism for horizontal stresses generated by platform soil self-weight;
- base course lateral restraint mechanism for horizontal stresses generated by crawler tracks loading;
- membrane mechanism at the deck – subgrade interface.

Each of these three mechanisms produces tensile forces in geogrid reinforcement layers.
Sound engineering principles dictate the calculate of these tensile forces and the overall tensile forces generated in each layer of geosynthetics, and then selection of the appropriate geosynthetic for each layer based on a limit state criterion.
Since the situation deals with temporary working platforms, the limit state criterion cannot be failure but rather the serviceability limit state, thus the deformations shall be limited.
In order to mobilize its tensile strength, the geosynthetic would need to strain and the deformation needed to mobilize this mechanism could exceed the serviceability requirements of the working platforms. These strain can lead to settlement depression between the contact planes. However the layered earth structure compensates for the settlement depressions in each subsequent soil layer, such that the upper surface of the earth structure is manufactured as a flat plane. The geosynthetic reinforcement retains a permanent strain which is not critical, however, to serviceability consideration; both theory and practical experience suggest that geosynthetic strain shall be limited to 5 %.
The above mentioned limit strain criterion shall be applied to the short term tensile strength of the geosynythetic, as measured in a wide width tensile test according to EN ISO 10319 standard.

4.1 *Multi-layer model*

The general scheme of the proposed design model (Korulla et Al, 2015) includes the following layers:
- asphalt course AC (the wearing course and the binder layer are considered as only one layer of thickness the total thickness of both layers.
- base course BC;
- subbase course SB;
- subgrade SG.

Therefore a 4 layers model has been developed for geosynthetics design: the general scheme of the model and all symbols that will be used for subsequent calculations are shown in Figure 3.
The model assumes that the track load is applied as a uniform vertical pressure $\sigma_{v0} = p$ on a rectangular area; this load spreads in the 3 layers of the platform structure (AC, BC and SB) according to their load spreading angles α1, α2, α3.

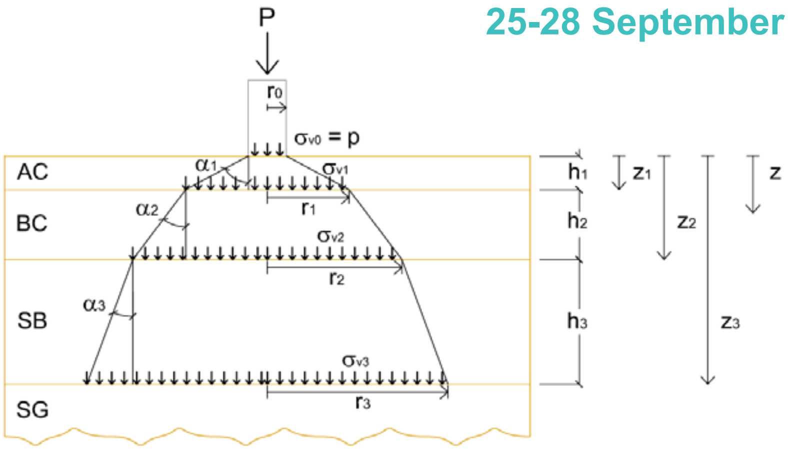

Figure 3. General scheme of the multi-layers model with different soil characteristics

In the proposed method, at least the base course shall be present and shall be reinforced with geogrids; the asphalt course may not be present (in the case of a temporary working platform or unpaved road) and, if present, it is not reinforced; the subbase course may be present or not; when it is present, it may be either reinforced with geogrids or unreinforced.

The tensile force T_{zi}, generated in the i-th geogrid layer by the horizontal thrust of the soil above it, can be easily calculated based on classic geotechnical theory (Rimoldi & Grimod, 2015).

The first geosynthetic layer, at the interface with the subgrade, is subject to the highest vertical deformations, when the first soil layer is spread and compacted, due to the settlement of the soft subgrade; the next geosynthetic layers, instead, are far less subject to vertical displacements. Hence we can reasonably assume that the first geogrid layer is subject to the tensioned membrane mechanism, therefore the first geogrid can be considered as a catenary layer, while for the next layers such mechanism is negligible (Figure 4).

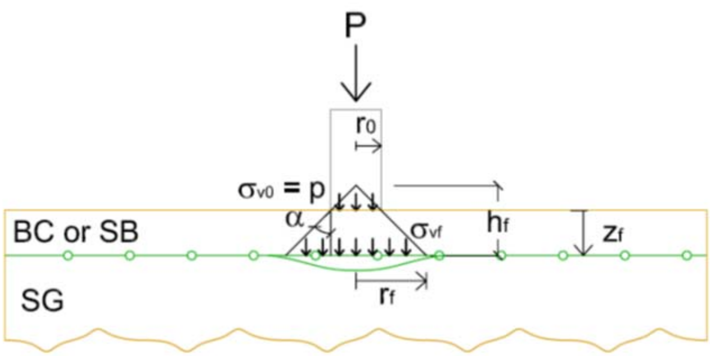

Figure 4. Scheme of the first geogrid layer

4.2 *Geogrid selection and check*

The total horizontal force that the i-th geogrid layer has to withstand is then:

$$T_{tot\text{-}i} = T_{zi} + T_{Pi} + T_m \qquad (4)$$

where:

T_{zi} = Force due to horizontal soil thrust in the i-th geogrid layer
T_{Pi} = Force due to horizontal stresses generated by wheel loading in the i-th geogrid layer
T_m = Force due to membrane mechanism at the interface with subgrade
The i-th geogrid layer shall be able to provide a tensile force equal to or larger than $T_{tot\text{-}i}$ at a maximum strain of 5 % (Rimoldi and Simons, 2013).

5 RECENT UK EXPERIENCE

5.1 *Ince Park biomass energy plant, Cheshire*

The Static Method enabled the design of one of the biggest recent applications of a temporary working platform in the UK, where 120,000 m^2 of geosynthetics reinforcement material has been laid over a very soft cohesive subgrade.

The designed £100M biomass energy plant replaces the previously bioethanol plant. The biomass energy plant would take up to 175,000 tons of fuel per annum and use the latest technology to provide enough renewable electricity to meet the average needs of approximately 37,000 households. It would also have the potential to supply hot water or steam for use in local industry or business, increasing the plant's efficiency.

The site is located at Ince (near Helsby) in Cheshire, approximately 2 km north-northeast of Junction 14 of the M56 motorway and about 2 km northwest of Helsby railway station. The site lies on Ince Marshes, which form part of the southern flood plain of the River Mersey. It is located about 500 m south of the Manchester Ship Canal, which runs from west to east along the south bank of the river.

The foundation works, worth approximately £1m with the piles structure for the power plant, were installed in January 2016. The contract required the installation of approximately 990 piles with square cross section of 350 mm sides, and 30 m average length. The piles were installed using two heavy piling rig machines simultaneously. On site also a heavy crawler crane was operating, supporting the related works.

The soils encountered in the top 8-10 m below ground level at the Ince Park site comprise alluvial clays and peat. The cone profiles clearly show an upper 'crust' of stronger material, up to approx. 1.5 m thick, which is typical of alluvial clays. The trend of the undrained strength profile below this crust is to increase linearly with depth at a rate consistent with that of a normally consolidated clay.

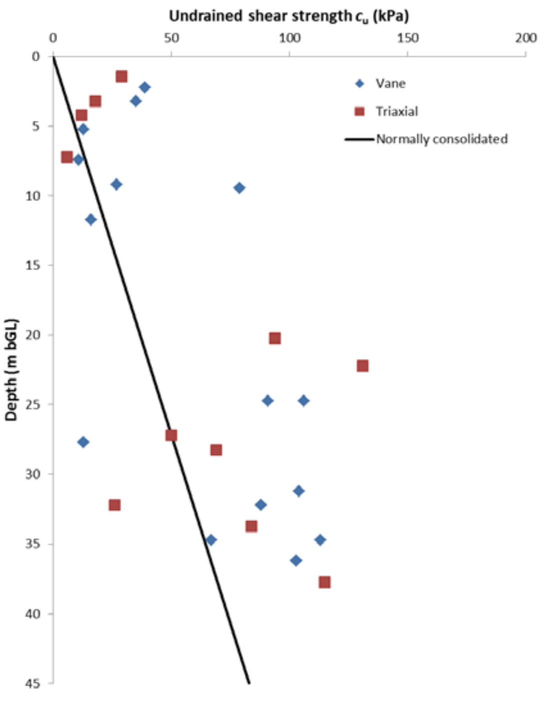

Figure 5. Derived values of undrained shear strength from the available ground investigations

Based on the evidence presented in Figure 5, assuming the alluvial clay at this site is normally consolidated, the relationship between its undrained strength and depth below ground level have been considered as:

$$c_u = 0.23\ \sigma'_v = 0.23\ (\gamma - \gamma_w)\ z = 1.84\ z \qquad (5)$$

where c_u = undrained shear strength (kPa); σ'_v = vertical effective stress (i.e. overburden pressure) in the soil; z = depth below ground level; γ = weight density of soil below the water table (from the laboratory data, assumed to be 18 kN/m^3); and γ_w = weight density of water (assumed to be 10 kN/m^3).

Any beneficial effect of the alluvial crust have been ignored, owing to the uncertain nature of the fine soil at very shallow depths.

The subgrade strata have been assumed to provide CBR = 0.25 % (c_u = 7.5kPa).

Rutting and deformations of the deck/platform can be limited by reducing the allowable bearing capacity through a proper Factor of Safety FS: a value FS = 1.5 already provides a good reduction of deformations and displacements; a value FS = 2÷3 shall be selected when allowable deformations are required to be minimal.
In this case at Ince Park a Factor of Safety = 1.5 has been considered.
Many unreinforced working platforms are constructed using a coarse free draining compacted granular soil. Commonly the material is a crushed brick and/or concrete demolition debris. When material of this type is screened to produce soil with a grading similar to that of a class 6F2 or 6F5 fill (Specification for Highway Works, Highway England), the material may reasonably be expected to have the potential to develop an angle of friction of 45˚. However, the angle of friction can be sensitive to the angularity and grading of the material, the fines content and the degree of compaction achieved. Thus the design considered a friction angle of 35° with a load spread angle of 40 degree.
For comparison purpose, an initial analysis considering a geosynthetic reinforced working platform following the BRE BR470 and the modified method to allow the consideration of subgrade shear strength of < 20kPa (K.S. Miller, 2003) has been done.
The input parameter provided by the main contractor for the piling rig machine and the typical BR470 loading case are reported in Table 1.

Loading Case 1 Travelling	Loading Case 2 Operating (Pile Driving)
Track Width = 0.88m	Track Width = 0.88m
Effective Track Length = 2.22m	Effective Track Length = 1.22m
Pressure under tracks is 145kPa	Pressure under tracks is 295kPa

Table 1. Input data provided with the typical BR470 loading cases for the equipment used on site.

The BRE BR470 output considering the use of a high strength geosynthetic reinforcement (with a strength of 130 kN/m in both MD and CM direction) overlying the very soft cohesive subgrade produced a result of 1.65 m thickness platform.
According to the information received and considering the initial BR470 result, a new design have been produced using the Static Method for the crane and piling rig machine temporary working platforms.
For the piling rig machine a maximum loading of 295 kPa has been assumed, according to the client data, with following assumed characteristics:

- track width = 0.9 m
- track length = 4.70 m (with contact track/crawler length = 4 m)

The working piling platform designed, for this case, has a thickness up to 1.20m of compacted granular material with a combination of one layer of high strength polyester woven geotextile and three layers of high tenacity polyester woven biaxial geogrids. The high strength geotextile has been chosen at the interface with the existing wet subgrade material as it is able to provide the reinforcement and the separation function together in one product.

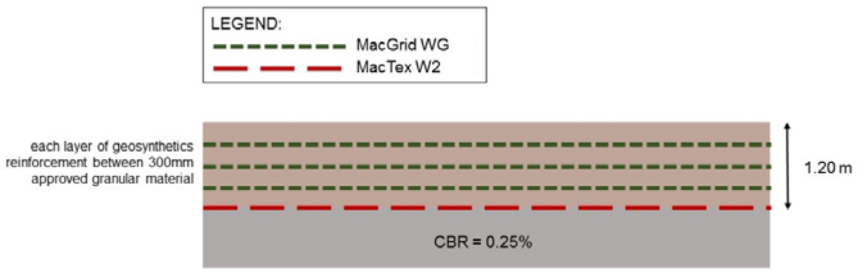

Figure 6. Working piling platform supporting the piling machine with a design thickness of 1.20m

For the heavy crane the average bearing pressure under the tracks has been quoted as around 80 kPa. For design purposes the maximum distributed loading under the tracks during its operational period on the working platform has been assumed equal to 2 times the average value. Therefore the worst case crane loading as 160 kPa acting under the 5.94 m × 0.76 m tracks has been assumed. The thickness of geosynthetics reinforced granular material required was 900mm. A similar design approach using the MacRead Studio software has been adopted also for design of the soil stabilisation of the site haul roads and compound/car park areas (with a minimum thickness granular reinforced solution of 300 mm).
Considering the footprint area of the project equal to 24,000 m^2, the output generated by the Static Method have provided a thickness platform reduction up to 30% compared to BRE BR470 results.

Figure 7. Multi-layer geosynthetics reinforced granular working platform during installation (October 2015)

Even if the procedure is more suited to pavement design where a CBR measurement is required, plate load testing have been carried out to double check the consistency of the designed working piling platform:

- nr 5 tests were carried out on top of the finished 1.20 m deep platform giving CBR values in the range 14 - 28%;
- nr 2 tests were carried out on top of the 400 mm deep platform acting as the car park, giving CBR values of 4.3 % and 11 %;
- nr 1 test was carried out on top of the first 300 mm of installed platform. This test recorded a CBR of 3.2 %.

The bearing pressure applied by the plate, which gave 1.26 mm of settlement, ranged from 57 kPa to 201 kPa. The main contractor also performed settlement monitoring on the working platform, on the areas where the heaviest traffic and loading took place (piling rig and artic wagons movement), recording only 20 mm settlement. This value has been recorded for an exceptional occasion after a heavy rain storm event, where the fines of the 6F5 material used to build up the platform rises to the top and the movement of the piling rigs on it combined with the 8-10 m of peat below.

Figure 8. Piling dig rig machines on site during operation (January 2016)

5.2 *Canning Town phase 2, London*

Forming part of the £3.7 billion Canning Town and Custom House Regeneration Programme, Hallsville Quarter is a catalyst for the transformation of the wider area, forming a new, thriving and prosperous district centre for this emerging area of East London, in the London Borough of Newham. Phase 2 provides a gateway into Canning Town's new district centre, with the beginning of the new pedestrianized high street which runs down the spine of the entire development area. Shops, cafés, restaurants and a 196-bedroom hotel animate and bring life to the space, while landmark residential towers provide 349 private rented, private for sale, and affordable shared ownership homes.

The proposed scheme includes a basement for parking beneath the majority of the Phase 2 site. The geotechnical investigation indicated the site area to be underlain by Alluvium. Given the nature, the thickness and the presence of soft alluvial clays the main scheme designer recommended that piled foundations were adopted to

support the proposed building structures. The Static Method was then considered for creating the temporary working platform using an undrained shear strength of the foundation soil c_u = 13 kPa.
The solution designed with biaxial geogrids supported the weight of the largest crane (110 tons) plus the maximum lift load, resulted in an applied pressure transmitted through the crawler track of 140 kPa. This load was applied over an area 0.80 m × 5.50 m.
The diaphragm wall has been constructed from the existing ground level. A prepared working piling platform was then designed to support this temporary works (Area 1). After the diaphragm wall had been constructed a deep excavation was undertaken and another working piling platform at the lower level was installed to allow the CFA, 33 m deep, piling operation (Area 2). After the excavation phase during July 2015, the second stage with CFA piling was completed in September 2015.

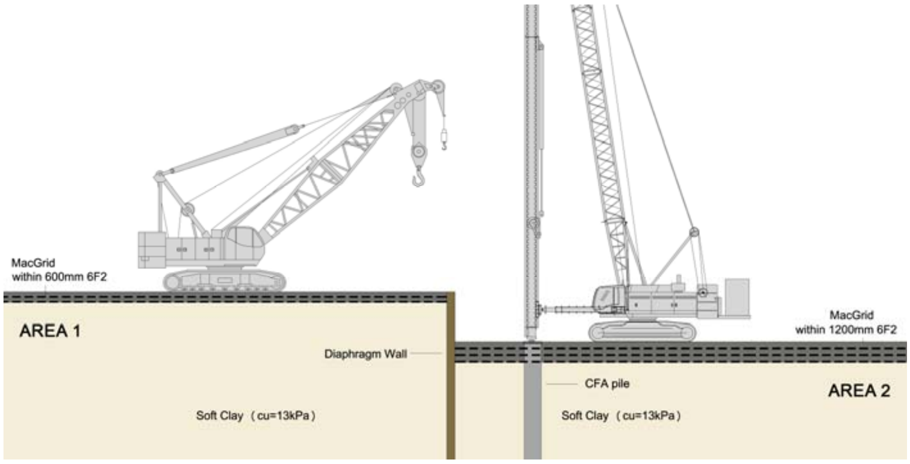

Figure 9. Indicative scheme of the two designed working platforms

6 CONCLUSION

Both CIRIA SP123 and BRE BR470 methods do not fully cover the design of working platform consisting of several layers of geosythetics reinforcement overlying a very soft cohesive subgrade and the limitation of those guideline are explained in the present paper.
The proposed design method is developed on the theory of static load distribution in unreinforced and reinforced cohesive soil, while the multi-layer geogrid design is based on a specific load distribution model which allowed the working strain level and tensile forces in reinforcement to be calculated and compared with set design values.
Since 2015, when the Static Method was introduced in the UK, several designs and projects has been developed proving the consistency of the theoretical method.
It is worth mentioning that the proposed method has been used worldwide and checked by third parties as the transparency of the output result. The reduction in thickness achievable by the described design methodology make quite clear the financial and the considerable environmental saving provided.
Economic savings in imported granular fill and subgrade undercut and disposal can be very significant. The relative ease of construction afforded by using geosynthetics reinforcement can speed up the construction of the soil platform, thus reducing the installation time.

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