Working platforms for tracked plant – BR 470 guideline and a revised approach to stabilisation design with multiaxial hexagonal geogrids

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ABSTRACT: Working platforms are likely to be an important part of many projects to support cranes or piling rigs. The BR 470 good practice guide for working platforms for tracked plant has the aim of providing guidance for the design, construction, operation and maintenance of working platforms. The guide includes a method of calculating bearing capacity based on a punching shear mechanism, with provision for including the strengthening effect of geosynthetics. By way of developing these techniques further, finite element analysis (FEA) was applied to examine in detail the mechanical behaviour of working platforms. Mechanisms were identified which were confirmed by physical testing and it was found that all were enhanced by the inclusion of geogrid resulting in mechanical stabilisation of the granular layer and much improved bearing capacity. A parametric study by FEA identified a simple linear relationship, validated by physical testing, between bearing capacity and geometry which could be used in routine design calculations for granular layers with and without geogrid.

1 INTRODUCTION

Many construction projects invariably require working platforms for cranes or piling rigs over soft subgrades. Platforms of this type are generally considered to be temporary works, often with little or no investigation and design to ensure safe operating conditions for the heavy plant which will be supported. Inadequate design of such working platforms can result in poor working conditions, such that frequent refilling or re-grading may be required with associated delays. In severe cases heavy plant, especially tracked cranes, may become unstable resulting in collapse or over-turning, as shown in Figure 1. These accidents frequently result in injuries or fatalities, such that they become health and safety issues, and lengthy investigations may result, including detailed scrutiny of soil data, loadings and the design method used to dimension the working platform. In order to provide a more formal approach to designing working platforms, the Building Research Establishment (BRE) in United Kingdom published a good practice guide “Working platforms for tracked plant” referred to here by its reference, BR 470 (BRE, 2004).

Figure 1. Bearing failure beneath heavy tracked crane [Source: http://www.heavyliftnews.com/accidents/tragic-crane-accident-vungtau-vietnam]

This paper provides a detailed outline of BR 470, including derivation of the bearing capacity calculation as well as the method for adding the strengthening effect of a geosynthetic, which relies solely on its tensile strength. A BRE supplement to BR 470 entitled “Use of structural geosynthetic reinforcement” (BRE, 2011) provides an avenue to develop alternative approaches for the design of working platforms, which is the main aim of this paper.

Finite element analysis (FEA) has been applied to examine the behaviour of working platforms. Alternative mechanisms have been identified which may be enhanced by the inclusion of multiaxial hexagonal geogrids which have been demonstrated as creating true mechanical stabilisation of the granular layer and much improved bearing capacity at small deformations. A parametric study by FEA identified a simple, linear relationship, validated by physical testing, between bearing capacity and geometry which could be used in routine design calculations for granular layers with and without multiaxial hexagonal geogrid.

2 THE AUSTRALIAN CONTEXT

In Australia, mobile crane operation is defined as a "high risk activity" (Safe Work Australia, 2015) whereas operation of a piling rig is not, even after intense lobbying by the piling industry. Therefore, the attitude of the piling industry towards safety has been proactive and the Piling and Foundation Specialists Federation have developed initiatives towards the safe design, operation and maintenance of working platforms to reduce the potential for serious incidents.

In terms of working platform safety, the attitude of the Australian piling industry is not unlike that of their UK counterparts where one-third of accidents in the industry arise from defective working platforms (PFSF, 2018). With deeper foundations becoming a more common requirement, modern piling equipment has become heavier with a higher centre of gravity creating new challenges for the safe design, operation and maintenance of working platforms.

Working platforms are classified under Temporary Works and could potentially be used by other trades during and after piling or crane operations. Therefore, the responsibility for the design, construction, maintenance and repair of a working platform is typically the party having continuous control over all the project activities, namely the Principal Contractor, not solely the piling or crane contractor. The introduction of a Working Platform Certificate (WPC) has been effective in the UK to reduce the rate of safety incidents related to working platforms. The WPC has also recently been adopted in Australia to increase awareness of working platform safety and highlight the importance of maintenance of the platform during the contract. The WPC is signed by the Principal Contractor to confirm that the working platform has been appropriately designed, built in accordance with the design and will be adequately maintained to retain the integrity of the platform. It is then handed to the piling contractor before the start of any site work.

Worksafe Victoria (2014) provides a guideline on managing safety for foundation works including the design, set-up and operation of piling and foundation working platforms. This guideline states that a competent person (a geotechnical engineer) must design the working platform and assess any changes to the operation of the platform such as substitution of piling equipment or reinstatement of excavations.

Look & Honeyfield (2016) describe the case study of a working platform at the Port of Brisbane, in which the BR 470 method is taken as a reference, although other methods of calculation are also used. They note that the BR 470 method provides a working platform thicker than commonly used successfully in Australian practice, but also note that the BR 470 approach is the nearest to a "standard" procedure and cannot therefore be disregarded. It is also the experience of the Authors of this paper that the guidance in BR 470 is being used in Australian practice.

3 OUTLINE OF THE BR470 METHOD

3.1 *Basic approach*

The Building Research Establishment (BRE) in UK published a good practice guide to the design, installation, maintenance and repair of ground-supported working platforms for tracked plant in 2004, with report reference "BR 470", a term commonly used to refer to this guide, also used in this paper. The development of this guide was initiated by the UK Federation of Piling Specialists (FPS) to improve practices related to the use of piling and associated specialist plant, and promote the implementation of minimum design, maintenance and repair standards. The UK Health and Safety Executive (HSE) worked closely with FPS with the aim of supporting the principle of reducing accidents by the use of properly designed, prepared and maintained working platforms. Importantly the guidance provided had the aim of not being over-prescriptive which might limit the scope for innovation and the development of cost-effective solutions, however the principal objective remained to promote safety.

The design of working platforms for tracked plant is a geotechnical design process and should be carried out by a competent person. Appropriate and sufficient ground investigation is vital to ensure the provision of an adequate working platform, which should include adequate characterisation of near-surface materials and their strength. Where a weak subgrade is particularly soft or loose, some form of stabilisation or ground treatment may be considered to improve the properties of the ground.

On some sites where particularly difficult conditions are encountered, a more sophisticated approach is warranted. This may involve the use of other design methods or more sophisticated techniques such as finite element analysis (FEA).

In some situations, it may be economical to incorporate geosynthetics to strengthen the working platform as an alternative to using a greater platform thickness. Geosynthetics are generally placed between the granular material of the working platform and the subgrade, or within the platform towards its base. Geofabrics are normally used to separate a granular platform from a cohesive subgrade and to act as a filter. Geogrids are normally used to strengthen the platform. It is important to distinguish between these two functions of geosynthetics. Owing to the ductile nature of polymeric reinforcement, ultimate tensile capacity may occur at very high strain beyond the serviceability requirements of the reinforced platform. Tensile strength adopted for design should be appropriate to the required performance, and it may be necessary to specify strength at a specific strain or apply a general reduction factor to the ultimate strength where this occurs at high strains. The likelihood of damage to geogrids during installation should be taken into account and an adequate thickness of platform material placed over the top. Consideration should be given to a filter fabric layer to minimise the upward migration of fines into the platform material.

Radically simplified stress distributions are recommended for use in design calculations. Input is required in terms of loaded areas and maximum ground pressure, with appreciation of likely variability. The full range of load distributions and lifting arrangements should be considered. Non-uniform load distributions can be transformed into equivalent uniform loads over a reduced area, for example a trapezoidal distribution may be modelled as a uniform distribution using the method of Meyerhof (1953). Special consideration should be given to the pressures from loads imposed by outrigger pads and skid mounted rigs. Design for wheeled plant is not covered.

Two load cases are considered, and several loading conditions and combinations should be examined to establish the most adverse situation for each case.

Load case 1: operator unlikely to be able to aid recovery from an imminent failure: standing, travelling and handling (in crane mode, lifting piles, etc).

Load case 2: operator can control the load safely by releasing load or reducing power to aid recovery from a platform failure (installing or extracting casing or augur, travelling with a fixed mast).

The installation method used should ensure that material strengths used in design are achieved, which should be part of the specification. Plate tests may be used to verify the adequacy of a working platform, but the size of the plate should be as close as possible the same as the size of the plant being used.

Various aspects of working platforms are identified as needing further research. These include failure mechanisms and design methods for multi-layer systems in 3-D, stabilised subgrades, performance of granular materials at low stress and a database of both successful and unsuccessful platform types and designs.

3.2 *The basic design approach*

Appendix A of BR 470 outlines a simple method of carrying out design calculations which is appropriate for many routine cases, based on a method developed by Meyerhof (1974) for a footing punching through a strong platform material into a weak underlying subgrade. The method is a major simplification and is semi-empirical in nature. In this section the method is described for the case of cohesive subgrades where strength is characterised by the undrained shear strength. The method is considered suitable for the case where the working platform is relatively thin, and the bearing resistance is then calculated as the sum of the shear required to punch through the platform on a vertical plane combined with the bearing capacity of the subgrade. This approach is considered to be conservative and is outlined in Figure 2.

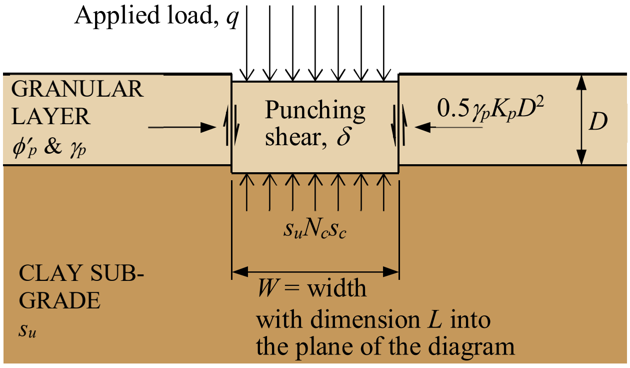

Figure 2. Punching shear calculation method in BR470

It is helpful to appreciate the background to the formula for bearing resistance (R) given in BR 470. R is given in units of stress and has two components, called R_s and R_p in this paper. The component from the clay subgrade is $R_s = s_u N_c s_c$ as shown in Figure 2 (where N_c is the bearing capacity factor given by $2 + \pi$ and s_c is the shape factor).

The component from the punching shear is not so immediately obvious. It is assumed that passive pressure is created along the sides of the prism of platform material as it is pushed downwards. To create passive pressure implies significant outward deformation, presumably created by dilation as the punch boundary shears. This would require a well compacted working platform. The force per unit length around the punch is given by $0.5\gamma_p K_p D^2 \times \tan\delta$, where $\delta = 2\phi'_p/3$. If this force is summed around the perimeter of the punch and then divided by the area of the applied load, this expression is derived for R_p.

$$\begin{aligned} R_p &= \frac{0.5\gamma_p K_p D^2 \tan\delta (W+L)\times 2}{WL} \\ &= \frac{\gamma_p K_p D^2 \tan\delta}{W}\left[1+\frac{W}{L}\right] = \frac{\gamma_p K_p D^2 \tan\delta \times s_p}{W} \end{aligned} \tag{1}$$

This is the equation found in Appendix A1 for the component of resistance from the punch, where s_p is the shape factor, given by $(1 + W/L)$.

However, there are limitations on the applicability of the method outlined in Appendix A. The working platform should be appreciably stronger than the subgrade, but the subgrade should be neither excessively soft with a lower limit of $s_u > 20$ kPa, nor excessively stiff with an upper limit of $s_u < 80$ kPa. Punching shear may not be applicable for very thick working platforms (where thickness/loaded width $D/W > 1.5$), so the bearing capacity of the platform itself should be checked too. Very thin platforms will have negligible benefit, so that minimum thickness should be the lesser of $0.5W$ (for light plant only) or 300mm.

The load factors, which are effectively factors of safety, required by BR 470 are given in Table 1 for the two load cases mentioned previously.

Table 1. Values of load factor required by BR470

Loading condition	Platform required	
	No	Yes
Case 1	2.0	1.6
Case 2	1.5	1.2

3.3 *Adding geosynthetics to the basic approach*

Appendix A1 includes a sub-section which gives the method of calculation for adding the resistance from structural geosynthetic reinforcement. The design strength of the reinforcement should be evaluated by applying a minimum factor of 2.0 to the tensile strength, such that $T_d = T_{ult}/2$. It is proposed that the contribution of the reinforcement to the total bearing resistance is calculated in a simplified way based on the punching failure mechanism.

The contribution to the total resistance of the punch mechanism from the strength of the geosynthetic reinforcement is denoted in this paper as R_g, and given as $R_g = 2T_d/W$ in Appendix A1 of BR 470. There is no explanation of the derivation of this resistance, but the most likely explanation is as follows.

On installation, the geosynthetic is laid horizontally, in which case it has no vertical component of resistance to the applied vertical load. Footnote 19 in Appendix A1.1 of BR 470 refers to publications on this topic, which in general invoke the tensioned membrane mechanism in order to provide vertical resistance from horizontally laid geosynthetic reinforcement under granular pavements. Based on this, it seems most likely that the assumption used is that the plane of the geosynthetic is deformed where the punch enters the clay subgrade, as depicted in Figure 3. In this arrangement, there is a short length of geosynthetic in the vertical direction, with unit resistance given by T_d. If this resistance is summed around the punch perimeter and then divided by the punch area, the following expression is derived:

$$R_g = \frac{T_d(W+L)\times 2}{WL} = \frac{2T_d}{W}\left[1+\frac{W}{L}\right] = \frac{2T_d s_p}{W} \qquad (2)$$

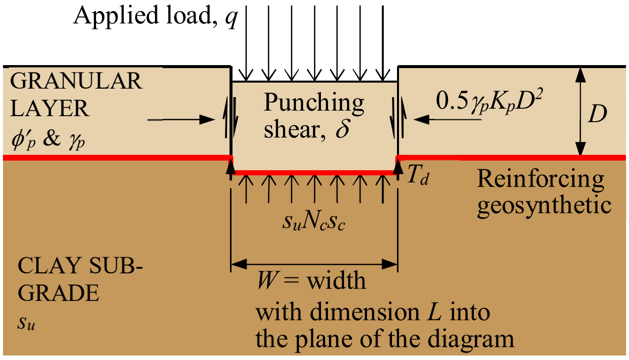

Figure 3. Punching shear calculation adding geosynthetic

It appears that either the shape factor (s_p) is ignored or, alternatively, the geosynthetic resistance is only taken into account along the long sides of the punch. Whichever is the case, there might be concerns about the nature of this mechanism, in particular about the magnitude of deformation necessary to create it, which is likely to be considerable. If the punch has moved downwards by a considerable distance, then it is questionable if it is still appropriate to use peak shear strength in the calculation of R_p which relies on the frictional strength of the platform fill

3.4 *A review seven years on*

BRE published a brief supplementary document in 2011, entitled "Use of structural geosynthetic reinforcement" (BRE, 2011) and described as "a review seven years on". Importantly this document acknowledges that BR 470 can embrace alternative approaches for the design of mechanically stabilised working platforms, provided that the objective of safety is preserved, and that the approaches are based on credible and representative research. This research should be interpreted and formulated according to the geotechnical discipline and validated by well documented case studies.

The next two sections of this paper describe such a method, based on alternative mechanisms compared to those depicted in Figures 2 and 3. The contribution of a structural geosynthetic is a result of confinement of the aggregate particles of the working platform resulting in mechanical stabilisation of the layer.

4 MECHANICAL STABILISATION

BR 470 describes a structural geosynthetic as "reinforcement", and its contribution to resistance is its tensile strength. The mechanism and resulting design method described in the following section of this paper take into account the contribution of the geosynthetic, in this case a stiff multiaxial hexagonal geogrid as shown in Figure 4, by "mechanical stabilisation". This is an important distinction, which has only been fully understood and established in the last 10 years or so. The principal difference between the two mechanisms can be described as follows. In the case of reinforcement, relatively high strains and, therefore, high loads are created in the geosynthetic, a situation which is very clear in reinforced soil structures such as retaining walls. In pavements the reinforcement function is required when the geosynthetic acts as a tensioned membrane, in which case it must be anchored beyond the edges of the wheel-path, and a large deformation created by way of a deep rut or surface depression, so that the upward component of the force generated in the deformed geosynthetic helps to support the load. As clarified by Giroud (2018), the tensioned membrane effect is relatively small, and can only be applied in cases of channelised traffic on unsurfaced roads, where large surface rutting may be acceptable.

Definitions of mechanical stabilisation by geosynthetics have been established, for example in EOTA Report TR 41 (European Organisation for Technical Approvals, 2012) stabilisation has this rather long definition: "the beneficial consequence on the serviceability of an unbound granular layer via the inhibition of the movement of the particles of that layer under applied load. This is the result of the mechanical effect of confinement on an aggregate layer, resulting from the mechanism of interlock provided by a stiff geogrid structure. The function of stabilisation is provided by the interlocking of the aggregate with the geogrid and subsequent confinement of the particles". Stabilisation has also been defined by ISO (International Standards Organisation) in the draft update of ISO 10318, as well as by IGS (International Geosynthetics Society) who have now added "stabilisation" to the list of functions of geosynthetics.

Figure 4. Interlocking mechanism of stiff geogrid providing lateral confinement and mechanical stabilisation

5 T-VALUE DESIGN METHOD

Granular layers can be placed and compacted over low strength soils to improve their bearing capacity for tracked plant. The installation of geogrid at the base and sometimes within the granular layer improves bearing capacity, allowing thinner granular layers to be installed bringing cost and time savings in construction. Existing bearing capacity calculation methods often incorporate the geogrid benefit in terms of a tensile strength obtained from testing geogrid specimens "in air" but this is not suited to multi-axial hexagonal geogrid whose primary function is mechanical stabilisation rather than reinforcement. Until recently, the performance of granular layers stabilised by such geogrid was characterised as a load spread angle obtained from physical testing either by direct measurement of stress distribution on the subgrade surface or by back-calculation from measured bearing capacity obtained from field testing.

Lees (2017a) developed a new method to characterise stabilisation by testing the shear strength of stabilised granular materials as one composite material in a large triaxial compression test. The failure envelopes of stabilised aggregates were incorporated into constitutive models used to simulate the material in finite element analyses (FEA). FEA was then used to predict the bearing capacity of a range of geometries and clay subgrade shear strengths, validated by the results of full-scale and centrifuge model testing. An approximately linear relationship (Equation 3) was identified between dimensionless bearing capacity (q_u/q_s) and geometrical (H/B) ratios (where q_u and q_s are the bearing capacity of the layered system and subgrade alone respectively, H is the granular layer thickness and B is the foundation width). The slope of the linear relationship was called the load transfer efficiency T which can be determined by full-scale testing and parametric study by numerical analysis (e.g. FEA). It was found to vary exponentially with subgrade shear strength in a similar way to that described by Ballard et al (2011) in a parametric study using discrete layer optimisation techniques.

$$\frac{q_u}{q_s} = 1 + T\frac{H}{B} \tag{3}$$

Back-analysis of a number of instrumented plate load tests on granular layers overlying soft subgrades (Lees, 2017b) showed that geogrid stabilisation increases the load transfer efficiency T of granular layers by several mechanisms, as shown in Figure 5.

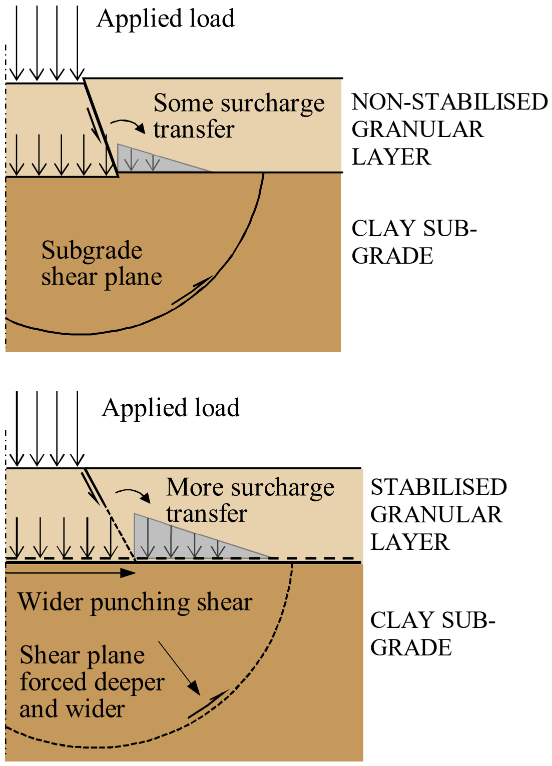

Figure 5. Mechanisms of bearing capacity improvement brought by geogrid-stabilisation

The enhanced strength of the stabilised granular layer results in punching shear occurring at a higher surface load and at a greater angle, which improves load spread to the subgrade and forces the bearing capacity mechanism deeper and wider, thereby further enhancing overall bearing capacity. Additionally, more of the applied load is transferred beyond the punching shear mechanism to a region where it counter-balances the subgrade bearing capacity mechanism, allowing larger load to be applied at the surface.

A parametric study in FEA including the range of parameters encountered in practical working platform applications was used to derive relationships between T and s_u for a range of granular layer types, with and without geogrid products, validated by full-scale testing to bearing capacity failure. An example of a full-scale loading test on a working platform built in Laem Chabang, Thailand, is described by Dobie et al (2018), and the resulting data point is included in Figure 6 as "load test" compared to the design curves for the "*Geogrid A*" used, providing further validation.

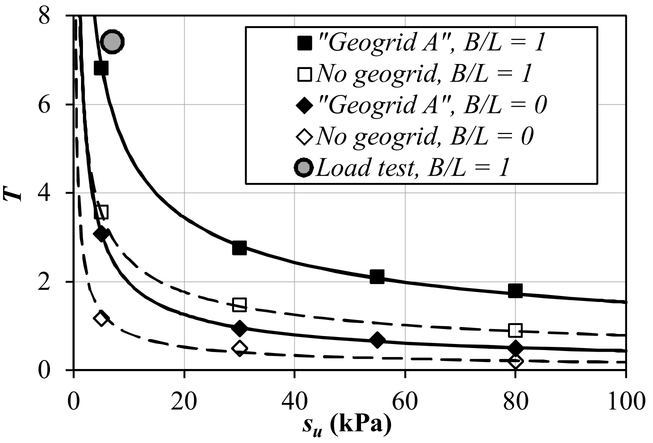

Figure 6. Surcharge transfer design method including data from Laem Chabang case study

6 CONCLUSIONS

A detailed description of the BR 470 guideline includes an outline of the mechanisms used to develop the design equations, as well as the limitations of the method in terms of dimensions and subgrade strength. The technique used to add the resistance from a reinforcing geosynthetic appears to require the assumption of tensioned membrane, implying that significant deformation of the platform would be required.

A supplement to BR 470 (BRE, 2011) acknowledges that alternative approaches for the design of mechanically stabilised working platforms may be used, provided that the objective of safety is preserved, and that the approaches are based on credible and representative research. This research should be formulated according to the geotechnical discipline and validated by well documented case studies.

The T-Value method described above provides a new approach to designing working platforms, based on a punching mechanism in a form which is close to observed behaviour and meeting all the aims of the BR 470 supplement. The geogrids used confine aggregate particles sufficiently effectively to create mechanical stabilisation of the working platform. Fundamental behaviour has been established from failure envelopes measured in large triaxial tests, without and with stabilisation geogrids, permitting the development of constitutive models used to simulate the aggregate/geogrid composite in FEA. The stabilisation geogrids provide enhanced performance of the working platform with small surface deformation.

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