Case study: performance of a geogrid stabilised working platform constructed over extremely soft dredged silt

Michael Dobie
Tensar International Limited, Indonesia

Andrew Lees
Tensar International Limited, Cyprus

Jiraphan Khanardnid
CUEL Limited, Thailand

ABSTRACT: This case study describes the construction of a working platform forming part of a fabrication yard for offshore equipment in Laem Chabang, Thailand. Subsoil was extremely soft dredged silt, and loadings were high, coming from heavy cranes and the equipment being fabricated. The working platform was required to provide adequate performance for many years. Various solutions were investigated, including the use of geosynthetic materials, and the final design consisted of a granular layer stabilised with two layers of geogrid. To verify the design, a load test was carried out using concrete slabs, which were arranged to apply 115t over a 2m x 2m area, thereby applying almost 300 kPa contact pressure. The test confirmed that this load could be supported by the working platform with minimal settlement, and the observed behaviour also demonstrated how the geogrid stabilised granular layer was acting as a strengthened mattress, thereby sustaining greater load spread over a large area at the surface of the underlying silt. This type of behaviour from geogrid stabilised layers is generally difficult to quantify, going far beyond simple load spread or membrane techniques. The complex interactions were simulated by finite element analysis to derive a new "surcharge transfer" design method for working platforms. This case study was back-analysed using the new design method for which a good match was obtained considering the site conditions, thereby providing valuable validation of the new design method. Importantly, this working platform has been providing the required performance for more than 10 years since construction.

Keywords: working platform, soft subsoil, load test, design

1 INTRODUCTION

Working platforms are an essential element of many construction projects, especially where heavy plant must be operated over soft subsoils. Such pavements are generally considered to be temporary works, often with little or no investigation and design to ensure safe operating conditions for the heavy plant involved. Inadequate design of such working platforms can result in very poor working conditions, such that frequent re-filling or re-grading may be required with associated down-time and delays. In severe cases heavy plant, especially tracked cranes, may become unstable resulting in collapse or overturning, and many pictures of such accidents may be found. In severe cases these accidents result in injuries or fatalities, such that they become health and safety issues, and inevitably lengthy investigations result, which are likely to include detailed scrutiny of soil data, loading 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" more than 10 years ago, generally referred to by its report reference, BR470 (Building Research Establishment, 2004). A detailed discussion of BR470 is beyond the scope of this paper, but it does also provide for the inclusion of the benefits of geosynthetics in working platform design and construction, which is the main theme of this paper.

Although working platforms are often built for very short term use, for example to provide access to install piles or vertical drains, they can also be used for much longer term purposes. One common longer term use of working platforms is for the construction of fabrication yards, in particular for the fabrication of offshore equipment. Inevitably such developments will be close to the sea in order to provide suitable access to deploy the equipment being fabricated, in which case poor ground conditions may frequently be expected and loads from both the cranes being used and from the fabricated units are likely to be high.

This paper outlines some early experience of using geogrids in a heavy duty working platform, together with an important discussion concerning the definitions of stabilisation and reinforcement. The design and performance of a working platform built more recently at Laem Chabang in Thailand was verified by carrying out a large-scale loading test. This test provides an opportunity to make a comparison with a "surcharge transfer" design method for working platforms developed recently by the second author.

2 WORKING PLATFORMS AND MECHANICAL STABILISATION

A good example of a working platform built as part of a fabrication yard is described by Yong et al (1990), built at Pasir Gudang, Malaysia in 1987. This working platform was 1m thick, and used two layers of a stabilisation geogrid to provide an enhanced performance under the expected loadings. The performance was investigated by carrying out trafficking trials using a heavy crane. Several years after the initial construction, the fabrication yard was extended, and a further trafficking trial was carried out to examine the performance of the geogrid stabilised working platform, and compare this performance with a similar profile reinforced with a woven geotextile. The details of this testing are reported by Ong & Dobie (2013), and the cross-section through the trial section is shown in Figure 1.

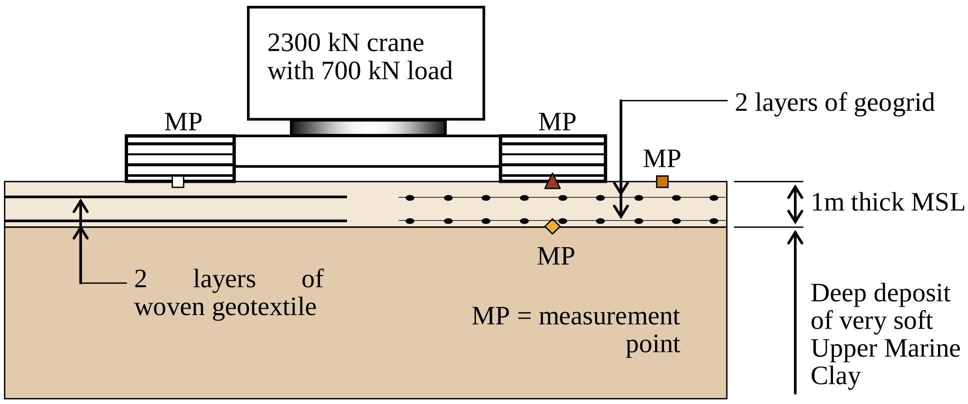
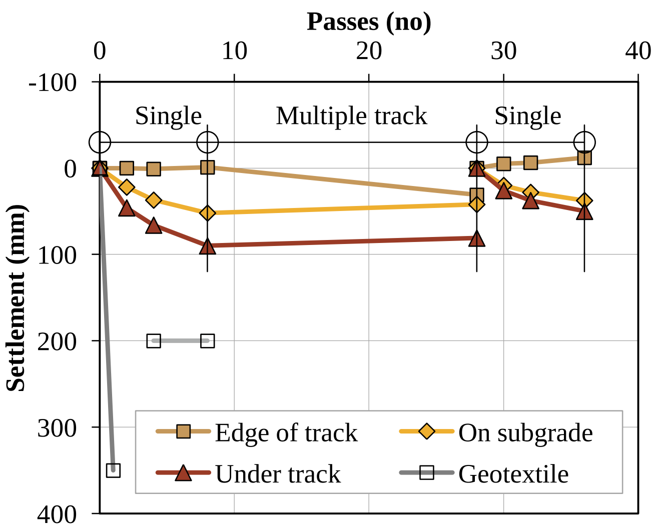


Figure 1. Cross-section of trial carried out on the Pasir Gudang working platform (after Ong & Dobie, 2012)

The results from the trafficking trial, carried out using a heavily loaded crawler crane, as indicated in Figure 1, are shown in Figure 2. The difference in performance between the geogrid stabilised section and the geotextile reinforced section is very clear to see, and on the basis of this result, the geogrid stabilised arrangement was adopted for construction of the extension to the fabrication yard at Pasir Gudang.



Trial procedure with geogrid
(1) 8 passes along single track
(2) 20 passes along multiple track
(3) Refill ruts
(4) 8 more passes along single track
(5) Measuring settlement at three measurement points (MP) as shown on Figure 3

Trial procedure with geotextile
(1) First pass gives 350mm rut
(2) Rut filled, then further passes quickly result in 200mm rut

Figure 2. Settlement versus number of passes from the second crane trafficking trial (after Ong & Dobie, 2012)

An important distinction is made in the description of the Pasir Gudang trial above, namely that the geogrid provided the function of "stabilisation", whereas the geotextile acted as "reinforcement". This is an important distinction, which has only been fully understood and established in the last 10 years or so. In fact the title of the Yong et al paper is "Reinforced soil working platform for offshore jacket fabrication yard", however the function of the geogrid was stabilisation, a distinction not appreciated in 1990. 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 (2006), 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.

Stabilisation, or mechanical stabilisation (in order to distinguish it from lime or cement stabilisation), takes place when aggregate or soil particles interlock with the apertures of a stiff geogrid, resulting in confinement of the particles, as shown in Figure 3. This combination of geogrid and aggregate may be considered as a composite. If a geogrid is able to develop this interaction effectively, then significant benefits will result in terms of the mechanical performance of the composite layer, and these benefits will be seen as very small surface deformation, implying very small deformation of the geogrid itself. Although sophisticated discrete element modelling of mechanically stabilised layers has been carried out to investigate this behaviour (for example, see Jas et al, 2015), the vast majority of data which demonstrate the mechanical stabilisation benefit and confirm its magnitude are full-scale tests, both cyclic plate-loading tests and trafficking trials, of a similar nature to the information shown in Figure 2.

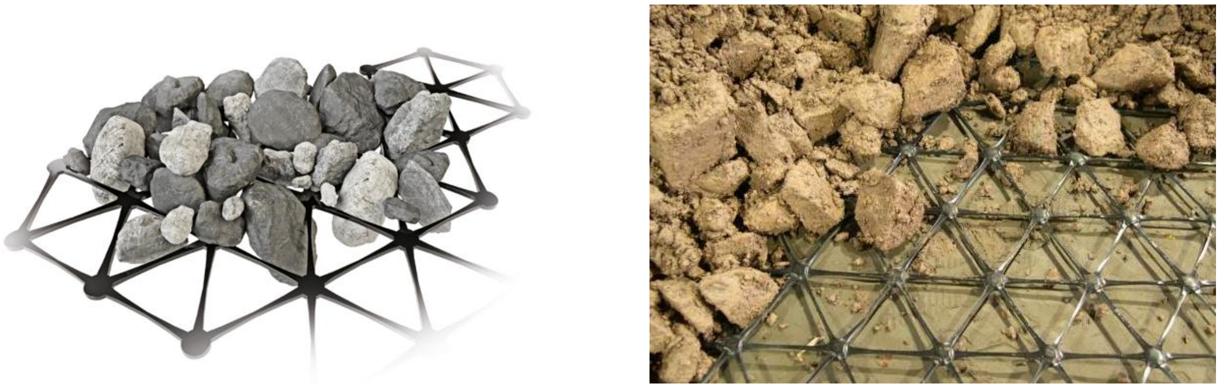


Figure 3. Interlocking mechanism of stiff geogrid providing lateral confinement and stabilisation

Definitions of 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), as well as more recently by IGS (International Geosynthetics Society) who have now included "stabilisation" as a specific geosynthetic function.

A further simple performance based definition is that effective mechanical stabilisation of an aggregate layer results in retention of the thickness and geometry of that layer throughout the life of the pavement. This is particularly important when considering the alternative tensioned membrane mechanism, which relies on reinforcement. Giroud (2006) also made the important point that the tensioned membrane is not applicable to unpaved areas, because the traffic is not channelised. Working platforms are trafficked areas, therefore the only mechanism relevant to the use of geosynthetics in this situation is stabilisation.

3 WORKING PLATFORM BUILT AT LAEM CHABANG

An offshore equipment fabrication yard in Laem Chabang, Thailand, required extension in 2007 in order to increase capacity. The available area had been used to dump silt dredged from the adjacent wharf-front during operations to maintain adequate water depth. The dredged silt was of an extremely soft consistency, which can be seen in the left-hand photo in Figure 4. Various techniques were considered in order to create a working platform over the dredged silt, including the use of geotextiles. An alternative method was proposed using stabilisation geogrids, based on previous experience of successful installations, such as at Pasir Gudang described in the previous section. Due to the high loads expected, both from cranes and the offshore equipment being fabricated, a relatively thick working platform was suggested, including two layers of a stabilisation geogrid. Being a fabrication yard, the expected working life of the platform would most likely be many years, as outlined briefly in the introduction,

As part of the procedure for verifying the proposed design, a simple load test was carried out using large concrete slabs which were readily available on the site as aids to fabrication. A view of the final load test arrangement on reaching maximum load is shown in the right-hand photo in Figure 4. It can be seen that the load is applied by three small concrete slabs and five large slabs. The details of this final test arrangement are given in Figure 5, together with approximate dimensions and layer thicknesses. The final load resulted in a mean pressure of almost 300 kPa over the 4 m^2 area of the lowest slab causing a major crack (see Figure 4 right) to develop around the perimeter of the stabilised area.

Figure 4. Laem Chabang fabrication yard: initial ground conditions (left) and final load test arrangement (right)

Based on the results of the loading test, it was decided to use the pavement construction method indicated in the lower part of Figure 5, including two layers of stabilisation geogrid, over all locations where the silt was present, with a total area of about 50,000 m^2. This construction was carried out in 2007, and the working platform is still providing adequate service at the current date, around 10 years later. During its working life the platform has supported a wide range of heavy loads, from large crawler and other cranes to the items of equipment being pre-fabricated.

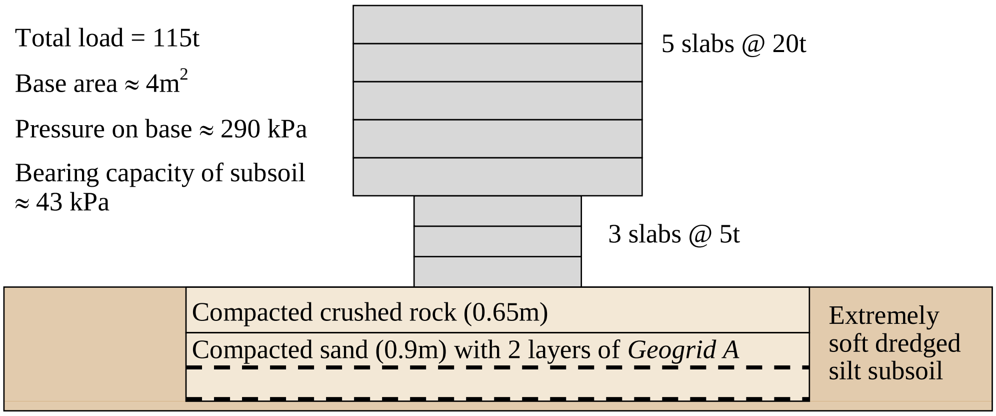


Figure 5. Details of the mechanically stabilised working platform at Laem Chabang and load test arrangement

4 SURCHARGE TRANSFER DESIGN METHOD

4.1 *Background*

Calculation of the bearing capacity of a granular layer overlying a soft soil arises often in the design of foundations and unpaved roads as well as working platforms. Different methods exist, perhaps the most commonly used being the semi-empirical Hannah and Meyerhof (1980) method and the load spread method, as summarized by Craig and Chua (1990). The drawbacks of these methods include the difficulty of determining key parameters defining the complex interaction between the layers and including the effects of stabilisation of the granular layer. Many studies (e.g. Adams & Collin, 1997; Yetimoglu et al, 1994; Das et al, 1994) have shown the significantly improved bearing capacity brought by geogrid stabilisation, yet no reliable, simple method of its calculation has been available.

Lees (2017a) addressed this need by identifying an approximately linear relationship 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. It was found to vary exponentially with subgrade shear strength as shown for the centrifuge test data (Okamura et al, 1998) for strip and circular surface footings on a sand layer overlying clay in Figure 6.

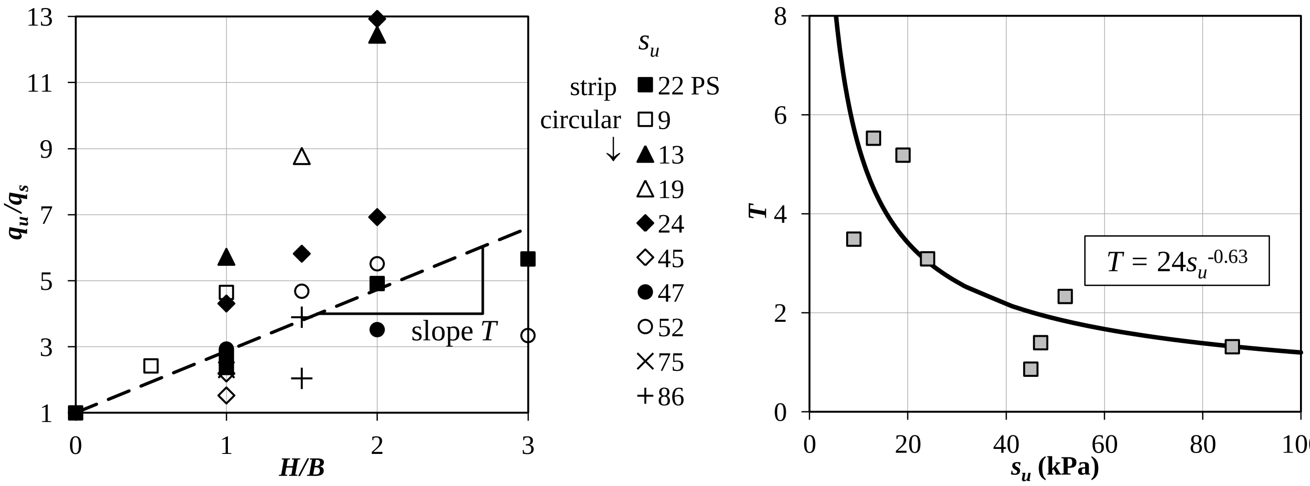


Figure 6. Load-transfer efficiency T derived from centrifuge test data of bearing capacity of sand layer overlying clay (Okamura et al, 1998).

Ballard et al (2011) obtained a similar exponential relationship between an equivalent load spread angle and subgrade shear strength in a parametric study using discrete layer optimisation techniques.

Back-analysis of a number of instrumented plate load tests on granular layers overlying soft subgrades (Lees, 2017a) revealed that geogrid stabilisation increases the load transfer efficiency T of granular layers by several mechanisms, as shown in Figure 7. 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.

To take account of all these beneficial mechanisms explicitly in a design method would result in an overly-complicated analysis. Rather, they are all taken into account by advanced numerical methods using finite element analysis (FEA). Parametric study 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. Constitutive model parameters for the granular layers were obtained from very large triaxial compression tests performed on compacted specimens of the material with and without geogrid products installed at the mid-height.

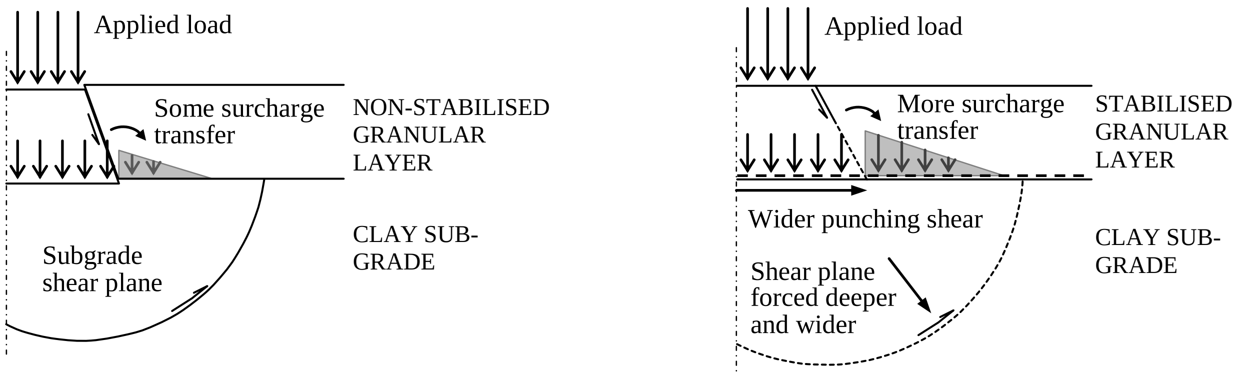


Figure 7. Mechanisms of bearing capacity improvement brought by geogrid-stabilisation.

Rather than modelling the geogrid explicitly (e.g. with tensile membrane elements), the stabilising effect of geogrid on the granular layer was simulated using the c'-profile method (Lees, 2017b) by adding an increment of strength to the soil in the form of apparent cohesion c' at the geogrid elevation, decreasing to the non-stabilised value at, typically, 0.3m above and below the geogrid plane. This method has been found to produce significantly more accurate simulations of plate load tests of geogrid-stabilised soils than the membrane element, as described by Lees (2017b).

The derived T-s_u relationships can then be used in the routine ultimate limit state design of working platforms on fine-grained subgrades for the granular layer and geogrid product types included. This design method was coined the "surcharge transfer" design method after one of the geogrid-stabilisation mechanisms that it takes into account.

4.2 *Application to this case study*

Back-calculation of the T value of the stabilised granular layer utilised in this case study is presented in Figure 8. The relationships between T and subgrade shear strength were derived for a granular material with and without the geogrid used at this site (denoted "*Geogrid A*"). The bearing capacity q_u of 290 kPa obtained in the test with the estimated subgrade bearing capacity q_s of 43 kPa gives a bearing capacity ratio of 6.7. Using the linear relationship in Equation (1) adopted in the new design method with 1.55m granular layer thickness and 2m loaded width, a T value of 7.4 was obtained. This was plotted on the graph of T-s_u relationships derived by FEA parametric study shown in Figure 8 and was located close to the line with *"Geogrid A"* stabilising a granular layer for B/L=1.

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

$$6.7 = 1 + T\frac{1.55}{2} \rightarrow T = 7.4 \tag{2}$$

where q_u = applied stress, q_s = ultimate bearing capacity of the underlying subgrade, T = load transfer efficiency, H = thickness of granular layer and B = width of applied load.

Therefore, the location of the point from this case study on Figure 8 provides good validation of this new design approach. In fact, the true bearing capacity may be higher because failure occurred around the perimeter of the stabilised layer.

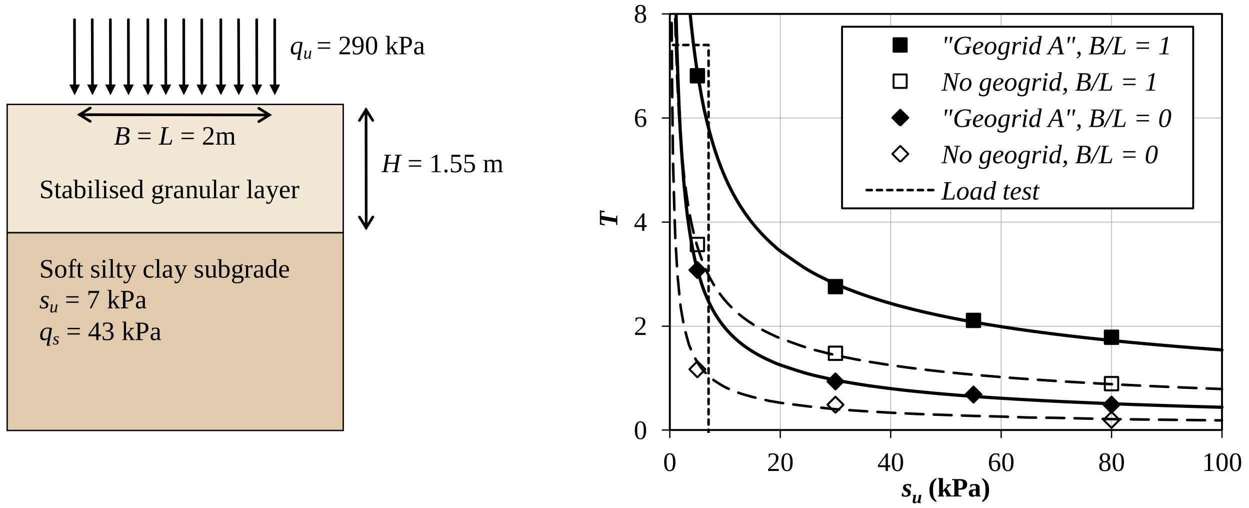


Figure 8. Surcharge transfer design method applied to case study.

5 DISCUSSION AND CONCLUSIONS

Working platforms are likely to be an important element of many civil engineering projects, either as temporary works or for more permanent use, but with a target to provide safe access for heavy plant over soft or weak subsoils. The good practice guide BR470 (Building Research Establishment, 2004) provides guidance to designers and operators of working platforms, and although published in the United Kingdom, it is being used as a guide in other countries. BR470 does provide guidance on the use of geosynthetics, and importantly BRE published a brief supplementary document in 2011, entitled “Use of structural geosynthetic reinforcement” (Building Research Establishment, 2011) and described as “a review seven years on”. Importantly this document acknowledges that BR470 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.

This paper describes two working platforms, built 20 years apart, but both as fabrication yards for offshore equipment. The platform at Pasir Gudang was tested using simple trafficking trials with a heavy crane, in both cases indicating that the geogrid stabilised platform provided adequate performance. The fabrication yard at Laem Chabang, which is the main subject of this paper, was built over slightly poorer ground conditions, and is slightly thicker, although consisting of a combination of a lower geogrid stabilised sand layer and an upper crushed rock aggregate layer. The large-scale load test carried out on this working platform provides valuable information about its performance.

A long time after both fabrication yards were constructed, Lees (2017a) developed a new “surcharge transfer” design method for working platforms, which is described in the previous section. This provides an alternative method for designing working platforms incorporating the beneficial effects of stabilisation geogrids, compared to the method given in the original BR470 guide (Building Research Establishment, 2004) which only incorporates the strength of the geosynthetic. However the method is based on credible and representative geotechnical principles and research, a target given in the 2011 supplementary review of BR470 (Building Research Establishment, 2004) outlined above. This research includes both very large triaxial tests to provide data in order to establish fundamental behaviour of the geogrid/aggregate stabilised composite, as well as numerical analysis in order to apply this behaviour to the complex problem of designing a working platform. Importantly the large-scale load test carried out on the Laem Chabang working platform provides validation by a well-documented case study, also a target of the BRE470 supplementary advice (Building Research Establishment, 2004).

Both working platforms described in this paper were constructed using stabilisation geogrids, although the term was not known in 1987, and was only just being developed at the time when the Laem Chabang platform was constructed. However it is now well established that this distinction concerning the function of a geosynthetic used to enhance the mechanical performance of a working platform is vital. Stabilisation geogrids provide enhanced performance with very little surface deformation of the platform, compared to reinforcing geosynthetics which must use the tensioned membrane mechanism in order to develop a beneficial mechanical effect. Although suitable for channelised traffic on unsurfaced pavements which can tolerate the large surface ruts required to form the tensioned membrane in the geosynthetic, this mechanism is not applicable to the design of working platforms, which are unpaved areas with random traffic patterns. The "surcharge transfer" design method for working platforms is based on the use of granular materials combined with stabilisation geogrids for which the fundamental behaviour has been established by carrying out very large triaxial tests.

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