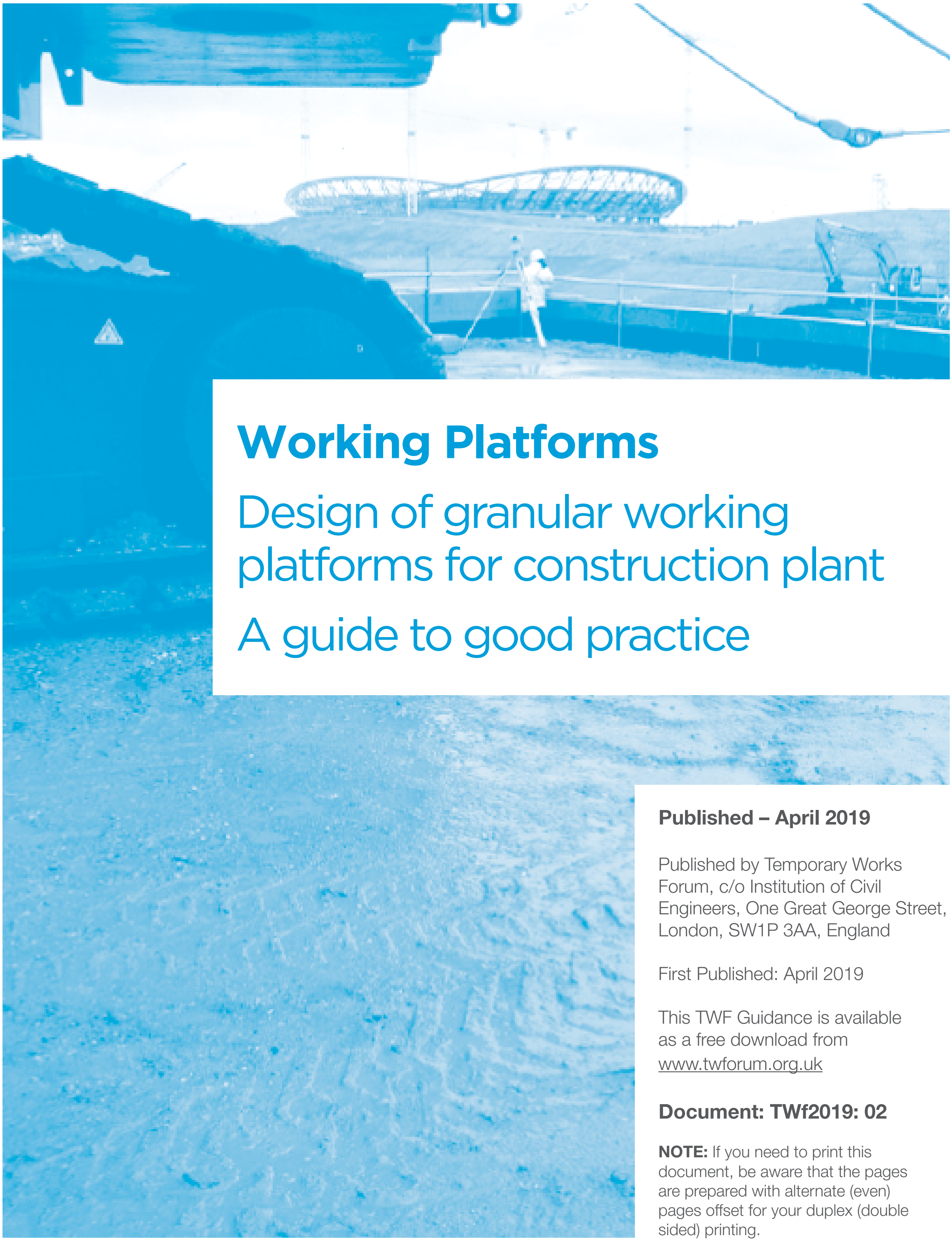

Working Platforms

Design of granular working platforms for construction plant

A guide to good practice

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Foreword

Temporary granular platforms for construction plant (including haul roads and general hard standings) are a necessary feature of almost all construction sites but the need to ensure that they are adequate for the intended use is often overlooked. Furthermore, the design is frequently only derived from previous experience. This has, on occasions, resulted in significant incidents of over-turning plant that result in, at best, cost and delay or, at worst, injury and/or death.

While current methods for the technical design of granular working platforms have proved generally reliable, it is recognised that there is a lack of consistency on how and when they are applied, resulting in varying degrees of economy (and possibly un-economic design in certain instances). In addition, the introduction of the 'Eurocodes' (although not entirely applicable) has brought about an increased expectation that temporary structures should be designed in line with current national standards.

It is not intended here to replace current guidance but it is hoped that this document will supplement current guidance and provide an overall approach that addresses the aforementioned issues.

This guide is, therefore, aimed at:

- providing recommendations for the overall design of working platforms;
- improving the application of current structural design methods;
- suggesting a suitable method for the application of Eurocodes;
- considering ways of achieving greater economy while maintaining a suitable level of reliability with regard to the particular risks under consideration;
- providing an introduction to related health and safety and sustainability issues.

The guidance offered here is intended primarily for temporary works designers, in particular less experienced engineers. It is also, however, intended to act as an aid to others involved in the procurement and use of granular working platforms.

Acknowledgements

The Temporary Works Forum gratefully acknowledges the contribution made by members of the working party in the preparation of this guidance.

We also wish to express our gratitude to the various interested parties that engaged with the working group, for their contribution to and endorsement of this document.

Additionally, thanks are expressed to Dr Hitesh Halai of City, University of London, who – at the request of the TWf directors - undertook a peer review of the text to provide an opinion on whether the 'TWf method' provides a valid and safe approach to the design of granular working platforms.

Thanks also go to John Allen (Group Technical Services, MACE) for his assistance with proof-reading.

Disclaimer

This TWf Guide is not a design code, but is intended to be used in conjunction with the current British Standards and other referenced documents as a guide to good practice. It is in no way intended to preclude the use of other codes and methods of design or the application of alternative solutions. Designers are expected to use their own engineering judgement to determine the best solution and appropriate methods for design.

Although the Temporary Works Forum (TWf) does its best to ensure that any advice, recommendations or information it may give either in this publication or elsewhere is accurate, no liability or responsibility of any kind (including liability for negligence) howsoever and from whatsoever cause arising, is accepted in this respect by the Forum, its servants or agents.

Readers should note that the documents referenced in this TWf Guide are subject to revision from time to time and should therefore ensure that they are in possession of the latest version.

1 General matters

1.1 Scope

This TWf Guide provides advice on the general approach to design of granular platforms, for construction plant and vehicles, and the detailed analytical design thereof.

It should be understood that this guide doesn't directly apply to classes of plant or operations where the use of granular platforms is neither practical nor necessary (e.g. bulk earthworks). In such cases, the suitability and stability of plant should be confirmed by the plant provider.

Recommendations for designers on relevant factors to be used and considerations to be incorporated into the design of granular working platforms are included. Detailed advice on the installation, maintenance and removal of granular platforms is not included here but the appropriate guidance is otherwise referenced.

The purpose of granular platforms may include use as general hardstandings, site access/haul roads and working platforms for operations such as crane lifts and piling. As such, this guide will consider and offer different advice relating to the various common applications. In addition, the guide will give consideration both to granular platforms without geosynthetics and to those that are reinforced or mechanically stabilised with geosynthetics.

This guide doesn't extend to cover the design or specification of load spreading methods or equipment (e.g. grillages, outrigger pads, etc.) but does consider their influence on the design of the granular platform.

Further, this guide does not cover:

- specialist methods for ground improvement and/or support (e.g. soil stabilisation, vibro piling, buoyant foundations, etc.);
- stability of adjacent slopes or retaining structures;
- temporary highways that will be used by the public;
- structural capacity of below ground structures (e.g. services, basements, chambers, etc.) beneath the platform;
- structural capacity of below ground services (e.g. pipelines) beneath the platform;
- instability that may arise from below ground operations adjacent to or beneath the platform (e.g. CFA over-flighting);
- design checks for proprietary demountable products (e.g. timber bog mats, metal trackway, etc.).

All these items should, nonetheless, be considered separately and the appropriate design checks and/or temporary works undertaken where needed.

1.2 Definitions

Granular Working Platform

A temporary geotechnical structure, consisting of compacted granular fill, installed to allow construction plant and vehicles to travel and/or operate on site.

Temporary Works Coordinator (TWC)

Competent person with responsibility for the co-ordination of all activities related to temporary works. This is usually expected to be a site based role delegated to a member of staff that attends the relevant site.

Temporary Works Designer (TWD)

Competent person or organisation appointed to carry out the design of temporary works.

Permanent Works Designer (PWD)

Competent person or organisation appointed to carry out the design of permanent works.

1.3 Legislation

In brief, the design of working platforms is subject to the same legislation that governs all construction works. This is amply covered elsewhere but, for the purposes of this guidance, the reader's attention is drawn to the relevant sections of the Health and Safety at Work, etc. Act 1974 (HSW1974) [1] and the Construction (Design and Management) Regulations 2015 (CDM2015) [2].

Section 6 of HSW1974 covers the obligation of manufacturers and suppliers to provide sufficient information for the safe use of "articles" and "substances" at work. In the context of this document, this can be taken to mean "plant" and "materials". An important distinction however is that the expression "article" does not refer to structures such as the completed piling platform.

In addition, Section 6 also implies an obligation on the user of "articles" and "substances" to use them "properly". If this is not complied with, the manufacturer/supplier is not obliged to provide further information.

The implication of Section 6 is that manufacturers and suppliers of plant or geosynthetics should be expected to provide any information that is necessary for the safe design of working platforms. At the same time, they cannot be expected to provide additional information to extend their use, e.g. in support of novel designs or innovations.

Within Part 4 of CDM2015, consideration must be given to Regulations 19 (Stability of structures), 27 (Traffic routes) and 28 (Vehicles).

Regulations 19 and 28 are of particular relevance to the detailed structural design of working platforms, while Regulations 27 and 28 are relevant to the general design and layout. Further, the over-arching requirement to “prevent or control the un-intended movement of any vehicle” should be viewed as a key requirement of the design.

1.4 Responsibilities

CDM2015 also places a requirement on all parties to check their own and each other’s competence to undertake design or construction activities. Working platforms are no exception to this and, in particular, the design of working platforms must always be undertaken under the supervision of a suitably experienced and qualified engineer (with appropriate geotechnical knowledge).

The design, installation, use, maintenance and removal of working platforms is expected to be managed, just as any other temporary works, in accordance with the recommendations of BS 5975:2008+A1:2011, Code of practice for temporary works procedures (etc.) [3[1]], which describes the roles and responsibilities of various parties involved in the delivery of temporary works. While the code covers the general duties for various defined roles, the roles of the TWC and TWD are key to the process and it is, therefore, additionally recommended that the following specific tasks should be undertaken in relation to the design of working platforms.

1.4.1 Temporary Works Co-ordinator

- Obtain/provide information about the site which should include:
  - ground investigation reports (desk study, factual report, interpretive report, geotechnical baseline report);
  - supplementary testing/inspection for upper layers (trial pit, plate bearing tests);
  - topographical surveys;
  - supplementary information for above- and below-ground services and structures that may be affected;
  - dimensional constraints that may apply (reduced levels, gradients, edge distances);
  - plan of intended location for the working platform;
  - information about adjacent features such as batters, retaining walls, roads, railways, rivers, canals, etc.
- Obtain/provide information about all plant and vehicles, in the various modes of operation/configurations, which may include:
  - dimensioned drawings;
  - weights of components;
  - axle loads and axle spacing;
  - outrigger loads;
  - track ground bearing pressures;
  - details of outrigger mats or other ‘load spreading’ devices (if supplied/used);
  - lift charts.
- Obtain/supply information about the materials to be used including:
  - specification of any preferred granular fill;
  - visual description of any preferred granular fill (if not to recognised specification);
  - details of any preferred geosynthetic material(s).

1.4.2 Temporary Works Designer

- Comply with duties under CDM2015 (in particular the principles of prevention and provide relevant information).
- Request any additional information required for production of safe design, not yet provided by TWC.
- Prepare plans and sections of the platform as appropriate (particularly required where proximity to adjacent structures/property needs to be clearly defined and/or where different forms of construction may be in use for different plant/purposes).
- Analytical/numerical calculations to demonstrate the suitability of the proposed details
- Assessment of test results (on formation and/or platform) to confirm suitability of the actual structure.
- Specification to cover materials, workmanship and testing (this may be based on standard specifications and/or manufacturer’s instructions but it is recommended that it is included on the drawing).
- A clear statement of the anticipated ground conditions and loadings that can be accepted by the platform.
- Further information regarding remedial actions (e.g. soft formation), maintenance and removal of the platform.

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[1] New edition due in 2019

- Further health, safety and environmental information regarding safe use and any significant residual risk (e.g. maximum gradient, minimum edge distance, requirement for waste licencing, etc.).

1.5 Reliability

In all cases, the aim of any design is to achieve a sufficiently reliable design balanced with the need for economy. A reasonable compromise needs to be struck to achieve a sufficiently safe design while avoiding excessive over design.

The level of reliability required for any structure is based on the perceived risk of collapse and the associated likely consequences. The level of reliability achieved for a structure is a product of the accuracy of input data, design method and the construction process.

Although it is not possible to categorically confirm the level of reliability of current design methods, they can be said to appear sufficiently reliable as no failures have been attributed to any short coming in them.

The partial factors being used for UK application of the Eurocodes are not entirely consistent with the current methods of granular platform design. They are calibrated for the design of permanent works and do not necessarily reflect the uncertainty (or certainty) associated with the design of granular platforms.

The Eurocodes, however, do set out a framework for assessing the possible consequences of failure and required levels of reliability. This may provide a means to calibrate the factors applied and achieve an approach that is consistent with the specific needs of granular platform design.

Regardless of their exact level of reliability, all design methods make allowances for possible deviations in input data, either by use of global (lumped) factors or by the introduction of partial factors. This assumes the input data is assessed in a consistent manner (e.g. use of moderately conservative soil parameters) depending on the quality of available data.

Hence, for any given method, the quality of the input data can significantly influence both the reliability and the economy of a design. In the case of granular platforms, the following should be considered:

- **Ground information** – Lack of information forces the designer to make conservative assumptions about subgrade parameters, while good information allows the designer to make a more accurate assessment.
- **Specification of fill material** – Knowing the type and source, including any quality controls applied by the producer allows proper assessment of strength parameters.
- **Specification of geosynthetics** – Knowing the type and source, including any test data and/or certification provided for the product, allows proper assessment of appropriate design parameters (e.g. strength, deformation, load spread angle, etc.).
- **Plant loadings** – Where the supplier is not able to accurately assess the loads and supply suitable ground loads/pressures and/or the designer has to make the assessment from first principles this may lead to the use of a more conservative approach.
- **Operational controls** – Where the operator can apply direct control to reduce or eliminate certain loads or the plant will not be operated under certain conditions or for certain tasks then the designer may be able to discount a more onerous load case e.g. pile extraction when driving permanent piles.
- **Quality of construction/maintenance** – This depends on the designer’s knowledge of the contractor’s quality management, preferred working methods and maintenance measures; if it is known that the contractor will apply rigorous controls then more favourable parameters or factors may be appropriate.
- **Use of inspection and testing** – Depending on the contractor’s preferred method of working, the designer can recommend testing to confirm the assumed parameters for the subformation and the platform material as placed.

1.6 Economy

Research suggests that there is no single method that will yield the ‘thinnest’ safe platform thickness under all circumstances. However, regardless of which method is adopted, it is recommended that the same method is used consistently, for similar plant and/or ground conditions. (It is not considered good practice to vary methods simply to get the most economical answer.)

In terms of the design of platforms, it is generally the input data which has the greatest influence on the economy that can be achieved. The factors identified in **Section 1.5** should be carefully considered and better information obtained if deemed necessary.

In terms of the general form of the platform structure, subject to specific verification on a case by case basis, the following may be considered:

- It is understood that, as a general “rule of thumb”, a layer of geogrid is equivalent in cost to 100mm of granular fill, i.e. the introduction of geogrid can be justified economically if it reduces the platform depth by 100mm or more.
- The introduction of a geosynthetic can reduce the thickness of the granular by up to 60% depending on the site and product specific conditions.
- If a platform (particularly a haul road) is going to be in place for a significant period then granular platforms are more economical but for shorter durations it can prove more efficient to use a demountable solution such as timber bog mats.
- If direct loading is resulting in excessive platform thickness it can be worth considering introducing general load spreading through a structural layer such as timber bog mats.
- If contamination, leading to deterioration of the platform, is likely then it may be worth protecting it from below with geotextile and from above with timber bog mats, metal trackway or a concrete blinding.

In all events it is generally recommended that higher quality material, workmanship and maintenance is specified and provided. This reduces platform thickness required while providing greater load bearing capacity and durability, resulting in greater overall economy. **Poorly constructed/maintained working platforms, using lower quality material, can rapidly deteriorate to a point where only the lightest of plant operations can be safely supported and, ultimately prove to be a false economy** (see also **Section 3.4.4** and **Table 1**).

1.7 Occupational health and safety

The responsibilities of CDM2015 duty holders are covered elsewhere but it is worth mentioning some specific advice relating to the design of granular platforms.

CDM2015 creates a new duty holder, the Principal Designer (PD). One of the main duties of the PD is to ensure the provision of adequate Pre-Construction Information (PCI); this includes any available information and any information that should reasonably be made available. It is widely recognised that information for the design of working platforms is often inadequate and it is hoped that this will lead to improved information being made available.

Since the introduction of CDM in 1994, all designers have had a duty to apply the principles of prevention – to eliminate or reduce risks to health and safety and inform others of significant or unusual residual risks.

As a general rule, the construction, maintenance and removal of granular platforms does not involve unusual or significant risks and it is reasonable to expect that a competent contractor will understand and adequately control those risks. Also, it is not an explicit requirement that a designer will complete a written Designer’s Risk Assessment (DRA). However, it is considered advisable for designers to complete a record both as evidence of compliance and as a prompt to consider whether *unusual/significant risks* are present in any particular design.

In all events, the principles of prevention should always be observed and to this end the following matters should be considered:

- **Vehicle movements** – Separate details for vehicular areas and designated footways; include separation/demarcation on layouts; consider lines of sight.
- **Slips/trips/falls** – Avoid particle size that is so large it becomes difficult to walk over.
- **Silicates** – specify materials that are free from harmful silicates.
- **Particulates/dust** – Avoid materials with high fines content.
- **Contaminants/asbestos containing material** – Ensure materials are ‘clean’, particularly re-cycled aggregates.
- **Instability due to substandard formation** – Provide instructions for inspection and testing plus remedial action.
- **Instability due to degradation of platform** – Use materials that have larger particle size/low fines content; provide note on drawing regarding maintenance; provide protective layers.
- **Instability due to surface gradient** – Not usually considered to be a hazard on granular platforms but timber, metal or plastic mats must not be used on any significant gradient; incidents of lateral sliding have occurred with both types of mat, including one known fatality.

1.8 Environment and sustainability

In similar manner, although there is no legal obligation on designers, the principles of “Best Available Technique Not Entailing Excessive Cost” (BATNEEC) should be applied.

The principle savings that are available involve keeping the platform to the minimum thickness possible (subject always to reliability). The main positive effects this has are to reduce use of fresh materials, disposal of waste and carbon footprint. The possibility of completely avoiding the importation and removal of granular fill should also be explored.

In addition, based on the previous experience of TWf members, the following possible measures are suggested:

- **Re-cycled material** – This is currently considered normal practice and would generally be expected simply on basis of cost; some caution may need to be exercised in terms of quality (even when standard specifications are used) and it is important to check that they are Waste & Resources Action Programme (WRAP)[2] approved.
- **On-going use** – Where material is in good enough condition and it proves economical, a contractor may re-use material in another location or on another site on the basis that it remains within "the chain of utility" i.e. it remains useful and is therefore, by definition, not waste. This will, however, be subject to obtaining a "waste exemption" from the Environment Agency (EA)[3].
- **Re-use by others** – Where you have no further use for it, by definition material becomes "waste" but if material is in good enough condition it may be transferring to another party subject to an exemption notification – this may include leaving material in place, possibly as part of the permanent asset.
- **Use of permanent works** – It may be possible to use permanent works as designed, with additional load spreading such as timber mats or with additional material thickness; this is often a necessary part of the construction process.
- **SUDS** – Granular platforms by their nature are porous and act as a form of sustainable drainage measure; if surfacing is applied to protect from contamination then due consideration should be given to maintaining the drainage path to avoid undue concentration of runoff; for example by using porous surfacing or by providing French drains.
- **Oil spills** – Although this may usually be a minor issue, the inclusion of a suitable geotextile can help to capture most oil spills and prevent leaching into underlying soils.
- **Dust** – In dry periods this can prove to be a significant nuisance so (again) granular fill with a relatively low fines content can be desirable.
- **Flood plains** – Where haul roads and platforms are constructed within flood plains they can take up allowable volume; the volume calculated for the granular fill should take account of the voids as they will provide "storage" for flood water.

2 Current methods, guidance and standards

2.1 Background

Historically, the design of granular working platforms for construction plant has not been carried out in a consistent manner across the industry. In the past, the methods have generally consisted of what might loosely be described as "empirical", and have largely been based on previous experience of suitable materials and thickness. Additionally, formal design methods have been used such as classical bearing capacity methods, for crane and piling platforms, or the TRRL LR1132 [4] method, for haul roads.

One of the alternative approaches that has been adopted is the use of plate loading tests to prove platform capacity. Another is the use of design methods developed by specialist geosynthetic manufacturers.

The publication of CIRIA SP123 [5] and BRE BR470 [6] introduced new analytical design procedures for the design of both un-reinforced and reinforced granular platforms. CIRIA SP123 has not been widely used but BRE BR470 has become the expected reference for design of platforms for tracked plant, driven by demand from piling contractors and Clients.

With the introduction of the Eurocodes, EC7 [7] has become the national standard for most geotechnical design. More recently, in the latest issues of BS8004 (Foundations) [8] and BS8006 (Strengthened/reinforced soils) [9], both SP123 and BR470 have been recognised as accepted methods for the geotechnical design of granular working platforms. Design of granular working platforms is, therefore, now expected to be undertaken using methods in SP123 and BR470, or otherwise in a manner that complies with EC7.

Sections 2.2 to **2.8** describe in more detail some of the key features of these methods and documents together with others that are relevant to the design of granular platforms.

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[2] *http://www.wrap.org.uk*

[3] *https://www.gov.uk/government/organisations/environment-agency*

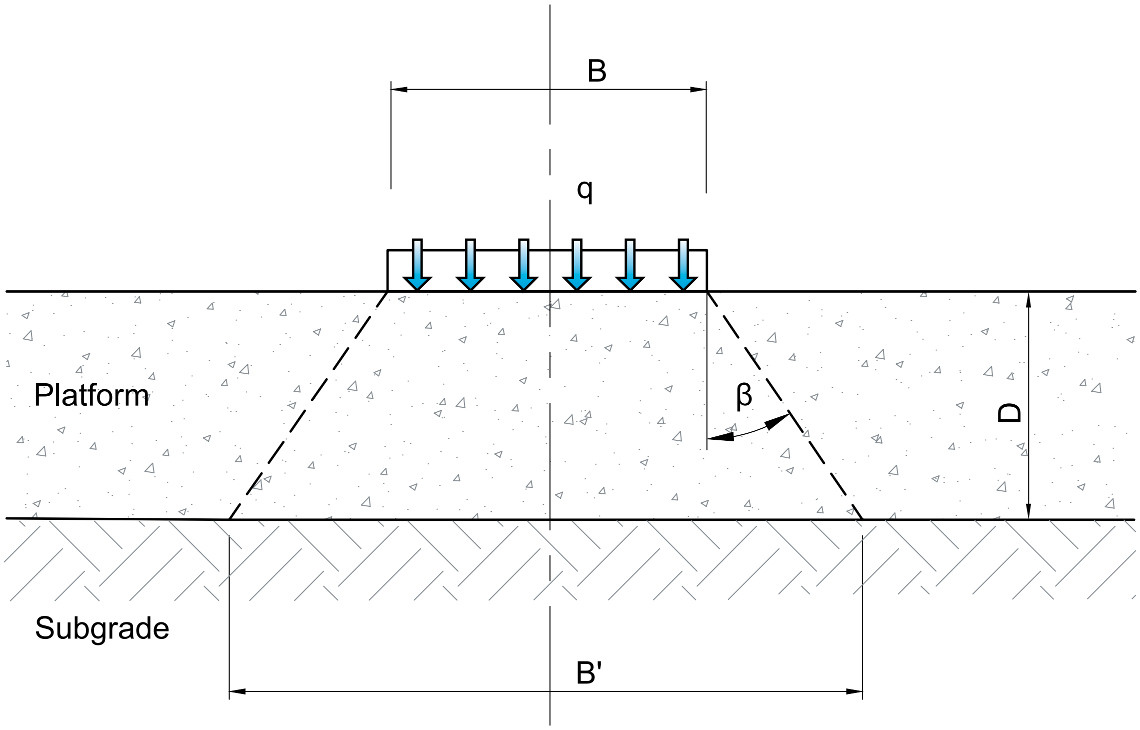

Figure 1 – Load spread model

2.2 Bearing capacity method (shallow spread foundations)

When designing for track and outrigger loads, it has been common practice to use the classical bearing capacity methods normally used for shallow pad foundations, incorporating the use of the platform to spread the load and thus reduce pressures on the underlying formation. (This is also known as the 'projected area method'.)

The loads are taken to be dispersed based on a defined load spread angle (β), as shown in **Figure 1**. The structural capacity of the platform and the deformation limits are verified by calculating the ultimate bearing capacity and applying a suitable factor of safety, usually in the range 1.5 to 2.5, to arrive at an 'allowable bearing capacity'.

The load spread angle can vary significantly and is difficult to predict reliably. However, for the purposes of design, the load spread angle has previously been taken to be equivalent to 1h:2v for platforms without geosynthetics. For platforms with geosynthetics, some proprietary geosynthetic manufacturers use a load spread angle of 1h:1v or more[4], where this can be validated with appropriate test evidence.

For platforms where the formation is underlain by a layer of soft/weak soil, the procedure may be repeated in a similar manner to check the bearing capacity of the soft strata, allowing for dispersal down to the top of the lower strata.

Although this method has been successfully used for many years, there are a number potential issues:

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[4] *'h' is horizontal and 'v' is vertical*

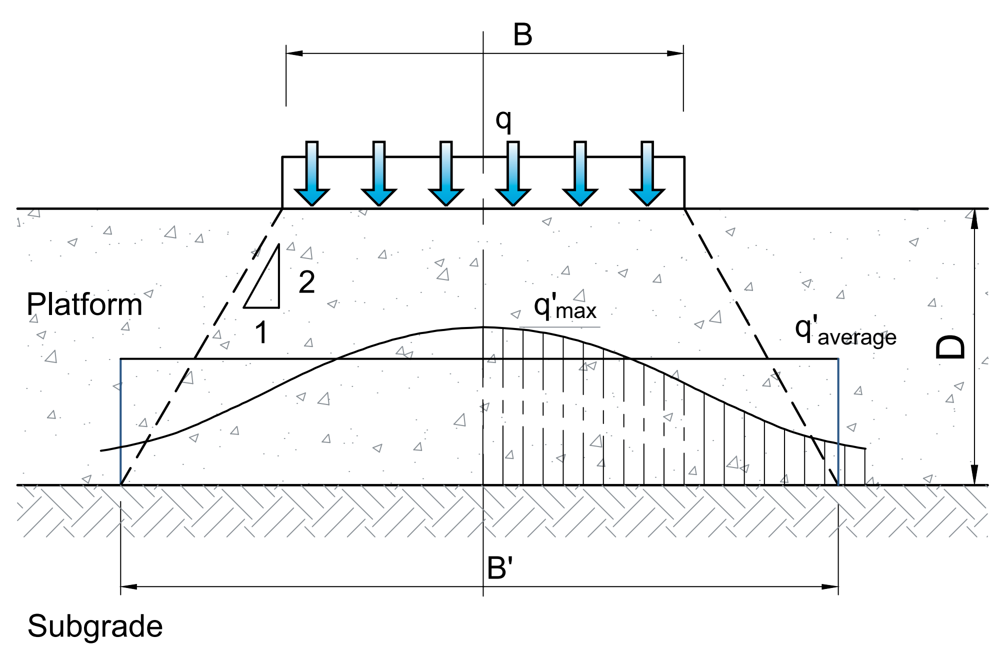

Figure 2 – Actual pressure on formation compared with average derived from load spread

- The average pressure on the formation underestimates the pressure in the centre and overestimates pressure at the edges, as shown in **Figure 2**; this can result in the formation being overstressed in the centre; design of permanent foundations has normally accounted for this by using a factor of safety not less than 3;
- In practice, the effective load spread may be less and therefore the effective area less than that assumed, resulting in the overall bearing capacity being overestimated;
- The vertical loads cause net outward pressures within the platform material which may result in shear stress on the formation; this can reduce the vertical load carrying capacity of the formation by up to 50% (CIRIA SP123);
- The apparent angle of load dispersal is not always 1h:2v; it has been shown that the angle of load dispersal can vary between 0° and approximately 50° depending upon geometry, loads and platform and subgrade strengths and deformation characteristics; this can mean the effective area is either over or under estimated. (Fannin, Burd & Frydman).

2.3 TRRL LR1132, The structural design of bituminous roads (1984)

The method provided in LR1132 [4], Appendix C, is applicable when designing for vehicle movements, particularly when designing haul roads. The design method is empirical and is based on tests that established the number of passes of standard axles that will result in a set wheel rut depth. This is a simple procedure but it depends on a realistic assessment of the subgrade CBR and vehicle 'load spectrum'.

The design procedure is as follows:

- define the 'load spectrum' for the numbers of each different vehicle and the number and weight of each vehicle's axles.
- convert the vehicles into 'standard' axles and determine the total number of standard axles.
- determine the CBR for the formation.
- read the required platform thickness (in terms of CBR and number of axles) from chart.

As the 'failure' mode is based on a nominal maximum rut depth, this should also be treated as an observational method. If excess rut depth develops too rapidly in practice the platform thickness will need to be increased. Although this means the structure has, in a sense, failed, the method has the merit of keeping the haul road thickness to a minimum and only providing additional thickness if and where it proves necessary.

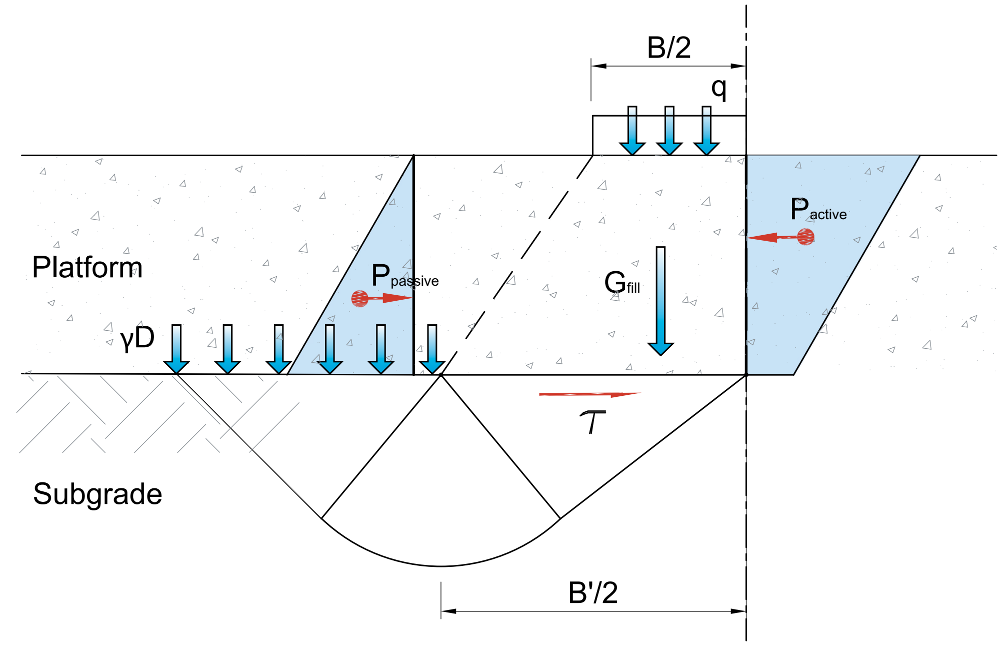

Figure 3 – Lateral shear model (after CIRIA SP123)

2.4 CIRIA SP123, Soil reinforcement with geotextiles (1996)

CIRIA SP123 [5] provides guidance on the use of geosynthetic reinforcement in various soil structures. Chapter 12 describes a methodology to determine the capacity of both un-reinforced and reinforced granular platforms on cohesive subgrades.

The analytical method is based on classical bearing capacity methods but makes an allowance for lateral stresses in the platform material, as shown in **Figure 3**. In the un-reinforced case, the lateral loads are considered to be carried as a horizontal shear stress by the formation. The resultant load is therefore inclined and requires the inclusion of a 'load inclination factor' which has the effect of reducing the bearing capacity. In the reinforced case, the lateral shear at the formation is carried by the reinforcement, thus allowing the full bearing capacity to be used. As the method is only considered for cohesive formations, no term is included for the weight of the platform or the surcharge on the formation (as these would be self-cancelling).

The method uses a partial factor approach, applying ULS checks on bearing capacity and geosynthetic reinforcement strength and SLS checks on geosynthetic reinforcement. For both ULS and SLS, the factor on load is unity, but various strength/material factors are applied to the formation, platform material and geosynthetics.

The main limitations of the method are:

- **Granular subgrades are not covered** – It is suggested that the analytical method should only be used for soft cohesive subgrades.
- **Arbitrary angle of load spread** – Although advice is offered, the selection of angle of load spread is somewhat subjective and has to be assumed prior to commencing the calculations; this entails a risk of over-estimating the angle and thus the bearing capacity; however, this issue can be addressed as follows:
  - use the Burd & Frydman method for the derivation of β for platforms without geosynthetics (see **Section 2.10.2.3**);
  - for geosynthetic reinforced/stabilised granular platforms, specific advice should be sought from the material manufacturer to obtain a value for β validated by past experience and appropriate experimental testing evidence.
- **Zero friction between load and platform** – The analysis assumes no friction between the underside of the wheel/track/pad and the top of the platform; this is possible (i.e. skidding) but is not necessarily realistic for many design situations.
- **Zero vertical friction within the platform material** – The active and passive lateral pressures are calculated on the basis that there is no friction at the vertical interface, i.e.

δ=0°; this can be considered conservative as there will be internal friction acting at the interface.

- **Complexity of calculations** – The full analytical method is relatively complex; the authors of SP123 accordingly suggest that it is best suited to use with a computer and also offered an alternative design method using charts.
- **Single strata subformation** – The design method is only valid for single strata with no alternative offered for multi-layered subgrades; it is assumed that the designer is expected to take the worst case soil parameters.

The following matters are also considered:

- **Partial material factors for geosynthetic reinforcement** – There are a number of separate factors used to cover duration of load, ambient temperature, mechanical damage, environmental degradation and design strength.
- **Strain conditions** – The load capacity of geosynthetics depends on the assumed strain condition needed to limit the deformation; strains in the range 2% (recommended) to 5% (maximum) are suggested.
- **3-dimensional case** – Bearing capacity factor Nc, at different ratios of horizontal shear on the formation to shear strength of the formation τ/s_u, for both the plane strain (2D) and axi-symmetric (3D) cases.
- **Tyre load model** – A method is provided for deriving wheel patch loads based on the wheel load and tyre pressure.
- **Cyclic loading** – A method is offered for factoring static wheel loads to represent the effect of cyclic loading depending on the number of repetitions.

2.5 BRE BR470, Working platforms for tracked plant (2004)

BRE BR470 [6] provides an overall framework reference for the design, installation and maintenance of granular platforms. It covers un-reinforced and reinforced granular platforms on both cohesive and non-cohesive subgrades. It also provides, possibly, the most widely used analytical methods currently used for granular platforms.

The analytical method 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 (see **Section 2.10.2.1**). 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, as shown in **Figure 4**. Checks on bearing capacity are deemed to satisfy limits on settlement.

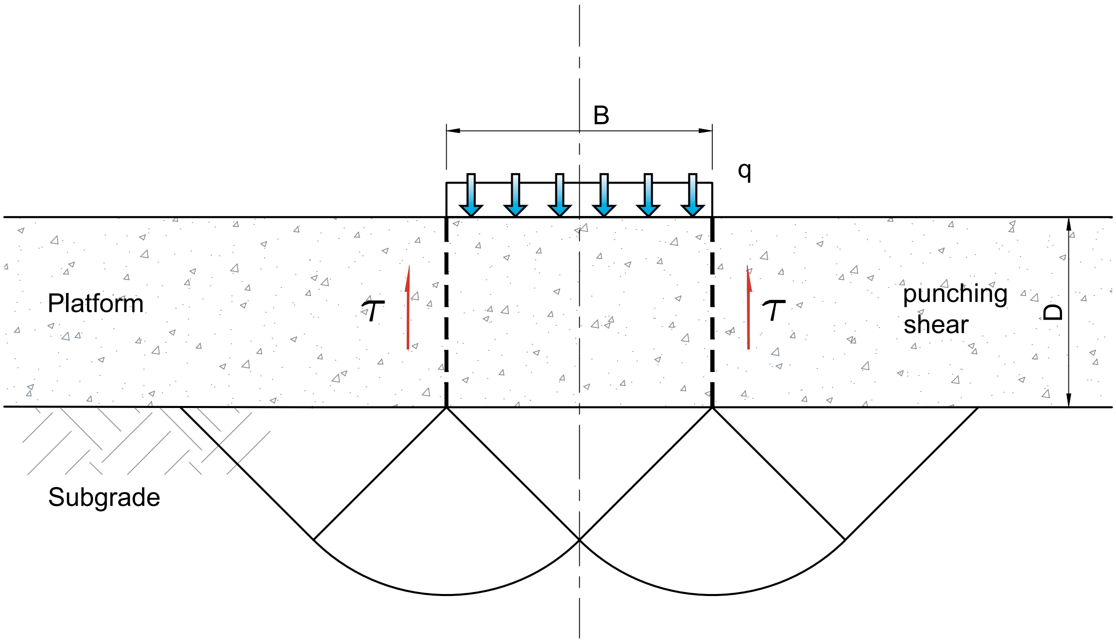

Figure 4 – Punching shear model (after BRE BR470)

It is important to note that, for this specific application, the Meyerhof model excludes both the weight of the platform and any benefit from surcharge and these are therefore not included. Also, in line with Meyerhof, the method assumes that no lateral shear effects occur at the formation level, allowing full bearing capacity to be used.

Unlike the SP123 model, geosynthetic reinforcement is not considered to provide lateral restraint. Instead is considered to provide additional vertical restraint at the punching perimeter, which further reduces the bearing pressure on the formation.

This is not a limit state method and the empirically derived factors should not be viewed as partial factors. Instead, the method adopts a variable factor on the imposed load, in the range 1.05 to 2.00, depending on load case and the element being considered. No strength factors are applied to the formation or fill but a factor of 2 is applied to geosynthetic reinforcement *ultimate* tensile strength, to limit deformation under load to an acceptable amount.

It should be noted that there is no insistence in the document that the BR470 method should be used; the design can equally be undertaken using any other accepted method.

Some of the known limitations of the analytical method are:

- **Sensitivity to input parameters** – In practice, the analytical method has proved extremely sensitive to the values used for the platform material and subgrade strengths; it is recognised that to achieve an economical design, the use of appropriate design parameters needs to be supported with good ground investigation and site testing of the platform.
- **Limited range for cohesive subgrades** – The calculations are only considered valid for un-drained cohesion greater than 20 kPa and less than 80 kPa.
- **Single strata subformation** – The design method is only valid for single strata with no alternative offered for multi-layered subgrades; it is assumed that the designer is expected to take the worst case soil parameters.
- **Geosynthetic reinforcement mechanism** – The proposed method of analysis is only representative if punching type failure occurs through the platform and in the subgrade; for most subgrades this is not considered to be representative of the actual failure mode (see also **Section 2.9.2**, regarding the BRE supplement to BR470, issued in 2011, concerning the incorporation of structural geosynthetic reinforcement/stabilisation).

2.6 Eurocode 7, Geotechnical design (2004/2007)

Eurocode 7 (EC7) [7] comprise two parts, BS EN 1997-1:2004+A1:2013 (General rules) [10] and BS EN 1997-2:2007 (Geotechnical investigation and testing) [11], together with respective national annexes. EC7 is now the accepted standard for geotechnical design within the UK and is widely used for the design of permanent works. To date, however, EC7 has only been partly used for temporary structures and is not generally used for the design of working platforms.

EC7 provides great flexibility in the methods of design adopted, encompassing empirical, analytical, numerical and observational methods. It will, therefore, support methods currently in use, modified where necessary to meet the fundamental requirements for limit state design set out in the Eurocodes.

However, EC7 doesn't provide any specific advice on the analytical design of working platforms. Clause 5, the use of fills to improve foundations, and Clause 6, the design of spread foundations, both include relevant advice but this primarily aimed at the design of permanent foundations. Also, it should be noted that reinforced/stabilised soils are not covered by EC7 at all (See BS 8004, Clause 2.7, and BS 8006, Clause 2.8; both of which provide specific advice on working platforms.)

In addition, the full application of EC7, as prescribed by the UK Annex, to the design of platforms without geosynthetics presents a number of difficulties that will take time to resolve. These include:

- **Factors are inconsistent with current outputs** – In particular, the partial factor γ_f has a disproportionate effect on the global factor of safety; use of the prescribed value of 1.25 leads to global factors up to 4 on bearing capacity.
- **Variable partial factor for actions** – Reduction in partial factor on actions is allowed for where “the operator can control the load safely”, e.g. the special load case 2 recognised in BR470.
- **Direct assessment of actions and strengths** – Where actions and soil parameters are directly assessed these may be used as the design values; however there is no specific advice on what constitutes direct assessment.
- **Dynamic and/or cyclic enhancement** – There is a general requirement to allow for dynamic and/or cyclic effects but it is unclear how this must be applied when considering effects on the ground.

- **Settlement checks required** – Design verifications are normally required for both bearing capacity (at ULS) and deformation/settlement (at SLS) which is outside of current practice.
- **Geotechnical Design Report (GDR)** – There is a requirement on the designer to record design decisions within a GDR; this represents a change design practice which will take some time for full adoption.

It should be noted that EC7 must be read in conjunction with EC0 (Basis of design) [12] and EC1 (Actions) [13].

2.7 BS 8004:2015, Foundations

BS 8004 [8] is a code of practice – written as NCCI for EC7 – which provides advice on the limit state design of various types of foundations in line with the general requirements of EC7. It does not fully cover design methods appropriate to the design of working platforms. However, BS 8004, Clause 4.9.3, refers the reader to CIRIA SP123 and BRE BR470 as guidance. In addition, it contains related general advice on the design of spread foundations which provide acceptable methods to calculate either a design bearing resistance (Clause 5.4.1) or a presumed bearing resistance (Clause 5.4.4).

2.8 BS 8006-1:2010, Strengthened/reinforced soils and other fills

BS 8006 [9], Part 1, is a code of practice that provides advice on the limit state design of various reinforced soil structures (walls, slopes, embankments on soft formations) in line with the general requirements of EC7. It contains related general advice on design of reinforced soil structures but does not cover any specific design method for granular working platforms. However, BS 8006-1 Clause 8.3.2.15, states that working platforms are outside of its scope and refers the reader to CIRIA SP123 and BRE BR470. In addition, it should be noted that BS 8006-1 Clause 1.1 states that although it is to be read in conjunction with EC7, EC7 itself is *not* to be used for the design of reinforced soil structures.

2.9 Alternative methods

2.9.1 Plate loading tests

One option when designing granular platforms can be to undertake plate bearing tests on the formation and/or on the finished platform by way of validation for the capacity of the platform. This method needs to be treated with great caution as the plate loading test equipment is normally not representative of the loaded area, particularly in the case of tracks and outrigger pads.

It is possible that a test using the normal plate size (300 to 450mm diameter), applied to the surface of a working platform, will have almost no influence at all on the subgrade. By way of mitigation, a large diameter loading plate can be used but this brings with it the practical difficulty and cost of providing sufficient kentledge to achieve a suitable amount of ground bearing pressure.

Plate loading tests alone can only be considered acceptable when:

- the plate is of appropriate diameter relative to the actual track/pad;
- the load applied is sufficient to provide an adequate margin relative to the applied pressures – depending on perceived risk a suggested range might be 50-100%;
- a sufficient number of tests are carried out – with due allowance for the geometry of the site and potential variability in the ground;
- the measured settlements are acceptable – considering the operating requirements of plant likely to use the platform;
- there is adequate confidence in the piling mat formation – which may be determined by inspection during construction.

2.9.2 Geosynthetic manufacturers' design methods

It is stated in BR470 that alternative methods may be adopted and the use of geosynthetic manufacturer's design methods was expanded on in a supplement, "Use of 'structural geosynthetic reinforcement' – a BRE review seven years on" (issued by the BRE in 2011) [14].

In addition to the standards and guidance documents that are available, a great deal of product design and development has also been undertaken over the years by geosynthetic manufacturers. This has resulted in the development of various design methodologies that are bespoke to their products. Such alternative methods are deemed acceptable for the design of temporary working platforms, provided that the manufacturers can produce sufficient evidence that their proprietary methods have been validated by extensive past experience and by appropriate experimental testing. The methods and the assumptions used vary between manufacturers but can include:

- increased angle of load spread;
- enhancement of formation bearing capacity (by elimination of horizontal shear);
- experimental determination of load distribution improvement factor (for reinforced vs un-reinforced platforms);

- use of bespoke partial factors;
- reduction in granular layer thickness based on empirical trafficking data (bespoke to individual manufacturers).

When using the advice and design methods provided by geosynthetic manufacturers it is also recommended that:

- experimental testing and theoretical design is representative of actual installation and use conditions;
- experimental testing and theoretical design are validated by representative case studies;
- products are certified by an independent accreditation body, e.g. CE Marking or equivalent;
- design responsibility is clearly defined and the manufacturer carries suitable professional indemnity insurance;
- the design methods and/or software developed for an individual manufacturer or product is bespoke and must not be used for other manufacturers or products.

It should be noted that certain manufacturers' methods rely heavily on empirical data and are not as "transparent" as more analytical methods as there are no calculation outputs that can be readily checked. While these empirical methods have proved reliable in practice and are indemnified by the manufacturers when they undertake the design, there can be potential issues where a third party check is required. It is recommended that, in these cases, the design and checking methodology is agreed between all parties prior to proceeding with the design.

For further information on manufacturers' design methods see **Appendix F**.

2.9.3 Commercially available software

At the time of writing, there does not appear to be any software on the market specifically aimed at the design of working platforms. In general, the software available falls into the following categories:

- software developed by geosynthetic manufacturers;
- user-developed spreadsheets and mathpads;
- software intended for the design permanent spread foundations;
- finite element analysis packages.

Software is sometimes developed by geosynthetic manufacturers to reflect the design methods specifically used for their own product. As such, the recommendations in **Section 2.9.2** apply.

Many companies and individuals have also developed calculations on spreadsheets or mathpads to carry out design in accordance with existing analytical methods (such as BRE470). It is recommended that any such spreadsheet or mathpad should be independently validated to ensure the results given are consistent with the expected output.

Programmes specifically intended for the design of spread foundations can be adapted for the design of granular working platforms, if they allow for design of multi-layered soils (to replicate the working platform scenario of dense granular layer over weaker formation). There are a number of commercially available programs for the design of strip footings or pad foundations, which will analyse bearing capacity and/or immediate settlement. In addition, many of these programs allow for analysis to be carried out in accordance with EC7 in addition to traditional methods.

For programmes that analyse bearing capacity it should be noted that:

- Often, the software available includes the design of a concrete foundation. This is not relevant to the design of working platforms. The designer must consider whether the load spread of the outrigger pad is accurately mimicked by the concrete;
- The methods of analysis usually follow one of the standard methods which would be used in hand calculations. Options for analysis often include Brinch Hansen or Terzaghi.

For programmes that analyse immediate settlement it should be noted that:

- A surcharge is placed on the soil at ground level. This surcharge should be the pressure beneath the outrigger mat. If settlement programs are used, it is important to verify the ability of the mat to spread the load uniformly;
- An 'allowable' settlement must be selected in order to carry out the calculation. This settlement should be selected to suit the operating requirements of the plant in question;
- Various theories can be chosen for analysis. The most common options are Janbu, Buismann, Schmertmann, Burland & Burbidge, Elastic, Oedometric.

As an alternative, the designer may wish to consider the use of Finite Element Analysis (FEA) for the design of working platforms. FEA involves detailed numerical analysis in either 2D or 3D, providing a direct analysis of all stresses and deformations likely to occur for each load case. This can allow a quicker and more accurate simulation of the works out on site including the effects on nearby structures, slopes, or other features. In addition, sensitivity analysis can be performed relatively quickly to assess possible consequences of variation in design assumptions.

The use of FEA is not normally commercially justified for use in the routine design of working platforms, however it may be required for difficult or complex ground conditions and/or where risks to adjacent assets are significant. In addition, to ensure the results are valid, a high quality site investigation (including stiffness parameters) is also required. This is not always readily available and may need to form part of the business case where FEA is considered.

For further information on commercially available software, see **Appendix G**.

2.10 Further reading

There is a substantial body of relevant work and as much of this as possible is included in the references (**Appendix C**). The reader should, however, particularly acquaint themselves with the contents of the documents that follow.

2.10.1 General guidance

2.10.1.1 ICE, Temporary works: Principles of design and construction

Chapter 5 [15] is dedicated to introducing the reader to the wider aspects of working platform and haul road design, construction and maintenance. The fundamental mechanics, use of LR1132 and considerations of layout are discussed[5].

2.10.1.2 CIRIA, C703 Stability of cranes on site

Guidance on the safe use of cranes of all types [16]. The document includes information on load distribution for different ground conditions and the positioning of plant relative to embankments and retaining structures. The document also includes a simplified method for calculating the bearing capacity of outrigger pads.

NOTE: The method used for assessing ground bearing capacities is based on a now withdrawn (1986) version of British Standard BS 8004, Code of practice for foundations.

2.10.1.3 Freight Transport Association, Designing for deliveries

A document [17] aimed primarily at the design of paved areas for delivery vehicles in industrial and commercial premises. It contains data for vertical alignment and plan layout of roads and loading areas, including dimensioned diagrams for vehicle tracking. (Currently out of print but useful if a copy is available.)

2.10.1.4 Highways Agency, Design Manual for Roads and Bridges

A series of design documents providing guidance on the design of permanent highway works. Volume 4, in particular, provides guidance on highway loadings, road structure and alignments which can be relevant to the design of granular platforms. This will be of particular relevance when using permanent capping/sub-base layers as temporary roads or working platforms. The documents can be obtained free of charge via the Highways Agency website[6].

2.10.1.5 Highways Agency, Specification for Highway Works

This [19] comprises Volume 1 of the Manual of Contract Documents Highway Works and provides a specification widely used for granular working platforms. It will be of particular relevance when using permanent capping/sub-base layers as temporary roads or working platforms. In particular, Series 600 and 800 provide specifications for formation preparation, suitable fill materials and compaction regimes. The documents can be obtained free of charge via the Highways Agency website[7].

2.10.1.6 Network Rail, NR/L3/INI/CP0063 Piling adjacent to the running line

This document [20] provides Network Rail's requirements for the undertaking piling operations close to an open line (trains still running). It provides detailed advice on the design and approval of piling platforms together with detailed information on the risks and controls associated with the operation of various types of piling rigs and cranes.

At the time of writing, NR advises that NR/L3/INI/CP0063 is under review and a number of modifications in scope and content are proposed, e.g. the principles used should not just be limited to cranes associated with piling works. It is recommended that the reader seeks clarification on the applicability and scope of CP0063 from NR for all works involving cranes

2.10.1.7 Construction Plant-hire Association, Ground conditions for construction plant

This document [21] provides general information on the management of plant stability and is mainly aimed at SMEs. It provides useful background on specific considerations for various types of plant. It also introduces basic

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[5] *New edition due in 2019*

[6] *http://www.standardsforhighways.co.uk/ha/standards/dmrb/*

[7] *http://www.standardsforhighways.co.uk/ha/standards/mchw/vol1/index.htm*

considerations for identifying ground and ensuring adequate plant stability including basic table for outrigger pad capacity. The document also includes a simplified method for calculating the bearing capacity of outrigger pads.

NOTE: The method used for assessing ground bearing capacities is based on a now withdrawn (1986) version of British Standard BS 8004, Code of practice for foundations.

2.10.2 Research Papers

2.10.2.1 Meyerhof / Hanna (1974, 1978, 1980, 1981)

Three papers (1974 [22], 1978 [23], 1980 [24]) relating a laboratory study on the ultimate capacity of footings on a granular layer over a cohesive subgrade together with a similar study of a strong granular layer over a weak granular layer (1981 [25]). The results of this work forms much of the basis of the analytical method used in BRE BR470.

In particular, the use of a reduced value for the effective angle of friction at the punching boundary is discussed. In addition, the 1980 and 1981 papers provide a more accurate method of assessing the ratio δ/ϕ based on the ratio of bearing capacities q_2/q_1, in the case of a cohesive formation, and the ratio of shear strength ϕ_2/ϕ_1, in the case of a granular formation.

2.10.2.2 Milligan et al (1989)

A paper in two parts, the first [26] outlining the theoretical analysis and the second [27] providing supporting evidence. These papers complement the analytical method described in CIRIA SP123. The main point of interest is that the assumed zero friction, between the base and the top of the granular platform, appears to be strongly supported by the results of large scale tests.

2.10.2.3 Burd and Frydman (1996)

This was a parametric study [28] using numerical (finite element and finite difference) methods on the capacity of footings on a sand layer overlying clay. The study showed that the angle of load spread varies (β=0°-55°), depending on the relative stiffness of the platform compared with the subgrade.

Interestingly, possibly counter-intuitively, the results suggested that the load spread angle will reduce as the subgrade strength increases. Further, it appears to suggest that load spread angles equal to or less than the normally accepted 1h:2v should be expected for most working platform configurations.

NOTE: This does not cover granular subgrades.

3 Overall design

3.1 Design brief

The design brief should be developed as normally required (for any temporary works design) but in particular the following information must be obtained/supplied if relevant:

- Plant data sheets (dimensions, configurations, weights, axle loads, etc.).
- Outrigger loads or track ground bearing pressures from the supplier.
- Full ground investigation report (or relevant borehole sections).
- Details of any load spreading measures to be used, e.g. outrigger pads, timber mats.
- Plan of the working platform and/or haul roads.
- Lift plan.
- Topographical survey.
- Existing services survey (above and below ground).
- Existing structures survey (below ground chambers, retaining walls, etc.).
- Constraints on reduced levels (formation, top of platform).
- Proposed compaction plant/method.
- Period (from date to date) of use.
- Any information on existing shallow mining activities or other potential void inducing activities (i.e. chalk or salt dissolution, etc.).
- General construction traffic and their payloads including type of lorries, wagons, etc. to be used to construct the working platform and an estimate of their total journeys.
- In-service construction traffic, i.e. any plant, other than piling rigs or cranes, that will traffic the working platform following its completion and during its design life.
- Any works that may involve excavating through the platform and planned method of reinstatement.

3.2 Design life

In general, granular working platforms are in service for less than a year although, on large projects, they may be in service for a number of years. The durability of the platform should be considered in terms of its overall structural integrity (based on limits of deformation) and the resistance of the surface to mechanical degradation. This is only partially affected by the intended working life time as most of the impact is due to use. The effects of weather may, however, need to be considered so the period that the platform is in the most use (e.g. if it is to be heavily trafficked during the winter) may be relevant.

Whilst the platform may be used as a 'temporary' platform for a short duration, if it is to be subsequently incorporated into the permanent works then the platform materials need to satisfy any durability requirements as specified by the permanent works designer.

3.3 Design check category

As with all temporary works, it is recommended that any design is appropriately classified in terms of the 'design check category', as recommended in BS 5975:2008+A1:2011, Code of practice for temporary works procedures (etc.).

Normally, the design of working platforms is expected to fall into Category 1 or Category 2. However, the selection of design check category depends on the circumstances of each specific case (certainty of the input information, complexity of the design, the scale of the work, likely consequences of failure). It is not, therefore, possible to be definitive but further advice can be found in TWf2014:02 'Client's guide to temporary works' [29].

3.4 Design information

3.4.1 Site/ground information

Sufficient general information about the site will normally be available, in the scheme design details and ground/site investigation reports, to obtain a general understanding of the site topography and geology. This can be of particular relevance in establishing locations that may have deeper deposits of made ground, underlying soft strata or mine workings.

However, even when a relatively comprehensive investigation has been undertaken, the scope of ground investigations frequently omits the necessary detailed investigation and testing needed for the design of temporary works. Working platforms are no exception to this, unless the GI is intended for the design of a road/rail structure. Where it is intended for the design of permanent structural foundations, there is often little more than descriptions of upper soil strata available.

To further address any lack of information, the recommended approach is to use one or a combination of the following:

- obtain further information from the site team;
- use appropriately conservative parameters based on available soil descriptions;
- provide a range of solutions for different ground conditions together with a suitable inspection and testing regime to be used during construction.

3.4.1.1 Available ground information

Detailed information on the results of field investigations, in-situ testing and laboratory testing will be found in the Factual Report. Further useful guidance may be available within an Interpretive Report. In some instances, the design must be based on a Geotechnical Baseline Report as this forms part of the contract.

Further information may also be available via the British Geological Survey website. The interactive map of on-shore boreholes provides general information about superficial and underlying deposits together with numerous borehole records. Although the quality of information in the boreholes is highly variable, there is often enough information to proceed with the design, even if it needs to be heavily qualified.

3.4.1.2 Additional ground investigation

Examples of simple inspections and tests that can be carried out by the site team might include:

- **Trial pits** – To a suitable depth below formation accompanied with visual and tactile inspection and description of soils including consistency/density.
- **Use of simple in-situ test equipment** – What these lack in accuracy is compensated for in quantity of tests that can be economically carried out to provide confidence in consistency across a site:
  - **Pen penetrometer** – Very quick and portable; provides direct reading for cu.
  - **Clegg impact hammer** – Provides a direct reading that can be correlated to CBR; use where a large area needs to be surveyed to provide qualitative understanding of changes in ground across the site

NOTE: The correlation to CBR values is not entirely accurate and ideally should be supplemented with a limited number of CBR tests.

  - **Hand shear vane** – Provides a direct reading of c_u; results need to be treated with caution as they are subject to operator error.
  - **MEXE Cone penetrometer** – Provides a direct reading of CBR to a depth of 600mm into the formation; primarily for clay subgrades.

- **Ground penetrating radar** – Provides indication of sub-surface structures and services plus will show changes on soil density thus giving qualitative data on strata and soft spots;
- **Checks on water levels** – In trial pits and/or any available piezometers.

These simple tests should, where appropriate, be backed up with a smaller sample of higher quality tests. In terms of more formal ground investigation methods, that would need to be carried out by a suitably accredited (e.g. by UKAS) organisation, the following are recommended:

- **Plate loading test** – Provide direct results for bearing capacity but are limited by practical limits in terms of plate size and kentledge required; can only be considered to test a limited depth; 300 to 600mm diameters generally preferred but larger 760mm diameter is available; use within trial pits if necessary.
- **California Bearing Ratio (CBR) test** – For haul roads, etc. not requiring a full analytical design the CBR can be used directly but the full test results can also be used to derive in-situ bearing capacity and soil parameters by back analysis; can only be considered to test a limited depth.
- **Dynamic probe** – Useful for qualitative investigation of underlying strata but can be used to derive quantitative values such as CBR and c_u;

NOTE: The correlation to CBR values is not entirely accurate and ideally should be supplemented with a limited number of CBR tests.

- **Standard Penetration Test (SPT)** – Associated with boreholes and window samples but recognised as a commonly accepted means of assessing soil consistency and strength; where additional window samples and borehole are ordered, ensure that sufficient near surface SPT are requested.

It should be noted that the results of CBR and plate loading tests on clays are weather dependent and should be used with caution. During summer months, clay may appear significantly stronger than during the winter when its moisture content is higher. Reliance on results obtained during the summer may lead to significant overestimation of bearing capacity.

It should also be noted that CBR tests and plate bearing tests are sometimes confused. They may appear the same in principle but CBR tests refer to a reference specimen and should be carried out with a 50mm diameter plunger and limited in scope to particle sizes not greater than 20mm. Plate bearing tests can be of varying size and give a direct value for bearing pressure.

3.4.1.3 Scope of ground investigation

Regardless of the source, it is important to obtain ground information to a suitable depth, which should be greater than the estimated depth of influence (see **Section 4.2.3**). As an initial guide, for bearing capacity checks, it is suggested that the depth of ground investigation should be a minimum of:

- 2m in all circumstances;
- 1.5 times the width for outrigger pads;
- 3 times the width for tracks;
- 5m in at least one location, where the underlying geology is indistinct.

For a design that will include settlement checks, these depths should be doubled. These depths will also need to be increased where there is reason to believe the site has underlying soft ground.

Sampling and testing (both in-situ and laboratory) should be selected to provide the parameters that are relevant to the method of design being used. For working platforms this will normally be some or all of:

- undrained shear strength, c_u
- peak angle of friction, ϕ
- undrained modulus of elasticity, E_u
- California Bearing Ratio, CBR

The number of investigation locations required will depend on a number of factors such as:

- Size of the site – It is recommended that there should be at least:
  - 1 No. appropriate type of investigation point per 1,000m^2, with a minimum of 3 No. per site;
  - boreholes (or window samples), to an appropriate depth, at a maximum spacing of 100m, with a minimum of 1 No. per site.
- Potential consequences and/or risk of failure – For unusually onerous conditions involving a relatively high level potential consequence, both the quality and quantity of investigations will need to be increased, particularly if FEA is expected to be used for the design.

This should be taken as initial guidance only. In all cases, there must be sufficient to allow the designer to make a reasonable assessment of soil parameters to achieve both safety and economy in the design. All investigations and tests must also be undertaken in accordance with accepted practice and current applicable standards.

3.4.1.4 Soil parameters

Where parameters are derived from tests, the derivation of soil parameters should be undertaken by the ground investigation supplier in accordance with Part 2 of EC7. The designer must interpret the derived results to arrive at a suitable characteristic value.

Characteristic soil parameters for an EC7 compliant design should be a “cautious estimate”, which may be taken to be similar to the “moderately conservative” values used prior to the introduction of the Eurocodes. This may be achieved by a suitable empirical estimate or be based on a statistical analysis if appropriate.

3.4.2 Scope of plant/vehicle movements/loads

For any scheme, a general understanding of the scope of plant operations likely take place on the platform should be established including, if appropriate, operations during construction of the platform. This should cover:

- the nature of plant to be used;
- magnitude of loads to be transported/handled;
- any repetitive activities that will take place e.g. number of dump truck movements;
- contingency for un-planned movements.

3.4.3 Load data for individual plant and vehicles

The information about plant and vehicles should be obtained directly from the manufacturer and/or supplier as appropriate. This may include the following:

- dimensional information – overall and for individual components, various configurations;
- weights – overall and for individual components including counterweights;
- lift capacity charts;
- outrigger loads;
- track pressures and bearing lengths;
- axle layouts;
- axle/wheel loads;
- tyre pressures;
- turning circle dimensions;
- vertical clearance requirements.

In particular, it is preferable that the outrigger loads and ground bearing pressures should be obtained from the manufacturer/supplier. This may range from a simple ‘worst case’ rating to values calculated using plant specific software. It is important in all cases to understand whether:

- the values provided are simple static values or if they have an allowance for dynamic effects built in;
- effects of wind have been allowed for;
- ancillary attachments have been accounted for;
- effects of an out of plumb condition have been considered.

Currently, much of the information provided, does not include for the effects of wind loading, unless specifically requested by the platform designer. This can prove to be significant in specific circumstances e.g. crane lifts of turbine blades.

At present, however, there are still some suppliers who are unable to provide such information due to the use of old plant which didn’t carry any such data. In these cases it is still necessary for the best information available to be obtained even if it means the supplier undertaking direct testing. For example, there would be nothing preventing the supplier of an old crane from physically measuring all of the key dimensions and undertaking load cell tests for various lift configurations.

3.4.4 Platform fill

The nature and shear strength of the platform material is of great importance as the analytical design can be particularly sensitive to the exact value of internal shear strength available. Due to this factor alone, the exact quantitative and qualitative nature of the fill material and its specification should be treated as being of high importance.

It has been common practice to use simple general descriptions such as “75 down crusher run” or “hardcore” when ordering fills for hardstandings, haul roads and working platforms. However, in the interests of ensuring material of suitable strength and thereby minimising platform thickness, it may be worthwhile extending the description to include a more complete specification.

One approach, which has gained a level of general acceptance, is to use standard descriptions as tabulated in the Standard Specification for Highway Works [19], e.g. 6F2 or 6F5 (recycled materials). As a note of caution, it is essential that the full set of requirements contained in the relevant Tables (Series 600) are considered as the type of material, grading requirements and uniformity can vary significantly.

Another approach may be to build a specification from scratch based on previous experience and suggested requirements in recognised guidance. Key items to consider are:

- nature and proportions of base material (crushed brick, concrete, stone);

- exclusion of unwanted contaminants (soil, timber, reinforcement);
- grading limits:
  - limitation on proportion of fines (15% maximum silt/clay sized particles);
  - graded/sized to engage geogrids and avoid local punching of geotextiles;
  - uniformity coefficient (<5 for open graded, >10 for uniformly graded);
  - sized to minimise effects of scrubbing, etc.
- resistance of base material to fragmentation/crushing (10% fines test, Los Angeles Coefficient, etc.);
- particle shape (should be angular/sub-angular).

Other matters the designer should consider, with regard to material specification, include:

- The type of material selected should suit the conditions, preferred construction methods and/or available plant:
  - gap graded materials placed with little compaction provide in-situ shear strength values in the range ϕ=35°-40°; the platform will be thicker but relatively little compactive effort is needed;
  - conversely, well graded materials require proper compaction in layers but will provide a much higher in-situ shear strength values (ϕ=45°-50°) resulting in thinner platforms.
- It has been shown that the shear strength is also significantly affected by contamination; for example, introduction of 20% slurry content has been shown to reduce the shear strength by approximately 10°.
- Larger maximum particle sizes tend to provide higher values of shear strength due to scale effects of the ratio of particle size to platform depth and wheel/track/pad width.
- Maximum particle size must be limited, as follows:
  - not greater than 150mm in all cases;
  - not greater than $^{2}/_{3}$ the size of compaction layers;
  - to suit the operation to be undertaken, e.g. 75mm maximum may be needed for driving piles.
- If the platform material is very well graded and heavily compacted it may be difficult for some equipment, e.g. it has been known to be necessary for platforms to need to be pre-bored through to allow penetration of a Vibroflot.

Ultimately, regardless of the method of specification, it is advisable to obtain specific test data for a particular material source to confirm suitability. Key information would be the type of material, grading curve and large shear box results.

The design value of the shear strength for the platform material is a subject of debate among practitioners, with some asserting platforms can have a very high strength while others take a more conservative view to account for deficiencies in material, construction and maintenance. Ultimately, when assessing the characteristic shear strength of the platform material, the designer must take due account of a number of factors such as:

- nature of the fill material;
- proposed method of compaction;
- planned inspection and testing;
- expected maintenance regime;
- expected amount of traffic;
- duration that the platform will be in use;
- possible effects of weather;
- likelihood of significant contamination.

Table 1 illustrates the variation of platform shear strength, depending on the particular circumstances. It should be noted that the figures provided are purely indicative and are intended as a guide to values that might be appropriate.

Table 1 – Indicative characteristic shear strength values for platform fill

Description	ϕ_{fill}	Quality controls
Brick and concrete “hardcore” laid with little to no compaction and not protected from contamination	30-35°	Little to no quality control or maintenance
Specified gap graded material laid with nominal compaction and protected below with geotextile	35-40°	Nominal quality control and maintenance
Specified well graded material laid and fully compacted to DoT Specification and protected below with geotextile	40-45°	Full quality control; regular inspection and maintenance
Specified well graded material laid and fully compacted to DoT Specification, formally tested and protected below with geotextile	>45°	Full quality control; test results reviewed by designer; regular inspection and maintenance

In addition, when considering the results of shear box tests it is important to be aware that:

- shear boxes that are undersized (relative to aggregate size) may produce misleading results, with shear strength being potentially overestimated by up to 10°;
- the characteristic value should be determined at a 95% percent confidence limit; this can be up to 10° less than the mean;
- to obtain a statistically meaningful characteristic value requires at least 3 random samples to be tested; further samples will increase the degree of certainty and may improve the characteristic value itself;
- peak values may be used for fully compacted material; constant volume values should be used if compaction is expected to be minimal.

3.4.5 Geosynthetics

Geosynthetics used in working platforms are usually geotextiles or geogrids. These may be supplied separately or bonded together as a single product. Geotextiles are primarily used as a protective separation layer to reduce contamination of the platform material but will also provide a degree of reinforcement/ stabilisation. Geogrids are used specifically to provide reinforcement/stabilisation of the granular fill. Geosynthetic cellular confining systems may also be used in working platforms, to provide stabilisation, but these are far less common.

Where geosynthetics are laid beneath or within a granular platform, they will act to improve the structure of the platform and minimise deformations during trafficking and loading through either or a combination of the following two principal mechanisms:

- tension membrane effect;
- lateral restraint via friction and/or interlock/ confinement.

As the geosynthetic acts in tension under the load, it restrains the outward movement of the fill material (from under the load) and thus reduces or eliminates horizontal shear on the formation, thereby, improving the bearing capacity. In addition, by improving interlock/confinement, the geosynthetic acts to increase the load spread angle, thereby increasing the effective bearing area and the overall bearing resistance.

For reinforcing geogrids, in order to mobilise its tensile strength, the geosynthetic would need to strain and the deformation needed to mobilise this mechanism could exceed the serviceability requirements of the working platforms. Thus, when reinforcing geosynthetics are used in working platforms, the tensile strength used should be for small strains, typically in the range of 2 to 5%, in order to keep the mobilising deformations within acceptable limits.

For non-reinforcing stabilisation geogrids, the mechanism is lateral restraint and interlock/ confinement. The radial stiffness of the geogrid

Return to the contents

limits the lateral strains, thereby, restricting lateral aggregate particle movement, increasing the load spread and consequently improving the bearing resistance.

Another way geosynthetic can improve platform performance is to confine the lateral movement of the lowest layers of the fill when they are compacted. When the reinforcement is not in place, the weaker underlying formation will not provide as much restraint, which results in less dense/strong layers of fill near the formation. With the reinforcement in place, the strength of the platform material is improved both overall and particularly close to the formation.

The inclusion of all geosynthetics also helps improve the ability of working platforms to resist repeated/cyclic loadings by reducing subgrade strain/deformation. Studies have demonstrated that the fatigue resistance of reinforced/stabilised platforms is significantly higher than that of platforms without geosynthetics, resulting in increased design life. This is particularly applicable to the provision of haul roads and hardstandings, due to the duration and frequency of use. It should also be noted that the introduction of a geosynthetic can also reduce differential settlement thus providing improved stability of plant.

It is important to note that sufficient deadweight is required over a geosynthetic to prevent it from pulling laterally through the ground and to allow it to strain adequately to do work when loaded. A minimum thickness of fill and an anchorage length may, therefore, need to be specified. Where it is not possible to achieve the necessary anchorage length, one solution is to wrap the geosynthetic back into the platform. In all cases, the supplier's advice should be sought.

Geotextiles used for working platforms must have sufficient resistance to puncture to minimise damage from the fill in order to maintain exclusion of contaminants and tensile capacity. They must also be sufficiently porous to allow drainage of the platform material.

All geosynthetics used for working platforms should be configured to provide an equal degree of restraint longitudinally and transversely to any load. This may be achieved through the use of multiple cross laid uniaxial geosynthetics. If any doubt exists, the properties in the weakest direction must be used for the purposes of design.

The particle size of the fill needs to be related to the mesh size of any geogrid selected. Conversely, where a certain fill has been selected, the geogrid needs to be selected to suit the specified maximum particle size. It is recommended that the designer should refer to the relevant manufacturer's product data and/or technical support team to confirm suitability in either case.

Various characteristics are needed for the analytical design of reinforced/stabilised platforms and may include some or all of the following:

- tensile strength – at an acceptable level of strain;
- stiffness – to avoid undue deformation under loads;
- load distribution improvement ratio;
- geometric properties of geogrid – together with any limitations on fill particle size;
- friction characteristics – for pull out;
- punching resistance;
- resilience against damage;
- durability in service;
- maximum spacing between layers;
- minimum depth of fill over the uppermost layer;
- minimum lap length and/or jointing requirements;
- product specific partial factors;
- empirically proven performance characteristics.

In all cases, it is important to note that the contribution of the geosynthetic to the performance of a granular working platform varies between the different types of geosynthetics available in the market. Direct substitution of alternative geosynthetics in proprietary geosynthetic working platform designs is considered inadvisable due to the specific differences in product development. It is, therefore, strongly recommended that any geosynthetic substitution should be accompanied by a geosynthetic specific design.

3.5 Detailing

3.5.1 Platform thickness

From BR470, the following limits are suggested:

- For platforms without geosynthetic the minimum platform thickness should be the lesser of 300mm or half the track width; the maximum thickness is 1.5x track width.
- For reinforced/stabilised platforms the minimum platform thickness should be 300mm; the maximum thickness is 1.0x track width.
- Minimum cover over geosynthetic reinforcement should be 300mm.

It should be noted that the minimum cover over geosynthetic reinforcement may be reduced to 150mm where further advice is obtained from a geosynthetic manufacturer.

3.5.2 Spacing of geosynthetic reinforcement

Under certain circumstances more than one layer of geosynthetics may be necessary or prove beneficial. While the positioning of the layers within the platform can be relatively arbitrary, it is recommended that:

- they are evenly spaced;
- vertical spacing should not exceed 450mm;
- vertical spacing should not be less than 150mm.

It should be noted that this may be varied where further advice is obtained from a geosynthetic manufacturer.

3.5.3 Geometry

3.5.3.1 Plan layout

This is not generally of critical importance but, depending on the exact circumstances, consideration should be given to:

- adequate working space for the plant and associated equipment;
- edge restriction zones (which must be clearly marked on site);
- horizontal sight lines;
- vehicle turning circles/tracking;
- vehicle/pedestrian segregation; pedestrian zones may be encroached if movement is controlled by a banksman;
- encroachment on key assets/third party properties (e.g. rail);
- encroachment on existing features (such as retaining walls, embankments, water, etc.);
- any adjacent buried structures, basements vaults etc;
- width of temporary roads – are they sufficient for two way traffic and can they see each other approaching in sufficient time, or do vehicles need passing points or traffic control.

3.5.3.2 Vertical alignment

If relevant, vertical alignment should be included in the detailed design. In such cases, consideration should be given to the following:

- maximum allowable gradient for the plant/vehicles when travelling – consider risk of skidding and loss of traction on loose surface material;
- vertical curves for change in gradient – to avoid grounding and maintain vertical sight lines;
- the allowable “out of plumb” for operating plant – operating capacity may be compromised, additional overturning moments may be significant;
- maximum cross camber – in particular adverse camber should be avoided;
- minimum cross falls - to ensure adequate drainage of the formation;
- use of additional thickness at the bottom of ‘ramps’ – to cope with longitudinal loads;
- use of positive drainage at low points – to avoid standing water.

3.5.4 Edge Details

3.5.4.1 Edge distances

This is the perpendicular distance between the outside edge of the loaded patch and the effective edge of the platform, i.e. the top of an unconfined edge.

The minimum edge distance is needed to ensure:

- mobilisation of punching shear resistance within the platform;
- mobilisation of ground bearing support due to platform surcharge (if used);
- pull out resistance of geosynthetic reinforcement (for BR470 method);
- acceptable surcharge condition near embankments or retaining walls.

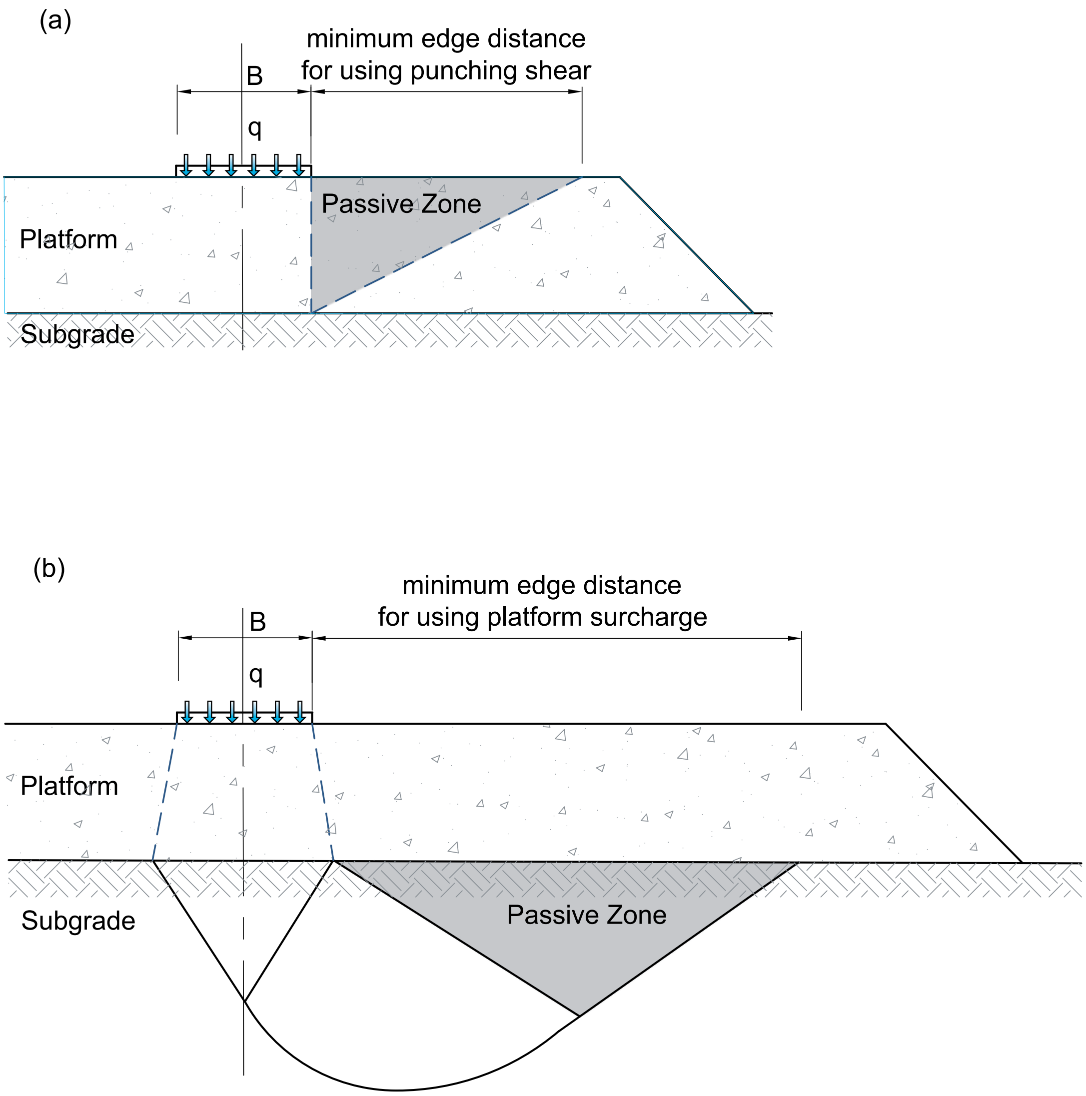


Figure 5 - Minimum edge distances for (a) allowing benefit from punching resistance and (b) allowing benefit from surcharge due to the platform)

Typically the dimension used will be the greater of:

- The width of the 'passive zone' within the platform needed to mobilise the punching shear resistance, **Figure 5(a)**;
- The width of the 'passive zone' within the formation for general bearing failure (where the platform surcharge is considered), **Figure 5(b)**;
- Minimum embedment length advised by the geosynthetic manufacturer – to provide sufficient pull out resistance of geosynthetic reinforcement (this applies only when using BR470 method);
- Nominal minimum of half the machine width (this applies only when using BR470 method);
- As specified by project specific slope or retaining wall stability calculations (where applicable).

The edge of the working area must be clearly marked to define an exclusion zone between the working area and the edge of the platform.

Where geosynthetics are used, and there is insufficient width to provide the required embedment, additional advice should be sought from the manufacturer with regard to achieving pull-out resistance.

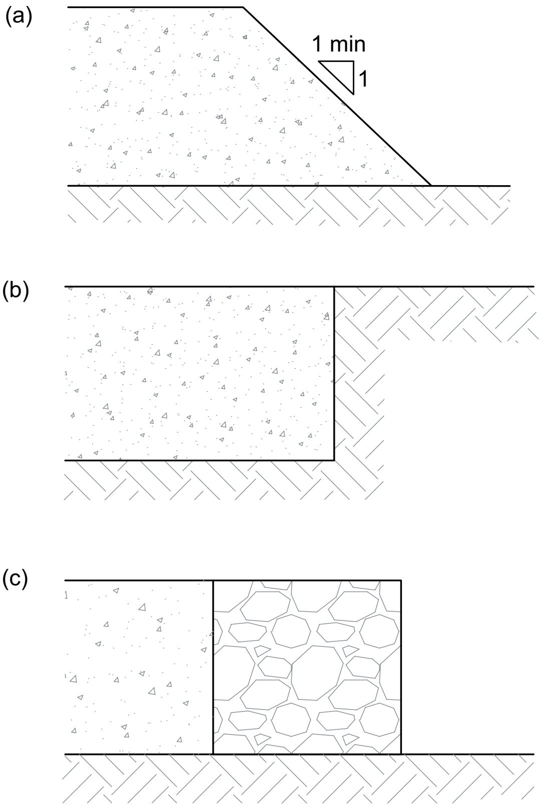


Figure 6 - Suggested acceptable edge restraint details - (a) free edge, (b) road box, (c) gravity wall (e.g. gabion baskets)

3.5.4.2 Edge restraint

Not usually considered to be a feature of working platforms as, in practice, an un-confined edge is considered normal. However, where edge distances cannot be achieved some other form of edge confinement may be required.

Depending on circumstances, the following restraints may be used:

- edge of the ‘road box’ where it cuts into sub-soil, **Figure 6(a)**;
- geosynthetic reinforced/stabilised ‘retaining wall’ arrangement, **Figure 6(b)**;
- small gravity walls such as gabion baskets, precast concrete road barriers, interlocking pre-cast blocks (e.g. Legato), timber baulks or concrete filled sand bags, **Figure 6(c)**.

Where necessary – due to depth of fill or site layout – additional design calculations may be required to confirm that slopes will be stable at free edges or that any lateral loading from the platform will be adequately supported by the proposed edge restraint. Such calculations should be undertaken in an appropriate manner and as normally required for slopes or retaining structures.

In addition, any drainage should be constructed in such a way that the edge stability of the working platform is not compromised.

3.5.5 Durability

It is important to maintain both the minimum thickness of platforms and the engineering properties of the fill. If either becomes compromised, the structural integrity of the platform may be in doubt.

The durability of the platform should be considered in terms of its overall structural integrity (based on limits of deformation) and the resistance of the surface to mechanical degradation. It is important, in all cases, to monitor and maintain platforms in an acceptable condition but certain matters should be considered in their design and specification to minimise the amount of maintenance that may be required.

In terms of its structure and surface deformation, the durability of the working platform is controlled by the magnitude, frequency and overall number of loading events it undergoes and this should be adequately controlled by appropriate methods of design. The weather can affect the foundation strength and possibly the overall strength of the platform due to the introduction of moisture. This can be controlled by either considering moisture within the geotechnical design or by introducing appropriate detailing to ensure the platform is adequately drained.

By their nature, the durability of un-bound surfaces is somewhat limited and they will be subject to a degree of scrubbing and other local effects from wheels and tracks, which has the effect of reducing platform thickness. This can be mitigated by use of larger aggregate sizes (or by provision of a bound surface if it will prove economical).

Contamination from fines and water can introduce a slurry into the voids of the granular fill which has the effect of reducing the internal angle of friction and degrading the capacity of the platform. This is likely to be "tracked" in to the platform surface as works proceed and also wet subgrade soils can be 'squeezed' into the platform from below. The overall impact of contamination can be to substantially reduce the internal angle of friction of the platform and make the effective thickness of the platform considerably thinner than the designed thickness, ultimately leading to failure.

Another concern may be the strength of the aggregate, particularly where re-cycled brick is used. It is important to ensure that the crushing strength of the recycled aggregate is suitable. Where 'house brick' may be included in the mix it may be necessary to specify a maximum proportion to be mixed with crushed concrete.

Possible mitigation against mechanical degradation and contamination may include:

- provide a geotextile separation layer to prevent migration of fines/water up into the platform; (This is considered generally advisable unless the whole of the stripped subgrade area is clean granular material.);
- provide a 'sacrificial' layer added to the structural minimum thickness (accompanied with advice to replace said layer if it becomes contaminated);
- where a sacrificial layer is used, a "warning layer" of geotextile may also be incorporated beneath the sacrificial layer;
- use larger open graded materials to minimise disturbance and allow free drainage;
- provide a bound surface (if it will prove economical overall).

3.5.6 Drainage

It is not intended to cover drainage of granular platforms in any detail but, normally, they are expected to be free draining with little to no run-off impact. Single or gap graded aggregates will provide the most free draining platforms but compacted well graded fill should still be sufficiently porous to allow adequate drainage under normal circumstances.

Due consideration should, however, be given to ensuring the formation has suitable falls to allow excess moisture to drain out of the platform, rather than "pooling" at some low point in the middle. If this is allowed to happen it could result in softening of the subgrade.

It should be noted that the falls in the formation needn't match falls at the platform surface. Depending on the type of plant to be used, the surface may need to be at shallower gradients to allow for plant stability.

In some cases, however, positive drainage of some form may have to be provided e.g. if any form of surfacing is introduced or if there are low points in the formation where water may accumulate. In these cases it is further recommended that any:

- positive drainage is contained/discharged using SUDS type solutions where possible;
- final discharge of run-off should be subject to the same controls as other water discharges, e.g. from excavations.

3.6 Production information

3.6.1 Drawings

The content of drawings depends on the exact requirements (sometimes Client-driven) and may range from a marked up contract drawing to a fully detailed drawing issued for construction. In all cases, the information conveyed must be adequate for the site team to be able to safely construct the platform. The information may include:

- **Platform structure detail** – Full details of materials, thickness, edge detail, expected underlying subformation.
- **Plan layout and finished levels/gradients** – Particularly where different platform structures will be used in different areas, distances from boundaries or other structures are of significance or where approval is sought from a third party; where appropriate include reduced levels for the formation and/or top of platform.
- **Long sections and cross sections** – May be needed for take-off or where gradients or transitions are important.
- **Further details, if appropriate** – e.g. drainage, surfacing.

It is also preferred that general specifications; inspection and testing requirements; SHE information; and, further instructions for maintenance and repair should be included on the drawing. Where this is not possible a clear reference to other documents containing that information should be included.

A sample drawing is included in **Appendix E** which shows the level of information that is appropriate to the design of a working platform for a piling rig.

3.6.2 Specifications

The specification for construction of the platform should cover materials, workmanship and use. It should generally be based upon or refer to standard specifications (e.g. Specification for Highway Works), standards, guidance documents and/or supplier literature.

Exact content will vary but may include (as necessary and if required):

- material specifications for fill and geosynthetics including any testing requirements;
- method specification for layers, passes, compaction plant – usually by reference to a standard specification;
- instructions for the identification removal and replacement of obvious 'soft' spots; this may include proof rolling or use of GPR;
- dimensional tolerances – including minimum thickness and edge distances for the platform, lap lengths for geosynthetics, tolerance on levels and plan positions, central positioning of outrigger on pad;
- caution/instruction referencing maximum travelling and operating speeds (e.g. rope speed, slewing speed, etc.) if these are considered to have a significant effect.

3.6.3 Inspection and testing

Any inspections and tests that are deemed necessary to confirm the adequacy of the construction should also be included by the designer. This may include separate testing for both the formation and finished platform to confirm that strength and deformation parameters are within acceptable margins and/or comply with design assumptions. The type, frequency and acceptance criteria should be provided for all specified tests. All applicable standards and/or equipment supplier's guidance for execution of tests should also be referenced.

Tests that might typically be used are:

- **Plate bearing tests** – Small diameter plate bearing tests can be used to check the platform and formation separately; back analysis can be used to check the installed platform complies with strength and/or deformation parameters used in the design; when testing the working platform material, the plate diameter must not exceed 50% of the working platform thickness but should be at least three times the maximum particle size.
- **Light weight deflectometer** – Relatively portable and quick to use; provides a rapid indication of in-situ elastic modulus.
- **Clegg impact hammer** – Provides a general indication of strength and deformation characteristics; due to its portability and speed of use, can provide a rapid indication of consistency over a larger area; if required the readings can be related to CBR.

NOTE: The correlation to CBR values is not entirely accurate and ideally should be supplemented with a limited number of CBR tests).

- **Nuclear density meter** – Can be used to determine the relative density of the in-situ compacted platform material and thereby confirm likely strength parameters.

The frequency of plate bearing tests should be:

- For the working platform:
  - a minimum of three tests per site;
  - at least one test per 500m^2 for sites up to 3,000m^2;
  - at least one additional test per 1,000m^2 for areas over and above 3,000m^2.
- For the subgrade, as for the platform but this should be increased if the subgrade is known to be significantly variable over the site;
- In all cases, additional tests should be carried out if initial results are variable.

In particular, when dealing with access roads/working platforms over peat, what is encountered on site is often at variance to the ground investigation (GI) information. In addition, the actual effects of rapid loading and unloading cycles in sensitive soils such as peat are unpredictable. As such it is recommended that:

- soil properties should always be confirmed on site prior to construction;
- actual settlement performance should be monitored as the pavement construction is advanced and compared with criteria assumed in the design;
- provisional platform thicknesses should be provided to meet a range of possible conditions to allow any necessary variations to be made as soon as possible after the site observations.

3.6.4 Safety, health and environmental (SHE) information

It is not expected that the Designer's Risk Assessment (DRA) will identify any unusual or significant health and safety risks or that any significant environmental impacts will be identified in relation to working platforms.

Nonetheless, even if no DRA has been completed, it is recommended that the drawing should include a 'SHE box' - or equivalent – to allow the outcome of the designer's assessment to be recorded. This provides an opportunity for the designer to:

- communicate any unusual/significant hazards; or
- otherwise confirm that no unusual/significant hazards were identified.

In addition, a general note should be added to the effect that any significant changes that arise must be referred to the designer. This may include, for example, differing ground conditions, unforeseen obstructions or changes to the permanent works.

3.6.5 Maintenance and repair

Instructions for maintenance/repair should be included by the designer as necessary. These may include, but are not limited to, the following:

- the mat must be regularly maintained during operation to eliminate the presence of any rutting that may occur; maximum allowable rut depth should be stated;
- the mat must be kept free from any build-up of soil on the surface; where necessary contaminated platform material should be removed and replaced with fresh compacted fill;
- soft spots must be immediately removed and replaced with new compacted material as they occur; the softened area should be inspected for the effects of saturation and if necessary additional drainage measures introduced;
- bored piles should be filled up to the top of the platform or the void otherwise supported;
- it is preferable if to avoid cutting through the platform but if it is un-avoidable then it must be reinstated in a manner that maintains the platform's performance; this may be achieved in a similar manner to that for public highway, backfilling in compacted layers with selected excavated material, or with compacted granular material, or perhaps foamed concrete, etc.;
- where geosynthetics are cut through (except by piling), they must be replaced and tied into the layers on all sides in accordance with the manufacturers recommendations; minimum lap length and/or jointing requirements should be included;
- additionally, the capacity of the platform over newly laid services should be subject to a separate check on structural capacity of services installed; in some cases those services may require additional protective measures such as a concrete raft.

4 Analytical design

4.1 Introduction

As discussed in **Sections 1** to **3**, the analytical design of platforms has, historically, been carried out using a number of methods. The industry is currently in a state of transition with the design of temporary works changing over to comply with the structural Eurocodes. With publication of this guide, the current standards and guidance are summarised in **Figure 7**.

The codified methods for the geotechnical design of working platforms within the UK are now governed by BS 8006:2010, for strengthened/reinforced platforms, and EC7/BS 8004:2015, for platforms without geosynthetics. It should be noted that BS 8006:2010 includes a statement that *"… BS EN 1997-1:2004 is not for use in the design … of reinforced soil"*.

BS 8006:2010 does not directly cover working platforms but it does permit the use of the analytical design methods in BR470 and SP123 for the design of reinforced/stabilised working platforms. However, it is also somewhat incomplete as it doesn't cater for circumstances that fall outside of the scope of those two documents. In these cases, it will be necessary to use an alternative method, and it is recommended that this is undertaken with the assistance of a geosynthetic manufacturer.

EC7 is supplemented by BS 8004:2015, as NCCI. In turn, BS 8004:2015 refers to PAS 8812:2015 [30], BR470 and SP123 as guidance for the design of un-reinforced working platforms. Further, PAS 8812:2015 also refers to BR470 and SP123 as suitable methods for the design of working platforms. The direction given is, therefore, somewhat ambiguous as it doesn't preclude the use of BR470 or SP123, but equally does not state that designs undertaken using BR470 or SP123 comply fully with EC7.

This Section (4) is, therefore, primarily intended to provide the reader with advice on a recommended method for the analytical design granular platforms without geosynthetics to satisfy the requirements of EC7 and BS8004:2015. This will be referred to subsequently as the "TWf method". It should be noted that there is no intention that the TWf method should fully replace existing methods but may provide a suitable alternative method, particularly where:

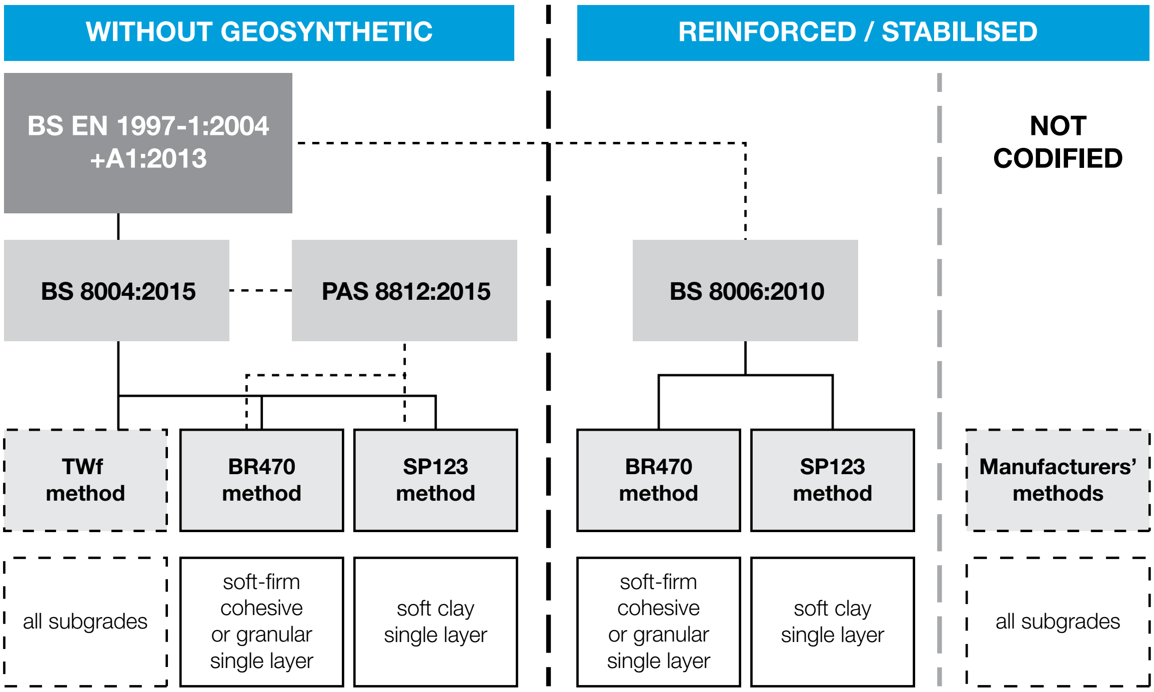


Figure 7 - Relationship of UK design codes to recommended methods for the analytical design of working platforms

- existing methods are not accepted as they are not EC7 compliant;
- multiple soil layers are present.

The details of the TWf method are fully described in **Section 4.7. Sections 4.2** to **4.6** are intended to provide the reader with background information as an aid to understanding the basis of the suggested method.

4.2 Platform and foundation mechanics

4.2.1 The granular platform

The fundamental mechanism employed in providing support to plant and vehicles with a granular platform is the same as that for any other pavement structure. The platform is constructed using material that is stronger than the formation and is intended to reduce the ground pressure imposed on the underlying formation to an acceptable level.

The required thickness of the platform depends on the strength and stiffness of the platform and that of the underlying subformation. In general, the required platform thickness is determined on the basis of a limiting bearing capacity. Alternatively, a limiting deformation/settlement can also be used.

It should be recognised that the load bearing capacity and deformation/settlement are related to the soil-structure interaction. On the one hand, a certain amount of deformation is needed to mobilise the internal strength of both the fill material and the underlying subformation soil. On the other hand, deformation needs to be kept within reasonable limits which in turn limits the bearing capacity.

The mode of failure for a granular platform is that of general downward and outward movement of the platform and underlying formation, as shown in **Figure 8**, leading to:

- vertical deformation of the platform and subgrade beneath the load;
- corresponding upward heave of the formation and platform adjacent to the load;
- outward horizontal strain at the formation.

The horizontal strain at the formation level is indicative of: (a) the development of tensile horizontal strains in the subgrade beneath the footing; and (b) the development of confining passive lateral pressure in the surrounding platform material. Depending on the equilibrium strain condition there may be a certain amount of horizontal shear that develops in the

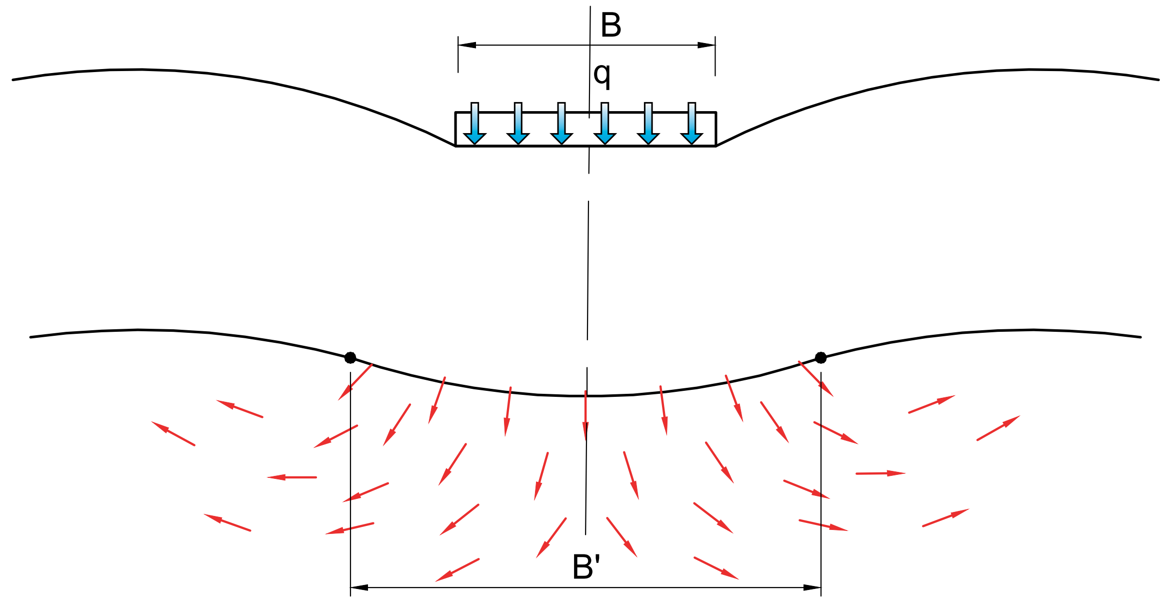


Figure 8 - Displacement vectors for subformation (after Fannin 1986)

subformation. Where the platform is loose and/or the subgrade is very soft that horizontal shear may be significant and will cause significant reduction in subgrade bearing capacity.

It should be noted that the deformed shape of the formation is indicative of an apparent angle of load spread. The concave section directly under the load can be seen to be under a compressive downward pressure. This can therefore be regarded as the bearing area at formation level, shown in **Figure 9**.

The deformed shape, and therefore the apparent load spread angle, will be dependent on a number of factors. Primarily this includes the ratio of platform to subgrade strength and the relative geometry of the patch load breadth to the platform depth.

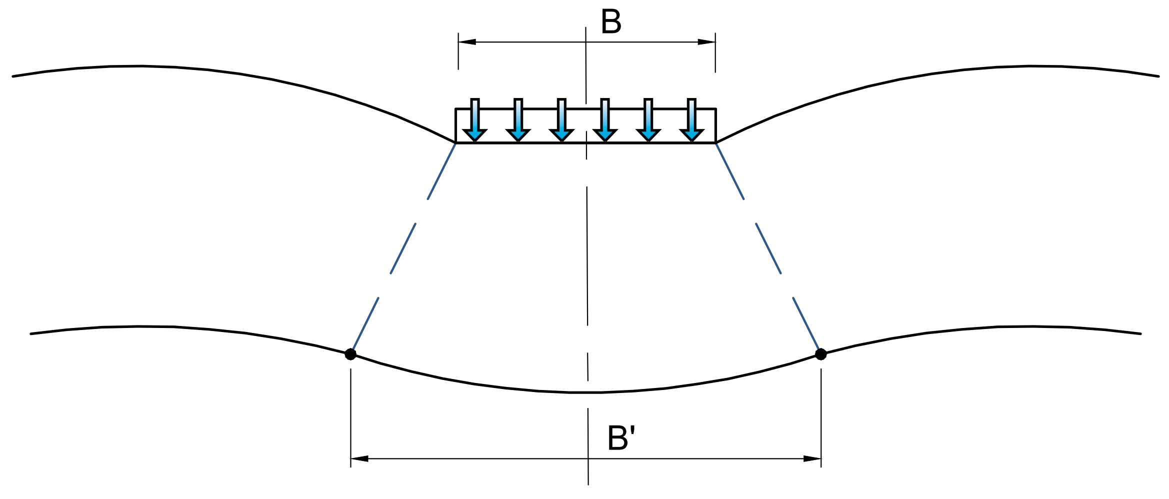


Figure 9 - General form of displacement (after Fannin 1986)

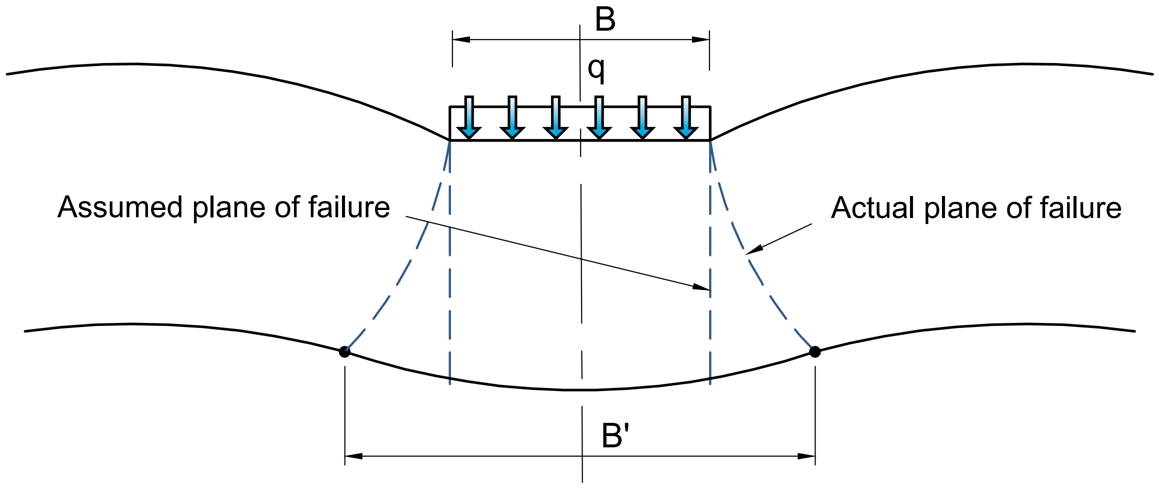


Figure 10 - Actual and assumed punching failure planes (after Hanna 1980)

As the failure develops, the load starts to punch through the platform and curved shear planes develop between the edge of the load and the formation, as shown in **Figure 10**. This leads to the development of punching shear resistance at the perimeter of the load. It should be noted that although the theoretical model for punching adopts a vertical perimeter it should be recognised that $\delta < \phi$. This is due to three main factors:

1. the actual shape of the shear plane is inclined, reducing the effect of the lateral passive resistance;
2. the additional strain needed to mobilise the lower layer means the upper layer exceeds peak shear and mobilised shear strength will therefore be less than peak;
3. the lower layer allows greater vertical strain to take place reducing horizontal strain and thereby limiting the development of passive pressure.

4.2.2 The subformation

The subformation provides resistance to the net load effects from the platform. The mechanics and the formulae for bearing capacity and immediate settlement under load of shallow strip and spread foundations are described in **Sections 4.2.4** and **4.2.5** and more extensively in various texts on soil mechanics and foundation design. (Some recommended texts are listed in **Appendix C**, to which the reader is also referred.)

In brief, at limiting load conditions, shear failure will develop in soils with the exact mode of failure characterised as general, local or punching depending on the strength and stiffness of the subformation.

4.2.2.1 General shear failure

General shear failure occurs in relatively stiff soils of normal density. Shear planes develop in each direction, between the edges of the foundation and the ground surface, accompanied by vertical settlement of the foundation and heave of the adjacent ground, as shown in **Figure 11**. An ‘active’ wedge develops beneath the foundation which is resisted by a ‘passive’ wedge each side, each connected by an intermediate zone defined by a spiral. Ultimate failure is usually catastrophic and occurs very suddenly due to failure of the shear plane on one side resulting in toppling.

4.2.2.2 Local shear failure

Local shear failure occurs in relatively weak and compressible soils of low density. In this case, due to a high degree of soil compression beneath the foundation, shear planes do not fully develop before failure, as shown in **Figure 12**. The ultimate bearing capacity is less well defined than in the general case but failure is relatively slow and primarily observed as excessive settlement with little to no tilting. For most foundations this is not considered ‘catastrophic’ but, as settlement governs, for plant it is important to consider the potential for instability and overturning where this type of failure occurs on one side only.

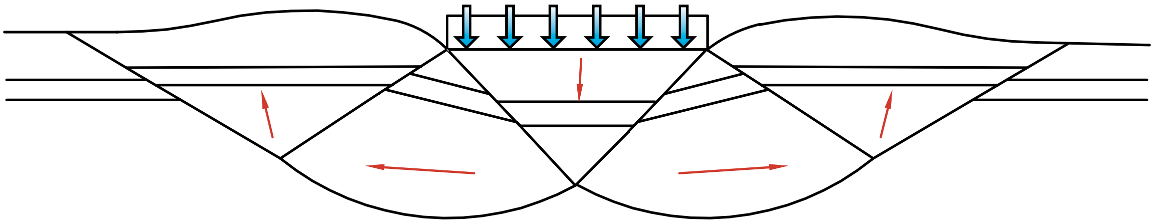


Figure 11 - General shear failure pattern and settlement profile

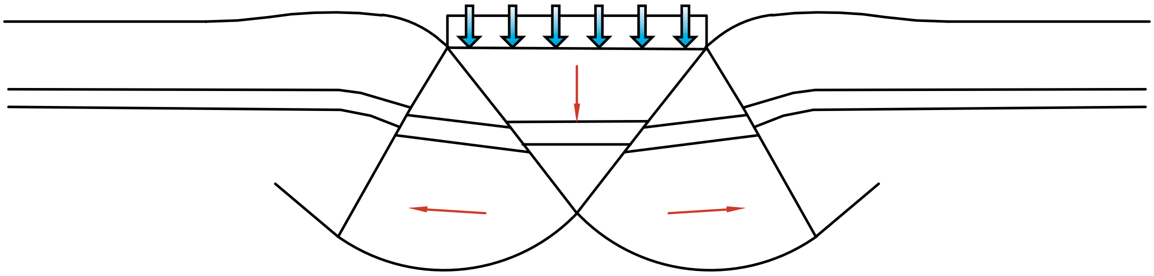


Figure 12 - Local shear failure pattern and settlement profile

4.2.2.3 Punching shear failure

Punching shear failure occurs in very weak and compressible soils with very low density. In this case, the shear planes do not develop. The large settlement is accompanied by vertical shearing around the perimeter of the foundation with no adjacent heave, as shown in **Figure 13**. As for local failure, the ultimate bearing capacity is poorly defined and failure involves relatively slow excessive settlement with no apparent tilting. For most foundations this is not considered ‘catastrophic’ but, as settlement governs, for plant it is important to consider the potential for instability and overturning where this type of failure occurs on one side only.

4.2.3 Depth of influence

It is important to ensure that the bearing capacity and settlement characteristics for the subformation soils are considered to a suitable depth, termed the “depth of influence”. This is an important consideration when determining the depth to which ground investigation should be undertaken. (It is also the reason that small plate bearing tests are not representative of actual plant loads.)

For spread foundation design this has historically been accepted as the depth at which the increase in vertical pressure diminishes to 20% of the applied bearing pressure (q) at the surface. It is normal to adopt the pressure

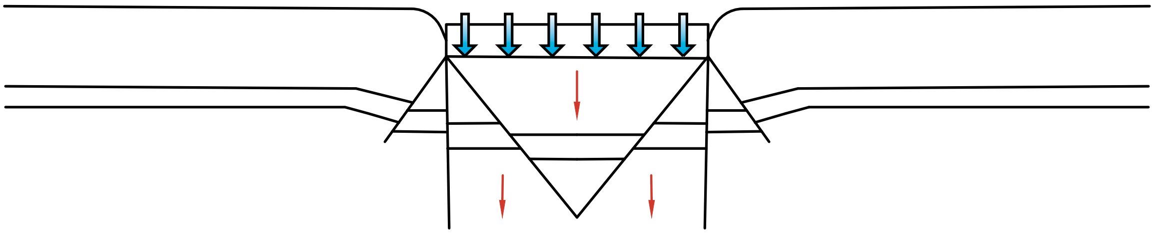


Figure 13 - Punching shear failure pattern and settlement profile

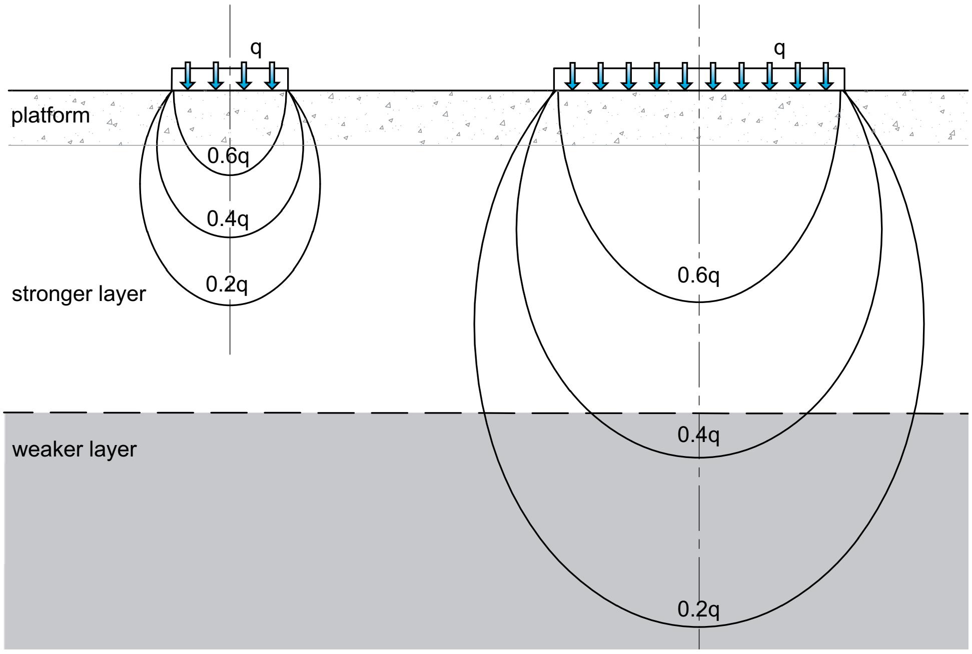


Figure 14 - Depth of influence for bearing defined by pressure bulbs

bulb generated by the Boussinesq formula to define this depth, as shown in **Figure 14**. The depth of influence is dependent on the shape of the footing and is approximately 1.5B for a circular pad and 3.0B for a strip foundation. The key reason for adopting this requirement is to ensure that any underlying soft strata that might influence the bearing capacity are identified and considered.

However, as EC7 includes further requirements for settlement calculations, it should be noted that the 'depth of influence' for settlement is *not* the same as the 'depth of influence' defined for bearing capacity. Instead it is defined as the point at which the increase in vertical stress, due to the applied bearing pressure (q), is equal to 20% of the (existing) vertical stress from the effective overburden pressure, as shown in **Figure 15**.

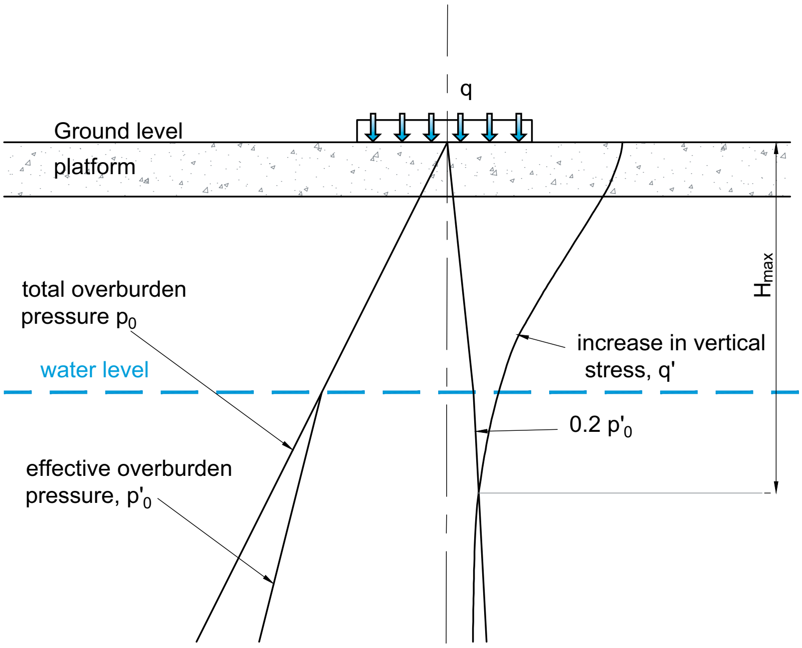


Figure 15 - Depth of influence for settlement defined by overburden pressure

The depth of influence for a granular platform will differ from that of a solid structural footing. The granular platform can be considered to be part of the overall soil depth when assessing the maximum depth of influence for the imposed load. This is because the ground bearing pressure from the load will be dissipated through the granular platform as well as the underlying soil. Consequently the depth of influence for the load is measured from the top of the platform rather than the formation level.

4.2.4 General bearing capacity

The accepted analytical method for calculating the bearing capacity of a formation is to use a form of the equations derived from Terzaghi's bearing capacity theory, as amended by others (Brinch-Hansen, Meyerhof, Skempton, Vesic).

$$q_u = \underset{\text{cohesion term}}{\underset{\uparrow}{cN_c s_c i_c d_c}} \quad + \quad \underset{\text{self-weight term}}{\underset{\uparrow}{0.5\gamma B N_\gamma s_g i_g d_g}} \quad + \quad \underset{\text{surcharge term}}{\underset{\uparrow}{q_0 N_q s_q i_q d_q}}$$

where:

N_c N_γ N_q	are bearing capacity factors
s_c s_γ s_q	are shape factors
i_c i_γ i_q	are load inclination factors
d_c d_γ d_q	are depth factors

The basic mechanism for general shear failure of a rough base is illustrated in **Figure 16**. The ground is treated as either fine grained (c_u>0, ϕ=0) or coarse grained (c_u=0, ϕ>0).

It should be noted that the 'surcharge' term should only be applied if the edge of the platform extends a suitable amount past the edge of the loaded area. This should be taken to be a minimum of 4B for a coarse grained subgrade and 2B for a fine grained subgrade (see also **Figure 5**).

Where soils have an SPT with N<5, local or punching shear failure can be expected at the ultimate limit state (Vesic, 1973). For these types of soils, the characteristic values of c_u and tan ϕ are multiplied by a factor of 2/3 and then applied to the bearing capacity calculation in the normal manner (Terzaghi, 1943).

4.2.4.1 Multiple soil layers

The bearing capacity theory (see **4.2.4**) applies to homogeneous soils. However, bearing capacity must be checked to a depth at which the increase in vertical pressure diminishes to 20% of the applied bearing pressure at the surface.

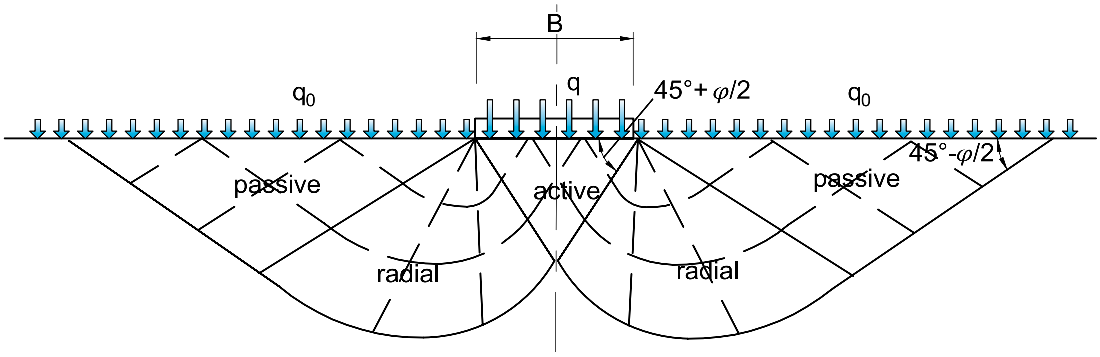


Figure 16 - Definitions for general bearing capacity equation

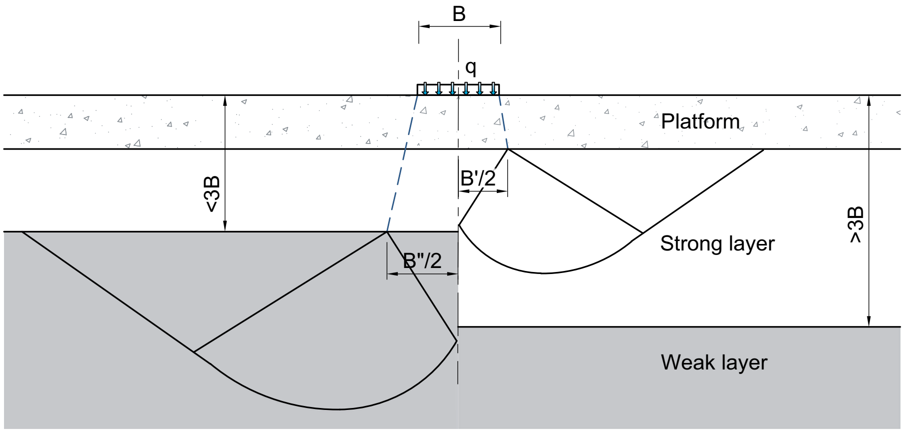


Figure 17 - Definitions for multiple soil layers

Where this depth of soil contains more than one layer, the following rules should be applied:

1. Where depth to top of weak layer > 3B (**Figure 17**, right side), check general shear in the upper layer only (as increase in stress in the lower layer is not considered significant).
2. Where depth to top of weak layer H ≤ 3B (**Figure 17**, left side):
    a for weaker soil overlying a stronger soil, check general shear in the upper layer (ignoring the increased strength of the underlying layer);
    b for stronger soil overlying a weaker soil, check general shear failure for each layer, using a suitably reduced bearing pressure/distributed loading at the interface with the lower, weaker, layer.

The pressure at the interface between layers should be the maximum bearing pressure (under the centre of the load) derived by the Bousinesq theory for elastic stress. The effective area, breadth, length and load spread angle should then be derived using that maximum bearing pressure.

Lateral load effects within the upper layer, resulting in shear stress on the surface of the lower layer, should be calculated in a similar manner to the method adopted for the platform, and the resulting load inclination factors derived for the lower layer.

4.2.4.2 Effect of groundwater

The formula for general bearing capacity assumes that water is at a sufficient depth that it cannot influence the capacity of the formation. However, in practice it may be necessary to allow for groundwater where it is at a level less than B (or B') below the foundation level, as shown in **Figure 18**. This may be achieved by introducing two additional factors, w_γ and w_q, to be applied to the 'weight' and 'surcharge' terms of the bearing capacity equation respectively.

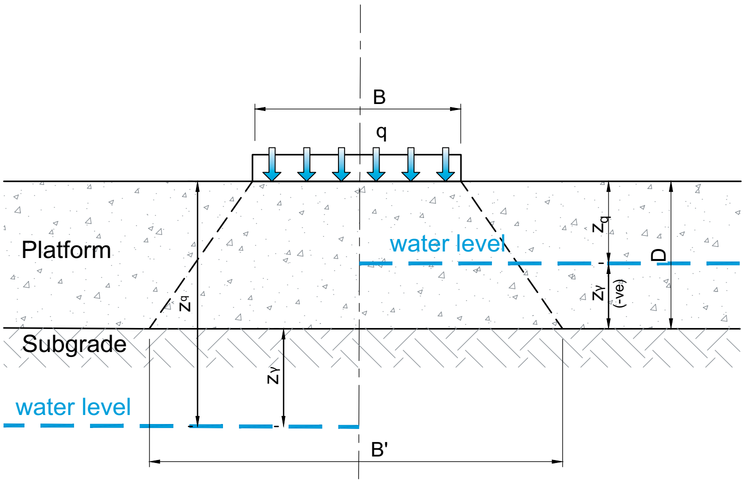


Figure 18 – Definitions for ground water equations

The first factor is applied to the ‘self-weight’ term and is used to reflect the average buoyant weight of subformation soils within a depth equal to the breadth of the foundation and is calculated thus:

$$w_\gamma = 0.5[1+(z_\gamma/B')] \qquad \text{but } 0.5 \leq w_\gamma \leq 1.0$$

where, z_γ is depth of water table below the formation and B’ is the effective breadth of the loaded area.

The second factor is applied to the ‘surcharge’ term and is used to reflect the buoyant uplift applied to the surcharge soils above the formation level and is calculated thus:

$$w_\gamma = 0.5[1+(z_q/D)] \qquad \text{but } 0.5 \leq w_q \leq 1.0$$

where, z_q is depth of water table below the surface and D is the depth of the formation level below the surface.

The respective factors are included in the terms of the bearing capacity formula, from **Section 4.2.4**, thus:

$$q_u = cN_c s_c i_c d_c + 0.5\gamma BN_\gamma s_\gamma i_\gamma d_\gamma w_\gamma + q_0 N_q s_q i_q d_q w_q$$

4.2.5 Immediate settlement

The recommended method is to calculate the settlement for a discrete layer thickness using the theory and formula described by Janbu, Bjerrum and Kjaersli (1956).

The form of the equation for immediate settlement in a discrete layer is given as:

$$\text{Immediate settlement,} \quad \rho_i = \mu_0\ \mu_1\ q\ B\ /\ E$$

Where μ_0 and μ_1 are factors read from graphs in terms of the relative depth of formation below surface and relative thickness of layer below the formation respectively. The overall discrete depth below the surface is defined as described in **Section 4.2.3**. Multiple strata are dealt with by using the different elastic moduli for each layer in turn and summing the individual quantified settlements accordingly.

For further detail, see **Section 4.7.8**. Example calculations are provided in **Appendix D**.

4.3 Functional requirements

4.3.1 Platform strength

The platform material itself should have sufficient strength to resist the direct effects of the imposed load. This includes:

- material strength of the aggregates, dealt with by adopting a suitable specification;
- bearing resistance to vertical actions based on the N_γ term of the accepted formula for general bearing capacity (see also **Section 4.7.5**).

When assessing the bearing resistance of the platform, the possibility of groundwater at or above the formation should be considered and the calculation based on submerged density if appropriate.

4.3.2 Formation bearing capacity

The formation must provide adequate resistance to vertical actions based on the accepted formula for general bearing capacity.

This may or may not include allowance for the following:

- weight of the platform material (as a surcharge component);
- horizontal shear on the formation (from lateral stress in the platform);
- resistance to horizontal shear (by geosynthetics);
- relative stiffness of the subgrade;
- presence of multiple soil strata;
- presence of groundwater;
- proximity of adjacent loads (e.g. groups of outrigger pads).

4.3.3 Deformation/settlements

The formation must be stiff enough to limit deformation/settlement to acceptable limits for the plant in question. This may include both absolute limits or slope limits. The designer should give due consideration to the geometry of the ground and plant and any working limits on verticality for the plant.

The exact acceptance criteria will vary depending on the nature of the plant considered and the gradient of the platform surface. Where ever possible, appropriate acceptance criteria should be obtained from the plant supplier and/or operator which may vary depending on the exact nature and size of the plant and the operation being undertaken. In all cases, the settlement limits should be agreed as part of the design brief.

If it is not possible to obtain clear requirements, suggested guide values for general use are:

- absolute settlement to be not greater than the lesser of B/10 or 50mm;
- differential settlement across tracks to be not greater than 5 mm/m (approximately 0.3°);

- differential settlement across outriggers to be not more than 10mm/m (approximately 0.6°).

A distinction needs to be drawn between SLS and ULS criteria. In most limit state designs, deformation/settlement is treated purely as an SLS criteria. However, in the case of working platforms, settlements can lead to a ULS condition. (In all cases, calculations are undertaken using SLS actions.)

SLS conditions can include those in which an item of plant cannot operate within accepted tolerances (e.g. driving piles) or cannot move (e.g. slewing). The criteria for these conditions will be to meet the stated operating requirements for the plant.

ULS conditions are those which may lead to overturning of plant. The criteria for these conditions will need to be based on what is termed “tolerable settlement” for the individual loads and overall instability resulting from differential settlement.

In general, bearing failure occurs at deformations exceeding 20% of the width of the loaded area. It is also generally accepted that where deformations are restricted to 10%, the calculated bearing pressure can be taken to be the ultimate capacity. This is termed “tolerable settlement”.

By inspection, it can be seen that in general the SLS settlement limits will be more onerous than ULS limits and will, therefore, act as a satisfactory check. However, it should be noted that further consideration may need to be given to the effects of:

- platforms constructed on significantly variable subgrades (including soft spots or hard spots;
- dynamic impact and vibration on loose or soft formations;
- consolidation settlement of clays.

4.4 Actions

4.4.1 Load cases

BR470 established the principle of considering two different load cases for tracked piling plant, based on the level of operational control available:

- Load case 1 = standing, travelling, handling
- Load case 2 = driving, extracting

For load case 2, it is possible for the driver to recover from an impending collapse by ceasing the driving or extracting activity, thus reducing the imposed loads to an acceptable level. For load case 1, no such intervention is possible. To reflect this difference in operational control, load case 2 load factors are generally 75% of the load case 1 factors.

However, for other plant there are generally no such distinctions and factors appropriate to load case 1 should always be used. There are few exceptions to this rule and the loads exerted are unlikely to be of concern (e.g. inclined loads exerted by horizontal directional drilling rigs).

4.4.2 Imposed loads

Imposed loads such as wheel loads, track ground bearing pressures and outrigger loads should generally be available from suppliers of plant. However, there will be instances when the designer needs to calculate imposed loads from first principles (e.g. older plant, to check imposed loads supplied by others).

The magnitude of the imposed loads will include contributions from a number of load elements including plant weight, duty (operational) loads and wind loads. The magnitude will also depend on the exact configuration and displacement of the load elements.

When obtaining imposed loads from a supplier it is necessary to establish whether they already include partial load factors or dynamic enhancement factors. When calculating imposed loads from first principles it is recommended that they are calculated in the first instance as un-factored characteristic loads and further factors are applied later.

A certain amount of caution is needed when considering the loads imposed by outriggers when used in conjunction with tracks or tyres, e.g. CFA piling rigs, mini piling rigs, loader lorries, MEWPs, tele-handlers. Due to the statically indeterminate load condition, it is frequently assumed that the full load is sustained by the outriggers which can result in significant over-estimation of the loads on the outriggers.

While operational loads may be completely sustained by the outriggers, they are usually partly carried by the tracks or tyres. For example:

- In the case of piling rigs, the outriggers will be operated with a pressure relief valve that allows the ground pressure exerted by the feet to be balanced with and matched to that exerted by the tracks;
- In the case of lorry loaders, the outriggers are intended to act as stabilisers with most of the load still carried by the tyres.

In such cases, it is preferable to use loads derived from test data, if possible. The reader is advised to obtain advice from the supplier/manufacturer.

It is not normally considered necessary to design granular working platforms for horizontal imposed loadings such as braking, accelerating, 'nosing', cornering, etc. However, certain circumstances may require more detailed consideration, for example where gradients exceed 1 in 10.

4.4.2.1 Plant weight

In all cases, the basic weight of the plant will need to be included in the assessment. Accurate weights, sizes and relative positions of all major individual components are needed, preferably together with centres of gravity.

Typically the major components for a mobile crane might only include chassis, vehicle cab, crane cab, counterweight and jib. However, this level of detail is sufficient to obtain reasonably accurate results.

4.4.2.2 Operational loads

Operational loads may include pile driving or extracting, crane lift loads, transported payloads, etc.

As with plant weight, the weights of items being lifted may be provided by a supplier or they might be assessed by direct calculation based on volume and density. It is also important to consider the volume, density and projected area of lifted objects. Items of relatively low density and large surface area could be subject to a 'sail' effect which can cause significant horizontal forces and increase the effective radius of lift.

The operating force applied (e.g. by piling or drilling rigs) will need to be provided by the plant supplier. It is also important to understand whether the data supplied allows for dynamic effects (e.g. due to vibration).

4.4.2.3 Wind loads

It should be noted that wind loads are not always included in loadings provided by the plant supplier. For some plant items and for certain configurations it may be possible to ignore the effects of wind due to the nature of the plant and/or the operation of the plant being limited to working wind speed.

However, for many items of plant and for certain types of load the wind loading can be critical. It may, therefore, be necessary to calculate wind effects from first principles.

Wind loads should be obtained from BS 5975 and/or EC1, in particular Clauses 3.1 and 4.7 of BS EN 1991-6:2005. For temporary situations the wind pressures may be reduced (compared with permanent situations) as follows:

- Where operational controls are known to apply, such as a working wind speed, it is reasonable use wind loads based on that speed.
- The basic wind pressures may be modified by applying a probability coefficient, c_{prob}. The probability coefficient is related to a return period which is in turn related to the expected duration of the works (e.g. for a duration of less than 3 days, a return period of 2 years is recommended and $c_{prob} = 0.83$).
- A seasonal factor, c_{season}, may also be used for works undertaken entirely within a certain time of the year (e.g. during summer months, April to September, $c_{season} = 0.83$).

4.5 Derivation of ground bearing pressure/ patch loads

4.5.1 Outriggers (and spreader pads)

It is preferable to obtain outrigger loads calculated by the plant supplier for the specific task. There are occasions when it may be necessary or desirable to derive these from first principles. The initial calculation is undertaken for the minimum and maximum values of the outrigger loads based on plant, duty and wind loads, as indicated in **Figure 19**. These are then converted to a patch load depending on the shape and size of the spreader pad.

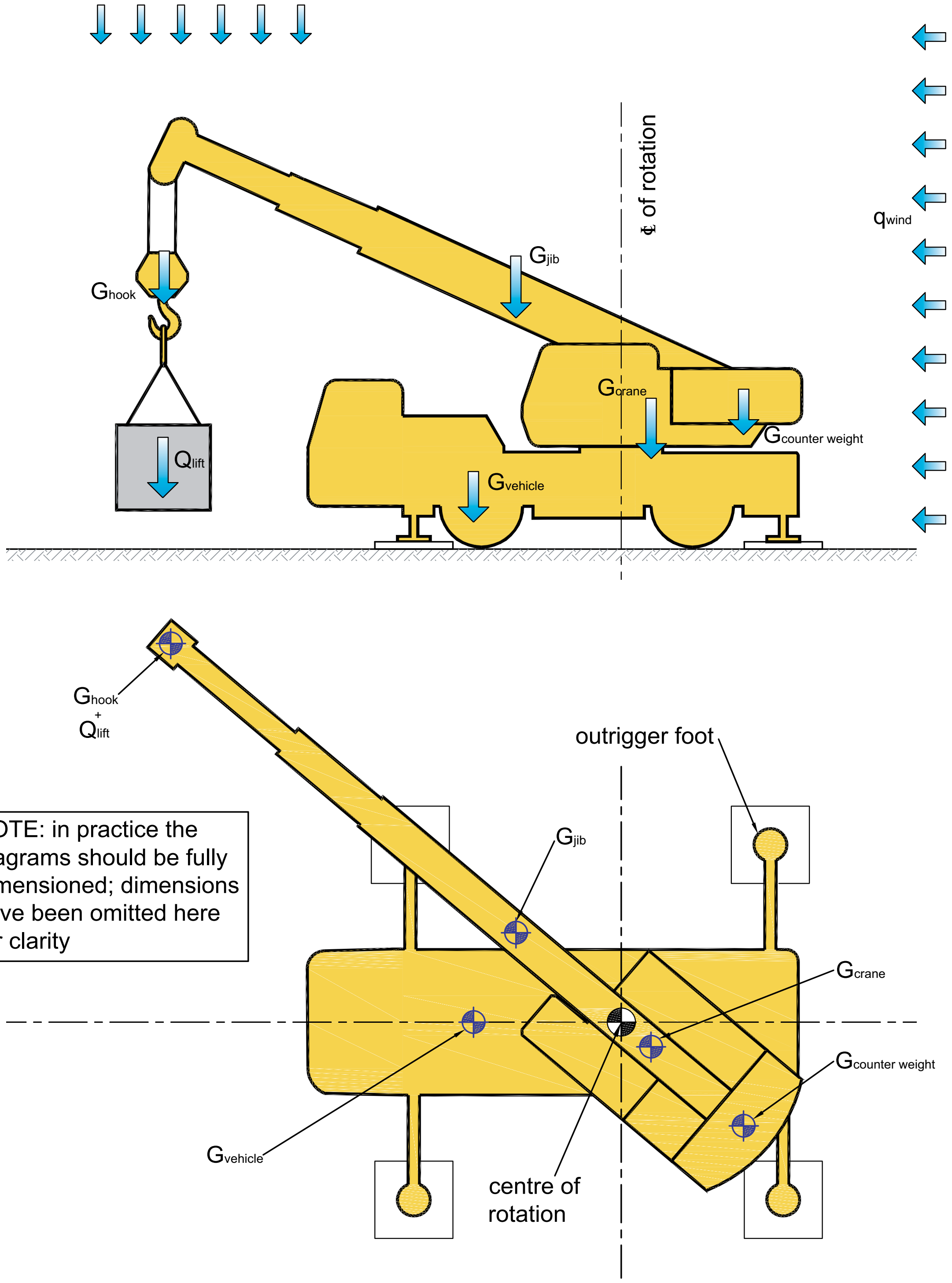
As an aid to understanding, a dimensioned sketch should be drawn in elevation with each component and action identified. This could be based on drawings from the supplier or be a simple diagram.

Derivation of the maximum and minimum outrigger loads is a simple process of geometric analysis to obtain the outrigger loads due to each component. The outrigger loads should be obtained:

- for the maximum laden and un-laden condition;
- with the load positioned over each axis and over the outrigger (closest to the centre of rotation);
- with wind acting from in front and from behind the jib.

It should be noted that:

- the maximum outrigger load may not occur with a jib directly over the outrigger and additional positions either side should be checked to confirm;
- the worst case for cranes is often for no load and jib up, as the counterweight causes greater overturning than the lift load.



NOTE: in practice the diagrams should be fully dimensioned; dimensions have been omitted here for clarity

Figure 19 - Example of actions associated with assessing outrigger loads for a mobile crane

The imposed patch load is defined by the maximum outrigger load distributed on a suitable bearing pad. Unless otherwise specified it is generally assumed that the outrigger will be positioned on the centre of the pad and that the loading regime will be concentric. The effects of any minor deviation/eccentric loading may be assumed to be covered by the use of partial factors. Accordingly the effective dimensions of the pad are taken to be the actual dimensions.

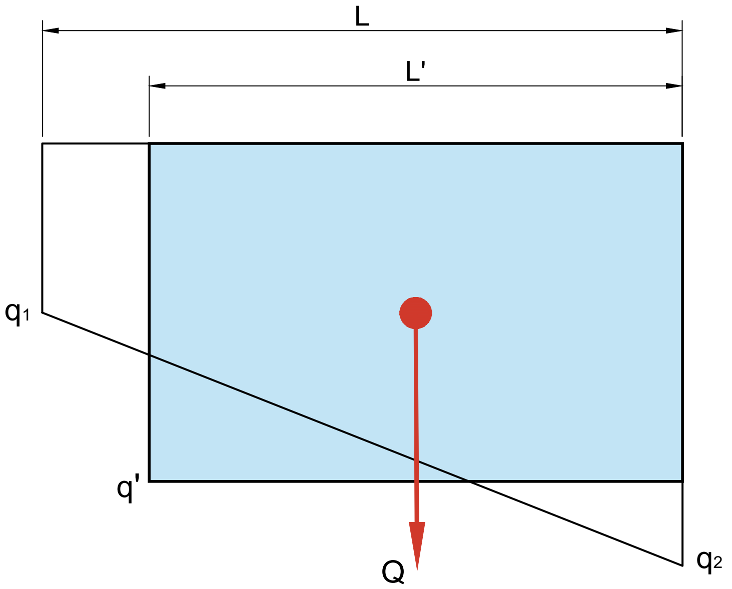
The design of the bearing pad is outside of the scope of this document but it should be noted that the selected pad must be of suitable strength and stiffness.

WARNING:

Lack of bearing pad stiffness can cause excessive bearing stress concentration at the centre of the pad, reducing the effective dimensions of the pad, possibly resulting in over-estimation of bearing capacity. The TWC must ensure that the appropriate product information is obtained, or additional design calculations undertaken, to confirm that the proposed bearing pads are of adequate strength and stiffness to fulfil design requirements.

4.5.2 Tracks

It is preferable to obtain ground bearing pressures calculated by the plant supplier for the specific task. For piling rigs this will normally be in the form of equivalent rectangular stress blocks but other suppliers may provide trapezoidal or triangular stress blocks. If necessary, the designer may convert to an equivalent rectangular stress block, as shown in **Figure 20**.

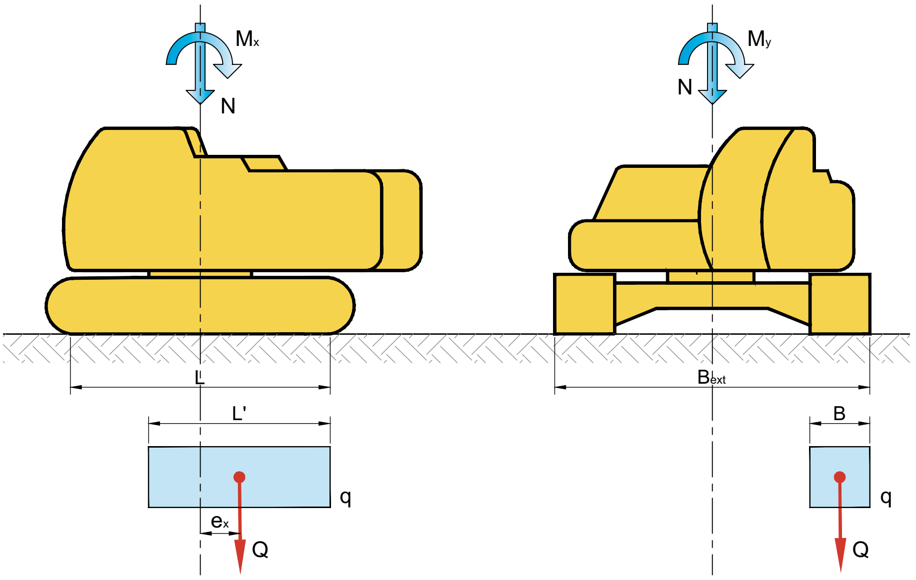


$Q = BL.(q_1+q_2)/2$

$L' = BL^2.(2.q_1+q_2)/(3.Q)$

$q' = Q/BL'$

Figure 20 - Conversion from trapezoidal/triangular stress block to rectangular stress block



$e_x = M_x/N$

$L' = L-2.e_x$

$Q_N = N/2$

$Q_y = M_y/(B_{ext}-B)$

$Q = Q_N + Q_y$

$q = Q/BL'$

NOTE:

For stability $Q_y < Q_N$

Figure 21 - Conversion from trapezoidal/triangular stress block to rectangular stress block

Derivation of the rectangular stress block from first principles is similar to that used for outrigger loads. Firstly, the total vertical load and overturning moments are derived from the basic geometry and actions. A rectangular stress block may then be derived, by simple statics, as shown in **Figure 21**.

4.5.3 Wheels

Although the actual contact areas and pressure for tyres can be complex, for the purposes of designing working platforms, patch loads for wheels may be determined on the basis of the load per wheel and the operating tyre pressure. A suitable method can be found in of SP123, Section 12.7.5.

Axle loads and tyre inflation pressures are usually available from supplier. Individual wheel loads can be derived based on the wheel configuration.

4.6 Design factors

4.6.1 Partial factors

Partial factors are intended to deal with levels of uncertainty and are used to convert characteristic values to design values, such that the design calculation has a desired level of reliability. They are therefore calibrated on the assumption that the design inputs and the construction process will have a certain level of reliability.

Table 2 - ULS partial factors (NOTE: Factor on shear angle is applied to tanφ)

		EC7		SP123
		comb 1	comb 2	
permanent action	γ_G	1.35	1.00	1.00
variable action	γ_Q	1.50	1.30	1.00
cohesion	γ_C	1.00	1.40	1.25
shear angle	γ_f	1.00	1.25	1.25
resistance	γ_R	1.00	1.00	n/a

EC7 and CIRIA SP123 are both limit state approaches with various partial factors for actions and material strength. The UK annex for EC7 directs the use of design approach 1 which uses two distinct sets of partial factors, combination 1 and combination 2 (see **Table 2**, for comparison).

In practice, the factor of 1.25 on tanϕ results in factors of 2.3 to 2.9 on N_γ. From this it can be seen that, for working platforms, combination 2 will always be the controlling set of factors for bearing capacity calculations. It is, therefore, only considered necessary to apply combination 2 for the design of granular working platforms.

Although closer assessment of the applied loads might suggest that some loads may be treated as part 'permanent action' and part 'variable action' (e.g. crane outriggers), for simplicity and the avoidance of error it is recommended that the loads applied to working platforms should be wholly treated as a variable action.

Most loads will be similar to BRE470 'load case 1' in nature and be subject to the standard partial factor. However, Clause 2.4.7.1(5) of EC7 does allow the designer to reduce partial factors where it can be assumed the consequences of failure will be low. Hence, the special 'load case 2' identified for piling rigs can be reduced based on the reasoning given in BR470, i.e. that, "*… the rig … operator can control the load safely*" and the likely consequence would be limited to stopping the operation. Based on the relative values of case 1 and case 2 factors given in BR470, the recommended value to be used for 'load case 2' is Q_γ=1.00.

In terms of the partial factors on material strength it should be noted that, due to the large reduction in N_γ (when γ_ϕ=1.25 is applied), it is apparent that the current partial factor is not entirely suitable for the design of working platforms on granular formations. The factor currently used is suitable for permanent spread foundations as: (a) they will have the benefit of surcharge; and (b) higher overall factors are appropriate. However, the loads on working platforms are applied on the surface (of the platform material) or close to an edge where the benefit of surcharge on the formation is not available.

As a consequence, for platforms on granular formations, it is necessary to ensure a sufficient edge distance is provided if surcharge is to be considered. Including the surcharge from the platform will result in a platform thickness that is reasonably consistent with past experience. Where this surcharge is not available, this will not be the case.

In addition, this causes a problem when checking the platform material itself. Again, the factors from EC7 produce results that are not consistent with past experience.
As an alternative approach, therefore, it is recommended that the platform material be checked for 'presumed bearing capacity' as described in BS 8004:2010. In this method, the actions and shear strength are not factored and an overall factor applied to the calculated resistance (equivalent to what used to be an 'allowable bearing capacity'). This represents a minor departure from the UK annex but is still consistent with the use of design approach 2 from EC7.

4.6.2 Dynamic enhancement factor

Historically, dynamic effects have not been included within calculations for granular working platforms. However, EC1 includes a general requirement to apply a 'dynamic enhancement factor' (confusingly denoted ϕ) to moving loads e.g. runway cranes, forklift trucks, trains.

The designer should, therefore, consider whether the particular circumstances of a design warrant further investigation and/or inclusion of dynamic effects within the calculation. If appropriate, the static characteristic value for loads from plant should be multiplied by an appropriate dynamic factor to obtain a characteristic dynamic load. It should be noted this is *not* the design value and still needs to be multiplied by any applicable partial factor.

With all plant there will be some effects arising from the acceleration and deceleration of moving parts. This includes:

- vibration due to motors or driving equipment;
- lurching, braking and acceleration during slewing;
- lurching, braking and acceleration during travel;
- acceleration/retardation of load during lifting operations;
- impact or sudden release of load;
- change of direction of moving plant/vehicles.

Whether dynamic effects are significant depends on a number of factors, such as:

- **Maximum speed of travel/movement as an indicator of acceleration** – Very low speeds may make any dynamic effects negligible. For example, from EC1, for trains travelling at less than 5m/s the dynamic enhancement factor is unity.
- **Regularity and gradient of the travelling surface** – This is generally unlikely to be a factor for platform design due to the general functional need for level and smooth platforms.
- **The stiffness of underlying subgrade** – Softer and more plastic ground will have a greater damping effect thus reducing the accelerations at ground level.
- **Subgrade response** – Soils are known to generally respond with higher bearing capacity under rapid loading conditions (which will normally be sufficient to counter the increased load).
- **The proportion of load undergoing acceleration** – Based on simple inertia, the dynamic effect on a load being lifted will be very much reduced for the item of plant as a whole.

Considering the above in relation to granular working platforms and their use, and based on past experience, it is recommended that dynamic effects are generally deemed to be relatively insignificant and allowed for within the partial factors. Ordinarily, therefore, the dynamic enhancement factor should be taken to be unity.

However, it is further recommended that the designer should give consideration to specific additional actions that might arise due to dynamic effects and treat these separately. Examples of these are:

- additional centripetal forces imposed by plant/vehicles when changing (vertical) direction at the base of a ramp;
- the effect of loads near the top of the mast on cased secant pile (CSP) rigs which can impose a significant effect on ground pressure when accelerating or braking.

4.6.3 Repeated/cyclic load enhancement factor

EC7 calls for specific consideration of, *"… actions, that are applied repeatedly …"*. In addition, BS 8004:2015 echoes this by advising that certain matters be considered in respect of cyclic loading.

CIRIA SP123 provides advice, based on studies of repeated passes of wheel loads, on enhancement of loads depending on the number of load repetitions. A formula is provided to determine an enhancement factor depending on the total number of passes and the nature of the subgrade. It is stated that for anything less than 5 load repetitions no enhancement is required; which implies that anything in excess of 5 repetitions does require enhancement.

This doesn't appear to agree with general experience when using tracked plant or outrigger mats on working platforms, for which cyclic loading has not normally been considered. However, the study of cyclic loading by Delmas (1986) suggests that for a direct cyclic vertical loading in a fixed location, there would be little effect on the bearing capacity below approximately 100 repetitions. Further, only a 10% deterioration on bearing capacity was observed after 2,000 repetitions.

In general, therefore, it is recommended that:

- For tracked plant and outrigger pads, effects due to cyclic loading can be considered to be relatively minor and otherwise accounted for by using the standard partial factors.
- For wheels, where specific design is deemed necessary, an enhancement should be applied to the characteristic load, in accordance with the advice given in SP123.

4.7 TWf method

4.7.1 General approach

It should be recognised that no analytical model fully replicates the complex interaction that takes place in a real platform under load. However, the following recommendations provide reasonable but conservative assumptions and simplifications that allow the reader to undertake an analytical design of a working platform with no geosynthetic reinforcement/stabilisation, to comply with EC7 and BS 8004:2015 (see Figure 22).

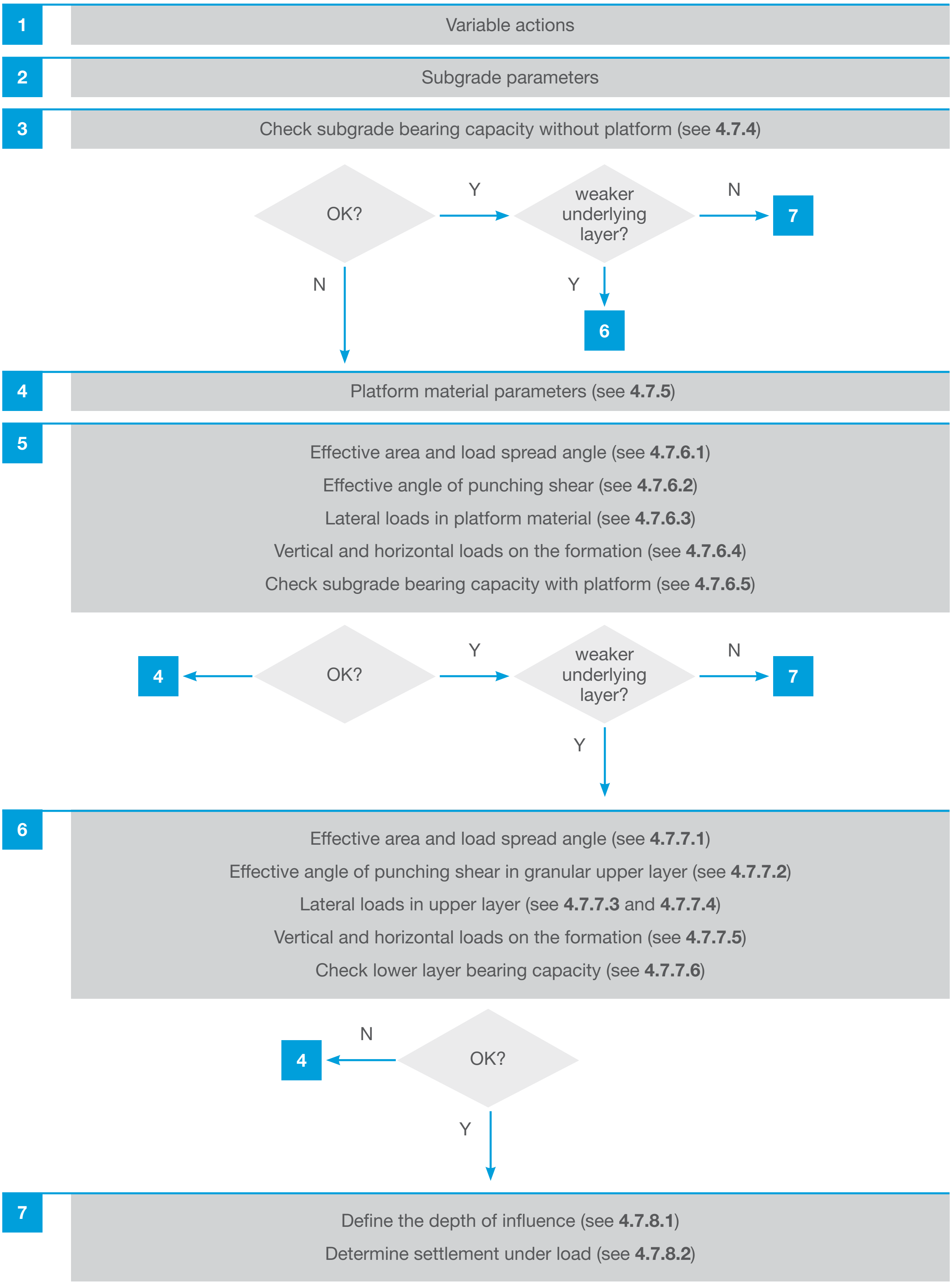
The general approach adopted is as follows:

- Undertake ULS checks for bearing capacity and SLS checks for immediate settlement.
- Follow the accepted general steps from BR470 for checking bearing capacity of each element in turn (existing ground, platform material, platform formation).
- Adapt and extend the SP123 model to use on both cohesive and granular subgrades, using additional accepted geotechnical practice.
- Derive nominal effective area (and nominal load spread angle) using the maximum increase in vertical pressure beneath the centre of the load calculated using Bousinesq theory (to avoid underestimation of pressure on subgrade).
- Adopt an absolute maximum load spread angle of 26.6° (2V:1H) to avoid overestimation of effective area.
- Assess lateral pressure in the platform or upper granular subgrades, and hence the horizontal shear on the formation, based on values of δ/ϕ derived from Hanna & Meyerhof (1980, 1981).
- Assess lateral pressure in upper cohesive subgrades, and hence the horizontal shear on the formation, based on net lateral pressure including un-drained cohesion without adhesion at the ‘vertical’ shear boundary.
- Use BS 8004:2015 and BS EN 1997-1:2004+A1:2013 as a basis for assessing the bearing capacity of the existing ground/subgrade.
- Use BS 8004:2015 as a basis for assessing the presumed bearing capacity of the platform material.
- Adopt ULS combination 2 partial factors only (as these control in all cases).
- Adopt reduced γ_Q=1.00 for special load case 2 (piling rigs).

It should be noted that:

- The “TWf method” is provided purely as an EC7-compliant method to be used as an alternative to other existing methods (such as BR470 or SP123) if it is considered appropriate.
- SLS (immediate settlement) calculations are required to control the risk of local and punching failure modes.
- The method currently relies on load spread only, without allowance for punching shear resistance (conservative assumption due to limits of currently available research).
- The method currently ignores any benefit from friction between the underside of the load and the top of the platform (conservative assumption due to limits of currently available research).
- The method currently ignores any benefit from the scale effects of relatively small bearing areas (conservative assumption due to limits of currently available research).
- Due to the relative complexity of the calculations, it is recommended that the method be used with a spreadsheet or mathpad application.

Figure 22 - Flowchart for the TWf method (EC7/BS8004:2015 compliant design)



4.7.2 Design actions

Calculate total design actions in accordance with EC7.

Loads imposed by mats, platform material and subgrade soils shall be treated as permanent actions and may be taken to be the net weight. In all cases, $\gamma_G = 1.00$.

All loads imposed by plant shall be treated as variable and be derived based on patch dimension, characteristic pressure and the following partial factors (see **Section 4.6.1**). For:

Case 1, $\gamma_{Q1} = 1.30$

Case 2, $\gamma_{Q2} = 1.00$

Where applicable, calculate total bearing pressure applied to top of platform to include weight of mats (or other load spreading device):

Bearing pressure, $q = (Q + G_{mat})/A$

where, area of patch load, $A = B.L$

4.7.3 Design strengths

Calculate design strengths in accordance with EC7, for the platform material and subformation soils based on the appropriate partial factors (see **Section 4.6.1**).

For angle of friction, $\gamma_\phi = 1.25$

For undrained shear strength, $\gamma_c = 1.40$

4.7.4 Capacity of existing ground

Undertake an ULS check in accordance with EC7, on the general bearing capacity of the existing ground ***without a platform*** using an appropriate version of the bearing capacity formula. It is recommended that the formulae from BS 8004:2015, Section 5.4.1, be used. For coarse grained soils, assume 'rough foundation' conditions apply. Where groundwater is within B of the surface, additionally, use buoyancy factors as described in **Section 4.2.4.2**.

The ground is treated as either fine grained ($c_u > 0$, $\phi = 0$) or coarse grained ($c_u = 0$, $\phi > 0$) and there is no overburden. Hence, only one relevant term (cohesion or weight) is applied from the bearing capacity equation.

If the ground proves to be adequate at the surface, a subsequent ULS check should be made on the capacity of any underlying weaker layers within the depth of influence (as described in **Section 4.7.7**).

If the underlying weaker layer proves to be adequate, a subsequent SLS check should be made on immediate settlement (as described in **Section 4.7.8**).

If the existing ground proves to be adequate, a platform need not be provided unless it is needed for general serviceability reasons, e.g. to prevent deterioration of a clay subgrade and provide a clean working area.

If the ground is not adequate, design will proceed for the granular platform.

4.7.5 Granular platform

Undertake a 'prescriptive' check on the general bearing capacity of the platform material. It is recommended that Formula (26) for 'presumed bearing resistance' from BS 8004:2015, Clause 5.4.4.2.1, be used together with a $\gamma_{Rv,SLS} = 2.0$. For coarse grained soils, assume 'rough foundation' conditions apply.

For convenience, selected values are given in **Table 3**. Values may be interpolated.

Table 3 - Presumed bearing capacity of platform material (kPa)

ϕ (°)	N_γ	$\gamma_{p,k}$ (kN/m³)	B (mm)				
			250	500	1,000	2,000	4,000
30	16	17	17	35	69	138	277
35	37	18	42	85	170	339	679
40	87	19	104	207	415	830	1660
45	202	20	253	506	1012	2024	4047
50	468	21	615	1230	2461	4922	9843

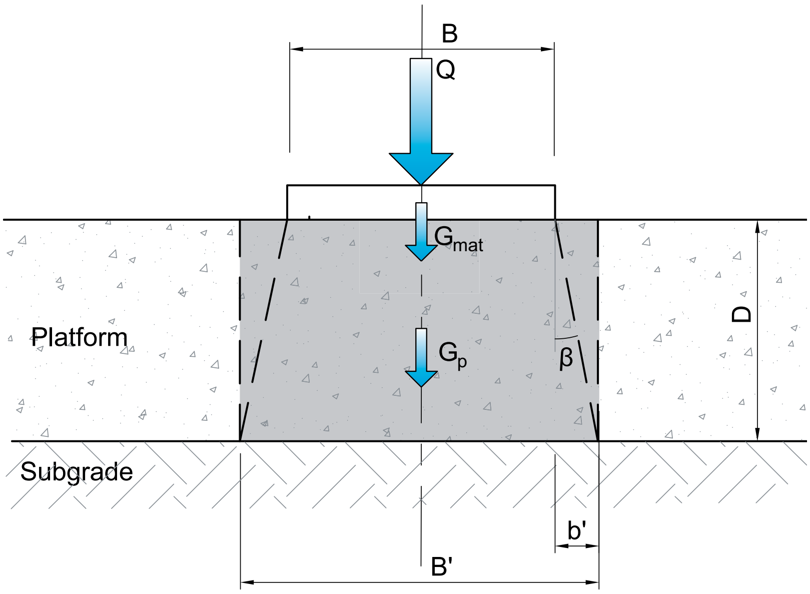


Figure 23 - Geometry and actions for bearing check on formation

4.7.6 Platform subgrade

The bearing capacity of the platform subgrade must be adequate to resist the live load, the self-weight of load spreading devices and the self-weight of the platform. The self-weight of the platform should be considered over the effective width as shown in **Figure 23**. Determination of effective width is described in **4.7.6.1**.

Both the vertical and horizontal loads applied to the subgrade are required to determine the bearing capacity and are derived from the active and passive pressures generated in the platform material, as shown in **Figure 24** and described in **4.7.6.2**, **4.7.6.3** and **4.7.6.4**.

4.7.6.1 Effective area and load spread angle

With reference to **Figure 23**, using characteristic values, determine the increase in vertical pressure, q’, at formation level and beneath the centre of the patch load, based on charts shown in **Figure 25**.

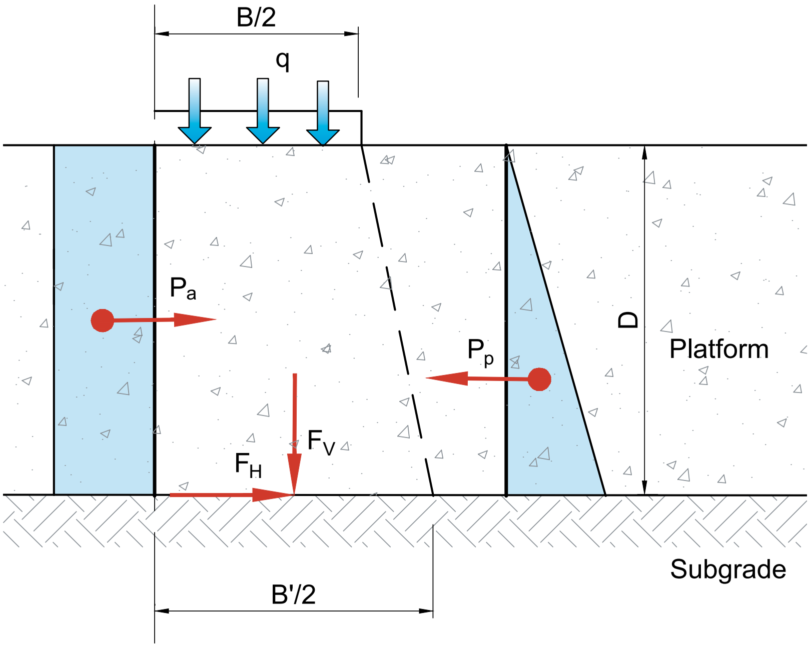


Figure 24 - Forces acting within platform and on the formation

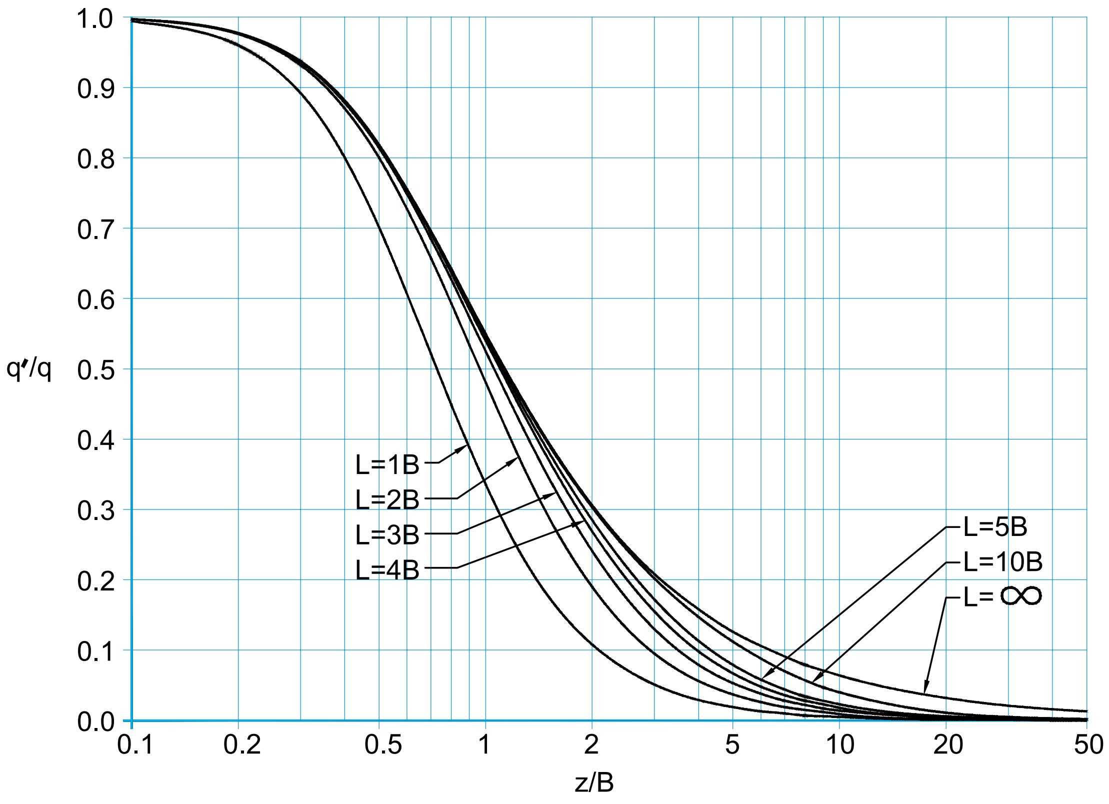


Figure 25 - Graphs for pressure beneath the centre of a foundation (after Janbu, Bjerrum and Kjaernsli, 1956)

Derive effective area, breadth and length,
$A' = B'.L' = (Q + G_{mat})/q'$

Derive effective breadth and length of patch area at formation level by simple geometry, assuming increase in breadth and length are equal ($B' - B = L' - L = x$) and solving as a quadratic.

Taking:

$B' = B + x$

$L' = L + x$

Then:

$A' = (B + x).(L + x)$

$= BL + (B+L)x + x^2$

Re-arranging and substituting, A=BL:

$0 = x^2 + (B + L)x + (A - A')$

Hence, from the standard solution for a quadratic:

$a = 1$

$b = B + L$

$c = A - A'$

where,

$x = (-b + \sqrt{(b^2-4ac)}) / 2a$

From simple geometry, determine effective angle of load spread b and check that $\beta \leq 26.6°$.
If $\beta > 26.6°$ restrict effective breadth, length and area such that $\beta = 26.6°$.

NOTE: It should be noted that the derived effective area, dimensions and load spread angle are conservative notional values and do not necessarily represent the exact values that will occur in practice.

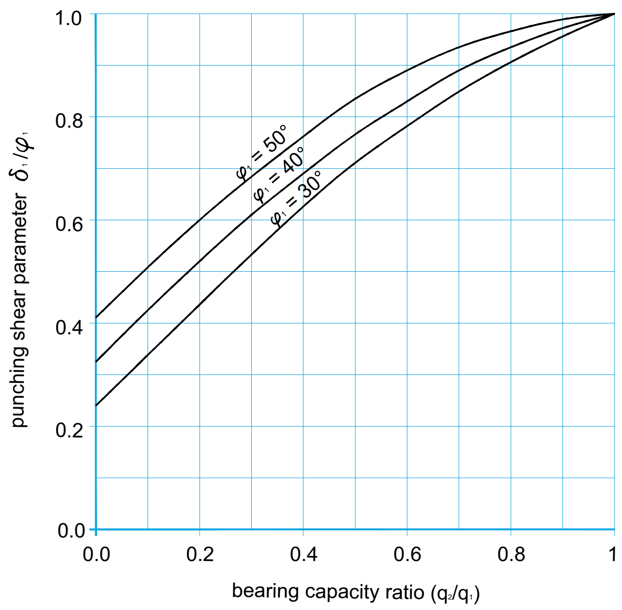


Figure 26 – δ/ϕ for cohesive formation (after Hanna & Meyerhof, 1980)

4.7.6.2 Effective angle of punching shear

Using characteristic values for platform fill and subgrade strength, derive values of $\delta_{\phi ill}/\phi_{fill}$ from charts by Hanna & Meyerhof (1980) and Hanna (1981).

NOTE: This is to allow for apparent vertical friction at the edge of the loaded area when deriving lateral earth pressure coefficients; it is not intended to be used to derive punching shear resistance.

For cohesive subgrades use charts shown in **Figure 26**, where:

For platform fill, $q_1 = q_p = 0.5\gamma_p B N_{g,p}$

For formation, $q_2 = q_{s1} = c_{u,s1} N_{c,s1}$

For granular subgrades use charts shown in **Figure 27**, where:

For platform fill, $\phi_1 = \phi_p$

For formation, $\phi_2 = \phi_s$

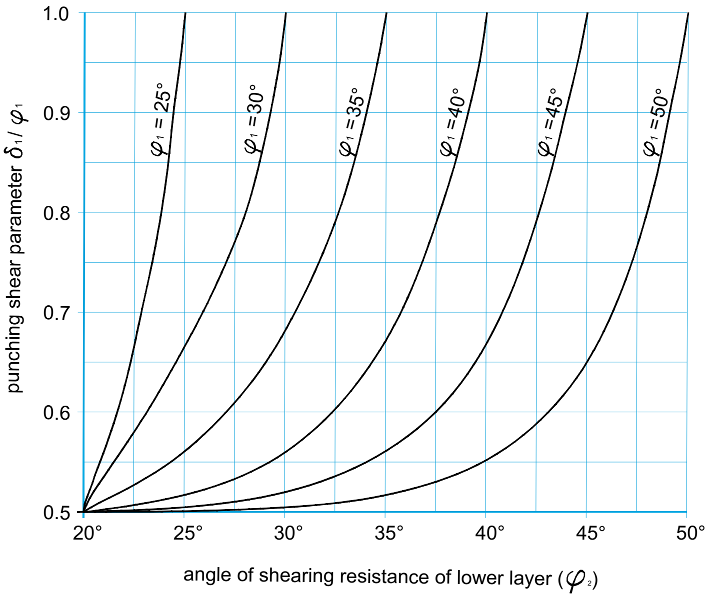


Figure 27 – δ/ϕ for granular formation (after Hanna, 1981)

4.7.6.3 Lateral loads in the platform material

With reference to **Figure 24**, using the derived value for δ_p/ϕ_p, derive $K_{a,p}$ and $K_{p,p}$ for the platform material using one of the methods found in BS EN 1997-1:2004+A1:2013, Annex C, or by direct calculation using Coulomb's formulae, as follows:

$$K_{a,p} = \{\sin(90-\phi_p) / (\sqrt{\sin(90+\delta_p)} + \sqrt{(\sin(\phi_p+\delta_p).\sin\phi_p)})\}^2$$

$$K_{p,p} = \{\sin(90+\phi_p) / (\sqrt{\sin(90-\delta_p)} - \sqrt{(\sin(\phi_p+\delta_p).\sin\phi_p)})\}^2$$

NOTE: Where the punching perimeter is assumed to be vertical and the platform is assumed to be horizontal.

Using design values, determine the increase in vertical pressure, $q_{av,p}$, beneath the centre of the patch load, at mid-level of the platform, based on charts shown in **Figure 25** (taking $q' = q_{av,p}$).

Calculate lateral line loads:

active lateral load (kN/m), $P_{a,p} = K_{a,p}q_{av,p}D$

passive lateral load (kN/m), $P_{p,p} = K_{p,p}\gamma_p D^2/2$

4.7.6.4 Vertical and horizontal loads on the formation

Calculate line loads on the formation:

Horizontal load (kN/m), $F_{H,s} = P_{a,p} - P_{p,p}$ but not < 0

Vertical load (kN/m), $F_{V,s} = (qB + \gamma_p DB')/2$

The calculated line load values are used to determine the inclination factors based on relevant equations from BS 8004:2015, Clause 5.4.1, and BS EN 1997-1:2004+A1:2013, Annex D.

NOTE: It should be noted that, although the vertical load is considered beneficial, based on the "single source principle" it should be multiplied by the same partial factors used to derive the horizontal load.

4.7.6.5 Subgrade bearing capacity

Undertake an ULS check, in accordance with EC7, on the general bearing capacity of the subgrade using an appropriate version of the bearing capacity formula. It is recommended that the formulae from BS 8004:2015, Clause 5.4.1, and the inclination factor for cohesive subgrades from BS EN 1997-1:2004+A1:2013, Annex D, be used. For coarse grained soils, assume 'rough foundation' conditions apply. Where groundwater is within B' of the surface, additionally, use buoyancy factors as described in **Section 4.2.4.2**.

The ground is treated as either fine grained ($c_u > 0$, $\phi = 0$) or coarse grained ($c_u = 0$, $\phi > 0$) and the surcharge term is used based on the platform weight density and depth. The surcharge term may only be applied if the necessary edge distance is provided, as shown in **Figure 5**.

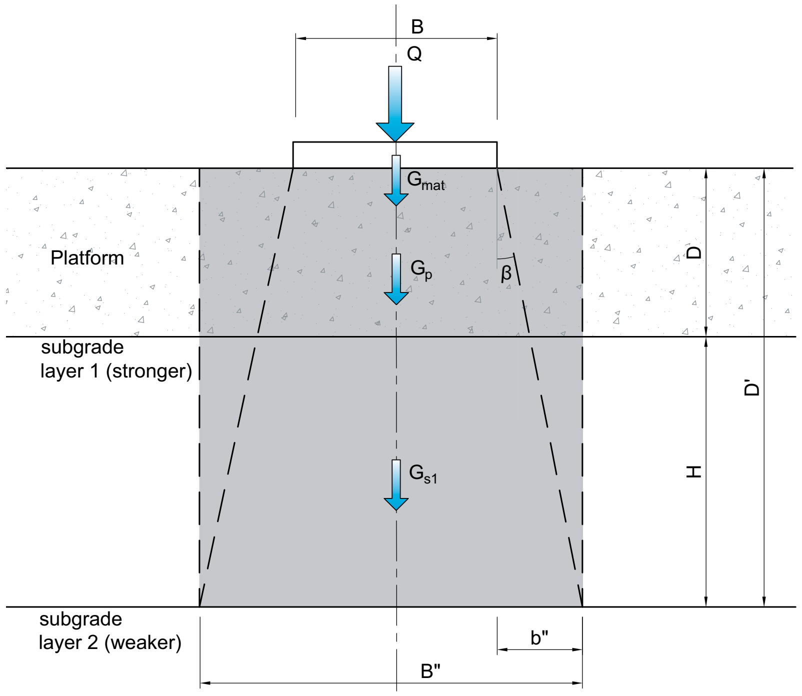


Figure 28 - Geometry and actions for bearing check on underlying weaker layer

4.7.7 Underlying weaker layer

4.7.7.1 Effective area and load spread angle

Using characteristic values, determine the increase in vertical pressure, q”, beneath the centre of the patch load, at the top of the lower layer using charts shown in **Figure 25** (taking q’ = q”).

Derive effective area, breadth and length,
$A” = B”.L” = (Q+G_{mat})/q”$

Derive effective breadth and length of patch area at formation level by simple geometry, assuming increase in breadth and length are equal (B” - B = L” - L = x) and solving as a quadratic.

From simple geometry, determine effective angle of load spread b and check that $\beta \leq 26.6°$.
If $\beta > 26.6°$ restrict effective breadth, length and area such that $\beta = 26.6°$.

NOTE: It should be noted that the effective area, dimensions and load spread angle derived above are conservative notional values and do not necessarily represent the exact values that will occur in practice.

4.7.7.2 Effective angle of punching shear

For a granular upper layer, using characteristic strength values for the upper layer and the lower layer, derive values of δ_{s1}/ϕ_{s1} from charts by Hanna & Meyerhof (1980) and Hanna (1981).

For a cohesive lower layer use chart shown in **Figure 26**, where:

For upper layer, $q_1 = 0.5\gamma_{s1}BN_{g,s1}$

For lower layer, $q_2 = c_{u,s2}N_{c,s2}$

For a granular lower layer use chart shown in **Figure 27**, where:

For upper layer, $\phi_1 = \phi_{s1}$

For lower layer, $\phi_2 = \phi_{s2}$

4.7.7.3 Lateral loads in a granular upper layer

Using the derived value for δ_{s1}/ϕ_{s1}, derive $K_{a,s1}$ and $K_{p,s1}$ for the platform material using one of the methods found in BS EN 1997-1:2004+A1:2013, Appendix C - or by direct calculation using Coulomb’s formulae - as follows:

$$K_{a,s1} = \{\sin(90 - \phi_{s1}) / (\sqrt{}\sin(90 + \delta_{s1}) + \sqrt{}(\sin(\phi_{s1} + \delta_{s1}).\sin\phi_{s1}))\}^2$$

$$K_{p,s1} = \{\sin(90 + \phi_{s1}) / (\sqrt{}\sin(90 - \delta_{s1}) - \sqrt{}(\sin(\phi_{s1} + \delta_{s1}).\sin\phi_{s1}))\}^2$$

NOTE: The punching perimeter is assumed to be vertical and the top of the upper layer is assumed to be horizontal.

Using design values, determine the increase in vertical pressure, $q_{av,s1}$, beneath the centre of the patch load, at mid-level of the upper layer, using charts shown in **Figure 25** (taking q’ = $q_{av,s1}$).

Calculate lateral line loads:

Active lateral load (kN/m),
$P_{a,s1} = K_{a,s1}(\gamma_p D+q_{av,s1}).H$

Passive lateral load (kN/m),
$P_{p,s1} = K_{p,s1}\gamma_{s1}H^2/2$

4.7.7.4 Lateral loads in a cohesive upper layer

For a cohesive upper layer, assume that adhesion at the punching perimeter is zero and take lateral earth pressure coefficients to be:

$K_{a,s1} = K_{p,s1} = 1$

$K_{ac,s1} = K_{pc,s1} = 2$

Using design values, determine the increase in vertical pressure, qav,s1, beneath the centre of the patch load, at mid-level of the upper layer, using charts shown in **Figure 25** (taking q’ = $q_{av,s1}$).

Calculate lateral line loads:

Active lateral load (kN/m),
$P_{a,s1} = ((K_{a,s1}(\gamma_p D+q_{av,s1})) -K_{ac,s1}c_{u,s1})H$

Passive lateral load (kN/m),
$P_{p,s1} = ((K_{p,s1}\gamma_{s1}H/2)+ K_{ac,s1}c_{u,s1})H$

4.7.7.5 Vertical and horizontal loads on the underlying layer

Calculate horizontal load (kN/m),
$F_{H,s2} = P_{a,s1}-P_{p,s1}$ but not < 0

Calculate vertical load (kN/m),
$F_{V,s2} = (qB + ((\gamma_p D+g_{s1}H) B”))/2$

The calculated line load values are used to determine the inclination factors based on relevant equations from BS 8004:2015, Clause 5.4.1, and BS EN 1997-1:2004+A1:2013, Annex D.

NOTE: It should be noted that the vertical load is treated as beneficial.

4.7.7.6 Underlying layer bearing capacity

Undertake an ULS check in accordance with EC7, on the general bearing capacity of the lower layer using the SP123 model and an appropriate version of the bearing capacity formula. It is recommended that the formulae from BS 8004:2015, Clause 5.4.1, and the inclination factor for cohesive subgrades from BS EN 1997-1:2004+A1:2013, Annex D, be used. For coarse grained soils, assume ‘rough foundation’ conditions apply. Where groundwater is within B” of the surface – additionally - use buoyancy factors as described in **Section 4.2.4.2.**

The lower layer is treated as either fine grained ($c_u > 0, \phi = 0$) or coarse grained ($c_u = 0, \phi > 0$) and the surcharge term is used based on the upper layer weight density and depth, with the platform surcharge being ignored.

4.7.8 Immediate settlement

4.7.8.1 Define the depth of influence

Calculate 20% of net overburden at suitable regular depth intervals e.g. every 0.5m or 1.0m.

Using characteristic values, determine the increase in vertical pressure, at the same depth intervals, beneath the centre of the patch load, at formation level using charts shown in **Figure 25**.

Plot both lines and find intersection point to determine overall depth of influence for immediate settlement calculations, as shown in **Figure 15**.

4.7.8.2 Determine settlement under load

Undertake SLS check on immediate settlement, in accordance with EC7.

General maximum allowable values may be taken as:

- absolute settlement to be not greater than the lesser of B/10 or 50mm;
- differential settlement across tracks to be not greater than 5 mm/m (approximately 0.3°);
- differential settlement across outriggers to be not more than 10mm/m (approximately 0.6°).

The exact acceptability criteria will vary on a case by case basis, depending on the nature of the plant considered, the gradient of the platform surface and the type of operation. Appropriate values should be agreed with the plant supplier and/or operator.

Using characteristic values, determine the settlement for each layer based on formulae and charts developed by Janbu, Bjerrum and Kjaernsli (1956), previously described in **Section 4.2.5**:

For all cases D/B for a surface load is zero, giving $\mu_0 = 1$.

Values for μ_1 may be taken from charts shown in **Figure 29**.

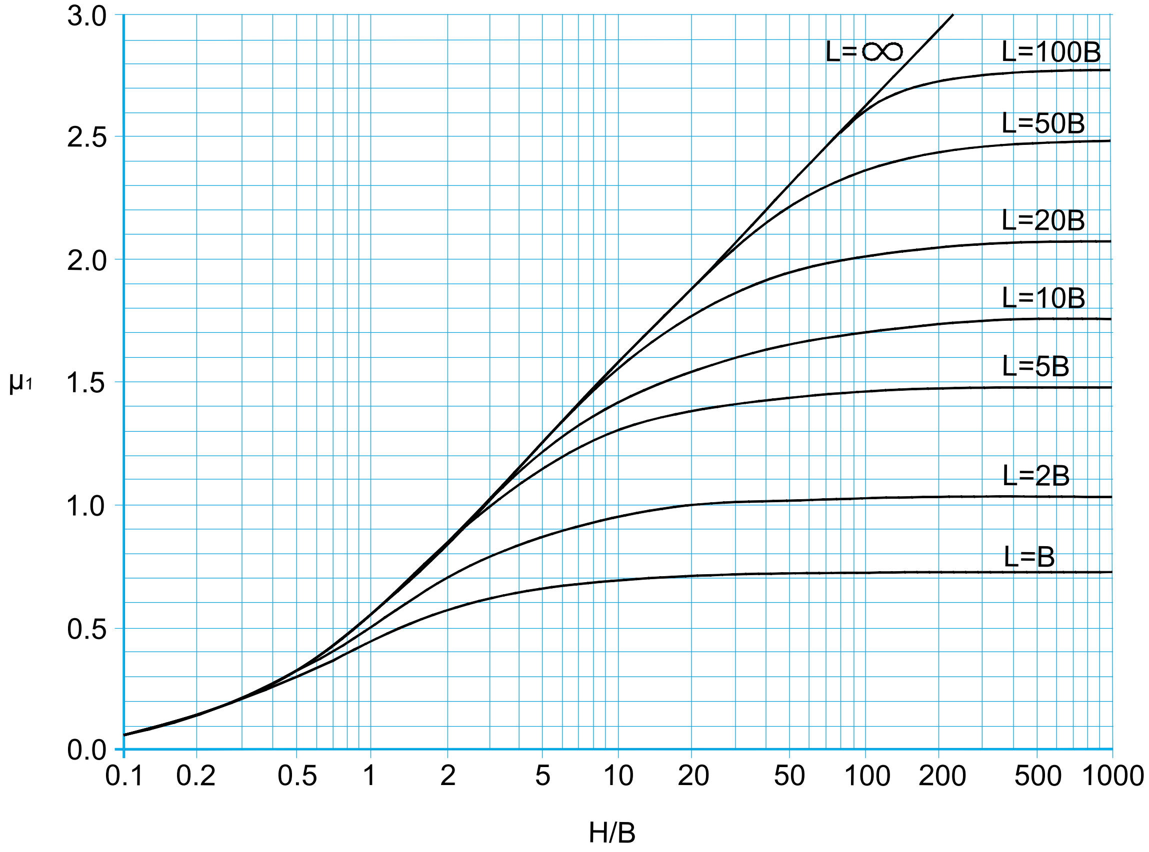


Figure 29 - Graphs for the determination of factor μ_1 for immediate settlement (after Janbu, Bjerrum and Kjaernsli, 1956)

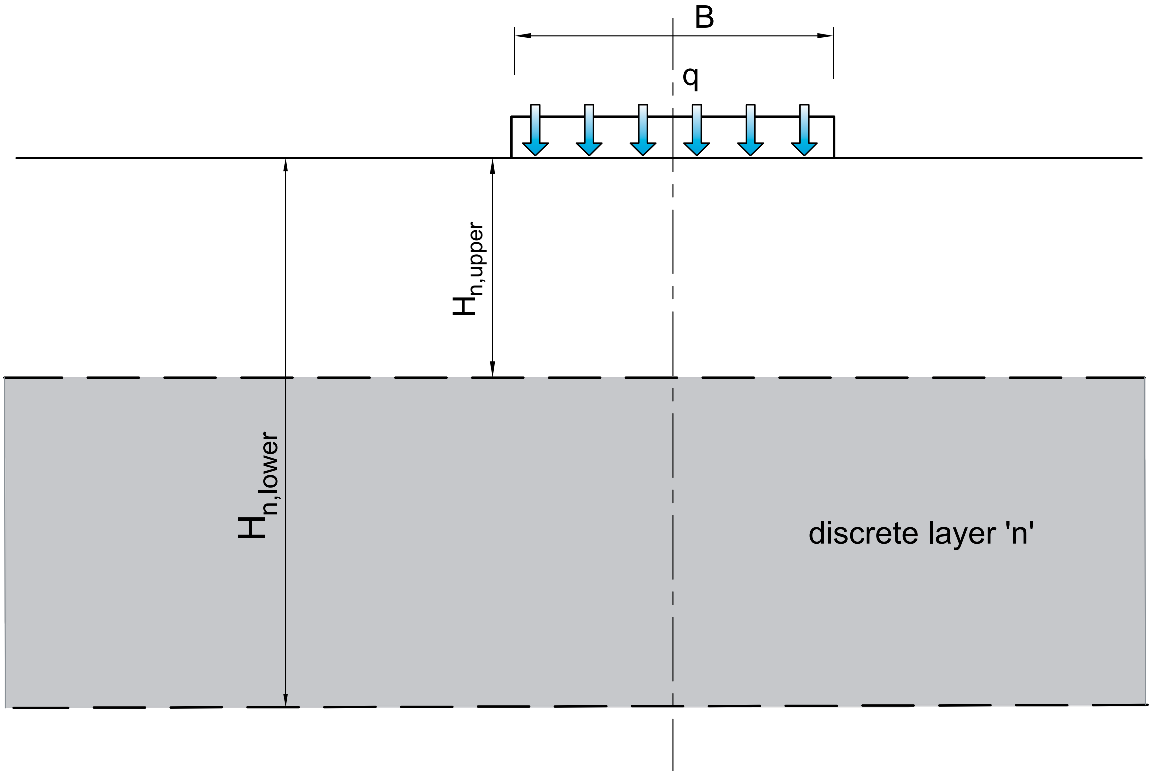


Figure 30 – Diagram of discrete layer

Calculate immediate settlement for each discrete layer in turn, as shown in Figure 30, as follows:

Calculate ratio for underside of layer, $H_{n,lower} / B$

From charts in Figure 29, obtain factor, $\mu_{1,n,lower}$

Calculate ratio for top of layer, $H_{n,upper} / B$

From charts in Figure 29, obtain factor, $\mu_{1,n,upper}$

Calculate total settlement of layer, $\rho_n = q\ B\ (\mu_{1,n,lower} - \mu_{1,n,upper}) / E_{u,n}$

Sum to give the total immediate settlement under the load, $\rho_i = \Sigma\rho_n$

Calculate maximum slope due differential settlement, $i = \rho_i / L$

APPENDIX A - Notation

A	Area of patch load applied to surface of platform
A'	Area of patch load applied to formation beneath platform
A"	Area of patch load applied to underlying weaker layer
B	Width of patch load applied to surface of platform
B'	Width of patch load applied to formation beneath platform
B"	Width of patch load applied to underlying weaker layer
c_u	Undrained shear strength
$c_{u,punch}$	Reduced undrained shear strength for very soft fine grained soils
D	Depth of platform fill
$d_c\ d_g\ d_q$	Depth factors (for bearing capacity)
E_u	Undrained elastic modulus
$F_{H,s}$	Horizontal load applied at formation level
$F_{V,s}$	Vertical load applied at formation level
$F_{H,s2}$	Horizontal load applied at top of underlying layer
$F_{V,s2}$	Vertical load applied at top of underlying layer
G_{mat}	Permanent load due to mat (or other load spreading device)
G_p	Permanent load due to platform
G_s	Permanent load due to upper layer overlying a weaker layer
H	Depth from formation level to top of underlying weaker layer
H_{max}	Overall depth of influence for immediate settlement
$H_{n,lower}$	Depth from top of platform to underside of a discrete soil layer
$H_{n,upper}$	Depth from top of platform to top of a discrete soil layer
$i_c\ i_\gamma\ i_q$	Load inclination factors (for bearing capacity)
$K_{a,p}$	Coefficient of active lateral earth pressure for platform material
$K_{p,p}$	Coefficient of passive lateral earth pressure for platform material
$K_{a,s1}$	Coefficient of active lateral earth pressure for subgrade upper layer
$K_{p,s1}$	Cohesive coefficient of passive lateral earth pressure for subgrade upper layer
$K_{ac,s1}$	Coefficient of passive lateral earth pressure for subgrade upper layer
$K_{pc,s1}$	Cohesive coefficient of active lateral earth pressure for subgrade upper layer
L	Length of patch load applied to surface of platform
L'	Length of patch load applied to formation beneath platform
L"	Length of patch load applied to underlying weaker layer
$N_c\ N_\gamma\ N_q$	Bearing capacity factors
$P_{a,p}$	Active lateral earth load in platform
$P_{p,p}$	Passive lateral earth load in platform
$P_{a,s1}$	Active lateral earth load in granular subgrade upper layer
$P_{p,s1}$	Passive lateral earth load in granular subgrade upper layer
q	Bearing pressure applied to surface of platform
q_0	Surcharge applied adjacent to
q'	Bearing pressure applied to formation beneath platform
q"	Bearing pressure applied to underlying weaker layer
$q_{av,p}$	Vertical increase in pressure at platform mid-depth
$q_{av,s1}$	Vertical increase in pressure at granular subgrade upper layer mid-depth
q_p	Bearing capacity of platform material
q_s	Bearing capacity of subgrade
q_{s1}	Bearing capacity of subgrade upper layer
q_{s2}	Bearing capacity of subgrade lower layer
Q	Variable load applied to surface of platform (either directly or indirectly)
$s_c\ s_\gamma\ s_q$	Shape factors (for bearing capacity)
$w_\gamma\ w_q$	Bouyancy factors (for bearing capacity)
β'	Angle of load spread to formation level
β''	Angle of load spread to top of underlying layer
δ_p	Angle of punching shear in platform
δ_{s1}	Angle of punching shear in granular subgrade upper layer
ϕ	Angle of friction
ϕ_{punch}	Reduced angle of friction for very weak coarse grained soils
ϕ_p	Angle of friction for platform material
ϕ_s	Angle of friction for subgrade
ϕ_{s1}	Angle of friction for subgrade upper layer
ϕ_{s2}	Angle of friction for subgrade lower layer
γ_c	Partial factor on undrained strength
γ_G	Partial factor on case 1 variable load (or pressure)
γ_p	Weight density of platform material
γ_{Q1}	Partial factor on case 1 variable load (or pressure)
γ_{Q2}	Partial factor on case 2 variable load (or pressure)
γ_s	Weight density of subgrade soil
γ_f	Partial factor on angle of friction
μ_0,μ_1	Immediate settlement factors
ρ_n	Net settlement for a discrete soil layer
$\rho_{n,lower}$	Settlement for depth extending to the underside of a discrete soil layer
$\rho_{n,upper}$	Settlement for depth extending to the top of a discrete soil layer

APPENDIX B - Abbreviations

BATNEEC	Best Available Technique Not Entailing Excessive Cost
BGL	Below Ground Level
BRE	Building Research Establishment
BS	British Standard
CBR	California Bearing Ratio
CDM2015	Construction (Design and Management) Regulations 2015
CFA	Continuous Flight Auger
CPA	Construction Plant-hire Association
CIRIA	Construction Industry Research and Information Association
DMRB	Design Manual for Roads and Bridges
DRA	Designer's Risk Assessment
EA	Environment Agency
EC0	Eurocode 0 (BS EN 1990, Basis of design)
EC1	Eurocode 1 (BS EN 1991, Actions)
EC7	Eurocode 7 (BS EN 1997, Geotechnical design)
EN	European Norm
FEA	Finite Element Analysis
FPS	Federation of Piling Specialists
FTA	Freight Transport Association
GDR	Geotechnical Design Report
GI	Geotechnical Investigation
GPR	Ground Penetrating Radar
HA	Highways Agency
HSE	Health and Safety Executive
HSW1974	Health and Safety at Work etc. Act 1974
ICE	Institution of Civil Engineers
IGS	International Geosynthetics Society
LUL	London Underground
MCDHW	Manual of Contract Documents Highway Works
MEWP	Mobile Elevating Work Platform (sometimes known as a 'Cherry Picker')
NCCI	Non Contradictory Complementary Information
NFDC	National Federation of Demolition Contractors
NR	Network Rail
PAS	Publicly Available Specification
PD	Principal Designer
PWD	Permanent Works Designer
SHE	Safety, Health and Environmental
SLS	Serviceability Limit State
SME	Small and Medium-sized Enterprises
SUDS	Sustainable Urban Drainage Systems
TRRL	Transport and Road Research Laboratory
TWC	Temporary Works Co-ordinator
TWD	Temporary Works Designer
TWf	Temporary Works Forum
UKAS	The United Kingdom Accreditation Service
ULS	Ultimate Limit State
WRAP	Waste & Resources Action Programme

APPENDIX C - References and bibliography

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APPENDIX D – TWf method: Worked example calculations

This appendix includes worked example calculations of the "TWf method" for granular platforms without geosynthetics, to comply with the requirements of EC7 and BS 8004:2015.

The calculations have been carried out using spreadsheet software. They are presented here in a sub-divided format to aid understanding. In practice, the various sections would be combined into single calculation sets.

It should be noted that, for brevity, only the final values of platform thickness are shown in these examples. In practice the design thickness for the platform is found by simple iteration (trial and error). Use of a spreadsheet calculation is therefore recommended.

Appendix D1 - Piling rig on single layer of mixed made ground with high water table

Determine the platform thickness for a 100 Te piling rig operating on a made ground subgrade overlying medium dense gravel and stiff clay. Groundwater level is close to formation level. Due to the routine nature of the load and ground, a ULS check on subgrade capacity is deemed adequate.

Piling Rig data:

Width of tracks, $B = 1.00\text{m}$

Length of tracks, load case 1, $L_1 = 3.62\text{m}$

Length of tracks, load case 2, $L_2 = 2.79\text{m}$

Ground bearing pressure, load case 1, $q_1 = 215\text{kPa}$

Ground bearing pressure, load case 2, $q_2 = 290\text{kPa}$

Ground Data:

Granular soil parameters, $\phi_k = 29°$, $\gamma_k = 17\text{kN/m}^3$

Cohesive soil parameters, $c_u = 20\text{kPa}$

Depth to groundwater, $z_\gamma = 1.00\text{m}$

Platform material:

Angle of internal friction, $\phi_{pk} = 40°$

Density, $\gamma_k = 20\text{kN/m}^3$

Outputs:

For detailed calculations see **Appendix D1.1, D1.2, D1.3** and **D1.4**.

Minimum thickness for load case 1 and 2 and both sets of soil parameters, $D_{min} = 1.38\text{m}$.

The combination of load case 1 and cohesive parameters governs.

Appendix D1.1 – ULS check for load case 1 & granular parameters

1 VARIABLE ACTIONS

applied load breadth

$B =$ 1.00 m

applied load length

$L =$ 3.62 m

applied load area

$A = BL$

$= 1.00 \times 3.62 =$ 3.62 m^2

characteristic applied ground bearing pressure

$q_k =$ 215.00 kPa

partial factor on variable actions

$\gamma_Q =$ 1.30

design applied ground bearing pressure

$q_d = \gamma_Q q_k$

$= 1.30 \times 215.00 =$ 279.50 kPa

design applied load

$Q_d = q_d A$

$= 279.50 \times 3.62 =$ 1011.79 kN

2 SUB-GRADE PARAMETERS

sub-grade material characteristic angle of internal friction

$\varphi_{sk} =$ 29.00 °

partial factor on sub-grade strength

$\gamma_\varphi =$ 1.25

sub-grade material design angle of internal friction

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi)$

$= \tan^{-1}((\tan 29.00)/1.25) =$ 23.91 °

sub-grade material density

$\gamma_s =$ 17.00 kN/m^3

depth of groundwater below formation

$z_\gamma =$ 1.00 m

3 SUB-GRADE BEARING RESISTANCE WITHOUT PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd}$

$= 0.1054e^{0.168 \times 23.91} =$ 5.85

design shape factor for gravity term

$s_{\gamma d} = 1-(0.4B/L)$

$= 1-(0.4 \times 1.00/3.62) =$ 0.89

design bearing resistance

$V_{Rd} = 0.5\gamma_s B N_{\gamma d} s_{\gamma d} A$

$= 0.5 \times 17.00 \times 1.00 \times 5.85 \times 0.89 \times 3.62 =$ 160.20 kN

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*

UTILISATION

Q_d/V_{Rd} = 1011.79/160.20 = **6.32**

utilisation >1.00 therefore FAIL

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_φ = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_\varphi)$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

5.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = 0.73 m

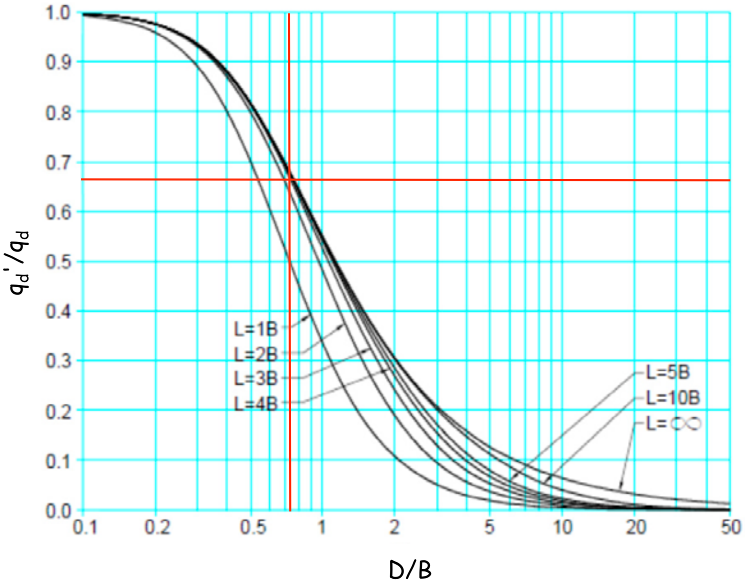
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

D/B = 0.73/1.00 = 0.73

ratio of applied load length to breadth

L/B = 3.62/1.00 = 3.62



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d'/q_d =$ 0.67

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*

design effective pressure

$q_d' = \rho_q \, q_d$

$= 0.67 \times 279.50 =$ 187.27 kPa

design effective area

$A' = Q_d / q_d'$

$= 1011.79/187.27 =$ 5.40 m^2

find load spread width and angle solving with quadratic equation

quadratic factors

$a =$ 1.00

$b = L+B$

$= 3.62+1.00 =$ 4.62

$c = A-A'$

$= 3.62-5.40 =$ -1.78

quadratic solution

$x = -b + \sqrt{(b^2-4ac)} / 2a$

$= (-4.62 + \sqrt{(4.62^2 - 4 \times 1.00 \times -1.78)}) / (2 \times 1.00) =$ 0.36 m

load spread width

$b' = x / 2$

$= 0.36/2 =$ 0.18 m

load spread angle

$\beta = \tan^{-1} (b' / D)$

$= \tan^{-1}(0.18/0.73) =$ 13.85 °

maximum load spread width for β=26.6°

$b'_{max} = D / 2$

$= 0.73/2 =$ 0.37 m

b'<b'max therefore use b'

effective breadth

$B' = \min \{ [B + 2b'] ; [B + 2b'_{max}] \}$

$= \min \{ [1.00+(2 \times 0.18)] ; [1.00+ (2 \times 0.37)] \} =$ 1.36 m

effective length

$L' = \min \{ [L + 2b'] ; [L + 2b'_{max}] \}$

$= \min \{ [3.62+(2 \times 0.18)] ; [3.62+ (2 \times 0.37)] \} =$ 3.98 m

5.2 EFFECTIVE ANGLE OF PUNCHING SHEAR

find design punching shear angle (figure 27)

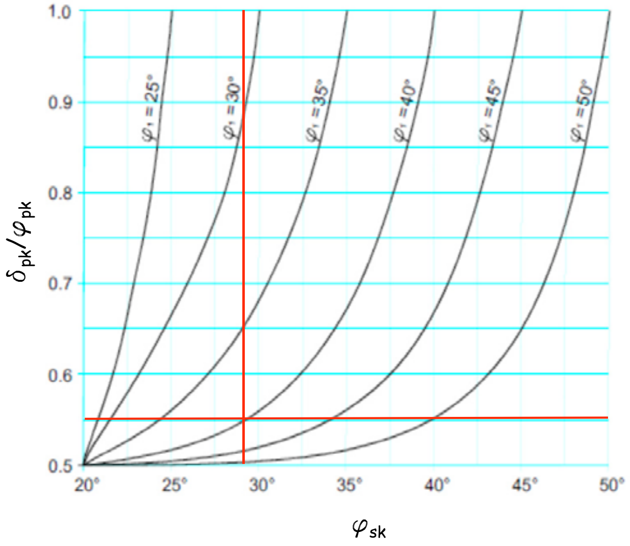
platform material characteristic angle of internal friction

$\varphi_{pk} =$ 40.00 °

sub-grade material characteristic angle of internal friction

$\varphi_{sk} =$ 29.00 °

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*



nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{pk} / \varphi_{pk} =$ 0.55

design punching shear angle

$\delta_{pd} = \rho_\delta \;\; \varphi_{pd}$

$= 0.55 \text{x} 33.87 =$ 18.63 °

5.3 LATERAL LOADS IN PLATFORM

coefficient of active lateral earth pressure for platform

$K_{apd} = ((\sin(90-\varphi_{pd})/(\surd\sin(90+\delta_{pd})+\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90-33.9)/(\surd\sin(90+18.6)+\surd(\sin(33.9+18.6)\text{x}\sin33.9)))^2 =$ 0.26

coefficient of passive lateral earth pressure for platform

$K_{ppd} = ((\sin(90+\varphi_{pd})/(\surd\sin(90-\delta_{pd})-\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90+33.9)/(\surd\sin(90-18.6)-\surd(\sin(33.9+18.6)\text{x}\sin33.9)))^2 =$ 7.24

find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

mid-point depth of platform

$D_{mid} = D / 2$

$= 0.73/2 =$ 0.37 m

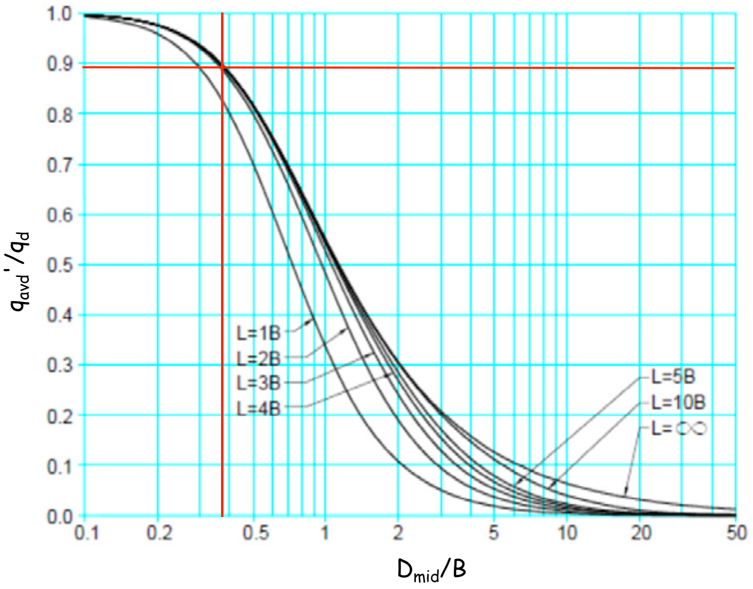
mid-point depth to breadth ratio

$D_{mid}/B = 0.37/1.00 =$ 0.37

ratio of applied load length to breadth

$L/B = 3.62/1.00 =$ 3.62

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}'/q_d =$ 0.89

average vertical pressure due to load

$q_{avd}' = \rho_q \, q_d$

$= 0.89 \times 279.50 =$ 248.76 kPa

active lateral load in fill (per lin m)

$P_{apd} = K_{apd}(q_{avd}' + \gamma_p D/2)D$

$= 0.26 \times (248.76 + (20.00 \times 0.73/2)) \times 0.73 =$ 48.60 kN/m

passive lateral load in fill (per lin m)

$P_{ppd} = K_{ppd} \gamma_p D^2/2$

$= 7.24 \times 20.00 \times 0.73^2/2 =$ 38.58 kN/m

5.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE

horizontal load on sub-grade (per lin m)

$F_{Hs} = P_{apd} - P_{ppd}$

$= 48.60 - 38.58 =$ 10.02 kN/m

vertical load on sub-grade (per lin m)

$F_{Vs} = (q_d B + \gamma_p D B')/2$

$= ((279.50 \times 1.00) + (20.00 \times 0.73 \times 1.36))/2 =$ 149.68 kN/m

5.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE

characteristic permanent action due to platform self weight

$G_{pk} = \gamma_{pk} D B' L'$

$= 20.00 \times 0.73 \times 1.36 \times 3.98 =$ 79.03 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*

design permanent action due to platform self weight

$G_{pd} = \gamma_G \, G_{pk}$

$= 1.00\text{x}79.03 =$ 79.03 kN

total design vertical action

$V_{Ed} = G_{pd}+Q_d$

$= 79.03+1011.79 =$ 1090.82 kN

5.6 SUB-GRADE BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd}$

$= 0.1054e^{0.168\text{x}23.92} =$ 5.85

bearing capacity factor for overburden term

$N_{qd} = e^{\pi \tan\varphi sd} \tan^2(45+\varphi_{sd}/2)$

$= e^{\pi\text{x}\tan 23.92} \tan^2(45+(23.92/2)) =$ 9.51

shape factor for gravity term

$s_{\gamma d} = 1\text{-}(0.4B'/L')$

$= 1\text{-}(0.4\text{x}1.36/3.98) =$ 0.86

shape factor for overburden term

$s_{qd} = 1+(\tan\varphi_{sd}B'/L')$

$= 1+(\tan 23.92\text{x}1.36/3.98) =$ 1.15

inclination factor exponent

$m = (2+(B'/L'))/(1+(B'/L'))$

$= (2+(1.36/3.98))/(1+(1.36/3.98)) =$ 1.75

inclination factor for gravity term

$i_{\gamma d} = \min\{ 1.0 \,;\, [(1\text{-}(F_{Hs}/F_{Vs}))^{m+1}] \}$

$= \min\{ 1.0 \,;\, [(1\text{-}(10.02/149.68))^{(1.75+1)}] \} =$ 0.83

inclination factor for overburden term

$i_{qd} = \min\{ 1.0 \,;\, [(1\text{-}(F_{Hs}/F_{Vs}))^{m}] \}$

$= \min\{ 1.0 \,;\, [(1\text{-}(10.02/149.68))^{1.75}] \} =$ 0.89

depth factor for gravity term

$d_{\gamma d} =$ 1.00

depth factor for overburden term (tan^{-1}(D/B') is expressed in radians)

$d_{qd} = 1+2\tan\varphi_{sd}(1\text{-}\sin\varphi_{sd})^2\tan^{-1}(D/B')$

$= 1+(2\text{x}\tan 23.92\text{x}(1\text{-}\sin 23.92)^2\text{x}\tan^{-1}(0.73/1.36)) =$ 1.15

groundwater factor for gravity term

$w_{\gamma d} = \min\{1.0 \,;\, \max\{ 0.5 \,;\, [0.5(1+(z_\gamma/B'))] \} \}$

$= \min\{1.0 \,;\, [\max\{ 0.5 \,;\, [0.5\text{x}(1+(1.00/1.36))] \}] \} =$ 0.87

depth of groundwater below top of platform

$z_q = z_\gamma+D$

$= 1.00+0.73 =$ 1.73 m

groundwater factor for surcharge term

$w_{qd} = \min\{1.0 \,;\, [\max\{ 0.5 \,;\, [0.5(1+(z_q/D))] \}] \}$

$= \min\{1.0 \,;\, [\max\{ 0.5 \,;\, [0.5\text{x}(1+(1.73/0.73))] \}] \} =$ 1.00

Appendix D1.1 – ULS check for load case 1 & granular parameters – *continued*

bearing resistance

$V_{Rd} = (0.5\gamma_s B' N_{\gamma d} s_{\gamma d} i_{\gamma d} d_{\gamma d} w_{\gamma d} + \gamma_p D N_{qd} s_{qd} i_{qd} d_{qd} w_{qd}) B' L'$

$= ((0.5\text{x}17.0\text{x}1.36\text{x}5.85\text{x}0.86\text{x}0.83\text{x}1.00\text{x}0.87)$

$+(20.0\text{x}0.73\text{x}9.51\text{x}1.15\text{x}0.89\text{x}1.15\text{x}1.00))\ \text{x}1.36\text{x}3.98 =$ 1111.90 kN

UTILISATION

V_{Ed}/V_{Rd} = 1090.82/1111.90 = **0.98**

utilisation ≤1.00 therefore PASS

Appendix D1.2 – ULS check for load case 2 & granular parameters

1 VARIABLE ACTIONS

applied load breadth

$B =$ 1.00 m

applied load length

$L =$ 2.79 m

applied load area

$A = BL$

$= 1.00 \times 2.79 =$ 2.79 m^2

characteristic applied ground bearing pressure

$q_k =$ 290.00 kPa

partial factor on variable actions

$\gamma_Q =$ 1.00

design applied ground bearing pressure

$q_d = \gamma_Q q_k$

$= 1.00 \times 290.00 =$ 290.00 kPa

design applied load

$Q_d = q_d A$

$= 290.00 \times 2.79 =$ 809.10 kN

2 SUB-GRADE PARAMETERS

sub-grade material characteristic angle of internal friction

$\varphi_{sk} =$ 29.00 °

partial factor on sub-grade strength

$\gamma_\varphi =$ 1.25

sub-grade material design angle of internal friction

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi)$

$= \tan^{-1}((\tan 29.00)/1.25) =$ 23.91 °

sub-grade material density

$\gamma_s =$ 17.00 kN/m^3

depth of groundwater below formation

$z_\gamma =$ 1.00 m

3 SUB-GRADE BEARING RESISTANCE WITHOUT PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd}$

$= 0.1054e^{0.168 \times 23.91} =$ 5.85

design shape factor for gravity term

$s_{\gamma d} = 1-(0.4B/L)$

$= 1-(0.4 \times 1.00/2.79) =$ 0.86

design bearing resistance

$V_{Rd} = 0.5\gamma_s B N_{\gamma d} s_{\gamma d} A$

$= 0.5 \times 17.00 \times 1.00 \times 5.85 \times 0.86 \times 2.79 =$ 119.31 kN

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*

UTILISATION

Q_d/V_{Rd} = 809.10/119.31 = **6.78**

utilisation >1.00 therefore FAIL

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_{φ} = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi})$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

5.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = **0.74** **m**

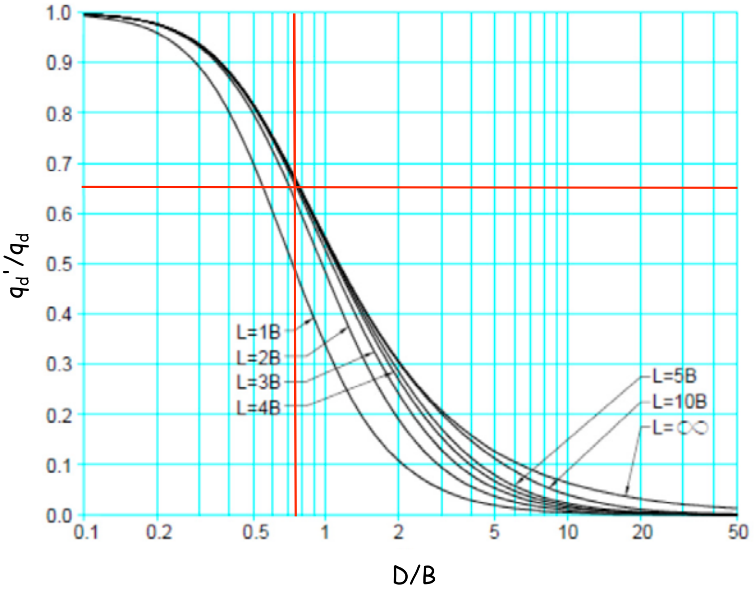
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

D/B = 0.74/1.00 = 0.74

ratio of applied load length to breadth

L/B = 2.79/1.00 = 2.79



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d'/q_d =$ 0.66

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*

design effective pressure

$q_d' = \rho_q \, q_d$

$= 0.66 \times 290.00 =$ 191.40 kPa

design effective area

$A' = Q_d / q_d'$

$= 809.10/191.40 =$ 4.23 m^2

find load spread width and angle solving with quadratic equation

quadratic factors

$a =$ 1.00

$b = L+B$

$= 2.79+1.00 =$ 3.79

$c = A-A'$

$= 2.79-4.23 =$ -1.44

quadratic solution

$x = -b + \sqrt{(b^2-4ac)} / 2a$

$= (-3.79 + \sqrt{(3.79^2 - 4 \times 1.00 \times -1.44)}) / (2 \times 1.00) =$ 0.35 m

load spread width

$b' = x / 2$

$= 0.35/2 =$ 0.18 m

load spread angle

$\beta = \tan^{-1} (b' / D)$

$= \tan^{-1}(0.18/0.73) =$ 13.67 °

maximum load spread width for $\beta = 26.6°$

$b'_{max} = D / 2$

$= 0.74/2 =$ 0.37 m

b'<b'max therefore use b'

effective breadth

$B' = \min \{ [B + 2b'] ; [B + 2b'_{max}] \}$

$= \min \{ [1.00+(2 \times 0.18)] ; [1.00+ (2 \times 0.37)] \} =$ 1.36 m

effective length

$L' = \min \{ [L + 2b'] ; [L + 2b'_{max}] \}$

$= \min \{ [2.79+(2 \times 0.18)] ; [2.79+ (2 \times 0.37)] \} =$ 3.15 m

5.2 EFFECTIVE ANGLE OF PUNCHING SHEAR

find design punching shear angle (figure 27)

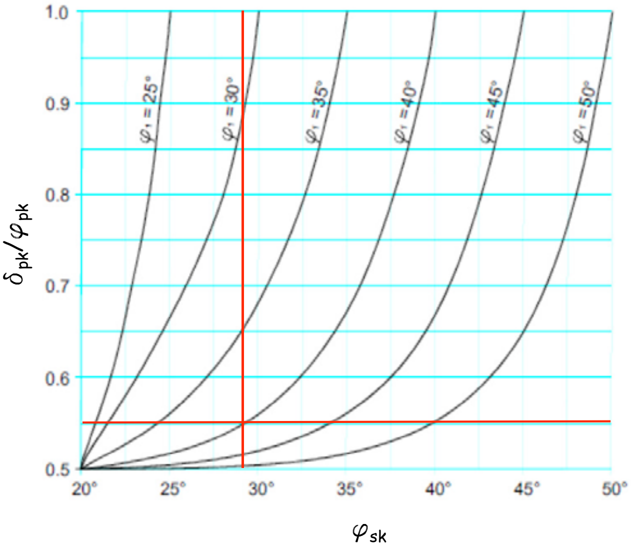
platform material characteristic angle of internal friction

$\varphi_{pk} =$ 40.00 °

sub-grade material characteristic angle of internal friction

$\varphi_{sk} =$ 29.00 °

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*



nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{pk} / \varphi_{pk} =$ 0.55

design punching shear angle

$\delta_{pd} = \rho_\delta \ \varphi_{pd}$

$= 0.55 \text{x} 33.87 =$ 18.63 °

5.3 LATERAL LOADS IN PLATFORM

coefficient of active lateral earth pressure for platform

$K_{apd} = ((\sin(90-\varphi_{pd})/(\surd\sin(90+\delta_{pd})+\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90-33.9)/(\surd\sin(90+18.6)+\surd(\sin(33.9+18.6)\text{x}\sin33.9)))^2 =$ 0.26

coefficient of passive lateral earth pressure for platform

$K_{ppd} = ((\sin(90+\varphi_{pd})/(\surd\sin(90-\delta_{pd})-\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90+33.9)/(\surd\sin(90-18.6)-\surd(\sin(33.9+18.6)\text{x}\sin33.9)))^2 =$ 7.24

find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

mid-point depth of platform

$D_{mid} = D / 2$

$= 0.74/2 =$ 0.37 m

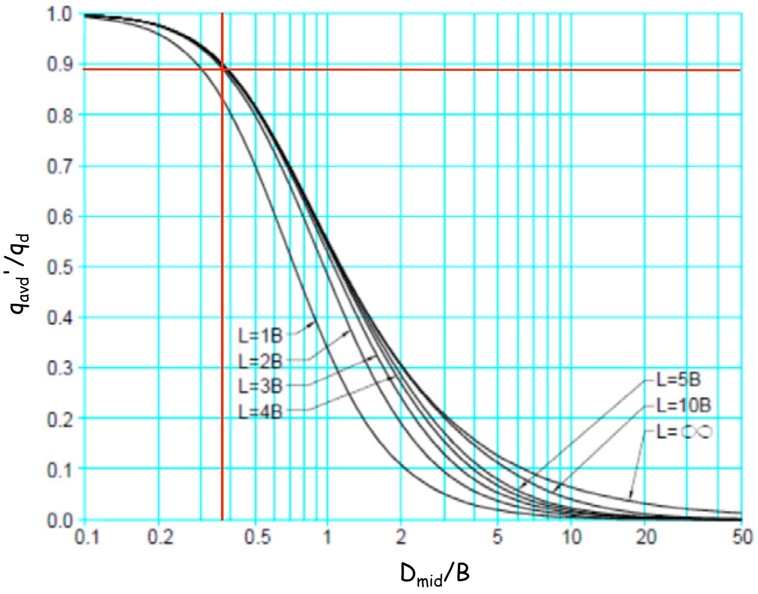
mid-point depth to breadth ratio

$D_{mid}/B = 0.37/1.00 =$ 0.37

ratio of applied load length to breadth

$L/B = 2.79/1.00 =$ 2.79

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}'/q_d =$ 0.89

average vertical pressure due to load

$q_{avd}' = \rho_q\, q_d$

$= 0.89 \times 290.00 =$ 258.10 kPa

active lateral load in fill (per lin m)

$P_{apd} = K_{apd}(q_{avd}' + \gamma_p D/2)D$

$= 0.26 \times (258.10 + (20.00 \times 0.74/2)) \times 0.74 =$ 51.08 kN/m

passive lateral load in fill (per lin m)

$P_{ppd} = K_{ppd}\gamma_p D^2/2$

$= 7.24 \times 20.00 \times 0.74^2/2 =$ 39.65 kN/m

5.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE

horizontal load on sub-grade (per lin m)

$F_{Hs} = P_{apd} - P_{ppd}$

$= 51.08 - 39.65 =$ 11.43 kN/m

vertical load on sub-grade (per lin m)

$F_{Vs} = (q_d B + \gamma_p D B')/2$

$= ((290.00 \times 1.00) + (20.00 \times 0.74 \times 1.36))/2 =$ 155.06 kN/m

5.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE

characteristic permanent action due to platform self weight

$G_{pk} = \gamma_{pk} D B' L'$

$= 20.00 \times 0.74 \times 1.36 \times 3.15 =$ 63.40 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*

design permanent action due to platform self weight

$G_{pd} = \gamma_G \, G_{pk}$

$= 1.00x63.40 =$ 63.40 kN

total design vertical action

$V_{Ed} = G_{pd}+Q_d$

$= 63.40+809.10 =$ 872.50 kN

5.6 SUB-GRADE BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd}$

$= 0.1054e^{0.168x23.92} =$ 5.85

bearing capacity factor for overburden term

$N_{qd} = e^{\pi \tan\varphi sd} \tan^2(45+\varphi_{sd}/2)$

$= e^{\pi x \tan 23.92} \tan^2(45+(23.92/2)) =$ 9.51

shape factor for gravity term

$s_{\gamma d} = 1-(0.4B'/L')$

$= 1-(0.4x1.36/3.15) =$ 0.83

shape factor for overburden term

$s_{qd} = 1+(\tan\varphi_{sd}B'/L')$

$= 1+(\tan 23.92x1.36/3.15) =$ 1.19

inclination factor exponent

$m = (2+(B'/L'))/(1+(B'/L'))$

$= (2+(1.36/3.15))/(1+(1.36/3.15)) =$ 1.70

inclination factor for gravity term

$i_{\gamma d} = \min\{ 1.0 \; ; \; [(1-(F_{Hs}/F_{Vs}))^{m+1}] \}$

$= \min\{ 1.0 \; ; \; [(1-(11.43/155.06))^{(1.70+1)}] \} =$ 0.81

inclination factor for overburden term

$i_{qd} = \min\{ 1.0 \; ; \; [(1-(F_{Hs}/F_{Vs}))^{m}] \}$

$= \min\{ 1.0 \; ; \; [(1-(11.43/155.06))^{1.70}] \} =$ 0.88

depth factor for gravity term

$d_{\gamma d} =$ 1.00

depth factor for overburden term (tan^{-1}(D/B') is expressed in radians)

$d_{qd} = 1+2\tan\varphi_{sd}(1-\sin\varphi_{sd})^2\tan^{-1}(D/B')$

$= 1+(2x\tan 23.92x(1-\sin 23.92)^2x\tan^{-1}(0.74/1.36)) =$ 1.16

groundwater factor for gravity term

$w_{\gamma d} = \min\{1.0 \; ; \; \max\{ 0.5 \; ; \; [0.5(1+(z_\gamma/B'))] \} \}$

$= \min\{1.0 \; ; \; [\max\{ 0.5 \; ; \; [0.5x(1+(1.00/1.36))] \}] \} =$ 0.87

depth of groundwater below top of platform

$z_q = z_\gamma+D$

$= 1.00+0.74 =$ 1.74 m

groundwater factor for surcharge term

$w_{qd} = \min\{1.0 \; ; \; [\max\{ 0.5 \; ; \; [0.5(1+(z_q/D))] \}] \}$

$= \min\{1.0 \; ; \; [\max\{ 0.5 \; ; \; [0.5x(1+(1.74/0.74))] \}] \} =$ 1.00

Appendix D1.2 – ULS check for load case 2 & granular parameters – *continued*

bearing resistance

$V_{Rd} = (0.5\gamma_s B' N_{\gamma d} s_{\gamma d} i_{\gamma d} d_{\gamma d} w_{\gamma d} + \gamma_p D N_{qd} s_{qd} i_{qd} d_{qd} w_{qd}) B' L'$

$= ((0.5 \times 17.0 \times 1.36 \times 5.85 \times 0.83 \times 0.81 \times 1.00 \times 0.87)$

$+(20.0 \times 0.73 \times 9.51 \times 1.19 \times 0.88 \times 1.16 \times 1.00)) \times 1.34 \times 3.13 =$ $\boxed{901.90}$ kN

UTILISATION

$V_{Ed}/V_{Rd} = 872.50/901.90 =$ $\boxed{\mathbf{0.97}}$

utilisation ≤1.00 therefore PASS

Appendix D1.3 – ULS check for load case 1 & cohesive parameters

1 VARIABLE ACTIONS

applied load breadth

$B =$ 1.00 m

applied load length

$L =$ 3.62 m

applied load area

$A = BL$

$= 1.00\text{x}3.62 =$ 3.62 m^2

characteristic applied ground bearing pressure

$q_k =$ 215.00 kPa

partial factor on variable actions

$\gamma_Q =$ 1.30

design applied ground bearing pressure

$q_d = \gamma_Q q_k$

$= 1.30\text{x}215.00 =$ 279.50 kPa

design applied load

$Q_d = q_d A$

$= 279.50\text{x}3.62 =$ 1011.79 kN

2 SUB-GRADE PARAMETERS

sub-grade material characteristic undrained cohesion

$c_{uk} =$ 20.00 kPa

partial factor on sub-grade strength

$\gamma_c =$ 1.40

sub-grade material design undrained cohesion

$c_{ud} = c_{uk} / \gamma_c$

$= 20.00/1.40 =$ 14.29 kPa

3 SUB-GRADE BEARING RESISTANCE WITHOUT PLATFORM

bearing capacity factor for cohesion term

$N_c =$ 5.14

shape factor for cohesion term

$s_{cd} = 1 + (0.21\ B / L)$

$= 1+(0.21\text{X}1.00/3.62) =$ 1.06

design bearing resistance

$V_{Rd} = c_{ud}\ N_c\ s_{cd}\ B\ L$

$= 14.29\text{x}5.14\text{x}1.06\text{x}1.00\text{x}3.62 =$ 281.84 kN

UTILISATION

$Q_d/V_{Rd} = 1011.79/281.84 =$ 3.59

utilisation >1.00 therefore FAIL

Appendix D1.3 – ULS check for load case 1 & cohesive parameters– *continued*

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_{φ} = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi})$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

5.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = **1.38** **m**

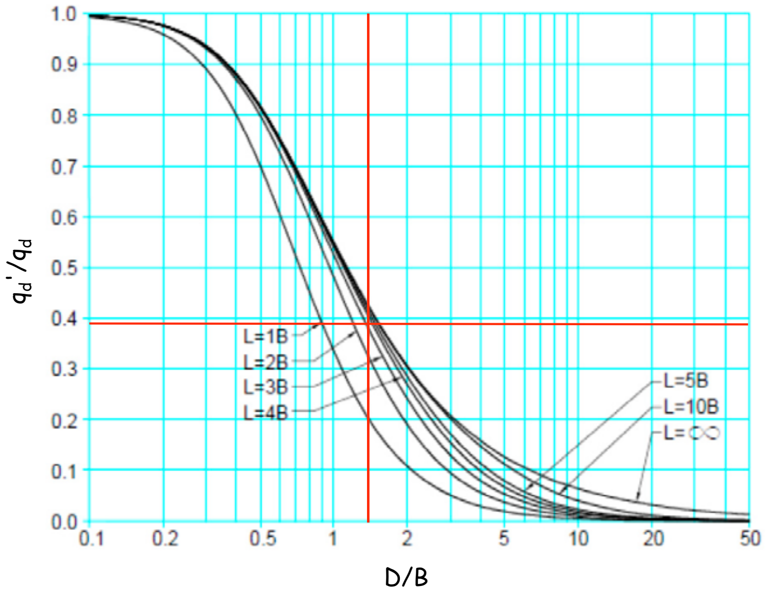
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

$D/B = 1.38/1.00 =$ 1.38

ratio of applied load length to breadth

$L/B = 3.62/1.00 =$ 3.62



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d'/q_d$ 0.39

design effective pressure

$q_d' = \rho_q \, q_d$

$= 0.39 \times 279.50 =$ 109.01 kPa

Appendix D1.3 – ULS check for load case 1 & cohesive parameters – *continued*

design effective area

$A' = Q_d / q_d'$

$= 1011.79/109.01 =$ 9.28 m^2

find load spread width and angle solving with quadratic equation

quadratic factors

$a =$ 1.00

$b = L+B$

$= 3.62+1.00 =$ 4.62

$c = A-A'$

$= 3.62-9.28 =$ -5.66

quadratic solution

$x = -b + \sqrt{}(b^2-4ac) / 2a$

$= (-4.62 + \sqrt{}(4.62^2 - 4x1.00x-5.66)) / (2x1.00) =$ 1.01 m

load spread width

$b' = x / 2$

$= 1.01/2 =$ 0.51 m

load spread angle

$\beta = \tan^{-1} (b' / D)$

$= \tan^{-1}(0.51/1.38) =$ 20.28 °

maximum load spread width for β=26.6°

$b'_{max} = D / 2$

$= 1.38/2 =$ 0.69 m

b'<b'max therefore use b'

effective breadth

$B' = \min \{ [B + 2b'] ; [B + 2b'_{max}] \}$

$= \min \{ [1.00+(2x0.51)] ; [1.00+ (2x0.69)] \} =$ 2.02 m

effective length

$L' = \min \{ [L + 2b'] ; [L + 2b'_{max}] \}$

$= \min \{ [3.62+(2x0.50)] ; [3.62+ (2x0.69)] \} =$ 4.64 m

5.2 EFFECTIVE ANGLE OF PUNCHING SHEAR

nominal bearing capacity factor for gravity term

$N_\gamma = 0.1054\ e^{0.168\varphi pk}$

$= 0.1054xe^{0.168x40}$ 87.36

nominal bearing capacity of platform material

$q_{Rp} = 0.5N_\gamma B\gamma_p$

$= 0.5x87.36x1.00x20.00 =$ 873.60 kPa

nominal bearing capacity of sub-grade material

$q_{Rs} = N_c c_{uk}$

$= 5.14x20.00 =$ 102.80 kPa

Appendix D1.3 – ULS check for load case 1 & cohesive parameters – *continued*

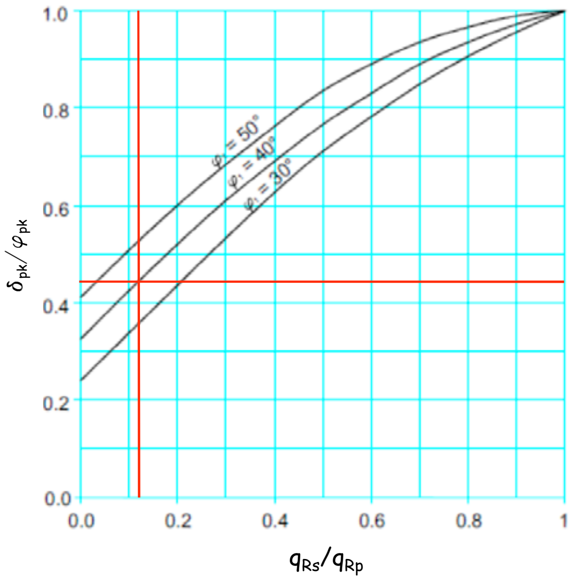
find design punching shear angle (figure 26)

ratio of nominal bearing capacities

q_{Rs}/q_{Rp} = 102.80/873.60 = 0.12

platform material characteristic angle of internal friction

φ_{pk} = 40.00°



nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{pk} / \varphi_{pk}$ = 0.44

design punching shear angle

$\delta_{pd} = \rho_\delta \quad \varphi_{pd}$

= 0.44x33.87 = 14.90°

5.3 LATERAL LOADS IN PLATFORM

coefficient of active lateral earth pressure for platform

$K_{apd} = ((\sin(90-\varphi_{pd})/(\surd\sin(90+\delta_{pd})+\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90-33.9)/(\surd\sin(90+14.9)+\surd(\sin(33.9+14.9)\sin33.9)))^2 =$ 0.26

coefficient of passive lateral earth pressure for platform

$K_{ppd} = ((\sin(90+\varphi_{pd})/(\surd\sin(90-\delta_{pd})-\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2 =$

$= ((\sin(90+33.9)/(\surd\sin(90-14.9)-\surd(\sin(33.9+14.9)\sin33.9)))^2 =$ 6.12

find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

mid-point depth of platform

$D_{mid} = D/2$

= 1.38/2 = 0.69 m

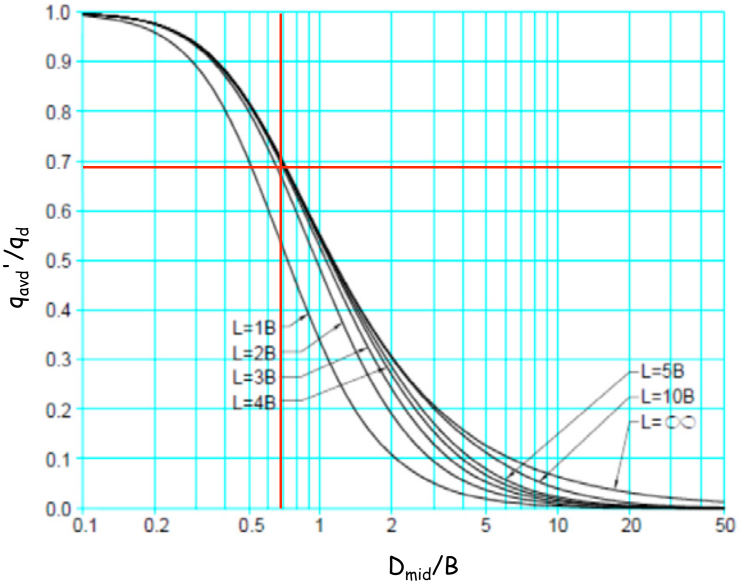
mid-point depth to breadth ratio

D_{mid}/B = 0.69/1.00 = 0.69

ratio of applied load length to breadth

L/B = 3.62/1.00 = 3.62

Appendix D1.3 – ULS check for load case 1 & cohesive parameters – *continued*



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}'/q_d =$ 0.69

average vertical pressure due to load

$q_{avd}' = \rho_q\ q_d$

$= 0.69 \times 279.50 =$ 192.86 kPa

active lateral load in fill (per lin m)

$P_{apd} = K_{apd}(q_{avd}' + \gamma_p D/2)D$

$= 0.26 \times (192.86+(20.00 \times 1.38/2)) \times 1.38 =$ 74.15 kN/m

passive lateral load in fill (per lin m)

$P_{ppd} = K_{ppd}\gamma_p D^2/2$

$= 6.12 \times 20.00 \times 1.38^2/2 =$ 116.55 kN/m

5.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE

horizontal load on sub-grade (per lin m)

$F_{Hs} = P_{apd} - P_{ppd}$

$= 74.15 - 116.55 =$ -42.40 kN/m

vertical load on sub-grade (per lin m)

$F_{Vs} = (q_d B + \gamma_p D B')/2$

$= ((279.50 \times 1.00)+(20.00 \times 1.38 \times 2.02))/2 =$ 167.63 kN/m

5.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE

characteristic permanent action due to platform self weight

$G_{pk} = \gamma_{pk} D B' L'$

$= 20.00 \times 1.38 \times 2.02 \times 4.64 =$ 258.69 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

Appendix D1.3 – ULS check for load case 1 & cohesive parameters – *continued*

design permanent action due to platform self weight

$G_{pd} = \gamma_G\, G_{pk}$

$= 1.00 \times 258.69 =$ 258.69 kN

total design vertical action

$V_{Ed} = G_{pd} + Q_d$

$= 258.69 + 1011.79 =$ 1270.48 kN

5.6 SUB-GRADE BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for cohesion term

$N_{cd} =$ 5.14

shape factor for cohesion term

$s_{cd} = 1 + (0.21\, B'/L') + (0.17\, \sqrt{(D/B')})$

$= 1 + (0.21 \times 2.02/4.64) + (0.17 \times \sqrt{(1.38/2.02)}) =$ 1.23

depth factor for cohesion term

$d_{cd} = 1 + 0.27\sqrt{(D/B')}$

$= 1 + 0.27\sqrt{(1.38/2.02)} =$ 1.22

inclination factor for cohesion term

$i_{cd} = \min \{ [0.5(1+\sqrt{(1-(2F_{Hs}/(B'c_{ud})))}] ; 1.00 \} =$

$= \min \{ [0.5(1+\sqrt{(1-(2 \times -42.40/(2.02 \times 14.29)))}] ; 1.00 \} =$ 1.00

total bearing resistance

$V_{Rd} = (c_{ud} N_{cd} s_{cd} d_{cd} i_{cd} + \gamma_p D) B' L' =$

$= ((14.29 \times 5.14 \times 1.23 \times 1.22 \times 1.00) + (20.00 \times 1.38)) \times 2.02 \times 4.64 =$ 1291.76 kN

UTILISATION

$V_{Ed}/V_{Rd} = 1270.48/1291.76 =$ 0.98

utilisation ≤1.00 therefore PASS

Appendix D1.4 – ULS check for load case 2 & cohesive parameters

1 VARIABLE ACTIONS

applied load breadth

$B =$ 1.00 m

applied load length

$L =$ 2.79 m

applied load area

$A = BL$

$= 1.00 \times 2.79 =$ 2.79 m^2

characteristic applied ground bearing pressure

$q_k =$ 290.00 kPa

partial factor on variable actions

$\gamma_Q =$ 1.00

design applied ground bearing pressure

$q_d = \gamma_Q q_k$

$= 1.00 \times 290.00 =$ 290.00 kPa

design applied load

$Q_d = q_d A$

$= 290.00 \times 2.79 =$ 809.10 kN

2 SUB-GRADE PARAMETERS

sub-grade material characteristic undrained cohesion

$c_{uk} =$ 20.00 kPa

partial factor on sub-grade strength

$\gamma_c =$ 1.40

sub-grade material design undrained cohesion

$c_{ud} = c_{uk} / \gamma_c$

$= 20.00/1.40 =$ 14.29 kPa

3 SUB-GRADE BEARING RESISTANCE WITHOUT PLATFORM

bearing capacity factor for cohesion term

$N_c =$ 5.14

shape factor for cohesion term

$s_{cd} = 1 + (0.21\ B / L)$

$= 1+(0.21 \text{X} 1.00/2.79) =$ 1.08

design bearing resistance

$V_{Rd} = c_{ud}\ N_c\ s_{cd}\ B\ L$

$= 14.29 \times 5.14 \times 1.08 \times 1.00 \times 2.79 =$ 221.32 kN

UTILISATION

$Q_d/V_{Rd} = 809.10/221.32 =$ 3.66

utilisation >1.00 therefore FAIL

Appendix D1.4 – ULS check for load case 2 & cohesive parameters – *continued*

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_{φ} = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi})$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

5.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = **1.38** **m**

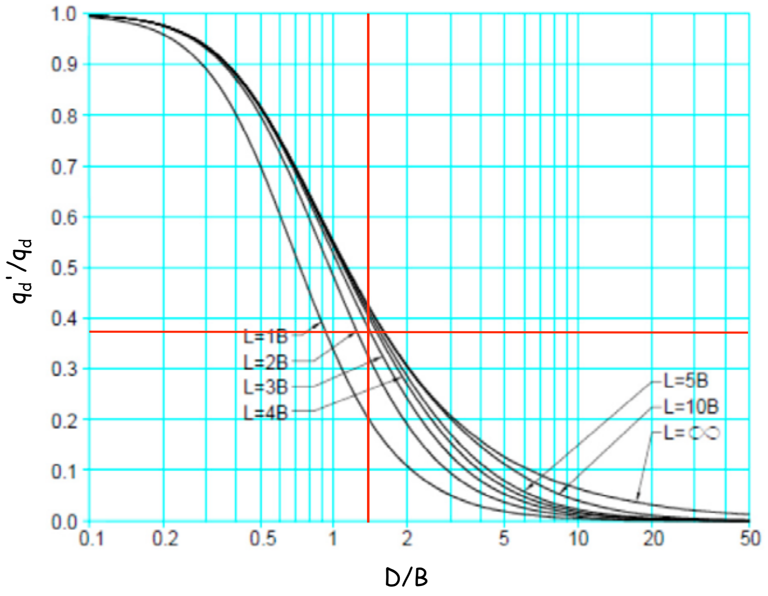
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

D/B = 1.38/1.00 = 1.38

ratio of applied load length to breadth

L/B = 2.79/1.00 = 2.79



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d'/q_d$ 0.37

design effective pressure

$q_d' = \rho_q \, q_d$

$= 0.39 \times 290.00 =$ 107.30 kPa

Appendix D1.4 – ULS check for load case 2 & cohesive parameters – *continued*

design effective area

$A' = Q_d / q_d'$

$= 809.10/107.30 =$ 7.54 m^2

find load spread width and angle solving with quadratic equation

quadratic factors

$a =$ 1.00

$b = L+B$

$= 2.79+1.00 =$ 3.79

$c = A-A'$

$= 2.79-7.54 =$ -4.75

quadratic solution

$x = -b + \sqrt{(b^2-4ac)} / 2a$

$= (-3.79 + \sqrt{(3.79^2 - 4x1.00x-4.75)}) / (2x1.00) =$ 0.99 m

load spread width

$b' = x / 2$

$= 0.99/2 =$ 0.50 m

load spread angle

$\beta = \tan^{-1} (b' / D)$

$= \tan^{-1}(0.50/1.38) =$ 19.92 °

maximum load spread width for β=26.6°

$b'_{max} = D / 2$

$= 1.38/2 =$ 0.69 m

b'<b'max therefore use b'

effective breadth

$B' = \min \{ [B + 2b'] ; [B + 2b'_{max}] \}$

$= \min \{ [1.00+(2x0.50)] ; [1.00+ (2x0.69)] \} =$ 2.00 m

effective length

$L' = \min \{ [L + 2b'] ; [L + 2b'_{max}] \}$

$= \min \{ [2.79+(2x0.50)] ; [2.79+ (2x0.69)] \} =$ 3.79 m

5.2 EFFECTIVE ANGLE OF PUNCHING SHEAR

nominal bearing capacity factor for gravity term

$N_\gamma = 0.1054\ e^{0.168\varphi pk}$

$= 0.1054xe^{0.168x40}$ 87.36

nominal bearing capacity of platform material

$q_{Rp} = 0.5N_\gamma B\gamma_p$

$= 0.5x87.36x1.00x20.00 =$ 873.60 kPa

nominal bearing capacity of sub-grade material

$q_{Rs} = N_c c_{uk}$

$= 5.14x20.00 =$ 102.80 kPa

Appendix D1.4 – ULS check for load case 2 & cohesive parameters – *continued*

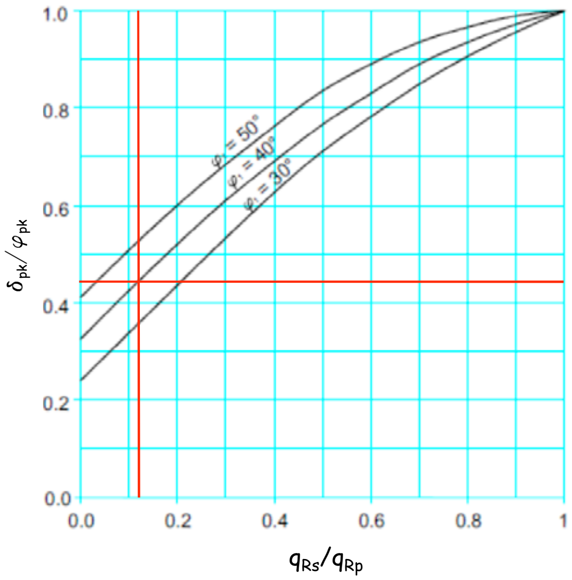
find design punching shear angle (figure 26)

ratio of nominal bearing capacities

q_{Rs}/q_{Rp} = 102.80/873.60 = 0.12

platform material characteristic angle of internal friction

φ_{pk} = 40.00°



nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{pk} / \varphi_{pk}$ = 0.44

design punching shear angle

$\delta_{pd} = \rho_\delta \ \varphi_{pd}$

= 0.44x33.87 = 14.90°

5.3 LATERAL LOADS IN PLATFORM

coefficient of active lateral earth pressure for platform

$K_{apd} = ((\sin(90-\varphi_{pd})/(\sqrt{\sin(90+\delta_{pd})}+\sqrt{(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})}))^2$

$= ((\sin(90-33.9)/(\sqrt{\sin(90+14.9)}+\sqrt{(\sin(33.9+14.9)\sin 33.9)}))^2 =$ 0.26

coefficient of passive lateral earth pressure for platform

$K_{ppd} = ((\sin(90+\varphi_{pd})/(\sqrt{\sin(90-\delta_{pd})}-\sqrt{(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})}))^2 =$

$= ((\sin(90+33.9)/(\sqrt{\sin(90-14.9)}-\sqrt{(\sin(33.9+14.9)\sin 33.9)}))^2 =$ 6.12

find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

mid-point depth of platform

D_{mid} = D/2

= 1.38/2 = 0.69 m

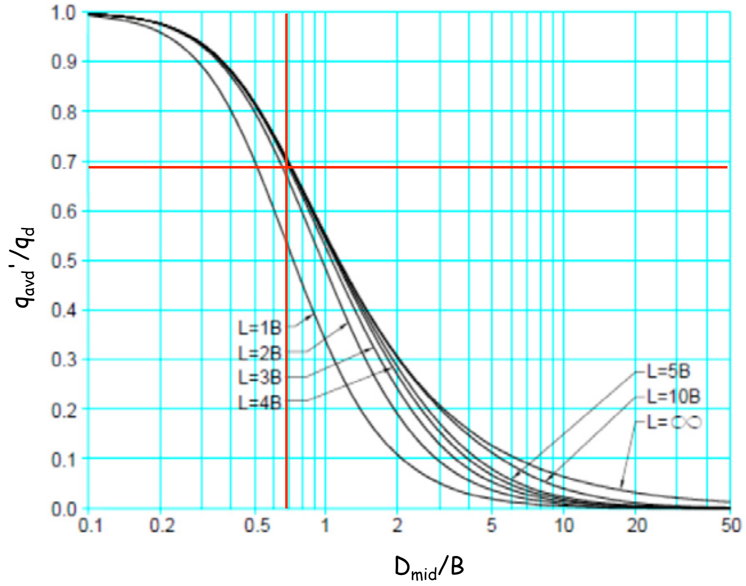
mid-point depth to breadth ratio

D_{mid}/B = 0.69/1.00 = 0.69

ratio of applied load length to breadth

L/B = 2.79/1.00 = 2.79

Appendix D1.4 – ULS check for load case 2 & cohesive parameters – *continued*



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}'/q_d =$ 0.69

average vertical pressure due to load

$q_{avd}' = \rho_q\, q_d$

= 0.69x290.00 = 200.10 kPa

active lateral load in fill (per lin m)

$P_{apd} = K_{apd}(q_{avd}' + \gamma_p D/2)D$

= 0.26x(200.10+(20.00x1.38/2))x1.38 = 76.75 kN/m

passive lateral load in fill (per lin m)

$P_{ppd} = K_{ppd}\gamma_p D^2/2$

= $6.12\text{x}20.00\text{x}1.38^2/2$ = 116.55 kN/m

5.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE

horizontal load on sub-grade (per lin m)

$F_{Hs} = P_{apd} - P_{ppd}$

= 76.75-116.55 = -39.80 kN/m

vertical load on sub-grade (per lin m)

$F_{Vs} = (q_d B + \gamma_p D B')/2$

= ((290.00x1.00)+(20.00x1.38x2.00))/2 = 172.60 kN/m

5.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE

characteristic permanent action due to platform self weight

$G_{pk} = \gamma_{pk} D B' L'$

= 20.00x1.38x2.00x3.79 = 209.21 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

Appendix D1.4 – ULS check for load case 2 & cohesive parameters – *continued*

design permanent action due to platform self weight

$G_{pd} = \gamma_G \, G_{pk}$

$= 1.00 \times 209.21 =$ 209.21 kN

total design vertical action

$V_{Ed} = G_{pd} + Q_d$

$= 209.21 + 809.10 =$ 1018.31 kN

5.6 SUB-GRADE BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for cohesion term

$N_{cd} =$ 5.14

shape factor for cohesion term

$s_{cd} = 1 + (0.21\,B'/L') + (0.17\,\surd(D/B'))$

$= 1+(0.21 \times 2.00/3.79)+(0.17 \times \surd(1.38/2.00)) =$ 1.25

depth factor for cohesion term

$d_{cd} = 1+0.27\surd(D/B')$

$= 1+0.27\surd(1.38/2.00) =$ 1.22

inclination factor for cohesion term

$i_{cd} = \min \{ [0.5(1+\surd(1-(2F_{Hs}/(B'c_{ud}))))] \,;\, 1.00 \} =$

$= \min \{ [0.5(1+\surd(1-(2 \times -39.80/(2.00 \times 14.29))))] \,;\, 1.00 \} =$ 1.00

total bearing resistance

$V_{Rd} = (c_{ud} N_{cd} s_{cd} d_{cd} i_{cd} + \gamma_p D) B' L' =$

$= ((14.29 \times 5.14 \times 1.25 \times 1.22 \times 1.00)+(20.00 \times 1.38)) \times 2.00 \times 3.79 =$ 1058.26 kN

UTILISATION

V_{Ed}/V_{Rd} = **1018.31/1058.26** = **0.96**

utilisation ≤1.00 therefore PASS

Return to the contents

Appendix D2 - Crane outrigger on granular subgrade overlying soft clay

Determine the platform thickness for an 800 Te mobile crane undertaking a lift on a gravel subgrade overlying a thick layer of soft clay. Outrigger loads are distributed using a fabricated steel outrigger pad. Due to the nature of the load and ground, a full SLS check on settlement is included.

Crane outrigger load and outrigger pad data:

Maximum outrigger load,	$Q_k = 1750kN$
Width of outrigger pad,	$B = 2.0m$
Length of outrigger pad,	$L = 3.0m$
Shortest length between outriggers,	$Lx = 7.2m$

NOTE: In this instance, the self-weight of the outrigger pad is considered to be negligible.

Ground Data:

Layer	depth	ϕ_k	c_u	γ_k	E_u
	(mBGL)	(°)	(kPa)	(kN/m^3)	(MPa)
medium dense GRAVEL	0 - 4.0	34	-	20	24
soft CLAY	4.0 -	-	20	20	10

Groundwater encountered at 2.00m BGL.

Platform material:

Angle of internal friction,	$\phi_{pk} = 40°$
Density,	$\gamma_k = 20kN/m^3$
Modulus of elasticity,	$E_u = 75kN/m^2$

Outputs:

For detailed calculations, see **Appendix D2.1, D2.2** and **D2.3.**

Minimum platform thickness, $D_{min} = 0.55m$.

The ULS check on subgrade layer 1 governs.

Appendix D2.1 – ULS check on subgrade layer 1

1 VARIABLE ACTIONS

outrigger pad breadth

$B =$ 2.00 m

outrigger pad length

$L =$ 3.00 m

outrigger pad area

$A = BL$

$= 2.00\times3.00 =$ 6.00 m^2

characteristic applied crane outrigger load

$Q_k =$ 1750.00 kN

partial factor on variable actions

$\gamma_Q =$ 1.30

design applied load

$Q_d = \gamma_Q Q_k$

$= 1.30\times1750.00 =$ 2275.00 kN

design applied ground bearing pressure

$q_d = Q_d/A$

$= 2275.00/6.00 =$ 379.17 kPa

2 SUB-GRADE LAYER 1 PARAMETERS

sub-grade material characteristic angle of internal friction

$\varphi_{sk1} =$ 34.00 °

partial factor on sub-grade strength

$\gamma_\varphi =$ 1.25

sub-grade material design angle of internal friction

$\varphi_{sd1} = \tan^{-1}((\tan\varphi_{sk}) / \gamma_\varphi)$

$= \tan^{-1}((\tan34.00)/1.25) =$ 28.35 °

sub-grade material density

$\gamma_{s1} =$ 20.00 kN/m^3

depth of groundwater below formation

$z_\gamma =$ 2.00 m

3 SUB-GRADE LAYER 1 BEARING RESISTANCE WITHOUT PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd1}$

$= 0.1054e^{0.168\times28.35} =$ 12.34

design shape factor for gravity term

$s_{\gamma d} = 1-(0.4B/L)$

$= 1-(0.4\times2.00/3.00) =$ 0.73

design bearing resistance

$V_{Rd} = 0.5\gamma_{s1}BN_{\gamma d}s_{\gamma d}A$

$= 0.5\times20.00\times2.00\times12.34\times0.73\times6.00 =$ 1080.98 kN

UTILISATION

$\mathbf{Q_d/V_{Rd1} = 2275.00/1080.98 =}$ **2.10**

utilisation >1.00 therefore FAIL

Appendix D2.1 – ULS check on subgrade layer 1 – *continued*

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_{φ} = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi})$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

5.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = **0.55 m**

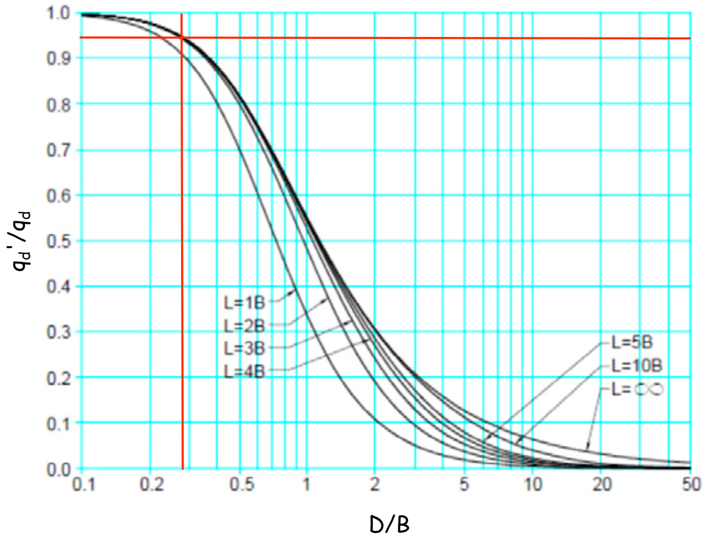
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

D/B = 0.55/2.00 = 0.28

ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d'/q_d =$ 0.94

design effective pressure

$q_d' = \rho_q\, q_d$

$= 0.94 \times 379.17 =$ 356.42 kPa

design effective area

$A' = Q_d / q_d'$

$= 2275.00/356.42 =$ 6.38 m^2

Appendix D2.1 – ULS check on subgrade layer 1 – *continued*

find load spread width and angle solving with quadratic equation

quadratic factors

$a =$ 1.00

$b = L+B$

$= 3.00+2.00 =$ 5.00

$c = A-A'$

$= 6.38-6.00 =$ -0.38

quadratic solution

$x = -b + \sqrt{}(b^2-4ac) / 2a$

$= (-5.00 + \sqrt{}(5.00^2 - 4\times1.00\times-0.38)) / (2\times1.00) =$ 0.07 m

load spread width

$b' = x / 2$

$= 0.07/2 =$ 0.04 m

load spread angle

$\beta = \tan^{-1} (b' / D)$

$= \tan^{-1}(0.04/0.55) =$ 4.16 °

maximum load spread width for β=26.6°

$b'_{max} = D / 2$

$= 0.55/2 =$ 0.28 m

b'<b'max therefore use b'

effective breadth

$B' = \min\{ [B + 2b'] ; [B + 2b'_{max}] \}$

$= \min\{ [2.00+(2\times0.04)] ; [2.00+ (2\times0.28)] \} =$ 2.08 m

effective length

$L' = \min\{ [L + 2b'] ; [L + 2b'_{max}] \}$

$= \min\{ [3.00+(2\times0.04)] ; [3.00+ (2\times0.28)] \} =$ 3.08 m

5.2 EFFECTIVE ANGLE OF PUNCHING SHEAR

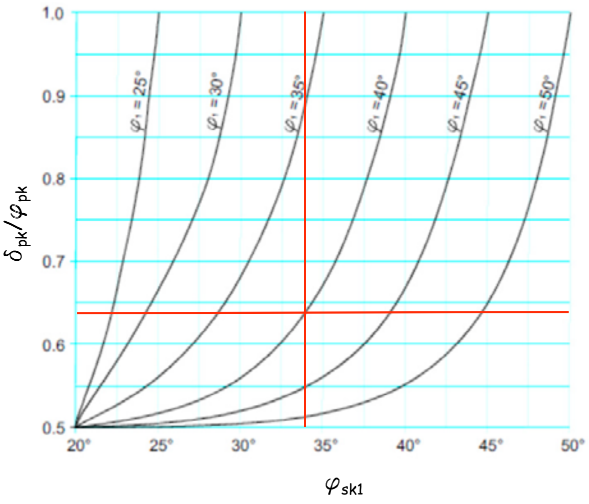
find design punching shear angle (figure 27)

platform material characteristic angle of internal friction

$\varphi_{pk} =$ 40.00 °

sub-grade material characteristic angle of internal friction

$\varphi_{sk1} =$ 34.00 °



Appendix D2.1 – ULS check on subgrade layer 1 – *continued*

nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{pk} / \varphi_{pk} =$ 0.64

design punching shear angle

$\delta_{pd} = \rho_\delta \; \varphi_{pd}$

$= 0.64 \text{x} 33.87 =$ 21.68 °

5.3 LATERAL LOADS IN PLATFORM

coefficient of active lateral earth pressure for platform

$K_{apd} = ((\sin(90-\varphi_{pd})/(\surd\sin(90+\delta_{pd})+\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90-33.9)/(\surd\sin(90+21.7)+\surd(\sin(33.9+21.7)\text{x}\sin 33.9)))^2 =$ 0.26

coefficient of passive lateral earth pressure for platform

$K_{ppd} = ((\sin(90+\varphi_{pd})/(\surd\sin(90-\delta_{pd})-\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2$

$= ((\sin(90+33.9)/(\surd\sin(90-21.7)-\surd(\sin(33.9+21.7)\text{x}\sin 33.9)))^2 =$ 8.42

find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

mid-point depth of platform

$D_{mid} = D / 2$

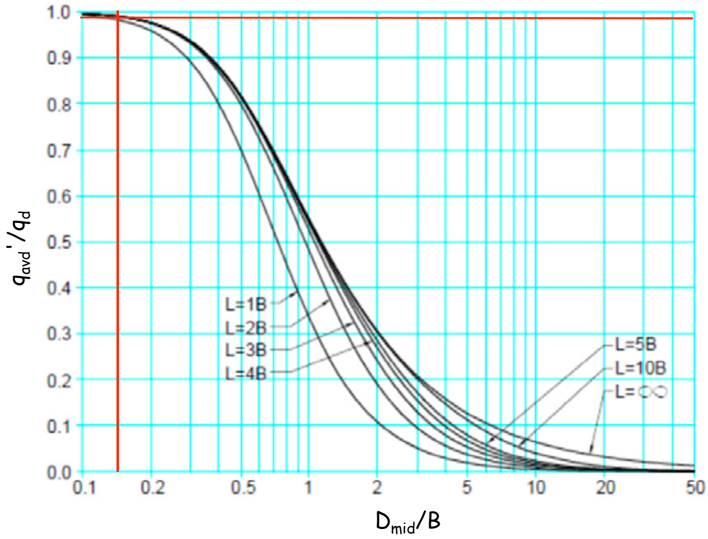
$= 0.55/2 =$ 0.28 m

mid-point depth to breadth ratio

$D_{mid}/B = 0.28/2.00 =$ 0.14

ratio of applied load length to breadth

$L/B = 3.00/2.00 =$ 1.50



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}'/q_d =$ 0.99

average vertical pressure due to load

$q_{avd}' = \rho_q \; q_d$

$= 0.99 \text{x} 379.17 =$ 375.38 kPa

active lateral load in fill (per lin m)

$P_{apd} = K_{apd}(q_{avd}' + \gamma_p D/2)D$

$= 0.26 \text{x} (375.38+(20.00 \text{x} 0.55/2)) \text{x} 0.55 =$ 54.47 kN/m

passive lateral load in fill (per lin m)

$P_{ppd} = K_{ppd}\gamma_p D^2/2$

$= 8.42 \text{x} 20.00 \text{x} 0.55^2/2 =$ 25.47 kN/m

Appendix D2.1 – ULS check on subgrade layer 1 – *continued*

5.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE LAYER 1

horizontal load on sub-grade layer 1 (per lin m)

$F_{Hs1} = P_{apd}-P_{ppd}$

$= 54.47-25.47 =$ 29.00 kN/m

vertical load on sub-grade layer 1 (per lin m)

$F_{Vs1} = (q_dB+\gamma_pDB')/2$

$= ((379.17x2.00)+(20.00x0.55x2.08))/2 =$ 390.61 kN/m

5.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE LAYER 1

characteristic permanent action due to platform self weight

$G_{pk} = \gamma_{pk}DB'L'$

$= 20.00x0.55x2.08x3.08 =$ 70.47 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

design permanent action due to platform self weight

$G_{pd} = \gamma_G\, G_{pk}$

$= 1.00x70.47 =$ 70.47 kN

total design vertical action

$V_{Ed} = G_{pd}+Q_d$

$= 70.47+2275.00 =$ 2345.47 kN

5.6 SUB-GRADE LAYER 1 BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for gravity term

$N_{\gamma d} = 0.1054e^{0.168\varphi sd1}$

$= 0.1054e^{0.168x28.35} =$ 12.34

bearing capacity factor for overburden term

$N_{qd} = e^{\pi\tan\varphi sd1}\tan^2(45+\varphi_{sd1}/2)$

$= e^{\pi x\tan 28.35}\tan^2(45+(28.35/2)) =$ 15.30

shape factor for gravity term

$s_{\gamma d} = 1-(0.4B'/L')$

$= 1-(0.4x2.08/3.08) =$ 0.73

shape factor for overburden term

$s_{qd} = 1+(\tan\varphi_{sd}B'/L')$

$= 1+(\tan 28.35x2.08/3.08) =$ 1.36

inclination factor exponent

$m = (2+(B'/L'))/(1+(B'/L'))$

$= (2+(2.08/3.08))/(1+(2.08/3.08)) =$ 1.60

inclination factor for gravity term

$i_{\gamma d} = \min\{\,1.0\,;\,[(1-(F_{Hs1}/F_{Vs1}))^{m+1}]\,\}$

$= \min\{\,1.0\,;\,[(1-(29.00/390.61))^{(1.60+1)}]\,\} =$ 0.82

inclination factor for overburden term

$i_{qd} = \min\{\,1.0\,;\,[(1-(F_{Hs1}/F_{Vs1}))^{m}]\,\}$

$= \min\{\,1.0\,;\,[(1-(29.00/390.61))^{1.60}]\,\} =$ 0.88

depth factor for gravity term

$d_{\gamma d} =$ 1.00

depth factor for overburden term ($\tan^{-1}(D/B')$ is expressed in radians)

$d_{qd} = 1+2\tan\varphi_{sd1}(1-\sin\varphi_{sd1})^2\tan^{-1}(D/B')$

$= 1+(2x\tan 28.35x(1-\sin 28.35)^2x\tan^{-1}(0.55/2.08)) =$ 1.08

Appendix D2.1 – ULS check on subgrade layer 1 – *continued*

groundwater factor for gravity term

$w_{\gamma d} = \min\{1.0 ; \max\{ 0.5 ; [0.5(1+(z_{\gamma}/B'))] \} \}$

$= \min\{1.0 ; [\max\{ 0.5 ; [0.5\times(1+(2.00/2.08))] \}] \} =$ 0.98

depth of groundwater below top of platform

$z_q = z_{\gamma}+D$

$= 2.00+0.55 =$ 2.55 m

groundwater factor for surcharge term

$w_{qd} = \min\{1.0 ; [\max\{ 0.5 ; [0.5(1+(z_q/D))] \}] \}$

$= \min\{1.0 ; [\max\{ 0.5 ; [0.5\times(1+(2.55/0.55))] \}] \} =$ 1.00

bearing resistance

$V_{Rd} = (0.5\gamma_{s1}B'N_{\gamma d}s_{\gamma d}i_{\gamma d}d_{\gamma d}w_{\gamma d}+\gamma_p DN_{qd}s_{qd}i_{qd}d_{qd}w_{qd})B'L'$

$= ((0.5\times20.0\times2.08\times12.34\times0.73\times0.82\times1.00\times0.98)$

$+(20.0\times0.55\times15.30\times1.36\times0.88\times1.08\times1.00))\times2.08\times3.08 =$ 2358.24 kN

UTILISATION

V_{Ed}/V_{Rd1} = 2345.47/2358.24 = 0.99

utilisation ≤1.00 therefore PASS

Appendix D2.2 – ULS check on subgrade layer 2

1 VARIABLE ACTIONS

outrigger pad breadth

$B =$ 2.00 m

outrigger pad length

$L =$ 3.00 m

outrigger pad area

$A = BL$

$= 2.00 \times 3.00 =$ 6.00 m^2

characteristic applied crane outrigger load

$Q_k =$ 1750.00 kN

partial factor on variable actions

$\gamma_Q =$ 1.30

design applied load

$Q_d = \gamma_Q Q_k$

$= 1.30 \times 1750.00 =$ 2275.00 kN

design applied ground bearing pressure

$q_d = Q_d/A$

$= 2275.00/6.00 =$ 379.17 kPa

2.1 SUB-GRADE LAYER 1 PARAMETERS

sub-grade layer 1 thickness

$H =$ 4.00 m

sub-grade layer 1 characteristic angle of internal friction

$\varphi_{sk1} =$ 34.00 °

partial factor on sub-grade strength

$\gamma_\varphi =$ 1.25

sub-grade layer 1 design angle of internal friction

$\varphi_{sd1} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi)$

$= \tan^{-1}((\tan 34.00)/1.25) =$ 28.35 °

sub-grade layer 1 density

$\gamma_{s1} =$ 20.00 kN/m^3

2.2 SUB-GRADE LAYER 2 PARAMETERS

sub-grade layer 2 characteristic undrained cohesion

$c_{uk2} =$ 20.00 kPa

partial factor on sub-grade strength

$\gamma_c =$ 1.40

sub-grade layer 2 design undrained cohesion

$c_{ud2} = c_{uk} / \gamma_c$

$= 20.00/1.40 =$ 14.29 kPa

Appendix D2.2 – ULS check on subgrade layer 2 – *continued*

4 PLATFORM PARAMETERS

select platform material based on presumed bearing capacity (table 3)

platform material characteristic angle of internal friction

φ_{pk} = 40.00 °

partial factor on platform material strength

γ_{φ} = 1.25

platform material design angle of internal friction

$\varphi_{pd} = \tan^{-1}((\tan\varphi_{pk})/\gamma_{\varphi})$

$= \tan^{-1}((\tan 40.00)/1.25) =$ 33.87 °

platform material density

γ_p = 20.00 kN/m^3

6.1 EFFECTIVE AREA, DIMENSIONS AND LOAD SPREAD ANGLE

PLATFORM THICKNESS

D = **0.55** **m**

total depth to top of sub-grade layer 2

D' = H+D =

= 4.00+0.55 = 4.55 m

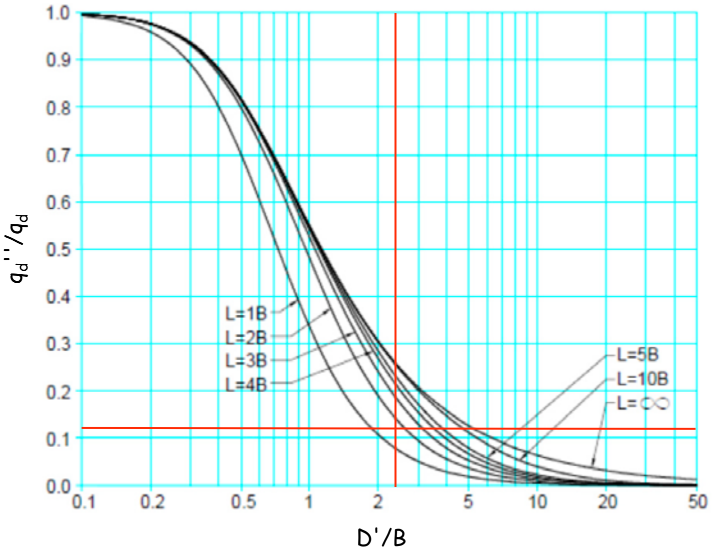
find ratio of applied pressure to effective pressure at formation (figure 25)

ratio of applied load breadth to platform depth

D'/B = 4.55/2.00 = 2.28

ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_d''/q_d$ 0.12

Appendix D2.2 – ULS check on subgrade layer 2 – *continued*

design effective pressure

$q_d'' = \rho_q\, q_d$

= 0.12x379.17 = 45.50 kPa

design effective area

$A'' = Q_d / q_d''$

= 2275.00/45.50 = 50.00 m^2

find load spread width and angle solving with quadratic equation

quadratic factors

a = 1.00

b = L+B

= 3.00+2.00 = 5.00

c = A-A'

= 6.00-50.00 = -44.00

quadratic solution

$x = -b + \sqrt{(b^2-4ac)} / 2a$

$= (-5.00 + \sqrt{(5.00^2 - 4x1.00x-44.00)}) / (2x1.00) =$ 4.59 m

load spread width

b'' = x / 2

= 4.59/2 = 2.30 m

load spread angle

$\beta = tan^{-1} (b'' / D)$

$= tan^{-1}(2.30/4.55) =$ 26.82 °

maximum load spread width for β=26.6°

$b''_{max} = D / 2$

= 4.55/2 = 2.28 m

b''>b''max therefore use b''max

effective breadth

$B'' = \min \{ [B + 2b''] ; [B + 2b''_{max}] \}$

= min { [2.00+(2x2.30)] ; [2.00+ (2x2.28)] } = 6.56 m

effective length

$L'' = \min \{ [L + 2b''] ; [L + 2b''_{max}] \}$

= min { [3.00+(2x2.30)] ; [3.00+ (2x2.28)] } = 7.56 m

6.2 EFFECTIVE ANGLE OF PUNCHING SHEAR IN SUB-GRADE LAYER 1

nominal bearing capacity factor for gravity term for sub-grade layer 1

$N_\gamma = 0.1054\ e^{0.168\varphi sk1}$

$= 0.1054xe^{0.168x34}$ 31.88

nominal bearing capacity of sub-grade layer 1

$q_{Rs1} = 0.5 N_\gamma B \gamma_p$

= 0.5x31.88x2.00x20.00 = 637.60 kPa

Appendix D2.2 – ULS check on subgrade layer 2 – *continued*

bearing capacity factor for cohesion term for sub-grade layer 2

N_c = 5.14

nominal bearing capacity of sub-grade layer 2

$q_{Rs2} = N_c c_{uk2}$

= 5.14x20.00 = 102.80 kPa

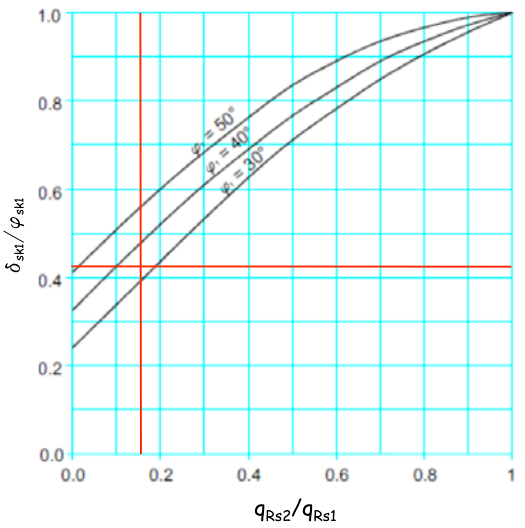
find design punching shear angle (figure 26)

ratio of nominal bearing capacities

q_{Rs2}/q_{Rs1} = 102.80/637.60 = 0.16

sub-grade layer 1 characteristic angle of internal friction

φ_{pk} = 34.00 °



nominal punching shear parameter (from chart)

$\rho_\delta = \delta_{sk1} / \varphi_{sk1}$ = 0.42

design punching shear angle

$\delta_{sd1} = \rho_\delta \ \varphi_{sd1}$

= 0.42x28.35 = 11.91 °

6.3 LATERAL LOADS IN SUB-GRADE LAYER 1

coefficient of active lateral earth pressure for platform

$K_{asd1} = ((\sin(90-\varphi_{sd1})/(\surd\sin(90+\delta_{sd1})+\surd(\sin(\varphi_{sd1}+\delta_{sd1})\sin\varphi_{sd1})))^2$

$= ((\sin(90-28.3)/(\surd\sin(90+11.9)+\surd(\sin(28.3+11.9)\sin28.3)))^2 =$ 0.33

coefficient of passive lateral earth pressure for platform

$K_{psd1} = ((\sin(90+\varphi_{pd})/(\surd\sin(90-\delta_{pd})-\surd(\sin(\varphi_{pd}+\delta_{pd})\sin\varphi_{pd})))^2 =$

$= ((\sin(90+28.3)/(\surd\sin(90-11.9)-\surd(\sin(28.3+11.9)\sin28.3)))^2 =$ 4.09

find ratio of applied pressure to effective pressure at mid-depth of sub-grade layer 1 (figure 25)

mid-point depth of sub-grade layer 1

H_{mid} = (H/2)+D =

= (4.00/2)+0.55 = 2.55 m

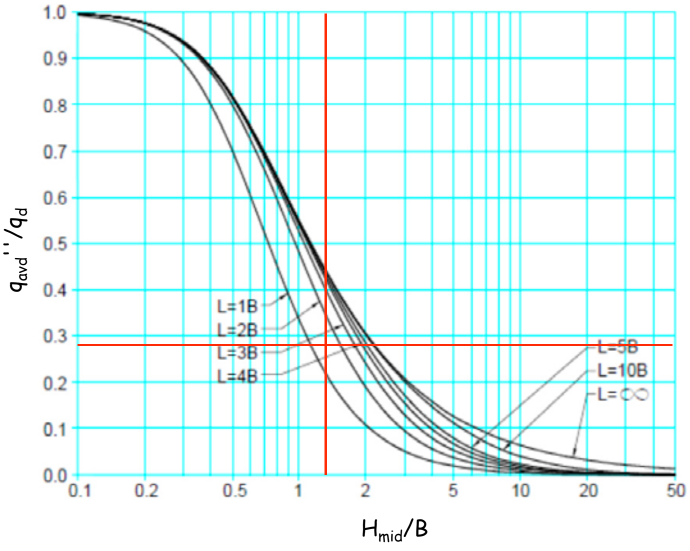
Appendix D2.2 – ULS check on subgrade layer 2 – *continued*

mid-point depth to breadth ratio

H_{mid}/B = 2.55/2.00 = 1.28

ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50



ratio of applied pressure to effective pressure (from chart)

$\rho_q = q_{avd}''/q_d$ = 0.28

average vertical pressure due to load

$q_{avd}'' = \rho_q\, q_d$

= 0.28x379.17 = 106.17 kPa

active lateral load in fill (per lin m)

$P_{asd1} = K_{asd1}(q_{avd}'' + \gamma_{s1}H/2)H$

= 0.33x(106.17+(20.00x4.00/2))x4.00 = 192.94 kN/m

passive lateral load in fill (per lin m)

$P_{psd1} = K_{psd1}\gamma_{s1}D^2/2$

= $4.09\text{x}20.00\text{x}4.00^2/2$ = 654.40 kN/m

6.4 HORIZONTAL AND VERTICAL LOADS ON SUB-GRADE LAYER 2

horizontal load on sub-grade (per lin m)

$F_{Hs2} = P_{asd1} - P_{psd1}$

= 192.94-654.40 = -461.46 kN/m

vertical load on sub-grade (per lin m)

$F_{Vs2} = (q_dB+(\gamma_pD+\gamma_{s1}H)B'')/2$

= ((379.17x2.00)+(20.00x0.55+20.00x4.00)x6.56))/2 = 677.65 kN/m

Appendix D2.2 – ULS check on subgrade layer 2 – *continued*

6.5 TOTAL VERTICAL LOAD EFFECT ON SUB-GRADE LAYER 2

characteristic permanent action due to platform self weight

$G_{pk} = (\gamma_p D+\gamma_{s1}H)B''L''$

$= (20.00 \times 0.55+20.00 \times 4.00) \times 6.56 \times 7.56 =$ 4513.02 kN

partial factor for permanent actions

$\gamma_G =$ 1.00

design permanent action due to platform self weight

$G_{pd} = \gamma_G \, G_{pk}$

$= 1.00 \times 4513.02 =$ 4513.02 kN

total design vertical action

$V_{Ed} = G_{pd}+Q_d$

$= 4513.02+2275.00 =$ 6788.02 kN

6.6 SUB-GRADE LAYER 2 BEARING RESISTANCE WITH PLATFORM

bearing capacity factor for cohesion term

$N_{cd} =$ 5.14

shape factor for cohesion term

$s_{cd} = 1 + (0.21\ B''/L'') + (0.17\ \sqrt{}(D'/B''))$

$= 1+(0.21 \times 6.56/7.56)+(0.17 \times \sqrt{}(4.55/6.56)) =$ 1.32

depth factor for cohesion term

$d_{cd} = 1+0.27\sqrt{}(D'/B'')$

$= 1+0.27\sqrt{}(4.55/6.56) =$ 1.22

inclination factor for cohesion term

$i_{cd} = \min\{\ [0.5(1+\sqrt{}(1-(2F_{Hs2}/(B''c_{ud2}))))]\ ;\ 1.00\ \} =$

$= \min\{\ [0.5(1+\sqrt{}(1-(2x-461.46/(6.56 \times 14.29))))]\ ;\ 1.00\ \} =$ 1.00

total bearing resistance

$V_{Rd} = (c_{ud2}N_{cd}s_{cd}d_{cd}i_{cd}+\gamma_p D+\gamma_{s1}H)B''L'' =$

$= ((14.29 \times 5.14 \times 1.32 \times 1.22 \times 1.00)+(20.00 \times 0.55)+(20.00 \times 4.00))$

$\times 6.56 \times 7.56 =$ 10379.19 kN

UTILISATION

V_{Ed}/V_{Rd2} = 6788.02/10379.19 = ***0.65***

utilisation ≤1.00 therefore PASS

Appendix D2.3 – SLS check on immediate settlement

1 VARIABLE ACTIONS

outrigger pad breadth

$B =$ 2.00 m

outrigger pad length

$L =$ 3.00 m

outrigger pad area

$A = BL$

$= 2.00 \times 3.00 =$ 6.00 m^2

characteristic applied crane outrigger load

$Q_k =$ 1750.00 kN

design applied ground bearing pressure

$q_k = Q_k/A$

$= 1750.00/6.00 =$ 291.67 kPa

2.1 SUB-GRADE LAYER 1 PARAMETERS

sub-grade layer 1 thickness

$H =$ 4.00 m

sub-grade layer 1 density

$\gamma_{s1} =$ 20.00 kN/m^3

sub-grade layer 1 elastic modulus

$E_{u1} =$ 24.00 MPa

2.2 SUB-GRADE LAYER 2 PARAMETERS

sub-grade layer 2 density

$\gamma_{s2} =$ 20.00 kN/m^3

sub-grade layer 2 undrained elastic modulus

$E_{u2} =$ 10.00 MPa

4 PLATFORM PARAMETERS

PLATFORM THICKNESS

$D =$ 0.55 m

platform material density

$\gamma_p =$ 20.00 kN/m^3

platform material elastic modulus

$E_{up} =$ 75.00 MPa

Appendix D2.3 – SLS check on immediate settlement – *continued*

7.1 DEPTH OF INFLUENCE

find depth for 20% overburden = increase in pressure due to loading (figure 25)

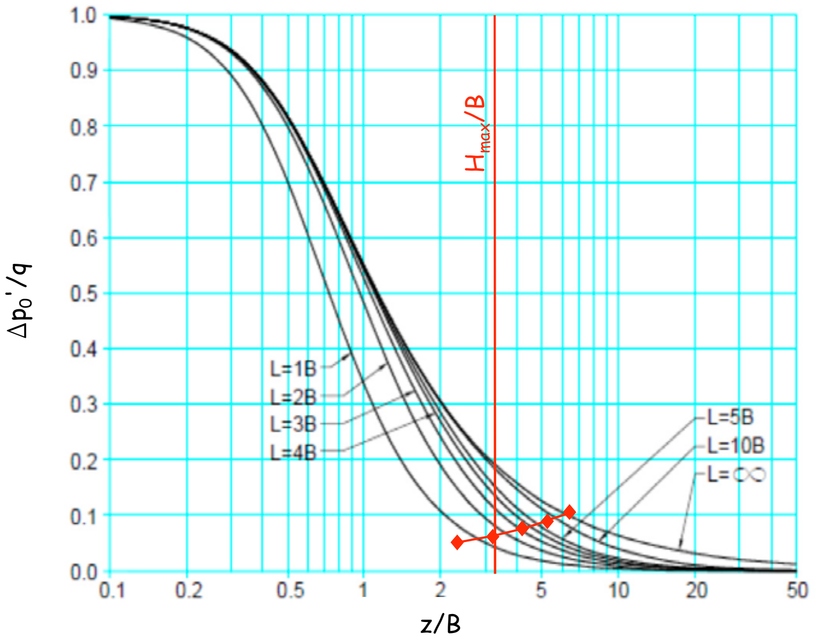
ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50

plot points for $0.2Dp'_0/q$ vs z/B ◆—◆—◆

ground water level — — — —

z (m)	z/B	Δz (m)	γ' (kN/m^3)	g' $= \Delta z.\gamma'$ (kPa)	$\Delta p_0'$ $= \Sigma g'$ (kPa)	$\Delta p_0'/q$	$0.2\Delta p_0'/q$
0.55	0.28	0.55	20.00	11.00	11.00	0.04	0.01
1.55	0.78	1.00	20.00	20.00	31.00	0.11	0.02
2.55	1.28	1.00	20.00	20.00	51.00	0.17	0.03
3.55	1.78	1.00	10.00	10.00	61.00	0.21	0.04
4.55	2.28	1.00	10.00	10.00	71.00	0.24	0.05
6.55	3.28	2.00	10.00	20.00	91.00	0.31	0.06
8.55	4.28	2.00	10.00	20.00	111.00	0.38	0.08
10.55	5.28	2.00	10.00	20.00	131.00	0.45	0.09
12.55	6.28	2.00	10.00	20.00	151.00	0.52	0.10
14.55	7.28	2.00	10.00	20.00	171.00	0.59	0.12
16.55	8.28	2.00	10.00	20.00	191.00	0.65	0.13



Appendix D2.3 – SLS check on immediate settlement – *continued*

ratio of depth of influence to applied load breadth (intersection of curves)

$\rho_H = H_{max}/B =$ 3.20

depth of influence

$H_{max} = \rho_H B$

$= 3.60\text{x}2.00 =$ 6.40 m

7.2 SETTLEMENT IN PLATFORM

find settlement in platform (figure 29)

depth to underside of platform

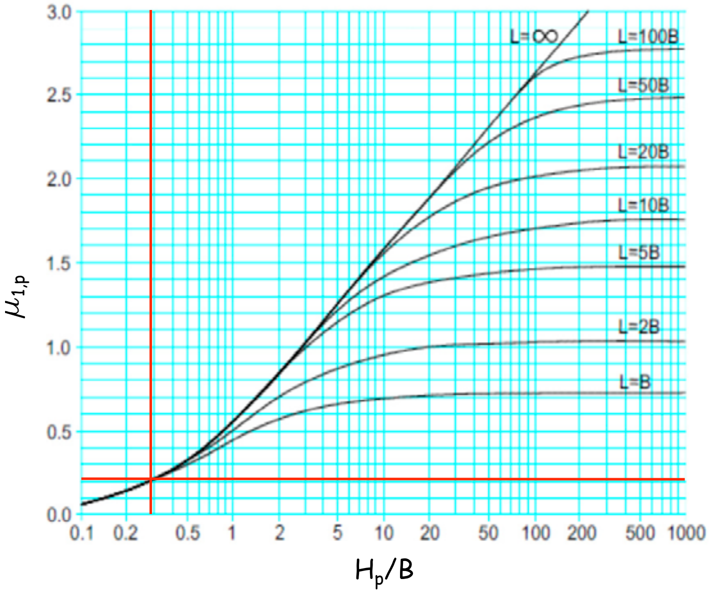
$H_p = D =$ 0.55 m

ratio of depth to applied load breadth

$H_p/B = 0.55/2.00 =$ 0.28

ratio of applied load length to breadth

$L/B = 3.00/2.00 =$ 1.50



settlement factor

$\mu_{1,p} =$ 0.20

settlement in platform

$\rho_1 = qB\mu_{1,p}/E_{up}$

$= (291.67\text{x}2.00\text{x}0.20/(75\text{x}10^3))\text{x}10^{-3} =$ 1.56 mm

Appendix D2.3 – SLS check on immediate settlement – *continued*

7.3 SETTLEMENT IN SUB-GRADE LAYER 1

find settlement in sub-grade layer 1 (figure 29)

depth to underside of layer 1

H_1 = D+H

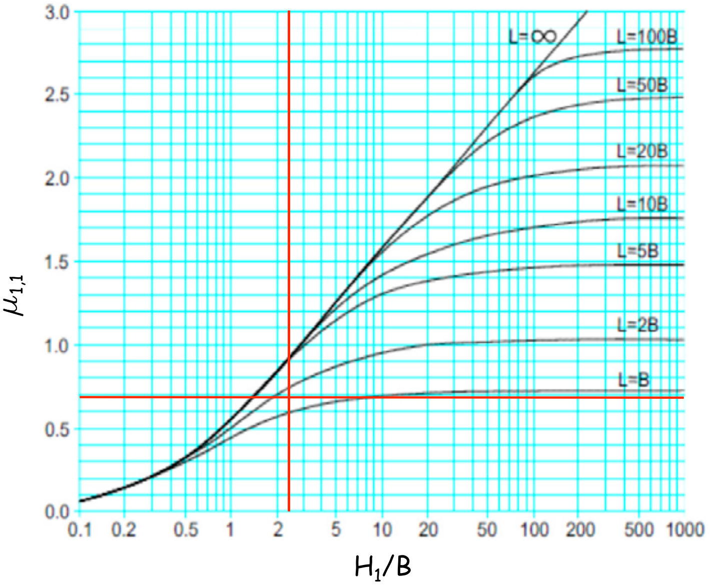
= 0.55+4.00 = 4.55 m

ratio of depth to applied load breadth

H_1/B = 4.55/2.00 = 2.28

ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50



settlement factor

$\mu_{1,1}$ = 0.68

settlement in layer 1

$\rho_2 = qB(\mu_{1,1}-\mu_{1,p})/E_{u1}$

= $(291.67 \times 2.00 \times (0.68-0.20)/(24 \times 10^3)) \times 10^{-3}$ = 11.67 mm

7.4 SETTLEMENT IN SUBGRADE LAYER 2

find settlement in sub-grade layer 2 (figure 29)

depth to underside of layer 2 (= depth of influence)

$H_2 = H_{max}$ = 6.40 m

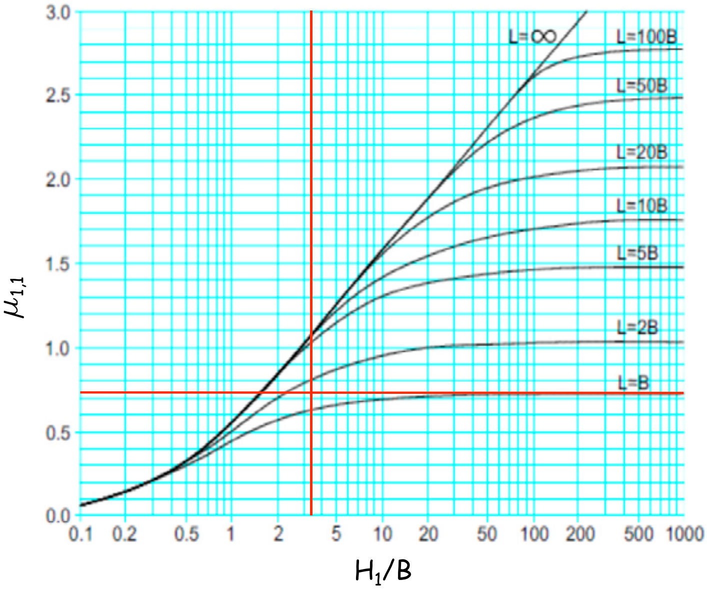
ratio of depth to applied load breadth

H_2/B = 7.20/2.00 = 3.20

Appendix D2.3 – SLS check on immediate settlement – *continued*

ratio of applied load length to breadth

L/B = 3.00/2.00 = 1.50



settlement factor

$\mu_{1,2}$ = 0.71

settlement in layer 2

$\rho_2 = qB(\mu_{1,2}-\mu_{1,1})/E_{u2}$

= (291.67x2.00x(0.72-0.68)/(10x10^3))x10^{-3} = 1.75 mm

7.5 ABSOLUTE SETTLEMENT

absolute settlement

$\rho_E = \rho_1+\rho_2+\rho_3$

= 1.56+11.67+2.33 = 14.98 mm

allowable absolute settlement

ρ_{max} = min { [B/10] ; 50mm }

= min {(2.00/10)x10^3 ; 50.00} = 50.00 mm

UTILISATION

ρ_E/ρ_{max} = 15.56/50.00 = 0.30

utilisation ≤1.00 therefore PASS

Appendix D2.3 – SLS check on immediate settlement – *continued*

7.6 DIFFERENTIAL SETTLEMENT

shortest plan distance between centres of outrigger feet

L_x = 7.20 m

maximum differential settlement

$\Delta\rho_E = \rho_E/L_x$

= 15.56/7.20 = 2.08 mm/m

allowable differential settlement

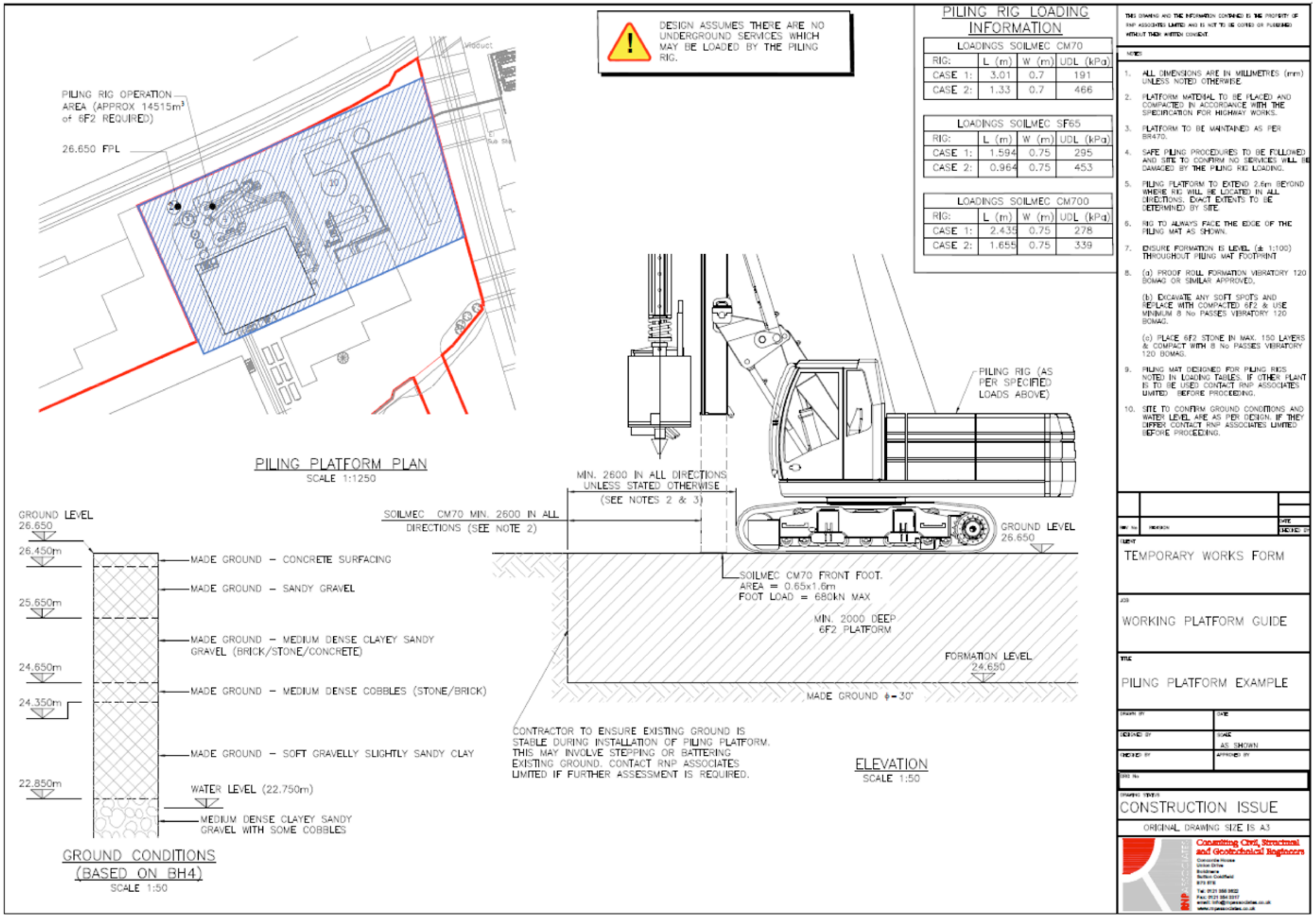
$\Delta\rho_{max}$ = 10.00 mm/m

UTILISATION

$\Delta\rho_E/\Delta\rho_{max}$ = 2.16/10.00 = 0.21

utilisation ≤1.00 therefore PASS

APPENDIX E - Example drawing



PILING RIG LOADING INFORMATION

LOADINGS SOILMEC CM70			
RIG:	L (m)	W (m)	UDL (kPa)
CASE 1:	3.01	0.7	191
CASE 2:	1.33	0.7	466

LOADINGS SOILMEC SF65			
RIG:	L (m)	W (m)	UDL (kPa)
CASE 1:	1.594	0.75	295
CASE 2:	0.964	0.75	453

LOADINGS SOILMEC CM700			
RIG:	L (m)	W (m)	UDL (kPa)
CASE 1:	2.435	0.75	278
CASE 2:	1.655	0.75	339

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NOTES

1. ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNLESS NOTED OTHERWISE.
2. PLATFORM MATERIAL TO BE PLACED AND COMPACTED IN ACCORDANCE WITH THE SPECIFICATION FOR HIGHWAY WORKS.
3. PLATFORM TO BE MAINTAINED AS PER BR470.
4. SAFE PILING PROCEDURES TO BE FOLLOWED AND SITE TO CONFIRM NO SERVICES WILL BE DAMAGED BY THE PILING RIG LOADING.
5. PILING PLATFORM TO EXTEND 2.6m BEYOND WHERE RIG WILL BE LOCATED IN ALL DIRECTIONS. EXACT EXTENTS TO BE DETERMINED BY SITE.
6. RIG TO ALWAYS FACE THE EDGE OF THE PILING MAT AS SHOWN.
7. ENSURE FORMATION IS LEVEL (± 1:100) THROUGHOUT PILING MAT FOOTPRINT
8. (a) PROOF ROLL FORMATION VIBRATORY 120 BOMAG OR SIMILAR APPROVED.

   (b) EXCAVATE ANY SOFT SPOTS AND REPLACE WITH COMPACTED 6F2 & USE MINIMUM 8 No PASSES VIBRATORY 120 BOMAG.

   (c) PLACE 6F2 STONE IN MAX. 150 LAYERS & COMPACT WITH 8 No PASSES VIBRATORY 120 BOMAG.
9. PILING MAT DESIGNED FOR PILING RIGS NOTED IN LOADING TABLES. IF OTHER PLANT IS TO BE USED CONTACT RNP ASSOCIATES LIMITED BEFORE PROCEEDING.
10. SITE TO CONFIRM GROUND CONDITIONS AND WATER LEVEL ARE AS PER DESIGN. IF THEY DIFFER CONTACT RNP ASSOCIATES LIMITED BEFORE PROCEEDING.

APPENDIX F - Geosynthetic manufacturers' methods

Table F1 - Geosynthetic manufacturers' design methods

Manufacturer/ supplier	Relevant product	Basis of design method	Research and case study information	Software	Contact details
Geosynthetics Ltd.	Tenax LBOHM/ LBO Ekotex Rhyno	Reinforced soil Raft concept; Angle of load distribution; Deformation modulus at low strains	Tenax TNXROAD TDS006 (2001); Modulus increase analysis Tenax LBO series Vognserup (Denmark) (1999); Tenax-596-IDReport (2011)	Reinforced soil Raft Tenax spreadsheet; TNXROAD Software; Tenax UnPaveRoad Software; Modulus increase spreadsheet	Telephone: +44(0)1455 617139 engineering@ geosyn.co.uk
Maccaferri UK	Macgrid, MacTex, Paralink, Paragrid	Boussinesq theory (Das, 1990); Barenberg (1980); Giroud and Noiray (1981);	Rimoldi & Simons (2013); Korulla et al (2015)	MacRead Studio (Geogrid design, Giroud-Han, Leng-Gabr, BCR method and Static method for rectangular and circular area)	Telephone: +44 (0) 1865 770555 Fax: +44 (0) 1865 774550 E-mail: oxford@ uk.maccaferri. com.co.uk
Tensar	Triax/SS	Load Spread, Load Factor, Empirical trafficking FEA and T-Value Method	EOTA TR 041 (2012); Watts K and Jenner C (2008); Dalwadi & Dixon (2015); Lees (2019)	Proprietary spreadsheets and TensarPave	T. +44(0)1254 262431 info@tensar. co.uk
Huesker	Stabilenka Robutec Fortrac T Fortrac M Duogrid Ringtrac	ULS analysis; SLS analysis; General stability; Flow-Deformation coupled analysis; Punch; Consolidation and settlement over time, Slope stability, Anchorage analysis; BRE design guide	Various field trials with measurements	PLAXIS 2D/3D; GGU-Stability; Mathcad; GGU-Consolidation; Stress distribution spreadsheet; Br. Calc Ringtrac	T: +44(0)1925 629393 info@HUESKER. co.uk

NOTE: This list is not exhaustive and other suitable manufacturers may be available.

APPENDIX G - Commercially available software

Table G1 - Currently available software packages that may be used for the design of working platforms

Provider	Package	Multi-layer	Bearing capacity	Immediate settlement	2D FEA	3D FEA	EC7
Bentley	Spread Footing	✓	Brinch-Hansen	Janbu Buismann			
Bentley	FEM Basic	✓					
Bentley	STAAD Foundation	✓				✓	
DC-Software	DC-Bearing	✓	Terzaghi Brinch Hansen				✓
DC-Software	DC-Settle			✓			✓
DC-Software	DC-Footing						✓
Fine Software	GEO5 - FEA				✓		
Fine Software	GEO5 - Spread Footing	✓	Brinch-Hansen				✓
Fine Software	GEO5 - Settlement	✓		Janbu Buismann			
Geo Advanced	GeoBP		Terzaghi	Schmertmann			
GeoLogismiki	ECBear (Freeware)	x	✓				✓
GeoLogismiki	SteinN (Freeware or Pro)	✓		Steinbrenner and Fox			
GeoStru	LOADCAP		Terzaghi Meyerhof Hansen Brinch-Hansen	Elastic Oedmetric Schmertmann Burland & Burbidge Vesic Zienkiewicz			
GGU Software	GGU Footing	✓	Terzaghi Meyerhoff Hansen	Vesic			✓
Midas	GTS NX	✓			✓	✓	
Novotech Software	Peyanj		Hansen Steinbrenner and Goodier Terzaghi				
Oasys Software	Safe	✓			✓		
Plaxis	Plaxis	✓			✓	✓	
SoilStructure	Shallow Foundation		Vesic	✓			

NOTE: This list is not exhaustive and other suitable packages may be available.

Notes:

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