TECHNICAL NOTE

Economic design of working platforms for tracked plant

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Introduction

BR 470 Working platforms for tracked plant[1] was published in 2004 and provides good practice guidance on the design, installation, maintenance and repair of ground supported working platforms constructed of granular material for the use of tracked plant.

Previously there was no published or widely used simple design method for these working platforms, and since 2004 the BR 470 design method has been used extensively. However, some users have reported that this design method leads to unnecessarily (and uneconomically) large platform thicknesses.

The calculations involved in the design method are particularly sensitive to the the angle of friction of the granular working platform material and the shear strength of the sub-grade. This paper demonstrates this sensitivity and recommends how testing can be used to provide safe but still economical design parameters, with case studies of examples of testing.

Historical overview

Development of the BR 470 design method included a rigorous benchmarking process, using a range of types and sizes of piling rigs, to verify that the platform thicknesses calculated would be economical and safe.

The benchmarking also showed the sensitivity of the design process to the input strength parameters for the platform material and the sub-grade which supports the platform.

In general, the granular materials used for working platform construction are well graded, in order to provide a readily compactable material with good frictional properties.

The conclusion reached during the benchmarking was that the angles of friction in common use for design are often conservative.

Waste & Resources Action Programme (WRAP) produced a report[2] which includes test results for construction demolition waste (CDW), both concrete based and brick based. Tests on compacted material showed that both types of CDW could provide angles of friction in excess of 60°.

It is not suggested that values of this magnitude be used for the purposes of working platform design, but the tests do demonstrate the potential for angles of friction that can be obtained. Although BR 470 does not specifically recommend a maximum value to be taken for the angle of friction of the granular material, the highest design value tabled in BR 470 is 50°.

Design

Working platforms are temporary geotechnical structures providing a stable working surface for piling rigs, mobile cranes and other heavy construction equipment. Many working platforms are constructed on compressible sub-grades of low shear strength which may be composed of loose or soft heterogeneous made ground which is difficult to sample and test.

Whether the requirement to provide design parameters for temporary works, including platform design, is not considered when site investigations are specified, or sampling and testing difficulties are encountered, it is too often the case that routine site investigations do not provide adequate information on the strength of the platform sub-grade.

Many unreinforced working platforms are constructed using a coarse free-draining compacted granular soil. Commonly the material is a crushed brick and/or concrete demolition arising.

When material of this type is screened to produce soil with a grading similar to that of a class 6F2 fill (*Specification for Highway Works*), the material may reasonably be expected to have the potential to develop an angle of friction of 45˚ or more.

However, the angle of friction can be sensitive to the angularity and grading of the material, the fines content and the degree of compaction achieved.

If working platform designers do not have reliable and appropriate geotechnical information for the sub-grade, and if they lack any certainty about the nature and properties of the material to be used to construct the platform, it is inevitable that they will be cautious and adopt conservative parameters.

Design parameter sensitivity

In the BRE design method, the calculated thickness of the platform is critically dependent on the chosen sub-grade and platform shear strength values. Figures 1 and 2 (below) show how the calculated platform thickness varies for typical input values for case 1 loading of a 0.7m wide track on a soft cohesive sub-grade.

Figure 1 shows an example for a sub-grade shear strength of 35kPa. A 5˚ (12%) increase in the friction angle of the platform material from 40˚ to 45˚ yields a 150mm (27%) reduction in the required platform thickness from 550mm to 400mm.

Figure 2 shows an example for a platform material with an angle of friction of 45°. A 17% increase in the subgrade shear strength from 30kPa to 35kPa yields a 90mm (18%) reduction in the required platform thickness from 490mm to 400mm.

The Federation of Piling Specialists website (www.fps.org.uk) has a number of reference documents relating to working platforms, all of which can be accessed by non-FPS members, and one document provided is *Working Platform Design Sensitivity*[3]. This document shows examples of sensitivity data for a number of different types of piling rig for variation of the angle of friction of the working platform granular material and of the cohesive strength of the underlying sub-grade. Typically, an increase in the angle of friction of 5˚ for the platform material reduces the calculated required »

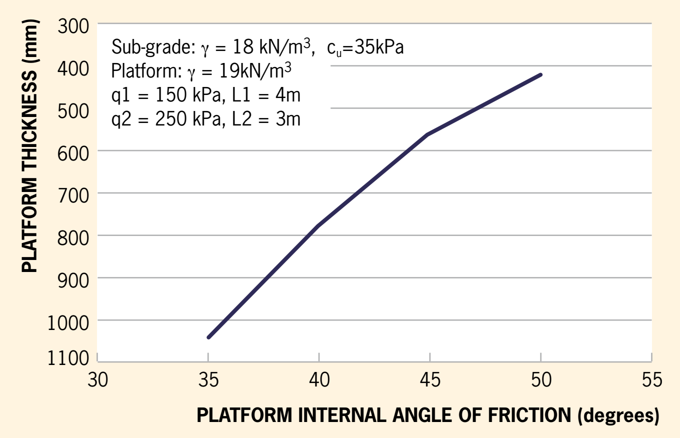

Figure 1: Platform thickness v internal angle of friction

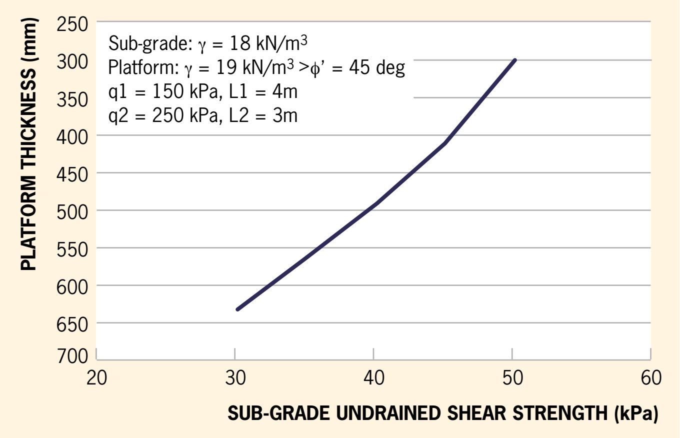

Figure 2 Platform thickness v sub-grade undrained shear strength

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» thickness of the platform by about 20%.The calculated platform thickness is also sensitive to the assumed strength of the sub-grade, and as a generalisation, if the strength of the sub-grade is doubled, the calculated platform thickness is approximately halved.

The economics of providing a working platform are mainly governed by the cost of obtaining, laying and compacting suitable granular fill. Design parameter verification is essential to ensure safe and economic working platform design and, as is common practice for construction materials, verification requires testing.

For the sub-grade it is most important that it is inspected when stripped ready for platform construction, to ensure there are no soft or hard spots or other features to be dealt with, and to test to verify its assumed strength. This testing can be carried out in situ in a short time and at the same time as the sub-grade is inspected, with strength measurement aided by the use of a pocket penetrometer or a small hand shear vane, or more reliably by using plate load tests.

For the working platform material, if the facilities are available, time permits, and the area of platform to be constructed warrants the cost, preliminary plate load tests on a trial section of compacted material will provide data that will reduce the need to adopt conservative and uneconomic design parameters.

Plate bearing tests

There is a number of different types of test that can be carried out for working platforms, summarised in Table 1.

Plate bearing tests are carried out in accordance with BS1377 part 9[4] on the surface of the layer to be tested using a rigid circular steel plate bearing on the soil and loaded by jacking a column reacting against a "deadman" such as a heavy mechanical excavator.

Set up for plate bearing test

The number of tests it is appropriate to carry out depends on the size of the site, available site investigation information on the sub-grade (often very limited) and any preliminary testing carried out. Also, at the time of testing, the consistency of the results should be considered, and a sufficient number of tests carried out to provide a reliable set of results.

The economics of testing for working platforms depends on the particular project, its timescale and physical scale. With the sensitivity of platform thickness dependent on the angle of friction of the platform material (+5° for angle of friction = save 20% thickness) and the shear strength of the sub-grade (double sub-grade strength = halve platform thickness) the economic value of testing is not difficult to calculate.

It should also be said that, from the point of view of improving the safety of working platforms, design based on verification by testing is certainly preferable to the use of guessed and untested parameters, even if they appear to be conservative.

Depending on site arrangements, it should be possible to carry out three to six plate tests in a day and, having mobilised the equipment and technician to site, the time available should be used to carry out as many tests as possible. For many sites, one day for testing the sub-grade and one day for testing the platform would be reasonable, depending on the consistency of results obtained. A wide range of results may indicate variable materials, or variable workmanship, and in either case additional testing may be appropriate.

Plate bearing test analysis

Sub-grade test

These will either be carried out on the surface of the sub-grade, when it has been stripped down to formation level, at shallow depth below the surface of the sub-grade, or possibly in a small excavation through a constructed working platform. In all cases, the effect of any overburden pressure is small and for simplicity the achieved or assessed ultimate bearing stress from a test (q_{ult}) can be related to the shear strength by the equation $q_{ult} = c_u \times N_c$. For a circular plate at shallow depth, N_c can be taken as $(2+\pi) \times 1.2 = 6.17$.

Platform material test.

This test may be carried out on a trial area or on the constructed platform, but the analysis is the same in both cases. For analysing the results of a circular plate loading test, to derive the angle of friction, the ultimate bearing pressure is given by $q_{ult} = 0.5 \times y \times B \times N_\gamma \times s_\gamma$ (γ=platform material density, B=plate diameter, N_γ=bearing capacity factor s_γ = shape factor). $N\gamma = \tan(1.32\phi) \times (e^{\pi \tan\phi}) \times \tan^2(45+\phi/2) - 1$, $s_\gamma = 0.0336\phi + 0.0000672\phi^2$ (Reference 5).

Platform proof loading

This test is carried out with a larger diameter plate, and the test response will depend on the platform material angle of friction and the sub-grade shear strength. Within the geometrical and strength limits set by BR 470, such a test could be analysed using the punching shear mechanism adapted for a

Type of test and purpose	Preliminary platform material testing	Sub-grade – verification of shear strength	Platform material – verification of angle of friction	Proof loading of constructed platform
Plate diameter (B)	Minimum 300mm	Minimum 300mm	At least 3 x maximum particle size and not greater than half the platform thickness. Ideally at least 300mm, but smaller 225mm diameter may be used for platforms less than 600mm thick.	Generally 600mm or equal to the rig/crane track width.
Test load	Minimum test load calculated for potential 50° angle of friction for platform material (10 tonnes for 300mm diameter plate)	Calculate plate ultimate bearing pressure (qult) for sub-grade shear strength to be verified and use test pressure of at least 2/3 qult.	Calculate plate ultimate bearing pressure (qult) for angle of friction to be verified and use test load of at least 2/3 qult.	Test load calculated from critical design value of track bearing pressure (characteristic value x loading factor)
Test analysis	Use curve fitting or Chin analysis to derive ultimate load capacity achieved.	Use curve fitting or Chin analysis to derive ultimate load capacity achieved.	Use curve fitting or Chin analysis to derive ultimate load capacity achieved.	Use verified sub-grade shear strength to analyse test to verify platform angle of friction. Also assess plate test settlements.
Comment	Preliminary test trial area at least 10B x 10B x 3B thick of compacted platform material.	Avoid cobbles, boulders and obstructions.	Multiple tests required and use lower bound test result for verification of angle of friction.	Consider acceptability criteria in advance of test. If no sub-grade testing available, dig through platform (outside piling area) and carry out sub-grade tests.

Table 1: Summary of plate testing for working platforms

cylindrical failure mode. The equation for the ultimate plate bearing pressure (pult) is as follows:

$$pult = (c_u \times N_c) + (2 \times D^2 \times \gamma \times Kp.Tan\delta)/B$$

Where c_u=sub-grade shear strength, N_c=bearing capacity factor (6.17), D=platform thickness, γ=platform material density, Kp.Tanδ=punching shear coefficient from BR 470.

Use of this test to assess the angle of friction of the platform material will depend on the reliability of the sub-grade shear strength used in the design or derived from subsequent testing.

However, as a plate of similar diameter to the track width has a bearing area smaller than the effective bearing area of the track loading, the response of the plate test will not be directly representative of the response of the platform to the rig loading applied to the full loaded track area.

Acceptability criteria for tests on a particular site should be considered in advance of testing, taking into account the loading to be applied and the sensitivity to the possible variability of the sub-grade and platform material parameters..

Case studies

Case Study 1: Plate testing on granular working platform material (maximum particle size 75mm), with a 300mm diameter plate (see figure 3).

At the maximum applied test pressure of 2,250 kPa, the loading is not showing any signs of approaching failure. Even if the maximum applied test pressure was taken as an ultimate value it would be indicating an angle of frictionof 48°, i.e actual angle of friction greater than 50°. The working platform design was based on an angle of friction of 40° for the platform material and the resulting platform thickness required was 450mm. If the platform design could have been based on an angle of friction of 50° the platform thickness could have been reduced to 300mm.

Case study 2: Plate testing on loose granular made ground sub-grade with 450mm diameter plate

Load displacement curves from a series of plate bearing tests on a loose granular made ground sub-grade were extrapolated to notional failure using a log-linear curve fitting technique, (see figure 4). The ultimate bearing stress was defined as that which induced 10% R plate settlement. Given the variability in the test response, a low bound ultimate bearing stress of 330kPa was taken and this allowed an angle of internal friction of 40˚ to be demonstrated. The piling platform was subsequently calculated to be the default minimum of 50% of the piling rig track width.

Case Study 3: A working platform for a tracked mobile crane was tested using a 300mm diameter plate

The load displacement response, shown in Figure 5, was found to be less stiff than that of the clay sub-grade beneath, which was separately tested, and significant strain hardening observed in the test made interpretation uncertain. The back calculated friction angle for the platform based on an ultimate bearing stress of 150 kPa was found to be 38˚.

The designer's assumed value was 45˚. On further examination, it became apparent that the platform material had not been compacted other than nominally beneath the tracks of the mobile crane. After re-compaction, the platform was re-tested and the design value of angle of internal friction shown to be satisfactory.

Conclusions and Recommendations

The working platform design process set out in BR 470 is sensitive to the angle of friction of the granular platform material and the shear strength of the sub-grade.

If conservative input design parameters are used then the platform thicknesses produced will also be conservative.

More detailed reporting of shallow depth soil strengths from site investigations would improve the economics, reliability and safety of working platforms. If appropriate for the site and project, preliminary testing of the platform material will provide data from which the angle of friction of the platform can be derived, and then used for the platform design.

This will not only ensure that the design is economical, but being based on actual data it will be more reliable and safer than a design based on guessed and untested parameters, even if they appear to be conservative.

Verification of design parameters improves the economics and safety of working platform design, and plate loading tests are recommended as the preferred means of testing the sub-grade and the platform material for design validation and construction quality control purposes.

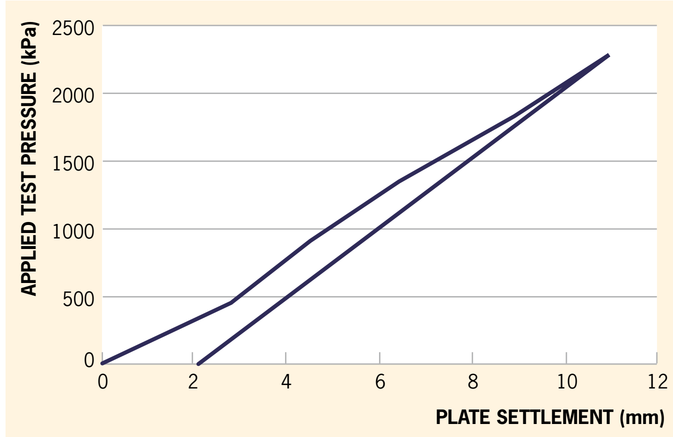

Figure 3: Working platform material plate loading test

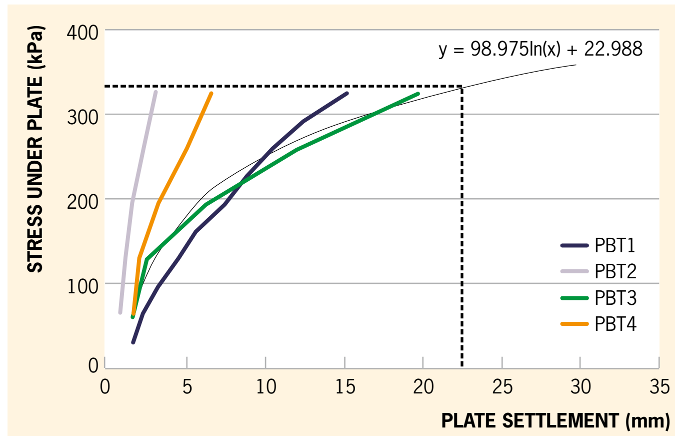

Figure 4: Plate bearing tests on loose granular sub grade

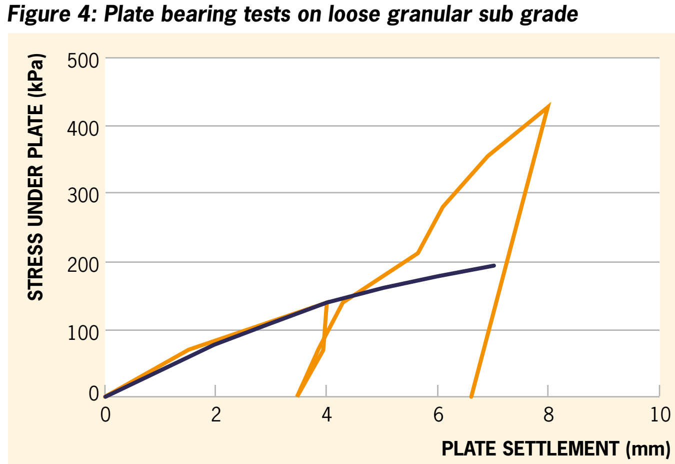

Figure 5: Plate bearing tests on uncompacted platform

References

1. *Working platforms for tracked plant.* BR 470. Building Research Establishment. 2004.
2. *Ground Engineering as potential end uses for recycled and secondary aggregates.*
3. *The Waste & Resources Action Programme*. June 2004.
Working Platform Design Sensitivity. Federation of Piling Specialists website. www.fps.org.uk
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5. Two and three-dimensional bearing capacity of footings in sand. Lyamin AV et al, *Geotechnique* 57, No.8, 647-662, 2007.