Plate bearing tests for working platforms

G. Tanghetti, R. J. Goodey, A.M. McNamara & H. Halai
City, University of London. London, UK.

ABSTRACT: During piling and other construction works, a working platform is often constructed across the site. These platforms comprise aggregate material placed and compacted to a designed thickness. Satisfactory performance of the platform may be confirmed by a plate bearing test. Current guidance given on plate bearing testing of granular soils suggests that the plate be at least five times the nominal size of the coarsest material. For a working platform this may be large and the reaction load required from plant and resources to carry out the bearing test may become excessively high. The aim of the research presented in this paper was to investigate the effect of particle to plate size ratios to establish if the use of a smaller plate would still allow a reliable test to be performed on site. Plate bearing tests were carried out in a centrifuge using a large, coarse grained limestone. The limestone was graded to a scale representation of 6F2 material, a commonly specified particle size distribution for working platforms. The size of plate was varied and the load displacement response recorded. The measured bearing capacity was correlated with the ratio of particle to plate size.

1 BACKGROUND

Plate bearing capacity tests represent a good method to investigate the behaviour of soils, especially the bearing capacity near the ground surface and the possible settlement under a certain load. The test is usually adopted when shallow foundations are to be used, or when temporary works requiring a working platform such as piling rigs or cranes are required on site. The standards applicable to this test are: the British Standard (BS) 1377 Part 9 and the American Society for Testing and Materials (ASTM) D1194. BS1377 refers to in situ plate bearing tests in this way:

"This method covers the determination of the vertical deformation and strength characteristics of soil in situ by assessing the force and amount of penetration with time when a rigid plate is made to penetrate the soil. Uses are to evaluate the ultimate bearing capacity, the shear strength and deformation parameters of the soil beneath the plate without entailing the effects of sample disturbance. The method may be carried out at the ground surface, in pits, trenches or adits, and at depth in the bottom of borehole"

It is common practice for the plate diameter in this test to vary, usually from 300mm to 1000mm. It is important to note that a bigger plate is often preferred, when available, in order to better mimic the actual conditions imposed by the foundation.

An important issue connected with the choice of plate size is the possible scale effect associated with testing soils where the ratio between plate diameter and maximum particle size is too small. With respect to this requirement, the standard BS1377 provides a specific indication of the minimum plate size which can be allowed in a plate bearing capacity test:

BS 1377-9:1990 (notes 4.1.2):
"When testing granular soil the plate diameter should exceed at least five times the nominal size of the coarsest material"

The implication of this limit provided by the standard is that the same response (in terms of stress-settlement) should be obtained for any plate size which is fulfilling this ratio value. There are, however, some difficulties in the interpretation and application of this guidance:

1. It is not completely clear what exactly is meant by "nominal size of the coarsest material". Dependent on interpretation is could relate to the maximum particle size, the D_{50} value or some other characteristic.
2. Working platforms are typically constructed using well graded sub-base granular material, such as one conforming to the 6F2 grading, which could

be fresh aggregate or recycled demolition material (comprising concrete, brick and other materials). 6F2 grading is characterized by large particle size (up to 120mm) and the large size of the particles would require a big plate diameter (up to 600mm) in order to satisfy the limit proposed by the standard.

Assuming the "nominal size" refers to the maximum particle size of the material, the biggest problem related to plate bearing capacity tests remains, in this application, the large size of the plate and the resulting high reaction load required to conduct the bearing test.

The main objectives of the research presented here is to understand if a smaller ratio between the diameter and particle size could be adopted during tests without changes in the results. In this way a cheaper procedure could be adopted for testing materials containing large particle sizes.

2 INTRODUCTION

A series of plate bearing capacity tests were carried out at City, University of London using the geotechnical centrifuge facility.

The tests were executed by the use of different plate sizes in order to verify if a scale effect can be associated with the use of plates with a diameter to maximum particle size ratio smaller than five (minimum value suggested in BS1377-9).

The material used for these tests is a grey Devonian limestone sourced from a quarry in Ashburton, Newton Abbot, UK. The limestone was graded with the intention of representing a scaled version of 6F2 material, commonly used for the construction of working platforms. Since the definition of 6F2 material covers a large range of particle size distributions, an average curve placed between minimum and maximum values of particle size distribution characterizing the 6F2 class (shown in Figure 1) was chosen as representative. The maximum particle size (90mm) was then scaled down to a value of 3mm, such that the acceleration level chosen to spin up the centrifuge model was equivalent to N=30g. The measured properties of the test material are summarised in Table 1.

Table 1. Properties of test sample

Property	Value
Minimum void ratio (e_{min})	0.332
Maximum void ratio (e_{max})	0.346
Specific gravity (G_s)	2.73
D_{50} (mm)	0.5
D_{max} (mm)	3.35
D_{min} (mm)	< 0.18
γ, average value (kN/m^2)	20.05

The bearing capacity tests on this material were carried out using different plate diameters in order to verify the effect of diameter of the plate to maximum particle size ratio and therefore confirming or contradicting the indications presented in BS1377.

Assuming an acceleration level of 30g, the plate diameters used (7.8mm, 12mm, 16.9mm, 23.7mm and 39.7mm) represent prototype values of 234mm, 360mm, 507mm, 711mm and 1191mm respectively. The corresponding B/D_{max} ratio (where B represents the plate diameter of the test and D_{max} the maximum particle size of the samples) was therefore equal to 2.3, 3.6, 5, 7.1 and 11.9 respectively, so that both higher and lower values of B/D_{max} ratio were tested to verify the effect of the ratio changes on the obtained stress/settlement curve for each test.

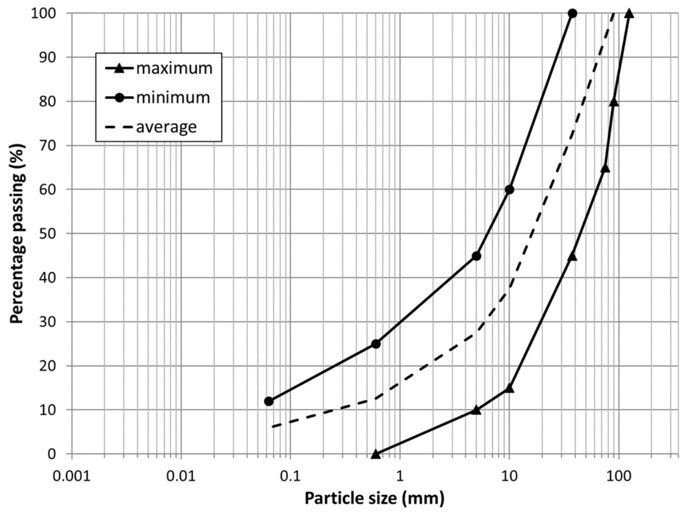

Figure 1. Grading curves representing minimum - maximum particle size values for 6F2 (solid lines) and the particle size distribution chosen to be scaled down for the test material (dashed line)

3 APPARATUS AND TESTING

3.1 Apparatus

The test was carried out in a circular centrifuge tub (working as container for the sample) with a loading frame above (whose function was to drive the plate into the soil at a constant rate of penetration equal to 1mm/minute).

The test was driven for about twelve minutes such that the total penetration of the plate into the soil corresponded to approximately twelve millimetres, significantly further than might be expected in order to capture all features on the stress/settlement curve.

A large tub (having an internal height of 300mm and a diameter of 420mm) was chosen with the intention of avoiding boundary effects due to the proximity of the plate to the sides and base of the tub. The design chart presented by Ullah et al. (2017) provides a method to verify if the model geometry might be affected by boundary effects considering the ratio L_{BD}/D (where L_{BD} is defined as the distance measured from the centre of the plate to the inner edge of the tub and D is the diameter of the plate). It can be seen from the chart (Figure 2) that for uniform sand (D/H_s

= 0, where H_s represents the thickness of sand) the minimum L_{BD}/D ratio allowed is equal to five. Considering that the maximum plate diameter used for the tests was equal to 39.7mm, the diameter of the tub was considered large enough to prevent or reduce possible boundary effects.

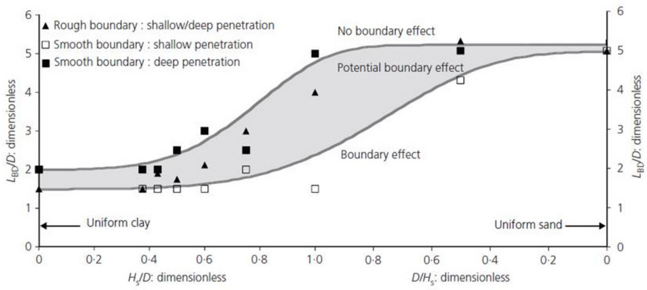

Figure 2. Centrifuge test design chart for estimating the safe normalized lateral boundary distance, Ullah et al. (2017)

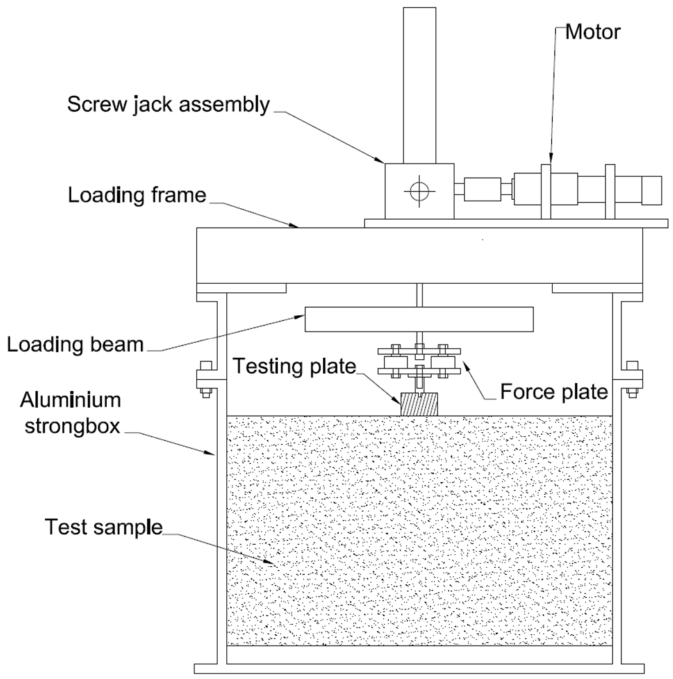

Figure 3. Test equipment and instrumentation

The second important component of the testing apparatus, the loading frame, was used to push the plate into the sample and measure the force variation with increasing settlement. The frame consists of (Figure 3): a motor and screw jack assembly, a loading beam, a force plate and the test plate.

The motor and screw jack drives the plate into the soil through the stiff loading beam, to which the force plate and the test plate were connected. The force plate is comprised of three load cells sandwiched between two stainless steel plates. Use of three loads cells in this arrangements prevented bending moments (which may arise from uneven seating of the plate on the test sample) to be eliminated. The total force acting on the plate was then calculated as sum of the readings from the three load cells.

Displacement of the plate was not measured directly but rather from knowledge of the precise speed of the jack and the time elapsed.

4 TEST SAMPLE PREPARATION

As a first step, the limestone was dry sieved using the method described in BS1377: Part 2 (1990). Once sieved, the different fractions were combined to create a particle size distribution corresponding to a scaled down (by a factor of 30) sample of 6F2 material.

The limestone was then placed into the tub, which was filled up in such a way that the height of sample was the same for each test (approximately 250mm). The sample was placed in around seven layers, each one comprising about 10kg of material. The material was distributed inside the tub and each layer was accurately tamped before placing of the next one. The tamping operation was executed by hitting a heavy circular plate (placed on the soil surface) with a mallet. This led to some variance in compaction near the boundary which was corrected by manually tamping with a wooden block. This method of tamping gave a compact sample characterised by a low voids ratio of about 0.33. After the filling procedure, the distance (Δh) between the top of the tub and sample surface was measured in fourteen different positions in order to get an average height of the sample (calculated from the difference between internal height of the tub and average value of Δh). The height and diameter of the sample were used to evaluate its volume and, therefore, its voids ratio.

Preparation was completed by spinning the sample in the centrifuge for a short time (five minutes) with the intention of compacting the sample before starting the test. This further step ensuring that a repeatable, compact sample was obtained for each test. The height of the sample was checked again in order to ensure an accurate measure of voids ratio was obtained before testing.

4.1 Test procedure

After compaction the loading frame, instrumentation and test plate were mounted on the centrifuge model. The sample was spun in the centrifuge at an acceleration value of 30g. During testing the motor and screw jack assembly pushed the plate into the sample at a constant rate of penetration, while the force plate measured the total force applied by the use of the three load cells.

Once the test was concluded it was possible to evaluate the settlement of the plate compared with the measured bearing capacity values. Therefore, for each test, a stress/settlement curve was generated. These curves were compared in order to evaluate the presence of any possible scale effect due to the use of small plate sizes.

5 TEST RESULTS

The results obtained from all tests are presented in Figure 4 as the variation of bearing stress (q) against the settlement of the plate (w).

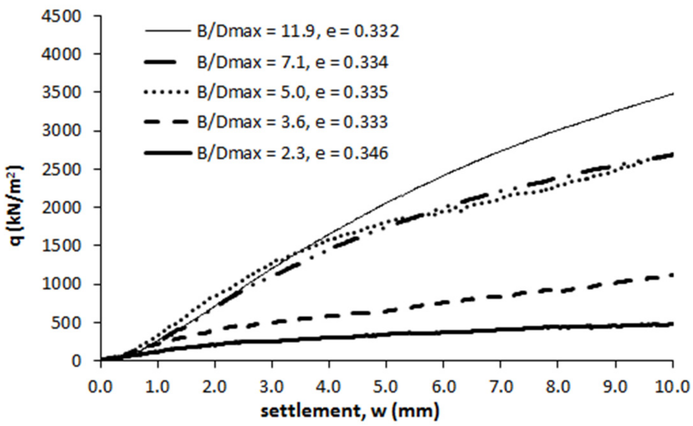

Figure 4. Bearing stress–settlement variation obtained from testing the same granular soil with different plate diameter sizes

From Figure 4 it can be observed that there is a general increase in plate bearing capacity with increase in plate size.

For a B/D_{max} ratio equal to 7.1 and 5, which considering the scale factor N=30, represented prototype plates of 711 mm and 507 mm respectively, show a similar response. This is in accordance with the guidance from BS1377 Part 9 (1990), which suggests a plate diameter to nominal particle size ratio larger than five.

For a B/D_{max} ratio equal to 11.9 (representing a prototype plate of 1191 mm), the results showed higher values of bearing capacity compared with 7.1 and 5 ratios. The difference in stress value seems to increase with the settlement and may be related to a boundary effect due to a low L_{BD}/D ratio. Given that L_{BD}/D=5.3 which is a value just larger than the minimum value of 5 indicated by Ullah et al. (2017), it is reasonable to consider the presence of an effect on results due to the proximity of the tub boundaries.

Tests conducted with a B/D_{max} of 2.3 and 3.6 (representing prototype plates diameter of 234 mm and 360 mm respectively) show significantly different results when compared with tests conducted at B/D_{max} = 7.1 and 5. They displayed lower bearing capacity values, apparently decreasing with the size of plate. For these tests the plate diameter to maximum particle size ratio was significantly lower than that recommended.

6 BACK CALCULATION OF FRICTION ANGLE

Plate bearing tests are often used to confirm the working platform design. The primary input into the design of the platform is the angle of friction of the granular material. The effective angle of friction can be back calculated from the results obtained using a simple bearing capacity formulation for a circular footing, shown in Equation 1 (Das, 2010):

$$q_{ult} = \sigma'_{zD} N_q + 0.3\gamma' B N_\gamma \quad (1)$$

where q_{ult} = ultimate bearing capacity; σ'_{zD} = vertical effective stress at the depth the foundation is laid; γ' = effective unit weight; B = diameter of the foundation; N_q, N_γ = bearing capacity factors.

Figure 5 shows the angle of friction obtained by this method for each of the tests. It can be seen that once the plate diameter exceeds five times the maximum particle size the angle of friction is relatively constant at around 51.5°. At these high friction angles small variations in the value adopted would have a significant impact on the predicted capacity of any working platform design.

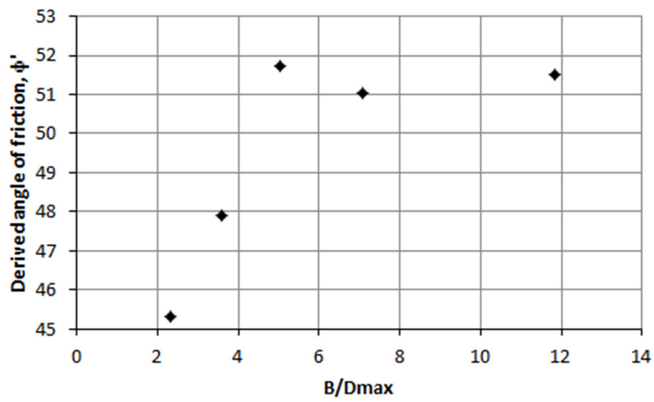

Figure 5. Angle of friction of platform material obtained from test results

7 CONCLUSION AND FURTHER WORK

From the series of bearing capacity tests carried out using centrifuge modelling techniques it can be observed that plate diameter to maximum particle size ratio has an influence on results concerning the values of bearing capacity of the soil.

In particular, the results seem to confirm the validity of the BS1377 Part 9 (1990), which impose for plate tests on soils a plate diameter to nominal particle size exceeding five. This nominal particle size can be considered to be the maximum particle size in the material.

For plates corresponding to lower ratios the soil showed a different response manifesting a lower value of bearing capacity, which seems to decrease with reducing the plate diameter.

Another observation is related to the boundary effect which was found when testing the sample with the largest plate diameter. This phenomenon was observed for a test characterized by a boundary distance to plate diameter ratio equal to 5.3, very close to the lower value of 5 according to the chart presented by Ullah et al. (2017). It should, of course, be noted that this type of effect is unlikely to be present during full scale site testing.

Further tests could be carried out in future in order to investigate if a plate diameter to maximum particle size ratio between 3.6 and 5 could be used during testing without a change in results. This would be useful to understand if a slightly lower limit of ratio could be allowed without scale effects on results. This would then permit a smaller diameter (and thus cheaper equipment) to be used when testing granular soils having a large particle size.

REFERENCES

British Standards Institution. 1990c. British Standard Methods of Test for Soils for Civil Engineering Purposes: Part 2. Classification Tests, BS 1377. *British Standards Institution, London.*

British Standards Institution. 1990b. British Standard Methods of Test for Soils for Civil Engineering Purposes: Part 9. In-Situ Tests, BS 1377. *British Standards Institution, London.*

Das, B., 2010. Principles of Foundation Engineering (7th edition). *Cengage, Stamford, USA.*

Highways Agency 2004. Manual of Contract Documents for Highway Works – Volume 1 Specification for Highway Works. *The Stationary Office, London.*

Halai, H., McNamara, A.M. & Stallebrass, S.E. 2012. Centrifuge modelling of plate bearing tests. *Second European Conference on Physical Modelling in Geotechnics, 23-24 April, Delft University of Technology, Netherlands.*

Ullah, S.N., Hu, Y., Stanier, S. & White, D. 2017. Lateral boundary effects in centrifuge foundation tests. *International Journal of Physical Modelling in Geotechnics* 17(3): 144-160.