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The effectiveness of buried mass concrete thrust blocks as a means of lateral support for excavations

Efficacité de blocs massifs de béton (« thrust blocks ») enfouis comme moyens de butée dans des excavations

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ABSTRACT

Shallow embedded concrete blocks are frequently used to provide lateral support to raking props in temporary excavation works. In the field, the block is usually cast below the total excavation depth and before the excavation commences. The block provides passive support to the prop at the start of excavation. The results are examined of preliminary investigations conducted on model thrust blocks embedded within the soil bed and subjected to equivalent prop loading in a high g centrifuge environment. A lead screw driven by an electric motor was used to apply inclined prop forces onto thrust blocks embedded near the surface. The details of the relationship between the load on the block and its displacement have been measured for a limited range of inclination angles and block sizes. The study will enable a better understanding of the likely ground movements associated with excavations supported in this way and will help to assess the viability of the method especially when used near to sensitive structures.

RÉSUMÉ

Dans le cas d’excavations temporaires, des blocs de béton (« thrust blocks ») enfouis peu profonds sont souvent utilisés comme soutiens latéraux aux pieux de soutènement inclinés. Sur le chantier, les blocs sont habituellement coulés sous la profondeur totale d’excavation et avant que l’excavation commence. Le bloc sert de butée au pieu de soutènement au début de l’excavation. Les résultats d’études préliminaires conduites sur un modèle réduit de ces « thrust blocks » testé dans la centrifugeuse sont examinés. Une vis conduite par un moteur électrique a été utilisée pour appliquer les forces de butée sur des blocs enfouis près de la surface. Une relation entre force exercée sur le bloc et déplacement a été mesurée pour un nombre limité d’angles d’inclinaison et de tailles de blocs. Cette étude permettra une meilleure compréhension des mouvements de sol lors d’ excavations soutenues de cette facon. Elle permettra aussi d’évaluer la viabilité de cette méthode près de structures sensibles.

1 INTRODUCTION

For retaining walls requiring temporary support during basement construction, the use of a series of raking props supported on mass concrete thrust blocks is both popular and inexpensive since they allow good access, can be constructed quickly and permit the excavation to proceed in a continuous operation. However, increasing concern over movements in the ground behind retaining walls has meant that the stiffness of support provided by this method has been questioned especially where party walls or other sensitive structures are nearby. A series of centrifuge tests has been carried out to investigate the displacement of model thrust blocks subjected to inclined loads in fine sand.

2 BACKGROUND

Recent work in this area has been undertaken in France and the USA where the results of research to develop theory and tests aimed at better predictions of passive earth pressures is reported by Soubra and Regenass (2000) and Duncan and Mokwa (2001).

Meyerhof (1951,1953) conducted research into the bearing capacity of foundations under eccentric and inclined loads and Meyerhof and Hanna (1981) carried out 1g tests on surface and buried circular and strip footings under axial and inclined loads. They found that recommended values of bearing pressure were conservative when applied to inclined loads suggesting that there may be scope for increased allowable bearing pressure. Other work that has resulted in empirical design factors to allow for inclined loads has been described by Brinsch-Hansen (1970) and Vesic (1973). Subsequently, Georgiadis and Butterfield (1987) conducted 1g tests on foundations subjected to eccentric and inclined loads and concluded, contrary to the assumptions of previously published data, that the load displacement behaviour was highly non linear. Such findings are consistent with recent advances in understanding of soil behaviour and resulted in the development of a method for predicting the non linear response of footings on sand under eccentric and inclined loads. However, whilst the non linear load displacement response is known to be important Muhs (1965) demonstrated that large scale 1g tests of the type conducted by Georgiadis and Butterfield may not provide accurate predictions of field behaviour.

With a geotechnical centrifuge it is possible to test small scale models under accelerations of many times the Earth’s gravity such that stress distributions in the model correspond to prototype scale. Centrifuge tests relating to bearing capacity problems have tended to confirm the uncertainties surrounding the 1g test results. Consequently, the advantages offered by such small scale model testing have led to significant additional work over the last 25 years on bearing capacity problems by, amongst others, Ovesen (1975), Yamaguchi et al (1976), Kimura et al (1985), Kutter et al (1988), Pu and Ko (1988), Kusakabe et al (1991) and Aiban and Znidarcic (1995). Recently, Perkins and Madson (2000) proposed a design approach for the bearing capacity of shallow foundations on sand based on the results of 50 full scale and centrifuge model tests in sand.

Soubra and Regenass (2000) considered the 3-dimensional effects surrounding the development of passive earth pressure. They found that although the 2-dimensional passive earth pressure problem has been well researched over the years, the only significant previous work on 3-dimensional effects had been conducted by Blum (1932) who proposed a simple extension into three dimensions of the Coulomb mechanism in which frictional forces at the lateral planes are neglected. Soubra and Regenass (2000) carried out numerical analyses which showed close agreement with Blum (1932) for loose sand. However, they found that passive resistance in dense sand was greatly underestimated by the approach of Blum (1932). This suggests the possibility of significant 3-dimensional effects associated with discrete embedded structures which would have important implications for the effectiveness of thrust blocks (Figure 1). Currently, the design of thrust blocks is based on simple earth pressure theory although considerable uncertainty exists regarding appropriate factors of safety to control ground movements. Concerns over the capacity of thrust blocks have recently led to monitoring which indicated considerable stiffness and implying very conservative design. The requirement is therefore to establish realistic load/displacement charts to enable economy and confidence in design.

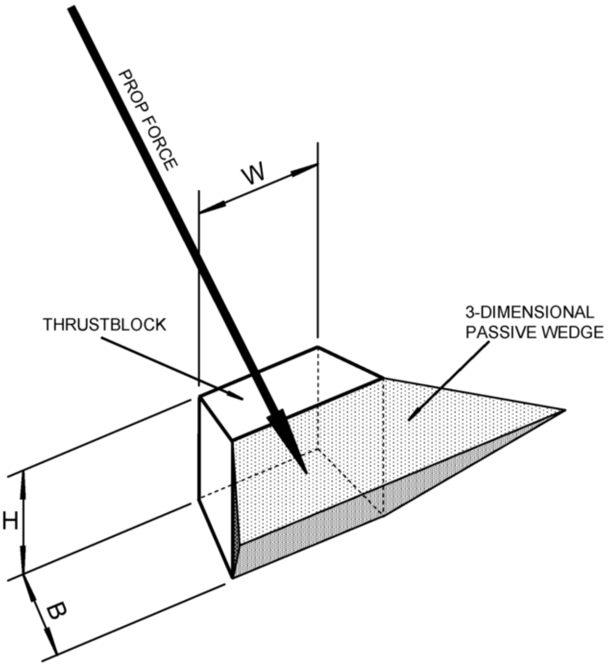

Figure 1 Three dimensional passive wedge behind a thrust block

3 EXPERIMENTAL METHOD

A series of model tests was carried out at 80g on the Acutronic 661 geotechnical centrifuge at the London Geotechnical Centrifuge Centre at City University. Schofield and Taylor (1988) describe the centrifuge in detail.

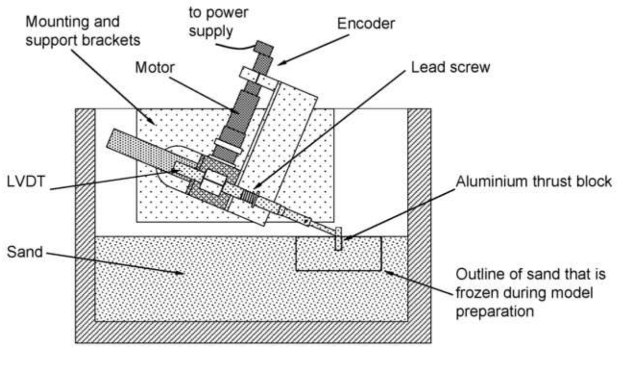

Figure 2 General set-up of apparatus

The soil used was Leighton Buzzard sand, fraction D. This is a silica sand ($G_s = 2.65$) with rounded / sub-rounded grains, particle size d_{10} of 0.16 mm and a uniformity coefficient U_c (d_{60}/d_{10}) of 1.20, and critical state angle of friction $\phi' = 32.4°$. A 200mm deep sample of the medium dense sand was prepared in a 550mm long x 200mm wide plane strain strong box, onto which the apparatus shown in Figure 2 was mounted. The model thrust block (seen on the right) was manufactured from aluminium and coated with the same sand, which was glued to the surface with epoxy resin, to provide a rough surface. The thrust block was pushed into the sand by means of a prop consisting of a lead screw, driven by an electric motor. The motor was controlled by a remote computer driving the thrust block at a rate of 0.1mm/minute, although the rate of drive could be varied if required. The apparatus was manufactured in such a way as to allow the prop inclination to be varied. For the tests reported prop angles of 20°, 30° and 40° relative to horizontal were used. A 5kN capacity static load cell was positioned between the lead screw and the model thrust block. This allowed measurement of the prop load whilst an LVDT was used to measure the thrust block displacement along the line of thrust.

Most of the sand sample was placed dry around the apparatus although special measures were taken to ensure that a consistent and reliable density of sand, without voids immediately around the thrust block, was achieved. Here sample preparation consisted of mixing a small amount of water into some sand (7% by weight). This was then compacted into a 150mm x 100mm x 60mm deep polythene container to a uniform level. The model thrust block and its prop were held in position on the surface of this sand bed using a retort stand and further sand was compacted into the container until full. By this method the depth of embedment of the thrust block was closely controlled and a perfectly flat sand surface was created for use in the model. The sand sample and container were then frozen producing a solid block which, after removal of the polythene container, was mounted onto the actuator and placed into the strongbox. Dry sand was packed around the frozen block, the surrounding surface levelled and then the sample was left to thaw. This technique resulted in a good degree of repeatability of the sand preparation and gave confidence in the consistency of density in the immediate vicinity of the thrust block.

Following the thawing of the sand block some water remained in the sample near to the thrust block. During spin up of the centrifuge most of this water moved towards the base of the strongbox but it is noted that upon completion of the tests the sand remained damp (approximately 2.5% water content). The friction angle of samples of the same sand, with similarly low water contents, were measured using shear box tests and were not found to vary discernibly from tests on dry sand.

The completed model was placed on the centrifuge swing and the test procedure was as follows:

- Spin sample to 80g
- Advance the thrust block at 0.1mm/min until 1mm displacement was achieved
- Advance the thrust block at 1mm/min until approximately 5mm total displacement was achieved
- Advance the thrust block at 2mm/min until approximately 15mm total displacement was achieved

Load and position were monitored throughout with data readings at 1 second intervals.

In total, six tests were conducted as shown in Table 1

Table 1 Summary of tests undertaken

Test	Thrust block embedment	Prop Angle
TB1	20mm	20°
TB2	20mm	30°
TB3	20mm	40°
TB4	30mm	20°
TB5	30mm	30°
TB6	30mm	40°

4 RESULTS AND OBSERVATIONS

In Figure 3 raw data showing the magnitude of load with increasing horizontal displacement is shown for the tests on thrust blocks of 20mm embedment and is also typical of tests on thrust blocks of 30mm embedment.

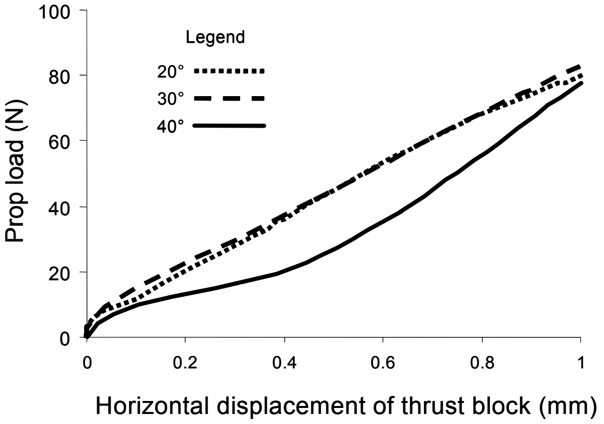

Figure 3 Graph showing load against displacement for 20mm embedment thrust blocks

Test TB3 with a 40° prop angle exhibited the classic three-phase response seen previously for example in the centrifuge model tests described by Ovesen (1979) of surface foundations subjected to increasing vertical axial load. The initial response is quite stiff. In the second phase, the soil strength becomes fully mobilised locally to the thrust block and the load-deformation response tends to flatten out. As the prop is advanced further, the third phase is reached with the thrust block being pushed to increasing depth of soil where the greater effective stresses result in increasing resistance. The initial relatively stiff-phase would be considered an acceptable load-deformation response at prototype scale. In the third phase, the stiffness appears to increase again although the associated strains to reach this would be unrealistic for prototype applications which would probably be limited to values equivalent to $\delta = 0.15$mm – 0.3mm at model scale.

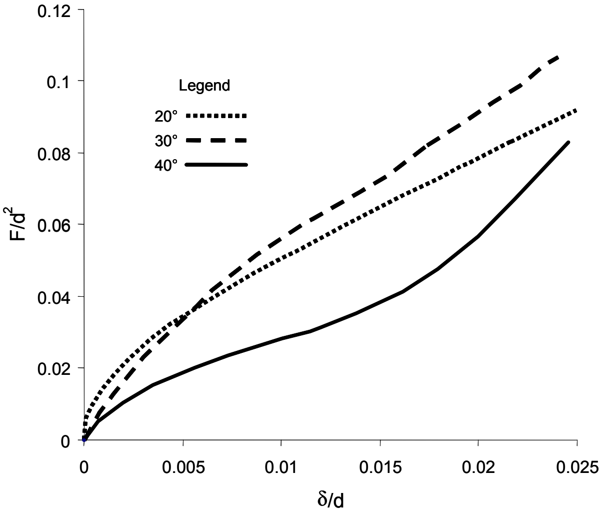

Figure 4 Graph showing load against displacement normalised by the depth of the thrust block for 20mm embedment thrust blocks

The thrust blocks subjected to 20° and 30° prop loading exhibit an extended initial phase of the classic response described above. In the second phase, the load-displacement response did not flatten out and appeared merged with the third phase. It is an interesting observation that following the initial stiff response, the load resistance developed by the 20° and 30° props was markedly greater than that of the 40° prop suggesting a different mechanism of mobilisation of soil strength.

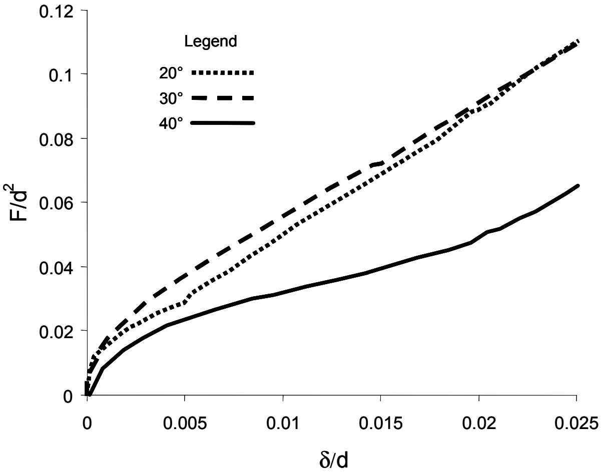

Figure 5 Graph showing load against displacement normalised by the depth of the thrust block for 30mm deep thrust blocks

In Figure 4 and Figure 5 the load/displacement behaviour for tests TB1, TB2 and TB3 and TB4, TB5 and TB6 are shown respectively. In each figure, the ordinate F (N), the total force acting along the line of the prop, is normalised by d^2, where d corresponds to the depth of thrust block embedment in mm. The abscissa is δ the displacement, normalised by d (mm), the depth of thrust block embedment. Both axes are corrected for increasing thrust block embedment depth as the prop is advanced.

Normalising the data by d^2 assumes that the thrust block capacity is governed by embedment depth and the applicability of simple earth pressure theory. Comparison of the magnitude of load/displacement in the two figures appears to support this. It is not possible to discern whether the three-dimensional effects that are thought to exist are significant in the response of the thrust blocks. However, the three phase stress/strain behaviour observed in Figure 3 is very apparent for the 40° prop angles for both depths of thrust blocks tested and absent in the shallower prop angle tests. This gives credence to the suggestion that another mechanism may govern the thrust block resistance in these tests.

In Figure 6 and Figure 7 the initial, stiff response phase of the tests are shown in detail. In these figures the maximum values of normalised displacements relate to prototype displacements of about 10mm. For a thrust block with 30mm embedment (Figure 6) the greater stiffness associated with props of shallow angle is evident even at very small displacements. However, the results are not necessarily consistent for the 20mm embedment thrust blocks (Figure 5) which indicate greater stiffness associated with the 30° prop but only a very limited increase associated with the 20° prop.

It is reasonable to assume that the application of predominantly horizontal load to an embedded foundation would be dominated by the development of passive resistance in front of the foundation and the development of shear resistance mainly at the base and also at the sides of the foundation. The proportions of each would be governed by the inclination of the applied load and for increasingly steeper load angles it would be expected that elements of more traditional bearing resistance would become increasingly significant. The relative contributions of the different modes of shear resistance would also depend on the strains needed to mobilise them.

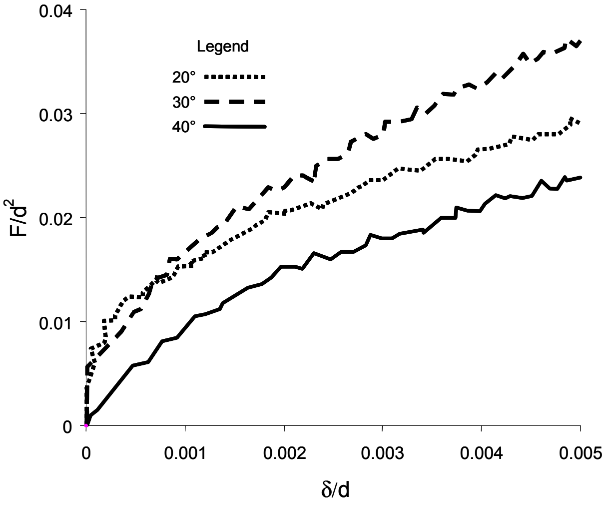

Figure 6 Graph showing load against displacement normalised by the depth of the thrust block for 20mm deep thrust blocks at small displacements

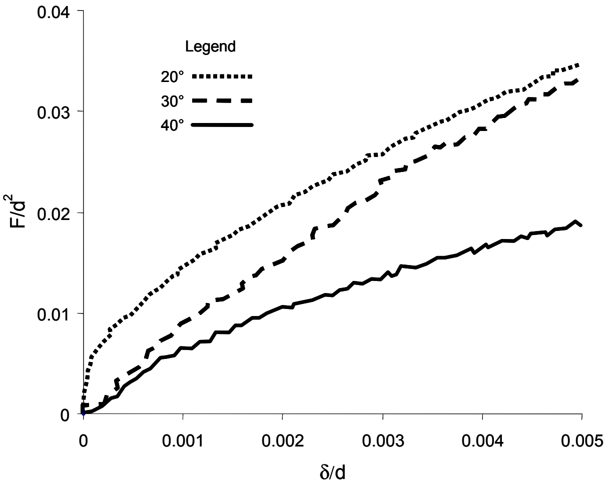

Figure 7 Graph showing load against displacement normalised by the depth of the thrust block for 30mm deep thrust blocks at small displacements

5 CONCLUSIONS

A series of preliminary tests on the performance of thrusts blocks in dry sand has been undertaken. Thrust blocks are essentially shallow foundations but subject to loading that has a horizontal component that can be significantly greater than the vertical component. The measured responses indicate that the thrust blocks exhibit a similar general behaviour to vertically loaded foundations with an initial stiff response followed by a change in response as plastic strains develop in the soil and the foundation is also pushed to greater depth and into soil with increasing in situ effective stress. Even though these are only preliminary tests there is clear evidence of a different mechanism of load transfer into the soil surrounding the thrust block depending on the inclination of the prop load. Slightly surprisingly, the tests with shallow prop angles of 20° and 30° exhibited a stiffer response that the tests with a 40° prop. It is not known if it is significant that the change in behaviour occurred as the prop angle changed from being less than the angle of friction of the soil to greater than the angle of friction. Further tests and analyses are needed to investigate this.

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