

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Assessment of lumpy fill profile using miniature cone penetrometer

Détermination d'un remblai de déchets en utilisant un pénétromètre à cône miniature

C.F. Leung, J.C. Wong & S.A. Tan – *Centre for Soft Ground Engineering, Department of Civil Engineering, National University of Singapore, Singapore*

ABSTRACT: A series of centrifuge model tests has been conducted to investigate the performance of reclamation fill consisting of clay lumps and voids between lumps. In conjunction with the study, a miniature cone penetrometer has been developed to evaluate the strength profile of such lumpy fill during centrifuge flight. The effects of lump size, surcharge and in-situ soil strength on the strength profile are examined.

1 INTRODUCTION

Recent coastal development works in Singapore has led to a high demand of dumping grounds for soils dredged from the seabed. On the other hand, land reclamation works require large quantities of fill material. A research study is being carried out at the National University of Singapore (NUS) to evaluate the feasibility of using dredged soils as reclamation fill. Along the West Coast of Singapore, the seabed soils generally consist of residuals soils and weathered rocks of sedimentary origin with in-situ standard penetration resistance value of 10 and above. During dredging operation, the soils are typically removed from the seabed using a clam-shell grab resulting in lumps of average diameter ranging from 0.5 m to 1.5 m. A schematic profile of a proposed reclamation fill made up of dredged clay lumps is shown in Fig. 1. The profile of the fill is expected to be highly variable due to the presence of voids between lumps. A series of centrifuge model tests has been conducted at NUS to investigate the strength and consolidation characteristics of such lumpy fill. In conjunction with the study, a miniature cone penetrometer has been developed to evaluate the strength profile of the clay lumps during centrifuge flight. In this paper, details of the penetrometer test results with regards to the assessment of lumpy fill profile and strength are presented.

2 MINIATURE CONE PENETROMETER

In recent years, miniature cone penetrometers have been developed at several research institutions to examine the soil strength during centrifuge flight. These include the studies at Cambridge University (Almeida & Parry 1988), five European laboratories (Renzi et al. 1994), the University of Colorado (Esquivel & Ko 1994) and Manchester University (Tani & Craig 1995). These researchers had established that the measured cone resistance is affected by factors such as the shape and size of the cone, the compressibility of the seal material at the shoulder of the cone, the rate of cone penetration, the stress history, permeability and fabric of the soil. Tani & Craig (1995) evaluated the performance of a 10-mm diameter miniature cone during centrifuge flight and found that the cone does not pick up the presence of the rigid base of the soil container until it is about 4 cone diameter above the base. Researchers also noted that the pore pressure acting at the recessed top of the cone base can cause a decrease in the measured cone resistance, q_c , and a corrected cone resistance, q_{T_1} , is introduced to account for such effect. The cone resistance is often calibrated against a laboratory vane shear device

and empirical factors are obtained to correlate either q_c or q_{T_1} to the undrained shear strength of the soil.

The details of the miniature cone penetrometer developed for the present study are shown in Fig. 2. The penetrometer essentially consists of an outer pipe with an external diameter of 6.3 mm and a wall thickness of 0.5 mm. The cone tip is connected to an inner solid rod of 4 mm diameter and a rosette load cell is attached to the top of the rod. As there is an all round clearance of 0.65 mm between the outer pipe and the inner rod, only the cone tip resistance is registered by the load cell when the cone penetrometer is being pushed into the clay during centrifuge flight. The cone penetration is activated by a servo-controlled electro-hydraulic close-loop system shown in Fig. 3.

Almeida & Parry (1988) had shown that calibration of cone penetrometer against laboratory vane shear device performed at 1g and at high g yield reasonably close results. Thus for convenience, the calibration of the cone penetrometer for the present study is carried out using kaolin clay in a large calibration chamber at 1g as an in-flight vane shear apparatus has yet to be developed. The vane shear tests were carried out using a commercially available device while the cone penetrometer tests were conducted at a penetration rate of 2.5 mm/s using the servo-controlled system described earlier. Various correlation factors are obtained for clay with different strength and OCR.

3 TESTS ON LUMPY FILL

A series of centrifuge model tests has been conducted to examine the behaviour of lumpy fill. The results of the preliminary tests have been reported by Leung et al. (1996). All the tests were carried out at 100g on the NUS geotechnical centrifuge. Details of the NUS centrifuge are given in Lee et al. (1991). The centrifuge model setup, which consists of a strong box comprising the test compartment with a perspex front face, is shown in Fig. 4. To simulate different prototype conditions, clay lumps with sizes ranging from 10 mm to 40 mm having different in-situ strengths are tested. Large blocks of dredged clay samples are collected from the field and subsequently consolidated to their desired strengths in large containers in the laboratory. Clay lumps of irregular shape and desired size are then carefully extracted from the consolidated clay bed. The behaviour of clay lumps under self weight consolidation is investigated in the first stage of each test and the behaviour of clay lumps under sand surcharge is examined in the second stage of each test. It should be noted that the clay lumps are placed at 1g and water is only

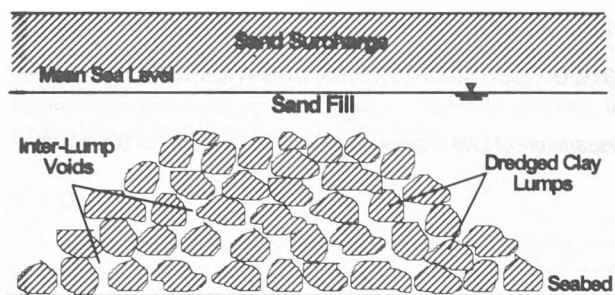


Fig. 1. Schematic profile of lumpy fill.

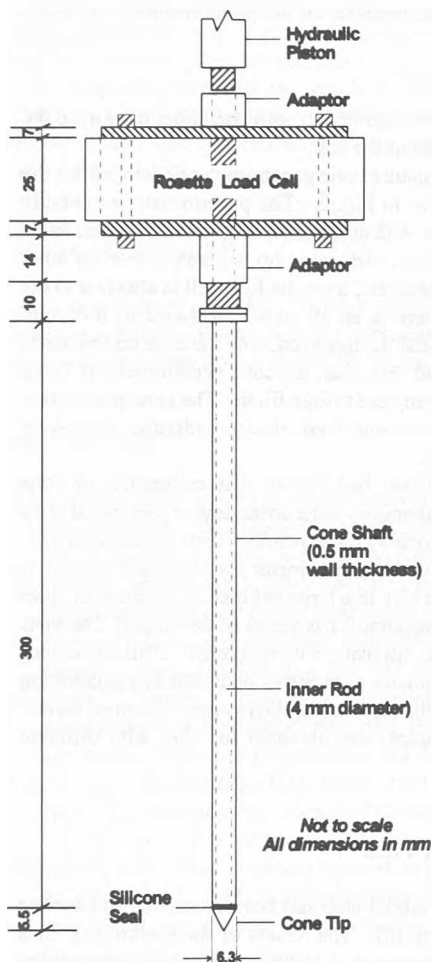


Fig. 2. Miniature cone penetrometer.

introduced into the test model when the centrifuge reaches 100g. The sand surcharge is also placed at 1g when the centrifuge is brought to rest between the two stages of each test. Displacement transducers are employed to measure the vertical settlement of the lumpy fill. In several tests, cone penetration tests are conducted to monitor the lumpy fill profile at different times. The cone penetrometer is manually shifted from one location to another when the centrifuge was brought to rest in between the stages of a particular test.

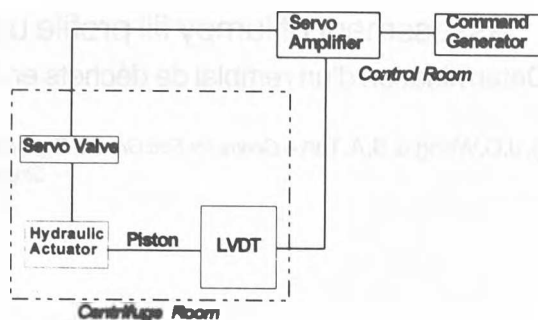


Fig. 3. Layout of control circuit.

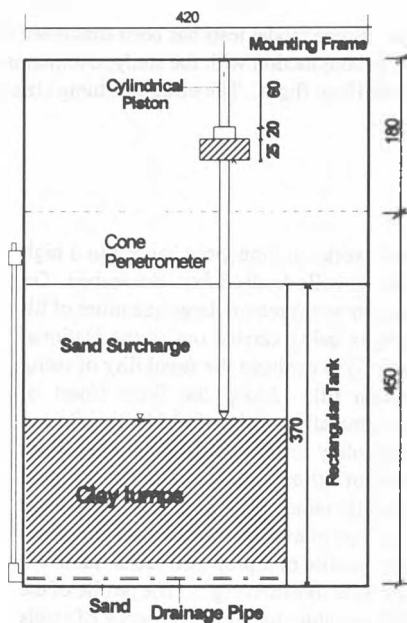


Fig. 4. Centrifuge model setup.

4 EFFECTS OF MODEL LUMP SIZE AND SURCHARGE

Tani & Craig (1995) found that the influence zone below the pile tip could be around 4 times cone diameter. As the cone employed in the present study is 6.3 mm, the influence zone is hence estimated to be about 25 mm. To evaluate the effect of influence zone, cone penetration tests were performed on model clay lumps with average diameter ranging from 10 mm to 40 mm. The clay has a strength of equivalent standard penetration resistance N value of about 20. The thickness of the lumpy fill is noted to reduce significantly due to the gravity turn-on effect when the centrifuge is accelerated from at rest position to 100g field. The initial thickness of the lumpy fill is taken when the centrifuge reaches 100g. The first test was carried out in 40 mm clay lumps without sand surcharge and its initial thickness is measured to be about 12.5 cm. Thus there is an average of about 3 lumps at any given location. At 100g, the simulated prototype clay lump is 4 m and the prototype fill height is 12.5 m. For this and subsequent tests, the rate of cone penetration is fixed at 2.5 mm/s and the sampling rate for q_c is fixed at 5 readings per second. Hence, q_c values are effectively taken at every 0.5 mm interval.

Fig. 5 shows the variation of cone tip resistance (q_c) versus depth for the first test. The scatter of test data is due to the noise signals in the electrical slip rings. Despite the scatter, a clear trend of the lumpy fill profile consisting of lumps and inter-lump voids is evident. For the first 3 cm depth, the magnitude of the measured q_c value is small, having an average value of about 200 kPa. This rather low magnitude can be attributed to the small soil overburden

pressure. For the next 2.5 cm depth, the q_c values are practically zero, strongly indicating the presence of void at that locality. From 5.5 cm depth onwards, q_c gradually increases with depth and reaches a maximum magnitude of 620 kPa at between 6.5 cm to 8 cm depth. The q_c value then decreases again to about 350 kPa at around 8.5 cm depth indicating another void around that location. The q_c value subsequently increases to 800 kPa at around 10 cm depth. Another void is detected at around 11.5 cm depth as the q_c value decreases to 550 kPa before it increases again when the cone is within the vicinity of the base of the strong box. The location of the three probable voids within the path of the cone penetrometer is shown in Fig. 5. The test results suggest that the cone is capable of detecting the interlayer lumps and voids for the relatively large 40-mm model lumps. Based on the measured q_c values, the undrained shear strength values of the upper, middle and lower clay lumps are estimated to be about 25 kPa, 60 kPa and 80 kPa, respectively, using correlation factors established from the calibration tests.

The second test was conducted on 20 mm clay lumps having an initial thickness of 18 cm and same in-situ strength as the lumps in the first test. Fig. 6(a) shows the variation of cone tip resistance with depth during the first stage of the test where there is no surcharge on the lumpy fill. It is evident that there are variations in the q_c values at intermediate depths indicating the presence of voids between lumps. However, the detection of voids is clearly not as distinct as in the first test. This is as expected as the estimated height of the influence zone is about the same size as a 20 mm lump. The range of q_c values, and hence the undrained shear strength, of the lumpy fill are of similar order of magnitude for the two tests. Similar observations were noted for the measured cone tip resistances with depth for a test carried out on 10 mm lumps.

In part two of the test on 20 mm lumps, a 9 cm sand surcharge is placed on the lumpy fill. After six hours of consolidation at 100g (i.e. about 6.8 years of simulated prototype soil consolidation), the height of lumpy fill is noted to reduce by about 4 cm. The variation of cone tip resistance with depth at this juncture is given in Fig. 6(b). In the relatively stiff sand surcharge stratum, the cone tip resistance increases significantly with depth. The softer lumpy fill is felt by the penetrometer when the cone is within 1 cm (i.e. slightly less than 2 cone diameter) above the sand/clay lump boundary represented by the reduction in the cone resistance below this depth. The cone tip resistance only gradually picks up at greater depth when the overburden pressure is substantially larger. The uneven magnitude of the cone tip resistance against depth clearly indicates that there are weak zones within the lumpy fill. However, the relatively large q_c magnitudes in the weak zones suggest that the voids between the lumps have probably been closed up. The measured q_c values under surcharge are substantially larger than those under no surcharge condition, indicating that the strength of the soil has significantly increased due to the closing-up of the inter-lump voids. The percentage increase in shear strength after surcharge is determined to range between 50% to 100%.

5 EFFECT OF ORIGINAL SOIL STRENGTH

All the above tests were conducted on clay lumps with original strength of equivalent N value of 20. To examine the effect of original soil strength, two additional tests on 10 mm clay lumps were conducted: one on N = 10 (i.e. softer soil) and the other one on N = 40 (i.e. significantly stiffer soil). It is noted that the height of lumpy fill for the lumps with N = 40 is higher even though the same weight of lumps are placed in the strong box. This is attributed to the stiffer nature of the soil and hence creating more voids between lumps.

Fig 7 shows the variation of q_c with depth for the clay lumps with N value of 10 at two different times under a surcharge loading of 260 kPa. The first set of readings is taken almost immediately after

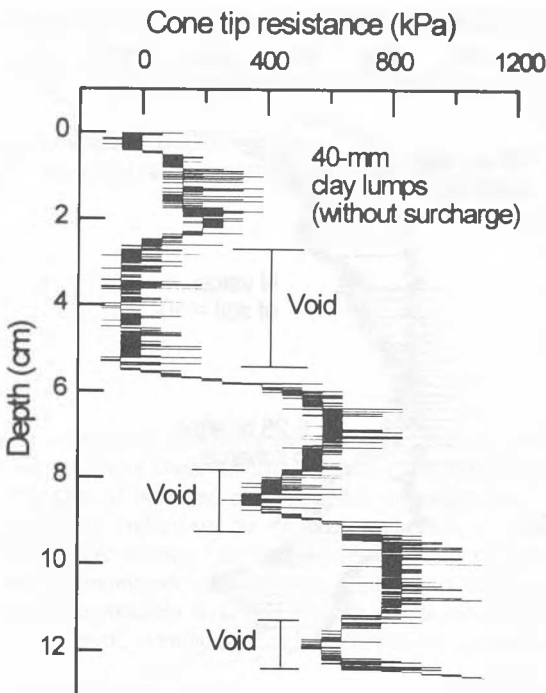


Fig. 5. Variation of cone resistance with depth.

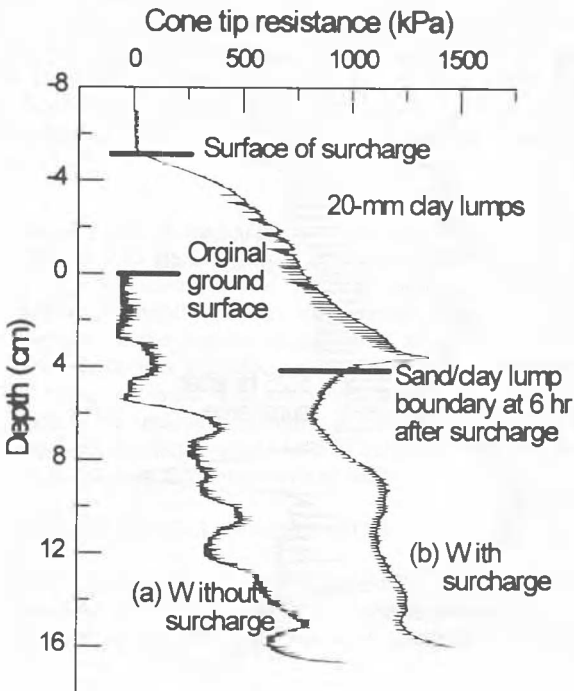


Fig. 6. Variation of cone resistance with depth.

the centrifuge reaches 100g and the second set of readings is taken at 5.25 hours (i.e. about 6 years of simulated prototype soil consolidation). The q_c values for the surcharge layer have been omitted in both cases for clarity. It is evident that the soil strength of the lumpy fill increases significantly and the average soil strength is found to increase by about 30% after soil consolidation.

Fig. 8 shows the variations of q_c with depth for the clay lumps with N value of 40. The rather large q_c values at around 9.5 cm depth is believed to be caused by the presence of a small hard seashell at that location. The magnitude of surcharge load and the timing of the two cone penetration tests are identical to that of the test with clay lump

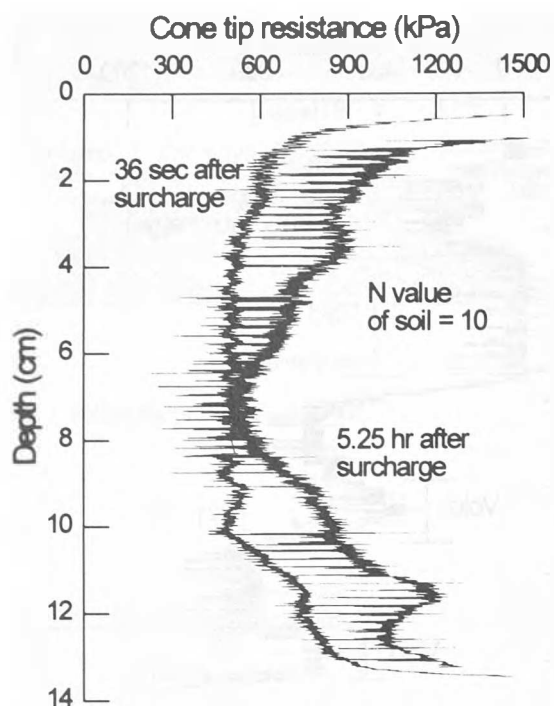


Fig. 7. Variation of cone resistance with depth.

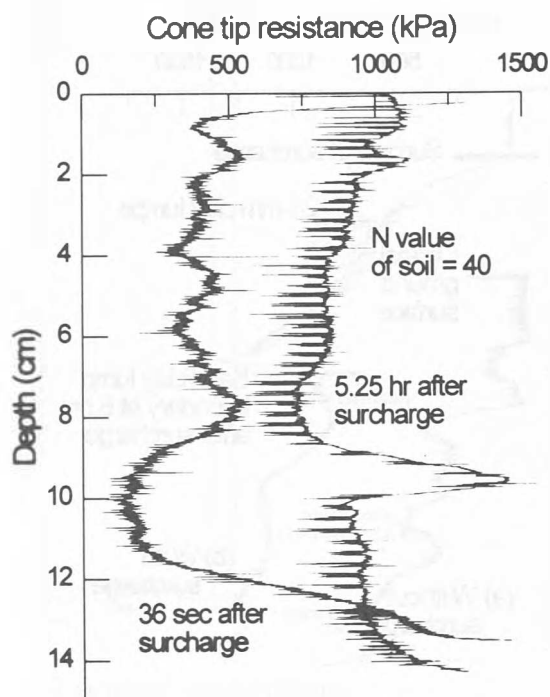


Fig. 8. Variation of cone resistance with depth.

having $N = 10$. For clay lump with $N = 40$, the percentage increase in soil strength after soil consolidation is determined to be about 100% which is significantly higher than that for clay lumps with $N = 10$.

6 CONCLUSION

A miniature cone penetrometer has been developed to evaluate the profile of fill materials consist of clay lumps and voids between lumps during centrifuge flight. It is established that the 6.3 mm diameter cone is capable of determining the lumpy fill profile. The

identification of interlayer voids and lumps is highly successful for the larger model lumps, though the identification is clearly not as distinct in clay lumps with sizes smaller than 20 mm. Despite this, the miniature cone penetrometer developed is found to be a useful tool for the determination of average shear strength of lumpy fill under various loading conditions for model clay lumps of all sizes. This capability has been demonstrated through the studies on the performance of lumpy fill with regards to the effects of surcharge and original soil strength.

ACKNOWLEDGEMENTS

The necessary funding for the present study is supported by research grants RP 930646 and 940674 funded by NUS and the National Science Technology Board of Singapore. The authors wish to acknowledge Dr G P Karunaratne, A/Prof Y K Chow and the technologists from the NUS geotechnical centrifuge laboratory for their contributions towards this research study.

REFERENCES

- Almeida, M.S.S. & R.H.G. Parry 1988. Miniature vane and cone penetration tests during centrifuge flight. *Vane Shear Strength Testing in Soils: Field and Laboratory Studies*: 209-219. Philadelphia: ASTM.
- Esquivel, E.R. & H.Y. Ko 1994. Development of a miniature piezocone. *Proc. Int. Conf. Centrifuge 94*. 89-94. Rotterdam: Balkema.
- Lee, F.H., T.S. Tan, C.F. Leung, K.Y. Yong, G.P. Karunaratne & S.L. Lee 1991. *Proc. Int. Conf. Centrifuge 91*. 11-17, Rotterdam: Balkema.
- Leung, C.F., A.H. Lau, J.C. Wong & G.P. Karunaratne 1996. Centrifuge model tests of dredged material. *Proc. 2nd Int. Conf. on Soft Soil Engineering*. (1)401-406. Nanjing: Hohai University Press.
- Renzi, R., J.F. Corte, G. Rault, G. Bagge, M. Gui & J. Laue 1994. Cone penetration tests in the centrifuge: experience of five laboratories. *Proc. Int. Conf. Centrifuge 94*. 77-82. Rotterdam: Balkema.
- Tani, K. & W.H. Craig 1995. Development of centrifuge cone penetration test to evaluate the undrained shear strength profile of a model clay bed. *Soils and Foundations*. 35(2):37-47.