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CENTRIFUGE MODELLING OF THE EFFECT OF OVERLYING STRATA ON THE GROUND MOVEMENTS INDUCED BY TUNNELLING IN CLAY

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1. INTRODUCTION

The increased need for accurate predictions of tunnelling induced ground movement has led to growing research interest in recent years. Few, however, have addressed the problem of tunnelling in layered ground or the associated subsurface movements. This paper presents the results of a series of centrifuge model tests aimed at investigating ground movements above tunnels driven in clay overlain by coarse grained materials. Attention is focused on the effect of the stiffness of overlying strata on the movements in the clay layer.

2. CENTRIFUGE MODEL TESTS

Figure 1 shows a sketch of the model used in the centrifuge tests, which represents a plane strain section through a tunnel excavated in layered ground. The model was tested at 100g and this corresponded to a prototype tunnel of 5m diameter excavated in a block of soil 55m wide and up to 22m deep. To prepare the model the clay was consolidated in the model container to a maximum vertical effective stress of 500kPa and swelled back under a vertical stress of 250kPa. It was then removed from the consolidation press and the tunnel was excavated, marker beads were placed on the front of the clay for later image analysis and sand was rained on to the clay surface. The model was then ready for the centrifuge test.

The tunnel was supported by compressed air pressure within a latex rubber membrane. As the centrifuge speed increased to give the test acceleration of 100g, the air pressure was adjusted so that it always balanced the overburden pressure at tunnel axis level. After a period of about 16 hours, which allowed the pore pressures to reach equilibrium, excavation of the tunnel was simulated by reducing the supporting air pressure at a rate of approx. 100 kPa/min.

In this paper two tests are described. TH-1 had a geometry in which the soil cover was layered with 36mm dense dry sand overlying 1.5D(D:tunnel diameter=50 mm) of clay. In TH-2 , the soil cover was layered with 42mm loose dry sand overlaying 1.5D of clay. The vertical effective stress profile through the clay layer of thickness 1.5D immediately above the tunnel crown, was the same for each test.

3. TEST RESULTS AND DISCUSSION

The pressure reduction phase is illustrated in Figure 2: the settlements are those above the tunnel crown measured by the LVDTs. Settlement obviously increased with reducing tunnel support pressure and the settlement of the clay/sand interface was greater than the settlement of the sand surface on the tunnel centreline(Smax). Since volumetric straining could occur in the sand layer, the volume of the settlement trough above the tunnel at the sand surface is unlikely to be identical to that in the clay.

Normalised transverse settlement troughs, determined from LVDT measurements, for volume loss of 10%, are plotted in Figure 3 for the clay/sand interface and Figure 4 for the upper sand surface. Gaussian distribution curves (Peck,1969) have been superimposed onto the data. The Gaussian distribution can be written as

$$S = S_{max} \exp\left(\frac{-x^2}{2i^2}\right)$$

where S is settlement
Smax is the maximum settlement at tunnel centreline
x is the horizontal distance from the tunnel centreline in the transverse direction
i is the distance from the tunnel centreline to the point of inflection

Settlement troughs of both the clay/sand interface and sand surfaces fit reasonably with Gaussain distribution curves. The settlement troughs in TH-1 are wider than those in TH-2. TH-1 had larger stiffness of the upper layer than TH-2. The stiffness of the upper layer has a significant influence on the settlement troughs at the clay/sand interface.

The average distributions of i with depth determined from image analysis are shown in Figure 5. Also plotted on Figure 5 is the distribution of i assuming commonly used values

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of K of 0.5 and 0.3 in the clay and sand layers respectively. It is clear that the tests indicate overall a wider zone of influence of tunnel induced movements than suggested by assuming a constant value of K for the clay stratum. i values from TH-1 are generally larger than those from TH-2, showing clearly that the stiffness of the upper layer affects the subsurface settlements.

4. CONCLUSIONS

The results of the two centrifuge experiments are summarized in the following conclusions:

1)Settlements troughs are reasonably represented by Gaussian distribution curves.

2)The type of upper strata has a significant influence on the settlements in the lower layer.

REFERENCES

Peck, R.B. 1969. Deep excavations and tunnelling in soft ground. Proceedings of 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico, State of the Art Volume, pp.225-290.

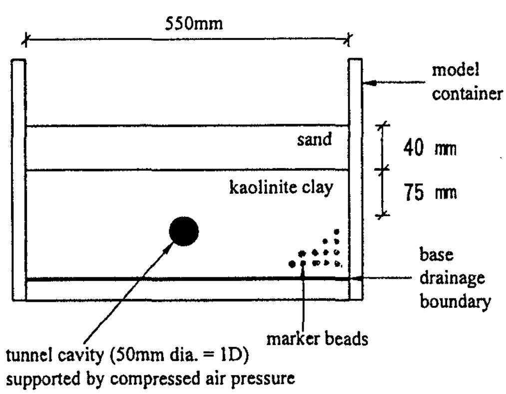

Figure 1 Schematic diagram of the centrifuge model

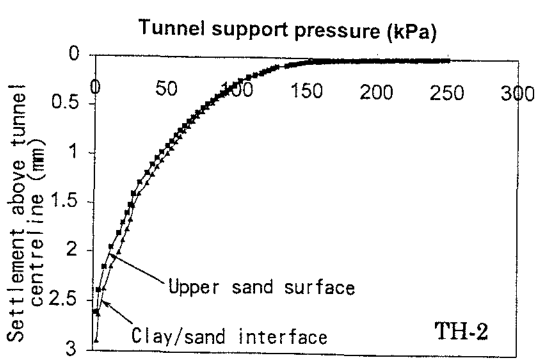

Figure 2 Settlements above tunnel at clay/sand interface and upper sand surface during the test

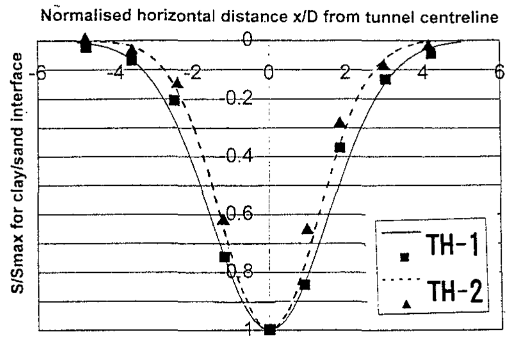

Figure 3 Normalised troughs at the clay/sand interface

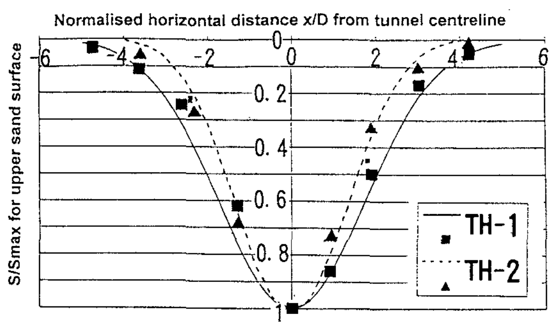

Figure 4 Normalised troughs at the upper sand surface

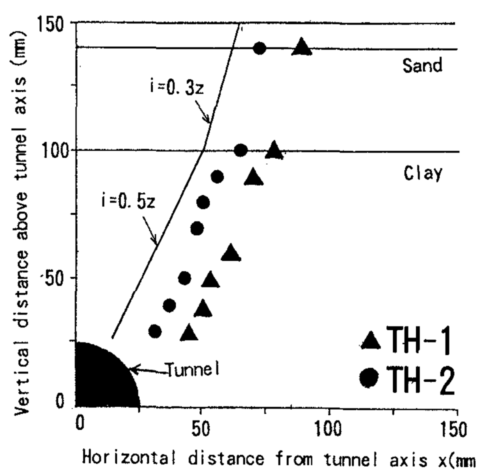

Figure 5 Distribution i with depth