Settlement of Structures on Uncompacted Rubbish

Tassement des Structures sur Déblais Non-Compactés

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SYNOPSIS This paper describes the foundation design for reducing differential settlement but allowing settlement of three structures founded on uncompacted rubbish. The observed and predicted settlements using Tan's (1971) method are discussed. It is found that (i) the use of a raft, and a raft cum timber pile foundation on rubbish dump is effective in minimising differential settlement and (ii) Tan's (1971) method predicts fairly accurately the rate and total settlement of the structures founded on rubbish fill.

INTRODUCTION

The rapidity with which industrialisation and urban renewal take place in landscarce Singapore has brought about the construction of many building projects in areas with very poor soil conditions. One such scheme is the Cleansing Depot and Refuse Transfer Station at Tannery Lane. This project entails the construction of two-single auxiliary blocks and a double-storey office block. The ground on which the three structures are to be founded consists of rubbish dumps of varied description underlain by a thick layer of very soft marine clay overlying a stratum of loose sand. The obvious foundation solution for the said soil conditions would be to bring the structures by means of piles on to a bearing stratum beyond the loose sand. Such a solution however was found to be uneconomical and unacceptable as it would incur a foundation cost amounted to about 30% of the building cost. To obviate this difficulty the two single-storey auxiliary blocks are placed on a floating raft foundation while the two-storey office block is founded on a raft cum short timber pile foundation. In the substructure design allowance is made for the buildings to settle but at the same time keeping the differential settlement to a minimum. This design enables the foundation cost to be reduced to within the acceptable of 10% of the building cost. To check on the performance of the foundation settlement studs have been inserted in the columns of the buildings and settlement readings have been continuously taken over a four-year period. In the paper some details of the foundation design are described and the observed and predicted settlements of the three structures are discussed.

LOCATION AND SOIL CONDITIONS

The location of the three blocks is shown in Fig. 1. The office block is a two storey R.C. structure while the auxiliary blocks B and C are single storey R.C. portal frame structures. Four boreholes have been sunk in the area and the borehole logs are shown in

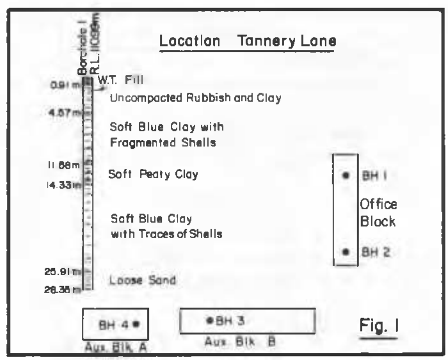

Fig. 1

The soil consists generally of a 1 m top layer of man-made fill of gravel stones, laterite and clays. Below this is a 4 m thick layer of uncompacted rubbish and clays. A stratum of soft marine clay with fragmented shells and having thickness of about 8 m underlies the rubbish. Following this is a soft peaty clay layer of about 3 m thickness overlying a second layer of soft marine clay. In the case of boreholes 3 and 4 a stratum of stiff clay of about 3 m thickness (similar to that found elsewhere in Singapore see Tan 1972) is sandwiched between the soft peaty clay and the second layer of soft marine clay whose thickness varies between 10 m to 13 m. A loose sand layer underlies this stratum of soft marine clay.

The uniformity of the subsoil conditions and the separation of the soft marine clay into two layers are very revealing geologically. It is believed that the bottom layer of marine clay is deposited during the Pleistocene period (Tan 1972). Subsequently, when the sea regresses this marine clay is uplifted and undergoes dessication resulting in the formation of the stiff clay as is evidenced in boreholes 3 and 4. When the sea next transgresses the top stratum of marine clay is formed. The marine origin of the clay is clearly evidenced by the presence of the fragemented shells.

The soft marine clay is normally consolidated. Its average index and geotechnical properties are: LL = 80%, PL = 30%, natural water content 70%, bulk density 1.58 g/ml, clay fraction 50%, vane shear strength 10.0 kN/m^2, compression index C_c = 0.80 and $\frac{C_c}{1+e_o}$ = 0.27. The sensitivity is about 5.

FOUNDATION DETAILS

The high compressibility of the marine clay and the uncompacted rubbish fill suggests that the three structures might have to be founded on piles. However, this idea was subsequently abandoned because of the high piling cost and the relative unimportance of the three structures. It was finally decided that the two single storey auxiliary blocks could be founded on raft foundations and allowed to settle. The two storey office block being more importance of the three would be constructed on a raft supported by tanalised timber piles spaced at equal intervals, the idea being to reduce total and differential settlements to a minimum.

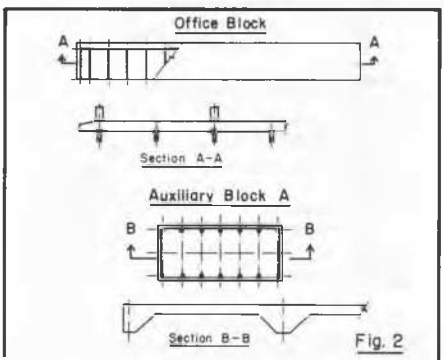

Fig. 2

Figure 2 presents the plan and elevation of the two foundation types. The figure shows, for the two single storey blocks, the raft consists of 225 mm reinforced concrete slab thickened to 750 mm by ground beams supporting the columns. This raft which also serves as the ground floor slab rests on a specially compacted fill of about 1.0 m thickness. A bearing capacity of 30 kN/m^2 has been assumed for this raft. For the case of the double storey office building, the reinforced concrete raft of uniform thickness 300 mm acts as a large pile cap for the tanalised timber friction piles each of which is driven to a depth of 12 m. The piles are spaced at 1.8 m c/c longitudinally and 1.5 m c/c laterally. Unlike the single storey raft, this present one supports the ground beams which in turn carry a 100 mm uniformly thick ground floor slab. Thus between the raft and the ground floor slab there is a void in between the ground beams. Similar to the single storey raft, the office block raft is founded on a specially compacted fill.

SETTLEMENT OBSERVATION

The positions of the settlement points are shown in Figs. 3, 4 and 5.

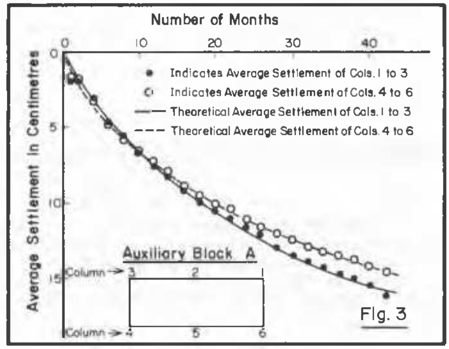

Fig. 3

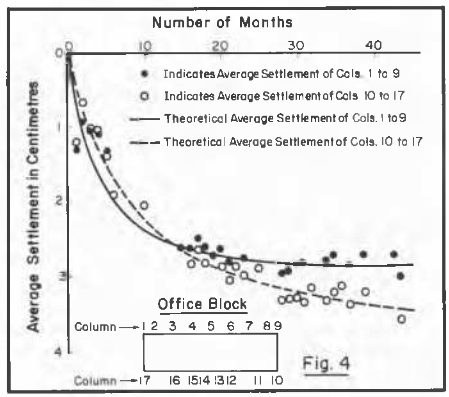

Fig. 4

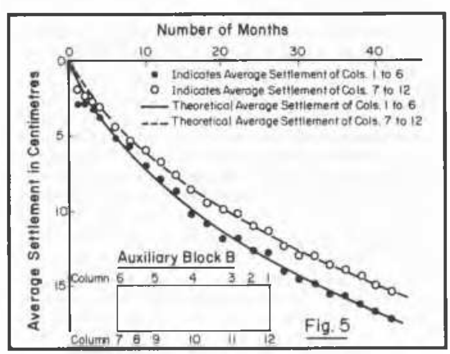

Fig. 5

These points are made by drilling the 'Red Head' self drilling hollow anchors into the reinforced concrete columns. The open ends of the anchors are closed by means of mild steel plugs. In order to make a settlement observation the plug is removed and temporarily replaced by a cylindrical mild steel stud which is screwed right into the hollow anchor. An invar staff is then placed on the extruded end of the stud and measurement is made using a precision survey level. A temporary bench marked some distance away is used for the settlement observation.

The observed time-settlement curves for the three structures are presented in Figs. 3, 4, and 5. It is interesting to note that the total settlement and differential settlements over the four-year period for the two one-storey structures are much higher than that for the two-storey office block. The order of the difference is about five times suggesting that the use of the raft cum timber pile foundation in the latter case has succeeded in reducing the differential and the total settlements considerably under the same loading conditions.

It is noted that the average differential settlement of about 15 mm occurring at the single storey buildings has resulted in some cracks appearing in the brick walls. Some hairline cracks have also appeared in the office blocks because of a differential settlement of about 5 mm. But both these cracks have posed no danger as structurally the three buildings are sound as no crack has yet appeared in the columns or beams. This indicates the decision not to use end bearing piles to effect a saving in foundation cost is probably justified as the differential settlements for both the single storey buildings and the office block have been reduced to practically the minimum. However, the total settlement for the single storey blocks appears to be continuing while that for the office block seems to flatten off. This increase in settlement will no doubt present little structural problem because of the uniformity.

ANALYSIS OF SETTLEMENT

The theoretical settlement analysis of the three structures is made difficult by the presence of the uncompacted rubbish whose compressibility and date of burial are unknown. To overcome this difficulty the empirical method proposed by Tan (1971) is adopted. In his method Tan (1971) found that an equation of the form $\frac{t}{\delta} = Mt + C$ is a straight line when the ratio $\frac{t}{\delta}$ is plotted against t, where δ is the total settlement at any time t after the excess pore water pressure has dissipated, and M and C are empirical constants. The ultimate settlement δ_{ult} is given by $\frac{1}{M}$ the inverse slope of the $\frac{t}{\delta}$ vs t plot while the intercept C gives an indication of the amount of instantaneous settlement.

Fig. 6 gives a typical $\frac{t}{\delta}$ vs t plot for the auxiliary block B. Except for the initial few points the plot is essentially linear thus confirming Tan's (1971) observation. The curved portion of the plot is attributed probably to the hydrodynamic time lag during the primary consolidation phase. Tan (1971) suggests that if the primary consolidation had been instantaneous then the whole portion of the plot would have been linear.

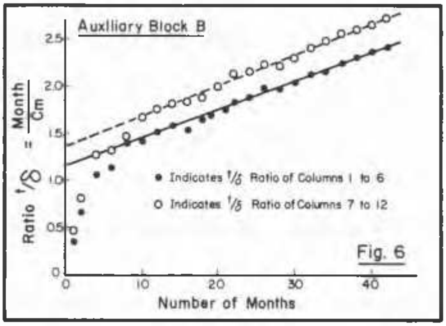

Fig. 6

Using the values of M and C evaluated fromthe $\frac{t}{\delta}$ vs t graphs, the calculated settlement-time curves have been plotted (Figs. 3 to 5). The figures show that the theoretical curves not only predict reasonably correctly the total settlement but also the rate of settlement. The agreement is surprisingly remarkable. This is probably because actual settlement readings and not laboratory values have been used in estimating C and M. The agreement indicates that (i) Tan's empirical method can be used for structures (the two auxiliary blocks) founded directly on rubbish and also partly on rubbish as the case of the office block in addition to those founded on clays described by Tan 1971. (ii) differential settlement between the two longitudinal edges of the structures can also be fairly accurately predicted.

CONCLUSIONS

It is concluded that:

(i) the use of a raft and raft cum timber pile foundation on rubbish dump is effective in ensuring uniform settlement thus minimising differential settlement. The raft cum timber pile foundation under the same loading condition also results in reducing the total settlement by as much as 5 times when compared with one without the timber piles, and

(ii) Tan's (1971) method predicts reasonably accurately the rate and total settlement of structures founded on rubbish fill.

ACKNOWLEDGEMENT

The paper described is published with the permission of the Director of Public Works Singapore.

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