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Geotechnical design parameters for the construction of Bangkok Metro

Hokkaido University student ○ Surendra Bahadur Tamrakar
Ditto Associate Professor Satoru Shibuya
Ditto Professor Toshiyuki Mitachi

Introduction

Sutthisan is one of the stations, which lies along the northern line of Bangkok Metro. The construction of this underground mass transportation system has been underway in Bangkok along with Metropolitan Rapid Transit Authority (MRTA) Initial system project in Thailand. The reinforced concrete wall is currently being constructed to a depth to about 30 m from the ground level. Various field and laboratory tests such as down-hole seismic survey (SCPT), field vane shear (FVS), piezocone (CPTU), consolidated undrained triaxial compression (MTX), cyclic triaxial (CTX), consolidation (both CRS and Oedomenter), bender element (BET) and constant volume direct shear box (DSB) tests were performed and the test results are presented here as design parameters.

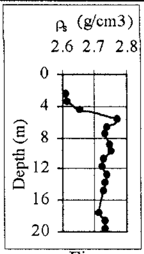

Fig. 1

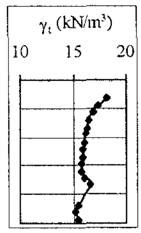

Fig. 2

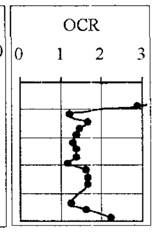

Fig. 3

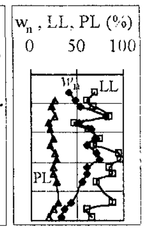

Fig. 4

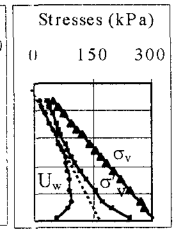

Fig. 5

Test results

The subsoil layer of Sutthisan can be divided into three layers. The top most is the weathered crust, which extends down to 4 m depth from the ground level. The middle one is the soft clay lying in between 4 to 15 m depths and the last one is the stiff clay, which extends down from 15 m to 22 m depths. Beyond 22 m depth, there is a sand layer.

Excluding the weathered layer, OCR value ranges from 1.2 to 1.7. A steady value of OCR is seen from 6-12 m depth, which might be due to the recent consolidation undertaking from the over pumping of underground water (Fig. 3). At the weathered crust, water content varies from 47 to 54% whereas at the soft clay it is closer towards the liquid limit and at the stiff clay, it approaches towards the plastic limit (Fig. 4). The GWL, as measured on Nov. 1997, lies at 1 m below the ground surface. Due to the excessive pumping of underground water, a non-hydrostatic distribution of pore water pressure is seen below 7 m depth and it reaches almost to zero at 22 m depth (Fig. 5). Compression index, C_c and swelling index, C_s were found from constant strain rate (CRS) and oedometer tests respectively. The variations of λ (=$0.434C_c$) and κ (=$0.434C_s$) with depth are plotted in Fig. 6. In soft clay, both λ and κ values show gradual increase with depth.

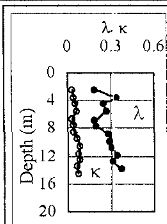

Fig. 6

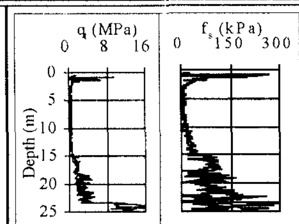

Fig. 7

Piezocone test results were shown in Fig. 7. At the weathered crust, both cone resistance, q_t and skin friction, f_s show the higher values. In the soft clay, the q_t value lies within 1 MPa whereas it increased to more than double in stiff clay. The f_s varies from 10-50 kPa in soft clay and reached to more than 100 kPa in stiff clay. No distinguishable sand layers are seen within the clay layers. Fig. 8 shows the seismic cone test results. Here, the in-situ shear wave velocity, V_s is measured to calculate the field shear stiffness. G_f $\{=(\gamma_t/g)V_s^2\}$ where γ_t is the total unit weight and g is the gravitational acceleration. The shear wave velocity lies within 100m/sec at soft clay layer and reaches to almost double at stiff clay layer.

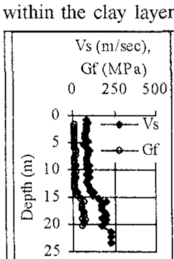

Fig. 8

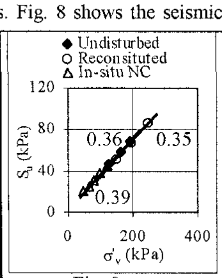

Fig. 9

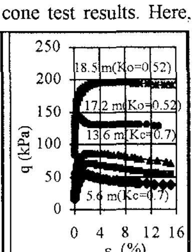

Fig. 10

In DSB, three types of tests were performed; (i) sample recompressed to in-situ effective overburden pressure, (ii) twice in-situ effective overburden pressure and (iii) reconstituted samples. The ratio of shear stress (S_u/σ'_v) for soft clay as shown in Fig. 9 for all three tests lies within 0.35 to 0.39. This shows the least effect of aging in Sutthisan clay. The angle of shearing resistance, ϕ'_{ds} and effective cohesion, c' values for sample recompressed to in-situ effective over burden pressure are 26° and 0 kPa for the soft clay and 26.6° and 30 kPa for the stiff clay respectively. The stress – strain relationship of MTX is shown in Fig. 10. Most of the samples failed at the strain of 1.5 to 2%. The ϕ' value derived from the results of the soft clay samples at the depths of 5.6 m and 9.6 m is about 34° with c' equals to zero. Pseudo-elastic young's modulus, E_{max} is found at small strain range of the order of 0.001%. The variation of E_{sec} with axial strain, ε_a shown in Fig. 11, points out the strong dependency of the stiffness at small strain range less than 0.1%. G_{max} = $E_{max}/3$ is accounted for the calculation of shear stiffness. The variation of equivalent shear modulus, G_{eq} and damping ratio, h calculated

Bangkok clay, Seismic cone, Field and lab tests.

Pin 060-8628, Sapporo-Shi, Kita-Ku, Kita-13, Nishi-8, Tel. (011)-706-6193 Fax. (011)-726-2296

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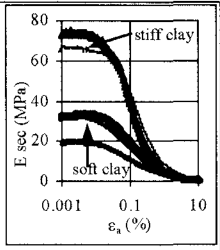

Fig. 11

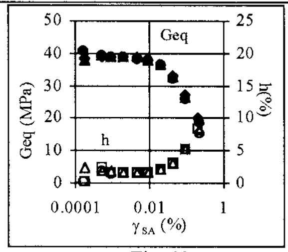

Fig. 12

in CTX are shown in Fig. 12. The strong dependency of stiffness with small strain is seen and the relationships are not affected by the no. of cycles (represented by different symbols). The hysteretic damping ratio was about 2-3% upto γ_{SA} of 0.01% and it increased to about 15% at γ_{SA} of 1%.

Design Parameters

Undrained shear strength

The profiles of S_u obtained from different tests are shown in Fig. 13. In soft clay, $S_{u(FVS)}$ varies from 18 to 33 kPa and $S_{u(DSB)}$ varies from 18 to 50 kPa. $S_{u(MTX)}$ values are higher than others in soft clay. At stiff clay, shear strength exceeds 50 kPa and reach up to 150 kPa (DSB).

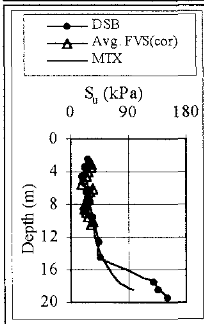

Fig. 13

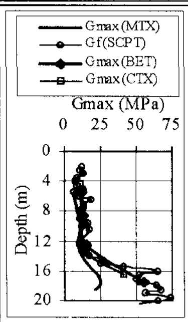

Fig. 14

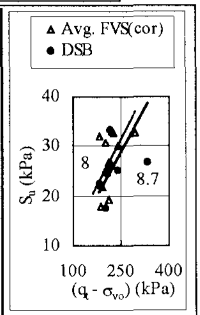

Fig. 15

Strain-level-dependency of stiffness

To observe the sample disturbance, G_f (believed to be free from disturbances) is compared with G_{max} and G_{eq} obtained from various lab tests and are plotted with depth in Fig. 14. The G_{max} value obtained from Bender element tests (BET) is found to be closer with G_f values. But the deviations of $G_{max(MTX)}$ from G_f might be due to sample disturbance. Fig. 11 and 12 showed the variation of stiffness with strains. In Fig. 11, stiffness decrease curves for soft clay samples are almost same. But the stiffness curves for stiff clay are more stiffer and brittle in response.

Estimation of S_u and G_f

Piezocone tests along with FVS or other shear tests were carried out in order to define a cone factor, N_{kt} $\{=(q_t-\sigma_{vo})/S_u\}$. In Fig. 15, N_{kt} value for soft clay layer is found as 8 and 8.7 in relation with $S_{u(FVS)}$ and $S_{u(DSB)}$ respectively. The following empirical equations might be used to estimate the G_f of Sutthisan clay with the constants 3500 and 18000 respectively (Fig. 16):

$G_f = 3500*e^{-1.5}*\sigma'_v{}^{0.5}*K_{0nc}{}^{0.25}*(OCR)^{0.125}$

$G_f = 18000*(1+e)^{-2.4}*\sigma'_v{}^{0.5}*K_{0nc}{}^{0.25}*(OCR)^{0.125}$

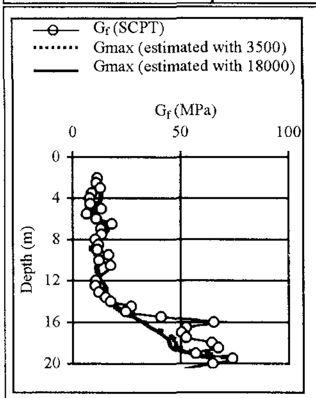

Fig. 16

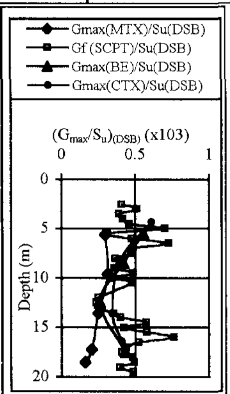

Fig. 17

Conclusions

1. Soft clay layer extends down to 15 m depth over the stiff clay layer, which is about 5 m thickness. Sand layer extends down to 40 m below stiff clay layer.

2. Non-hydrostatic distribution of water head due to the excessive pumping of ground water was seen below 7 m depth and reaches almost zero at 20 m depth. GWL was seen at 1 m depth below the ground surface.

3. OCR value ranged from 1.2 to 1.7 within the soft and stiff clay layers. Both the compression and swelling indexes were gradually increased with depth in soft clay.

4. The angle of shearing resistance, ϕ'_{ds} and ϕ' obtiained from DSB and MTX are 26° to 26.6° (soft to stiff clays) and 34° (soft) respectively. Similarly, the effective cohesion obtained are 0 to 30 kPa (soft to stiff clays) for DSB and 0 kPa for MTX respectively.

5. The shear wave velocity for soft clay was found as 100m/sec and it reached to almost double at stiff clay layer.

6. In average, undrained shear strength varied from 20 kPa at 4 m depth to 50 kPa at 15 m depth. However, a significant increased up to 150 kPa was seen at stiff clay layer. Since the stress ratio lies within 0.35 to 0.39 (soft clay), we could say that the soil is least affected by aging.

7. From the examination of both MTX and CTX tests, we could say that the stiffness of the Sutthisan soil strongly depends on the small strain values. The rigidity index $\{G_f/S_{u(DSB)}\}$ at strains less than 0.001% varies from 350 to 500 (Fig. 17).

8. The estimated values of cone factor, N_{kt} are 8.7 and 8.0 in relation with S_u from DSB and FVS respectively.

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