[TH-01] GEOTECHNICAL INVESTIGATION FOR RECLAMATION OF MUMBAI PORT

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ABSTRACT: An extensive offshore geotechnical investigation campaign was conducted for the proposed 90 hectare marine reclamation for port extension works at Mumbai. The investigation comprised of conventional borehole sampling, laboratory tests and various in-situ field tests such as Piezo Cone Penetrations Tests (CPT), Cone dissipation tests, and field Vane Shear Tests (VST). Investigations revealed the total clay thickness around 4 to 22m, with top layer found to be very soft to soft clay underlined by stiffer layer and basaltic bed rock of various weathering grade. The crux of the site characterization was to comprehend the consolidation and strength characteristics of the upper soft marine clay. The consolidation parameters were required for the design of ground improvement works in estimating the magnitude and rate of consolidation up on the application of reclamation fill load and future container yard loads. The stability parameters were needed to check the stability of the reclamation fill during construction and in permanent shore protection works.

KEYWORDS: geotechnical investigation, radial consolidation, dissipation test, cone penetration tests

1 Introduction

A container terminal was proposed in a 90 hectare land to accommodate container stack yards and associated structures for port development works in Mumbai. The bathymetric survey showed seabed level varying from +1.5 mCD to -1.5mCD whereas the mean sea level was +2.5mCD. An extensive offshore geotechnical investigation campaign conducted in the area revealed estuarine deposits of soft marine clay of thickness ranging from 4 to 22.5m which was further underlain by basalt rock.

Figure 1 shows the plan of the Geotechnical Investigation showing the location of various marine boreholes extending over 90 hectare area. The investigation comprised of a) 89 numbers of boreholes through conventional drilling and sampling, b) 63 number of Cone Penetration Tests (CPT) with pore pressure measurement, c) Cone dissipation tests and d) Field vane shear tests (VST). In addition to the routine laboratory tests, specialist tests such as radial consolidation and extended 1D oedometer tests for secondary compression were also conducted to obtain the consolidation parameters. Consolidation and compressibility parameters were obtained through laboratory tests, whilst the shear strength parameters were characterized from the CPT resistance and vane shear tests.

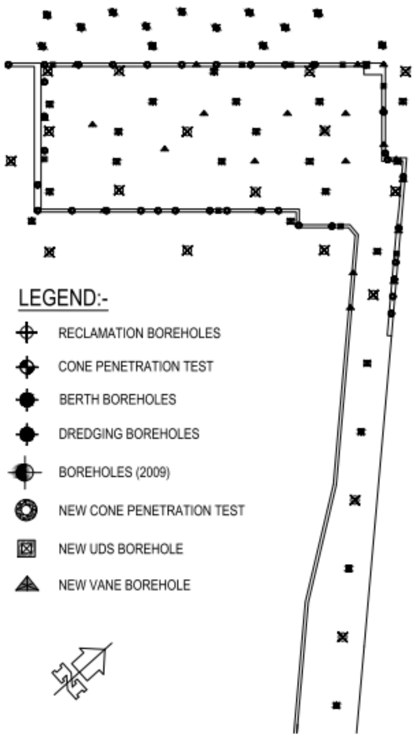

Fig. 1 Geotechnical investigation plan

2 Investigation tests and results

2.1 SPT N Values

As shown in Figure 2, the SPT 'N' value varied from 0 to 4 in soft marine clay up to -12 to -14mCD and gets slightly stiffer down the depth. Marine clay was followed by a thin layer of sandy gravel layer with an average 'N' value of 50.

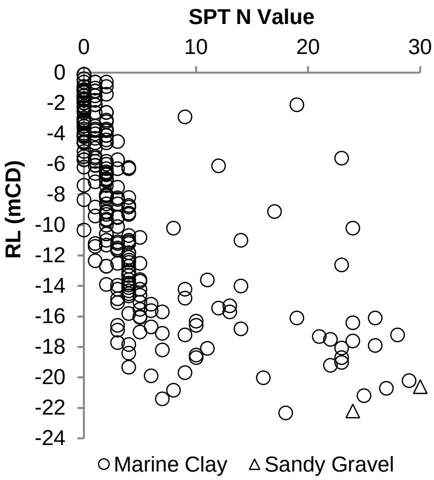

Fig.2 SPT 'N' values

2.2 Atterberg limits

Liquid Limit was observed to be in the range of 70% to 110%, with Plasticity Index around 30% to 80%. The Natural Moisture Content (NMC) varied from 60% to 120% and was close to the liquid limit.

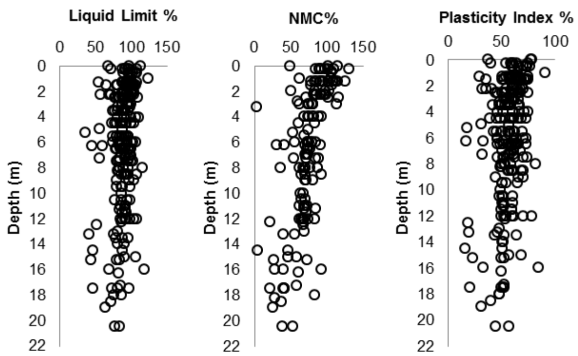

Fig.3 Atterberg limits

2.3 Undrained shear strength

One of the critical strength parameters such as undrained shear strength, C_u of marine clay was derived from the cone penetration resistance using equation (1).

$$C_u = (q_T - P_0)/N_{kT} \quad (1)$$

Where $q_T = q_c + u\,(1 - a)$; a is the cone correction around 0.75; N_{kT} is the cone correlation factor.

A number of Field Vane Shear Tests (VST) were conducted in close proximity to CPTs to estimate the correlation factor N_{kT}. N_{kT} factors were found to be higher in the shallower depth and reduced along the depth as shown in Table 1. The top 2 to 3m of marine clay was found to be extremely soft with undrained shear strength C_u ranging from 5kPa to 7kPa as shown in Figure 4. Below 2 to 3m depth, the C_u was found to be increasing with the depth at the gradient of 2.85 kPa/m. A typical shear strength profiles obtained in one of the reclamation zones are given in Figure 4.

Table 1 Cone correlation factor N_{kT}

Depth (m)	N_{kT}
0 -5	25
5 - 6	20
>6	15

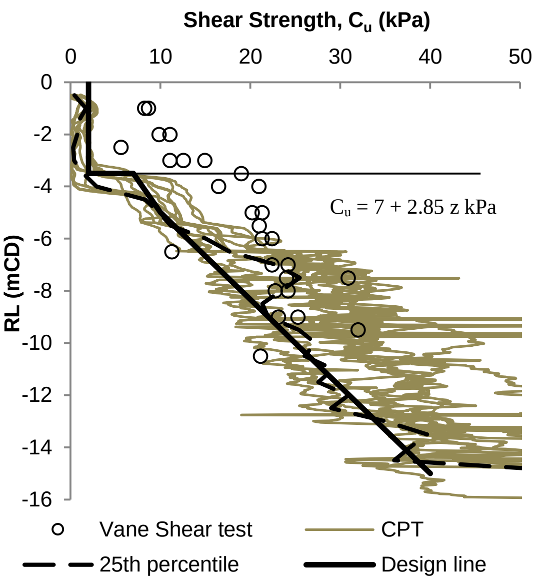

Fig.4 Undrained shear strength with depth

2.4 Coefficient of consolidation (C_v, C_h)

Conventional 1D oedometer consolidation tests were carried out for different ranges of effective stress on the retrieved clay samples. It was noted that the consolidation coefficient reducing with the increase in the effective stress. As the estimated preloading for the reclamation was in the range of 100 to 200 kPa, the coefficient of vertical consolidation (C_v) corresponding to this pressure range was found to be around 0.8 to 4.5 m^2/year. Similarly, C_h value measured using radial consolidation tests was in the range of 1.9 to 4.25 m^2/year, yielding the C_h/C_v ratio of 2.1 to 2.5. The variations of these parameters along the depth are shown in Figure 5.

Few cone dissipation tests were also conducted at certain depths by interrupting the cone penetration and monitoring the excess pore pressure dissipation with time. C_h values were calculated from the modified time factor derived using the strain path solution method (Teh and Houlsby, 1991). The in-situ C_h values were estimated to be in the range of 3.4 to 4.86m^2/year and found to be in the similar range of values noted in radial consolidation tests.

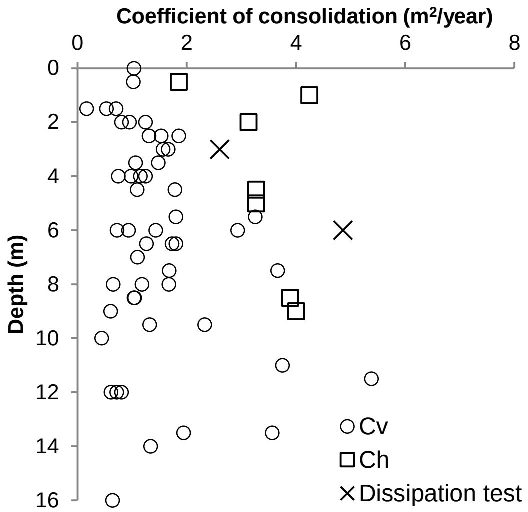

Fig.5 Coefficient of consolidation C_v & C_h

2.5 Primary consolidation parameter

As the Compression Ratio (CR) is one of the key parameters to estimate the magnitude of primary consolidation settlement, number of oedometer tests were conducted in clay samples. As shown in Figure 6, the observed Compression Ratio (CR) was in the range of 0.15 to 0.35.

2.6 Secondary consolidation parameter

As the secondary compression index C_α is required to estimate the magnitude of secondary consolidation post the end of primary consolidation and reclamation hand over, several extended odometer testing's were carried out. During such tests, the consolidation loads were continued and extended up to 12 days post 24 hours after the end of primary consolidation. The measured C_α values were in the range of 0.015 to 0.035 as shown in Figure 7. Figure 8 shows the compression index ratio C_α/C_c ratio of 0.033 which was found to be in similar range proposed by Mesri (Mesri et al 1977).

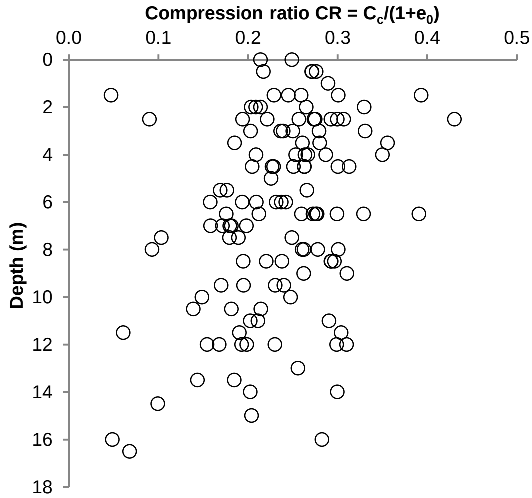

Fig.6 Compression ratio with Depth

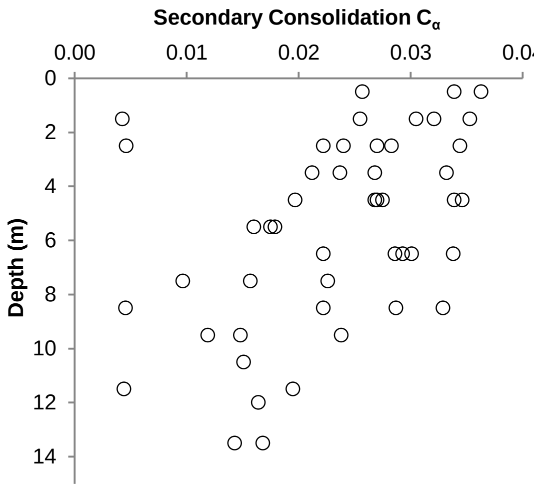

Fig.7 Secondary compression index C_α

2.7 Preconsolidation pressure and OCR

The preconsolidation pressure obtained from the one dimensional consolidation tests, clearly showed that clay was over consolidated with OCR in the range of 2 to 5 in the top portion, which might presumably resulted from the aging and desiccation process. The OCR was found to be reducing with the depth as shown in Figure 9.

2.8 Organic content

Various test results showed the organic content in the marine clay between the range of 5% and 15%, at some locations it was up to 20%.

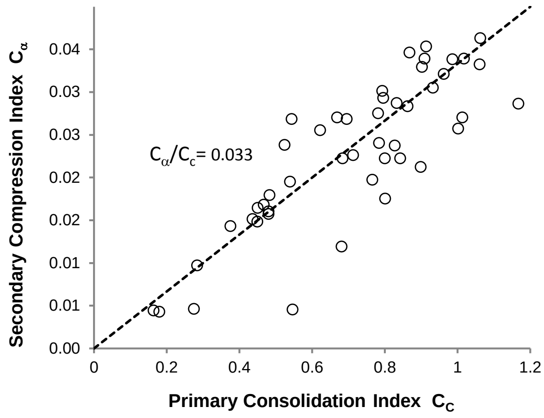

Fig.8 Compression index ratio C_α/C_c

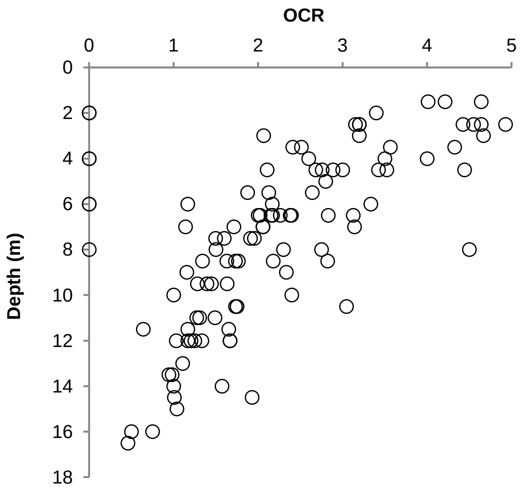

Fig.9 OCR with Depth

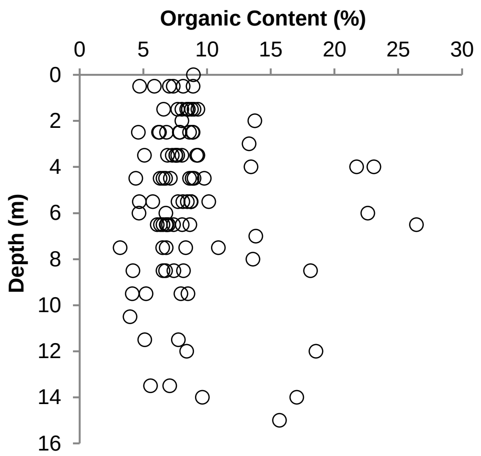

Fig.10 Organic content with depth

3 Conclusion

Various geotechnical investigations were carried out to comprehend the characteristics of upper soft marine clay in the reclamation and ground improvement works for Mumbai port development. Some of the key characteristics of soft clay such as compressibility and consolidation parameters were found to be crucial for the estimation of both magnitude and rate of consolidation. Similarly, the strength parameters such as undrained shear strength were found to be vital to check the stability of the temporary reclamation and permanent shoring bunds. An extensive investigations were conducted which revealed a wide variations in the geotechnical parameters over the vast reclamation area. Hence, the reclamation area was discretized into 11 zones and the design parameters for each of the zones were established. Table 2 summarizes the typical range of design parameters established for various zones of reclamation.

Table 2 Summary of design parameters for clay

Density	15 kN/m^3
Plasticity Index, I_p	30 to 80
Liquid limit, LL	70 to 110
Natural Moisture Content, NMC	60 to 120
Compression Index, C_c	0.5 to 0.95
Initial Void ratio, e_o	1.4 to 2.5
Compression Ratio CR, $C_c/1+e_0$	0.19 to 0.3
Coefficient of Vertical Consolidation, C_v (m^2/year)	0.8 to 1.7
Coefficient of Horizontal Consolidation, C_h (m^2/year)	1.9 to 4.25
C_h/C_v	2.1 to 2.5
Secondary compression index, C_α	0.016 to 0.034
C_α/C_c	0.023 to 0.055
OCR	1.5 to 3.4

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