LAND SUBSIDENCE IN SOUTH CALCUTTA

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ABSTRACT

In this paper two approaches have been mentioned to calculate subsidence. One is based on the linear theory (considering elastic property of the material) and the other on the logarithmic theory. In the linear theory coefficient of volume compressibility (denoted as m_v) indicates the nature of soil towards compression and in the logarithmic theory compression index (denoted as C_c) indicates the same. The top 30 m. of the subsurface soil stratification in Calcutta generally indicates softer clayey soil in the first 15 m. having higher m_v values and relatively stiffer clayey soil between 15 m. and 30 m. having lower m_v values. Further below the compressibility of the layers diminishes due to increasing overburden pressure also. In the analysis section for subsidence in a certain locality in South Calcutta, firstly data of soil characteristics and properties in different layers and change in piezometric level or depth of water table from 1958 to 1999 are represented. Based on these data intergranular pressures for different layers are calculated and finally total subsidence in the said time span are estimated using the logarithmic theory. This comes out to be 0.4739 m. from 1958 to 1999 and hence estimated subsidence rate is 11.56 mm/year.

Keywords: *Land Subsidence, Soil Consolidation, Groundwater*.

1. INTRODUCTION

Analyzing Terzaghi's theory [1] on compressibility of soils and other later developments on this (e.g. Colijn and Potma [2], Taylor [3], Abbot [4], Terzaghi and Peck [5], Roberts [6], Gambolati *et al.* [7], Bull and Poland [8] etc.), two approaches have been made to calculate subsidence. One is based on the linear theory (considering elastic property of the material) and the other on the logarithmic theory.

According to the linear theory, subsidence is given by

$$S_u = (P_{i2} - P_{i1})\frac{Z_1}{E} = m_v (P_{i2} - P_{i1}) Z_1 \qquad (1)$$

and according to the logarithmic theory, subsidence is given by

$$S_u = Z_1 C_u \log(P_{i2}/P_{i1}) \qquad (2)$$

where Z_1 = thickness of the soil layer prior to compression,
P_{i1} = intergranular pressure when ground water table is at initial piezometric level,
P_{i2} = increased intergranular pressure when water table is at final piezometric level due to drawdown,
m_v = Coefficient of volume compressibility = reciprocal of the *compression modulus E*,

$C_u = \frac{C_c}{e_1 + 1}$, C_c being called the *compression index*, slope of the essentially linear portion of e vs $\log P_i$ curve and e_1 being the void ratio of the soil layer prior to compression.

2. GENERAL STRATIFICATION OF SUBSURFACE SOIL OF CALCUTTA

The top 30 m. of the subsurface soil strata in Calcutta consists mainly of successive layers of clay, silty clay and clayey silt, and can be subdivided into two horizons based on the relative compressibility of the different strata. The upper clay horizon (top 15 m.) generally consists of softer components, whereas the clay below 15 m depth, consists of much stiffer materials (Bhattacharya *et al.* [9]). This stratification is generally referred to as the Normal Calcutta Deposit and is found to exist over most of the study area. A general classification of the Normal Calcutta Deposit along with the m_v values after Dastidar and Ghosh [10] is shown in Table 1. A perusal of the Table reveals that the clay layer between 15 m. and 30 m. is relatively stiff as indicated by the low m_v value. Further below, the compressibility of the layers will be even less because of the increasing overburden pressure and, therefore, they may not play a significant role in land subsidence.

Table 1: Stratification of Normal Calcutta Deposit (after Dastidar and Ghosh, 1967)

Stratum	Depth (m)	Description	Coefficient of volume compressibility m_v (cm^2/kg)
I	0 – 5	Firm grey silty clay	0.014
II	5 – 15	Soft grey clay with wood stumps	0.04
III	15 – 20	Bluish grey clay with kankar	0.01
IV	20 – 25	Laminated brown clay, silt	0.01
V	25 –30	Stiff mottled grey and yellow clay with kankar	0.01
VI	>30	Mottled silty clay laminated with parting of golden brown silty sand	

3. VARIATIONS IN PIEZOMETRIC LEVELS IN SOME PARTS OF CALCUTTA

During the period 1956 – 93, the decline of piezometric level was maximum in Gobra – Tiljala area and of the magnitude of 8.29 m., however, during the period 1993 – 99, the decline is of the order of around 1 m. as obtained from Central Ground Water Board annual reports. In sharp contrast to this in Kasba – Gariahat – Dhakuria region of South Calcutta, the piezometric drop was 6.82 m. during the period 1958 – 94 whereas the piezometric level changes from 9.07 m. below Ground Level in April 1994 to 15.18 m. below Ground Level in April 1999 in the same region as per Central Ground Water Board reports, and hence a total drop of 12.93 m. in piezometric level is observed during the period 1958 – 1999 in this region of South Calcutta. It should also be mentioned that piezometric drop in this region is one of the greatest in recent times (i.e. in the period 1995 – 1999) in Calcutta. It should be noted that the pre-monsoon month April is chosen as the reference month for comparison and this is also in accordance with the recent literature on land subsidence (Agarwal [11]) which states that land subsidence “occurred in the pre-monsoon period when the water table happened to be the deepest and recharge to groundwater is least or negligible.”

4. ANALYSIS OF SUBSIDENCE IN A PART OF SOUTH CALCUTTA

4.1. SOIL CHARACTERTISTICS AND GROUNDWATER LEVELS

The site whose soil profile is described below is very close to Gariahat Crossing and lies in the region of South Calcutta mentioned above.

Table 2: Soil Profile and Laboratory Test Results

Layer (in terms of depth below Ground Level)	Description	Dry Density (γ_d) [gm/cm^3]	Sp. Gr. (G)	Water Content (w) [%]	$C_u = \frac{C_c}{e_1 + 1}$
0.0 – 2.0 m.	Yellowish grey,firm clayey silt with little fine sand	1.5	2.7	20	0.09
2.0 – 4.0 m.	Yellowish grey, loose to firm silty fine sand with clay	1.48	2.67	19	0.15
4.0 – 14.0 m.	Dark grey, soft to medium silty clay with plenty of decomposed organic matter and/or decayed wood	1.34	2.61	30	0.12
14.0 –21.0 m.	Bluish grey/ greyish yellow, stiff silty clay with calcareous nodules	1.54	2.67	24	0.07
21.0 –26.5 m.	Light yellowish grey, firm to hard clayey silt and silty clay/sandy silt with clay	1.58	2.72	20	0.06
26.5 –30.0 m.	Greyish yellow, stiff silty clay with rusty brown patches	1.49	2.69	28	0.11

The water table was at 3.85 m. below Ground Level in the year 1958 and has gone down to 15.18 m. below Ground Level in the year 1999 in this region.

4.2. CALCULATION OF INTERGRANULAR PRESSURES OF SOIL LAYERS

Table 3: Calculation of Intergranular Pressures in the years 1958 and 1999 at Gariahat area (based on data as detailed in Section 4.1)

Depth [m]	Porosity $\eta = 1 - \frac{\gamma_d}{G\gamma_w}$ [%]	Unit wt. of soil $\gamma = (1-\eta)G\gamma_w + \eta\gamma_w$ [gm/cm^3]	Total Pressure P_t [kg/cm^2]	P_h at Apr., 1958 P_{h1} [kg/cm^2]	P_{i1} $=(P_t - P_{h1})$ [kg/cm^2]	P_h at Apr., 1999 P_{h2} [kg/cm^2]	P_{i2} $=(P_t - P_{h2})$ [kg/cm^2]
2	44.44	1.7	0.34	0	0.34	0	0.34
4	44.57	1.67	0.674	0.015	0.659	0	0.674
14	48.66	1.64	2.314	1.015	1.299	0	2.314
21	42.32	1.78	3.56	1.715	1.845	0.582	2.978
26.5	41.91	1.78	4.539	2.265	2.274	1.132	3.407
30	44.61	1.77	5.1585	2.615	2.615	1.482	3.6765

4.3. CALCULATION OF SUBSIDENCE

Table 4: Calculation of Subsidence at Gariahat area with logarithmic theory (from 1958 to 1999)

Depth [m]	P_{i1} [kg/cm^2]	P_{i2} [kg/cm^2]	Average P_{i1} [kg/cm^2]	Average P_{i2} [kg/cm^2]	Z_1 [m]	C_u	$S_i = Z_i C_u \log(P_{i2}/P_{i1})$ [m]
2	0.34	0.34					
			0.4995	0.507	2	0.15	0.00194
4	0.659	0.674					
			0.979	1.494	10	0.12	0.22028
14	1.299	2.314					
			1.507	2.646	7	0.07	0.1198
21	1.845	2.978					
			1.9945	3.1925	5.5	0.06	0.06742
26.5	2.274	3.407					
			2.40875	3.54175	3.5	0.11	0.06446
30	2.615	3.6765					
						Total =	0.4739

5. CONCLUSION

The total estimated amount of subsidence in Kasba – Gariahat – Dhakuria region is 47.39 cm. from 1958 to 1999, i.e. in 41 years. Hence estimated subsidence rate in this region is 11.56 mm./year. Since this entire region is more or less uniformly subsiding, no visible ground crack or collapse of building or structure has been reported till now. However, the tilting of the front foyer of a large institutional building near Gariahat is probably an evidence of the result of such prolonged and continuous subsidence. In Kasba – Gariahat – Dhakuria region, the subsidence rate (without considering rebound or swelling which may be maximum 10%) is estimated to be 11.56 mm./year for a decline of piezometric level by 12.93 m.

6. REFERENCES

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