EJGE

Land Subsidence in Far South-Suburban Calcutta

Dr. Amartya Kumar Bhattacharya
BCE (Hons.) (Jadavpur), MTech (Civil) (IIT Kharagpur), PhD (Civil) (IIT Kharagpur), Cert.MTERM (AIT Bangkok), CEng(I), FIE, FACCE(I), FISH, FIWRS, FIPHE, FIAH, FAE, MIGS, MIGS – Kolkata Chapter, MIGS – Chennai Chapter, MISTE, MAHI, MISCA, MIAHS, MISTAM, MNSFMFP, MIIBE, MICI, MIEES, MCITP, MISRS, MISRMTT, MAGGS, MCSI, MMBSI
Chairman and Managing Director, MultiSpectra Consultants,
23, Biplabi Ambika Chakraborty Sarani,
Kolkata – 700029, West Bengal, INDIA.
e-mail: dramartyakumar@gmail.com

Sweta Kumari, Varsha Kumari, Kumar Daksh, Pankaj Kumar, Anurag
Students of Integrated MTech in Water Engineering and Management (Civil Engineering),
Central University of Jharkhand, Ranchi - 835205, Jharkhand, INDIA, and
Interns, MultiSpectra Consultants,
23, Biplabi Ambika Chakraborty Sarani,
Kolkata – 700029, West Bengal, INDIA.
e-mail: swetakumari0809@gmail.com, varsha.kumari@cuj.ac.in,
kumar.daksh@cuj.ac.in, mepankajbgp@gmail.com, kanurag611@gmail.com

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. In the present paper, subsidence is analysed for two localities in far south-suburban Calcutta. At these two localities, subsidence rates are 9.675 mm/year and 10.83 mm/year.

KEYWORDS: Land Subsidence, Soil Consolidation, Groundwater.

INTRODUCTION

Calcutta, presently re-named as Kolkata, is located in eastern India in the state of West Bengal at the lower end of the Ganga plain. The area forms a part of the lower deltaic plains of the Ganga river system.

In Calcutta, the sustainable yield is the critical factor determining groundwater extraction at present. Soil consolidation leading to land subsidence may be the factor determining the rate of groundwater extraction in the future. Since the purified surface water originating from the river Ganges which is supplied by the Calcutta Municipal Corporation is insufficient for the population, groundwater is being tapped by hand-pumps and heavy duty tube-wells. Apart from these there are many tube-wells installed by private industries, housing estates and high-rise apartment blocks. Due to over-pumping of groundwater, the water level of the aquifer underlying Calcutta is getting depressed resulting in consolidation of the subsoil causing land subsidence.

In this paper, the subsidence at two sites in far south-suburban Calcutta have been calculated based upon the available information from reliable sources.

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 is indicated by the low m_v value. Further below, the compressibility of the layers is even less because of the increasing overburden pressure and, therefore, they do not play a significant role in land subsidence.

Table 1: Stratification of Normal Calcutta Deposit (after Dastidar and Ghosh [10])

Stratum	Depth below Ground Level (in metre)	Description	Coefficient of volume Compressibility m_v (cm^2/kg)
1	0-5	Firm grey silty clay	0.014
2	5-15	Soft grey clay with wood stumps	0.04
3	15-20	Bluish grey clay with kankar	0.01
4	20-25	Laminated brown clay, silt	0.01
5	25-30	Stiff mottled grey and yellow clay with kankar	0.01
6	>30	Mottled silty clay laminated with parting of golden brown silty sand	

Variations in Piezometric Levels in some Parts of Calcutta

Sikdar et al. [12] found that during the period of 1956 – 1993, the decline of piezometric level was maximum in Gobra – Tiljala area and was of the magnitude of 8.29 m. However, during the period 1993 – 1999, it was of the order of around 1 m as per the annual reports of Central Ground Water Board. In sharp contrast to this, in Kasba –Gariahat – Dhakuria region of South Calcutta, the piezometric drop was found to be 6.82 m during the period 1958 – 1994 (Sikdar et al. [12]) whereas the piezometric level changed from 9.07 m below G.L. in April 1994 to 15.18 m. below G.L. in April, 1999, in the same region as per

C.G.W.B. reports. Hence a total drop of 12.93 m in piezometric level was observed during the period 1958 – 1999 in this region of South Calcutta. It should also be mentioned that piezometric drop in this region was one of the greatest in recent times (i.e. in the period 1995 – 1999) in Calcutta (Patra and Bhattacharya [13]). 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 [14]) 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."

As per 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

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

and according to the logarithmic theory, subsidence is given by

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

where Z1 = thickness of the soil layer prior to compression,

Pi1 = intergranular pressure when ground water table is at initial piezometric level,

Pi2 = increased intergranular pressure when water table is at final piezometric level due to drawdown,

mv = Coefficient of volume compressibility = reciprocal of the compression modulus E,

Cu = Cc/e1+1, Cc being called the compression index, slope of the essentially linear portion of e vs log Pi curve and e1 being the void ratio of the soil layer prior to compression.

VARIATIONS IN PIEZOMETRIC LEVELS IN SOME PARTS OF FAR SOUTH-SUBURBAN CALCUTTA

Site No 1: Tolly's Nullah at Garia Area.

From the piezometric level contour map of Biswas and Saha [12], initial piezometric surface (above mean sea level) in this area in 1956 was +0.00 m. Final piezometric surface in April, 2000, was -12.00 m as per SWID [13]. As per SWID [13], at Tolly's Nullah at Garia area, depth of water level below ground level was 8.64 m in April, 2000, and the water table was 1.64 m below ground level in April, 1956.

Site No 2: Sonarpur Railway Station.

As per from SWID [13], in the Sonarpur Railway Station area, depth of water level below ground level was 6.94 m April, 2000, and in April ,1956, the water table was 0.94 m below G.L.

Analysis of Subsidence in some Parts of Far South-Suburban Calcutta

Site No 1: Subsidence Analysis near Tolly's Nullah at Garia.

The site whose soil profile is described below, is near Tolly's Nullah at Garia and lies in Far South-Suburban Calcutta.

Groundwater Levels

The water table was 1.64 m below Ground Level in the year 1956 and went down to 7 m below Ground Level in April, 2000.

Table 2: Soil Profile near Tolly's Nullah at Garia and Laboratory Test Results

Layer (in terms of Depth below G.L.)	Description	Dry Density (g_d) [gm/cm^3]	Specific Gravity (G_s)	Water content (w) [%]	$C_u = \frac{C_c}{e_1+1}$
0.0-4.0m	Tan grey, loose clayey silt with fine sand	1.36	2.69	38	0.12
4.0-6.5m	Grey, medium silty clay	1.40	2.69	34	0.11
6.5-22.5m	Grey, medium clayey silt with fine sand and kankar	1.48	2.72	30	0.11
22.5-31.5m	Grey, dense sandy silt/ silty sand	1.58	2.74	24	0.04

Table 3: Calculation of Intergranular Pressures in the years 1956 and 2000 near Tolly's Nullah at Garia.

Depth	Porosity	Unit wt. of	Total	P_h	P_{i1}=(P_1-	P_h at April,	P_{i2} = (P_1-

	ɳ = 1-Y_d/GY_w [%]	soil Y =(1-ɳ)$GY_{w+}WY_w$ [gm/cm^3]	pressure P_1 [kg/cm^2]	at Apr 1956	P_{h1}) [kg/cm^2]	2000 Ph_2[kg/cm^2]	P_{h2}) [kg/cm^2]
4	49.44	1.74	0.696	0.236	0.46	0	0.696
6.5	47.96	1.74	1.131	0.486	0.824	0	1.131
22.5	45.59	1.78	3.979	2.086	1.893	1.386	2.593
31.5	42.34	1.82	5.617	2.986	2.631	2.286	3.331

Table 4: Calculation of Subsidence near Tolly's Nullah at Garia with logarithmic theory (from 1956 to 2000)

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	Subsidence $S_u=Z_1C_n\log(P_{i2}/P_{i1})$ [m]
4	0.46	0.696	0.46	0.696	4	0.12	0.08632
6.5	0.824	1.131	0.642	0.9135	2.5	0.11	0.04212
22.5	1.893	2.593	1.059	1.473	16	0.11	0.25221
31.5	2.631	3.331	1.452	1.937	9	0.04	0.04505
Total							0.4257

From 1956 to 2000, i.e., in 44 years, subsidence in this area is around 42.57 cm, and hence, subsidence rate is 0.967 cm/year or 9.675 mm/year.

Site No 2: Subsidence Analysis near Sonarpur Railway Station

Groundwater Levels

The water table was 0.94 m below Ground Level in the year 1956 and went down to 6.94 m below Ground Level in April, 2000, as per SWID [13].

Table 5: Soil Profile near Sonarpur Railway Station and Laboratory Test Results

Layer (in terms of depth G.L.)	Description	Dry Density (g_d) [gm/cm^3]	Sp. Gr. (G_s)	Water content (w) [%]	C_c
0.0-1.0 m	Filled up material comprising	1.26	2.66	31	0.11

	heterogeneous soil mixed up with brickbats kankars, etc.				
1.0-4.0 m	Brownish grey, medium silty clay,	1.28	2.61	27	0.13
4.0-7.5 m	Dark grey, medium clayey silt with semi-decomposed/decayed wood	1.17	2.58	42	0.17
7.5-13.0 m	Grey, medium sandy silt	1.41	2.64	27	0.07
13.0-22.0 m	Grey, medium to dense silty fine sand	1.49	2.71	23	0.05
22.0-30.0 m	Grey, dense silty fine sand with mica	1.58	2.74	24	0.04

Table 6: Calculation of Intergranular Pressures in the years 1956 and 2000 near Sonarpur Railway Station.

Depth [m]	Porosity $\eta=1$	Unit wt. of soil	Total pressure p_1 [kg/cm^2]	P_h at April 1958	$P_{i1}=(P_t-P_{h1})$ [kg/cm^2]	P_h at April 1999 P_{h2} [kg/cm^2]	$P_{i2}=(P_t-P_{h2})$ [kg/cm^2]
4	50.96	1.55	0.622	0.306	0.316	0	0.622
7.5	54.65	1.59	1.1785	0.656	0.5225	0.056	1.1225
13	46.59	1.68	2.1025	1.206	0.8965	0.606	1.4965
22	45.02	1.72	3.6505	2.106	1.5445	1.506	2.1445
30	42.34	1.82	5.1065	2.906	2.2005	2.306	2.8005

Table 7: Calculation of Subsidence near Sonarpur Railway Station with logarithmic theory (from 1956 to 2000)

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	Subsidence $S_u=Z_1C_n\log(P_{i2}/P_{i1})$ [m]
1	0.151	0.157	0.151	0.157	1	0.11	0.00186
4	0.316	0.622	0.2335	0.3895	3	0.13	0.0866
7.5	0.5225	1.1225	0.3298	0.6338	3.5	0.17	0.1688
13	0.8965	1.4965	0.4715	0.8495	5.5	0.07	0.0984

22	1.5445	2.1445	0.6861	1.1085	9	0.05	0.0666
30	2.2005	2.8005	0.9385	1.3905	8	0.04	0.0546
Total							0.4768

From 1956 to 2000, i.e., in 44 years, subsidence in this area is around 47.686 cm, and hence, subsidence rate is 1.083 cm/year or 10.83 mm/year.

DISCUSSION AND CONCLUSION

At these two localities in far south suburban-Calcutta, subsidence rates are 9.675 mm/year and 10.83 mm/year.

It may be mentioned that the groundwater level is still declining and hence the land subsidence is continuing even now. In general, the groundwater level below Calcutta is saucer-shaped with the lowest groundwater level below Central Calcutta and higher groundwater levels at the edges of the city. Over the years groundwater level has gone down beneath the whole of Calcutta but the decline in groundwater level has been more at the edges of Calcutta than at the centre and so the saucer-shaped groundwater level has tended to become more flat. It may also be mentioned that since the horizontal dimensions involved in the problem of land subsidence below a city is of the order of kilometres whereas the vertical dimensions involved is of the order of metres, the Winkler assumption is valid for computing soil consolidation due to groundwater depletion. It may also may noted that a generalised formula for soil consolidation due to superstructure loading and groundwater depletion has not yet been developed. Indubitably, the total soil consolidation below buildings in Calcutta is due to the combined effects of superstructure loading and groundwater depletion. It is the suggestion of the authors that, in the absence any formula for soil consolidation that takes into account both superstructure loading and groundwater depletion, the soil consolidation due to superstructure loading and the soil consolidation due to groundwater depletion be calculated separately and algebraically added linearly. This linear addition method can then be checked with field observations and suitable modifications to the linear addition method can be made if necessary.

Finally, since the horizontal dimensions are large in comparison to the vertical dimensions, no collapse of any structure of building due to groundwater depletion has been reported so far. In theory, there may be tilting of buildings resulting from differential settlement of foundations. This phenomenon, together with arc-like cracks on an upper-floor ceiling, has been observed in a multi-storeyed building in south-west Calcutta. It is worthy of mention that the building had a deep tube-well at a corner of its premises and the arc-like cracks were approximately centered no the deep tube-well. Also, tilting of the front foyer of the building of the Ramakrishna Mission Institute of Culture at Golpark is probably an evidence of the result of such prolonged and continuous subsidence. The ground floor of a sixty-five year old building in a heavily subsiding area in the southern part of Calcutta has shown cracks in wall and ceiling (Figs. 1 and 2) which is most probably are result of land subsidence due to groundwater depletion.

Figure 1:

Figure 2:

In recognition on the diverse ill effects of the declining groundwater piezometric level in the city, the Calcutta Municipal Corporation, based on the findings of a study released in June 1997, has already imposed restrictions on installing deep tubewells, particularly at high-rise residential buildings within the city.

REFERENCES

1. Terzaghi, K., Theoretical Soil Mechanics, Wiley, New York, 1943.
2. Colijn, P. J. and Potma J., Weg-en Waterbouwkunde, I, Groundmechanica, Kosmos, Amsterdam, 1944.

3. Taylor, D. W., Fundamentals of Soil Mechanics, John Wiley & Sons, Inc., New York, 1958.
4. Abbott, M. B., One-dimensional consolidation of multi-layered soils, Geotechnique, 1960, Vol. 10, pp. 151 – 165.
5. Terzaghi K. and Peck R. B., Soil Mechanics in Engineering Practice, John Wiley & Sons, Inc., New York, 1967.
6. Roberts J. E., Sand compression as a factor in oil field subsidence, Proc. Tokyo Symp. on Land Subsidence, IASH-UNESCO, 1969, pp. 368–376.
7. 7. Gambolati G. and Freeze R. A., Mathematical simulation of the subsidence of Venice. 1. Results, Water Resources Research, 1974, Vol. 10, pp. 563–577.
8. 8. Bull W. B. and Poland J. F., Land subsidence due to groundwater withdrawal in the Los Banos – Kettleman City area, California. Part 3. Interrelations of water-level change, change in aquifer-system thickness, and subsidence, U. S. Geological Survey Prof. Paper, 1975, 437 - G, 62 pp.
9. Bhattacharya A. K., Ray S., Majumdar P. K. and Sengupta P. K. "Hydrogeology of Calcutta," Proceedings, International Conference - Water and Wastewater, Perspectives of Developing countries, 11-13 December, 2002, New Delhi, pp. 567-571.
10. Patra M. N., Bhattcharya A. K. and Sikdar P.K., Land subsidence in Kolkata due to over-abstraction of groundwater, Proceedings, ACCE Annual Convention 2002 and National Seminar on Recent Challenges in Civil Engineering, 21-22 June, 2002, Hyderabad, Vol. II, pp. 33-36.
11. Dastidar A. G. and Ghosh P. K., A study of subsoil conditions of Calcutta, Journal Institute of Engineers (India), 1967, Vol. 48(3), pp. 692–714.
12. Sikdar P. K., Biswas A. B. , and Saha A.K., "A study on the possible land subsidence in Calcutta and Howrah cities due to groundwater overdraft". Indian Journal of Geology, 1996, Vol. 5, No. 3, pp.193-200.
13. Patra M. N. and Bhattcharya A. K., Unpublished studies, 2003.
14. Agarwal C. S., Geomorphological Study for Land Subsidence in a part of District Farrukhabad, Hydrology Journal, 2002, Vol. 25(1), pp. 61–68.
15. Poddar, S.K. (1994). A study on the behaviour of the groundwater table. M.E.Thesis, B.E.College (D.U.), Howrah.
16. Sikder, P.K. (1999). Development dynamics and management of groundwater in and around Kolkata, India. Indian Journal of Geology, Vol. 71, No.3.
17. http://education.vsnl.com/swid-wbidd/kolkata.html

Editor's note. This paper may be referred to, in other articles, as:
Dr. Amartya Kumar Bhattacharya, Sweta Kumari, Varsha Kumari, Kumar Daksh, Pankaj Kumar, and Anurag: "Land Subsidence in Far South-Suburban Calcutta" *Electronic Journal of Geotechnical Engineering*, 2018 (23.03), pp 347-374. Available at ejge.com.