GeoVadis: The Future of Geotechnical Engineering –
Juneja, Joseph & Dasaka (Eds)
© 2025 The Author(s), ISBN: 978-1-041-08552-2

Estimation of OCR and coefficient of consolidation for typical Kolkata deposit using DMT dissipation

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ABSTRACT: Subsurface investigations using Dilatometer Marchetti Test (DMT) were conducted in Kolkata at three locations predominantly consisting of silts. The over consolidation ratio (OCR) derived from the horizontal stress index (K_D) as per Marchetti (1980) showed unrealistically high values (OCR > 2) compared to laboratory results. To address this discrepancy, DMTA dissipation tests were performed and the OCRs before and after dissipation are evaluated. The OCR values obtained from the dissipation tests align more closely with the earlier laboratory findings. Based on the results, a correction factor incorporating the OCR estimated directly from the DMT and the results obtained post-dissipation was recommended. Additionally, in-situ DMTA dissipation versus log-time curves were analyzed to estimate the horizontal coefficient of consolidation (C_h) for the typical Kolkata silty soil deposits. It is also intended to build on previous research and provide a reference dataset and case study for futuristic work in developing seismic resistant structures.

1 INTRODUCTION

Kolkata, an important metropolitan city of the eastern part of India serves as a financial hub, attracting investments in commercial projects, high rise residential infrastructure projects, import-export activities, advanced transportation systems, cultural heritage and tourism. In order to cope with safe design, cost effective construction and resilient infrastructure in a megacity like Kolkata, which is also seismically active and extremely flood prone area, a comprehensive geotechnical characterization of the subsoil deposits is needed inevitably. The city has been subjected to huge infrastructural damages in past earthquake events such as the Great Shillong earthquake (1897) and the Bihar-Nepal earthquake (1934). Kolkata city felt strong tremors due to the recent catastrophic Myanmar earthquake on 28 March 2025, although being quite distant from the seismic source and this event serves as a constant reminder of the potential threat by future earthquakes in the region. From a geological perspective, Kolkata, placed in the Bengal Basin, consists of Quaternary fluvio-deltaic sediments comprising primarily silt, sand and clay. Urbanization and overpopulation of the city has forced the city development and planning authorities to expand its territory towards the northeastern part, especially towards areas like Salt Lake, Rajarhat and Newtown. These areas were initially developed by an extensive filling of dredged silts from the Ganges river.

DOI: 10.1201/9781003645931-42

Subsoil at depths of 12-13 m is predominantly unconsolidated, variable in soil properties, potentially liquefiable and has extremely low standard penetration test (SPT) 'N' values up to 5 along this depth. Beyond this depth, an increase in N-value of 16 on average and above is observed for the entire city. This significant difference demarcates the boundary between Holocene and age-old Pleistocene deposits (Nandy 2007). Recent studies on the liquefaction potential assessment of these Holocene deposits reveal high liquefaction susceptibility at depths ranging from 7-15 m for varying seismic conditions (Sett et al. 2024). In view of the seismic vulnerability of the city and to cater to massive urbanization and city expansion, a comprehensive seismic microzonation (SM) is urgently needed such that mitigation strategies are well planned in advance and the associated seismic risk is minimum. Ground response analysis (GRA) is a vital element of SM as it maps the subsoil seismic response and earthquake associated hazard of a study area. The highest level of SM [i.e., Level 3 according to the guidelines issued by the TC4-ISSMGE (1999)], is possible to be achieved when high quality geotechnical characterization of the study area is performed. Additionally, purposely planned geotechnical and geophysical investigations coupled with numerical ground response studies are also carried out to quantitatively define the seismic hazard and geotechnical risks. In the current study, the sophisticated Seismic Dilatometer Marchetti Test (SDMT) is used to obtain the in-situ field data like shear wave velocity (V_s), undrained cohesion (c_u), angle of internal friction (ϕ), horizontal stress index (K_D), material index (I_D), Dilatometer modulus (E_D) and vertical drained constrained modulus (M_{DMT}) of the subsoil profiles in the study area. These parameters are correlated to determine other important geotechnical parameters such as the coefficient of consolidation, permeability coefficient and overconsolidation ratio (OCR). The selected sites within the study area were strategically chosen to ensure that SDMTs were conducted adjacent to pre-existing borehole locations (Figure 1).

2 GEOTECHNICAL CHARACTERIZATION OF SUBSOIL USING DMT

Multi-field test-based geotechnical characterization has become increasingly adopted for major civil engineering constructions to establish soil stratigraphy for comprehensive analysis and engineering design. A detailed subsurface investigation, including standard penetration tests (SPTs) and 10 SDMTs are conducted in close vicinity at the study areas: Laketown, Rajarhat, and Salt Lake to determine the subsoil characteristics. The DMT tests are conducted at an interval of 0.2 m to obtain the continuous profile as the DMT probe penetrates through the soil at a standard penetration rate of 2 cm/s. Two readings, A and B, corresponding to a membrane deflection of 0.1 mm and 1.1 mm, respectively, are recorded to determine the lift-off pressure (p_o) and deflection pressure (p_1). The recorded readings are subsequently corrected for membrane stiffness to obtain the corrected p_0 and p_1 for use in determining the intermediate DMT parameters such as I_D, K_D and E_D. The typical I_D and K_D profiles of the three study areas are presented in Figure 2.

The subsoil at Rajarhat is primarily composed of fine-dominated soils with silts or sandy silts present to a depth of 6 m. The silts are underlain by thick deposits of approximately 14-15 m silty clay. Lenses of clayey silt, as indicated by I_D, are present along the profile up to a depth of 20 m. The laboratory tests indicate low to medium plasticity for the silts and silty clay. The water table is located at a shallow depth of 2 m below the ground level with prevailing hydrostatic conditions. Salt Lake is located south of Rajarhat and is typically a reclaimed land. The soil conditions at the site mainly comprise 10 m of highly decomposed organic wood, peat and mud overlain by stiff to medium stiff silty clay or clayey silt. Dense and non-plastic silty sands with lenses of clay prevail at depths greater than 17 m. The water table is located at 3.5 m below the ground level. Soft to medium stiff clayey silt/silty clay constitutes the topsoil of Laketown. The sandy silts with intermediate plasticity and consist of lenses of loose silty sands, as indicated by the subsoil profile from DMT, are present below the topsoil. The water table at the location is deep and is at a depth of 5-6 m below the existing surface. All the three sites considered in the study majorly comprise of fines dominated soils and hence DMT dissipation tests are conducted at selected depths to determine the actual/real strength and compressibility characteristics of the soil under drained conditions.

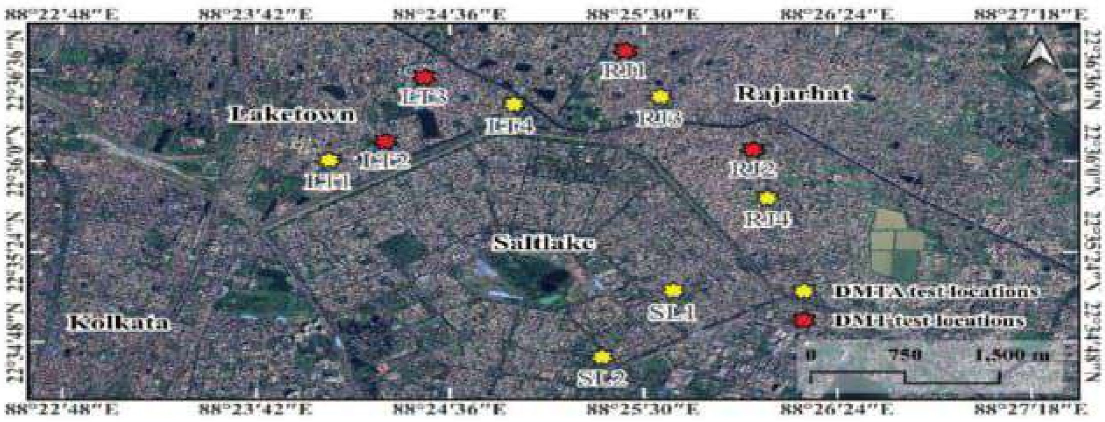

Figure 1. Locations of the study areas.

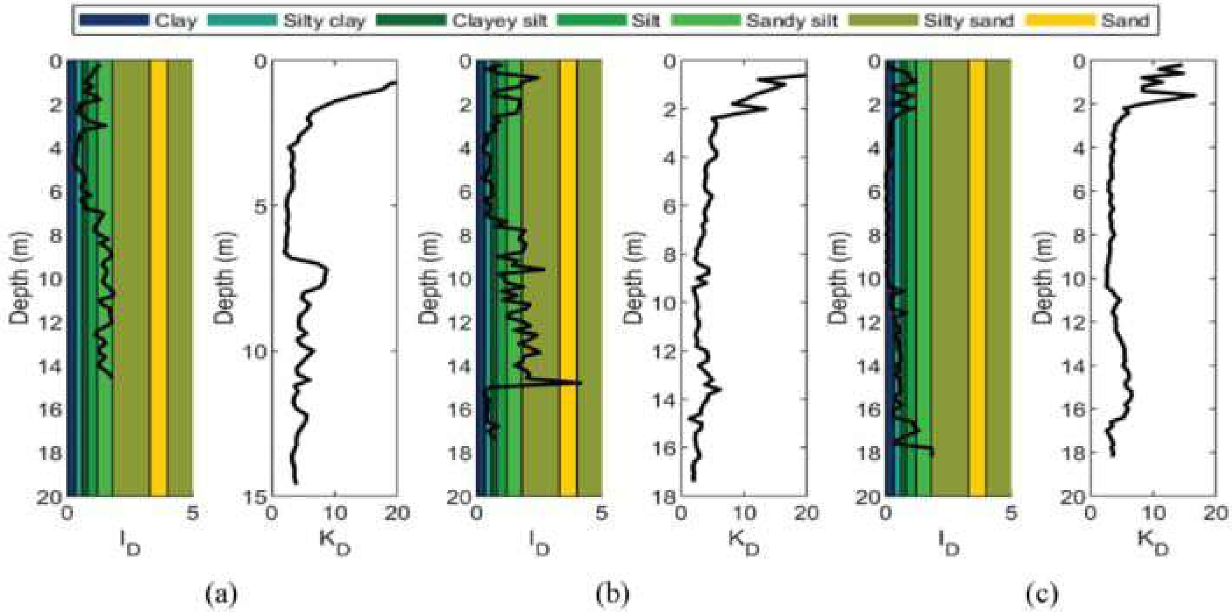

Figure 2. Representative I_D and K_D profiles of a) Laketown b) Rajarhat and c) Salt Lake.

3 DISSIPATION TESTS

The penetration of the DMT blade into the soil produces an additional porewater pressure over the existing hydrostatic pressure that alters the localized drainage conditions of the soil at the depth of testing. In freely draining soils like sands, the developed pore pressure dissipates quickly, thus creating drained conditions during the tests. While, in soils with low permeability such as clays, the pore water pressure dissipation occurs over a longer time resulting in undrained conditions. Several researchers reported that DMT is basically a drained test in sands and an undrained test in clays (Campanella & Robertson 1991; Marchetti et al., 2001). However, for intermediate soils such as silts and clayey silts, DMT correspond to partially drained conditions and requires the degree of drainage to interpret the DMT results (Schnaid et al. 2016). Further, both p_0 and p_1 are influenced by the dissipation of the porewater pressure, it is necessary to determine these parameters under known drainage conditions for accurate estimation of geotechnical properties. Hence dissipation tests are performed to obtain the DMT parameters corresponding to drained conditions in silts and clayey silts. Besides, providing the drained parameters, DMT dissipation tests are also used for estimating the horizontal coefficient of consolidation (C_h) of these soils.

3.1 *DMTA dissipation test*

Several types of DMT dissipation tests such as DMTA (Marchetti & Totani 1989), DMTC method (Robertson et al. 1988) and $DMTA_2$ method (ASTM 2001) are in practice. The current study adopts the DMTA test to evaluate the drained characteristics of intermediate soils. In DMTA, sufficient time is provided for the soil to dissipate the excess porewater pressure and the decay of the horizontal stress during the dissipation time is observed i.e., only A readings are continuously recorded without any further membrane expansion. The dissipation test is stopped until a reasonably constant value of A is achieved. The results obtained from the dissipation tests are plotted against time to obtain the decay curve. The point of contraflexure of the decay curve is assessed for determining the C_h. A total of nine dissipation tests comprising of four tests each in silts and clayey silts and one test in silty sand are performed at various depths for assessing the influence of porewater pressure dissipation on the geotechnical parameters, particularly OCR. A summary of the locations and depths of the dissipation tests conducted at the study areas are tabulated in Table 1. Figure 3 represents the typical decay curves from the dissipation tests in silty sands, silts and clayey silts.

Figure 3 indicate that the variation of p_0 with dissipation time is very less for silty sands compared to silt and clayey silt indicating the prevalence of nearly drained conditions in silty sands during the DMT test. Unlike the silt sands, silts and clayey silts are perceived to be largely influenced by dissipation of porewater as indicated by the greater variation in p_0 before and after dissipation with maximum variation observed for clayey silts.

Table 1. Details of the dissipation tests conducted at the study areas.

Study area	DMT No.	Depth (m)	Type of soil
Laketown	LT2	6.8	Clayey silt
	LT2	10.4	Silty sand
	LT3	16.6	Silt
Rajarhat	RJ3	7.4	Silt
	RJ3	17.4	Clayey silt
	RJ4	6	Silt
	RJ4	18	Clayey silt
Salt Lake	SL1	17.2	Clayey silt
	SL2	7	Silt

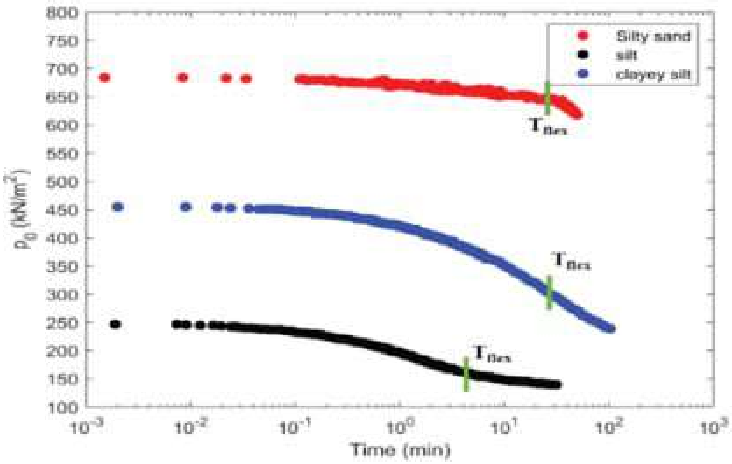

Figure 3. Typical DMT dissipation plots for silty sand, silt and clayey silt.

3.2 *Overconsolidation ratio and coefficient of compressibility from DMT*

The parameters obtained from the DMT are used for determining various index and engineering properties, particularly for fine grained soils, such as shear strength (S_u), coefficient of earth pressure at rest (K_0), overconsolidation ratio (OCR) and compressibility characteristics. K_D is highly sensitive to stress history and the variation of K_D along the depth is observed to be similar to the variation of OCR, particularly for normally consolidated clay like soils (Marchetti 1980; Jamiolkowski et al. 1988). OCR is defined as the ratio of preconsolidation pressure to the existing pressure. It significantly influences the mechanical properties of the soil such as compressibility, shear strength and permeability of soils. It helps in predicting the characterizing the soil behavior, predict the soil response and finds several applications in geotechnical practices such as foundation designs, slope stability analysis, consolidation settlement analysis, numerical modelling etc. The OCR of clay like soils from DMT is calculated from Marchetti (1980) as

$$OCR_{DMT} = (0.5K_D)^{1.56} \tag{1}$$

C_h is the rate of change in the horizontal volume of the soil per unit increase in vertical effective stress. It provides essential information relating to the lateral soil deformations that are necessary in the design of retaining walls, deep excavation systems, reinforced earth walls etc. Often laboratory tests such as consolidation tests under isotropic and anisotropic conditions are used for determining the C_h. However, C_h from DMT can be obtained by means of dissipation tests. The data recorded from the DMTA dissipation tests is used for obtaining the decay curve or the variation of lift off pressure with dissipation time. The p_o vs log t plot is fitted with a cubic polynomial to obtain the decay curve and the time corresponding to the point of contraflexure of the decay the decay curve is determined as T_{flex}. The C_h as per Marchetti (1989) is evaluated as

$$C_h\left(cm^2/s\right) = 7/T_{flex} \tag{2}$$

The OCR and C_h evaluated at respective depths for the study areas are presented in Table 2.

Table 2. OCR and C_h of silt and clayey silt from DMT

Study area	DMT No.	Depth (m)	Type of soil	OCR	C_h (cm^2/s)
Laketown	LT2	6.8	Clayey silt	1.87	0.0163
	LT3	16.6	Silt	4.18	0.0289
Rajarhat	RJ3	7.4	Silt	1.98	0.0431
	RJ3	17.4	Clayey silt	1.00	0.0221
	RJ4	6	Silt	2.18	0.0822
	RJ4	18	Clayey silt	1.00	0.0509
Salt Lake	SL1	17.2	Clayey silt	1.33	0.0203
	SL2	7	Silt	1.98	0.0670

3.3 *OCR before and after dissipation*

The OCR evaluated from K_D may not be a representative of the true OCR for intermediate soils like silts and clayey silts due to the partially drained conditions. K_D depends upon the rate of dissipation of porewater pressure and exhibit different values under drained and undrained conditions. Particularly, the use of the uncorrected OCR for ground response analysis or liquefaction assessment may result in conservative or overestimated values. Marchetti (1980) emphasizes the necessity for a site-specific calibration of the OCR values for reliable estimates. In the present study, the OCR of silts and clayey silts are evaluated based on K_D obtained before and after dissipation of the pore pressure to observe the extent of variation. The OCR after dissipation is determined from the K_D calculated from the lift-off pressure (po) corresponding to the T_{flex} from the decay curve. Based on the OCRs obtained before and after dissipation, a correction factor to obtain the representative OCR of the intermediate soils is recommended as

$$C_{ocr} = OCR_{afterdissipation}/OCR_{beforedissipation} \tag{3}$$

The correction factors for OCR of silt and clayey silt obtained from the analysis of the results before and after dissipation are presented is Table 3

4 DISCUSSION OF RESULTS

The dissipation tests in intermediate soils such as silty sands, silts and clayey silts indicated that K_D is largely influenced by the drainage conditions prevailing during the test. The excess pore

Table 3. Variation in OCR before and after dissipation and the corresponding correction factors.

Study area	DMT No.	Depth (m)	Type of soil	OCR (before dissipation)	OCR (after dissipation)	C_{ocr}
Laketown	LT2	6.8	Clayey silt	1.87	1.08	0.61
	LT3	16.6	Silt	4.18	3.43	0.82
Rajarhat	RJ3	7.4	Silt	1.98	1.22	0.62
	RJ3	17.4	Clayey silt	1.00	0.62	0.62
	RJ4	6	Silt	2.18	1.35	0.62
	RJ4	18	Clayey silt	1.00	0.45	0.45
Salt Lake	SL1	17.2	Clayey silt	1.33	0.79	0.59
	SL2	7	Silt	1.98	1.34	0.68

pressure when dissipated, produced a substantial variation in the values of p_o particularly for clayey silts and silts. The variation of K_D before and after dissipation is found to be lower for silty sands (as assessed from p_0) compared to other intermediate soils. The relatively higher permeability of silty sands enables quicker dissipation of pore pressures thereby exhibiting nearly drained conditions. However, in order to obtain true or representative parameters of silts or clayey silts, a dissipation test is warranted. The OCR determined from the DMT before and after dissipation indicated a variation of about 38-54% for clayey silts and 18-38% in silts. This indicates that the standard DMT owing to the undrained or partially drained conditions in clay like soils yields slightly higher values of OCR. Similar results were reported by Choo et al. (2016). OCR is an important parameter used in ground response analysis and liquefaction studies of clay like soils that are necessary for seismic microzonation and hazard assessment. The use of OCR predicted without dissipation tests results in conservative estimates which does not serve the purpose of reliable seismic risk assessment. Hence a correction factor incorporating the effect of dissipation of porewater pressure on OCR should be incorporated in the analysis. Based on the results obtained before and after dissipation a correction factor of 0.567 and 0.685 is applicable to typical Kolkata clayey silts and silts respectively. In the absence of dissipation tests in clay like soils, the recommended correction factors can be used for obtaining the representative values of OCR of the study areas. The OCR of clayey silts and silts obtained after the dissipation test at the study areas are in the range of 0.45-1.08 and 1.22-3.43, respectively. Further the C_h of the soils are evaluated using the dissipation tests and is found to be in range of 0.016-0.051 cm^2/s for clayey silts and 0.029 to 0.082.cm^2/s for silts.

5 CONCLUSIONS

Based on the DMTA dissipation tests conducted at the study areas, the following conclusions are drawn:

1. The lift off pressure and subsequently K_D are highly sensitive to the drainage conditions during the DMT tests particularly in intermediate soils such as silts and clayey silts.
2. The relatively higher permeability of silty sands compared to clayey silt and silt result in quicker dissipation of pore water pressure leading to drained conditions and subsequently lower variation in K_D before and after dissipation.
3. The OCR from standard DMT in silts and clayey silts is slightly higher due to undrained or partially drained conditions and warrants a dissipation test for obtaining representative OCR values of soils for use in advanced analysis such as ground response analysis or liquefaction assessment.
4. An average correction factor of 0.567 and 0.685 are recommended for use in typical Kolkata clayey silts and silts to obtain representative OCR values in the absence of dissipation tests.
5. The horizontal coefficient of consolidation of clayey silt and silt, evaluated from dissipation tests, are in the range of 0.016-0.051 cm^2/s and 0.029 to 0.082.cm^2/s, respectively.

REFERENCES

ASTM D6635-01. 2001. Standard Test Method for Performing the Flat Plate Dilatometer. Book of Standards, 04.09.

Campanella, R.G., & Robertson, P.K. 1991. Use and interpretation of a research dilatometer. *Canadian Geotechnical Journal* 28(1): 113–126.

Choo, H., Lee, W., Hong, S.J. & Lee, C. 2016. Application of the dilatometer test for estimating undrained shear strength of Busan New Port clay. *Ocean Engineering* 115: 39–47.

Jamiolkowski, M., Ghionna, V., Lancellotta, R. & Pasqualini, E. 1988. New correlations of penetration tests for design practice. *Penetration testing; Proc., intern. symp.-1, Orlando, Fla, 20-24 March 1988*, Rotterdam: Balkema.

Marchetti, S., & Totani, G. 1989. "C_h evaluations from DMTA dissipation curves". *Proc. XII ICSMFE, Rio de Janeiro*.

Marchetti, S., 1980. In situ tests by flat dilatometer. *Journal of the Geotechnical Engineering Division, ASCE* 106(3): 299–321.

Marchetti, S., Monaco, P., Totani, G., & Calabrese, M. 2001. The flat dilatometer test (DMT) in soil investigations. Report of ISSMGE Technical Committee 16 on Ground Property Characterisation from In-situ Testing. In Proceedings of International Conference on in-situ measurement of soil properties, Bali, Indonesia.

Nandy, D.R., 2007. Need for seismic microzonation of Kolkata megacity. *Workshop on Microzonation; Proc., Indian Institute of science, Bangalore, India*, 26–27 June 2007.

Robertson, P.K., Campanella, R.G., Gillespie, D. & By, T. 1988. Excess pore pressures and the flat dilatometer test. *Penetration testing; Proc., intern. symp.-1, Orlando, Fla, 20-24 March 1988*, Rotterdam: Balkema.

Schnaid, F., Odebrecht, E., Sosnoski, J. & Robertson, P.K. 2016. Effects of test procedure on flat dilatometer test (DMT) results in intermediate soils. *Canadian Geotechnical Journal* 53(8): 1270–1280.

Sett, S., Chattopadhyay, K.K., & Ghosh, A., 2024. Reliability-based seismic liquefaction hazard mapping of Kolkata Metropolitan City, India, using ordinary kriging technique. Bulletin of the Engineering Geology and the Environment. 83(4): 1–23.