Estimation of OCR and Compression Index by Different Methods

Zeeshan Firdous, V. Padmavathi, and M. R. Madhav

Abstract Preconsolidation stress ($\sigma_c^{'}$) is an important parameter to understand the stress history of the soil and in calculating settlements. Accurate determination of settlement depends largely on the accuracy of $\sigma_c^{'}$. Several researchers have proposed different methods to obtain $\sigma_c^{'}$ from e-log $\sigma^{'}$ plot. Determination of preconsolidation stress relies on the graphical approach of Casagrande method. This method depends on identification of the point of maximum curvature on the e-log $\sigma^{'}$ curve which is highly subjective and leaves room for errors. Several methods have been proposed in the literature for interpretation of preconsolidation stress based on curve fitting rather than subjective judgment. These approaches are based on graphical interpretation of void ratio (e) versus effective stress ($\sigma^{'}$), log e versus log $\sigma^{'}$, log (1 + e) versus log $\sigma^{'}$ plots. The methods used in this study are semi-logarithmic [1, 2, 3, 4], bi-logarithmic [5, 6, 7] and based on variation of constrained modulus with effective stress [8]. In this study, test data taken from the three (Egypt, California and India) different locations around the world is analysed. Compression index (C_c) and over consolidation ratio (OCR) are determined using the above methods and the variation is studied.

Keywords Preconsolidation stress · Void ratio · Effective stress · Compression index and OCR

Zeeshan Firdous (✉)
Geotechnical Engineering, Department of Civil Engineering, JNTUH College of Engineering, Hyderabad, India
e-mail: zeeshanf97@gmail.com

V. Padmavathi
Department of Civil Engineering, JNTUH College of Engineering, Hyderabad, India

M. R. Madhav
JNT University, IIT Hyderabad, Hyderabad, India

C. Atalar and F. Çinicioğlu (eds.), *5th International Conference on New Developments in Soil Mechanics and Geotechnical Engineering*, Lecture Notes in Civil Engineering 305, https://doi.org/10.1007/978-3-031-20172-1_13

1 Introduction

Oedometer test provides one-dimensional soil deformation behaviour. Soil exhibits a bilinear response, when the oedometer test data is plotted on a semi logarithmic graph. The deformations are small below certain effective stress and beyond it, the deformations are large which lead to more compressed structure of the soil. That particular effective stress is known as preconsolidation stress, $\sigma_c^{'}$ and is required to estimate the consolidation settlement of soft soils. The ratio between $\sigma_c^{'}$ and in-situ vertical effective stress, $\sigma_0^{'}$, is known as Over Consolidation Ratio (OCR). The concept of preconsolidation stress and its importance is well defined in geotechnical engineering. Hence, different methods have been proposed by researchers to estimate preconsolidation stress from Oedometer test results. Methods proposed by Casagrande [1], Pacheco Silva [3], [5], Schmertmann [4], Nagaraj et al. [2], Oikawa [6], Sridharan [7] and Janbu [8] are analysed in this paper by considering the data from three (Egypt, California and India) sites available in the literature. These methods have a common assumption that the soil response varies from stiffer to softer at $\sigma_c^{'}$. The present work also compares the variation of OCR and C_c based on the above mentioned methods.

2 Interpretation of $\sigma_c^{'}$

Casagrande [1] estimated preconsolidation stress from the e-log $\sigma^{'}$ curve. This method interprets a large range of estimated preconsolidation stress, if the point of maximum curvature is not well defined. As illustrated in Fig. 1a, a point B on the curve is selected at maximum curvature. Horizontal and tangential lines are drawn passing through point B. A bisector is drawn at the same point, bisecting the angle between horizontal and tangential lines. Virgin compression line is extended backward and the intersection point of this line with the bisector is located at point D. The stress corresponding to point D is preconsolidation stress, $\sigma_c^{'}$. . According to Silva [3] method, a horizontal line AB, is drawn passing through initial void ratio, e_0, of the specimen on the e-log $\sigma^{'}$ plot as illustrated in Fig. 1b. A line, CD is drawn from the straight line portion of the virgin compression curve until it intersects the line AB at point C. A vertical line is dropped down from the point C, until it intersects the e-log $\sigma^{'}$ curve at point E. Another line is extended in horizontal direction from the point E, to line CD to get an intercept, F. The stress corresponding to the point F, is preconsolidation stress. Figure 1c describes Nagaraj et al. [2] method, $\sigma_c^{'}$ is obtained from the point of intersection of a horizontal line from e_0, and a line normal to the laboratory e-log $\sigma^{'}$ curve at the point of maximum curvature. A horizontal line passing through $0.4e_0$ intersects the virgin compression curve at point C. Compression index is obtained from the line joining point D and point C. Schmertmann [4] has proposed a method to correct the compression curve from soil samples subjected to disturbance. The method is detailed in Fig. 1d. Point C is marked at the intersection of virgin compression curve with a horizontal line drawn from void ratio of $0.4e_0$. The backward extension of the linear portion of the curve ABC meets the horizontal line DE at point F. A smooth curve EG is drawn from point E, parallel to the recompression curve. The stress corresponding to point G is preconsolidation stress $\sigma_c^{'}$.

Oikawa [6] method (Fig. 1e) summarises that, a compression curve is drawn for $\sigma^{'}$ on logarithmic scale and log(1 + e) on linear scale along X and Y axes respectively. The linear parts of compression curve are extended to get an intersection point A as shown in Fig. 1. The stress corresponding to the point A is $\sigma_c^{'}$. The same procedure [6] is followed by Butterfield [5], Fig. 1f, to find $\sigma_c^{'}$, with ln $\sigma^{'}$ and ln(1 + e) along X and Y axes respectively. Sridharan [7], illustrated the interpretation of $\sigma_c^{'}$ from the intersection of linear fit lines of 'e -$\sigma^{'}$ 'curve plotted on logarithmic (base 10) scales as illustrated in Fig. 1g. Janbu [8] proposed that the preconsolidation stress is determined from a plot of constrained modulus, M, which is inverse of coefficient of volume compressibility, versus the effective stress on a linear scale as shown in Fig. 1h, The stress corresponding to a marked drop of M, is the preconsolidation stress, $\sigma_c^{'}$.

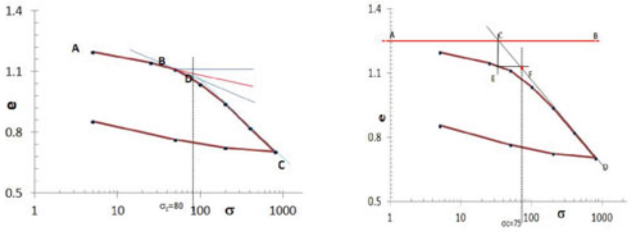
3 Results and Interpretation

The preconsolidation stress, OCR and Compression index are estimated using the methods specified in Sect. 2 for the e-log $\sigma^{'}$ curves taken from three sites located in Egypt [], California [9] and India [10]. The e-log $\sigma^{'}$ data was obtained from samples collected from Egypt site at depths of 15 m, 23 m and 30 m in a borehole, also at 8 m and 10 m depths from different bole holes. Profile of California site marks the presence of soft soil deposits with ground water table at ground level. Top layer of soil consists of highly plastic (CH) and low plastic (CL) clays of varying compressibility. e-log $\sigma^{'}$ plots are given for samples at various depths taken from boreholes at several locations.

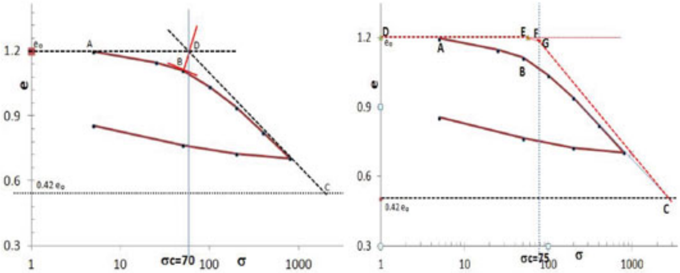
3.1 Comparison of OCR Obtained from Different Methods

Overconsolidation ratio is estimated using the preconsolidation stress obtained from the different methods proposed by Casagrande [1], Silva [3], Nagaraj et al. [5, 2], Oikawa [6], Sridharan [7], Schmertmann [4] and Janbu [8] and presented in Table 1.

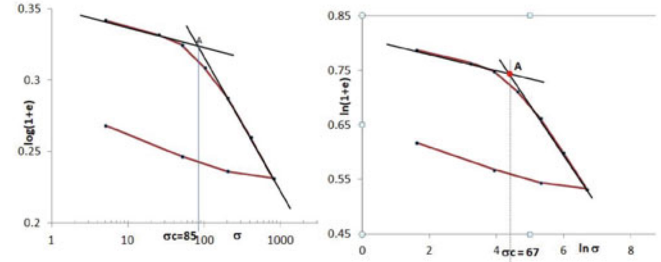
Results from Silva [3] method show small variation from those of Casagrande [1] method. This is because Silva [3] method is independent of the drawing scale while Casagrande [1] method is scale dependent. Nagaraj et al. [2] and Schmertmann [4] methods predict true in situ OCR by making corrections to sample disturbance. OCR obtained from Janbu [8] method are lower than the values from Casagrande [1] method for all the three sites. Janbu [8] method results in the highest deviations



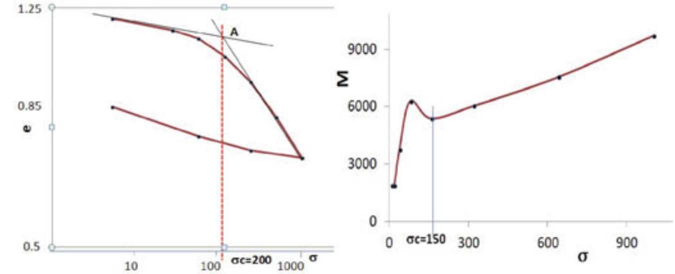
a) e-logσ' plot (Casagrande - 1936) **b)** e-logσ' plot (Silva - 1970)



c) e-logσ' plot (Nagaraj et al. - 1989) **d)** e-logσ' plot (Schmertmann - 1955)



e) log(1+e)-log σ' plot (Oikawa – 1987) **f)** ln(1+e)- ln σ' plot (Butterfield - 1979)



g) log e – log σ' plot (Sridharan et al. - 1991) **h)** M – σ' plot (Janbu - 1969)

Fig. 1 Different methods for interpretation of σ_c'

Table 1 OCR obtained from different methods

Site	Casagrande [11]	Silva [3	Nagaraj et al. [12]	Butterfield [1]	Oikawa [6]	Sridharan [7]	Schmertmann, [4]	Janbu [8]
Egypt	1.40	1.10	1.60	1.25	1.40	1.90	1.20	0.90
	0.75	0.43	1.25	0.76	0.75	1.06	1.00	1.00
	0.95	1.00	1.10	1.17	0.81	0.95	1.00	1.00
	3.57	3.07	3.54	2.59	2.71	2.86	3.93	2.14
	1.80	1.55	1.30	1.30	1.25	1.50	1.30	0.90
California	17.39	14.78	16.52	14.78	14.78	14.35	13.04	13.91
	1.96	1.43	1.70	2.63	2.38	2.14	1.31	1.90
	21.43	18.57	17.14	21.36	18.57	19.29	29.29	5.71
	3.70	2.59	4.07	5.19	4.63	5.56	2.22	1.48
	2.77	2.13	2.04	3.94	3.83	4.00	1.38	1.06
	2.26	1.66	1.72	2.20	2.60	3.10	1.56	3.20
	15.26	13.84	8.68	13.95	14.47	14.47	21.05	8.42
	33.33	33.33	18.33	31.11	33.33	33.33	44.44	35.56
India	9.34	9.87	7.42	7.89	7.89	8.16	9.47	2.89
	1.40	1.23	1.05	1.18	1.30	1.58	1.32	1.40
	2.08	1.89	1.60	1.89	1.79	1.75	1.70	1.42
	2.34	2.20	1.70	2.34	2.10	2.30	2.30	1.00
	1.01	1.04	0.83	1.03	1.01	1.04	1.00	1.04
	3.60	3.60	2.80	3.00	3.00	3.00	4.40	5.20
	1.15	1.27	1.09	1.07	1.00	1.13	1.13	1.00
	2.34	2.66	1.70	2.34	2.13	2.34	4.36	1.60
	1.10	1.34	1.00	1.32	1.22	1.46	1.95	1.10

as it does not clearly specify the steps to follow for graphical interpretation. Hence, it depends on the user's experience and judgement. The values show more variation for high $\sigma_c^{'}$ and higher OCR. This might be due to higher recompression up to the point at which it reaches $\sigma_c^{'}$. Virgin compression occurs beyond $\sigma_c^{'}$. This unloading–reloading process might cause more disturbances and hence the deviation is observed. Butterfield [5], Oikawa [6] and Sridharan [7] methods give comparable values of OCR.

Table 2 illustrates the variation in OCR obtained from Silva [3], Nagaraj et al. [2], Butterfield [5], Oikawa [6], Sridharan [7], Schmertmann [4] and Janbu [8] methods with those from Casagrande [1] method.

The range of variation of OCR presented in table 2 is from −30% to 20%, −40% to 20%, −30% to 40%, −28% to 42%, −31% to 38%, −20% to 33% and −50% to 44% for the results obtained from Silva [3], Nagaraj et al. [2], Schmertmann [4], Butterfield [5], Oikawa [6], Sridharan [7] and Janbu [8] methods respectively. Minimum range of deviation is noticed from Silva [3] and Sridharan [7] methods.

Table 2 Variation of OCR from Casagrande [11] method

Methods	Average variation of OCR from Casagrande [11] method (%)	Range of variation of OCR from Casagrande [11] method (%)
Silva [3]	−8	−30 to 20
Nagaraj et al. [12]	−15	−40 to 20
Schmertmann [4]	4	−30 to 40
Butterfield [1]	2	−28 to 42
Oikawa [6]	−2	−31 to 38
Sridharan [7]	10	−20 to 33
Janbu [8]	−23	−50 to 44

Butterfield [5], Oikawa [6] and Sridharan [7] methods yield similar range of results. Hence, their application would be more conservative in estimation of $\sigma_c^{'}$. Janbu [8] method shows a greater deviation of OCR from −50% to 44%.

3.2 Comparison of C_c Obtained from Different Methods

Compression index, C_c, is estimated from the Eq. 1 by Casagrande [1], Silva [3], Nagaraj et al. [2] and Schmertmann [3] methods.

$$C_C = \frac{\Delta e}{\Delta \log \sigma'} \quad (1)$$

Compression index, C_c, from Butterfield [5] and Oikawa [6] methods is estimated from the relationship between C_c and C_c' given by Eq. (2). Sridharan [7] established a relationship between C_c and C_c'' as shown in Eq. (3).

$$C_c = \frac{C_c^{'} - 0.0192}{0.19} \quad (2)$$

$$C_c = \frac{C_c^{''} - 0.1067}{0.23} \quad (3)$$

where C_c'—slope of log(1 + e) vs log $\sigma^{'}$ plot (Fig. 1) or slope of ln(1 + e) vs ln $\sigma^{'}$ plot (Fig. 1).

C_c"—slope of log e vs log $\sigma^{'}$ plot (Fig. 1)

C_c—Compression index.

The compression index values thus estimated are presented in Table 3.

Casagrande [1] and Silva [3] methods predict identical estimates of Compression index. Results from Nagaraj et al. [2] and Schmertmann [4] methods show greater deviation from those of Casagrande [1] method. This is because these two methods

Table 3 Compression index obtained from different methods

Site	Casagrande [11]	Silva [3]	Nagaraj et al. [12]	Schmertmann [4]	Butterfield [1]	Oikawa [6]	Sridharan [7]
Egypt	0.55	0.52	0.68	0.66	0.55	0.54	0.69
	0.49	0.47	0.63	0.66	0.48	0.49	0.73
	0.57	0.60	0.68	0.67	0.59	0.61	0.16
	0.31	0.30	0.41	0.38	0.30	0.32	0.20
	0.42	0.45	0.67	0.50	0.39	0.41	0.35
California	0.30	0.31	0.38	0.30	0.28	0.30	0.31
	0.20	0.21	0.27	0.24	0.23	0.22	0.15
	0.48	0.47	0.53	0.49	0.54	0.45	0.48
	0.31	0.32	0.41	0.35	0.36	0.33	0.41
	0.18	0.20	0.24	0.22	0.23	0.22	0.24
	0.17	0.17	0.20	0.19	0.18	0.17	0.29
	0.16	0.16	0.18	0.26	0.16	0.15	0.09
	0.25	0.24	0.25	0.31	0.25	0.26	0.19
India	0.30	0.33	0.35	0.39	0.28	0.30	0.30
	0.38	0.38	0.41	0.45	0.33	0.37	0.41
	0.22	0.20	0.22	0.23	0.22	0.18	0.13
	0.42	0.43	0.44	0.46	0.48	0.47	0.74
	0.33	0.32	0.32	0.31	0.30	0.34	0.34
	0.36	0.37	0.38	0.40	0.36	0.37	0.38
	0.29	0.31	0.36	0.35	0.30	0.30	0.33
	0.27	0.29	0.32	0.43	0.24	0.23	0.14
	0.38	0.41	0.31	0.49	0.28	0.30	0.28

make corrections to sample disturbance. Butterfield [5] and Oikawa [6] methods predict similar values of compression index as both the methods study bilogarithmic variation between specific volume and effective stress.

Table 4 illustrates the variation in C_c obtained from Silva [3], Butterfield [5], Schmertmann [4], Nagaraj et al. [2], Oikawa [6], Sridharan [7] and Janbu [8] methods with those from Casagrande method.

From table 4, the range of variation of C_c from Silva [3], Nagaraj et al. [2], Schmertmann [4], Butterfield [5], Oikawa [6] and Sridharan [7] is from −10% to 9%, −18% to 33%, −7% to 62%, −27% to 54%, −21% to 10% and −49% to 50% respectively. The minimum range of deviation is observed for Silva [3] and Oikawa methods. The maximum range of deviation is for Sridharan [7] and Schmertmann [4] method.

Table 4 Variation of C_c from Casagrande method

Methods	Average variation of C_c from Casagrande [11] method (%)	Range of variation of C_c from Casagrande [11] method (%)
Silva [3]	2	−10 to 9
Nagaraj et al. [12]	18	−18 to 33
Schmertmann [4]	20	−7 to 62
Butterfield [1]	3	−27 to 54
Oikawa [6]	3	−21 to 10
Sridharan [7]	1	−49 to 50

4 Conclusions

Preconsolidation stress, $\sigma_c^{'}$, is estimated from eight methods mentioned in the literature. The OCR and C_c estimated from different methods are compared with the values obtained from Casagrande [1] method. Results from Casagrande [1] method varied with those from Silva [3] method on the basis of drawing scale, otherwise both the methods predict similar results. The results from Schermtmann [4] and Nagaraj [2] method can be utilised in obtaining true in situ behaviour of soil. Among all the methods considered, Butterfield [5], Oikawa [6] and Sridharan [7] methods provided the most comparable estimates. Values from Janbu [8] method show greater deviation.

References

1. Casagrande A (1936) The determination of the preconsolidation load and its practical significance. Proc First Int Conf Soil Mech Found Eng 3:60–64
2. Nagaraj TS, Murthy BRS, Vatsala A, Joshi RC (1990) Analysis of compressibility of sensitive soils. J Geotechn Eng 116(01):105–118
3. Silva PF (1970) A new graphical construction for determination of the pre-consolidation stress of a soil sample. Proceedings of the 4th Brazilian Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, Brazil, 225–232
4. Schmertmann JNM (1955) The undisturbed consolidation behavior of clay. From Research to Practice in Geotechnical Engineering, Transactions of the American Society of Civil Engineers, American Society of Civil Engineers (ASCE), 1201–1233
5. Butterfield R (1979) A natural compression law for soils (an advance on e-log p'). Geotechnique 24(04):469–479
6. Oikawa H (1987) Compression curve of soft soils. Soils Found 27(3):99–104
7. Sridharan JBT (1991) Improved technique for estimation of preconsolidation pressure. Geotechnique 41(2):263–268
8. Janbu N (1969) Settlement calculations based on the tangent modulus concept. Soil Mechanics and Foundation Engineering, The Technical University of Norway, Trondheim 32
9. Robb ESM, Judd K, Gregg LF (2016) Teaching consolidation: case study of preloading with vertical drains. Int J Geoeng Case Histories 4:222–233
10. Madhav MR (2022) Personal contacts

11. Donatas U, Ieva L, Domas G (2016) Over consolidation ratio determination of cohesive soil. historical experience and challenges of geotechnical problems in Baltic sea region. Proceedings of 13th baltic sea geotechnical conference, lithuanian geotechnical society, Lithuania, pp 22–24, September 2016
12. Santagata MC, Germaine JT (2002) Sampling disturbance effects in normally consolidated clays. J Geotechn Geoenviron Eng 128(12):997–1006
13. Kirstein A, Liu J (2017) Evaluation of different methods for identification of Preconsolidation pressure for Champlain sea clay using CRS tests. Geo Ottawa conference paper, October 2017
14. Yang X, Jia Y, Liu H, Shan H (2009) Characteristics and causes of the Preconsolidation stress of soils in the yellow river delta. J Ocean Univ China 08(3):215–221