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A Study on Effect of Sample Disturbance in Estimating Settlement of Foundations

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Abstract. Geotechnical properties of soil estimated from laboratory tests are generally affected by sample disturbance. It is difficult to deal with sample disturbance during the laboratory testing of soft soil. Estimation of preconsolidation stress from laboratory tests is highly affected by sample disturbance. The concept of preconsolidation stress is useful in analyzing and predicting settlement behavior of soft soils. Hence accurate determination of preconsolidation stress is important for settlement analysis.

Estimation of preconsolidation stress depends on graphical methods. Many graphical approaches are available in the literature for estimation of preconsolidation stress from the laboratory consolidation tests. In this study, the consolidation test data is taken from (Egypt, California, Vietnam and India) different locations around the world. The effect of sample disturbance on the compression curve for estimation of preconsolidation stress and settlement of soft soils is presented. The approaches used for determining the preconsolidation stress from the consolidation tests are based on graphical interpretation procedures of void ratio (e) versus effective stress (σ') data. The methods used in this study are semi-logarithmic (Casagrande-1936 and Schmertmann-1955). The true in situ settlements from the true in situ compression curves are estimated and compared with the settlements obtained from the laboratory curves.

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Keywords: Void Ratio, Effective Stress, Preconsolidation Stress, Compression Index, Settlement.

1 Introduction

Oedometer test provides one-dimensional soil deformation behavior. 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 high which leads to more compressed structure of the soil. That particular effective stress is known as preconsolidation stress, σ'_c. Compression index (C_c), Recompression index (C_r) and the over consolidation ratio (OCR), can be obtained from the soil deformation behavior. These are important factors to estimate the consolidation settlement of soft soils.

Sample disturbance is the most difficult issue that influences the engineering properties of the soil. It is related to the changes in the stress, water content and structure that a soil undergoes during sampling. In soft clays, the sample quality effects the preconsolidation pressure calculated from the lab tests and can lead to misinterpretation. Hence, it is important to treat the engineering properties obtained from a lab test to obtain the true in situ characteristics of the soil. Sample disturbance influences the shape of the compression curve, compressibility parameters and the preconsolidation pressure. It causes a significant reduction in the preconsolidation pressure obtained from one-dimensional deformation. Ladd and Lambe (1963) shown through their research that disturbance can lead to a decrease in the preconsolidation stress by as much as 80% of the true in situ preconsolidation stress. The effect of sample disturbance on soft clays is presented in the Fig.1. Increasing sample disturbance results in more rounded compression curve which shows an increase in the slope of recompression curve (C_r) and a decrease in the slope of virgin compression line.

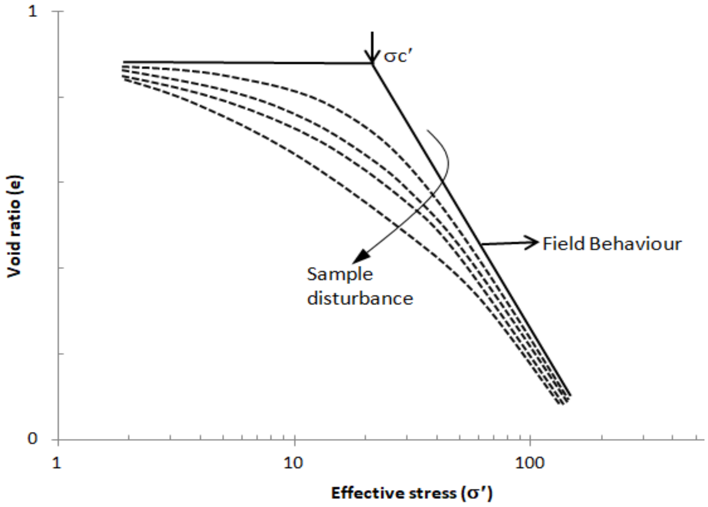

Fig. 1. Void ratio vs log Effective stress

2 Estimation of preconsolidation stress (σ_c')

Preconsolidation stress, σ_c', is an important parameter in estimating the consolidation settlement of soft soils. Casagrande's method (1936) is the oldest and the most commonly used technique to estimate the preconsolidation pressure. This method estimates the preconsolidation stress from the e-logσ' curve. This method interprets a large range of estimated preconsolidation stress, if the point of maximum curvature is not well defined. As presented in the Fig.2, a point B on the curve is selected at maximum curvature. A horizontal and a tangential line are drawn passing through the point B. A bisector is drawn at the same point, bisecting the angle between horizontal and tangential lines. Virgin compression line is extended backward to intersect the bisector at point D. The stress corresponding to point D is preconsolidation stress, σ_c'.

Schmertmann (1955) has proposed a method to correct the compression curve from soil samples subjected to disturbance. The method is detailed in Fig.3. 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 the preconsolidation stress $\sigma_c^{'}$.

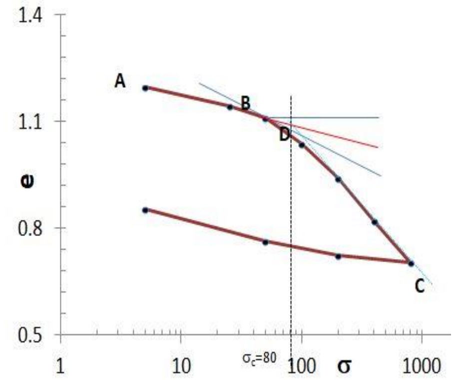

Fig. 2. e-log$\sigma^{'}$ plot (Casagrande - 1936)

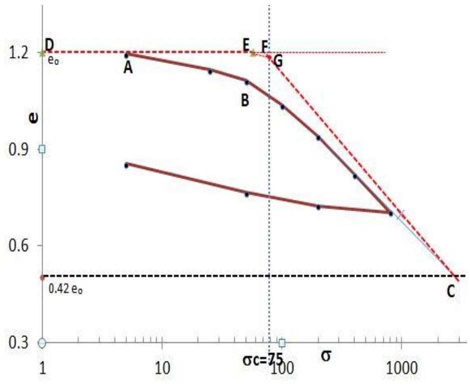

Fig. 3. e-log$\sigma^{'}$ plot (Schmertmann - 1955)

3 Estimation of settlements

The consolidation settlement of Normally Consolidated (NC) soil with a layer of thickness H and an initial void ratio e_0 is given by

$$S = \frac{C_c * H}{1+e_0} * \log\left[\frac{\sigma_0' + \Delta\sigma'}{\sigma_c'}\right] \quad (1)$$

where S is the total settlement, C_c is the compression index corresponding to the slope of the virgin compression line on the e-logσ' plot, $\Delta\sigma'$ is the increase in stress and σ_0' is the in situ vertical effective stress.

For Over Consolidated soils (OC), the equation can have two forms:

When the maximum effective stress is less than the preconsolidation pressure of the soil, $\sigma_0' + \Delta\sigma' < \sigma_c'$, the settlement is due to the recompression. The equation is given by

$$S = \frac{C_r * H}{1+e_0} \log\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right) \quad (2)$$

where C_r is the recompression index corresponding to the slope of the recompression curve on e-logσ'plot

When $\sigma_0' + \Delta\sigma' > \sigma_c'$, the settlement is due to both compression and recompression. Hence, the equation is given by

$$S = \frac{C_r * H}{1+e_0} * \log\left[\frac{\sigma_c'}{\sigma_0'}\right] + \frac{C_c * H}{1+e_0} * \log\left[\frac{\sigma_0' + \Delta\sigma'}{\sigma_c'}\right] \quad (3)$$

4 Comparison of consolidation parameters from laboratory curve and field compression curve

The e-log$\sigma^{'}$ curves are taken from different sites in India (Bombay, Kerala, West Bengal), Egypt, California and Vietnam. Fig.4 illustrates the laboratory compression curve, Casagrande's reconstructed curve and Schmertmann's true in situ curve. The consolidation parameters obtained from the laboratory tests are compared with the parameters obtained from true in situ curve.

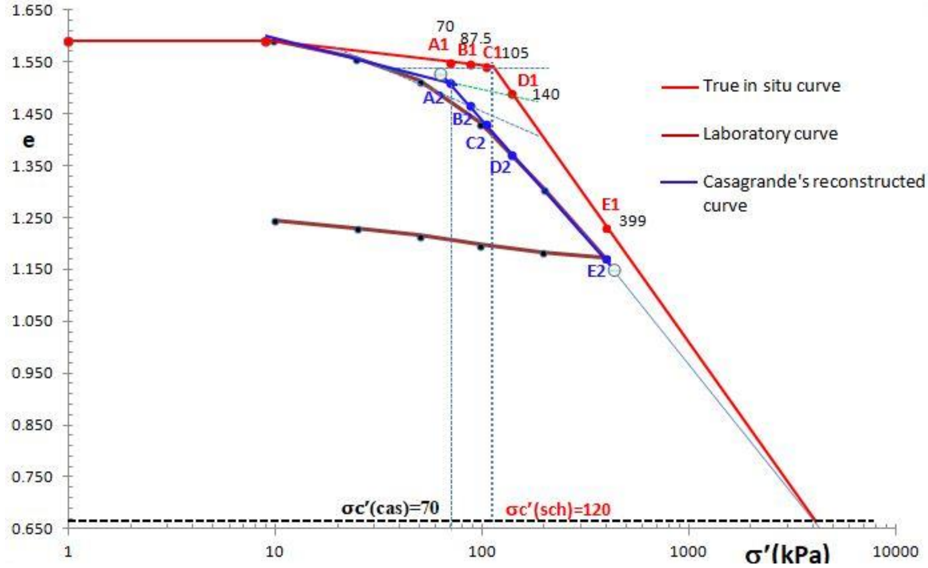

Fig. 4. Casagrande's reconstructed curve and Schmertmann's true in situ compression curve

Table 1. Consolidation parameters from laboratory curve and true in situ compression curve.

Sample No.	Consolidation parameters	Laboratory curve	Casagrande's reconstructed curve (1936)	True in situ curve (Schmertmann 1955)
1	σ'_c	145	145	160
	C_r	0.329	0.201	0.093
	C_c	0.487	0.487	0.664
2	σ'_c	215	215	265
	C_r	0.336	0.189	0.123
	C_c	0.635	0.635	0.819
3	σ'_c	225	225	290
	C_r	0.114	0.102	0.039
	C_c	0.293	0.293	0.328
4	σ'_c	400	400	525
	C_r	0.112	0.097	0.065
	C_c	0.306	0.306	0.342
5	σ'_c	385	385	400
	C_r	0.083	0.06	0.015
	C_c	0.188	0.188	0.210
6	σ'_c	450	450	470
	C_r	0.093	0.08	0.022

	C_c	0.2445	0.2445	0.298
7	σ'_c	95	95	100
	C_r	0.099	0.094	0.03
	C_c	0.191	0.191	0.216
8	σ'_c	70	70	80
	C_r	0.103	0.055	0.034
	C_c	0.179	0.179	0.203
9	σ'_c	55	55	60
	C_r	0.185	0.169	0.077
	C_c	0.379	0.379	0.438
10	σ'_c	65	65	80
	C_r	0.361	0.238	0.146
	C_c	0.952	0.952	1.162
11	σ'_c	80	80	100
	C_r	0.2057	0.143	0.092
	C_c	0.402	0.402	0.465
12	σ'_c	56	56	80
	C_r	0.085	0.126	0.082
	C_c	0.389	0.389	0.47
13	σ'_c	85	85	100
	C_r	0.445	0.332	0.186
	C_c	1.105	1.105	1.316
14	σ'_c	70	70	120
	C_r	0.166	0.138	0.049
	C_c	0.45	0.45	0.60
15	σ'_c	105	105	120
	C_r	0.183	0.133	0.049
	C_c	0.498	0.498	0.598
16	σ'_c	120	120	140
	C_r	0.216	0.249	0.066
	C_c	0.678	0.678	0.78
17	σ'_c	58	58	67
	C_r	0.246	0.246	0.059
	C_c	0.647	0.647	0.795
18	σ'_c	82	82	90
	C_r	0.199	0.321	0.049
	C_c	0.385	0.385	0.88
19	σ'_c	80	80	90
	C_r	0.256	0.266	0.113
	C_c	0.528	0.528	0.732

From table 1, it can be observed that the preconsolidation pressure, σ_c', from the true in situ compression is greater than the σ_c' value obtained from laboratory curve. It can be inferred that sample disturbance decreases the σ_c' value. The recompression index C_r obtained from true in situ curve is less than the C_r obtained from laboratory curve. The Compression index C_c from true in situ compression curve is greater than the value obtained from laboratory curve. This implies that the sample disturbance causes an increase in the recompression index C_r and decrease in the Compression index, C_c.

5 Comparison of settlements from laboratory curve and true in situ settlements

The data is analyzed to estimate the settlement of an earth embankment resting on the soft clay layer of 5 m thickness and a fill material of 1 m thickness. The soft clay is considered to have an average saturated unit weight of 18kN/m^3 with the groundwater table at the surface. The settlements estimated using the parameters obtained from the laboratory curve are compared with those obtained from Casagrande's reconstructed curve and the newly constructed true in situ curve. The settlements are estimated for final stresses corresponding to $\sigma'_{c(\text{Cas})}$, $1.25\sigma'_{c(\text{Cas})}$, $1.5\sigma'_{c(\text{Cas})}$, and $2\sigma'_{c(\text{Cas})}$ which are represented in the Fig.4 by the points A1&A2, B1&B2, C1&C2, D1&D2 and E1&E2 on the true in situ curve and laboratory curve respectively.

Table 2. Settlements estimated from laboratory curve and true in situ compression curves

Settlement(mm)					Settlement ratios	
Sample No.	Final stress (kPa)	Laboratory compression curve	Casagrande's reconstructed curve	True in situ compression curve	$\frac{S_{sch}}{S_{cas}}$	$\frac{S_{sch}}{S_{cas-r}}$
1	$\sigma'_{c(\text{Cas})}$=145	580	354	164	0.28	0.46
	$1.25\sigma'_{c(\text{Cas})}$=181.25	692	466	258	0.37	0.56
	$1.5\sigma'_{c(\text{Cas})}$=217.5	783	557	383	0.49	0.69
	$2\sigma'_{c(\text{Cas})}$=290	927	701	579	0.62	0.83
2	$\sigma'_{c(\text{Cas})}$=215	765	429	280	0.37	0.65
	$1.25\sigma'_{c(\text{Cas})}$=268.75	917	581	320	0.35	0.55
	$1.5\sigma'_{c(\text{Cas})}$=322.5	1042	706	481	0.46	0.68
	$2\sigma'_{c(\text{Cas})}$=430	1238	903	735	0.59	0.81
3	$\sigma'_{c(\text{Cas})}$=225	339	303	117	0.34	0.39
	$1.25\sigma'_{c(\text{Cas})}$=281.25	429	393	129	0.30	0.33
	$1.5\sigma'_{c(\text{Cas})}$=337.5	503	467	199	0.40	0.43
	$2\sigma'_{c(\text{Cas})}$=450	619	583	329	0.53	0.57
4	$\sigma'_{c(\text{Cas})}$=400	416	360	241	0.58	0.67
	$1.25\sigma'_{c(\text{Cas})}$=500	509	452	261	0.51	0.58
	$1.5\sigma'_{c(\text{Cas})}$=600	584	528	327	0.56	0.62
	$2\sigma'_{c(\text{Cas})}$=800	704	648	460	0.65	0.71
5	$\sigma'_{c(\text{Cas})}$=385	353	258	63.5	0.18	0.25
	$1.25\sigma'_{c(\text{Cas})}$=481.25	419	324	125	0.3	0.39
	$1.5\sigma'_{c(\text{Cas})}$=577.5	473	378	185	0.39	0.49

	$2\sigma'_{c(\mathrm{Cas})}$=770	558	463	281	0.50	0.61
6	$\sigma'_{c(\mathrm{Cas})}$=450	373	321	89	0.24	0.28
	$1.25\sigma'_{c(\mathrm{Cas})}$=562.5	450	397	165	0.37	0.42
	$1.5\sigma'_{c(\mathrm{Cas})}$=675	512	460	241	0.47	0.52
	$2\sigma'_{c(\mathrm{Cas})}$=900	611	559	361	0.59	0.65
7	$\sigma'_{c(\mathrm{Cas})}$=95	140	133	45	0.32	0.33
	$1.25\sigma'_{c(\mathrm{Cas})}$=118.75	187	180	52	0.28	0.29
	$1.5\sigma'_{c(\mathrm{Cas})}$=142.5	225	218	130	0.58	0.60
	$2\sigma'_{c(\mathrm{Cas})}$=190	286	279	198	0.69	0.71
8	$\sigma'_{c(\mathrm{Cas})}$=70	133	71	44	0.33	0.61
	$1.25\sigma'_{c(\mathrm{Cas})}$=87.5	186	123	73	0.40	0.60
	$1.5\sigma'_{c(\mathrm{Cas})}$=105	228	166	122	0.53	0.73
	$2\sigma'_{c(\mathrm{Cas})}$=140	295	233	198	0.67	0.85
9	$\sigma'_{c(\mathrm{Cas})}$=55	168	154	70	0.42	0.46
	$1.25\sigma'_{c(\mathrm{Cas})}$=68.75	270	256	150	0.56	0.59
	$1.5\sigma'_{c(\mathrm{Cas})}$=82.5	354	340	247	0.70	0.73
	$2\sigma'_{c(\mathrm{Cas})}$=110	486	472	399	0.82	0.85
10	$\sigma'_{c(\mathrm{Cas})}$=65	365	242	148	0.41	0.61
	$1.25\sigma'_{c(\mathrm{Cas})}$=81.25	600	476	202	0.34	0.42
	$1.5\sigma'_{c(\mathrm{Cas})}$=97.5	791	668	435	0.55	0.65
	$2\sigma'_{c(\mathrm{Cas})}$=130	1094	970	805	0.74	0.83
11	$\sigma'_{c(\mathrm{Cas})}$=80	274	190	122	0.45	0.64
	$1.25\sigma'_{c(\mathrm{Cas})}$=100	380	297	146	0.38	0.49
	$1.5\sigma'_{c(\mathrm{Cas})}$=120	467	384	246	0.53	0.64
	$2\sigma'_{c(\mathrm{Cas})}$=160	604	521	405	0.67	0.78
12	$\sigma'_{c(\mathrm{Cas})}$=56	71	105	68	0.97	0.65
	$1.25\sigma'_{c(\mathrm{Cas})}$=70	165	199	89	0.54	0.44
	$1.5\sigma'_{c(\mathrm{Cas})}$=84	243	276	125	0.52	0.45
	$2\sigma'_{c(\mathrm{Cas})}$=112	364	398	272	0.75	0.68
13	$\sigma'_{c(\mathrm{Cas})}$=85	474	353	198	0.42	0.56
	$1.25\sigma'_{c(\mathrm{Cas})}$=106.25	696	575	297	0.43	0.52
	$1.5\sigma'_{c(\mathrm{Cas})}$=127.5	877	756	513	0.58	0.68
	$2\sigma'_{c(\mathrm{Cas})}$=170	1163	1042	853	0.73	0.82
14	$\sigma'_{c(\mathrm{Cas})}$=70	165	138	49	0.30	0.35
	$1.25\sigma'_{c(\mathrm{Cas})}$=87.5	266	238	60	0.23	0.25
	$1.5\sigma'_{c(\mathrm{Cas})}$=105	347	320	69	0.20	0.22
	$2\sigma'_{c(\mathrm{Cas})}$=140	476	449	169	0.35	0.38
15	$\sigma'_{c(\mathrm{Cas})}$=105	253	184	69	0.27	0.37
	$1.25\sigma'_{c(\mathrm{Cas})}$=131.25	363	294	128	0.35	0.44
	$1.5\sigma'_{c(\mathrm{Cas})}$=157.5	453	384	237	0.52	0.62
	$2\sigma'_{c(\mathrm{Cas})}$=210	595	526	407	0.68	0.77
16	$\sigma'_{c(\mathrm{Cas})}$=120	319	368	98	0.31	0.27
	$1.25\sigma'_{c(\mathrm{Cas})}$=150	465	514	160	0.34	0.31
	$1.5\sigma'_{c(\mathrm{Cas})}$=180	584	633	297	0.51	0.47
	$2\sigma'_{c(\mathrm{Cas})}$=240	772	822	514	0.66	0.63

17	$\sigma'_{c(\mathrm{Cas})}$=58	161	161	39	0.24	0.24
	1.25$\sigma'_{c(\mathrm{Cas})}$=72.5	279	279	97	0.35	0.35
	1.5$\sigma'_{c(\mathrm{Cas})}$=87	375	375	215	0.57	0.57
	2$\sigma'_{c(\mathrm{Cas})}$=116	527	527	401	0.76	0.76
18	$\sigma'_{c(\mathrm{Cas})}$=82	208	336	52	0.25	0.16
	1.25$\sigma'_{c(\mathrm{Cas})}$=102.5	287	414	161	0.56	0.39
	1.5$\sigma'_{c(\mathrm{Cas})}$=123	351	478	307	0.87	0.64
	2$\sigma'_{c(\mathrm{Cas})}$=164	452	579	538	1.19	0.93
19	$\sigma'_{c(\mathrm{Cas})}$=80	266	277	118	0.44	0.43
	1.25$\sigma'_{c(\mathrm{Cas})}$=100	376	386	202	0.54	0.52
	1.5$\sigma'_{c(\mathrm{Cas})}$=120	465	475	326	0.70	0.69
	2$\sigma'_{c(\mathrm{Cas})}$=160	606	616	522	0.86	0.85

From table 2, it can be observed that the true in situ settlements are significantly less than the settlement values obtained from the laboratory compression curve. The settlements obtained from laboratory compression curve are over estimated due to sample disturbance. It can be observed that when the sample is subjected to higher stress, the settlement ratio approximates to 1 which implies that at higher stress, the settlement obtained from laboratory compression curve is equal to the settlements estimated from true in situ curve. The effect of sample disturbance decreases, when the sample is subjected to higher stresses.

6 Results and discussion

This study has provided an insight on the effect of sample disturbance on the preconsolidation pressure and the shape of the compression curve. The recompression index C_r obtained from true in situ curve is less than the C_r obtained from laboratory curve. The Compression index C_c from true in situ compression curve is greater than the value obtained from laboratory curve. This implies that the sample disturbance causes an increase in the recompression index C_r and decrease in the Compression index C_c. The true in situ recompression and compression indices give better understanding of the changes in the compression curve and the preconsolidation pressure. The important conclusion from this is that due to sample disturbance, the settlements obtained from laboratory compression curve are over estimated. This proves that the disturbance has a significant effect on the reliability of the laboratory test data. Hence the engineering properties from laboratory test data should be modified to derive the true in situ characteristics of the soil.

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