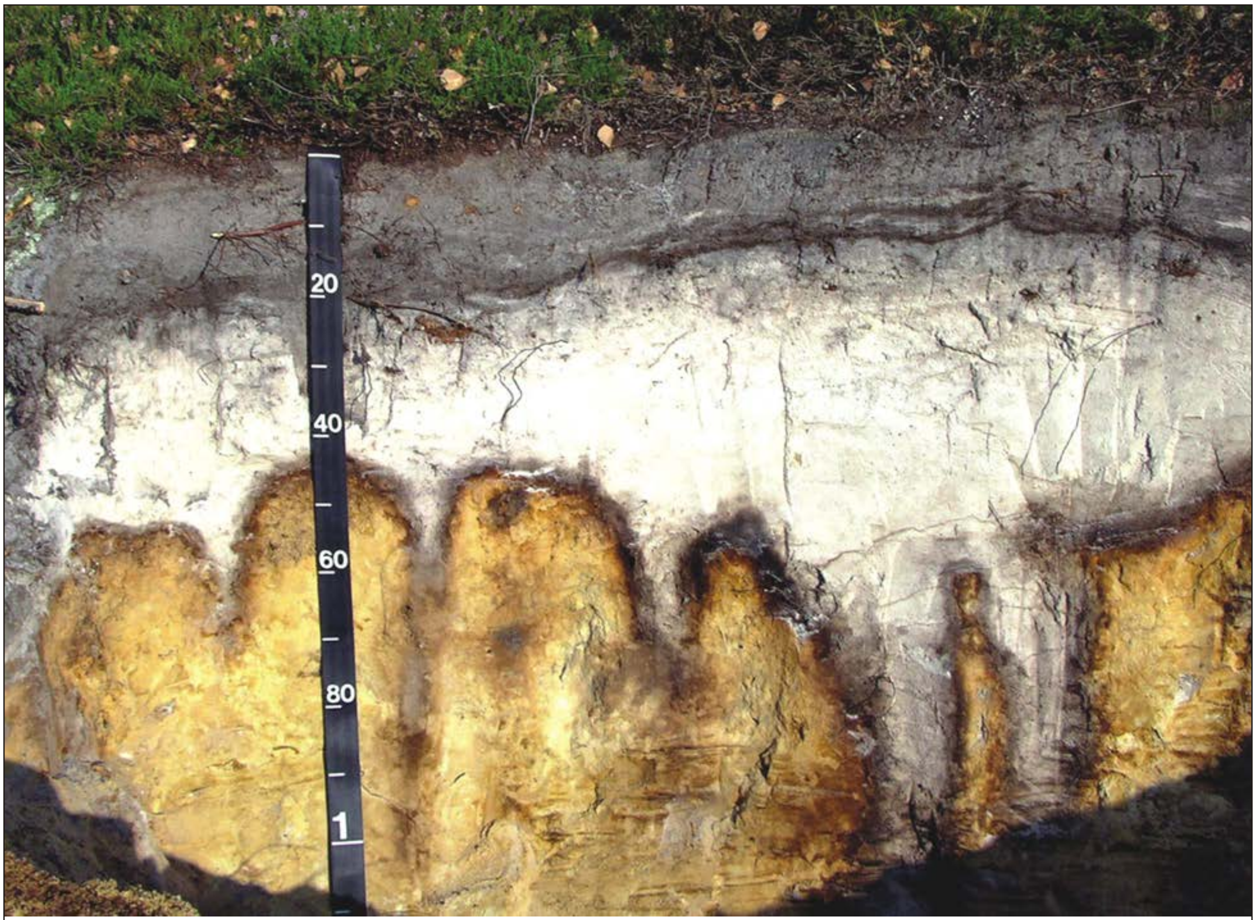

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Influence of Compaction Curve Modeling on Void Ratio and Pre-Consolidation Stress*

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Abstract: The objective of this study is to investigate the influence of different consolidation curve models on the initial void ratio values and through which on the obtained pre-consolidation stress. Further, this study verifies the dependence of pre-consolidation stress on the initial void ratio value measured at 1 kPa. This was done in order to check the trend between the consolidation curve models and the deviation in pre-consolidation stresses. Three different Oedometer tests have been carried out which were denoted as undisturbed, disturbed and disturbed-rewetted. The curves were fitted using two different curve models (Assouline and Van Genuchten models) and the graphical calculation of the pre-consolidation stress was done using two different methods (Casagrande and Silva methods). The curve models are applied on the compaction data obtained from the soil classified as loamy sand. A good consolidation curve fit to the data (R^2 ranging between 0.97 and 0.99) has been verified for a wide range of applied stresses (0 to 2500 kPa), including stresses less than the pre-consolidation stress. Huge differences in the initial void ratio values (Δe ranging between 0.003 and 0.423) have been observed with different curve models and with which a huge difference in pre-consolidation stresses (ΔP ranging between 0 and 57 kPa) have been observed. This study clearly showed that the pre-consolidation value obtained was mainly dependent on the curve fitting model and also on the calculating method. This study also showed a dependence of pre-consolidation stress over the void ratio measured at 1 kPa.

Key words: Void ratio, curve modeling, pre-consolidation stress

INTRODUCTION

The problem with the curve fitting models is that the curve models assume sigmoidal shape (classical S-curve). This assumption leads into erroneous predictions of pre-consolidation stresses. The pre-consolidation stress can also be erroneous due to its dependence on the calculating methods. This work gives an idea on the dependence of pre-consolidation stress by comparing two different curve fitting models and also two different calculating methods.

Curve fitting is one of the most important steps in determining the pre-consolidation stress value. The basic mathematical description of soil compaction is the relationship between the stress and void ratio or bulk density and is drawn on a semi-logarithmic graph. In which the effective stress is drawn on the logarithmic scale. In this logarithmic model it is not possible to define the void ratio or bulk density values at zero stress.

To overcome this problem Bailey *et al*. (1986) have developed a three parameter equation (Eq. 1), which is in disagreement with the experimental observations. Assouline *et al*. (1997) have modified Eq. 1 and 2 with only two parameters. Further Fritton (2001) have given a new equation with three parameters Eq. 3, in which he has shown that the bulk density is a function of applied stress plus one but in the terms of physics, bulk density is only expressed as a function of applied stress. Assouline (2002) has modified his old equation from 1997 and gave a new equation with three parameters Eq. 4.

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$$\text{In}(\rho) = \text{In}(\rho_o) - (a + b\sigma)(1\text{-exp}^{-c\sigma}) \tag{1}$$

$$\rho(\sigma) = \rho_o + (\rho_m\text{-}\rho_o)(1\text{-exp}^{-c\sigma}) \tag{2}$$

where, ρ_o is soil bulk density at zero stress and a, b and c are empirical parameters:

$$\rho = \rho_m - (\rho_m - \rho_o)\{1 + [\alpha(\sigma + 1)]^n\}^{-m} \tag{3}$$

where, ρ_m is soil particle density and α, n and m are empirical fitting parameters:

$$\rho = \rho_o + (\rho_{max} - \rho_o)[1 - \exp^{-(k\sigma)\omega}];\ \omega > 0 \tag{4}$$

where, ρ_{max} and k are fitting parameters and ω as the third parameter

Baumgartl and Köck (2004) have shown that it is possible to use a mathematical formulation of the model of water retention curves to describe the volume change in soil. The water retention curves are commonly modeled using the Van Genuchten (1980) (Eq. 5).

Baumgartl and Köck (2004) have modified the Van Genuchten (1980) equation by replacing moisture ratios by void ratios as given in Eq. 6. Equation 5 is modified into equation Eq. 6 by interchanging the symbols θ_r (residual water content) with the minimum void ratio value (e_{min}) and θ_s (saturated water content) with the maximum void ratio value (e_{max}). All the equations from Eq. 1 till Eq. 4 and 6 are derived based on the assumption that the curves have sigmoidal shape (classical S-curve):

$$\theta = \theta_r + (\theta_s - \theta_r)/[1+ (\alpha h)^n\,]^m;\ m = 1 - 1/n \tag{5}$$

where, θ_r is the residual water content and θ_s is the saturated water content, h is the suction pressure, α and n are empirical parameters.

$$e = e_{min} + (e_{max} - e_{min}) / [1+ (\alpha\sigma)^n\,]^m;\ m = 1 - 1/n \tag{6}$$

where, e_{max} is the void ratio at zero stress, e_{min} is the minimum void ratio and σ is the applied stress, α and n are empirical fitting parameters.

In all cases e_{min} was fitted, while e_{max} was both set to the effective void ratio, which represents the status of the sample after induced collapse and relief of the strain (constraint) and best fitted, respectively (free fit).

All these different models suggested by Fritton (2001), Assouline (2002), modified Van Genuchten (1980) are derived and based on the assumption that the stress curve has an asymptotic shape (classical S-shape). When the curves are fitted freely and also with the constraint of the initial void ratio values (i.e., by fixing the initial void ration value), the curves show a variation in their behaviour and do not show similarities, with which the values of pre-consolidation stress varies (Cavalieri *et al*., 2008).

The objective of this study is to show the dependence of pre-consolidation stress on the curve fitting models and on the calculating methods. The dependence of pre-consolidation stress was evaluated with two different curve fitting models with and without constraint. Further the dependence with respect to the calculating methods was evaluated.

MATERIALS AND METHODS

The study was carried out from Oct 2006 to May 2007. As a metastable test soil, Saalian glacial till was used, which covers the spoil heaps from reclamation purposes in the Lusatian lignite-mining district in the Eastern Germany, 120 km South-East of Berlin. The glacial till was chosen as metastable test soil due to its re-compaction behavior under both field and laboratory conditions. The test material was collected from the Northern most opencast lignite mining pit Jänschwalde (51°49' N, 14°34' E) from depths of 4 and 8 m, respectively. The depths 4 and 8 m were chosen based on the carbonate content of the profile. The carbonate content was measured using Scheibler-Dietrich apparatus which was 0.1 and 5.3%, respectively from the 4 and 8 m depths. According to the USDA soil texture classification, the test soil represents high compacted sandy loam with 69.7% sand, 25.8% silt and 4.5% clay.

The stress-strain behaviour of undisturbed soil samples reflect the undisturbed conditions in field, where as the stress-strain behaviour measured under air dried (disturbed) soil samples reflect the situation during summer when the glacial till dries during transport on the conveyor belt before deposition. With the specific saturation (rewetted) of dry pre-loaded soil samples, the effect of saturation and re-compaction (0, 5, 10 and 20 kPa) by rain was simulated at both the depths. Undisturbed samples were collected from the field in the Oedometer rings directly and were transported to the laboratory for carrying out the consolidation experiments. For the disturbed and disturbed-rewetted experiments substrate was collected from the field and the samples for the different investigations were prepared in the laboratory. On the basis of the stress-strain behaviour experiments and against the background of the soil properties, the goal of this work was to model the effective stress in the rewetted soil i.e., the pre-consolidation stress obtained after curve fitting should be equal to the pre-loads. It should be shown that the stress corresponds with the load of the overlying soil column.

Pre-consolidation stresses were determined using the graphical illustrations plotted with effective stress on x-axis and void ratio on y-axis. The effective stress values were the stress values applied on the sample in Oedometer (0 to 2500 kPa). Void ratio (e) values were derived from bulk density (r_{soil}) and particle density ($r_{particle}$) using Equation 7 (Mcbride and Joosse, 1996). The measured particle density of 2.65 Mg m^{-3} is used in the calculation:

$$(e) = (r_{particle} / r_{soil}) - 1 \tag{7}$$

Curve Fitting

The curve fitting was carried out using the standard models Assouline (2002) and Modified Van Genuchten (1980) with the help of a software Sigmaplot. The consolidation curves were fitted freely first (free fit) i.e., the curves were fitted for the best fit, in which there were no limiting constraints, i.e., the curves were freely fitted. In the second step the consolidation curves were fitted by fixing the initial void ratio to the measured value (constraint), i.e., the curves were fitted with a constraint (initial void ratio value), in which the value of the initial void ratio was substituted directly in the equation. The consolidation curves were also fitted by considering the initial void ratio measured with 1 kPa (denoted as with 1 kPa) and also by not considering the initial void ratio at 1 kPa (denoted as Without 1 kPa). This variation of considering and not considering the initial void ratio at 1 kPa was chosen as there wasn't any difference in between the void ratio values measured between 1 and 10 kPa. Eventhough there was no difference in the measured stress values between 1 and 10 kPa, the consolidation curve models have showed a huge deviation when the stress value measured at 1 kPa was taken into consideration compared to the curve model when the value at 1 kPa was not considered.
The second objective of this work was to verify the dependence of pre-consolidation stress on the initial void ratio value measured at 1 kPa. This was done in order to check the trend between the consolidation curves, whether there is any change or shift in the point of maximum curvature and the values of the pre-consolidation stresses.

Pre-Consolidation Stress

At stresses smaller than the pre-consolidation stress the soil is essentially elasto-plastic and not purely elastic i.e., the stress values below the pre-consolidation load are not completely elastic and recoverable, as often assumed theoretically. This can be explained as the only one time elastic rebound after the relief of the strain at the point where the pre-consolidation stress is calculated. In the range of pure elastic, recoverable volume change is very small and it cannot be completely recovered. The second objective in curve fitting clearly demonstrates this elasto-plastic behaviour as the stress values considered were below the pre-consolidation stress. This behaviour also shows a deviation in the pre-consolidation stress values obtained. Pre-consolidation stresses were obtained graphically using Casagrande (1936) method and Silva (1970) method.

Casagrande (1936) Method

A graphical procedure developed by Casagrande (1936) was regarded as a standard method. Casagrande (1936) has developed this method empirically from a large number of tests on different types of soil and has used it to derive the pre-consolidation stress with a satisfactory degree of accuracy.

Figure 1 demonstrates the Casagrande's procedure using data from a uniaxial compression test: One first determines the position of the Virgin Compression Line (VCL) with a sufficient number of points. Then on the preceding branch the point T which corresponds to the smallest radius of curvature has been found and draws through this point a tangent (Tt) to the curve and a horizontal line (Th). The angle between these two lines is then bisected (Tb) and the point of intersection of this bisecting line with the virgin line has been determined, which approximately corresponds to the pre-consolidation stress (P) of the soil in the ground. RCL is the regression compression line which is drawn parallel to the x-axis from the initial void ratio value (e_o) measured. Casagrande (1936) determined the point corresponding to the smallest radius of curvature visually. The visual determination is very subjective and scale-dependent.

Silva (1970) Method

Another method was proposed by Silva (1970) to determine pre-consolidation stress (P), which is widely used in Brazil. Similar to Casagrande's (1936) method, Silva's method uses an empirical

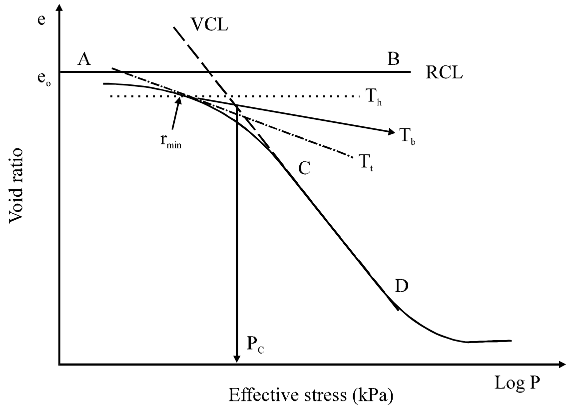

Fig. 1: Graphical method (Casagrande, 1936) for determination of the pre-compression stress. The intersection of the virgin compression line and the bisecting line b corresponds to the pre-compression stress (P)

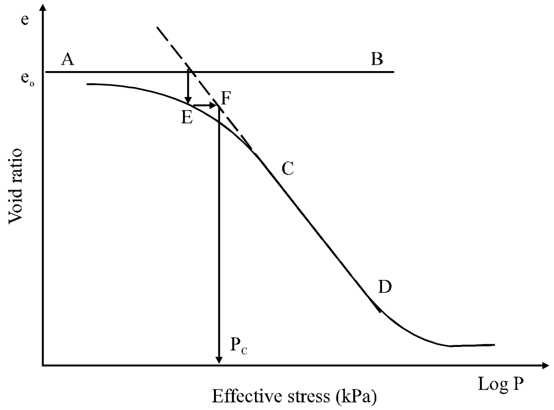

Fig. 2: Determination of pre-consolidation stress value using the Silva (1970) construction

construction from the e - log P curve, where e is the void ratio and P is the vertical effective stress. The pre-consolidation stress is determined graphically from the oedometer test data as shown in Fig. 2. First the horizontal line (AB) is drawn, which represents the initial void ratio (e_0) value. The virgin compression line (CD) has been drawn which is represented by dashed line and is extended till it meets the AB line.

From the point at which the virgin compression line meets the maximum void ratio line, a line is drawn in vertically downward direction till it meets the curve, which is represented by E. From point E a horizontal line is drawn which extends up to the virgin compression line (F). The effective stress value at the point F is the pre-consolidation stress (P).

The Casagrande (1936) method is highly subjective as it varies from person to person in finding out the point of maximum curvature. This problem is solved by the Silva (1970) method. The pre-consolidation stress value obtained using Silva (1970) method is not subjected to interpretation. Therefore, the value obtained will be same always and is not prone to errors. Silva (1970) method is independent of the drawing scale, whereas the Casagrande (1936) method is scale dependent.

RESULTS

Curve Fitting with the Changes Observed in Initial Void Ratio

The stress-strain curves were fitted for the best fit (free fit) and were also fitted by fixing (constraint) the initial void ratio value measured at 1 kPa (Fig. 3, 4). The fitting of curves were differentiated by considering and also by not considering the maximum void ratio value at 1 kPa. The curve fitting regression constant R^2 was 0.99 when the curves were fitted freely without the void ratio value at 1 kPa and the R^2 value was ranging in between 0.97 and 0.99 for the curves fitted with constraint using Assouline (2002) model (Fig. 3). The R^2 value was 0.99 for all the curves fitted with modified Van Genuchten (1980) model (Fig. 4).

The R^2 value obtained was ranging in between 0.97 and 0.99 indicating a very good consolidation curve fit with Assouline (2002) and Van Genuchten (1980) models (Fig. 3, 4). The curve fitting regression constant value was obtained directly when the curves were modeled in Sigmaplot software using different curve models.

The differences in initial void ratio values (Δe) were calculated by measuring the difference between the curves fitted freely and the curves fitted with constraint. The Δe values were ranging in between 0.0067 to 0.423 with Assouline (2002) model (Table 1) and 0.0002 to 0.077 with Van Genuchten (1980) model (Table 2). A huge difference in initial void ratio values was observed between

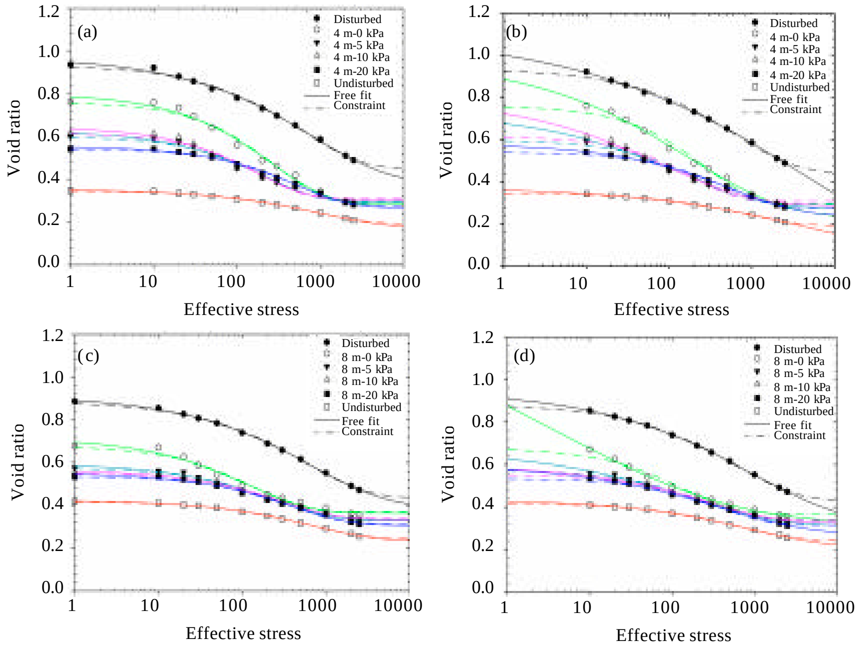

Fig. 3: Stress-strain curves drawn using Assouline (2002) model for the samples collected from 4 m and 8 m depths. The curves were fitted freely (free fit) and were also fitted by fixing the initial void ratio (constraint-dashed line), (a) 4 m depth samples with 1 kPa (assouline), (b) 4 m depth samples without 1 kPa (assouline), (c) 8 m depth samples with 1 kPa (assouline) and (d) 8 m depth samples without 1 kPa (assouline)

Table 1: Differences in Initial void ratio value (Δe) after modeling the data using Assouline curve model with and without constraint

	With 1 kPa					Without 1 kPa				
Tests	Free Fit	R^2	Constraint	R^2	Δe	Free Fit	R^2	Constraint	R^2	Δe
4 m depth										
Disturbed	0.9730	0.997	0.9366	0.994	0.0364	1.1138	0.999	0.9366	0.993	0.1772
4 m-0 kPa	0.8011	0.991	0.7614	0.986	0.0396	0.9850	0.997	0.7614	0.984	0.2236
4 m-5 kPa	0.6245	0.989	0.5995	0.986	0.0250	0.7295	0.995	0.5995	0.983	0.1300
4 m-10 kPa	0.6437	0.985	0.6143	0.979	0.0294	0.8012	0.993	0.6143	0.975	0.1869
4 m-20 kPa	0.5566	0.997	0.5433	0.995	0.0133	0.5848	0.999	0.5433	0.994	0.0415
Undisturbed	0.3548	0.998	0.3478	0.997	0.0070	0.3750	0.999	0.3478	0.997	0.0272
8 m depth										
Disturbed	0.9126	0.999	0.8865	0.998	0.0261	0.9525	0.999	0.8865	0.998	0.0660
8 m-0 kPa	0.7151	0.985	0.6777	0.979	0.0374	1.1007	0.998	0.6777	0.973	0.4230
8 m-5 kPa	0.5962	0.993	0.5776	0.989	0.0186	0.6667	0.996	0.5776	0.988	0.0891
8 m-10 kPa	0.5669	0.996	0.5549	0.995	0.0120	0.5948	0.998	0.5549	0.994	0.0399
8 m-20 kPa	0.5520	0.994	0.5365	0.991	0.0155	0.6049	0.998	0.5365	0.989	0.0684
Undisturbed	0.4255	0.998	0.4188	0.997	0.0067	0.4365	0.999	0.4188	0.997	0.0177

the curves fitted freely and the curves fitted with constraint and the difference increased when the void ratio value at 1 kPa was not considered. The difference in the initial void ratio values were higher with Assouline (2002) model compared to Van Genuchten (1980) model. The curves fitted freely resulted in higher initial void ratio values at 1 kPa where as the void ratio value at the final applied stress was lesser. The difference in the void ratio values observed decreased with increasing pre-loads.

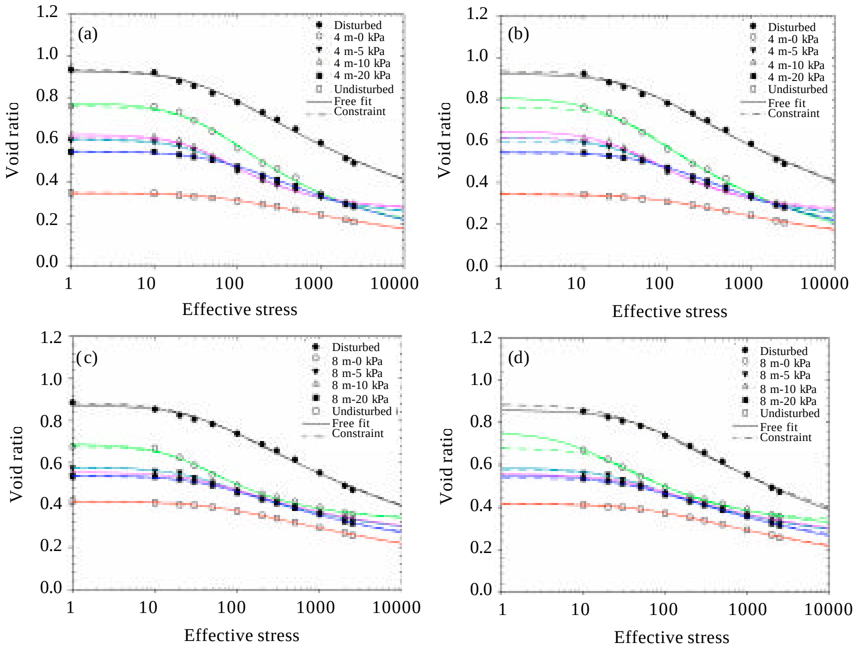

Fig. 4: Stress-strain curves drawn using modified Van Genuchten (1980) model for the samples collected from 4 m and 8 m depths. The curves were fitted freely (free fit) and were also fitted by fixing the initial void ratio (constraint-dashed line), (a) 4 m depth samples with 1 kPa (Van Genunchten), (b) 4 m depth samples without 1 kPa (Van Genunchten), (c) 8 m depth samples with 1 kPa (Van Genunchten) and (d) 8 m depth samples without 1 kPa (Van Genunchten)

Table 2: Differences in Initial void ratio value (Δe) after modeling the data using Van Genuchten curve model with and without constraint

	With 1 kPa					Without 1 kPa				
Tests	Free Fit	R^2	Constraint	R^2	Δe	Free Fit	R^2	Constraint	R^2	Δe
4 m depth										
Disturbed	0.9312	0.994	0.9366	0.994	0.00	0.9217	0.993	0.9366	0.993	0.00
4 m-0 kPa	0.7764	0.996	0.7614	0.996	0.015	0.8077	0.998	0.7614	0.995	0.0463
4 m-5 kPa	0.6058	0.997	0.5995	0.997	0.0063	0.6183	0.998	0.5995	0.997	0.0188
4 m-10 kPa	0.6251	0.996	0.6143	0.994	0.0108	0.6465	0.997	0.6143	0.993	0.0322
4 m-20 kPa	0.5466	0.999	0.5433	0.999	0.0033	0.5487	0.999	0.5433	0.998	0.0054
Undisturbed	0.3452	0.996	0.3478	0.995	0.00	0.3431	0.996	0.3478	0.995	0.00
8 m depth										
Disturbed	0.8748	0.996	0.8865	0.995	0.00	0.8589	0.998	0.8865	0.994	0.00
8 m-0 kPa	0.6882	0.996	0.6777	0.995	0.0005	0.7543	0.999	0.6777	0.993	0.0766
8 m-5 kPa	0.5805	0.998	0.5776	0.998	0.0029	0.5861	0.998	0.5776	0.997	0.0085
8 m-10 kPa	0.5554	0.999	0.5549	0.999	0.0015	0.5551	0.999	0.5549	0.999	0.0002
8 m-20 kPa	0.5420	0.998	0.5365	0.998	0.0055	0.5516	0.999	0.5365	0.997	0.0151
Undisturbed	0.4162	0.998	0.4188	0.998	0.00	0.4138	0.998	0.4188	0.997	0.00

Changes in Pre-Consolidation Stress

The pre-consolidation stress was calculated using Silva (1970) and Casagrande (1936) methods after the curves were fitted with Assouline (2002) model and modified Van Genuchten (1980) model (Table 3, 4). The curves with different fits resulted in different pre-consolidation stress values. Differences in the pre-consolidation stress values were due to the shift in RCL and VCL lines.

Table 3: Differences in pre-consolidation stress (ΔP) using Casagrande (1936) method with 1kPa and without 1 kPa

	Casagrande (1936) method											
	Assouline model						Van Genuchten model					
	With 1 kPa			Without 1 kPa			With 1 kPa			Without 1 kPa		
Samples	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP
4 m depth												
Disturbed	66	80	14	50	101	51	36	33	0*	47	36	0*
4 m-0 kPa	40	70	30	11	56	45	24	30	6	18	31	13
4 m-5 kPa	34	50	16	10	48	38	26	28	2	20	29	9
4 m-10 kPa	29	46	17	7	46	39	23	26	3	16	30	14
4 m-20 kPa	80	100	20	58	95	37	58	61	2	52	59	7
Undisturbed	101	103	2	32	78	46	69	61	0*	85	60	0*
8 m depth												
Disturbed	56	69	13	48	76	28	36	35	0*	50	28	0*
8 m-0 kPa	16	29	13	0	28	28	15	17	2	6	18	12
8 m-5 kPa	32	45	13	10	44	34	22	23	1	19	21	2
8 m-10 kPa	42	57	15	26	54	28	29	29	0	30	30	0
8 m-20 kPa	56	78	22	27	75	48	37	40	3	28	42	14
Undisturbed	91	101	10	72	100	28	60	58	0*	62	56	0*

*Negative values

Table 4: Differences in pre-consolidation stress (ΔP) using Silva (1970) method with 1kPa and without 1 kPa

	Silva (1970) method											
	Assouline model						Van Genuchten model					
	With 1 kPa			Without 1 kPa			With 1 kPa			Without 1 kPa		
Samples	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP	Free fit	Constraint	ΔP
4 m depth												
Disturbed	47	70	23	17	59	42	30	31	1	30	40	10
4 m-0 kPa	35	52	17	9	49	40	14	18	4	19	30	11
4 m-5 kPa	31	49	18	9	41	32	21	22	1	19	27	8
4 m-10 kPa	28	42	14	6	40	34	21	23	2	16	27	11
4 m-20 kPa	85	100	15	51	90	39	50	54	4	51	57	6
Undisturbed	100	120	20	43	100	57	56	61	5	53	76	23
8 m depth												
Disturbed	49	60	11	32	59	27	36	25	0*	27	45	18
8 m-0 kPa	16	21	5	0	14	14	12	14	2	5	16	11
8 m-5 kPa	28	38	10	10	39	29	20	21	1	18	21	3
8 m-10 kPa	20	30	10	21	48	27	26	26	0	18	18	0
8 m-20 kPa	44	65	21	21	68	47	21	25	4	15	30	15
Undisturbed	37	46	9	64	89	25	36	31	0*	49	60	11

*Negative values

Casagrande (1936) method resulted in higher values compared to Silva (1970) method. The pre-consolidation stress values obtained look realistic with the preloads (almost equal) applied when the curves were fitted freely without the void ratio value at 1 kPa.

Table 3 and 4 give the values of the pre-consolidation stresses with the differences observed when the curve was fit freely and when the curve was fitted with a constraint of the initial void ratio. From Table 3 and 4, it can be observed that the differences in the pre-consolidation values were very less with Van Genuchten curve model compared to the Assouline curve model. The Casagrande (1936) method showed slight overestimation of the pre-consolidation stresses compared to the Silva (1970) method. This overestimation in Casagrande (1936) method lead into a high difference in the preconsolidation stresses when the curves were fitted freely and with constraint.

DISCUSSION

The use of different methods lead into the different results of pre-consolidation stress values, through which affecting the estimation of soils load bearing capacity. Overestimated or underestimated pre-consolidation values lead towards erroneous conclusions regarding remediation. The pre-consolidation stresses obtained lacked consistencies i.e., the variation in the values were very high similar to the reported heterogeneity of the models by Baumgartl and Köck (2004). The coefficient of variation with curves fitted with constraint of initial void ratio was higher compared to the curves fitted freely. The coefficient of variation with Van Genuchten (1980) model was lower compared to Assouline (2002) model. Pre-consolidation stress differed with different curve fitting models and also differed with different calculating methods studied, indicating the dependence of the pre-consolidation stress over the curve fitting models and calculating methods (Gregory *et al*., 2006).

The pre-consolidation stress obtained were higher with the curves fitted with constraint compared to the curves fitted freely which could be due to the shift in point of maximum curvature towards right side.

Gregory *et al*. (2006) evaluated different methods of fitting for different soils by comparing the estimates of pre-consolidation stress produced with known values and found that the Casagrande (1936) method overestimated the known pre-loads. In accordance with this the pre-consolidation stress calculated using Casagrande (1936) method were higher compared to Silva (1970) method with the pre-loads. The pre-consolidation stress values were more realistic with Silva (1970) method when the curves were fitted freely without 1 kPa.

Cavalieri *et al*. (2008) assumed that the soil has already undergone stresses more then 10 kPa and with which they did not use the value measured below 10 kPa which in our case is with 1 kPa. As the samples were collected from depths of 4 and 8 m in this study, it could be expected to have undergone stresses more then 10 kPa due to the above soil profile acting as overburden pressure.

CONCLUSIONS

The study gives an impression on the dependence of curve fitting models and calculating methods on the pre-consolidation stress. Before determining the pre-consolidation stress it is very important to carefully select the curve fitting model and calculating method as overestimation and underestimations lead into erroneous calculations.

Curve fitting is one of the most important steps in determining the pre-consolidation stress. There are different curve fitting models, out of which the two important models (Assouline (2002) and Van Genuchten (1980) models) have been investigated in this study. The curve fitting regression constant R^2 was ranging between 0.97 and 0.99 with both the models indicating a very good curve fit. The results of the pre-consolidation stresses displayed huge differences with respect to the two different models considered. Van Genuchten (1980) model gave better results compared to the Assouline (2002) model. The pre-consolidation stress values were almost equal to the pre-loads as expected when the curves fitted freely.

Another step which is also important is the method of determining pre-consolidation stress. This study compares two mainly used graphical methods (Casagrande, 1936; Silva, 1970). Casagrande (1936) method gave overestimated results; where as Silva (1970) gave realistic values. The differences in the pre-consolidation stresses were high between both the methods with the Assouline (2002) curve model. The differences were very low with Van Genuchten (1980) model.

As a third step in this work the effect of the void ratio value measured at 1 kPa on the curve modeling and through which on the pre-consolidation stress has been checked. The values of initial void ratio and pre-consolidation stress values differed significantly depending on the curve fitting models with 1 kPa (Δe ranging from 0.00 to 0.0396 and ΔP ranging from 2 to 57) and also without 1 kPa (Δe ranging from 0.00 to 0.423 and ΔP ranging from 0 to 23) and with different calculating methods (Table 1-4). Huge differences in the initial void ratios and through which a huge difference in pre-consolidation stresses have been observed when the value at 1 kPa was considered (with 1 kPa) and not considered (without 1 kPa).

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