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Preconsolidation Pressure from Soil Index and Plasticity Properties

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ABSTRACT: Some natural deposits of soils under go heavy compression in their geological history due to the weight of overlying soils. These soils are called preconsolidated or over consolidated and have been subjected to larger stresses in the past than at present. The magnitude of expected settlement depends on the magnitude of loading of subsurface soils relative to magnitude of preconsolidation pressure. Preconsolidation pressure is generally determine using consolidation test data. Consolidation test is time consuming. In this paper attempt is made to determine preconsolidation pressure using soil index and plasticity characteristics. Numbers of datasets are used for studying preconsolidation pressure with soil index and plasticity characteristics. Various methods of evaluation of preconsolidation pressure are compared for different compressibility soils.

1 Introduction

The preconsolidation stress p_c, is the maximum effective stress to which the soil has been exposed may result from loading . Geological evidence of past loadings should be used to estimate the order of magnitude of preconsolidation stresses before laboratory tests are performed. The casagrandes method of obtaining the preconsolidation pressure from consolidation test is based on the point of greatest curvature. The preconsolidation stress or maximum effective past pressure Pc experienced by the foundation soil is a principle factor in determining the magnitude of settlement of structure supported by the soil. Pc is maximum effective stress to reach the situ soil has been consolidated by previous loading; it is boundary between recompression and virgin consolidation pressure applied to the foundation that exceed the maximum past pressure expressed by the soil may cause substantial settlement. The ratio of pre-consolidation pressure and present overburden pressure is known as over consolidation ratio (OCR). Based on OCR soils are classified as normally consolidated, over consolidated or under consolidated. Selection of consolidation parameters such as compression index (C_c) , Recompression index (C_r) or coefficient of volume change (m_v) is on the basis of OCR for computing consolidation settlement.

2 Review on various graphical methods

Researchers found many graphical methods to evaluate preconsolidation pressure and these methods are usually based on the relationship of experimental void ratio (e) and effective consolidation pressure (p') All these methods are operator dependent as they require accurate reading of logarithmic scale, drafting capability and proper judgment of selecting the points. Casagrande Method, e-logp' (1936) is the oldest method to evaluate preconsolidation pressure. This method remains a standard method in comparision to other methods (Jose et al,1989). IS 8009:1976 (part – 1) recommends Casgrande method to determine inter granular pressure. This method gives good results provided there is a well- defined break point in the e–log p'. It is based on the assumption that the soil experiences a change in stiffness, from a stiff response to a soft response, close to the preconsolidation stress. Schemertmann Method, e–log p' (1955) is the adjustment of laboratory consolidation test results with an attempt to compensate for nominal sample disturbance effect. This method is basically for soft soil and not useful for stiff soil. Janbu Method (1969) propose that the consolidation stress could be determined from a plot of the constrained modulus ($M = 1/ m_v$, where m_v is the coefficient of volume compressibility) versus the axial stress in linear scale. Janbu suggested that for clays with high sensitivity and low OCR, p'_c might often show up more distinctly in the stress – strain curve plotted using a linear scale.Pacheco Silva Method, e–log p' (1970) seems very simple to draw and gives accurate results. It is very fast method and does not require any subjective interpretation results. It is not scale-dependent. It is more easy to use in soft soil where change in compressibility is not much evident. It is widely used in Brazil. Pacheco Silva uses an empirical construction from e–log p' curve, where *e* is void ratio and p' effective stress. The author suggested that the method is very fast and easy for determining the of preconsolidation pressure from odeometer tests. Method does not require subjective interpretation of test result and it is not scale dependent. Butterfield Method, (1979) is based on the plot of variation between effective stress and volume change of specimen. The butterfield method has several variations in the literature such as log (1+e) - logσ' ln (1+e) – lnσ' approach. The pre-consolidation pressure is defined as the intersection point of two fitted lines. Tavenas Method, (1979) assumed the linear relationship between strain energy and effective stress for the recompression part used directly from the laboratory recompression curve without considering the under – reloading portion of the test. For over consolidated samples, the stress-strain energy curve consists of two parts. The first part of the curve sharply rises than the second part. The intersection point of two–fitted lines is defined as preconsolidation pressure. Jose Method, log e – log p' is a very simple approximate method to evaluate preconsolidation pressure. In this method intersection of two distinct straight lines, This is a direct method and free from any judgment errors in the location of maximum curvature point. Chetia, and Bora Method (1998) primarily considers the effects of stress history, their characterization and assessment in terms of their overconsolidation ratios (OCR). The major objective of the study is to establish an empirical relationship between the OCR and e/e_L ratio. Nagaraj & Murthy (1986) proposed the following generalized relationship to predict the preconsolidation pressure of overconsolidated saturated uncemented soils. Strain energy – log stress Method , p' ΔH /H –log p'(2000) is proposed to determine p_c'. It is based on the Tavena method and according to Senol et al (2000) this method gave highest correlation coefficient as compared to other graphical methods in a particular condition. Senol (2005) tried to determine the method which gives less deviation (%) from the average values of preconsolidation pressure out of Casagrande, Travenas, Senol methods. In the concluding part the author proved that new method i.e. Senol method gave 16.5% deviation compared to Casagrande -41% and, Tavenas 24%. thus Senol method gives more reliable results in a particular soil condition. Tan (2005) compared the results of graphical methods (Casagrande**,** Tavena, Butterfield) among ANN model was compared with actual preconsolidation pressure and among each other. It is found that ANN model has larger determination coefficient, lower SDR, lower RMSE, and lower MAE as compared to other methods.

3 Sub soil characteristics of alluvial deposits of study area

The subsoil characteristics of Surat city situated in south Gujarat region of Gujarat state in India and surroundings are studied. The study area is divided in the different zones of Surat and Surat urban development authorities (SUDA).The soil in most of the zones are stratified alluvial deposits under the alternate floods and tides. The city is subjected to frequent floods. The laboratory results of soil samples of different zones and different locations are studied. The depth of soil is about 3 m to 7 m for different locations representing the maximum stress zone for shallow foundations. The average range of soil properties are shown for alluvial deposits of Surat and surroundings in Table -1.

Table 1 Subsoil characteristics of alluvial soils of study area.

Soil Properties	Most Range
Liquid Limit (w_L)	30 – 60
Plastic Limit (w_p)	20 – 30
Plasticity Index (I_p)	15 – 30
Void Ratio (e_0)	0.6 – 0.9
Dry unit weight kN/m^3 (γ_d)	14 – 16
Water Content (w)	15 – 30
Porosity (n_0) %	40 – 46
Fines %	60 - 90
Clay %	20 – 30
Silt %	40 – 60
Compression Index (C_c)	0.15 – 0.30
Compression Ratio ($C_{c'}$)	0.12 – 0.18
Soil Classification	Low to High Compressible Fine Grained Soil

4 Empirical correlations for pre-consolidation Pressure and over consolidation ratio

The stress history and present state of stress which influences settlement computation is reflected by pre-consolidation pressure. The pre-consolidation pressure of a soil sample is generally determined by using direct or graphical procedure applied on experimental results. The determination methods of pre-consolidation pressure are Casagrande method (1936) (e-logσ') Schmertmann (1955) (e -logσ'), Janbu (1969) (ΔH/H - σ') Butter field Ln(1+ e) - logσ', Tavenas (1979) (ΔH/H - σ'), Burmister (ΔH/H - σ'), Vanzelst (ΔH/H - σ'), Strain energy – log stress (1979) (σΔH/H - σ'). The graphical method proposed by Casagrande is widely used for determination of Pre-consolidation pressure in practice. Senol (1997) et al, suggested that strain energy - log stress shows better results than other methods with a higher value of correlation coefficient. The ratio of pre-consolidation pressure and present overburden pressure is known as over consolidation ratio (OCR). Based on OCR soils are classified as normally consolidated, over consolidated or under consolidated. Selection of consolidation parameters such as compression index (C_C), Recompression index (C_r) or coefficient of volume change (m_v) is on the basis of OCR for computing consolidation settlement. The correlations are also suggested by researchers to obtain Pre-consolidation pressure and OCR stats and Kulhavy (1984), Nagaraj and Murthy (1985), Chetia and Bora (1998) etc. Table-2 shows typical ranges of over consolidation margin for classification of normal or heavy consolidated soils.

Table 2. Typical ranges of Over Consolidation Margins (OCM)

OCM (KPa)	Classification
0	Normally Consolidated
0 – 100	Slightly over consolidated
100 – 400	Moderately over consolidated
> 400	Heavily over consolidated

Nagraj et al (1991) shows that the position of rebound paths depends on the value of maximum preconsolidation pressure Pc and hence equation for generalized compression path for over consolidation states can be derived incorporating this additional parameter Pc as

$$e \backslash e_L = 1.122 - 0.188 \log Pc - 0.0463\ Po . \quad (1)$$

Using soil index and consolidation test data of alluvial deposits of south Gujarat region new empirical correlations are derived for pre consolidation pressure kN/m^2 and over consolidation ratio for alluvial deposits .

$$P_c = 137.924 - 0.179\ p_o - 30.48\ (e/e_L)\ kN/m^2 \quad (2)$$

$$OCR = 1.85 - 0.007\ p_o - 0.255\ (e/e_L) \quad (3)$$

Where
e = void ratio,
e_L = void ratio at liqlid limit,
p_c = preconsolidation presssure in kN/m^2,
p_0 = existing over burden pressure in kN/m^2

Fig 1 shows comparison of pre-consolidation pressure from test results and correlations. Predicted preconsolidation pressure is also compared with preconsolidation pressure using ANN as shown in fig 2. Fig 3 shows comparison of predicted and measured over consolidation ratio.

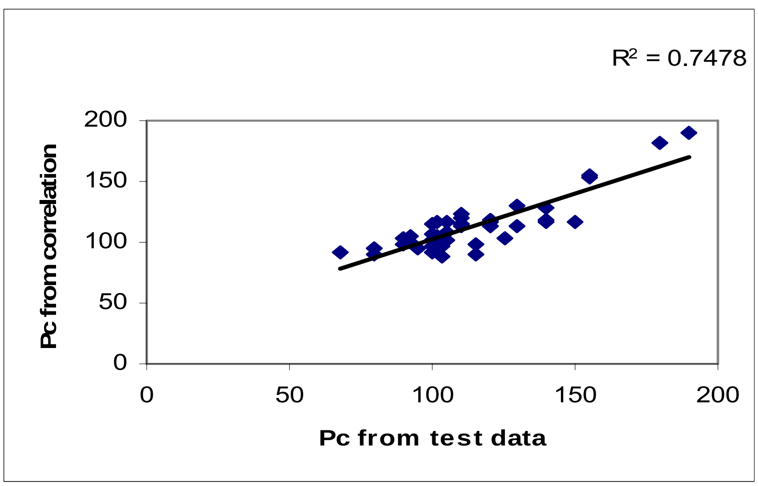
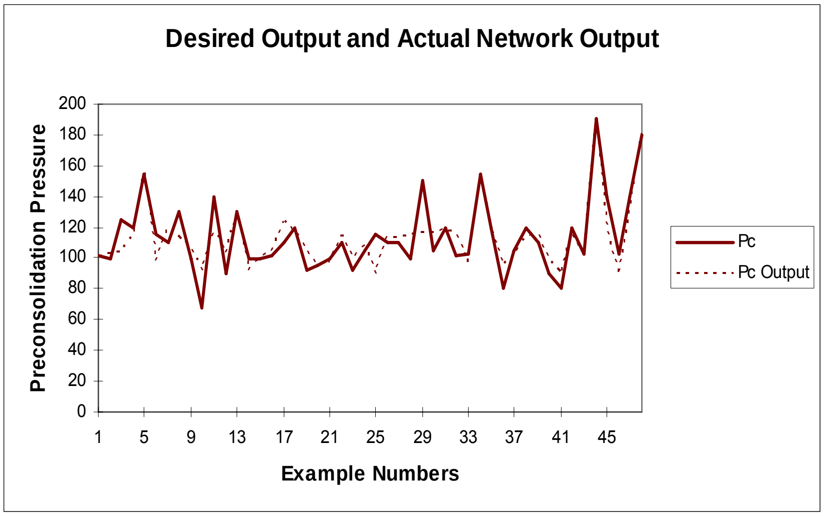


Figure 1 Comparison of preconsolidation pressure from test results and correlation



Performance	Pc
MSE	139.290043
NMSE	0.253502261
MAE	8.739715753
Min Abs Error	0.058898319
Max Abs Error	33.6828836
r	0.864737417

Figure 2 Predicted preconsolidation pressure compared with preconsolidation pressure using ANN

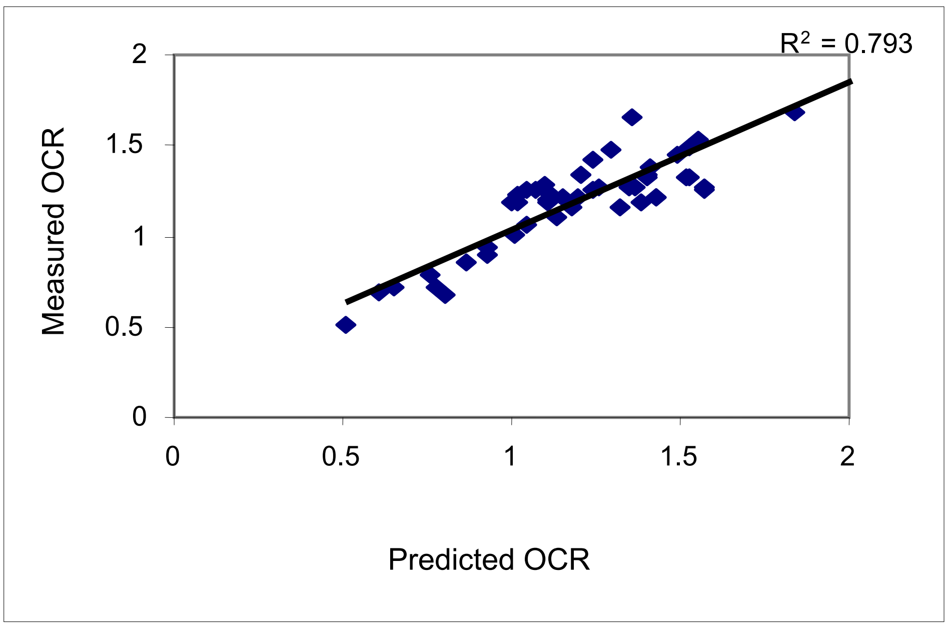


Figure 3 Predicted and measured over consolidation ratio

5 Conclusion

Using soil index and consolidation test data new empirical correlations are derived for pre consolidation pressure kN/m^2 and over consolidation ratio for alluvial deposits .

$$P_c = 137.924 - 0.179P_o - 30.48\ (e/e_L)\ \ kN/m^2 \quad R^2 = 0.7478 \tag{4}$$

$$OCR = 1.85 - 0.007\ P_o - 0.255\ (e/e_L) \quad R^2 = 0.793 \tag{5}$$

6 References

Baligh M and Fuleihan N F (1978)" Consolidation theory with stress reduction due to settlement " *Journal of Geotechnical Engineering ASCE*

Bayan G K (2005) Prediction of historical loading condition of alluvium soil : Problem and possible new solution – A case study National Symposium on Prediction methods in geotechnical engineering Geopredict – 2005, IIT Madras pp 113-118

Bowles J E (1996) *Foundation Analysis and Design* 5th edition Mc Graw-Hill Book Company Inc. New York

Celik S Tan O (2005) Determination of preconsolidatioon pressure with artificial neural network , Civil Engineering and Eenvironmental system Vol.22 No. 4 pp 217-230

Chai J.C., Miura N., Zhu H., & Yadhbir (2004) "Compression & consolidation characteristics of structured natural clay" *Canadian Geotechnical Journa*l. **41** pp 1250 – 1258.

Chetia M, Bora P K (1998) Estimation of over consolidated ratio of saturated uncemented clays from simple parameters, *Indian Geotechnical Journal* Vol. **28** No. 2 pp 177 – 194

Clementio R V (2005) "An oedometer test study on the preconsolidation stress on of glaciomarine clays" *Canadian Geotechnical Journal* . **42** pp 372-374

Dais junior M. S. & Pierce F. J. (1995) "A simple procedure for estimating preconsolidation pressure from soil compression curves". *Soil technology* . **8** pp 139 -151.

David J D , Appolonia Charles C Ladd (1971) "Initial settlement of structures on clay " *Journal of soil mechanics and foundation engineering Division*

Grammatikopoulous I. N. (2006), "Study of preconsolidation pressure values derived by modified casagrande method". *Electronic Journal of Geotechnical Engineering* pp 1 - 8.

Grozic J. L. H., lunne T. & Pande S. (2003) "An odeometer test study on the preconsolidation stress of glaciomarine clays". *Canadian Geotechnical Journal*. **40** pp 857 - 872.

Krishnamohan R. (1992), "Compression of e-log p method for the determination of preconsolidation stress". *Canadian Geotechnical Journa*l **22** (4) pp 215 - 226.

Larsson R. & Ahnberg H. (2005) "On the evalution of undrained shear strength and preconsolidation pressure from common field test in clay". *Canadian Geotechnical Journal*. **42** pp 1221 - 1231.

Morissette L., St-Louse M. W. & Mcrostie G. C. (2001) "Empirical settlement prediction in over consolidated Champlain sea clays". *Canadian Geotechnical Journal*l. **38** pp 720 – 731

Mosaddeghi M. R., Hemmat A., Hajabbasi M. A. & Alexadrou A.(2005), "Pre-consolidation stress and its relation with the physical and mechanical properties of a structurally unstable soil in central iron". Soil tillage research Vol.70 pp 53 - 64.

Nagaraj T. S., Shrinivasa murthy B. R., & Vatsala A. (1991), "Prediction of soil behaviors –part ii- saturated uncemented soil". *Canadian Geotechnical Journal* **21** (1) pp 137 - 163.

Nagaraj T S , Shrinivasa murthy B R , Vatsala A (1994) " Analysis and Prediction of soil behavior " Wiley Eastern Limited

Santagata M. C. & Germaine J. T. (2002), " Effect of OCR on Sampling disturbance of cohesive soil and evaluation of laboratory reconsolidation procedure *Canadian Geotechnical journal*. 459 – 475

Santagata M., Sinifield J. V. & Germaine J. T. (2006), "Laboratory simulation of field sampling; comparison with ideal sampling & field data". *Journal of Geotechnical Engineering* ASCE. **132** , pp 351 - 362.

Senol A.,Hatipogla M.& Ozudogru T.Y. (2005) "The calculation of pre-consolidation pressure result of various 'CL' sub grades Proceedings of International conference on Problematic soils Geoprobe Cyprus

Senol A , Seglamer A (2000) " Determination of Pre-consolidation pressure with a new srain energy –log stress method " *Electronic Journal of Geotechnical Engineering* pp 1-11

Tanaka H., Ritoh F.& Omukai N. (2002), "Quality of samples retrieved from great depth & its influence on consolidation properties". *Canadian Geotechnical Journal* . **39** pp 1288 - 1301.

Wang L. D. & Frost J. D.(2004) "Dissipated strain energy method for determining preconsolidation pressure". *Canadian geotechnical Journal* . **41** pp 760 - 768.