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Evaluation of OCR Prediction Methods utilizing PCPT Data

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피조콘시험결과를 활용한 OCR결정법의 평가

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Abstract The purpose of this study is to evaluate the capability of representative existing methods through which OCR of clayey soils can be predicted utilizing PCPT data. The existing methods include Schmertmann method, Chen and Mayne method using pore water pressures measured immediately behind the cone base u_2, Lunne et al. method, and the latest Abu-Farsakh method. The lab. and in-situ test results, conducted in Incheon port area, were used for the study. The predicted OCR values from the methods were compared with the reference values estimated from laboratory oedometer test. Lunne et al.(k=0.5) method provided relatively better result while all the prediction methods underestimated OCR.

요 약 본 연구에서는 피조콘시험결과를 활용하여 점성토의 과압밀비를 결정하는 대표적 방법들을 비교 평가하였다. 비교 대상으로, 가장 대표적 방법인 Schmertmann 법, Chen and Mayne 법(콘베이스에서 측정하는 u_2 법), Lunne 등 법 및 가장 최근에 발표된 Abu-Farsakh 법을 선정하였다. 각 방법의 비교연구를 위하여 인천항 지역에서 수행된 실내 및 현장시험 결과를 활용하였다. 고려된 모든 방법은 과압밀비를 과소평가하였으며, 그 중 Lunne et al. 법이 k=0.5 경우에 있어 가장 양호를 결과를 보여주었다.

Key Words : Piezocone, OCR, Pore Water Pressure, u_1, u_2

1. Introduction

PCPT(piezocone penetration test) data have played an important role in predicting OCR(overconsolidation ratio) for clayey soils, while there are no reliable methods for sandy soils except for the indirect way in which in-situ Ko(coefficient of later stress) is utilized through empirical correlations(Lunne et al. 1997)[1].

The methods to derive OCR from PCPT data fall into two main categories. One is that OCR is estimated based on the undrained shear

strength su.(Schmertmann 1975, 1978, Andressen et al. 1979)[2-4]. The other is based directly on the PCPC data, specially pore pressure measurement(Sully et al. 1988, Powell et al. 1988, Mayne 1991, 1993, Chen and Mayne 1994, Lunne et al. 1997)[1,5-9]. Besides them, the method using support vector machine, which is a statistical learning theory based on a structural risk minimization principle, was proposed by Samui et al. (2008); however, the method has been accepted as just trial yet[10].

OCR values were predicted from four methods; first, Schmertmann method which is representative among the methods based on the undrained shear strength, second and third, Chen and Mayne and Lunne et al. methods

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which were most typical among the methods based on direct PCPT data, fourth, Abu-Farsakh(2007) method which is involved in the method directly utilizing PCPT data but most recent[11]. OCR values predicted from the four methods were compared with the reference value obtained from the oedometer test for the subsoils in Incheon port area.

2. Methods for Estimating OCR

OCR can be obtained from the undrained shear strength method based on Schmertmann(1975, 1978) as follows: (1)estimate su from PCPT data(Kim 2009) (2)compute S=su/σ'_{vo} using the effective vertical stress σ'_{vo} (3)estimate the corresponding normally consolidated value of S_1=(su/σ'_{vo})NC using plasticity index I_p(Eq. 1, Tumay et al. 1995) (4)estimate OCR value from the correlation chart(Fig. 1, Andressen et al. 1979) or the correlations(Eq. 2 by Schmertmann 1978)[2-4,12-14].

$$S_1 = (s_u/\sigma'_{vo})_{NC} = 0.11 + 0.0037\, I_p \quad (1)$$

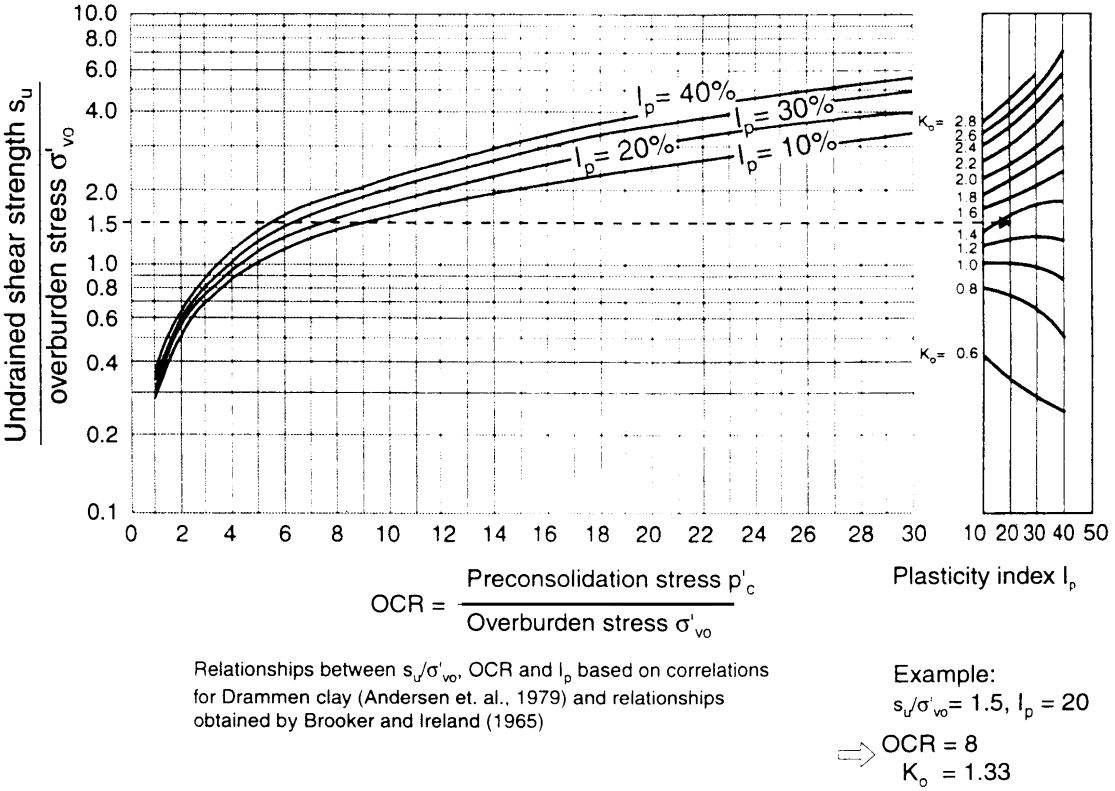
$$OCR = (S/S_1)^{1.13 + 0.04(S/S_1)} \quad (2)$$

Mayne(1991, 1993) and Chen and Mayne(1994) proposed the following correlations as in Eqs. 3 and 4[7-9]. Pore pressures measured at different locations along the cone are generalized as those with the filter element located at the cone tip(face or apex) u_1 and those with the filter element located immediately behind the cone base u_2. qt indicates the tip resistance corrected for the unequal end area effect[1,13].

$$OCR = 0.81\left(\frac{q_t - u_1}{\sigma'_{vo}}\right) \quad (3)$$

$$OCR = 0.46\left(\frac{q_t - u_2}{\sigma'_{vo}}\right) \quad (4)$$

Lunne et al.(1997) recommended the following correlations(Eq. 5):



[Fig. 1] OCR and Ko from undrained strength and plasticity index(Andressen et al. 1979)

$$OCR = k\left(\frac{q_t - \sigma_{vo}}{\sigma_{vo}'}\right) \quad (5)$$

where k value is 0.3 in average with a range of 0.2 to 0.5[1].

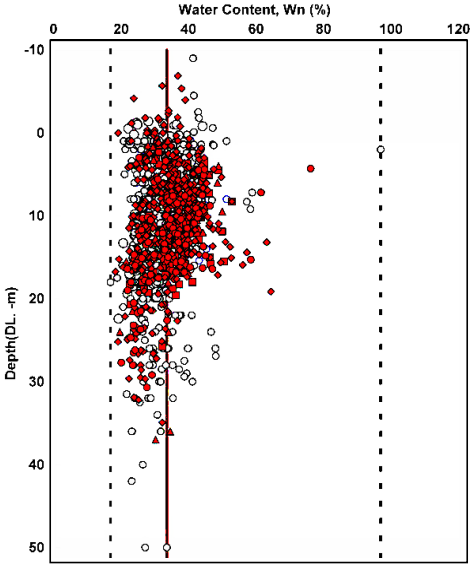
Abu-Farsakh(2007) obtained the following equations for the Louisiana clayey soils[11].

$$OCR = 0.161\left(\frac{q_t - u_1}{\sigma_{vo}'}\right) \quad (6)$$

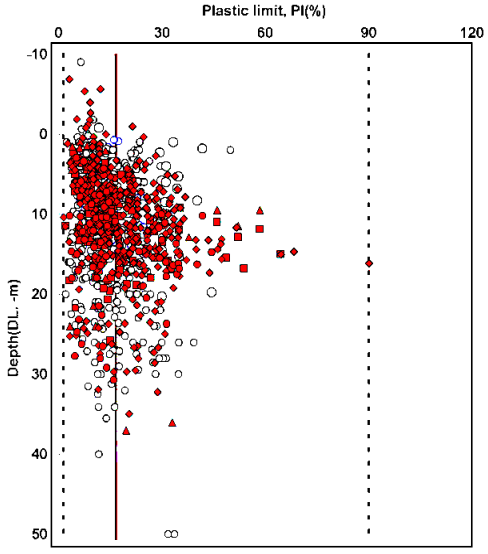
$$OCR = 0.152\left(\frac{q_t - \sigma_{vo}}{\sigma_{vo}'}\right) \quad (7)$$

3. PCPT and Lab. Test

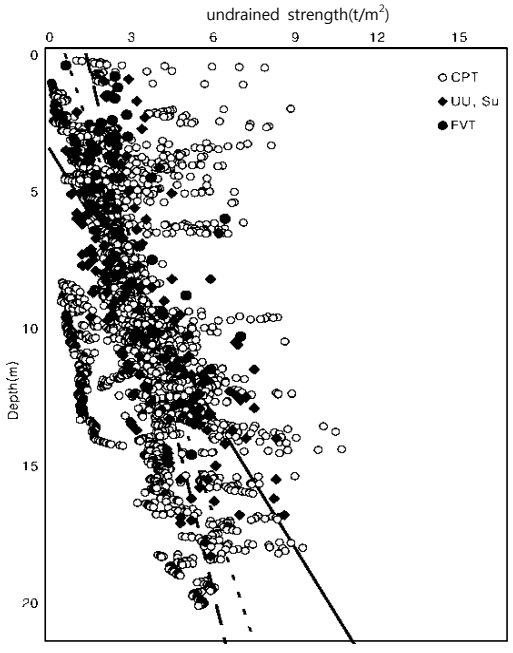
The experimental results of lab. and in-situ testings conducted at Incheon port were used in this study(Shin et al. 2009)[15]. The subsurface ground consists mainly of lowly to highly plastic clayey soils with deep depth of over 30 m. Fig. 2 presents the profiles of several geotechnical properties of the soils. Liquidity index value



(a) Water Content Profile



(b) Plastic Limit Profile



(c) Undrained Strength Profile

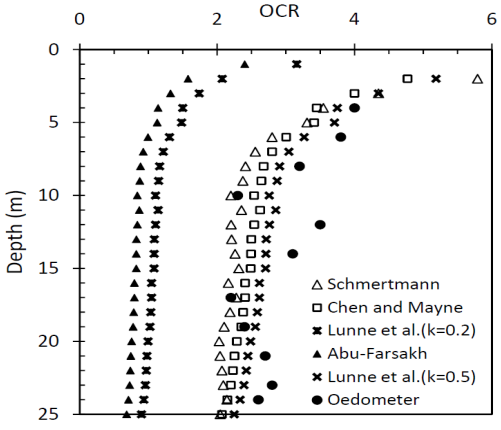
[Fig. 2] Geotechnical Properties of Investigated Site(Shin et al. 2009)[15]

ranges zero to 2.0 and the soils could be classified mainly as normally to lightly consolidated clay. Specific gravity were 2.58 to 2.76. Saturated unit weight was valued at 1.65 to 2.1 t/m^3. The value of Initial void ratio ranges 0.614 to 1.921. The undrained shear strength values from triaxial and uniaxial testings were alike, and showed the

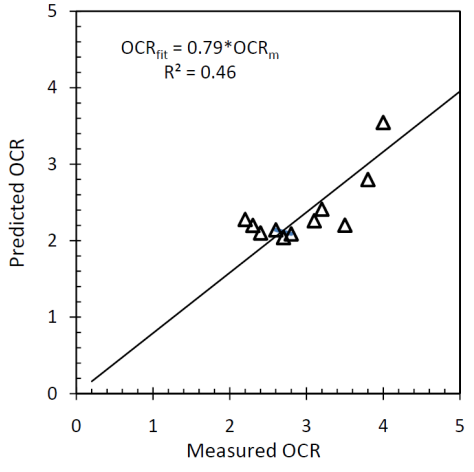
increasing tendency with depth.

4. Analysis of Results

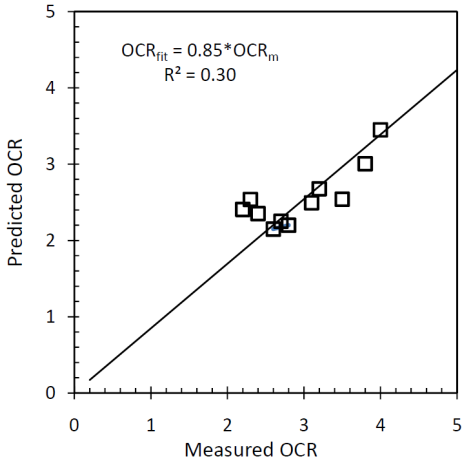
Fig. 3 presents OCR values from the various prediction methods stated above and the oedometer test. The u_2 Chen and Mayne method was used since the u1 piezocone penetrometer was not used, whereas u_2 penetrometer was essentially used for the correction of unequal end area effect in this study like other common cases. In Lunne et al. method, the two cases of k=0.2 and 0.5, instead of k=0.3 case which is generally thought representative in the method, were shown to investigate the results between the two boundary values.



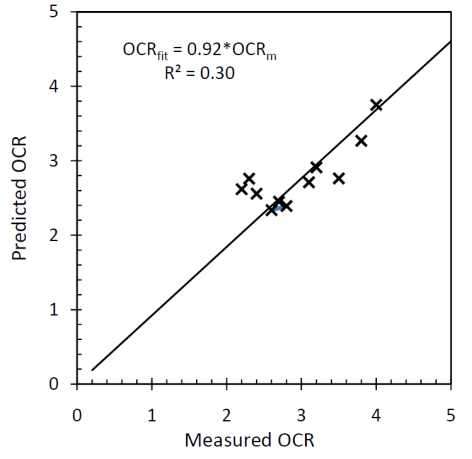
[Fig. 3] Measured and Predicted Profiles of OCR



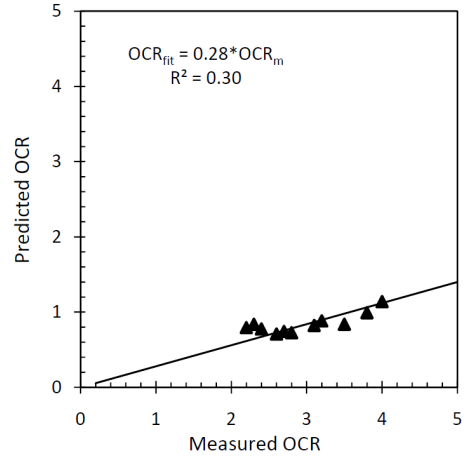
(a) Schmertmann(1975, 1978) Method



(b) Chen and Mayne(1994) u_2 Method



(c) Lunne et al.(1997)(k=0.5) Method



(d) Abu-Farsakh(2007) Method

[Fig. 4] Measured and Predicted OCR from Various Methods

Fig. 4 provides the measured and predicted OCR values of each method. The best fit line of the predicted to the measured OCR OCR_{fit}/OCR_m and the coefficient of determination R^2 were estimated and presented.

All the prediction methods underestimated the OCR values in general. This is fundamentally not as same as the most previous studies[1,2,9,11]. It needs to be noted that the prediction method does not always give conservative results.

Lunne et al. method provided best results for k=0.5, whereas the prediction for k=0.2 case was not good, which implies two important investigations: one is the Lunne et al. method may produce reasonable results though the method itself is relatively simple, the other is the reliability of the result of the method depends on the value of the constant k so the value should be determined with much caution considering the distant prediction results for k=0.2.

The equation of Lunne et al. method contains the total vertical stress, as in Eq. (5), which is a more comprehensive term than the detail terms such as u_2 in Chen and Mayne method and undrained shear strength in Schmertmann method. It can be thought such detail terms might produce discrepancy otherwise they are not precisely estimated as all terms in interpreting piezocone test results are affected by complex factors.

Although the Abu-Farsakh method is latest, it is actually nothing but the Lunne et al. method with k=0.152, which was a chosen value for the Louisiana clay but not for the Incheon soils utilized in this study. The evaluation of an appropriate value of k for each area in needed.

5. Conclusions

In this study, the representative methods to predict OCR values from piezocone test results (Schmertmann, Chen and Mayne u_2, Lunne et al., the latest Abu-Farsakh methods) were compared with oedometer test results for the subsoils in Incheon port area. The following conclusions could be made.

- All the prediction methods generally underestimated the OCR values.
- The prediction from Lunne et al. (k=0.5) method presented the best agreement with the oedometer test results.
- Lunne et al. method could be widely utilized; however, the constant k value should be determined with great caution.
- It was observed that the prediction methods using u_2 pore water pressure could give reasonable results without u1 measurement.

References

[1] T. Lunne, P. K. Robertson, J. J. M. Powell, *Cone Penetration Testing*, Blackie Academic and Professional, 1997.

[2] J. H. Schmertmann, "Measurement of in situ shear strength", *Pro. the ASCE Special Conf. on In Situ Measurement of Soil Properties*, Raleigh North Carolina, 2, pp. 57-138, 1975.

[3] J . H. Schmertmann, *Guidelines for Cone Penetration Test, Performance, and Design*, US Federal Highway Administration, Washington, DC, Report, FHWATS-78-209, 145, 1978.

[4] A. Andressen, T. Berre, A. Kleven, T. Lunne, "Procedures Used to Obtain Soil Parameters for Foundation Engineering in the North Sea", *Marine Geotechnology*, Vol. 3, No. 3, pp. 201-66, 1979.

[5] J. P. Sully, H. J. Echezuria, "In Situ Density Measurements with Nuclear Cone Penetrometer", *Proc. of the Int. Symposium on Penetration Testing, ISOPT-1*, Orlando, Vol. 2, Balkema Pub. Rotterdam, pp. 1001-1005, 1988.

[6] J. I. Powell, R. T. Quarterman, T. Lunne, "Interpretation and Use of the Piezocone Test in UK Clays", *Proc. of the ICE Geotechnology Conf. on Penetration Testing in UK*, pp. 151-156, 1988.

[7] P. W. Mayne, "Determination of OCR in Clays by Piezocone Tests using Cavity Expansion and Critical State Concepts", *Soils and Foundations*, Vol. 31, No. 2, pp. 65-76, 1991.

[8] P. W. Mayne, "In Situ Determination of Clay Stress History by Piezocone Predictive Soil Mechanics", Proc. of Wroth Memorial Symposium, Thomas Telford, London, pp. 483-495, 1993.

[9] B. S. Chen, P. W. Mayne, Profiling the Overconsolidtion Ratio of Clay by Piezocone Tests,

Report GIT-CEEGEO-94-1, Georgia Tech Research Corporation and Georgia Institute of Technology, School of Civil and Environmental Eng., Atranta, GA, 1994.

[10] P. Samui, T. G. Sitharam, P. U. Kurup, "OCR Prediction using Support Vector Machine based on Piezocone Data", J. of Geotechnical and Geoenvironmental Eng., Vol. 134, No. 6, pp. 894-898, 2008.

[11] M. Y. Abu-Farsakh, "Possible Evaluation of Overconsolidatio Ratio of Clayey Soils from Piezocone Penetration Tests", *GSP 162 Problematic Soils and Rocks and In Situ Chracterization*, ASCE, 2007.

[12] C. C. Ladd, R. Foott, K. Ishihara, F Scholsser, H. G. Poulos, "Stress-Deformation and Strength Characteristics", State-of-the-art report, *Proc. of the 9th Int. Conf. on Soil Mechanics and Foundtion Engineering*, Tokyo, 2, pp. 421-494, 1977.

[13] D. Kim, "Interpretation of Empirical Cone Factors for Determining Undrained Strength," *J. of Industry-Academy*, Vol. 10, No. 11, pp.3296-3302, 2009.

[14] M. T. Tumay, G. Z. Voyiadjis, P. R. Kurup, "Profiling OCR and Ko from Piezocone Penetration Tests," *Proc. of CPT'95, ndustry-Academy*, Linkoping, Sweden, Vol. 2, pp. 337-395, 1995.

[15] E. Shin, J. Kim, H. Kim, C. Lee, "Reliability Analysis of Geotechnical Properties in Incheon Port Area," *Proc. of KGS Spring Conf. 2009*, pp. 952-960, 2009.

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<Research Interests>
Geotechnical Engineering, Soils and Foundations, Ground Exploration and Testing, Constitutive Relations, Numerical Analysis, Underground