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콘관입 시험기를 이용한 정지토압계수와 과압밀비의 평가

Estimation on K0 and OCR Values Using Cone Penetration Test

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개요(SYNOPSIS): 과압밀된 점토지반의 정지토압계수(Ko)와 과압밀비(OCR)를 예측하기위하여 원위치 콘관입시험기(CPT)를 사용했다. 28개의 CPT 시험을 수행하여 구한 Ko 과 OCR 비을 위한 실험상관식은 기존에 삼축시험과 압밀시험을 통하여 결정된 상관식과 비교한 결과, 상당히 합리적인 식으로 판명되어 장차 유사한 현장에 적용가능하리라 사료된다. 본논문은 무엇보다도 국내에서도 현장에 적절한 상관식의 개발이 시급히 수행되어야함을 근본취지로 한다.

Introduction

The Cone Penetration Test (CPT) has been found to be one of the best methods to investigate site characterization in geotechnical engineering because the simplicity and cost-effectiveness of this test; the quality of the measured data and the reliability of the developed interpretation procedure have made the CPT outstanding tool to determine the soil stratification and basic soil parameters.

It is well known, however, that most empirical correlations for foundation design were developed from specific sites (e.g., Norway and Canadian soils for CPT based correlations). The applicability of these correlations is confined only to sites for which they were developed. Therefore, if these data have to be used for any rational design purpose, these correlations need to be modified for other site.

The purpose of this paper is to develop site-specific empirical correlations for K_0 and OCR values in desiccated, highly overconsolidated clay by using 28 Cone Penetration Tests performed at the highly overconsolidated clay site.

Descriptions of the Site

The site is located in the University of Houston Central Campus, Houston, Texas. The study site has been extensively investigated during last 10 years for deep foundation research such as single and group pile behaviors and drilled shaft behaviors. This site has been recently designated as a National Geotechnical Experimentation Site (NGES-UH).

Detailed geological descriptions of the site, geotechnical properties of soil and information of previous tests are presented by Dunnavant, (1986), Mahar and O'Neill (1983), O'Neill and Yoon (1995). A generalized soil profiles with depth are shown in Fig. 1. The depth of ground water is about 2m with some seasonal fluctuations. The site consists of Beaumont clay overlying the Montgomery clay formation. The Beaumont clay from ground surface to about 8m is highly overconsolidated due to desiccation, with OCR values decreasing with depth. Beaumont clay (layers I, IA and II in Fig. 3) is stiff to hard gray and tan clay with tan sandy clay, and Montgomery clay (layers III, IV and V in Fig. 3) is very stiff to hard gray sandy clay, interbedded with clay, sand and silt layers.

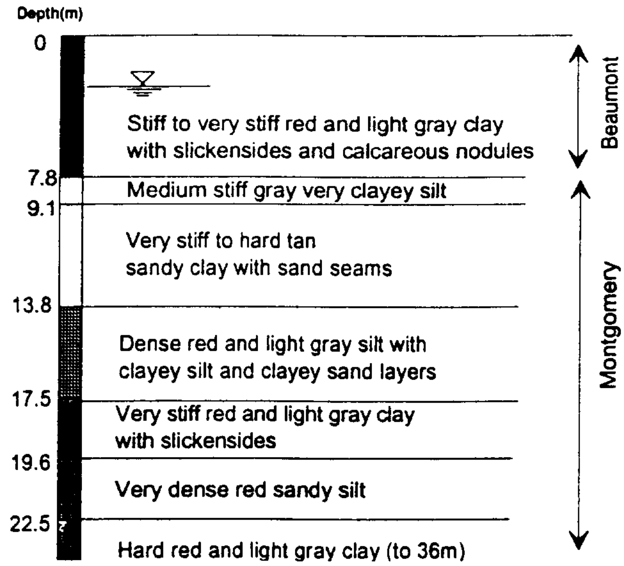


Fig. 1 General Soil Profiles of the NGES-UH Site.

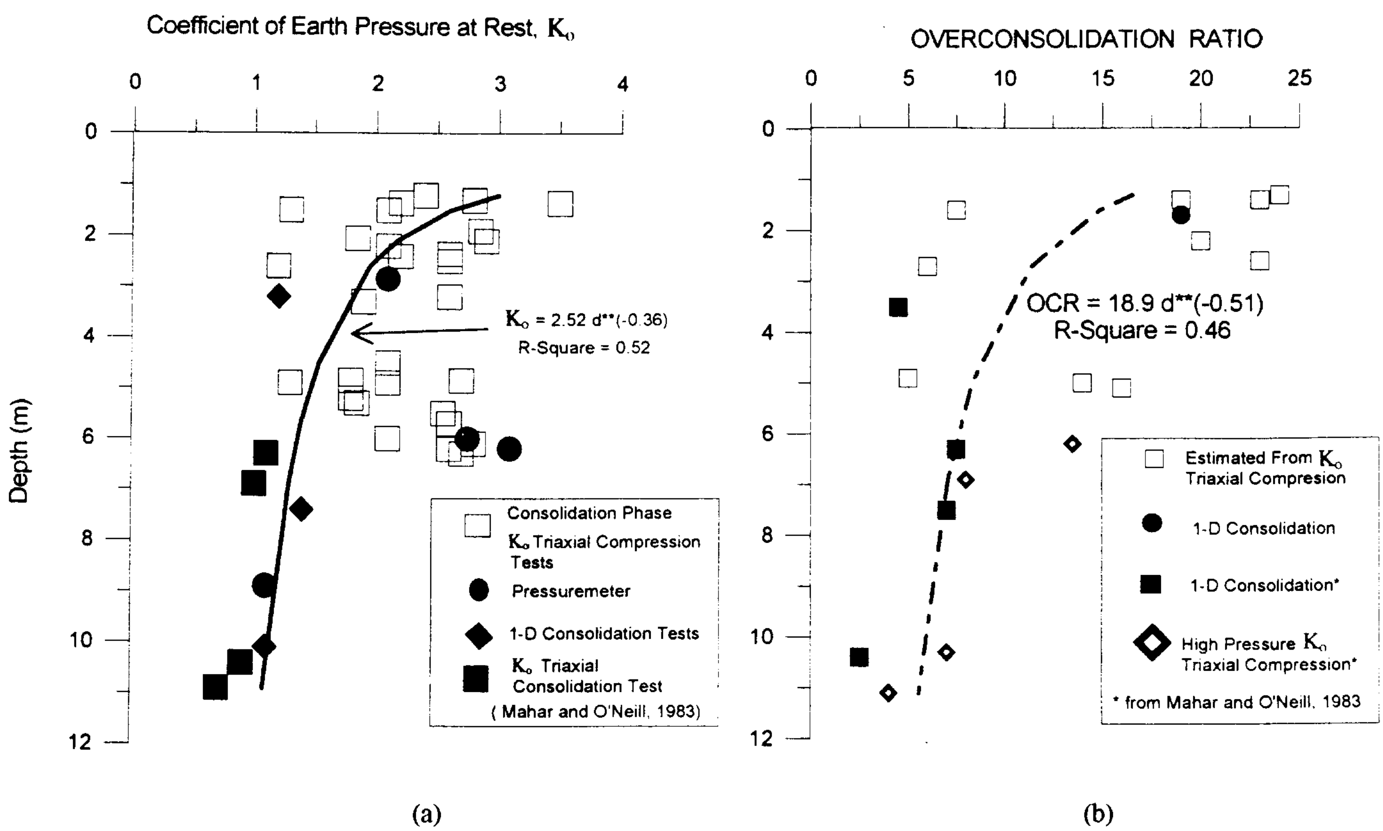


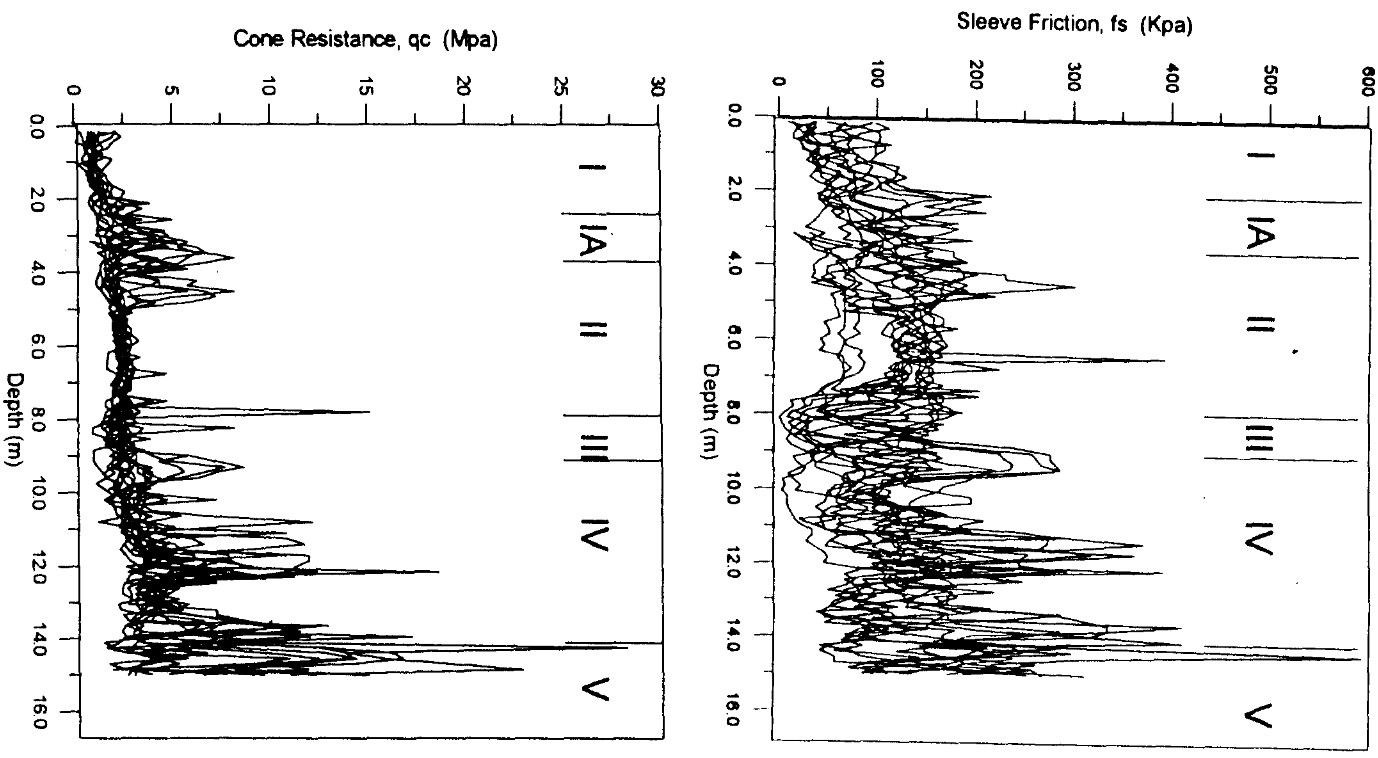
Fig. 2 Variation of OCR and K_0 with Depth for the NGES-UH Site (After Dunnavant, 1986)

Cone Penetration Test (CPT)

The CPT was first developed in the early 1930s in the Netherlands. Since then the CPT has become so accepted and trusted in European contries. During the last decade, the usefulness and practicality of the CPT have also been accepted in the North America and Japan and so on. The basis of the method is a probe pushed into the ground at a standard penetraion rate of 20mm/sec while sleeve friction and cone tip resistance are recoreded. It is obvious that the geotechnical engineer does not measure the "true" value of every geotechncial property in every single element of soil, but rather he/she attempts an estimate of the most probable value of the property in the point of space occupied by the element. The purpose of the investigation is to study the uncertainties in a site investigation and find out how to estimate their magnitude and how to take them into consideration.

The electric cone Penetrometer was used at NGES-UH with help of Fugro-Geoscience, co., for this study and appeared to be an excellent way to develop the necessary data. The electric cone Penetrometer indirectly provides strength data at 0.125 ft depth interval, and under ideal conditions up to 600 to 800 ft of soundings can be obtained per day. Be properly spacing the Penetrometer soundings, the required parameters for the spatial variability of Cone data were obtained . In order to perform the required statistical data analysis using the cone Penetrometer the cone data must be converted to the appropriate strength parameter.

Data from twenty seven CPT tests were used to evaluate the variability of the cone measurements. Fig. 2 shows that the sleeve friction (f_S) and cone tip resistance (q_C) have relatively high variation. At a given depth, these values can be used as indices of the variation in cone penetration resistance over the length of the NGES-UH site. A mean value of the quantity in question for six layers in vertical direction was calculated to describe spatial variation in soil profile. Fig. 2 shows that the cone resistance (q_C) varies significantly in the profile at depth of 7.8 m at the interface between Beaumont clay and Montgomery clay.



(a) (b)

Fig. 3 Variability of Cone Resistance (q_C) and Sleeve Friction (f_S) with Depth at the NGES-UH Site

K_o by CPT

Masood and Mitchell (1993) proposed a simple method to determine K_o value from CPT Sleeve Friction (f_s) data. They expressed the unit sleeve friction (f_s) measured during the penetration of a cone penetrometer as;

$$f_s = C_a + K_s \sigma'_v \tan\delta \tag{1}$$

where f_s = unit friction on the cone friction sleeve,
C_a = unit adhesion between soil and sleeve,
K_s = lateral earth pressure coefficient during penetration,
σ'_v = effective overburden pressure and
δ = angle of friction between soil and the sleeve.

To simplify equation (1), Masood and Mitchell (1993) assumed;

(i) C_a is negligible
(ii) $\delta = \phi/3$
(iii) $K_s = K_p = \tan^2(45 + \phi/2)$

Combining equation (1) with the above assumptions gives;

$$f_s = \sigma'_v \tan^2(45 + \phi/2) \tan(\phi/3) \tag{2}$$

Equation (2) can be described by;

$$f_s / \sigma'_v = \tan^2(45 + \phi/2) \tan(\phi/3) \tag{3}$$

The values of K_o for a normally consolidated soil formulated by Jaky (1944) can be written as;

$$(K_o)_{nc} = 1 - \sin\phi \tag{4}$$

in which $(K_o)_{nc}$ = the coefficient of lateral earth pressure at rest for normally consolidated clay.

For a overconsolidated soil, Mayne and Kulhawy (1982) suggested;

$$(K_o)_{oc} = (K_o)_{nc} (OCR)^{\sin\phi} \tag{5}$$

in which $(K_o)_{oc}$ = the coefficient of lateral earth pressure at rest for overconsolidated clay.

Therefore, equations (3), (4), and (5) provide the necessary relationships to determine $(K_o)_{oc}$. The effective stress friction angle ϕ can be estimated from equation (3) if cone sleeve friction (f_s) and effective overburden pressure (σ'_v) are available. Detailed descriptions of relationship between ϕ and f_s is referred in Masood and Michell (1993). OCR values of equation (5) can be determined from one-dimensional consolidation or CPTU (Oeill and Yoon, 1995).

The relationships among $f_s/\sigma'v$, OCR, and K_0 values are described in Fig. 4. These relationships are extended by the author for higher OCR values because the research site (NGES-UH) consists of highly overconsolidated clays (OCR>8).

Using the collected cone sleeve friction (f_s) data and representative OCR values from previous test results shown in Fig. 4 (Dunnavant, 1986), $(K_0)_{OC}$ in the desiccated and overconsolidated clay deposits was determined. Fig. 5 shows the results of $(K_0)_{OC}$.

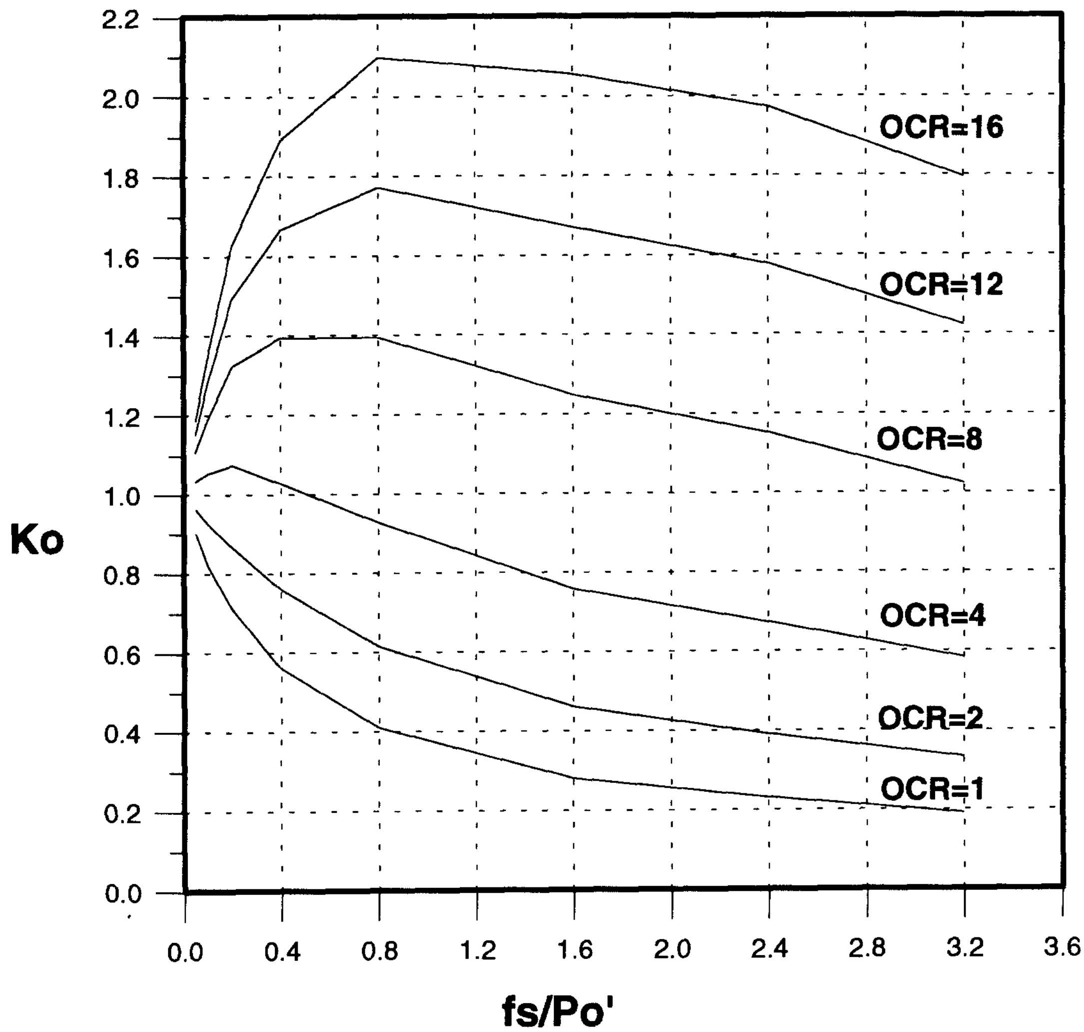


Fig. 4 K_0 as Function of Sleeve Friction and Overconsolidation Ratio for the NGES-UH (Modified after Masood and Mitchell, 1993)

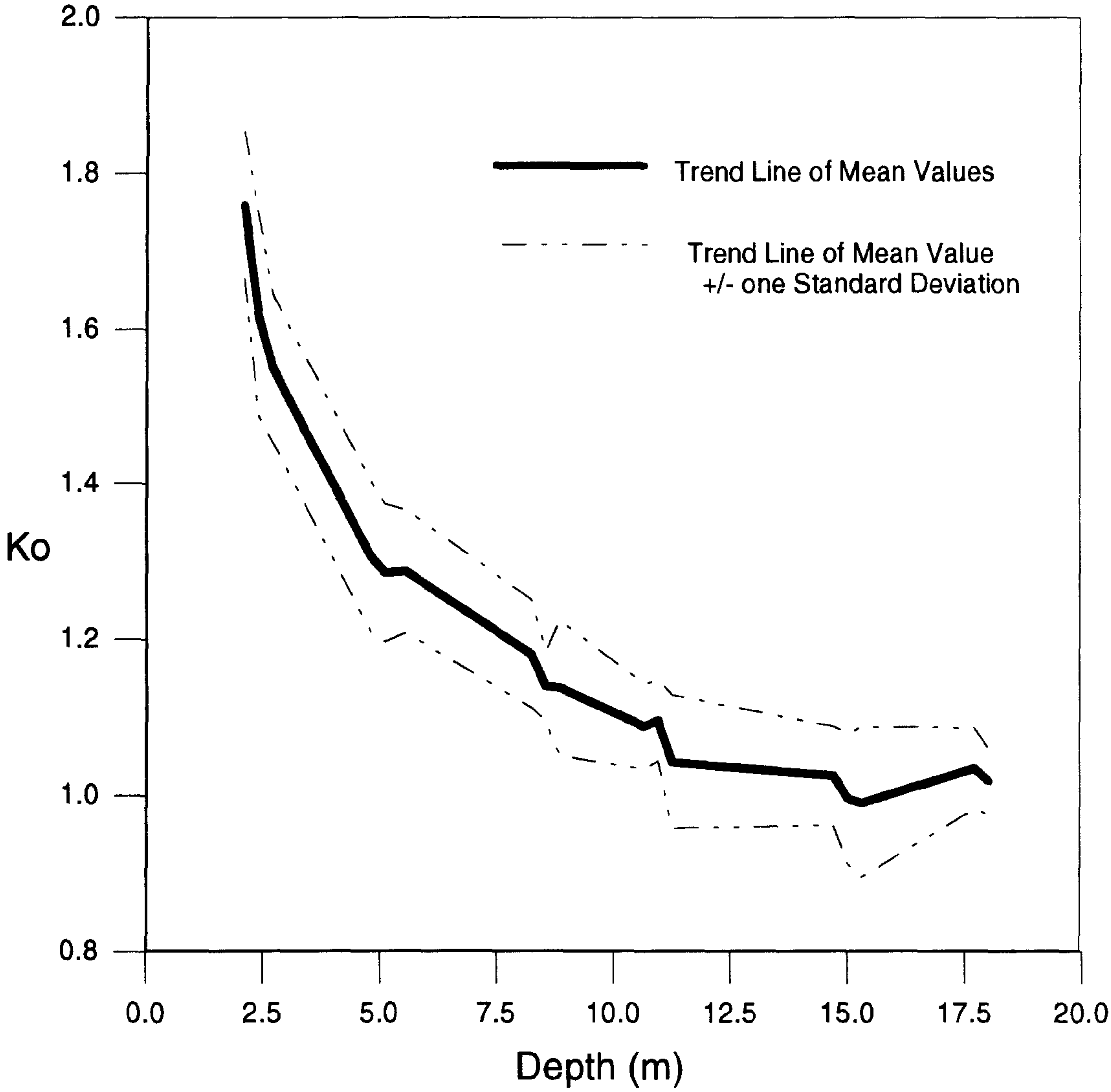


Fig. 5. Coefficient of Lateral Earth Pressure at Rest (K_0) Profiles for the NGES-UH Site.

OCR by CPT

Mayne and Kemper (1988) proposed the following correlation for cohesive soils:

$$OCR = k_c(q_c - \sigma'_v)/\sigma_v \quad (6)$$

where q_c = cone tip resistance,
k_c = correlation factor,
σ_v = total overburden pressure and
σ'_v = effective overburden pressure.

It was observed that the correlation factor, k_c, varies from 0.3 to 0.8 for electric CPT's and from 0.12 to 0.5 for mechanical CPT's. Due to the large range of k_c, it is recommended that the correlation factor be related to a soil property (i.e. plasticity index, activity, etc.) by performing CPT's at a given site where the stress history is already known.

Data of cone tip resistance, q_c, in Fig. 3 , OCR values in Fig. 2 and previous test results of total and effective overburden pressure from Dunnavant (1986) are used to determine k_c values for the NGES-UH. Fig. 6 shows the variation of correlation factors with depth for the NGES-UH. As expected, the variation of k_c is relatively high at surface layer due to desiccation (seasonal effects) and natural characteristics of surface layer consisting of gravel, sand and clay.

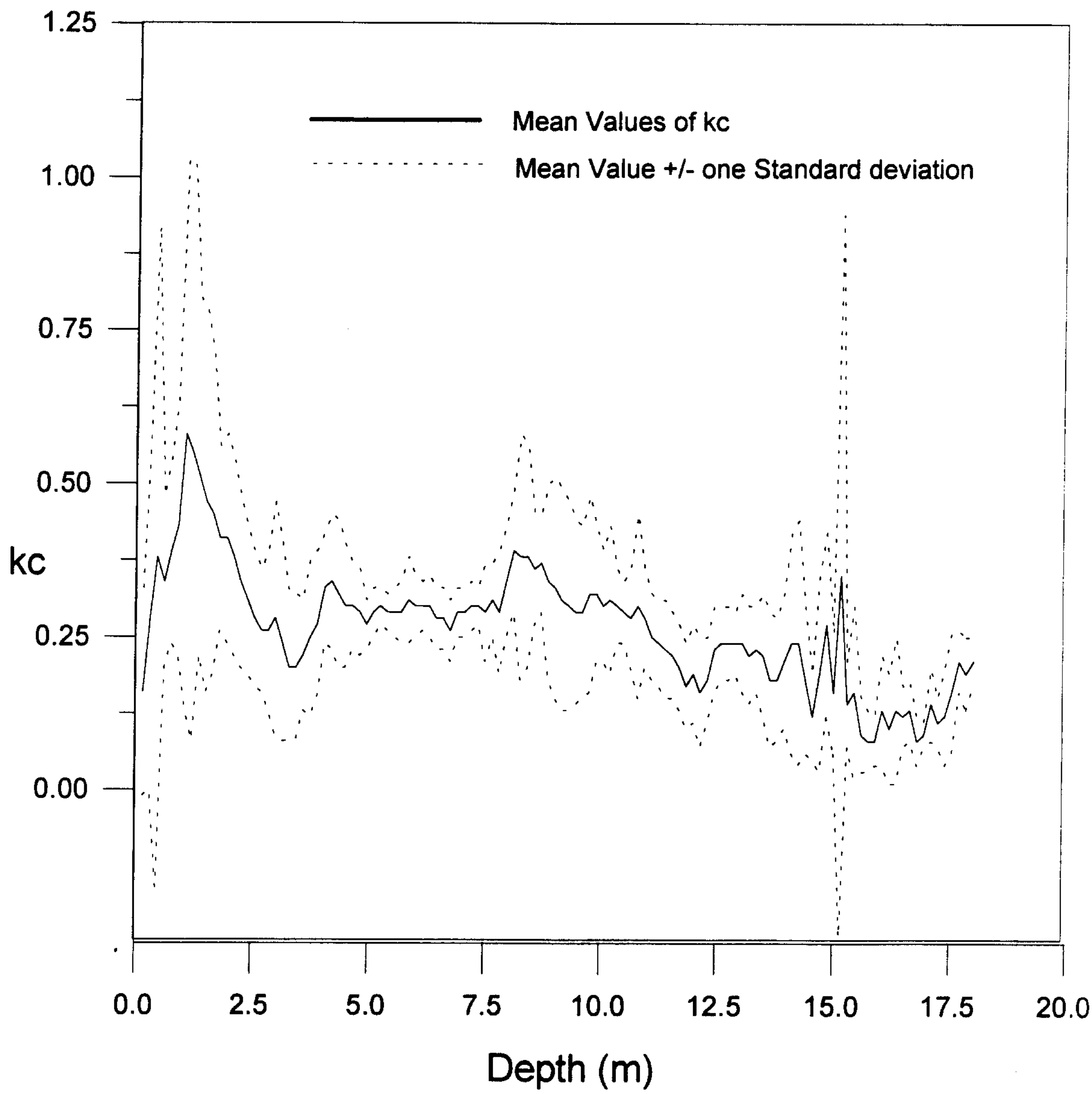


Fig. 6 Variation of Correlation Factor (k_c) with Depth at the NGES-UH Site

Discussion and Summary

On the basis of 28 CPT tests results in the desiccated, overconsolidated clay deposits, site specific empirical correlations are developed. These correlations herein need to be verified for other desiccated, overconsolidated clays for direct use for foundation design. Importantly, as the next fruitful research area, some empirical correlations for taking consider of undrained shear strength coefficient (s_u-N_k), Young's modulus (E) and pore pressure effect could be evaluated and developed. Effects of pore water pressure may be essential, especially in overconsolidated clay that has an erratic response of pore water pressure to evaluate the in-situ test results, which require cone penetrometer with measurement of pore pressure.

The following conclusions can be made.

1. A simple method for estimation of K_0 values from cone sleeve friction (f_s) suggested by Masood and Michell (1993) is found to be promising in the desiccated, overconsolidated clays.

2. Correlation factor (k_c) of empirical correlation, $OCR = k_c(q_c-\sigma'_v)/\sigma_v$, was estimated to be from 0.2 to 0.4 in the desiccated, overconsolidated NGES-UH Site.

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