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LIQUEFACTION POTENTIAL – EVALUATION WITH CPTs AND DMTs TWO CASE STUDIES IN KALOHORI THESSALONIKI CREECE

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ABSTRACT

Several authors have pointed out the importance of using redundant correlations for evaluating liquefaction potential especially for high risk projects. The compatibility between CPT (cone penetration tests) and DMT (Prof. Silvano Marchetti flat dilatometer tests) based methods of liquefaction resistance evaluation is examined, based on data from geotechnical investigations in two alluvial sites in Kalohori Thessaloniki Greece.

Keywords: Dilatometer tests, Kalohori, Thessaloniki

INTRODUCTION

The "simplified procedure", introduced by Seed & Idriss (1971), is currently used as a standard of practice for evaluating the liquefaction resistance of soils. This method requires the calculation of two terms: (1) the seismic demand on a soil layer generated by the earthquake, or cyclic stress ration CSR, and (2) the capacity of the soil to resist liquefaction, or cyclic resistance ration CRR. If CSR is greater than CRR, liquefaction can occur.

The cyclic stress ratio CSR is calculated by the following equation (Seed & Idriss 1971):

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = 0.65 \cdot \left(\frac{a_{\max}}{g} \bullet \frac{\sigma_{vo}}{\sigma'_{vo}} \right) r_d \qquad (1)$$

where $\tau_{\alpha v}$ = average cyclic shear stress, α_{max} = peak horizontal acceleration at ground surface generated by the earthquake, g = acceleration of gravity, σ_{vo} and σ'_{vo} = total and effective overburden stresses and r_d = stress reduction coefficient dependent on depth, generally in the range ≈ 0,8 to 1.The liquefaction resistance CRR is generally evaluated from in situ tests. The CRR curve separates two regions of the plot – "liquefaction" and "no liquefaction" – including data obtained at sites where surface effects of liquefaction were or were not observed in past earthquakes.

Several Authors have pointed out the importance of using redundant correlations for evaluating liquefaction potential. Robertson & Wride (1998) warned that CRR evaluated by CPT (preferred over SPT, due to its poor repeatability) may be adequate for low-risk, small-scale projects, while for medium-to high-risk projects they recommended to estimate CRR by more than one method.

Idriss & Boulanger (2004) observed that the reliability of any liquefaction evaluation depends directly on the quality of the site characterization, and it is often the synthesis of findings from several different procedures that provides the most insight and confidence in making final decisions.

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For this reason, the practice of using a number of in situ testing methods should continue to be the basis for standard practice, and the allure of relying on a single approach (e.g. CPT-only procedures) should be avoided.

FLAT DILATOMETER

The flat dilatometer is a stainless steel blade having a flat, circular steel membrane mounted flush on one side (Fig. 1).

The blade is connected to a control unit on the ground surface by a pneumatic-electrical tube (transmitting gas pressure and electrical continuity) running through the insertion rods. A gas tank, connected to the control unit by a pneumatic cable, supplies the gas pressure required to expand the membrane. The control unit is equipped with a pressure regulator, pressure gage(s), an audio-visual signal and vent valves.

The blade is advanced into the ground using common field equipment. Push rods are used to transfer the thrust from the insertion rig to the blade.

The general layout of the dilatometer test is shown in Fig. 2. The test starts by inserting the dilatometer into the ground. Soon after penetration, by use of the control unit, the operator inflates the membrane and takes, in about 1 minute, two readings:

The blade is then advanced into the ground of one depth increment (typically 20 cm) and the procedure is repeated at each depth.

The DMT is suitable for sands, silts and clays where the grains are small compared to the membrane diameter (60 mm). It is not suitable for gravels.

The DMT readings are highly accurate even in extremely soft nearly liquid soils. Clays can he tested from c_u = 2 – 4 kPa up to 1000 kPa. The range for moduli M is from 0,4 MPa up to 400MPa..

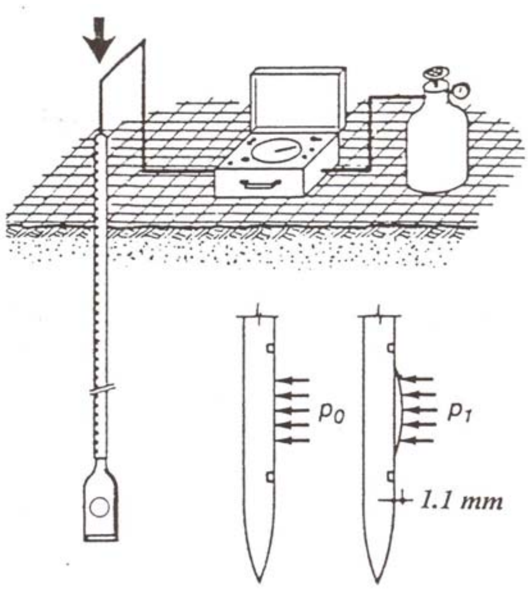

Fig. 1. The flat dilatometer – Front and side view
Fig.2.General layout of the Dilatometer Test

EVALUATION OF CRR FROM THE DMT HORIZONTAL STRESS INDEX KD

Marchetti (1982) and later studies (Robertson & Campanella 1986, Reyna & Chameau 1991) suggested that the horizontal stress index K_D from DMT ($K_D = (p_o - u_o)/\sigma'_{vo}$) is a suitable parameter to evaluate the liquefaction resistance of sands. Comparative studies have indicated that K_D is noticeably reactive to factors such as stress state/history (σ_h, OCR), pure prestraining, aging, cementation, structure – all factors increasing liquefaction resistance. Such factors are scarcely felt e.g. by q_c from CPT (see e.g. Huang & Ma 1994) and, in general, by cylindrical-conical probes.

As noted by Robertson & Campanella (1986), it is not possible to separate the individual contribution of each factor on K_D. On the other hand, a low K_D signals that none of the above factors in high, i.e. the sand is loose, uncemented, in a low K_0 environment and has little stress history. A sand under these conditions may liquefy or develop large strains under cyclic loading. The most significant factors supporting the use of K_D as an index of liquefaction resistance, listed by Monaco et al. (2005), are:

Sensitivity of DMT in monitoring soil densification
Sensitivity of DMT to prestraining
Correlation K_D – Relative density
Correlation K_D – In situ state parameter

Despite the complexity of the phenomena involved in the blade penetration, the reaction of the soil against the face of the blade could be seen as an indicator of the soil reluctance to a volume reduction. Fig.5. (Monaco et al. 2005) summarizes the various correlations developed to estimate CRR from K_D, expressed in form of CRR-K_D boundary curves separating possible "liquefaction" and "no liquefaction" regions.

The proposed CRR-K_D curve should be used in the same way as other methods based on the Seed & Idriss (1971) procedure: (1) Enter K_D in Fig. 5 to evaluate CRR. (2) Compare CRR with the cyclic stress ratio CSR generated by the earthquake calculated by Eq. 1.

This CRR-K_D curve applies to magnitude M = 7.5 earthquakes. Also, the proposed CRR-K_D curve applies properly to "clean sand" (fines content ≤ 5%). Of course, the method is affected by the same restrictions which apply, in general, to the Seed & Idriss (1971) procedure (level to gently sloping ground, limited depth range).

In many everyday problems, a full seismic liquefaction analysis can be avoided if the soil is clearly liquefiable or non liquefiable. Guidelines of this type would be practically helpful to engineers. A tentative identification of minimum values of K_D for which a clean sand (natural or sandfill) is safe against liquefaction (M = 7,5 earthquakes) is indicated in TC16 (2001):

Non seismic areas, i.e. very low seismic: $K_D > 1.7$
Low seismicity areas ($\alpha_{max}/g = 0.15$): $K_D > 4.2$
Medium seismicity areas ($\alpha_{max}/g = 0.25$): $K_D > 5.0$
High seismicity areas ($\alpha_{max}/g = 0.35$): $K_D > 5.5$

The above K_D values are marginal values, to be factorized by an adequate safety factor.

TWO CASE STUDIES USING CPT & DMT

A. *BASILAGAS S.A.*

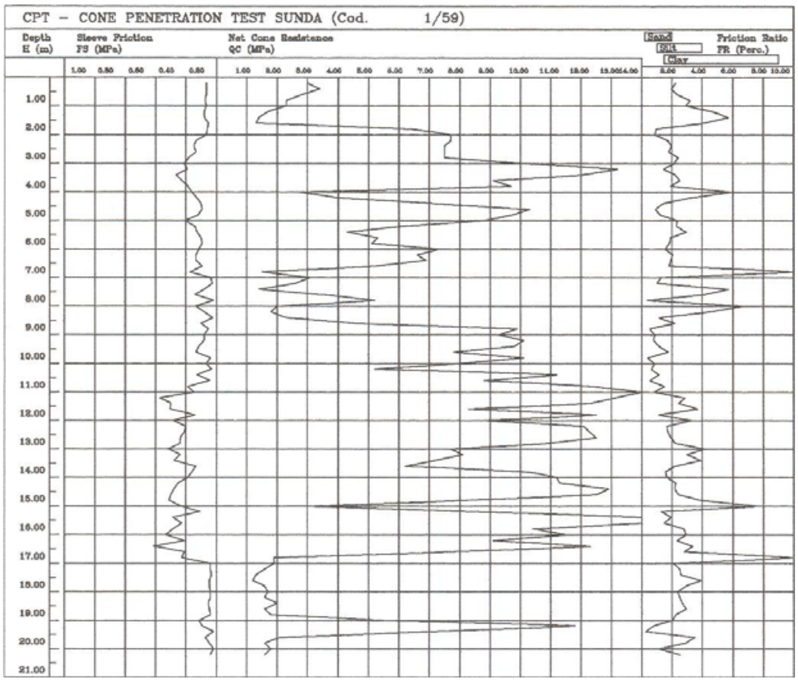

Figure 3a CPT

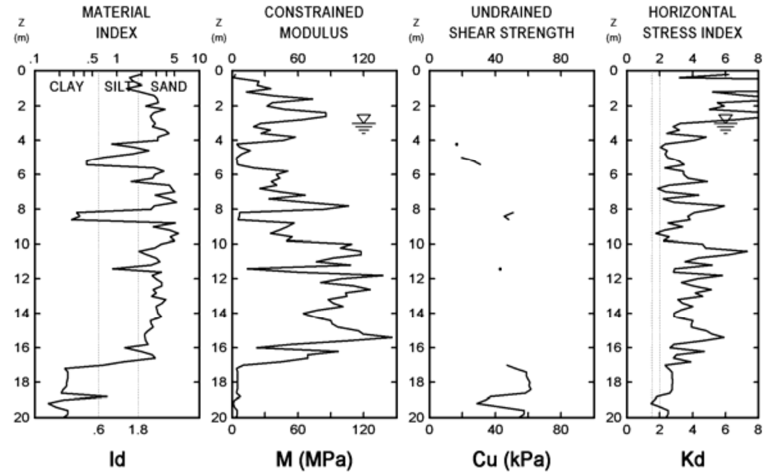

Figure 3b DMT

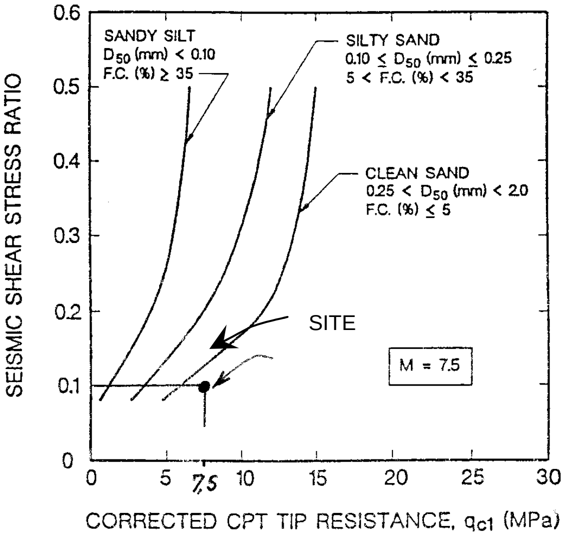

Figure 3c

$$SSR = 0{,}65 \bullet \frac{\alpha_{\max}}{g} \bullet \frac{\sigma_{vo}}{\sigma_{vo'}} \bullet r_d$$

$\alpha = 0{,}16 \bullet g$ $z = 3{,}50$ m

$\sigma_{vo} = \sigma_{vo'} = 20 \bullet 3{,}50 = 70$ kPa

$r_d = 1 - 0{,}012 \bullet z = 0{,}958$

S.S.R. $= 0{,}65 \bullet 0{,}16 \bullet 0{,}958 \cong 0{,}10$

$$C_q = \frac{1{,}8}{0{,}80 + \dfrac{70}{100}} = 1{,}2$$

$q_c' = c_q \bullet q_c = 1{,}20 \bullet 5{,}50 = 6{,}60$

B. KALTSOS ST.

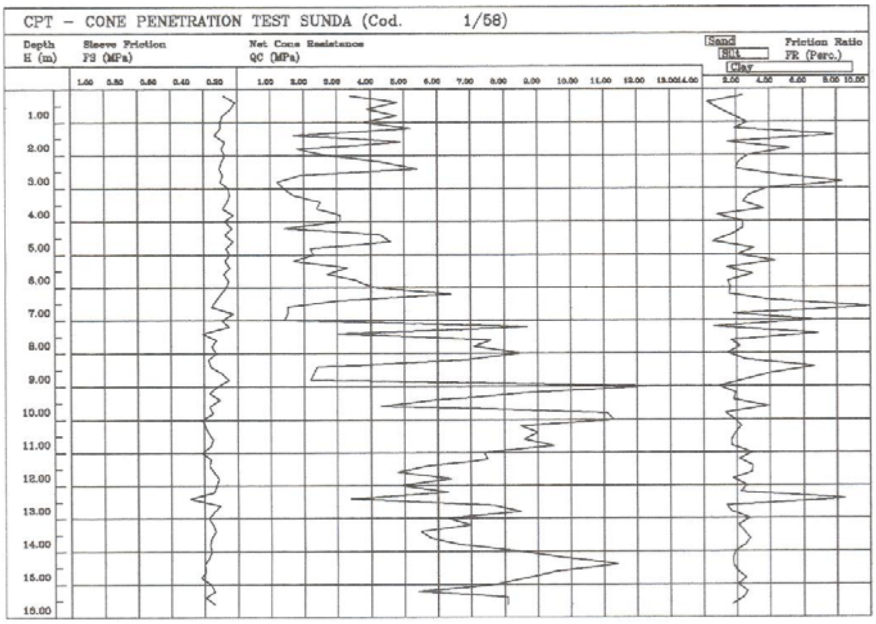

Figure 4a CPT

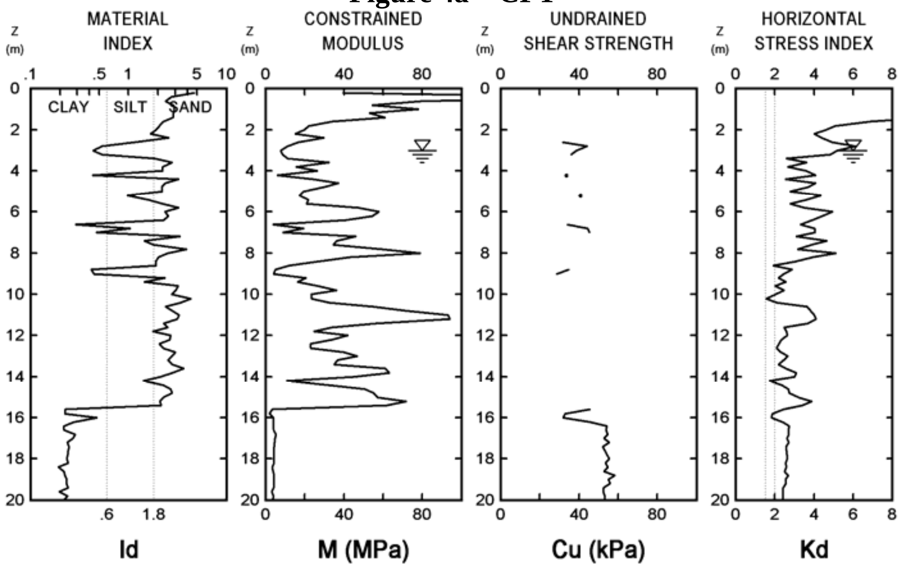

Figure 4b **DMT**

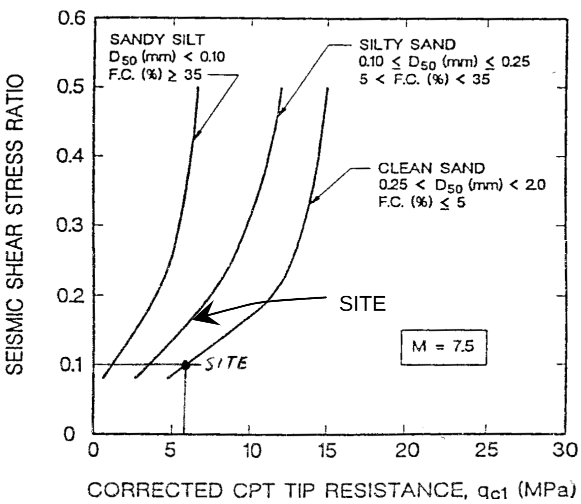

Figure 4c

$$SSR = 0{,}65 \bullet \frac{\alpha_{\max}}{g} \bullet \frac{\sigma_{\upsilon o}}{\sigma_{\upsilon o'}} \bullet r_d$$

$\alpha = 0{,}16 \bullet g$ $z = 1{,}50$ m

$\sigma_{\upsilon o} = \sigma_{\upsilon o}' = 20 \bullet 1{,}50 = 30$ kPa

$r_d = 1 - 0{,}012 \bullet z = 0{,}982$

S.S.R. $= 0{,}65 \bullet 0{,}16 \bullet 0{,}982 \cong 0{,}10$

$$C_q = \frac{1{,}8}{0{,}80 + \frac{\sigma_{\upsilon o}'}{100}} = 1{,}64$$

$q_c' = c_q \bullet q_c = 1{,}64 \bullet 3{,}50 = 5{,}74$

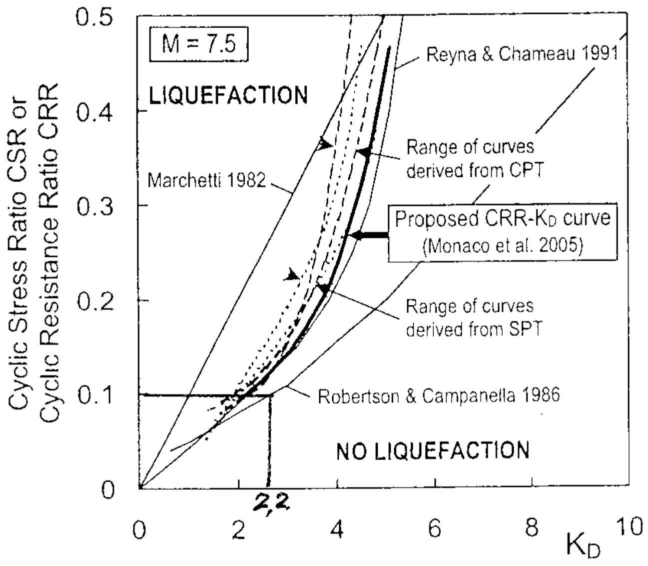

Figure 5. CRR – K_d curves

Figure 6. Penetrometer TG 73 – 200 kN

CONCLUSION

In both tested sites (as seen in attached figures), both methods show that the soil is barely not liquefiable.

The compatibility of the two methods has been verified.

Both DMT and CPT suffer from the fact that neither provides soil samples that can be classified regarding amount and type of fines.

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