TECHNICAL NOTE

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Estimating Liquefaction Potential of Sands Using the Flat Plate Dilatometer

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REFERENCE: Robertson, P. K. and Campanella, R. G., "**Estimating Liquefaction Potential of Sands Using the Flat Plate Dilatometer,**" *Geotechnical Testing Journal*, GTJODJ, Vol. 9, No. 1, March 1986, pp. 38-40.

ABSTRACT: A new flat plate dilatometer test (DMT) based method for liquefaction assessment of sand is presented. Field and laboratory data from a site near Vancouver, British Columbia, Canada are presented to provide a preliminary evaluation of the proposed DMT based liquefaction assessment method.

KEYWORDS: sands, liquefaction, in-situ testing, flat plate dilatometer

The flat plate dilatometer test (DMT) was developed in Italy by Marchetti [*1*]. The dilatometer is a flat plate 14 mm thick, 95 mm wide by 220 mm in length. A flexible stainless steel membrane 60 mm in diameter is located on one face of the blade. Readings are made every 20 cm in depth. The membrane is inflated using high pressure nitrogen gas supplied by a tube pre-threaded through the rods. As the membrane is inflated, the pressures required to just lift the membrane off the sensing disk (Reading A), and to cause 1-mm deflection at the center of the membrane (Reading B), are recorded. Readings are made from a pressure gage in the control box and entered on a standard data form. Full details of the test procedure are given in the *Dilatometer Users Manual* [*2*].

The dilatometer is pushed into the ground at a constant rate of penetration of 2 cm/s. Before and after each sounding the dilatometer is calibrated for membrane stiffness.

The dilatometer data (Readings A and B) are corrected for offset in the measuring gage and for membrane stiffness to values P_o and P_1, respectively.

Using the P_o and P_1 values, the following index parameters were proposed by Marchetti [*1*]

$$K_d = \frac{P_o - u_o}{\sigma'_{vo}} = \text{horizontal stress index} \quad (1)$$

$$I_d = \frac{P_1 - P_o}{P_o - u_o} = \text{material index} \quad (2)$$

$$E_d = 34.6(P_1 - P_o) = \text{dilatometer modulus} \quad (3)$$

where u_o is the assumed in-situ hydrostatic water pressure and σ'_{vo} is the in-situ vertical effective stress. The data are reduced using a computer program supplied with the instrument. Computer graphics facilities are used to generate the completed plots. An example of DMT results analyzed and displayed by the computer are shown in Fig. 1.

The dilatometer equipment is extremely simple to operate and maintain. The simplicity and low initial cost of the equipment are two of the main advantages of the DMT as an in-situ test method.

Liquefaction Assessment

Marchetti [*3*] suggested that the horizontal stress index K_d could be used as a parameter to assess the liquefaction resistance under level ground conditions of sands under cyclic loading. K_d appears to reflect the following soil variables

1. relative density, D_r;
2. in-situ stresses, K_o;
3. stress history and pre-stressing;
4. aging; and
5. cementation.

However, it is not possible to identify the individual responsibility of each variable. On the other hand, when K_d is low, none of these variables are high, that is, the sand is loose, uncemented, in a low horizontal stress environment and has little stress history. A sand under these conditions may liquefy or develop large strains under cyclic loading, using liquefaction as defined by Seed et al [*4*]. Marchetti [*3*] suggested the following tentative correlation between the cyclic stress ratio to cause liquefaction (τ_ℓ/σ'_{vo}) and the horizontal stress index K_d

$$\tau_\ell/\sigma'_{vo} \doteq K_d/10 \quad (4)$$

Chamber test results in sand [*1,5*] using the DMT show that the horizontal stress index parameter K_d, is related to relative density for normally consolidated ($K_o \simeq 0.40$), uncemented sand and in-situ stress K_o and stress history. Results presented by Bellotti et al [*5*] and Marchetti [*3*] are shown in Fig. 2. Results from two sites presented by Marchetti [*1*] are also included in Fig. 2. The relative density values of the sand deposits presented by Marchetti [*1*] were esti-

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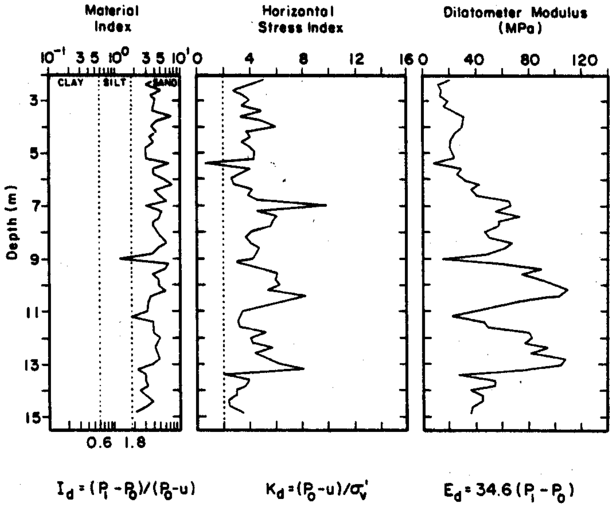

FIG. 1—*Typical DMT index parameters, McDonald's Farm Site, British Columbia.*

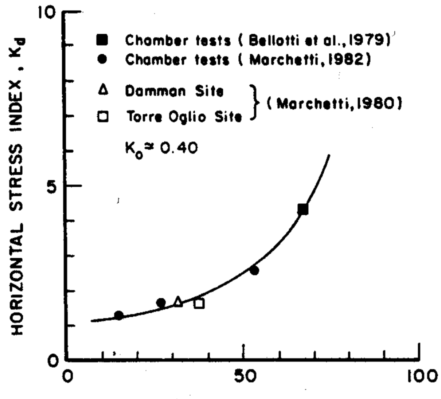

FIG. 2—*Correlation between horizontal stress index from DMT and relative density for normally consolidated, uncemented sand.*

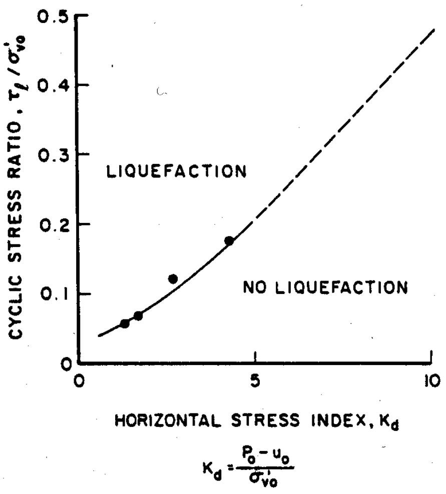

FIG. 3—*Proposed correlation between liquefaction resistance under level ground conditions and dilatometer horizontal stress index for sands.*

mated by the writers using available cone penetration testing (CPT) data.

If the relationship shown in Fig. 2 is combined with the field liquefaction resistance data produced by Christian and Swiger [6], and processed by Vaid et al [7], a liquefaction correlation with the DMT can be developed and is shown in Fig. 3. The liquefaction resistance curve by Christian and Swiger [6] was chosen because it appears to represent quite closely the observed field liquefaction behavior. The correlation proposed in Fig. 3 would predict cyclic stress ratios significantly lower than those predicted using the formula proposed by Marchetti (Eq 2).

Marchetti [3] has shown that K_d appears to increase with increases in K_o, aging, cementation, and stress history. Experience has shown that the liquefaction resistance also increases with these factors. Although the correlation shown in Fig. 3 is based on a $K_d - Dr$ relationship for normally consolidated, uncemented sands any increase in the above factors will produce an increase in apparent density and thus be reflected by an increase in liquefaction resistance.

The correlation proposed in Fig. 3 for DMT data is based on limited empirical data and requires considerable field verification. The DMT based method in Fig. 3 should be used in the same manner proposed by Seed et al [4] for level ground conditions using the standard penetration test (SPT) based method. However, the DMT data does not require modification for in-situ effective overburden pressure since this is accounted for in the K_d parameter.

The correlation shown in Fig. 3 is only applicable for testing in sands where penetration and expansion occur under drained conditions. Testing in silty sands or silts may generate significant pore pressures, which would influence the measured K_d values [8].

Preliminary Evaluation of Proposed DMT Correlation

To evaluate the proposed DMT liquefaction assessment curve shown in Fig. 3, data were obtained at the University of British Columbia (UBC) research site for in-situ testing near Vancouver International Airport. The site (McDonalds Farm) is located on the north side of Sea Island on Ministry of Transport, Canada, land near the Municipality of Richmond [9]. The site is approximately level with the natural ground at elevation +1.6 m. Full details of the site are given by Campanella et al [9].

An example of typical DMT results from the UBC McDonald's Farm site is shown in Fig. 1. Sand exists from a depth of 2 to 15 m. The sand was deposited in a turbulent environment and is therefore relatively nonuniform in density. In general however, the sand increases in density with depth. The sand has a medium to coarse grain size with thin layers of medium to fine sand and some lenses of silty sand. A thin transition layer of fine sand with some silt exists from 13 to 15 m.

Ground water is approximately 1 m below existing ground surface and ground water pressures are approximately hydrostatic.

A field and laboratory study was performed that included CPT, SPT, and undisturbed sampling using a 86 mm inside diameter (ID)

(3⅜ in.), thin walled, fixed piston sample tube. Laboratory cyclic triaxial tests were performed on the undisturbed samples.

The liquefaction resistance of the sand was assessed using the proposed correlation shown in Fig. 3. A comparison between the cyclic stress ratios to cause liquefaction predicted from the proposed DMT, and the SPT and CPT based methods [*4,10*] and laboratory derived cyclic stress ratios are compared in Fig. 4. Good agreement is apparent between the DMT and laboratory, SPT and CPT derived liquefaction resistance.

The proposed correlation in Fig. 3 had no data beyond $K_d = 4.5$. However, the results shown in Fig. 4 indicate that the proposed extrapolation beyond $K_d = 4.5$ appears reasonable.

If the liquefaction resistance was predicted from the DMT data using the approach suggested by Marchetti [*4*] (Eq 2), the cyclic stress ratio to cause liquefaction would have been very much overpredicted, with an average value of about 0.4.

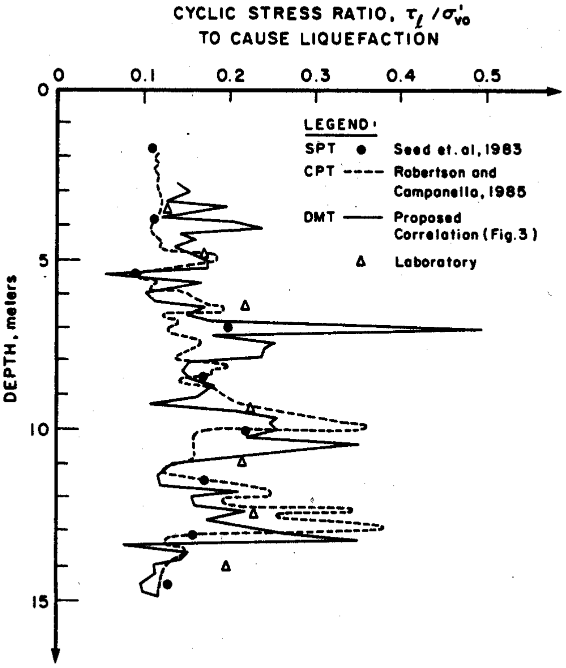

FIG. 4—*Comparison of predicted cyclic stress ratio to cause liquefaction from DMT, SPT, CPT, and laboratory testing at McDonald's Farm Site, British Columbia.*

Penetration in the sand deposit at McDonald's Farm occurred under drained conditions. Recent testing with a research dilatometer that incorporates a piezometer element on the diaphragm confirms that both penetration and membrane expansion occur under drained conditions. Results from another site (New Westminster) show that DMT testing in silts can generate significant pore pressures, which influence the measured K_d value and thus the resulting liquefaction assessment [*8*].

Full details of field and laboratory test data from the silt site (New Westminster) are given in a paper by Campanella and Robertson [*8*]. The proposed correlation shown in Fig. 3 is not recommended for DMT results in silt.

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