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Simplified DMT-based methods for evaluating liquefaction resistance of soils

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ABSTRACT

This paper presents simplified dilatometer test (DMT)-based methods for evaluation of liquefaction resistance of soils, which is expressed in terms of cyclic resistance ratio (CRR). Two DMT parameters, horizontal stress index (K_D) and dilatometer modulus (E_D), are used as an index for assessing liquefaction resistance of soils. Specifically, CRR–K_D and CRR–E_D boundary curves are established based on the existing boundary curves that have already been developed based on standard penetration test (SPT) and cone penetration test (CPT). One key element in the development of CRR–K_D and CRR–E_D boundary curves is the correlations between K_D (or E_D) and the blow count (N) in the SPT or cone tip resistance (q_c) from the CPT. In this study, these correlations are established through regression analysis of the test results of SPT, CPT, and DMT conducted side-by-side at each of five sites selected. The validity of the developed CRR–K_D and CRR–E_D curves for evaluating liquefaction resistance is examined with published liquefaction case histories. The results of the study show that the developed DMT-based models are quite promising as a tool for evaluating liquefaction resistance of soils.

1. Introduction

Simplified procedures to evaluate the liquefaction potential of soils generally consist of two steps: 1) to evaluate the *loading* to a soil caused by an earthquake and 2) to evaluate the *resistance* of a soil to triggering of liquefaction. The former is generally performed through an estimate of the cyclic stress ratio (CSR) as defined by the pioneering work of Seed and Idriss (1971). The latter is usually accomplished through an estimate of the cyclic resistance ratio (CRR). Because of the difficulty of sampling, CRR is generally determined with simplified methods, such as standard penetration test (SPT)-based methods (e.g., Seed and Idriss, 1971; Seed et al., 1985; Youd et al., 2001; Idriss and Boulanger, 2006), cone penetration test (CPT)-based methods (e.g., Robertson and Campanella, 1985; Robertson and Wride, 1998; Juang et al., 2003; Idriss and Boulanger, 2006), and shear wave velocity (V_s)-based methods (e.g., Andrus and Stokoe, 2000).

Although simplified methods based on SPT, CPT, and V_s are well established, and these *in situ* tests are well developed, use of dilatometer test (DMT) for liquefaction resistance evaluation has received a greater attention in recent years (e.g., Monaco et al., 2005, Monaco and Marchetti, 2007). The DMT is capable of measuring horizontal stresses and has an excellent operational repeatability. Thus, any improvement to the existing DMT-based methods for liquefaction resistance evaluation should be of interest to geotechnical engineers.

The focus of this paper is to develop a new DMT-based model for determining liquefaction resistance of soils. Because of the lack of a large database of case histories at sites where DMT measurements are available, the simplified DMT-based model is developed in this study based on a careful examination of the correlations between the DMT parameters and the parameters of the SPT and the CPT. These correlations along with the existing SPT- and CPT-based liquefaction boundary curves (i.e., CRR models) enable the establishment of the DMT-based boundary curves. The developed DMT-based model is then validated with case histories where the DMT measurements are available. These case histories include those published in the literature as well as those obtained in this study.

2. Existing simplified procedures for evaluating liquefaction potential of soils

A brief overview of the existing simplified procedures is presented in this section. The cyclic stress ratio (CSR) is defined by Seed and Idriss (1971). Depending on how the components of the CSR model are formulated, several forms of CSR formulation have been published. The “consensus” of the CSR formulation is described in Youd et al. (2001), and a more recent update is provided by Idriss and Boulanger (2006). Juang et al. (2006) found that the CSR calculated based on the recommendation of Youd et al. (2001) is very comparable with that recommended by Idriss and Boulanger (2006) for case histories they

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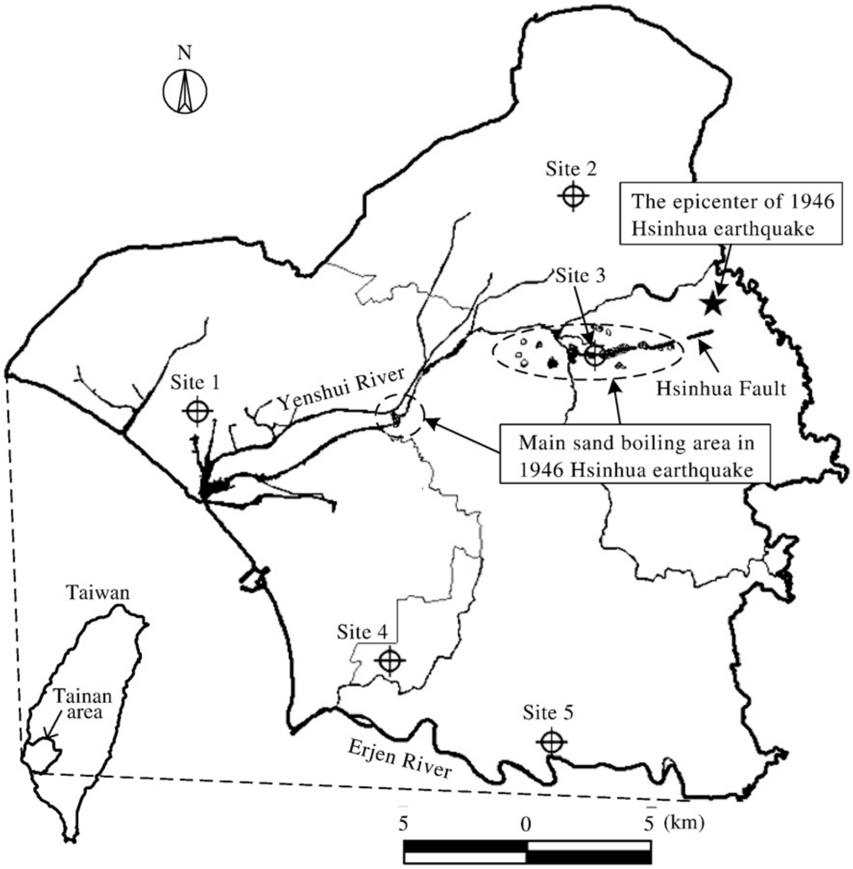

Fig. 1. Layout of five study sites in Tainan.

analyzed. Thus, in this study, the formulation recommended by Youd et al. (2001) is employed.

2.1. Estimate of CRR

The commonly-used SPT- and CPT-based methods as well as the existing DMT-based methods for estimating the CRR are briefly described as follows:

(1) SPT-based methods:

Youd et al. (2001) proposed an update of the CRR curve by Seed et al. (1985), which is expressed as:

$$\mathrm{CRR}_{7.5}=\frac{1}{34-(N_1)_{60\mathrm{cs}}}+\frac{(N_1)_{60\mathrm{cs}}}{135}+\frac{50}{\left(10(N_1)_{60\mathrm{cs}}+45\right)^2}-\frac{1}{200} \tag{1}$$

where $N_{1,60\mathrm{cs}}$ is the clean-sand equivalence of the corrected SPT blow count as per Youd et al. (2001). The subscript 7.5 in the $\mathrm{CRR}_{7.5}$ term indicates that this cyclic liquefaction resistance is evaluated at a moment magnitude of 7.5. Note that Eq. (1) is valid only for $N_{1,60\mathrm{cs}}<30$, while the sandy soil is considered un-liquefiable when $N_{1,60\mathrm{cs}}$ is greater than 30.

Idriss and Boulanger (2006) noted that the trend of the CRR curve proposed by Youd et al. (2001) would sharply increase as the $N_{1,60\mathrm{cs}}$ value approaches 30, which may be irrational and would cause the unreasonable results when conducting the probabilistic analysis. They proposed a new model as follows (Idriss and Boulanger, 2006):

$$\mathrm{CRR}_{7.5}=\exp\left\{\frac{(N_1)_{60\mathrm{cs}}}{14.1}+\left(\frac{(N_1)_{60\mathrm{cs}}}{126}\right)^2-\left(\frac{(N_1)_{60\mathrm{cs}}}{23.6}\right)^3+\left(\frac{(N_1)_{60\mathrm{cs}}}{25.4}\right)^4-2.8\right\}. \tag{2}$$

(2) CPT-based methods:

The CPT-based model proposed by Robertson and Wride (1998) is expressed by:

$$\mathrm{CRR}_{7.5}=0.833\left[\frac{q_{c1N,\mathrm{cs}}}{1000}\right]+0.05 \quad \text{for} \quad q_{c1N,\mathrm{cs}}<50 \tag{3a}$$

$$\mathrm{CRR}_{7.5}=93\left[\frac{q_{c1N,\mathrm{cs}}}{1000}\right]^3+0.08 \quad \text{for} \quad 50\le q_{c1N,\mathrm{cs}}<160 \tag{3b}$$

where $q_{c1N,\mathrm{cs}}$ is the clean-sand equivalence of the corrected cone tip resistance as per Robertson and Wride (1998).

(3) DMT-based methods:

The DMT-based methods for evaluating CRR include those by Marchetti (1982), Robertson and Campanella (1986), Reyna and Chameau (1991), Monaco et al. (2005), Grasso and Maugeri (2006), and Monaco and Marchetti (2007). The more recent development by Monaco et al. (2005), Grasso and Maugeri (2006), and Monaco and Marchetti (2007) are briefly reviewed herein.

Monaco et al. (2005) proposed a new CRR curve based on a study of the correlations between cone tip resistance (q_c) and relative density (Dr), between blow count (N) and Dr, and between DMT horizontal stress index (K_D) and Dr. Their DMT-based model is expressed as follows:

$$\mathrm{CRR}_{7.5}=0.0107K_D^3-0.0741K_D^2+0.2169K_D-0.1306. \tag{4}$$

Grasso and Maugeri (2006) further updated the CRR model by Monaco et al. (2005) into:

$$\mathrm{CRR}_{7.5}=0.0908K_D^3-1.0174K_D^2+3.8466K_D-4.5369 \tag{5a}$$

$$\mathrm{CRR}_{7.5}=0.0308e^{0.6054K_D} \tag{5b}$$

$$\mathrm{CRR}_{7.5}=0.0111K_D^{2.5307}. \tag{5c}$$