Disagreements in Liquefaction Susceptibility Criteria of Fine-Grained Soils and Implications for Design

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Introduction

We define liquefaction-susceptible soils as having a composition (mineralogy) with the potential for large pore pressure generation and strength loss if saturated and sheared undrained in a sufficiently loose state. For many years, the Chinese criteria was used as a means for evaluating liquefaction susceptibility of fine-grained soils. More recently, criteria derived from the performance of laboratory specimens subject to cyclic undrained testing are used in practice. These procedures were developed from differently formulated laboratory testing programs and different soil materials, and the results have some important distinctions that introduce large uncertainties for many projects. Here we summarize different approaches from literature for deriving susceptibility models, describe preferred approaches for modeling purposes, describe a database being generated to facilitate development of improved, next-generation models, and case histories particularly well suited to providing useful insights during model development.

Project Objectives

- Identify the differences between studies on liquefaction susceptibility of fine-grained soils as presented in Table 1 and Figure 2.
- Develop a relational database of laboratory tests performed for liquefaction susceptibility as shown in Figure 1. Introduce high-value new case histories.
- Query the database to develop regressions for liquefaction susceptibility.

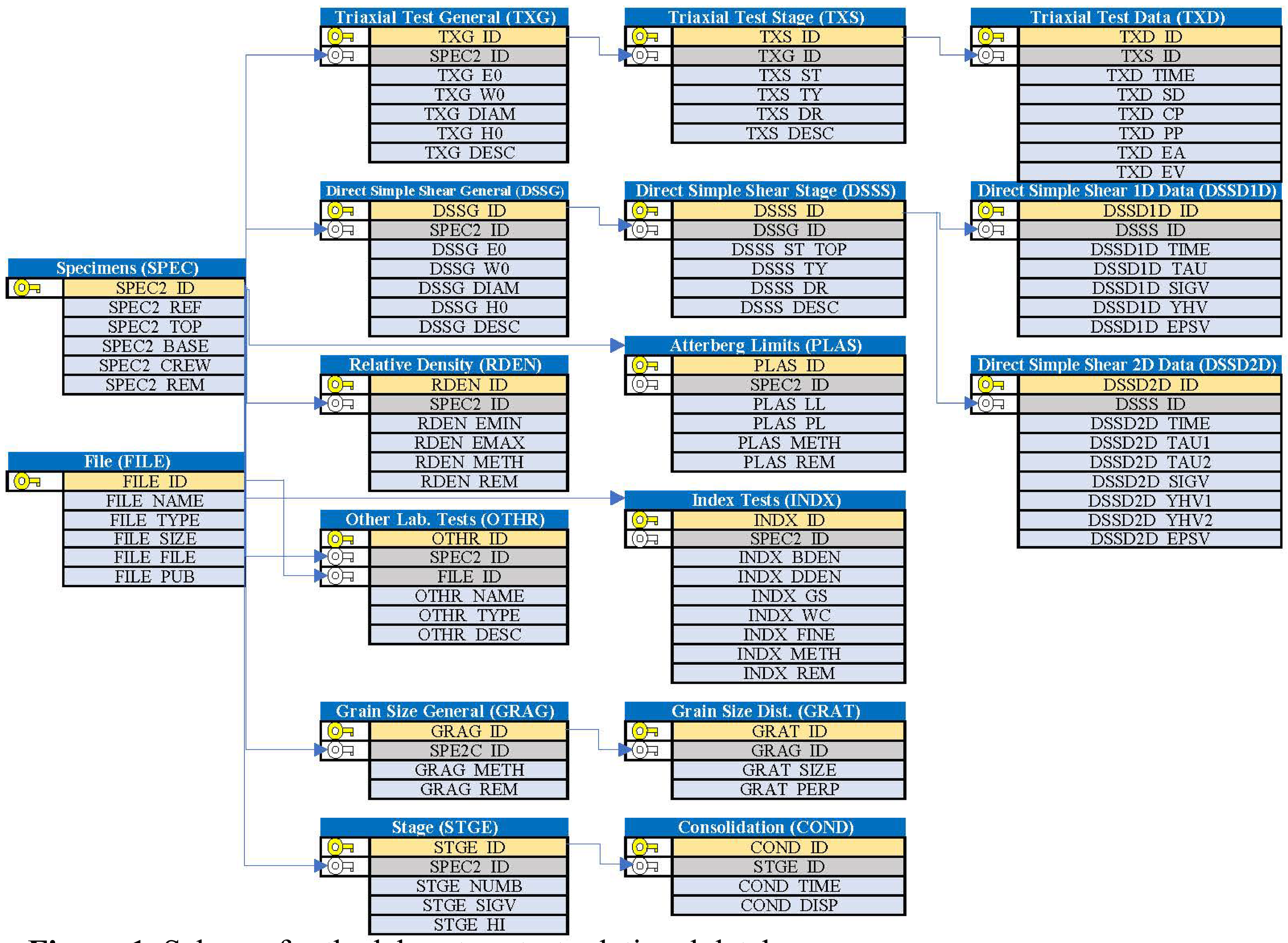

Figure 1. Schema for the laboratory test relational database

Challenges establishing susceptibility criteria from field case histories

- Ground failure can occur without liquefaction and be misidentified as liquefaction, for instance the bearing capacity failures of softened clays in in Wufeng, Taiwan during the 1999 Chi-Chi earthquake (Figure 3).
- Liquefaction can occur without ground failure as evident in the Ishihara (1985) criteria: a thick overlying non-liquefiable layer can prevent ground failure due to liquefaction of an underlying soil layer. Liquefaction can also occur in individual layers but not produce surface manifestation as observed in New Zealand (Cubrinovski et al., 2019)
- Liquefaction susceptibility criteria should not consider state despite the widespread use of water content over liquid limit, w_C/LL, (water content is a state, not a property of the soil that influences susceptibility).

High-Impact New Case Studies

- **Mihama Ward**: A site in Mihama Ward, Japan experienced varying degrees of liquefaction during the 2011 **M**9.1 Tohoku earthquake. The site has loosely deposited hydraulic fill low fines content near the pipes that ejected the material grading to a relatively high fines content away from the pipes. This could give insights into what properties of the soil caused susceptibility to liquefaction and when the susceptibility receded (Figure 4).
- **Searles Lake**: Searles Lake experienced extensive surface manifestation of liquefaction during both the **M**6.4 and **M**7.1 Ridgecrest Earthquakes. Narrow bands of liquefaction were captured using satellite interferometric synthetic aperture radar (InSAR) derived damage proxy maps (Figure 5) and verified in the field (Figure 6). Studying the areas that experienced liquefaction against the surrounding areas that did not could potentially give insights into liquefaction susceptibility and/or triggering.

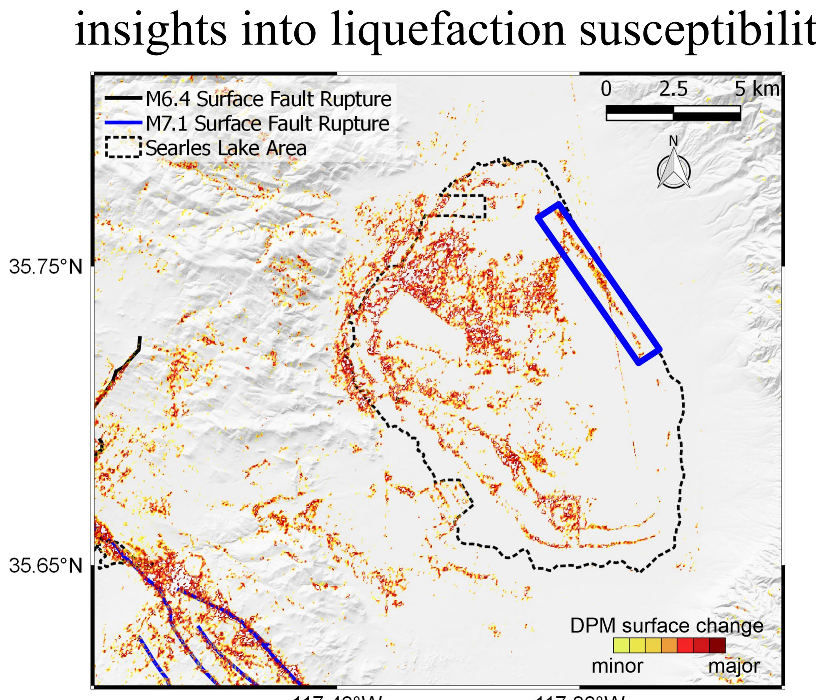

Figure 5. Damage proxy map of Searles Lake

Figure 6. Photograph of Narrow band of ejecta from liquefaction in Searles Lake

Table 1. Comparison of liquefaction susceptibility criteria

Name of Criterion	Basis for Study	Susceptible to Liquefaction if:
Wang "Chinese Criteria" (1979)	Case histories in China	Composition and state: *%CC* and w_C/LL
Modified Chinese Critera, Seed and Idriss (1982)	Case histories in China	Composition and State: *%CC*, *LL*, and w_C/LL
Youd (1998)	Review of Chinese criteria, Koester (1992), and physical considerations	Composition: *USCS*, *LL*, and *PI*
Martin et al. (1999)	None	Composition: *%CC*
Polito (1999)	Laboratory tests on synthetic soil	Composition: *PI* and *LL*
Andrews and Martin (2000)	Case histories in California, China, Japan	Composition: *%CC* and *LL*
Polito and Martin (2001)	Laboratory tests on synthetic soil	Composition: *PI* and *LL*
Seed et al. (2003)	Case histories in Turkey and Taiwan	Composition: *PI* and *LL*
Sancio (2003), Bray and Sancio (2004a,b)	Case histories in Adapazari, Turkey	Composition and State: *PI* and w_C/LL
Bray and Sancio (2006)	Laboratory tests on specimens from Adapazari, Turkey	Composition and State: *PI* and w_C/LL
Boulanger and Idriss (2006)	Laboratory tests on natural soil, soil mixtures, and mine tailings	Composition: *PI*
Bol et al. (2010)	Case histories in Adapazari, Turkey	Composition: *%CC*, *LL*, I_L, D_{50}

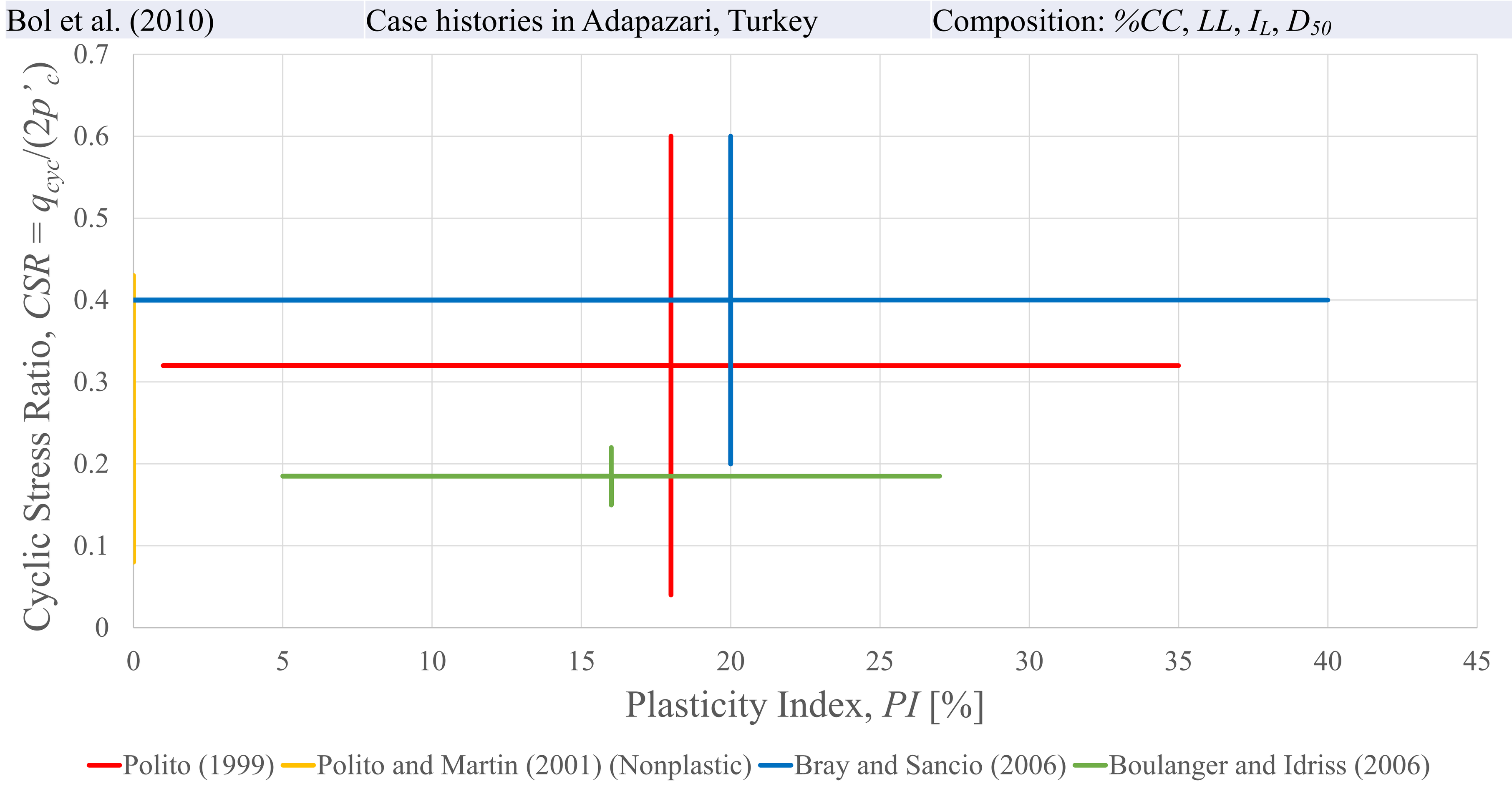

Figure 2. Ranges of PI and CSR for soils that were used to develop several criteria

Figure 3. Ground failure of high plasticity soil in Wufeng, Taiwan (Seed, 1999)

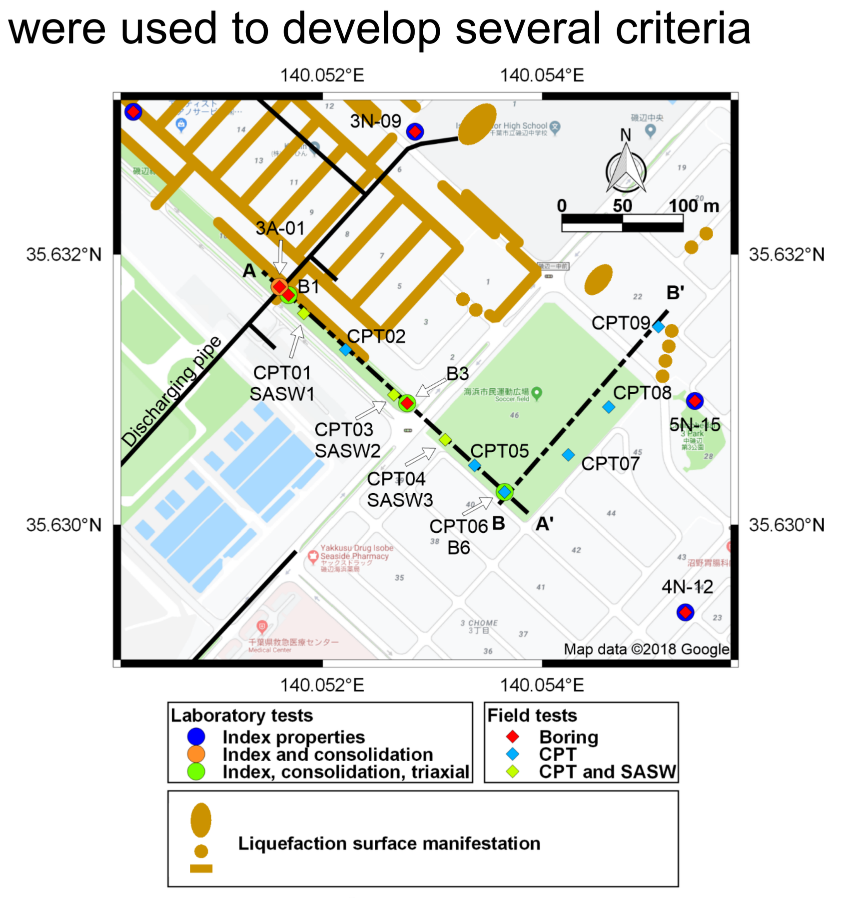

Figure 4. Map of the Mihama Ward site

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