Chapter 1

Introduction

1.1 Research Statement

Seismically induced soil liquefaction is a leading cause of damage and loss during earthquakes. This natural earthquake phenomenon is a function of the liquefaction resistance of the soil in relation to the cyclic stress induced by ground shaking. Liquefaction that occurs in a built-up environment can be a significant human hazard. The objective of this research was to define, in the most accurate and unbiased manner possible, the likelihood of initiation or "triggering" of seismically induced soil liquefaction.

Laboratory testing to assess the liquefiability of *in situ* soils is prone to sampling disturbance problems, and so fails to fully capture some of the more important variables such as prior seismic history, ageing affects, and field stress conditions, to name a few. The correlation of seismic field performance with *in situ* index tests has shown good results in assessment of the likelihood of initiation of liquefaction. The research reported herein presents development of correlations for assessment of liquefaction susceptibility based on use of the Cone Penetration Test (CPT) as the *in situ* index test for correlation.

In order to make the correlation as accurate and unbiased as possible, several important details relating to the interpretation of CPT data had to be worked out. This included the problems of accurate interpretation of CPT measurements in thin interbedded strata, and appropriate normalization of both tip and sleeve resistance measurements for effects of varying effective overburden stress.

A correlation is only as good as the quality of the data upon which it is based. One key objective was to assemble a database of the most highly scrutinized and consistently processed liquefaction and non-liquefaction field case histories available. To achieve this, strict protocols were established for processing and grading case history data according to the quality of information content. This database was then submitted for review to a panel of liquefaction experts.

Proper treatment of the resulting processed and screened data required a flexible and powerful statistical technique. Bayesian analysis provides just such a tool. This statistical technique can accommodate all forms of uncertainty associated with both the phenomena of liquefaction and our attempt to quantify this phenomenon. This technique also has the flexibility to fit any given mathematical form describing the physics of the failure mechanism. Reliability techniques were used to present the results in a probabilistic framework.

1.2 Limitations of Previous Studies

This work was undertaken to fill important gaps that were left by previous, similar CPT-based studies. A comprehensive list of previous work is included in Chapter 6. The most commonly used CPT-based liquefaction triggering correlation to date is that proposed by Robertson & Wride (1998) as presented in NCEER (1997) and Youd et al. (2001). This work provides the most usable and comprehensive CPT-based assessment of liquefaction triggering available. Some of the deficiencies of this work include; lack of a probabilistic assessment for an inherently uncertain problem, inconsistent treatment and processing of some of the field case histories, unconservative assessment of the effects of "fines" on soil liquefiability, and overly simplified treatment of normalization of CPT tip resistance for effective overburden stress effects. The result is a methodology of an undefined level of certainty, and one that is unconservative in soils with significant fines contents.

Other well-known studies, including Shibata & Teparaska (1988), Stark & Olson (1995), Suzuki et al. (1995), all employed a more limited database of field performance case histories than Robertson & Wride (1998). Recent work by Juang et al. (2000, 2003) presents probabilistic results, but uses a database with the same deficiencies as Robertson & Wride (1998).

1.3 Scope

This dissertation is composed of four technical papers and an appendix containing the entire processed CPT-based liquefaction field case history database. Additional chapters were added to include further research details, and to promote continuity.

Following the introduction, Chapter 2 is a technical paper that addresses the issue of thin layer corrections for the CPT. The proper treatment of a thin layer is critical to determining accurate tip measurements in that layer. This pertains to *in situ* measurements as a whole. In liquefaction assessment, thin layer corrections pertain to an embedded layer that has the potential for liquefaction yet an accurate measurement of its tip resistance is skewed by the relative "thinness" of this layer (and the presence of softer soils immediately above and/or below.)

Chapter 3 is a technical paper that describes the state of knowledge regarding normalization of tip and sleeve resistance for effective overburden stress effects. This section presents the use of field, laboratory, and theoretical analysis results to better define the influence that overburden stress has on a particular soil as measured by the CPT.

Chapter 4 outlines the details and protocols that were used in processing field performance case history data for inclusion in the database. It should be noted that although the procedures that were used to produce a consistent and unbiased database are described, this in no way eliminated the need for engineering judgment in assessing and quantifying each individual case history. Engineering judgment, however, was also applied in a democratic manner by employing a review panel to tackle the vagaries of site assessment, and to provide important consensus regarding key parameters.

Chapter 5 describes both conceptually and mathematically the Bayesian analysis approach as it applies to the problem of seismic soil liquefaction. A Bayesian framework proved to be immensely successful in dealing with the myriad forms and sources of uncertainties associated with liquefaction triggering assessment.

Chapter 6 presents the whole suite of liquefaction assessment results. Included is the full processed field case history database (in table format), and the final resulting correlation showing the threshold of liquefaction as contours of probability, deterministic contours accounting for the effects of "fines" on soil liquefiability, and comparison plots showing the results of these studies in relation to previous studies.

Chapter 7 presents the summary and conclusions, as well as recommendations for future work. Appendix A presents the entire field database in detail, with two pages of information for each field case history, including the statistics for each and the appropriate CPT tip and sleeve traces.