Implementing Probability of Liquefaction in Geotechnical Engineering Practice

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Abstract

Empirical Liquefaction Models (ELMs) are the standard approach for predicting the occurrence of soil liquefaction. These models are typically based on in situ index tests, such as the Standard Penetration Test (SPT) and Cone Penetration Test (CPT), and are broadly classified as deterministic and probabilistic models. The deterministic model provides a "yes/no" response to the question of whether or not a site will liquefy for the given conditions, whereas the probabilistic model provides an estimate of the probability of liquefaction (P_L), which is a quantitative and continuous measure of the liquefaction severity.

The recent advances in Performance-Based Earthquake Engineering (PBEE) requires an estimate of the P_L rather than a deterministic (yes/no) estimate for the design. The probabilistic methods were first introduced to liquefaction modeling in the late 1980's by Liao et al. (1988). But such methods are still not consistently used in routine engineering applications. This is primarily due to the limited guidance regarding which model to use, and the difficulty in interpreting the resulting probabilities. The implementation of probabilistic methods requires a threshold of liquefaction (TH_L). The need for a TH_L arises because engineering decisions require the site to be classified as either liquefiable or non-liquefiable. Thus, a site where $P_L < TH_L$ is classified as non-liquefiable and a site where $P_L > TH_L$ is classified as liquefiable. The researchers, who have used probabilistic methods have either come up with subjective TH_L or have used the established deterministic curves to develop the TH_L. However, the importance of the probabilistic approach warrants more objective guidelines for the determination of TH_L.

In this study, I provide a thorough and reproducible approach to interpret P_L using precision and recall and to compute the optimal TH_L that incorporates the costs associated with the risk of liquefaction and the costs associated with risk mitigation using a new metric that I developed called the Precision-Recall (P-R) cost curve. I also provide the P-R cost curves for the popular probabilistic models developed using Bayesian updating for SPT and CPT data by Cetin et al. (2004) and Moss et al. (2006) respectively. These curves should be immediately useful to a geotechnical engineer who needs to choose among different probabilistic ELMs and implement one for design purposes.

P-R Cost Curve:

Figure 1 presents a typical P-R cost curve, which consists of two plots. Figure 1a illustrates the choice of the threshold vs. precision and recall. Precision measures the accuracy of the predictions for a single class whereas, recall measures accuracy of predictions only considering predicted values.

$$\text{Precision} = P = TP/(TP + FP), \qquad \text{Recall} = R = TP/(TP + FN).$$

where the True Positive (*TP)* is the sum of instances of liquefaction correctly predicted, the False Positive (*FP)* is the sum of instances of non-liquefaction classified as liquefaction, and the False Negative (*FN)* is the sum of instances of liquefaction classified as non-liquefaction. For a given probabilistic approach, Figure 1a is developed by varying the threshold from 0 to 1 and by calculating the corresponding precision and recall values for each of these thresholds. Figure 1b presents the optimal TH_L vs. the ratio of the C_{FP} (C_{FP} = cost of predicting a true non-liquefaction instance as liquefaction) to the C_{FN} (C_{FN} = cost of predicting a true liquefaction instance as non-liquefaction) abbreviated as CR. The optimal TH_L is approximated by minimizing the cost

$$\text{Optimal}[TH_L]_j = min\left[FP_i \cdot CR_j + FN_i\right]$$

where i= entire range of threshold from 0 to 1, FP_i and FN_i are number of false positive and false negative values corresponding to i, and the index j takes on the range of the values of *CR* under consideration.

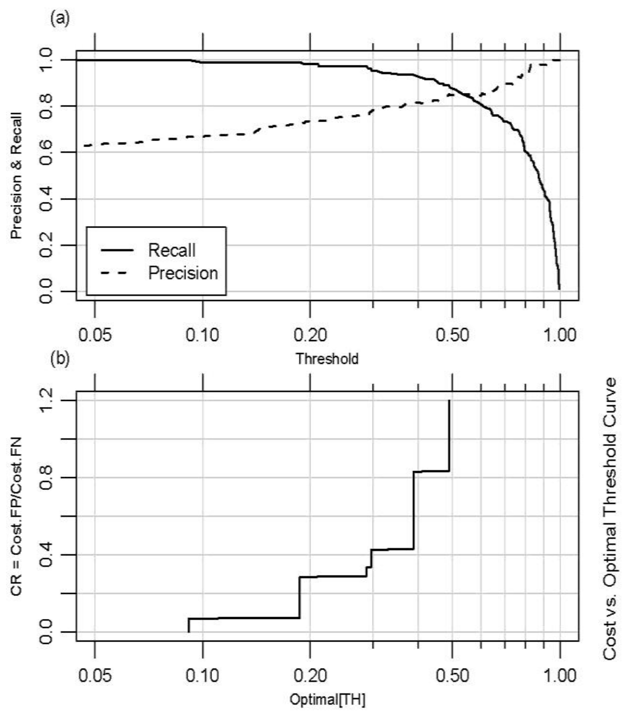

Figure 1: P-R cost curve used to determine the optimal threshold of liquefaction (TH_L) triggering for probabilistic evaluation (a) precision and recall vs. threshold (b) cost ratio vs. optimal TH_L.

Research Contribution to Geotechnical and Geoenvironmental Engineering Industry:

The liquefaction potential of a site is a major design consideration for a geotechnical engineer when dealing with saturated soil conditions. In planning a new project, the owner/investor expects the geotechnical engineer to present the level of liquefaction risk, to help in deciding whether or not to make the investment, or to increase the level of investment to improve its seismic performance and thus decrease the level of potential losses. In such situations, the P-R cost curve provides a comprehensive tool to compute the optimal TH_L for a site, decide whether the site would liquefy or not based on the TH_L, and to quantitatively present the risks associated with that decision. In addition to the probabilistic modeling of liquefaction potential, P-R cost curve can be used for any decision making problem where the cost of the risk and its mitigation can be quantified.

Reference:

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