Implementing Probability of Liquefaction in Geotechnical Engineering Practice

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Basic Definitions

- Process of changing a saturated cohesionless soil from a solid to liquid state due to increased pore pressure

Questions to the geotechnical engineer *(Seed 1987)*

- Given a likely seismic event, is the soil prone to liquefy?
- If liquefaction occurs, what consequences can be expected in terms of ground displacement?

Reference

Seed, H.B., Design problems in soil liquefaction, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, **Vol. 113(8), p.827-845**, 1987.

Empirical Liquefaction Models (ELMs)

In situ tests

- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- Shear wave velocity (Vs)
- Becker penetration test

Types of ELMs

- Deterministic: ”yes/no”
- Probabilistic: 0 to 1

Performance Based Earthquake Engineering (PBEE)

Deterministic ELMs

- Do not provide guidance for selection of sites
- Do not provide guidance for retrofitting

Probabilistic ELMs

- Introduced in late 1980's
- Preferred for PBEE, where decision has to be more quantitative
- Provides quantitative measure of the liquefaction severity

Current Limitations

Probabilistic ELMs

- Not consistently used in routine engineering applications
- Lack of guidance in interpreting the resulting probabilities
- Requires a threshold of liquefaction (TH_L)

Guidelines for TH_L

- Subjective *(Juang et al. 2002)*
- Based on the deterministic curve *(Cetin et al. 2004; Moss et al. 2006)*

References

Cetin, K. O., Seed, R. B., Der Kiureghian, A., Tokimatsu, K., Harder, L. F., Kayen, R. E., and Moss, R. E. S., Standard penetration test-based probabilistic and deterministic assessment of seismic soil liquefaction potential, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, **Vol. 130(12), p.1314-1340**, 2004.

Juang, C. H., Jiang, T., and Andrus, R. D., Assessing probability-based methods for liquefaction potential evaluation, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, **Vol. 128(7), p.580-589**, 2002.

Moss, R. E. S., Seed, R. B., Kayen, R. E., Stewart, J. P., Kiureghian, A. D., and Cetin, K. O., CPT-based probabilistic and deterministic assessment of in situ seismic soil liquefaction potential, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, **Vol. 132(8), p.1032-1051**, 2006.

Threshold of Liquefaction (TH_L)

Example

- Moss et al. (2006) recommend TH_L=0.15, where $P_L < TH_L$ is classified as non-liquefiable and a site where $P_L > TH_L$ is classified as liquefiable
- 3 sites with P_L= 10, 12.5, & 17.5%

Questions an investor would pose to a geotechnical engineer

- How confident we are with the decision that the site with P_L = 12.5% will not liquefy?
- Is it worth investing in a site that has P_L = 10% over a site that has P_L = 12.5%?
- The current literature does not provide guidance on how to answer some of these questions

Precision & Recall

$$\text{Precision} = TP/(TP + FP)$$
$$\text{Recall} = TP/(TP + FN)$$

True Positive (TP) = count of instances of liquefaction correctly predicted

False Positive (FP) = count of instances of non-liquefaction classified as liquefaction

False Negative (FN) = count of instances of liquefaction classified as non-liquefaction.

What it means for liquefaction?

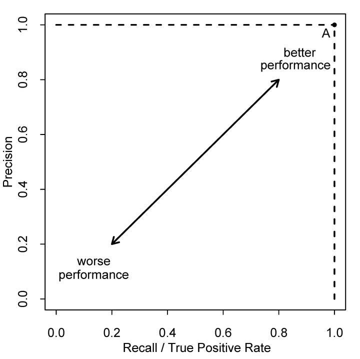
Precision of 1.0 = every case that is predicted as liquefaction experienced liquefaction, but this does not account for instances of observed liquefaction that are misclassified as non-liquefaction.

Recall of 1.0 = every instance of observed liquefaction is predicted correctly by the model, but this does not account for instances of observed non-liquefaction that are misclassified liquefaction.

How to Adapt Precision & Recall for Probabilistic ELMs?

- Calculate precision and recall by varying the TH_L from 0 to 1

Idealized precision-recall curve

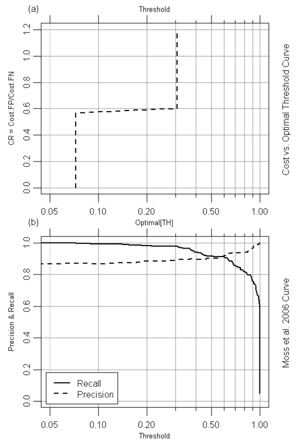


Precision-Recall (P-R) Cost Curve

Choosing the optimal threshold

$$Optimal[TH_L]_j = min[FP_i \cdot CR_j + FN_i]$$

i= entire range of threshold from 0 to 1,
FP_i = count of false positive
FN_i = count of false negative
$CR_j = (C_{FP})_j / C_{FN}$
C^*_{FP} = cost for site mitigation
C^*_{FN} = cost incurred in the event of liquefaction
* can be computed based on the PBEE recommended decision variables, the three D′s (Krawinkler, 2004).



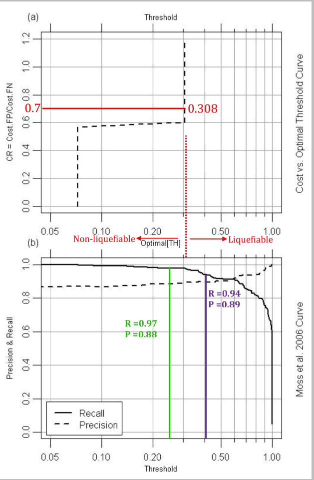
Reference

Krawinkler, H., Exercising performance-based earthquake engineering, *Proceedings of the Third International Conference on Earthquake Engineering*, **p.212-218**, 2004.

Case Study

Steps to use P-R cost curve

- Let us assume 2 cases with CR = 0.7
- CPT data is available from the site
- Choose Optimal[TH] = 0.308
- Case-1: P_L = 25%
- $P_L <$ Optimal[TH] : Case non-liquefiable
- R=0.97 : 3% chance the decision that site will not liquefy is wrong
- Case-2: P_L = 40%
- $P_L >$ Optimal[TH] : Case liquefiable
- P=0.89 : 11% chance the decision that site will liquefy is wrong



In Review

Oommen, T., Baise, L.,and Vogel, R., Objective Validation and Application of Empirical Liquefaction Models, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, **Vol. x(xx), p.xx-xx**, xxxx.

Conclusion

How does P-R cost curve help geotechnical engineers?

- It provides a comprehensive tool to compute the optimal TH_L
- It helps to decide whether the site would liquefy or not based on the optimal TH_L
- It helps to quantify the risks associated with that decision

In addition

- P-R cost curve tool developed in this study presents a framework that can be used for any probabilistic decision making problem where the cost of risk and its mitigation can be quantified