The Improvement of Field Tests Used for the Evaluation of a Soil's Liquefaction Resistance

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Abstract

A phenomenon of earthquakes known as liquefaction can cause severe damage and deformation to areas near an earthquake. Because of this, a focus of geotechnical engineering is the mitigation of these effects. In order for liquefaction's effects to be best mitigated, the desired soil's liquefaction resistance must be evaluated. The evaluation of a soil's liquefaction is based on a curve called the CRR curve, which is typically developed from a particular aspect of one of the four main field tests used for the evaluation of a soil's liquefaction resistance. However, these curves do not always lead to the accurate evaluation of a soil's liquefaction resistance, and as a result, many revisions have been made over time to the CRR curves and the tests used to develop these curves in the hopes of best evaluating soils' liquefaction resistance. While these revisions have led to more accurate CRR curves, there are still cases in which these curves lead to the inaccurate evaluation of a soil's liquefaction resistance, which suggests that future revisions can be made. This proposal strives to determine which test aspects are in most need of improvement in order to promote the continued improvement of a soil's liquefaction resistance evaluation.

Introduction

As one of the natural disasters of the world, earthquakes have been, are, and will continue to be of great concern because of their ability to cause significant damage to Earth and the structures built on and near the places at which they occur. Particularly, the phenomenon known as liquefaction can be the cause of significant damage. But what exactly is liquefaction? Imagine a person walking on a dirt path, and suddenly the path turned into water. While this is a simplified and dramatic representation of what happens during liquefaction, the concept still applies; liquefaction involves solid ground exhibiting liquid-like properties. From a technical standpoint, the term "liquefaction" has been used in multiple ways (Kramer 1996, Boulanger and Idriss 2004), yet in more easily understandable terms, liquefaction refers to a soil that "flows in a manner resembling a liquid" for a period of time, which is due to a reduction in the soil's ability to resist shear stresses, a type of stress that earthquakes cause (Castro et al. 1982). Thinking about the example of dirt turning into water, it is clear that the water could not support the weight of the person like the dirt could. Thus, because of this lack of support, if an area of ground starts to flow like a liquid, serious problems can occur.

While liquefaction is quite dense in terms of the technical knowledge necessary to understand its occurrence, it can be explained definitively. However, there is a variety of factors that influence a soil's resistance to liquefaction (Kramer 1996), and these factors cause the evaluation of a soil's resistance to liquefaction to be very individualized and complicated.

Background/Related Work and Motivation

A soil's liquefaction resistance is evaluated based on the estimation or calculation of two variables: the cyclic stress ratio (which expresses the seismic load on the soil) and the cyclic resistance ratio (the ability of a soil to resist liquefaction) (Youd et al. 2001). To determine a soil's resistance to liquefaction, it is placed on a graph that contains a cyclic resistance ratio (CRR) curve. A soil that falls above this curve on the graph is considered as significantly susceptible to liquefaction, whereas a soil that falls below this curve is considered as not susceptible (Youd et al. 2001). In order to create CRR curves, soils that are known to have undergone liquefaction during past earthquakes (commonly referred to as case history sites) are tested in various ways, which I will address shortly, and are then placed on their respective graphs (Seed et al. 1983, Kramer 1996). Once enough case history data has been gathered, CRR curves can be proposed for the particular parameters used to construct the graph.

There are four main tests used to evaluate a soil's liquefaction resistance: the standard penetration test (SPT), the cone penetration test (CPT), shear-wave velocity measurements (Vs), and the Becker penetration test (BPT) (Youd et al. 2001). Each of these tests collects data for the soil tested—for the SPT, one data parameter is the number of blows needed until a certain depth has been penetrated (Seed et al. 1985)—and this data is noted with the soil characteristics, such as its fines content, granular density, stiffness, damping, and void ratio (Kramer 1996).

Considering that there are multiple aspects of these tests that can be used as parameters, there are multiple CRR curves that are based on these parameters as well as other parameters, such as the magnitude of an earthquake or the fines content of a soil (the percent of soil particles smaller than .075 mm (Ueng et al. 2004)). These curves have been developed based on the parameters and correction factors that have been determined through the research and testing of soils (Youd et al. 2001, Idriss and Boulanger 2006), always keeping note of the characteristics of the soil tested as well as the data collected from the particular test or tests used on that soil. Despite the numerous CRR curves that have been developed, some soils that have plotted below their respective curve have experienced liquefaction while others that have plotted above their respective curve have not (Youd et al. 2001). These data points demonstrate that some CRR curves are not perfectly calibrated and can inaccurately suggest whether a soil is susceptible or resistant to liquefaction.

Since some CRR curves lead to inaccurate evaluations of certain soils' liquefaction resistance, this suggests that at least some factors that are used to place a soil on a particular CRR curve graph must need revision of some kind (Seed et al. 1985, Youd et al. 2001, Seed et al. 2003). Specifically, the tests that are used to evaluate a soil's liquefaction should be the first place to look for improvement, because a large portion of CRR curves are graphed according to CRR vs. some parameter of a particular test or CRR vs. some correction factor associated with a test parameter. As a result, much work has already been done to revise these tests and CRR curves, and some of those who have made these revisions have also called for further revisions to be made (Seed et al. 1983, Seed et al. 1985, Youd et al. 2001, Seed et al. 2003, Idriss and Boulanger 2006). Because the improvement of the four main tests and CRR curves will help engineers better evaluate a soil's liquefaction resistance, a key question must be answered to continue to improve their accuracy: Which aspects of which tests are most likely in need of improvement, and in what ways can these aspects most likely be improved?

Methods

To answer this question, I will gather as many sources as possible that contain evidence of a revision to at least one test aspect of one of the four tests listed above. In doing so, I will gain a more complete understanding of what revisions have been made as well as when, why, and how they have been made. I plan to work for 4 hours a day, searching for sources and then briefly commenting on what, when, why, and how a particular revision was made. I hope to log at least 30 sources over the course of 10 days, which puts me at an average of 3 sources per day.

I anticipate that each source I find will contain an average number of revisions of 2.5 +/- 0.5, leaving me with an estimated 75 +/- 15 total revisions found. The first places I will look for sources will be the Hannon Library and its databases and the American Society of Civil Engineers (ASCE) library and its databases. I believe that the ASCE library and its databases will provide the majority of my references since it focuses on civil engineering and has organized searches for each subgenre of civil engineering, such as geotechnical engineering. With this strategy and goal for my search, I feel confident that I will collect enough evidence to provide an accurate depiction of the previous revisions that have been made to particular test aspects as well as an accurate suggestion of which aspects most likely need improvement.

Expected Results

From my research, I will produce a paper detailing the test aspects that most likely need improvement and the ways in which these aspects might be best investigated for improvement. In this paper, the most notable feature will be a table that counts the number of times a particular aspect of a test has been revised. The purpose of this table is to keep an organized record of previous revisions for each test aspect that allows for all test aspects to be easily compared to each other and within the particular test that they belong to. I expect that there will indeed be test aspects that seem to need improvement, that the ones that most likely need improvement will be those that have been least revised, and that the ways in which these can be improved will be through their use on case history sites for which the results will be analyzed by professionals.

Conclusion

Liquefaction's potential to cause damage and deformation to areas near an earthquake requires engineers to work on mitigating these negative effects, and the accurate evaluation of a soil's liquefaction is the first step in best mitigating liquefaction's effects. Yet the CRR curves used to evaluate a soil's liquefaction resistance are not perfect, and although the CRR curves and the four main tests used to evaluate a soil's liquefaction resistance have been revised, further revisions are necessary for the development of the most accurate liquefaction resistance evaluation. Through my research, I hope to determine which test aspects most likely need revision so I can help direct professionals to investigate these test aspects. In their use and analysis of these tests and test aspects, I hope that these professionals will be able to further refine the accuracy of the tests and CRR curves that are used in the evaluation of a soil's liquefaction resistance so engineers will know where to direct their mitigative efforts.

References

Adalier, K., Elgamal, A. (2004). "Mitigation of liquefaction and associated ground deformations by stone columns." *Engineering Geology*, 72(3-4), 275-291.

Bao et al. (2019). "Soil liquefaction mitigation in geotechnical engineering: An overview of recently developed methods." *Soil Dynamics and Earthquake Engineering*, 120, 273-291.

Boulanger, R. W., Idriss, I. M. (2004). *Evaluating the Potential for Liquefaction or Cyclic Failure of Silts and Clays,* Department of Civil & Environmental Engineering, University of California Davis, Davis, California.

Castro et al. (1982). *Liquefaction Induced by Cyclic Loading*, Geotechnical Engineers Inc., Winchester, Massachusetts.

Idriss, I. M., Boulanger, R. W. (2006). "Semi-empirical procedures for evaluating liquefaction potential during earthquakes." *Soil Dynamics and Earthquake Engineering,* 26(2-4), 115-130.

Kramer, S. (1996). *Geotechnical Earthquake Engineering*, Prentice-Hall Inc., Upper Saddle River, New Jersey.

Li, X. S., Wang, Y. (1998). "Linear Representation of Steady-State Line for Sand." *Journal of Geotechnical and Geoenvironmental Engineering*, 124(12).

Seed et al. (1983). "Evaluation of Liquefaction Potential Using Field Performance Data." *Journal of Geotechnical Engineering*, 109(3), 458-482.

Seed et al. (1985). "Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations." *Journal of Geotechnical Engineering*, 111(12), 1425-1445.

Seed et al. (2003). "Recent Advances in Soil Liquefaction Engineering: A Unified and Consistent Framework." *Proceedings of the 26th Annual ASCE Los Angeles Geotechnical Spring Seminar*, College of Engineering University of California, Berkley, Long Beach, California.

Ueng et al. (2004). "Definition of fines and liquefaction resistance of Maoluo River soil." *Soil Dynamics and Earthquake Engineering*, 24(9-10), 745-750.

Youd et al. (2001). "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils." *Journal of Geotechnical and Geoenvironmental Engineering*, 127(10), 817-833.

Budget/Timeline

The general plan for research has been given above in the Methods section. To more specifically explain that plan, I will break down the dates and times that I plan to do my research, as well as the stipend I request as a part of this research.

I plan to work 5 days a week for 2 consecutive weeks after the 2021 Spring Semester has ended. The proposed dates are June 7th – June 11th and June 14th – June 18th. Each day, I plan to work from 9:00 AM – 1:00 PM. My work will consist of finding sources that contain evidence of revision to at least one of the aspects of one of the tests and then noting when, why, and how this revision took place. I request a stipend totaling $600, which is based on a $15 per hour rate. Thus, with this rate of $15 per hour, 4 hours per day, and 10 days, the total will be $600. Any time I spend outside of the 40 hours dedicated to this research will not be considered to apply to the work the stipend has been allocated for.