SPLiq: A New Performance-Based Assessment Tool for Liquefaction Triggering and its Associated Hazards using the SPT

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ABSTRACT
Performance-based analysis procedures for liquefaction and several of its effects have been presented in the literature by many researchers in recent years. Unfortunately, these procedures are difficult for most engineers to implement on routine geotechnical engineering projects because of their computational rigor in the consideration of the uncertainties associated with seismic loading, soil property characterization, liquefaction triggering, and prediction of various liquefaction effects (e.g., lateral spread, free-field settlement). Simplified performance-based analysis procedures have been developed in recent years as a solution to this challenge. This paper introduces a new analysis spreadsheet for the standard penetration test named *SPLiq* (Simplified Probabilistic Liquefaction Analysis Tool) that incorporates recently developed simplified performance-based analysis procedures for liquefaction triggering, lateral spread displacement, free-field post-liquefaction settlement, and seismic slope stability. When coupled with liquefaction reference parameter maps, *SPLiq* is a powerful yet convenient analytical resource that can closely approximate the results from a full performance-based liquefaction hazard assessment at three different return periods. In this paper, *SPLiq* is described and the simplified performance-based procedures that it incorporates are briefly summarized. An example application of the spreadsheet is presented and discussed. Limitations of the spreadsheet are also presented and discussed. Directions for obtaining *SPLiq* for use in design are also provided.

1 INTRODUCTION

Much research effort has been exercised on developing improved prediction models for liquefaction triggering hazard and its associated effects including lateral spread displacement, post-liquefaction settlement, and seismic slope stability. This effort is good and necessary to reduce epistemic uncertainty in the prediction of liquefaction-related hazards. However, all of these improved prediction models developed for liquefaction triggering and its effects generally treat the input ground motion as a known parameter, which it certainly is not in the case of *a priori* design. To account for uncertainty (both epistemic and aleatory) in the ground motions used in a liquefaction hazard analysis, engineers have relied upon probabilistic seismic hazard analysis (PSHA) to produce probabilistic ground motion estimates.

Over the past twenty years, most engineers have adopted a simplified technique to incorporate probabilistic ground motions from a PSHA into a liquefaction hazard analysis. This approach involves specifying a single return period or hazard level for design (commonly a return period of 2,475 years), obtaining the ground motions associated with the return period from the uniform hazard response spectrum, and using the probabilistic deaggregation results for that ground motion to produce estimates of earthquake moment magnitude and/or source-to-site distance to use in liquefaction and lateral spread hazard analyses. The resulting probabilistic ground motion and corresponding moment magnitude and/or source-to-site distance are used deterministically in a liquefaction hazard analysis. This technique has been termed the "pseudo-probabilistic" approach (Rathje and Saygili 2008), and has been shown by many researchers (e.g., Kramer and Mayfield 2007; Juang et al. 2008; Rathje and Saygili 2008; Mayfield et al. 2010; Franke et al. 2014a,b; Franke and Kramer 2014) to produce inaccurate and inconsistent hazard estimates of liquefaction and its effects across different seismic environments. Unfortunately, the pseudo-probabilistic approach is widely adopted and specified or implied in many of the current seismic design provisions.

Many researchers have introduced probabilistic or "performance-based" methods of analyzing ground deformation hazards to offset the undesirable effects and inaccuracies introduced by the common pseudo-probabilistic approach (e.g., Kramer and Mayfield 2007, Juang et al. 2008; Rathje and Saygili 2008; Franke and Kramer 2014; Kramer et al. 2014). Unfortunately, these performance-based methods require numerous probabilistic calculations and iterations, which are difficult for most engineering practitioners to apply on routine engineering projects. Simplified performance-based methods (e.g., Mayfield et al. 2010; Rathje and Saygili 2011; Franke et al. 2014b; Ekstrom and Franke 2016; Ulmer and Franke 2016; Franke et al. 2016) have been introduced to closely approximate the results of a performance-based analysis at a desired return period, thus allowing engineering practitioners to enjoy the benefits of a performance-based approach without the “pain” associated with the numerous probabilistic calculations that would have otherwise been required.

This paper introduces a new computational spreadsheet for the implementation of simplified performance-based methods in engineering design to compute liquefaction triggering, lateral spread displacement, free-field post-liquefaction settlement, and seismic slope stability hazards using the standard penetration test (SPT). The spreadsheet is called Simplified Probabilistic Liquefaction Analysis Tool, or *SPLiq*. The spreadsheet is being developed as part of a Federal Highways Administration (FHWA) Transportation Pooled Fund Study involving the state departments of transportation from Utah (lead), Alaska, Connecticut, Idaho, Montana, Oregon, and South Carolina (TPF 2016). This paper will provide a very brief introduction of *SPLiq* and the simplified performance-based analysis method that it incorporates. An overview of the spreadsheet will be provided, and a brief demonstrative example analysis will be presented.

2 OVERVIEW OF THE SIMPLIFIED PERFORMANCE-BASED APPROACH

Due to space limitations, it is impossible to provide a detailed review and summary of the simplified performance-based liquefaction hazard analysis methods that *SPLiq* incorporates. The interested reader is referred to original sources in the literature (Mayfield et al. 2010; TPF 2016; Ekstrom and Franke 2016; Ulmer and Franke 2016; Franke et al. 2016; Franke et al. 2017) to learn the background and specific equations involved with these methods. Instead, this paper will generally focus on the overall basis and methodology that comprises the simplified performance-based approach.

The simplified performance-based approach relies upon two critical assumptions: 1) uncertainties related to the ground motions and the liquefaction hazard can be accounted for through a previously-performed performance-based analysis of the site or region using a uniform “reference” soil profile and site geometry, and 2) the reference performance-based analysis results can be adjusted or corrected for actual site conditions (i.e., soil profile and site geometry) with a linear of log-linear correction function to closely approximate the results that would have been obtained if a site-specific performance-based analysis had been performed.

The first assumption cited above is the key that simplifies the methodology and allows it to be applied in a practical manner on most engineering design projects. Uncertainties related to ground motions and liquefaction hazard must be accounted for, and the only way to account for them is through a full performance-based analysis. However, if this analysis can be performed ahead of time by the researchers using a reference set of site conditions, then the results of the analysis can be compiled and mapped for different return periods of interest. These maps are referred to as reference parameter maps (Franke et al. 2016), and are the starting point for the simplified performance-based method.

The second assumption cited above relates to the idea that reference performance-based results can be corrected for site-specific soil and topographic conditions. This idea is not new, and has been applied with the US Geological Survey (USGS) National Seismic Hazard Maps since 2002, in which ground motions corresponding to a reference bedrock material with average shear wave velocity $V_{s,30} = 760$ meters per second are corrected for local site conditions using a site amplification factor that accounts to some degree for site response effects based on a generalized site classification. With the simplified performance-based liquefaction hazard methodology, the pseudo-probabilistic assumption is used to compute a correction function as:

$$\Delta = y_{site,PP} - y_{ref,PP} \tag{1}$$

where Δ is the correction function, $y_{site,PP}$ is the liquefaction or effects value computed by the engineer using site-specific input and the pseudo-probabilistic assumption for input ground motions, and $y_{ref,PP}$ is the liquefaction or effects value computed by the engineer using the reference site conditions and the pseudo-probabilistic assumption for input ground motions. Once Δ is computed, then it can be applied to produce performance-based hazard estimates as:

$$y_{site,PB} = y_{ref,PB} + \Delta \tag{2}$$

where $y_{site,PB}$ is the approximated site-specific performance-based hazard estimate, and $y_{ref,PB}$ is the reference performance-based hazard value obtained from the appropriate reference parameter map.

From Equations (1) and (2), it can be seen that the pseudo-probabilistic assumption is used to estimate the correction function for the performance-based liquefaction hazard. It is important for the reader to understand that the using the pseudo-probabilistic approach to estimate Δ does not introduce egregious error into the approximation of the site-specific performance-based hazard estimate. Recent studies have shown that the approximated hazard estimates from the simplified performance-based method generally fall within ±5% of the full site-specific performance-based hazard estimates for more than 85% of the cases that were evaluated (TPF 2016). Furthermore, using the pseudo-probabilistic assumption to estimate the correction function is much different than using the pseudo-probabilistic assumption to directly approximate the full performance-based hazard values, as is performed by most engineers today. Such an approach does not take into consideration ground motions from other return periods other than the target return period, nor does it take into account uncertainty associated with the liquefaction hazard.

3 *SPLIQ*: A TOOL FOR THE SIMPLIFIED PERFORMANCE-BASED ASSESSMENT OF LIQUEFACTION HAZARD

SPLiq was developed as a user-friendly tool to implement simplified performance-based liquefaction analysis methods in a practical manner for engineering design. It was developed using Microsoft *Excel*®, and is compatible with *Excel 2010* and later. *SPLiq* uses raw SPT field values to provide probabilistic estimates of liquefaction triggering, post-liquefaction free-field settlement, lateral spread displacement, and Newmark seismic slope displacement for return periods of 475, 1033, and 2475 years. The spreadsheet requires input from one or more reference parameter maps for the hazard(s) of interest, and is therefore not a stand-alone analysis tool. This section will briefly discuss several of the analysis options that *SPLiq* offers to users, a description of the various worksheets in the spreadsheet, and the type and format of the output that is produced. A screenshot of *SPLiq* Version BETA 1.9 is presented in Figure 1.

3.1 Analysis Options

SPLiq offers the user significant flexibility and options in performing a liquefaction hazard analysis. The spreadsheet is capable of running both a simplified performance-based (i.e., probabilistic) analysis and a user-defined deterministic analysis. Results from these two types of analyses are prepared on different output sheets to assist the engineer in making comparisons between the two. For the simplified performance-based analysis, the user currently can specify a return period of 475, 1033, or 2475 years. However, if the user desires to analyze a different return period, then he/she simply needs to provide the input from an appropriate reference parameter map.

Liquefaction triggering can be evaluated in *SPLiq* using Boulanger and Idriss (2012, 2014) model and/or the Cetin et al. (2004) model for the SPT. All specified field SPT blowcounts are automatically corrected in the spreadsheet for energy efficiency, rod length, sampler type, borehole diameter, hammer drop height, overburden pressure, and fines content. The spreadsheet allows the user to manually specify liquefaction susceptibility for each soil layer and an age correction factor (Hayati and Andrus 2009), though *SPLiq* does not currently calculate the latter automatically for the user. *SPLiq* allows the user to specify whether the analysis should use the SPT-independent magnitude scaling factor (MSF) presented in Boulanger and Idriss (2012), or the SPT-dependent MSF presented in Boulanger and Idriss (2014). The spreadsheet also allows the liquefaction triggering results (both performance-based and user-specified deterministic) to be expressed either as a factor of safety or a probability of liquefaction.

Post-liquefaction free-field settlement is computed in *SPLiq* using the Ishihara and Yoshimine (1992) laboratory-based volumetric strain curves with the

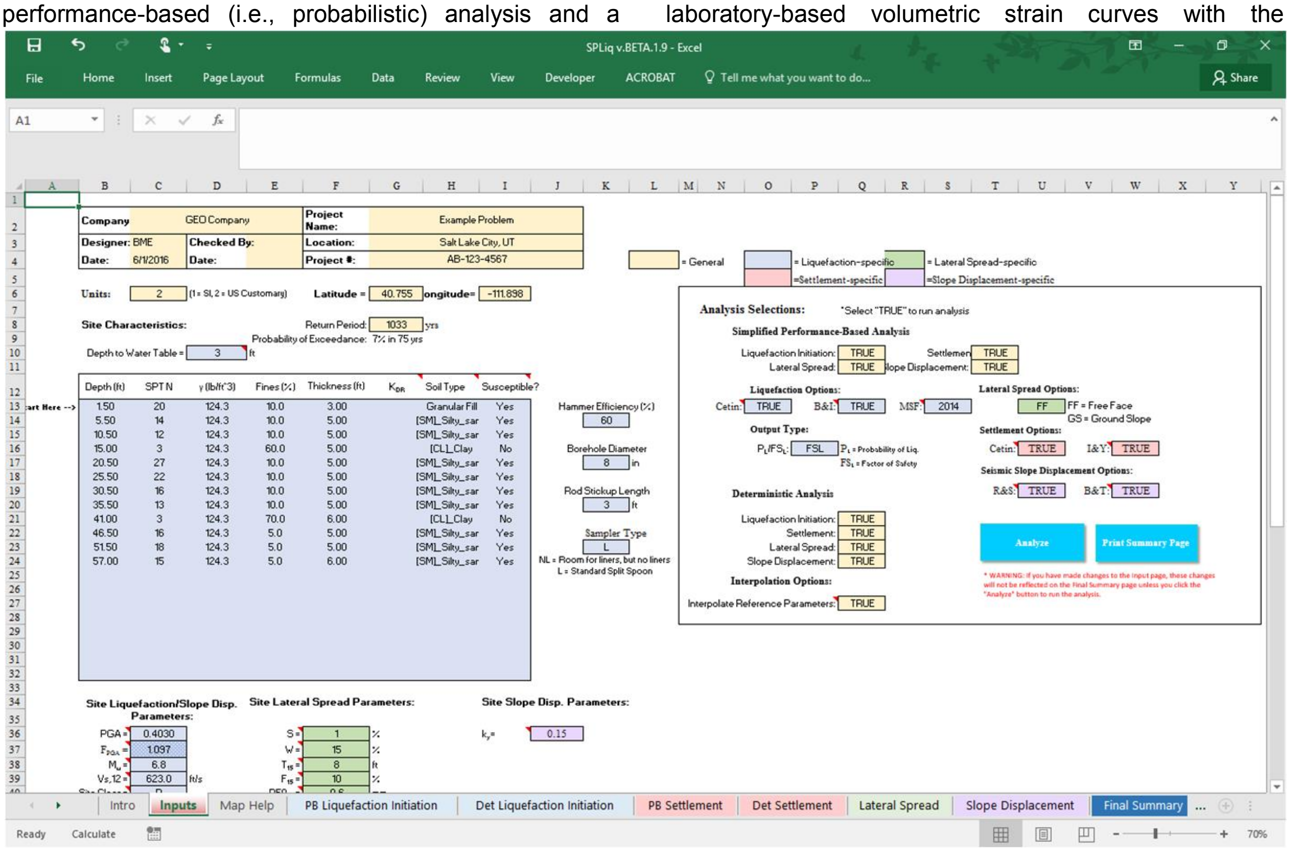

Figure 1. Screenshot of the Inputs worksheet on *SPLiq* version Beta 1.9

Boulanger and Idriss (2012, 2014) liquefaction triggering results, and the Cetin et al. (2009a) laboratory-based volumetric strain curves with the Cetin et al. (2004) liquefaction triggering results. The spreadsheet also applies a correction to the computed results from each method based on calibrations against actual free-field settlement case histories observed from the field (Cetin et al. 2009b). The spreadsheet does not account for any other potential vertical deformation mechanisms in the soil such as bearing capacity failure, volumetric strain due to sand ejecta, or soil-foundation-structure interaction (Dashti et al. 2010a,b). Therefore, the predicted settlements only apply to free-field conditions and must be considered with careful engineering judgment if being applied to soil located beneath structures of embankments.

SPLiq estimates both performance-based and user-defined deterministic lateral spread displacements with the Youd et al. (2002) empirical model for the SPT. The user must manually define the various inputs into the model including the cumulative thickness of the lateral spreading layer (T_{15}), the average fines content of that cumulative layer in percent, (F_{15}), the mean grain size of that cumulative layer in mm ($D50_{15}$), and either the slope gradient (*S*) or the free-face ratio (*W*). *SPLiq* will allow the user to analyze either a free-face site geometry or a ground slope site geometry, but it will not analyze both simultaneously.

Finally, *SPLiq* performs performance-based and deterministic Newmark seismic slope displacement calculations using the simplified rigid-block models presented by Bray and Travasarou (2007) and Rathje and Saygili (2009). To use these models, the user simply needs to define a constant yield coefficient for the slope. However, because the analysis is based in the rigid block assumption with a constant yield coefficient, the user should be cautious and understand that the analysis is modeling what is often a very complex and dynamic phenomenon with a rather simplistic model. As such, the user may benefit from using the seismic slope displacement estimates as a relative index or indicator of slope deformation potential rather than a predictor of actual deformations.

3.2 Worksheets

SPLiq is currently comprised of 12 worksheets that the user can access and utilize in the performance-based liquefaction hazard analysis. This section will briefly describe the purpose and content of each worksheet.

3.2.1 Intro

This worksheet documents the spreadsheet title, authors, and version number. This spreadsheet version should be referenced when citing *SPLiq* in a technical report or article.

3.2.2 Inputs

This worksheet is the control center for *SPLiq,* and is where the user will specify most of the analysis options.

Inputs related to project information, geotechnical information, SPT hammer information, geographic coordinates, topographic information, and seismic loading information are organized according to color, and are tied to specific hazards. The user can specify either metric or English units for both the inputs and the outputs. Performance-based and/or deterministic analysis of liquefaction triggering, lateral spread displacement, post-liquefaction free-field settlement, and Newmark seismic slope stability can be initiated from this worksheet. The various models incorporated into the analysis can also be specified and selected on this worksheet. A screenshot of the Inputs worksheet is shown in Figure 1.

3.2.3 Map Help

This worksheet provides instructions on how the user can read a performance-based reference parameter map. An example map is shown on the worksheet, and guidance is provided on how interpolation is to be performed with the various contour lines.

3.2.4 Calculation Worksheets

The calculation worksheets are comprised of the Performance-Based (PB) Liquefaction Initiation, Deterministic (Det) Liquefaction Initiation, PB Settlement, Det Settlement, Lateral Spread, and Slope Displacement worksheets. These worksheets provide the step-by-step calculations in estimating the various liquefaction-related hazards at the specified return period for the various selected models. The worksheets are locked to the user so that no unauthorized changes can be made, thus ensuring valid and consistent calculations. All desired changes must be made by the user on the Inputs worksheet.

3.2.5 Final Summary

The Final Summary worksheet is where *SPLiq* displays the computed output for both the performance-based and deterministic hazard calculations. The output is designed to be transparent and well-suited for checking. A screenshot of the Final Summary worksheet is presented in Figure 2. The output in this worksheet can be conveniently printed for quality assurance and archival in project folders.

3.2.6 References

The References worksheet provides useful tips, variable definitions, tabulated input values, and citations related to each of the hazards evaluated by *SPLiq*. The information pertaining to each hazard is organized in columns for convenient referencing and can be printed by user.

3.2.7 Interpolation

The Interpolation worksheet provides reference information regarding how *SPLiq* can be used in the absence of reference parameter maps. Per feedback from trial users, gridded reference parameter values that were used to develop reference parameter maps for the states of Utah, Idaho, Montana, South Carolina, and Connecticut (TPF 2016) were incorporated into a hidden worksheet in *SPLiq*. Given the latitude and longitude information provided on the Inputs worksheet, and given the "Interpolate Reference Parameter" option is set to "True," *SPLiq* will apply an inverse distance weighted (IDW) interpolation scheme to estimate reference parameter inputs at the selected return period. Therefore, the Interpolation worksheet is only a reference, and does not perform any analytical operation.

It should be mentioned that because of the internal database of reference parameter values that is built into *SPLiq* for the states of Utah, Idaho, Montana, South Carolina, and Connecticut, the file size of *SPLiq* is currently quite large at 18 Megabytes. As simplified performance-based reference parameter map values are developed for more states (e.g., Alaska and Oregon in 2017), it will be impractical and unsustainable to add those data values to the internal database within *SPLiq*. Instead, a likely solution will probably involve the development of a stand-alone website that performs the IDW interpolation scheme for a specified latitude/longitude coordinate and return period, and then returns the appropriate reference parameter inputs that should be used with *SPLiq*. While any additional discussion of this future project is beyond the scope of this paper, it is useful for the reader to understand the new developments that will be happening in the near future.

4 DEMONSTRATIVE EXAMPLE

An example application will be shown here to demonstrate the usefulness of *SPLiq* in performing probabilistic analysis of liquefaction triggering and its related effects.

4.1 Example Site Location and Topography

Consider a highway bridge abutment and approach embankment that is being evaluated for liquefaction-induced ground deformations. For this example, assume that the bridge abutment is located along Interstate 15 in Utah at latitude/longitude 40.6867° N 111.9029° W. A schematic sketch of the bridge abutment is shown in Figure 3. Note from Figure 3 that the hypothetical highway overpass is constructed on native soil that has uniform slope gradient of 2%. The approach embankment is comprised of structural fill. Also note from Figure 3 that a slope failure surface is sketched beneath the abutment, representing the hypothetical critical failure surface identified through a separate two-dimensional slope stability analysis. Details regarding the height of the embankment, foundation and abutment, and shear strength parameters for the native and non-native soil are not necessary for the demonstration of *SPLiq*, and are therefore not included in this example.

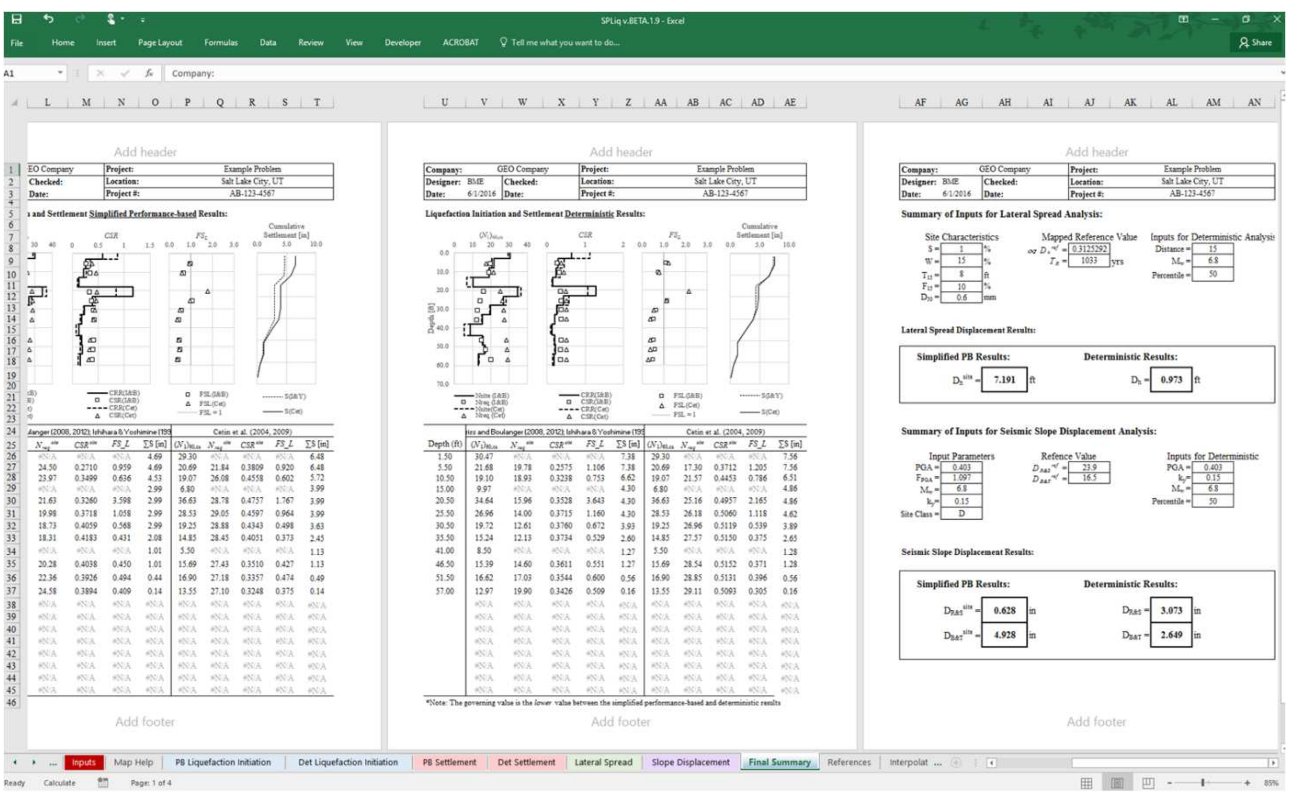

Figure 2. Screenshot of the output produced on the Final Summary worksheet of *SPLiq* version Beta 1.9

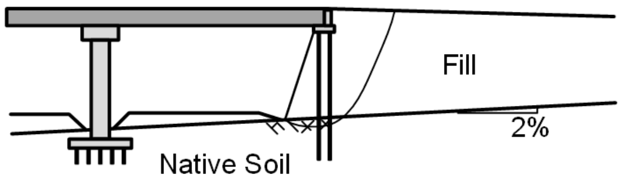

Figure 3. A schematic sketch of an example highway bridge overpass

4.2 Example Soil Profile

Generalized soil properties for the native soil shown in Figure 3 are presented in Table 1. For this example, the site is classified as a Site Class D (i.e., $V_{s,30} = 180\ \mathrm{m/sec}$ to $360\ \mathrm{m/sec}$). A unit weight of 19.3 kN/m^3 is used with the clay soils, and a unit weight of 18.5 kN/m^3 is used with the sand and silt soils. Ground water is located at a depth of 1 meter below the ground surface. From the values presented in Table 1, lateral spread modeling parameters are computed (Youd et al. 2002). The cumulative thickness of liquefaction-susceptible soil with SPT resistance less than 15 blows per 0.3 meter (i.e., T_{15}) is 3.5 meters, the average fines content for the soil comprising T_{15} (i.e., F_{15}) is 36%, and the mean grain size for the soil comprising T_{15} (i.e., $D50_{15}$) is 0.03 mm.

Table 1. Native soil properties for example

Soil Type	Thickness (m)	SPT Resistance, $(N_1)_{60}$	Fines (%)	Mean Grain Size (mm)
Lean Clay, medium plasticity	2	17	87	---
Silty Sand	1.2	13	17	0.05
Silty Clay, medium plasticity	2.3	10	94	---
Sandy Silt	0.9	11	65	0.01
Lean Clay, medium plasticity	5	5	98	---
Silty Sand	1.4	8	34	0.03
Lean Clay, medium plasticity	25+	7	90+	---

4.3 Analysis Specifications for Example

All liquefaction triggering, lateral spread displacement, post-liquefaction free-field settlement, and Newmark seismic slope displacement analysis for this example is performed with *SPLiq* Version Beta 1.92. Analyses are performed at two return periods: 1,033 years (i.e., 7% probability of exceedance in 75 years; hazard level that is commonly used for design of a typical bridge in Utah), and 2,475 years (i.e., 3% probability of exceedance in 75 years; hazard level that is commonly used for design of an essential bridge in Utah). Mean earthquake moment magnitudes and probabilistic peak ground accelerations were obtained from the 2008 USGS interactive online deaggregation and were entered into *SPLiq* at the return periods of interest. Rather than use a physical reference parameter map to obtain performance-based reference parameters, the interpolation function in *SPLiq* was used to automatically develop input reference parameters based on the specified latitude and longitude coordinates.

For the liquefaction triggering analysis, both the Cetin et al. (2004) and Boulanger and Idriss (2012) triggering models were selected. Corresponding probabilistic free-field post-liquefaction settlements were computed with those triggering models using the Cetin et al. (2009a) and Ishihara and Yoshimine (1992) volumetric strain models, respectively. Newmark seismic slope displacements were computed for a range of yield coefficients with both the Bray and Travasarou (2007) and Rathje and Saygili (2009) rigid sliding block models to produce yield coefficient versus displacement curves at the two return periods of interest. These curves can be used with a separate slope stability analysis to produce a pile shear force versus ground displacement curve that can be used to evaluate bridge foundation performance through consideration of the pile-pinning effect and compatibility between pile displacements and induced ground deformations (Caltrans 2012).

For the sake of demonstration, only a performance-based analysis is performed in *SPLiq* for this example. No deterministic analysis results will therefore be presented.

4.4 Example Analysis Results

4.4.1 Liquefaction Triggering and Free-Field Settlement

Figure 4 presents the liquefaction triggering and post-liquefaction free-field settlement results for both a return period of 1,033 years (Figure 4a) and 2,475 years (Figure 4b). The terms "I&B," "Cet," and "I&Y" in the legend denote the Boulanger and Idriss (2012) triggering model, the Cetin et al. (2004) triggering model and/or the Cetin et al. (2009a) volumetric strain model, and the Ishihara and Yoshimine (1992) volumetric strain model, respectively.

As can be seen from Figure 4, liquefaction triggering is predicted to occur (i.e., $FS_L < 1.0$) for the three susceptible soil layers at both return periods. Predicted free-field post-liquefaction settlements range from 6.4 cm to 8.5 cm at a return period of 1,033 years, and from 11.8 cm to 13.1 cm at a return period of 2,475 years. Volumetric strains are shown to accrue only in the soil layers that are predicted to liquefy.

4.4.2 Lateral Spread Displacement

Performance-based lateral spread displacements for the native sloping ground are predicted to be 1.8 m at a return period of 1,033 years, 3.2 m at a return period of 2,475 years. While Youd et al. (2002) recommend considering a range of possible lateral spread displacements that vary between a factor of 0.5 and 2.0 of the median predicted displacement, such consideration is unnecessary with performance-based displacement predictions because the uncertainty in the displacement prediction is already accounted for in the performance-based calculations. If engineers desire to consider a range of displacements, they can instead consider a range of return periods with their corresponding displacements.

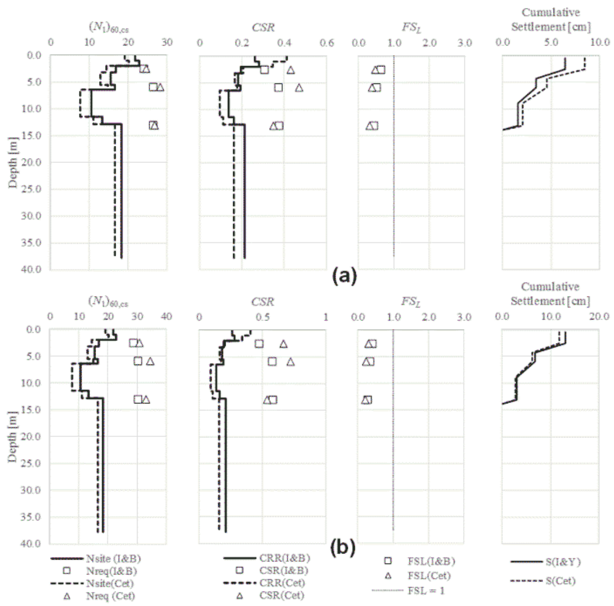

Figure 4. *SPLiq* liquefaction triggering and settlement output for the example at return periods of (a) 1,033 years and (b) 2,475 years

4.4.3 Newmark Sliding Block Displacements

Performance-based sliding block displacements using the Bray and Travasarou (2007) and Rathje and Saygili (2009) rigid sliding block models are presented in Figure 5 for a range of yield coefficients, k_y. The plot presented in Figure 5 was not developed in *SPLiq*, but the values used to create the plot were computed with *SPLiq*.

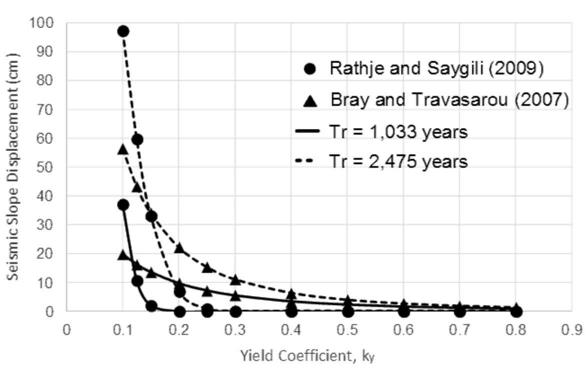

Figure 5. Performance-based estimates of Newmark seismic slope displacement for a range of yield coefficients for the example

5 DISTRIBUTION AND LIMITATIONS

SPLiq is spreadsheet developed by state transportation research funds, and will therefore be freely available to the public upon the release of *SPLiq* Version 1.0 during 2017. Copies of the spreadsheet will be available for download from the state DOT websites that funded its development (Utah, Idaho, Montana, Alaska, Oregon, South Carolina, and Connecticut), as well as from the faculty website for Prof. Franke (https://ceen.et.byu.edu/content/kevin-w-franke).

Users of *SPLiq* must remember that simplified performance-based analysis methods incorporated by the spreadsheet are an approximation of their corresponding full performance-based analysis methods, and must therefore be considered with careful engineering judgment. While the majority (i.e., >85%) of validation values performed during the spreadsheet's development fell within ±5% of the targeted values computed in a full performance-based analysis, a relatively small amount of points (i.e., <15%) were observed to deviate more than 5% from these values. Additional information regarding these errors is available in the study report (TPF 2016).

SPLiq users must also remember that the interpolation tool available in the spreadsheet is valid for use only in the states of Utah, Idaho, Montana, Oregon, Connecticut, and South Carolina (compatible with either the 2008 or 2014 USGS seismic hazard data), as well as Alaska (compatible only with the 2008 USGS seismic hazard data). However, *SPLiq* can be used manually for any site in the world as long as a performance-based reference parameter map for the hazard(s) of interest is available at the desired return period(s).

The accuracy of any performance-based analysis procedure is largely dependent upon the uncertainty associated with the predictive model that is used in the procedure and the quality of the site-specific geotechnical and/or topographical data provided by the engineer. Poor site characterization will certainly lead to poor and inaccurate hazard predictions, regardless of the level of sophistication of the engineering analysis. As with all empirically derived models, there are recommended valid ranges for the model input parameters and the resulting predicted displacements. Any model extrapolation with performance-based procedures must be carefully evaluated with reasonable engineering judgment.

6 CONCLUSION

This paper has introduced a new analytical tool named Simplified Probabilistic Liquefaction Analysis Tool (or *SPLiq*) for the simplified performance-based analysis of liquefaction triggering, free-field post-liquefaction settlement, lateral spread displacement, and Newmark seismic slope displacement. The spreadsheet is currently still under development and testing, but will become available for free to the public in 2017. The spreadsheet requires the use of performance-based reference parameter values for the desired hazard(s) at the site(s) of interest to be used. Currently, such values have been developed and mapped only for the US states of Utah, Idaho, Montana, Oregon, Alaska, South Carolina, and

Connecticut, but future studies will likely develop and map reference parameter values for other states as well.

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