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SPLIQ USER'S MANUAL

VERSION 1.41

Prepared For:

Utah Department of Transportation
Research and Innovation Division

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| 16. Abstract This user's manual includes a step-by-step process for using a spreadsheet tool called <i>SPLIQ</i> to perform simplified calculations for performance-based probabilistic earthquake hazard analysis while using Standard Penetration Test (SPT) data from site soil borings. The simplified models provide estimates of liquefaction triggering, lateral spread displacements, post-liquefaction settlements, and seismic slope displacements. These simplified models were developed and validated, as documented in UDOT Research Report No. UT-16.16 from the TPF-5(296) pooled fund study that was funded by the Alaska, Connecticut, Idaho, Montana, South Carolina, Oregon, and Utah Departments of Transportation. Liquefaction reference parameter maps, which are used together with the <i>SPLIQ</i> tool, were developed for these seven states for the 475, 1033, and 2475 year return periods. | | | | | |
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LIST OF TERMS

Liquefaction Triggering Terms

| | |
|------------------------|---|
| a_{max} | peak ground surface acceleration |
| CRR | cyclic resistance ratio |
| $CRR_{PL=50\%}$ | median CRR (CRR corresponding to a probability of liquefaction of 50%) |
| CSR | cyclic stress ratio |
| CSR^{ref} | uniform hazard estimate of CSR associated with the reference soil profile |
| CSR^{site} | site-specific uniform hazard estimate of CSR |
| ΔCSR_{σ} | correction factor for vertical stress |
| ΔCSR_{Fpga} | correction factor for soil amplification |
| ΔCSR_{rd} | correction factor for shear stress reduction |
| ΔCSR_{MSF} | correction factor for magnitude scaling factor |
| $\Delta CSR_{K\sigma}$ | correction factor for overburden pressure |
| ΔCSR | difference between CSR^{site} and CSR^{ref} values |
| FC | finer content (%) |
| FS_L | factor of safety against liquefaction triggering |
| FS_L^{site} | site-specific uniform hazard estimate of FS_L |
| F_{PGA} | soil amplification factor |
| K_{σ} | overburden correction factor (Idriss and Boulanger model) |
| K_{DR} | correction factor for age of sand deposits from Hayati and Andrus (2009) |
| MSF | magnitude scaling factor |
| M_w | mean moment magnitude |
| N | SPT blow count (uncorrected) |
| $(N_I)_{60}$ | SPT resistance corrected to 60% efficiency and 1 atm pressure |
| $(N_I)_{60,cs}$ | clean sand-equivalent SPT corrected to 60% efficiency and 1 atm pressure |

| | |
|----------------------|---|
| N_{req} | SPT resistance required to resist or prevent liquefaction |
| N_{req}^{ref} | uniform hazard estimate of N_{req} associated with the reference soil profile |
| N_{req}^{site} | site-specific uniform hazard estimate of N_{req} |
| ΔN_L | difference between N_{site} and N_{req} values |
| P_a | atmospheric pressure (1 atm, 101.3 kPa, 0.2116 psf) |
| PGA | peak ground acceleration |
| P_L | probability of liquefaction |
| r_d | shear stress reduction coefficient |
| SPT | Standard Penetration Test |
| $V_{s,12}$ | average shear wave velocity in upper 12 m (39.37 ft) of soil profile |
| z | depth to middle of soil profile layer |
| γ | unit weight of soil (i.e. pcf, kN/m ³ , etc.) |
| σ_ϵ | error term for either model + parametric uncertainty or parametric uncertainty |
| σ_T | error term for both model and parametric uncertainty |
| σ_v | total vertical stress in the soil |
| σ'_v | effective vertical stress in the soil |
| Λ_{FSL*} | mean annual rate of not exceeding some given value of FS_L |
| $\lambda_{N_{req}*}$ | mean annual rate of not exceeding some given value of N_{req} |
| τ_{cyc} | equivalent uniform cyclic shear stress |
| Φ | standard normal cumulative distribution function |

Lateral Spread Displacement Terms

| | |
|-------|--|
| D_H | median computed permanent lateral spread displacement (m) |
| R | closest horizontal distance from the site to the source (km) |
| M | earthquake moment magnitude |

| | |
|---------------------|---|
| W | free-face ratio (%) |
| S | ground slope (%) |
| T_{15} | cumulative thickness (in upper 20 m) of all saturated soil layers with corrected SPT blowcounts (i.e., $(N_1)_{60}$) less than 15 blows/foot (m) |
| F_{15} | average fines content of the soil comprising T_{15} (%) |
| $D50_{15}$ | average mean grain size of the soil comprising T_{15} (mm) |
| L | Loading Parameter |
| S | Site Parameter |
| D | transformed (e.g. log, ln, square root) lateral spread displacement |
| \square | uncertainty term (used in lateral spread displacement model) |
| $[\log D_H]^{site}$ | logarithm of the lateral spread displacement adjusted for site-specific conditions |
| $[\log D_H]^{ref}$ | logarithm of the lateral spread displacement corresponding to the reference site |
| ΔD_H | adjustment factor for lateral spread displacement |
| D_H^{site} | site-specific hazard-targeted lateral spread displacement |

Post-Liquefaction Free-Field Settlement Terms

| | |
|----------------------|---|
| CRR | cyclic resistance ratio |
| CRR^{ref} | cyclic resistance ratio associated with the reference soil profile |
| CRR^{site} | cyclic resistance ratio for the site profile |
| CSR | cyclic stress ratio |
| CSR^{ref} | uniform hazard estimate of CSR associated with the reference soil profile |
| CSR^{site} | uniform hazard estimate of CSR associated with the site specific soil profile |
| $CSR_{SS,20,1D,atm}$ | adjusted CSR to account for multi-directional shaking effects |
| CSR^{site} | site-specific uniform hazard estimate of CSR |
| DF_i | depth factor for soil sub-layer |
| D_R | relative density |

| | |
|---------------------|---|
| FC | finer content (%) |
| F_{PGA} | soil amplification factor |
| FS_{Liq} | factor of safety against liquefaction triggering |
| FS_L^{site} | site-specific uniform hazard estimate of FS_L |
| F_α | limiting factor of safety (used in Ishihara and Yoshimine model) |
| F_α^{ref} | limiting factor of safety associated with reference soil profile |
| F_α^{site} | limiting factor of safety associated with site soil profile |
| K_{md} | multidirectional correction factor for unidirectional applied loading |
| K_{Mw} | magnitude correction factor |
| K_σ | non-linear increase in cyclic resistance correction factor |
| min(.) | use minimum value inside parentheses mathematical operator |
| M_w | mean moment magnitude |
| N | SPT blow count (uncorrected) |
| $(N_1)_{60}$ | SPT resistance corrected to 60% efficiency and 1 atm pressure |
| $(N_1)_{60,cs}$ | clean sand-equivalent SPT corrected to 60% efficiency and 1 atm pressure |
| N_{req} | SPT resistance required to resist or prevent liquefaction |
| N_{req}^{ref} | uniform hazard estimate of N_{req} associated with the reference soil profile |
| N_{req}^{site} | site-specific uniform hazard estimate of N_{req} |
| N_{site} | standard penetration test resistance of site profile layer |
| P_a | atmospheric pressure (1 atm, 101.3 kPa, 0.2116 psf) |
| PGA | peak ground acceleration |
| P_L | probability of liquefaction |
| $s_{profile}$ | estimated total settlement for soil profile using equivalent strain approach |
| SPT | Standard Penetration Test |
| t_i | thickness of soil sub-layer |
| $V_{s,12}$ | average shear wave velocity in upper 12 m (39.37 ft) of soil profile |
| z_{cr} | maximum depth at which vertical strain can occur ($z_{cr} = 18 \text{ meters}$) |
| $\Delta\varepsilon$ | site-specific adjustment factor |

| | |
|--|--|
| ϵ_v | vertical strain |
| $\epsilon_{v,\text{calibrated}}^{\text{site}}$ | site-specific strain calibrated for model non-linearity |
| ϵ_v^{ref} | vertical strain for the reference soil profile |
| ϵ_v^{site} | site-specific vertical strain |
| $\epsilon_{v,\text{eqv.}}$ | equivalent vertical strain for entire soil profile |
| $\epsilon_{v,\text{max}}$ | maximum limiting vertical strain for a soil layer |
| γ | unit weight of soil (e.g. pcf, kN/m ³ , etc.) |
| γ_{max} | maximum limiting shear strain |
| γ_{min} | minimum limiting shear strain |
| $\lambda_{\epsilon,v,i}$ | mean annual rate of exceeding vertical strain |
| $\mu_{\ln\epsilon}$ | mean value of the natural logarithm of vertical strain |
| σ_ϵ | error term for either model + parametric uncertainty or parametric uncertainty |
| σ'_{vo} | effective vertical stress in the soil |
| Φ | standard normal cumulative distribution function |
| Φ^{-1} | inverse standard normal cumulative distribution function |

Seismic Slope Displacement Terms

| | |
|---------------|--|
| $\ln D$ | natural logarithm of seismic slope displacement (cm) |
| k_y | yield acceleration (g) |
| PGA | peak ground acceleration (g) |
| M | earthquake moment magnitude (g) |
| σ_{ln} | standard deviation for the scalar model |
| λ_D | mean annual rate of not exceeding a seismic slope displacement value |
| D | seismic slope displacement (cm) |
| GM_i | single ground motion parameter |
| T_s | initial fundamental period of the sliding mass (s) |

| | |
|----------------|---|
| f_a | soil amplification factor (from AASHTO 2012 Values of site factor table) |
| $\ln D^{site}$ | natural log of seismic slope displacement adjusted for the site-specific conditions |
| $\ln D^{ref}$ | natural log of seismic slope displacement corresponding to the reference site |
| $\Delta \ln D$ | adjustment factor for seismic slope displacement |
| k_y^{site} | yield acceleration adjusted for site-specific conditions (g) |
| PGA^{site} | peak ground acceleration adjusted for site-specific conditions (g) |
| k_y^{ref} | yield acceleration for the corresponding to the reference site (g) |
| PGA^{ref} | peak ground acceleration corresponding to the reference site (g) |
| f_a^{site} | soil amplification factor adjusted for site-specific conditions |
| f_a^{ref} | soil amplification factor corresponding to the reference site |

ONLINE MAP DATABASE ACCESS INFORMATION (for use with *SPLiq*)

URL: <https://tethys.byu.edu/apps/lfhazard/map/>

1.0 DEVELOPMENT OF *SPLIQ*

1.1 Overview

This section explains the components of the simplified liquefaction assessment tool *SPLiq*, and provides some guidance for how the tool should be used. The simplified models used in *SPLiq* were developed and validated, as documented in UDOT Research Report No. UT-16.16 from the TPF-5(296) pooled fund study that was funded by the Alaska, Connecticut, Idaho, Montana, South Carolina, Oregon, and Utah Departments of Transportation. The current version of the *SPLiq* spreadsheet tool is available on the TPF-5(296) pooled fund study webpage and also from the Utah Department of Transportation (Research and Geotechnical Divisions) and Brigham Young University (Department of Civil and Environmental Engineering).

1.2 Description of Tool Components

1.2.1 Inputs

This section of the spreadsheet is the starting place of the analysis. Here, the user may select which analyses and options he or she would prefer (Figure 1-1) and enter the soil profile information (Figure 1-2), mapped reference values, and other parameters, which are necessary for the simplified performance-based procedure (Figure 1-3). The input cells are color coded to help the user understand what is needed for each hazard. Liquefaction triggering inputs are blue, Lateral Spread inputs are green, Strain inputs are red, and Seismic Slope Displacement inputs are purple. At the bottom of the sheet, there is a section for deterministic inputs if the user would like to consider a deterministic analysis as well.

Analysis Selections: *Select "TRUE" to run analysis

Simplified Performance-Based Analysis

Liquefaction Initiation & Settlement: TRUE
 Lateral Spread: TRUE
 Slope Displacement: TRUE

Liquefaction Initiation and Settlement Options:

Cetin: TRUE B&I/Y: TRUE

Output Type:

P_L/FS_L : FSL P_L = Probability of Liq.
 FS_L = Factor of Safety

Lateral Spread Options:

GS FF = Free Face
 GS = Ground Slope

Seismic Slope Displacement Options:

R&S: TRUE B&T: TRUE

Deterministic Analysis

Liquefaction Initiation & Settlement: TRUE
 Lateral Spread: TRUE
 Slope Displacement: TRUE

Analyze

Print Summary Page

* WARNING: if you have made changes to the input page, these changes will not be reflected on the Final Summary page unless you click the "Analyze" button to run the analysis.

Figure 1-1 Analysis Selections section on the *Inputs* tab.

Water Level at Time of Drilling = ft
 Design Water Table Depth = ft

| Depth (ft) | N (bpf) | Sampler Type | γ (lb/ft ³) | Fines (%) | Thickness (ft) | K_{DR} | Soil Type | Susceptible? |
|------------|---------|--------------------------|--------------------------------|-----------|----------------|----------|----------------|--------------|
| 1.50 | 20 | Standard SS (2-in OD) | 124.3 | 10.0 | 3.00 | | Granular Fill | Yes |
| 5.50 | 14 | Non-Standard (3-in OD) | 124.3 | 10.0 | 5.00 | | [SM] Silty_sar | Yes |
| 10.50 | 12 | Non-Standard (2.5-in OD) | 124.3 | 10.0 | 5.00 | | [SM] Silty_sar | Yes |
| 15.00 | 3 | D&M SS (3.25-in OD) | 124.3 | 60.0 | 4.00 | | [CL] Clay | No |
| 20.50 | 27 | Custom Factor | 124.3 | 10.0 | 7.00 | | [SM] Silty_sar | Yes |
| 25.50 | 22 | Standard SS (2-in OD) | 124.3 | 10.0 | 3.00 | | [SM] Silty_sar | Yes |
| 30.50 | 16 | Standard SS (2-in OD) | 124.3 | 10.0 | 7.00 | | [SM] Silty_sar | Yes |
| 35.50 | 13 | Custom Factor | 124.3 | 10.0 | 3.00 | | [SM] Silty_sar | Yes |
| 41.00 | 3 | Custom Factor | 124.3 | 70.0 | 8.00 | | [CL] Clay | No |
| 45.00 | 3 | Custom Factor | 124.3 | 5.0 | 3.00 | | [SM] Silty_sar | Yes |
| 51.50 | 18 | Custom Factor | 124.3 | 5.0 | 7.00 | | [SM] Silty_sar | Yes |
| 57.00 | 5 | Custom Factor | 124.3 | 5.0 | 4.00 | | [SM] Silty_sar | Yes |

Hammer Efficiency (%)
 Borehole Diameter in
 Rod Stickup Length ft
 Sampler Type
 L = Standard Split Spoon
 NL = Room for liners, but no liners
 Convert SPT N Custom Factor:

Figure 1-2 Soil profile input section.

| | | |
|---|---|--|
| <p>Ground Motion Parameters:</p> <p>PGA = 0.4400</p> <p>F_{PGA} = 1.060</p> <p>M_w = 6.8</p> <p>$V_{s,12}$ = 623.0 ft/s</p> <p>Site Class = D</p> <p><input type="checkbox"/> 1 = Calculate F_{PGA} Automatically</p> <p><input type="checkbox"/> 2 = User-defined F_{PGA} value entered in box above</p> <p>MSF = 2014</p> | <p>Site Lateral Spread Parameters:</p> <p>s = 1.5 %</p> <p>W = 16 %</p> <p>$T_{1,s}$ = 10 ft</p> <p>$F_{1,s}$ = 11 %</p> <p>$D_{50,1,s}$ = 5 mm</p> | <p>Site Slope Disp. Parameters</p> <p>k_y = 0.20</p> |
| <p>Mapped/Interpolated Reference Values:</p> <p>Liq. Initiation/Settlement:</p> <p>$CSR(\%)^{ref}$ = 35.14</p> <p>N_{req}^{ref} = 49.09</p> <p>$\epsilon_{v,csite}(\%)^{ref}$ = 2.30</p> <p>$\epsilon_{v,tst}(\%)^{ref}$ = 2.30</p> | <p>Lateral Spread Disp:</p> <p>$Log D_x^{ref}$ = 0.55</p> | <p>Seismic Slope Disp:</p> <p>D_{RAS}^{ref} = 2.43</p> <p>D_{SAT}^{ref} = 2.65</p> |
| <p>Deterministic Analysis Parameters:</p> <p>Liq. Initiation/Settlement/Slope Disp:</p> <p>PGA = 0.7300</p> <p>F_{PGA} = 1</p> <p>M_w = 6.8</p> <p>Percentile = 84</p> <p><input type="checkbox"/> 1 = Calculate F_{PGA} automatically</p> <p><input type="checkbox"/> 2 = User-defined F_{PGA} value entered in box above</p> | <p>Lateral Spread Disp:</p> <p>Distance = 1.11 km</p> <p>M_w = 7</p> <p>Percentile = 85</p> | <p>Seismic Slope Disp:</p> <p>Percentile = 85</p> |

Figure 1-3 Ground motion and reference input parameters.

1.2.2 Online Interactive Reference Parameter Database

All liquefaction reference parameters necessary to use the simplified performance-based liquefaction hazard analysis models included in *SPLiq* can be obtained online for the seven participating states (i.e., Alaska, Connecticut, Idaho, Montana, Oregon, South Dakota, and Utah) at <https://tethys.byu.edu/apps/lfhazard/map/>. A blue button for automatically accessing this online database using an internet browser is included on the Inputs worksheet.

1.2.3 Simplified Performance-based Liquefaction Triggering Tabs

1.2.3.1 PB Liquefaction Initiation

This section of the spreadsheet shows the calculations for the simplified performance-based (PB) liquefaction initiation procedure. The Boulanger and Idriss (2012) model is simplified as derived in the Year 1 Quarter 1 report of this research. The Cetin et al. (2004) model is simplified as derived in the Mayfield et al. (2010) publication. This section also provides the calculations for correcting field SPT blow counts to values of $(N_1)_{60,cs}$. The user is not required to do anything on this page. This section is simply for reference if the engineer would like to see the calculation process.

1.2.3.2 Deterministic Liquefaction Initiation

This section of the spreadsheet calculates deterministic liquefaction initiation values. The formulas from the deterministic Idriss and Boulanger (2008) model and from the deterministic Cetin et al. (2004) model are used here. The user is not required to do anything on this page. This section is simply for reference if the engineer would like to see the calculation process.

1.2.4 Simplified Performance-based Post- Liquefaction Settlement Tabs

Simplified performance-based settlement calculations are performed on the *PB Settlement* tab. The *Det Settlement* tab contains calculations to perform a deterministic analysis of liquefaction settlement. Both the performance based and deterministic calculations are based on the Ishihara and Yoshimine (1992) and Cetin et al. (2009) settlement models. The derivation of the simplified model is presented in the Quarter 1 Year 2 report of this study. These sheets are available for review by the user but do not require any input or changes from the user. All calculations are done automatically when the “Analyze” button on the *Inputs* tab is selected

1.2.5 Simplified Performance-based Lateral Spread Displacement Tabs

This portion of the spreadsheet determines the simplified and deterministic lateral spread displacements based on the Youd et al (2002) empirical model and the simplified procedure developed in study TPF-5(296). The deterministic and simplified equations can be seen on this

page, and all lateral spread calculations are performed on this page. This sheet does not require any input from the user. The calculations are performed when the “Analyze” button on the input page is clicked. This section is to provide a reference to the engineer.

1.2.6 Simplified Performance-based Seismic Slope Displacement Tabs

This section of the spreadsheet computes the simplified and deterministic seismic slope displacements based on the Rathje and Saygili (2009) and the Bray and Travasarou (2007) models. The derivation of the simplified model is explained in Quarter 1 Year 2 report. This sheet is to provide the user information about how the displacements are being computed, but do not require any input or changes from the user. When the user clicks the “Analyze” button in the input page all calculations will be done automatically.

1.2.7 Final Summary Tab

This section shows the final results of the analyses chosen on the *Inputs* tab. The format of this section is already set up for easy printing. The headers of each page are associated with the project information entered on the *Inputs* tab. The first page provides a summary of inputs from the *Inputs* tab to facilitate easy checking of the inputs. The following pages show the results of the analyses. To print only the pages with the user-specified analyses, return to the *Inputs* tab and click the “Print Final Summary” button. The print preview window will appear and show only the user-specified analyses.

1.2.8 References

This tab provides references for the models used in this spreadsheet and further guidance for using this spreadsheet.

2.0 SUGGESTED SIMPLIFIED PROCEDURE

The following sections describe the suggested simplified procedure for assessing liquefaction triggering hazard, lateral spread displacement, post-liquefaction settlement, and seismic slope displacement.

2.1 Simplified Performance-based Liquefaction Triggering

- 1) Select an appropriate return period (T_R) for your project (this may depend on the intended use of the building, code requirements, etc.).
- 2) Retrieve the reference liquefaction loading value (i.e. N_{req}^{ref} or $CSR\%$) from the maps or the interactive map database with the desired return period and model (i.e. Cetin et al, 2004 or Boulanger and Idriss, 2012). Note that provided N_{req}^{ref} maps are based on the Cetin et al. model and $CSR\%$ maps are based on the Boulanger and Idriss model.
- 3) Enter the required soil profile information into the *Inputs* tab (See Figure 2-1). Required values include depth to center of the sublayer, field SPT blowcount, unit weight (γ), fines content in percent, and thickness of each sublayer. An optional parameter is K_{DR} , a correction factor for age of sand deposits from Hayati and Andrus (2009). This value is not required, but may be used to increase the CRR of particular soil layers. Enter the hammer information, which is used for $(N_I)_{60,cs}$ corrections.
 - a. Soil profile information can be entered in either SI or English customary units. Select the desired option by clicking the associated toggle above the soil profile table. Make sure that the values you enter for the soil profile are in the correct units.
 - b. Even though the zone of interest to the user may not include sublayers near the ground surface, all sublayers above the zone of interest must be included in the inputs tab so that the effective stress calculations will work properly. In other words, begin at the ground surface and include all sublayers down to the end of the zone of interest. Note: the maximum number of sublayers is 20.
 - c. At each depth, a Sampler Type can be chosen using a drop down menu. The sampler dimensions can be entered on the right for Hammer Efficiency (%), Borehole Diameter, Rod Stickup Length, and Sampler Type. If Custom Factor

is chosen for Sampler Type, the user can enter their own custom conversion factor.

- d. The user can also enter the water level at time of drilling and the design water level (i.e. water level at time of earthquake). $(N_I)_{60,cs}$ is calculated from the ground water at time of drilling—all other calculations are performed using the design ground water depth.

Units: (1 = SI, 2 = US Customary) Latitude = Longitude =

Site Characteristics: Return Period: yrs
 Probability of Exceedance: 2% in 50 yrs

Water Level at Time of Drilling = ft
 Design Water Table Depth = ft

| Depth (ft) | N (bpf) | Sampler Type | γ (lb/ft ³) | Fines (%) | Thickness (ft) | K_{DR} | Soil Type | Susceptible? |
|------------|---------|--------------------------|--------------------------------|-----------|----------------|----------|----------------|--------------|
| 1.50 | 20 | Standard SS (2-in OD) | 124.3 | 10.0 | 3.00 | | Granular Fill | Yes |
| 5.50 | 14 | Non-Standard (3-in OD) | 124.3 | 10.0 | 5.00 | | [SM]_Silty_san | Yes |
| 10.50 | 12 | Non-Standard (2.5-in OD) | 124.3 | 10.0 | 5.00 | | [SM]_Silty_san | Yes |
| 15.00 | 3 | D&M SS (3.25-in OD) | 124.3 | 60.0 | 4.00 | | [CL]_Clay | No |
| 20.50 | 27 | Custom Factor | 124.3 | 10.0 | 7.00 | | [SM]_Silty_san | Yes |
| 25.50 | 22 | Standard SS (2-in OD) | 124.3 | 10.0 | 3.00 | | [SM]_Silty_san | Yes |
| 30.50 | 16 | Standard SS (2-in OD) | 124.3 | 10.0 | 7.00 | | [SM]_Silty_san | Yes |
| 35.50 | 13 | Custom Factor | 124.3 | 10.0 | 3.00 | | [SM]_Silty_san | Yes |
| 41.00 | 3 | Custom Factor | 124.3 | 70.0 | 8.00 | | [CL]_Clay | No |
| 45.00 | 3 | Custom Factor | 124.3 | 5.0 | 3.00 | | [SM]_Silty_san | Yes |
| 51.50 | 18 | Custom Factor | 124.3 | 5.0 | 7.00 | | [SM]_Silty_san | Yes |
| 57.00 | 5 | Custom Factor | 124.3 | 5.0 | 4.00 | | [SM]_Silty_san | Yes |

Hammer Efficiency (%)

Borehole Diameter in

Rod Stickup Length ft

Sampler Type

L = Standard Split Spoon
 NL = Room for liners, but no liners

Convert SPTN Custom Factor:

Figure 2-1 Soil profile information.

- 4) On the *Inputs* tab under “Analysis Selections” (See Figure 1-1), select the desired models and analyses. If the user wishes to use a deterministic analysis as an upper-bound to the performance-based results, the user should select the appropriate deterministic checkbox.
- 5) On the *Inputs* tab, enter liquefaction triggering parameters to be used in the simplified performance-based correction factors (derived in the Year 1 Quarter 1 report). The calculations will be performed in the spreadsheet automatically, but a few parameters must be provided by the user:
 - a. *PGA*: Peak Ground Acceleration should be retrieved from the USGS Interactive Deaggregation website (<https://earthquake.usgs.gov/hazards/interactive/>) at the return period specified

in step 1. Note that the website uses exceedance probabilities instead of return periods. Use Table 2-1 to convert return periods to exceedance probabilities.

Table 2-1. Conversions between Return Period and Exceedance Probability for use in the USGS interactive deaggregations website.

| Return Period | Exceedance Probability | |
|---------------|------------------------|---------|
| | Percent | Years |
| 475 | 10 (15) | 50 (75) |
| 1,039 (1,033) | 2 (7) | 21 (75) |
| 2,475 | 2 (3) | 50 (75) |

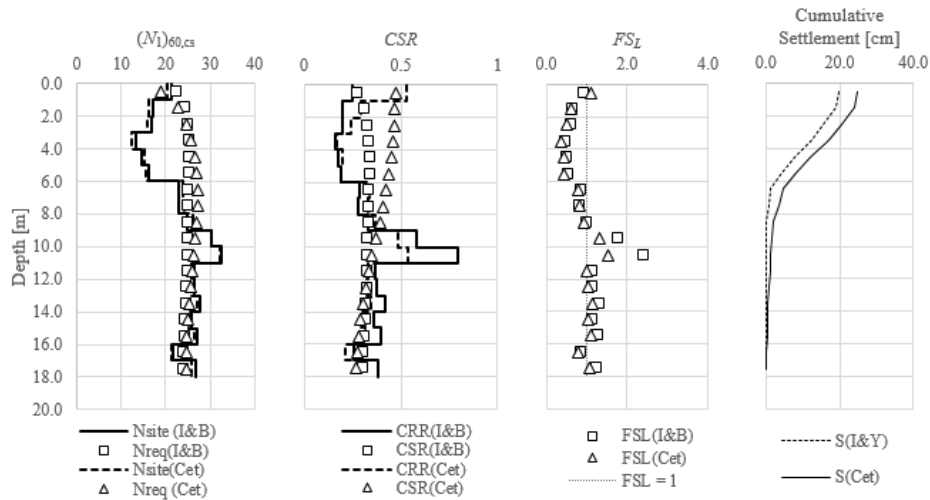
After entering the latitude and longitude of the site, exceedance probability, Spectral Period of 0.0 seconds, and $V_{s,30}$ of 760 m/s, retrieve the PGA from the output report. This value is necessary for estimating the F_{pga} . An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.

- b. F_{pga} : If the user checks the “Calculate F_{pga} automatically” checkbox, the spreadsheet will calculate F_{pga} according to the 2012 AASHTO code. However, this cannot be done if the Site Class is F (see notes about Site Class below), and therefore, the user must specify an F_{pga} value based on a site response analysis.
- c. M_w : The mean moment magnitude (M_w) is used to calculate the MSF correction factor as discussed in the Year 1 Quarter 1 report. The value for M_w is found in the same output report created to find the PGA value. An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.
- d. $V_{s,12}$: The shear wave velocity in the upper 12m (40 ft) is only required when using the Cetin et al (2004) model. For further guidance in calculating this value, see the *References* tab of the spreadsheet.
- e. Site Class: The site class is necessary for calculating the F_{pga} . Site class is determined based on soil type and soil properties. See the *References* tab of the spreadsheet for further help in determining site class.

- 6) On the *Inputs* tab under “Mapped Reference Values”, enter the mapped values retrieved as part of step 2. At least one of the two parameters ($CSR(\%)^{ref}$ or N_{req}^{ref}) is necessary for analysis, but be aware of which model each of these parameters is associated with (see step 2). Also report the return period associated with the chosen map (this value will not be used in any calculations, but will be displayed on the final summary page for reference).
- 7) If the user wishes to use a deterministic analysis as an upper-bound to the performance-based results, the user should enter the deterministic values of PGA , M_w , and percentile of the PGA to be considered. This percentile value is not used in any calculations, but will be displayed on the final summary page for reference. The user must also specify a site class for the soil or provide a user-defined value for F_{pga} .
 - a. Deterministic values of PGA and M_w should be assessed by an experienced individual with proper training in deterministic seismic hazard analysis (DSHA).
 - b. It is suggested (as explained previously in this report) that a deterministic analysis should be considered when the engineer suspects that the project could benefit from a deterministic cap. In areas of low seismicity, this is likely unnecessary.
- 8) Several dropdown lists are displayed near the top of the *Inputs* tab (under the *Simplified Performance-Based Analysis* section) which allow the user to select which analyses (liquefaction initiation, settlement, lateral spread, or seismic slope stability), models (Cetin et al or Boulanger and Idriss), and options (P_L or FS_L) the user would like to consider. Select the desired analyses, models, and options before proceeding to the next step.
- 9) Once everything is correctly entered into the *Inputs* tab, click “Analyze”. The calculations will be displayed on the *PB Liquefaction Initiation* and *Det. Liquefaction Initiation* tabs.
- 10) The *Final Summary* tab displays plots, tables and a summary of inputs in a printable format. The headers of these pages will reflect information such as company name, project name/number, date, etc. entered at the top of the *Inputs* tab. An example final summary output is seen in Figure 2-2.

| | | | |
|------------------|-------------|-------------------|--------------------|
| Company: | GEO Company | Project: | Trial Run |
| Drawn by: | B. Error | Checked: | L. Astorga |
| Date: | 3/18/2016 | Location: | Salt Lake City, UT |
| | | Project #: | AB-123-4567 |

Liquefaction Initiation and Settlement Simplified Performance-based Results:



| Depth (m) | Idriss and Boulanger (2008, 2012); Ishihara & Yoshimine (1992) | | | | | Cetin et al. (2004, 2009) | | | | |
|-----------|--|------------------|--------------|--------|---------------|---------------------------|------------------|--------------|--------|---------------|
| | $(N_1)_{60,cs}$ | N_{req}^{site} | CSR^{site} | FS_L | $\sum S$ [cm] | $(N_1)_{60,cs}$ | N_{req}^{site} | CSR^{site} | FS_L | $\sum S$ [cm] |
| 0.50 | 21.23 | 22.48 | 0.2740 | 0.922 | 19.67 | 20.26 | 18.79 | 0.4738 | 1.112 | 24.90 |
| 1.50 | 17.21 | 24.33 | 0.3131 | 0.640 | 19.09 | 16.32 | 22.88 | 0.4701 | 0.622 | 24.21 |
| 2.50 | 16.86 | 24.84 | 0.3260 | 0.603 | 15.69 | 15.76 | 24.68 | 0.4650 | 0.524 | 20.77 |
| 3.50 | 13.29 | 25.26 | 0.3375 | 0.480 | 12.30 | 12.28 | 25.77 | 0.4584 | 0.376 | 16.93 |
| 4.50 | 14.70 | 25.31 | 0.3389 | 0.516 | 7.92 | 15.10 | 26.47 | 0.4497 | 0.439 | 12.00 |
| 5.50 | 16.08 | 25.31 | 0.3389 | 0.556 | 4.30 | 15.60 | 26.89 | 0.4386 | 0.441 | 8.19 |
| 6.50 | 23.02 | 25.13 | 0.3337 | 0.853 | 1.33 | 23.96 | 27.09 | 0.4250 | 0.796 | 4.73 |
| 7.50 | 22.80 | 25.14 | 0.3240 | 0.842 | 0.77 | 24.24 | 27.11 | 0.4000 | 0.812 | 2.28 |

Figure 2-2 Example final summary for liquefaction initiation and settlement.

2.2 Simplified Performance-based Post-Liquefaction Settlement

- 1) All input data and model options are entered and changed on the *Inputs* tab of the simplified tool (Figure 1-1 through Figure 1-3).
- 2) Enter the latitude, longitude and select the appropriate return period located at the top of the *Inputs* tab. Options available to select are: 475, 1033, and 2475 year return periods.
- 3) Enter the required soil profile information in the appropriate cells. Please note that the simplified tool only allows for 20 soil sub-layers; therefore, divide or combine the soil profile properties accordingly (Figure 1-2).

- 4) In the “Analysis Selections:” section of the *Inputs* tab, choose the liquefaction hazard analysis to be run (Figure 1-1).
 - a. The “Cetin” settlement analysis cannot be run without also performing the “Cetin” liquefaction initiation model; likewise, the “I&Y” (Ishihara and Yoshimine) settlement model cannot be run without also performing the “B&I” (Boulanger and Idriss) initiation procedure.
 - b. You may also choose to run a deterministic liquefaction initiation/ settlement analysis in the “Analysis Selections:” section.

- 5) Enter the required settlement parameters on the “Inputs” tab (Figure 1-3):
 - a. *PGA*: Peak Ground Acceleration should be retrieved from the USGS Interactive Deaggregation website (<https://earthquake.usgs.gov/hazards/interactive/>) at the return period specified in step 1. Note that the website uses exceedance probabilities instead of return periods. Use Table 2-1 to convert return periods to exceedance probabilities.
 After entering the latitude and longitude of the site, exceedance probability, Spectral Period of 0.0 seconds, and $V_{s,30}$ of 760 m/s, retrieve the *PGA* from the output report. This value is necessary for estimating the F_{pga} . An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.
 - b. F_{pga} : If the user chooses to “Calculate F_{pga} automatically” by inputting “1” into the corresponding cell, the spreadsheet will calculate F_{pga} according to the 2012 AASHTO code. However, this cannot be done if the Site Class is F (see notes about Site Class below), and therefore, the user must specify an F_{pga} value based on a site response analysis.
 - c. M_w : The mean moment magnitude (M_w) is used to calculate the MSF correction factor as discussed in the Year 1 Quarter 1 report. The value for M_w is found in the same output report created to find the *PGA* value. An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.

- d. $V_{s,12}$: The shear wave velocity in the upper 12m (40 ft) is only required when using the Cetin et al (2004) model for liquefaction initiation calculations only. If the user is just running the seismic slope displacement analysis he or she does not need to worry about the value that is entered in this box.
 - e. Site Class: The site class is necessary for calculating the F_{pga} . Site class is determined based on soil type and soil properties. See the *References* tab of the spreadsheet for further help in determining site class.
- 6) Enter the applicable mapped reference values for $CSR (\%)^{ref}$, N_{req}^{ref} , $\varepsilon_{v,Cetin}(\%)^{ref}$, $\varepsilon_{v,I\&Y}(\%)^{ref}$ obtained from the appropriate liquefaction hazard map (both model and return period).
 - 7) The user can also enter in a PGA, F_{PGA} , M_W , and Percentile in the corresponding cells to perform a deterministic analysis.
 - 8) Once everything is correctly entered into the *Inputs* tab, click “Analyze”. The calculations will be displayed on the *Final Summary* tab.
 - 9) The *Final Summary* tab displays plots, tables and a summary of inputs in a printable format. The headers of these pages will reflect information such as company name, project name/number, date, etc. entered at the top of the *Inputs* tab. An example final summary output is seen in Figure 2-2.

2.3 Simplified Performance-based Lateral Spread Displacement

- 1) Select an appropriate return period (T_R) for your project (this may depend on the intended use of the building, code requirements, etc.).
- 2) Retrieve the logged reference lateral spread value (D_H^{ref}) from the map or the interactive map database with the desired return period.
- 3) Enter the required soil profile information into the *Inputs* tab. Required values include T_{15} (cumulative thickness of sand or gravel layers with SPT blow counts less than 15), W or S (which are terms based on site geometry), D_{50} (the mean grain size of the T_{15} layers), and F_{15} (the fines content of the T_{15} layers). Specific bounds for these parameters are clearly presented in the *References* Tab. An example of the information provided can be seen in Figure 2-3.

- a. The user must choose whether the analysis is for the Free Face or Ground Slope conditions.
- b. Soil profile information can be entered in either SI or English customary units. Select the desired option by clicking the associated toggle above the soil profile table.

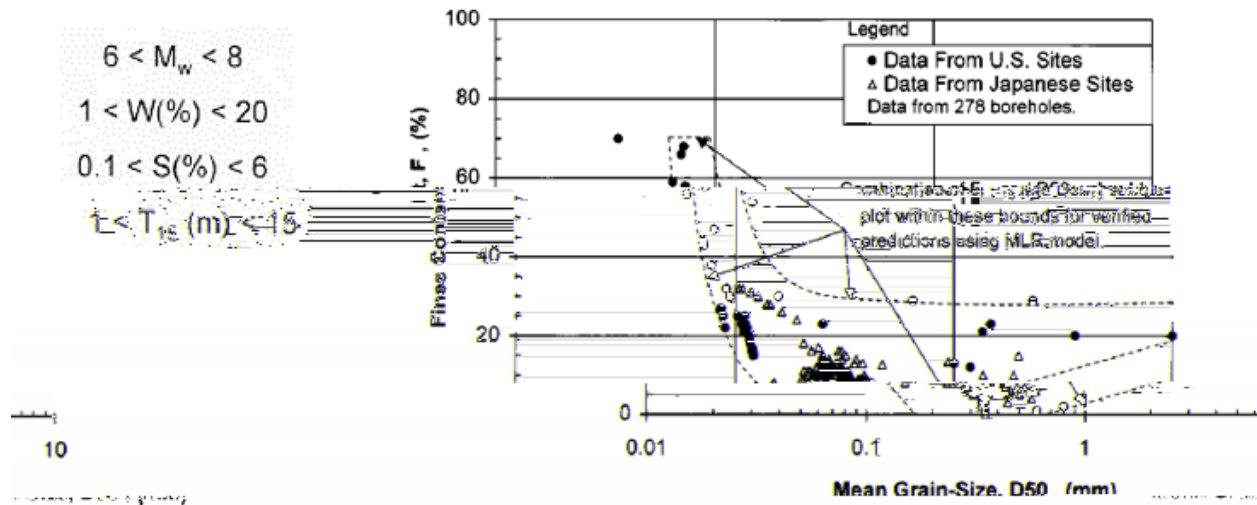


Figure 2-3 Recommended ranges of parameters for lateral spread analysis.

- 4) On the *Inputs* tab under “Analysis Selections”, select the desired models and analyses (See Figure 1-1). If the user wishes to use a deterministic analysis as an upper-bound to the performance-based results, the user should select the appropriate deterministic checkbox.
- 5) On the *Inputs* tab under “Mapped Reference Values”, enter the mapped values retrieved as part of step 2. Also report the return period associated with the chosen.
- 6) If the user wishes to use a deterministic analysis as an upper-bound to the performance-based results, the user should enter the deterministic values of M_w (moment magnitude of fault), R (source-to-site distance), and percentile of the M_w to be considered. This percentile value is required for the deterministic calculations.
 - a. Deterministic values of M_w and R should be assessed by an experienced individual with proper training in deterministic seismic hazard analysis (DSHA).

- b. It is suggested (as explained previously in this report) that a deterministic analysis should be considered when the engineer suspects that the project could benefit from a deterministic cap. In areas of low seismicity, this is likely unnecessary.
- 7) Several dropdown menus are displayed near the top of the *Inputs* tab which allow the user to select which analyses (liquefaction initiation, settlement, lateral spread, or seismic slope stability), models (Cetin et al or Boulanger and Idriss), and options (P_L or FS_L) the user would like to consider. Select the desired analyses, models, and options before proceeding to the next step.
 - 8) Once everything is correctly entered into the *Inputs* tab, click “Analyze”. The calculations will be displayed on the *Lateral Spread* tab.
 - 9) The *Final Summary* tab displays plots, tables and a summary of inputs in a printable format. The headers of these pages will reflect information such as company name, project name/number, date, etc. entered at the top of the *Inputs* tab. An example of the lateral spread results section is shown below.

Summary of Inputs for Lateral Spread Analysis:

| Site Characteristics | Mapped Reference Value | Inputs for Deterministic Analysis |
|---|---|--|
| S = <input type="text" value="4"/> % | $\log D_h^{ref} = $ <input type="text" value="0.042999"/> | Distance = <input type="text" value="7"/> |
| W = <input type="text" value="1"/> % | $T_R = $ <input type="text" value="1033"/> yrs | $M_w = $ <input type="text" value="6.81"/> |
| $T_{15} = $ <input type="text" value="2"/> ft | | Percentile = <input type="text" value="87"/> |
| $F_{15} = $ <input type="text" value="10"/> % | | |
| $D_{50} = $ <input type="text" value="1"/> mm | | |

Lateral Spread Displacement Results:

| Simplified PB Results: | Deterministic Results: |
|--|---|
| $D_h^{site} = $ <input style="width: 80px;" type="text" value="1.298"/> ft | $D_h = $ <input style="width: 80px;" type="text" value="0.871"/> ft |

Figure 2-4 Example of Final Summary of Lateral Spread Displacement Analysis

2.4 Simplified Performance-based Seismic Slope Displacement

- 1) Select an appropriate return period (T_R) for your project (this may depend on the intended use of the building, code requirements, etc.).
- 2) Open the simplified performance-based liquefaction hazard assessment tool (provided as part of this report). Under “Analysis Selections” choose the analysis to perform.

Analysis Selections: *Select "TRUE" to run analysis

Simplified Performance-Based Analysis

Liquefaction Initiation & Settlement: TRUE
 Lateral Spread: TRUE
 Slope Displacement: TRUE

Liquefaction Initiation and Settlement Options:
 Cetin: TRUE B&I&Y: TRUE

Output Type:
 P_L/FS_L : FSL P_L = Probability of Liq.
 FS_L = Factor of Safety

Lateral Spread Options:
 GS FF = Free Face
 GS = Ground Slope

Seismic Slope Displacement Options:
 R&S: TRUE B&T: TRUE

Deterministic Analysis

Liquefaction Initiation & Settlement: TRUE
 Lateral Spread: TRUE
 Slope Displacement: TRUE

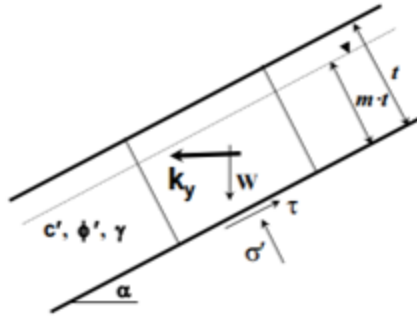
* WARNING: if you have made changes to the Input page, these changes will not be reflected on the Final Summary page unless you click the "Analyze" button to run the analysis.

Figure 2-5 Analysis Selections for Slope Displacement

- 3) Enter the required site slope displacement parameters on the *Inputs* tab. Some of the parameters will be the same as those you will enter for site liquefaction analysis in which case the values need to be filled just once.
 - a. *PGA*: Peak Ground Acceleration should be retrieved from the USGS Interactive Deaggregation Website (<https://earthquake.usgs.gov/hazards/interactive/>) at the return period specified in step 1. Note that the website uses exceedance probabilities instead of return periods. Use Table 2-1 to convert return periods to exceedance probabilities.

After entering the latitude and longitude of the site, exceedance probability, Spectral Period of 0.0 seconds, and $V_{s,30}$ of 760 m/s, retrieve the PGA from the output report. This value is necessary for estimating the F_{pga} . An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.

- b. F_{pga} : If the user checks the “Calculate F_{pga} automatically” checkbox, the spreadsheet will calculate F_{pga} according to the 2012 AASHTO code. However, this cannot be done if the Site Class is F (see notes about Site Class below), and therefore, the user must specify an F_{pga} value based on a site response analysis.
- c. M_w : The mean moment magnitude (M_w) is used to calculate the MSF correction factor as discussed in the Year 1 Quarter 1 report. The value for M_w is found in the same output report created to find the PGA value. An example of where this number is located in the output report is provided in the *References* tab of the spreadsheet.
- d. $V_{s,12}$: The shear wave velocity in the upper 12m (40 ft) is only required when using the Cetin et al (2004) model for liquefaction initiation calculations only. If the user is just running the seismic slope displacement analysis he or she does not need to worry about the value that is entered in this box.
- e. Site Class: The site class is necessary for calculating the F_{pga} . Site class is determined based on soil type and soil properties. See the *References* tab of the spreadsheet for further help in determining site class.
- f. k_y : The yield acceleration represents the horizontal acceleration (in units of g) that results in a factor of safety of 1.0 which initiates sliding in the slope. This value is necessary for computation of seismic slope displacements for both Rathje & Saygili (2009), and Bray & Travararou (2007) models. See the *References* tab and Figure 2-6 for help in determining k_y .



$$k_y = \frac{(FS - 1) \cdot g}{(\cos \alpha \cdot \tan \phi' + 1 / \tan \alpha)} \quad FS = \frac{c'}{\gamma \cdot t \cdot \sin \alpha} + \frac{\tan \phi'}{\tan \alpha} - \frac{\gamma_w \cdot m \cdot \tan \phi'}{\gamma \tan \alpha}$$

Figure 2-6 Infinite Slope Conditions to calculate k_y (Rathje and Saygili, 2009).

- 4) Retrieve the logged reference seismic slope displacement value (D^{ref}) for both the Rathje & Saygili (2009) and Bray & Travararou (2007) models from the map with the desired return period or use the interactive map database.
- 5) If the user wishes to use a deterministic analysis as an upper-bound to the performance-based results, the user should enter the deterministic values of PGA , M_w , and percentile of the PGA to be considered. This percentile value is not used in any calculations, but will be displayed on the final summary page for reference.
 - a. Deterministic values of PGA and M_w should be assessed by an experienced individual with proper training in deterministic seismic hazard analysis (DSHA).
 - b. It is suggested (as explained previously in this report) that a deterministic analysis should be considered when the engineer suspects that the project could benefit from a deterministic cap. In areas of low seismicity, this is likely unnecessary.
- 6) Several dropdown menus are displayed near the top of the *Inputs* tab which allow the user to select which analyses (liquefaction initiation, settlement, lateral spread, or seismic slope stability) and models (Rathje & Saygili or Bray & Travararou), the user

would like to consider. Select the desired analyses, models, and options before proceeding to the next step.

- 7) Once everything is correctly entered into the *Inputs* tab, click “Analyze”. The calculations will be displayed on the *Final Summary* tab.
- 8) The *Final Summary* tab displays plots, tables and a summary of inputs in a printable format. The headers of these pages will reflect information such as company name, project name/number, date, etc. entered at the top of the *Inputs* tab. An example of the seismic slope displacement analysis is shown below.

Summary of Inputs for Seismic Slope Displacement Analysis:

| Input Parameters | | Reference Value | | Inputs for Deterministic Analysis | |
|--------------------|------|--------------------|-----|-----------------------------------|------|
| PGA = | 0.44 | $D_{R\&S}^{ref}$ = | 2.4 | PGA = | 0.73 |
| F _{PGA} = | 1.06 | $D_{B\&T}^{ref}$ = | 2.7 | k_y = | 0.2 |
| M_w = | 6.77 | | | M_w = | 6.8 |
| k_y = | 0.2 | | | Percentile = | 85 |
| Site Class = | D | | | | |

Seismic Slope Displacement Results:

| Simplified PB Results: | | Deterministic Results: | |
|------------------------|----------|------------------------|-----------|
| $D_{R\&S}^{site}$ = | 0.197 in | $D_{R\&S}$ = | 26.873 in |
| $D_{B\&T}^{site}$ = | 0.538 in | $D_{B\&T}$ = | 11.996 in |

Figure 2-7 Example of Final Summary of Seismic Slope Displacement Analysis