SPLIQ USER'S MANUAL

VERSION 1.42

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By using the *SPLiq* program, the user agrees to full responsibility for any damages or liability that result from the use of the program or data therein. The authors are not liable for any damages or liability ensuing as a result of the use of this program or data obtained from this program.

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INTRODUCTION

This user's manual includes a step-by-step process for using a spreadsheet tool called *SPLiq* 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 *SPLiq* tool, were developed initially for these seven states for the 475, 1033, and 2475 year return periods. Based on follow-up work underway using other funding, the authors plan on making these types of maps available for additional states in the coming months for use with the *SPLiq* tool.

This manual was updated for *SPLiq* version 1.42 and includes the new URL for the online Reference Map Database for use with *SPLiq*: https://tethys.byu.edu/apps/lfhazard/. Feedback on the *SPLiq* tool and the online map database may be directed to the UDOT Research & Innovation Division and Dr. Kevin Franke of Brigham Young University. For additional information on the original pooled fund study TPF-5(296) research, see the following links:

TPF-5(296) Simplified SPT Performance-Based Assessment of Liquefaction and Effects, https://www.pooledfund.org/Details/Study/538

Franke et al. (2016), "Simplified Standard Penetration Test Performance-Based Assessment of Liquefaction and Effects," prepared by Brigham Young University for the Utah Department of Transportation Research Division, **Report No. UT-16.16**, May 2016, https://trid.trb.org/View/1597508

Franke, K.W. (2018), "Simplified Standard Penetration Test Performance-Based Assessment of Liquefaction and Effects: Updated Liquefaction Parameter Mapping - Addendum Report," prepared by Brigham Young University for the Utah Department of Transportation Research and Innovation Division, **Report No. UT-18.11**, September 2018, https://trid.trb.org/View/1597511

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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	fines 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)
$(N_1)_{60}$	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}
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
λ_{Nreq*}	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
□	uncertainty term (used in lateral spread displacement model)
$\left[\log D_H\right]^{site}$	logarithm of the lateral spread displacement adjusted for site-specific conditions
$\left[\log D_H\right]^{ref}$	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	fines 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 associate 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 meters)*
$\Delta\varepsilon$	site-specific adjustment factor

ε_v	vertical strain
$\varepsilon_{v,calibrated}^{site}$	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
$\varepsilon_{v,eqv.}$	equivalent vertical strain for entire soil profile
$\varepsilon_{v,max}$	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
$\lambda_{\varepsilon,v,i}$	mean annual rate of exceeding vertical strain
$\mu_{ln\varepsilon}$	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/

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 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. Note that many of the cells on the *Inputs* tab have red flags in the top-right corner. This means that the user may hover his/her mouse over the flag, and an instructive text box will appear to provide more information to the user regarding that cell.

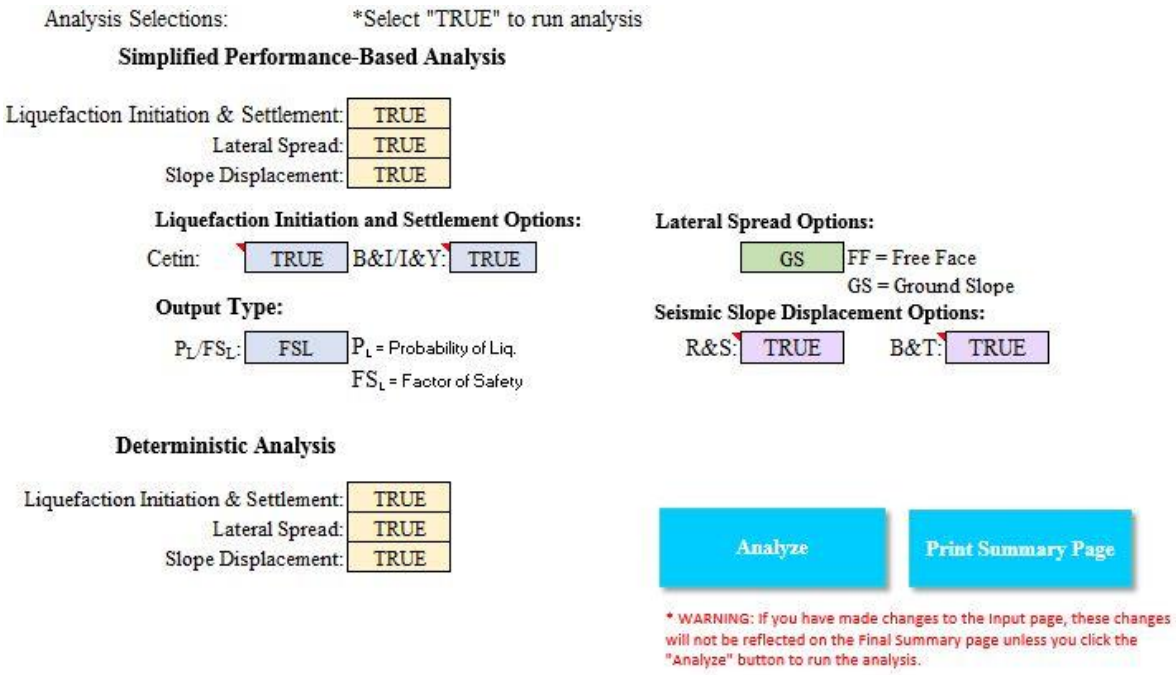


Figure 1-1 Analysis Selections section on the *Inputs* tab.

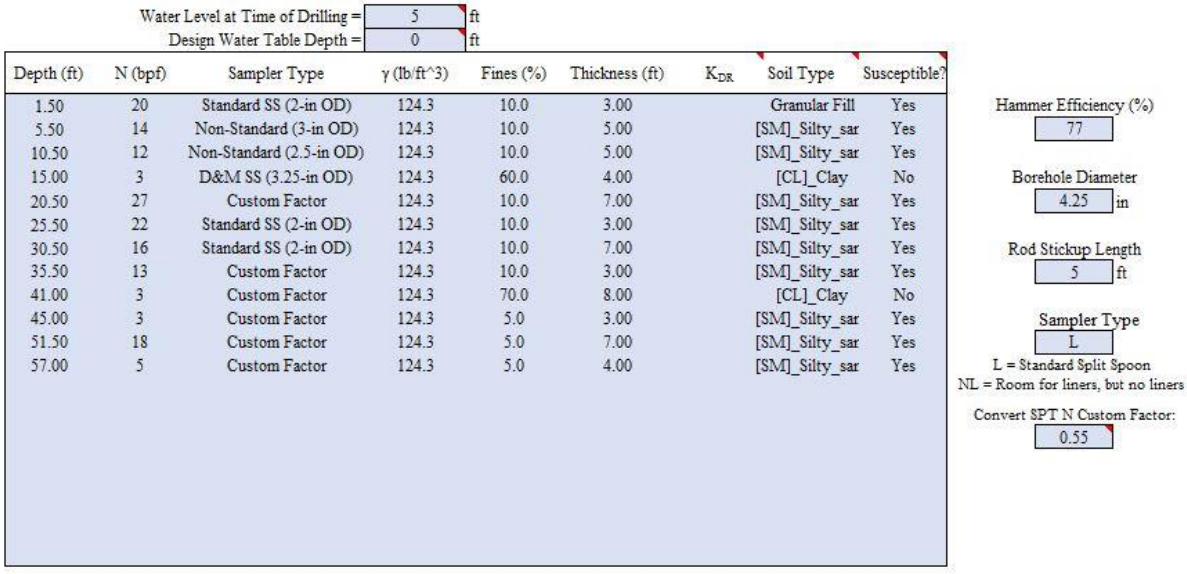


Figure 1-2 Soil profile input section.

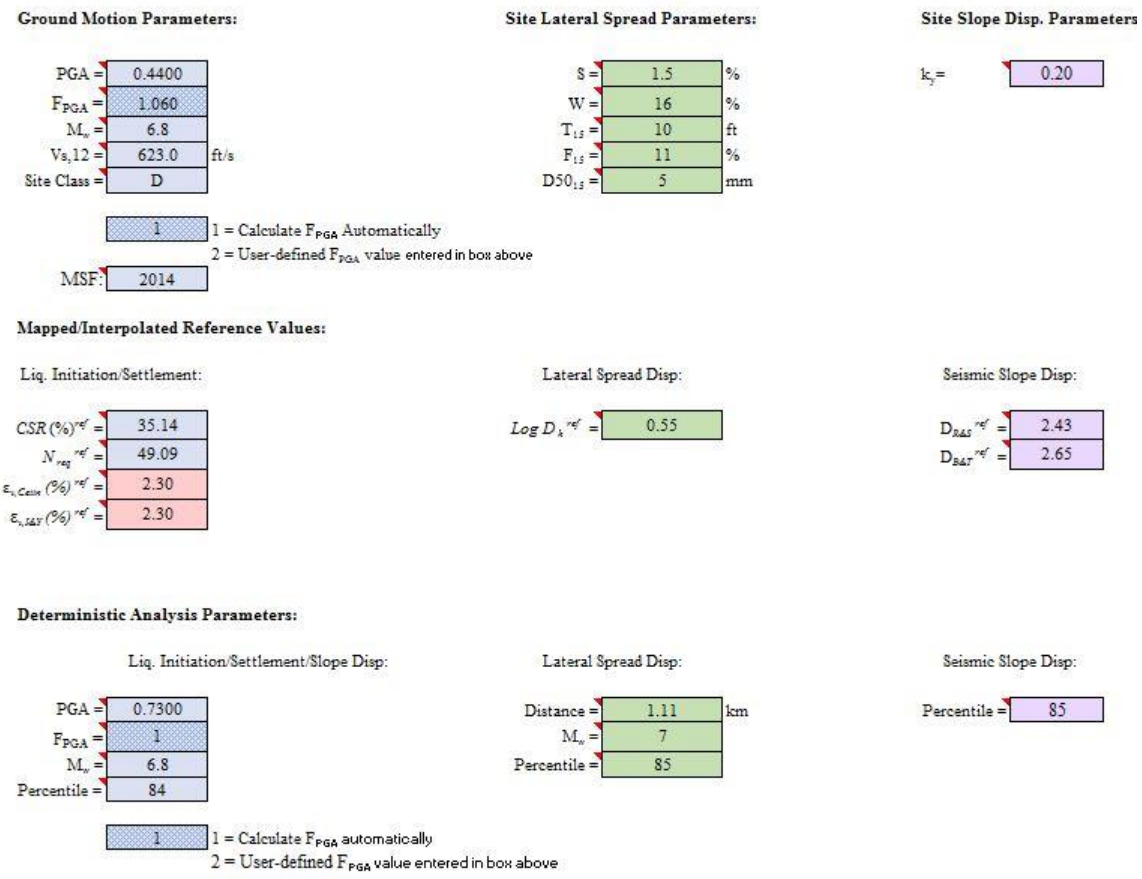


Figure 1-3 Ground motion and reference input parameters.

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/. The authors plan on making these types of maps and parameters available for additional states for use with the *SPLiq* tool. 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.

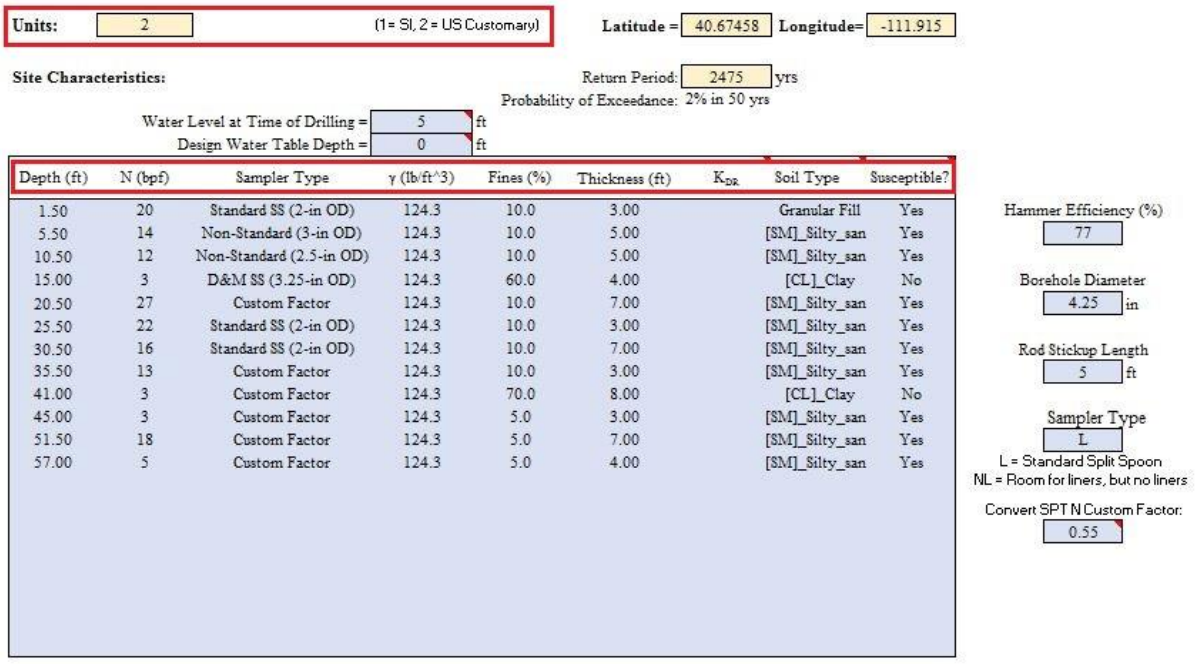
2.0 SUGGESTED SIMPLIFIED PROCEDURE

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 clicking on the blue button labeled "Reference Map Database" on the *Inputs* tab will open the online database in an internet browser. Select the SPT model type. Additional guidance steps are provided in a list next to the blue button in the spreadsheet. See also the *Map Help* tab for an example reference parameter map. 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. The reference parameter data from the Tethys database allows the user to select USGS data based on its 2008 seismic source model or its 2014 seismic source model. The user should select whichever seismic source model is consistent with the code requirements that he/she is using. In general, it is recommended to use the more recent seismic source model when possible/allowed. Some states (e.g., Alaska) do not have a 2014 seismic source model available. For those states, only the 2008 data is available and/or will be defaulted to if 2014 is selected from the list of options. The user should also select the same year from the USGS interactive deaggregation tool when retrieving mean magnitude and *PGA*.
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 $(N_1)_{60,cs}$ 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). $(N_1)_{60,cs}$ is calculated from the ground water at time of drilling—all other calculations are performed using the design ground water depth.



Units: 2 (1= SI, 2 = US Customary) Latitude = 40.67458 Longitude= -111.915

Site Characteristics:

Return Period: 2475 yrs

Probability of Exceedance: 2% in 50 yrs

Water Level at Time of Drilling = 5 ft

Design Water Table Depth = 0 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 (%): 77

Borehole Diameter: 4.25 in

Rod Stickup Length: 5 ft

Sampler Type: L

L = Standard Split Spoon

NL = Room for liners, but no liners

Convert SPT N Custom Factor: 0.55

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 (Unified Hazard Tool) (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, if needed.

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

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

After entering the Edition/model (Dynamic: Alaska 2007; Dynamic: Conterminous U.S. 2014, selecting the most recent version; or Dynamic: Conterminous U.S. 2008 if using the 2008 USGS seismic source model data on Tethys), latitude and longitude of the site, return period or exceedance probability, Spectral Period of 0.0 seconds (Peak Ground Acceleration), and $V_{s,30}$ of 760 m/s (Site Class B/C boundary), compute deaggregation on the website and retrieve the *PGA* from the output report. This value is necessary for estimating the F_{pga}.

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 that should be used is located under **Mean (over all sources)** on the deaggregation output..

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.

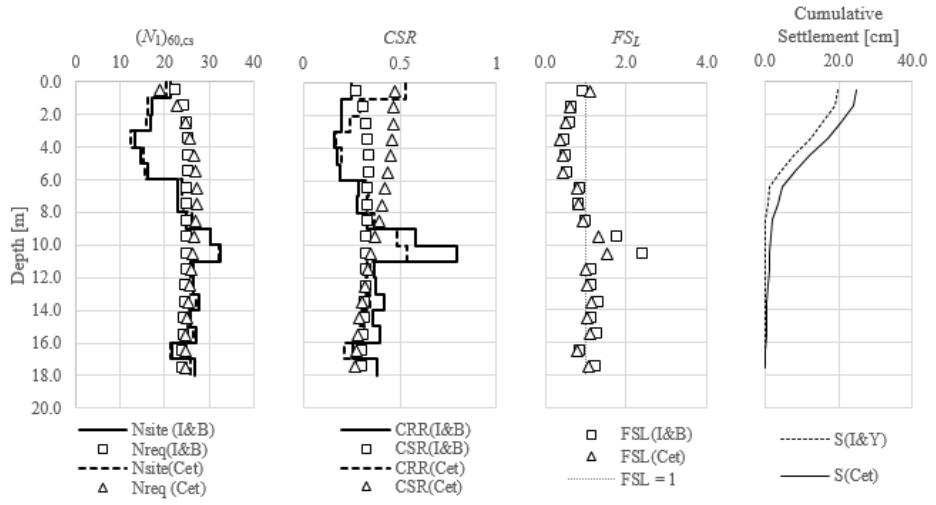
6) On the *Inputs* tab under "Mapped Reference Values", enter the mapped values retrieved as part of step 2. At least one of the two parameters ($CSR(\%)^{ref}$ or $N_{req}{}^{ref}$) is necessary for analysis, but be aware of which model each of these parameters is associated with

(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) Save the file. 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 shown in Figure 2-2.

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

Liquefaction Initiation and Settlement Simplified Performance-based Results:



	Idriss and Boulanger (2008, 2012); Ishihara & Yoshimine (1992)					Cetin et al. (2004, 2009)				
Depth (m)	$(N_1)_{60,cs}$	N_{req}^{site}	CSR^{site}	FS_L	∑S [cm]	$(N_1)_{60,cs}$	N_{req}^{site}	CSR^{site}	FS_L	∑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

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 (Unified Hazard Tool) (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, if needed.

      After entering the Edition/model (see notes in Section 2.1 above), latitude and longitude of the site, return period or exceedance probability, Spectral Period of 0.0 seconds (Peak Ground Acceleration), and $V_{s,30}$ of 760 m/s (Site Class B/C boundary), retrieve the *PGA* from the output report. This value is necessary for estimating the F_{pga}.
   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 that should be used is located under **Mean (over all sources)** on the deaggregation output.
   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 shown 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.

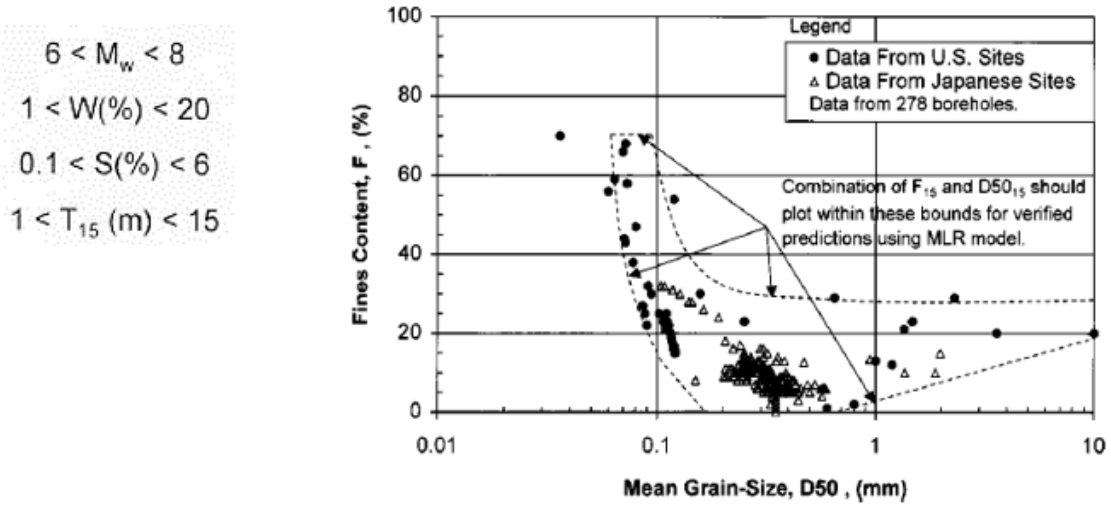
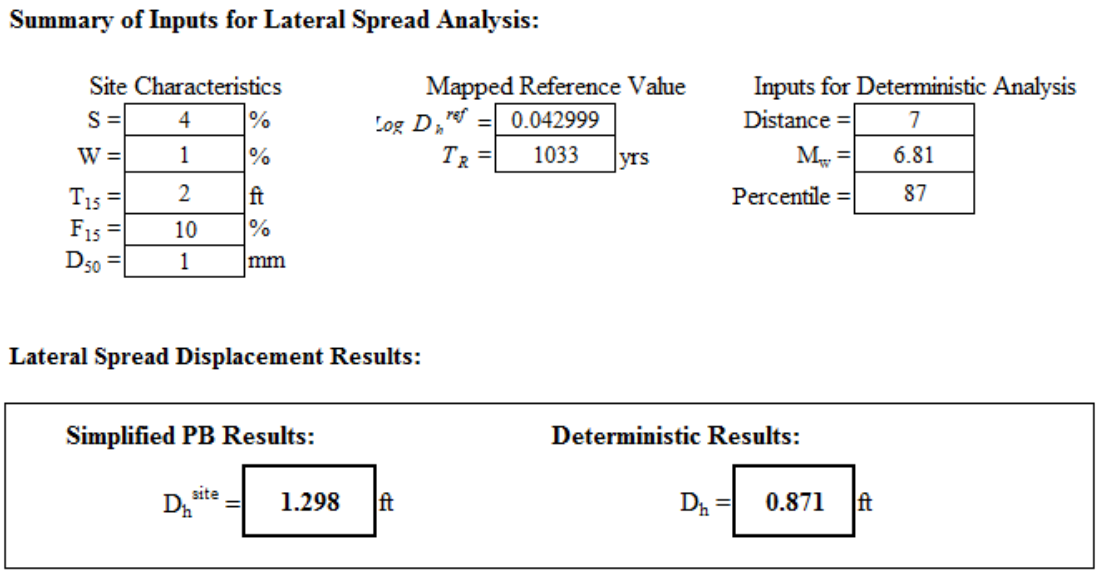


Figure 2-3 Recommended ranges of parameters for lateral spread analysis.

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 analysis.
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 in Figure 2-4.



Summary of Inputs for Lateral Spread Analysis:

Site Characteristics		
S =	4	%
W =	1	%
T_{15} =	2	ft
F_{15} =	10	%
D_{50} =	1	mm

Mapped Reference Value		
$Log\ D_h^{ref}$ =	0.042999	
T_R =	1033	yrs

Inputs for Deterministic Analysis	
Distance =	7
M_w =	6.81
Percentile =	87

Lateral Spread Displacement Results:

Simplified PB Results:			**Deterministic Results:**		
D_h^{site} =	**1.298**	ft	D_h =	**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 *SPLiq* tool. Under "Analysis Selections" choose the analysis to perform.

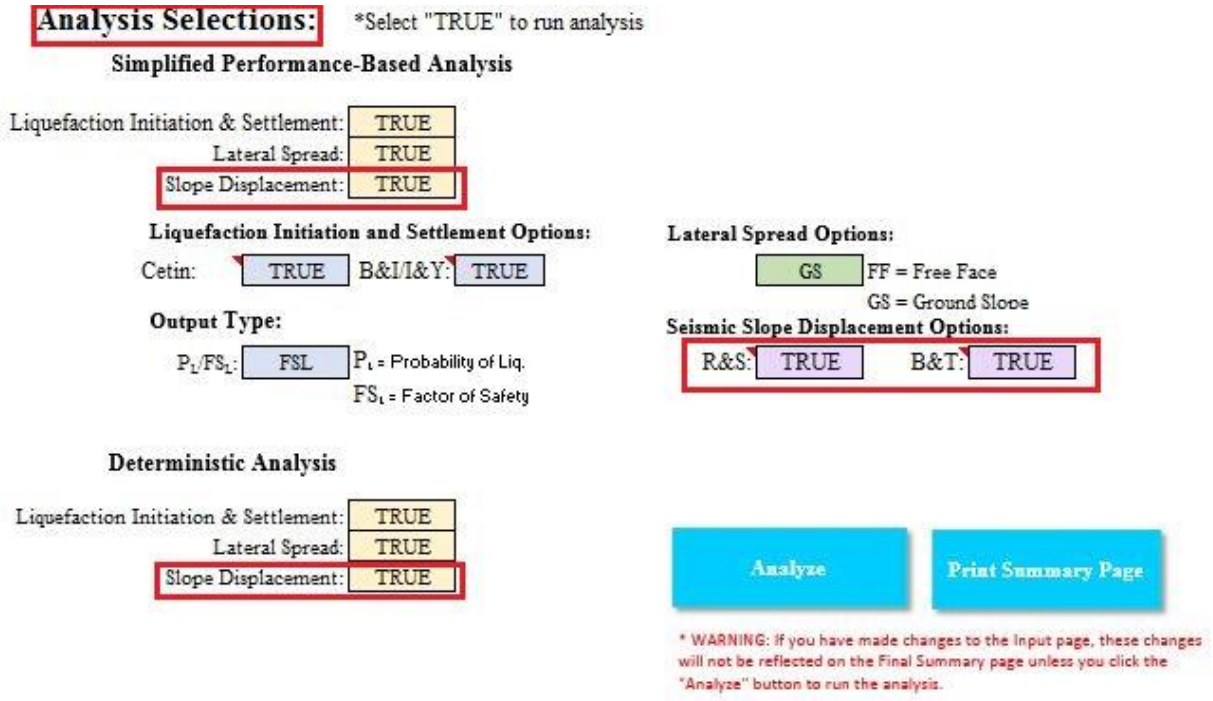


Figure 2-5 Analysis Selections for Slope Displacement

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 (Unified Hazard Tool) (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, if needed.

After entering the Edition/model (see notes in Section 2.1 above), latitude and longitude of the site, return period or exceedance probability, Spectral Period of 0.0 seconds (Peak Ground Acceleration), and $V_{s,30}$ of 760 m/s (Site Class B/C boundary), retrieve the *PGA* from the output report. This value is necessary for estimating the F_{pga}.

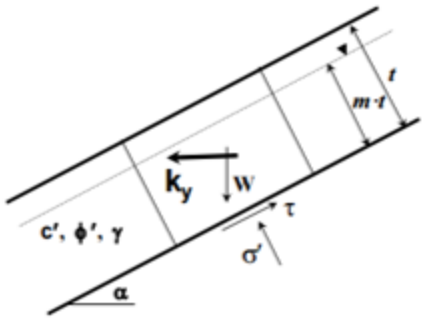
b. F_{pga}: If the user checks the "Calculate F_{pga} automatically" checkbox, the spreadsheet will calculate F_{pga} according to the 2012 AASHTO code. However, this cannot be done if the Site Class is F (see notes about Site Class below), and therefore, the user must specify an F_{pga} value based 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 that should be used is located under **Mean (over all sources)** on the deaggregation output.

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 & Travasarou (2007) models. See the *References* tab and Figure 2-6 for help in determining k_y.



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

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

4) Retrieve the logged reference seismic slope displacement value (D^{ref}) for both the Rathje & Saygili (2009) and Bray & Travasarou (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 & Travasarou), 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 results section is shown in Figure 2-7 below.

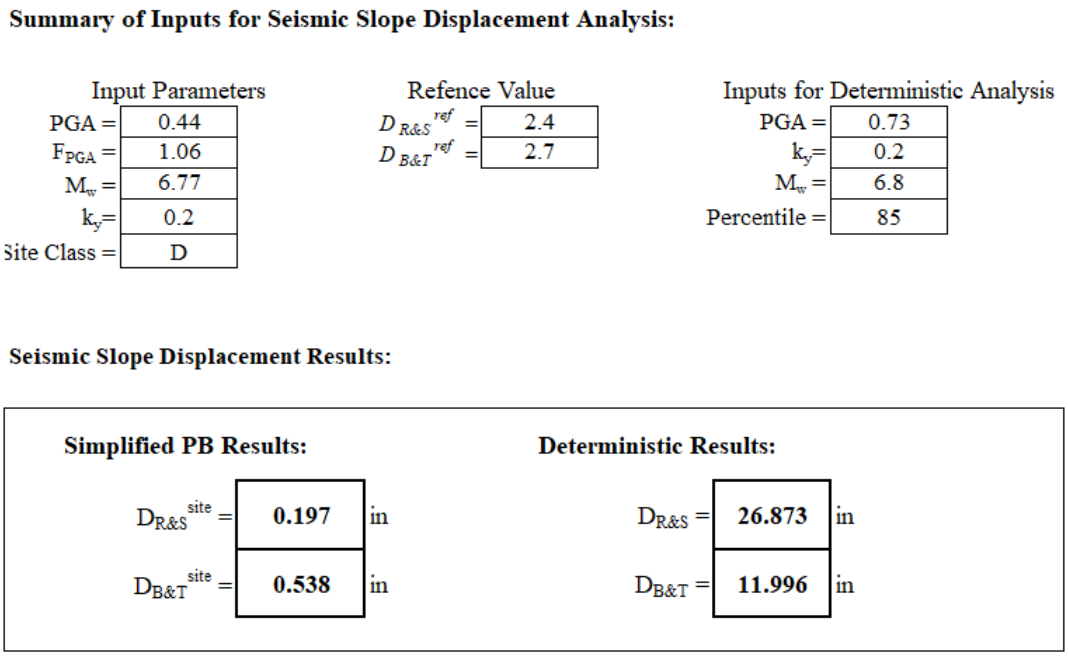


Figure 2-7 Example of Final Summary of Seismic Slope Displacement Analysis

2.5 Guidance on Interpretation of Analysis Results

In interpreting the results from the analysis, there is likely to be some discrepancies between the various methods that were selected. These discrepancies are a good thing and help to quantify how much uncertainty or variability may exist in the problem. There is no widely accepted approach for how to interpret liquefaction hazard analysis results, and engineers must apply their own engineering judgment. In general, we recommend that both a deterministic analysis (i.e.,

scenario-based) and a performance-based analysis be performed. Whichever provides the *smaller* result should be used for design. This approach may seem counter-intuitive to engineers who are accustomed to always selecting the larger hazard for design. However, when performing seismic hazard analysis, it is customary to select the smaller of the deterministic analysis and the probabilistic analysis. This approach prevents the engineer from selecting a ground motion that is too large such that is unlikely to occur during the lifespan of the infrastructure, and also from selecting an unrealistically inflated probabilistic value that can be commonly computed in areas of high seismicity. It is important, however, that the engineer does not confuse a pseudo-probabilistic analysis (i.e., a scenario-based analysis in which the *PGA* and magnitude are taken from the deaggregation results of a single return period) with a deterministic analysis. The deterministic analysis should incorporate an appropriate *PGA* and magnitude estimate from a single earthquake event on a single specified fault. These parameters are typically estimated using empirical magnitude prediction equations and ground motion prediction equations such as those associated with NGA West2. Given that these types of equations are not necessarily intuitive, only professionals with experience and training in seismic hazard analysis should obtain these parameters for deterministic liquefaction hazard analysis.