Report No. UT-22.02

CPTLIQ USER'S MANUAL

VERSION 1.42

Prepared For:

Utah Department of Transportation
Research & Innovation Division

January 2022

RESEARCH

Keeping Utah Moving
Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

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ACKNOWLEDGMENTS

The authors acknowledge the Utah, Oregon, South Carolina, and Connecticut Departments of Transportation for funding this research for pooled fund study TPF-5(338). The views and opinions presented in this report represent those of its authors, and may not represent those of the state agencies funding this research.

TECHNICAL REPORT ABSTRACT

<table>
<tr><td>1. Report No.
UT-22.02</td><td>2. Government Accession No.
NA</td><td>3. Recipient's Catalog No.
NA</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
CPTLIQ USER'S MANUAL
VERSION 1.42</td><td>5. Report Date
January 2022</td></tr>
<tr><td>6. Performing Organization Code
NA</td></tr>
<tr><td colspan="2">7. Author(s)
Kevin W. Franke, Jingwen He, Jenny L. Blonquist</td><td>8. Performing Organization Report No.
NA</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Brigham Young University
Department of Civil and Environmental Engineering
368 Clyde Building
Provo, UT 84602-4009</td><td>10. Work Unit No.
42074 15D</td></tr>
<tr><td>11. Contract or Grant No.
16-9826</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Utah Department of Transportation
4501 South 2700 West
P.O. Box 148410
Salt Lake City, UT 84114-8410</td><td>13. Type of Report & Period Covered
User's Manual
July 2017 – August 2021</td></tr>
<tr><td>14. Sponsoring Agency Code
PIC No. UT15.402</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration</td></tr>
<tr><td colspan="3">16. Abstract
This user's manual includes a step-by-step process for using a spreadsheet tool called CPTLiq to perform simplified calculations for performance-based probabilistic earthquake hazard analysis while using Cone Penetration Test (CPT) data from site CPT soundings of soils. The simplified models provide estimates of liquefaction triggering, lateral spread displacements, and post-liquefaction settlements. These simplified models were developed and validated, as documented in two UDOT research report volumes for Phases 1 and 2 of the TPF-5(338) pooled fund study that was funded by the Utah, Oregon, South Carolina, and Connecticut Departments of Transportation. Liquefaction reference parameter maps, which are used together with the CPTLiq tool, were developed for these four states for the 475, 1039, and 2475 year return periods, as documented in the Phase 2 final report volume.</td></tr>
<tr><td colspan="2">17. Key Words
CPTLiq, Lateral Spread Displacements, Liquefaction Triggering, Post-Liquefaction Settlements, Performance-based Engineering Reference Maps, Simplified Models, Seismic Hazards, Cone Penetration Test</td><td colspan="2">18. Distribution Statement
Not restricted. Available through:
UDOT Research & Innovation Div.
4501 South 2700 West
P.O. Box 148410
Salt Lake City, UT 84114-8410
www.udot.utah.gov/go/research</td><td rowspan="2">23. Registrant's Seal
NA</td></tr>
<tr><td>19. Security Classification
(of this report)
Unclassified</td><td>20. Security Classification
(of this page)
Unclassified</td><td>21. No. of Pages
26</td><td>22. Price
NA</td></tr>
</table>

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LIST OF TERMS

a	net area ratio
a_{max}	peak ground surface acceleration
C_{FC}	regression fitting parameter that can be used to minimize uncertainty
C_N	overburden correction factor (Robertson Method)
CPT	Cone Penetration Test
CRR	cyclic resistance ratio
CSR	cyclic stress ratio
DF	depth weighting factor
D_R	relative density
D_H	horizontal displacement
FC	fines content (%)
fs	CPT sleeve friction
F_a	soil amplification factor
g	acceleration due to gravity
H	the free face height H
Ic	soil behavior type index
IND	indicator of the occurrence of liquefaction
Kc	soil behavior type correction factor
$\mathrm{K_H}$	depth correction factor
$K\alpha$	initial shear stress correction factor
K_σ	overburden stress correction factor
λ	annual rate of exceedance or equal to 1/return period
LD	lateral displacement
LDI	lateral displacement index
L	the distance from toe of the free face
M	magnitude of earthquake event
M_w	moment magnitude of earthquake loading

MSF_{max}	the upper limit for MSF
N_{amax}	number of subdivided peak acceleration increments
N_M	number of subdivided Magnitude increments
N_{req}	required SPT/blow count resistance to resist liquefaction
ΔN_L	difference between $(N_1)_{60,cs}$ and N_{req} (Mayfield et al. 2010)
n	stress exponent (Robertson (2009))
P_a	atmospheric pressure (1 atm, 101.3 kPa, 0.2116 psf)
PGA	peak ground acceleration
P_L	probability of liquefaction
q_c	uncorrected CPT tip resistance
q_{c1N}	normalized CPT penetration resistance
q_{c1Ncs}	clean-sand equivalent normalized CPT tip resistance Robertson and Wride (1998) and Boulanger and Idriss
q_{req}	required cone tip resistance to resist liquefaction
q_t	corrected cone tip stress
R	ratio of baseline value to corrected value
$\lambda_{\varepsilon v}$	mean annual rate of exceeding a specified strain
ε_v	volumetric strain
$\varepsilon_{v,max}$	maximum vertical strain
Q_{tn}	cone tip resistance corrected for overburden stress
Q_{tncs}	clean-sand equivalent normalized CPT tip resistance Robertson (2009)
r_d	shear stress reduction coefficient
S	the ground slope
S_a	actual settlement observed
δ_a	represents the coefficient of variation of S_a
S_p	vertical liquefaction-induced settlement
T_R	return period
u	CPT pore pressure

μ_a	mean of actual observed settlement
z	depth from ground surface to depth of interest
z_{max}	the deepest liquefiable layer
γ	unit weight of soil
$\gamma_{\max}$	maximum cyclic shear strain
$\lambda_{\gamma\max}$	mean annual rate of exceeding the maximum cyclic shear strain
$\varepsilon_{ln(R)}$	total uncertainty
$\sigma_{ln(R)}$	model uncertainty
σ_{total}	total uncertainty
σ_{vo}	soil overburden pressure
σ'_{vo}	effective soil overburden pressure
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
τ_{cyc}	equivalent uniform cyclic shear stress
$(N_1)_{60,cs}$	corrected SPT blow count
Φ	standard normal cumulative distribution function

ONLINE REFERENCE MAP DATABASE ACCESS INFORMATION
(for use with *CPTLiq*)

URL: https://tethys.byu.edu/apps/lfhazard/

1.0 DEVELOPMENT OF *CPTLIQ*

1.1 Overview

This section explains the components of the simplified liquefaction assessment tool *CPTLiq*, and provides some guidance for how the tool should be used. The simplified models used in *CPTLiq* were developed and validated, as documented in two UDOT research report volumes for Phases 1 and 2 of the TPF-5(338) pooled fund study that was funded by the Utah, Oregon, South Carolina, and Connecticut Departments of Transportation. The current version of the *CPTLiq* spreadsheet tool is available on the TPF-5(338) pooled fund study webpage and also from the Utah Department of Transportation (Research & Innovation Division, and Geotechnical Division) and Brigham Young University (Department of Civil and Environmental Engineering).

In Section 1.2 the components of *CPTLiq* are described. Each of these components is contained within a separate tab in the *CPTLiq* MS Excel spreadsheet.

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 and deterministic procedures (Figure 1-4), and options for corrections/modifications (Figure 1-4). Once inputs are correctly entered, the user may click on the blue "Analyze" button to begin the analysis tool. *CPTLiq* limits the number of data rows to 1,500 depth increments. Due to the size and complexity of CPT data, it may take several seconds (or several minutes if using the optional CPT modifications/corrections) for the spreadsheet to complete all the calculations. Consider decreasing depth increments, if necessary by thinning the number of rows, thereby increasing the depth increment between rows (i.e., enter readings at every 0.1 depth increment rather than entering readings at every 0.01 depth increment).

The mapped reference parameter values were developed using a generic reference soil profile and performance-based methods across a grid of points in the state of interest. The development of these reference parameter values, the grid points, and the details of the performance-based analysis are described in the Phase 2 report volume associated with this research. The reference parameter maps are available in the Phase 2 report or the interactive reference map database for a few states. A link to the Reference Map Database and a blue button hyperlinked to the database are provided in the *Inputs* tab of the spreadsheet (Figure 1-3). The current URL to the Reference Map Database is: https://tethys.byu.edu/apps/lfhazard/

Along with some general inputs, the input cells on the *Inputs* tab are color coded to help the user understand what is needed for each hazard. Liquefaction triggering inputs are blue, Settlement inputs are red, and Lateral Spread inputs are green. 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.

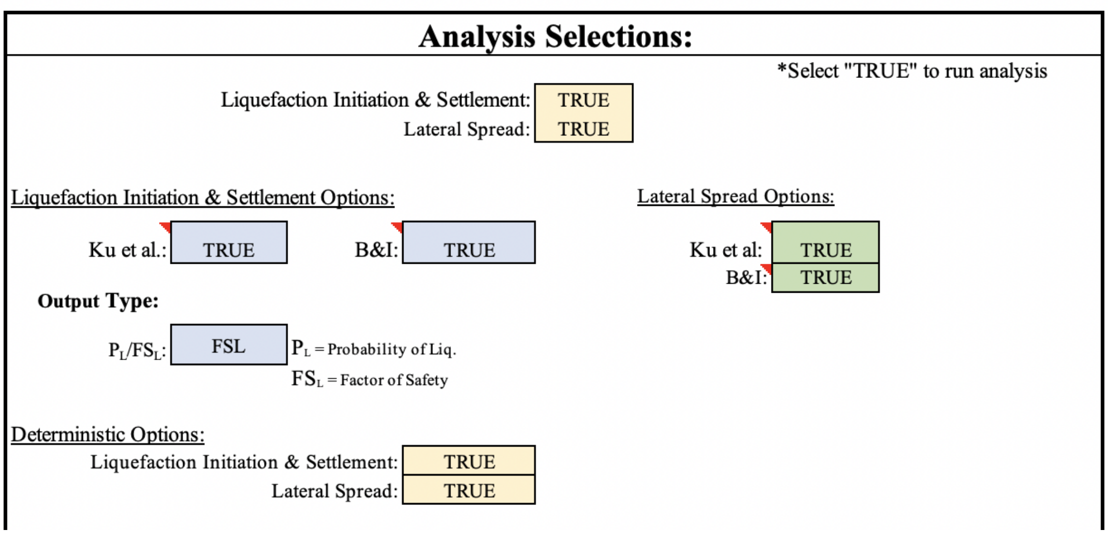
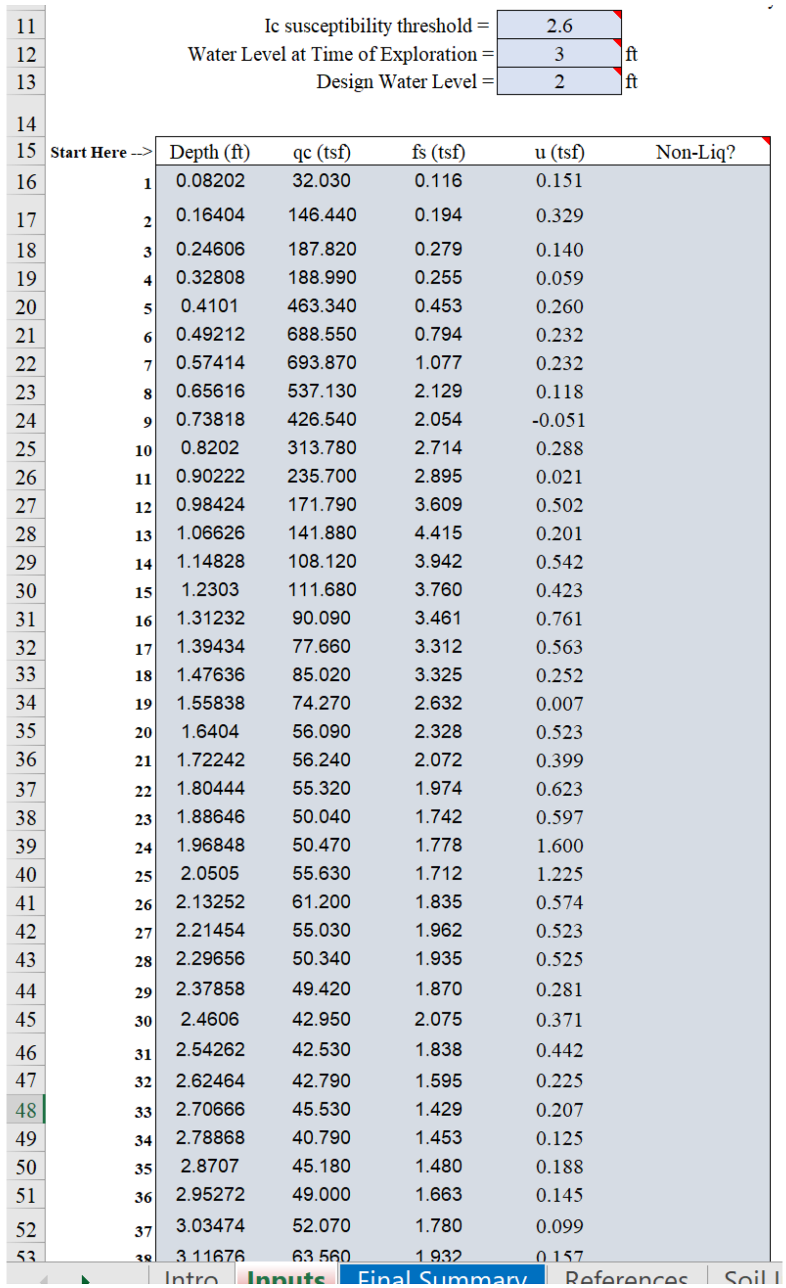


Figure 1-1: Analysis Selections section on the *Inputs* tab



Ic susceptibility threshold = 2.6
Water Level at Time of Exploration = 3 ft
Design Water Level = 2 ft

Start Here -->	Depth (ft)	qc (tsf)	fs (tsf)	u (tsf)	Non-Liq?
1	0.08202	32.030	0.116	0.151	
2	0.16404	146.440	0.194	0.329	
3	0.24606	187.820	0.279	0.140	
4	0.32808	188.990	0.255	0.059	
5	0.4101	463.340	0.453	0.260	
6	0.49212	688.550	0.794	0.232	
7	0.57414	693.870	1.077	0.232	
8	0.65616	537.130	2.129	0.118	
9	0.73818	426.540	2.054	-0.051	
10	0.8202	313.780	2.714	0.288	
11	0.90222	235.700	2.895	0.021	
12	0.98424	171.790	3.609	0.502	
13	1.06626	141.880	4.415	0.201	
14	1.14828	108.120	3.942	0.542	
15	1.2303	111.680	3.760	0.423	
16	1.31232	90.090	3.461	0.761	
17	1.39434	77.660	3.312	0.563	
18	1.47636	85.020	3.325	0.252	
19	1.55838	74.270	2.632	0.007	
20	1.6404	56.090	2.328	0.523	
21	1.72242	56.240	2.072	0.399	
22	1.80444	55.320	1.974	0.623	
23	1.88646	50.040	1.742	0.597	
24	1.96848	50.470	1.778	1.600	
25	2.0505	55.630	1.712	1.225	
26	2.13252	61.200	1.835	0.574	
27	2.21454	55.030	1.962	0.523	
28	2.29656	50.340	1.935	0.525	
29	2.37858	49.420	1.870	0.281	
30	2.4606	42.950	2.075	0.371	
31	2.54262	42.530	1.838	0.442	
32	2.62464	42.790	1.595	0.225	
33	2.70666	45.530	1.429	0.207	
34	2.78868	40.790	1.453	0.125	
35	2.8707	45.180	1.480	0.188	
36	2.95272	49.000	1.663	0.145	
37	3.03474	52.070	1.780	0.099	
38	3.11676	63.560	1.932	0.157	

Figure 1-2: Soil profile input section

Probabilistic Analysis Parameters:

PGA =	0.64	S(%) =	2.5
F_{PGA} =	1.10	W (L/H) =	0
M_w =	6.83		
Site Class =	D		

USGS Interactive Deaggregation

Fpga Calc = 1

1) Obtain *PGA* AND M_w through USGS Interactive Deaggregation Tool using the blue button.
2) In the "Input" section, select a model from the "Edition" dropdown menu. Select "Dynamic: Conterminous U.S. 2014 [most recent version]" if using the 2014 USGS seismic source model or "Conterminous U.S. 2008 [most recent version]" if using the 2008 USGS seismic source model.
3) Enter Latitude and Longitude of site or choose location using a map.
4) Site Class must reflect a shear wave velocity of 760 m/s; select "760 m/s (B/C boundary)" from the "Site Class" drop down menu.
5)Spectral Period must be set at "Peak ground acceleration".
6) Enter appropriate Time Horizon (Return Period) of 475, 1033, or 2475 years.
7)Scroll down to "Deaggregation" section and click "Compute Deaggregation".

URL: https://earthquake.usgs.gov/hazards/interactive/

Mapped Reference Values:

$CSR\ (\%)^{ref}$ =	81.91
$q_{rea}^{\ ref}$ =	196.17
$\varepsilon_{v,ku}\ (\%)^{ref}$ =	2.32
$\varepsilon_{v,B\&I}\ (\%)^{ref}$ =	3.28
$\gamma_{max,KU}^{\ ref}(\%)$ =	12.21
$\gamma_{max,BI}^{\ ref}(\%)$ =	28.94

1) Obtain reference parameters using the blue button.
2) Select "CPT"
3) Select State, Model, Year, Return Period.
4) Select location on map or enter latitude and longitude.
5)Reference Values will populate within a pop-up in the browser.

Reference Map Database

URL: http://tethys.byu.edu/apps/lfhazard/

Deterministic Analysis Parameters:

PGA =	0.64
F_{PGA} =	1.10
M_w =	6.83
Percentile =	85.00
Fpga Calc =	1

Figure 1-3: Analysis Parameters

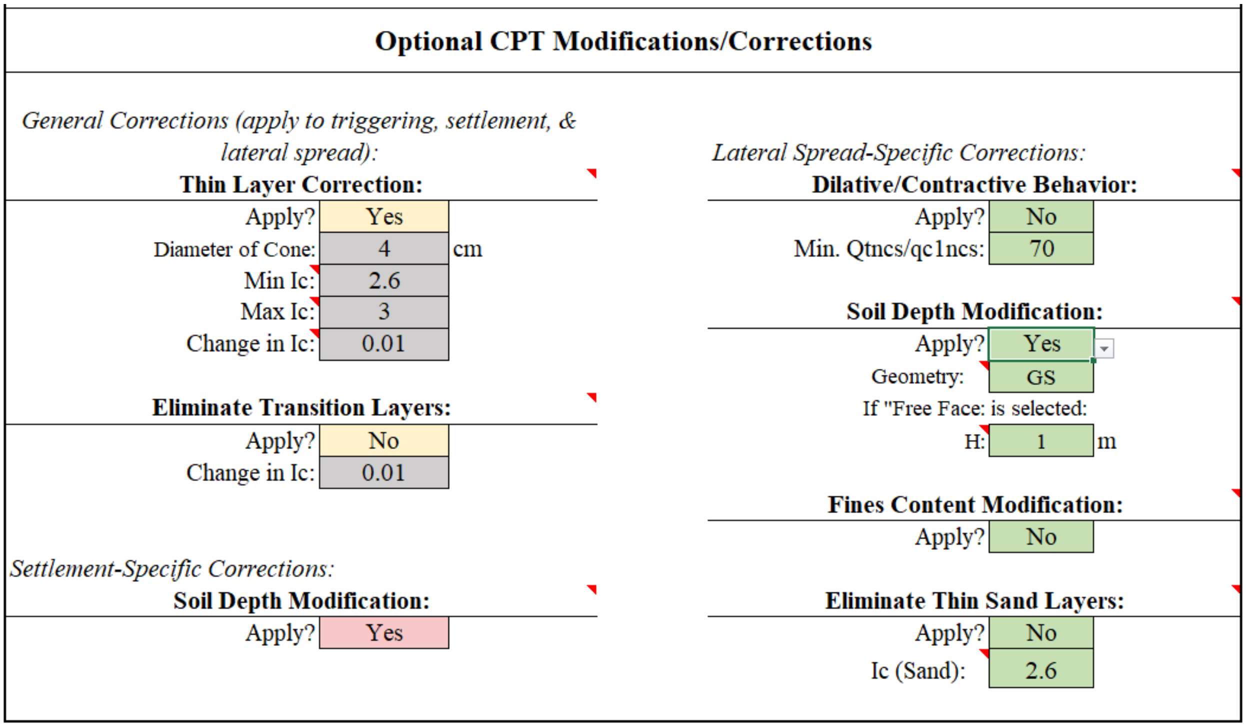


Figure 1-4: Options for Corrections/Modifications

1.2.2 Soil Info

This section performs intermediate calculations to be used later in the spreadsheet. Some of these intermediate calculations include the iterative process to compute the soil behavior index, *Ic*, conversion of inputs to metric units for the simplified procedure, calculating q_{c1ncs} and Q_{tncs}, etc. This section also contains intermediate steps for the thin layer and transition layer corrections.

1.2.3 Map Help

This section shows an example of a liquefaction parameter map and shows how to retrieve the mapped reference liquefaction loading value, lateral spread displacement value, or post-liquefaction settlement value.

1.2.4 Simplified Performance-based Liquefaction Triggering Tabs

1.2.4.1 PB Liquefaction Initiation

This section of the spreadsheet shows the calculations for the simplified performance-based liquefaction initiation procedure. The Boulanger and Idriss (2014) and Ku et al. (2012) model is simplified as detailed in the Final Report of this research (Phase 2). 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.

1.2.4.2 Deterministic Liquefaction Initiation

This section of the spreadsheet calculates deterministic liquefaction initiation values. The formulas for the deterministic Idriss and Boulanger (2008) model and from the deterministic Robertson and Wride (2010) 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.

1.2.5 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) settlement model. The simplified procedure uses Factor of Safety obtained from the Boulanger and Idriss (2014) and Ku et al. (2012) liquefaction triggering procedures. These sheets are available for review from the user but do not require any input or changes from the user.

1.2.6 Simplified Performance-based Lateral Spread Displacement Tabs

This portion of the spreadsheet determines the simplified and deterministic lateral spread displacements based on the Zhang et al. (2004) empirical model and the simplified procedure developed in study TPF-5(338). 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. This section is to provide a reference to the engineer.

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 formatted 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, post-liquefaction settlement, and lateral spread 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 mapped reference value (reference liquefaction loading value) (i.e. q_{req}^{ref} and/or $CSR^{ref}(\%)$) from the maps or the interactive reference map database with the desired return period and model (i.e. Ku et al., 2012 or Boulanger and Idriss, 2014). Note that clicking on the blue button labeled "Reference Map Database" on the *Inputs* tab will open the online database in an internet browser. 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 the provided q_{req}^{ref} maps are based on the Ku et al. (2012) model, and the $CSR^{ref}(\%)$ maps are based on the Boulanger and Idriss model (2014). 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, which was not mapped in this study but will be mapped in future studies) 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 the *qc, fs,* and *u* (commonly found from CPT soundings data) and water table depth. An optional input is the "Non-Liq" column. The spreadsheet already computes susceptibility based on triggering results. This value is not required, but

allows the user to manually indicate if a layer is non-liquefiable, if desired. Layers indicated as “NL” will not be considered in liquefaction analyses.

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. The user can also enter the water level at time of exploration and the design water level (i.e. water level at time of earthquake). q_{c1ncs} is calculated using the design ground water depth.

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

Latitude = 40.621 Longit

Site Characteristics:

Return Period: 2475 yrs

Probability of Exceedance: 2% in 50 yrs

Ic susceptibility threshold = 2.6

Water Level at Time of Exploration = 3 ft

Design Water Level = 2 ft

rt Here -->	Depth (ft)	qc (tsf)	fs (tsf)	u (tsf)	Non-Liq?
1	0.08202	32.030	0.116	0.151	
2	0.16404	146.440	0.194	0.329	
3	0.24606	187.820	0.279	0.140	
4	0.32808	188.990	0.255	0.059	
5	0.4101	463.340	0.453	0.260	
6	0.49212	688.550	0.794	0.232	
7	0.57414	693.870	1.077	0.232	
8	0.65616	537.130	2.129	0.118	
9	0.73818	426.540	2.054	-0.051	
10	0.8202	313.780	2.714	0.288	
11	0.90222	235.700	2.895	0.021	
12	0.98424	171.790	3.609	0.502	
13	1.06626	141.880	4.415	0.201	
14	1.14828	108.120	3.942	0.542	
15	1.2303	111.680	3.760	0.423	
16	1.31232	90.090	3.461	0.761	
17	1.39434	77.660	3.312	0.563	
18	1.47636	85.020	3.325	0.252	
19	1.55838	74.270	2.632	0.007	
20	1.6404	56.090	2.328	0.523	
21	1.72242	56.240	2.072	0.399	
22	1.80444	55.320	1.974	0.623	
23	1.88646	50.040	1.742	0.597	
24	1.96848	50.470	1.778	1.600	
25	2.0505	55.630	1.712	1.225	
26	2.13252	61.200	1.835	0.574	
27	2.21454	55.030	1.962	0.523	
28	2.29656	50.340	1.935	0.525	
29	2.37858	49.420	1.870	0.281	
30	2.4606	42.950	2.075	0.371	
31	2.54262	42.530	1.838	0.442	
32	2.62464	42.790	1.595	0.225	

Probabilistic

PGA = 0.6

F_{PGA} = 1.1

M_w = 6.8

Site Class = D

Fpga Calc = 1

1) Obtain *PGA* AND M_w t
2) In the "Input" section, se
U.S. 2014 [most recent ver
[most recent version]" if us
3) Enter Latitude and Long
4) Site Class must reflect a
drop down menu.
5)Spectral Period must be s
6) Enter appropriate Time I
7)Scroll down to "Deaggre

URL: https:/

Mapped Refere

$CSR\,(\%)^{ref}$ = 81.

$q_{rea}^{\ ref}$ = 196.

$\varepsilon_{v,ku}\,(\%)^{ref}$ = 2.3

$\varepsilon_{v,B\&I}\,(\%)^{ref}$ = 3.2

$\gamma_{max,KU}^{\ ref}(\%)$ = 12.

$\gamma_{max,BI}^{\ ref}(\%)$ = 28.

1) Obtain reference
2) Select "CPT"
3) Select State, Mod
4) Select location on
5)Reference Values

URL: http://t

Deterministic A

PGA = 0.6

F_{PGA} = 1.1

M_w = 6.8

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. 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. 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: 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}. 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 selects "1" from the "Fpga Calc" dropdown menu, the spreadsheet will calculate F_{pga} according to the 2012 AASHTO code. Otherwise, a "2" indicates that a user-defined F_{pga} is entered. 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 r_d correction factor as discussed in the study TPF-5(338) Final Reports. The value for M_w that should be used is located under **Mean (over all sources)** on the deaggregation output.

d. 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 q_{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 pages 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. For computing F_{pga} for the deterministic analysis, the user can either enter '1' to automatically compute F_{pga} using the same soil site classification specified in the probabilistic analysis parameters input, or can enter '2' to specify a different site-specific F_{pga} value

   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 the Phase 2 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 "Analysis Selections" section) which allow the user to select which analyses (liquefaction

initiation, settlement, or lateral spread), models (Ku 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.

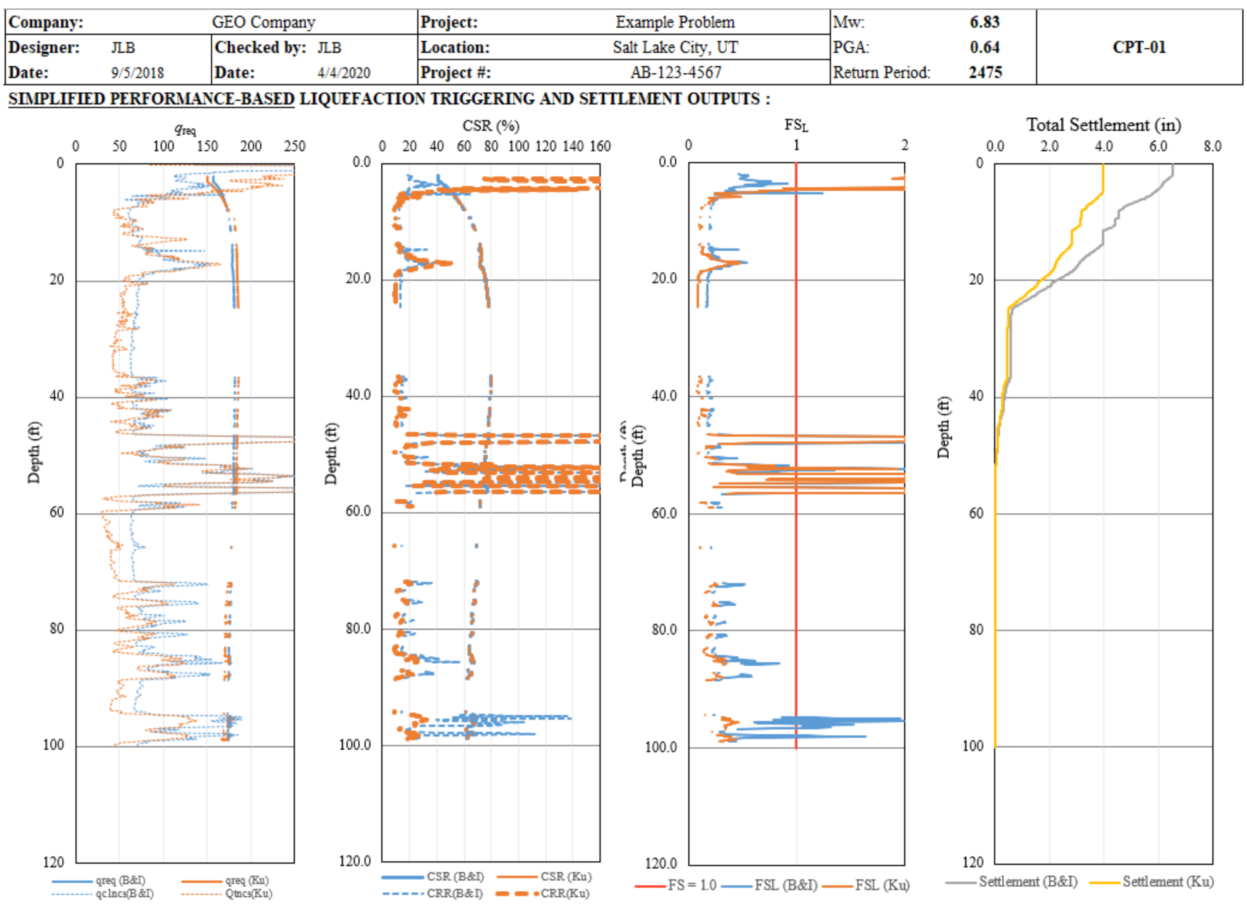


Figure 2-2: Example Final Summary for Simplified Liquefaction Initiation and Settlement

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 1-4).
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 1,500 soil sub-layers; therefore, shorten the soil profile inputs 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 settlement analyses cannot be run without also performing corresponding liquefaction initiation model. Thus, the liquefaction initiation and settlement options are grouped together.
   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 1-4):
   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 Table 2-1to convert return periods to exceedance probabilities, if needed.

      After entering the Edition/model (Dynamic: Conterminous U.S. 2014), 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}. 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 r_d correction factor as discussed in the TPF-5(338) Final Reports. The value for M_w that should be used is located under **Mean (over all sources)** on the deaggregation output.

d. 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 $CSR\ (\%)^{ref}$, q_{req}^{ref}, $\varepsilon_{v,Ku}(\%)ref$, $\varepsilon_{v,B\&I}(\%)^{ref}$ 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 ($\gamma_{max,BI}^{ref}(\%)$, $\gamma_{max,Ku}^{ref}(\%)$) from the map or the interactive reference map database with the desired return period.
3) Enter the required soil profile information into the *Inputs* tab. Required values include *W* (free-face ratio) or *S* (ground slope gradient). Both of these terms are based on site geometry. Figures are provided in the *References* tab to demonstrate how these

parameters should be calculated for a site. If uncertain whether *W* or *S* should be used at a site, it is generally recommended to compute displacements with each, and then select whichever provides the more conservative (i.e., largest) predicted displacement.

   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.

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), 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 *PGA* 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, or lateral spread), models (Ku 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 2-3.

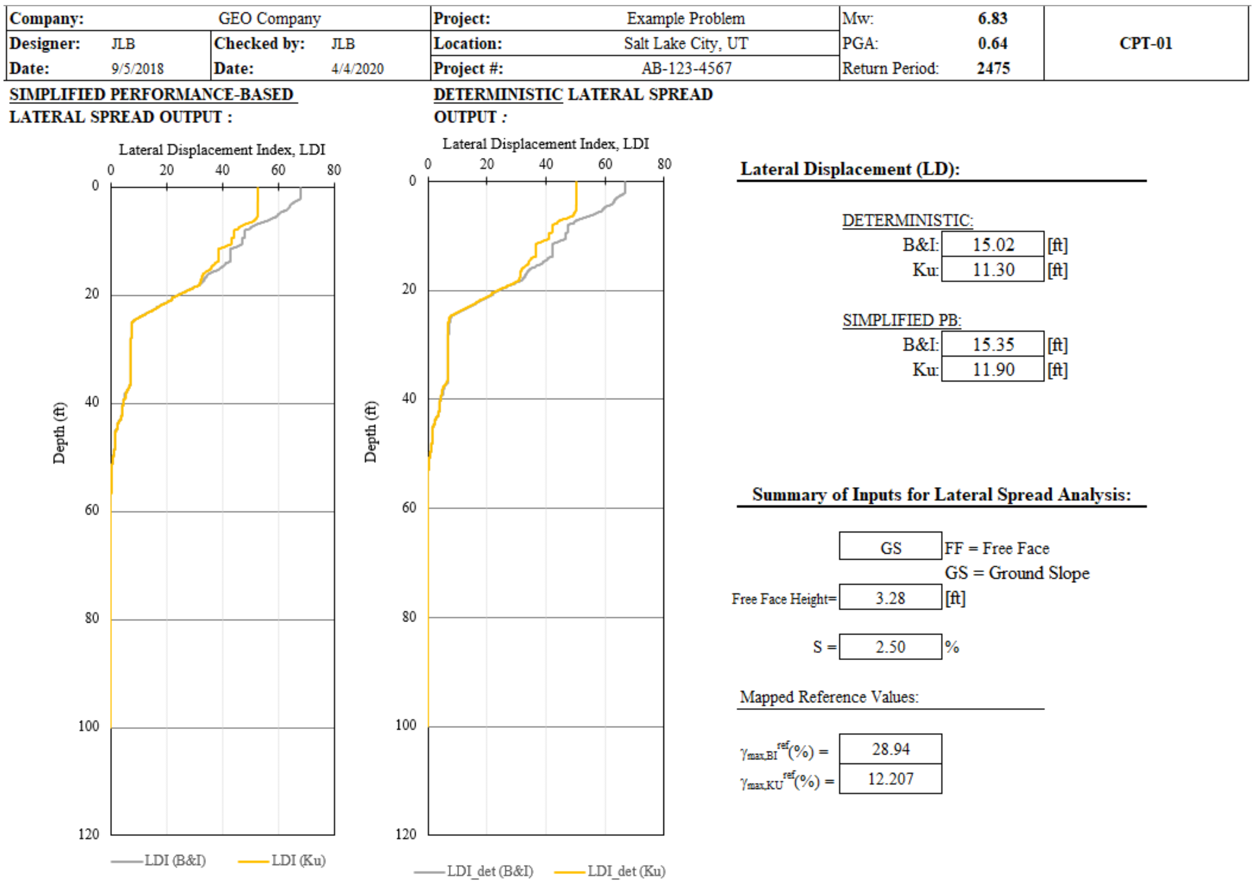


Figure 2-3: Example of Final Summary of Lateral Spread Displacement Analysis

2.4 Corrections and Modifications

Several correction and modification options were added to the functionality of *CPTLiq*. Each of these corrections are described in further detail in the *References* tab or in the Phase 1 final report associated with the research project.

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.