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SIMPLIFIED CPT PERFORMANCE-BASED ASSESSMENT OF LIQUEFACTION AND EFFECTS: TASKS 5, 6, & 7

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16. Abstract
The purpose of the research being performed is to provide the benefit of the full performance-based probabilistic earthquake hazard analysis, without requiring special software, training, and experience. To do this, simplified models of liquefaction triggering, post-liquefaction settlement, and lateral spread displacement that approximate the results of the full probabilistic analysis were developed. The goal of these simplified methods is to be user-friendly, requiring only simple calculations and a liquefaction parameter map. The simplified procedures are based on the Boulanger and Idriss (2014) probabilistic liquefaction triggering model, the Ku et. al (2010) (probabilistic version of Robertson and Wride (2009)) for liquefaction triggering; Juang et al. (2013) for post-liquefaction settlements; and lastly, Zhang et al (2004) for lateral spread displacement.

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

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
$CSR_{correction}$	correction function for CSR when using the 2014 MSF
$CSR^{site}_{corrected}$	CSR^{site} that is corrected when using the 2014 MSF
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)
MSF	magnitude scaling factor
M_w	mean moment magnitude
q	CPT resistance
q_{c1Ncs}	clean sand-equivalent SPT corrected
q_{req}	CPT resistance required to resist or prevent liquefaction
q_{req}^{ref}	uniform hazard estimate of q_{req} associated with the reference soil profile
q_{req}^{site}	site-specific uniform hazard estimate of q_{req}
Δq_L	difference between q_{site} and q_{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
CPT	Cone 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_{FS_L*}	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

Post-Liquefaction Settlement Terms

D_R	relative density
IND_i	the probability of liquefaction occuring
M	model bias correction factor
N	number of layers
S_p	total ground surface settlement
$\Delta\varepsilon$	site-specific correction factor
ΔZ_i	the i^{th} layer's thickness
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
$\varepsilon_{v,pseudo}^{ref}$	vertical strain for the reference soil profile using pseudo-probabilistic approach
$\varepsilon_{v,pseudo}^{site}$	site-specific vertical strain using pseudo-probabilistic approach
$\sigma_{\ln(S)}$	model uncertainty
σ'_{vo}	effective vertical stress in the soil
Φ	standard normal cumulative distribution function

Lateral Spread Displacement Terms

Dl	lateral displacement
H	height of the free face
L	distance to the free face
LDI	lateral displacement index
S	ground slope (%)
$\Delta\gamma$	site-specific correction factor

γ_{max}	maximum cyclic shear strain
$\gamma_{v,simp}^{site}$	final site-specific horizontal strain
γ_{max}^{ref}	horizontal strain for the reference soil profile
γ_{max}^{site}	site-specific horizontal strain
$\gamma_{v,approx}^{ref}$	horizontal strain for the reference soil profile using semi-probabilistic approach
$\gamma_{v,approx}^{site}$	site-specific horizontal strain using semi-probabilistic approach

EXECUTIVE SUMMARY

The purpose of the research presented is to provide the benefit of the full performance-based probabilistic earthquake hazard analysis, without requiring special software, training, and experience. To do this, simplified models of liquefaction triggering, post-liquefaction settlement, and lateral spread displacements that approximate the results of the full probabilistic analysis were developed. These simplified methods are designed to require only a few simple equations and a liquefaction parameter map. This report provides the derivation and validation of these simplified models, addressing Tasks 5, 6, and 7 of the TPF-5(338) research contract.

The simplified procedure using the Boulanger and Idriss (2014) probabilistic liquefaction triggering model is derived based on principles from the Mayfield et al. (2010) derivation of the simplified procedure for the Cetin et al. (2004) probabilistic liquefaction triggering model. The simplified Ku et al. (2012) procedure is based on the Robertson and Wride (2009) empirical liquefaction triggering model. The simplified procedure for predicting post-liquefaction settlement is derived based on the Juang et al. (2013) model. The simplified procedure for predicting lateral spread displacements is derived based on the Zhang et al. (2004) model. The procedures are based on retrieving a reference parameter value (i.e. CSR^{ref} (%), q_{req}^{ref} ε_v^{ref} (%), and $\gamma_{\max}^{ref}(\%)$) from a hazard-targeted liquefaction parameter map, and calculating site-specific correction factors to adjust the reference value to represent the site-specific conditions. The simplified procedures were validated by comparing the results of the simplified analysis with a full performance-based analysis for 10 cities of varying seismicity using 20 different soil profiles.

1.0 INTRODUCTION

1.1 Problem Statement

The purpose of Task 5 through 7 of this project is to develop a simplified performance-based method that closely approximates full-probabilistic analysis results for liquefaction triggering, post-liquefaction free-field settlement, and lateral spread. A validation study will be conducted to ensure the simplified models provide results that adequately approximate the results from full performance-based model at a given return period.

1.2 Objectives

The objective of this report is to provide the derivation and validation of simplified performance-based procedures which closely approximate the results of full probabilistic analysis for liquefaction triggering, post-liquefaction free-field settlements, and lateral spread displacement. The main objectives of this report include:

- Introduce the original models used to determine liquefaction hazards (i.e. liquefaction triggering, lateral spread displacement, and post-liquefaction settlement) and provide derivations and development of the simplified methods

- Validate the simplified models by performing a site-specific analysis for several different sites using the simplified and full models

These objectives specifically address Tasks 5, 6, and 7 of the TPF-5(338) research contract.

1.3 Scope

This phase of research focuses on the development and validation of the simplified performance-based method for Liquefaction Triggering, Settlement, and Lateral Spread. The validation study compared the results from the simplified performance-based methods to full-performance based analyses at 10 different cities and 20 soil profiles.

This report is organized to include the following sections:

- Development of the simplified method for Liquefaction Triggering
- Development of the simplified method for Post-Liquefaction Settlement
- Development of the simplified method for Lateral Spread Displacement
- Validation results for Liquefaction Triggering
- Validation results for Post-Liquefaction Settlement
- Validation results for Lateral Spread Displacement
- Conclusions
- Appendices

2.0 BACKGROUND OF SEISMIC HAZARD ANALYSIS

The purpose of this section is to provide a brief background of different type of seismic hazard analysis that will be referred to throughout the report. Through the history of earthquake design, several types of analysis have been created to help engineers choose a representative earthquake to incorporate into design projects. This is important because this information dictates how infrastructures are designed to resist earthquakes. The following sections will describe how different seismic hazard analyses are used and referred to in this report.

2.1 Deterministic Approach

A deterministic seismic hazard analysis designs for the earthquake that generates the largest and most significant ground motion that may occur at the site. The corresponding ground motion (i.e., $a_{\max}$) and the moment magnitude (i.e., M_w) from this earthquake are used to calculate the factor of safety against liquefaction, FS_L, using either the Robertson and Wride (2009) model or the Boulanger and Idriss (2014) model. Then this FS_L is applied to a deterministic calculation of earthquake effects.

2.2 Pseudo-Probabilistic Approach

The pseudo-probabilistic seismic hazard analysis involves using a probabilistic seismic hazard analysis (PSHA) to decide the ground motion and moment magnitude. The selection of ground motion is usually done by the USGS deaggregation tool. The moment magnitude can be either the mean (i.e., average) magnitude or the modal (i.e., most occurring) magnitude. Then these values are applied to either the Robertson and Wride (2009) model or the Boulanger and Idriss (2014) model to calculate FS_L in a deterministic manner. This FS_L is also applied to a deterministic calculation of earthquake effects. The pseudo-probabilistic approach accounts for some uncertainty in ground motions, but ignores the inherent uncertainty within the triggering of liquefaction and the calculation of its effects.

2.3 Performance-Based Approach

The performance-based approach is a fully-probabilistic seismic analysis developed by the Pacific Earthquake Engineering Research (PEER) Center. To apply the PEER framework to liquefaction triggering, FS_L hazard curves are developed using Kramer and Mayfield (2007) performance-based earthquake engineering (PBEE) approach. A detailed description of the performance-based liquefaction triggering procedure is described in the Section 3.2.2 of this report. The developed FS_L hazard curves will then be applied to a PBEE post-liquefaction analysis to obtain post-liquefaction settlement and lateral spread displacement.

2.4 Semi-Probabilistic Approach

The semi-probabilistic approach calculates FS_L using performance-based liquefaction triggering procedure and then applies this FS_L to deterministic settlement and lateral spread calculation. This method accounts for the inherent uncertainty in predicting liquefaction triggering but fails to account for the uncertainty in calculating post-liquefaction settlement and lateral spread.

3.0 DERIVATION OF THE SIMPLIFIED MODELS

3.1 Overview

This section provides the derivation of the simplified liquefaction triggering, post-liquefaction settlement, and lateral spread displacement models. The original models will be discussed and the derivation process for the simplified models will be presented in detail.

3.2 Performance-based Liquefaction Triggering Evaluation

This section will provide the necessary background to understand the simplified performance-based liquefaction triggering procedure. The Boulanger and Idriss (2014) and Ku et al. (2012), (probabilistic version of Robertson and Wride [2009]) models will be introduced, followed by the derivation and validation of these models.

3.2.1 Empirical Liquefaction Triggering Models

In engineering practices today, the most commonly used approach to evaluate liquefaction triggering potential was first introduced by Seed and Idriss (Seed and Idriss 1971; Seed 1979; Seed and Idriss 1982; and Seed et al. 1985). This simplified empirical method compares the cyclic stress ratio (CSR) to the cyclic resistance ratio (CRR). The CSR represents the seismic demand or loading of a soil and the CRR represents the soil's resistance to seismic loading. The method proposed by Seed and Idriss to compute the cyclic stress ratio (CSR) can be expressed as:

$$CSR = 0.65 \frac{a_{\max}}{g} \frac{\sigma_v}{\sigma_v'} r_d \frac{1}{MSF} \tag{1}$$

where σ_v' is the effective vertical stress in the soil, $a_{\max}/g$ is the peak ground surface acceleration as a fraction of gravity, σ_v is the total vertical stress in the soil, r_d is a shear stress reduction coefficient, and where MSF is the magnitude scaling factor.

The cyclic resistance ratio (CRR), or the cyclic stress required to initiate liquefaction, is more difficult to compute, but is typically interpreted from in-situ tests (i.e., SPT penetration tests, CPT penetration tests, shear wave velocity, etc.). These results are then compared to databases and liquefaction case histories. Graphically, CRR is the dividing line between "liquefaction" and "non-liquefaction" cases. It also represents a combination of CSR values and in-situ soil test values at which liquefaction triggers.

Engineers and geologists commonly quantify liquefaction triggering using a factor of safety against liquefaction triggering, FS_L. This parameter is calculated as:

$$FS_L = \frac{\text{Resistance}}{\text{Loading}} = \frac{CRR}{CSR} \tag{2}$$

Kramer and Mayfield (2007) and Mayfield et al. (2010) introduced an alternative method to quantify liquefaction triggering. CRR is to be a function of soil resistance measured using in-situ test values. In this report, where the cone penetration test is used, CRR can be expressed as a function of q_{c1Ncs}, which is the clean-sand equivalent, corrected CPT tip resistance for the soil layer. From the CRR function, the CPT resistance required to resist or prevent liquefaction, q_{req}, can be obtained for a given seismic loading (i.e., CSR). This results in FS_L to be computed as:

$$FS_L = \frac{CRR}{CSR} = \frac{CRR(q_{c1Ncs})}{CRR(q_{req})} \tag{3}$$

where $CRR(q)$ denotes that *CRR* is a function of given value of CPT resistance, *q*.

Mayfield et al. (2010) defined the relationship between the actual SPT resistance for the given layer, N_{site}, and N_{req} :

$$\Delta N_L = N_{site} - N_{req} \tag{4}$$

This relationship can be adapted for CPT resistance for the given layer, q_{site}, and q_{req} as:

$$\Delta q_L = q_{site} - q_{req} \tag{5}$$

The relationship between *CSR*, *CRR*, N_{site}, and N_{req} (or q_{site} and q_{req}) is shown graphically in Figure 3-1, after Mayfield et al. (2010).

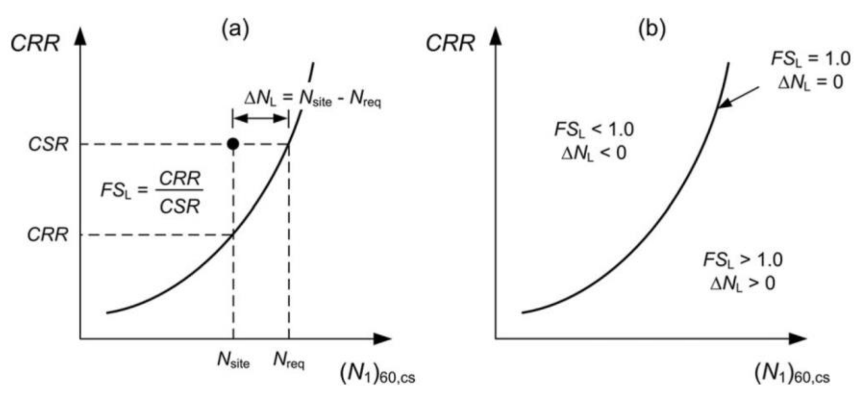

Figure 3-1 Schematic illustration of: (a) definitions of FS_L and ΔN_L; (b) relationship between FS_L and ΔN_L (after Mayfield et al. 2010)

3.2.2 Performance-based Liquefaction Triggering Assessment

The simplified empirical liquefaction triggering models require engineers to select seismic loading parameters (i.e., peak ground surface acceleration a_{max} and moment magnitude M_w) to adequately represent an earthquake. This is a simple procedure when only a single seismic source contributes to the loading. However, this presents a problem when multiple seismic sources are present and contribute differently to the seismic hazard. In more complex cases, a probabilistic seismic hazard analysis (PSHA) is performed. The PSHA calculates the seismic hazard associated with a specified return period or likelihood of occurrence with the use of deaggregation tools. From the deaggregation results, a single magnitude (mean or modal) and peak ground acceleration are given for a targeted return period. Unfortunately, Kramer and Mayfield (2007) showed that these methods of assessment introduced bias into hazard calculations.

Potential biases introduced into the liquefaction triggering assessment through the improper and/or incomplete utilization of probabilistic ground motions and liquefaction triggering models could be reduced through the implementation of a performance-based approach (Franke et al. 2014a). Kramer and Mayfield (2007) presented such an approach, which utilized the probabilistic framework for performance-based earthquake engineering (PBEE) developed by the Pacific Earthquake Engineering Research Center (Cornell and Krawinkler 2000; Krawinkler 2002; Deierlein et al. 2003). This implementation of the PEER PBEE framework assigned the joint occurrence of M_w and a_{max} as an intensity measure, and either FS_L or N_{req} as the engineering demand parameter. The Kramer and Mayfield (2007) approach produces liquefaction hazard curves for each layer in a soil profile while using ground motions in a probabilistic manner. This section will present a basic background of the Kramer and Mayfield performance-based approach, but further information can be found in Kramer and Mayfield (2007). Even though the approach is SPT based (i.e. $N_{req,}$ $(N_1)_{60}$), the same principles and ideas follow for performance-based approaches for CPT-based methods (i.e. $q_{req,}$ q_{c1Ncs}).

Kramer and Mayfield (2007) demonstrated that a hazard curve for FS_L could be developed using the following relationship:

$$\Lambda_{FS_L^*} = \sum_{j=1}^{N_M} \sum_{i=1}^{N_{a_{max}}} P\left[FS_L > FS_L^* \mid a_{\max_i}, m_j\right] \Delta\lambda_{a_{\max_i}, m_j} \tag{6}$$

where $\Lambda_{FS_L^*}$ is the mean annual rate of *not* exceeding some given value of factor of safety, FS_L^*; $P[FS_L < FS_L^* \mid a_{\max_i}, m_j]$ is the conditional probability that the actual factor of safety is less than FS_L^* given peak ground surface acceleration $a_{\max_i}$, and moment magnitude m_j; $\Delta\lambda_{a_{\max_i}, m_j}$ is the incremental joint mean annual rate of exceedance for $a_{\max_i}$ and m_j; and N_M and $N_{a_{max}}$ are the number of magnitude and peak ground acceleration increments into which the intensity measure "hazard space" is subdivided.

The conditional probability component of Equation (6) can be solved with any selected probabilistic liquefaction triggering relationship, but that relationship must be manipulated to compute the desired probability.

Similar to the relationship for computing a hazard curve for FS_L, Kramer and Mayfield (2007) derived a relationship for computing a hazard curve for N_{req} as:

$$\lambda_{N_{req}^*} = \sum_{j=1}^{N_M} \sum_{i=1}^{N_{a_{max}}} P\left[N_{req} > N_{req}^* \mid a_{\max_i}, m_j\right] \Delta\lambda_{a_{\max_i}, m_j} \tag{7}$$

where λ_{Nreq*} is the mean annual rate of exceeding some given clean sand-equivalent required SPT resistance, N_{req}^* , and $P[N_{req} < N_{req}^* \mid a_{\max_i}, m_j]$ is the conditional probability that the actual N_{req} is greater than N_{req}^* given peak ground surface acceleration $a_{\max_i}$ and moment magnitude m_j.

3.3 Simplified Liquefaction Triggering Model

The Kramer and Mayfield (2007) performance-based liquefaction triggering procedure summarized in Section 3.2.2 is an effective solution to mitigating the deficiencies introduced by the conventional liquefaction triggering approach. Unlike conventional approaches where seismic contributions are only considered at a given return period, this probabilistic performance-based approach considers seismic contributions from *all* hazard levels and *all* earthquake magnitudes (Kramer and Mayfield 2007). However, the Kramer and Mayfield (2007) performance-based procedure considers *all* the seismic loading contributions from *all* return periods, not just return periods given by design. Unfortunately, the Kramer and Mayfield procedure is relatively sophisticated and difficult for many engineers and geologists to apply in a practical manner. Specialized computational tools such as *WSliq* (Kramer 2008), *PBliquefY* (Franke et al. 2014c), and *CPTLiquefY* (Franke et al. 2018) have been developed to assist these professionals in implementing the performance-based procedure. However, even the availability of computational tools is not sufficient for many professionals, who routinely need to perform and/or validate liquefaction triggering hazard calculations in a rapid and efficient manner.

An ideal solution to this dilemma would be the introduction of a new liquefaction analysis procedure that combined the simplicity and user-friendliness of traditional liquefaction hazard maps with the flexibility and power of a site-specific performance-based liquefaction triggering analysis. Mayfield et al. (2010) introduced such a procedure, which was patterned after the map-based procedure used in most seismic codes and provisions for developing probabilistic ground motions for engineering design. Franke et al. (2014d) later refined the Mayfield et al. simplified procedure for easier implementation in seismic codes and provisions.

Mayfield et al. (2010) demonstrated with the Cetin et al. (2004) liquefaction model that probabilistic estimates of liquefaction resistance (i.e. N_{req} or q_{req}) can be computed for a reference soil profile across a grid of locations to develop contour plots called liquefaction parameter maps. A liquefaction parameter map incorporating N_{req} or q_{req} can be a useful tool to evaluate the seismic demand for liquefaction at a given return period because N_{req} or q_{req} is directly related to *CSR* (i.e. Figure 3-1). Mayfield et al. demonstrated how these mapped "reference" values of N_{req} could be adjusted for site-specific conditions and used to develop site-specific uniform hazard estimates of N_{req} (i.e., N_{req}^{site}) and/or FS_L (i.e. FS_L^{site}) at the targeted return period or hazard level. The derivation of the simplified method for the Cetin et al. (2004) liquefaction triggering model will not be included in this report but is presented in detail in Mayfield et al. (2010).

The most widely used CPT-based methods for liquefaction initiation evaluation are the Boulanger and Idriss (2014) model and the Robertson and Wride (2009) model. The Ku et al. (2012) probabilistic version of the Robertson and Wride (2009) liquefaction triggering model will also be used in this study. This report will derive a simplified probabilistic method incorporating these models by using the framework introduced by Mayfield et al. (2010).

3.3.1 Liquefaction Parameter Maps & Reference Profile

As previously discussed, liquefaction loading maps are an important part to the simplified method as it provides the benefits of site-specific performance-based analysis while being user-friendly. While liquefaction parameter maps will not be included in this report, the purpose of this section is to give a brief introduction to what role these maps play in the simplified method and briefly discuss the use of the reference profile. Figure 3-2 presents a generic soil profile representing a reference site that was applied in this study. This profile is similar to the one originally introduced by Mayfield et al. (2010) and used for the simplified Cetin et al. (2004) procedure and simplified Boulanger and Idriss (2012) procedure derived by Ulmer (2015). This reference soil profile is used to find reference values a depth of 6 meters for the targeted return period (T_R) or hazard level for all the models (triggering, settlement, and lateral spread) in this report. The goal of the liquefaction loading maps is to allow users to easily interpret reference values from the liquefaction loading maps to be used in simplified method calculations. For the simplified Boulanger and Idriss (2014) and simplified Ku et al (2012) triggering procedures, reference values for q_{req} and CSR will be mapped, respectively. For the simplified settlement and lateral spread procedures, reference values for $\varepsilon_v(\%)$ and $\gamma_{\max}(\%)$ will be mapped separately. Because these values associated with the reference soil profile do not represent any actual soil profile, reference values are distinguished using the terms q_{req}^{ref}, CSR^{ref}, $\varepsilon_v^{ref}(\%)$ and $\gamma_{\max}^{ref}(\%)$. By computing these hazard-targeted values at different locations across a geographic area, contoured maps can be created. Detailed steps on how these values are used in the simplified methods will be discussed in each corresponding section. Because *CSR*, ε_v ,and $\gamma_{\max}$ are often a decimal, mapping these values in percent allows for more precise contour mapping, as well as easier interpretation and interpolation for design engineers. At this point in the study, liquefaction loading/parameter maps have not yet been created for the simplified methods. However, Figure 3-3 presents a liquefaction loading map of $CSR^{ref}(\%)$ at a return period of 1,033 years for a portion of the Salt Lake Valley in Utah from a previous study. The maps that will be subsequently developed in Task 8 from this study will appear similar.

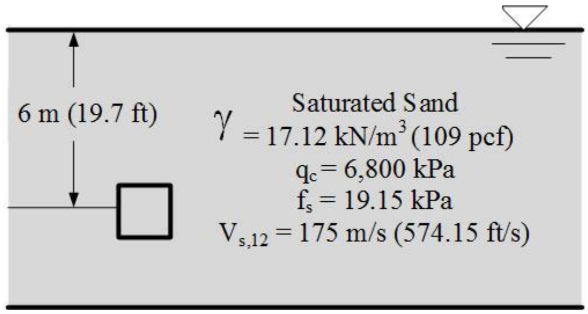

Figure 3-2. Reference soil profile used to develop liquefaction loading maps in the proposed simplified uniform hazard liquefaction procedure

Figure 3-3. Liquefaction loading map (T_R = 1,033 years) showing contours of CSR^{ref}(%) for a portion of the Salt Lake Valley in Utah (after Ulmer 2015)

In future reports, further discussion on the interpretation and use of these maps will be covered. To account for site-specific conditions, a procedure will subsequently be derived and presented to correct the mapped liquefaction loading values to site-specific liquefaction loading values. These can then be used to compute site-specific performance-based estimates of liquefaction triggering, settlement, and lateral spread at a targeted return period. The following sections will show the simplified method derivations for the Boulanger and Idriss (2014) liquefaction triggering model and the Ku et al. (2012) model (probabilistic version of the Robertson and Wride (2009) model). The derivations for the simplified settlement and lateral spread procedures will follow.

3.3.2 Simplified Procedure Using the Boulanger and Idriss (2014) Probabilistic Liquefaction Triggering Model

According to the probabilistic liquefaction triggering relationship developed by Boulanger and Idriss (2012), the probability of liquefaction P_L is given as:

$$P_L = \Phi\left[-\frac{\ln(CRR_{P_L=50\%}) - \ln(CSR)}{\sigma_T}\right] \tag{8}$$

where Φ represents the standard normal cumulative distribution function, σ_T is the total uncertainty of the liquefaction model, and $CRR_{P_L=50\%}$ is the cyclic resistance ratio corresponding to a probability of liquefaction of 50% (i.e. median *CRR*), which is computed as:

$$CRR_{P_L=50\%} = \exp\left[\frac{q_{c1Ncs}}{113} + \left(\frac{q_{c1Ncs}}{1000}\right)^2 - \left(\frac{q_{c1Ncs}}{140}\right)^3 + \left(\frac{q_{c1Ncs}}{137}\right)^4 - 2.60\right] \tag{9}$$

Unlike the Mayfield et al. (2010) simplified liquefaction procedure, which incorporates the Cetin et al. (2004) liquefaction model, the simplified uniform hazard liquefaction procedure for the Boulanger and Idriss (2014) liquefaction model cannot be derived to solve for q_{req}^{site} in a convenient manner because of the 4^{th}-order polynomial equation in *CRR* (i.e. Equation (9)). Fortunately, this simplified procedure can be modified to incorporate *CRR* and *CSR* instead of

q_{req}, which greatly simplifies the derivation of the new procedure, and makes it somewhat more intuitive.

By substituting q_{req}^{ref} into Equation (9), the median *CSR* associated with the reference site (i.e. CSR^{ref}) at the targeted return period can be computed. CSR^{ref} represents a uniform hazard estimate of the seismic loading that must be overcome to prevent liquefaction triggering if the reference soil profile existed at the site of interest.

3.3.2.1 Site-Specific Correction for CSR^{ref}

Because CSR^{ref} was developed using the reference soil profile, it must be corrected for site-specific soil conditions and depths to be used in computing site-specific uniform hazard values of FS_L, P_L, and q_{req}. If CSR^{site} represents the site-specific uniform hazard value of *CSR*, then CSR^{ref} and CSR^{site} can be related as:

$$\ln(CSR^{site}) = \ln(CSR^{ref}) + \Delta CSR \tag{10}$$

where ΔCSR is a site-specific correction factor. By rearranging Equation (10), we can solve for ΔCSR as:

$$\Delta CSR = \ln(CSR^{site}) - \ln(CSR^{ref}) = \ln\left[\frac{CSR^{site}}{CSR^{ref}}\right] \tag{11}$$

Similar to Equation (1), the magnitude- and stress-corrected *CSR* for level or near-level ground according to Boulanger and Idriss (2014) is computed as:

$$CSR_{M=7.5,\sigma'_v=1atm} = 0.65\frac{a_{\max,i}}{g}\frac{\sigma_v}{\sigma_v'}\left(r_d\right)_j\frac{1}{\left(MSF\right)_j}\frac{1}{K_\sigma} = 0.65\frac{\sigma_v}{\sigma'_v}\frac{(F_{pga}\cdot PGA_{rock})}{g}r_d\frac{1}{MSF}\frac{1}{K_\sigma} \tag{12}$$

where F_{pga} is the soil amplification factor corresponding to the peak ground acceleration (*PGA*), and PGA_{rock} is the *PGA* corresponding to bedrock (i.e. V_s=760 m/s). Equations for r_d, *MSF*, and K_σ are provided in later sections of this report. If Equation (12) is substituted into Equation (11) then Equation (11) can be rewritten as:

$$\Delta CSR = \ln\left[\frac{0.65\left(\frac{\sigma_v}{\sigma'_v}\right)^{site}\left(\frac{F_{pga}^{site}\cdot PGA_{rock}^{site}}{g}\right)\cdot r_d^{site}\cdot\left(\frac{1}{MSF^{site}}\right)\cdot\left(\frac{1}{K_\sigma^{site}}\right)}{0.65\left(\frac{\sigma_v}{\sigma'_v}\right)^{ref}\left(\frac{F_{pga}^{ref}\cdot PGA_{rock}^{ref}}{g}\right)\cdot r_d^{ref}\cdot\left(\frac{1}{MSF^{ref}}\right)\cdot\left(\frac{1}{K_\sigma^{ref}}\right)}\right] \tag{13}$$

Because there should be no difference in the ground motions between the reference soil profile and the actual soil profile, $PGA_{rock}^{site} = PGA_{rock}^{ref}$. Therefore, Equation (13) can be simplified as:

$$\begin{aligned}\Delta CSR &= \ln\left(\frac{\left(\frac{\sigma_v}{\sigma'_v}\right)^{site}}{\left(\frac{\sigma_v}{\sigma'_v}\right)^{ref}}\right) + \ln\left(\frac{F_{pga}^{site}}{F_{pga}^{ref}}\right) + \ln\left(\frac{r_d^{site}}{r_d^{ref}}\right) - \ln\left(\frac{MSF^{site}}{MSF^{ref}}\right) - \ln\left(\frac{K_\sigma^{site}}{K_\sigma^{ref}}\right)\\ &= \Delta CSR_\sigma + \Delta CSR_{F_{pga}} + \Delta CSR_{r_d} + \Delta CSR_{MSF} + \Delta CSR_{K_\sigma}\end{aligned} \tag{14}$$

where ΔCSR_σ, ΔCSR_{Fpga}, ΔCSR_{rd}, ΔCSR_{MSF}, and $\Delta CSR_{K\sigma}$ are site-specific correction factors for stress, soil amplification, shear stress reduction, earthquake magnitude, and overburden pressure, respectively.

3.3.2.2 Correction for Vertical Stress, ΔCSR$_\sigma$

The relationship for the stress correction factor, ΔCSR_σ is defined as:

$$\Delta CSR_\sigma = \ln\left[\frac{\left(\frac{\sigma_v}{\sigma'_v}\right)^{site}}{\left(\frac{\sigma_v}{\sigma'_v}\right)^{ref}}\right] \tag{15}$$

If the liquefaction parameter map for CSR^{ref} (%) was developed using the reference soil profile shown in Figure 3-2, then Equation (15) can be simplified as:

$$\Delta CSR_{\sigma} = \left[\frac{\left(\frac{\sigma_v}{\sigma'_v} \right)^{site}}{2.34} \right] \tag{16}$$

3.3.2.3 Correction for Soil Amplification, ΔCSR_{Fpga}

The relationship for the soil amplification factor, ΔCSR_{Fpga} is defined as:

$$\Delta CSR_{F_{pga}} = \ln\left(\frac{F_{pga}^{site}}{F_{pga}^{ref}} \right) \tag{17}$$

If the value of F_{pga}^{ref} for the reference soil profile is fixed at 1, then the correction factor for soil amplification can be written as:

$$\Delta CSR_{F_{pga}} = \ln\left(\frac{F_{pga}^{site}}{1} \right) = \ln(F_{pga}^{site}) \tag{18}$$

Thus, the only parameter required to calculate the soil amplification factor is the F_{pga}^{site} value from AASHTO 2012 Table 3.10.3.2-1 corresponding to the site of interest. The *PGA* value used to determine F_{pga}^{site} from the table should be calculated from the USGS 2014 interactive deaggregation website for the return period of interest (e.g., 2% probability of exceedance in 21 years, T_R = 1039).

3.3.2.4 Correction for Shear Stress Reduction, ΔCSR_{rd}

The shear stress reduction factor, r_d, was defined by Boulanger and Idriss (2012, 2014) as:

$$r_d = \exp[\alpha + \beta \cdot M_w] \tag{19}$$

$$\alpha = -1.012 - 1.126 \sin\left(\frac{z}{11.73} + 5.133 \right) \tag{20}$$

$$\beta = 0.106 - 0.118 \sin\left(\frac{z}{11.28} + 5.142 \right) \tag{21}$$

where z represents sample depth in meters and M_w is the mean moment magnitude. Thus, the equation for ΔCSR_{rd} becomes:

$$\Delta CSR_{r_d} = \ln\left(\frac{r_d^{site}}{r_d^{ref}}\right) = \ln\left(\frac{\exp\left(\alpha^{site} + \beta^{site} \cdot M_w^{site}\right)}{\exp\left(\alpha^{ref} + \beta^{ref} \cdot M_w^{ref}\right)}\right) \tag{22}$$

Both the site soil profile and the reference soil profile experience the same ground motions, so $M_w^{site} = M_w^{ref}$ Therefore, Equation (22) can be written as:

$$\Delta CSR_{r_d} = \left(\alpha^{site} - \alpha^{ref}\right) + M_w^{site}\left(b^{site} - b^{ref}\right) \tag{23}$$

For the reference soil profile used in this study (Figure 3-2), α^{ref} = -0.3408 and $\mathbf{b}^{ref}$ = 0.0385. Thus, Equation (23) becomes:

$$\Delta CSR_{r_d} = \left(a^{site} - 0.341\right) + M_w^{site}\left(b^{site} - 0.0385\right) \tag{24}$$

Equation (24) can also be written in terms of depth to the site-specific soil layer (in meters) from the ground surface, z^{site} as:

$$\Delta CSR_{r_d} = \left(-0.6712 - 1.126\sin\left(\frac{z^{site}}{11.73} + 5.133\right)\right) + M_w^{site}(0.0675 + 0.118\sin\left(\frac{z^{site}}{11.28} + 5.142\right) \tag{25}$$

3.3.2.5 Correction for Magnitude Scaling Factor, ΔCSR_{MSF}

If the *MSF* as calculated in the Idriss and Boulanger (2010, 2012) model is to be used, then there should be no difference in the earthquake magnitude between the reference soil profile and the actual soil profile. In this case, $MSF^{site} = MSF^{ref}$ which indicates that $\Delta CSR_{MSF} = 0$ and therefore ΔCSR_{MSF} can be excluded from Equation (14).

However, since this simplified procedure is incorporating the Boulanger and Idriss (2014) model, the updated MSF is calculated as $MSF = f(q_{c1Ncs})$. Because MSF is a function of q_{c1Ncs}

it is possible that $MSF^{site} \neq MSF^{ref}$ because it is likely that q_{c1Ncs} varies with depth in the actual soil profile. Thus ΔCSR_{MSF} must be included in Equation (14). Using the equation for *MSF* from the updated Boulanger and Idriss (2014) model, this correction factor can be written as:

$$\Delta CSR_{MSF} = -\ln\left(\frac{MSF^{site}}{MSF^{ref}}\right) = -\ln\left[\frac{1+(MSF_{\max}^{site}-1)(8.64\exp\left(-\frac{M_w^{site}}{4}\right)-1.325}{1+(MSF_{\max}^{ref}-1)(8.64\exp\left(-\frac{M_w^{ref}}{4}\right)-1.325}\right] \tag{26}$$

$$MSF_{\max} = 1.09 + \left[\frac{q_{c1Ncs}}{180}\right]^3 \leq 2.2 \tag{27}$$

where q_{c1Ncs} represents the clean sand-equivalent CPT. Note that there is no difference in the magnitude of the ground motions between the reference map and the site. Thus, M_w^{ref} can be replaced with M_w^{site}. Therefore, if the liquefaction parameter map for CSR^{ref} (%) was developed using the reference soil profile shown in Figure 3-2, then $MSF_{\max}^{ref}$ = 1.269 and Equation (25) can be written as:

$$\Delta CSR_{MSF} = -\ln\left[\frac{1+\left(MIN\left\{\begin{matrix}\left(\frac{q_{c1Ncs}}{180}\right)^3+0.09\\1.2\end{matrix}\right\}\right)\cdot\left(8.64\exp\left(-\frac{M_w^{site}}{4}\right)-1.325\right)}{2.326\exp\left(-\frac{M_w^{site}}{4}\right)+0.643}\right] \tag{28}$$

The value of ΔCSR_{MSF} must be calculated for each layer in the soil profile because $MSF_{\max}^{site}$ is a function of q_{c1Ncs}, which likely varies throughout the soil profile. The value of M_w^{site} is the mean moment magnitude from the 2014 USGS interactive deaggregation website for the return period of interest (e.g., 2% probability of exceedance in 21 years, T_R = 1039). This should be the same value as M_w^{site} used to calculate the ΔCSR_{rd} term in Equation (25)

3.3.2.6 Correction for Boulanger and Idriss (2014) Magnitude Scaling Factor, ΔCSR_{MSF}

During the validation process, the simplified method was observed to be sensitive to the ΔCSR_{MSF} factor when using the 2014 MSF. A bias based on return period was observed, and a correction function was created as a result. This correction function incorporates the mean magnitude, M_w, and is to be applied after the simplified CSR (CSR^{site}) is computed when using the 2014 MSF calculations. The correction function is given as:

$$CSR_{correction} = 0.2107\left(M_w\right)^2 - 2.8309M_w + 10.362 \tag{29}$$

where M_w is the mean magnitude from the deaggregation at the return period of interest at the given location.

For a given location and its corresponding mean magnitude, the $CSR_{correction}$ can be computed using Equation (29)**.** Then, the simplified CSR value at each layer ($(CSR^{site})_i$) at the given location is divided by the correction factor, resulting in a corrected simplified CSR. The user may select which MSF version they wish to use. If the 2012 MSF is used, ΔCSR_{MSF} =0. If the 2014 MSF is used *without* the correction, ΔCSR_{MSF} is computed as outlined in section 2.3.2.5. Finally, if the 2014 MSF *with* the correction is used, ΔCSR_{MSF}.is computed as outlined in section 2.3.2.5 *and* the correction function ($CSR_{correction}$) is applied *after* the simplified CSR has been computed. The validation section will provide more details on this correction.

3.3.2.7 Correction for Overburden Pressure, $\Delta CSR_{K\sigma}$

Both the 2010 and 2014 versions of the Boulanger and Idriss model use the same overburden correction factor, K_σ:

$$K_\sigma = 1 - C_\sigma \ln\left(\frac{\sigma'_v}{P_a}\right) \leq 1.1 \tag{30}$$

$$C_\sigma = \frac{1}{37.3 - 8.27\left(q_{c1Ncs}\right)^{0.264}} \leq 0.3 \tag{31}$$

where P_a is 1 atmosphere of pressure (i.e. 1 atm, 101.3 kPa, 0.2116 psf). Note that the value q_{c1Ncs} must be computed using the equations found in Idriss and Boulanger (2008, 2010). Idriss and Boulanger (2010) commented that the K_σ limit of 1.1 has a somewhat negligible effect. Therefore, the simplified method derived here will not use the restriction on K_σ. However, the limit of 0.3 for values of C_σ will be incorporated. Now the correction term $\Delta CSR_{K\sigma}$ can be written as:

$$\Delta CSR_{K_\sigma} = -\ln\left(\frac{K_\sigma^{site}}{K_\sigma^{ref}}\right) = -\ln\left(\frac{1 - C_\sigma^{site}\ln\left(\frac{(\sigma_v^{'})^{site}}{P_a}\right)}{1 - C_\sigma^{ref}\ln\left(\frac{(\sigma_v^{'})^{ref}}{P_a}\right)}\right) \quad (32)$$

If the liquefaction parameter map for CSR^{ref} (%) was developed using the reference soil profile shown in Figure 3-2, then C_σ^{ref} = 0.108, K_σ^{ref} = 1.09, and Equation (32) would become:

$$\Delta CSR_{K_\sigma} = -\ln\left(\frac{1 - \left(MIN\left\{\begin{matrix}0.3 \\ \dfrac{1}{37.3 - 8.27\left(q_{c1Ncs}\right)^{0.264}}\end{matrix}\right\}\right)\cdot\ln\left(\frac{(\sigma_v^{'})^{site}}{P_a}\right)}{1.09}\right) \quad (33)$$

3.3.2.8 Equations for CSR^{site}, q_{req}^{site}, FS_L, and P_L

Once the CSR^{ref} (%)is obtained from the appropriate (i.e. hazard-targeted) map and the appropriate correction factors are computed using Equations (16), (18),(25),(28) (neglected if using Idriss and Boulanger 2012 *MSF* instead of the updated Boulanger and Idriss 2014 *MSF*) and (33) the site-specific hazard-targeted CSR^{site} can be computed for site-specific soil layer *i* using the following equation (from Equation (10)):

$$\left(CSR^{site}\right)_i = \exp\left[\ln\left(\frac{CSR^{ref}(\%)}{100}\right) + \left(\Delta CSR_\sigma\right)_i + \left(\Delta CSR_{F_{pga}}\right)_i + \left(\Delta CSR_{r_d}\right)_i + \left(\Delta CSR_{MSF}\right)_i + \left(\Delta CSR_{K_\sigma}\right)_i\right] \quad (34)$$

If the Boulanger and Idriss 2014 MSF correction (Section 3.3.2.6) is chosen, the corrected simplified CSR, $CSR_{corrected}^{site}$, is computed as:

$$CSR^{site}_{corrected} = \frac{(CSR^{site})_i}{CSR_{correction}} = \frac{(CSR^{site})_i}{0.2107(M_w)^2 - 2.8309M_w + 10.362} \quad (35)$$

where M_w is the mean magnitude of the site. To compute , q^{site}_{req}, FS_L, and P_L ,the appropriate CSR (CSR^{site} or $CSR^{site}_{corrected}$) should be used.

To calculate q^{site}_{req} , FS_L, or P_L for site-specific soil layer *i*., CSR^{site} can be plugged into the corresponding equations. To solve for the uniform-hazard FS_L for the soil layer *i*, use Equation (9):

$$\left(FS_L\right)_i = \frac{\left(CRR^{site}\right)_i}{\left(CSR^{site}\right)_i} = \frac{\exp\left[\frac{\left(q_{c1Ncs}\right)_i}{113} + \left(\frac{\left(q_{c1Ncs}\right)_i}{1000}\right)^2 - \left(\frac{\left(q_{c1Ncs}\right)_i}{140}\right)^3 + \left(\frac{\left(q_{c1Ncs}\right)_i}{137}\right)^4 - 2.60\right]}{\left(CSR^{site}\right)_i} \quad (36)$$

To solve for the uniform hazard P_L for the soil layer *i*, use the following relationship:

$$\left(P_L\right)_i = \Phi\left[-\frac{\frac{\left(q_{c1Ncs}\right)_i}{113} + \left(\frac{\left(q_{c1Ncs}\right)_i}{1000}\right)^2 - \left(\frac{\left(q_{c1Ncs}\right)_i}{140}\right)^3 + \left(\frac{\left(q_{c1Ncs}\right)_i}{137}\right)^4 - 2.60 - \ln\left[\left(CSR^{site}\right)_i\right]}{\sigma_\varepsilon}\right] \quad (37)$$

where σ_ε is 0.506 if parametric uncertainty (i.e., uncertainty in measuring q_{c1Ncs} and estimating seismic loading) is neglected, and σ_ε is 0.276 if parametric uncertainty is considered.

Finally, Δq_L (or ΔN_L after the Mayfield et al. 2010 procedure) for soil sublayer *i* can be computed as:

$$\Delta q_L = \left[q_{c1Ncs}\right]_i - \left(q^{site}_{req}\right)_i \quad (38)$$

where $\left(q^{site}_{req}\right)_i$ can be closely approximated as:

$$q_{req}^{site} = -0.4021 \cdot \left(\ln\left(\frac{1}{\left(CSR^{site}\right)_i} \right) \right)^4 - 3.367 \cdot \left(\ln\left(\frac{1}{\left(CSR^{site}\right)_i} \right) \right)^3 - 8.761 \cdot \left(\ln\left(\frac{1}{\left(CSR^{site}\right)_i} \right) \right)^2 - 21.38 \cdot \left(\ln\left(\frac{1}{\left(CSR^{site}\right)_i} \right) \right) + 186.3 \quad (39)$$

3.3.3 Simplified Procedure Using the Ku et al. (2012) model [Probabilistic version of Robertson and Wride (2009)]

The deterministic Robertson and Wride (2009) model is one of the most widely-used methods for CPT-based liquefaction triggering evaluation. With the increasing popularity of performance-based procedures, Ku et al. (2012) developed a probabilistic version of the Robertson and Wride (2009) model. From this point on in the report, the simplified procedure will be referred to as the simplified Ku et al. (2012) method.

The simplified procedure follows a similar setup (Equation (10)) for the simplified Boulanger and Idriss (2014) method. Unlike the Boulanger and Idriss method, it is easier to isolate q_{req} in the Robertson and Wride (2009) equations. Thus, the framework of the simplified procedure can be expressed as:

$$q_{req}^{site} = q_{req}^{ref} + \Delta q_{req} \quad (40)$$

where q_{req}^{site} is the simplified method approximation of q_{req} , q_{req}^{ref} is the reference value provided by the liquefaction parameter maps, and Δq_{req} is the site-specific correction factor. Δq_{req} is expressed as:

$$\Delta q_{req} = \left[q_{req}^{site} \right]_{pseudo} - \left[q_{req}^{ref} \right]_{pseudo} \quad (41)$$

where $\left[q_{req}^{site} \right]_{pseudo}$ is the q_{req} computed for the site using information from a pseudo analysis, and $\left[q_{req}^{ref} \right]_{pseudo}$ is the q_{req}^{ref} computed for the reference soil profile using information from a pseudo analysis. The simplified procedure only requires the engineer to compute the Δq_{req} factor.

The probability of liquefaction, P_L is expressed as:

$$P_L = 1 - \Phi\left[\frac{0.102 + FS_L}{\sigma}\right] \quad (42)$$

where Φ represents the standard normal cumulative distribution function, FS_L is the factor of safety against liquefaction computed using the Robertson and Wride (2009) method, and σ is equal to 0.276 for model uncertainty or 0.3537 total uncertainty.

Remembering the relationship for FS_L=CRR/CSR, Equation (42) becomes:

$$P_L = 1 - \Phi\left[\frac{0.102 + \ln(CRR) - \ln(CSR)}{\sigma}\right] \quad (43)$$

where CSR and CRR are expressed as:

$$CSR = 0.65\left(\frac{\sigma_v}{\sigma_v^{'}}\right)\left(\frac{a_{\max}}{g}\right) r_d \left(\frac{1}{MSF}\right)\left(\frac{1}{K_\sigma}\right) \quad (44)$$

$$CRR = \begin{cases} 93\left[\dfrac{q_{req}^*}{1000}\right]^3 + 0.08 & \text{for } 50 \le q_{req}^* < 160 \\ 0.833\left[\dfrac{q_{req}^*}{1000}\right] + 0.05 & \text{for } q_{req}^* < 50 \end{cases} \quad (45)$$

where q_{req}^* is the q_{req} that corresponds to a P_L=50%. Equation (43) is re-arranged to solve for CRR as:

$$\ln(CRR) = \ln(CSR) + \sigma \cdot \Phi^{-1}\left[1 - P_L\right] - 0.102 \quad (46)$$

$$CRR = \exp^{\left(CSR + \sigma \cdot \Phi^{-1}[1 - P_L] - 0.102\right)} \quad (47)$$

For a CRR corresponding to a probability of liquefaction of 50%, the standard normal cumulative distribution function, Φ, is equal to 0. By setting Equation (45) equal to Equation (47), q_{req}^* can be isolated and expressed as:

$$\text{For } q_{req}^* < 50, \qquad q_{req}^* = \left[\frac{\exp[\ln(CSR) - 0.102] - 0.05}{0.833}\right] \cdot 1000 \quad (48)$$

For $50 \le q^*_{req} < 160$, $$q^*_{req} = \left[\frac{\exp\left[\ln\left(CSR\right) - 0.102\right] - 0.08}{93} \right]^{\frac{1}{8}} \cdot 1000 \tag{49}$$

For $q^*_{req} > 160$, $$q^*_{req} = -91.63\left(CSR\right)^{-0.2524} + 273.8 \tag{50}$$

For Robertson and Wride (2009), q_{req} values greater than 160 are not defined by an equation and are considered "non-susceptible" to liquefaction (personal communication, P. Robertson, 2017). However, in a probabilistic analysis, a possibility of liquefaction triggering must be defined and quantified for all soil penetration resistances. Therefore, for this study, Boulanger and Idriss (2014) triggering relationships were assumed for q_{req} >160. An equation was fit to the Boulanger and Idriss (2014) CRR curve for q_{req} values greater than 160 and solved for q_{req}. Therefore q^*_{req} >160 is expressed as shown in Equation (50).

To compute q^*_{req}, Equations (48), (49), and (50) are used iteratively. Given CSR, the user enters Equation (48) and computes q^*_{req}. If the resulting q^*_{req} is less than 50, the q^*_{req} for that soil layer is computed using Equation (48). If the resulting q^*_{req} is not less than 50, the user continues to Equation (49) and computes q^*_{req}. If the resulting q^*_{req} falls within the range of 50 and 160, q^*_{req} is computed using Equation (49). If the resulting q^*_{req} does not fall within the range, q^*_{req} for that soil layer is computed using Equation (50).

3.3.3.1 Equations for q^{site}_{req}, FS_L, P_L, Δq_L, and CSR^{site}

Once the q^{ref}_{req} and CSR^{ref} values are obtained from the liquefaction parameter maps, Δq_{req} can be computed. $\left[q^{site}_{req}\right]_{pseudo}$ is computed at each layer in the soil profile using site-specific information at the location of interest. $\left[q^{ref}_{req}\right]_{pseudo}$ is computed for the reference profile using reference values at a depth of 6m also at the location of interest. The $\left[q^{ref}_{req}\right]_{pseudo}$ value will only change between different locations as the CSR^{ref} will also change. The equation to compute q^{site}_{req} is presented as:

$$q_{req}^{site} = q_{req}^{ref} + \Delta q_{req} \tag{51}$$

$$\Delta q_{req} = \left[q_{req}^{site} \right]_{pseudo} - \left[q_{req}^{ref} \right]_{pseudo} \tag{52}$$

Once q_{req}^{site} is computed, it can be then used to compute FS_L and P_L. To solve for the uniform-hazard FS_L for the soil layer *i*:

$$\left(FS_L\right)_i = \frac{\left(CRR\right)_i}{\left(CSR\right)_i} = \frac{CRR\left(q_{site}\right)}{CRR\left(q_{req}^{*}\right)} = \frac{\left(CRR\left(q_{c1Ncs}\right)\right)_i}{\left(CRR\left(q_{req}^{*}\right)\right)_i} \tag{53}$$

where CRR is calculated using Equations (45) and (9). To solve for the uniform hazard P_L for the soil layer *i*, use the following relationship:

$$\left(P_L\right)_i = 1 - \Phi\left[\frac{0.102 + \ln\left((FS_L)_i\right)}{\sigma_\varepsilon}\right] \tag{54}$$

where $\left(FS_L\right)_i$ is computed for each layer from Equation (53).

Then, Δq_L for soil sublayer *i* can be easily computed using the simplified q_{req}^{site} as:

$$\Delta\left(q_L\right)_i = \left[q_{c1Ncs}\right]_i - \left[q_{req}^{site}\right]_i \tag{55}$$

The process to compute CSR_{Ku}^{site} (Ku subscript added to distinguish from the Boulanger and Idriss CSR^{site}) involves the use of q_{req}^{site} and is compute computed as:

$$CSR_{Ku}^{site} = \exp\left(0.102 + \ln\left(CRR(q_{req}^{site})\right)\right) \tag{56}$$

Recalling from the previous section, for values of q_{req} >160, the Boulanger and Idriss (2014) relationship takes over. When computing CSR_{Ku}^{site}, the q_{req}^{site} that is to be used, Equation (56) needs to be checked. For values of q_{req}^{site} >160, the CSR_{Ku}^{site} procedure uses the CSR^{site} from the simplified Boulanger and Idriss (2014) method (i.e., Equation (34)). For q_{req}^{site} <160, values, CSR_{Ku}^{site} can be computed following Equation (56) using the Robertson and Wride (2009) CRR equations.

(Note: When using the Boulanger and Idriss (2014) CSR^{site}, remember there are different methods to calculate CSR^{site} based on which MSF version is used (See 3.3.2.6)).

3.4 Performance-Based Post-liquefaction Free-field Settlement Models

This section will provide a brief overview of the Ishihara and Yoshimine (1992) and Juang (2013) post-liquefaction free-field settlement models and how Juang (2013) fit into the performance-based settlement calculation.

3.4.1 Ishihara and Yoshimine (1992) Settlement Method

Ishihara and Yoshimine (1992) produced a deterministic procedure to calculate post-liquefaction ground settlement based on volumetric strains in liquefiable soils. This volumetric strain is a function of the factor of safety against liquefaction, FS_L. Ishihara and Yoshimine summarized the relationship between FS_L, $\gamma_{\max}$ and D_r using the curves presented in Figure 3-4. In this Figure, volumetric strain is referred to as $\gamma_{\max}$. For the rest of the report, volumetric strain will be denoted as $\varepsilon_{v,}$ to be distinguished from the horizontal strain in the lateral spread section.

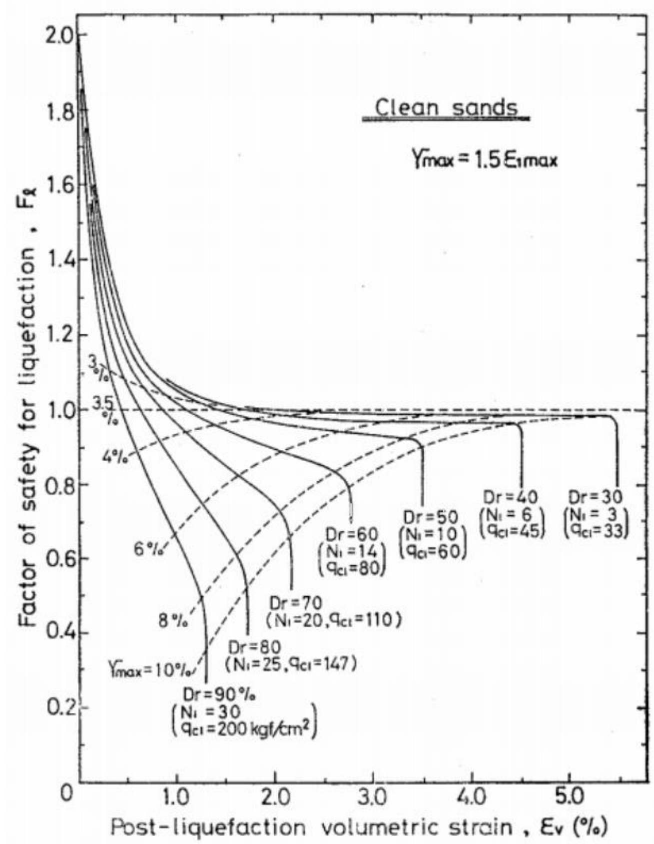

Figure 3-4. The relationship between FS_L, $\gamma_{\max}$ and D_r (after Ishihara & Yoshimine, 1992).

The procedure for applying the Ishihara and Yoshimine (1992) method is given as follows: first, FS_L for each layer of the soil profile is calculated using a liquefaction triggering procedure (e.g., Robertson and Wride, 2009; Boulanger and Idriss, 2014). Second, a relative density is obtained for each layer using Tatsuka et al. (1990):

$$D_r = -85 + 76 \log \frac{q_c}{\sqrt{\sigma_v^{'}}} \tag{57}$$

where q_c is the cone tip resistance and σ_v' is the vertical effective stress. Third, volumetric strain, ε_v, is obtained using the FS_L, and D_r calculated previously for each layer from the Ishihara and Yoshimine strain curves (Figure 3-4). Fourth, the settlement of each layer is the product of each layer's strain and thickness. Finally, the predicted total ground surface settlement (Sp) is computed by summating each layer's settlement as:

$$S_p = \sum_{i=1}^{N} \varepsilon_v \Delta Z_i \tag{58}$$

where ε_v is volumetric strain for the i[th] layer, N is number of layers, and ΔZ_i is the i[th] layer's thickness.

3.4.2 Juang et al. (2013) Procedure

Juang et al. (2013) calculated post-liquefaction settlements by applying the Ishihara and Yoshimine (1992) method probabilistically for the cone penetration test (CPT). The method adds probabilistic parameters to equation (58) to account for the probability of liquefaction triggering by using the following equation:

$$S_p = M\sum_{i=1}^{N}\varepsilon_v \Delta Z_i IND_i \tag{59}$$

where ε_v is volumetric strain for the i^{th} layer, N is number of layers, M represents a modal bias correction factor equal to 1.0451, IND_i represents the probability of liquefaction occurring, which it is defined in equation (60), and ΔZ_i is the i^{th} layer's thickness.

The model bias correction factor M was calculated by Juang et al. (2013) by calibrating their model against settlement case histories from the field. Juang et al. (2013) present the IND_i as probability of liquefaction (P_L), which is calculated as:

$$IND_i = P_L = 1 - \Phi\left\{\frac{0.102 + \ln(FS_L)}{\sigma_{\ln(S)}}\right\} \tag{60}$$

where Φ represents the standard normal cumulative distribution function, and $\sigma_{ln(S)}$ represents the model uncertainty and is equal to 0.276.

One significant disadvantage associated with the Juang et al. (2013) model is that the model was based on the binomial assumption that both liquefied and non-liquefied soils can cause liquefaction settlement. Hatch (2017) re-solved the maximum likelihood equation developed by Juang et al. (2013) to neglect the possibility of non-liquefied layers contributing to post-liquefaction settlement. The resulting values of M and $\sigma_{\ln(s)}$ are 1.014 and 0.3313, respectively. Any potential error introduced by this simplification is accounted for in the larger value of model uncertainty, $\sigma_{\ln(s)}$. These re-solved values are used in the computational tool CPTLiquefy.

For the Juang et al. (2013) procedure, ε_v is calculated by using a curve-fitted equation based on the Ishihara and Yoshimine (1992) curves (Figure 3-4), given as:

$$\varepsilon_v(\%) = \left\{ \begin{array}{lll} 0 & \text{for} & \text{FS} \geq 2 \\ \min\left\{ \begin{array}{c} \dfrac{a_0 + a_1 \ln(q)}{\dfrac{1}{(2-FS)} - \left[a_2 + a_3 \ln(q)\right]} \\ b_0 + b_1 \ln(q) + b_2 \ln(q)^2 \end{array} \right\} & \text{for} & 2\text{-}\dfrac{1}{a_2 + a_3 \ln(q)} < FS < 2 \\ b_0 + b_1 \ln(q) + b_2 \ln(q)^2 & \text{for} & \text{FS} \leq 2\text{-}\dfrac{1}{a_2 + a_3 \ln(q)} \end{array} \right\} \tag{61}$$

where $a_0 = 0.3773,\ a_1 = -0.0337,\ a_2 = 1.5672,\ a_3 = -0.1833,\ b_0 = 28.45,\ b_1 = -9.3372,\ b_2 = 0.7975$ and $q = q_{t1Ncs}$.

3.5 Simplified Post-liquefaction Free-field Settlement Models

The performance-based method of calculating post- liquefaction settlement in Section 3.4 is an effective solution to mitigate the deficiencies introduced by the conventional (i.e. "pseudo-probabilistic") method. However, the performance-based approach is complex and difficult to use. Performing a performance-based analysis may not be practical for professionals who need to routinely perform settlement calculations in a rapid and efficient manner.

An ideal solution to this dilemma is the introduction of a new procedure that combines the simplicity of traditional liquefaction hazard maps with the accuracy of a site-specific performance-based liquefaction hazard analysis. Section 3.3 of this report presents such a simplified procedure that has been developed for calculating liquefaction triggering.

In a manner similar to that developed for simplified liquefaction triggering, vertical strains for a reference profile, ε_v^{ref}, can be probabilistically computed across a grid of geographic locations. These results can be used to develop contours for the vertical strains that correspond to various return periods. These maps are called the volumetric strain reference parameter maps. ε_v^{ref} is actually a proxy for the seismic loading that impacts post-liquefaction settlement, and it needs to be adjusted for site-specific conditions. A detailed derivation for the correction equations, using both the Boulanger and Idriss (2014) and the Ku et al. (2012) probabilistic liquefaction triggering models will be given. For consistency, all vertical strains will be in percent in the simplified performance-based method.

3.5.1 Site-Specific Correction for Reference Strain using Boulanger and Idriss (2014) Probabilistic Liquefaction Triggering Model

Because ε_v^{ref} was calculated using the reference soil profile, it must be corrected for site-specific soil conditions and depths before obtaining ε_v^{site}. A variety of relationships have been tested to relate ε_v^{ref} and ε_v^{site}. These relationships include:

$$\varepsilon_v^{site} = \varepsilon_v^{ref} - \Delta\varepsilon \tag{62}$$

$$\ln\left(\varepsilon_v^{site} + a\right)^b = \ln\left(\varepsilon_v^{ref} + a\right)^b + \Delta\varepsilon \tag{63}$$

$$\ln(\varepsilon_v^{site} + a)^b = \ln\left(\varepsilon_v^{ref} + a\right)^b \cdot \Delta\varepsilon \tag{64}$$

where a and b are constants ranging from 0.001 to 1000. A constant a was added to both ε_v^{site} and ε_v^{ref} to prevent a value of zero from occurring in the natural log operators.

After performing preliminary assessment, Equation (65) is found to best predict the volumetric strain calculated by the performance-based method.

$$\ln\left(\varepsilon_v^{site} + 1000\right) = \left(\ln\left(\varepsilon_v^{ref} + 1000\right)\right)^{\frac{1}{3}} \cdot \Delta\varepsilon \tag{65}$$

where $\Delta\varepsilon$ is a site-specific correction factor. Rearranging Equation (65), we can solve for the correction factor $\Delta\varepsilon$ as:

$$\Delta\varepsilon = \frac{\ln(\varepsilon_v^{site} + 1000)}{(\ln(\varepsilon_v^{ref} + 1000))^{1/3}} \tag{66}$$

ε_v^{site} in Equation (66) represents the probabilistic strain in the sublayer of interest and is unknown. To simplify the analysis, both ε_v^{ref} and ε_v^{site} can be approximated using the pseudo-probabilistic approach. This is an appropriate simplification because the same errors introduced by using the pseudo-probabilistic method should occur in both ε_v^{ref} and ε_v^{site}. These errors are minimized when performing the division in Equation (66). Thus, the equation for the correction factor may be approximated as:

$$\Delta\varepsilon \cong \frac{\ln\left(\varepsilon_{v,pseudo}^{site} + 1000\right)}{\left(\ln\left(\varepsilon_{v,pseudo}^{ref} + 1000\right)\right)^{\frac{1}{3}}} \tag{67}$$

where ε_v^{ref} and ε_v^{site} are volumetric strains calculated using pseudo-probabilistic method with FS_L computed using the mean magnitude from the deaggregation of PGA at the return period of interest.

Once the correction factor for a given soil sublayer is computed, site-specific strains are computed as:

$$\varepsilon_v^{site} = \exp\left(\ln\left(\varepsilon_v^{ref} + 1000\right)^{\frac{1}{3}} \cdot \Delta\varepsilon\right) - 1000 \tag{68}$$

where ε_v^{ref} is the volumetric strain obtained from the reference volumetric strain parameter map.

Equation (68) results in ε_v^{site} values that are non-linearly biased. A calibration equation was developed to correct this non-linear bias. The final simplified site strain can be calculated as:

$$\varepsilon_{v,calibrated}^{site}(\%) = \begin{cases} 0 & \text{for } \varepsilon_v^{site} \le 0 \\ 0.05 \cdot \varepsilon_v^{site} & \text{for } 0 < \varepsilon_v^{site} \le 1.7 \\ 0.975 \cdot \sqrt{2.5 \cdot \left[\dfrac{\left(\varepsilon_v^{site}\right)^3}{3.25} - 1.5 \right]} & \text{for } \varepsilon_v^{site} > 1.7 \end{cases} \quad (69)$$

where ε_v^{site} is the site strain as calculated in Equation (68). Once $\varepsilon_{v,calibrated}^{site}$ has been computed, the following equation may be applied to obtain the simplified performance-based settlement for the entire profile.

$$S_p = M \sum_{i=1}^{N} \varepsilon_{v,calibrated}^{site} \Delta Z_i \quad (70)$$

where M represents the re-solved modal bias correction factor equal to 1.014, $\varepsilon_{v,calibrated}^{site}$ is the simplified site strain calculated from Equation (69), and ΔZ_i is the i^{th} layer's thickness.

3.5.2 Site-Specific Correction for Reference Strain using the Ku et al. (2012) model

The framework presented in Section 3.5.1 can also be applied to the Ku et al. (2012) model. A preliminary assessment was also performed to relate ε_v^{ref} and ε_v^{site}. Equation (71) was found to minimize the difference between the full-performance based method and the simplified method.

$$\ln\left(\varepsilon_{v,pseudo}^{site} + 100\right) = \left(\ln\left(\varepsilon_{v,pseudo}^{ref} + 100\right)\right)^{\frac{1}{3}} \cdot \Delta\varepsilon \quad (71)$$

As explained in Section 3.5.1, the correction factor, Δε, can be approximated using pseudo-probabilistic estimates of ε_v^{ref} and ε_v^{site}. $\Delta\varepsilon$ for a given soil sublayer using the Ku et al. (2012) model can then be estimated as:

$$\Delta\varepsilon \cong \frac{\ln\left(\varepsilon_{v,pseudo}^{site}+100\right)}{\left(\ln\left(\varepsilon_{v,pseudo}^{ref}+100\right)\right)^{\frac{1}{3}}} \tag{72}$$

where ε_v^{ref} and ε_v^{site} are volumetric strains calculated using pseudo probabilistic method.

The site-specific strain for the soil sublayer can be computed as:

$$\varepsilon_v^{site} = \exp\left(\ln\left(\varepsilon_v^{ref}+100\right)^{\frac{1}{3}}\cdot\Delta\varepsilon\right)-100 \tag{73}$$

where ε_v^{ref} is the volumetric strain obtained from the reference volumetric strain parameter map.

Again, due to the non-linearity of the model, a calibration equation was developed to obtain the final site specific strains as:

$$\varepsilon_{v,calibrated}^{site}(\%) = \left\{\begin{array}{cc} 0 & \varepsilon_v^{site} \le 0 \\ 0.322\cdot\varepsilon_v^{site} & 0< \varepsilon_v^{site} \le 1.8 \\ 0.805\cdot\sqrt{8\cdot\left[\frac{(\varepsilon_v^{site})^2}{3}-1\right]} & \varepsilon_v^{site} > 1.8 \end{array}\right\} \tag{74}$$

$\varepsilon_{v,calibrated}^{site}$ can then be applied to Equation (70) to obtain the total settlement using the Ku et al. (2012) model for FS_L,

3.5.3 Summary

The simplified method for calculating site-specific settlement consists of the following steps:

1. Obtain a reference strain, ε_v^{ref}, from a liquefaction parameter map. These values are calculated using the full performance-based method.
2. Calculate the correction factor, $\Delta\varepsilon$, with $\varepsilon_{v,pseudo}^{site}$ and $\varepsilon_{v,pseudo}^{ref}$.

3. Compute site-specific strains, $\varepsilon_{v,calibrated}^{site}$.
4. Compute total settlement for the whole soil profile.

3.6 Empirical Lateral Spread Displacement Model

Empirical methods use large databases of earthquake case histories to create a predictive relationship. These relationships are developed using a statistical procedure known as a multilinear regression. They should be used only within the recommended range because extrapolation of an empirical model can lead to large amounts of error.

Empirical models for predicting lateral spread displacements are widely used because they are reliable, easy to understand, and easy to incorporate into engineering software. Multiple empirical predictive relationships have been created over the years; some common relationships recognized in industry today are Youd et al. (2002) and Zhang et al. (2004). The simplified performance-based method developed in this study will be using the Zhang et al. (2004) procedure, as it is the most common procedure for predicting lateral spread displacements using the CPT.

3.6.1 Zhang et al. (2004) Procedure

The predictive relationships for lateral spread displacements as laid out by Zhang et al. (2004) are the first that incorporate both SPT and CPT case histories, with 150 SPT results and 41 CPT results. With far fewer case histories for the CPT, caution must be taken to not extrapolate outside the bounds of the data. An estimate of lateral spread displacement can be made with a CPT sounding of tip resistance, sleeve friction and pore pressure with depth.

The following are the steps for the Zhang et al. (2004) procedure. To begin the calculation, an estimate of relative density (D_r) must be made for every soil layer as shown, using Tatsuoka et al. (1990):

$$D_r = -85 + 76\log\left(q_{c1N}\right) \tag{75}$$

where q_{c1N} is the corrected cone tip resistance. In the Robertson and Wride (1998) liquefaction triggering procedure, this value is referred to as Q_{tn}, while in the Boulanger and Idriss (2016) liquefaction triggering procedure this value is simply q_{c1N}.

The maximum cyclic shear strain (γ_{max}) can then be determined using the known value of D_r and the FS_L from the liquefaction triggering procedure. Figure 3-5 represents the relationship between maximum cyclic shear strain and factor of safety for different relative densities. These curves are based on data from Ishihara and Yoshimine (1992) and Seed (1979).

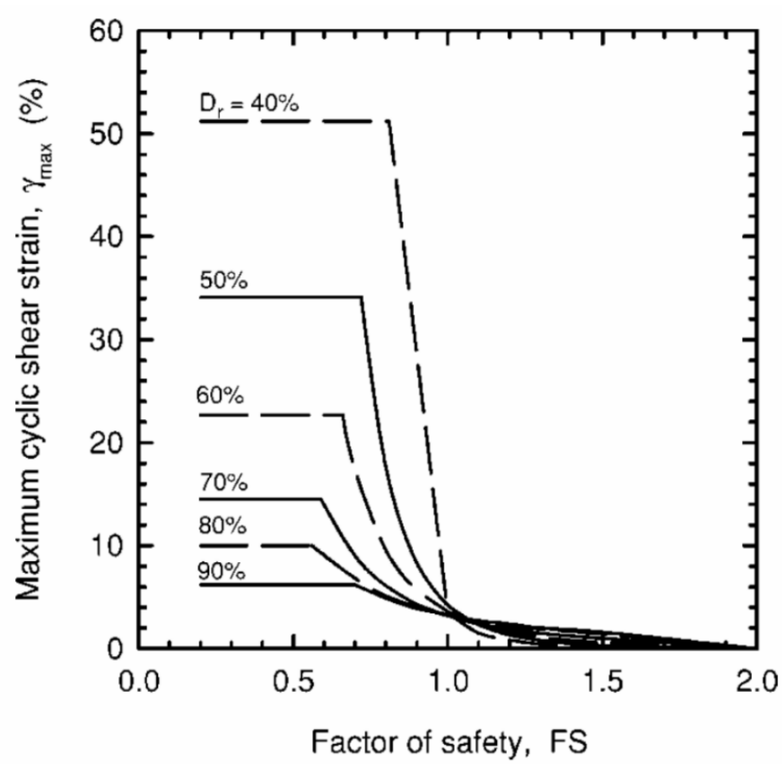

Figure 3-5. The relationship between maximum cyclic shear strain and factor of safety for different relative densities (after Zhang et al. (2004)).

With values of γ_{max} known for each soil layer, the lateral displacement index (LDI) can be calculated by integrating γ_{max} with depth, as presented in Equation (76).

$$LDI = \int_0^{Z_{max}} \gamma_{max} dz \tag{76}$$

where Z_{max} is the maximum depth below all the potential liquefiable layers with an FS_L less than 2.0.

The actual value of the lateral displacement (LD) is a function of LDI and the site geometry. There are three types of site geometries considered: (1) gently sloping ground, (2) level ground near a free face, and (3) gently sloping ground near a free face. For sites with gently sloping ground, LD is calculated using Equation (77).

$$LD = (S + 0.2) \cdot LDI \quad \text{for } 0.2\% < S < 3.5\% \tag{77}$$

where S is the ground slope measured in percent.

For sites with level ground near a free face, LD is calculated using Equation (78).

$$LD = 6 \cdot \left(\frac{L}{H}\right)^{-0.8} \cdot LDI \quad \text{for } 4 < \frac{L}{H} < 40 \tag{78}$$

where L is the distance to the free face and H is the height of the free face. The same units must be used for L and H. For sites with gently sloping ground near a free face, Equation (78) is also used because the data points for gently sloping ground with a free face lie generally within the scatter of the results for nearly level ground with a free face (Zhang et al, 2004).

3.7 Simplified Performance-based Lateral Spread Model

Similar to the simplified post-liquefaction settlement method, a generic reference site is used to compute lateral spread. A series of performance-based lateral spread analyses are performed across a grid to develop contour maps of horizontal strains corresponding to return periods of interest. These maps are called reference horizontal strain maps.

The simplified performance-based post-liquefaction lateral spread procedure builds upon the recently developed simplified performance-based liquefaction triggering models, the Boulanger and Idriss (2014) probabilistic liquefaction triggering model and the Ku et al. (2012)

model. The procedure requires FS_L calculated from one of these two triggering models. A detailed derivation of the correction equations using both of these triggering models will be given. For consistency, all horizontal strains will be in percent in the simplified performance-based method.

3.7.1 Site-Specific Correction for Reference Strain using Boulanger and Idriss (2014) Probabilistic Liquefaction Triggering Model

The framework in Section 3.5 may also be applied to develop the simplified lateral spread method. A preliminary assessment was performed to find the best-fit relationship between $\gamma_{\max}^{ref}$ and $\gamma_{\max}^{site}$. Some of the tested relationships include:

$$\gamma_{\max}^{site} = \gamma_{\max}^{ref} \cdot \Delta\gamma \tag{79}$$

$$\ln(\gamma_{\max}^{site} + a)^b = \ln(\gamma_{\max}^{ref} + a)^b + \Delta\gamma \tag{80}$$

$$\ln(\gamma_{\max}^{site} + a)^b = \ln(\gamma_{\max}^{ref} + a)^b \cdot \Delta\gamma \tag{81}$$

where a and b are constants ranging from 0.001 to 1000. A constant a was added to both between $\gamma_{\max}^{ref}$ and $\gamma_{\max}^{site}$ to prevent a value of zero from occurring in the natural log operators.

Preliminary test results show that the following equation can minimize the difference between the performance-based horizontal strains and the simplified horizontal strains.

$$\ln\left(\gamma_{\max}^{site} + 0.01\right) = \ln(\gamma_{\max}^{ref} + 0.01) \cdot \Delta\gamma \tag{82}$$

where $\Delta\gamma$ is a site-specific correction factor. Rearranging Equation (82) , we can solve for the correction factor $\Delta\gamma$ as:

$$\Delta\gamma = \frac{\ln(\gamma_{\max}^{site} + 0.01)}{\ln(\gamma_{\max}^{ref} + 0.01)} \tag{83}$$

For the simplified method, both $\gamma_{\max}^{ref}$ and $\gamma_{\max}^{site}$ are computed using semi-probabilistic method. The semi-probabilistic method is applied as follows: first, obtain the relative density, D_r , for the reference profile using the q_{c1N} value from the liquefaction triggering section. Second, with D_r and FS_L, calculated from the simplified trigging models, $\gamma_{\max}$ is found using Figure 3-5. This is called the semi-probabilistic method because FS_L is obtained using the simplified performance-based method and then applied to Figure 3-5 in a deterministic manner in the semi-probabilistic method. The approximated horizontal strains computed with the semi-probabilistic method are denoted as $\gamma_{\max,approx}^{ref}$ and $\gamma_{\max,approx}^{site}$. Equation (83) may be written as:

$$\Delta\gamma \cong \frac{\ln\left(\gamma_{\max,approx}^{site} + 0.01\right)}{\ln(\gamma_{\max,approx}^{ref} + 0.01)} \tag{84}$$

Once the correction factor for a given soil sublayer is computed using Equation (84), site-specific adjusted horizontal strains can be computed as:

$$\gamma_{\max}^{site}(\%) = \begin{cases} 0.86 \cdot \exp\left(\ln\left(\gamma_{\max}^{ref} + 0.01\right) \cdot \Delta\gamma\right) - 0.01 & \text{for } \; 0 < \gamma_{\max,approx}^{site} \leq 51.2 \\ 51.2 & \text{for } \; \gamma_{\max,approx}^{site} \geq 51.2 \end{cases} \tag{85}$$

where $\gamma_{\max}^{ref}$ is the horizontal strain obtained from the reference horizontal strain parameter map.

Equation (85) may result in $\gamma_{\max}^{site}$ values that are negative or larger than 51.2. The following conditions are applied to obtain the final simplified performance-based horizontal strains:

$$\gamma_{\max,simp}^{site}(\%) = \begin{cases} 0 & \text{for } \gamma_{\max}^{site} \leq 0 \\ \gamma_{\max}^{site} & \text{for } 0 < \gamma_{\max}^{site} < 51.2 \\ 51.2 & \text{for } \gamma_{\max}^{site} \geq 51.2 \end{cases} \tag{86}$$

Once $\gamma_{\max,\mathrm{simp}}^{ref}$ has been computed, Equations (76) thru (78) from Section 3.6.1 may be applied to obtain the overall lateral displacement for the entire soil profile.

3.7.2 Site-Specific Correction for Reference Strain using the Ku et al. (2012) model

The procedure presented in Section 3.7.1 can also be applied to the Ku et al. (2012) triggering model. The same equation can be used to define the horizontal correction factor, $\Delta\gamma$.

$$\Delta\gamma \cong \frac{\ln\left(\gamma_{\max,approx}^{site}+0.1\right)}{\left(\ln\left(\gamma_{\max,approx}^{ref}+0.1\right)\right)^{\frac{1}{3}}} \tag{87}$$

where $\gamma_{\max,approx}^{ref}$ and $\gamma_{\max,approx}^{site}$ are the horizontal strains computed using the semi-probabilistic method. For the Ku et al. (2012) triggering model, Q_{tn} is used to obtain the relative density, D_r, as shown in Equation (75). Then FS_L needs to be obtained from the simplified triggering model. With D_r , FS_L and Figure 3-5, the approximated horizontal strains, $\gamma_{\max,approx}^{ref}$ and $\gamma_{\max,approx}^{site}$ may be calculated.

Once $\Delta\gamma$ has been computed for the desired soil sublayer, the site-specific post-liquefaction horizontal strains can be computed as:

$$\gamma_{\max}^{site}(\%) = \begin{cases} 0 & \text{for } \gamma_{\max,approx}^{site} = 0 \\ \exp\left(\ln\left(\gamma_{\max}^{ref}+0.1\right)^{\frac{1}{3}}\cdot\Delta\gamma\right)-0.1 & \text{for } 0 < \gamma_{\max,approx}^{site} \le 51.2 \\ 51.2 & \text{for } \gamma_{\max,approx}^{site} = 51.2 \end{cases} \tag{88}$$

where $\gamma_{\max}^{ref}$ is the horizontal strain obtained reference horizontal strain parameter map.

Conditions are also applied to obtain the final simplified performance-based horizontal strains:

$$\gamma_{\max,simp}^{site}(\%) = \begin{cases} \gamma_{\max}^{site} & \text{for } \gamma_{\max}^{site} < 51.2 \\ 51.2 & \text{for } \gamma_{\max}^{site} \ge 51.2 \end{cases} \tag{89}$$

$\gamma_{\max,simp}^{ref}$ can then be applied to Equations (76) thru (78) to obtain the overall lateral spread for the site specific soil profile.

3.7.3 Simplified Strain Summary

The simplified method for calculating site-specific lateral spread consists of the following steps:

1. Obtain a reference horizontal strain, $\gamma_{\max}^{ref}$, from a liquefaction parameter map. These values are calculated using the full performance-based method.

2. Calculate the correction factor, $\Delta\gamma$, with $\gamma_{\max,approx}^{ref}$ and $\gamma_{\max,approx}^{site}$.
3. Compute site-specific strains, $\gamma_{\max,simp}^{ref}$.
4. Compute total lateral spread for the whole soil profile.

4.0 VALIDATION OF THE SIMPLIFIED MODELS

4.1 Overview

The effectiveness of the simplified performance-based procedure introduced in this report depends on how closely they approximate the results of a complete site-specific probabilistic seismic hazard analysis. To evaluate the accuracy of the introduced simplified procedures, a comparison between the simplified and full performance-based methods will be performed for ten sites throughout the United States. These sites will be evaluated for three different return periods: 475, 1033, and 2475 years with 20 different soil profiles.

4.1.1 Sites used in the Analysis

The sites chosen for the analysis were selected based on the range of seismicity of each site, as well as their distribution across the United States. **Error! Reference source not found.** lists the location of these sites as well as their latitudes and longitudes.

Table 1. Locations of cities used in validation

Site	Latitude	Longitude
Butte	46.003	-112.533
Charleston	32.726	-79.931
Eureka	40.802	-124.162
Memphis	35.149	-90.048
Portland	45.523	-122.675
Salt Lake City	40.755	-111.898
San Francisco	37.775	-122.418
San Jose	37.339	-121.893
Santa Monica	34.015	-118.492

Seattle	47.53	-122.3

4.1.2 CPTLiquefY

The site-specific analysis for the full performance-based method was performed using CPTLiquefY. CPTLiquefY was developed by a group of students at Brigham Young University. The 2014 USGS ground motion deaggregations were used in both the full and simplified methods.

To calculate the site-specific CSR^{site}, 20 soil profiles were applied at each site. The parameters associated with these soil profile are presented in Figure 4-1.

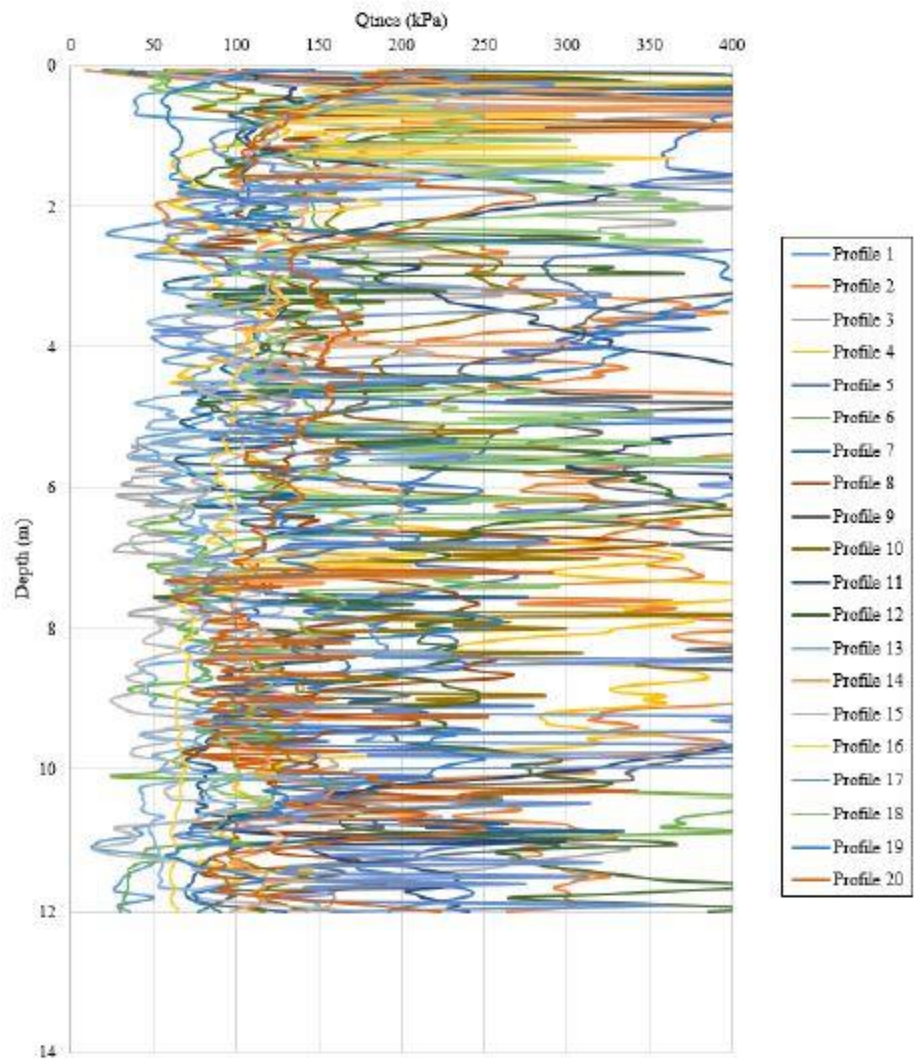

Figure 4-1. Site-specific soil profile used to validate the simplified performance-based model.

4.2 Simplified Liquefaction Triggering Model Validation

For the Boulanger and Idriss (2014) model, several validation studies were conducted. In Section 3.3.2.6, the use of different MSF versions was discussed. Therefore, there are several plots shown in Figure 4-2, Figure 4-3, and Figure 4-4 to demonstrate the effect of ΔCSR_{MSF} on the simplified method and to help the user decide which MSF version to use in the simplified calculations. Overall, regardless of which MSF version is used, the plots indicate a strong relationship between the simplified and full performance-based procedure. Note: In the computational tool *CPTLiquefY*, FS_L was not capped, which resulted in very large numbers. However, for plotting purposes, FS_L was capped at 3.

4.2.1 2014 MSF without Correction

Originally, it was only intended to use the 2014 MSF (with no corrections) for the simplified method. However, once the validation of the Boulanger and Idriss (2014) model was completed, there was much more scatter in the data than anticipated. This is most noticeable in the FS_L plot (Figure 4-3b). Upon further study, a bias based on return period and magnitude was observed and a correction function was created. Overall, the approximation follows a 1:1 trend and has a minimum R^2 of 0.9. The q_{req} exhibits the poorest fit among all the parameters. It was observed that lower seismicity areas (i.e. Butte and Charleston) contributed to the scatter seen in Figure 4-3e for lower values of $q_{req.}$ However, without the correction, using the uncorrected 2014 MSF still results in a good simplified approximation of full performance-based results.

4.2.2 2014 MSF with Correction

After the correction function (Equation (35) was applied to CSR^{site}, the general fit and scatter of the simplified method improved. While q_{req} still exhibited the lowest R^2 (0.9338), the fit was also slightly improved. By applying the correction to CSR^{site} , the simplified method more closely approximates full performance-based results. However, there are several things to note when using the correction. In Figure 4-4d and Figure 4-4e, there are data points that fall further from the 1:1 trendline. From a preliminary study, it was observed that these points came from Butte at the 475-year return period which also correlates to the lowest magnitude (M_w=6.24) included in this study. It is possible that this correction is not a good fit for low seismicity areas at low return periods, but further studies to address this specific question must be conducted. Overall, by applying the correction function to CSR^{site}, the simplified method better approximates the full-performance-based results than using the 2014 MSF without the correction.

<u>4.2.3 2012 MSF Plot</u>

When the 2012 MSF is incorporated into the simplified method, there is noticeably less scatter and a higher R^2 when compared to the other plots. The most noticeable improvement from the uncorrected 2014 MSF plot (Figure 4-3) is the $q_{req.}$ When using the 2012 MSF the simplified approximation of q_{req} exhibits much less scatter for lower values of q_{req} . The purpose of conducting a validation study using the 2012 MSF is to show the effect of the MSF on the simplified method and to show that the 2012 MSF is still a valid option to use in simplified calculations.

<u>4.2.4 Ku et al. (2012) Plot</u>

In Figure 4-5 the comparison plots for the simplified Ku et al. (2012) model are shown. Remembering Section 3.3.3, the Robertson and Wride (2009) model does not define q_{req} values greater than 160. Thus, the Boulanger and Idriss (2014) equations have been used. For the CSR plot (Figure 4-5e), the simplified Boulanger and Idriss (2014) values of CSR were used when q_{req} was greater than 160. For this plot, the $CSR^{site}_{corrected}$ was used (the corrected CSR^{site} when using 2014 MSF). With an overall average R^2 = 0.993, the Ku et al. (2012) simplified procedure closely approximate full performance-based results.

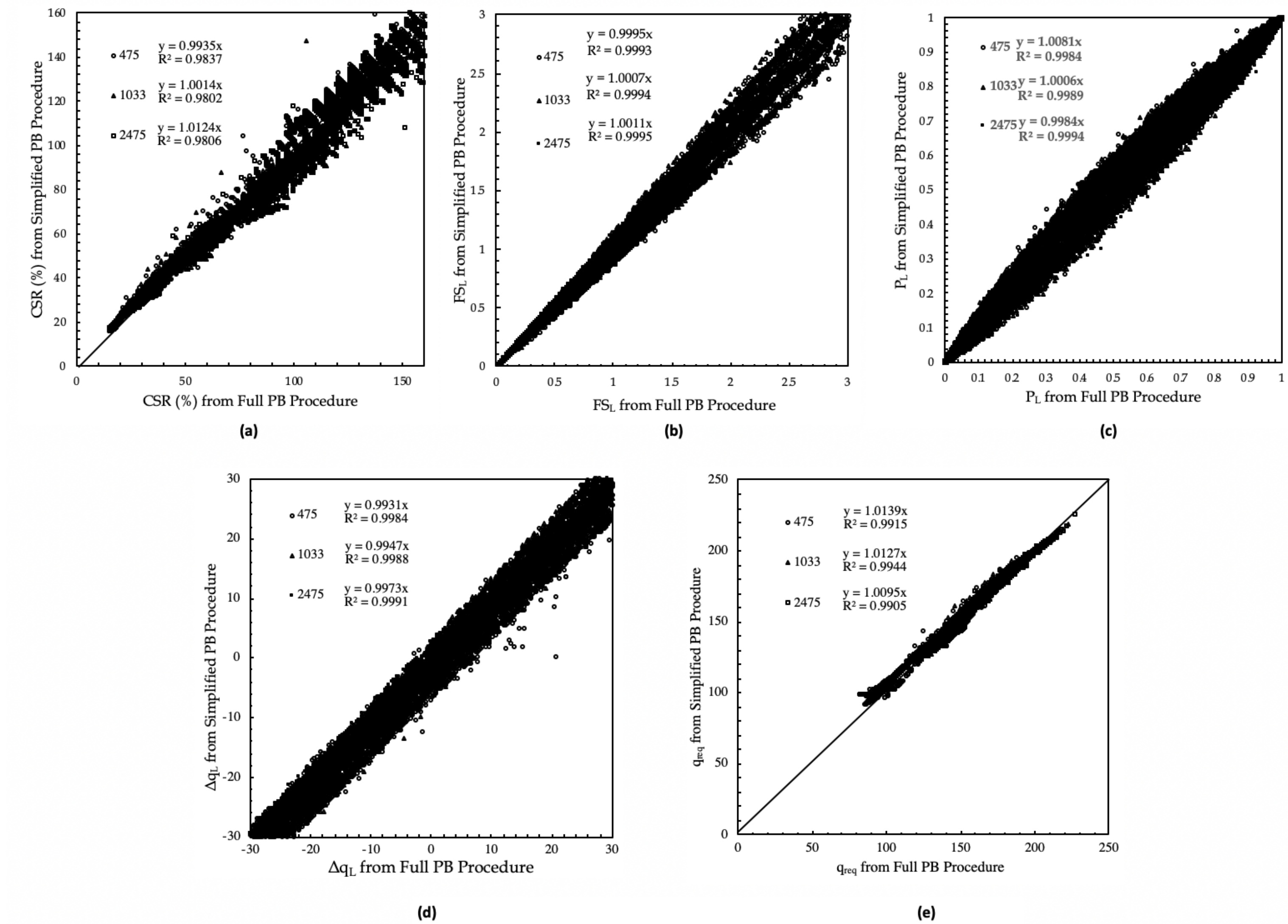

Figure 4-2. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures for (a) CSR^{site}(%), (b) FS_L, (c) P_L, and (d) Δq_L, (e) q_{req} for the Boulanger and Idriss(2014) model using the 2012 MSF.

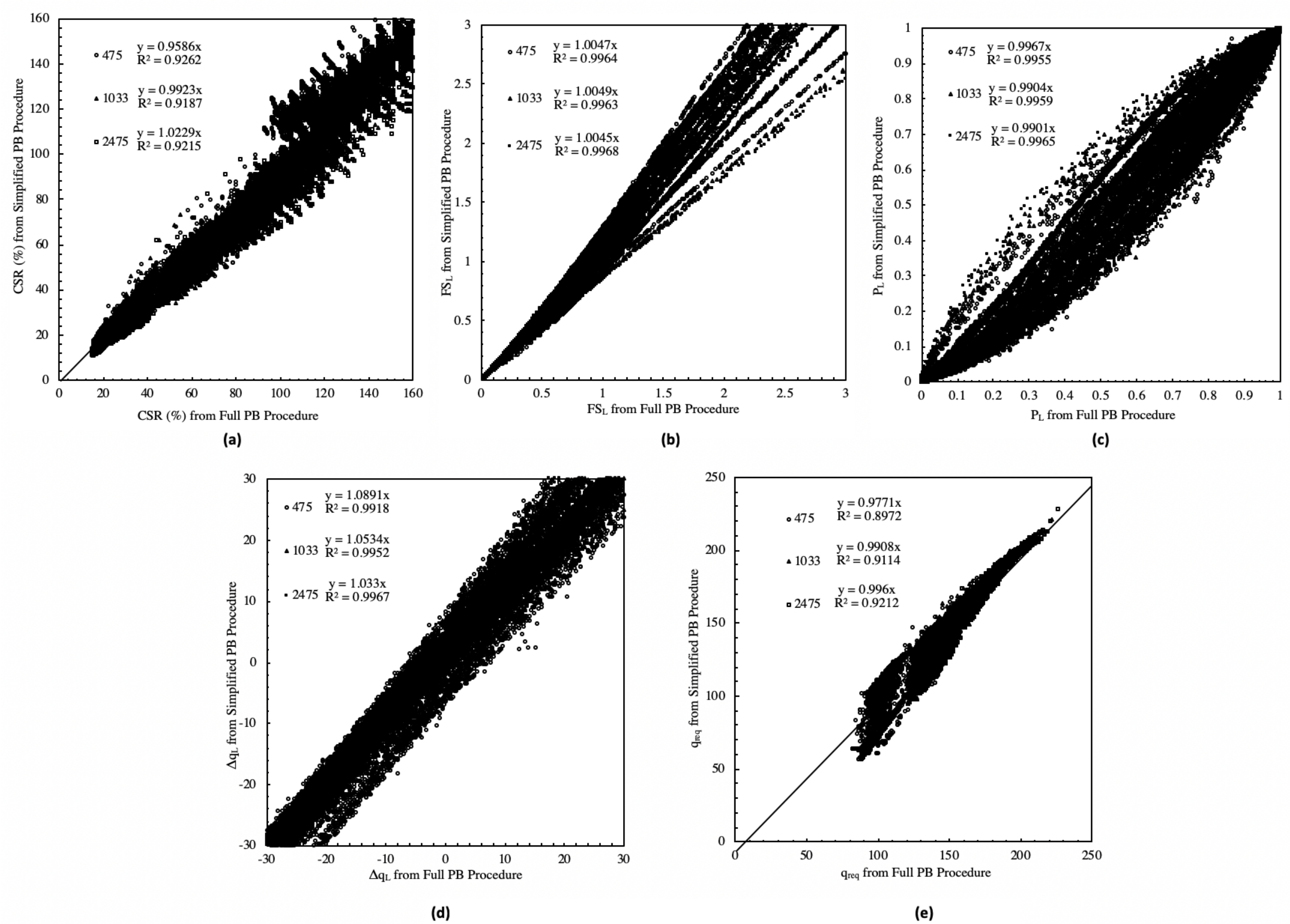

Figure 4-3. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures for (a) CSR^{site}(%), (b) FS_L, (c) P_L, and (d) Δq_L, and (e) q_{req} for the Boulanger and Idriss(2014) model using the 2014 MSF WITHOUT correction.

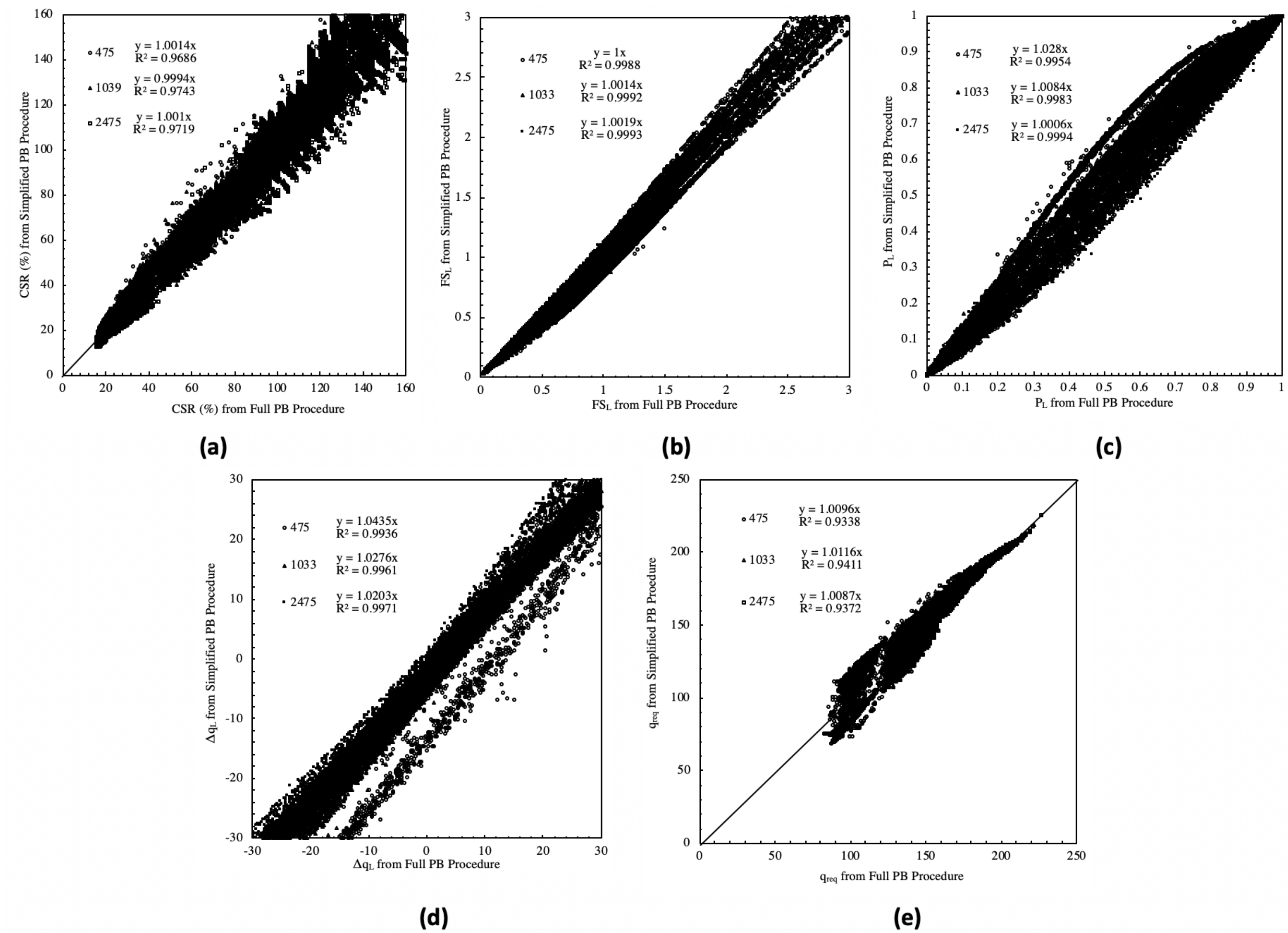

Figure 4-4. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures for (a) CSR^{site}(%), (b) FS_L, (c) P_L, (d) Δq_L, and (e) q_{req} for the Boulanger and Idriss (2014) model using the 2014 MSF with bias correction

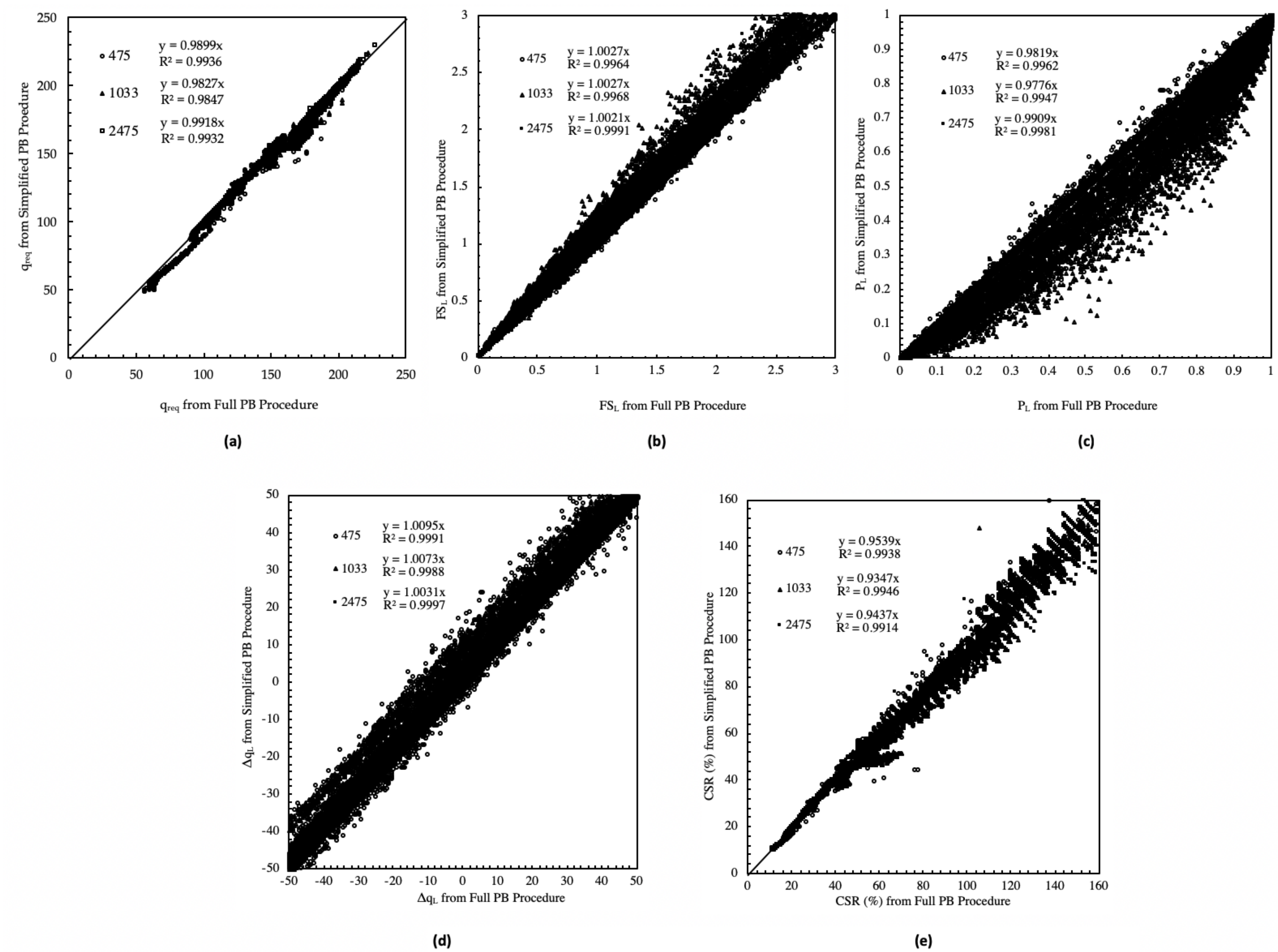

Figure 4-5. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures for (a) q_{req}, (b) FS_L, (c) P_L, (d) Δq_L, and (e) CSR^{site}(%) for the Ku et al. (2012) model.

4.3 Simplified Post-liquefaction Free-field Settlement Model Validation

4.3.1 Site Profiles

A full performance-based analysis was performed for 20 different soil profiles in 10 different cities across the United States. The simplified procedure was performed for these soil profiles using both the Boulanger and Idriss (2014) and Ku et al. (2012) models as explained in Section 3.5. All of the analyzed profiles had an assumed water table at the ground surface.

4.3.2 Validation of the Simplified Settlement Method Using Boulanger and Idriss (2014) Model

Individual sub-layer strains and post-liquefaction settlements were computed using both the full performance-based method and the simplified procedures summarized in Section 3.5.1. The total settlements from both procedures were plotted against each other. The results can be seen in Figure **4-6** . The full performance-based results are plotted on the x-axis and the simplified method results are plotted on the y-axis. Ideally, the plotted values should line up on a 1:1 (i.e., 45-degree angle) line.

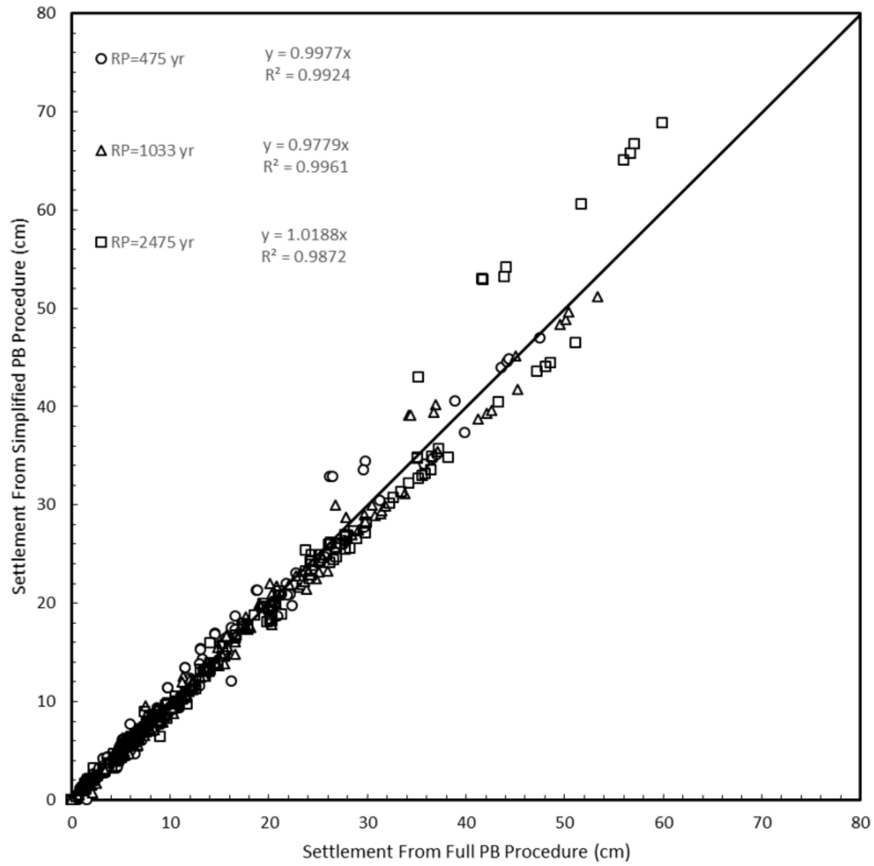

Figure 4-6. Boulanger and Idriss (2014) Performance-Based Total Settlement vs. Simplified Settlement Separated by Return Period.

Figure **4-6** shows that the trendlines have slopes ranging from 0.9779 to 1.0188 for the three return periods of interest, and R^2 values from 0.9872 to 0.9961. The simplified method is able to closely estimate the total ground surface settlements within 4cm error, especially when no more than 30 cm of total settlement is predicted. Larger errors (i.e., 10cm) are observed in predicted total settlement greater than 30 cm.

4.3.3 Validation of the Simplified Settlement Method Using Ku et. al (2012) Model

The full performance-based results were also plotted against the simplified method with the Ku et. al (2012) triggering model. The results are presented in Figure 4-7. Again, an ideal fit would be a 1:1 slope trend in the data.

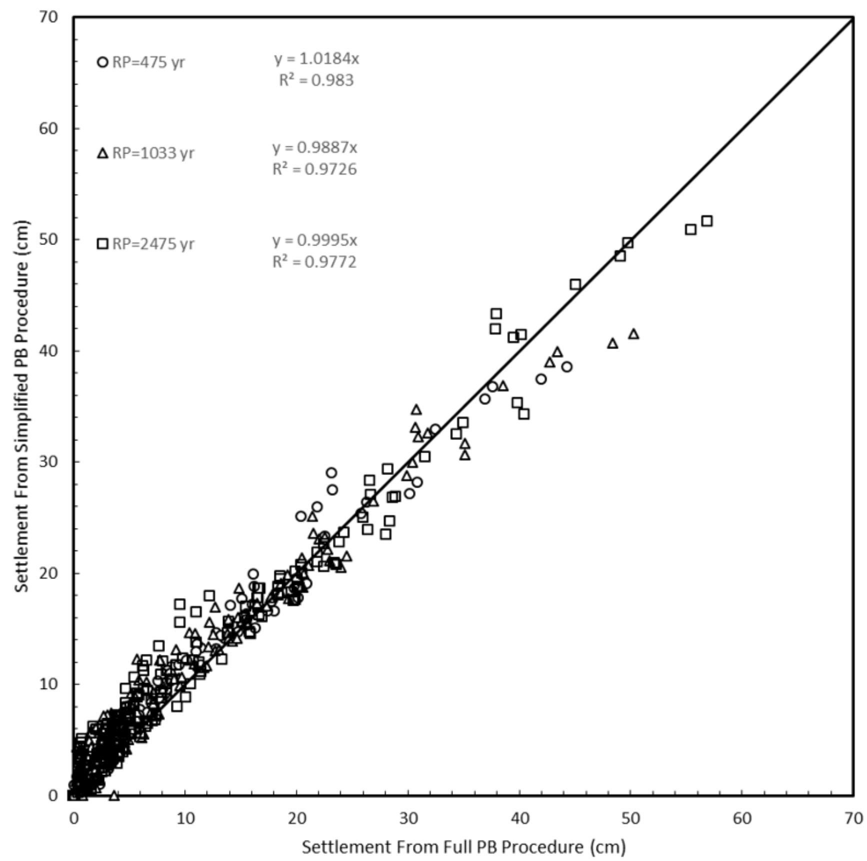

Figure 4-7. Ku et. al (2012) Performance-Based Total Settlement vs. Simplified Settlement Separated by Return Period.

Figure 4-7 shows that a general 1:1 trend is also found with the Ku et. al (2012) triggering method. The lowest R^2 value among all three return periods is 0.9726, indicating a close relationship between the performance-based method and the simplified method. Overall, the simplified method estimates the performance-based method with less than 8 cm error for all return periods and settlement ranges.

4.3.4 Comparison of Using Pseudo-Probabilistic Results and Semi-Probabilistic Results to Obtain the Correction Factor

Pseudo probabilistic results are used to obtain the correction factor for the volumetric strain, as shown in Equations (67) and (72). It is chosen over the semi-probabilistic method due to its ability to minimize the errors introduced by using the simplified performance-based settlement method. Figure **4-8** shows the comparisons of using both the pseudo-probabilistic method and the semi-probabilistic method. It is observed that pseudo-probabilistic approximation of $\Delta\varepsilon$ produces less scatter in the simplified performance-based results.

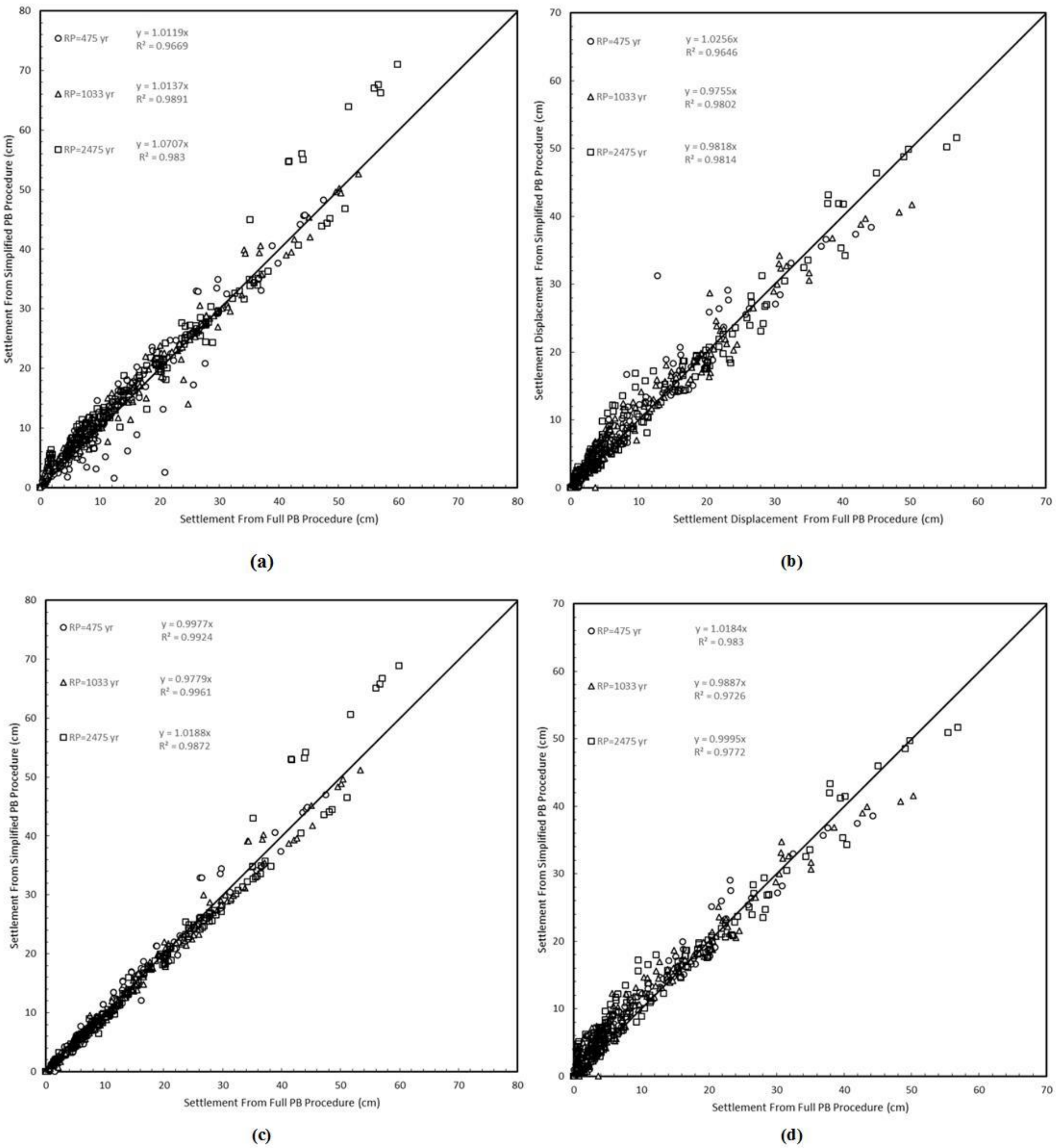

Figure 4-8. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures Using (a) Semi-Probabilistic Results for B&I (2014), (b) Semi-Probabilistic Results for Ku (2012), (c) Pseudo-Probabilistic Results for B&I (2014) and (d) Pseudo-Probabilistic Results for Ku (2012) to Estimate the Correction Factor.

4.4 Simplified Lateral Spread Displacement Model Validation

As with the settlement validation, a full performance-based lateral spread analysis and a simplified performance- based lateral spread analysis were performed for the 20 different soil profiles in 10 different cities across the United States. The same reference profile was used. A ground slope of 1% was used to perform all the calculations.

4.4.1 Validation of the Simplified Lateral Spread Method Using Boulanger and Idriss (2014) Model

Using the selected soil profiles, the lateral spread displacement was determined for each site using the simplified and full-performance based models. When using the performance-based approach with Boulanger and Idriss (2014) triggering model, Section 3.3.2.6 showed that a simplified approach could better approximate probabilistic estimates of liquefaction triggering if a correction equation for earthquake magnitude is applied. For completeness, results are presented in this section that show lateral spread displacements computed with the correction applied and no correction applied. These results are presented in Figure **4-9** and Figure 4-10.The full performance-based results are plotted on the x-axis and the simplified method results are plotted on the y-axis. Ideally, the plotted values should line up on a 1:1 (i.e., 45-degree angle) line.

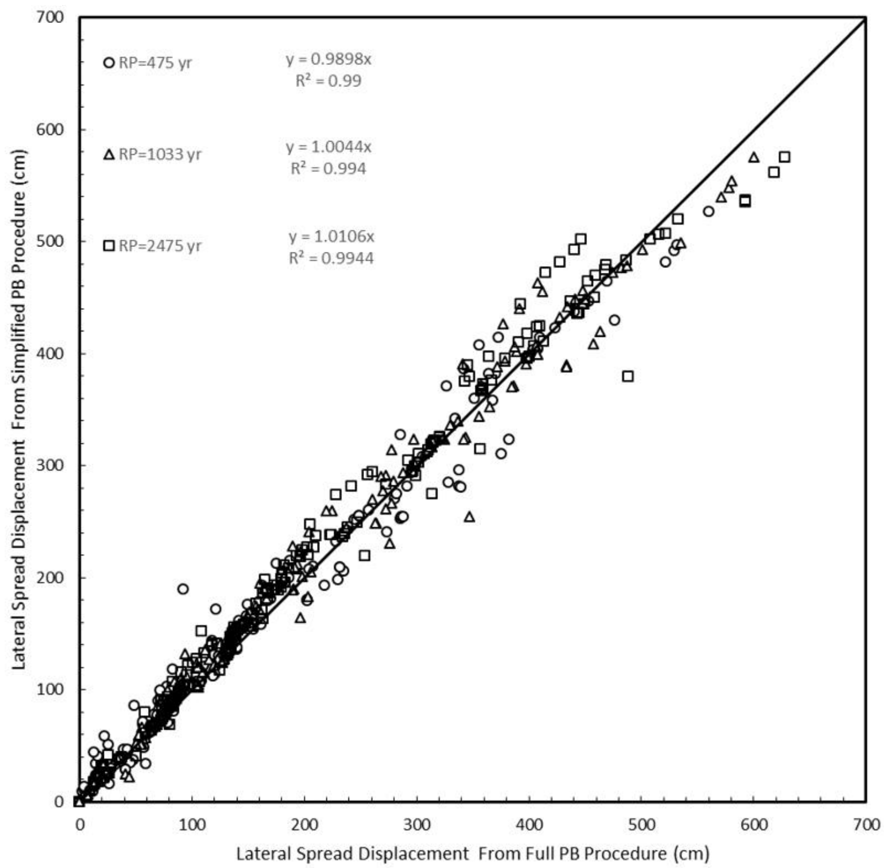

Figure 4-9 Boulanger and Idriss (2014) without MSF Correction Full Performance-Based Lateral Spread Displacements vs. Simplified Lateral Spread Displacements.

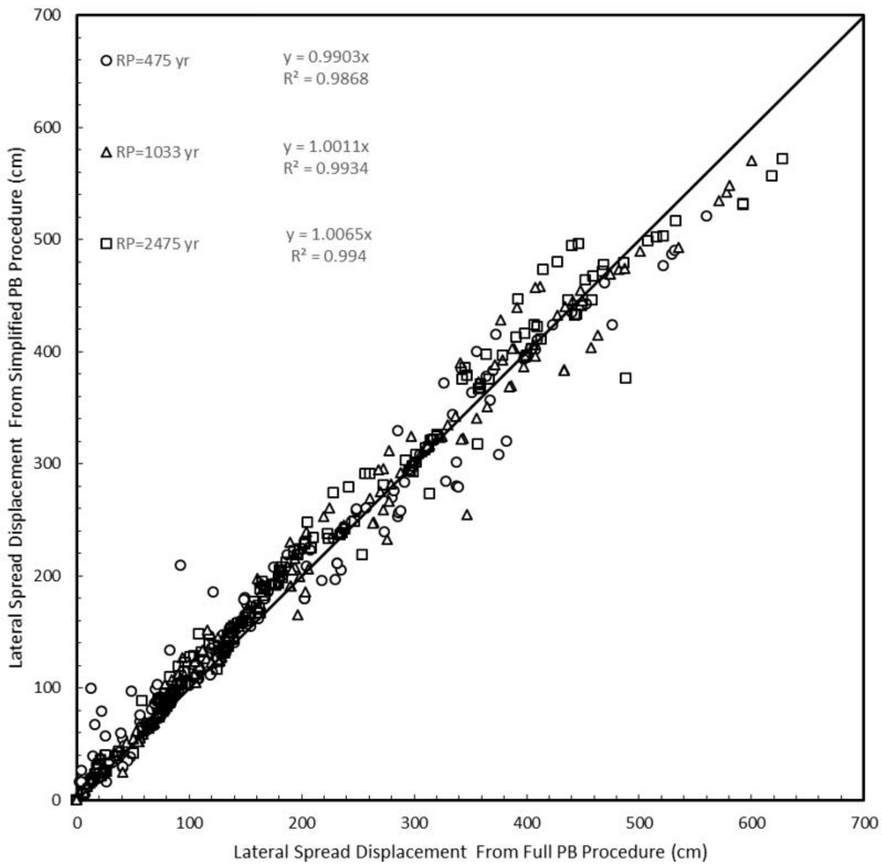

Figure 4-10 Boulanger and Idriss (2014) with MSF Correction Full Performance-Based Lateral Spread Displacements vs. Simplified Lateral Spread Displacements.

Both Figure **4-9** and Figure 4-10 show that all three return periods have a trend line close to y=x. The R^2 value for each return period is larger than 0.9868, indicating that there is a strong relationship between the full performance-based method and the simplified method. Overall, the simplified method is able to predict the full performance-based method within 50cm when the lateral displacement is less than 2m. Larger errors (i.e., 100cm) are observed when the predicted lateral spread displacement is larger than 2m.

These figures also show that applying the magnitude correction provides a slightly less biased approximation of the full performance-based approach. Therefore, the application of the correction function is recommended when using the Boulanger and Idriss (2014) model.

4.4.2 Validation of the Simplified Lateral Spread Method Using the Ku et. al (2012) Model

The full performance based results were also plotted against the simplified method with the Ku et. al (2012) triggering model. The results are presented in Figure 4-11. Again, an ideal fit would be a 1:1 slope trend in the data.

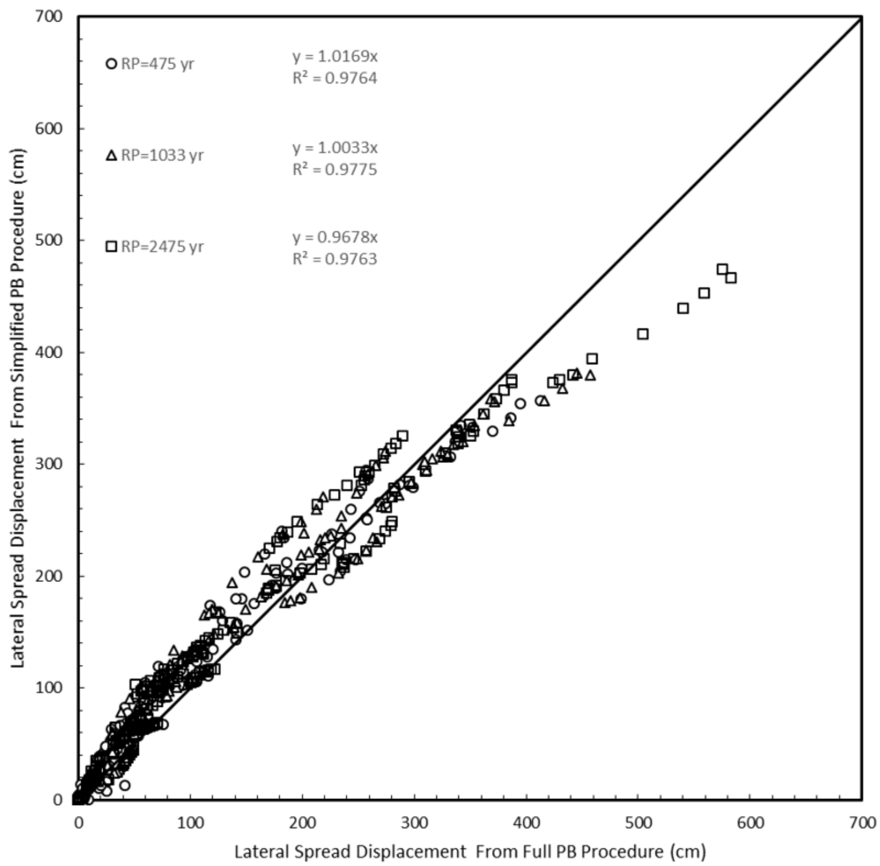

Figure 4-11 Ku et al. (2012) Full Performance-Based Lateral Spread Displacements vs. Simplified Lateral Spread Displacements.

Figure 4-11 show that all three return periods have a trend line close to y=x. The R^2 value for each return period is larger than 0.9763, indicating that the simplified method is able to estimate the full performance-based method with some scatter. It is observed that the simplified method generally overestimates the lateral spread displacement when the displacement is smaller than 2m, and underestimate it when the displacement is larger than 3.5m. Overall, the discrepancy between the simplified method and the full performance-based method is less than 75cm for all return periods and displacement ranges.

4.4.3 Comparison of Using Pseudo-Probabilistic Results and Semi-Probabilistic Results to Obtain the Correction Factor

Semi-probabilistic results are used to obtain the correction factor for the horizontal strain, as shown in Equations (84) and (87). It is chosen over the pseudo-probabilistic method due to its ability to minimize the errors introduced by using the simplified performance-based lateral spread method. Figure 4-12 shows the comparisons of using both the pseudo-probabilistic method and the semi-probabilistic method. It is observed that semi-probabilistic approximation of $\Delta\gamma$ produces less scatter in the simplified performance-based results.

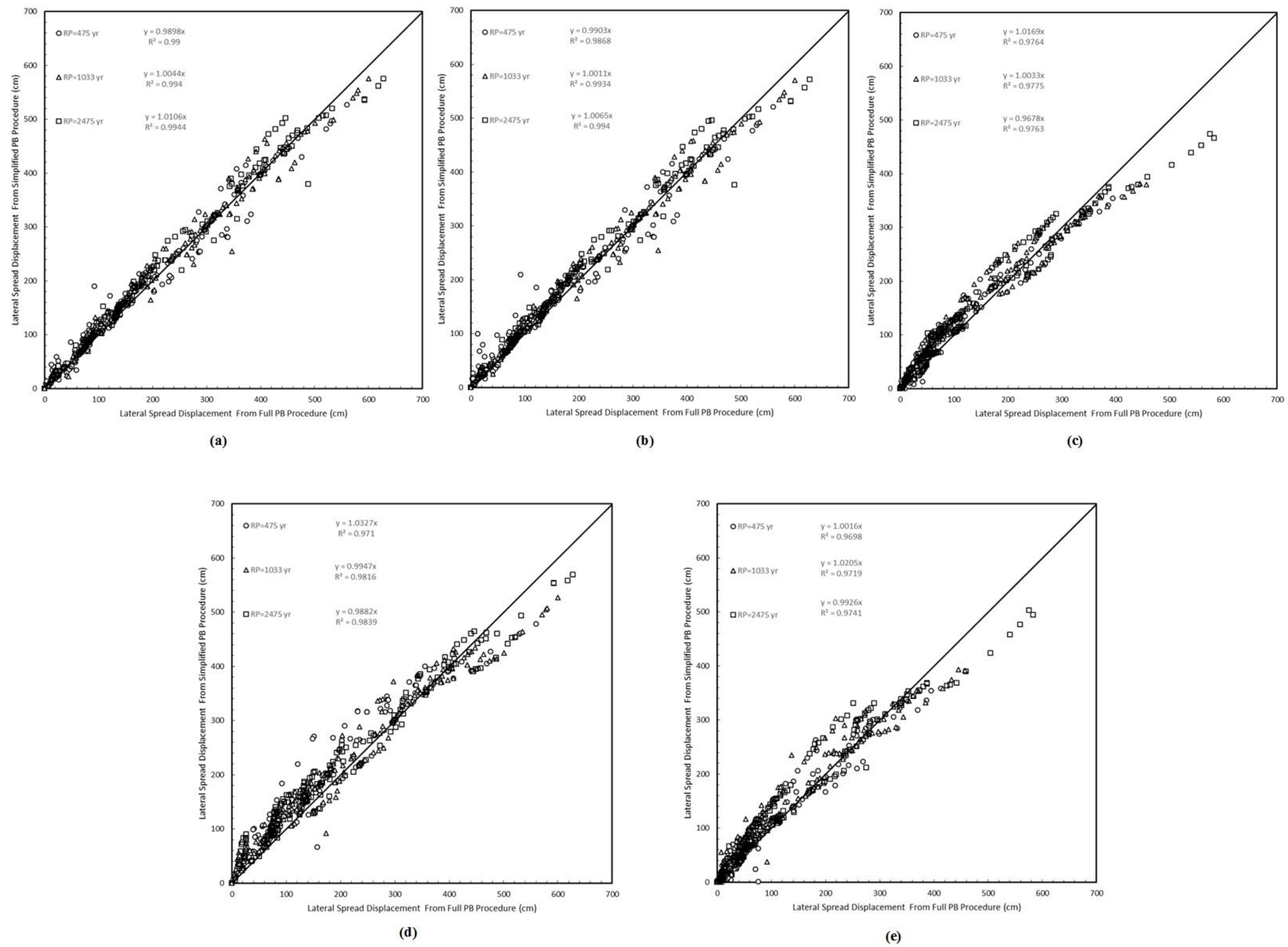

Figure 4-12. Comparative Scatter Plots for Simplified and Full Performance-Based Procedures Using (a) Semi-Probabilistic Results for B&I (2014) without correction, (b) Semi-Probabilistic Results for B&I (2014) with correction, (c) Semi-Probabilistic Results for Ku (2012), (d) Pseudo-Probabilistic Results for B&I (2014) and (e) Pseudo-Probabilistic Results for Ku (2012) to Estimate the Correction Factor

5.0 CONCLUSIONS

5.1 Summary

The purpose of the research performed was to provide the benefit of the full performance-based probabilistic earthquake hazard analysis, without requiring special software, training, and experience. To accomplish this goal, simplified models of liquefaction triggering, lateral spread displacements, post-liquefaction settlement, and seismic slope displacements were developed that reasonably approximate the results of full performance-based analyses. The objective of this report was to introduce the original models used to determine earthquake hazards (i.e. liquefaction triggering, post-liquefaction settlement, and lateral spread displacement) and provide in-depth derivations that demonstrate the development of the simplified methods and validate the simplified models by performing a site-specific analysis for several different sites.

5.2 Limitations and Challenges

During the production of this report, a correction for the Boulanger and Idriss (2014) model was created for the liquefaction triggering parameter, CSR. This correction applies to the simplified Boulanger and Idriss (2014) model when the 2014 MSF is used. Using the plots provided, the user may use their judgment to choose which MSF version to use. It is also important to remember that the simplified Ku et al. (2012) model uses Boulanger and Idriss (2014) relationships to define values of $q_{req} > 160$.

In the computational tool CPTLiquefy, γ_{max} was capped at 51.2% (Zhang et al., 2012). Users of the simplified performance-based lateral spread procedure need to be aware that all the lateral spread correction equations are based on the assumption that γ_{max} does not exceed 51.2%. Modifications to the equations may be needed if a new maximum value has been re-set.

Users of the simplified performance-based methods should be aware that the simplified method is trying to estimate the results of a very complex procedure with a few correction equations, errors are inevitable. In addition, even though the cities and soil profiles that have been selected represent a diverse combination of seismicity and soil conditions, the correction equations may not perform as well for other locations and profiles that have not been tested.

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APPENDIX A: Supplementary Validation Data

The following tables are supplementary to the validation results of this report but are too lengthy to include in its entirety. The complete tables are included in the supplemental Excel Workbooks. Details needed to access these workbooks and distinguish the information will be given in the Appendix.

Liquefaction Triggering

Table A-1-These are the values used in the calculation of CSR^{site} and q_{req}^{ref} for each of the ten cities in the study.

Table A-2-This is a sample table showing the validation results for the simplified Boulanger and Idriss (2014) liquefaction triggering procedure. However, only the data for Salt Lake City for Profile 1 is shown here.

Table A-3- This is a sample table showing the validation results for simplified Ku et al. (2012) liquefaction triggering procedure. However, only the data for Salt Lake City for Profile 1 is shown here.

Supplemental Excel Workbooks

In each of the provided Excel Workbooks for Liquefaction Triggering, there are 11 tabs- 10 tabs are for each city included in the study and 1 tab includes the reference values as shown in Table A-1. Each tab is named to distinguished between cities. In each tab, the name of the city is shown again along with the name of the data being presented (i.e. Simplified Boulanger & Idriss (2014)). Beneath the title, there are 20 tables corresponding to the 20 profiles, each similar to the one shown in in Table A-2. The Profile # is clearly labeled at the top of each table and along the left hand side.

Each Excel Workbook is named to clearly identify what data is being presented. For reference, the following list will list each workbook and its name and a short description of what is included. The same information that will be shown below is also provided in the corresponding workbooks:

-*Boulanger&Idriss(2014)_FullPB*-This workbook contains the full probabilistic results of the liquefaction triggering procedure for the Boulanger and Idriss (2014) model.

-*Simplified_Boulanger&Idriss(2014)_*2012*MSF*-This workbook contains the results for the simplified Boulanger and Idriss (2014) model if the **2012 MSF** is used.

-*Simplified_Boulanger&Idriss(2014)_2014MSF_Corrected*-This workbook contains the results for the simplified Boulanger and Idriss (2014) model if the **2014 MSF** is used **AND** the correction for CSR^{site} is used.

-*Simplified_Boulanger&Idriss(2014)_2014MSF_NOCorrection*-This workbook contains the results for the simplified Boulanger and Idriss (2014) model if the **2014 MSF** is used and **NO CORRECTION** is applied to CSR^{site} .

-*Kuetal(2012)_Simplified*-This workbook contains the results for the simplified Ku et al. (2012) model.

-*Kuetal(2012)_FullPB*-This workbook contains the full probabilistic results of the liquefaction triggering procedure for the Ku et al. (2012) model.

Post-Liquefaction Settlement

Table A-4- This is a sample table showing the validation results for the simplified post-liquefaction settlement using the pseudo-probabilistic approach to approximate the correction factor. Only the data for Salt Lake City for Profile 1 is shown here.

As with the triggering section, there are 10 tabs in each of the workbook. Each tab is named after the city that has been analyzed in the study. All 20 profiles are shown in each tab, similar to the one shown in in Table A-4. The Profile # is clearly labeled along the left hand side, followed by the return period. Results from both Boulanger and Idriss (2014) and Ku et al. (2012) triggering procedures are shown on the table.

Each Excel Workbook is named according to what data is being presented. For reference, a list of these workbooks and a short description is included:

- *Settlement_semi*- the simplified and performance-based results of post-liquefaction settlement using semi-probabilistic result to obtain the correction factor.

-*Settlement_Pseudo*-This workbook contains the simplified and performance-based results of post-liquefaction settlement using pseudo-probabilistic approximation to obtain the correction factor.

Lateral Spread Displacement

Table A-5- This is a sample table showing the validation results for the simplified post-liquefaction lateral spread displacement using the semi-probabilistic approach to approximate the correction factor. A MSF correction equation is applied to the Boulanger and Idriss (2014) triggering model. Only the data for Salt Lake City for Profile 1 is shown here.

As with the settlement section, there are 10 tabs in each of the workbook. Each tab is named after the city that has been analyzed in the study. All 20 profiles are shown in each tab, similar to the one shown in in Table A-5. The Profile # is clearly labeled along the left hand side, followed by the return period. Results from both Boulanger and Idriss (2014) and Ku et al. (2012) triggering procedures are shown on the table.

Each Excel Workbook is named according to what data is being presented. For reference, a list of these workbooks and a short description is included:

- *Lateralspread_semi*- the simplified and performance-based results of post-liquefaction settlement using semi-probabilistic result to obtain the correction factor. MSF Correction is not applied to the Boulanger and Idriss (2014) procedure.

- *Lateralspread_semi_MSF*- the simplified and performance-based results of post-liquefaction settlement using semi-probabilistic result to obtain the correction factor. MSF Correction is applied to the Boulanger and Idriss (2014) procedure.

-*Lateralspread_Pseudo*-This workbook contains the simplified and performance-based results of post-liquefaction settlement using pseudo-probabilistic approximation to obtain the correction factor.

Table A 1. Reference values for the Simplified Liquefaction Triggering Procedures

Location	$T_R = 475$					$T_R = 1033$					$T_R = 2475$				
	q_{req}^{ref} [Ku et al.]	$\%CSR^{ref}$ [B&I]	Mean M	PGA	F_{pga}	q_{req}^{ref} [Ku et al.]	$\%CSR^{ref}$ [B&I]	Mean M	PGA	F_{pga}	q_{req}^{ref} [Ku et al.]	$\%CSR^{ref}$ [B&I]	Mean M	PGA	F_{pga}
Butte	39.884	12.808	6.24	0.084	1.6	81.115	18.748	6.25	0.126	1.549	111.901	27.308	6.25	0.19	1.42
Charleston	96.541	23.512	6.31	0.233	1.367	152.395	47.955	6.59	0.464	1.136	179.444	86.742	6.77	0.825	1.1
Eureka	185.801	113.269	7.81	0.707	1.1	196.671	192.287	7.89	1.053	1.1	204.618	302.441	7.96	1.495	1.1
Memphis	101.775	22.928	6.73	0.203	1.397	150.782	43.454	6.84	0.371	1.229	176.641	77.84	6.88	0.609	1.1
Portland	112.232	25.163	7.35	0.176	1.447	146.033	42.359	7.47	0.28	1.32	173.185	68.61	7.55	0.426	1.174
Salt Lake City	121.323	28.684	6.74	0.234	1.366	165.789	53.716	6.78	0.446	1.154	179.351	86.424	6.8	0.710	1.1
San Francisco	171.354	64.373	7.28	0.423	1.177	181.166	92.965	7.36	0.561	1.1	189.037	131.228	7.43	0.736	1.1
San Jose	175.433	74.413	6.93	0.514	1.1	183.401	102.035	6.98	663	1.1	190.477	140.507	7.04	0.828	1.1
Santa Monica	167.269	56.264	6.7	0.437	1.163	178.635	84.025	6.79	0.607	1.1	187.898	124.474	6.89	0.831	1.1
Seattle	148.733	44.99	6.96	0.327	1.273	172.555	67.105	7.01	0.474	1.126	182.114	96.663	7.05	0.685	1.1

Table A 2**.** Sample Table for Simplified Boulanger and Idriss (2014) Liquefaction Triggering Procedure Results

Salt Lake City

Simplified PB- Boulanger and Idriss (2014)

Using 2014 MSF (WITH correction)

PROFILE 1

PROFILE 1		$T_R = 475$					$T_R = 1033$					$T_R = 2475$				
Depth (m)	q_{c1Ncs} site	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L
0.1	59.42	176.120	67.032	0.181	1.000	-116.700	187.435	105.576	0.115	1.000	-128.015	194.885	161.505	0.075	1.000	-135.465
0.2	90.29	170.588	56.532	0.272	0.995	-80.298	183.725	89.156	0.172	1.000	-93.435	192.199	136.478	0.113	1.000	-101.909
0.3	90.86	168.989	54.052	0.286	0.993	-78.129	182.651	85.251	0.181	1.000	-91.791	191.432	130.503	0.118	1.000	-100.572
0.4	72.44	169.884	55.414	0.241	0.998	-97.444	183.231	87.319	0.153	1.000	-110.791	191.838	133.610	0.100	1.000	-119.398
0.5	58.15	171.120	57.404	0.209	0.999	-112.970	184.053	90.415	0.133	1.000	-125.903	192.424	138.315	0.087	1.000	-134.274
0.6	75.27	170.694	56.704	0.240	0.998	-95.424	183.781	89.366	0.153	1.000	-108.511	192.233	136.751	0.100	1.000	-116.963
0.7	70.88	170.908	57.054	0.231	0.998	-100.028	183.921	89.904	0.147	1.000	-113.041	192.333	137.565	0.096	1.000	-121.453
0.8	110.02	168.366	53.141	0.349	0.981	-58.346	182.269	83.938	0.221	0.999	-72.249	191.174	128.588	0.144	1.000	-81.154
0.9	109.93	167.518	51.945	0.357	0.979	-57.588	181.700	82.050	0.226	0.998	-71.770	190.771	125.696	0.148	1.000	-80.841
1	89.08	168.034	52.666	0.289	0.993	-78.954	182.010	83.067	0.183	1.000	-92.930	190.977	127.162	0.120	1.000	-101.897
1.1	93.41	167.381	51.757	0.305	0.991	-73.971	181.579	81.657	0.193	0.999	-88.169	190.674	125.021	0.126	1.000	-97.264
1.2	103.36	166.481	50.551	0.343	0.983	-63.121	180.993	79.810	0.217	0.999	-77.633	190.266	122.237	0.142	1.000	-86.906
1.3	121.41	164.836	48.475	0.439	0.948	-43.426	179.932	76.656	0.278	0.994	-58.522	189.534	117.500	0.181	1.000	-68.124
1.4	187.41	156.208	39.770	3.061	0.014	31.202	174.423	63.444	1.919	0.099	12.987	185.793	97.678	1.246	0.332	1.617
1.5	254	155.636	39.296	658.467	0.000	98.364	174.043	62.688	412.757	0.000	79.957	185.531	96.515	268.090	0.000	68.469
1.6	208.38	155.215	38.952	9.827	0.000	53.165	173.762	62.142	6.160	0.000	34.618	185.337	95.676	4.001	0.003	23.043
1.7	136.23	161.867	45.108	0.592	0.850	-25.637	177.990	71.452	0.374	0.974	-41.760	188.192	109.616	0.244	0.997	-51.962
1.8	82.19	165.344	49.100	0.293	0.992	-83.154	180.199	77.426	0.186	1.000	-98.009	189.695	118.515	0.121	1.000	-107.505
1.9	86.78	165.102	48.800	0.306	0.990	-78.322	180.043	76.975	0.194	0.999	-93.263	189.588	117.840	0.127	1.000	-102.808
2	78.64	165.467	49.253	0.284	0.994	-86.827	180.278	77.658	0.180	1.000	-101.638	189.750	118.863	0.118	1.000	-111.110
2.1	72.06	165.757	49.617	0.268	0.995	-93.697	180.465	78.212	0.170	1.000	-108.405	189.880	119.695	0.111	1.000	-117.820
2.2	59.46	166.142	50.109	0.242	0.998	-106.682	180.714	78.957	0.153	1.000	-121.254	190.051	120.811	0.100	1.000	-130.591
2.3	74.69	165.914	49.817	0.272	0.995	-91.224	180.575	78.540	0.173	1.000	-105.885	189.958	120.206	0.113	1.000	-115.268
2.4	64.93	166.511	50.590	0.249	0.997	-101.581	180.968	79.732	0.158	1.000	-116.038	190.232	122.010	0.103	1.000	-125.302
2.5	47.1	166.984	51.218	0.215	0.999	-119.884	181.275	80.688	0.137	1.000	-134.175	190.446	123.449	0.089	1.000	-143.346
2.6	72.17	166.470	50.535	0.264	0.996	-94.300	180.948	79.670	0.167	1.000	-108.778	190.221	121.935	0.109	1.000	-118.051
2.7	73.97	166.499	50.574	0.267	0.995	-92.529	180.970	79.739	0.169	1.000	-107.000	190.238	122.045	0.111	1.000	-116.268
2.8	72.06	166.563	50.657	0.263	0.996	-94.503	181.011	79.866	0.167	1.000	-108.951	190.266	122.238	0.109	1.000	-118.206
2.9	128.35	163.409	46.801	0.502	0.913	-35.059	179.006	74.090	0.317	0.988	-50.656	188.896	113.629	0.207	0.999	-60.546
3	185.73	155.814	39.442	2.862	0.019	29.916	174.170	62.939	1.793	0.124	11.560	185.621	96.915	1.165	0.382	0.109
3.1	188.5	155.514	39.195	3.265	0.010	32.986	173.974	62.553	2.046	0.079	14.526	185.487	96.327	1.329	0.287	3.013
3.2	188.5	155.355	39.066	3.276	0.010	33.145	173.869	62.349	2.053	0.078	14.631	185.416	96.014	1.333	0.285	3.084
3.3	175.46	157.029	40.471	1.841	0.114	18.431	174.931	64.479	1.155	0.388	0.529	186.130	99.209	0.751	0.714	-10.670
3.4	105.28	164.313	47.849	0.369	0.976	-59.033	179.557	75.596	0.234	0.998	-74.277	189.262	115.823	0.152	1.000	-83.982
3.5	104.73	164.271	47.799	0.367	0.976	-59.541	179.528	75.517	0.233	0.998	-74.798	189.242	115.701	0.152	1.000	-84.512
3.6	118.28	163.293	46.669	0.438	0.948	-45.013	178.906	73.820	0.277	0.994	-60.626	188.817	113.168	0.181	1.000	-70.537
3.7	113.74	163.508	46.914	0.413	0.960	-49.768	179.039	74.178	0.261	0.996	-65.299	188.907	113.695	0.170	1.000	-75.167
3.8	126.17	162.520	45.811	0.497	0.917	-36.350	178.412	72.524	0.314	0.989	-52.242	188.480	111.229	0.205	0.999	-62.310
3.9	120.46	162.900	46.229	0.455	0.940	-42.440	178.651	73.146	0.288	0.993	-58.191	188.642	112.151	0.188	1.000	-68.182
4	99.09	164.209	47.726	0.348	0.981	-65.119	179.479	75.381	0.221	0.999	-80.389	189.205	115.476	0.144	1.000	-90.115
4.1	71.51	165.260	48.995	0.270	0.995	-93.750	180.145	77.271	0.171	1.000	-108.635	189.659	118.286	0.112	1.000	-118.149
4.2	60.88	165.699	49.544	0.247	0.997	-104.819	180.432	78.113	0.157	1.000	-119.552	189.858	119.556	0.102	1.000	-128.978
4.3	89.53	164.556	48.138	0.317	0.988	-75.026	179.698	75.991	0.201	0.999	-90.168	189.353	116.381	0.131	1.000	-99.823
4.4	79.95	164.887	48.537	0.291	0.993	-84.937	179.907	76.585	0.185	1.000	-99.957	189.496	117.263	0.121	1.000	-109.546
4.5	76	164.981	48.652	0.282	0.994	-88.981	179.966	76.755	0.179	1.000	-103.966	189.536	117.513	0.117	1.000	-113.536
4.6	82.19	164.718	48.334	0.298	0.992	-82.528	179.799	76.277	0.189	1.000	-97.609	189.421	116.800	0.123	1.000	-107.231
4.7	108.07	163.345	46.729	0.389	0.969	-55.275	178.925	73.872	0.246	0.997	-70.855	188.825	113.215	0.161	1.000	-80.755
4.8	99.09	163.769	47.214	0.352	0.980	-64.679	179.191	74.590	0.223	0.998	-80.101	189.005	114.279	0.145	1.000	-89.915
4.9	79.95	164.684	48.292	0.293	0.992	-84.734	179.775	76.210	0.186	1.000	-99.825	189.405	116.697	0.121	1.000	-109.455
5	83.96	164.403	47.956	0.304	0.991	-80.443	179.593	75.698	0.193	0.999	-95.633	189.279	115.926	0.126	1.000	-105.319
5.1	92.16	163.881	47.342	0.330	0.986	-71.721	179.256	74.766	0.209	0.999	-87.096	189.047	114.528	0.136	1.000	-96.887
5.2	87.06	164.191	47.706	0.314	0.989	-77.131	179.457	75.320	0.199	0.999	-92.397	189.186	115.361	0.130	1.000	-102.126
5.3	53.14	166.050	49.991	0.231	0.998	-112.910	180.672	78.830	0.146	1.000	-127.532	190.028	120.661	0.096	1.000	-136.888
5.4	56.09	166.007	49.936	0.236	0.998	-109.917	180.646	78.751	0.150	1.000	-124.556	190.011	120.547	0.098	1.000	-133.921
5.5	61.37	165.868	49.758	0.247	0.997	-104.498	180.556	78.483	0.156	1.000	-119.186	189.949	120.147	0.102	1.000	-128.579
5.6	62.5	165.860	49.748	0.249	0.997	-103.360	180.553	78.474	0.158	1.000	-118.053	189.948	120.137	0.103	1.000	-127.448
5.7	91.41	164.195	47.710	0.325	0.987	-72.785	179.471	75.359	0.206	0.999	-88.061	189.200	115.445	0.134	1.000	-97.790
5.8	250	153.587	37.677	422.163	0.000	96.413	172.715	60.179	264.307	0.000	77.285	184.630	92.710	171.565	0.000	65.370
5.9	71.01	165.435	49.212	0.268	0.995	-94.425	180.278	77.658	0.170	1.000	-109.268	189.757	118.911	0.111	1.000	-118.747
6	83.36	164.728	48.345	0.300	0.991	-81.368	179.819	76.335	0.190	0.999	-96.459	189.441	116.920	0.124	1.000	-106.081
6.1	75.28	165.188	48.907	0.279	0.994	-89.908	180.119	77.194	0.177	1.000	-104.839	189.648	118.216	0.115	1.000	-114.368
6.2	67.78	165.608	49.429	0.261	0.996	-97.828	180.394	78.000	0.165	1.000	-112.614	189.839	119.434	0.108	1.000	-122.059
6.3	84.37	164.728	48.345	0.303	0.991	-80.358	179.823	76.347	0.192	0.999	-95.453	189.445	116.947	0.125	1.000	-105.075
6.4	81.2	164.877	48.526	0.294	0.992	-83.677	179.920	76.622	0.186	1.000	-98.720	189.512	117.361	0.122	1.000	-108.312
6.5	75.67	165.163	48.875	0.280	0.994	-89.493	180.106	77.157	0.177	1.000	-104.436	189.640	118.167	0.116	1.000	-113.970
6.6	92.44	164.124	47.626	0.329	0.986	-71.684	179.434	75.254	0.208	0.999	-86.994	189.177	115.306	0.136	1.000	-96.737
6.7	99.42	163.570	46.984	0.355	0.980	-64.150	179.076	74.277	0.225	0.998	-79.656	188.931	113.837	0.147	1.000	-89.511
6.8	107.06	162.915	46.247	0.389	0.969	-55.855	178.654	73.155	0.246	0.997	-71.594	188.642	112.153	0.160	1.000	-81.582
6.9	107.95	162.795	46.113	0.394	0.967	-54.845	178.577	72.953	0.249	0.997	-70.627	188.589	111.848	0.162	1.000	-80.639
7	102.8	163.196	46.561	0.370	0.975	-60.396	178.835	73.633	0.234	0.998	-76.035	188.766	112.871	0.153	1.000	-85.966
7.1	112.2	162.320	45.594	0.417	0.958	-50.120	178.271	72.162	0.264	0.996	-66.071	188.379	110.660	0.172	1.000	-76.179
7.2	110.33	162.449	45.734	0.407	0.962	-52.119	178.354	72.375	0.257	0.996	-68.024	188.436	110.980	0.168	1.000	-78.106
7.3	94.73	163.671	47.101	0.339	0.984	-68.941	179.141	74.453	0.215	0.999	-84.411	188.976	114.102	0.140	1.000	-94.246
7.4	78.89	164.596	48.186	0.291	0.993	-85.706	179.738	76.105	0.184	1.000	-100.848	189.386	116.585	0.120	1.000	-110.496
7.5	78.02	164.627	48.223	0.289	0.993	-86.607	179.759	76.163	0.183	1.000	-101.739	189.401	116.673	0.119	1.000	-111.381
7.6	89.06	163.977	47.454	0.321	0.988	-74.917	179.339	74.994	0.203	0.999	-90.279	189.112	114.917	0.132	1.000	-100.052
7.7	93.76	163.619	47.041	0.337	0.984	-69.859	179.109	74.365	0.213	0.999	-85.349	188.954	113.972	0.139	1.000	-95.194

7.8	106.99	162.569	45.865	0.392	0.968	-55.579	178.433	72.579	0.248	0.997	-71.443	188.491	111.288	0.162	1.000	-81.501
7.9	107.99	162.430	45.714	0.397	0.966	-54.440	178.343	72.347	0.251	0.997	-70.353	188.429	110.940	0.164	1.000	-80.439
8	110.09	162.219	45.485	0.409	0.962	-52.129	178.207	72.001	0.258	0.996	-68.117	188.336	110.421	0.168	1.000	-78.246
8.1	117.63	161.477	44.699	0.454	0.941	-43.847	177.731	70.807	0.287	0.993	-60.101	188.011	108.629	0.187	1.000	-70.381
8.2	94.55	163.326	46.707	0.342	0.983	-68.776	178.919	73.856	0.216	0.999	-84.369	188.823	113.205	0.141	1.000	-94.273
8.3	76.55	164.301	47.835	0.288	0.993	-87.751	179.547	75.568	0.182	1.000	-102.997	189.254	115.775	0.119	1.000	-112.704
8.4	94.67	163.225	46.593	0.343	0.983	-68.555	178.853	73.681	0.217	0.999	-84.183	188.778	112.942	0.141	1.000	-94.108
8.5	82.02	163.927	47.397	0.303	0.991	-81.907	179.305	74.901	0.192	0.999	-97.285	189.088	114.771	0.125	1.000	-107.068
8.6	91.67	163.320	46.700	0.333	0.985	-71.650	178.914	73.842	0.211	0.999	-87.244	188.819	113.181	0.137	1.000	-97.149
8.7	87.28	163.512	46.918	0.320	0.988	-76.232	179.036	74.170	0.202	0.999	-91.756	188.903	113.673	0.132	1.000	-101.623
8.8	89.87	163.297	46.674	0.328	0.986	-73.427	178.898	73.799	0.208	0.999	-89.028	188.808	113.115	0.135	1.000	-98.938
8.9	95.49	162.884	46.211	0.348	0.981	-67.394	178.632	73.096	0.220	0.999	-83.142	188.625	112.059	0.144	1.000	-93.135
9	93.12	162.959	46.296	0.340	0.983	-69.839	178.679	73.221	0.215	0.999	-85.559	188.658	112.244	0.140	1.000	-95.538
9.1	91.04	163.015	46.358	0.334	0.985	-71.975	178.714	73.313	0.211	0.999	-87.674	188.681	112.380	0.138	1.000	-97.641
9.2	98.51	162.462	45.749	0.361	0.978	-63.952	178.358	72.387	0.228	0.998	-79.848	188.438	110.990	0.149	1.000	-89.928
9.3	99.9	162.307	45.580	0.368	0.976	-62.407	178.258	72.130	0.232	0.998	-78.358	188.369	110.603	0.151	1.000	-88.469
9.4	94.11	162.617	45.917	0.346	0.982	-68.507	178.456	72.638	0.219	0.999	-84.346	188.504	111.363	0.143	1.000	-94.394
9.5	83.4	163.151	46.509	0.312	0.989	-79.751	178.797	73.532	0.198	0.999	-95.397	188.737	112.701	0.129	1.000	-105.337
9.6	82.21	163.132	46.489	0.310	0.990	-80.922	178.784	73.498	0.196	0.999	-96.574	188.728	112.647	0.128	1.000	-106.518
9.7	88.02	162.747	46.061	0.328	0.986	-74.727	178.536	72.847	0.207	0.999	-90.516	188.557	111.669	0.135	1.000	-100.537
9.8	81.23	163.024	46.368	0.308	0.990	-81.794	178.713	73.310	0.195	0.999	-97.483	188.678	112.361	0.127	1.000	-107.448
9.9	75.41	163.217	46.583	0.293	0.992	-87.807	178.835	73.634	0.185	1.000	-103.425	188.761	112.844	0.121	1.000	-113.351
10	80.34	162.924	46.257	0.307	0.990	-82.584	178.647	73.137	0.194	0.999	-98.307	188.632	112.097	0.127	1.000	-108.292
10.1	109.95	160.977	44.183	0.420	0.957	-51.027	177.399	69.997	0.265	0.996	-67.449	187.781	107.392	0.173	1.000	-77.831
10.2	101.88	161.520	44.744	0.382	0.972	-59.640	177.746	70.843	0.241	0.998	-75.866	188.017	108.657	0.157	1.000	-86.137
10.3	88.26	162.297	45.569	0.332	0.985	-74.037	178.242	72.088	0.210	0.999	-89.982	188.354	110.520	0.137	1.000	-100.094
10.4	92.16	162.001	45.251	0.345	0.982	-69.841	178.051	71.605	0.218	0.999	-85.891	188.224	109.794	0.142	1.000	-96.064
10.5	106.86	160.938	44.143	0.407	0.962	-54.078	177.370	69.928	0.257	0.996	-70.510	187.760	107.280	0.167	1.000	-80.900
10.6	105.41	160.955	44.161	0.400	0.965	-55.545	177.380	69.951	0.253	0.997	-71.970	187.766	107.312	0.165	1.000	-82.356
10.7	250	148.271	34.003	467.782	0.000	101.729	169.230	54.412	292.323	0.000	80.770	182.259	83.903	189.574	0.000	67.741
10.8	70.69	162.730	46.041	0.286	0.993	-92.040	178.514	72.790	0.181	1.000	-107.824	188.538	111.560	0.118	1.000	-117.848
10.9	73.69	162.579	45.876	0.294	0.992	-88.889	178.418	72.540	0.186	1.000	-104.728	188.473	111.187	0.121	1.000	-114.783
11	66.83	162.837	46.159	0.277	0.994	-96.007	178.584	72.972	0.175	1.000	-111.754	188.587	111.837	0.114	1.000	-121.757
11.1	65.53	162.921	46.253	0.274	0.995	-97.391	178.641	73.120	0.173	1.000	-113.111	188.626	112.063	0.113	1.000	-123.096
11.2	69.34	162.766	46.081	0.283	0.994	-93.426	178.542	72.861	0.179	1.000	-109.202	188.559	111.676	0.117	1.000	-119.219
11.3	69.17	162.743	46.055	0.283	0.994	-93.573	178.527	72.823	0.179	1.000	-109.357	188.549	111.620	0.117	1.000	-119.379
11.4	250	148.618	34.223	464.778	0.000	101.382	169.472	54.780	290.361	0.000	80.528	182.429	84.482	188.274	0.000	67.571
11.5	67.45	162.759	46.074	0.279	0.994	-95.309	178.539	72.854	0.176	1.000	-111.089	188.557	111.668	0.115	1.000	-121.107
11.6	65.74	162.816	46.137	0.275	0.995	-97.076	178.576	72.952	0.174	1.000	-112.836	188.584	111.818	0.113	1.000	-122.844
11.7	64.41	162.879	46.206	0.272	0.995	-98.469	178.619	73.062	0.172	1.000	-114.209	188.613	111.987	0.112	1.000	-124.203
11.8	63.77	162.913	46.244	0.270	0.995	-99.143	178.642	73.122	0.171	1.000	-114.872	188.629	112.080	0.112	1.000	-124.859
11.9	250	148.915	34.412	462.218	0.000	101.085	169.678	55.094	288.702	0.000	80.322	182.573	84.977	187.179	0.000	67.427
12	64.84	162.887	46.215	0.273	0.995	-98.047	178.628	73.086	0.172	1.000	-113.788	188.621	112.031	0.113	1.000	-123.781

Table A 3. Sample Table for Simplified Ku et al. (2012) Liquefaction Triggering Procedure Results

Salt Lake City

Simplified PB-Ku et al. (2012) [Probabilistic Robertson and Wride (2009)]

(Using 2014 MSF w/ Correction for Boulanger and Idriss (2014) CSR)

PROFILE 1		$T_R = 475$					$T_R = 1033$					$T_R = 2475$				
Depth (m)	q_{c1Ncs} site	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L	q_{req}	$\%CSR^{site}$	FS_L	P_L	Δq_L
0.1	59.42	157.761	49.296	0.180	1.000	-121.551	176.859	105.576	0.102	1.000	-140.649	188.155	161.505	0.064	1.000	-151.945
0.2	90.29	153.896	46.396	0.294	0.999	-76.486	173.431	89.156	0.178	1.000	-96.021	185.067	136.478	0.112	1.000	-107.657
0.3	90.86	152.706	45.532	0.324	0.998	-69.736	172.376	85.251	0.200	1.000	-89.406	184.116	130.503	0.127	1.000	-101.146
0.4	72.44	152.935	45.698	0.210	1.000	-108.765	172.579	87.319	0.129	1.000	-128.409	184.299	133.610	0.082	1.000	-140.129
0.5	58.15	153.671	46.232	0.197	1.000	-114.911	173.232	90.415	0.120	1.000	-134.472	184.887	138.315	0.076	1.000	-146.127
0.6	75.27	153.632	46.203	0.201	1.000	-112.882	173.197	89.366	0.122	1.000	-132.447	184.856	136.751	0.077	1.000	-144.106
0.7	70.88	153.721	46.268	0.199	1.000	-113.681	173.276	89.904	0.121	1.000	-133.236	184.927	137.565	0.076	1.000	-144.887
0.8	110.02	152.986	45.734	0.460	0.972	-47.186	172.624	83.938	0.283	0.999	-66.824	184.340	128.588	0.179	1.000	-78.540
0.9	109.93	152.372	45.292	0.631	0.845	-28.232	172.080	82.050	0.391	0.991	-47.940	183.849	125.696	0.248	1.000	-59.709
1	89.08	152.007	45.031	0.549	0.921	-36.557	171.755	83.067	0.342	0.997	-56.305	183.557	127.162	0.217	1.000	-68.107
1.1	93.41	146.065	40.953	0.651	0.822	-26.035	171.459	81.657	0.373	0.994	-51.429	183.291	125.021	0.237	1.000	-63.261
1.2	103.36	145.400	40.517	0.592	0.884	-31.760	171.207	79.810	0.338	0.997	-57.567	183.063	122.237	0.215	1.000	-69.423
1.3	121.41	144.649	40.029	0.707	0.756	-21.099	170.921	76.656	0.403	0.989	-47.371	182.806	117.500	0.257	1.000	-59.256
1.4	187.41	143.709	39.425	30.818	0.000	79.211	170.560	63.444	17.510	0.000	52.360	182.481	97.678	11.178	0.000	40.439
1.5	254	142.972	38.957	5.81E+06	0.000	162.518	170.276	62.688	3.29E+06	0.000	135.214	182.225	96.515	2.10E+06	0.000	123.265
1.6	208.38	142.443	38.624	354.807	0.000	105.407	170.071	62.142	200.763	0.000	77.779	182.040	95.676	128.413	0.000	65.810
1.7	136.23	142.159	38.447	1.374	0.117	19.651	169.961	71.452	0.777	0.665	-8.151	181.941	109.616	0.497	0.954	-20.131
1.8	82.19	142.149	38.440	0.478	0.964	-44.789	169.957	77.426	0.270	1.000	-72.597	181.937	118.515	0.173	1.000	-84.577
1.9	86.78	142.075	38.394	0.449	0.976	-48.725	169.928	76.975	0.254	1.000	-76.578	181.912	117.840	0.162	1.000	-88.562
2	78.64	142.217	38.482	0.318	0.998	-73.217	169.983	77.658	0.180	1.000	-100.983	181.961	118.863	0.115	1.000	-112.961
2.1	72.06	142.397	38.595	0.394	0.990	-57.217	170.053	78.212	0.223	1.000	-84.873	182.024	119.695	0.143	1.000	-96.844
2.2	59.46	142.584	38.712	0.293	0.999	-80.264	170.126	78.957	0.166	1.000	-107.806	182.090	120.811	0.106	1.000	-119.770
2.3	74.69	142.851	38.880	0.227	1.000	-107.401	170.229	78.540	0.128	1.000	-134.779	182.183	120.206	0.082	1.000	-146.733
2.4	64.93	143.457	39.264	0.193	1.000	-121.447	170.463	79.732	0.109	1.000	-148.453	182.393	122.010	0.070	1.000	-160.383
2.5	47.1	143.787	39.475	0.263	1.000	-90.957	170.590	80.688	0.149	1.000	-117.760	182.508	123.449	0.095	1.000	-129.678
2.6	72.17	143.767	39.461	0.362	0.995	-62.957	170.582	79.670	0.206	1.000	-89.772	182.501	121.935	0.131	1.000	-101.691
2.7	73.97	143.941	39.573	0.232	1.000	-104.591	170.649	79.739	0.132	1.000	-131.299	182.561	122.045	0.084	1.000	-143.211
2.8	72.06	144.001	39.611	0.383	0.992	-59.041	170.672	79.866	0.218	1.000	-85.712	182.582	122.238	0.139	1.000	-97.622
2.9	128.35	143.863	39.523	1.070	0.316	4.217	170.619	74.090	0.608	0.868	-22.539	182.534	113.629	0.388	0.991	-34.454
3	185.73	143.624	39.370	5.900	0.000	54.656	170.527	62.939	3.351	0.000	27.753	182.451	96.915	2.140	0.007	15.829
3.1	188.5	143.420	39.241	5.292	0.000	52.780	170.449	62.553	3.004	0.000	25.751	182.381	96.327	1.919	0.017	13.819
3.2	188.5	143.256	39.137	4.511	0.000	49.794	170.386	62.349	2.559	0.002	22.664	182.324	96.014	1.635	0.047	10.726
3.3	175.46	143.069	39.018	2.814	0.001	39.651	170.314	64.479	1.595	0.054	12.406	182.259	99.209	1.019	0.366	0.461
3.4	105.28	142.901	38.912	0.769	0.675	-15.951	170.249	75.596	0.436	0.980	-43.299	182.200	115.823	0.279	1.000	-55.250
3.5	104.73	142.834	38.870	0.656	0.817	-25.474	170.223	75.517	0.372	0.994	-52.863	182.177	115.701	0.238	1.000	-64.817
3.6	118.28	142.764	38.825	0.768	0.676	-16.034	170.195	73.820	0.435	0.981	-43.465	182.152	113.168	0.278	1.000	-55.422
3.7	113.74	142.643	38.749	0.753	0.696	-17.223	170.149	74.178	0.426	0.983	-44.729	182.110	113.695	0.273	1.000	-56.690
3.8	126.17	142.648	38.753	0.766	0.679	-16.178	170.151	72.524	0.434	0.981	-43.681	182.112	111.229	0.277	1.000	-55.642
3.9	120.46	142.572	38.705	0.752	0.697	-17.282	170.121	73.146	0.426	0.983	-44.831	182.085	112.151	0.272	1.000	-56.795
4	99.09	142.501	38.661	0.556	0.915	-35.491	170.094	75.381	0.314	0.999	-63.084	182.061	115.476	0.201	1.000	-75.051
4.1	71.51	142.487	38.652	0.368	0.994	-61.947	170.088	77.271	0.208	1.000	-89.548	182.056	118.286	0.133	1.000	-101.516
4.2	60.88	142.528	38.677	0.300	0.999	-78.088	170.104	78.113	0.170	1.000	-105.664	182.070	119.556	0.109	1.000	-117.630
4.3	89.53	142.491	38.654	0.454	0.974	-47.991	170.090	75.991	0.257	1.000	-75.590	182.057	116.381	0.164	1.000	-87.557
4.4	79.95	142.481	38.648	0.390	0.991	-57.921	170.086	76.585	0.221	1.000	-85.526	182.054	117.263	0.141	1.000	-97.494
4.5	76	142.482	38.648	0.366	0.995	-62.412	170.086	76.755	0.207	1.000	-90.016	182.054	117.513	0.132	1.000	-101.984
4.6	82.19	142.459	38.634	0.395	0.990	-57.189	170.077	76.277	0.223	1.000	-84.807	182.046	116.800	0.143	1.000	-96.776
4.7	108.07	142.372	38.580	0.567	0.906	-34.222	170.044	73.872	0.321	0.998	-61.894	182.016	113.215	0.205	1.000	-73.866
4.8	99.09	142.279	38.521	0.503	0.951	-41.599	170.007	74.590	0.284	0.999	-69.327	181.983	114.279	0.182	1.000	-81.303
4.9	79.95	142.250	38.503	0.373	0.994	-61.010	169.996	76.210	0.211	1.000	-88.756	181.973	116.697	0.135	1.000	-100.733
5	83.96	142.166	38.451	0.456	0.973	-47.766	169.964	75.698	0.258	1.000	-75.564	181.943	115.926	0.165	1.000	-87.543
5.1	92.16	142.101	38.410	0.363	0.995	-63.071	169.938	74.766	0.205	1.000	-90.908	181.921	114.528	0.131	1.000	-102.891
5.2	87.06	142.079	38.396	0.319	0.998	-73.059	169.930	75.320	0.180	1.000	-100.910	181.913	115.361	0.115	1.000	-112.893
5.3	53.14	142.233	38.492	0.254	1.000	-96.373	169.989	78.830	0.143	1.000	-124.129	181.967	120.661	0.092	1.000	-136.107
5.4	56.09	142.352	38.567	0.257	1.000	-95.012	170.036	78.751	0.145	1.000	-122.696	182.009	120.547	0.093	1.000	-134.669
5.5	61.37	142.484	38.650	0.283	0.999	-83.964	170.087	78.483	0.160	1.000	-111.567	182.055	120.147	0.102	1.000	-123.535
5.6	62.5	142.550	38.691	0.286	0.999	-82.630	170.113	78.474	0.162	1.000	-110.193	182.078	120.137	0.104	1.000	-122.158
5.7	91.41	142.484	38.649	0.340	0.997	-67.884	170.087	75.359	0.192	1.000	-95.487	182.054	115.445	0.123	1.000	-107.454
5.8	250	142.478	38.646	455.780	0.000	107.522	170.085	60.179	257.927	0.000	79.915	182.052	92.710	164.968	0.000	67.948
5.9	71.01	142.464	38.637	0.289	0.999	-81.714	170.079	77.658	0.164	1.000	-109.329	182.047	118.911	0.105	1.000	-121.297
6	83.36	142.409	38.603	0.340	0.997	-67.949	170.058	76.335	0.192	1.000	-95.598	182.028	116.920	0.123	1.000	-107.568
6.1	75.28	142.396	38.595	0.274	1.000	-87.256	170.053	77.194	0.155	1.000	-114.913	182.024	118.216	0.099	1.000	-126.884
6.2	67.78	142.490	38.653	0.295	0.999	-79.660	170.089	78.000	0.167	1.000	-107.259	182.057	119.434	0.107	1.000	-119.227
6.3	84.37	142.491	38.654	0.367	0.995	-62.151	170.090	76.347	0.208	1.000	-89.750	182.057	116.947	0.133	1.000	-101.717
6.4	81.2	142.411	38.604	0.367	0.995	-62.181	170.059	76.622	0.208	1.000	-89.829	182.029	117.361	0.133	1.000	-101.799
6.5	75.67	142.379	38.584	0.334	0.998	-69.359	170.046	77.157	0.189	1.000	-97.026	182.018	118.167	0.121	1.000	-108.998
6.6	92.44	142.330	38.553	0.423	0.984	-52.500	170.027	75.254	0.240	1.000	-80.197	182.001	115.306	0.153	1.000	-92.171
6.7	99.42	142.252	38.505	0.481	0.963	-44.402	169.997	74.277	0.272	1.000	-72.147	181.974	113.837	0.174	1.000	-84.124
6.8	107.06	142.209	38.477	0.530	0.934	-38.389	169.980	73.155	0.300	0.999	-66.160	181.958	112.153	0.192	1.000	-78.138
6.9	107.95	142.121	38.423	0.557	0.914	-35.361	169.946	72.953	0.315	0.999	-63.186	181.928	111.848	0.201	1.000	-75.168
7	102.8	142.041	38.372	0.510	0.947	-40.691	169.915	73.633	0.288	0.999	-68.565	181.899	112.871	0.185	1.000	-80.549
7.1	112.2	141.947	38.314	0.603	0.873	-30.557	169.878	72.162	0.340	0.997	-58.488	181.866	110.660	0.218	1.000	-70.476
7.2	110.33	141.855	38.257	0.584	0.891	-32.445	169.843	72.375	0.330	0.998	-60.433	181.835	110.980	0.211	1.000	-72.425
7.3	94.73	141.792	38.217	0.447	0.977	-49.012	169.818	74.453	0.252	1.000	-77.038	181.812	114.102	0.162	1.000	-89.032
7.4	78.89	141.735	38.182	0.355	0.996	-64.755	169.796	76.105	0.200	1.000	-92.816	181.792	116.585	0.128	1.000	-104.812
7.5	78.02	141.729	38.179	0.344	0.997	-67.159	169.794	76.163	0.194	1.000	-95.224	181.790	116.673	0.124	1.000	-107.220
7.6	89.06	141.700	38.160	0.404	0.989	-55.730	169.782	74.994	0.228	1.000	-83.812	181.780	114.917	0.146	1.000	-95.810
7.7	93.76	141.620	38.111	0.446	0.977	-49.130	169.751	74.365	0.252	1.000	-77.261	181.752	113.972	0.161	1.000	-89.262

7.8	106.99	141.547	38.066	0.548	0.921	-36.297	169.722	72.579	0.309	0.999	-64.472	181.726	111.288	0.198	1.000	-76.476
7.9	107.99	141.458	38.011	0.566	0.907	-34.378	169.688	72.347	0.319	0.998	-62.608	181.695	110.940	0.204	1.000	-74.615
8	110.09	141.417	37.985	0.567	0.906	-34.247	169.672	72.001	0.320	0.998	-62.502	181.680	110.421	0.205	1.000	-74.510
8.1	117.63	141.363	37.952	0.647	0.827	-26.253	169.651	70.807	0.365	0.995	-54.541	181.662	108.629	0.234	1.000	-66.552
8.2	94.55	141.280	37.901	0.455	0.974	-47.850	169.618	73.856	0.257	1.000	-76.188	181.632	113.205	0.164	1.000	-88.202
8.3	76.55	141.225	37.867	0.347	0.997	-66.645	169.597	75.568	0.195	1.000	-95.017	181.613	115.775	0.125	1.000	-107.033
8.4	94.67	141.162	37.828	0.451	0.975	-48.422	169.572	73.681	0.254	1.000	-76.832	181.591	112.942	0.163	1.000	-88.851
8.5	82.02	141.110	37.796	0.373	0.994	-61.250	169.551	74.901	0.210	1.000	-89.691	181.572	114.771	0.135	1.000	-101.712
8.6	91.67	141.042	37.754	0.433	0.981	-51.092	169.525	73.842	0.244	1.000	-79.575	181.548	113.181	0.156	1.000	-91.598
8.7	87.28	140.948	37.696	0.394	0.991	-57.508	169.488	74.170	0.222	1.000	-86.048	181.515	113.673	0.142	1.000	-98.075
8.8	89.87	140.869	37.648	0.343	0.997	-67.479	169.457	73.799	0.193	1.000	-96.067	181.487	113.115	0.124	1.000	-108.097
8.9	95.49	140.797	37.604	0.463	0.971	-46.837	169.429	73.096	0.260	1.000	-75.469	181.462	112.059	0.167	1.000	-87.502
9	93.12	140.693	37.540	0.456	0.973	-47.723	169.388	73.221	0.257	1.000	-76.418	181.425	112.244	0.165	1.000	-88.455
9.1	91.04	140.601	37.484	0.381	0.993	-59.871	169.352	73.313	0.214	1.000	-88.622	181.393	112.380	0.137	1.000	-100.663
9.2	98.51	140.427	37.378	0.494	0.956	-42.767	169.283	72.387	0.277	1.000	-71.623	181.331	110.990	0.178	1.000	-83.671
9.3	99.9	140.229	37.258	0.500	0.953	-42.019	169.206	72.130	0.281	1.000	-70.996	181.261	110.603	0.180	1.000	-83.051
9.4	94.11	140.001	37.119	0.467	0.969	-46.351	169.116	72.638	0.262	1.000	-75.466	181.180	111.363	0.168	1.000	-87.530
9.5	83.4	139.780	36.986	0.410	0.987	-54.930	169.029	73.532	0.230	1.000	-84.179	181.101	112.701	0.148	1.000	-96.251
9.6	82.21	139.558	36.852	0.387	0.992	-58.928	168.941	73.498	0.217	1.000	-88.311	181.022	112.647	0.139	1.000	-100.392
9.7	88.02	139.333	36.716	0.428	0.983	-51.963	168.852	72.847	0.240	1.000	-81.482	180.942	111.669	0.154	1.000	-93.572
9.8	81.23	139.120	36.589	0.387	0.992	-59.040	168.767	73.310	0.216	1.000	-88.687	180.866	112.361	0.139	1.000	-100.786
9.9	75.41	138.917	36.468	0.354	0.996	-65.597	168.687	73.634	0.198	1.000	-95.367	180.793	112.844	0.127	1.000	-107.473
10	80.34	138.711	36.345	0.383	0.992	-59.761	168.605	73.137	0.214	1.000	-89.655	180.720	112.097	0.138	1.000	-101.770
10.1	109.95	138.493	36.216	0.613	0.863	-29.463	168.518	69.997	0.342	0.997	-59.488	180.641	107.392	0.220	1.000	-71.611
10.2	101.88	138.281	36.090	0.537	0.929	-37.611	168.433	70.843	0.299	0.999	-67.763	180.565	108.657	0.193	1.000	-79.895
10.3	88.26	138.075	35.969	0.434	0.981	-51.255	168.351	72.088	0.242	1.000	-81.531	180.491	110.520	0.156	1.000	-93.671
10.4	92.16	137.861	35.843	0.463	0.970	-46.911	168.266	71.605	0.258	1.000	-77.316	180.414	109.794	0.166	1.000	-89.464
10.5	106.86	137.645	35.717	0.589	0.886	-31.875	168.179	69.928	0.328	0.998	-62.409	180.336	107.280	0.211	1.000	-74.566
10.6	105.41	137.400	35.573	0.450	0.976	-48.860	168.081	69.951	0.250	1.000	-79.541	180.248	107.312	0.161	1.000	-91.708
10.7	250	137.194	35.453	496.820	0.000	112.806	167.998	54.412	276.194	0.000	82.002	180.173	83.903	178.117	0.000	69.827
10.8	70.69	137.084	35.389	0.260	1.000	-97.254	167.954	72.790	0.145	1.000	-128.124	180.133	111.560	0.093	1.000	-140.303
10.9	73.69	136.948	35.310	0.273	1.000	-92.368	167.899	72.540	0.152	1.000	-123.319	180.084	111.187	0.098	1.000	-135.504
11	66.83	136.904	35.285	0.209	1.000	-117.074	167.881	72.972	0.116	1.000	-148.051	180.068	111.837	0.075	1.000	-160.238
11.1	65.53	136.912	35.290	0.196	1.000	-121.792	167.885	73.120	0.109	1.000	-152.765	180.071	112.063	0.070	1.000	-164.951
11.2	69.34	136.794	35.221	0.276	1.000	-91.514	167.837	72.861	0.153	1.000	-122.557	180.028	111.676	0.099	1.000	-134.748
11.3	69.17	136.677	35.154	0.271	1.000	-93.327	167.790	72.823	0.151	1.000	-124.440	179.986	111.620	0.097	1.000	-136.636
11.4	250	136.562	35.088	501.997	0.000	113.438	167.744	54.780	278.458	0.000	82.256	179.944	84.482	179.759	0.000	70.056
11.5	67.45	136.476	35.038	0.246	1.000	-102.996	167.709	72.854	0.137	1.000	-134.229	179.913	111.668	0.088	1.000	-146.433
11.6	65.74	136.416	35.004	0.238	1.000	-106.306	167.685	72.952	0.132	1.000	-137.575	179.891	111.818	0.085	1.000	-149.781
11.7	64.41	136.392	34.989	0.230	1.000	-109.052	167.675	73.062	0.128	1.000	-140.335	179.882	111.987	0.082	1.000	-152.542
11.8	63.77	136.353	34.967	0.271	1.000	-93.723	167.659	73.122	0.150	1.000	-125.029	179.868	112.080	0.097	1.000	-137.238
11.9	250	136.294	34.933	504.216	0.000	113.706	167.635	55.094	279.426	0.000	82.365	179.846	84.977	180.462	0.000	70.154
12	64.84	136.237	34.901	0.239	1.000	-106.007	167.612	73.086	0.132	1.000	-137.382	179.826	112.031	0.085	1.000	-149.596

Table A 4. Sample Table for Workbook *Settlement_semi*

Profile			B&I (2014)						Ku (2012)					
			Simplified Performance-based				Full PB		Simplified Performance-based				Full PB	
Profile #	RP	Depth (m)	ε_v^{ref} (%)	Δε	ε_v^{site} (%)	Sp (cm)	ε_v^{site} (%)	Sp (cm)	ε_v^{ref} (%)	Δε	ε_v^{site} (%)	Sp (cm)	ε_v^{site} (%)	Sp (cm)
	475	0.1	2.02347	3.62857	5.30396	34.50358	4.37913	29.78590	1.24428	2.79380	5.91748	29.03019	5.41974	23.15782
		0.2	2.02347	3.62803	2.73444		2.79491		1.24428	2.78063	2.45893		2.24863	
		0.3	2.02347	3.62802	2.70107		2.73517		1.24428	2.77968	2.16020		1.82082	
		0.4	2.02347	3.62830	3.98517		3.50674		1.24428	2.78987	4.94311		4.47430	
		0.5	2.02347	3.62861	5.46130		4.25840		1.24428	2.79242	5.57658		4.99014	
		0.6	2.02347	3.62825	3.75360		3.40729		1.24428	2.79143	5.33087		4.78028	
		0.7	2.02347	3.62833	4.12056		3.62546		1.24428	2.79177	5.41690		4.85429	
		0.8	2.02347	3.62782	1.72848		2.12793		1.24428	2.77670	0.96168		0.64715	
		0.9	2.02347	3.62782	1.73238		2.07957		1.24428	2.77503	0.51450		0.32778	
		1	2.02347	3.62804	2.80587		2.61883		1.24428	2.77576	0.55417		0.43857	
		1.1	2.02347	3.62799	2.55676		2.47625		1.24428	2.77536	0.53255		0.37034	
		1.2	2.02347	3.62788	2.04173		2.24141		1.24428	2.77592	0.56315		0.46108	
		1.3	2.02347	3.62773	1.21625		1.72953		1.24428	2.77508	0.51700		0.32351	
		1.4	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.01235	
		1.5	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.00000	
		1.6	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.00000	
		1.7	2.02347	3.62764	0.39790		1.15049		1.24428	2.76486	0.00000		0.09346	
		1.8	2.02347	3.62814	3.24491		2.79275		1.24428	2.77766	1.42476		0.86319	
		1.9	2.02347	3.62807	2.94604		2.78648		1.24428	2.77817	1.62897		1.04614	
		2	2.02347	3.62819	3.49637		3.11974		1.24428	2.78230	2.94968		2.71282	
		2.1	2.02347	3.62830	4.01789		3.20206		1.24428	2.77933	2.04505		1.56942	
		2.2	2.02347	3.62857	5.29956		3.84755		1.24428	2.78387	3.38709		3.07672	
		2.3	2.02347	3.62826	3.79965		3.30688		1.24428	2.79424	6.02495		5.13722	
		2.4	2.02347	3.62845	4.68750		3.82730		1.24428	2.80508	8.65951		7.14800	
		2.5	2.02347	3.62894	7.14515		4.64550		1.24428	2.78662	4.11551		3.75639	
		2.6	2.02347	3.62830	4.00847		3.27217		1.24428	2.78004	2.27432		1.90184	
		2.7	2.02347	3.62827	3.85841		3.35703		1.24428	2.79212	5.50212		4.78571	
		2.8	2.02347	3.62830	4.01789		3.22232		1.24428	2.77937	2.05641		1.60992	
		2.9	2.02347	3.62768	0.88854		1.46801		1.24428	2.76668	0.06255		0.14626	
		3	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.03016	
		3.1	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.03199	
		3.2	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.03527	
		3.3	2.02347	3.62670	0.00000		0.00000		1.24428	2.76367	0.00000		0.04932	
		3.4	2.02347	3.62787	1.94944		2.08119		1.24428	2.77476	0.49993		0.28326	
		3.5	2.02347	3.62787	1.97587		2.10878		1.24428	2.77559	0.54494		0.39232	
		3.6	2.02347	3.62775	1.35675		1.73491		1.24428	2.77483	0.50370		0.28486	
		3.7	2.02347	3.62779	1.56013		1.85075		1.24428	2.77493	0.50911		0.29716	
		3.8	2.02347	3.62770	0.99553		1.50692		1.24428	2.77485	0.50475		0.28692	
		3.9	2.02347	3.62774	1.25894		1.66616		1.24428	2.77494	0.50966		0.29822	
		4	2.02347	3.62793	2.25440		2.25487		1.24428	2.77657	0.88716		0.57416	
		4.1	2.02347	3.62832	4.06540		3.19940		1.24428	2.78008	2.28876		1.88501	
		4.2	2.02347	3.62854	5.13084		3.74045		1.24428	2.78335	3.24281		2.92804	
		4.3	2.02347	3.62804	2.77951		2.54096		1.24428	2.77802	1.57058		0.99330	
		4.4	2.02347	3.62817	3.40172		2.86743		1.24428	2.77943	2.07703		1.60544	
		4.5	2.02347	3.62824	3.69583		3.01673		1.24428	2.78016	2.31391		1.90757	
		4.6	2.02347	3.62814	3.24491		2.78257		1.24428	2.77932	2.04032		1.55346	
		4.7	2.02347	3.62784	1.81824		1.99197		1.24428	2.77646	0.81234		0.54816	
		4.8	2.02347	3.62793	2.25440		2.23749		1.24428	2.77726	1.25042		0.74419	
		4.9	2.02347	3.62817	3.40172		2.85733		1.24428	2.77996	2.25111		1.81708	
		5	2.02347	3.62811	3.12686		2.70630		1.24428	2.77803	1.57609		0.99469	
		5.1	2.02347	3.62801	2.62710		2.56827		1.24428	2.78034	2.37023		2.00557	
		5.2	2.02347	3.62807	2.92875		2.75486		1.24428	2.78229	2.94842		2.69875	
		5.3	2.02347	3.62874	6.14665		4.23840		1.24428	2.78917	4.76616		4.18382	
		5.4	2.02347	3.62866	5.72868		4.06007		1.24428	2.78858	4.61812		4.06848	
		5.5	2.02347	3.62853	5.07421		3.70000		1.24428	2.78489	3.66166		3.26092	
		5.6	2.02347	3.62850	4.94753		3.63412		1.24428	2.78451	3.55826		3.16451	
		5.7	2.02347	3.62802	2.66965		2.60157		1.24428	2.78115	2.61696		2.30925	
		5.8	2.02347	3.62668	0.00000		0.00000		1.24428	2.76332	0.00000		0.00000	
		5.9	2.02347	3.62832	4.10900		3.26268		1.24428	2.78428	3.49795		3.09622	
		6	2.02347	3.62812	3.16651		2.82527		1.24428	2.78118	2.62518		2.28218	
		6.1	2.02347	3.62825	3.75278		3.13619		1.24428	2.78589	3.92453		3.46585	
		6.2	2.02347	3.62839	4.40499		3.36558		1.24428	2.78374	3.35190		2.95352	
		6.3	2.02347	3.62811	3.10009		2.68225		1.24428	2.78012	2.29959		1.85694	
		6.4	2.02347	3.62815	3.31339		2.77335		1.24428	2.78014	2.30563		1.86029	
		6.5	2.02347	3.62824	3.72150		2.99219		1.24428	2.78146	2.70844		2.30714	
		6.6	2.02347	3.62800	2.61113		2.39568		1.24428	2.77865	1.80723		1.24378	
		6.7	2.02347	3.62792	2.23759		2.17627		1.24428	2.77760	1.39910		0.84430	
		6.8	2.02347	3.62785	1.86531		1.96283		1.24428	2.77691	1.07786		0.65084	
		6.9	2.02347	3.62784	1.82402		1.92643		1.24428	2.77660	0.90294		0.57734	

Profile 1	1039	2.2	2.62710	3.62857	5.81837	4.62610	2.01160	2.78387	3.79304	3.85921
		2.3	2.62710	3.62826	4.29423	4.04028	2.01160	2.79424	6.39771	6.18544
		2.4	2.62710	3.62845	5.19531	4.62972	2.01160	2.80508	9.02891	8.42675
		2.5	2.62710	3.62894	7.69943	5.52831	2.01160	2.78662	4.50533	4.60009
		2.6	2.62710	3.62830	4.50571	3.97530	2.01160	2.78004	2.73439	2.68514
		2.7	2.62710	3.62827	4.35371	4.09296	2.01160	2.79212	5.87748	5.77576
		2.8	2.62710	3.62830	4.51525	3.91277	2.01160	2.77937	2.53534	2.40319
		2.9	2.62710	3.62768	1.55104	2.06300	2.01160	2.77347	0.51154	0.25701
		3	2.62710	3.62743	0.07668	0.00000	2.01160	2.77151	0.40518	0.06366
		3.1	2.62710	3.62742	0.07594	0.00000	2.01160	2.77157	0.40826	0.06741
		3.2	2.62710	3.62742	0.07594	0.00000	2.01160	2.77166	0.41310	0.07347
		3.3	2.62710	3.62746	0.07966	0.07201	2.01160	2.77198	0.43055	0.09771
		3.4	2.62710	3.62787	2.46100	2.65899	2.01160	2.77482	0.72385	0.48104
		3.5	2.62710	3.62787	2.48606	2.69204	2.01160	2.77559	1.17398	0.66308
		3.6	2.62710	3.62775	1.92202	2.31290	2.01160	2.77483	0.73578	0.48398
		3.7	2.62710	3.62779	2.10095	2.42475	2.01160	2.77493	0.80501	0.50452
		3.8	2.62710	3.62770	1.62917	2.10549	2.01160	2.77485	0.74969	0.48766
		3.9	2.62710	3.62774	1.83907	2.24725	2.01160	2.77494	0.81169	0.50645
		4	2.62710	3.62793	2.75352	2.84843	2.01160	2.77657	1.59731	0.98488
		4.1	2.62710	3.62832	4.56342	3.89370	2.01160	2.78008	2.74772	2.65649
		4.2	2.62710	3.62854	5.64654	4.50651	2.01160	2.78335	3.65321	3.69884
		4.3	2.62710	3.62804	3.26967	3.16072	2.01160	2.77802	2.11067	1.72427
		4.4	2.62710	3.62817	3.89249	3.52295	2.01160	2.77943	2.55399	2.38957
		4.5	2.62710	3.62824	4.18924	3.68990	2.01160	2.78016	2.77097	2.66935
		4.6	2.62710	3.62814	3.73478	3.42867	2.01160	2.77932	2.52081	2.33565
		4.7	2.62710	3.62784	2.33763	2.57147	2.01160	2.77646	1.55117	0.93815
		4.8	2.62710	3.62793	2.75352	2.83040	2.01160	2.77726	1.85329	1.30737
		4.9	2.62710	3.62817	3.89249	3.51217	2.01160	2.77996	2.71301	2.57683
		5	2.62710	3.62811	3.61634	3.34385	2.01160	2.77803	2.11529	1.72994
		5.1	2.62710	3.62801	3.11866	3.22027	2.01160	2.78034	2.82320	2.79517
		5.2	2.62710	3.62807	3.41823	3.42723	2.01160	2.78229	3.36973	3.48954
		5.3	2.62710	3.62874	6.68161	5.07311	2.01160	2.78917	5.14740	5.08546
		5.4	2.62710	3.62866	6.25560	4.87067	2.01160	2.78858	5.00097	4.95217
		5.5	2.62710	3.62853	5.58887	4.45795	2.01160	2.78489	4.06044	4.04612
		5.6	2.62710	3.62850	5.45991	4.38294	2.01160	2.78451	3.95956	3.94014
		5.7	2.62710	3.62802	3.16074	3.25518	2.01160	2.78115	3.05437	3.08347
		5.8	2.62710	3.62731	0.06527	0.00000	2.01160	2.77053	0.35187	0.01267
		5.9	2.62710	3.62832	4.60764	3.96798	2.01160	2.78428	3.90082	3.86401
		6	2.62710	3.62812	3.65609	3.48777	2.01160	2.78118	3.06213	3.03661
		6.1	2.62710	3.62825	4.24682	3.83335	2.01160	2.78589	4.31774	4.26889
		6.2	2.62710	3.62839	4.90812	4.07914	2.01160	2.78374	3.75889	3.70831
		6.3	2.62710	3.62811	3.58951	3.31278	2.01160	2.78012	2.75773	2.59259
		6.4	2.62710	3.62815	3.80360	3.41130	2.01160	2.78014	2.76331	2.59367
		6.5	2.62710	3.62824	4.21520	3.65694	2.01160	2.78146	3.14092	3.03090
		6.6	2.62710	3.62800	3.10290	2.99455	2.01160	2.77865	2.31356	1.99756
		6.7	2.62710	3.62792	2.73722	2.75502	2.01160	2.77760	1.96991	1.47720
		6.8	2.62710	3.62785	2.38169	2.53003	2.01160	2.77691	1.72581	1.12959
		6.9	2.62710	3.62784	2.34303	2.48907	2.01160	2.77660	1.60737	0.99290
		7	2.62710	3.62789	2.57502	2.63758	2.01160	2.77719	1.82595	1.26124
		7.1	2.62710	3.62780	2.16329	2.35865	2.01160	2.77614	1.42058	0.82229
		7.2	2.62710	3.62782	2.24117	2.40818	2.01160	2.77633	1.50059	0.88852
		7.3	2.62710	3.62798	2.97790	2.88166	2.01160	2.77824	2.18443	1.79373
		7.4	2.62710	3.62819	3.96958	3.46402	2.01160	2.78071	2.92814	2.75047
		7.5	2.62710	3.62820	4.03442	3.51306	2.01160	2.78116	3.05596	2.89788
		7.6	2.62710	3.62804	3.29710	3.07423	2.01160	2.77921	2.48813	2.21129
		7.7	2.62710	3.62799	3.03035	2.89397	2.01160	2.77828	2.19694	1.80374
		7.8	2.62710	3.62785	2.38498	2.48732	2.01160	2.77676	1.66800	1.05519
		7.9	2.62710	3.62784	2.34099	2.44858	2.01160	2.77656	1.59427	0.97510
		8	2.62710	3.62782	2.25129	2.40057	2.01160	2.77656	1.59052	0.97103
		8.1	2.62710	3.62776	1.94727	2.18777	2.01160	2.77579	1.26813	0.71228
		8.2	2.62710	3.62798	2.98729	2.84479	2.01160	2.77816	2.15644	1.73403
		8.3	2.62710	3.62823	4.14639	3.52328	2.01160	2.78116	3.05543	2.86360
		8.4	2.62710	3.62798	2.98102	2.84062	2.01160	2.77825	2.18638	1.77628
		8.5	2.62710	3.62814	3.74702	3.29100	2.01160	2.78020	2.78148	2.54521
		8.6	2.62710	3.62801	3.14582	2.93045	2.01160	2.77863	2.30830	1.94199
		8.7	2.62710	3.62807	3.40464	3.15661	2.01160	2.77961	2.60687	2.37170
		8.8	2.62710	3.62803	3.24951	3.16877	2.01160	2.78139	3.12057	3.00428
		8.9	2.62710	3.62797	2.93746	2.79079	2.01160	2.77809	2.13399	1.68924
		9	2.62710	3.62799	3.06509	2.84802	2.01160	2.77822	2.17638	1.74506
		9.1	2.62710	3.62802	3.18157	3.05447	2.01160	2.78005	2.73843	2.53003
		9.2	2.62710	3.62793	2.78262	2.67568	2.01160	2.77762	1.97789	1.45471
		9.3	2.62710	3.62792	2.71343	2.63779	2.01160	2.77755	1.95513	1.42146
		9.4	2.62710	3.62798	3.01109	2.80003	2.01160	2.77813	2.14732	1.69134

9.5	2.62710	3.62812	3.65352		3.21965		2.01160	2.77938	2.54016		2.24897	
9.6	2.62710	3.62814	3.73381		3.21573		2.01160	2.78007	2.74347		2.44852	
9.7	2.62710	3.62806	3.35935		2.99279		2.01160	2.77900	2.42388		2.05377	
9.8	2.62710	3.62815	3.80149		3.24600		2.01160	2.78016	2.77067		2.47385	
9.9	2.62710	3.62825	4.23611		3.49011		2.01160	2.78140	3.12422		2.86493	
10	2.62710	3.62817	3.86422		3.27675		2.01160	2.78036	2.82729		2.53243	
10.1	2.62710	3.62782	2.25722		2.31378		2.01160	2.77637	1.51585		0.88206	
10.2	2.62710	3.62790	2.61794		2.53962		2.01160	2.77727	1.85398		1.25747	
10.3	2.62710	3.62806	3.34534		2.97129		2.01160	2.77908	2.44913		2.06720	
10.4	2.62710	3.62801	3.11858		2.83079		2.01160	2.77849	2.26426		1.82140	
10.5	2.62710	3.62785	2.39043		2.38568		2.01160	2.77670	1.64687		1.00237	
10.6	2.62710	3.62786	2.45513		2.57567		2.01160	2.77883	2.37131		2.00685	
10.7	2.62710	3.62731	0.06527		0.00000		2.01160	2.77053	0.35187		0.01196	
10.8	2.62710	3.62833	4.63616		4.18775		2.01160	2.79188	5.81862		5.68365	
10.9	2.62710	3.62828	4.37669		4.02024		2.01160	2.78970	5.27900		5.20657	
11	2.62710	3.62841	5.00132		4.38311		2.01160	2.80769	9.66033		8.08625	
11.1	2.62710	3.62843	5.13318		4.50356		2.01160	2.81488	11.40296		9.11169	
11.2	2.62710	3.62836	4.75995		4.26728		2.01160	2.78941	5.20680		5.28598	
11.3	2.62710	3.62836	4.77540		4.27685		2.01160	2.79023	5.41138		5.43928	
11.4	2.62710	3.62731	0.06527		0.00000		2.01160	2.77053	0.35187		0.01187	
11.5	2.62710	3.62839	4.94042		4.37996		2.01160	2.79544	6.69181		6.38758	
11.6	2.62710	3.62843	5.11115		4.48731		2.01160	2.79774	7.25203		6.84804	
11.7	2.62710	3.62846	5.25089		4.57563		2.01160	2.79992	7.77928		7.28706	
11.8	2.62710	3.62847	5.31996		4.61878		2.01160	2.79055	5.49060		5.67842	
11.9	2.62710	3.62731	0.06527		0.00000		2.01160	2.77053	0.35187		0.01183	
12	2.62710	3.62845	5.20511		4.54808		2.01160	2.79765	7.22996		6.87959	
0.1	3.19321	3.62857	6.31809	54.18053	6.01911	44.08425	2.60930	2.79380	6.57806	43.30250	7.49170	37.95456
0.2	3.19321	3.62803	3.68389		4.06876		2.60930	2.78063	3.23438		3.69346	
0.3	3.19321	3.62802	3.65070		4.01164		2.60930	2.77968	2.96913		3.26324	
0.4	3.19321	3.62830	4.95456		4.98847		2.60930	2.78987	5.61377		6.34008	
0.5	3.19321	3.62861	6.48126		5.92455		2.60930	2.79242	6.23989		7.00995	
0.6	3.19321	3.62825	4.71668		4.85336		2.60930	2.79143	5.99663		6.73193	
0.7	3.19321	3.62833	5.09396		5.13227		2.60930	2.79177	6.08175		6.82905	
0.8	3.19321	3.62782	2.72248		3.26655		2.60930	2.77670	2.06091		1.51109	
0.9	3.19321	3.62782	2.72598		3.20086		2.60930	2.77503	1.44718		0.74764	
1	3.19321	3.62804	3.75511		3.83022		2.60930	2.77576	1.73184		1.00819	
1.1	3.19321	3.62799	3.50788		3.66047		2.60930	2.77536	1.58096		0.85325	
1.2	3.19321	3.62788	3.01064		3.40789		2.60930	2.77592	1.79208		1.07347	
1.3	3.19321	3.62773	2.29226		2.85092		2.60930	2.77508	1.46617		0.75361	
1.4	3.19321	3.62684	0.03000		0.02247		2.60930	2.76506	0.11941		0.04994	
1.5	3.19321	3.62668	0.01427		0.00000		2.60930	2.76332	0.02581		0.00000	
1.6	3.19321	3.62668	0.01427		0.00000		2.60930	2.76383	0.05289		0.02407	
1.7	3.19321	3.62764	1.81768		2.31850		2.60930	2.77279	0.53820		0.24757	
1.8	3.19321	3.62814	4.19744		4.08080		2.60930	2.77766	2.37002		2.14226	
1.9	3.19321	3.62807	3.89555		4.12312		2.60930	2.77817	2.52615		2.45297	
2	3.19321	3.62819	4.45343		4.54661		2.60930	2.78230	3.68598		4.26792	
2.1	3.19321	3.62830	4.98823		4.59991		2.60930	2.77933	2.86952		3.04323	
2.2	3.19321	3.62857	6.31352		5.42941		2.60930	2.78387	4.09961		4.62802	
2.3	3.19321	3.62826	4.76392		4.78351		2.60930	2.79424	6.68482		7.26911	
2.4	3.19321	3.62845	5.67946		5.45313		2.60930	2.80508	9.31448		9.79886	
2.5	3.19321	3.62894	8.22854		6.45116		2.60930	2.78662	4.80258		5.45299	
2.6	3.19321	3.62830	4.97853		4.69140		2.60930	2.78004	3.06939		3.37033	
2.7	3.19321	3.62827	4.82425		4.84060		2.60930	2.79212	6.16612		6.79510	
2.8	3.19321	3.62830	4.98823		4.61644		2.60930	2.77937	2.87927		3.07192	
2.9	3.19321	3.62768	2.06026		2.57212		2.60930	2.77347	0.57522		0.36170	
3	3.19321	3.62688	0.03339		0.03989		2.60930	2.76746	0.24892		0.09576	
3.1	3.19321	3.62681	0.02719		0.01318		2.60930	2.76776	0.26478		0.10114	
3.2	3.19321	3.62681	0.02706		0.01285		2.60930	2.76828	0.29318		0.10979	
3.3	3.19321	3.62733	0.07678		0.40987		2.60930	2.77084	0.43191		0.14348	
3.4	3.19321	3.62787	2.92432		3.21206		2.60930	2.77482	1.35555		0.67054	
3.5	3.19321	3.62787	2.94893		3.25079		2.60930	2.77559	1.66855		0.92582	
3.6	3.19321	3.62775	2.40360		2.83855		2.60930	2.77483	1.36268		0.67483	
3.7	3.19321	3.62779	2.57430		2.95766		2.60930	2.77493	1.40549		0.70356	
3.8	3.19321	3.62770	2.13109		2.62121		2.60930	2.77485	1.37108		0.68012	
3.9	3.19321	3.62774	2.32544		2.76857		2.60930	2.77494	1.40975		0.70635	
4	3.19321	3.62793	3.21315		3.42444		2.60930	2.77657	2.01868		1.39416	
4.1	3.19321	3.62832	5.03714		4.59939		2.60930	2.78008	3.08217		3.33073	
4.2	3.19321	3.62854	6.13862		5.29501		2.60930	2.78335	3.96228		4.44997	
4.3	3.19321	3.62804	3.72880		3.77383		2.60930	2.77802	2.48052		2.36629	
4.4	3.19321	3.62817	4.35689		4.18146		2.60930	2.77943	2.89702		3.04972	
4.5	3.19321	3.62824	4.65745		4.36981		2.60930	2.78016	3.10450		3.33896	
4.6	3.19321	3.62814	4.19744		4.07537		2.60930	2.77932	2.86547		2.99110	

	4.7	3.19321	3.62784	2.80358	3.11920	2.60930	2.77646	1.97881	1.32518
	4.8	3.19321	3.62793	3.21315	3.40481	2.60930	2.77726	2.24533	1.87191
	4.9	3.19321	3.62817	4.35689	4.16963	2.60930	2.77996	3.04889	3.23772
	5	3.19321	3.62811	4.07785	3.97983	2.60930	2.77803	2.48479	2.37504
	5.1	3.19321	3.62801	3.57734	3.86004	2.60930	2.78034	3.15471	3.49283
	5.2	3.19321	3.62807	3.87818	4.09346	2.60930	2.78229	3.68480	4.24181
	5.3	3.19321	3.62874	7.19239	5.93935	2.60930	2.78917	5.43956	6.00523
	5.4	3.19321	3.62866	6.75865	5.70946	2.60930	2.78858	5.29409	5.85219
	5.5	3.19321	3.62853	6.07992	5.23806	2.60930	2.78489	4.36292	4.82775
	5.6	3.19321	3.62850	5.94867	5.15276	2.60930	2.78451	4.26349	4.70913
	5.7	3.19321	3.62802	3.61950	3.89816	2.60930	2.78115	3.37798	3.79462
	5.8	3.19321	3.62668	0.01427	0.00000	2.60930	2.76653	0.19855	0.02268
	5.9	3.19321	3.62832	5.08204	4.68543	2.60930	2.78428	4.20564	4.62321
2475	6	3.19321	3.62812	4.11797	4.14930	2.60930	2.78118	3.38550	3.73146
	6.1	3.19321	3.62825	4.71583	4.53812	2.60930	2.78589	4.61699	5.07542
	6.2	3.19321	3.62839	5.38740	4.80817	2.60930	2.78374	4.06605	4.44946
	6.3	3.19321	3.62811	4.05079	3.94212	2.60930	2.78012	3.09178	3.24121
	6.4	3.19321	3.62815	4.26700	4.05131	2.60930	2.78014	3.09714	3.24104
	6.5	3.19321	3.62824	4.68376	4.32916	2.60930	2.78146	3.46196	3.70687
	6.6	3.19321	3.62800	3.56155	3.58354	2.60930	2.77865	2.66967	2.62142
	6.7	3.19321	3.62792	3.19698	3.31541	2.60930	2.77760	2.35113	2.06648
	6.8	3.19321	3.62785	2.84661	3.06726	2.60930	2.77691	2.13140	1.61173
	6.9	3.19321	3.62784	2.80884	3.02048	2.60930	2.77660	2.02741	1.40753
	7	3.19321	3.62789	3.03652	3.18421	2.60930	2.77719	2.22074	1.79727
	7.1	3.19321	3.62780	2.63435	2.87675	2.60930	2.77614	1.86796	1.15650
	7.2	3.19321	3.62782	2.70972	2.93061	2.60930	2.77633	1.93551	1.25363
	7.3	3.19321	3.62798	3.43656	3.45560	2.60930	2.77824	2.54895	2.40487
	7.4	3.19321	3.62819	4.43491	4.11014	2.60930	2.78071	3.25586	3.40089
	7.5	3.19321	3.62820	4.50056	4.16626	2.60930	2.78116	3.37952	3.55910
	7.6	3.19321	3.62804	3.75636	3.67157	2.60930	2.77921	2.83445	2.83399
	7.7	3.19321	3.62799	3.48897	3.46806	2.60930	2.77828	2.56060	2.41079
	7.8	3.19321	3.62785	2.84983	3.01636	2.60930	2.77676	2.08039	1.50242
	7.9	3.19321	3.62784	2.80685	2.97285	2.60930	2.77656	2.01604	1.38334
	8	3.19321	3.62782	2.71954	2.92161	2.60930	2.77656	2.01279	1.37740
	8.1	3.19321	3.62776	2.42753	2.68968	2.60930	2.77579	1.74294	0.99919
	8.2	3.19321	3.62798	3.44594	3.41239	2.60930	2.77816	2.52294	2.33305
	8.3	3.19321	3.62823	4.61401	4.17674	2.60930	2.78116	3.37901	3.51779
	8.4	3.19321	3.62798	3.43968	3.40814	2.60930	2.77825	2.55077	2.37751
	8.5	3.19321	3.62814	4.20981	3.91451	2.60930	2.78020	3.11459	3.17709
	8.6	3.19321	3.62801	3.60455	3.50839	2.60930	2.77863	2.66473	2.54687
	8.7	3.19321	3.62807	3.86450	3.76828	2.60930	2.77961	2.94740	3.00730
	8.8	3.19321	3.62803	3.70856	3.79100	2.60930	2.78139	3.44219	3.68306
	8.9	3.19321	3.62797	3.39620	3.35165	2.60930	2.77809	2.50211	2.28101
	9	3.19321	3.62799	3.52372	3.41436	2.60930	2.77822	2.54147	2.33682
	9.1	3.19321	3.62802	3.64039	3.65743	2.60930	2.78005	3.07326	3.17317
	9.2	3.19321	3.62793	3.24204	3.22244	2.60930	2.77762	2.35843	2.02168
	9.3	3.19321	3.62792	3.17338	3.18111	2.60930	2.77755	2.33765	1.98588
	9.4	3.19321	3.62798	3.46971	3.36082	2.60930	2.77813	2.51447	2.27781
	9.5	3.19321	3.62812	4.11537	3.83626	2.60930	2.77938	2.88386	2.87254
	9.6	3.19321	3.62814	4.19646	3.82916	2.60930	2.78007	3.07810	3.06811
	9.7	3.19321	3.62806	3.81894	3.57736	2.60930	2.77900	2.77361	2.65442
	9.8	3.19321	3.62815	4.26486	3.86343	2.60930	2.78016	3.10421	3.09540
	9.9	3.19321	3.62825	4.70497	4.14022	2.60930	2.78140	3.44574	3.51463
	10	3.19321	3.62817	4.32830	3.89859	2.60930	2.78036	3.15865	3.15770
	10.1	3.19321	3.62782	2.72530	2.82110	2.60930	2.77637	1.94853	1.25506
	10.2	3.19321	3.62790	3.07889	3.07081	2.60930	2.77727	2.24596	1.78523
	10.3	3.19321	3.62806	3.80485	3.55418	2.60930	2.77908	2.79749	2.66813
	10.4	3.19321	3.62801	3.57726	3.39613	2.60930	2.77849	2.62345	2.41225
	10.5	3.19321	3.62785	2.85516	2.90008	2.60930	2.77670	2.06187	1.43331
	10.6	3.19321	3.62786	2.91856	3.12865	2.60930	2.77883	2.72399	2.62907
	10.7	3.19321	3.62668	0.01427	0.00000	2.60930	2.76715	0.23199	0.02201
	10.8	3.19321	3.62833	5.11102	4.96653	2.60930	2.79188	6.10748	6.71396
	10.9	3.19321	3.62828	4.84757	4.77565	2.60930	2.78970	5.57038	6.16369
	11	3.19321	3.62841	5.48216	5.18552	2.60930	2.80769	9.94637	9.40271
	11.1	3.19321	3.62843	5.61626	5.32662	2.60930	2.81488	11.69110	10.57740
	11.2	3.19321	3.62836	5.23679	5.05702	2.60930	2.78941	5.49860	6.26106
	11.3	3.19321	3.62836	5.25250	5.06798	2.60930	2.79023	5.70204	6.43700
	11.4	3.19321	3.62668	0.01427	0.00000	2.60930	2.77053	0.41517	0.02193
	11.5	3.19321	3.62839	5.42024	5.18598	2.60930	2.79544	6.97830	7.52539
	11.6	3.19321	3.62843	5.59386	5.30860	2.60930	2.79774	7.53776	8.05231
	11.7	3.19321	3.62846	5.73600	5.40927	2.60930	2.79992	8.06466	8.54745
	11.8	3.19321	3.62847	5.80627	5.45853	2.60930	2.79055	5.78087	6.72204
	11.9	3.19321	3.62668	0.01427	0.00000	2.60930	2.77053	0.41517	0.02189

Profile			B&I (2014)						Ku (2012)					
Profile #	RP	Depth (m)	Simplified Performance-based				Full PB		Simplified Performance-based				Full PB	
			γ_{max}^{ref} (%)	$\Delta\gamma$	γ_{max}^{site} (%)	LD (cm)	γ_{max}^{site} (%)	LD (cm)	γ_{max}^{ref} (%)	$\Delta\gamma$	γ_{max}^{site} (%)	LD (cm)	γ_{max}^{site} (%)	LD (cm)
		0.1	14.2938	1.4018	51.2000	320.1552	51.2000	381.6044	5.2079	2.7822	51.2000	265.9187	51.2000	269.2017
		0.2	14.2938	1.4018	51.2000		51.2000		5.2079	2.6850	24.0679		40.2786	
		0.3	14.2938	1.3223	28.9891		45.0358		5.2079	2.4534	18.2633		21.9949	
		0.4	14.2938	1.4018	51.2000		51.2000		5.2079	2.7814	26.9974		51.2000	
		0.5	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		0.6	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		0.7	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		0.8	14.2938	1.2502	23.9249		31.9574		5.2079	2.3304	15.7685		8.6377	
		0.9	14.2938	1.0755	15.0309		18.3872		5.2079	1.8597	8.9800		2.9915	
		1	14.2938	1.0725	14.9090		20.9386		5.2079	1.9470	9.9704		3.6418	
		1.1	14.2938	1.0604	14.4355		19.5521		5.2079	1.7442	7.8166		3.1204	
		1.2	14.2938	1.1191	16.8786		21.6414		5.2079	2.0623	11.4465		4.1460	
		1.3	14.2938	1.2052	21.2263		23.2624		5.2079	2.0136	10.7988		3.4850	
		1.4	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.2514	
		1.5	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
		1.6	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
		1.7	14.2938	0.8528	8.3059		5.3680		5.2079	0.4203	1.5464		1.1816	
		1.8	14.2938	1.1054	16.2735		23.0030		5.2079	2.0337	11.0609		6.0062	
		1.9	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		35.4185	
		2	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		49.4738	
		2.1	14.2938	1.1746	19.5681		29.8696		5.2079	2.1645	12.9345		10.5511	
		2.2	14.2938	1.3223	28.9891		49.2542		5.2079	2.4621	18.4518		29.7706	
		2.3	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		2.4	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		2.5	14.2938	1.3938	35.0655		51.2000		5.2079	2.6262	22.4398		44.1615	
		2.6	14.2938	1.2634	24.7824		39.3789		5.2079	2.3660	16.4544		18.2674	
		2.7	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
		2.8	14.2938	1.1746	19.5681		30.1763		5.2079	2.1668	12.9702		11.0102	
		2.9	14.2938	0.8895	9.1605		7.5456		5.2079	0.7511	2.3375		1.5857	
		3	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.6249	
		3.1	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.6456	
		3.2	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.6818	
		3.3	14.2938	0.0058	0.8648		0.0000		5.2079	-1.6269	0.0000		0.8193	
		3.4	14.2938	0.9780	11.5922		13.3198		5.2079	1.3114	4.6378		2.4100	
		3.5	14.2938	0.9812	11.6929		13.5085		5.2079	1.6415	6.9090		3.0191	
		3.6	14.2938	0.9234	10.0256		9.7045		5.2079	1.3050	4.6022		2.4110	
		3.7	14.2938	0.9386	10.4393		10.7385		5.2079	1.3454	4.8330		2.4795	
		3.8	14.2938	0.8969	9.3424		7.8035		5.2079	1.3103	4.6319		2.4204	
		3.9	14.2938	0.9161	9.8324		9.1471		5.2079	1.3477	4.8467		2.4841	
		4	14.2938	1.0136	12.7467		15.5683		5.2079	1.9240	9.6992		4.0494	
		4.1	14.2938	1.1784	19.7670		30.1119		5.2079	2.2142	13.7267		13.1053	
		4.2	14.2938	1.2905	26.6333		44.2182		5.2079	2.4343	17.8504		27.5338	
		4.3	14.2938	1.0663	14.6673		19.4923		5.2079	2.0650	11.4828		6.8770	
		4.4	14.2938	1.1191	16.8786		24.0988		5.2079	2.1710	13.0349		10.8810	
		4.5	14.2938	1.1472	18.1912		26.7672		5.2079	2.2210	13.8374		13.4722	
		4.6	14.2938	1.1054	16.2735		22.8162		5.2079	2.1635	12.9197		10.5295	
		4.7	14.2938	0.9614	11.0917		12.1183		5.2079	1.9105	9.5434		3.8682	
		4.8	14.2938	1.0136	12.7467		15.4598		5.2079	1.9966	10.5807		5.2105	
		4.9	14.2938	1.1191	16.8786		24.0356		5.2079	2.2055	13.5844		12.5880	
		5	14.2938	1.1024	16.1438		22.3308		5.2079	2.1615	12.8876		7.9047	
		5.1	14.2938	1.4018	51.2000		51.2000		5.2079	2.7270	25.3022		39.4751	
		5.2	14.2938	1.4018	51.2000		51.2000		5.2079	2.7742	26.7663		48.7017	
		5.3	14.2938	1.3887	34.5937		51.2000		5.2079	2.7517	26.0565		51.2000	
		5.4	14.2938	1.3735	33.2242		51.2000		5.2079	2.7254	25.2558		51.2000	
		5.5	14.2938	1.2464	23.6867		38.7451		5.2079	2.5195	19.7599		34.3507	
		5.6	14.2938	1.2390	23.2231		37.7074		5.2079	2.4935	19.1557		32.3309	
		5.7	14.2938	1.3653	32.4991		48.4846		5.2079	2.6171	22.1973		33.5498	
		5.8	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
		5.9	14.2938	1.2433	23.4899		36.7648		5.2079	2.4826	18.9090		31.3872	
	475	6	14.2938	1.2601	24.5645		36.3744		5.2079	2.4718	18.6682		24.9188	
		6.1	14.2938	1.3051	27.6890		43.5027		5.2079	2.5836	21.3285		39.7647	
		6.2	14.2938	1.2038	21.1445		33.1332		5.2079	2.4554	18.3059		29.1809	
		6.3	14.2938	1.0939	15.7840		21.8168		5.2079	2.2171	13.7743		13.2650	
		6.4	14.2938	1.1112	16.5273		23.3738		5.2079	2.2188	13.8009		13.3340	
		6.5	14.2938	1.1495	18.3033		27.0591		5.2079	2.3195	15.5657		19.3431	
		6.6	14.2938	1.0505	14.0630		18.1714		5.2079	2.1153	12.1956		8.5133	
		6.7	14.2938	1.0118	12.6836		15.2869		5.2079	2.0282	10.9884		5.8885	
		6.8	14.2938	0.9674	11.2713		12.3724		5.2079	1.9610	10.1387		4.5679	
		6.9	14.2938	0.9621	11.1137		12.0357		5.2079	1.9269	9.7333		4.0613	

Table A 5 Sample Table for Workbook *LateralSpread_semi*

7	14.2938	0.9924	12.0478		13.9504		5.2079	1.9891	10.4855		5.0425	
7.1	14.2938	0.9437	10.5821		10.8061		5.2079	1.8475	8.8496		3.4709	
7.2	14.2938	0.9500	10.7594		11.2547		5.2079	1.8955	9.3740		3.6594	
7.3	14.2938	1.0380	13.5999		17.1212		5.2079	2.0836	11.7421		7.3447	
7.4	14.2938	1.1267	17.2253		24.6995		5.2079	2.2647	14.5793		15.7912	
7.5	14.2938	1.1330	17.5138		25.2791		5.2079	2.2982	15.1744		17.8318	
7.6	14.2938	1.0688	14.7653		19.5318		5.2079	2.1561	12.8059		10.0519	
7.7	14.2938	1.0433	13.7953		17.4958		5.2079	2.0868	11.7861		7.4189	
7.8	14.2938	0.9679	11.2847		12.3191		5.2079	1.9445	9.9400		4.2632	
7.9	14.2938	0.9619	11.1054		11.9362		5.2079	1.9231	9.6889		3.9648	
8	14.2938	0.9508	10.7823		11.2471		5.2079	1.9220	9.6762		3.9478	
8.1	14.2938	0.9256	10.0843		9.4415		5.2079	1.6816	7.2504		3.1173	
8.2	14.2938	1.0389	13.6351		17.1017		5.2079	2.0766	11.6437		7.0574	
8.3	14.2938	1.1434	18.0053		26.1641		5.2079	2.2981	15.1720		17.7040	
8.4	14.2938	1.0383	13.6116		17.0296		5.2079	2.0841	11.7489		7.2702	
8.5	14.2938	1.1063	16.3143		22.6642		5.2079	2.2240	13.8873		13.3334	
8.6	14.2938	1.0547	14.2200		18.2714		5.2079	2.1140	12.1771		8.2584	
8.7	14.2938	1.1887	20.3119		28.2738		5.2079	2.3471	16.0861		15.6843	
8.8	14.2938	1.2926	26.7836		38.2767		5.2079	2.5373	20.1842		28.4142	
8.9	14.2938	1.0337	13.4483		16.6243		5.2079	2.0709	11.5648		6.8239	
9	14.2938	1.0468	13.9239		17.5809		5.2079	2.0816	11.7138		7.1268	
9.1	14.2938	1.2222	22.2065		30.5010		5.2079	2.4093	17.3262		18.9188	
9.2	14.2938	1.0169	12.8589		15.3365		5.2079	2.0303	11.0164		5.7123	
9.3	14.2938	1.0090	12.5912		14.7819		5.2079	2.0242	10.9367		5.5548	
9.4	14.2938	1.0414	13.7238		17.0740		5.2079	2.0743	11.6116		6.7867	
9.5	14.2938	1.1593	18.7843		26.2082		5.2079	2.3031	15.2641		13.4003	
9.6	14.2938	1.1101	16.4782		22.6450		5.2079	2.2130	13.7064		12.3562	
9.7	14.2938	1.0744	14.9860		19.6228		5.2079	2.1414	12.5818		8.9636	
9.8	14.2938	1.1106	16.5001		22.7541		5.2079	2.2209	13.8359		12.6732	
9.9	14.2938	1.1561	18.6258		26.9726		5.2079	2.3154	15.4890		18.1983	
10	14.2938	1.1162	16.7506		23.2245		5.2079	2.2370	14.1045		13.4521	
10.1	14.2938	0.9512	10.7958		10.9825		5.2079	1.8333	8.6993		3.4775	
10.2	14.2938	0.9977	12.2174		13.8612		5.2079	1.9968	10.5831		4.8006	
10.3	14.2938	1.0732	14.9365		19.3985		5.2079	2.1472	12.6699		8.9477	
10.4	14.2938	1.0521	14.1205		17.7040		5.2079	2.1034	12.0225		7.3377	
10.5	14.2938	0.9686	11.3069		11.9653		5.2079	1.9384	9.8678		3.8638	
10.6	14.2938	1.2131	21.6781		26.0973		5.2079	2.3899	16.9290		13.5054	
10.7	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
10.8	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
10.9	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.1	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.2	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.3	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.4	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
11.5	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.6	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.7	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.8	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
11.9	14.2938	-1.6402	0.0023		0.0000		5.2079	-1.6269	0.0000		0.0000	
12	14.2938	1.4018	51.2000		51.2000		5.2079	2.7822	51.2000		51.2000	
0.1	21.1148	1.4018	51.2000	414.6505	51.2000	463.0888	9.5900	2.7822	51.2000	320.3427	51.2000	343.7611
0.2	21.1148	1.4018	51.2000		51.2000		9.5900	2.6850	34.0002		51.2000	
0.3	21.1148	1.3223	48.5521		51.2000		9.5900	2.4534	25.0521		34.6765	
0.4	21.1148	1.4018	51.2000		51.2000		9.5900	2.7814	38.6095		51.2000	
0.5	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
0.6	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
0.7	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
0.8	21.1148	1.2502	38.9597		45.4797		9.5900	2.3304	21.2946		17.9489	
0.9	21.1148	1.0755	22.8668		26.7801		9.5900	1.9545	12.9533		5.3803	
1	21.1148	1.0725	22.6543		28.9556		9.5900	1.9470	12.8262		6.4563	
1.1	21.1148	1.0604	21.8314		27.3558		9.5900	1.9161	12.3119		5.5164	
1.2	21.1148	1.1191	26.1171		31.0435		9.5900	2.0607	14.9090		7.8648	
1.3	21.1148	1.2052	33.9649		35.8979		9.5900	2.2205	18.4186		7.4388	
1.4	21.1148	-0.0078	0.8312		0.0000		9.5900	-1.6269	0.0000		0.5125	
1.5	21.1148	-1.6402	0.0000		0.0000		9.5900	-1.6269	0.0000		0.0000	
1.6	21.1148	-1.6402	0.0000		0.0000		9.5900	-1.6269	0.0000		0.1432	
1.7	21.1148	0.8626	11.9385		10.7648		9.5900	1.1985	4.7322		2.1233	
1.8	21.1148	1.1054	25.0465		31.8151		9.5900	2.0337	14.3860		11.1213	
1.9	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
2	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
2.1	21.1148	1.1746	30.9410		40.3848		9.5900	2.1645	17.1040		18.5976	

Profile 1	1039	2.2	21.1148	1.3223	48.5521	51.2000	9.5900	2.4621	25.3385	42.2111
		2.3	21.1148	1.4018	51.2000	51.2000	9.5900	2.7822	51.2000	51.2000
		2.4	21.1148	1.4018	51.2000	51.2000	9.5900	2.7822	51.2000	51.2000
		2.5	21.1148	1.3938	51.2000	51.2000	9.5900	2.6262	31.4642	51.2000
		2.6	21.1148	1.2634	40.5645	51.2000	9.5900	2.3660	22.3218	29.4214
		2.7	21.1148	1.4018	51.2000	51.2000	9.5900	2.7822	51.2000	51.2000
		2.8	21.1148	1.1746	30.9410	40.6713	9.5900	2.1668	17.1561	19.1060
		2.9	21.1148	0.8895	12.9621	12.9967	9.5900	1.5658	7.7314	2.7507
		3	21.1148	0.0346	0.9471	0.0000	9.5900	-1.6269	0.0000	1.1870
		3.1	21.1148	-1.6402	0.0000	0.0000	9.5900	-1.6269	0.0000	1.2238
		3.2	21.1148	-1.6402	0.0000	0.0000	9.5900	-1.6269	0.0000	1.2850
		3.3	21.1148	0.3216	2.2853	0.5787	9.5900	0.2616	1.3103	1.5164
		3.4	21.1148	0.9780	16.9777	19.7341	9.5900	1.7965	10.5063	4.2101
		3.5	21.1148	0.9812	17.1468	19.9728	9.5900	1.8427	11.1696	5.2501
		3.6	21.1148	0.9234	14.3747	15.4581	9.5900	1.7806	10.2872	4.1909
		3.7	21.1148	0.9386	15.0567	16.6491	9.5900	1.7894	10.4072	4.3130
		3.8	21.1148	0.8969	13.2575	13.3548	9.5900	1.7824	10.3107	4.2094
		3.9	21.1148	0.9161	14.0577	14.8498	9.5900	1.7903	10.4193	4.3217
		4	21.1148	1.0136	18.9295	22.5608	9.5900	1.9240	12.4410	7.1474
		4.1	21.1148	1.1784	31.3018	40.7475	9.5900	2.2142	18.2663	22.0381
		4.2	21.1148	1.2905	44.0564	51.2000	9.5900	2.4343	24.4263	39.5102
		4.3	21.1148	1.0663	22.2338	27.4692	9.5900	2.0650	14.9940	12.7120
		4.4	21.1148	1.1191	26.1171	33.2418	9.5900	2.1710	17.2509	19.0471
		4.5	21.1148	1.1472	28.4583	36.5807	9.5900	2.2210	18.4293	22.4944
		4.6	21.1148	1.1054	25.0465	31.6459	9.5900	2.1635	17.0823	18.5506
		4.7	21.1148	0.9614	16.1401	18.3244	9.5900	1.9105	12.2202	6.7875
		4.8	21.1148	1.0136	18.9295	22.4662	9.5900	1.9966	13.6970	9.4899
		4.9	21.1148	1.1191	26.1171	33.1843	9.5900	2.2055	18.0569	21.3935
		5	21.1148	1.1024	24.8179	31.1146	9.5900	2.1615	17.0354	15.2547
		5.1	21.1148	1.4018	51.2000	51.2000	9.5900	2.7270	35.9353	51.2000
		5.2	21.1148	1.4018	51.2000	51.2000	9.5900	2.7742	38.2438	51.2000
		5.3	21.1148	1.3887	51.2000	51.2000	9.5900	2.7517	37.1230	51.2000
		5.4	21.1148	1.3735	51.2000	51.2000	9.5900	2.7254	35.8623	51.2000
		5.5	21.1148	1.2464	38.5152	51.2000	9.5900	2.5195	27.3334	47.7299
		5.6	21.1148	1.2390	37.6524	50.1952	9.5900	2.4935	26.4102	45.3290
		5.7	21.1148	1.3653	51.2000	51.2000	9.5900	2.6171	31.0881	48.6345
		5.8	21.1148	-1.6402	0.0000	0.0000	9.5900	-1.6269	0.0000	0.1237
		5.9	21.1148	1.2433	38.1488	49.4982	9.5900	2.4826	26.0339	44.1872
		6	21.1148	1.2601	40.1559	49.9023	9.5900	2.4718	25.6675	37.8850
		6.1	21.1148	1.3051	46.0641	51.2000	9.5900	2.5836	29.7443	51.2000
		6.2	21.1148	1.2038	33.8149	44.4959	9.5900	2.4554	25.1167	41.5090
		6.3	21.1148	1.0939	24.1849	30.3840	9.5900	2.2171	18.3364	22.2360
		6.4	21.1148	1.1112	25.4948	32.3364	9.5900	2.2188	18.3756	22.3278
		6.5	21.1148	1.1495	28.6593	36.9268	9.5900	2.3195	20.9919	29.6275
		6.6	21.1148	1.0505	21.1869	25.8473	9.5900	2.1153	16.0266	15.5548
		6.7	21.1148	1.0118	18.8222	22.2676	9.5900	2.0282	14.2818	10.8333
		6.8	21.1148	0.9674	16.4400	18.6818	9.5900	1.9610	13.0658	8.1857
		6.9	21.1148	0.9621	16.1769	18.2719	9.5900	1.9269	12.4894	7.1768
		7	21.1148	0.9924	17.7446	20.6268	9.5900	1.9891	13.5609	9.1600
		7.1	21.1148	0.9437	15.2930	16.8219	9.5900	1.8820	11.7670	6.0539
		7.2	21.1148	0.9500	15.5871	17.3502	9.5900	1.8955	11.9807	6.3923
		7.3	21.1148	1.0380	20.3891	24.5673	9.5900	2.0836	15.3689	13.6187
		7.4	21.1148	1.1267	26.7329	34.0274	9.5900	2.2647	19.5254	25.3820
		7.5	21.1148	1.1330	27.2467	34.7522	9.5900	2.2982	20.4089	27.8516
		7.6	21.1148	1.0688	22.4040	27.5779	9.5900	2.1561	16.9160	17.9295
		7.7	21.1148	1.0433	20.7252	25.0447	9.5900	2.0868	15.4325	13.7673
		7.8	21.1148	0.9679	16.4624	18.6471	9.5900	1.9445	12.7830	7.6202
		7.9	21.1148	0.9619	16.1630	18.1815	9.5900	1.9231	12.4263	7.0256
		8	21.1148	0.9508	15.6251	17.3550	9.5900	1.9220	12.4083	6.9930
		8.1	21.1148	0.9256	14.4712	15.2945	9.5900	1.8575	11.3911	5.4528
		8.2	21.1148	1.0389	20.4495	24.5766	9.5900	2.0766	15.2265	13.1524
		8.3	21.1148	1.1434	28.1251	35.8989	9.5900	2.2981	20.4053	27.7338
		8.4	21.1148	1.0383	20.4092	24.4957	9.5900	2.0841	15.3788	13.5445
		8.5	21.1148	1.1063	25.1185	31.5385	9.5900	2.2240	18.5028	22.4143
		8.6	21.1148	1.0547	21.4583	26.0529	9.5900	2.1140	15.9998	15.2611
		8.7	21.1148	1.1887	32.2929	39.4519	9.5900	2.3471	21.7697	26.6581
		8.8	21.1148	1.2926	44.3415	51.2000	9.5900	2.5373	27.9836	42.3719
		8.9	21.1148	1.0337	20.1286	24.0178	9.5900	2.0709	15.1124	12.7623
		9	21.1148	1.0468	20.9468	25.2177	9.5900	2.0816	15.3279	13.3309
		9.1	21.1148	1.2222	35.7690	42.8545	9.5900	2.4093	23.6339	30.9739
		9.2	21.1148	1.0169	19.1207	22.4438	9.5900	2.0303	14.3221	10.6584
		9.3	21.1148	1.0090	18.6651	21.7599	9.5900	2.0242	14.2074	10.3596
		9.4	21.1148	1.0414	20.6020	24.6186	9.5900	2.0743	15.1801	12.7877

9.5	21.1148	1.1593	29.5244		36.4890		9.5900	2.3031	20.5425		23.6567	
9.6	21.1148	1.1101	25.4080		31.6433		9.5900	2.2130	18.2365		21.3017	
9.7	21.1148	1.0744	22.7885		27.8252		9.5900	2.1414	16.5889		16.5381	
9.8	21.1148	1.1106	25.4468		31.7556		9.5900	2.2209	18.4272		21.7321	
9.9	21.1148	1.1561	29.2390		37.0684		9.5900	2.3154	20.8776		28.5197	
10	21.1148	1.1162	25.8900		32.3578		9.5900	2.2370	18.8233		22.7353	
10.1	21.1148	0.9512	15.6475		17.1502		9.5900	1.9001	12.0526		6.2096	
10.2	21.1148	0.9977	18.0313		20.6815		9.5900	1.9968	13.7005		8.9649	
10.3	21.1148	1.0732	22.7021		27.5878		9.5900	2.1472	16.7175		16.5547	
10.4	21.1148	1.0521	21.2862		25.4762		9.5900	2.1034	15.7753		13.9458	
10.5	21.1148	0.9686	16.4995		18.3645		9.5900	1.9384	12.6803		7.0622	
10.6	21.1148	1.2131	34.7951		38.6153		9.5900	2.3899	23.0351		25.5188	
10.7	21.1148	-1.6402	0.0000		0.0000		9.5900	-1.6269	0.0000		0.1135	
10.8	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
10.9	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.1	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.2	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.3	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.4	21.1148	-1.6402	0.0000		0.0000		9.5900	-1.6269	0.0000		0.1128	
11.5	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.6	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.7	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.8	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
11.9	21.1148	-1.6402	0.0000		0.0000		9.5900	-1.6269	0.0000		0.1126	
12	21.1148	1.4018	51.2000		51.2000		9.5900	2.7822	51.2000		51.2000	
0.1	28.1444	1.4018	51.2000	571.6179	51.2000	627.8781	14.3912	2.7822	51.2000	394.5949	51.2000	459.4017
0.2	28.1444	1.4018	51.2000		51.2000		14.3912	2.6850	41.4353		51.2000	
0.3	28.1444	1.3223	51.2000		51.2000		14.3912	2.4534	30.0194		47.4743	
0.4	28.1444	1.4018	51.2000		51.2000		14.3912	2.7814	47.3847		51.2000	
0.5	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
0.6	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
0.7	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
0.8	28.1444	1.2502	51.2000		51.2000		14.3912	2.3304	25.2893		27.2936	
0.9	28.1444	1.0755	31.1477		35.4725		14.3912	1.9545	14.9686		7.9518	
1	28.1444	1.0725	30.8312		37.5349		14.3912	1.9470	14.8137		9.5018	
1.1	28.1444	1.0604	29.6080		35.6491		14.3912	1.9161	14.1879		8.1086	
1.2	28.1444	1.1191	36.0226		40.8662		14.3912	2.0607	17.3620		11.8798	
1.3	28.1444	1.2052	48.0194		48.4659		14.3912	2.2205	21.6997		11.6687	
1.4	28.1444	0.2756	2.1493		0.2641		14.3912	-1.6269	0.0000		0.7873	
1.5	28.1444	-1.6402	0.0000		0.0000		14.3912	-1.6269	0.0000		0.0000	
1.6	28.1444	-1.6402	0.0000		0.0000		14.3912	-1.6269	0.0000		0.2355	
1.7	28.1444	0.8626	15.2978		15.6946		14.3912	1.5527	8.5285		3.1400	
1.8	28.1444	1.1054	34.4103		41.2380		14.3912	2.0337	16.7202		16.6861	
1.9	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
2	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
2.1	28.1444	1.1746	43.3620		51.2000		14.3912	2.1645	20.0689		26.8726	
2.2	28.1444	1.3223	51.2000		51.2000		14.3912	2.4621	30.3816		51.2000	
2.3	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
2.4	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
2.5	28.1444	1.3938	51.2000		51.2000		14.3912	2.6262	38.1806		51.2000	
2.6	28.1444	1.2634	51.2000		51.2000		14.3912	2.3660	26.5781		40.6577	
2.7	28.1444	1.4018	51.2000		51.2000		14.3912	2.7822	51.2000		51.2000	
2.8	28.1444	1.1746	43.3620		51.2000		14.3912	2.1668	20.1335		27.4214	
2.9	28.1444	0.8895	16.7384		18.2229		14.3912	1.6353	9.5755		4.0110	
3	28.1444	0.3197	2.4909		0.3941		14.3912	-1.6269	0.0000		1.7862	
3.1	28.1444	0.2340	1.8695		0.1831		14.3912	0.0644	0.9934		1.8404	
3.2	28.1444	0.2319	1.8561		0.1803		14.3912	0.2484	1.3117		1.9294	
3.3	28.1444	0.6162	6.7169		2.4094		14.3912	0.8288	3.0590		2.2631	
3.4	28.1444	0.9780	22.4873		26.3414		14.3912	1.7965	12.0026		6.1673	
3.5	28.1444	0.9812	22.7325		26.6382		14.3912	1.8427	12.8032		7.6814	
3.6	28.1444	0.9234	18.7440		21.1697		14.3912	1.7806	11.7388		6.1272	
3.7	28.1444	0.9386	19.7189		22.5960		14.3912	1.7894	11.8833		6.3083	
3.8	28.1444	0.8969	17.1562		18.6895		14.3912	1.7824	11.7670		6.1556	
3.9	28.1444	0.9161	18.2922		20.4582		14.3912	1.7903	11.8978		6.3216	
4	28.1444	1.0136	25.3304		29.8463		14.3912	1.9240	14.3448		10.5306	
4.1	28.1444	1.1784	43.9155		51.2000		14.3912	2.2142	21.5104		31.1327	
4.2	28.1444	1.2905	51.2000		51.2000		14.3912	2.4343	29.2287		51.2000	
4.3	28.1444	1.0663	30.2056		35.9078		14.3912	2.0650	17.4664		18.9779	
4.4	28.1444	1.1191	36.0226		43.0339		14.3912	2.1710	20.2509		27.4259	
4.5	28.1444	1.1472	39.5701		47.1531		14.3912	2.2210	21.7129		31.6770	
4.6	28.1444	1.1054	34.4103		41.0709		14.3912	2.1635	20.0421		26.7996	

		4.7	28.1444	0.9614	21.2764	24.6479	14.3912	1.9105	14.0764	9.9734
		4.8	28.1444	1.0136	25.3304	29.7536	14.3912	1.9966	15.8766	14.1695
		4.9	28.1444	1.1191	36.0226	42.9769	14.3912	2.2055	21.2504	30.3630
		5	28.1444	1.1024	34.0668	40.4634	14.3912	2.1615	19.9841	23.0541
		5.1	28.1444	1.4018	51.2000	51.2000	14.3912	2.7270	43.9278	51.2000
		5.2	28.1444	1.4018	51.2000	51.2000	14.3912	2.7742	46.9112	51.2000
		5.3	28.1444	1.3887	51.2000	51.2000	14.3912	2.7517	45.4615	51.2000
		5.4	28.1444	1.3735	51.2000	51.2000	14.3912	2.7254	43.8337	51.2000
		5.5	28.1444	1.2464	51.2000	51.2000	14.3912	2.5195	32.9110	51.2000
		5.6	28.1444	1.2390	51.2000	51.2000	14.3912	2.4935	31.7391	51.2000
		5.7	28.1444	1.3653	51.2000	51.2000	14.3912	2.6171	37.6991	51.2000
		5.8	28.1444	-1.6402	0.0000	0.0000	14.3912	-1.6269	0.0000	0.2057
		5.9	28.1444	1.2433	51.2000	51.2000	14.3912	2.4826	31.2622	51.2000
	2475	6	28.1444	1.2601	51.2000	51.2000	14.3912	2.4718	30.7980	51.1458
		6.1	28.1444	1.3051	51.2000	51.2000	14.3912	2.5836	35.9816	51.2000
		6.2	28.1444	1.2038	47.7873	51.2000	14.3912	2.4554	30.1012	51.2000
		6.3	28.1444	1.0939	33.1173	39.5071	14.3912	2.2171	21.5976	31.3680
		6.4	28.1444	1.1112	35.0846	41.9174	14.3912	2.2188	21.6462	31.4813
		6.5	28.1444	1.1495	39.8760	47.5667	14.3912	2.3195	24.9100	40.2190
		6.6	28.1444	1.0505	28.6531	33.9240	14.3912	2.1153	18.7377	22.9404
		6.7	28.1444	1.0118	25.1733	29.5185	14.3912	2.0282	16.5924	16.2143
		6.8	28.1444	0.9674	21.7094	25.1132	14.3912	1.9610	15.1057	12.1377
		6.9	28.1444	0.9621	21.3295	24.6113	14.3912	1.9269	14.4037	10.5778
		7	28.1444	0.9924	23.6009	27.5064	14.3912	1.9891	15.7101	13.6619
		7.1	28.1444	0.9437	20.0578	22.8591	14.3912	1.8820	13.5264	8.8699
		7.2	28.1444	0.9500	20.4801	23.4979	14.3912	1.8955	13.7856	9.3729
		7.3	28.1444	1.0380	27.4748	32.3642	14.3912	2.0836	17.9274	20.3079
		7.4	28.1444	1.1267	36.9529	44.0261	14.3912	2.2647	23.0776	35.1545
		7.5	28.1444	1.1330	37.7307	44.9206	14.3912	2.2982	24.1808	38.1135
		7.6	28.1444	1.0688	30.4588	36.0785	14.3912	2.1561	19.8364	26.0541
		7.7	28.1444	1.0433	27.9708	32.9595	14.3912	2.0868	18.0057	20.5279
		7.8	28.1444	0.9679	21.7417	25.0881	14.3912	1.9445	14.7611	11.2903
		7.9	28.1444	0.9619	21.3094	24.5181	14.3912	1.9231	14.3270	10.3698
		8	28.1444	0.9508	20.5349	23.5120	14.3912	1.9220	14.3052	10.3199
		8.1	28.1444	0.9256	18.8816	21.0530	14.3912	1.8575	13.0710	7.9995
		8.2	28.1444	1.0389	27.5638	32.3960	14.3912	2.0766	17.7522	19.6817
		8.3	28.1444	1.1434	39.0635	46.3607	14.3912	2.2981	24.1762	37.9940
		8.4	28.1444	1.0383	27.5044	32.3016	14.3912	2.0841	17.9396	20.2418
		8.5	28.1444	1.1063	34.5185	40.9911	14.3912	2.2240	21.8044	31.6372
		8.6	28.1444	1.0547	29.0549	34.2268	14.3912	2.1140	18.7046	22.6262
		8.7	28.1444	1.1887	45.4390	51.2000	14.3912	2.3471	25.8849	37.5538
		8.8	28.1444	1.2926	51.2000	51.2000	14.3912	2.5373	33.7378	51.2000
		8.9	28.1444	1.0337	27.0910	31.7278	14.3912	2.0709	17.6119	19.1467
		9	28.1444	1.0468	28.2981	33.2132	14.3912	2.0816	17.8770	19.9691
		9.1	28.1444	1.2222	50.8168	51.2000	14.3912	2.4093	28.2291	42.9779
		9.2	28.1444	1.0169	25.6105	29.8039	14.3912	2.0303	16.6418	16.0663
		9.3	28.1444	1.0090	24.9436	28.9624	14.3912	2.0242	16.5013	15.6203
		9.4	28.1444	1.0414	27.7889	32.4942	14.3912	2.0743	17.6952	19.2507
		9.5	28.1444	1.1593	41.1947	47.4332	14.3912	2.3031	24.3477	33.8581
		9.6	28.1444	1.1101	34.9540	41.2020	14.3912	2.2130	21.4733	30.3826
		9.7	28.1444	1.0744	31.0310	36.4660	14.3912	2.1414	19.4318	24.4278
		9.8	28.1444	1.1106	35.0123	41.3254	14.3912	2.2209	21.7103	30.9132
		9.9	28.1444	1.1561	40.7592	47.9054	14.3912	2.3154	24.7670	39.0495
		10	28.1444	1.1162	35.6802	42.0780	14.3912	2.2370	22.2029	32.1252
		10.1	28.1444	0.9512	20.5670	23.3266	14.3912	1.9001	13.8729	9.2186
		10.2	28.1444	0.9977	24.0185	27.6699	14.3912	1.9968	15.8808	13.5891
		10.3	28.1444	1.0732	30.9024	36.1997	14.3912	2.1472	19.5908	24.4742
		10.4	28.1444	1.0521	28.8001	33.5953	14.3912	2.1034	18.4279	21.0281
		10.5	28.1444	0.9686	21.7953	24.8267	14.3912	1.9384	14.6361	10.6062
		10.6	28.1444	1.2131	49.3049	51.2000	14.3912	2.3899	27.4750	37.1188
		10.7	28.1444	-1.6402	0.0000	0.0000	14.3912	-1.6269	0.0000	0.1882
		10.8	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		10.9	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.1	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.2	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.3	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.4	28.1444	-1.6402	0.0000	0.0000	14.3912	-1.6269	0.0000	0.1879
		11.5	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.6	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.7	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.8	28.1444	1.4018	51.2000	51.2000	14.3912	2.7822	51.2000	51.2000
		11.9	28.1444	-1.6402	0.0000	0.0000	14.3912	-1.6269	0.0000	0.1880