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LIQUEFACTION POTENTIAL ANALYSES

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LIQUEFACTION POTENTIAL ANALYSES

INTRODUCTION

This calculation package was prepared as part of the In-Lake Waste Deposit (ILWD) geotechnical stability evaluation for the Onondaga Lake Bottom Site. Specifically, the purpose of this package is to present liquefaction potential analyses for the ILWD area. The ILWD area consists of Sediment Management Unit (SMU) 1 and limited portions of SMUs 2, 7, and 8. Liquefaction potential of the Solvay Waste (SOLW) and the underlying soils was evaluated for existing conditions.

Since the details of the isolation cap are currently being developed, the evaluation of the capped condition is not explicitly included herein. The liquefaction potential evaluation of the existing SOLW and underlying soils will not be affected by the installation of a cap (anticipated to be approximately 3-ft thick) at slopes that are similar to existing conditions, and therefore will not need to be updated for post-capping conditions. However, liquefaction potential of the cap itself will be addressed during the Intermediate Capping Design.

The remainder of this calculation package presents: (i) technical framework; (ii) subsurface stratigraphy and material properties; (iii) methodology; (iv) results; and (v) conclusions.

TECHNICAL FRAMEWORK

A technical framework for the proposed liquefaction evaluation is presented in this section. Defining a framework is important because the term "liquefaction" is used to describe a variety of phenomena in the literature. A description of the different liquefaction mechanisms and liquefaction potential evaluation procedures are presented in the following sections.

Liquefaction Mechanisms

Kramer [1996] writes the following about the term "liquefaction":

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"The term liquefaction.....has historically been used in conjunction with a variety of phenomena that involve soil deformations caused by monotonic, transient, or repeated disturbance of saturated cohesionless soils under undrained loading conditions. The generation of excess pore pressure under undrained loading conditions is a hallmark of all liquefaction phenomena".

Generally liquefaction phenomena can be divided into two main groups: (i) flow liquefaction (or true liquefaction); and (ii) cyclic mobility (or cyclic liquefaction). These two types of "liquefaction" phenomena are illustrated in Figure 1 and explained in the following paragraphs.

Flow liquefaction can occur when the shear stress required for static equilibrium of a soil mass (static shear stress, τ_d in Figure 1) is greater than the shear strength of the soil in its liquefied state (S_{us} in Figure 1). The shear strength of the soil in its liquefied state is also referred to as the undrained steady state shear strength or residual undrained shear strength in the literature. This shear strength is less than the peak shear strength for strain softening soils and is the same as the peak shear strength for strain hardening soils. Deformations produced by flow liquefaction are driven by static shear stresses and can be very large [Kramer 1996]. Flow liquefaction can be initiated by seismic loading, vibrations such as pile driving, geophysical exploration, blasting, and/or monotonic loading (static liquefaction). Flow liquefaction stress paths due to monotonic loading and cyclic loading are illustrated in Figure 1(a). The above discussion about flow liquefaction is generally applicable to cohesionless soils and soils with low plasticity. The term liquefaction is not generally used for cohesive soils that show "clay-like" behavior. However, undrained shear strength of sensitive clays or cemented soils can reduce from their undisturbed undrained shear strength to remolded undrained shear strength when disturbed and show a "flow liquefaction"-like behavior.

Cyclic mobility can be initiated by cyclic loading (i.e., seismic or periodic wave loading) resulting in the development of incremental deformations during loading [Kramer 1996]. It can occur when the static shear stress is less than the shear strength of the liquefied soil, and it will not result in flow liquefaction, which is discussed in the previous paragraph. However, if the static shear stress is greater than the shear strength of the liquefied soil, cyclic mobility can act as a trigger to push the stress path past the peak shear strength and lead to flow liquefaction. Conversely, if cyclic loading is not strong enough to trigger cyclic mobility, flow liquefaction is not likely to occur under that same loading. Cyclic mobility stress path due to cyclic loading is illustrated in Figure 1(b). Monotonic

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loading stress paths for the same soil are also provided in this figure to illustrate that the soil deforming due to cyclic mobility still has shear strength to resist shear stresses.

While the term cyclic mobility or cyclic liquefaction is generally used for cohesionless soils and soils with low plasticity, the term cyclic softening is used to describe the behavior of silty and clayey soils during earthquakes [Boulanger and Idriss, 2007].

Liquefaction Potential Evaluation Procedures

The state-of-practice for evaluating the liquefaction potential does not explicitly account for different liquefaction mechanisms. State-of-practice procedures are mainly based on case histories of occurrences and non-occurrences of liquefaction due to past earthquakes. Occurrences (or non-occurrences) of liquefaction are determined by presence (or absence) of surface manifestations of liquefaction such as sand boils, ground cracking, slope movements, and/or flow failures. Surface manifestations are generally present if high pore pressures are generated due to seismic loading and "liquefaction" is triggered. Therefore, if soils at a particular site are deemed to be not susceptible to liquefaction based on methods used in state-of-practice, further analyses such as post-liquefaction slope stability or flow liquefaction are not needed for seismic loading.

An initial step in performing a liquefaction potential evaluation is application of screening criteria based on geotechnical properties to evaluate whether subsurface materials are potentially liquefiable. Seismic loading is not considered in this screening evaluation. In general, soils that show "clay-like" behavior are not susceptible to liquefaction. Boulanger and Idriss [2007] proposed a procedure to evaluate the potential for cyclic softening of silty and clayey soils based on undrained static shear strengths and seismic loading. The screening criteria and the Boulanger and Idriss [2007] procedure to evaluate to seismic loading, and therefore cover all forms of "liquefaction" due to seismic loading.

The state-of-practice for liquefaction analysis for cohesionless soils is based on empirical correlations based on insitu soil tests such as Standard Penetration Tests (SPT) or Cone Penetration Tests (CPT). The effect of seismic loading is considered in this approach. This procedure was developed based on field case histories where evidence of liquefaction was or was not observed after earthquakes, and, therefore, covers all forms of "liquefaction" due to seismic loading.

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In addition to the state-of-practice based methods, potential for flow liquefaction or sensitivity for loss of shear strength can be directly evaluated for soils based on stress-strain behavior during laboratory tests such as undrained triaxial tests. A pronounced strain softening behavior where the shear strength peaks at relatively low strains and then drops significantly to reach a steady state or residual value may be an indication of the potential to liquefy under certain conditions. On the other hand, a strain hardening behavior where the shear strength peaks at the soil is strained or a limited strain softening behavior where the shear strength peaks and then drops slightly to reach a steady value indicates that flow liquefaction or sensitivity is not an issue. These three types of soil behavior are illustrated in Figure 2. It is noted that liquefaction due to cyclic mobility may still be triggered in a strain hardening soil depending on the acceleration and magnitude of the seismic loading.

SUBSURFACE STRATIGRAPHY AND MATERIAL PROPERTIES

Subsurface soils in the ILWD area consist of primarily seven strata (from top to bottom): (i) SOLW; (ii) marl; (iii) silt and clay; (iv) silt and sand; (v) sand and gravel; (vi) till; and (vii) shale. Standard Penetration Tests (SPT) were conducted in most of the borings to measure the SPT blow count values. Samples of SOLW, marl, and silt and clay were collected during the investigations for laboratory testing of index properties, shear strength, and compressibility. A detailed description of the development of the subsurface model and geotechnical parameters is presented in Appendix A titled "Summary of Subsurface Stratigraphy and Material Properties".

SOLW, marl, and silt and clay units can be classified as mainly MH, MH and CH, and CL and CH type material based on the Unified Soil Classification System (USCS). SPT values for SOLW, marl, and silt and clay mainly ranged from 0 to 7 (with most of the reported blow counts being 0). Plasticity index values for SOLW mainly ranged from 10 to 80. Most of the SOLW samples had water contents that were higher than their liquid limits. However, under laboratory undrained shearing, 12 out of 17 SOLW samples (two to three specimens were tested for each sample) showed strain hardening ductile behavior. Out of the remaining five samples, three showed limited strain-softening behavior and two showed gradual strain softening behavior. Based on laboratory triaxial test results, an undrained shear strength ratio of 0.35 for SOLW, marl, and silt and clay were selected to model the shear strength under undrained conditions. SPT values for the deeper soil layers mainly ranged from 20 to 100. Table 1 summarizes the material properties of each subsurface layer (i.e., SOLW and soils).

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METHODOLOGY

The liquefaction potential evaluation methodology used for the ILWD area is presented in this section. Screening criteria, Boulanger and Idriss [2007] evaluation procedure for "cohesive" soils, and Seed and Idriss [1971] evaluation procedure for "cohesionless" soils are applied to evaluate the potential for triggering liquefaction. In addition, the potential for flow liquefaction and/or sensitive behavior is directly evaluated for SOLW using stress paths observed in static triaxial tests. This evaluation is described in the following five steps:

- 1. A general screening is conducted to assess the liquefaction potential of the ILWD. Several screening criteria are used in state-of-practice for evaluating the liquefaction potential of cohesive soils (generally soils that can be classified as ML, CL, MH, CH or combinations of these). These screening criteria are developed from actual field evidence of both liquefaction and no liquefaction in different soil types and supplemental laboratory studies. These criteria cover both flow and cyclic liquefaction due to seismic loading. The following three criteria were used in the screening evaluation presented in this calculation package:
 - a. Chinese criteria [Wang 1979] has been widely used for the past two decades in US engineering practice to screen liquefaction potential of soils. Soil is considered susceptible if all three of the following conditions are met:
 - percent finer than 0.005 mm $\leq 15\%$
 - Liquid Limit $\leq 35\%$
 - Water Content $\geq 0.9 \text{ x Liquid Limit}$

Figure 3 presents these criteria in a chart format.

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- b. Andrews and Martin [2000] presented screening criteria to evaluate the liquefaction susceptibility of silty and clayey sands. These criteria are based on clay fraction (minus 0.002 mm) and Liquid Limit of soils. Figure 4 presents these criteria in a tabular form.
- c. Bray and Sancio [2006] evaluated several case histories and performed laboratory cyclic triaxial tests to develop screening criteria based on water content, Liquid Limit, and Plasticity Index. These criteria and the data used to develop them are shown in Figure 5.
- 2. Cyclic stresses caused by seismic loading within soil units need to be evaluated for liquefaction analyses. The cyclic stresses on the soils are calculated as follows to evaluate the liquefaction potential for "cohesive" soils and "cohesionless" soils described below in steps 3 and 4, respectively.
 - a. Design bedrock acceleration for a contingency level seismic event (i.e., a seismic event with a 10 percent chance of exceedance in 50 years) was established using United States Geological Survey (USGS) seismic hazard maps [USGS, 2008].
 - b. The design earthquake magnitude was established using deaggregated seismic hazard provided by USGS. Deaggregation is done to identify the earthquake that is contributing the most to the total hazard at the site.
 - c. Maximum ground surface acceleration for the contingency level seismic event was estimated by considering potential for amplification using the chart proposed by Idriss [1990] for soft soil sites. This chart is presented in Figure 6. Application of this chart in lieu of site response analyses based on time histories is generally considered to be conservative.
 - d. Cyclic Stress Ratio (CSR) was evaluated using the simplified procedure proposed by Seed and Idriss [1971]. The steps involved and equations used are described below.

$$CSR_{M} = 0.65r_{d} \frac{a_{\max}}{g} \frac{\sigma_{v_{0}}}{\sigma_{v_{0}}}$$

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Where:

CSR_M = Cyclic Stress Ratio due to an earthquake with magnitude M;

 r_d = stress reduction factor;

a_{max} = maximum ground surface acceleration;

g = gravitational acceleration;

 σ_{v0} = total vertical stress; and

 $\sigma_{v0}' =$ effective vertical stress.

The r_d value was calculated using the following equation presented in NCEER [1997] to approximate the mean values of the possible range of r_d .

$$r_{d} = \frac{\left(1.000 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5}\right)}{\left(1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2}\right)}$$

Where:

z = depth below ground surface in meters.

3. Cyclic softening potential was evaluated for cohesive soils using the procedure proposed by Boulanger and Idriss [2007]. This procedure is similar to the Seed and Idriss [1971] simplified procedure used for liquefaction evaluation of cohesionless soils, with some modifications for application to cohesive soils. Because this procedure evaluates the potential for significant pore pressure increase due to seismic loading, it covers all forms of "liquefaction" due to seismic loading. The steps involved and equations used are described below.

$$CRR_{M} = 0.8 \frac{S_{U}}{\sigma_{v0}} K_{\alpha} MSF$$

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Where:

CRR_M = Cyclic Resistance Ratio for an earthquake with magnitude M;

 S_U = static undrained shear strength;

 k_{α} = correction factor for driving static shear stresses; and

MSF = Magnitude Scaling Factor.

The k_{α} is a function of the driving static shear stresses or slope angle. For the mild overall slopes of the ILWD area ranging from three to five degrees, k_{α} can be assumed to be one.

The MSF for clay type soils can be calculated using the equation proposed by Boulanger and Idriss [2007] as illustrated in Figure 7.

$$MSF = 1.12 \exp\left(\frac{-M_W}{4}\right) + 0.828$$
, and $MSF \le 1.13$ (for clay)

Factor of safety against liquefaction (FS_{liq}) can be calculated as follows:

$$FS_{liq} = \frac{CRR_M}{CSR_M}$$

4. Liquefaction potential was evaluated for cohesionless soils using the simplified procedure proposed by Seed and Idriss [1971]. Because this procedure evaluates the potential for significant pore pressure increase due to seismic loading, it covers all forms of "liquefaction" due to seismic loading. The steps involved in this SPT based procedure and equations used are described below.

Figure 8 presents the relationship between SPT blow counts and $CRR_{7.5}$ based on case histories [NCEER, 1997]. The corrected normalized SPT blow count, $(N_1)_{60}$ can be calculated by the following equation presented by NCEER [1997].

$$(N_1)_{60} = N_m C_N C_E C_B C_R C_S$$

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Where:

 N_m = measured SPT blow count;

 C_N = correction for overburden pressure;

 C_E = correction for energy ratio;

 C_B = correction for borehole diameter;

 C_R = correction for rod length; and

 C_{S} = correction for sampler.

C_N can be calculated as follows:

$$C_N = \sqrt{\frac{P_a}{\sigma_{vo}}}$$

Where:

 P_a = atmospheric pressure (2117 psf).

The other corrections will be applied based on NCEER [1997] procedures as needed.

The MSF for cohesionless soils can be calculated using the equation proposed by Idriss [2007], as illustrated in Figure 7.

$$MSF = 6.9 \exp\left(\frac{-M_{W}}{4}\right) - 0.058$$
, and $MSF \le 1.8$ (for sand)

CRR_M is calculated by multiplying CRR_{7.5} by the MSF.

 FS_{liq} can be calculated as presented in step 3 above.

5. The potential for flow liquefaction or sensitivity for loss of shear strength can be directly evaluated for soils based on stress-strain behavior during laboratory tests

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such as undrained triaxial tests, as discussed in the technical framework section. Stress-strain plots for SOLW were compared with standard stress-strain plots for strain hardening, limited strain softening, and strain softening soil behavior. These three types of soil behavior were illustrated in Figure 2. It is noted that liquefaction due to cyclic mobility cannot be evaluated with this procedure; however, it will be evaluated in the steps described previously.

RESULTS

The liquefaction potential evaluation results are presented in this section, and the steps in this section directly correspond to the steps in the methodology section.

- 1. Application of screening criteria used in state-of-practice for evaluating the liquefaction potential of cohesive soils indicates that SOLW, marl, and silt and clay units in the ILWD area are not susceptible to liquefaction.
 - a. Figure 9 presents the application of the Chinese Criteria for SOLW, marl, and silt and clay. Based on these criteria these soils can be considered not susceptible to liquefaction.
 - b. Liquid limits for SOLW, marl, and silt and clay are greater than 32. Based on the lab results, the clay content (particle size less than 0.002 mm) typically ranges from 5% to 30% for SOLW, from 20% to 43% for marl, and from 14% to 50% for silt and clay. The average clay content was calculated to be 14%, 30%, and 30% for SOLW, marl, and silt and clay, respectively. Per the screening criteria proposed by Andrews and Martin [2000] if clay content is greater than or equal to 10% and liquid limit greater than or equal to 32, soils can be considered not susceptible to liquefaction. If clay content is less than 10% or liquid limit is less than 32, further studies are required. Therefore, in general SOLW, marl, and silt and clay are not considered susceptible to liquefaction based on these criteria.
 - c. Figure 10 presents the application of the criteria proposed by Bray and Sancio [2006] to SOLW, marl, and silt and clay. Values of water content, liquid limit, and plasticity index were used to classify samples as susceptible, moderately susceptible, and not susceptible to liquefaction.

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Out of a total of 101 SOLW samples, 3, 11, and 87 samples were classified as susceptible, moderately susceptible, and not susceptible to liquefaction, respectively. Out of a total of 35 marl samples, 1, 0, and 34 were classified as susceptible, moderately susceptible, and not susceptible to liquefaction, respectively. Out of a total of 47 silt and clay samples, 3, 9, and 35 were classified as susceptible, moderately susceptible, and not susceptible to liquefaction, respectively. A few samples being classified as susceptible to liquefaction are not likely to cause overall liquefaction of the ILWD. Therefore, based on these criteria, these soils are not considered susceptible to liquefaction.

- 2. The cyclic stresses on the soils are calculated using the following steps:
 - a. Figure 11 presents the peak ground acceleration with a 10% probability of exceedance in 50 years [USGS, 2008]. A latitude of 43° 04' N and a longitude of 76° 11' W were used for the ILWD area to obtain a PGA value of 0.025g (0.02478g) using the interactive maps from the USGS website. Attachment 1 presents the deaggregated seismic hazard for the 10% probability of exceedance in 50 year event. It is noted that the deaggregated hazard was based on the 2002 USGS hazard maps because deaggregated hazard, a 5.3 moment magnitude was selected for use in liquefaction analyses as explained in Attachment 1.
 - b. Maximum ground surface acceleration of 0.09g was estimated for this seismic event by considering potential for amplification using the recommended mean relation in the chart presented in Figure 6. Application of this chart in lieu of site response analyses based on time histories is generally considered to be conservative.
 - c. Table 2 presents the CSR values calculated using the simplified procedure proposed by Seed and Idriss [1971]. The calculated CSR values are plotted with depth in Figure 12. The calculated CSR values generally ranged from 0.10 at 70 feet depth in the silt and clay unit to 0.25 near the top of the SOLW.

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- 3. Table 2 presents the CRR values for cohesive soils calculated using the procedure proposed by Boulanger and Idriss [2007]. A normalized static strength ratio of 0.35 was used for SOLW, marl, and silt and clay as presented in Table 1 and Appendix A titled "Summary of Subsurface Stratigraphy and Material Properties". For the mild overall slopes of the ILWD area ranging from three to five degrees, k_{α} was assumed to be one. A MSF value of 1.13 was calculated. The calculated CRR values are plotted with depth in Figure 12. The calculated CRR values generally ranged from 0.32 for the marl and the silt and clay units to 0.55 for the SOLW. Calculated factors of safety against liquefaction are plotted in Figure 13. Calculated factors of safety against liquefaction ranged from about 2.2 to 2.3 for SOLW, 1.5 to 1.7 for marl, and 1.9 to 3.1 for silt and clay units. In liquefaction analyses, calculated factors of safety of 1.0 to 1.2 are considered adequate to conclude that adverse effects due to pore pressure buildup are unlikely. Therefore, based on this analysis, SOLW, marl, and silt and clay units in the ILWD area are not considered to be susceptible to liquefaction during the design seismic event established in step 2.
- 4. Uncorrected SPT blow counts for deeper soil units such as silt and sand, and sand and gravel ranged from 20 to 100 or more. An uncorrected SPT blow count of 20 is very conservatively assumed for demonstration purposes. It is assumed that energy correction is not required because SPT testing was done per standard US practice. After the application of overburden correction, one can calculate corrected blow count values (N_{1,60}) of about 13 to 20 for depths of 70 feet to 120 feet. Based on Figure 8, these correspond to CRR_{7.5} values of about 0.14 to 0.22. An MSF value of 1.7 can be calculated for cohesionless soils based on Figure 7. Therefore, calculated CRR_M values range from about 0.24 to 0.37. These values are much greater than the CSR_M value of 0.10 calculated for 70 feet. CSR_M values below 70 feet will be even smaller. Therefore, based on this simple analysis, the silt and sand, and sand and gravel units are not considered susceptible to liquefaction during the design seismic event established in step 2.
- 5. Figures 14 and 15 present the stress-strain and q-p' paths, respectively, for SOLW under laboratory consolidated undrained monotonic triaxial tests. These tests were conducted with applied effective confining stresses that are in the general range of insitu effective vertical stresses. Under laboratory undrained shearing,

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12 out of 17 SOLW samples (two to three specimens were tested for each sample) showed strain-hardening ductile behavior. Out of the remaining five samples, three showed limited strain-softening behavior (OL-STA-20052, OL-STA-20038, and OL-SB-10131 in Figure 14) and two showed gradual strain softening behavior (OL-SB-10133 and OL-SB-10135 in Figure 14). This gradual softening appears different from the sudden strength loss that is typical of soils susceptible to flow liquefaction or sensitive behavior. Therefore, based on these tests one can conclude that SOLW in the ILWD area is not likely to be susceptible to flow liquefaction or show sensitive behavior.

CONCLUSIONS

Liquefaction potential of the Solvay Waste (SOLW) and the underlying soils was evaluated for existing conditions. Based on the results summarized herein, the ILWD and underlying soils are not considered to have the potential for liquefaction or cyclic softening during the contingency level seismic event. In addition, the SOLW does not appear to have the potential for sensitive behavior or loss of shear strength.

As indicated previously, since the details of the isolation cap are currently being developed, the evaluation of the capped condition is not explicitly included herein. The liquefaction potential evaluation of the existing SOLW and underlying soils will not be affected by the installation of a cap (anticipated to be approximately 3-ft thick) at slopes that are similar to existing conditions, and therefore will not need to be updated for post-capping conditions. However, liquefaction potential of the cap itself will be addressed during the Intermediate Capping Design.

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Client: Honeywell Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.: GD4014 Task No.: 02

Tables

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Table 1. Summary of material properties

	General		Typical Range of	Typical Range of	Typical Range of	Typical Range of	Typical Range of	Typical	Total Unit	Undr S	ained Shear trength ¹
Material	Classification	Liquid Limit (%)	Plastic Limit (%)	Water Content (%)	Plasticity Index	Liquidity Index	Fines Content	Range of SPT N value	Weight (pcf)	From UU (psf)	From CU (psf)
Silt ²	NA	NA	NA	NA	NA	NA	NA	NA^1	98	NA	NA
SOLW	MH	40 - 146	30 - 80	40 - 260	10 - 80	1.0 - 6.4	65 - 100	$0 - 7^3$	81	245	$S_u / \sigma'_v = 0.35^4$
Marl	MH and CH	60 - 80	25 - 45	35 - 85	20 - 50	0.4 – 1.1	96 - 100	$0 - 4^3$	98	350	$S_u/\sigma'_v = 0.35$
Silt/Clay	CL and CH	32 - 70	20 - 45	20 - 80	15-40	0.4 - 1.0	93 - 100	0 ³	108	350	$S_u/\sigma'_v = 0.35$
Silt/Sand	NA	NA	NA	NA	NA	NA	NA	20 - 80	120	NA	NA
Sand/Gravel	NA	NA	NA	NA	NA	NA	NA	20 to > 100	120	NA	NA
Till	NA	NA	NA		NA	NA	NA	> 100	120	NA	NA
Shale	NA	NA	NA	NA	NA	NA	NA	> 100	120	NA	NA

Notes:

¹NA – Not Applicable
²Properties of marl are also considered applicable for the silt overlying the Solvay waste in certain areas of the ILWD.
³SPT N values are zero at most of the depths within the SOLW, marl, and silt/clay layers.
⁴ The undrained shear strength ratio of normally consolidated SOLW was estimated to be 0.35 as presented in the Data Package accounts for the insitu overconsolidation of SOLW. The shear strength ratio of 0.35 used herein conservatively assumes normally consolidated conditions and is used only to simplify the

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Table 2. Calculation of CSR, CRR, and factor of safety against liquefaction

Unit weight of water =	62.4 pcf
Maximum surface acceleration =	0.09 g
K-alpha =	1
OCR model parameter, m =	0.8
Earthquake magnitude =	5.3
Magnitude scaling factor for cohesive soils =	1.13

Depth (ft)	Depth (m)	Idealized Soil Type	Unit Weight (pcf)	Vertical Effective Stress (psf)	Vertical Total Stress (psf)	Sress Reduction Factor	Equivalent Cyclic Shear Stress (psf)	CSR _M	Cu/Sigv' - NC	OCR	Cu/Sigv' - OC	CRR _{7.5}	CRR _M	FSliq
0	0.0	SOLW	81	0	0	1.00	0		0.35	2.0	0.61	0.49	0.55	
5	1.5	SOLW	81	93	405	0.99	23	0.25	0.35	2.0	0.61	0.49	0.55	2.18
10	3.0	SOLW	81	186	810	0.98	46	0.25	0.35	2.0	0.61	0.49	0.55	2.20
15	4.6	SOLW	81	279	1,215	0.97	69	0.25	0.35	2.0	0.61	0.49	0.55	2.22
20	6.1	SOLW	81	372	1,620	0.96	91	0.24	0.35	2.0	0.61	0.49	0.55	2.25
25	7.6	SOLW	81	465	2,025	0.94	112	0.24	0.35	2.0	0.61	0.49	0.55	2.29
30	9.1	SOLW	81	558	2,430	0.92	131	0.23	0.35	2.0	0.61	0.49	0.55	2.34
35	10.7	Marl	98	736	2,920	0.89	152	0.21	0.35	1.0	0.35	0.28	0.32	1.52
40	12.2	Marl	98	914	3,410	0.85	170	0.19	0.35	1.0	0.35	0.28	0.32	1.70
45	13.7	Silt and Clay	108	1,142	3,950	0.80	186	0.16	0.35	1.0	0.35	0.28	0.32	1.94
50	15.2	Silt and Clay	108	1,370	4,490	0.75	198	0.14	0.35	1.0	0.35	0.28	0.32	2.18
55	16.8	Silt and Clay	108	1,598	5,030	0.70	207	0.13	0.35	1.0	0.35	0.28	0.32	2.43
60	18.3	Silt and Clay	108	1,826	5,570	0.66	215	0.12	0.35	1.0	0.35	0.28	0.32	2.68
65	19.8	Silt and Clay	108	2,054	6,110	0.62	222	0.11	0.35	1.0	0.35	0.28	0.32	2.91
70	21.3	Silt and Clay	108	2,282	6,650	0.59	230	0.10	0.35	1.0	0.35	0.28	0.32	3.12

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Figures



Figure 1. Monotonic and cyclic soil behaviors leading to different liquefaction mechanisms [Castro, 1976].

Notes: the following is noted in regards to the terminology used in this figure and the text:

- 1. The terms static loading and monotonic loading are used to describe similar loading.
- 2. Cyclic loading may include seismic (earthquake) or periodic wave loading.
- 3. "Instability and flow" corresponds to flow liquefaction behavior.
- 4. "Deformations of stable soil" corresponds to cyclic mobility (or cyclic softening).





Figure 2. Undrained stress-strain behavior of soils. (Figures from: (a) Kramer [1996]; and (b) Yamamuro & Covert [2001]).

Notes: the following is noted in regards to the terminology used in this figure and the text:

- 1. The term dilation in the figure corresponds to the strain hardening behavior described in the text.
- 2. The term limited liquefaction in the figure corresponds to the limited strain softening behavior described in the text.
- 3. The term liquefaction in the figure corresponds to the strain softening behavior described in the text.



Figure 3. Modified Chinese criteria for screening liquefaction potential [Finn et al., 1994] (figure taken from Seed et al., 2001).

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	Liquid Limit ¹ < 32	Liquid Limit ≥ 32
		Further Studies
Clay Content ²	Susceptible	Required
< 10%		
		(Considering
		plastic non-clay
		sized grains –
		such as Mica)
	Further Studies	
Clay Content ²	Required	Not Susceptible
≥10%		
	(Considering non-	
	plastic clay sized	
	grains – such as	
	mine and quarry	
	tailings)	

Notes:

- 1. Liquid limit determined by Casagrande-type percussion apparatus.
- 2. Clay defined as grains finer than 0.002 mm.

Figure 4. Liquefaction susceptibility of silty and clayey sands [Andrews and Martin, 2000] (figure taken from Seed et al., 2001).



Figure 5. Liquefaction susceptibility criteria with data plotted from: (a) laboratory cyclic triaxial testing; (b) field data from Turkey (Kocaeli) earthquake; (c) field data from Northridge earthquake; (d) field data used for developing Chinese criteria; and (e) field data from Taiwan (Chi-Chi) earthquake [Bray and Sancio, 2006].



Figure 6. Relationship between peak acceleration on rock and soft soil sites [Idriss, 1990].

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Figure 7. MSF correlations proposed by Boulanger and Idriss for clayey and sandy soils [2007].

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Client: Honeywell		Project:	Ononda	aga Lake ILW	D Stability	Project/ Proposal No.:	GD4014	I Ta	sk No.:	02



Figure 8. Relationship between SPT blow counts and CRR based on case histories [NCEER, 1997].

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Figure 9. Application of Chinese criteria for SOLW, marl, and silt and clay.





Figure 10. Application of the criteria proposed by Bray and Sancio [2006] for SOLW, marl, and silt and clay.



Figure 11. Peak ground acceleration with a 10% probability of exceedance in 50 years [USGS, 2008]. A latitude of 43° 04' N and a longitude of 76° 11' W were used to obtain the PGA value using the interactive maps from the USGS website.



Figure 12. Calculated CSR and CRR values for SOLW marl, and silt and clay.



Figure 13. Calculated FS_{liq} values for SOLW marl, and silt and clay.



Figure 14. Consolidated undrained monotonic triaxial test stress-strain paths for SOLW (note that effective confining stresses applied in the lab are marked for each test).



Figure 14. Consolidated undrained monotonic triaxial test stress-strain paths for SOLW (note that effective confining stresses applied in the lab are marked for each test) (continued).



Figure 15. Consolidated undrained monotonic triaxial test q-p' stress paths for SOLW.



Figure 15. Consolidated undrained monotonic triaxial test q-p' stress paths for SOLW (continued).



Figure 15. Consolidated undrained monotonic triaxial test q-p' stress paths for SOLW (continued).

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Client: Honeywell		Project:	Ononda	aga Lake SCA	30% Design	Project/ Proposal N	lo.: GD	3944	Task No.:	09

Attachment 1

Deaggregated Seismic Hazard

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Written by: Ming Zhu		Date: 3/27/2008 Reviewed by:	R. Kulasingam/Jay Beech	Date:	3/28/2008
Client: Honeywell	Project:	Onondaga Lake SCA 30% Design	Project/ Proposal No.: GD	3944 T	ask No.: 09

This attachment presents the deaggregated seismic hazard for the 10% probability of exceedance in a 50-year event, which is based on the 2002 United States Geological Survey (USGS) maps. The following paragraphs describe how a 5.3 moment magnitude was selected for the liquefaction analyses based on the deaggregation.

Conventional engineering methods for evaluation of soil liquefaction potential are deterministic. Required (deterministic) input parameters for evaluation of soil liquefaction include design earthquake magnitude, M (which is a proxy for duration of strong ground shaking) and free-field (zero-period) Peak Ground Acceleration (PGA).

In the Central and Eastern U.S., seismic hazard (and therefore PGA) is typically governed by multiple seismic sources at various distances. Probabilistic seismic hazard analysis is conducted in order to account for these multiple seismic source – distance pairs. The result of the probabilistic seismic hazard analysis is the PGA for a given return period. The contribution of each seismic source in evaluation of the PGA in a probabilistic seismic hazard analysis can be assessed by a process called deaggregation.

Deaggregation does not result in a single earthquake magnitude–distance pair. The result of deaggregation is a series of seismic hazard matrices (usually 3 to 5 matrices, each for a different period of oscillation, as available at the United States Geological Survey, USGS web site). For an evaluation of soil liquefaction potential, zero-period PGA is required. Hence, a 0.1-second matrix (matrix with the lowest period available from the USGS web page) is considered for this site.

A review of the 0.1-second matrix reveals the following three candidate magnitudedistance pairs:

M 4.81 at 36.3 km (Epsilon = 4.53) M 5.25 at 115.3 km (Epsilon = 3.39) M 5.72 at 164.7 km (Epsilon = 3.27)

These above-listed magnitude-distance pairs have the largest Epsilon and hence, dominate the PGA estimate for this site (zero Epsilon corresponds to the median motion; Epsilon = 2 corresponds to median plus one standard deviation motion; larger Epsilon=larger PGA).

An inspection of the above-listed candidate events indicates that the PGA evaluated for this site corresponds to M 4.81. However, M 4.81 at 36.3 km pair is associated with a relatively low duration of strong ground shaking (5.9 seconds as opposed to 18.5 seconds from the M 5.25 event at a distance of 115.3 km). Therefore, Geosyntec selected the highest evaluated PGA (i.e., PGA that corresponds to an M 4.81 event at 36.3 km) and

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duration (i.e., duration that corresponds to M 5.25 event) for an evaluation of soil liquefaction at this site. This is a conservative approach.

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*** Deaggregation of Seismic Hazard at Three Periods of Spectral Accel. *** *** Data from U.S.G.S. National Seismic Hazards Mapping Project, 1996 version *** PSHA Deaggregation. %contributions. site: Lake Onondaga long: 76.20000 W., lat: 43.0600 N. Return period: 475yrs. 2.00 s. PSA =0.0127989g. Computed annual rate=.21076E-02 DIST(KM) MAG(MW) ALL-EPS EPSILON>2 1<EPS<2 0<EPS<1 -1<EPS<0 -2<EPS<-1 EPS<-2 13.1 4.87 0.121 0.037 0.065 0.019 0.001 0.000 0.000 13.7 5.27 0.250 0.022 0.091 0.106 0.029 0.001 0.000 35.4 5.30 0.262 0.044 0.134 0.082 0.002 0.000 0.00064.1 5.33 0.163 0.062 0.094 0.007 0.000 0.000 0.000 5.34 0.090 0.054 0.036 0.000 0.000 0.000 89.6 0.000 114.5 5.35 0.115 0.087 0.028 0.000 0.000 0.000 0.000 0.090 138.7 5.35 0.101 0.011 0.000 0.000 0.000 0.000 164.8 5.36 0.133 0.130 0.003 0.000 0.000 0.000 0.000 190.1 5.36 0.082 0.082 0.000 0.000 0.000 0.000 0.000 210.1 5.36 0.076 0.076 0.000 0.000 0.000 0.000 0.000 234.6 5.37 0.093 0.093 0.000 0.000 0.000 0.000 0.000 259.7 5.37 0.057 0.057 0.000 0.000 0.000 0.000 0.000 284.5 5.37 0.067 0.067 0.000 0.000 0.000 0.000 0.000 5.71 13.6 0.212 0.006 0.037 0.091 0.067 0.010 0.000 0.255 36.1 5.74 0.522 0.027 0.155 0.082 0.002 0.000 65.2 5.76 0.514 0.051 0.226 0.219 0.018 0.000 0.000 90.0 5.77 0.418 0.060 0.233 0.125 0.000 0.000 0.000 110.3 5.78 0.474 0.083 0.292 0.099 0.000 0.000 0.000 0.974 0.210 0.633 135.6 5.78 0.130 0.000 0.000 0.000 165.3 5.79 1.135 0.311 0.760 0.064 0.000 0.000 0.000 190.3 5.79 0.816 0.275 0.521 0.021 0.000 0.000 0.000 210.3 5.80 0.841 0.330 0.510 0.002 0.000 0.000 0.000 234.9 5.80 1.164 0.525 0.639 0.000 0.000 0.000 0.000 259.8 5.81 0.805 0.413 0.392 0.000 0.000 0.000 0.000 284.8 5.81 1.048 0.621 0.427 0.000 0.000 0.000 0.000 309.9 5.81 0.662 0.434 0.228 0.000 0.000 0.000 0.000 334.7 5.82 0.828 0.593 0.235 0.000 0.000 0.000 0.000 364.3 5.82 0.662 0.536 0.126 0.000 0.000 0.000 0.000 389.7 5.82 0.361 0.318 0.043 0.000 0.000 0.000 0.000 410.0 5.82 0.278 0.251 0.026 0.000 0.000 0.000 0.000 434.5 0.296 5.83 0.315 0.019 0.000 0.000 0.000 0.000 0.204 464.3 5.83 0.207 0.002 0.000 0.000 0.000 0.000 489.2 5.83 0.102 0.102 0.000 0.000 0.000 0.000 0.000 509.7 5.84 0.072 0.072 0.000 0.000 0.000 0.000 0.000 534.1 5.84 0.073 0.073 0.000 0.000 0.000 0.000 0.000 13.9 6.21 0.111 0.003 0.016 0.039 0.039 0.014 0.001 37.2 6.23 0.414 0.011 0.068 0.170 0.142 0.022 0.000

0.297

0.331

0.439

0.145

0.102

0.096

0.005

0.000

0.000

0.000

0.000

0.000

65.9

90.3

110.4 6.25

6.24

6.25

0.596

0.608

0.777

0.021

0.025

0.035

0.127

0.150

0.207

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136.0	625 17	01 0.089	0 529	1.026	0 147	0.000	0.000			
150.0	6.26 2.4	122 0.140	0.925	1.020	0.147	0.000	0.000			
100.4	6.26 1.0	122 0.140	0.855	1.020	0.100	0.000	0.000			
210.4	6 27 2 1	00 0.129	0.708	1.050	0.033	0.000	0.000			
210.4	6 27 2.1	47 0.200	1.626	1.074	0.007	0.000	0.000			
250.0	6 27 25	047 0.200	1.020	1.442	0.000	0.000	0.000			
239.9	0.27 2.3	0.242	1.558	0.957	0.000	0.000	0.000			
263.1	0.28 5.0	012 0.394	2.098	1.119	0.000	0.000	0.000			
309.9	0.28 2.4	0.309	1.327	0.030	0.000	0.000	0.000			
534.9 264.5	0.29 3.3	0/3 0.480	2.182	0.712	0.000	0.000	0.000			
504.5 290.9	0.29 2.9	04 0.495	2.012	0.458	0.000	0.000	0.000			
589.8	0.29 1.7	48 0.334	1.215	0.199	0.000	0.000	0.000			
410.1	6.30 1.4	134 0.306	1.009	0.119	0.000	0.000	0.000			
434./	6.30 1.7	0.429	1.230	0.092	0.000	0.000	0.000			
464.5	6.30 1.2	264 0.362	0.884	0.018	0.000	0.000	0.000			
489.3	6.30 0.6	00 0.218	0.452	0.000	0.000	0.000	0.000			
509.8	6.31 0.3	00 0.178	0.323	0.000	0.000	0.000	0.000			
534.3	6.31 0.3	0.214	0.327	0.000	0.000	0.000	0.000			
594.0	0.31 0.2	0.132	0.16/	0.000	0.000	0.000	0.000			
584.9	0.31 0.4	FIU 0.199	0.210	0.000	0.000	0.000	0.000			
37.6	6.72 0.1	6/ 0.004	0.023	0.059	0.059	0.021	0.001			
66.3	6./2 0.2	89 0.007	0.044	0.110	0.108	0.020	0.000			
90.4	6.72 0.3	24 0.009	0.052	0.130	0.122	0.012	0.000			
110.5	6.72 0.4	435 0.012	0.071	0.179	0.164	0.009	0.000			
136.2	6./3 1.0	0.030	0.181	0.454	0.386	0.009	0.000			
165.5	6./3 1.3	0.042	0.248	0.623	0.44/	0.000	0.000			
190.5	6./3 I.I	2/ 0.03/	0.218	0.548	0.324	0.000	0.000			
210.5	6./3 1.3	0.046	0.275	0.691	0.336	0.000	0.000			
235.5	6.73 2.2	0.081	0.486	1.220	0.430	0.000	0.000			
260.0	6./3 1.8	57 0.073	0.436	1.08/	0.260	0.000	0.000			
285.4	6./3 2.9	0.124	0.743	1.//1	0.299	0.000	0.000			
310.1	6./4 2.1	82 0.099	0.593	1.346	0.143	0.000	0.000			
333.9	6./4 2.4	19 0.122	0.726	1.533	0.099	0.000	0.000			
364.3	6./4 1.8	534 0.099	0.591	1.113	0.031	0.000	0.000			
389.9	6./4 1.0	0.061	0.36/	0.620	0.001	0.000	0.000			
414.4	6./4 1.1	14 0.074	0.444	0.655	0.000	0.000	0.000			
439.8	6.74 0.6	0.048	0.285	0.360	0.000	0.000	0.000			
464.8	6.75 0.8	6/4 0.066	0.391	0.418	0.000	0.000	0.000			
489.8	6.75 0.5	00 0.041	0.243	0.216	0.000	0.000	0.000			
509.7	6.75 0.3	0.034	0.201	0.152	0.000	0.000	0.000			
534.3	6.75 0.4	109 0.039	0.233	0.136	0.000	0.000	0.000			
559.9	6.75 0.2	48 0.026	0.154	0.068	0.000	0.000	0.000			
585.3	6.75 0.3	0.041	0.232	0.082	0.000	0.000	0.000			
37.7	7.20 0.1	00 0.002	0.014	0.034	0.034	0.014	0.002			
66.4	7.21 0.1	84 0.004	0.026	0.064	0.064	0.024	0.001			
90.4	7.21 0.2	14 0.005	0.030	0.076	0.076	0.026	0.000			

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Client: Honeywell Project:	Onondaga L	ake SCA	30% Des	sign	Project	Proposal	No.:	GD3944	Task No	.: 09
110.5	7.21 0.201	0.007	0.042	0 105	0 105	0.022	0.000			
110.5	7.21 0.291	0.007	0.042	0.105	0.105	0.033	0.000			
136.3	7.21 0.729	0.018	0.106	0.266	0.266	0.074	0.000			
165.5	7.21 0.975	0.024	0.145	0.365	0.365	0.076	0.000			
190.6	7.21 0.836	0.021	0.128	0.321	0.320	0.046	0.000			
210.6	7.21 1.031	0.027	0.161	0.405	0.395	0.042	0.000			
235.6	7.21 1.764	0.048	0.284	0.714	0.671	0.047	0.000			
260.0	7.22 1.535	0.043	0.255	0.641	0.569	0.026	0.000			
285.5	7.22 2.524	0.073	0.435	1.093	0.897	0.026	0.000			
310.1	7.22 1.945	0.058	0.347	0.872	0.656	0.011	0.000			
334.0	7.22 2.292	0.071	0.425	1.067	0.722	0.007	0.000			
364.4	7.22 1.776	0.058	0.346	0.869	0.502	0.001	0.000			
390.0	7.22 1.043	0.036	0.212	0.533	0.262	0.000	0.000			
414.5	7.22 1.202	0.043	0.256	0.642	0.261	0.000	0.000			
439.9	7.23 0.741	0.028	0.165	0.415	0.134	0.000	0.000			
464.9	7.23 0.976	0.038	0.228	0.564	0.145	0.000	0.000			
489.8	7.23 0.579	0.024	0.142	0.342	0.071	0.000	0.000			
509.6	7.23 0.454	0.019	0.116	0.271	0.047	0.000	0.000			
534.3	7.22 0.470	0.021	0.127	0.285	0.037	0.000	0.000			
560.0	7.22 0.296	0.014	0.085	0.180	0.017	0.000	0.000			
585.5	7.23 0.459	0.023	0.139	0.274	0.023	0.000	0.000			
Summary st	tatistics for abc	ove 2.0s l	PSA dea	aggregat	ion, $R=c$	listance,	e=epsil	on:		
Modal s	$r_{\rm c-site} R = 285$	1 km N	I = 6.33, 0	$e^{0} = 0.20$	71 from	neak (R	M) hin	5.		
Wodar S	Primar	v distanc	$e^{-0.20}$	· EDICE	NTP AT	peak (R,	wi) 0111			
MODE R*= 335	.0km; $M^*= 6.2$	9; EPS.I	NTERV	AL: 1 to	$\sim 2 \text{ sigm}$	a % CO	NTRIB	.= 2.182		
Principal sour	ces (faults) sub	duction	random	seismici	tv havin	σ >10%	contrib	ution)		
Source	·	% cont	r R(km	$M = \frac{1}{2}$	ensilon0	(mean v	alues)	actory		
CE	US gridded sei:	smicity F	Frankel	57 12	295.0	6 58 0	18			
CE	US gridded sei	smicity.	Foro att	42.88	282.7	5.45 0.1	36			
*********	****	******	******	******	******	******	*****	******	****	
PSHA Deaggregation	n. %contributio	ons. site:	Lake O	nondaga	long: 7	6.20000	W., lat	: 43.0600) N.	
Return period:	475vrs. 0.50 s	PSA = 0	0.048260	7g. Con	nouted a	nnual rat	e = .2110)4E-02		
DIST(KM) MAG(MW) ALL-EPS EI	PSILON	>2 1 <ei< td=""><td>PS < 2.0 <</td><td>EPS<1 -</td><td>1<eps<< td=""><td>0 -2<ei< td=""><td>PS<-1 EF</td><td>PS<-2</td><td></td></ei<></td></eps<<></td></ei<>	PS < 2.0 <	EPS<1 -	1 <eps<< td=""><td>0 -2<ei< td=""><td>PS<-1 EF</td><td>PS<-2</td><td></td></ei<></td></eps<<>	0 -2 <ei< td=""><td>PS<-1 EF</td><td>PS<-2</td><td></td></ei<>	PS<-1 EF	PS<-2	
12.9	4 83 0 834	0.034	0 205	0 429	0 161	0.005	0 000	0 1 21	~ _	
34.1	4.85 1.073	0.150	0.614	0.305	0.005	0.000	0.000			
63.5	4 87 0 444	0 224	0 2 2 0	0.000	0.000	0.000	0.000			
89.6	4 88 0 219	0.178	0.041	0.000	0.000	0.000	0.000			
115.1	4 89 0 296	0.279	0.017	0.000	0.000	0.000	0.000			
13.1	4.89 0.185	0.185	0.000	0.000	0.000	0.000	0.000			
157.7	4 90 0 217	0.105	0.000	0.000	0.000	0.000	0.000			
104.1	4.90 0.217	0.217	0.000	0.000	0.000	0.000	0.000			
107.0 200.8	4.90 0.103	0.103	0.000	0.000	0.000	0.000	0.000			
209.0	A 01 0.079	0.072	0.000	0.000	0.000	0.000	0.000			
255.8	4.71 0.0/3	0.073	0.000	0.000	0.000	0.000	0.000			

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Written by: Ming Zhu		Date	: 3/27	/2008	Review	ved by:	R. Ku	lasingan	n/Jay Be	ech Date	: 3/2	8/2008
Client: Honeywell	Project:	Onor	ndaga La	ake SCA	30% De	sign	Project	/ Proposa	al No.:	GD3944	Task No	o.: 09
	10.7	5.00	0.575	0.015	0.000	0.004	0 011	0.025	0.000			
	13.7	5.22	0.575	0.015	0.089	0.224	0.211	0.035	0.000			
	35.8	5.24	1.420	0.065	0.390	0.780	0.184	0.001	0.000			
	64.6	5.26	1.108	0.123	0.642	0.342	0.001	0.000	0.000			
	89.9	5.27	0.768	0.145	0.552	0.072	0.000	0.000	0.000			
	112.3	5.28	0.923	0.254	0.650	0.020	0.000	0.000	0.000			
	136.3	5.28	1.225	0.442	0.783	0.000	0.000	0.000	0.000			
	164.6	5.29	1.264	0.691	0.573	0.000	0.000	0.000	0.000			
	190.0	5.29	0.730	0.525	0.205	0.000	0.000	0.000	0.000			
	210.0	5.30	0.627	0.528	0.099	0.000	0.000	0.000	0.000			
	234.3	5.30	0.691	0.655	0.036	0.000	0.000	0.000	0.000			
	260.8	5.31	0.414	0.414	0.000	0.000	0.000	0.000	0.000			
	285.1	5.31	0.345	0.345	0.000	0.000	0.000	0.000	0.000			
	309.5	5.31	0.188	0.188	0.000	0.000	0.000	0.000	0.000			
	333.9	5.32	0.184	0.184	0.000	0.000	0.000	0.000	0.000			
	363.6	5.32	0.109	0.109	0.000	0.000	0.000	0.000	0.000			
	13.9	5.70	0.268	0.006	0.037	0.093	0.093	0.035	0.002			
	37.0	5.70	0.955	0.027	0.162	0.408	0.328	0.029	0.000			
	65.4	5.72	1.170	0.051	0.305	0.672	0.142	0.000	0.000			
	90.1	5.73	1.029	0.060	0.360	0.590	0.019	0.000	0.000			
	110.2	5.73	1.184	0.083	0.495	0.606	0.000	0.000	0.000			
	135.6	5.73	2.368	0.212	1.248	0.908	0.000	0.000	0.000			
	165.1	5.74	2.650	0.335	1.736	0.579	0.000	0.000	0.000			
	190.2	5.75	1.781	0.308	1.287	0.186	0.000	0.000	0.000			
	210.2	5.75	1.717	0.384	1.270	0.063	0.000	0.000	0.000			
	234.6	5.75	2.164	0.670	1.490	0.004	0.000	0.000	0.000			
	259.6	5.76	1.349	0.571	0.779	0.000	0.000	0.000	0.000			
	284.5	5.76	1.564	0.865	0.699	0.000	0.000	0.000	0.000			
	309.7	5.77	0.877	0.594	0.283	0.000	0.000	0.000	0.000			
	334.2	5.77	0.956	0.764	0.192	0.000	0.000	0.000	0.000			
	363.9	5.77	0.640	0.594	0.046	0.000	0.000	0.000	0.000			
	389.5	5.78	0.299	0.297	0.001	0.000	0.000	0.000	0.000			
	409.8	5.78	0.202	0.202	0.000	0.000	0.000	0.000	0.000			
	434.1	5.78	0.195	0.195	0.000	0.000	0.000	0.000	0.000			
	463.9	5.79	0.105	0.105	0.000	0.000	0.000	0.000	0.000			
	14.0	6.21	0.114	0.003	0.015	0.039	0.039	0.015	0.002			
	37.5	6.22	0.471	0.011	0.068	0.170	0.170	0.051	0.001			
	66.0	6.22	0.749	0.021	0.127	0.319	0.265	0.016	0.000			
	90.3	6.23	0.774	0.025	0.150	0.377	0.221	0.001	0.000			
	110.4	6.23	0.974	0.035	0.206	0.518	0.214	0.000	0.000			
	135.9	6.23	2.181	0.088	0.529	1.274	0.291	0.000	0.000			
	165.5	6.24	2.808	0.140	0.833	1.693	0.142	0.000	0.000			
	190.3	6.24	2.146	0.128	0.767	1.226	0.025	0.000	0.000			
	210.3	6.25	2.286	0.160	0.957	1.168	0.001	0.000	0.000			
	235.0	6.25	3.243	0.279	1.663	1.300	0.000	0.000	0.000			
	259.8	6.25	2.269	0.242	1.384	0.644	0.000	0.000	0.000			

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Written by: <u>Ming Zhu</u>		Date	3/27	/2008	Review	red by:	R. Ku	lasingan	n/Jay Be	ech Date	e: <u>3/2</u>	8/2008
Client: Honeywell	Project:	Onor	ndaga La	ıke SCA	30% De	sign	Project	/ Proposa	ıl No.:	GD3944	Task No	o.: 09
	2010	6.26	2 0 4 4	0.204	2.012	0.520	0.000	0.000	0.000			
	204.0	0.20	2.944	0.394	2.012	0.339	0.000	0.000	0.000			
	309.8	0.20	1.857	0.308	1.559	0.190	0.000	0.000	0.000			
	334.0	6.27	2.229	0.479	1.008	0.092	0.000	0.000	0.000			
	304.1	6.27	1.696	0.495	1.195	0.007	0.000	0.000	0.000			
	389.0	6.28	0.880	0.333	0.547	0.000	0.000	0.000	0.000			
	409.9	6.28	0.646	0.298	0.348	0.000	0.000	0.000	0.000			
	434.3	6.28	0.686	0.393	0.294	0.000	0.000	0.000	0.000			
	464.1	6.29	0.414	0.289	0.125	0.000	0.000	0.000	0.000			
	489.2	6.29	0.189	0.149	0.040	0.000	0.000	0.000	0.000			
	509.6	6.29	0.124	0.107	0.016	0.000	0.000	0.000	0.000			
	533.8	6.29	0.113	0.105	0.008	0.000	0.000	0.000	0.000			
	560.9	6.30	0.057	0.057	0.001	0.000	0.000	0.000	0.000			
	585.2	6.30	0.055	0.055	0.000	0.000	0.000	0.000	0.000			
	37.7	6.72	0.169	0.004	0.023	0.059	0.058	0.023	0.002			
	66.3	6.72	0.301	0.007	0.044	0.110	0.110	0.030	0.000			
	90.4	6.72	0.337	0.009	0.052	0.130	0.129	0.018	0.000			
	110.5	6.72	0.446	0.012	0.071	0.178	0.173	0.012	0.000			
	136.1	6.72	1.065	0.030	0.181	0.454	0.393	0.008	0.000			
	165.4	6.73	1.321	0.042	0.248	0.622	0.410	0.000	0.000			
	190.4	6.73	1.048	0.036	0.218	0.548	0.246	0.000	0.000			
	210.5	6.73	1.207	0.046	0.275	0.687	0.199	0.000	0.000			
	235.4	6.73	1.890	0.081	0.485	1.156	0.168	0.000	0.000			
	264.7	6.73	2.197	0.110	0.660	1.356	0.071	0.000	0.000			
	290.0	6.73	1.484	0.087	0.518	0.869	0.010	0.000	0.000			
	310.0	6.74	1.499	0.099	0.592	0.807	0.000	0.000	0.000			
	333.7	6.74	1.562	0.121	0.725	0.715	0.000	0.000	0.000			
	363.9	6.74	1.025	0.099	0.583	0.343	0.000	0.000	0.000			
	389.8	6.74	0.527	0.061	0.347	0.118	0.000	0.000	0.000			
	414.1	6.74	0.528	0.074	0.378	0.075	0.000	0.000	0.000			
	439.7	6.75	0.276	0.048	0.208	0.020	0.000	0.000	0.000			
	464.5	6.75	0.307	0.065	0.232	0.010	0.000	0.000	0.000			
	489.6	6.75	0.155	0.041	0.114	0.000	0.000	0.000	0.000			
	509.5	6.74	0.108	0.034	0.074	0.000	0.000	0.000	0.000			
	533.9	6.75	0.099	0.039	0.060	0.000	0.000	0.000	0.000			
	559.7	6.75	0.052	0.025	0.027	0.000	0.000	0.000	0.000			
	584.8	6 7 5	0.064	0.037	0.026	0.000	0.000	0.000	0.000			
	37.7	7.20	0.100	0.002	0.014	0.034	0.034	0.014	0.002			
	66.4	7 21	0.185	0.004	0.026	0.064	0.064	0.025	0.001			
	90.4	7.21	0.214	0.005	0.030	0.076	0.076	0.027	0.000			
	110.5	7 21	0.290	0.007	0.042	0 104	0 104	0.033	0.000			
	136.2	7.21	0.718	0.018	0.1042	0.266	0.266	0.063	0.000			
	165.5	7 21	0.942	0.074	0 1 4 5	0.364	0 3 5 9	0.049	0.000			
	190.5	7.21	0.780	0.024	0 1 2 8	0 3 2 1	0.207	0.077	0.000			
	210.5	7.21	0.709	0.021	0.120	0.321	0.297 0.341	0.022	0.000			
	210.5	7.21	1 568	0.027	0.101	0.712	0.541	0.010	0.000			
	255.5	1.44	1.500	0.040	0.204	0./13	0.311	0.011	0.000			

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Written by: Ming Zhu	Date: 3/27	/2008	Review	ed by:	R. Ku	lasingam	/Jay Be	ech Date	e: <u>3/28/2</u>	008
Client: Honeywell Project:	Onondaga La	ake SCA	30% De	sign	Project	Proposa	l No.:	GD3944	Task No.:	09
261.9	7 22 1 501	0.050	0 301	0 755	0 393	0.002	0.000			
286.4	7.22 1.301	0.050	0.301	0.755	0.375	0.002	0.000			
310.0	7.22 1.039	0.005	0.307	0.909	0.450	0.000	0.000			
333.8	7.22 1.498	0.058	0.347	0.040	0.233	0.000	0.000			
364.2	7.23 1.005	0.071	0.424	0.505	0.177	0.000	0.000			
389.9	7.23 0.645	0.035	0.212	0.367	0.031	0.000	0.000			
414.3	7.23 0.645	0.033	0.212	0.307	0.017	0.000	0.000			
439.8	7.24 0.388	0.045	0.255	0.192	0.003	0.000	0.000			
459.0	7.24 0.366	0.020	0.103	0.172	0.000	0.000	0.000			
489.7	7.24 0.407	0.024	0.132	0.097	0.000	0.000	0.000			
509.5	7.25 0.184	0.024	0.102	0.057	0.000	0.000	0.000			
533.9	7.25 0.104	0.01	0.105	0.001	0.000	0.000	0.000			
559.8	7.25 0.096	0.021	0.103	0.045	0.000	0.000	0.000			
585.2	7.26 0.132	0.014	0.005	0.020	0.000	0.000	0.000			
505.2	7.20 0.152	0.025	0.007	0.020	0.000	0.000	0.000			
Summary si Mean src Modal s MODE R*= 285	atistics for abo -site R= 229.7 rc-site R= 235 Primary .1km; M*= 6.2	ve 0.5s 1 km; M= .0 km; N distanc 6; EPS.1	PSA dea = 6.23; e A= 6.25; e metric INTERV	aggregat 0= 0.49 e0= 0. : EPICE VAL: 1 to	ion, R=c 9; e= 1.2 58 from NTRAL 0 2 sigma	listance, 22 for all peak (R a % CO	e=epsil l source ,M) bin NTRIB	lon: s. s.= 2.012		
Principal sour	ces (faults, sub	duction,	random	seismici	ity havin	g >10%	contrib	ution)		
Source		% cont	r. R(kn	n) M	epsilon0	(mean y	values)			
CE	JS gridded seis	smicity,I	Frankel	66.19	237.1	6.24 0	.47			
CE ***********	US gridded sei: ***********	smicity,	Γoro att ******	33.81 ******	215.3 (******	5.22 0. ******	.53 ******	*******	***	
PSHA Deaggregation	n. %contributio	ons. site:	Lake_O	nondaga	ı long: 7	6.20000) W., lat	: 43.0600 1	N.	
Return period:	475yrs. 0.10 s.	PSA = 0	0.070909	4g. Con	nputed a	nnual ra	te = .210	80E-02		
DIST(KM) MAG(MW) ALL-EPS EF	SILON	>2 1 <ei< td=""><td>PS<2 0<</td><td>EPS<1 -</td><td>1<eps<< td=""><td><0 -2<e< td=""><td>PS<-1 EPS</td><td><-2</td><td></td></e<></td></eps<<></td></ei<>	PS<2 0<	EPS<1 -	1 <eps<< td=""><td><0 -2<e< td=""><td>PS<-1 EPS</td><td><-2</td><td></td></e<></td></eps<<>	<0 -2 <e< td=""><td>PS<-1 EPS</td><td><-2</td><td></td></e<>	PS<-1 EPS	<-2	
13.9	4.81 1.461	0.034	0.206	0.516	0.516	0.180	0.009			
36.3	4.81 4.513	0.150	0.898	2.228	1.182	0.055	0.000			
64.4	4.82 3.813	0.282	1.679	1.826	0.026	0.000	0.000			
89.6	4.83 2.239	0.333	1.618	0.288	0.000	0.000	0.000			
114.6	4.84 2.696	0.774	1.903	0.020	0.000	0.000	0.000			
139.7	4.85 1.451	0.733	0.719	0.000	0.000	0.000	0.000			
163.5	4.86 1.444	1.142	0.302	0.000	0.000	0.000	0.000			
189.5	4.86 0.555	0.552	0.003	0.000	0.000	0.000	0.000			
209.4	4.87 0.339	0.339	0.000	0.000	0.000	0.000	0.000			
233.0	4.87 0.242	0.242	0.000	0.000	0.000	0.000	0.000			
262.2	4.88 0.103	0.103	0.000	0.000	0.000	0.000	0.000			
14.0	5.22 0.653	0.015	0.089	0.224	0.224	0.089	0.011			
37.1	5.22 2.464	0.065	0.390	0.980	0.902	0.126	0.001			
65.2	5.23 2.919	0.123	0.733	1.686	0.377	0.000	0.000			
89.9	5.24 2.241	0.145	0.864	1.229	0.004	0.000	0.000			
115.2	5.25 3.397	0.339	1.960	1.098	0.000	0.000	0.000			

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Written by: Ming Zhu		Date	Date: <u>3/27/2008</u> Reviewed by:				R. Kulasingam/Jay Bee			ech Date: 3/28/2008		
Client: Honeywell	Project:	Onondaga Lake SCA			30% Design		Project/ Proposal No.:		GD3944	Task No	.: 09	
	140.0	5 25	2 241	0 370	1 643	0 229	0.000	0.000	0.000			
	16/ 1	5.25	2.241	0.802	1.043	0.028	0.000	0.000	0.000			
	104.1	5.20	2.094	0.602	0.594	0.028	0.000	0.000	0.000			
	200.7	5.20	0.010	0.095	0.364	0.000	0.000	0.000	0.000			
	209.7	5.27	0.910	0.099	0.211	0.000	0.000	0.000	0.000			
	255.5	5.20	0.774	0.734	0.040	0.000	0.000	0.000	0.000			
	202.7	5.20	0.407	0.407	0.000	0.000	0.000	0.000	0.000			
	289.0	5.29	0.152	0.152	0.000	0.000	0.000	0.000	0.000			
	309.0	5.29	0.077	0.077	0.000	0.000	0.000	0.000	0.000			
	332.7	5.30	0.051	0.051	0.000	0.000	0.000	0.000	0.000			
	14.0	5.70	0.274	0.006	0.037	0.093	0.093	0.03/	0.006			
	57.5	5.70	1.141	0.027	0.163	0.408	0.408	0.130	0.004			
	65.8	5.70	1./28	0.051	0.305	0.767	0.585	0.020	0.000			
	90.1	5.71	1.613	0.060	0.360	0.901	0.291	0.000	0.000			
	112.6	5.72	2.169	0.106	0.633	1.303	0.128	0.000	0.000			
	136.5	5.71	3.005	0.190	1.132	1.642	0.041	0.000	0.000			
	164.7	5.72	3.267	0.335	1.881	1.052	0.000	0.000	0.000			
	189.9	5.73	1.872	0.308	1.348	0.217	0.000	0.000	0.000			
	209.9	5.73	1.549	0.385	1.125	0.039	0.000	0.000	0.000			
	234.0	5.74	1.578	0.650	0.929	0.000	0.000	0.000	0.000			
	263.2	5.75	1.025	0.694	0.331	0.000	0.000	0.000	0.000			
	289.3	5.75	0.399	0.352	0.046	0.000	0.000	0.000	0.000			
	309.2	5.76	0.268	0.264	0.004	0.000	0.000	0.000	0.000			
	333.2	5.76	0.208	0.208	0.000	0.000	0.000	0.000	0.000			
	362.8	5.77	0.089	0.089	0.000	0.000	0.000	0.000	0.000			
	14.0	6.21	0.114	0.003	0.016	0.039	0.039	0.016	0.003			
	37.7	6.21	0.493	0.011	0.068	0.170	0.170	0.067	0.006			
	66.2	6.22	0.859	0.021	0.127	0.320	0.319	0.071	0.000			
	90.3	6.22	0.913	0.025	0.150	0.377	0.344	0.017	0.000			
	110.3	6.22	1.133	0.035	0.207	0.519	0.369	0.004	0.000			
	135.8	6.23	2.414	0.089	0.529	1.296	0.500	0.000	0.000			
	165.2	6.23	2.835	0.140	0.834	1.666	0.195	0.000	0.000			
	190.2	6.24	1.938	0.128	0.768	1.022	0.020	0.000	0.000			
	210.1	6.24	1.842	0.160	0.925	0.757	0.000	0.000	0.000			
	234.5	6.25	2.210	0.280	1.398	0.532	0.000	0.000	0.000			
	260.6	6.26	1.372	0.290	0.952	0.130	0.000	0.000	0.000			
	284.9	6.25	1.198	0.342	0.833	0.023	0.000	0.000	0.000			
	309.5	6.26	0.629	0.283	0.346	0.000	0.000	0.000	0.000			
	333.7	6.27	0.579	0.371	0.208	0.000	0.000	0.000	0.000			
	363.3	6.28	0.309	0.259	0.050	0.000	0.000	0.000	0.000			
	389.2	6.29	0.117	0.114	0.003	0.000	0.000	0.000	0.000			
	409.5	6.29	0.066	0.066	0.000	0.000	0.000	0.000	0.000			
	433.4	6.30	0.051	0.051	0.000	0.000	0.000	0.000	0.000			
	37.7	6.72	0.171	0.004	0.023	0.059	0.059	0.023	0.004			
	66.4	6.72	0.315	0.007	0.044	0.110	0.110	0.042	0.002			
	90.4	6.72	0.358	0.009	0.052	0.130	0.130	0.038	0.000			
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Written by: Ming Zhu	Date:	3/27/2008	Reviewed by:	R. Kulasingam/Jay Be	ech Date:	: 3/28/20	008					
Client: Honeywell Proje	et: Onond	aga Lake SCA	30% Design	Project/ Proposal No.:	GD3944	Task No.:	09					
110	.4 6.72 (0.470 0.012	0.071 0.179	0.177 0.031 0.000								
136	.0 6.72 1	0.030	0.181 0.454	0.400 0.027 0.000								
165	.2 6.72	1.281 0.042	0.248 0.622	0.367 0.002 0.000								
190	.3 6.73 (0.945 0.037	0.218 0.518	0.172 0.000 0.000								
210	.3 6.73	1.004 0.046	0.275 0.581	0.102 0.000 0.000								
235	.0 6.73	1.385 0.081	0.486 0.779	0.039 0.000 0.000								
264	.2 6.73	1.345 0.111	0.636 0.599	0.000 0.000 0.000								
289	.8 6.73 (0.758 0.087	0.442 0.230	0.000 0.000 0.000								
309	.8 6.73 (0.656 0.099	0.439 0.118	0.000 0.000 0.000								
333	.0 6.74 (0.557 0.121	0.400 0.035	0.000 0.000 0.000								
363	.3 6.74 (0.274 0.094	0.180 0.000	0.000 0.000 0.000								
389	.5 6.75 (0.109 0.051	0.058 0.000	0.000 0.000 0.000								
413	.3 6.75 (0.084 0.054	0.031 0.000	0.000 0.000 0.000								
37	7 7.20 0	0.100 0.002	0.014 0.034	0.034 0.014 0.002								
66	4 7.20 0	0.188 0.004	0.026 0.064	0.064 0.026 0.003								
90	4 7.21 0	0.219 0.005	0.030 0.076	0.076 0.030 0.001								
110	.5 7.21 (0.296 0.007	0.042 0.105	0.105 0.037 0.001								
136	.2 7.21 (0.723 0.018	0.106 0.266	0.265 0.068 0.000								
165	.4 7.21 (0.919 0.024	0.145 0.365	0.336 0.049 0.000								
190	.5 7.21 (0.738 0.021	0.128 0.321	0.250 0.017 0.000								
210	.4 7.22 (0.846 0.027	0.161 0.403	0.248 0.007 0.000								
235	.3 7.22	1.291 0.048	0.284 0.664	0.295 0.001 0.000								
264	.5 7.23	1.431 0.065	0.387 0.780	0.200 0.000 0.000								
289	.9 7.23 (0.914 0.051	0.304 0.499	0.061 0.000 0.000								
309	.9 7.24 (0.874 0.058	0.338 0.454	0.023 0.000 0.000								
333	.4 7.24 (0.838 0.071	0.377 0.388	0.002 0.000 0.000								
363	.6 7.25 (0.485 0.058	0.265 0.161	0.000 0.000 0.000								
389	.6 7.26 (0.219 0.036	0.138 0.045	0.000 0.000 0.000								
413	.7 7.26 (0.192 0.041	0.131 0.020	0.000 0.000 0.000								
439	.5 7.27 (0.087 0.024	0.061 0.002	0.000 0.000 0.000								
464	.1 7.28 (0.085 0.030	0.055 0.000	0.000 0.000 0.000								
Summar Mean	v statistics for statistics for statistics for statistics for statistics for statistics for statistical statistics for statistical statistics for statistics	or above 0.1s I 158.8 km: M=	PSA deaggregat	ion, R=distance, e=epsi e= 1.13 for all source	lon: s.							
Mod	l src-site R	= 36.3 km: M	= 4.81; e0 = -0.0	61 from peak (R.M) bin								
	P	rimary distance	e metric: EPICE	NTRAL								
MODE R*=	37.5km; M*	[∗] = 4.81; EPS.∏	NTERVAL: 0 to	1 sigma % CONTRIB	.= 2.228							
Principal sources (faults, subduction, random seismicity having >10% contribution)												
Source: % contr. R(km) M epsilon0 (mean values)												
CEUS gridded seismicity, Frankel 67.06 171.9 5.90 0.30												
CEUS gridded seismicity, Toro att 32.95 132.0 5.68 0.29												
**********	*******	******	******	*******	********	**						