APPENDIX B

Engineering Analysis

APPENDIX B-1

Seismic Hazard Evaluation

APPENDIX B-1

SEISMIC HAZARD EVALUATION
LANDFILL E

The results of the seismic hazard evaluation performed by Geosyntec Consultants (Geosyntec) for Landfill E at the Presidio of San Francisco are presented in this appendix. The seismic hazard evaluation performed by Geosyntec for the site consists of identifying seismic sources near the site and developing a site-specific design 5% damped elastic acceleration response spectrum based on a deterministic seismic hazard analysis. This evaluation was performed by Dr. Jennifer Donahue, P.E. of Geosyntec, and reviewed by Dr. Christopher Hunt, P.E., G.E. of Geosyntec and Dr. Jonathan Bray, P.E. of the University of California at Berkeley.

SEISMIC SOURCES IDENTIFICATION

The seismic hazard evaluation is based on the Maximum Capable Earthquake (MCE) and the Maximum Probable Earthquake (MPE). The MCE is defined as the largest earthquake that appears to be reasonably capable of occurring under the conditions of the presently known geological framework. The MCE was previously referred to as the Maximum Credible Earthquake and more recently as the Maximum Earthquake, and these terms may be considered equivalent for this report. The MCE is defined in terms of its moment magnitude (M_w) and the closest source-to-site distance (R). The M_w of the MCE is the mean maximum magnitude of a seismic source using established correlations between fault parameters (e.g., fault area, fault length, or fault displacement) and earthquake magnitude. It should also be as large as the largest historical event to have occurred along the seismic source. The MPE is defined as the most damaging seismic event that has impacted the site within historic time (100+ years).

Landfill E is located within the Presidio of San Francisco, California. The site location is shown on Figure 1. Approximate coordinates of the geometric center of the site are 37.795 North Latitude and 122.458 West Longitude.

The San Andreas Fault Zone lies approximately 5.6 miles (9 km) due west of the site. The San Gregorio and Hayward faults lie approximately 8.7 miles (14 km) to the east and 12.5 miles (20 km) to the northwest, respectively. Several minor faults are found in the immediate surrounding region. Table 1 provides a list of earthquakes with $M_w = 5.5$ or greater within 100 km of the site from 1808 to present. As shown in Table 1, there has not been an occurrence of an earthquake on a nearby fault larger than the $M_w = 7.9$ San

Francisco earthquake that occurred in 1906. A M_w = 7.9 event is also the maximum magnitude for the San Andreas fault based on its fault characteristics (USGS 2003).

DETERMINISTIC SEISMIC HAZARD ANALYSIS

A site-specific deterministic seismic hazard analysis (DSHA) was performed using a geometric mean value of peak ground acceleration (PGA) evaluated using four NGA[1] empirically based ground motion predictive models (GMPE). The NGA relationships are the most reliable GMPEs currently available for shallow crustal earthquakes along active plate margins (i.e., California) and are the current industry standard. The NGA relationships include: Abrahamson & Silva (2008), Boore & Atkinson (2008), Campbell & Bozorgnia (2008), and Youngs & Chiou (2008). The Idriss (2008) relationship was not used as it does not directly estimate ground motion parameters as a function of a site's average shear wave velocity in the upper 30 meters of the site, which is a parameter known as V_{s30}. Using the identified active faults and the fault segmentation models adopted by the 2003 Working Group on California Earthquake Probabilities (USGS, 2003) within a 100 km radius of the site, the average of the four NGA relationships were used to find the PGA for the maximum magnitude of each seismic source.

The parameters used for the NGA attenuation relationships are shown in Table 2. The parameters used for the maximum magnitude event for the San Andreas fault is shown as an example. The important V_{s30} parameter of 390 m/sec (1280 ft/sec) was derived as the average of the measured shear wave velocity results for the soundings DAECPT 201, DAECPT 202, and DAECPT 203 for the earth materials located below the base of the landfill. When the three CPTs did not extend the full 30 meters into the native material, a conservative extrapolation was performed. The resulting spectrum was adjusted for the case of forward-directivity based on the recommendations of Abrahamson (2000) assuming maximum directivity effects.

The results of this analysis are shown in Table 3. The maximum PGA calculated for this site comes from a M_w = 7.9 rupture event on the San Andreas fault at a distance of 9 km. Due to the proximity of the San Andreas fault to this site, it is the controlling seismic source for this project. The MCE and MPE are equivalent, as both are defined by the 1906 San Francisco Earthquake. Thus, the MCE/MPE for this site is a strike-slip event on the San Andreas fault with M_w =7.9 and R = 9 km.

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[1] The NGA relationships were developed through a well-documented consensus research effort by five of the most respected teams of ground motion experts (Abrahamson and Silva, Boore and Atkinson, Campbell and Bozorgnia, Chiou and Youngs, and Idriss). They have been adopted by the USGS in the development of the Nation's seismic hazard maps.

The design PGA at the base of the landfill of 0.36 g was established based on this MCE/MPE earthquake scenario. The median 5% damped elastic spectral acceleration response spectrum at the base of landfill is shown in Figure 2 for the MCE/MPE design level event.

Some liquefaction and seismic deformation analyses require an estimate of the design PGA on the top deck of the landfill. Two methods were employed to estimate the seismic demand on the top deck of the landfill. Because the waste mass is composed of soil and soil-like materials, and the V_{s30} parameter is a reliable input into the NGA relationships, the NGA relationships were recalculated using the average shear wave velocity from the top deck of the landfill down 30 meters. The V_{s30} was measured as 320 m/sec (1050 ft/sec). The design PGA on the top deck of the landfill was also estimated to be 0.36 g, because the important V_{s30} parameter did not differ significantly from that used previously.

The second method employed a geotechnical site-specific seismic response analysis based on the work of Seed et al. (1997). The base rock motion PGA was estimated to be 0.32 g using the NGA relationships described previously with V_{s30} = 760 m/s, which represents a "California rock" site. The landfill and its foundation are classified as Site Class B_2 according to the Seed et al. (1997) method. Site Class B_2 is a medium depth (i.e., < 200 ft deep), stiff cohesive soil and or mix of cohesionless with stiff cohesive soils with V_s > 500 ft/sec). For Site Class B_2 at PGA_{rock} = 0.32 g, the PGA at the ground surface is estimated to be 0.36 g according to Seed et al. (1997). This is the same value estimated using the NGA relationships. Thus, Geosyntec will use the value of 0.36 g as the input into liquefaction and seismic deformation analyses when the PGA on the top deck of the landfill is required.

PROBABILISTIC SEISMIC HAZARD ANALYSIS

A goal of the probabilistic seismic hazard analysis (PSHA) is to quantify the rate (or probability) of exceeding various ground motion levels at a site given all possible earthquakes scenarios and the inherent variability of their resulting ground motions at the site. The PSHA involves three general steps:

1) specification of the seismic hazard source models;
2) specification of the ground motion predictive models; and
3) a probabilistic calculation that includes the element of time.

For this PSHA, the 2008 Interactive Deaggregation tool, which is available through the USGS, was used. The USGS 2008 Interactive Deaggregation tool employs modern seismic source characterization and PSHA techniques, including three NGA relationships (i.e., Boore & Atkinson 2008, Campbell & Bozorgnia 2008, and Youngs & Chiou 2008). It was developed through a consensus approach, and it is a robust tool for estimating ground motion parameters at different return periods at this site. The results of the PSHA are provided in Table 4. Results are also shown on Figure 3 as the hazard curve that captures the annual probability of exceedance, which is the inverse of the return period, versus PGA for the site. As the annual probability of exceedance of a ground motion level decreases (i.e., the return period increases), the probability of a larger PGA value being exceeded increases as well.

Once established, the hazard curve can then be deaggregated for each of the return periods to find which earthquake scenario contributes the most to the hazard. Deaggregation on the PGA between return periods of 70 to 2500 years yields an earthquake scenario with generally the same characteristics as the MCE/MPE developed through the DSHA. Based on the PSHA, the MCE/MPE design PGA value of 0.36g has a return period of approximately 200 years.

CONCLUSIONS AND RECOMMENDATIONS

The results of the seismic hazard evaluation performed for Landfill E at the Presidio of San Francisco have been presented. Although the results of the PSHA were presented to provide insights, the results of the DSHA will be employed to define the design PGA for this project. The median NGA-derived DSHA site-specific 5% damped elastic acceleration response spectrum will be utilized in further analysis such as seismic slope stability, seismic cover stability, and liquefaction evaluation.

The site-specific evaluation for the MCE/MPE (i.e., $M_w = 7.9$ & $R = 9$ km) produces a median PGA of 0.36 g. We recommend that this value of 0.36 g be utilized as the MCE/MPE-level PGA for Landfill E, both at its base and on its top deck. This recommendation is consistent with current standards of practice in California wherein the median ground motion parameter derived deterministically for the MCE event is used as the basis for seismic evaluation of municipal solid-waste landfills.

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Table 1

Earthquake Occurrences with $M_w \geq 5.5$

within 100km

Date	Latitude (N)	Longitude (W)	Magnitude (M_w)	Distance (km)
21-Jun-1808	37.8	122.6	5.5	12
3-Apr-1827	37.7	122.5	5.5	11
?-Jun-1838	37.3	122.15	7.4	61
27-Aug-1855	38.1	122.5	5.5	34
2-Jan-1856	37.3	122.5	5.7	55
15-Feb-1856	37.5	122.3	5.9	36
26-Nov-1858	37.5	121.8	6.2	67
4-Jul-1861	37.75	121.95	5.8	45
5-Mar-1864	37.55	121.86	6	60
21-May-1864	37.6	121.9	5.8	54
1-Oct-1856	37.1	121.8	5.9	97
8-Oct-1865	37.2	121.9	6.6	83
15-Jul-1866	37.7	121.5	6	85
21-Oct-1868	37.7	122.1	7	33
17-Feb-1870	37.1	122	5.9	87
2-Apr-1870	37.9	122.3	5.8	18
27-Jun-1882	37.1	121.9	5.8	92
26-Mar-1884	37	122.25	5.9	90
19-May-1889	38.1	121.8	6	67
31-Jul-1889	37.8	122.2	5.6	23
2-Jan-1891	37.3	121.8	5.8	80
12-Oct-1891	38.3	122.4	5.9	56
19-Apr-1892	38.4	122	6.6	78
21-Apr-1892	38.5	121.9	6.4	92
30-Apr-1892	38.4	121.8	5.6	89
9-Aug-1893	38.4	122.7	5.6	71
31-Mar-1898	38.2	122.5	6.4	45
2-Jun-1899	37.7	122.5	5.6	11
19-May-1902	38.3	122	5.5	69
11-Jun-1903	37.2	121.8	6.1	88
3-Aug-1903	37.3	121.8	6.2	80
18-Apr-1906	37.7	122.5	7.8 [1]	11
1-Jul-1911	37.25	121.75	6.4	87
24-Oct-1926	37.02	122.21	5.8	89
15-Feb-1927	36.95	122.27	5.9	96
2-Oct-1969	38.47	122.69	5.6	78
2-Oct-1969	38.46	122.69	5.7	77
24-Jan-1980	37.83	121.7715	5.8	61
24-Apr-1984	37.3097	121.6767	6.2	88
31-Mar-1986	37.479	121.6847	5.6	77
18-Oct-1989	37.0397	121.8773	6.9	99
3-Sep-2000	38.380	122.410	5.0	65
31-Oct-2007	37.430	121.770	5.6	73

Note:

1. There remains a slight disagreement between the California Geologic Survey and the United States Geologic Survey as to the magnituded of the 1906 earthquake. CGS states Mw = 7.8 and USGS states 7.9
2. Locations and magnitudes were obtained from the California Geological Survey - Regional Geologic Mapping Program (1800 - 2000) and from the USGS Historic United States Earthquakes (2000-Present), http://earthquake.usgs.gov/earthquakes/states/historical_state.php

Table 2
Parameters used in the NGA Relationships
(example: San Andreas, Full Rupture)

M	R_{RUP}	R_{JB}	R_X	U	F_{RV}	F_{NM}	F_{HW}	Z_{TOR}	δ	V_{S30}	$F_{Measured}$	$Z_{1.0}$	$Z_{2.5}$	W	F_{AS}
7.90	9.00	9.00	9.00	0	0	0	0	0.00	90	380	1	200	1.2	12.00	0

DEFINITION OF PARAMETERS:

AS08 = Abrahamson and Silva 2008 NGA Model
BA08 = Boore & Atkinson 2008 NGA Model
CB08 = Campbell & Bozorgnia 2008 NGA Model
CY08 = Chiou & Youngs 2008 NGA Model
M = Moment magnitude
R_{RUP} = Closest distance to coseismic rupture (km), used in AS08, CB08 and CY08.
R_{JB} = Closest distance to surface projection of coseismic rupture (km).
R_X = Horizontal distance from top of rupture measured perpendicular to fault strike (km), used in AS08 and CY08.
U = Unspecified-mechanism factor: 1 for unspecified; 0 otherwise, used in BA08
F_{RV} = Reverse-faulting factor: 0 for strike slip, normal, normal-oblique; 1 for reverse, reverse-oblique and thrust
F_N = Normal-faulting factor: 0 for strike slip, reverse, reverse-oblique, thrust and normal-oblique; 1 for normal
F_{HW} = Hanging-wall factor: 1 for site on down-dip side of top of rupture; 0 otherwise, used in AS08 and CY08
Z_{TOR} = Depth to top of coseismic rupture (km), used in AS08, CB08 and CY08
δ = Average dip of rupture plane (degrees), used in AS08, CB08 and CY08
V_{S30} = Average shear-wave velocity in top 30m of site profile
$F_{Measured}$ = Vs30 Factor: 1 if VS30 is measured, 0 if Vs30 is inferred, used in AS08 and CY08
$Z_{1.0}$ = Depth to 1.0 km/sec velocity horizon (m), used in AS08 and CY08
$Z_{2.5}$ = Depth of 2.5 km/s shear-wave velocity horizon (km), used in CB08
W = Fault rupture width (km), used in AS08
F_{AS} = Aftershock factor: 0 for mainshock; 1 for aftershock, used in AS08 and CY08

Table 3
Deterministic Earthquake Ground Motions within 100km

Fault	Fault Type (SS - Strike Slip, R-Reverse)	Recurrence Interval (yr)	Width (km)	Magnitude (M_w)	Distance (km)	Estimated Median PGA (g)
San Gregorio North	SS	930	13	7.2	14	0.24
San Gregorio South	SS	1653	12	7	53	0.08
San Gregorio, All	SS	1296	12	7.53	14	0.27
San Andreas, Peninsula Section	SS	1872	13	7.15	9	0.31
San Andreas, North Coast	SS	4075	11	7.45	14	0.26
San Andreas, Santa Cruz Mountains	SS	1372	15	7	68	0.06
San Andreas, All	SS	361	12	7.9	9	0.36
Rodgers Creek (Hayward)	SS	286	12	6.98	42	0.10
Northern Hayward	SS	387	12	6.49	20	0.14
Southern Hayward	SS	371	12	6.67	31	0.11
Hayward, All	SS	4446	12	7.26	20	0.19
Northern Calaveras	SS	359	13	6.78	37	0.10
Central Calaveras	SS	178	11	6.23	66	0.04
Southern Calaveras	SS	101	11	5.79	126	0.01
Calaveras, All	SS	1733	11	6.93	37	0.10
Northern Green Valley	SS	1075	14	6.02	58	0.03
Southern Green Valley	SS	2626	14	6.24	44	0.05
Concord	SS	1398	16	6.25	42	0.06
Concord and Green Valley	SS	701	14	6.71	42	0.08
Northern Greenville	SS	1249	15	6.66	49	0.07
Southern Greenville	SS	1437	15	6.6	57	0.05
Greenville, All	SS	5811	15	6.94	49	0.08
Mount Diablo Thrust	R	508	14	6.65	43	0.08
Point Reyes	R		12	7	23	0.16
West Napa	SS		10	6.5	45	0.07
Monte Vista-Shannon	R		9	6.7	51	0.07
Maacama (South)	SS		12	6.9	80	0.05
Hunting Creek - Berryessa	SS		12	7.1	84	0.05
Zayante-Vergeles	R		12	7	99	0.04
Sargent Fault Zone, NW Section	R	350	12	6.8	86	0.04

Table 4

Probabilistic Earthquake Ground Motions

PGA (g)	Probability of Exceedance	Return Period (yrs)	Probability of Exceedance (1/yrs)
0.89	2% in 50 years	2475	0.0004
0.69	5% in 50 years	975	0.0010
0.53	10% in 50 years	475	0.0021
0.39	20% in 50 years	224	0.0045
0.27	50% in 75 years	108	0.0093
0.22	50% in 50 years	72	0.0139

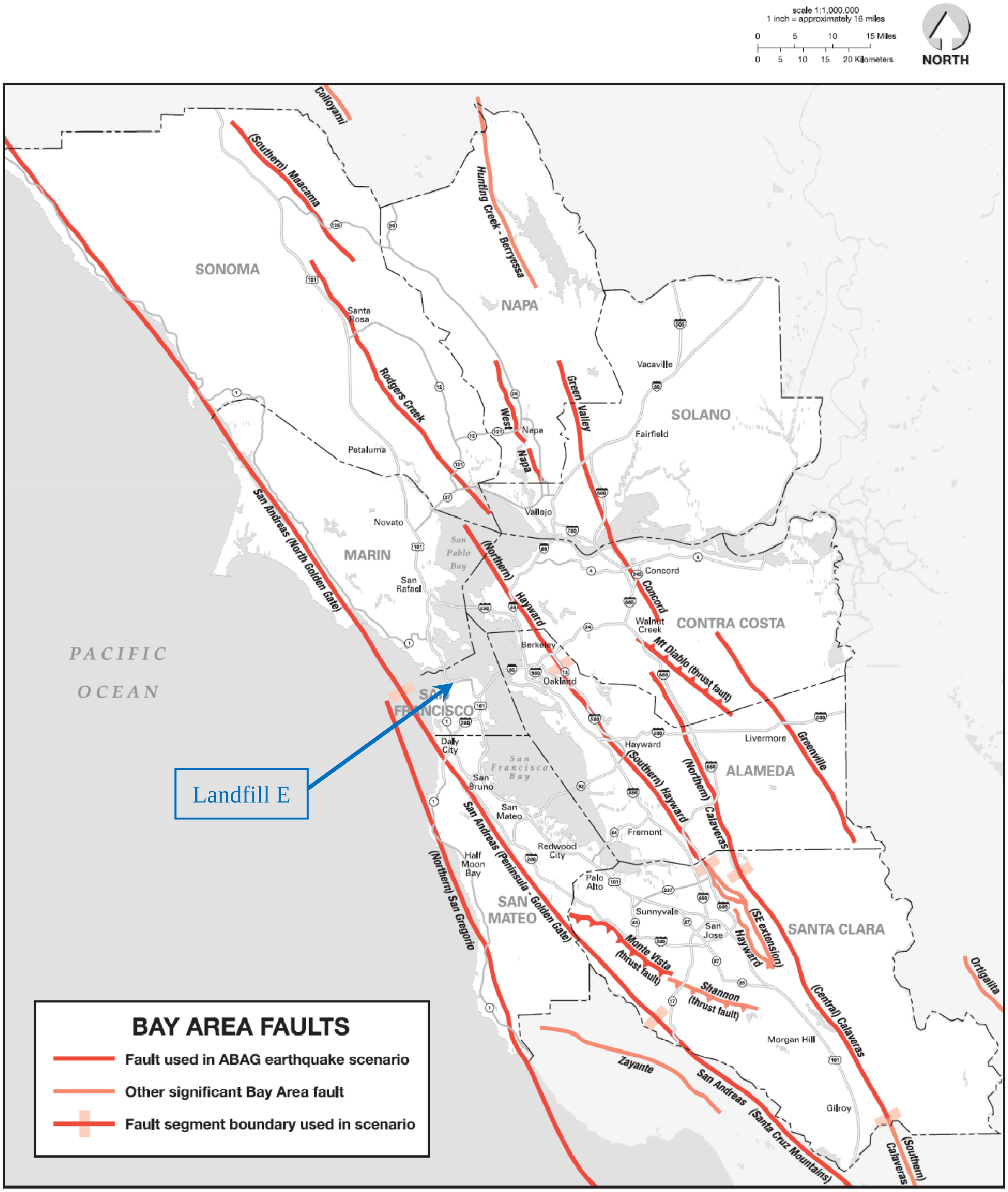

Figure 1: Map of Bay Area Faults

(Source: Association of Bay Area Governments, www.abag.gov)

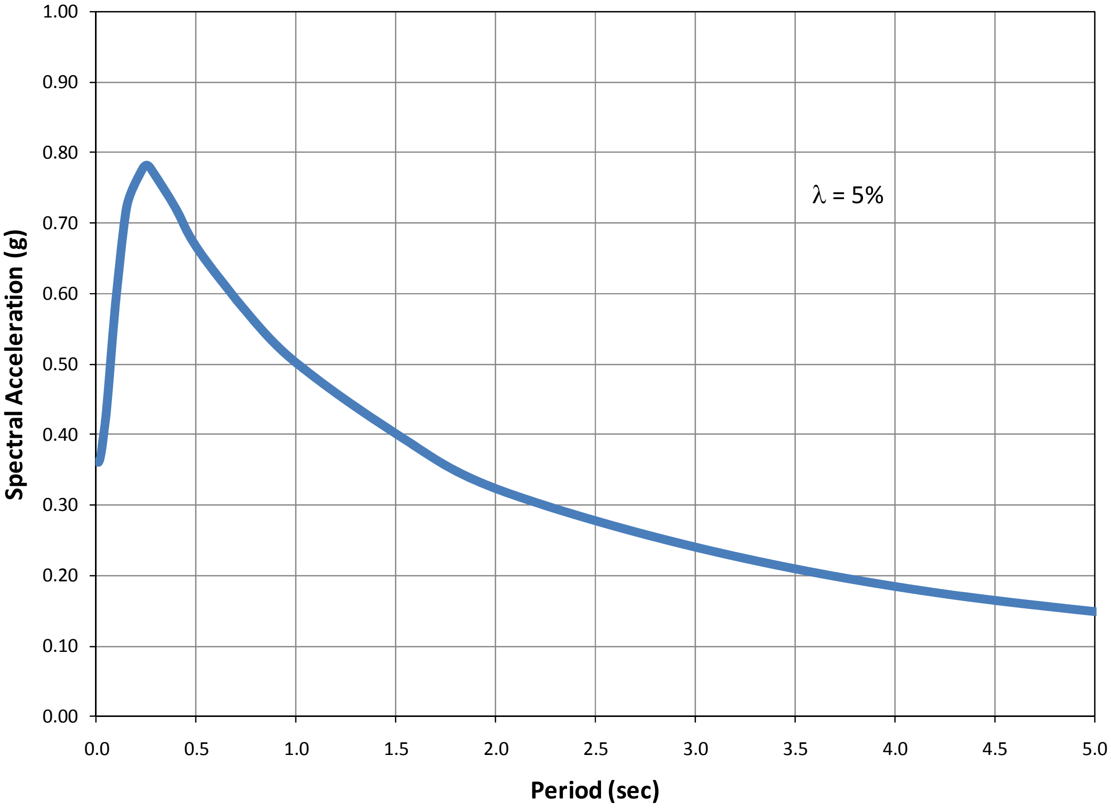

Figure 2: Site-specific design acceleration response spectrum (λ = 5%) using the median of four NGA relationships

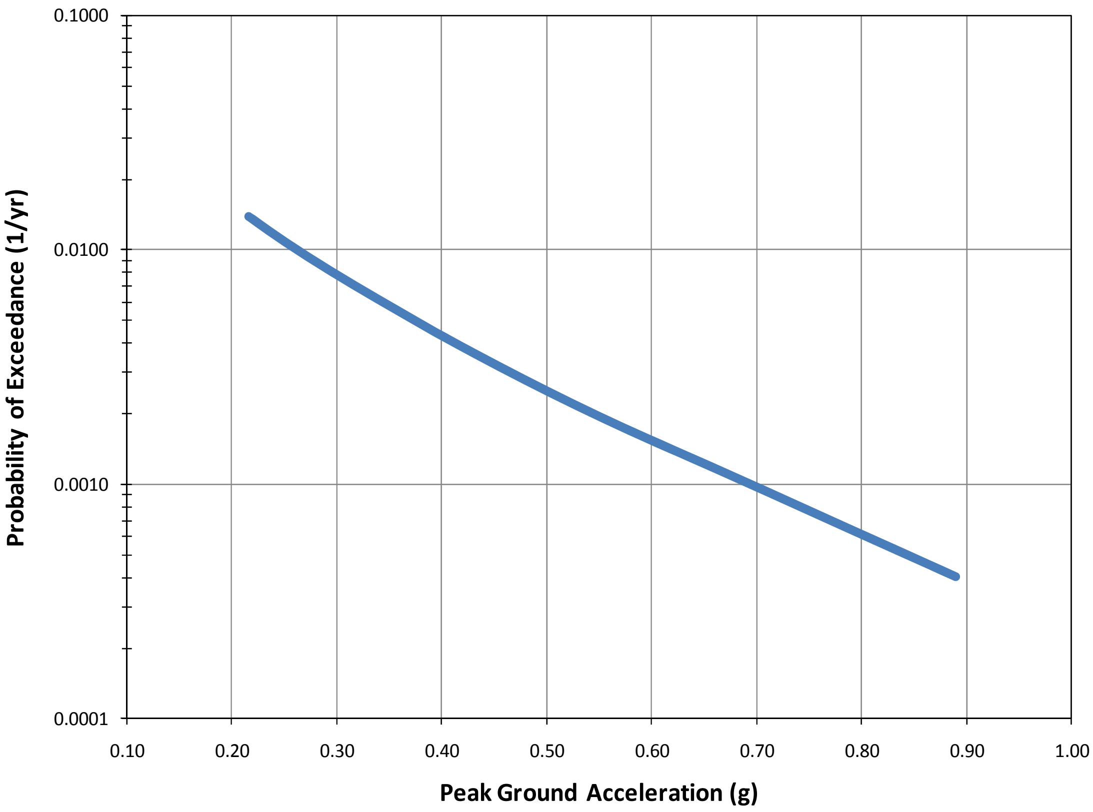

Figure 3: Peak ground acceleration (PGA) for return periods using probabilistic seismic hazard analysis