APPENDIX 1 Google Earth summary maps

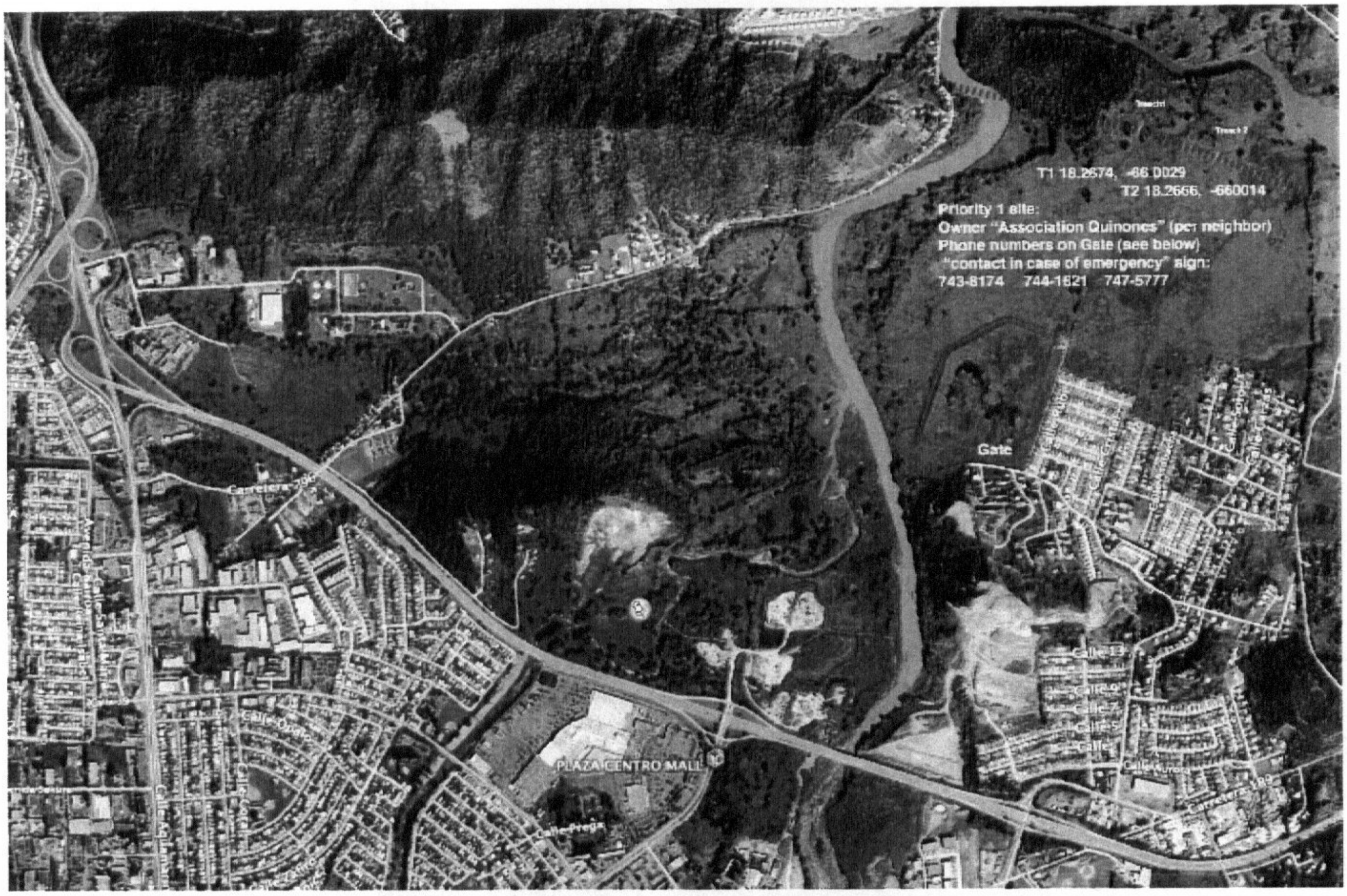

Figure A1a. Caguas-Gurabo G-Earth planning map. In all Figures north is up. Note Route 52 is at left side of Figure to west and Route 30 is in lower area of Figure. Apparent fault features include north and south-facing slope breaks which are aligned from Rte 52 to east of the Loiza River and several suggestive stream deflections. Features may result from fortuitous alignment of bedrock fault and/or joint patterns and erosion on younger surfaces controlled by bedrock boundaries. The association of several possible active fault features and a bedrock strand of the NPRFZ pose this site for primary investigation in the western Gurabo Valley area..

Figure A1b. Rio Blanco G-Earth planning map. Conjunction of possible fault-related stream deflections with location of the Pena Pobre strand of the NPRFZ immediately west of town of Rio Blanco . This association, and presence of late Quaternary and Holocene alluvial deposits in favor this site for primary investigation of potential active faulting in the eastern Gurabo Valley – Rio Blanco Valley area.. Lidar data for this area presented in Figure A3b.

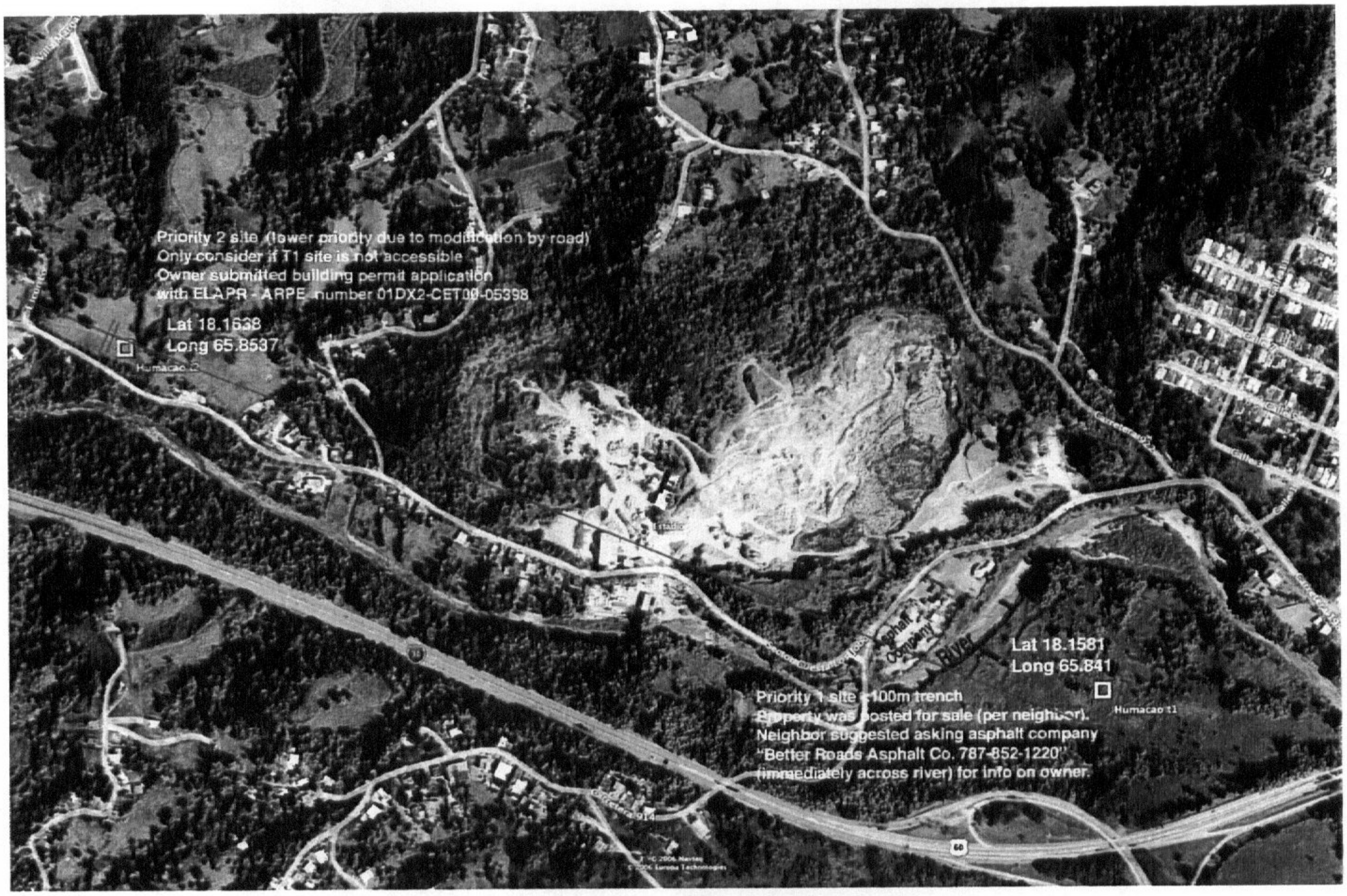

Figure A1c. Humacao River gorge G-Earth planning map. Bedrock mapping of fault in prominent linear valley immediately west of Humacao pose this site for investigation in the easternmost project area. Fault projection passes through broad terrace situated between Route 30-60 intersection and Humacao River. River deposits may record young motion, if present. Lidar data for area of Humacao River gorge sites rms: A3c.

APPENDIX 2 Air photos of selected sites – source stereo-photos dated 1936 and 193 7

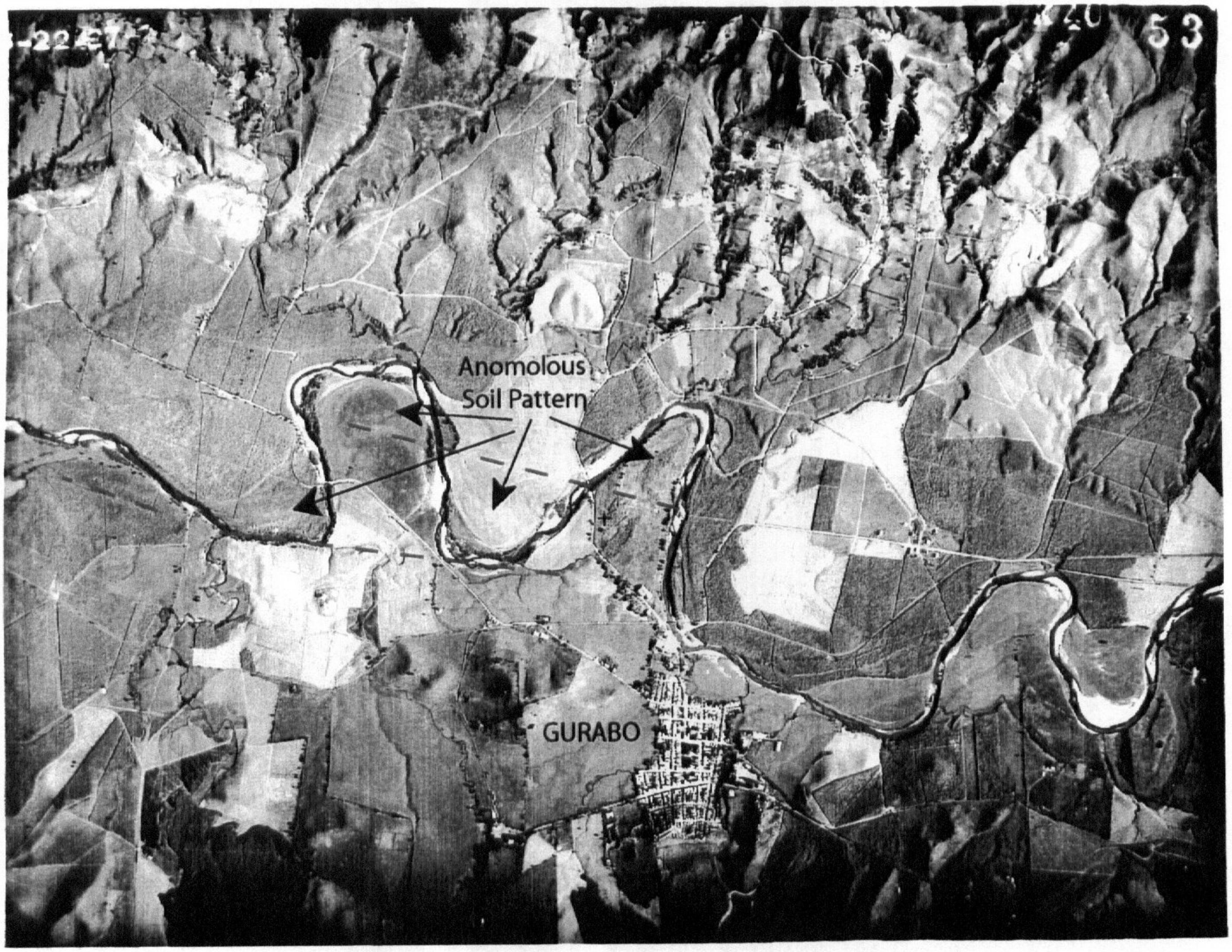

Figure A2a: Gurabo. Aerial photograph K40-53 taken in 1937 (scale: 1:18,000) shows anomalous soil pattern suggestive of sand blows and topographic lineaments across Quaternary deposits near Gurabo suggest that the Cerro Mula fault may be active.

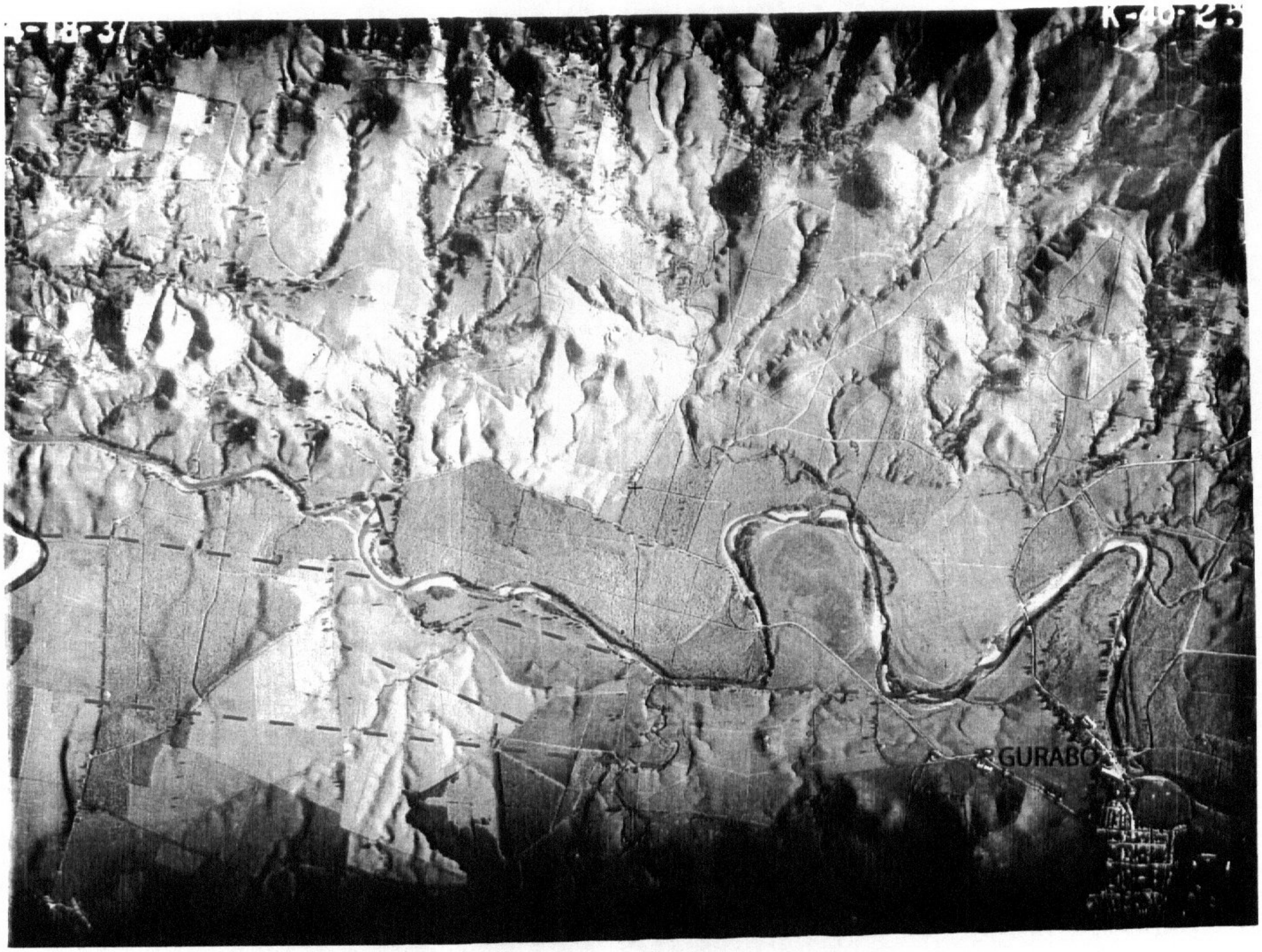

Figure A2b: Gurabo-Loiza. Aerial photograph K46-25 taken on April 18, 1937 (scale: 1:18,000) shows aligned linear river segments and topographic lineaments across Quaternary deposits near the confluence of Rio Gurabo and Rio Loiza suggest that the Cerro Mula fault may be active.

Figure A2c Maria Jimenez. Aerial photo K35-105 taken on February 3, 1937 (scale: 1:18,000) shows aligned topographic lineaments through saddles, along lateral valleys, and across stream deflections.

(continued in file "Valenciano-flt-A2.2.doc")

APPENDIX 2 cont'd Air photos of selected sites – source stereo-photos dated 1936 and 193 7

Figure A2d: Valenciano. Aerial photograph K-35-57 taken on February 3, 1937 (scale: 1:18,000) shows aligned linear river segments and topographic lineaments (shown in red) coincident with unnamed fault and other aligned topographic lineaments probably related to bedrock joints (shown in yellow).

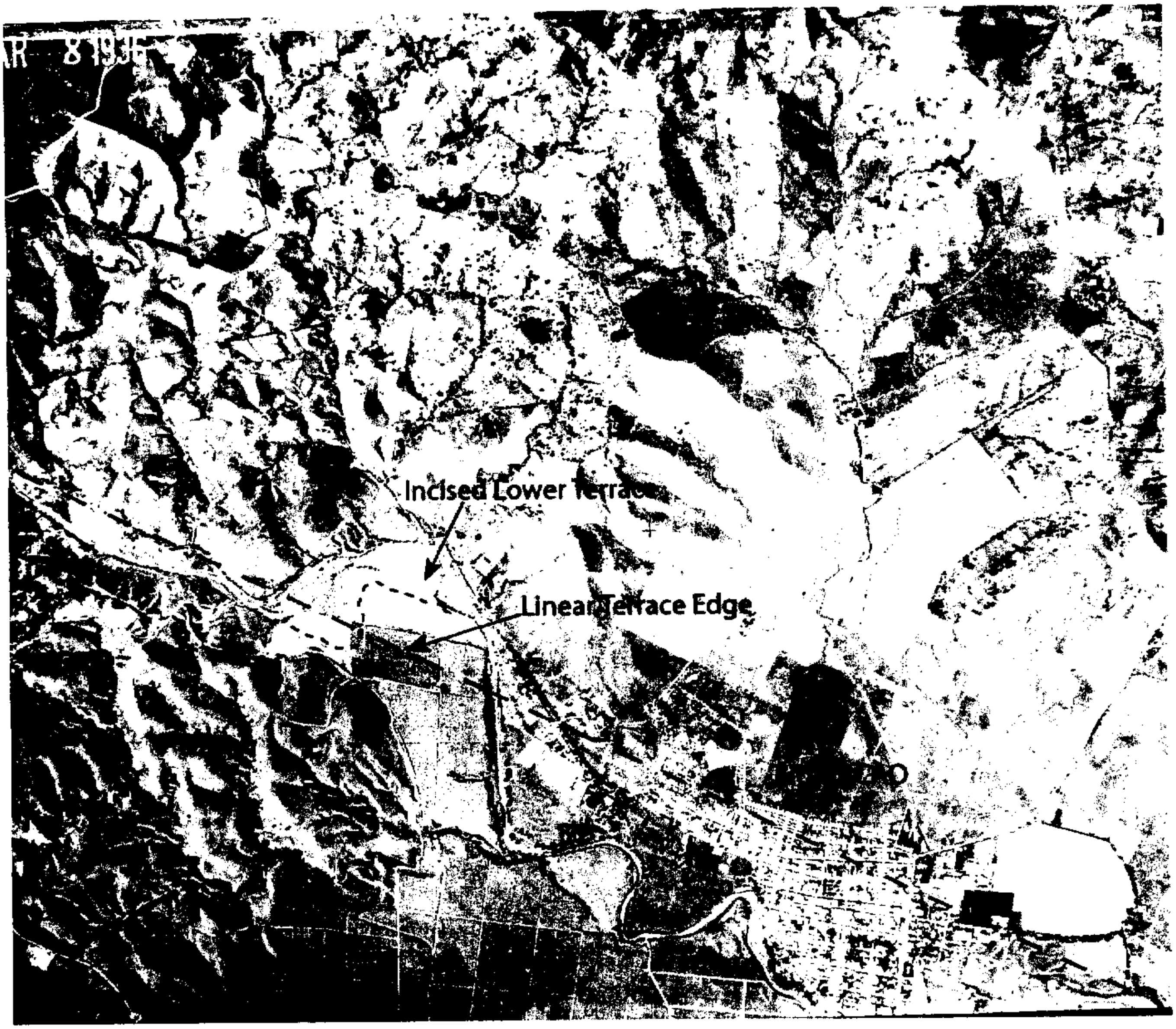

Figure A2e: Humacao. Aerial photograph K14-1407 taken on March 8, 1936 (scale: 1:18,000) shows aligned linear river valley and topographic lineaments across Quaternary deposits near Humacao.

Figure A2f: Rio Blanco. Aerial photograph K14-1343 taken on March 8, 1936 (scale: 1:18,000) shows aligned linear terrace risers and topographic lineaments across Quaternary deposits near Rio Blanco coincident with mapped trace of Pena Pobre fault. The sinuosity of Rio Blanco changes where crossed by the fault. It addition, the river channel changed to a more southerly course sometime during the Holocene.

APPENDIX 3 Lidar views of Caguas–Gurabo site, lower Valenciano Valley, loer Humacao gorge, Rio Blanco site.

Figure A3a. Lidar of view of area from northern Caguas to western Gurabo. North is up. Width of image 5.5 km. Area of the image is delineated in Figure 3. Linear edge on northern margin of prominent ridge extends to a pattern of slope breaks along similar trends to east. A topographic profile is inset across terrace feature to east. Features closely associated with mapped location of branch of Cerro Mula fault.

Figure A3b. Lidar of view of northwestern extent of Valenciano Valley. North is to right. Width of image 2.5 km. Area of the image is delineated in Figure 3. Middle section of Rio Valenciano (north trending) projects to gully containing shear indicators in bedrock (J. Joyce pers. comm.). Note linear pattern of eastern slope margin is suggestive of structural control. Blue line indicates site for further field examination.

Figure A3c. Lidar of view of lower area of Rio Humacao gorge and western Humacao (source USGS). Width of image 2.7 km. WNW to left. The area of the image is delineated in Figure 3. Pink line is derived from alignment of bedrock features on north side of gorge. Bedrock normal fault is mapped through gorge by published Humacao quadrangle geological map.

Figure A3d. Lidar of view of area from Rio Blanco to Pena Pobre (source USGS). North is at top. Width of image 2.9 km. The area of the image is delineated in Figure 3. Deflection of several streams by linear ridge west of Rio Blanco indicates faulting or bedrock control. Upper thickness of ridge is exposed along Rte 31, and is comprised of old alluvium. This feature projects to linear valleys to west and younger terrace surfaces immediately to east and west. Trend of features is proximate to but ~20° oblique to Pena Pobre bedrock fault as mapped.

APPENDIX G

GEOLOGIC EVALUATION STUDIES FOR THE RIO VALENCIANO DAM:
2. LIQUEFACTION STUDY – PHASE ONE – M. TUTTLE & ASSOCIATES

Preliminary Report

GEOLOGICAL EVALUATION STUDIES FOR THE RIO VALENCIANO DAM

2. Liquefaction Study-Phase One

Prepared For:
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January 7, 2006

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GEOLOGICAL EVALUATION STUDIES FOR THE RIO VALENCIANO DAM

2. Liquefaction Study-Phase One

Executive Summary

Initial findings point to Late Quaternary earthquakes strong enough to induce localized, but not widespread liquefaction, in the region of the proposed Rio Valenciano dam. The distribution of possible earthquake-induced liquefaction features along traces of the Cerro Mula, Pena Pobre, and an unnamed fault near Humacao faults may be due to site conditions or could reflect Holocene activity on those faults. Scenario earthquakes appear to overpredict earthquake-induce liquefaction suggesting that maximum magnitudes used in the analyses may have been too large. During phase two of the liquefaction study, reconnaissance for and study of liquefaction features as well as additional evaluation of scenario earthquakes will further constrain estimates of maximum magnitude earthquakes and their source areas.

1. INTRODUCTION

This report presents results of phase one of a liquefaction study that contributes to seismic hazard analysis for the proposed Rio Valenciano Dam near Juncos, Puerto Rico. The purpose of the liquefaction study is to provide an independent assessment of the maximum magnitude earthquakes and their sources to be used to develop seismic design parameters and ground motion records for the proposed dam. This study is supplemental to the prior seismic hazard assessment of Black and Veatch (2001), takes into account new information that has become available since then, and utilizes liquefaction analysis to evaluate the earthquake potential of onshore as well as offshore earthquake sources. This study also complements the on-going fault study focusing on the Great Northern Puerto Rico fault zone.

The primary goals of phase one of the liquefaction study are to determine whether scenario earthquakes are likely or not likely to induce liquefaction in Quaternary deposits in the greater Juncos region and to identify segments of rivers in the region, specifically Rio Blanco, Rio Gurabo, Rio Humacao, and Rio Loiza, for reconnaissance of earthquake-induced liquefaction features (Figure 1). Phase two of the study will include searching for earthquake-induced liquefaction features - proof positive of strong ground shaking - along selected river segments, documenting and dating any such features found, and reconciling field observations with evaluation of scenario earthquakes performed in phases one and two. Additional analysis of scenario earthquakes is anticipated to constrain estimates of the maximum magnitude earthquakes and their seismic areas. These estimates will be compared with those predicted by the ongoing fault study. General agreement of the results of the two studies will provide confidence that fault-predicted ground motions are not overestimated. However, if the liquefaction study indicates that the maximum magnitude earthquakes were much smaller than suggested by the fault study, the evidence for faulting, estimates of the maximum magnitude earthquakes, and attenuation relations used in calculations of ground motions will be revisited.

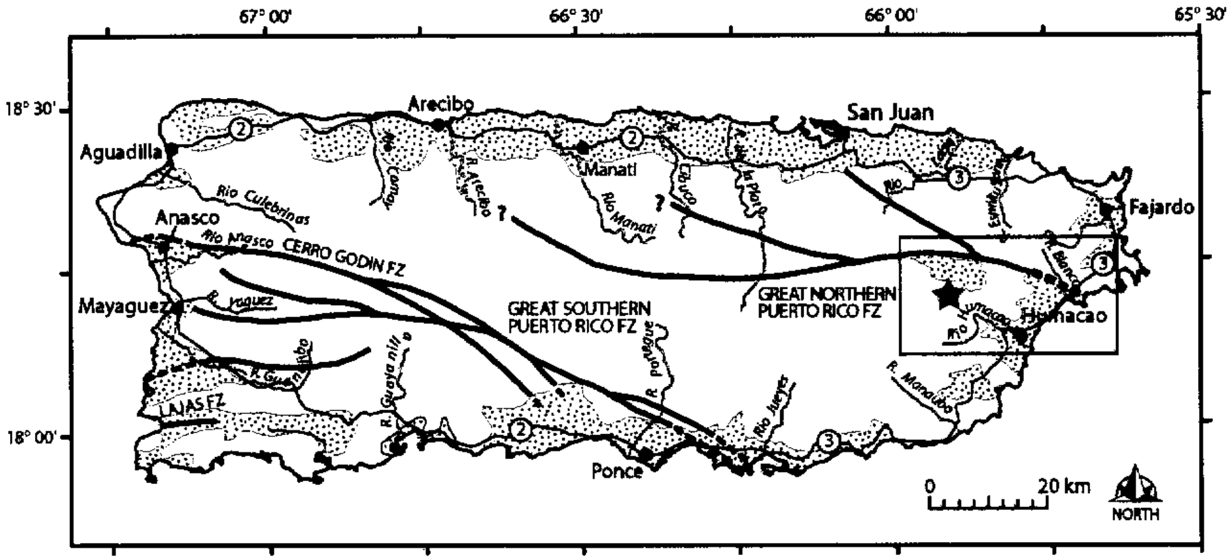

Figure 1. Map of Puerto Rico showing location of proposed Rio Valenciano dam site indicated by a star, study region outlined by box, Quaternary sediments (stippled pattern), and major onshore faults (heavy black lines) (e.g., Briggs, 1964; Geomatrix, 1988; Prentice and Mann, 2005). See fault study for detailed maps of onshore and offshore faults.

This report presents a brief summary of phase one of the liquefaction study, including a review of aerial photographs, compilation and tabulation of borehole data used in liquefaction analysis, evaluation of scenario earthquakes, and plans for phase two of the study.

2. SCOPE OF WORK

The scope of work for phase one of the liquefaction study includes the following tasks:

- Review background material including the previous seismic hazard assessment of the proposed Valenciano dam site by Black and Veatch (2000) and other reports relevant to earthquake hazards and surficial geology of the surrounding region (see References);
- Review aerial photographs of the region including the Rio Blanco, Rio Gurabo, Rio Humacao, and Rio Loiza valleys and identify surficial features that resemble sand blows resulting from earthquake-induced liquefaction as well as river segments that appear suitable for searches of liquefaction features;
- Compile and tabulate borehole data, including sediment descriptions and depths, blow counts (N), and water-table depths, previously collected for the Department of Transportation and Public Works at bridge crossings of rivers in the region including the Rio Blanco, Rio Gurabo, and Rio Loiza;
- Using borehole data and the cyclic-stress method of liquefaction potential analysis, evaluate whether or not sandy Quaternary deposits are likely, or not likely, to liquefy during scenario earthquakes.
- Provide a brief summary of the results of phase 1 of the liquefaction study and plans for phase two. A full report of the liquefaction study will be prepared at the end of phase two.

3. REVIEW OF AERIAL PHOTOGRAPHY

Aerial photography of the study region originally taken in 1936 and 1937 is reviewed for the presence of anomalous surficial features that might be related to earthquake-induced liquefaction. The photographs are excellent for this purpose because they are of high quality and were taken at a time when much of the region was deforested and because Caguas, Humacao, and Juncos were still small towns and major highways had not yet been constructed.

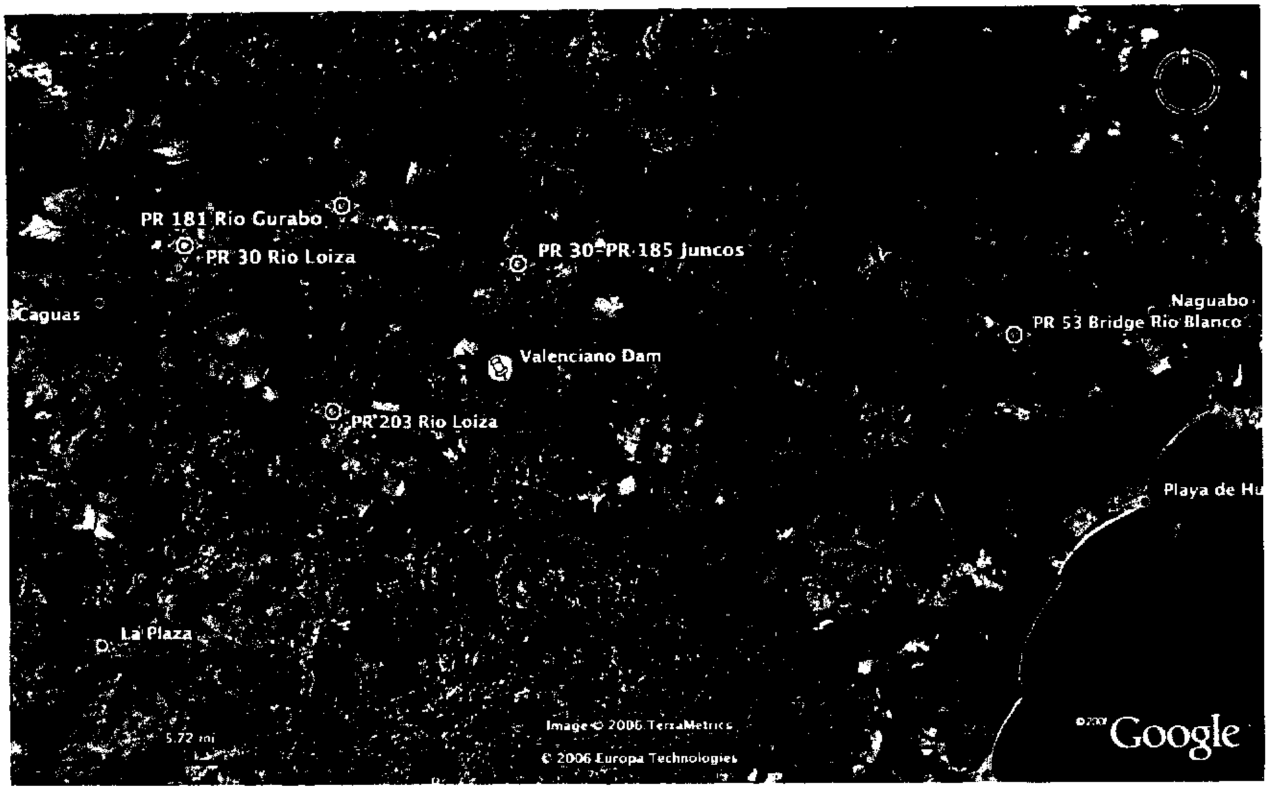

Figure 2. Google Earth image of study region (see Figure 1) showing rivers and locations of borehole sites relative to proposed Rio Valenciano dam.

We examined stereopairs of aerial photographs of the coastal area from Naguabo to Humacao, of the floodplains of the Rio Blanco, Rio Gurabo, and Rio Humacao, and along the Rio Valenciano (Figure 2). In addition, we examined photographs of the Rio Loiza floodplain from San Lorenzo to the confluence of the Rio Gurabo. Anomolous surficial features observed on the aerial photographs include (1) areas of light-colored patches that might reflect "sand blows" or surficial deposits of vented sand resulting from liquefaction of subsurface deposits during strong ground shaking, and (2) curvilinear lineaments and disturbed drainage in floodplain deposits that might be the result of lateral spreading. Examples of possible sand blows are shown in Figures 3 and 4. A summary of anomalous features identified during the review of aerial photography is provided in Table 1.

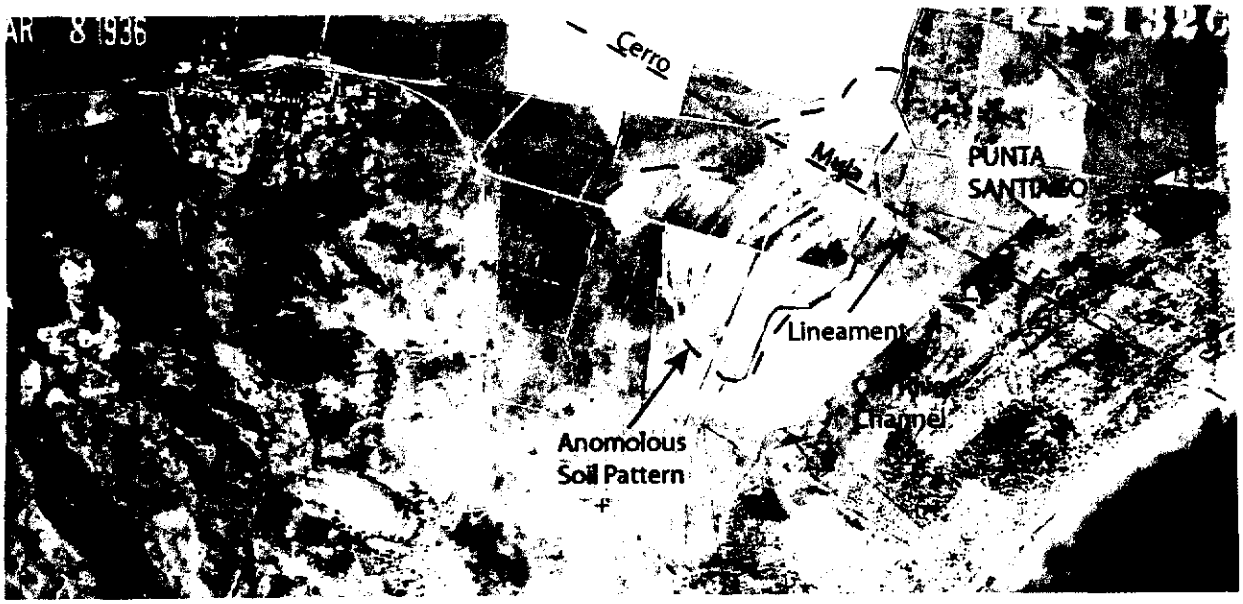

Figure 3. Aerial photograph K14-1326 taken on March 8, 1936 (scale: 1:18,000) shows elliptical and linear light-colored patches near mapped trace of Cerro Mula fault shown by red dashed line. Patches may be sand blows that formed above beach ridges and linear feature may be related to lateral spreading along nearby abandoned river channel or faulting along Cerro Mula.

The findings of the review of aerial photographs suggest that sand blows may have formed in a few areas including the floodplain of Rio Blanco near the trace of the Pena Pobre fault, in the floodplains of the Rio Gurabo near Gurabo, and the floodplain of Rio Anton Ruiz near Punta Santiago. The possible sand blow field along the Rio Blanco occurs near the trace of the Pena Pobre fault; the possible sand blow fields along the Rio Anton Ruiz and Rio Gurabo occur near the trace of the Cerro Mula fault. Other anomalous soil patterns occur along the Rio Blanco southwest of Nagaubo and along the Rio Humacao southeast of Humacao and may be related to lateral spreading. In addition, curvilinear cracks cross a possible terrace deposit along the Rio Valenciano upstream from the proposed dam site. The cracks are most likely related to static ground failure. However, liquefaction- and fault-related origins cannot be ruled out until the features are examined in the field.

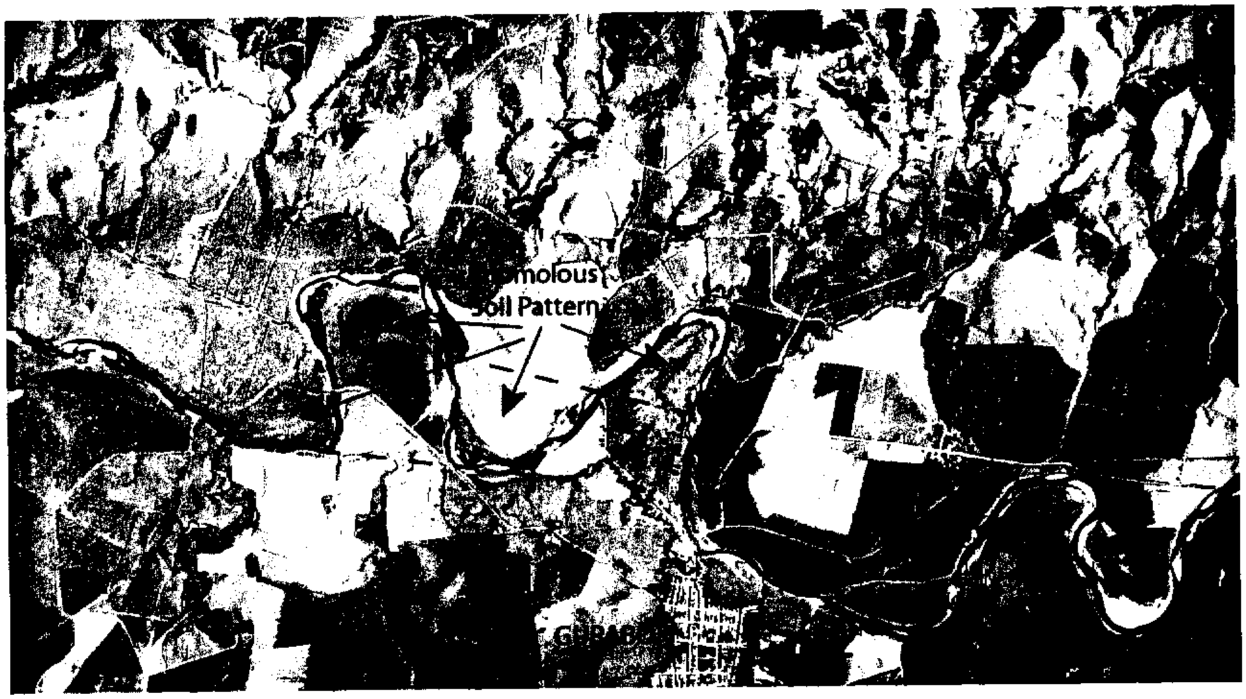

Figure 4. Aerial photograph K40-53 taken in 1937 (scale: 1:18,000) shows light-colored elliptical patches, possibly sand blows, above point bar deposits along Rio Gurabo. Features occur near topographic lineaments shown by red dashed lines that may be related to Cerro Mula fault.

Meandering portions of river segments with broad floodplains are usually the most likely places to find exposures of Holocene and Pleistocene fluvial deposits that may contain a record of strong earthquakes in the form of liquefaction features. The review of aerial photographs and 7.5 minute topographic maps (showing recent modifications of river channels for flood control) suggests that these conditions may be found along the Rio Blanco from the town of Rio Blanco to the coast, along the Rio Humacao in the vicinity and immediately upstream of Humacao, along the Rio Gurabo from Rio to Gurabo, and along the Rio Loiza in the vicinity of Caguas (Figures 2 and 4). These river segments will be targeted during reconnaissance for liquefaction features during phase 2. If exposure of river banks is inadequate to assess the presence or absence of liquefaction features, trenching possible sand blows identified during review of aerial photographs will be considered as an alternative approach.

Table 1. Review of Aerial Photographs for Identification of Anomalous Features Possibly Related to Faulting or Earthquake-Induced Liquefaction.

Location	Mapped Surficial Deposits[†]	Aerial Photographs* Reviewed	Features Possibly Related to Faulting	Features Possibly Related to Liquefaction
Rio Anton Ruiz floodplain in vicinity of Punta Santiago and Anton Ruiz	Quaternary alluvial plain and beach deposits (Qap, Qb)	K12-1278 to 1283 K14-1326 to 1328 K14-1339 to 1341 K14-1382 to 1383	K14-1326: Northwest oriented light-colored lineament coincident with mapped trace of Cerro Mula fault	K12-1280 and K14-1326: Beach ridges with small elliptical light-colored patches, possibly sand blows; K-14-1383: Small elliptical light-colored patches
Rio Blanco floodplain in vicinity of Naguabo and Rio Blanco	Quaternary alluvial plain and beach deposits (Qap, Qb)	K12-1284 to 1287 K14-1342 to 1345	K14-1342: Coincident with trace of Pena Pobre fault, river channel changes from fairly straight to meandering with large loops and prior channel abandoned for present more southerly course	K12-1284: Peculiar soil pattern near end of abandoned channel may be due to lateral spreading; K14-1342: Large elliptical light-colored patches near Rt 31 bridge.
Rio Humacao floodplain near Humacao	Quaternary alluvial plain and beach deposits (Qap, Qb)	K14-1328 (poor quality) K14-1336, 1337 (poor quality) K14-1385 K30-34 to 35 K14-1405 to 1407	K14-1385: Linear northwest-oriented depressions near abandoned channel of Rio Humacao between Santa Teresa and Humacao; K14-1406: Linear edge of upper terrace along trend of fault trace mapped along linear northwest oriented section of Rio Humacao	K14-1385: Anomolous soil pattern between abandoned and recent channels of Rio Humacao between Santa Teresa and Humacao
Rio Gurabo floodplain from Pena Pobre to confluence with Rio Loiza	Quaternary alluvium, piedmont fan and alluvial terrace deposits (Qal, Qft, Qt)	K14-1379 to 1381 K49-35 K14-1411 to 1413 K32-19 to 24 K32-61 to 66 K35-51 to 54 K35-101 to 105 K42-48 K40-52 to 55 K32-113 K46- 24 to 26 K41-49 to 51	K14-1380: Aligned linear stream segments and en echelon lineaments near mapped trace of Pena Pobre fault; K32-62 and K35-52: Aligned lineaments crossing and defining edge of alluvial terraces, also along linear river segments;	K35-52: From Rio to Gurabo, river is actively eroding alluvial deposits providing good exposure for reconnaissance; K40-53: Anomalous soil pattern in point bar deposits near Gurabo may be related to sand blows

Table 1 Continued. Review of Aerial Photographs for Identification of Anomalous Features Possibly Related to Faulting or Earthquake-Induced Liquefaction.

Location	Mapped Surficial Deposits†	Aerial Photographs* Reviewed	Features Possibly Related to Faulting	Features Possibly Related to Liquefaction
Rio Gurabo floodplain from Pena Pobre to confluence with Rio Loiza	Quaternary alluvium, piedmont fan and alluvial terrace deposits (Qal, Qft, Qt)	K14-1379 to 1381 K49-35 K14-1411 to 1413 K32-19 to 24 K32-61 to 66 K35-51 to 54 K35-101 to 105 K42-48 K40-52 to 55 K32-113 K46- 24 to 26 K41-49 to 51	K35-52 and K35-105: Aligned topographic lineaments through saddles, along lateral valleys, and across stream deflections; K40-53: Aligned lineaments crossing and defining edge of alluvial terraces; K46-25: Aligned topographic lineaments across Quaternary terraces, possible sag-ponds, and offset of terrace risers near trace of Cerro Mula fault	
Rio Loiza floodplain	Quaternary alluvium, terrace deposits (Qal, Qt)	K42-41 to 45 K32-108 to 110 K46-19 K41-49 to 51	None observed.	None observed; Holocene floodplain is very narrow
Rio Valenciano watershed	None mapped	K32-66 to 69 K35-53 to 58 K35-96 to 102	K32-67: Aligned linear northwest-oriented stream segments along mapped trace of unnamed fault; K35-57: Aligned linear northwest-oriented stream segments and depressions along mapped trace of unnamed fault	K35-57: Curvilinear cracks in possible terrace deposit near mapped trace of unnamed fault; K35-53: Lower river segment actively eroding alluvial deposits providing good exposure for reconnaissance

* Photographs taken in 1936 and 1937.

† Descriptions of Surficial Deposits (After Pease, 1968; Seiders, 1971; M'Gonigle, 1978; Rogers, 1979)

Alluvial plain deposits (Qap – Holocene and/or Pleistocene): stratified alluvial deposits composed of clay- to boulder-size detrital material; near coast, interfingering with and overlying beach deposits.

Alluvium (Qal – Holocene and/or Pleistocene): boulders, cobbles, gravel, sand, silt, and clay in floodplains and low terraces.

Beach deposits (Qb - Holocene and/or Pleistocene): fine to coarse sand and pebble deposits, including quartz, feldspar, shell, algal, coral fragments, and magnetite.

Piedmont fan and alluvial terrace deposits (Qft – Holocene and/or Pleistocene): sand, gravel, and clay containing cobbles and some boulders; mostly poorly stratified; fan deposits merge with alluvium.

Terrace deposits (Qt – Holocene and/or Pleistocene): sand, gravel, silt, and clay in terraces above present flood plain; includes some colluvial and alluvial-fan deposits.

4. COMPILATION OF BOREHOLE DATA

The Puerto Rico Department of Transportation and Public Works provided borehole data collected at bridge crossings of the Rio Blanco, Rio Gurabo, and Rio Loiza. The borehole sites include PR 53 bridge over the Rio Blanco south of Naguabo, PR 31 and PR 185 connector over the Rio Gurabo at Juncos, PR 181 bridge over the Rio Gurabo north of Gurabo, PR 30 bridge over the Rio Loiza near Caguas, and PR 203 bridge over Rio Loiza at San Lorenzo (Figure 2). We reviewed the borehole data from all these sites and selected representative layers that are sandy, less than 50 ft below the surface, below the water-table at least part of the year, and characterized by blow counts (N) of less than 30. The selected layers and their characteristics including sediment descriptions and depths, blow counts (N, a measure of soil density), and water-table depths, are presented in Appendix A.

5. EVALUATION OF SCENARIO EARTHQUAKES

Evaluation of scenario earthquakes using liquefaction potential analysis can help to place constraints on locations and magnitudes of paleoearthquakes. This is usually done using either the cyclic-stress method or the energy-stress method. We prefer the cyclic-stress method, also known as the simplified procedure (e.g., Seed and Idriss, 1982; Youd et al., 2001; Cetin and Seed et al., 2004) because it is well established and is suitable for many field and tectonic settings. The energy method is not at the same state of development as the simplified procedure.

Using appropriate ground motion relations, peak ground accelerations are estimated for earthquakes of various moment magnitudes (e.g., **M** 5.5, 6, 6.5, 7.0, and 7.5) at distances of interest from known or suspected sources. Having derived peak ground accelerations, cyclic stress ratios generated by the various scenario earthquakes are calculated. Using empirical relations between cyclic stress ratio and corrected blow counts, it is determined whether or not representative layers at a site would be likely, or not likely, to liquefy. By comparing results of this analysis with field observations, one or more scenario earthquake can be selected that may best reflect the locations and magnitudes of paleoearthquakes. Uncertainties in this method are related to identifying the layer that liquefied and estimating the susceptibility of the sediments at the time of the event. For this reason, we typically select several representative layers from different depths and with different blow counts, or N values, for each borehole.

In this study, we evaluate scenario earthquakes for both offshore and onshore seismic sources (Table 2; see fault study for detailed maps of onshore and offshore faults). For the offshore events, the sources include the Muertos trough and the Puerto Rico subduction zone and the Virgin Island Basin northern fault and the Virgin Island Basin southern fault. For the onshore events, we consider various members of the Great Northern Puerto Rico fault zone (GNPRFZ) including the Cerro Mula fault, the Pena Pobre fault, a combination of the Pena Pobre, Cerro Mula, and Limones faults as well as the more distant Salinas fault along the southern coast of the island. Fault parameters and maximum magnitude earthquakes are derived from geological studies and other seismic hazard assessments (see Table 2 references) and calculated using the rupture area-moment magnitude relation of Wells and Coppersmith (1994). We use the following attenuation relations to estimate peak ground acceleration for the various scenario earthquakes: Abrahamson and Silva (1997); Boore et al. (1997); Youngs et al. (1997); and Motazedian and Atkinson (2004). The relations of Boore et al. (1997) and Abrahamson and Silva (1997) are used in the evaluation of normal and strike slip faults and the relations of Youngs et al. (1997) and Motazedian and Atkinson (2004) are applied to subduction zone events. All these relations are well established and accepted for evaluation of these specific types of events. The relation of Motazedian and Atkinson is the only one of the four developed specifically for Puerto Rico. The seismic sources, maximum magnitude earthquakes, and attenuation relations considered in the evaluation of scenario earthquakes are summarized in the Table 2. The results of the evaluation are presented in eighteen tables in Appendix B and summarizes in Tables 3 and 4.

The results of the analyses show that a Muertos trough event of **M** 8.25 at a distance of 23 km below the study region would induce liquefaction of all layers considered at the Rio Blanco, Rio Gurabo, and Rio Loiza borehole sites. A Puerto Rico subduction zone event of similar magnitude but at a distance of 75 km would induce liquefaction of most layers at the three sites when the Youngs et al. (1997) attenuation relation is used but not when the Motezedian and Atkinson (2004) relation is applied. This is the only event for which the attenuation relations makes a significant difference in the results.

Table 2. Seismic Sources, Maximum Magnitude Earthquakes, and Attenuation Relations Considered in Evaluation of Scenario Earthquakes.

Seismic Sources	Style of Faulting	Fault Length x Width = Rupture Area	Maximum Magnitude M (±0.3 km)*	Attenuation Relations
1. Muertos Trough-East Segment (MT)#	Megathrust	220 x 85 = 18,700	8.25	1a. Youngs et al., 1997 1b. Motzedian and Atkinson, 2004
2. Puerto Rico Trench- Central segment (PRT)#	Megathrust	230 x 80 = 18,400	8.25	2a. Youngs et al., 1997 2b. Motzedian and Atkinson, 2004
3. Virgin Island Basin- Northern fault (VIBN)#	Normal	90 x 20 = 1,800	7.26	3a. Boore, Joyner and Fumal 1997 3b. Abrahamson and Silva 1997
4. Virgin Island Basin- Southern fault (VIBS)#	Normal	110 x 20 = 2,200	7.35	4a. Boore, Joyner and Fumal 1997 4b. Abrahamson and Silva 1997
5. Salinas fault#	Normal	21 x 25 = 525	6.74	5a. Boore, Joyner and Fumal 1997 5b. Abrahamson and Silva 1997
6. Unnamed fault in Rio Humacao and Valenciano valleys	Normal	20 x 30 = 600	6.79	6a. Boore, Joyner and Fumal 1997 6b. Abrahamson and Silva 1997
7. Cerro Mula fault (CM)§	Strike-slip	30 x 30 = 900	6.97	7a. Boore, Joyner and Fumal 1997 7b. Abrahamson and Silva 1997
8. Pena Pobre fault (PP)§	Strike-slip	20 x 30 = 600	6.79	8a. Boore, Joyner and Fumal 1997 8b. Abrahamson and Silva 1997
9. Cerro Mula-Pena Pobre-Limones fault (CM-PP-L)§ Δ	Strike-slip	70 x 30 = 2,100	7.33	9a. Boore, Joyner and Fumal 1997 9b. Abrahamson and Silva 1997

* Estimated using relation of Wells and Coppersmith, 1994.
# From URS Report, 2004.
† From Black and Veatch, 2000.
§ After M'Gonigle, 1978.
Δ After Seiders, 1971 and Pease, 1968.

Table 3. Summary of Results of Evaluation of Scenario Earthquakes Related to Subduction Zones and Normal Faults.

Seismic Source	Maximum Magnitude M	Site Distance (km)	Attenuation Relations	Peak Ground Acceleration a_{max}	Liquefaction Analysis Results[1]
1a. Muertos Trough-(MSZ)	8.25	All-23	1a. Youngs et al., 1997	0.369	L
1b. Muertos Trough-(MSZ)	8.25	All-23	1b. Motzedian and Atkinson, 2004	0.342	L
2a. Puerto Rico Trench-(PRSZ)	8.25	All-75	2a. Youngs et al., 1997	0.238	L, N, M
2b. Puerto Rico Trench-(PRSZ)	8.25	All-75	2b. Motzedian and Atkinson, 2004	0.050	N, M, L
3a. Virgin Island Basin-Northern fault (VIBN)	7.3	RB-30 JU-45 RG-50 RL-55 SL-50	3a. Boore, Joyner and Fumal, 1997	0.191 0.140 0.129 0.120 0.129	N, L N-L, M N N N, L
3b. Virgin Island Basin-Northern fault (VIBN)	7.3	RB-30 JU-45 RG-50 RL-55 SL-50	3b. Abrahamson and Silva, 1997	0.147 0.099 0.089 0.081 0.089	N, L N, L N N N, L
4a. Virgin Island Basin-Southern fault (VIBS)	7.4	RB-55 JU-65 RG-70 RL-75 SL-65	4a. Boore, Joyner and Fumal, 1997	0.126 0.111 0.105 0.100 0.111	N, L N, L N N N, L
4b. Virgin Island Basin-Southern fault (VIBS)	7.4	RB-55 JU-65 RG-70 RL-75 SL-65	4b. Abrahamson and Silva, 1997	0.085 0.071 0.066 0.062 0.071	N, L N, M N N N, L
5a. Salinas fault	6.7	RB-60 JU-50 RG-45 RL-40 SL-50	5a. Boore, Joyner and Fumal, 1997	0.082 0.088 0.102 0.118 0.088	N N, L/M N N N, L
5b. Salinas fault	6.7	RB-60 JU-50 RG-45 RL-40 SL-50	5b. Abrahamson and Silva, 1997	0.056 0.068 0.077 0.086 0.068	N N N N N, L/M

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely. Results are given in order of prevalence.

Table 4. Summary of Results of Evaluation of Scenario Earthquakes Related to GNRFZ.

Seismic Source	Maximum Magnitude M	Site Distance (km)	Attenuation Relations	Peak Ground Acceleration a_{max}	Liquefaction Analysis Results[1]
6a. Unnamed fault in Rio Humacao and Valenciano valleys	6.8	RB-10 JU-1 RG-5 RL-10 SL-5	6a. Boore, Joyner and Fumal, 1997	0.341 0.506 0.437 0.314 0.437	L, M, N L L L L, N
6b. Unnamed fault in Rio Humacao and Valenciano valleys	6.8	RB-10 JU-1 RG-5 RL-10 SL-5	6b. Abrahamson and Silva, 1997	0.322 0.638 0.487 0.322 0.487	L, M, N L L L L, M
7a. Cerro Mula fault (CM)	7.0	RB-5 JU-1 RG-1 RL-1 SL-5	7a. Boore, Joyner and Fumal, 1997	0.452 0.562 0.562 0.562 0.452	L, M L L L
7b. Cerro Mula fault (CM)	7.0	RB-5 JU-1 RG-1 RL-1 SL-5	7b. Abrahamson and Silva, 1997	0.519 0.677 0.677 0.677 0.519	L L L L L
8a. Pena Pobre fault (PP)	6.8	RB-1 JU-10 RG-15 RL-20 SL-15	8a. Boore, Joyner and Fumal, 1997	0.506 0.292 0.225 0.184 0.225	L L L L, M L, N, L/M
8b. Pena Pobre fault (PP)	6.8	RB-1 JU-10 RG-15 RL-20 SL-15	8b. Abrahamson and Silva, 1997	0.638 0.322 0.231 0.178 0.231	L L L L, N, M L, N
9a. Cerro Mula-Pena Pobre-Limones fault (CM-PP-L)	7.3	RB-1 JU-1 RG-1 RL-1 SL-5	9a. Boore, Joyner and Fumal, 1997	0.658 0.658 0.658 0.658 0.530	L L L L L
9b. Cerro Mula-Pena Pobre-Limones fault (CM-PP-L)	7.3	RB-1 JU-1 RG-1 RL-1 SL-5	9b. Abrahamson and Silva, 1997	0.741 0.741 0.741 0.741 0.570	L L L L L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely. Results are given in order of prevalence.

A **M** 7.3 earthquake produced by the Virgin Island Basin northern fault would likely induce liquefaction in three of eleven layers at Rio Blanco, in two to six of sixteen layers at Rio Gurabo in Juncos, in none of layers at Rio Gurabo at Gurabo or Rio Loiza at Caguas, and in only one of eight layers at Rio Loiza at San Lorenzo. An earthquake of **M** 7.4 generated by the Virgin Island Basin southern fault would also induce liquefaction in three of eleven layers at Rio Blanco, in one to four of sixteen layers at Rio Gurabo in Juncos, in none of layers at Rio Gurabo at Gurabo or Rio Loiza at Caguas, and in only one of eight layers at Rio Loiza at San Lorenzo. A **M** 6.7 earthquake on the Salinas fault would cause liquefaction of only one layer at Gurabo and one layer at Rio Loiza at San Lorenzo. Therefore, the effects of maximum magnitude earthquakes originating from the Virgin Island Basin would be minimal along the coast and almost non-existent about 15 km inland and an earthquake on the Salinas fault would be unlikely to produce liquefaction features in the study region.

Considering members of the GNPRFZ, an earthquake of **M** 6.8 generated by the unnamed fault in the Humacao-Valenciano valleys would likely induced liquefaction in all but one layer at Rio Blanco and possibly one layer at San Lorenzo. A **M** 7.0 on the Cerro Mula fault would probably liquefy all the layers at all the sites. An earthquake of **M** 6.8 on the Pena Pobre fault would induce liquefaction in all the layers at Rio Blanco, Juncos, and Gurabo, and most of the layers at Caguas and San Lorenzo. An even larger earthquake of **M** 7.3 resulting from a through-going rupture of the Pena Pobre, Cerro Mula, and Limones faults would liquefy all layers at all sites. Maximum magnitude earthquakes produce by members of the GNPRFZ would produce widespread liquefaction in the study region. The effects of smaller earthquakes produced by these local faults remain to be evaluated.

6. CONCLUSIONS AND PLANS FOR PHASE TWO

The review of aerial photography found that features resembling sand blows and lateral spreads resulting from earthquake-induced liquefaction occur in a few areas in close proximity to mapped faults. These areas include Rio Blanco near the trace of the Pena Pobre fault, Gurabo and Punta Santiago near the trace of the Cerro Mula fault, and Humacao near the trace of an unnamed fault. The signatures are subtle and not ubiquitous across younger floodplains. These interpretations will need to be field checked but suggest that ground shaking has been strong enough during the Holocene to induce liquefaction in these areas, but not so strong as to produce widespread liquefaction.

The evaluation of scenario earthquakes includes offshore and onshore maximum magnitude events and considers two attenuation relations per event. The analyses suggest that a **M** 8.25 earthquake produced by the Muertos trough would induce widespread liquefaction in fluvial deposits from the coast to Caguas. Depending on which attenuation relation is used in the analysis, a similar size event generated by the Puerto Rico subduction zone might also result in widespread liquefaction. Maximum magnitude earthquakes produced by members of the GNPRFZ, including the Cerra Mula and Pena Pobre faults and an unnamed fault in the Humacao-Valenciano valleys, or a through-going rupture on the Pena Pobre, Cerro Mula, and Limones fault also would induce widespread liquefaction in the study region. Maximum magnitude earthquakes on the Virgin Island Basin faults or the southern coastal Salinas fault would produce few if any liquefaction features in the region.

Although the review of aerial photographs suggests that earthquake-induced liquefaction features may have formed in several areas, it does not support widespread liquefaction in the region. The distribution of the features along fault trace may be fortuitous, perhaps due to site conditions, or could reflect Holocene activity on those faults. If the later, the distribution of liquefaction features might favor the GNPRFZ over the Muertos trough as the most significant seismic source for dam design. The initial evaluation of scenario earthquakes appears to overpredict earthquake-induced liquefaction in the region. This suggests that the maximum magnitude earthquakes used in the analysis may have been too large.

During phase 2 of the liquefaction study, reconnaissance will be conducted along selected segments of the Rio Blanco, Rio Humacao, Rio Gurabo, and Rio Loiza where exposure of Holocene deposits is more likely to occur in order to assess the presence or absence of liquefaction features. If exposure along rivers is inadequate to make this assessment, excavation of possible sand blows identified on aerial photographs will be considered as an alternative approach. Additional scenario earthquakes of smaller magnitudes, and larger distances in the case of a Muertos trough event, will be evaluated to better reconcile the prevalence and spatial distribution of liquefaction features and to further constrain the maximum magnitude earthquakes and their source areas to be used in the development of seismic design parameters and ground motion records for the proposed dam.

7. ACKNOWLEDGEMENTS

Many people contributed to this study including Prof. James Joyce of University of Puerto Rico in Mayaguez who led an introductory field trip and shared his insights of the geology of the study area; Dr. Alex Soto of GeoChim, Dr. Gabriel Alcaraz Emmanuelli, Dr. Ricardo Romero, and Mr. Edgardo Pagan of the Highway and Transportation Authority, and Dr. Carlos Regaldo of GeoConsult who provided borehole data for the liquefaction analysis; Mr. Jim Swaisgood of Swaisgood Consulting with whom we discussed seismic sources, scenario earthquakes, and attenuation relations; and Mariecarmen Cardova and Maher Lugo of CSA Group who provided maps and other assistance.

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Table 1. BOREHOLE DATA FOR RIO BLANCO.

Site Location	Boring	Sediment Depth ft	Water-table Depth ft	Blow Count	Description
PR 53 Over Rio Blanco Naguabo	S-1-2A	7	4	20	brown and gray, medium sand, fine to coarse grained, , little gravel, fine grained, sub-angular, trace silt and clay.
	S1-3A	14	6	18	brown and gray, medium sand, fine to coarse grained, , little gravel, fine grained, sub-angular, trace silt and clay.
	S1-4A	7	4	10	brown and gray, loose to medium sand, fine to coarse grained, some silt, little gravel, fine grained, sub-angular, trace clay
	S1-5A	12	4	6	gray, loose sand, medium to coarse grained sub-angular, sandy clay, little silt
	S1-7A	12	7	12	Olive and gray, medium sand, fine to coarse grained some gravel, sub-angular, trace silt occ. pebbles
	S1-10A	5	6	5	grayish brown, med sand, fine to coarse grained trace gravel, angular to sub-angular, trace silt
	S1-14A	10	9	10	gray, loose to medium sand, coarse grained, some gravel, fine grained, angular to sub-angular, little silt
	S1-16A	7	6	15	gray, medium sand, fine to coarse graind, gravelly

					fine grained,, sub-angular, trace silt
	S1-24A	7	6	9	gray, loose sand, fine to coarse grained, gravelly fine grained, sub-angular, little silt
	S1-28A	10	6	3	gray, loose sand, fine to coarse grained, gravelly, fine grained, little silt, trace clay
	S2-	16	7	14	brown and gray, medium silty sand, coarse grained, gravelly, fine grained, angular to sub-angular, trace silt

Table 1a. EVALUATION OF M 8.25 EARTHQUAKE PRODUCED BY THE MUERTOS SEISMIC ZONE FAULT USING ATTENUATION RELATION OF YOUNGS ET AL., 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 8.25 @23	0.369	S-1-2A	7	27	0.289	L
	M 8.25 @23	0.369	S1-3A	14	18	0.300	L
	M 8.25 @23	0.369	S1-4A	7	14	0.289	L
	M 8.25 @23	0.369	S1-5A	12	7	0.327	L
	M 8.25 @23	0.369	S1-7A	12	12	0.275	L
	M 8.25 @23	0.369	S1-10A	5	7	0.210	L
	M 8.25 @23	0.369	S1-14A	10	10	0.233	L
	M 8.25 @23	0.369	S1-16A	7	19	0.244	L
	M 8.25 @23	0.369	S1-24A	7	11	0.244	L
	M 8.25 @23	0.369	S1-28A	10	3	0.277	L
	M 8.25 @23	0.369	S2	16	13	0.293	L
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M~8.25@23	0.369	B-1	12.5	5	0.162	L
	M~8.25@23	0.369	B-2	10	7	0.153	L
	M~8.25@23	0.369	B-3	17	8	0.229	L
	M~8.25@23	0.369	B-4	10	5	0.201	L
	M~8.25@23	0.369	B-4	17.5	9	0.246	L
	M~8.25@23	0.369	B-5	10	3	0.222	L
	M~8.25@23	0.369	B-6	13	7	0.208	L
	M~8.25@23	0.369	B-7	17	9	0.233	L
	M~8.25@23	0.369	B-9	7	5	0.127	L
	M~8.25@23	0.369	B-10	10	9	0.143	L
	M~8.25@23	0.369	B-12	21	18	0.292	L
	M~8.25@23	0.369	B-16	38	10	0.264	L
	M~8.25@23	0.369	B-19	27	13	0.321	L
	M~8.25@23	0.369	B-21	14	8	0.316	L
	M~8.25@23	0.369	B-22	7	7	0.227	L
	M~8.25@23	0.369	B-24	7	4	0.318	L
PR 181 Over Rio Gurabo Gurabo	M~8.25@23	0.369	MB-103	25	7	0.202	L
	M~8.25@23	0.369	MB-104	25	5	0.206	L
	M~8.25@23	0.369	MB-105	15	14	0.277	L
	M~8.25@23	0.369	TB-3	30	13	0.292	L
PR 30 Over Rio Loiza Caguas	M~8.25@23	0.369	1	10	7	0.233	L
	M~8.25@23	0.369		20	11	0.280	L
	M~8.25@23	0.369	2	15	15	0.265	L
	M~8.25@23	0.369		25	15	0.285	L

	M~8.25@23	0.369		30	12	0.284	L
	M~8.25@23	0.369	7	15	11	0.236	L
	M~8.25@23	0.369		20	14	0.254	L
	M~8.25@23	0.369	8	10	6	0.224	L
	M~8.25@23	0.369		20	12	0.273	L
PR 203 Over Rio Loiza, San Lorenzo	M~8.25@23	0.369	S-16	14	8	0.231	L
	M~8.25@23	0.369	S-14	10	8	0.222	L
	M~8.25@23	0.369	S-13	6	15	0.172	L
	M~8.25@23	0.369	S-11	8	24	0.225	L
	M~8.25@23	0.369	S-8	17	18	0.322	L
	M~8.25@23	0.369	S-16	15	7	0.212	L
	M~8.25@23	0.369	S-17	14	5	0.428	L
	M~8.25@23	0.369	S-18	10	23	0.443	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 2a. EVALUATION OF M 8.25 EARTHQUAKE PRODUCED BY THE PUERTO RICO SEISMIC ZONE FAULT USING ATTENUATION RELATION OF YOUNGS ET AL., 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M8.25@75	0.238	S-1-2A	7	27	0.186	N
	M8.25@75	0.238	S1-3A	14	18	0.193	L
	M8.25@75	0.238	S1-4A	7	14	0.186	L
	M8.25@75	0.238	S1-5A	12	7	0.211	L
	M8.25@75	0.238	S1-7A	12	12	0.177	L
	M8.25@75	0.238	S1-10A	5	7	0.135	L
	M8.25@75	0.238	S1-14A	10	10	0.150	L
	M8.25@75	0.238	S1-16A	7	19	0.158	L
	M8.25@75	0.238	S1-24A	7	11	0.158	L
	M8.25@75	0.238	S1-28A	10	3	0.179	L
	M8.25@75	0.238	S2	16	13	0.189	L
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M8.25@75	0.238	B-1	12.5	5	0.104	L
	M8.25@75	0.238	B-2	10	7	0.099	L
	M8.25@75	0.238	B-3	17	8	0.148	L
	M8.25@75	0.238	B-4	10	5	0.130	L
	M8.25@75	0.238	B-4	17.5	9	0.159	L
	M8.25@75	0.238	B-5	10	3	0.143	L
	M8.25@75	0.238	B-6	13	7	0.134	L
	M8.25@75	0.238	B-7	17	9	0.150	L
	M8.25@75	0.238	B-9	7	5	0.082	L
	M8.25@75	0.238	B-10	10	9	0.092	L
	M8.25@75	0.238	B-12	21	18	0.188	L
	M8.25@75	0.238	B-16	38	10	0.170	L
	M8.25@75	0.238	B-19	27	13	0.207	L
	M8.25@75	0.238	B-21	14	8	0.204	L
	M8.25@75	0.238	B-22	7	7	0.146	L
	M8.25@75	0.238	B-24	7	4	0.205	L
PR 181 Over Rio Gurabo Gurabo	M8.25@75	0.238	MB-103	25	7	0.130	L
	M8.25@75	0.238	MB-104	25	5	0.133	L
	M8.25@75	0.238	MB-105	15	14	0.179	L
	M8.25@75	0.238	TB-3	30	13	0.188	L
PR 30 Over Rio Loiza Caguas	M8.25@75	0.238	1	10	7	0.150	L
	M8.25@75	0.238		20	11	0.181	L
	M8.25@75	0.238	2	15	15	0.171	L
	M8.25@75	0.238		25	15	0.184	L

	M8.25@75	0.238		30	12	0.183	L
	M8.25@75	0.238	7	15	11	0.152	L
	M8.25@75	0.238		20	14	0.164	L
	M8.25@75	0.238	8	10	6	0.145	L
	M8.25@75	0.238		20	12	0.176	L
PR 203 Over Rio Loiza, San Lorenzo	M8.25@75	0.238	S-16	14	8	0.149	L
	M8.25@75	0.238	S-14	10	8	0.143	L
	M8.25@75	0.238	S-13	6	15	0.111	M
	M8.25@75	0.238	S-11	8	24	0.145	N
	M8.25@75	0.238	S-8	17	18	0.208	L
	M8.25@75	0.238	S-16	15	7	0.137	L
	M8.25@75	0.238	S-17	14	5	0.276	L
	M8.25@75	0.238	S-18	10	23	0.286	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 3a. EVALUATION OF M 7.3 EARTHQUAKE PRODUCED BY THE VIRGIN ISLAND BASIN NORTH FAULT USING ATTENUATION RELATION OF BOORE, JOYNER AND FUMAL, 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Streee Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 7.3@30	0.191	S-1-2A	7	27	0.115	N
	M 7.3@30	0.191	S1-3A	14	18	0.119	N
	M 7.3@30	0.191	S1-4A	7	14	0.115	N
	M 7.3@30	0.191	S1-5A	12	7	0.130	L
	M 7.3@30	0.191	S1-7A	12	12	0.110	N
	M 7.3@30	0.191	S1-10A	5	7	0.084	L
	M 7.3@30	0.191	S1-14A	10	10	0.093	N
	M 7.3@30	0.191	S1-16A	7	19	0.097	N
	M 7.3@30	0.191	S1-24A	7	11	0.097	N
	M 7.3@30	0.191	S1-28A	10	3	0.110	L
	M 7.3@30	0.191	S2	16	13	0.117	N
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M 7.3@45	0.140	B-1	12.5	5	0.061	N
	M 7.3@45	0.140	B-2	10	7	0.058	N
	M 7.3@45	0.140	B-3	17	8	0.087	M
	M 7.3@45	0.140	B-4	10	5	0.076	L
	M 7.3@45	0.140	B-4	17.5	9	0.094	M
	M 7.3@45	0.140	B-5	10	3	0.084	L
	M 7.3@45	0.140	B-6	13	7	0.079	L
	M 7.3@45	0.140	B-7	17	9	0.088	M
	M 7.3@45	0.140	B-9	7	5	0.048	N
	M 7.3@45	0.140	B-10	10	9	0.054	N
	M 7.3@45	0.140	B-12	21	18	0.111	N
	M 7.3@45	0.140	B-16	38	10	0.100	M
	M 7.3@45	0.140	B-19	27	13	0.122	N
	M 7.3@45	0.140	B-21	14	8	0.120	L
	M 7.3@45	0.140	B-22	7	7	0.086	L
	M 7.3@45	0.140	B-24	7	4	0.121	L
PR 181 Over Rio Gurabo Gurabo	M 7.3@50	0.129	MB-103	25	7	0.049	N
	M 7.3@50	0.129	MB-104	25	5	0.050	N
	M 7.3@50	0.129	MB-105	15	14	0.067	N
	M 7.3@50	0.129	TB-3	30	13	0.070	N
PR 30 Over Rio Loiza Caguas	M 7.3@55	0.120	1	10	7	0.051	N
	M 7.3@55	0.120		20	11	0.062	N
	M 7.3@55	0.120	2	15	15	0.058	N
	M 7.3@55	0.120		25	15	0.063	N

	M 7.3@55	0.120		30	12	0.062	N
	M 7.3@55	0.120	7	15	11	0.052	N
	M 7.3@55	0.120		20	14	0.056	N
	M 7.3@55	0.120	8	10	6	0.049	N
	M 7.3@55	0.120		20	12	0.060	N
PR 203 Over Rio Loiza, San Lorenzo	M 7.3@50	0.129	S-16	14	8	0.081	N
	M 7.3@50	0.129	S-14	10	8	0.077	N
	M 7.3@50	0.129	S-13	6	15	0.060	N
	M 7.3@50	0.129	S-11	8	24	0.079	N
	M 7.3@50	0.129	S-8	17	18	0.113	N
	M 7.3@50	0.129	S-16	15	7	0.074	N
	M 7.3@50	0.129	S-17	14	5	0.150	L
	M 7.3@50	0.129	S-18	10	23	0.155	N

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 4a. EVALUATION OF M 7.4 EARTHQUAKE PRODUCED BY THE VIRGIN ISLAND BASIN SOUTH FAULT USING ATTENUATION RELATION OF BOORE, JOYNER AND FUMAL, 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 7.4@55	0.126	S-1-2A	7	27	0.099	N
	M 7.4@55	0.126	S1-3A	14	18	0.103	N
	M 7.4@55	0.126	S1-4A	7	14	0.099	N
	M 7.4@55	0.126	S1-5A	12	7	0.112	L
	M 7.4@55	0.126	S1-7A	12	12	0.094	N
	M 7.4@55	0.126	S1-10A	5	7	0.072	L
	M 7.4@55	0.126	S1-14A	10	10	0.080	N
	M 7.4@55	0.126	S1-16A	7	19	0.084	N
	M 7.4@55	0.126	S1-24A	7	11	0.084	N
	M 7.4@55	0.126	S1-28A	10	3	0.095	L
	M 7.4@55	0.126	S2	16	13	0.100	N
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M 7.4@65	0.111	B-1	12.5	5	0.049	N
	M 7.4@65	0.111	B-2	10	7	0.046	N
	M 7.4@65	0.111	B-3	17	8	0.069	N
	M 7.4@65	0.111	B-4	10	5	0.061	L
	M 7.4@65	0.111	B-4	17.5	9	0.074	N
	M 7.4@65	0.111	B-5	10	3	0.067	L
	M 7.4@65	0.111	B-6	13	7	0.063	N
	M 7.4@65	0.111	B-7	17	9	0.070	N
	M 7.4@65	0.111	B-9	7	5	0.038	N
	M 7.4@65	0.111	B-10	10	9	0.043	N
	M 7.4@65	0.111	B-12	21	18	0.088	N
	M 7.4@65	0.111	B-16	38	10	0.079	N
	M 7.4@65	0.111	B-19	27	13	0.097	N
	M 7.4@65	0.111	B-21	14	8	0.095	L
	M 7.4@65	0.111	B-22	7	7	0.068	N
	M 7.4@65	0.111	B-24	7	4	0.096	L
PR 181 Over Rio Gurabo Gurabo	M 7.4@70	0.105	MB-103	25	7	0.058	N
	M 7.4@70	0.105	MB-104	25	5	0.059	N
	M 7.4@70	0.105	MB-105	15	14	0.079	N
	M 7.4@70	0.105	TB-3	30	13	0.083	N
PR 30 Over Rio Loiza Caguas	M 7.4@75	0.100	1	10	7	0.063	N
	M 7.4@75	0.100		20	11	0.076	N
	M 7.4@75	0.100	2	15	15	0.072	N
	M 7.4@75	0.100		25	15	0.077	N

	M 7.4@75	0.100		30	12	0.077	N
	M 7.4@75	0.100	7	15	11	0.064	N
	M 7.4@75	0.100		20	14	0.069	N
	M 7.4@75	0.100	8	10	6	0.061	N
	M 7.4@75	0.100		20	12	0.074	N
PR 203 Over Rio Loiza, San Lorenzo	M 7.4@65	0.111	S-16	14	8	0.069	N
	M 7.4@65	0.111	S-14	10	8	0.067	N
	M 7.4@65	0.111	S-13	6	15	0.052	N
	M 7.4@65	0.111	S-11	8	24	0.068	N
	M 7.4@65	0.111	S-8	17	18	0.097	N
	M 7.4@65	0.111	S-16	15	7	0.064	N
	M 7.4@65	0.111	S-17	14	5	0.129	L
	M 7.4@65	0.111	S-18	10	23	0.133	N

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 5a. EVALUATION OF M 7.3 EARTHQUAKE PRODUCED BY THE SALINAS FAULT USING ATTENUATION RELATION OF BOORE, JOYNER AND FUMAL, 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 6.7 @60	0.082	S-1-2A	7	27	0.064	N
	M 6.7 @60	0.082	S1-3A	14	18	0.066	N
	M 6.7 @60	0.082	S1-4A	7	14	0.064	N
	M 6.7 @60	0.082	S1-5A	12	7	0.072	N
	M 6.7 @60	0.082	S1-7A	12	12	0.061	N
	M 6.7 @60	0.082	S1-10A	5	7	0.046	N
	M 6.7 @60	0.082	S1-14A	10	10	0.052	N
	M 6.7 @60	0.082	S1-16A	7	19	0.054	N
	M 6.7 @60	0.082	S1-24A	7	11	0.054	N
	M 6.7 @60	0.082	S1-28A	10	3	0.061	N
	M 6.7 @60	0.082	S2	16	13	0.065	N
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M 6.7@50	0.088	B-1	12.5	5	0.039	N
	M 6.7@50	0.088	B-2	10	7	0.036	N
	M 6.7@50	0.088	B-3	17	8	0.055	N
	M 6.7@50	0.088	B-4	10	5	0.048	N
	M 6.7@50	0.088	B-4	17.5	9	0.059	N
	M 6.7@50	0.088	B-5	10	3	0.053	N
	M 6.7@50	0.088	B-6	13	7	0.050	N
	M 6.7@50	0.088	B-7	17	9	0.055	N
	M 6.7@50	0.088	B-9	7	5	0.030	N
	M 6.7@50	0.088	B-10	10	9	0.034	N
	M 6.7@50	0.088	B-12	21	18	0.070	N
	M 6.7@50	0.088	B-16	38	10	0.063	N
	M 6.7@50	0.088	B-19	27	13	0.077	N
	M 6.7@50	0.088	B-21	14	8	0.075	N
	M 6.7@50	0.088	B-22	7	7	0.054	N
	M 6.7@50	0.088	B-24	7	4	0.076	L/M
PR 181 Over Rio Gurabo Gurabo	M 6.7@45	0.102	MB-103	25	7	0.056	N
	M 6.7@45	0.102	MB-104	25	5	0.057	N
	M 6.7@45	0.102	MB-105	15	14	0.077	N
	M 6.7@45	0.102	TB-3	30	13	0.081	N
PR 30 Over Rio Loiza Caguas	M 6.7@40	0.118	1	10	7	0.074	N
	M 6.7@40	0.118		20	11	0.089	N
	M 6.7@40	0.118	2	15	15	0.085	N
	M 6.7@40	0.118		25	15	0.091	N

	M 6.7@40	0.118		30	12	0.091	N
	M 6.7@40	0.118	7	15	11	0.075	N
	M 6.7@40	0.118		20	14	0.081	N
	M 6.7@40	0.118	8	10	6	0.072	N
	M 6.7@40	0.118		20	12	0.087	N
PR 203 Over Rio Loiza, San Lorenzo	M 6.7@50	0.088	S-16	14	8	0.055	N
	M 6.7@50	0.088	S-14	10	8	0.053	N
	M 6.7@50	0.088	S-13	6	15	0.041	N
	M 6.7@50	0.088	S-11	8	24	0.054	N
	M 6.7@50	0.088	S-8	17	18	0.077	N
	M 6.7@50	0.088	S-16	15	7	0.051	N
	M 6.7@50	0.088	S-17	14	5	0.102	L
	M 6.7@50	0.088	S-18	10	23	0.106	N

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 6a. EVALUATION OF M 6.8 EARTHQUAKE PRODUCED BY THE HUMACAO-VALENCIANO FAULT USING ATTENUATION RELATION OF BOORE, JOYNER AND FUMAL, 1997.

Site Location	M@Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 6.8 @10	0.314	S-1-2A	7	27	0.246	N
	M 6.8 @10	0.314	S1-3A	14	18	0.255	L
	M 6.8 @10	0.314	S1-4A	7	14	0.246	L
	M 6.8 @10	0.314	S1-5A	12	7	0.278	L
	M 6.8 @10	0.314	S1-7A	12	12	0.234	L
	M 6.8 @10	0.314	S1-10A	5	7	0.178	L
	M 6.8 @10	0.314	S1-14A	10	10	0.198	L
	M 6.8 @10	0.314	S1-16A	7	19	0.208	M
	M 6.8 @10	0.314	S1-24A	7	11	0.208	L
	M 6.8 @10	0.314	S1-28A	10	3	0.236	L
	M 6.8 @10	0.314	S2	16	13	0.249	L
Connector PR 31 and PR 185 Over Rio Gurabo Juncos	M 6.8@1	0.506	B-1	12.5	5	0.222	L
	M 6.8@1	0.506	B-2	10	7	0.209	L
	M 6.8@1	0.506	B-3	17	8	0.314	L
	M 6.8@1	0.506	B-4	10	5	0.276	L
	M 6.8@1	0.506	B-4	17.5	9	0.338	L
	M 6.8@1	0.506	B-5	10	3	0.304	L
	M 6.8@1	0.506	B-6	13	7	0.285	L
	M 6.8@1	0.506	B-7	17	9	0.319	L
	M 6.8@1	0.506	B-9	7	5	0.174	L
	M 6.8@1	0.506	B-10	10	9	0.196	L
	M 6.8@1	0.506	B-12	21	18	0.400	L
	M 6.8@1	0.506	B-16	38	10	0.362	L
	M 6.8@1	0.506	B-19	27	13	0.440	L
	M 6.8@1	0.506	B-21	14	8	0.433	L
	M 6.8@1	0.506	B-22	7	7	0.311	L
	M 6.8@1	0.506	B-24	7	4	0.436	L
PR 181 Over Rio Gurabo Gurabo	M 6.8@5	0.437	MB-103	25	7	0.239	L
	M 6.8@5	0.437	MB-104	25	5	0.244	L
	M 6.8@5	0.437	MB-105	15	14	0.328	L
	M 6.8@5	0.437	TB-3	30	13	0.345	L
PR 30 Over Rio Loiza Caguas	M 6.8@10	0.314	1	10	7	0.198	L
	M 6.8@10	0.314		20	11	0.238	L
	M 6.8@10	0.314	2	15	15	0.226	L
	M 6.8@10	0.314		25	15	0.243	L

	M 6.8@10	0.314		30	12	0.242	L
	M 6.8@10	0.314	7	15	11	0.201	L
	M 6.8@10	0.314		20	14	0.216	L
	M 6.8@10	0.314	8	10	6	0.191	L
	M 6.8@10	0.314		20	12	0.232	L
PR 203 Over Rio Loiza, San Lorenzo	M 6.8@5	0.437	S-16	14	8	0.273	L
	M 6.8@5	0.437	S-14	10	8	0.262	L
	M 6.8@5	0.437	S-13	6	15	0.203	L
	M 6.8@5	0.437	S-11	8	24	0.267	N
	M 6.8@5	0.437	S-8	17	18	0.382	L
	M 6.8@5	0.437	S-16	15	7	0.251	L
	M 6.8@5	0.437	S-17	14	5	0.507	L
	M 6.8@5	0.437	S-18	10	23	0.525	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 7a. EVALUATION OF M 7.0 EARTHQUAKE PRODUCED BY CERRO MULA FAULT USING ATTENUATION RELATION OF BOORE, JOYNER AND FUMAL, 1997.

Site Location	M @Distance km	amax	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results1
PR 53 Over Rio Blanco Naguabo	M 7.0 @5	0.452	S-1-2A	7	27	0.354	M
	M 7.0 @5	0.452	S1-3A	14	18	0.367	L
	M 7.0 @5	0.452	S1-4A	7	14	0.354	L
	M 7.0 @5	0.452	S1-5A	12	7	0.400	L
	M 7.0 @5	0.452	S1-7A	12	12	0.337	L
	M 7.0 @5	0.452	S1-10A	5	7	0.257	L
	M 7.0 @5	0.452	S1-14A	10	10	0.286	L
	M 7.0 @5	0.452	S1-16A	7	19	0.299	L
	M 7.0 @5	0.452	S1-24A	7	11	0.299	L
	M 7.0 @5	0.452	S1-28A	10	3	0.339	L
	M 7.0 @5	0.452	S2	16	13	0.359	L
Connector PR 31and PR 185 Over Rio Gurabo Juncos	M 7.0@1	0.562	B-1	12.5	5	0.247	L
	M 7.0@1	0.562	B-2	10	7	0.233	L
	M 7.0@1	0.562	B-3	17	8	0.349	L
	M 7.0@1	0.562	B-4	10	5	0.307	L
	M 7.0@1	0.562	B-4	17.5	9	0.375	L
	M 7.0@1	0.562	B-5	10	3	0.337	L
	M 7.0@1	0.562	B-6	13	7	0.317	L
	M 7.0@1	0.562	B-7	17	9	0.354	L
	M 7.0@1	0.562	B-9	7	5	0.194	L
	M 7.0@1	0.562	B-10	10	9	0.218	L
	M 7.0@1	0.562	B-12	21	18	0.444	L
	M 7.0@1	0.562	B-16	38	10	0.402	L
	M 7.0@1	0.562	B-19	27	13	0.489	L
	M 7.0@1	0.562	B-21	14	8	0.481	L
	M 7.0@1	0.562	B-22	7	7	0.346	L
	M 7.0@1	0.562	B-24	7	4	0.484	L
PR 181 Over Rio Gurabo Gurabo	M 7.0@1	0.562	MB-103	25	7	0.308	L
	M 7.0@1	0.562	MB-104	25	5	0.314	L
	M 7.0@1	0.562	MB-105	15	14	0.422	L
	M 7.0@1	0.562	TB-3	30	13	0.444	L
PR 30 Over Rio Loiza Caguas	M 7.0@1	0.562	1	10	7	0.355	L
	M 7.0@1	0.562		20	11	0.427	L
	M 7.0@1	0.562	2	15	15	0.404	L
	M 7.0@1	0.562		25	15	0.434	L

	M 7.0@1	0.562		30	12	0.433	L
	M 7.0@1	0.562	7	15	11	0.359	L
	M 7.0@1	0.562		20	14	0.387	L
	M 7.0@1	0.562	8	10	6	0.342	L
	M 7.0@1	0.562		20	12	0.416	L
PR 203 Over Rio Loiza, San Lorenzo	M 7.0 @5	0.452	S-16	14	8	0.283	L
	M 7.0 @5	0.452	S-14	10	8	0.271	L
	M 7.0 @5	0.452	S-13	6	15	0.210	L
	M 7.0 @5	0.452	S-11	8	24	M	L
	M 7.0 @5	0.452	S-8	17	18	0.395	L
	M 7.0 @5	0.452	S-16	15	7	0.260	L
	M 7.0 @5	0.452	S-17	14	5	0.525	L
	M 7.0 @5	0.452	S-18	10	23	0.543	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 8b. **EVALUATION OF M 6.8 EARTHQUAKE PRODUCED BY PENA POBRE FAULT USING ATTENUATION RELATION OF ABRAHAMSON AND SILVA, 1997.**

Site Location	M @ Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Streee Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M6.8 @1	0.638	S-1-2A	7	27	0.500	L
	M6.8 @1	0.638	S1-3A	14	18	0.518	L
	M6.8 @1	0.638	S1-4A	7	14	0.500	L
	M6.8 @1	0.638	S1-5A	12	7	0.565	L
	M6.8 @1	0.638	S1-7A	12	12	0.476	L
	M6.8 @1	0.638	S1-10A	5	7	0.363	L
	M6.8 @1	0.638	S1-14A	10	10	0.403	L
	M6.8 @1	0.638	S1-16A	7	19	0.423	L
	M6.8 @1	0.638	S1-24A	7	11	0.423	L
	M6.8 @1	0.638	S1-28A	10	3	0.479	L
	M6.8 @1	0.638	S2	16	13	0.506	L
Connector PR 31and PR 185 Over Rio Gurabo Juncos	M6.8@10	0.322	B-1	12.5	5	0.141	L
	M6.8@10	0.322	B-2	10	7	0.133	L
	M6.8@10	0.322	B-3	17	8	0.200	L
	M6.8@10	0.322	B-4	10	5	0.176	L
	M6.8@10	0.322	B-4	17.5	9	0.215	L
	M6.8@10	0.322	B-5	10	3	0.193	L
	M6.8@10	0.322	B-6	13	7	0.182	L
	M6.8@10	0.322	B-7	17	9	0.203	L
	M6.8@10	0.322	B-9	7	5	0.111	L
	M6.8@10	0.322	B-10	10	9	0.125	L
	M6.8@10	0.322	B-12	21	18	0.254	L
	M6.8@10	0.322	B-16	38	10	0.230	L
	M6.8@10	0.322	B-19	27	13	0.280	L
	M6.8@10	0.322	B-21	14	8	0.275	L
	M6.8@10	0.322	B-22	7	7	0.198	L
	M6.8@10	0.322	B-24	7	4	0.277	L
PR 181 Over Rio Gurabo Gurabo	M6.8@15	0.231	MB-103	25	7	0.126	L
	M6.8@15	0.231	MB-104	25	5	0.129	L
	M6.8@15	0.231	MB-105	15	14	0.173	L
	M6.8@15	0.231	TB-3	30	13	0.183	L
PR 30 Over Rio Loiza Caguas	M6.8@20	0.178	1	10	7	0.112	L
	M6.8@20	0.178		20	11	0.135	L
	M6.8@20	0.178	2	15	15	0.128	N
	M6.8@20	0.178		25	15	0.138	M

	M6.8@20	0.178		30	12	0.137	L
	M6.8@20	0.178	7	15	11	0.114	L
	M6.8@20	0.178		20	14	0.122	N
	M6.8@20	0.178	8	10	6	0.108	L
	M6.8@20	0.178		20	12	0.132	L
PR 203 Over Rio Loiza, San Lorenzo	M6.8@15	0.231	S-16	14	8	0.144	L
	M6.8@15	0.231	S-14	10	8	0.139	L
	M6.8@15	0.231	S-13	6	15	0.107	N
	M6.8@15	0.231	S-11	8	24	0.141	N
	M6.8@15	0.231	S-8	17	18	0.202	L
	M6.8@15	0.231	S-16	15	7	0.133	L
	M6.8@15	0.231	S-17	14	5	0.268	L
	M6.8@15	0.231	S-18	10	23	0.277	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

Table 9b. EVALUATION OF M 7.3 EARTHQUAKE PRODUCED BY PENA POBRE-CERRO MULA-LIMONES FAULT USING ATTENUATION RELATION OF ABRAHAMSON AND SILVA, 1997.

Site Location	M @ Distance km	a_{max}	Boring	Sediment Depth (ft)	Blow Count	Cyclic Stress Ratio	Results[1]
PR 53 Over Rio Blanco Naguabo	M 7.3 @1	0.741	S-1-2A	7	27	0.580	L
	M 7.3 @1	0.741	S1-3A	14	18	0.602	L
	M 7.3 @1	0.741	S1-4A	7	14	0.580	L
	M 7.3 @1	0.741	S1-5A	12	7	0.656	L
	M 7.3 @1	0.741	S1-7A	12	12	0.553	L
	M 7.3 @1	0.741	S1-10A	5	7	0.421	L
	M 7.3 @1	0.741	S1-14A	10	10	0.468	L
	M 7.3 @1	0.741	S1-16A	7	19	0.491	L
	M 7.3 @1	0.741	S1-24A	7	11	0.491	L
	M 7.3 @1	0.741	S1-28A	10	3	0.556	L
	M 7.3 @1	0.741	S2	16	13	0.588	L
Connector PR 31and PR 185 Over Rio Gurabo Juncos	M 7.3@1	0.741	B-1	12.5	5	0.325	L
	M 7.3@1	0.741	B-2	10	7	0.307	L
	M 7.3@1	0.741	B-3	17	8	0.460	L
	M 7.3@1	0.741	B-4	10	5	0.404	L
	M 7.3@1	0.741	B-4	17.5	9	0.495	L
	M 7.3@1	0.741	B-5	10	3	0.445	L
	M 7.3@1	0.741	B-6	13	7	0.418	
	M 7.3@1	0.741	B-7	17	9	0.467	L
	M 7.3@1	0.741	B-9	7	5	0.255	L
	M 7.3@1	0.741	B-10	10	9	0.287	L
	M 7.3@1	0.741	B-12	21	18	0.585	L
	M 7.3@1	0.741	B-16	38	10	0.530	L
	M 7.3@1	0.741	B-19	27	13	0.645	L
	M 7.3@1	0.741	B-21	14	8	0.634	L
	M 7.3@1	0.741	B-22	7	7	0.456	L
	M 7.3@1	0.741	B-24	7	4	0.638	L
PR 181 Over Rio Gurabo Gurabo	M 7.3@1	0.741	MB-103	25	7	0.406	L
	M 7.3@1	0.741	MB-104	25	5	0.414	L
	M 7.3@1	0.741	MB-105	15	14	0.556	L
	M 7.3@1	0.741	TB-3	30	13	0.586	L
PR 30 Over Rio Loiza Caguas	M 7.3@1	0.741	1	10	7	0.468	L
	M 7.3@1	0.741		20	11	0.563	L
	M 7.3@1	0.741	2	15	15	0.533	L
	M 7.3@1	0.741		25	15	0.573	L

	M 7.3@1	0.741		30	12	0.571	L
	M 7.3@1	0.741	7	15	11	0.474	L
	M 7.3@1	0.741		20	14	0.510	L
	M 7.3@1	0.741	8	10	6	0.450	L
	M 7.3@1	0.741		20	12	0.549	L
PR 203 Over Rio Loiza, San Lorenzo	M 7.3@5	0.570	S-16	14	8	0.356	L
	M 7.3@5	0.570	S-14	10	8	0.342	L
	M 7.3@5	0.570	S-13	6	15	0.265	L
	M 7.3@5	0.570	S-11	8	24	0.348	L
	M 7.3@5	0.570	S-8	17	18	0.498	L
	M 7.3@5	0.570	S-16	15	7	0.328	L
	M 7.3@5	0.570	S-17	14	5	0.662	L
	M 7.3@5	0.570	S-18	10	23	0.684	L

[1] L = liquefaction likely; M = liquefaction marginal; N = liquefaction not likely;

APPENDIX H

PRELIMINARY REPORT, SEISMIC DESIGN PARAMETERS PROPOSED RIO VALENCIANO DAM AND RESERVOIR – SWAISGOOD CONSULTING

PRELIMINARY REPORT

Seismic Design Parameters

Proposed Rio Valenciano Dam and Reservoir

prepared for:
CSA Group
San Juan, Puerto Rico

prepared by:
Swaisgood Consulting
Conifer, Colorado

11 January 2007
Rev 1 - 29 January 2007

PRELIMINARY REPORT
Seismic Design Parameters
Proposed Rio Valenciano Dam and Reservoir

Introduction

This report presents the results of a preliminary evaluation of the seismic design parameters to be included in the preliminary environmental impact statement for the proposed Rio Valenciano Dam and Reservoir. near Juncos, Puerto Rico. The proposed dam will be of roller-compacted concrete (RCC) construction, approximately 30 m high with a crest length of 250 m.

The specific objectives of the work described in this report were to:

- Provide an assessment of the general scale of the parameters of the Maximum Design Earthquake
- Establish probabilistic earthquake parameters and use these to define the Operating Basis Earthquake

Scope of Work

In order to fulfill the goals of the study several tasks were undertaken:

- The site was inspected between December 4 and December 8, 2006
- Information and findings were exchanged and discussed with the team of experts evaluating fault activity and performing liquefaction studies
- A review of past and current studies and other pertinent literature was performed
- All relevant data was accumulated and analyzed to produce the preliminary earthquake parameters. The procedures used in these analyses are consistent with current guidelines for selecting seismic parameters for dam design as recommended by the U.S. Army Corps of Engineers, the Federal Energy Regulatory Commission, the U.S. Bureau of Reclamation, and the U.S. Commission On Large Dams.

Preliminary Seismic Design Parameters

Deterministic Studies and Maximum Design Earthquake (MDE)

General

The deterministic technique of obtaining seismic parameters involves identifying an active or potentially active fault that is close to the site in question, estimating the maximum earthquake that the fault is capable of producing, and determining the Peak Ground Acceleration (PGA) that will be produced at the site from this event. This earthquake and its accompanying ground motion is known as the Maximum Credible Earthquake (MCE) for that particular fault..

The MCEs for all significant faults nearby the site are compared to determine the Maximum Design Earthquake (MDE). The MDE is the most critical of all the MCEs capable of affecting a structure. The MDE is determined after successively assuming that each MCE would occur along its associated fault at a location closest to the site with postulated capability of generating the event. The MCE that would result in the most severe consequences for the structure at the site represents the MDE.

Maximum Credible Earthquakes (MCE)

The prominent active faults closest to the Rio Valenciano were identified and their maximum credible magnitudes were estimated by the fault evaluation team. They include: 1) the Puerto Rico Trench – Shallow [M = 8.25]; 2) the Puerto Rico Trench –Deep [M = 7.75]; 3) the Muertos Trough – East [M = 8.25]; 4) the Virgin Islands Basin – North [M = 7.3]; and 5) the Virgin Islands Basin – South [M = 7.4]. The locations, types and assigned magnitudes of these faults are shown in Figure 1.

For each MCE, the associated PGA at the site was calculated using up to date attenuation relationships and the geometries listed in Figure 2. The locations of the fault zones shown in Figure 2 were estimated based on epicenter location and depth data from the USGS earthquake data base (USGS, 2006a) and studies by others (McCann and Mendoza, 2006; and LaForge and Hawkins, 1999).

The PGAs for the three megathrust (subduction zone) earthquakes were estimated using the attenuation correlations developed by Youngs et al (1997). Based on a comparison with two other recently published subduction zone relationships (Gregor et al, 2002; and Atkinson and Boore, 2003), it is believed that the Youngs et al method has the most appropriate degree of conservatism for critical engineered structures such as the Rio Valenciano dam. The PGAs for the normal faults were calculated using the attenuation relationships developed by Abrahamson and Silva, (1997). The resulting PGAs, both mean and mean plus one standard deviation (mean + s) are shown in Figure 2.

Maximum Design Earthquake (MDE)

Comparison of the MCE parameters listed in Figure 2 shows that an event produced by the Muertos Trough - East Fault would represent the MDE and is therefore recommended for use in subsequent analysis of the Rio Valenciano dam.

Based on Corps of Engineers guidelines (USACOE, 1999), for a dam of the scale and critical nature of the proposed Rio Valenciano structure, the mean + s MDE parameters and response spectrum should be used for design purposes. Accordingly, the MDE applied in the analyses should be a magnitude 8.25 earthquake along the Muertos Trough - East fault that produces a PGA of 0.46g at the site.

Target response spectra for the mean and the mean + s ground motions were developed for the MDE using Youngs et al (1997) attenuation relationships. The results are shown in Figure 3.

It is pointed out that if the on-going fault evaluation and paleoliquefaction studies identify previously unidentified active or potentially active faults that are close by the damsite, the MDE may change.

Pseudostatic Seismic Coefficient

A preliminary stability analysis of the Rio Valenciano dam will be performed using the pseudostatic method that employs a seismic coefficient. This number was calculated in accordance with guidelines provided by the Corps of Engineers (USACOE, 2003) as follows:

"The seismic coefficient used for the preliminary seismic stability evaluation of concrete hydraulic structures should be equal to 2/3 the effective peak ground acceleration (EPGA) expressed as a decimal fraction of the acceleration of gravity .The EPGA can be obtained by dividing the 0.30 second spectral acceleration, for the return period representing the design earthquake, by a factor of 2.5."

For the MDE at Rio Valenciano, the mean + s response spectrum is plotted in Figure 3. At the 0.30 sec period, the Spectral Acceleration is equal to 0.994g. This number divided by 2.5 is 0.397g and 2/3rds of this is 0.265g.

Based on these calculations, it is recommended that 0.27g be used as the seismic coefficient for the preliminary seismic stability analysis of Rio Valenciano dam.

Probabilistic Studies and Operating Basis Earthquake (OBE)

A probabilistic seismic hazard analysis uses the elements of the deterministic studies and adds an assessment of the likelihood that ground motions will occur during the specified time period. The probability or frequency of occurrence of different magnitude earthquakes on each significant seismic source and inherent uncertainties are directly accounted for in the analysis. The results of the probabilistic analyses are used to select the site ground motions based on the probability of exceedance of a given magnitude during the service life of the structure or for a given return period.

An Operating Basis Earthquake (OBE) is an earthquake that can reasonably be expected to occur within the service life of the project, that is, with a 50-percent probability of exceedence during the service life. (This corresponds to a return period of 144 years for a project with a service life of 100 years.) The dam, appurtenant structures and equipment should remain functional and damage should be easily repairable after the occurrence of earthquake motion equal to or less than the OBE. The OBE is determined by the probabilistic analysis.

The probabilistic assessment of the Rio Valenciano site was performed using the information from the USGS Seismic Hazard website (USGS, 2006b). The results were presented as the PGAs for return periods of 224, 475, 975, 2475, and 4975 years. The probability curve, extended with a regression analysis, is shown in figure 4.

Since the consequences of exceeding the OBE are primarily economic and not life safety-related, particular circumstances may be considered on a case-by-case basis, to justify the use of a more or less severe event. However, in accordance with the guidelines published by the U.S. Committee on Large Dams (USCOLD, 1999), it is recommended that the OBE for Rio Valenciano correspond to a 144-year return period. Therefore, a PGA of 0.13g is recommended for the OBE.

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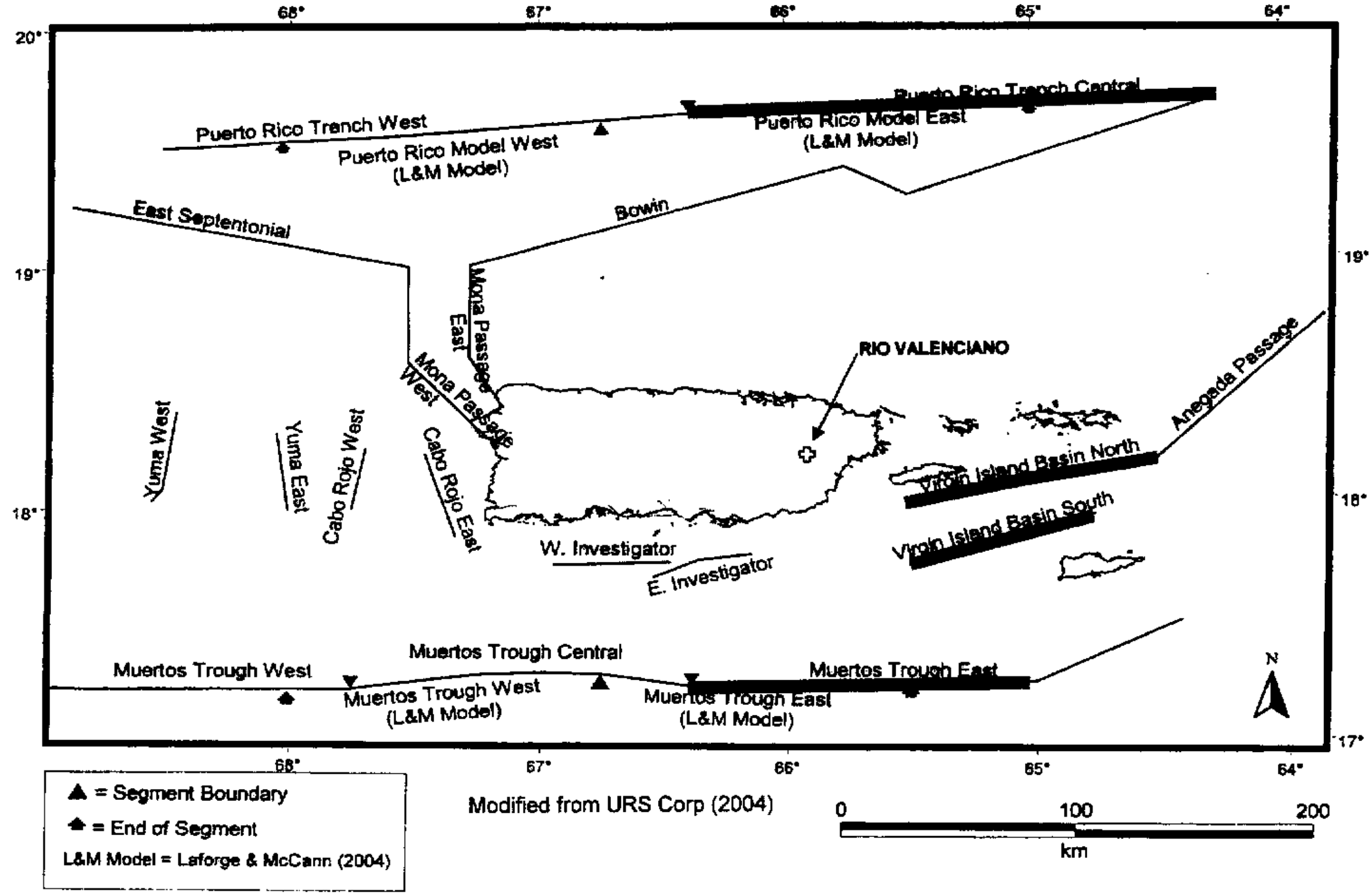
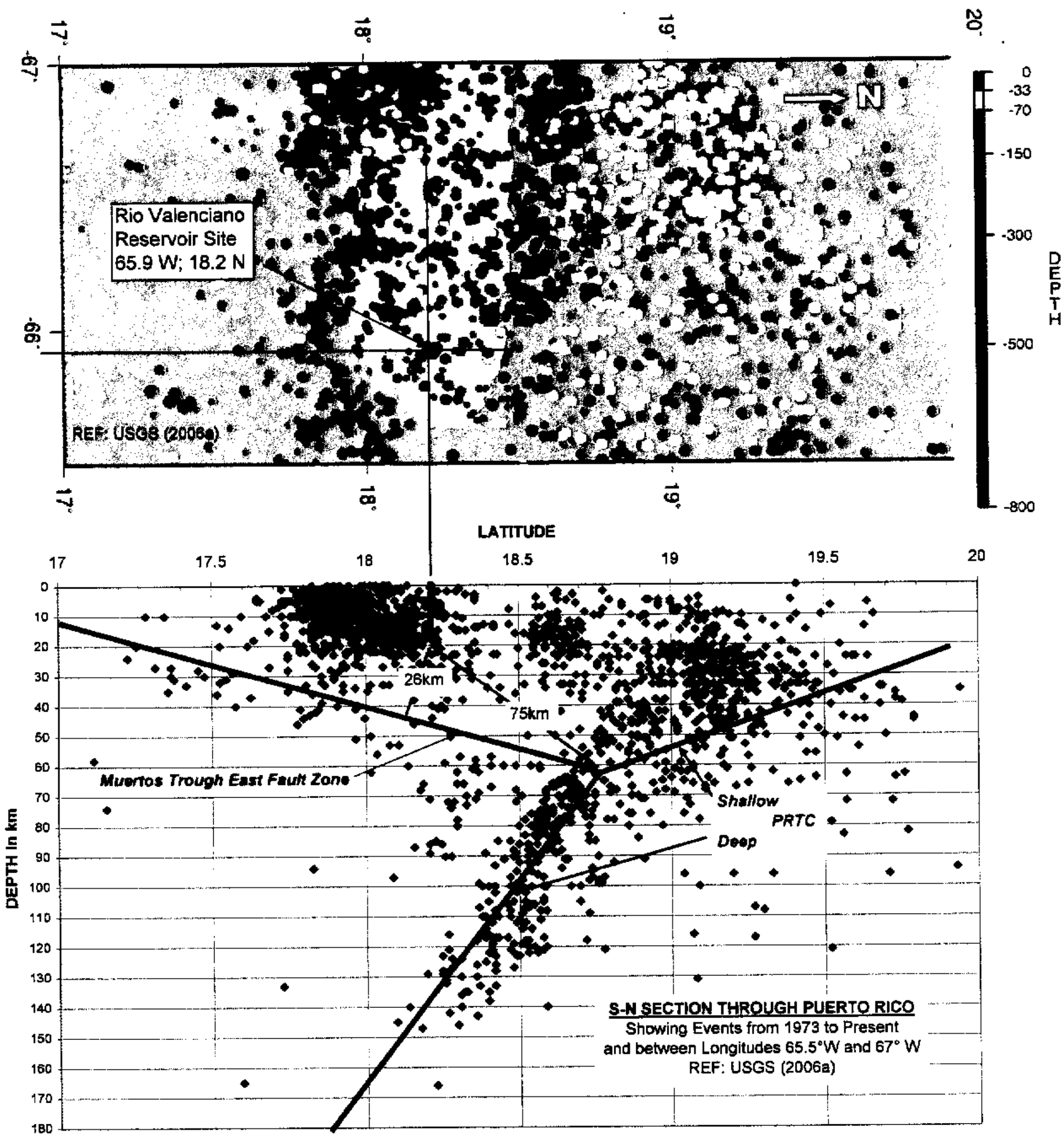


Fault Structure	Type	Magnitude **M**
PRTC -Shallow	Mega -Interface	8.25
PRTC-Deep	Mega-Intraslab	7.75*
Muertos Trough - East	Mega -Interface	8.25
Virgin Is.Basin - N	Normal	7.3
Virgin Is.Basin - S	Normal	7.4

Where: **M** - moment magnitude
* From Black & Veatch (2000)

Significant Active Faults and Maximum Magnitude Earthquakes

FIGURE 1

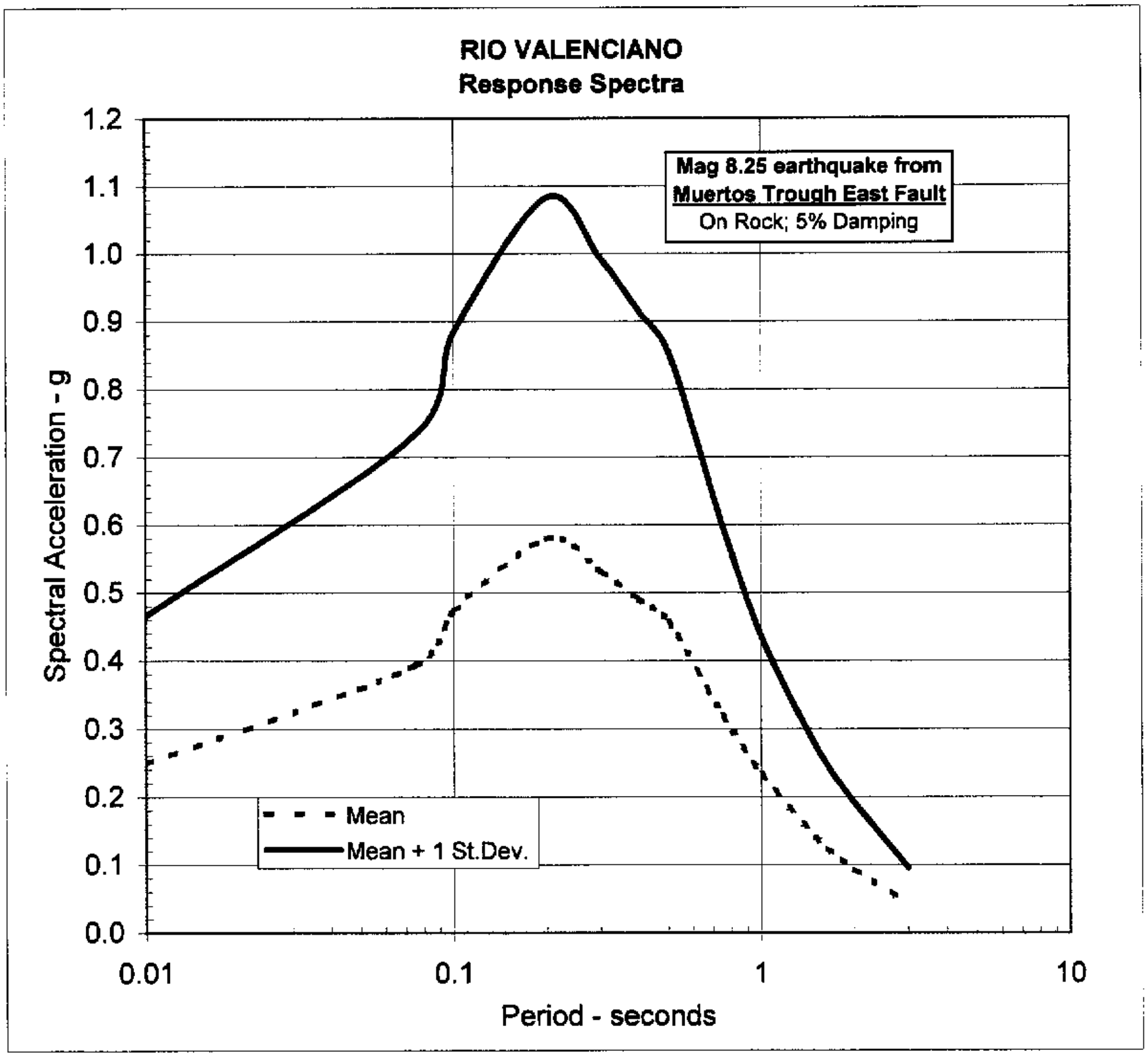


MCE Parameters Preliminary - 10 Jan 2007

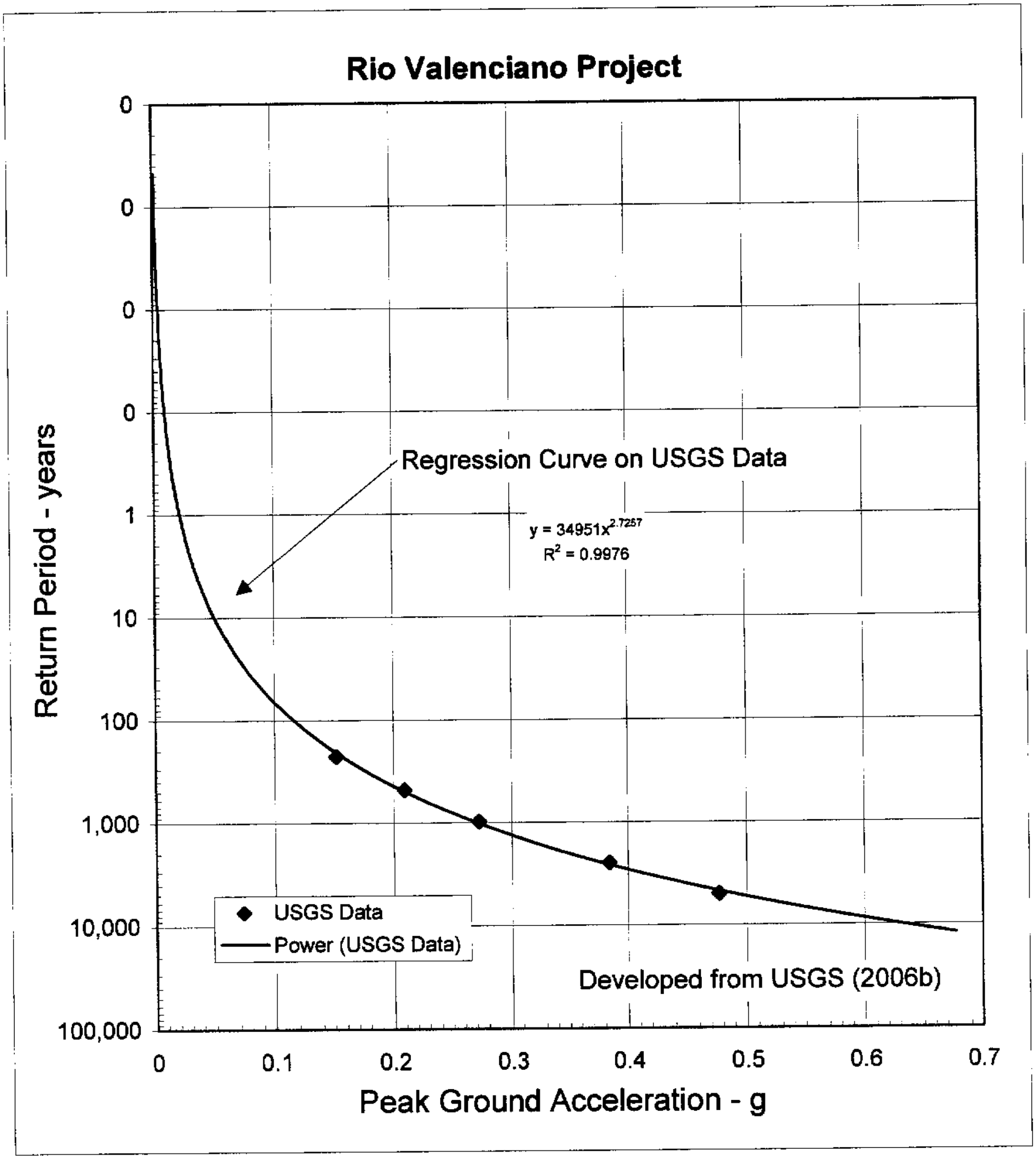
Fault Structure	Type	Magnitude **M**	*H*, km	r_{rup}, km	PGA - g (on rock) Mean	Mean + σ
PRTC -Shallow	Mega -Interface	8.25	40	75	0.15	0.28
PRTC-Deep	Mega-Intraslab	7.75	80	75	0.21	0.40
Muertos Trough - East	Mega -Interface	8.25	33	26	0.25	0.46
Virgin Is.Basin - N	Normal	7.3	20	45	0.10	0.17
Virgin Is.Basin - S	Normal	7.4	20	65	0.07	0.12

Where: **M** - moment magnitude
r_{rup} - source-to-site distance (km)
H - focal depth (km)

Maximum Credible Earthquake Parameters
FIGURE 2



MCE Response Spectra
FIGURE 3



Probabilistic Seismic Hazard

FIGURE 4

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GEO CIM, INC.
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PO Box 10872, San Juan PR 00922-0872
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LETTER OF TRANSMITTAL

DATE: 02/01/07 JOB NO. 3557-06

ATTENTION: Ing. Matt Moses

RE: Río Valenciano Dam Site
Juncos, Puerto Rico

CSA Architects & Engineers
Mercantil Plaza Building
Mezzanine Suite
San Juan, P.R. 00918
(Tel 754-6800)

WE ARE SENDING YOU _X__ Attached ___ Under separate cover via messenger the following items:

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			JUNCOS, PUERTO RICO

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