Dr. Thomas O'Rourke and Dr. Izzat M. Idriss, "Seismic Hazard and Stability Analysis Peer Review" (June 2020), with Curricula Vitae

EXHIBIT C

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June 19, 2020

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Gentlemen:

Subject: *Review of Seismic Hazard Studies*
Pebble Mine Project

1.0 INTRODUCTION

The purpose of this report is to summarize our review of seismic hazard reports relevant to the Pebble Mine Project currently under review by the U.S. Army Corps of Engineers (USACE) and other state, federal, and tribal entities. Initially, the following two documents were provided to us for this purpose:

- "Seismic Hazard Analysis for the Pebble Mine Project, Southwest Alaska (rev. 001d)", prepared by Dr. Nick Gregor and Dr. Linda Al Atik for K & L Gates, dated May 20,2020. For ease of reference, this report will be referenced as "2020 SHA Report".
- "Report on Seismicity Assessment and Seismic Design Parameters", prepared by Knight Piésold Ltd., Vancouver, Canada, for Pebble Limited Partnership, dated August 14, 2013. For ease of reference, this report will be referenced as "2013 KP Report".

We summarized the review of the 2020 SHA Report and the comparison with the results contained in the 2013 KP Report in a draft report that was submitted on June 5, 2020. Later that day, we received a file named "RFI 008g.pdf", which we were informed had been recently uploaded to the ACOE Website. File RFI 008g contains the two documents listed below:

- Report titled "Report on Seismicity Assessment and Seismic Design Parameters", prepared by Knight Piésold Ltd., Vancouver, Canada, for Pebble Limited Partnership, dated July 4, 2019. For ease of reference, this report will be referenced as "2019 KP Report".
- Memorandum covering "Main Embankment Stability Assessment – Static and Post-liquefaction", prepared by Knight Piésold Ltd., Vancouver, Canada, for Pebble Limited Partnership, dated July 8, 2019.

Our review of the 2019 KP Report, which is an update of the 2013 KP Report, is presented in Appendix A of this Report. Our review of the stability-assessment Memorandum is provided in a separate report.

Our review comments. observations, conclusions and recommendations are provided in this report, and cover the following topics:

- Seismic sources
- Earthquake ground motions models (GMMs)
- Probabilistic seismic hazard analysis (PSHA)
- Deterministic seismic hazard analysis (DSHA)
- Volcanism

We believe that Dr. Gregor and Dr. Al Atik have prepared a comprehensive report that provides seismic hazard results based on the current state of the art in completing such studies. The results of their report can be used to establish target earthquake ground motions for evaluating the seismic performance of all the components of the Pebble Mine.

Furthermore, we believe that the 2020 SHA Report supersedes both the 2013 and 2019 KP Reports for the following reasons:

- The assessment of the seismic sources in the 2020 SHA Report is more complete.
- The 2020 SHA Report includes up to date assignment of maximum magnitude, rupture distance, hypocentral distance and hypocentral depth for each seismic source. The 2013 and the 2019 KP Reports assigned same magnitudes to these sources, but chose to use epicentral distance[1]for the seismic characterization, which is inconsistent of how distance is defined in the earthquake ground motion models GMM used in the KP Reports.
- The 2020 SHA Report used the most currently available and applicable GMMs. The 2013 and the 2019 KP Reports used a number of GMMs that are out of date and not in use.
- The 2020 SHA Report placed no limitation on the maximum magnitude to use for calculating the spectral values for an earthquake occurring on the interplate. Both KP Reports used M = 8.5 to represent an M = 9.2 event. While this limitation had no effect of the selection of a "design" spectrum, it does reflect on the adequacy of the approach adopted for assessing the seismic hazard at this site.

Accordingly, we recommend that only the results of the probabilistic and deterministic hazard analyses included in the 2020 SHA Report be used for this project. The results presented in the 2013 and the 2019 KP Reports should not be used for this site.

2.0 SEISMIC SOURCES

The seismic sources identified in the 2020 SHA Report include crustal faults, interplate and intraslab subduction sources. The maximum magnitude, degree of activity, recurrence relationship, geometry, and other seismological parameters have been reasonably identified and the values assigned to each are appropriate.

The 2013 KP Report identified the same sources and included, in addition, a "background earthquake". Background earthquakes are often assigned to cover uncertainty associated with faults that may be present

[1] Epicentral distance, which represents a point on the earth's surface directly above what is considered to have been the initiating of the earthquake, which is defined as the hypocenter of the earthquake, has not been used in deriving earthquake ground motion models (GMMs) for several decades. Thus, although Knight Piésold use epicentral distance for the seismic source, the earthquake ground motions models selected by them use rupture distance and not epicentral distance.

at or near the site, but leave no surface expression and thus are assigned lower magnitudes, consistent with the absence of surface faulting. This background earthquake was assigned $M_W = 6.5$ in the 2013 KP Report.

The 2020 SHA Report calculated spectral values at the following three locations:

Tailings Storage Facility (TSF)	Latitude (N) – degrees	Longitude (W)) – degrees
Main	59.908	155.417
Pyritic (Area E)	59.897	155.336
South	59.841	155.457

The 2013 KP Report calculated spectral values at a location at the mine site at Latitude 59.9 degrees north and Longitude 155.3 degrees west. This location is approximately 0.4 km north and 2 km east of the location at the Pyritic TSF considered in the 2020 SHA Report.

Both reports assigned a magnitude 9.2[2] earthquake to the interplate source and a magnitude 8 earthquake to the deep intraslab source. The key crustal source described in both reports is the Lake Clark fault; the 2013 KP Report assigns a magnitude 7.5 earthquake while the 2020 SHA Report assigns a magnitude 7.6 to this fault.

The 2013 KP Report used an epicentral[3] distance of 120 miles (192 km) for the interplate earthquake and an epicentral distance of 50 miles (80 km) and a depth of 80 miles (128 km) to the deep intraslab earthquake. The 2020 SHA Report used a rupture distance of 222 km for the interplate earthquake and a hypocentral distance of 150 km and a depth of 135 km for the deep intraslab earthquake

There are two additional points to be addressed regarding the crustal source: (i) can this source be closer to the mine site; and (ii) should the Lake Clark fault be considered an extension of the Castle Mountain fault?

Regarding (i), the 2020 SHA Report states in page 16 that:

> " *… we model the terminus of the Lake Clark fault at the southwest end of Lake Clark, consistent with the findings from Haeussler and Saltus (2004). … future studies which would potentially extend this western terminus of the Lake Clark fault could impact the hazard results provided in this study, and we recommend that a re-analysis be performed in the future based on any updated characterizations of the Lake Clark fault.*"

It is also noteworthy that Knight Piésold had hypothesized an extension of the Lake Clark fault to place it as close as 7.5 miles (12 km) from the site, but indicated (in page 9 of the 2013 KP Report) that: "*Studies to examine the possible extent and alignment of the Lake Clark fault in the vicinity of the mine study area are ongoing.*" It is not clear if such studies had continued beyond 2013 and, if continued, what the findings have been.

Regarding (ii), the information in Figure A below suggests that these two faults be considered as a single source. The 2020 SHA Report indicates that the Castle Mountain fault has a strike slip mechanism and that the Lake Clark fault has a reverse mechanism. The 2013 PK Report suggests that the two faults have the same mechanism.

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[2] While the 2013 KP Report assigned M = 9.2 to the interplate source, page 17 of the report states: *"It should be noted that the level of ground shaking from a great earthquake of Magnitude 9+ is likely to be no larger than that from an event of about Magnitude 8 to 8.5."* Table 3-3 shows that M = 8.5 was used for calculating the earthquake ground motions

[3] See footnote No. 1.

The discussion in the 2020 SHA Report provides reasonable support for treating them as separate sources. We concur with that discussion and with the conclusion, but note that future investigations may support a location closer to the mine site as well as considering the two faults as a single source.

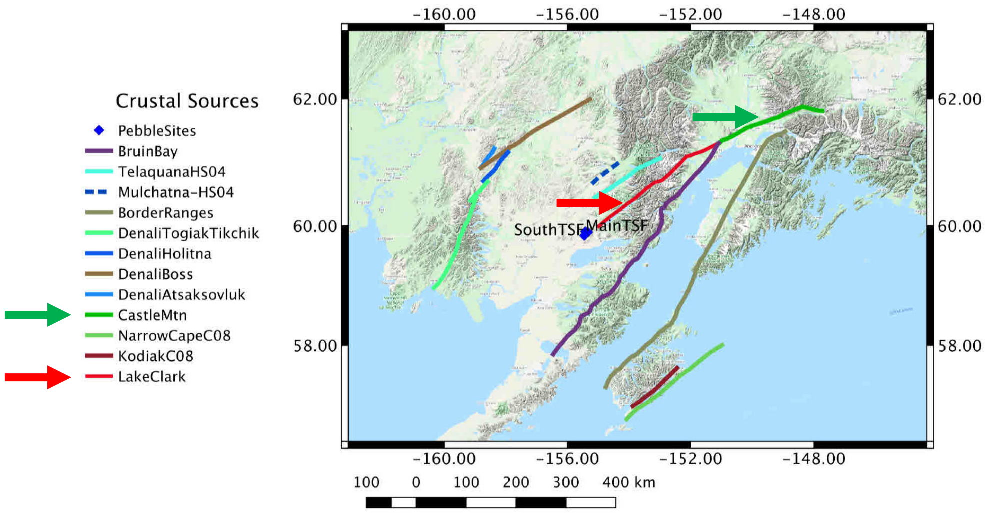


Figure 10. Characterized crustal fault used in the SHA.

Figure A Crustal faults identified in the 2020 SHA Report
[Figure 10 in the 2020 SHA Report]

3.0 EARTHQUAKE GROUND MOTIONS MODELS

The 2020 SHA Report used the NGA West2 earthquake ground motion models (GMMs) for crustal events, and the 2016 BC Hydro GMM for the subduction events for both the PSHA and the DSHA. For the PSHA, the NGA Subduction GMM recently developed by Kuehn et al. (2020) was also used; this GMM was assigned a weight of only 0.15 while the BC Hydro GMM was given a weight of 0.85. We concur with these selections.

The 2013 KP Report used the NGA West1 GMMs for the crustal events and the 1997 Youngs et al. GMM and the 2003 Atkinson and Boore GMM for the subduction events. Both the crustal and subduction GMMs have been superseded and neither set is currently in use.

4.0 PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

The 2020 SHA Report calculated seismic hazard results for mean annual frequency of exceedance (MAFE) as low as 10^{-4}, which corresponds to a return period of about 10000 years. The report also provides uniform hazard spectra (UHS) for average return periods of 475, 1000, 2475, 5000 and 10000 years. The largest contribution to the seismic hazard, by far, is the Intraslab source, which contributed about 84% to the spectral values for spectral periods, $T \leq 1$ second and at average return periods, ARP $\geq$ 1000 years.

The 2013 KP Report did not include a site specific probabilistic seismic hazard analysis. Instead, the United States Geological Survey (USGS) web site was used to obtain spectral values for a number of average return periods. The 2020 SHA Report shows a comparison of the PGA calculated in 2020 at the location of the

Main TSF and those included in the 2013 PK Report for average return periods of 475, 1000, 2475, 5000 and 10000 years; the ratio of the 2020 PGA divided by the 2013 PGA ranges from about 1.82 to 1.89.

The Pyritic TSF is the closet to the location used in the 2013 study. The values of PGA calculated at this location are listed below:

ARP* (years	2020 PGA** (g)	2013 PGA*** (g)	Ratio: 2020/2013
475	0.2729	0.14	1.95
1000	0.3555	0.19	1.87
2475	0.4828	0.25	1.93
5000	0.5949	0.31	1.92
10000	0.7273	0.38	1.91

** Average return period; ** from Table 11 in the 2020 SHA Report; *** from Table 3.1 in the 2013 KP Report*

The ratio at the Pyritic TSF location is comparable to the ratio obtained at the Main TSF location, but somewhat larger, ranging from about 1.87 to 1.95.

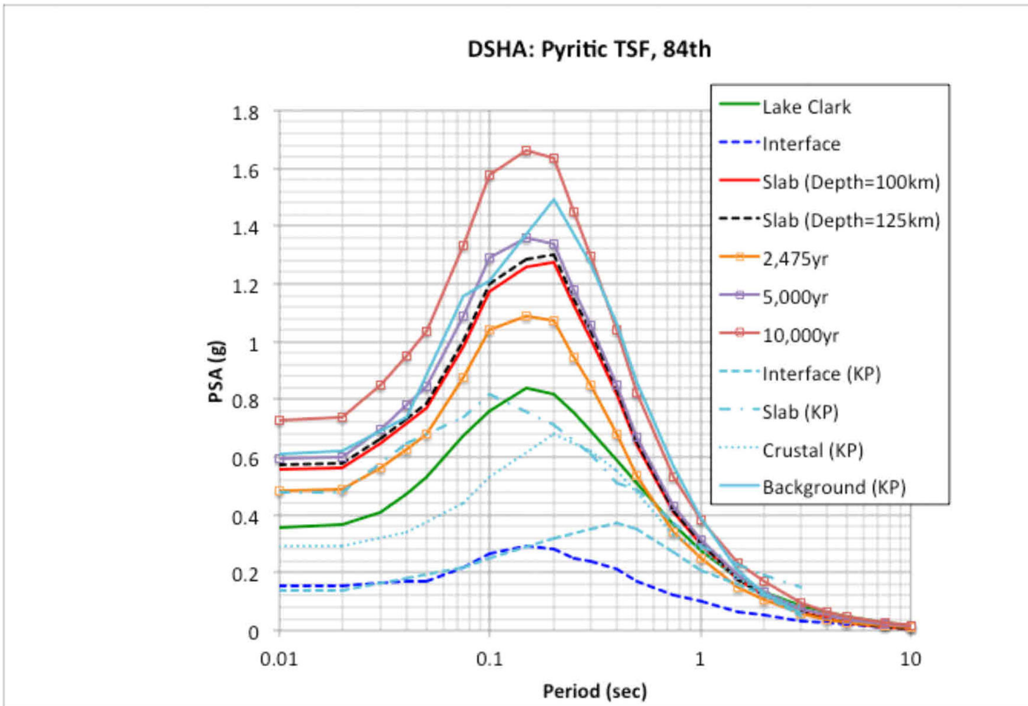
It is our experience that, while valuable for comparison purposes, the results obtained from the USGS website should not be used for design purposes for any critical structure. Our experience at other sites within the USA indicates that the results obtained from the USGS web site show comparatively high variability and provide spectral values: (i) somewhat larger than the results from a true site specific PSHA (such as that included in the 2020 SHA Report); (ii) about the same as the site specific PSHA; or (iii) smaller (sometimes significantly smaller, such as the case for this site as outlined above). It is emphasized that a true site specific PSHA is necessary for a critical project. A site specific PSHA was not provided in the Knight Piésold's reports.

5.0 DETERMINISTIC SEISMIC HAZARD ANALYSIS (DSHA)

Figure 66 in the 2020 SHA Report, part (a) of which is presented below in Figure B, presents the following spectra at the location of the Pyritic TSF:

- The 2020 UHS having average return periods 2475, 5000 and 10000 years.
- The deterministic 2020 84^{th}-percentile spectra for the crustal events, the deep Intraslab event (depth = 125 km), the shallower Intraslab event (depth = 100 km), and the Interface event.
- The deterministic 84^{th}-percentile spectra included in the 2013 KP Report for the Interface, Intraslab, crustal and background sources.

The deterministic 84^{th}-percentile spectrum for the deep Intraslab event (depth = 125 km) for periods, $T \leq 2$ sec, and that for the crustal event for periods, $T > 2$ sec, are the largest spectra calculated in 2020. The 2013 spectrum for the background source is larger than either of the latter spectra for periods longer than about 0.15 sec. As listed in Table 3.3 in the 2013 KP Report, the magnitude of this background event is 6.5. The duration of the motions associated with either the 2020 crustal event (M = 7.6) or the Intraslab event (M = 8) are sufficiently longer than the duration of the 2013 background event (M = 6.5) that the 2020 events, particularly the Intraslab event, would control the design.



(a)

Figure 66. 84th percentile DSHA scenario events (Pyritic TSF) spectra from the Knight-Piesold (2013) study and the current study plotted log-linear (a)

Figure B Spectra calculated in 2020 and those calculated in 2013 at the location of the Pyritic TSF [Part (a) of Figure 66 in the 2020 SHA Report]

The duration of shaking is very important because longer durations of ground motion at comparable accelerations will cause greater damage, especially for earth structures. For example, in assessing the potential for triggering liquefaction, a magnitude scaling factor (MSF) is used to reflect the effect of duration and to act as an equalizer between two events having different magnitudes. The most recent reference[4] on this issue has shown that MSF is not only a function of earthquake magnitude, but also depends on denseness of the soil being evaluated. For a medium dense sandy soil, having relative density of about 60%, this reference indicates that MSF $\approx$ 1.2 for M = 6.5 and MSF $\approx$ 0.92 for M = 8. Thus, for a magnitude 6.5 earthquake, it would require a PGA = 1.2/0.92 $\approx$ 1.3 times the PGA for a magnitude 8 earthquake to trigger liquefaction in this medium dense sandy soil. This would indicate that the PGA associated with the background earthquake used in the 2013 PK Report is equivalent to having a magnitude 8 earthquake with a PGA = 0.61/1.3 $\approx$ 0.468 g, which is significantly smaller than the PGA (0.574 g) reported in the 2020 SHA Report for the Intraslab event.

Not only is liquefaction triggered at lower acceleration levels for the deep Intraslab event, but the consequences of liquefaction in the form of ground deformation affecting TSF embankments and other mining facilities will be substantially more critical.

[4] Boulanger, R. W. and Idriss, I. M. (2014). "CPT and SPT Based Liquefaction Triggering Procedures", Report No. UCD/CGM-14/01, Department of Civil & Environmental Engineering, College of Engineering, University of California at Davis, April.

Liquefaction triggering and ensuing ground deformation are important issues that need to be part of the assessment of the proposed Pebble Mine site, lifelines, and port facilities. This issue is addresses further in our report covering our review of the aforementioned stability-assessment Memorandum by KP.

The two 2020 spectra identified above are presented in Figure C for the site of the Pyritic TSF. The spectrum for the deep Intraslab event (depth = 125 km)[5] is significantly larger than the spectrum for the crustal events for periods shorter than about one second. The spectrum for the crustal event is significantly larger than that for the deep intraslab event for periods longer than about 3 sec. The latter difference could be easily accommodated in the analyses by adjusting the spectrum-compatible time histories that will need to be constructed when evaluating the seismic performance of the various TSFs.

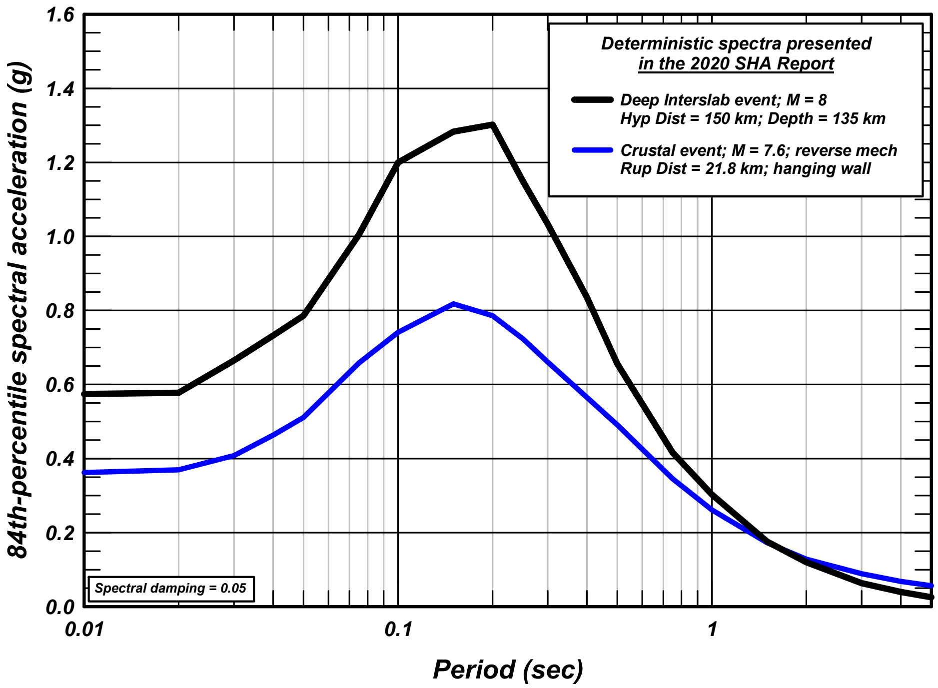


Figure C The 84th-percentile spectra calculated

Finally, it is useful to compare the results of the DSHA for the three sites considered in the 2020 SHA Report. The three spectra for the crustal event are shown in Figure D, and those for the deep Intraslab event are presented in Figure E. The largest spectrum for the crustal event is obtained at the location of the Pyritic TSF and the lowest at the South TSF. The spectra for the deep Intraslab event (Depth = 125 km) are essentially the same; the spectrum at the location of the Pyritic TSF has the largest values. Given the larger spectral values for both the deep Intraslab and crustal events, we suggest that the spectrum calculated for the Pyritic TSF be used as the unified design spectrum for all three sites.

[5] The actual depth for this event, as listed in Table 19 in the 2020 SHA Report, is 135 km. The figures in the report designate this event with "Depth = 125 km", as shown in Figure B (Figure 66 in the 2020 SHA Report). It should be noted that the hypocentral depth used in the BC Hydro GMM is equal to "min[actual depth, 120 km]", that is, the value of the depth parameter used in the BC Hydro model is the actual depth or120 km, whichever is smaller. Thus, if the actual depth is 90 km, the value used in the computation is 90 km, but if the actual depth is 135 km, then a value of 120 km is used in the calculation.

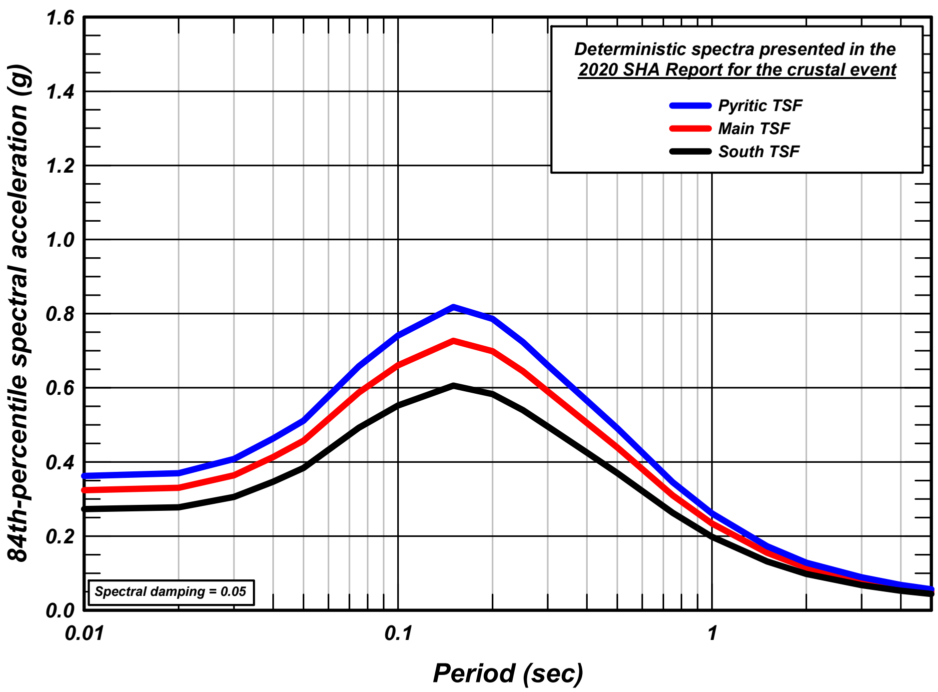


Figure D The 84th-percentile spectra for the crustal event calculated at the locations of each TSF

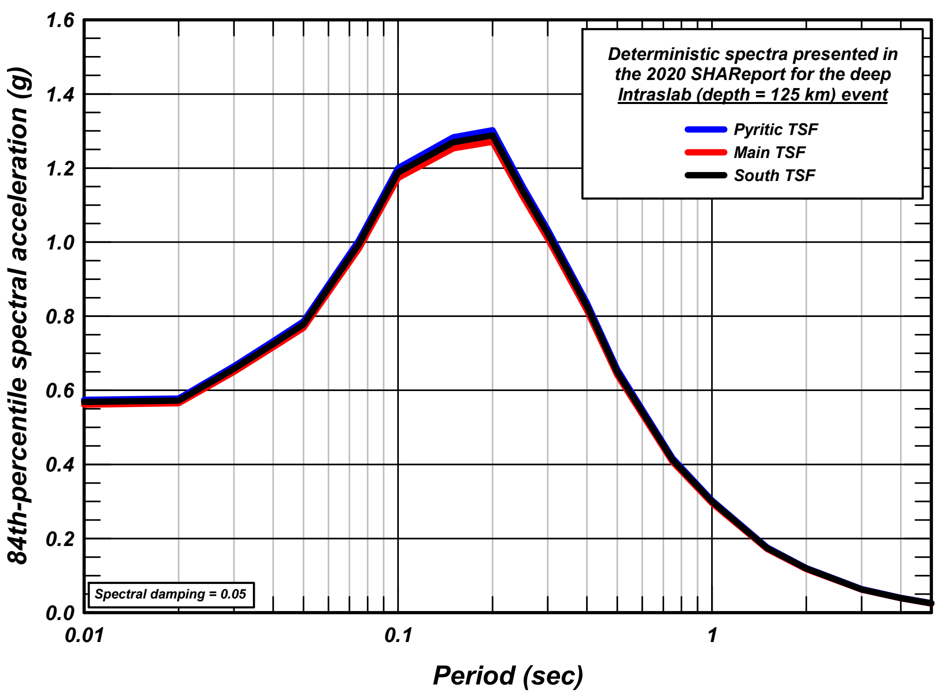


Figure E The 84th-percentile spectra for the deep Intraslab event (Depth = 125 km) calculated at the locations of each TSF

6.0 THE 2019 KP REPORT

The 2019 KP Report is an update of the 2013KP Report. A summary of the changes included in the 2019 Report and our review comments are presented in Appendix A of this report.

The spectrum recommended in the 2019 Report for the M8.0 deep Intraslab event is significantly greater than that recommended in the 2013 KP Report for the same event. This spectrum is compared to the spectra presented in the 2020 SHA Report for the three TSF locations in Figure F.

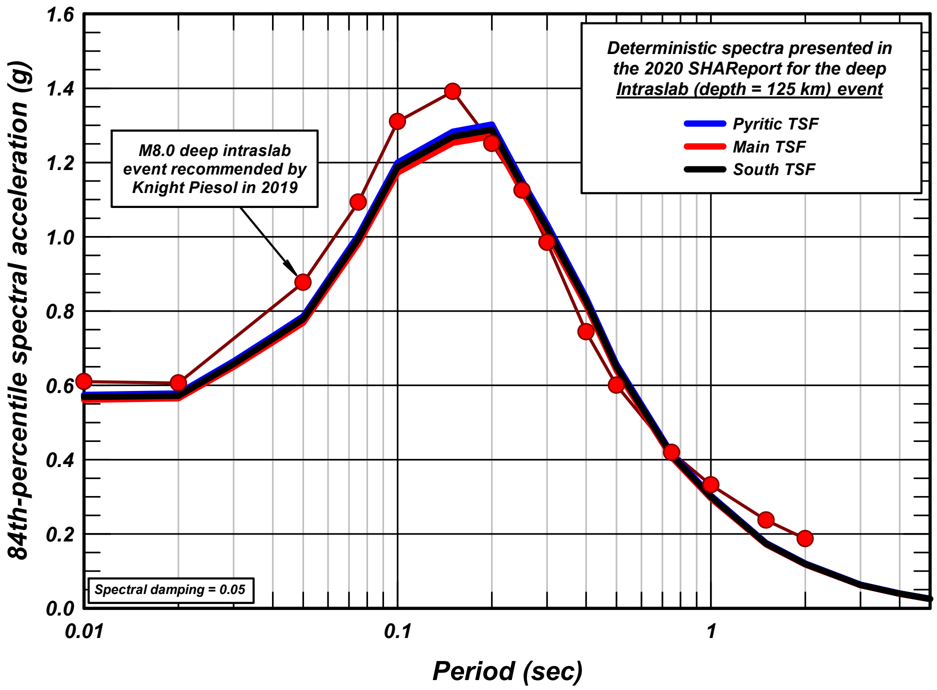


Figure F Comparison of the 84th-percentile spectra for the deep intraslab event presented in the 2020 SHA Report and shown in Figure E with the 84th-percentile spectrum recommended in the 2019 KP Report for the M8.0 deep intraslab event

The 2019 KP spectrum for the deep Intraslab event is about 6 to 11% larger than the spectrum presented in the 2020 SHA Report for the Pyritic TSF in the period range of 0.01 to 0.15 sec. The two spectra are practically identical over the period range from 0.2 to about 1 sec, and the KP spectrum is larger for longer periods.

As reported in Appendix A, however, we do not agree that the Atkinson and Boore (2003) GMM or the Zhao et al. (2006) GMM should be used for this site. Had Knight Piésold used the BC Hydro GMM, with the appropriate hypocentral depth and appropriate rupture depth, the two spectra would be practically the same.

As shown in Figure A-1d in Appendix A, the spectrum for the M6.5 background event recommended in the 2019 KP Report is slightly lower than that recommended in 2013. Therefore, as discussed in Section 5.0 above, the background event would not control the design.

7.0 VOLCANISM

The 2013 PK Report includes a section on volcanism (page 10) that is repeated in the 2019 KP Report (page 12), in which attention is drawn to volcanoes along the west shore of the Cook Inlet. In particular, a large volcano, Mount Saint Augustine, is located within ten miles of the locations of the potential Diamond Point and Amakdedori Ports. The volcanism section indicates that the 1883 eruption of Mount Saint Augustine produced a debris avalanche that resulted in a tsunami 33 ft high more than 62 miles from the volcano. Although the hazard from a tsunami generated by Mount Saint Augustine is considered minor in the KP Reports, this condition is qualified by the absence of a very large debris avalanche at high tide. The KP Reports also indicate that eruption of Mount Saint Augustine is likely to be repeated at any time, and that a tsunami could also occur as the result of a major earthquake around the Pacific Rim. A review undertaken for the current evaluation reveals eight eruptions of Mount Saint Augustine since and including the 1883 eruption and tsunami. The volcano erupted as recently as 2006.

In our opinion, the hazard of eruption, ensuing tsunami, and inundation and damage at the port sites represents a real threat, and should be considered as serious when planning the port and lifelines associated with the Pebble Mine. The American Society of Civil Engineers [ASCE] (Tsunami Loads and Effects Subcommittee of the ASCE/SEI Standards Committee, 2016) has developed a design standard[6] that needs to be considered for facilities subject to tsunami effects. Based on what we reviewed, the design standard for tsunami effects has not been referenced or considered in either Knight Piésold report. We recommend that the ASCE Standard be addressed for this project.

8.0 CONCLUDING REMARKS

Our review of the seismic hazard studies completed for this site confirms that the report prepared by Dr. Gregor and Dr. Al Atik, with peer review by Dr. Norman Abrahamson, is comprehensive and provides seismic hazard results based on the current state of the art in completing such studies. Events occurring on the deep Intraslab source dominate the seismic hazard at this site, and the spectra derived for this source in the 2020 SHA Report can be used for the analysis, evaluation and design of the TSFs at the Pebble Mine site. In our opinion, the 2020 SHA Report supersedes both the 2013 and 2019 KP Reports because:

- The assessment of the seismic sources in the 2020 SHA Report is more complete.
- The 2020 SHA Report includes up to date assignment of maximum magnitude, rupture distance, hypocentral distance and hypocentral depth for each seismic source. The 2013 and the 2019 KP Reports assigned same magnitudes to these sources, but chose to use epicentral distance[7], which is inconsistent of how distance is defined in the earthquake ground motion models GMM used in the KP Reports.
- The 2020 SHA Report used the most currently available and applicable GMMs. The 2013 and the 2019 KP Reports used a number of GMMs that are out of date and are not in use.
- The 2020 SHA Report placed no limitation on the maximum magnitude to use for calculating the spectral values for an earthquake occurring on the interplate. Both KP Reports used M = 8.5 to represent an M = 9.2 event. While this limitation had no effect of the selection of a "design" spectrum, it does reflect on the adequacy of the approach adopted for assessing the seismic hazard at this site.

It is extremely important to keep in mind that evaluating the seismic hazard and obtaining appropriate response spectra are only two of the critical steps in designing earthquake-resistant facilities. How these

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[6] ASCE Tsunami Loads and Effects Subcommittee of the ASCE/SEI Standards Committee, 2016, Chapter 6 in Minimum Design Loads for Buildings and Other Structures, ASCE Structural Engineering Institute, ASCE/SEI 7-16, Reston, VA.

[7] See Footnote No. 1.

spectra and associated ground motions are used, types of analyses, material properties assigned to the embankment soils, foundation layers and tailings, location of the phreatic surface, construction control, etc. are critical for meeting the design criteria and achieving an appropriate design..

We find that the analyses presented in the Memorandum covering "Main Embankment Stability Assessment – Static and Post-liquefaction", prepared by Knight Piésold Ltd., Vancouver, Canada, for Pebble Limited Partnership, dated July 8, 2019 to be inadequate to evaluate the seismic performance of the Pebble Mine embankments. Those analyses provide an unsuitable basis for earthquake-resistant facilities and are not appropriate for making decisions about such a large and important development. As noted in Section 1.0 above, our review of the stability assessment Memorandum is provided in a separate report.

The probabilistic seismic hazard analysis (PSHA) included in the 2020 SHA Report is site specific and can be used in assessing the seismic risk. The results of the PSHA presented in the 2013 KP Report and in the 2019 KP Report are not site specific and should not be used for this site.

The following appendices are attached and complete this report:

Appendix A — Review Of "Report on Seismicity Assessment and Seismic Design Parameters", Prepared by Knight Piésold, Dated July 4, 2019

Appendix B — Curricula Vitae of I. M. Idriss

Appendix C — Curricula Vitae of T. D. O'Rourke

As you requested, we have included the Curricula Vitae in Appendices B and C for your convenience.

We are pleased to be of assistance in making this review.

Sincerely,

I. M. Idriss

T. D. O'Rourke

APPENDIX A

REVIEW OF "REPORT ON SEISMICITY ASSESSMENT AND SEISMIC DESIGN PARAMETERS", PREPARED BY KNIGHT PIÉSOLD, DATED JULY 4, 2019

A.1 INTRODUCTORY REMARKS

For ease of reference, this report will be referenced as "2019 KP Report", which is an "update" of "the 2013 KP Report". The update consists of a minor change in the definition of the controlling crustal source and:

- replacing the 2008 NGA West1 earthquake ground motion models (GMMs) with the 2014 NGA West2 GMMs for calculating earthquake ground motions generated by crustal sources; and
- excluding the Youngs et al. (1997) GMM, retaining the Atkinson and Boore (2003) GMM and adding Zhao et al. (2006) GMM and the BC Hydro GMM (Abrahamson et al. 2016[8]) for calculating earthquake ground motions generated by crustal sources

There was no change in the approach used for the probabilistic seismic hazard analysis. The values of PGA presented in the 2019 KP Report, however, are slightly larger as summarized below:

Average Return Period (years)	PGA (g) presented in the	
	2013 PK Report	2019 PK Report
475	0.14	0.16
1,000	0.19	0.21
2,475	0.25	0.29
5,000	0.31	0.36
10,000	0.38	0.43

A.2 CHANGES FROM 2013 TO 2019

The following events were included for the mine site in the 2013 KP Report:

- *"Magnitude 9.2 interface subduction earthquake associated with the Alaska-Aleutian Megathrust, peak ground acceleration = 0.14 g*
- *Magnitude 8.0 deep intraslab (in-slab) subduction earthquake, peak ground acceleration = 0.48 g*
- *Magnitude 7.5 shallow crustal earthquake on the Lake Clark fault, peak ground acceleration = 0.29 g*
- *Magnitude 6.5 maximum background earthquake (shallow crustal event assumed to occur directly beneath potential mine site facilities), peak ground acceleration = 0.61 g"*

In the 2019 KP Report, the above seismic conditions were replaced as follows:

- *"M9.2 interface subduction earthquake associated with the Alaska-Aleutian Megathrust, peak ground acceleration = 0.16 g*
- *M8.0 deep intraslab (in-slab) subduction earthquake, peak ground acceleration = 0.61 g*
- *M7.5 shallow crustal earthquake on the Lake Clark fault, peak ground acceleration = 0.32 g*
- *M6.5 MBE shallow crustal event assumed to occur directly beneath potential mine site facilities, peak ground acceleration = 0.56 g"*

[8] Section 6.0 (References) in the 2019 KP Report has the correct authorship and reference for the BC Hydro GMM in page 34. Beginning in page 18, however, the 2019 KP Report references this GMM as Addo et al. (2016) for which there is no publication in the reference list. The correct authorship is: Norman Abrahamson, Nick Gregor and Kofi Addo.

The 2013 and 2019 spectra recommended by Knight Piésold for the M9.2 interface event are presented in Figure A-1a. Those for the M8.0 deep intraslab event, the M7.5 shallow crustal event and the M6.5 background event are presented in Figures A-1b, A-1c, and A-1d, respectively.

Comparing the values listed for these four events in the 2013 KP Report (Table 3.3 Rev B – page 20 of 33) and in the 2019 KP Report (Table 3.3 – page 23 of 37), each event was assigned the same magnitude, mechanism fault. The mechanism for the Lake Clark fault was identified as reverse in 2013, but was changed to strike slip in 2019, with no specific explanation. Also, the distance for the crustal event to the Mine Site was listed as 15 miles in 2013, but was changed to 14 miles in 2019, again with no explanation.

In this regard, it is noteworthy that both reports by Knight Piésold use a distance metric (epicentral distance) that has not been used in seismic hazard evaluations or in the development of earthquake ground motion models for decades. The GMMs that Knight Piésold used in 2013 and in 2019 have been derived in terms of "rupture distance", "hypocentral distance" and "Joyner-Boore distance". Other essential details regarding the parameters used by Knight Piésold for calculating the spectra presented in the 2013 or in the 2019 are missing.

A.3 REVIEW COMMENTS

1. The spectra recommended in the 2019 KP Report are not much different from those recommended in the 2013 KP Report, except for the spectrum pertaining to the M8.0 deep Intraslab event.
2. The change from the 2013 spectrum for the M8.0 deep Intrslab event was due to dropping the Youngs et al. (1997) GMM and adding the Zhao et al. (2006) GMM and the BC Hydro GMM, as noted in Section A.1 above. The 2006 Zhou et al. GMM was superseded by the publication of two papers in 2016[9].
3. We do not believe that it is appropriate to use the Atkinson and Boore (2003) GMM for this site. We also do not agree that the Zhao et al. (2006) or the 2016 GMMs should be used for this site.
4. We consider that the BC Hydro GMM, in the way it was used in the 2020 SHA Report, is currently the most appropriate approach for estimating earthquake ground motions at this site.
5. We do not agree that the spectral values for a magnitude 9.2 earthquake occurring on the interplate can be calculated using M = 8.5. There is absolutely no basis for this assumption. The BC Hydro GMM, which includes recordings from the 2010 M8.8 earthquake in Chile and 2011 M9.1 earthquake in Japan, suggests no such constraint.
6. The increase in spectral values for periods less than about 0.5 sec is of the order of 40% and about 60% in the period range of 1 to 5 sec for M = 9.2 compared to using M = 8.5 at a rupture distance of 190 km at a site with V_{S30} = 760 m/sec using the BC Hydro GMM.

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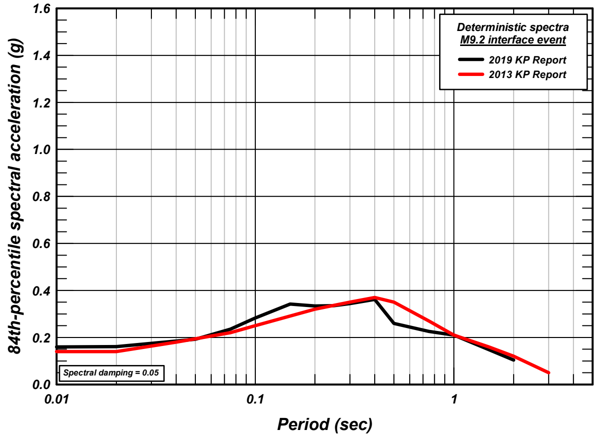
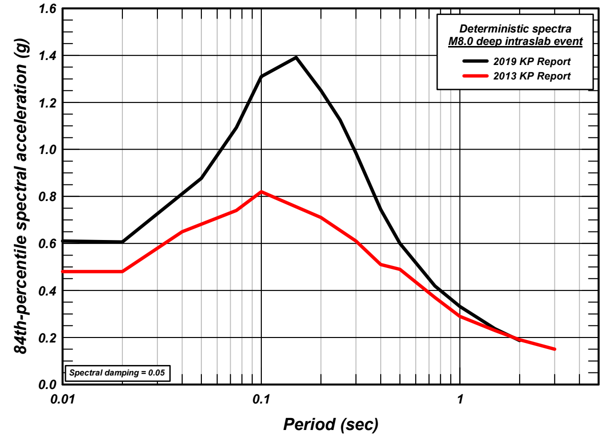
[9] The two papers published by Zhao et al. in 2016 are:

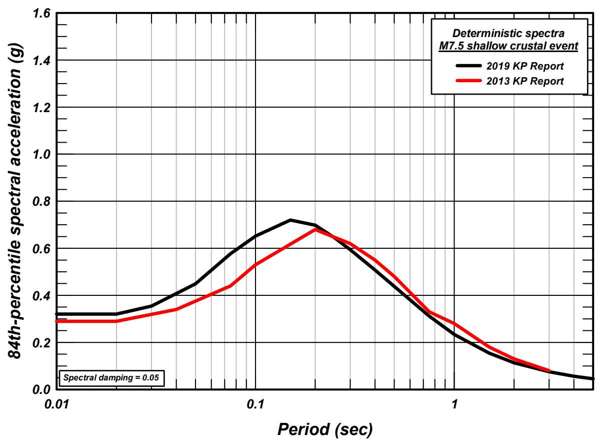
- Zhao, J. X., X. Liang, F. Jiang, H. Xing, M. Zhu, R. Hou, Y. Zhang, X. Lan, D. A. Rhoades, K. Irikura, Y. Fukushima, and P. G. Somerville (2016). "Ground-motion prediction equations for subduction interface earthquakes in Japan using site class and simple geometric attenuation functions", Bulletin of the Seismological Society of America, Vol. 106, No. 4, pp 1518–1534.
- Zhao, J. X., F. Jiang, P. Shi, H. Xing, H. Huang, R. Hou, Y. Zhang, P. Yu, X. Lan, D. A. Rhoades, P. G. Somerville, K. Irikura, and Y. Fukushima (2016). "Ground-motion prediction equations for subduction slab earthquakes in Japan using site class and simple geometric attenuation functions", Bulletin of the Seismological Society of America, Vol. 106, No. 4, pp 1535–1551.



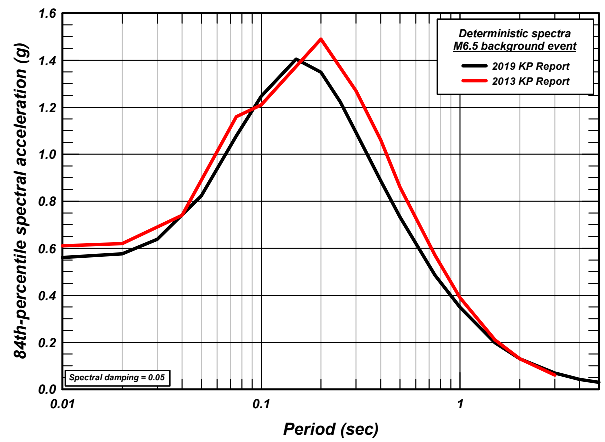
(a) M9.2 interplate event



(b) M8.0 deep intraslab event



(c) M7.5 shallow crustal event



(d) M6.5 background event

Figure A-1 Compariosn of spectra recommended by Knight Piésold for the Mine Site in 2013 and in 2019

APPENDIX B

CURRICULA VITAE OF I. M. IDRISS

I. M. IDRISS

AREAS OF TEACHING, RESEARCH AND PRACTICE

Geotechnical Earthquake Engineering; Geotechnical Engineering;
Embankment Dam Engineering; Numerical Modeling in Geotechnical Engineering.

EDUCATION

B.C.E. Civil Engineering, Rensselaer Polytechnic Institute 1958
M.S. Civil Engineering, California Institute of Technology 1959
Ph.D. Civil Engineering, University of California, Berkeley 1966

REGISTRATION

Civil Engineer: California, 1969
Geotechnical Engineer: California, 1987

PROFESSIONAL HISTORY

Independent Consulting Geotechnical Engineer, 1989 – date.

University of California, Davis, Department of Civil and Environmental Engineering, Professor Emeritus of Civil Engineering, 2004- to date; Professor 1989 – 2004.

University of California, Davis, Director, Center for Geotechnical Modeling, 1989 - 1996

Woodward-Clyde Consultants, Senior Consulting Principal and Vice President, Oakland, California, 1987-1989

Woodward-Clyde Consultants, Managing Principal of the Orange County, Los Angeles and Santa Barbara area offices, and Vice President, 1982-1987

Woodward-Clyde Consultants, Project Engineer to Principal, Vice President and Director, Oakland and San Francisco, California, 1969-1982

UCLA, Department of Civil Engineering, Adjunct Professor, 1984-1986

Stanford University, Dept. of Civil Engineering, Consulting Professor, 1978-1982

University of California, Berkeley, Department of Civil Engineering, Lecturer and Research Engineer, 1966-1975

Consultant to several architect-engineers and other firms, 1966-1969

Dames & Moore, Field Engineer to Senior Engineer, 1959-1966; 1968-1969

Moran, Proctor, Meuser & Rutledge, Field Engineer, summer, 1958

HONORS

Terzaghi Lecture, American Society of Civil Engineers (ASCE), 2019
George W. Housner Medal, Earthquake Engineering Research Institute (EERI), 2018
The Nabor Carrillo Lecture, Mexican Society of Geotechnical Engineering, 2016
Honorary Member, Earthquake Engineering Research Institute (EERI), elected in 2012
Arthur Casagrande Memorial Lecture, Geo-Institute of the Boston Society Section of ASCE, 2010
Ralph B. Peck Award & Lecture, ASCE, 2010
Distinguished Member, American Society of Civil Engineers (ASCE), elected in 2008
Ishihara Lecture, International Society of Soil Mechanics and Geotechnical Engineering, 2007
Honorary Member, Japanese Geotechnical Society, elected in 2005
Kenneth L. Lee Lecture Award, Los Angeles Section of ASCE, 2004
Distinguished Public Service Award, University of California, Davis, 1999
H. Bolton Seed Medal, ASCE, 1995
Member, US National Academy of Engineering, elected in 1989
Special Lectures:

- The Woodward Lecture, *Woodward-Clyde Consultants, 1973*
- Theme Lecture on "Evaluating seismic risk in engineering practice," *XI International Conference on Soil Mechanics and Foundation Engineering, 1985*
- The Wilson Lecture, *Shannon & Wilson / University of Washington, Seattle, 2006*
- The Schiffman Lecture, *Cornell University, 2010*
- The GZA Lecture, New York City Chapter of the GI-Institute, ASCE, 2012
- The de Alba Lecture, University of New Hampshire, 2016

Norman Medal, ASCE, 1977
Walter L. Huber Civil Engineering Research Prize, ASCE, 1975
J. James Croes Medal, ASCE, 1972
The Thomas A. Middlebrooks Award, ASCE, 1971
Chi Epsilon (Honorary Member, Rensselaer Polytechnic Institute Chapter)
Tau Beta Pi
Sigma Xi

SPECIAL ASSIGNMENTS

Invited lecturer at various universities in the United States, Central and Latin America, Canada, Japan, United Kingdom, India, China, and the Middle East (since 1967).

Invited lecturer and state-of the-art speaker at specialty conferences and special courses in the United States, Canada, Latin America, Far East, Europe and the Middle East (since 1970).

On-going assignments (Partial List)

2019-date: Consultant, geotechnical engineering and geotechnical earthquake engineering issues, Pebble Mine Project, Bristol Bay Reserve Association and K & L Gates.

2018-date: Member, Independent Technical Review Board, Tailings Storage Facility (TSF) at the Hidden Valley Mine in Papua New Guinea, Harmony Gold.

2018-date: Member, Geotechnical Expert Advisory Panel for Iona Island Wastewater Treatment Plant Project Definition, Metro Vancouver, British Columbia, Canada.

2018-date: Consultant, geotechnical engineering and geotechnical earthquake engineering issues, Tailings Storage Facilities in Australia and in Canada, BHP Billiton.

2016-date: Member, External Advisory Panel, Las Bambas Dams, Las Bambas Tailings Storage Facilities, Peru, MMG.

2013-date: Member, Board of Consultants for LADWP Water Projects, Los Angeles Department of Water and Power, Kleinfelder.

2008-date: Member, Design Review Board, Tailings Dam Expansion, Kennecott's Magna Tailings Facility, Utah, Kennecott Utah Corporation.

2004-date: Member, Technical Review Panel, Calaveras Dam, San Francisco Public Utility Commission.

1998-date: Member, Seismic Safety Peer Review Panel for the design of the New East Spans of the San Francisco – Oakland Bay Bridge, California Department of Transportation, Sacramento.

1996-date: Consultant to the Federal Energy Regulatory Commission, Office of Energy Projects, on various dam projects throughout the United States.

1995-date: Chairman, Technical Review Board for the Cleveland Dam, Vancouver, British Columbia, Metro Vancouver (formerly, Greater Vancouver Regional District).

Completed assignments (Partial List)

2018-2019: Consultant, geotechnical engineering and geotechnical earthquake engineering issues, Padcal Tailings Storage Facility, Philippines, GHD Consulting (Australia).

2016-2017: Chairman, Technical Review Board, Annacis Water Supply Tunnel, Vancouver, British Columbia, Metro Vancouver (formerly Greater Vancouver Regional District).

2016 -2017: Consultant to McDowell, Rice, Smith & Buchanan, Kansas City, re: geotechnical earthquake engineering issues, site in Anchorage, Alaska.

2013-2016: Consultant, re: geotechnical earthquake engineering issues, North Spur, Lower Churchill Project, Labrador, Canada, SNC-Lavalin Inc., St. John's, NL.

2015: Member, Panel of Experts, Upper Tamakoshi Hydroelectric Project, Nepal, Upper Tamakoshi Hydropower Limited, Nepal Electricity Authority.

2012-2013: Member, Lihir Independent Cofferdam Review Board, Kapit Cofferdam Project, Lihir Mine, Lihir Island, Papua New Guinea, Newcrest Mining Limited.

2011-2016: Chairman, Technical Construction Review Board, Port Mann Tunnel, Vancouver, British Columbia, Metro Vancouver (formerly, Greater Vancouver Regional District).

2010-2017: Chairman, Technical Design Review Board, Second Narrows Water Supply Tunnel, Vancouver, British Columbia, Metro Vancouver (formerly Greater Vancouver Regional District).

2009-2012: Chairman, Technical Review Panel, Los Vaqueros Reservoir Expansion Project, Contra Costa Water District.

2008-2018: Member, Cerro Verde External Technical Review Board, Linga Tailings Storage Facility, Cerro Verde, Peru, Freeport McMoRan, MWH.

2006-2018: Member, Cerro Corona Independent Geotechnical Technical Review Board, Cerro Corona Tailings Dam, Peru, Gold Fields Co., MWH.

2006-2010: Chairman, Technical Design Review Board, Port Mann Tunnel, Vancouver, British Columbia, Metro Vancouver (formerly Greater Vancouver Regional District).

2005-2018: Member, Cerro Verde External Technical Review Board, Enlozada Tailings Storage Facility, Cerro Verde, Peru, Freeport McMoRan, MWH.

1991-2004: Member, Seismic Advisory Board, California Department of Transportation, Sacramento.

1995-2007: Chairman, Technical Review Boards for the Seymour Falls Dam, Vancouver, British Columbia, Metro Vancouver (formerly, Greater Vancouver Regional District).

1997-2003: Member, US Technical Coordination Committee, US-Japan Cooperative Research Program, National Science Foundation.

2001-2003: Member, Panel on Seismic Issues, Airfield Development Bureau, San Francisco International Airport.

2000-2003: Member, Embankment Technical Review Board, 3rd Runway at the Seattle-Tacoma International Airport, HNTB, Seattle, on behalf of the Port of Seattle.

1989-2003: Consultant to Pacific Gas & Electric Company (PG&E) – Diablo Canyon Nuclear Plant, Humboldt Bay Plant, and various dams in Northern California.

1989-2002: Member, Consulting Board for Earthquake Analysis for the Division of Safety of Dams, Department of Water Resources, State of California.

1993-2001: Member, Highway Seismic Research Council Technical Group, National Center for Earthquake Engineering Research (NCEER).

1993-2000: Member, Board of Consultants, Eastside Reservoir Project (renamed Diamond Valley Project in 2000), Metropolitan Water District of Southern California.

1999: Member, Review Panel, Seismic Design Criteria for the Cooper River Bridges in Charleston, South Carolina, Parsons Brinckerhoff, New York City.

1990-1999: Chairman, Seismic Research Advisory Panel, California Department of Transportation, Sacramento

1994-1999: Member, Peer Review Panel for the San Francisco-Oakland Bay Bridge and other Toll Bridges in Northern & Southern California, California Department of Transportation, Sacramento.

1991-1996: Member, Advisory Council, Southern California Earthquake Center, Los Angeles

1994-1995: Member, Advisory Panel for OTA Assessment of the 'Federal Efforts to Reduce Earthquake Damage", Office of Technology Assessment, Congress of the United States.

1992-1995: Member, Ad Hoc Working Group on the Probabilities of Future Large Earthquakes in Southern California, Southern California Earthquake Center, USGS, California Office of Emergency Services & CDMG.

1991-1994: Member, Blue Ribbon Panel on the Marina Soil Study, Bureau of Engineering, Department of Public Works, City & County of San Francisco.

1988-1992: Member, State of California Board of Mining and Geology; Chairman: Geohazard Committee of the Board; also Chairman, Ad Hoc Committee on Deterministic / Probabilistic Seismic Hazard Evaluations.

1989-1990: Member, Governor's Board of Inquiry to investigate the collapse of the Cypress section of I-880 and the damage to the Bay Bridge during the 17 October, 1989 Loma Prieta earthquake.

1984-1985: Participant, Workshop on Liquefaction, Committee on Earthquake Engineering, National Research Council.

1981-1982: Consultant to UNESCO in Paris, France on geotechnical and earthquake engineering issues in the Middle East and North Africa.

1971-1981: Seismology Committee, Structural Engineers Association of Northern California; Chairman, Soil Structure Interaction Subcommittee, 1971-72 and 1977-79; Chairman, Subcommittee on Sliding and Overturning, 1979-81.

1975-1980: Consultant to the International Atomic Energy Agency, Vienna; participated in preparation of IAEA's Safety Guide on "Seismic Analysis and Testing of Nuclear Power Plants".

1974-1979: Structural Division, ASCE; Nuclear Structures and Materials Committee; Chairman, Ad Hoc Group on Soil-Structure Interaction.

TEACHING AND RESEARCH

Dr. Idriss was a member of the faculty in the Department of Civil Engineering at the University of California at Davis (UCD) from 1989 to 2004. He taught courses on basic soil mechanics and foundation engineering, advanced soil mechanics and foundation engineering, an undergraduate course in statics, geotechnical earthquake engineering, and earthfill and rockfill dams,.

While he was at UCD, he conducted research related to: characteristics of earthquake ground motions; equivalent linear and nonlinear response of soil deposits during earthquakes; response of earth and rock fill dams and landfills during earthquakes; liquefaction; mitigation and remediation of liquefaction; and ground deformations due to earthquake loading conditions. He has continued his research on these topics since retiring from UCD.

RECENT AND CURRENT CONSULTING ASSIGNMENTS

Dr. Idriss has been since 1989, and continues to be, a consultant to several Consulting Engineering Firms, Architect/Engineering Firms, private and public Research Organizations, Owners, and various State and Federal Agencies. The consulting assignments have included:

Earth Dams, Rockfill Dams, Tailings Dams, and Dikes:

Costa Oriental Dikes in Venezuela
Sardis Dam, Mississippi
Diamond Valley Reservoir and Dams (Eastside Reservoir & Dams), Southern California
O'Neill Forebay, Central California
Devil Canyon Second Afterbay, Southern California
Garvey Reservoir, Southern California
Xiaolangdi Project (Yellow River Hydroelectric Project), China
North Tailings Dam near Salt Lake City, Utah
Dams, Power & Water Distribution Facilities in British Columbia
Los Vaqueros Dam in Contra Costa County, California
Little Dalton, Big Dalton, Santa Anita and Sawpit Debris Dams, Calif.
Sacramento-San Joaquin Delta Levees
Seven Oaks Dam, Southern California
Tarbela Dam, Pakistan
Prado Dam, Southern California
Lake Almador & Lake Francis Dams, Northern California
Butte Valley Dam, Northern California
Success Dam, Central California
Cleveland & Seymour Falls Dams, British Columbia
Matahina Dam, North Island, New Zealand
Karapiro Dam, North Island, New Zealand
Waitaki Dams, South Island, New Zealand
Lopez Dam, San Luis Obispo, California
Saluda Dam, South Carolina
Pardee Dam, Northern California
New Hogan Dam, Northern California
Santee-Cooper Project, South Carolina
Wateree Dam, North Carolina
Cushman, Wynoochee, Mayfield, & Mossyrock Dams, Washington
Clackamas River Project, Oregon
Claytor Dam, Virginia
Wickiup Dam, Oregon
Diversion Dam, New York
Skookumchuck Dam, Washington
Calaveras Existing & Replacement Dams, California
Lafayette Dam, California
Cerro Verde Enlozada Tailings Dam, Peru
Cerro Verde Linga Tailings Dam, Peru
Crane Valley Dam, California
Wells, Rocky Reach & Rock Island Dams, Washington
Boundary Dam, Washington
Priest Rapids Dam, Washington
Wanapum Dam, Washington
Upper Reservoir of Taum Sauk Dam, Missouri

Greens Creek Mine Tailings Pile, Alaska
Cerro Corona Tailings Dams, Peru
Hebgen Dam, Montana
San Pablo Dam, California
Dillon Dam, Colorado
Williams Fork Dam, Colorado
Comanche Dam, California
Kennecott's Magna Tailings Facility, Utah
El Dorado Forebay Dam, California
Scoggins Dam, Oregon
Los Vaqueros Reservoir Expansion Project, California
San Luis Tailings Dams, Peru
Lihir Cofferdam Project, Papua New Guinea
Anderson Dam, California
North Haiwee Dam, California
Upper Stone Canyon Reservoir, California
Stone Canyon Dam, California
Bouquet Dam, California
North Spur, Lower Churchill Project, Labrador, Canada
Upper Tamakoshi Hydroelectric Project, Nepal
Chuspiri Water Dam, Peru
Las Bambas Tailings Dam, Peru
Chilhowee Dam, Tennessee
Rampart Dam, Colorado
Gross Dam, Colorado
Cutler Dam, Utah
Padcal Tailings Storage Facility, Phillipines
Olympic Dam, Australia
Tailings Dam, Hidden Valley Mine in Papua New Guinea
Quirke Dikes, Canada
Pebble Mine Tailings Facilities, Alaska

Industrial Projects:

Getty Fine Arts Center
San Francisco Marina
Treasure Island
Metro Bay Center
Port of Los Angeles
Bayer's Project Site in Taiwan
Third Runway at the Seattle-Tacoma International Airport
Airport Expansion at the San Francisco International Airport
Port of Anchorage
Iona Island Wastewater Treatment Plant

Landfill Projects:

Acme Landfill
Ox Mountain Landfill
Pacheco Landfill
Operating Industries Inc. (OII) Landfill
Chiquita Landfill
Edom Landfill

Sunshine Landfill
Elsmere Canyon Landfill
Western Regional Sanitary Landfill, Placer County, California

Nuclear Plants and Facilities:

CESSAR (Combustion Engineering Standard Plant)
Long Term Seismic Program (LTSP) for Diablo Canyon
Seismic Margin Assessment – Hatch Plant, Georgia
Seismic Margin Assessment (SMA) Methodology
LOTUNG experimental and analytical study
New Production Reactors
Ground Motion Guidelines at Nuclear Plant Sites
Replacement Tritium Facility (RTF) at Savannah River
IPEEE Geotechnical Review for Limerick Plant
IPEEE Geotechnical Review for Peach Bottom Plant
Defense Waste Processing Facility (DWPF) at Savannah River
In-Tank Precipitation Facility (ITP) at Savannah River
Humboldt Power Plant (Hazard Evaluation & ISFSI)
Prairie Island Nuclear Generating Plant
Diablo Canyon Nuclear Plant (Hazard Evaluation & ISFSI)
Independent Spent Fuel Storage Installation (ISFSI) – Hatch Plant, Georgia
Independent Spent Fuel Storage Installation (ISFSI) – Farley Plant, Alabama
Grand Gulf Nuclear Plant
PDCF at Savannah River Site (SSI analyses; Liquefaction Studies; Geotechnical Issues)
Salt Waste Processing Facility at Savannah River Site (Geotechnical Issues)
Yucca Mountain Project (Site Response Studies; Earthquake Ground Motions)
River Bend Nuclear Plant, COLA Application
Fermi Nuclear Plant, COLA Application
Dry Fuel Storage Facility, Crystal River 3 Nuclear Plant, Florida
Seismic Hazard Assessment Program, SONGS, Southern California
FLEX Dome Storage Building, Vogtle Nuclear Plant, Georgia

Bridges:

Seismic Vulnerability of Bridges for the Illinois Department of Transportation
Seismic Hazard Evaluation and Site Response for the Benicia and the Carquinez Bridges
Seismic Hazard Evaluation for Bridge Crossings in Southern California
Seismic Hazard Evaluation for Bridge Crossings in Northern California
Liquefaction & Remediation Assessment at the I-5/Route 56 Interchange in S. Calif.
I-880 Reconstruction in Oakland
Route 24/580/980 Interchange in Oakland
San Francisco-Oakland Bay Bridge (existing bridge)
Route 8/805 Interchange in San Diego
California State Toll Bridges in the San Francisco Bay Area
California State Toll Bridges in Southern California
New East Span of the San Francisco-Oakland Bay Bridge
Cooper River Bridges, Charleston, South Carolina

Other Projects:

Nonlinear behavior of soils
Geologic Hazards in the Summit Area of the Santa Cruz Mountains
Marina and South of Market Street Liquefaction Study

Watsonville Liquefaction & Remediation Assessment
The King Dome in Seattle
International Arrival Building at JFK in New York
Pacific Telephone Building, Oakland
Bel Marin Keys, Novato, California
Gas Pipeline Earthquake Performance R&D Project
Webster Street & Posey Tunnels, Alameda, California
BART Trans Bay Tube
Port Mann Water Supply Tunnel, Vancouver
Second Narrows Water Supply Tunnel, Vancouver
Annacis Water Supply Tunnel, Vancouver

for:

ABB Combustion Engineering
ABB Impell
Automated Engineering Services Corp
Bayer AG
BHP Billiton
Black & Veatch
B. C. Hydro
Brookhaven National Laboratory
Bristol Bay Reserve Association
CDM Federal Programs Corporation
CH2M HILL
City of San Francisco
Clean Water Services
Comartin-Reis
County of San Luis Obispo, California
Department of Transportation of the State of California
Department of Water Resources of the State of California
Division of Safety of Dams of the State of California
J. M. Duncan
Emcon Associates
Electric Power Research Institute (EPRI)
Electricity Corporation of New Zealand, Ltd (ECNZ)
EQE
Federal Energy Regulatory Commission
Flour of Canada
Forell / Elsesser Engineers, Inc.
Freeport McMoRan
GEI Consultants
Geomatrix Consultants
GeoPentech Consultants
GHD Consulting (Australia)
Golder Associates
Gold Fields
Harding Lawson Associates
Harmony Gold
HNTB
Hushmand Associates
RPK Structural Mechanics

King County, State of Washington
Kleinfelder, Inc.
Klohn Crippen Berger Ltd.
Lawrence Livermore National Laboratory
McDowell, Rice, Smith & Buchanan
Metro Vancouver (formerly Greater Vancouver Regional District)
Miller Pacific Engineering Group
MMG Mining, Lima, Peru
Morrison Knudsen Corporation
Newcrest Mining Limited
Parsons
Pacific Gas & Electric Co.
Parsons Brinckerhoff, New York City
Parsons Brinckerhoff, San Francisco
Port Authority of New York & New Jersey
Port of Los Angeles
Progress Energy, North Carolina
San Francisco Public Utility Commission
SNC-Lavalin Inc., St. John's, NL, Canada
Southern Company Services, Inc.
STS Consultants Ltd.
TAMS
Treadwell & Rollo
Upper Tamakoshi Hydropower Limited, Nepal Electricity Authority
URS Corporation (became part of AECOM in 2016)
US Army Corps of Engineers, Los Angeles District
US Army Corps of Engineers, Sacramento District
US Army Corps of Engineers' Waterways Experiment Station
US Bureau of Reclamation
US Department of Energy
VECTRA Technologies, Inc.
Washington Group International
Woodward-Clyde Consultants (became part of URS in 1997)
World Bank
Yellow River Conservancy Commission, China
Yucca Mountain Project

TEACHING, CONSULTING AND RESEARCH EXPERIENCE PRIOR TO 1989

Dr. Idriss taught undergraduate courses in soil mechanics and foundation engineering from 1967 until 1970 at the University of California in Berkeley. He also lectured at various seminars and graduate courses dealing with geotechnical earthquake engineering at UC Berkeley, UCLA and the University of Arizona from 1968 through 1975. He taught a graduate course on earthquake engineering at Stanford University from 1978 through 1982 and undergraduate courses in soil mechanics and foundation engineering in 1986 and 1987 at the University of California in Irvine. Dr. Idriss has also taught at special courses on earth- and rock-fill dams, soil dynamics, soil-structure interaction, site response, earthquake ground motions, liquefaction evaluations ... etc. throughout the United States, in Europe, Central and Latin America and Japan from 1970 to-date.

Prior to joining the faculty of the Civil Engineering Department at the University of California in Davis, Dr. Idriss had about 30 years of experience in soil mechanics and foundation engineering, with emphasis in geotechnical earthquake engineering during the latter 25 years. He developed or co-developed several analytical and empirical procedures to evaluate liquefaction potential, behavior of soil masses during earthquakes, seismic behavior of earth and rock fill dams (including post-earthquake considerations), and deterministic and probabilistic assessment of earthquake ground motions.

For a period of about 22 years, Dr. Idriss conducted and directed consulting assignments involving geotechnical earthquake engineering studies for earth, rock fill, and tailing dams, nuclear power plant sites, high-rise buildings, offshore platforms, and industrial facilities.

He also conducted and directed applied research studies. From 1973 through 1989, he directed and participated in multi-disciplinary projects for dams (earth, rock fill, tailings and concrete), commercial and industrial facilities, offshore platforms, nuclear power plant and LNG sites, pipelines, and generic multi-disciplinary projects.

From 1970 to 1989, Dr. Idriss conducted and directed geotechnical earthquake engineering studies for over 50 earth, rock fill, and tailing dams in California, Alaska, Alabama, North Carolina, New Mexico, Tennessee, Utah, Mexico, Guatemala, Costa Rica, Colombia, Argentina, Ecuador, Egypt, Morocco, and Algeria; and earthquake engineering studies (including ground motion characterization, assessment of liquefaction potential, evaluation of soil-structure interaction, and cyclic soil characterization) at over 25 nuclear plant sites in the United States, Europe, and the Middle East. Other geotechnical earthquake engineering projects include offshore platforms in California, Alaska, and New Zealand; and waterfront facilities, fossil plants, and hospital and office buildings in California, Idaho, Alaska, New Jersey, Texas, Italy, Puerto Rico, Iran, Guatemala, Nicaragua, Venezuela, Egypt, Saudi Arabia, Lebanon, and other locations.

Applied research and non-site-specific consulting assignments, during the period 1970 to 1989, included: *Soil-structure interaction studies for GESSAR and for General Electric's Standard Plant; Behavior of marine clay sediment during earthquake loading conditions; Behavior of marine clay sediments during wave loading conditions; Behavior of soil-pile-structure systems during earthquake; Soil-structure interaction studies and correlation with model field tests; Offshore Alaska seismic exposure studies; Probabilistic and deterministic assessment of ground motions; Engineering characterization of earthquake ground motions to develop guide-lines for seismic inputs for nuclear plants; Program for assessment and mitigation of earthquake risk in the Arab Region; Seismic margin assessment (SMA) methodology; Evaluation of the behavior of the Molikpaq due to ice loading conditions; Development of earthquake ground motions and dynamic soil properties for CESSAR (Combustion Engineering standard nuclear plant)*

Multi-disciplinary projects included:

- *Proposed Boruca Dam in Costa Rica*
- *San Onofre Nuclear Generating Station in southern California*
- *Seismic exposure studies for offshore Alaska*
- *Proposed offshore platform in southern California*
- *Bullards Bar Dam in northern California*
- *Bolsa Chica Development in southern California*
- *State Office Building in Anchorage, Alaska*
- *Honda Headquarters in southern California*
- *Costa Oriental Dikes in Lake Maracaibo Region, Venezuela*
- *Getty Fine Arts Center in Brentwood, California*

He conducted research related to the nonlinear behavior of soils under cyclic loading conditions. The results of this research have been applied to assessing performance of soft sediments during earthquakes. He has been engaged in other research activities that relate to significant duration of earthquakes, simplified procedures for assessment of soil-structure interaction, probabilistic review and assessment of recorded ground motions and associated spectra, and application of probabilistic techniques in geotechnical practice.

MEMBERSHIPS IN TECHNICAL SOCIETIES

American Society of Civil Engineers
Earthquake Engineering Research Institute
Canadian Dam Association
Canadian Geotechnical Society
Seismological Society of America
United States Society on Dams

PUBLICATIONS

Dr. Idriss has authored or co-authored about 240 technical papers and research reports on subjects related to the geotechnical aspects of earthquake engineering (seismic response of soil deposits; earth structures including slopes, earth and rock fill dams; dynamic soil material properties; liquefaction; soil-structure interaction; and probabilistic deterministic assessment of characteristics of ground motions). These papers have been published in the Journals of the Geotechnical Engineering Division, the Structural Engineering Division, and Proceedings of Specialty Conferences of the American Society of Civil Engineers; Bulletin of the Seismological Society of America; International Journal of Earthquake Engineering and Structural Dynamics; proceedings of World Conference on Earthquake Engineering, proceedings of the US National Conference on Earthquake Engineering, proceedings of the International Conference on Soil Mechanics and Foundation Engineering, proceedings of the Offshore Technology Conference, and proceedings of other international engineering meetings.

APPENDIX C

CURRICULA VITAE OF T. D. O'ROURKE

THOMAS D. O'ROURKE CURICULLUM VITAE

Current Position: Thomas R. Briggs Professor of Engineering, Civil and Environmental Engineering, Cornell University, 422 Hollister Hall, Ithaca, NY 14853-3501.

Education: Ph.D., University of Illinois at Urbana-Champaign, 1975; M.S.C.E., University of Illinois at Urbana-Champaign, 1973; B.S.C.E., Cornell University, 1970.

Academic Positions: Thomas R. Briggs Professor of Engineering, Cornell Univ. (1999-date); Member, Graduate Faculty in Field of Systems Engineering, Cornell Univ. (2011-date); Fulbright Fellowship, Senior Specialist Program with Office of Prime Minister and Cabinet, Wellington, NZ (2007); Overseas Fellow, Churchill College, University of Cambridge (2006- date); By-Fellow, Churchill College, University of Cambridge (1999); Erskine Fellowship, University of Canterbury, Christchurch, NZ (1999, 2015, & 2020); Professor of Civil and Environmental Engineering, Cornell Univ. (1987-1999); Member, Graduate Faculty in Field of Textiles and Fiber Science, Cornell Univ., Ithaca, NY (1989-date); Associate Professor of Civil and Environmental Engr., Cornell Univ. (1981-1987); Member, Graduate Faculty in Field of Geological Sciences, Cornell Univ. (1981-date); Visiting Lecturer, Royal School of Mines, Imperial College of Science and Technology (1985); Assistant Professor of Civil and Environmental Eng., Cornell Univ. (1978-1981); Assistant Professor of Civil Engineering, Univ. of Illinois at Urbana (1975-1978).

Awards and Distinctions: ***U.S. National Academy of Engineering*** (1993); ***Fellow of American Association for the Advancement of Science*** (2000); ***Distinguished Member of the American Society of Civil Engineers*** [ASCE] (2014); ***International Fellow of the Royal Academy of Engineering*** (2014); ***Corresponding Member of the Mexican Academy of Engineering*** (2017). Other distinctions (chronological order): ***C.A. Hogentogler Award***, Amer. Society for Testing & Materials (1976); ***Collingwood Prize,*** (1983); ***Walter L. Huber Civil Engineering Research Prize***, ASCE (1988); ***C. Martin Duke Award***, ASCE (1995); ***Outstanding Earthquake Spectra Paper***, Earthquake Engr. Research Inst. [EERI] (1996); ***Stephen D. Bechtel Pipeline Engineering Award***, ASCE (1997); ***University of Illinois Distinguished Alumnus Award*** (2000); ***National Science Foundation Distinguished Lecturer*** (2002); ***Trevithick Prize***, Institution of Civil Engineers (2002); ***Japan Gas Award***, Japan Gas Association (2003); ***University of Illinois Distinguished Service Award*** (2005); ***Ralph B. Peck Award***, ASCE (2005); ***Rankine Lecture***, British Geotechnical Association (2009); ***Academy of Geo-Professionals Honorary Diplomate*** [inaugural class], ASCE Geo-Institute (2009), ***EERI Distinguished Lecturer***, EERI (2012); ***EERI Honorary Membership***, EERI (2013); ***Geo-Institute Touring Lecturer***, ASCE (2013); ***Leval Lund Award***, ASCE (2014); ***Terzaghi Lecture***, ASCE GeoInstitute (2016); ***Housner Medal***, EERI (2016); ***Outstanding Earthquake Spectra Paper***, EERI (2016), ***IAEE Honorary Membership***, Int'l Assoc. for Earthquake Engr. [IAEE] (2017), ***G.E.O. Widera Literature Award***, American Society of Mechanical Engineers [ASME] (2018); ***Cross Canada Touring Lecturer*** (2018)**,** Canadian Geotechnical Society.

Teaching/Advising Awards and Distinctions: Kenneth A. Goldman '71 Excellence in Teaching Award (2003) and Daniel Lazar '29 Excellence in Teaching Award (1998), Cornell University; *ASCE Robert A. Ridgeway Award* (1983) Faculty Advisor, Cornell ASCE Student Chapter highest ranked U.S. student chapter, which designed and built a 50-m-long suspension bridge and wing-shaped children's pavilion in local parks, open to the public and providing service for more than 30 yrs.

Professional Experience: Geotechnical Engineer, Dames and Moore, Cranford, N.J. (1970); Field Instrumentation & Data Acquisition Specialist for Washington, DC Metro Construction, University of Illinois (1970-1975); Senior Research Associate, Transport and Road Research Laboratory, Crowthorne, U.K. (1976-1977); Geotechnical, Infrastructure, and Earthquake Engineering Consultant (1975-date).

Engineering Consultant: Consulting services on more than 130 projects in 13 different countries, including United States, United Kingdom, Angola, Canada, Ecuador, France, Mozambique, New Zealand, Nigeria, Russia, Trinidad, Turkey, and Venezuela. Chair or member of the consulting boards of many large underground construction projects, as well as peer reviews for projects associated with highway, rapid transit, water supply, and energy distribution systems. Many projects have included seismic design assessments. Representative projects include the Third NYC Water Tunnel, Bypass Tunnel for NYC Delaware Aqueduct, Boston Central Artery and Tunnel (CA/T), risk assessment for the First NYC Water Tunnel and NYC aqueducts, Tren Urbano Rapid Transit System, NYC Second Avenue

Subway and Fulton St. Transit Center, soft and hard rock tunneling for the Massachusetts Water Resources Authority, Dulles Airport underground expansion, San Francisco Transbay Transportation Center, TJPA Downtown Extension Project involving hard and soft ground tunneling, seismic design of tunnels in Turkey, Trans-Bay Tube Seismic Retrofit, seismic design for the San Francisco water supply (including the San Francisco Public Utilities Commission Crystal Springs By-Pass Tunnel, Bay Tunnel, Irvington Tunnel, and Bay Division Pipelines); Silicon Valley Rapid Transit System in San Jose, CA, geotechnical and seismic criteria for the Alaskan Way Viaduct in Seattle, WA; Los Angeles Headworks Reservoir, Stone Canyon and Bouquet Dams, Haiwee Reservoir, and Elizabeth Tunnel; San Francisco Auxiliary Water Supply System; Pacific Gas and Electric 270 kV electric transmission line in San Francisco. Peer review of earthquake redesign and recovery of Christchurch, NZ, including horizontal infrastructure (water supply, wastewater and drainage, roads and bridges) for Christchurch Earthquake Recovery Authority; liquefaction land damage for Earthquake Commission, NZ; foundation systems for residential structures for the Ministry of Business, Innovation, and Employment; and restoration of Lyttelton Port for the Lyttelton Port Company. Design contributions for foundations of LNG facilities in Trinidad, Angola, Nigeria, and Mozambique (for Bechtel). Boston CA/T: design/peer review of Bird Island Flats portion of Ted Williams Tunnel, Fort Point Channel deep soil mix ground stabilization and immersed tubes; excavation and tunneling effects on One Financial Center and Boston Metro Red Line. Chair, Board of Consultants for underground construction of Superconducting Super Collider, US DOE, as well as Energy Recovery Linac, Cornell Univ.

Teaching/Advising Experience: Supervision of 24 Ph.D. theses and doctoral students, 23 M.S. theses and masters students, and over 200 M. Eng. students and 10 M. Eng. design projects. Classes were taught to thousands of undergraduate and graduate students in the following courses: Planning and Engineering for Critical Infrastructure**,** Environmental Applications of Geotechnical Engineering**,** Retaining Structures and Slopes**,** Foundation Engineering**,** Introduction to Geotechnical Engineering**,** Civil and Environmental Engineering Design Project**,** Rock Engineering**,** Soil Dynamics**,** Graduate Soil Mechanics Laboratory**,** Geoenvironmental Engineering, and Tunnel Engineering**.** Courses jointly taught on sabbatical at Imperial College (1985) include Rock Dynamics and Graduate Tutorial in Rock Mechanics.

Professional Service: *President*: Earthquake Engineering Research Institute [EERI] (2003-04); ASCE Ithaca Section (1981-82). ***Vice President:*** EERI (2001-02). ***Chair:*** National Institute of Standards and Technology/Applied Technology Council Committee on National Lifelines Research and Implementation Roadmap (2013-2014); International Advisory Group, Center for Smart Infrastructure and Construction, University of Cambridge; EERI Honors Committee (2008-2010); EERI Development Committee (2005-07); Executive Committee, Institute for Civil Infrastructure Systems (1998-03); NSF COV Review of Civil Mechanical Systems Division (2001 and 2004); National Academy of Engineering, Section 4, Nomination Committee (2000-02); ASCE TCLEE Executive Committee (1998-01); Transportation Research Board (TRB) Subsurface Soil-Structure Interaction, A2K04 (1991-94); ASCE Earth Retaining Structures Committee (1986-90); ASCE TCLEE Executive Committee (1988-89); U.S. National Committee on Tunneling Technology (1987-88); ASCE TCLEE Gas and Liquid Fuel Lifelines Committee (1986-88); ASCE Underground Technology Research Council (1985-86). ***Member:*** International Committee of Visitors, Dept. of Engineering, University of Cambridge (2005- present); NIST Advisory Committee on Earthquake Hazard Reduction (2007-12); National Academies Board on Water Science and Technology (2008-10); National Academies Committee on New Orleans Regional Hurricane Protection Projects (2006-09); External Review Committee, Department of Civil and Environmental Engineering, University of California, Berkeley, CA (2005); International Committee to Review British Engineering Research, Royal Academy of Engineering and Engineering and Physical Sciences Research Council, U.K. (2004); Board of Directors, Consortium of Universities for Research in Earthquake Engineering (2001-06); International Evaluation Committee for College of Civil Engineering, Technion, Israel (2001); Advisory Board, Polytechnic University, Dept. of Civil and Environmental Engineering (1997-01); EERI Board of Directors (1998-2006); NSF Engineering Directorate Advisory Committee (1998-04); Executive Committee, Multidisciplinary Center for Earthquake Engineering Research [MCEER] (1997-08); National Institute of Building Sciences Utility Lifelines Subcommittee (1997-00); Mid-America Earthquake Center Board of Directors (1997-99); MCEER Research Committee (1996-1998); Southern Cayuga Lake Inter-municipal Water Commission (1996-97); National Research Council (NRC) Board on Energy and Environmental Systems (1994-96); NRC Energy Engineering Board (1993-94); NRC Committee for Infrastructure Technology Research Agenda (1992-94); NRC Geotechnical Board (1989-93); TRB

Committee on Subsurface Soil-Structure Interaction, A2KO4 (1985-90); ASCE Committee on Pipeline Crossings of Railroads and Highways (1984-2000); ASME Technical Subcommittee on Lifeline Earthquake Engineering (1982-83); Committee on Management of Construction, Building Futures Council (1983-85); ASCE Committee on Earth Retaining Structures (1982-86); ASCE TCLEE] Water and Sewage Committee (1981-92); ASCE TCLEE Gas and Liquid Fuel Lifelines Committee (1981-86); U.S. National Committee on Tunneling Technology, Subcommittee on Tunnel Design (1981-86); Construction Research Council Management of Construction Programs (1981-83); NRC BRAB Committee on Management of Urban Construction Programs (1979-81).

U.S. Congressional Testimony: before U.S. House of Representatives Science Committee on "National Earthquake Hazards Reduction Program: Disaster Resilient Communities" (2009), "National Earthquake Hazards Reduction Program" (2003), "The Turkey, Taiwan, and Mexico Earthquakes: Lessons Learned" (1999), and "Earthquakes in the Eastern United States" (1985).

Earthquake Reconnaissance Missions: Ecuador earthquake (1987); Armenia earthquake (1989) at invitation of USSR Academy of Science; Loma Prieta earthquake, CA (1989); Northridge earthquake, CA, (1994), Kobe earthquake, Japan (1995), Kocaeli earthquake, Turkey (1999), Chi-chi earthquake, Taiwan (1999), Canterbury Earthquake Sequence [after all 4 main shocks: Sept., 2010, Feb., 2011, 13 June, 2011 and 23 Dec., 2011]; and Tohoku earthquake, Japan (2011).

Patents: US Patents No. 5713393 for "frictionless pipe", Feb. 1998, and No. 8701469 for flexible substrate sensor system for environmental & infrastructure monitoring, Apr. 2014.

Research: Principal or co-principal investigator on more than 80 research projects, totaling over $30 million. Select programs and projects include: **1)** Co-principal investigator and member of Executive Committee of NSF Engineering Research Center, Multidisciplinary Center for Earthquake Engineering Research (1997-2008) with oversight responsibility for an 11-year research program exceeding $ 50 million. Personal research accomplishments include development of hydraulic network analyses of the earthquake response of water supplies, including applications for decision support by the Los Angeles Department of Water and Power (LADWP) for the Los Angeles water supply and the San Francisco Public Utilities Commission (SFPUC) and San Francisco Fire Department for the San Francisco auxiliary water supply; advanced geographical information systems (GIS) for earthquake effects on geographically distributed infrastructure, including the use of the LADWP water distribution system as a 1200 km^2 "strain gage" for the effects of the 1994 Northridge earthquake; and large-scale experiments on critical water and energy infrastructure to characterize earthquake performance and reduce seismic effects through fiber-reinforced polymeric reinforcement and special geotextile wrap to reduce shear transfer from soil in underground pipelines to near-zero conditions. **2)** Principal investigator for research team supported by the Gas Research Institute (GRI) on cased and uncased pipelines under highways and railroads (1987-93) that designed, built, and installed by auger boring 300-mm and 1000-mm nominal diameter high pressure (7 MPa) highly instrumented pipelines under the test railroad track at the U.S. Transportation Test Center, Pueblo, CO to collect data for scores of thousands of repetitive train loads; developed software packages for the design of pipeline crossings of highways and railroads distributed by GRI; and changed US practice for pipeline crossings through revisions in railroad standards and guidelines. **3)** Principal investigator (PI) supported by NSF to construct the Cornell Large Scale Lifelines Testing Facility as part of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), including PI for several multi-institutional research projects using the facility, and co-PI for the maintenance, operation and management of the facility (2002-current). This unique research facility has hosted scores of researchers and developed advanced databases, innovative sensors, and substantially improved characterization of underground infrastructure response to large ground deformation, including the performance of high density polyethylene pipelines being applied by LADWP and the Christchurch City Council in the reconstruction of the Christchurch, NZ water and wastewater distribution systems, unique design of the SFPUC Bay Division Pipeline (30% of San Francisco water supply) crossing of the Hayward Fault, and verification and quantification of the capabilities of in situ trenchless pipe lining technologies to retrofit existing lifelines against earthquake effects. **4)** Co-principal investigator and Chair of Executive Committee of Institute for Civil Infrastructure Systems (1998-03), supported by NSF. The Institute was headquartered at the Wagner School of Public Service at New York University, and developed guidelines and policy for infrastructure planning and construction through multi-disciplinary interaction among engineers and applied social scientists, including planners and economists. Research was undertaken for the Institute on the effects of the World Trade Center Disaster (9/11) on the New York City (NYC) water supply, electric power, telecommunication, and underground transportation networks, which revealed interdependencies among these systems that had never been recognized, contributing to protective measures for infrastructure in New York City and London. **5)** Principal investigator, supported by NSF, of a team of US and Japanese researchers for 20 years (1986-2006) on the effects of earthquake-induced ground failures on underground infrastructure. The collaboration resulted in 7 major workshops with published proceedings containing over 300 papers, 2 volumes of case histories, and many new modeling procedures and experimental findings that have improved the earthquake resistant design of lifeline systems worldwide.

Publications: First or co-author of over 400 papers and published reports, of which approximately 1/3 are in refereed journals. Select published papers include the 2009 Rankine Lecture: “Geohazards and large geographically distributed systems”, *Geotechnique*, LX (7), 503-543 and 2005 Peck Lecture: “Lessons learned for ground movements and soil stabilization from the Boston Central Artery”, *J. Geotech.& GeoEnvir.*, ASCE, 132(8), 966-989. Several papers were selected for awards, including Japan Gas Association Japan Gas Award (2003) for “Large scale experiments on buried steel pipelines with elbows subjected to permanent ground deformation”, *J. Str. Mech. & Earthquake Engr.*, JSCE, 20(1),1s-11s; ICE Trevithick Prize (2002) for “Geotechnical aspects of lifeline engineering”, *Proc. Inst. Civil Engrs. Geotech. Engr.*, 149(1), 13-26; EERI Outstanding Paper (1996) for “Earthquake performance of gas transmission pipelines”, *Earthquake Spectra*, 13(3), 493-527; ASCE Collingwood Prize (1983) for “Ground movements caused by braced excavations”, *J. Geotech. Engr. Div.*, 107(9), 1159-1178; ASTM C.A. Hogentogler Award (1976) for "Measurement of strut loads by means of vibrating-wire strain gages", *Performance Monitoring for Geotechnical Construction*, STP 584, 58-77.

Lectures and Presentations: Since 1995 delivered 180 invited lectures, keynote and conference presentations worldwide. Examples include: EERI Distinguished Lecture “The New Normal for Natural Disasters” presented at 2012 EERI Annual Meeting and 14 other locations, including University of Cambridge and Imperial College. Since 2009, named lectures include Rankine Lecture (British Geotechnical Association), Terzaghi Lecture (ASCE Geo-Institute), UC Berkeley Distinguished Geotechnical Lecture, Sowers Distinguished Lecture (Georgia Tech), Keiwit Lecture (Oregon State Univ.), Milligan Lecture (Queens University), Haley & Aldrich Lecture (Univ. of Massachusetts), Martin S. Kapp Lecture (ASCE NYC Met Section), Lovell Lecture (Purdue Univ.), Lee Lecture (ASCE Los Angeles Section), UC Davis Distinguished Lecture, Hilf Lecture (Univ. of Colorado), Shaw Lecture (Stanford Univ.), Richart Lecture (University of Michigan). Kersten Lecture (University of Minnesota), and 25 keynote lectures at conferences. Presented on behalf of NAE, CEATS Convocation (2011), and gave a lecture at RAE (2011) on “Critical Infrastructure, Hazards, and Sustainability” and keynote address at Royal Bank of England (2005) on “Complex Network Interdependence”. Selected as 2013 ASCE Geotechnical Touring Lecturer and 2018 Cross Canada Lecturer.

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June 23, 2020

Bristol Bay Reserve Association
Fishermen's Center Bldg.
1900 W. Nickerson, Ste. 320
Seattle, WA 98199

Gentlemen:

Subject: *Review of Stability Analyses of the Main Embankment completed by Knight Piésold*
Pebble Mine Project

1.0 INTRODUCTION

The purpose of this report is to summarize our review of portions of the material included in the file named "RFI 008g.pdf" pertaining to the Pebble Mine Project currently under review by the U.S. Army Corps of Engineers (USACE) and other state, federal, and tribal entities.

File "RFI 008g.pdf", which we received on June 5, 2020, included the material listed below:

- Memorandum covering "Main Embankment Stability Assessment – Static and Post-liquefaction", prepared by Knight Piésold Ltd., Vancouver, Canada, for Pebble Limited Partnership, dated July 8, 2019. For ease of reference, this memorandum will be referenced as "2019 KP Memo".
- Knight Piésold's responses to questions and/or requests for information by the USACE. For ease of reference, this memorandum will be referenced as "2019 KP Responses".

Our reviews of the 2019 KP Memo and the 2019 KP Responses are presented below in Section 2.0 and Section 3.0, respectively.

2.0 REVIEW OF THE 2019 KP MEMO

This memorandum presents the results of stability analyses for the Main Embankment considering the section shown in Figure 1. In the Knight Piésold's analyses, the embankment is considered to have the same properties throughout, i.e., no zoning. It is noteworthy that the properties of the triangular portions of Zone U ("*part of upstream shell founded on the starter dam*", as stated in page 1 in the 2019 KP Memo) cannot be assumed to be the same as the main body of the embankment. These triangular portions will be placed and then compacted over the tailings beach, which will preclude, especially in the lower lifts, achieving the same degree of compaction as the main parts of the embankment. Therefore, the shear strength parameters for these triangular zones will be less than those assumed by Knight Piésold (Table 3.1 in the 2019 KP Memo).

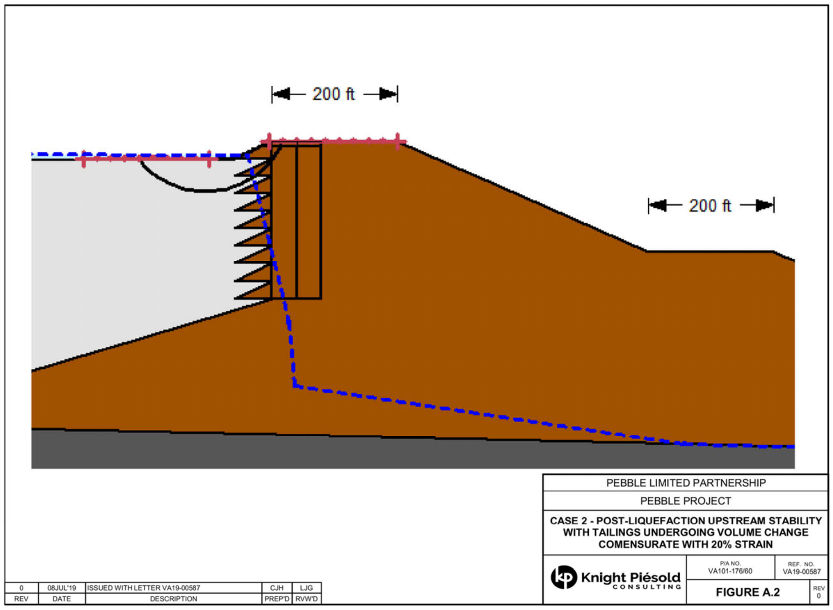

Figure 1 Cross section of main embankment showing critical surface calculated by KP
[Figure A-2 in the 2019 KP Memo; note that the title is not correct[1]]

Similarly, the phreatic surface (shown as the dashed blue line in all the figures in the 2019 KP Memo, including Figure A-2 above) is difficult to justify. The 2019 KP Responses includes the following statement: "*The current embankment concept is a flow through rockfill embankment with filter and transition zones within the embankment.*" However, no information is provided about the characteristics of either the filter or the transition zone. Knight Piésold needs to provide justification as to why the phreatic surface is not far closer to a horizontal line and much closer to the crest of the embankment if the design will result in "*a flow through rockfill embankment*".

The overestimation of shear strength in the triangular portions of Zone U as well as the unsupportable phreatic surface increases the safety factor against sliding in ways that are misleading and counterproductive for the Tailings Storage Facilities design. In our opinion the results of the stability analyses presented in the 2019 KP Memo are unusable to assess the safety of the proposed design.

Furthermore, we have not seen results of any geochemical waste rock investigation. Waste rock is proposed as rockfill to build the embankment. It is essential that investigations be completed to assess whether the waste rock is a potential acid generating material, thus making its use as rockfill unacceptable without major revisions in the design.

3.0 REVIEW OF THE 2019 KP RESPONSES

Part of File RFI 008g.pdf includes questions and/or requests for information that had been raised by the USACE as well as Knight Piésold's response to each. The questions/requests and responses pertain to:

1. Seismic analyses
2. Tailings liquefaction and seismic stability of upstream face
3. Future studies

[1] The title in Figure A-2 in the 2019 KP Responses document actually applies to what is presented in Figure A-1. The correct title for Figure A-2 is the title used in Figure A-1.

With respect to item 1, the 2019 KP Responses document uses the earthquake ground motions Knight Piésold had obtained in the seismic hazard analyses (SHA) inappropriately. The earthquake ground motions obtained in the SHA represent the motions at a rock outcrop at the mine site and definitely not the seismic response of the embankment. The large embankments will alter dynamically the bedrock motions so that the embankment seismic response will differ significantly from the motions used by Knight Piésold.

Even more problematic, Knight Piésold considered the PGA obtained in the SHA to represent seismic coefficients to be used in evaluating the potential deformations of the embankment.

In response to the USACE request: "*Provide information regarding propagation of bedrock acceleration through the embankment and tailings for each of the four design earthquakes*", Knight Piésold provided the following response:

> *"Seismic displacement analysis were performed using the Bray method. The Bray method considers the earthquake magnitude, the natural period of the dam structure (related to dam height and stiffness) and the spectral acceleration of the earthquake motion when estimating the seismic deformations. Therefore, the unique response spectrum defined for each design earthquake is considered in the analyses ..."*

This response does not address the request for information.

To use the Bray and Travasarou[2] method requires calculating the yield coefficient, k_y, which is the seismic coefficient that results in a factor of safety of one when applied to a selected segment (sometimes referred to as a wedge or sliding mass like the green portion shown in Figure 2 below). The last 8 pages of the 2019 KP responses include calculations of the yield coefficient for the wedge shown in Figure 2.

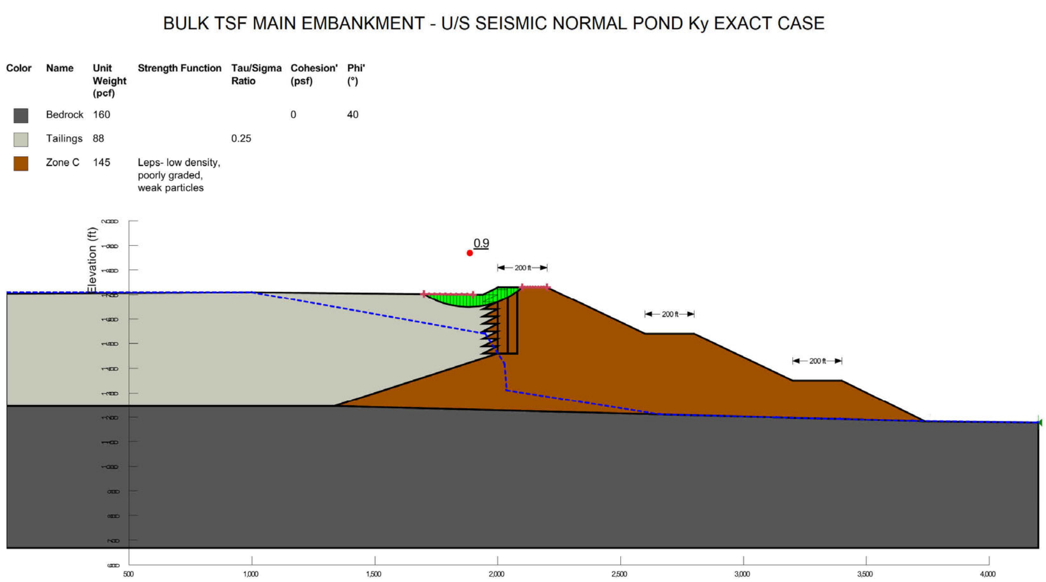

Figure 2 Wedge for which k_y is calculated by KP
[from the 2019 KP Responses document]

[2] Bray, J. D. and Travasarou, T. (2007). "Simplified procedure for estimating earthquake induced deviatoric slope displacements", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 133, No. 4, April 2007.

The phreatic surface (the blue dashed line in Figure 2) used in this calculation is impossible to justify. In addition, the use of the same shear strength parameters for the entire embankment is not justifiable, as noted in Section 2 above. These aspects render these calculations unusable to obtain values of k_y for this or any other wedge in the embankment-tailings.

Item 2 of the Knight Piésold responses above has been addressed in part by Section 2 of this report. Another item to consider for the embankments is deformation caused by liquefaction. As discussed in our report of June 19, 2020 on the subject of "*Review of Seismic Hazard Studies, Pebble Mine Project"*, liquefaction triggering and ensuing ground deformation are important issues that need to be part of the assessment of the proposed Pebble Mine site, lifelines, and port facilities. Based on what we have reviewed, we have not seen evidence that liquefaction triggering and ground deformation after liquefaction have been considered appropriately in any of Knight Piésold's reports and responses.

With respect to item 3 above, the 2019 Knight Piésold responses outline a number of studies to be completed as part of future studies. In particular, the responses indicate that an "*Initial Design Package*" for the tailings facilities would be submitted by the end of 2019. We are not aware that such a submittal had been made.

4.0 EMBANKMENT MATERIALS

We were provided on June 22, 2020 with a copy of the document titled "Pebble Project Definition", prepared by Pebble Limited Partnership and updated December 2019. This document provides description of the project and includes the following statement, in Section 3.4.4, that is particularly relevant to the stability of the embankments.

> "*The embankments will be constructed using suitable rockfill or earthfill materials, including quarried rock, NPAG and non-ML waste rock excavated from the open pit, if available, and stripped overburden.*" NPAG is "non-potentially acid generating" and ML is "metal leaching", as defined in the Acronyms and Abbreviations Section of the Pebble Project Definition Report.

Thus, it is possible that major portions of the embankment may consist of earthfill and entirely of rockfill as had been used in the 2019 KP Memo and the 2019 KP Responses documents covered in Sections 2 and 3 of this report. Thus, not only the strength of the rockfill in the triangular zones but also in other major parts of the embankment can be lower than assumed by Knight Piésold, thus rendering the stability analyses even less supportable.

The statement in Section 3.4.4 the Pebble Project Definition Report emphasizes the need to complete appropriate geochemical investigations of the rock to be obtained from quarries and the pit to assess whether these rocks are potentially acid generating or metal leaching. These investigations are important during the permit review process and should not be delayed until construction, as intimated in Section 6 of the Pebble Project Definition Report.

5.0 CONCLUDING REMARKS

The information included in the 2019 KP Memo and in the 2019 KP Responses have serious limitations:

1. The same shear strength parameters are assigned to the entire embankment, including the triangular portions of the upstream face of the embankment. This results in an overestimate of the shear strength of these triangular portions.
2. The phreatic line used in the static and post-liquefaction stability calculations is unsupportable.
3. The phreatic line used in the yield coefficient, ky, calculations is likewise unsupportable.
4. Major portions of the embankment could consist of earthfill whose shear strength would be overestimated using the strength parameters for rockfill.

Because of these limitations, we do not believe that these two documents provide sufficient information to judge the stability of the proposed tailings facility under static or earthquake loading conditions.

Furthermore, we have not seen results of any geochemical investigations. It is essential that appropriate geochemical investigations be completed to assess whether the quarried and waste rock are potential acid generating and/or metal leaching materials, thus making its use as rockfill unacceptable without major revisions in the design. These investigations are important during the permit review process and should not be delayed until construction, as intimated in Section 6 of the Pebble Project Definition Report.

We are pleased to be of assistance in making this review.

Sincerely,

I. M. Idriss　　　　T. D. O'Rourke