Appendix 4: Seismicity and Seepage Review Details
Review of the Delta Risk Management Strategy Report, Phase 1 (Draft 4)

Seismic Risk Review Details

A. The estimated frequency for islands failing due to earthquakes seems high in comparison to the historical record. Figure 13-2 in the DRMS report shows the following annual frequencies of having events with different numbers of islands fail due to earthquakes:

- one per 10 years of having at least one island fail (flood) due to an earthquake;
- one per 20 years of having at least ten islands fail due to an earthquake; and
- one per 100 years of having at least 40 islands fail due to an earthquake.

In contrast to this estimate, the historical record indicates that there have been no known failures of islands due to earthquakes in at least the last 100 years. Even if the historical record of earthquakes were extended further back to include the relatively active seismic period between 1850 and 1906 before the modern Delta was developed, there would potentially be only a handful of events (at most) where an earthquake may have caused hypothetical island failures if the Delta were in its present condition. More discussion and explanation of the apparent discrepancy between the historical record (at return periods of 10 or 20 years) and the predicted results is warranted. The use of Figure 13-8 to justify the estimated high frequencies of island failures is not very compelling because:

- it shows the probability of a large earthquake in the Bay area (not necessarily the Delta), and
- it does not show that the annual frequency for small-magnitude but frequent events (several islands failing every 10 or 20 years on average) is substantially higher than the historical record going back to 1850 (that is, including the more active period in the late 1800s).

An analysis of how the existing Delta would have performed in all of the historical earthquakes would be very helpful in putting these results into context and possibly informing the estimated frequencies. Also, at a minimum, the uncertainty bounds on the estimated frequencies in Figure 13-2 should be expanded (specifically, the lower bound should be dropped by about at least an order of magnitude) to reflect that there is apparently substantial uncertainty in predicting both the frequency of small-magnitude ground motions as well as the possibility of liquefaction in these events.

B. The argument that the levees were lower in the 1906 earthquake and therefore not as susceptible to failure is debatable (e.g. section 6.2.1). If levee failures are driven by liquefaction, the panel is not sure that smaller levees necessarily reduce liquefaction potential: can you show this using your liquefaction model? Also, the sands would have been younger and potentially more susceptible to liquefaction 100 years ago. It would be helpful to provide more discussion here since it is an important reference point in interpreting and understanding your results.

C. Simplified Analysis of Sherman Island

The following simplified analysis of the risk of levee failure due to earthquakes was conducted for Sherman Island to shed some light onto what is driving the results and whether they are reasonable.

First, Figure 6-11 in the DRMS report was used to develop the annual frequency for different ground peak ground accelerations, as shown below on Figure 1. Discrete intervals of acceleration were used to simplify the calculations – for example, a value of 0.1 g in the figure represents an acceleration between 0.075 and 0.125 g.

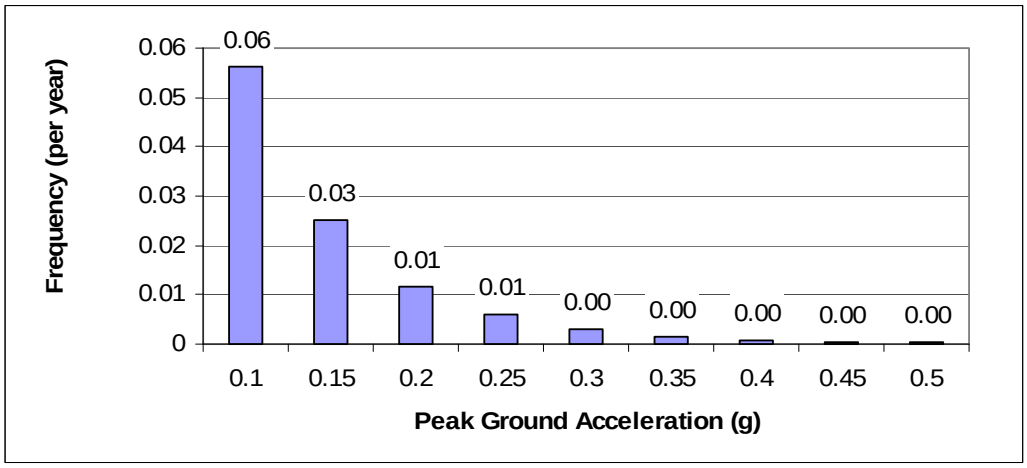

Figure 1

Next, we looked at Figure 6-37a to find that most of Sherman Island contains Vulnerability Class 4 with several small sections of Vulnerability Class 2. Then, we used Figure 6-137a to get the probability of failure as a function of the peak ground acceleration for these Vulnerability Classes, as shown below on Figure 2. For these Vulnerability Classes, the governing failure mode is liquefaction of the levee or its foundation.

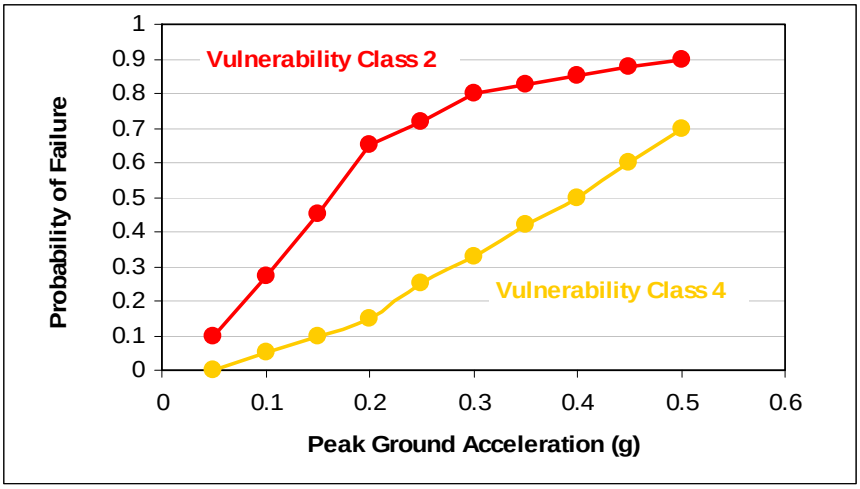

Figure 2

The use of Figure 6-37a in this simple analysis is an approximation because it corresponds to a magnitude 6.5 earthquake, which is a bit higher than the expected magnitude for an earthquake producing these ground motions at Sherman Island (Figure 6-26). If all of the possible magnitudes and distances were included explicitly in this calculation (as is done in the DRMS analysis), we suspect that the resulting probability of failure would be slightly lower than obtained in this simple analysis. Also, the information in Figure 6-37a corresponds to 2 feet of free board, which may be a bit lower (i.e., less freeboard) than the Mean Higher High Water level used in the DRMS analysis. Again, this approximation would potentially produce a slightly higher probability of failure with the simple analysis compared to the DRMS results.

Finally, we summed up the probability of failure for each Vulnerability Class as follows:

$$\begin{aligned} P(\text{Failure}) = {} & P(\text{Failure}|\text{pga} = 0.10\text{g})P(\text{pga} = 0.10\text{g}) \\ & + P(\text{Failure}|\text{pga} = 0.15\text{g})P(\text{pga} = 0.15\text{g}) \\ & + \ldots + P(\text{Failure}|\text{pga} = 0.50\text{g})P(\text{pga} = 0.50\text{g}) \end{aligned}$$

where $P(\text{Failure}|\text{pga} = \ldots)$ comes from Fig. 2 and $P(\text{pga} = \ldots)$ comes from Fig. 1. The results of these calculations are shown in the table below for Vulnerability Classes 2 and 4.

Table 1

		Class 2			Class 4		
pga	P(pga)	P(F|pga)	P(F|pga)*P(pga)	Contribution	P(F|pga)	P(F|pga)*P(pga)	Contribution
0.1	0.0563	0.27	0.0152	35%	0.05	0.0028	25%
0.15	0.0251	0.45	0.0113	26%	0.1	0.0025	22%
0.2	0.0118	0.65	0.0077	18%	0.15	0.0018	16%
0.25	0.0058	0.72	0.0042	10%	0.25	0.0015	13%
0.3	0.0030	0.8	0.0024	6%	0.33	0.0010	9%
0.35	0.0016	0.825	0.0013	3%	0.42	0.0007	6%
0.4	0.0009	0.85	0.0008	2%	0.5	0.0005	4%
0.45	0.0005	0.875	0.0005	1%	0.6	0.0003	3%
0.5	0.0003	0.9	0.0003	1%	0.7	0.0002	2%
		Total:	0.044		Total:	0.011	

The numbers in the boxes labeled “Total” are the annual probabilities of levee failure due to an earthquake for a reach with Vulnerability Class 2 or Class 4. The total probability of failure for the island is the probability that at least one reach fails. An approximation to obtain this probability is to assume that the event of failure is dominated by the single reach with the highest probability of failure (a reach with Vulnerability Class 2). Representing the entire island with the most vulnerable reach will produce a probability of failure for the island that is less than or equal to the value that would be obtained by accounting for all of the reaches that could fail. This approximation should be reasonable for Sherman Island since the number and length of reaches that are Vulnerability Class 2 is small and since the reaches that are Vulnerability Class 4 have a much smaller probability of failure (Table 1).

Therefore, the probability of failure due to earthquakes for Sherman Island obtained from this simplified analysis is 0.04. This result is similar to the DRMS result from the more complicated analysis, shown in Figure 13-7 (between 0.03 and 0.05 per year) and listed in Table 13-3 (0.037 per year).

In addition to providing a check on the DRMS results, this simple calculation is helpful because it highlights that the primary contribution to the probability of failure for Sherman Island is due to peak ground accelerations between 0.1 and 0.2 g (see columns labeled “Contribution” in Table 1). There are two significant aspects about this range of ground acceleration at Sherman Island:

1. The estimated frequencies for these ground motions are relatively high (return periods less than 100 years – see Figure 1 above or Figure 6-11 in the DRMS report), which is why they are driving the probability of failure. Such small return periods are not typically the focus in a Probabilistic Seismic Hazard Analysis (e.g., design return periods for structures and dams are typically on the order of 500 to 2,500 years). Also, there are historic data available to compare the actual ground motions that have occurred at Sherman Island that are relevant for such small high frequencies. For example, Figure 6-11 shows that the expected return period is 10 years for a peak ground acceleration exceeding 0.08 g. Based on over 50 years of records for a station at Antioch (close to Sherman Island), this ground motion has possibly (and not necessarily) been exceeded only once (in 1980).

Therefore, the estimated frequency of once per 10 years is higher than the historical record.

2. At these small accelerations, the potential for liquefaction is debatable. For example, using Appendix 6A as a guide, the cyclic stress ratios for peak ground accelerations of between 0.1 and 0.2 g would be between 0.05 and 0.1. If you look at the potential for liquefaction, which is obtained from Figure 6A-6 in the DRMS analysis and reproduced below as Figure 3), there are few actual data points where liquefaction occurred at a cyclic stress ratio of less than 0.1; it is an extrapolation to extend the curves showing the probability of liquefaction to these low stress ratios.

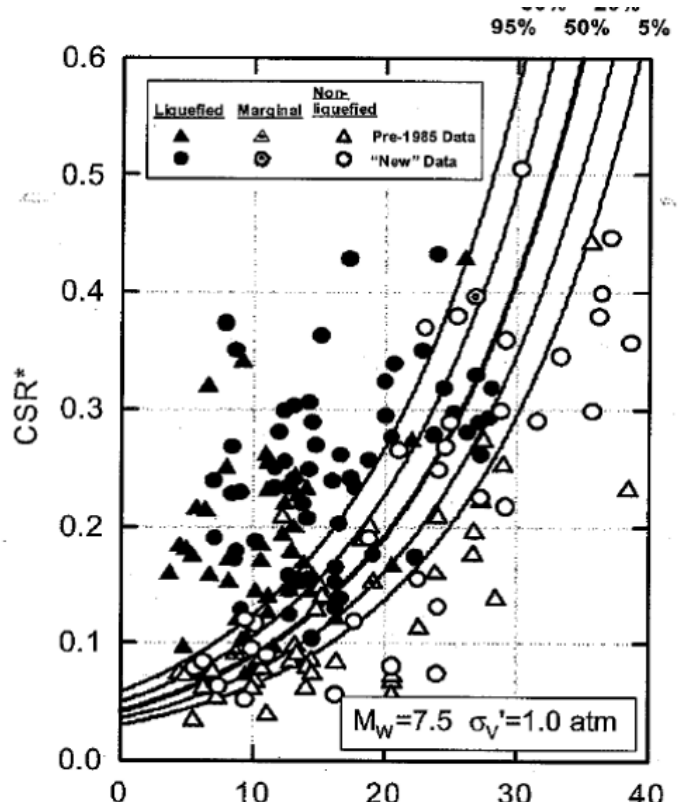

Figure 3 (taken from Figure 6A-6 in the DRMS Report)

This simplified analysis also indicates that the probability of failure for the Island is apparently dominated by the small lengths of reach that are the most vulnerable to liquefaction (Vulnerability Class 2). In moving forward, this information could be useful in reducing the seismic risk. Measures to reduce the potential for liquefaction over relatively small lengths of the levee could have a large impact on the total risk for this island. Conversely, small undetected lengths of levee (due to relatively sparse geotechnical and geologic information) could also have a large impact on the total risk. So, efforts to target the most vulnerable reaches, by clearly identifying, delineating and upgrading them, could be valuable in managing the overall seismic risk.

In summary, the results from this simple analysis of Sherman Island indicate that the overall DRMS results can be replicated (at least approximately) and that the seismic risk is driven by liquefaction of the most vulnerable reaches at relatively small ground accelerations. Additional information about the frequency of small ground motions (say peak ground accelerations of less than 0.2 g) and the potential for liquefaction at these small motions would be valuable in the future to better assess the seismic risk for the Delta.

Seepage Risk Review Details

Section 7.7.4.5 As discussed in our first review, the use of the exit gradient as an indicator of seepage failure is a challenge because the calculated gradient depends strongly on the resolution of the finite element mesh and local variations in physical properties. We recommend considering the use of an average gradient across the peat as a more robust indicator. Also, if the unit weight of the peat is really only 70 pcf, then the critical gradient (the gradient at which the effective stress in the peat goes to zero) is much less than 1.0 (in fact, it would be 0.12). Therefore, the statement that “the calculated vertical exit gradient of 0.4 would be insufficient to initiate an under-seepage problem” is not necessarily correct. We recognize that the peat may have tensile strength and may be able to sustain vertical effective stresses of zero without piping or failing; we would prefer to see data for this tensile strength and to see it considered explicitly in the analysis, instead of seeing failure defined with a critical gradient that does not have a physical basis. Also, if a smaller critical gradient were used, then the initial assumptions about the permeability of the peat, which were based on measurements, may have been reasonable, and would not have required adjusting to explain the case histories. Given the large potential for this failure mode, future work to better understand and model seepage failures would be very helpful to better assess the risk of failure due to flood events.