APPENDIX I-2

MEMO BY PROFESSOR TIMOTHY STARK: MINIMUM LIQUEFIED STRENGTH FOR STABILITY ANALYSES

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Memorandum

To: James K, Mitchell, Jonathan Bray, and Richard A. Mitchell,

From: Timothy D. Stark

CC: Gary Lass, Robbie Warner, and Curt Fuji

Date: 5/30/08

Re: Minimum Liquefied Strength for Stability Analyses
Newby Island Vertical Expansion

Background

From a soil mechanics point of view, I think it makes sense that there should be a minimum value of liquefied strength even though the vertical effective stress approaches zero when a strength ratio is used. This can be visualized as when the effective stress approaches zero, particles will, in the absence of massive volume expansion, still interfere with each other and develop local interparticle normal forces, that will provide some shear resistance. In addition, at low effective vertical stresses (σ') the potential for contractive shear behavior decreases. Riemer (1992) indicates that Su-liquefied/σ' should increase as σ' decreases based on laboratory testing. This data and the fact that the peak static friction angle of sand increases as the effective stress approaches zero provides additional support for the use of a minimum value of Su-liquefied at low effective confining stresses.

However if the liquefied strength is represented using a strength ratio, mathematically the liquefied strength approaches zero as the effective vertical stress approaches zero. At Newby Island the effective vertical stress decreases from the dike centerline to the outboard area of the dike because of a high water surface. Because the potentially liquefiable layer is shallow, a very low liquefied strength is estimated using the strength ratio method. Thus the question becomes, what minimum value of liquefied strength should be assigned to potentially liquefiable zones with a low effective vertical stress for this project?

To address this question, I reviewed the case histories that were used in Stark and Mesri (1992) and Olson and Stark (2002) to develop a relationship between liquefied strength ratio and penetration resistance. I found the following eighteen case histories that exhibit an effective vertical stress less than or approximately equal to 1000 psf. An effective vertical stress of 1000 psf at Newby Island corresponds to the effective vertical stress at a depth of 25 feet using a saturated unit weight of 105 pcf, and the water level at the ground surface.

Case Histories

The average liquefied strength and effective vertical stresses for the eighteen cases shown below are about 100 psf and 865 psf, respectively. (The corresponding strength ratio is 0.12 which is in agreement with 0.10 and 0.11 that is currently being used for the post-liquefaction stability analyses.) Also shown in the table is the mean normalized blowcount and/or mean normalized cone penetration resistance used to develop a relationship between liquefied strength ratio and penetration resistance in Stark and Mesri (1992) and Olson and Stark (2002). If there is an asterisk next to the blowcount value, it was estimated from the cone penetration tip resistance using the conversion between blowcount and tip resistance based on D_{50} presented in Stark and Olson (1995). If there are two asterisks next to the blowcount value, it was estimated from site observations.

Case History Number	Case History Name	Effective Vertical Stress (psf)	Best Estimate Undrained Liquefied Strength (psf)	Mean Normalized Blowcount $(N_1)_{60}$	Mean Normalized Cone Tip Resistance (q_{c1}) [MPa]
1	La Marquesa Dam D/S Slope	1000	111	9	
2	Nalband Railway Embankment	1100	119	9	
3	Nerlerk Berm Slide 1	616	52	9*	4.5
4	Nerlerk Berm Slide 2	650	36	7-8*	3.8
5	Nerlerk Berm Slide 3	925	32	7-8*	3.8
6	Lake Merced Bank	950	144	7-8	
7	Route 272 at Higashiarekinai	1030	100	6-7	
8	Helsinki Harbor	522	33	6**	
9	Chonan Middle School	1119	100	5-6	
10	Heber Road	800	100	5	
11	Hachiro-Gata Road Embankment	670	42	4-5	3.0
12	La Marquesa Dam U/S Slope	911	65	4-5	
13	Solfatara Canal Dike	955	50 – 75	4**	
14	Lake Ackerman Embankment	1076	81	4	
15	La Palma Dam	789	100	3-4	
16	Koda Numa Highway Embankment	485	25	3**	
17	Metoki Road Embankment	875	38	3**	
18	Mochi-Koshi Dike 2	1090	114	3	0.5

The table shows that the liquefied strength from the case histories varies from 25 to 150 psf for effective vertical stresses less than about 1000 psf and blowcounts values that vary from 3 to 9. As expected, the liquefied strength generally increases with increasing penetration resistance.

Recommended Minimum Liquefied Strength

Reviewing some of the CPT data provided by GLA and Rick Mitchell's summary of blowcounts, the blowcounts in the shallow and intermediate zone exhibit average values of $N_{1(60)}$ 7-9 and 12-14, respectively. The liquefied strength from a variety of methods using the average values of $N_{1(60)}$ are shown in the table below.

Parameter	Shallow Zone (~ elevation -10 feet)	Intermediate Zone (~ elevation -26 feet)
Average $N_{1(60)}$	7 - 9	12 – 14
Minimum Liquefied Strength from Stark and Mesri (1992) and Olson and Stark (2002) (psf)	100 - 125	200 - 250
Minimum Liquefied Strength from Seed and Harder (1990) (psf)	150 - 230	370 - 550
Minimum Liquefied Strength from Idriss and Boulanger (2008) (psf)	190 - 220	350 - 440

Using these average blowcounts and various liquefied strength methodologies, the liquefied strength varies from 100 to 230 psf for the shallow layer and 200 to 550 psf for the intermediate layer. The methods proposed by Seed and Harder (1990) and Idriss and Boulanger (2008) yield higher liquefied strengths probably because the trend line presented for each method reflects all case histories considered and not only the case histories with an effective vertical stress less than 1000 psf.

Because the project is utilizing a strength ratio approach, which assumes the liquefied strength is a function of the effective vertical stress, I relied a little more heavily on the Stark and Mesri (1992) and Olson and Stark (2002) data for effective vertical stresses less than or equal to 1000 psf to estimate the minimum liquefied strength. Based on this analysis, I recommend a minimum liquefied strength of 150 and 300 psf for the shallow and intermediate zones, respectively, for the post-liquefaction stability analyses. If new data becomes available during subsequent subsurface investigation, e.g., additional CPT and SPT data, these values of minimum liquefied strength should be re-assessed and new values assigned if appropriate.

Factor of Safety to Assign Liquefied Strengths

The seismic stability analysis performed by GLA consisted of performing a site response analysis and using the site response results and penetration resistance to compute the factor of safety (FS) against the triggering of liquefaction for the various soil layers or zones. If the FS against triggering was less than or equal to 1.3, the layer or zone was assumed to liquefy and it was assigned a liquefied strength for the purposes of seismic deformation analysis. Although this is generally consistent with California guidance, the approach is conservative because the liquefaction case histories used by me and others to back-calculate values of liquefied strength all exhibit static factors of safety less than unity. Moreover, it is reasonable to assume that the liquefied strength would be mobilized only if the triggering FS is near unity.

As a result of these considerations, deformation analyses that assume liquefied strengths for all horizons with a triggering safety factor less than 1.3 will tend to overestimate the potential seismic deformation and may also lead to overly conservative liquefaction mitigation requirements. Although, the GLA analyses completed to date are appropriate for preliminary design and permit-level documents, I recommend that final design of liquefaction mitigation measures be based on assigning liquefied strengths only to those horizons with a triggering FS less than 1.1. The net effect of this recommendation is that the thickness and extent of the zones that are assigned a liquefied strength in the stability analyses may be reduced. This is in agreement with the geologic setting that indicates the liquefiable layers are not massive and not continuous across the site.