Panama Canal Authority
Engineering and Projects Department
Engineering Division
Geotechnical Branch

Study on the effect of deepening on Gaillard Cut slopes

Volume 1

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Volume 1: Study on the Effect of Deepening on Gaillard Cut Slopes

1.0 Introduction

In Fiscal Year 2001, the Geotechnical Branch of the Engineering Division prepared excavation plans and a geological characterization of the channel bottom for the Second Deepening Program. Expansion Studies of the Canal have suggested that a deepening of the channel lower than elevation 34' PLD (10.36m) should be carried out to meet future demand. The main objective of this report is to study the effect of increasing the depth of the Canal on Gaillard Cut Slopes.

This report includes the stability analysis and design of Gaillard Cut slopes for two bottom elevations, 29' PLD (8.83m) and 24' PLD (7.31m). Furthermore, a cost estimate based on the required additional excavation is also included.

2.0 Geological Characterization

The rocks in the Canal, particularly in the Gaillard Cut, consist of a complex series of igneous flows and intrusive bodies, pyroclastic materials, and sedimentary strata of Tertiary age. The vulcanoclastic nature of the sedimentary rocks has made them susceptible to changes in texture and composition during their geological history; alteration of volcanic glass has resulted in their high content of clay minerals, mainly montmorillonite. It is recognized that rocks with high content of montmorillonite are the most problematic soft rocks.

Faulting is the most important geological structure in the Gaillard Cut. The Cut is so extensively faulted (one fault every 75 meters on average) that it gives the impression that the area has been subjected to immense stresses and thoroughly shattered. In the Canal area, at least two systems of faults have been identified: one that trends northeast, and the other in a northwest direction. The northeast striking faults are readily identified in the analysis of surveyed faults along the Gaillard Cut. Conversely, the northwest striking faults are not so easy to identify since they may be oriented roughly parallel to the Canal axis, and hence, difficult to survey along the Gaillard Cut shorelines. There is no doubt that faults must have intervened in most slope failures along the Canal because they are so numerous and are adversely oriented with respect to the Canal axis.

The stratigraphical columns developed for the main formations reveal the importance of particular lithological units within each formation. In the Cucaracha formation, the weakest layers are the tuffaceous, highly altered to clay minerals and slickensided, massive beds of clay shale. The carbonaceous, shaly siltstone beds are the weakest in the Culebra, La Boca and Gatuncillo formations, whilst the argillaceous tuffs are the weakest in the Las Cascadas formations. This also indicates that the lithocorrelation of units within a formation at the scale of the slope mass is more important than the formational correlation in a regional sense. All the formations are highly heterogeneous and anisotropic.

The present geological knowledge of the Gaillard Cut was gained through hundreds of borings and field mapping. The geological cross sections developed for this study are basically the integration of the following information: the ICC (1912) geological cross sections, the PCC geological cross sections (SK-3-13), WES geological map, Stewart's map, old PCC borings, recent geological explorations during Cut Widening Project (1992-2001) and the most recent surface mapping carried out along excavated banks of the Cut. Representative design geological cross sections are included in appendixes A and B.

3.0 Stability Analysis

3.1 Design Elevations

A new proposal to deepen the Gaillard Cut and Gatun Lake to lower elevations than 34' PLD (10.36m) has been suggested to accommodate future expansion of the Canal. To evaluate this proposal and the cost involved in deepening the Cut more than 3' (1.00m), stability analyses were performed for the following conditions (Figures 1a and 1b):

- Case 1: The bottom of the channel was placed at elevation 32' PLD (9.75m). This elevation represent the existing condition taking into account some overdredging. All slopes of the Cut Widening Program were designed for this bottom elevation.

- Case 2: The bottom of the channel was placed at elevation 32' PLD (9.75m), but a layer of very soft or weak material (blasted) was considered to elevation 27' PLD (8.23m).

- Case 3: The bottom of the channel was considered at elevation 27' PLD (8.23m). This condition also includes 2 feet of overdredge (29'-2'=27').

- Case 4.1 & 4.2: The same as case 3, but includes an underwater excavation in case 4.1 and a dry excavation (stabilization) in case 4.2

- Case 5: The bottom of the channel was placed at elevation 32' PLD (9.75m), but a layer of very soft or weak material (blasted) was considered to elevation 22' PLD (6.70m).

- Case 6: The bottom of the channel was considered at elevation 22' PLD (6.70m). This condition also includes 2 feet of overdredge (24'-2'=22').

- Case 7.1 & 7.2: The same as case 6, but includes an underwater excavation in case 7.1 and a dry excavation (stabilization) in case 7.2.

- Case 8: The bottom of the channel was placed at elevation 22' PLD (6.70m)., but a layer of very soft or weak material (blasted) was considered to elevation 16' PLD (4.87m). It also includes underwater excavation.

3.2 Shear Strength Models

Two shear strength models were used in this study: a soft rock model and a hard rock model.

Soft Rocks:

The stress-strain and strength properties of many soft argillaceous rocks are generally similar to those of an over-consolidated hard-fissured clay. When shearing an intact over-consolidated clay in drained conditions, the behavior is characterized by a sharp peak strength and initiation of dilation. After that, there is a post-peak drop in strength (strain softening) which may be considered as being due, firstly, to an increase in water content (dilatancy) and, secondly, to reorientation of clay particles parallel to the direction of shearing. At the end of the first stage, the "fully-softened" or "critical state" is reached. At larger displacements, when reorientation of clay particles is complete, the strength falls to and remains constant at the residual value.

All slopes on soft rocks were evaluated using either the fully-softened strength or the residual strength, depending of the initial conditions of the slopes (first-time or reactivation of a previous failure). The non-linear shear strength envelopes (derived from the backanalysis of past failures), which were used to model the fully-softened, and residual shear strengths have the following form:

$$\tau = \sigma_n \tan\left(\phi_1 + \frac{\phi_2}{\left(1 + \frac{\sigma_n}{b}\right)} \right)$$

Table 1 and Figure 2a summarizes these soft rock envelopes. Finally, all blasted materials in soft rocks were modeled using the residual shear strength envelope.

Hard Rocks:

Estimating the strength of rock masses is rather difficult because of the presence of discontinuities and weakness planes. Therefore, good engineering estimates of rock mass strength can be made by the use of empirical shear strength criteria. The criterion developed by Hoek and Brown was selected to model the strength of hard rock masses in Gaillard Cut. This criterion is generalized in the following equations:

$$\sigma_1 = \sigma_3 + \sigma_c \left(m \frac{\sigma_3}{\sigma_c} + s \right)^{1/2}$$

$$\sigma_n = \sigma_3 + \frac{\sigma_1 - \sigma_3}{A + 1}$$

$$\tau = (\sigma_n - \sigma_3)\sqrt{A}$$

$$A = 1 + \frac{m\sigma_c}{2(\sigma_1 - \sigma_3)}$$

The parameters *m* and *s* were evaluated from the analysis of past failures on hard rocks along the Gaillard Cut. In addition, the presence of a weakness plane (long persistent discontinuity) imposes a special condition on the failure mechanism. In this case, the strength of the slope mass is controlled by the strength of this discontinuity. The shear strength of discontinuities was modeled using the Barton joint strength criterion, which is expressed in the following equation:

$$\tau = \sigma_n \tan\left(\phi_b + JRC \log \frac{JCS}{\sigma_n}\right)$$

The parameters ϕ_b, JRC and JCS are the base friction angle, joint roughness coefficient and joint wall compressive strength respectively. These parameters were empirically estimated from the back analysis of past failures. Table 1 and Figure 2b summarize the strength envelopes developed for this study. Finally, all blasted materials in hard rocks were modeled using the Hoek-Brown criterion for poor quality rock mass.

3.3 Failure Mechanisms

The geometry of a landslide is determined by the structure of the slope mass, and many studies have correlated geotechnical characteristics with possible slide types, their geological and hydrogeological features.

The rock mass generally consists of a succession of different lithological materials; they show bedding planes (and other depositional structures) and may have numerous discontinuities (created by tectonic and other geological processes). Consequently, they exhibit a marked anisotropy in their strength and stress-strain proprieties. The failure geometry will be generally far from the traditional circular arc and will be determined by the structural setting in the slope mass. However, rotational failures are possible, but only under the following conditions: 1) the rock mass is closely jointed, and consists of fairly thick and homogeneous deposits; and 2) the discontinuities dip systematically and considerably into the slope.

In structurally controlled slides, failure will tend to occur along a preferred plane of weakness. This immediately suggests that the surface of failure will be a plane, a combination of planes, or a combination of a plane and arc (compound landslides), which follow the traces of structural discontinuities. In this case, the stability is determined principally by the plane of weakness in the rock mass and not by the strength of the rock itself.

The structural controlled failure of many slides along Gaillard Cut is well recognized. Experience with past failures in the Gaillard Cut suggests that the probable failure geometry will be one of those described in Figure 3. Rotational failure will occur where bedding dips into the slope or where the slope mass is closely jointed. Furthermore, a special case where a hard rock cap (see Figure 3) is present over soft rock at the head of the slope, the failure mechanism should include a large tension cracks in the stability analysis to avoid large negative (tension) interslice forces. Field evidence of this tension crack has been seen in Hodges Hill Slide and Contractor's Hill, for example.

On the other hand, the sedimentary nature of La Boca, Las Cascadas, Culebra and Cucaracha Formations, which generally consist of a succession of different lithological materials and they show bedding planes or other weakness planes, will produce translational movements when these planes dip toward the channel. For each representative cross section, a failure geometry was assumed based on the above mentioned observations.

3.4 Ground Water Condition for Analysis

Groundwater is one of the most significant factors in the behavior of slopes. The action of water in weathering, destroying diagenetic bonds, inducing swelling and reducing the shear strength is well recognized in the literature. In addition, water may cause differences in pore pressure due to seasonal variations of groundwater flow and submergence of a portion of a slope. Water not only increases the pore pressure, which reduces the shear resistance, but also increases the forces tending to cause instability by adding weight to the mass and exerting pressure in cracks.

For the stability analyses, the groundwater location was based on observed water levels (when possible), which have been colleted throughout the years from travel pipes, multi-point piezometers, Casagrande piezometers and corelogs as part of the Landslide Control Program. In no case, the average pore pressure ratio (Ru) for the critical slip surface was less than 0.30.

3.5 Results of Analyses

Stability analyses were carried out in selected sections. Each section is considered to represent a range of stations along the Cut. The selection of each representative station was based on:

- The terrain characteristics of the slope. Generally, the steepest and highest was considered to be the most critical.

- The geological and structural setting of the slope, implying that the area represented by the selected station has similar failure mechanism and shear strength model.

- The sliding activity of the area. The more active the smaller the area represented by the selected section.

Tables 2 and 3, and Figures 4 and 5 summarize the results of the stability analysis performed on each representative station under various conditions (as specified above). Appendices A and B assemble a detailed report on the stability analyses carried out on the selected sections.

4.0 Design and Excavation Volume

To estimate the volume of excavation required for the stabilization of the slopes that could be affected by deepening the Gaillard Cut beyond the 1.00m already planned, a preliminary excavation scheme was designed. Stabilization was considered necessary under the following conditions:

1. When the factor of safety of the existing condition (case 1) was less than 1.2, regardless the factor of safety under the various deepening conditions (cases 2 to 7).

2. When the factor of safety of the excavated condition (cases 4.1 and 7.1) was less than 1.2.

The excavation design was optimized to obtain a factor of safety equal to the existing condition (case 1). Tables 4a and 4b show the excavation volume required to comply with this condition on each selected area.

The volume of each sector was determined using the representative templates for each design station. These templates were chosen according to the topography of area and were constructed based on the stability analysis performed on the design stations. Once the templates were constructed, the volume of cut material was calculated for two different conditions: a) deepening the actual bottom of the channel to an elevation of 27' PLD, and b) deepening the actual bottom of the channel to an elevation of 22' PLD. Not all the design sections needed dry excavation to stabilize the slopes, but in all of them it was necessary to compute an underwater excavation. Volume estimates reflect two conditions as shown in tables 4a and 4b: 1) underwater excavation, and 2) Dry excavation respectively.

Total volume and costs estimate necessary to increase the stability of those area that will be affected by a deepening program of Gaillard Cut beyond the 1.00m already planned is summarized as follows:

Activity	Deepening to 29' PLD (8.84m) Evaluation Elevation: 27' PLD (8.22m)		Deepening to 24' PLD (7.31m) Evaluation Elevation: 22' PLD (6.70m)	
	Volume (m3)	Cost	Volume (m3)	Cost
Dry excavation	5,387,502	21,550,007	8,162,251	32,649,006
Underwater Excavation	923,165	13,847,478	2,574,882	38,623,227
Special Work at Purple Rock	Lump Sum	200,000	Lump Sum	200,000
Contingency		7,119,497		14,294,447
Total		42,716,981		85,766,679

5.0 Conclusions

1. The Gaillard Cut slopes are, in general, considered safe for the current Deepening Program (bottom elevation 34' PLD). The basic reason for this is that slopes during the Cut Widening Program were designed for a bottom elevation of 32.3' PLD (10.00m). Note that the widening did not touch half of the slopes. Especially important is that the widening was laid out to avoid affecting several sensitive areas.

2. There are only three areas that are considered problematic for the current Deepening Program: West Culebra Slide, East Culebra Slide and Purple Rock Slide. Remedial works are being planned for West Culebra and Purple Rock in Fiscal Year 2002 and for East Culebra in Fiscal Year 2003.

3. Stability analyses show that drilling and blasting to elevation 27' PLD, but not removing the material from the bottom of the channel has little effect in reducing the stability of the slopes. No further work is required for this condition, except in those considered sensitive areas. On the other hand, drilling and blasting to elevation 22' PLD does considerable reduce the stability of many slopes and a stabilization program will be required similar to (case 7.2).

4. Any deepening project that extends below elevation 34' PLD will affect the stability of the existing slopes in Gaillard Cut. It is estimated that if we deepen 5 more feet (1.50m) below elevation 34" PLD, 56 % of the slopes in Gaillard Cut will require some stabilization measure. In general, for every 3 feet (1.00m) that we go lower than 34' PLD will require 4 to 5 million cubic meter of additional excavation on the existing slopes.

5. Notwithstanding the above statement, a deepening project to lower the bottom of channel to a elevation less than 34' PLD can be accomplished successfully if we implement the adequate stabilization measures as described in this study.

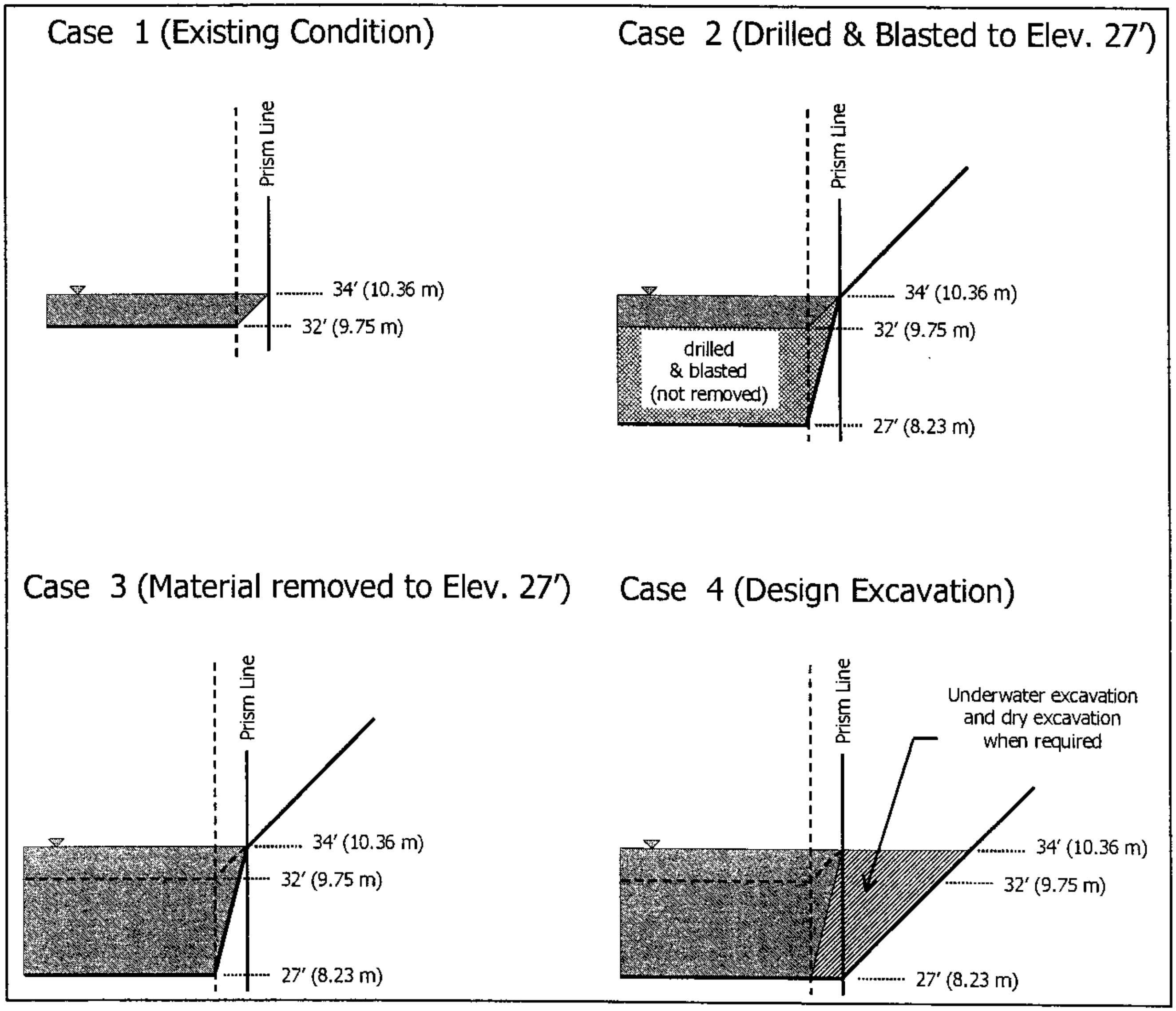

Figure 1a Design elevations for stability análisis and volume computation

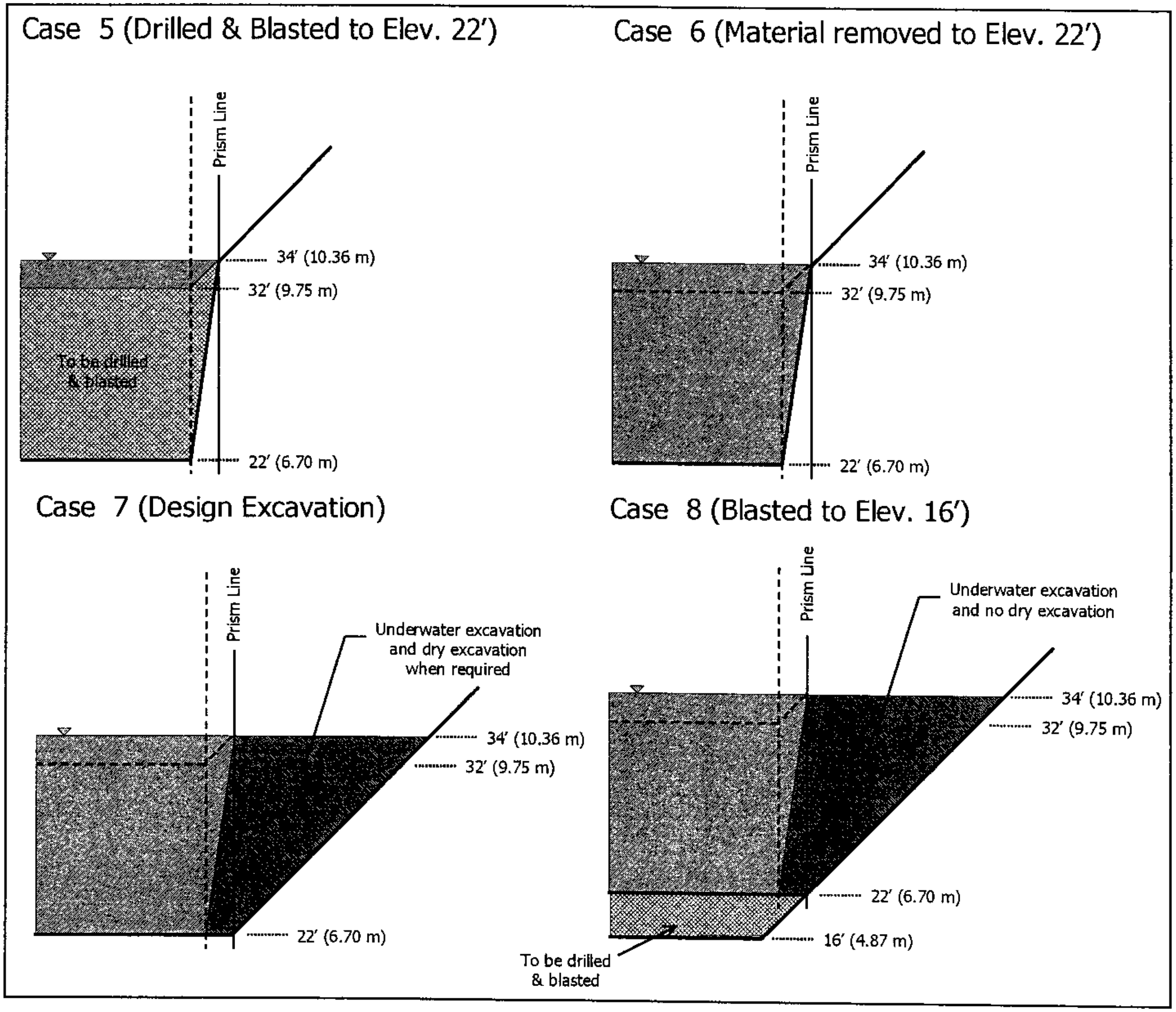

Figure 1b Design elevations for stability analysis and volume computation

Table 1 Design Shear Strength Envelopes

Fn. #	FORMATION	MECHANISMS	FUNCTION	EQUATION	BLASTED MATERIAL	UNIT WEIGHT
1	La Boca	First Time	Fully Softened	$\phi = 17.5 + 20.3 / (1+\sigma n / 200)$	No	21.2 - 22.0
2	La Boca	Reactivated	Residual	$\phi = 7.5 + 14.0 / (1+\sigma n / 150)$	Si	
7	Cucaracha	First Time	Fully Softened	$\phi = 13.5 + 17.1 / (1+\sigma n / 373)$	No	21.2 - 22.0
8	Cucaracha	Reactivated (lab)	Residual	$\phi = 7.4 + 8.7 / (1+\sigma n / 100)$	Si	
25	Cucaracha	Reactivated (backanalysis)	Residual	$\phi = 8.5 + 13.0 / (1+\sigma n / 100)$	Si	
26	Cucaracha	First time	Fully Softened	$\phi = 13.5 + 24.0 / (1+\sigma n / 373)$	No	
9	Culebra	First Time	Fully Softened (upper)	$\phi = 13.1 + 20.9 / (1+\sigma n / 120)$	No	21.2 - 22.0
10	Culebra	Reactivated	Residual	$\phi = 9.1 + 5 \log (2400 / \sigma n)$	Si	
11	Gatuncillo	First Time	Fully Softened	$\phi = 12.0 + 20.7 / (1+\sigma n / 362)$	No	21.2 - 22.0
12	Gatuncillo	Reactivated	Residual	$\phi = 7.3 + 6 \log (4600 / \sigma n)$	Si	
3	Las Cascadas (Tuff)	First Time	Fully Softened	$\phi = 14.2 + 10.7 / (1+\sigma n / 475)$	No	22.0 - 22.8
5	Las Cascadas (Tuff,)	Reactivated (lab)	Residual	$\phi = 5.0 + 8.5 / (1+\sigma n / 200)$	Si (for Tuff only)	
27	Las Cascadas (Weak Plane - La Pita)	Weak Plane (backanalysis)	Barton (σc=1110 psi)	$\phi = 8 + 10 \log (1110 / \sigma n)$	Si (for Agg. & An)	
4	Las Cascadas (Aggl. & Andesite)	First Time	Hoek & Brown	$m = 0.3$, $s = 0.0001$, $\sigma c = 1200$ psi	No	
6	Las Cascadas (Aggl. & Andesite)	Poor Quality Rock	Hoek & Brown	$m = 0.069$, $s = 0.000003$, $\sigma c = 1200$ psi	Si (for Agg. & An)	
16	Bas Obispo	Plane failure along a disc.(option 2)	Barton (σc=3000 psi)	$\phi = 16 + 5 \log (3000 / \sigma n)$	No	
17	Bas Obispo	Plane failure along a disc.(option 3)	Barton (σc=5515 psi)	$\phi = 16 + 5 \log (5515 / \sigma n)$	No	
13	Bas Obispo	First Time (option 1)	Hoek & Brown	$m = 0.34$, $s = 0.0001$, $\sigma c = 3000$ psi	No	
14	Bas Obispo	First Time (option 2)	Hoek & Brown	$m = 0.34$, $s = 0.0001$, $\sigma c = 5515$ psi	No	
18	Bas Obispo	Poor Quality Rock (option 1)	Hoek & Brown	$m = 0.069$, $s = 0.000003$, $\sigma c = 3000$ psi	Si	
19	Bas Obispo	Poor Quality Rock (option 2)	Hoek & Brown	$m = 0.069$, $s = 0.000003$, $\sigma c = 5515$ psi	Si	
20	Pedro Miguel Agg	First Time	Hoek & Brown	$m = 0.34$, $s = 0.0001$, $\sigma c = 5515$ psi	No	22.8 - 23.5
21	Pedro Miguel Agg	Reactivated & Plane Failure	Barton (σc=5515 psi)	$\phi = 16 + 5 \log (5515 / \sigma n)$	No	
22	Pedro Miguel Agg	Poor Quality Rock	Hoek & Brown	$m = 0.069$, $s = 0.000003$, $\sigma c = 5515$ psi	Si	
23	Basalt	First Time	Hoek & Brown	$m = 1.21$, $s = 0.0021$, $\sigma c = 7255$ psi	No	23.5
24	Basalt	Poor Quality Rock	Hoek & Brown	$m = 0.069$, $s = 0.000003$, $\sigma c = 7255$ psi	Si	

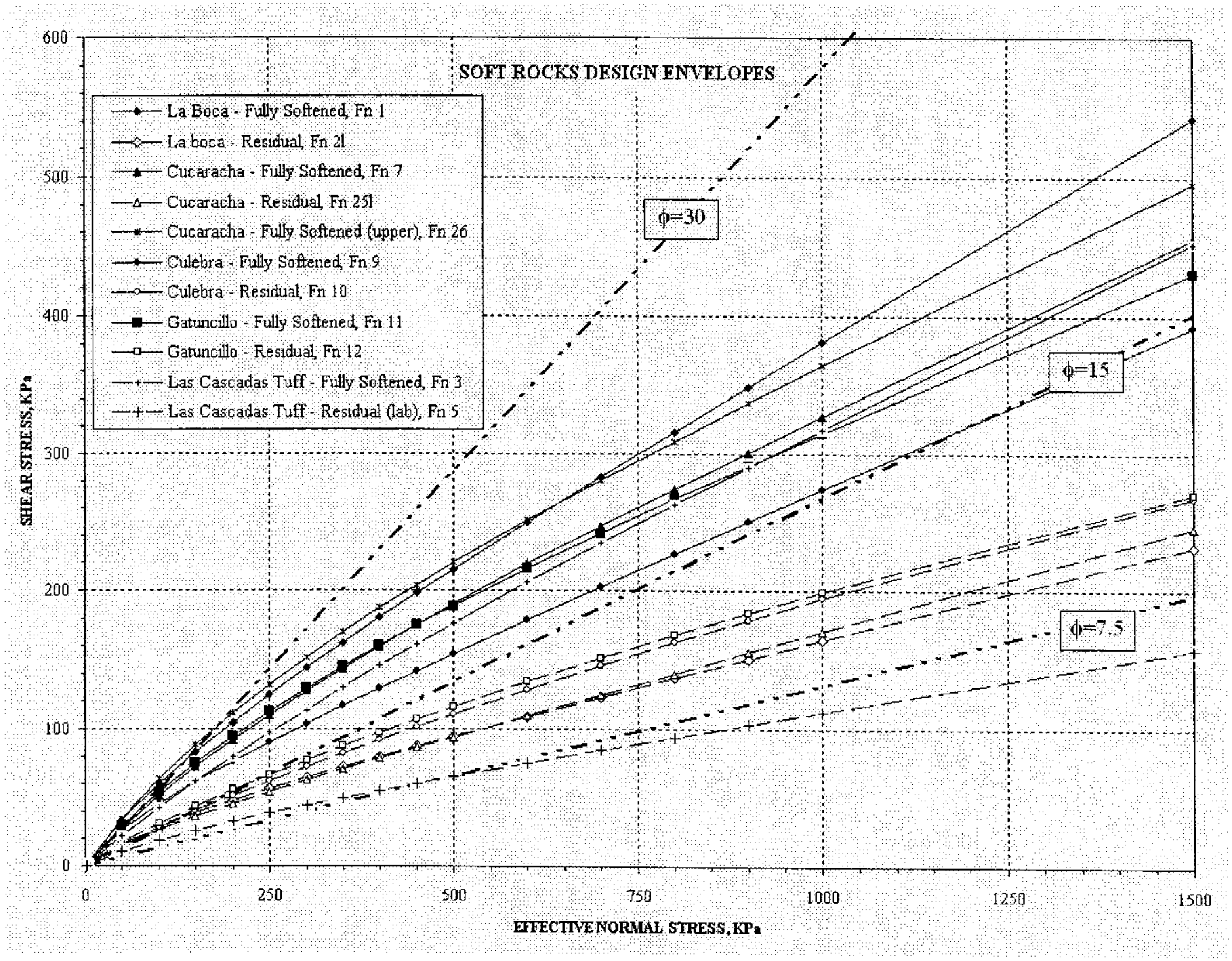

Figure 2a Soft Rocks Shear Strength Envelopes

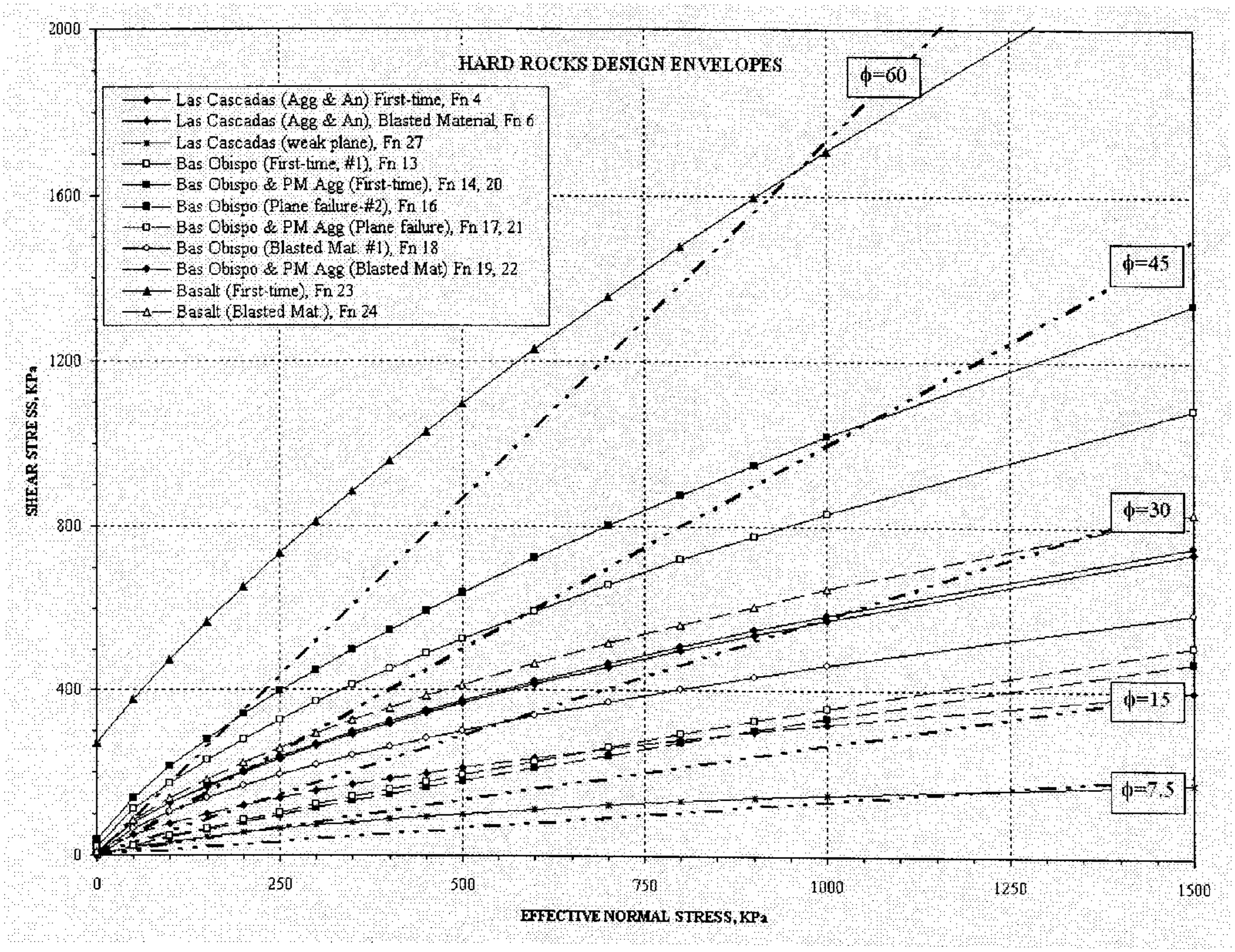

Figure 2b Hard Rocks Shear Strength Envelopes

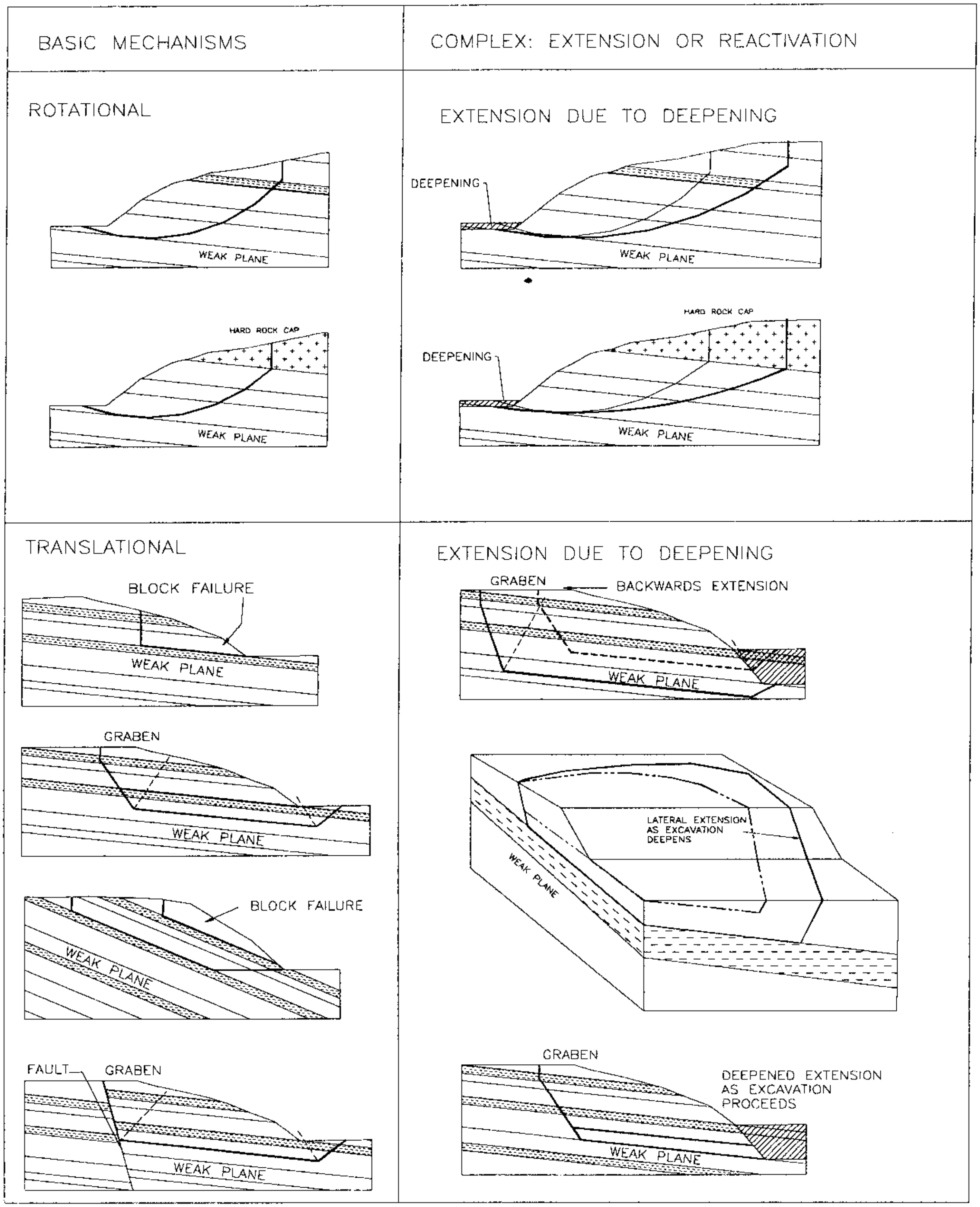

Figure 3 Assumed failure mechanisms as a function of structural setting

West Bank -Summary of Stability Analyses

Station	Representative Stations	Factor of Safety										Dry excavation is required
		Case 1	Case 2	Case 3	Case 4.1	Case 4.2	Case 5	Case 6	Case 7.1	Case 7.2	Case 8	
		Existing	27 ft (blasted)	27 ft (removed)	27 ft (design-underwater slope)	27 ft (design-&dry excav.)	22 ft (blasted)	22 ft (removed)	22 ft (design-underwater slope)	22 ft (design-&dry excav.)	16 ft (blasted)	
51k+600 W (1692+91)	50k+320 to 52k+160	2.834	2.814	2.772	2.684	2.684	2.744	2.691	2.501	2.501	2.486	NO
53k+171 W (1744+45)	52k+160 to 53k+780	1.261	1.245	1.214	1.182	1.238	1.198	1.168	1.122	1.200	1.092	YES
54k+300 W (1781+49)	53k+780 to 55k+000	0.976	0.972	0.958	0.889	1.021	0.944	0.908	0.861	1.000	0.862	YES
55k+930 W (1835+00)	55k+000 to 56k+740	1.864	1.850	1.800	1.797	1.797	1.800	1.752	1.694	1.694	1.689	NO
56k+898 W (1866+73)	56k+740 to 57k+050	1.359	1.349	1.318	1.267	1.267	1.307	1.279	1.213	1.330	1.198	YES
57k+098 W (1873+29)	57k+050 to 57k+475	3.847	3.847	3.829	3.792	3.792	3.822	3.794	3.744	3.744	3.733	NO
57k+820 W (1897+00)	57k+475 to 57k+925	0.971	0.971	0.959	0.949	1.012	0.958	0.952	0.937	1.037	0.937	YES
58k+120 W (1906+82)	57k+925 to 58k+760	1.006	1.005	0.990	0.980	1.046	0.989	0.973	0.937	1.001	0.955	YES
58k+887 W (1932+00)	58k+760 to 59k+000	1.070	1.069	1.062	1.054	1.054	1.062	1.055	1.042	1.188	1.041	YES
59k+070 W (1938+00)	59k+000 to 59k+260	1.000	0.999	0.990	0.978	1.107	0.988	0.982	0.963	1.121	0.961	YES
59k+485 W (1951+60)	59k+260 to 59k+780	0.962	0.960	0.955	0.944	1.169	0.953	0.952	0.941	1.160	0.916	YES
59k+881 W (1964+60)	59k+780 to 60k+050	0.933	0.931	0.921	0.914	0.938	0.920	0.910	0.900	0.936	0.897	YES
60k+240 W (1976+37)	60k+050 to 60k+400	1.039	1.037	1.015	1.010	1.056	1.013	0.992	0.980	1.048	0.978	YES
60k+950 W (1999+61)	60k+400 to 61k+240	1.190	1.183	1.152	1.117	1.372	1.144	1.122	1.069	1.309	1.052	YES
61k+600 W (2021+00)	61k+240 to 61k+900	1.417	1.414	1.382	1.356	1.356	1.380	1.351	1.315	1.315	1.309	NO
62k+000 W (2034+12)	61k+900 to 62k+200	1.072	1.055	1.042	1.030	1.092	1.028	1.001	1.001	1.090	0.935	YES
63k+050 W (2068+56)	62k+910 to 63k+150	2.493	2.486	2.451	2.442	2.442	2.443	2.413	2.397	2.397	2.384	N/A
63k+327 W (2077+65) (a)	63k+150 to 63k+725	2.220	2.220	2.212	2.204	2.197	2.212	2.205	2.194	2.187	2.194	N/A
63k+327 W (2077+65) (b)	63k+150 to 63k+725	1.245	1.235	1.216	1.089	1.174	1.156	1.123	1.033	1.108	1.007	N/A

Table 2 Summary of Stability Analyses (West Bank)

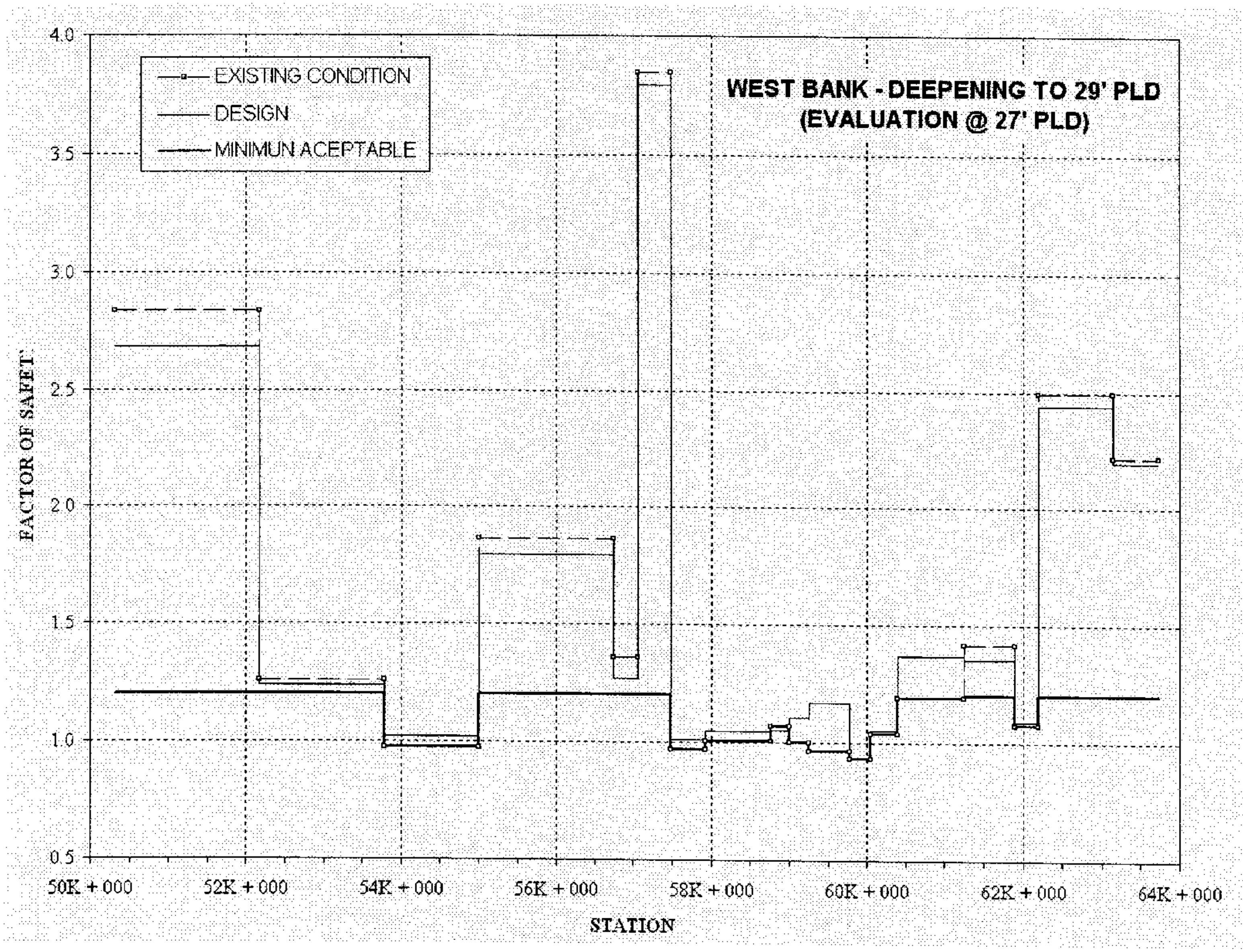

Figure 4a Results of stability analyses (West bank, elevation 27'PLD)

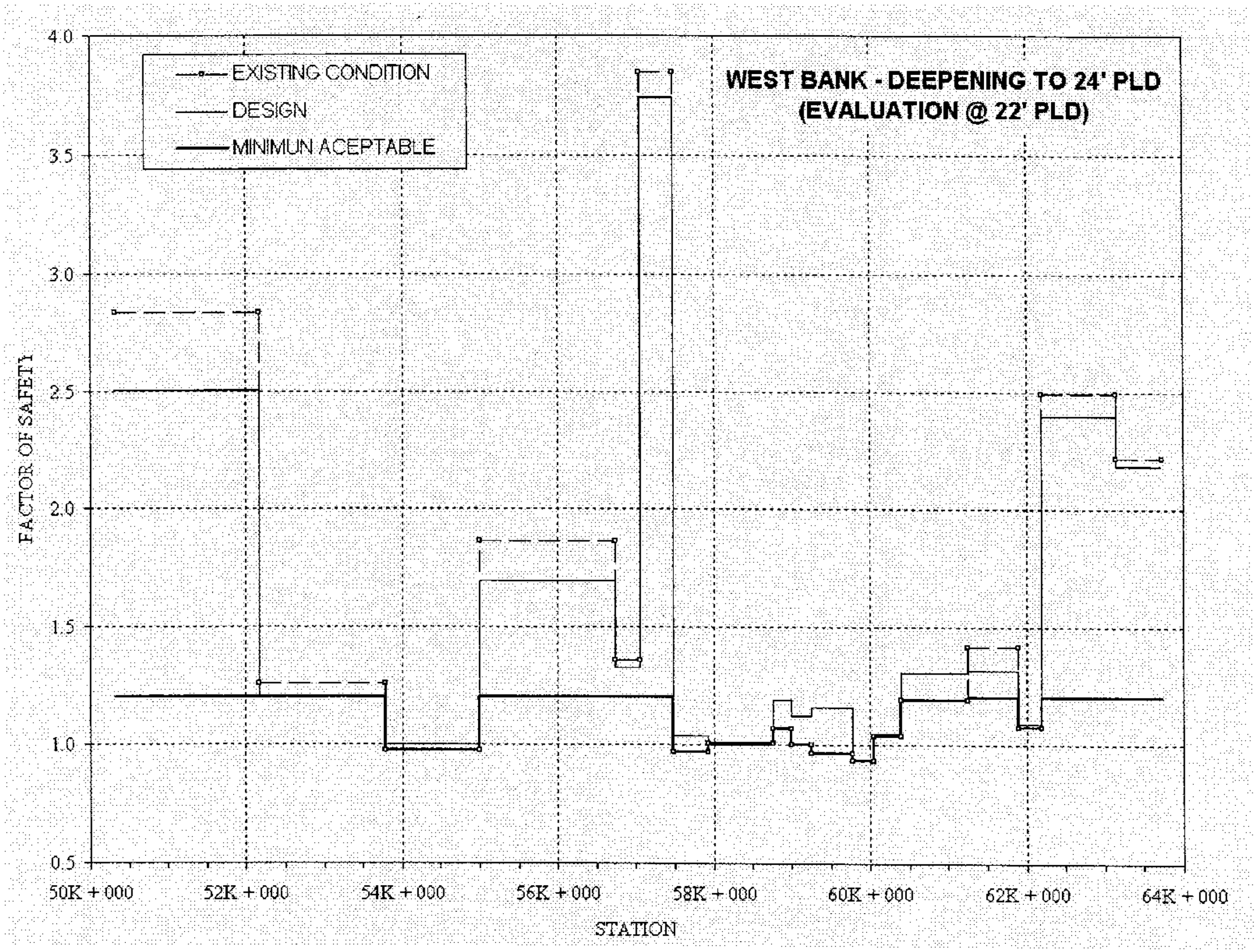

Figure 4b Results of stability analyses (West bank, elevation 22'PLD)

East Bank - Summary of Stability Analyses

Station	Representative Stations	Factor of Safety										Dry excavation is required
		Case 1	Case 2	Case 3	Case 4.1	Case 4.2	Case 5	Case 6	Case 7.1	Case 7.2	Case 8	
		Existing	27 ft (blasted)	27 ft (removed)	27 ft (design-underwater slope)	27 ft (design-&dry excav.)	22 ft (blasted)	22 ft (removed)	22 ft (design-underwater slope)	22 ft (design-&dry excav.)	16 ft (blasted)	
51k+328 E (1684+00)	50k+780 to 52k+060	2.925	2.883	2.828	2.727	2.727	2.776	2.687	2.523	2.523	2.479	NO
53k+371 E (1751+00)	52k+060 to 53k+550	1.508	1.496	1.437	1.433	1.433	1.439	1.396	1.362	1.362	1.346	NO
53k+950 E (1770+04)	53k+550 to 54k+880	1.345	1.330	1.272	1.195	1.195	1.221	1.147	1.056	1.212	1.021	YES
55k+280 E (1813+65)	54k+880 to 55k+400	1.038	1.021	1.000	0.985	1.065	0.976	0.947	0.914	1.034	0.908	YES
55k+830 E (1831+70)	55k+400 to 56k+000	0.991	0.988	0.970	0.958	0.996	0.961	0.947	0.917	0.990	0.917	YES
56k+460 E (1852+36) (a)	56k+000 to 56k+560	0.921	0.919	0.892	0.861	0.912	0.875	0.843	0.789	0.913	0.784	YES
56k+460 E (1852+36) (b)	56k+000 to 56k+560	1.091	1.090	1.077	1.020	1.061	1.054	1.029	0.944	1.050	0.936	
57k+060 E (1872+00) (a)	56k+560 to 57k+160	1.343	1.343	1.322	1.304	1.304	1.311	1.276	1.228	1.228	1.227	NO
57k+060 E (1872+00) (b)	56k+560 to 57k+160	1.291	1.288	1.274	1.271	1.271	1.269	1.254	1.234	1.234	1.230	
57k+270 E (1878+93)	57k+160 to 57k+320	2.996	2.982	2.957	2.927	2.927	2.927	2.864	2.763	2.763	2.754	YES
57k+635 E (1890+91)	57k+320 to 57k+675	1.290	1.289	1.281	1.271	1.271	1.280	1.248	1.225	1.225	1.223	NO
58k+035 E (1904+00)	57k+675 to 58k+295	1.001	0.992	0.962	0.861	0.996	0.950	0.923	0.795	1.006	0.772	YES
58k+520 E (1920+00)	58k+295 to 59k+600	1.054	1.053	1.048	1.046	1.046	1.047	1.045	1.041	1.125	1.041	YES
59k+668 E (1957+61)	59k+600 to 59k+800	0.931	0.931	0.928	0.927	1.036	0.928	0.926	0.922	1.035	0.922	YES
59k+918 E (1966+00)	59k+800 to 60k+050	1.345	1.345	1.340	1.333	1.333	1.340	1.332	1.324	1.324	1.324	NO
60k+244 E (1976+50)	60k+050 to 60k+355	1.051	1.051	1.047	1.045	1.045	1.047	1.043	1.039	1.063	1.039	YES
60k+412 E (1982+00) (a)	60k+355 to 60k+500	1.199	1.199	1.186	1.176	N/A	1.186	1.173	1.161	N/A	1.160	YES SPECIAL WORK
60k+412 E (1982+00) (b)	60k+355 to 60k+500	0.845	0.831	0.802	0.737	N/A	0.778	0.754	0.676	N/A	0.541	
60k+412 E (1982+00) (c)	60k+355 to 60k+500	0.794	0.794	0.793	0.634	N/A	0.753	0.717	0.588	N/A	0.588	
60k+594 E (1988+00) (a)	60k+500 to 60k+695	1.049	1.048	1.045	1.033	1.268	1.044	1.044	1.025	1.265	1.025	YES
60k+594 E (1988+00) (b)	60k+500 to 60k+695	1.023	1.014	0.965	0.896	1.022	0.956	0.891	0.812	0.954	0.785	
60k+747 E (1993+00) (a)	60k+695 to 60k+850	1.251	1.227	1.203	1.131	1.174	1.198	1.162	1.080	1.188	1.079	YES
60k+747 E (1993+00) (b)	60k+695 to 60k+850	0.996	0.987	0.981	0.960	1.015	0.981	0.936	0.950	1.059	0.938	
60k+747 E (1993+00) (c)	60k+695 to 60k+850	1.183	1.182	1.172	1.163	1.185	1.171	1.160	1.149	1.163	1.148	
61k+720 E (2025+00)	61k+420 to 61k+825	2.766	2.765	2.735	2.658	2.658	2.735	2.707	2.614	2.614	2.612	NO

Table 3 Summary of Stability Analyses (East Bank)

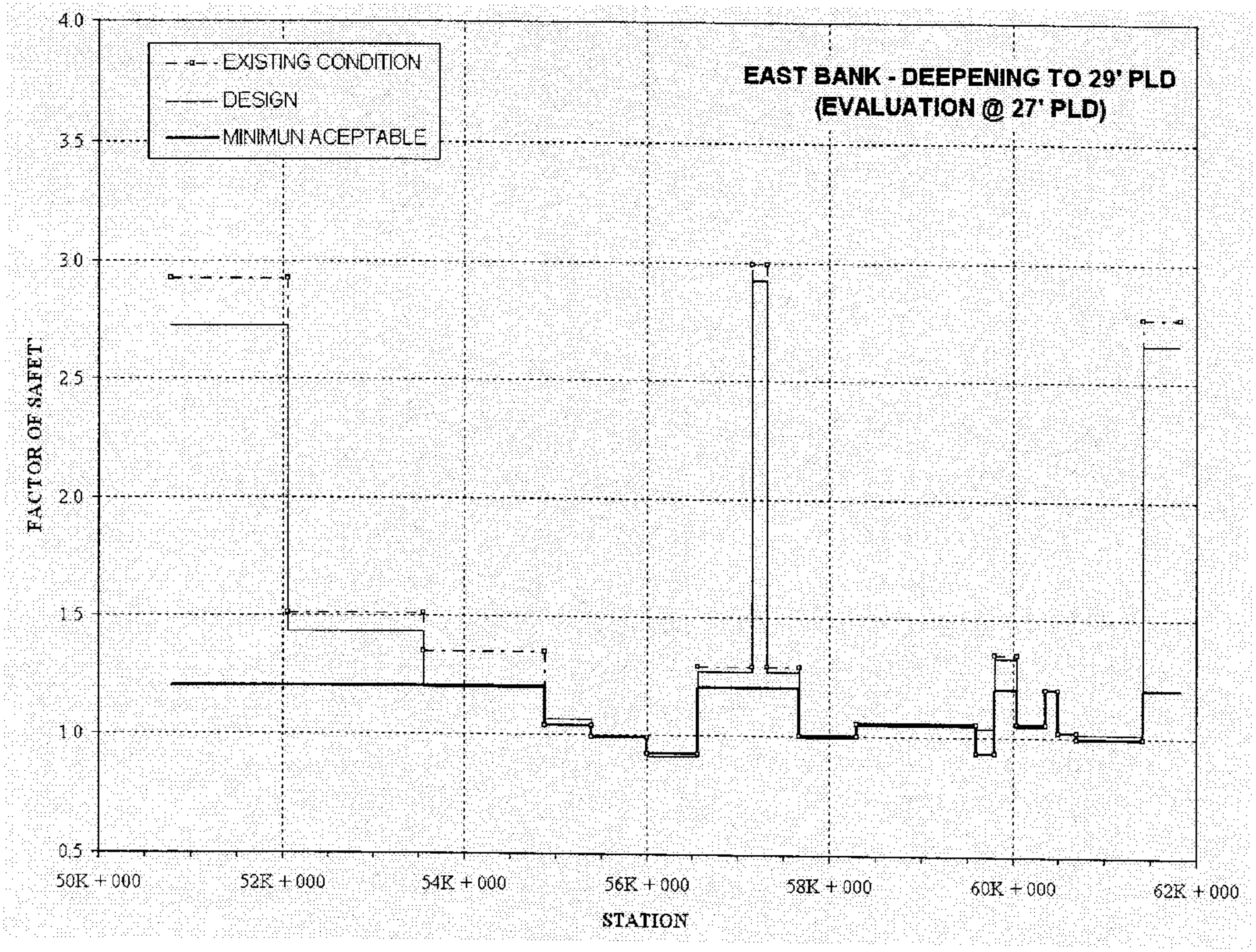

Figure 5a Results of stability analyses (East bank, elevation 27'PLD)

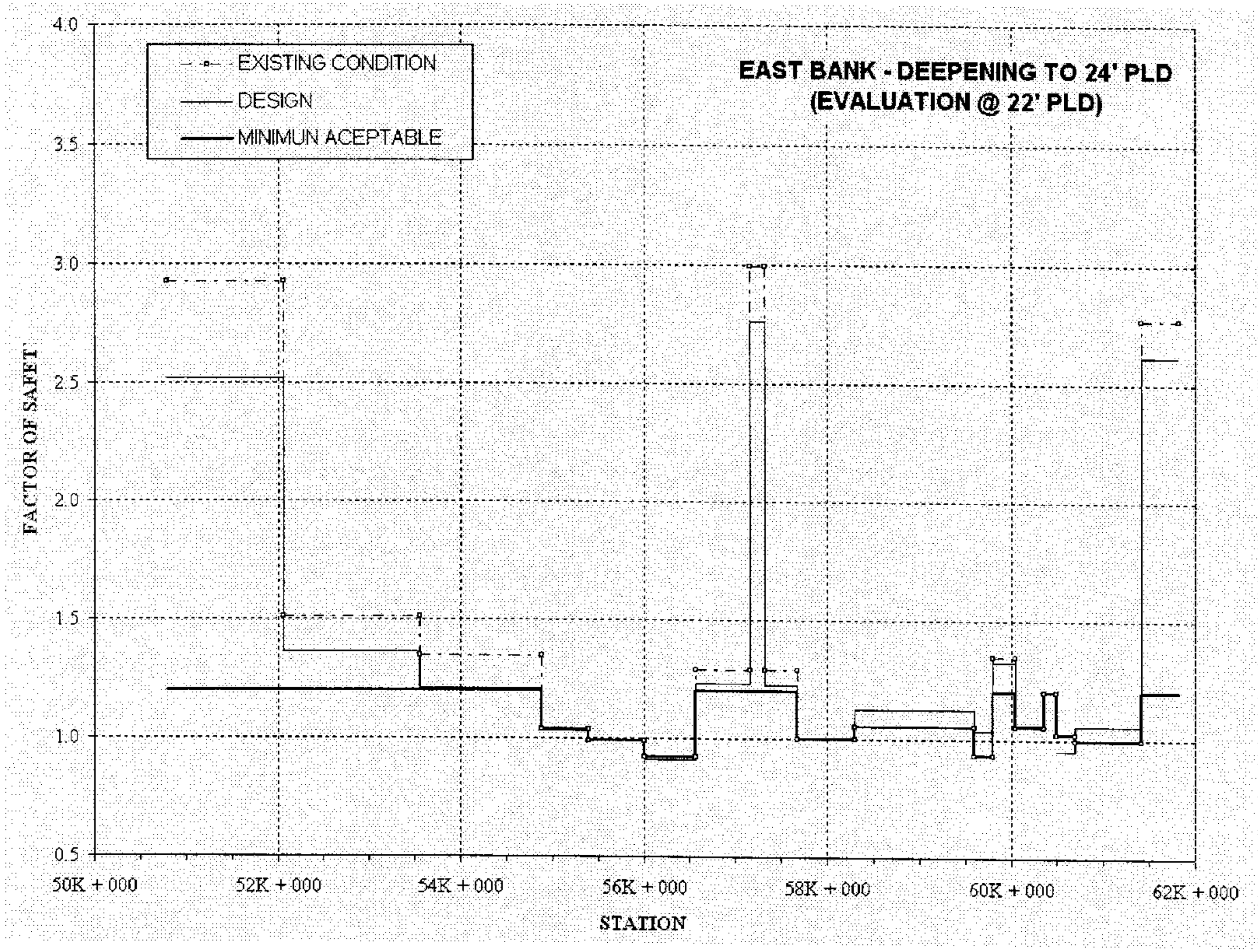

Figure 5b Results of stability analyses (East bank, elevation 22'PLD)

Table 4a Excavation Volume Summary (West Bank)

CHANNEL DEEPENING PROJECT (EXCAVATION VOLUME, m3

GAILLARD CUT - WEST SIDE

Sector	Station of Templates	Station West Side	Slope Condition	Excavation Type	Dry Exc. Volume	Underwater Exc. Volume	Total Exc. Volume
	50K + 320		Existing	Not Required	-----	-----	-----
Elliot	@	51K + 600	Design 27 feet	Underwater	6,629.2	59,247.4	65,876.6
	52K + 159		Design 22 feet	Underwater	31,789.9	163,488.9	195,278.8
	52K + 160		Existing	Not Required	-----	-----	-----
Borinquen	@	53K + 171	Design 27 feet	Dry & underwater	180,070.0	33,132.3	213,202.3
	53K + 779		Design 22 feet	Dry & underwater	455,397.6	146,108.5	601,506.0
	53K + 780		Existing	Not Required	-----	-----	-----
Las Casacadas	@	54K + 300	Design 27 feet	Dry & underwater	432,029.9	108,788.9	540,818.9
	54K + 999		Design 22 feet	Dry & underwater	537,958.8	142,133.5	680,092.3
	55K + 000		Existing	Not Required	-----	-----	-----
Cunette	@	55K + 930	Design 27 feet	Underwater	4,436.8	40,645.4	45,082.2
	56K + 739		Design 23 feet	Underwater	44,246.6	162,722.0	206,968.6
	56K + 740		Existing	Not Required	-----	-----	-----
Empire	@	56K + 898	Design 27 feet	Underwater	3,039.7	25,645.1	28,684.8
(West Empire Slide)	57K + 049		Design 22 feet	Dry & underwater	463,981.2	34,062.4	498,043.6
	57K + 050		Existing	Not Required	-----	-----	-----
Empire	@	57K + 098	Design 27 feet	Underwater	1,064.4	16,197.3	17,261.7
	57K + 474		Design 22 feet	Underwater	1,653.2	27,497.2	29,150.4
	57K + 475		Existing	Not Required	-----	-----	-----
Lirio	@	57K + 820	Design 27 feet	Dry & underwater	402,986.3	20,336.0	423,322.3
(Old Lirio Slide)	57K + 924		Design 22 feet	Dry & underwater	404,066.3	29,764.7	433,831.0
	57K + 925		Existing	Not Required	-----	-----	-----
Lirio	@	58K + 120	Design 27 feet	Dry & underwater	842,976.8	20,093.2	863,070.0
(Culebra Village Slide)	58K + 759		Design 22 feet	Dry & underwater	844,058.3	41,380.0	885,438.3
	58K + 760		Existing	Not Required	-----	-----	-----
Hodges Hill	@	58K + 887	Design 27 feet	Underwater	326.5	10,656.3	10,982.8
	58K + 999		Design 22 feet	Dry & underwater	234,854.0	17,033.4	251,887.3
	59K + 000		Existing	Not Required	-----	-----	-----
Hodges Hill	@	59K + 070	Design 27 feet	Dry & underwater	197,930.4	9,012.7	206,943.1

CHANNEL DEEPENING PROJECT (EXCAVATION VOLUME, m3

GAILLARD CUT - WEST SIDE

Sector	Station of Templates	Station West Side	Slope Condition	Excavation Type	Dry Exc. Volume	Underwater Exc. Volume	Total Exc. Volume
	59K + 259		Design 22 feet	Dry & underwater	237,435.1	15,411.5	252,846.7
	59K + 260		Existing	Not Required	-----	-----	-----
West Culebra	@	59K + 485	Design 27 feet	Dry & underwater	226,606.4	28,298.7	254,905.0
	59K + 779		Design 22 feet	Dry & underwater	226,632.3	41,097.5	267,729.8
	59K + 780		Existing	Not Required	-----	-----	-----
Model Slope	@	59K + 881	Design 27 feet	Dry & underwater	151,625.5	5,084.0	156,709.5
	60K + 049		Design 22 feet	Dry & underwater	193,858.1	11,752.1	205,610.2
	60K + 050		Existing	Not Required	-----	-----	-----
Contractor Hill	@	60K + 240	Design 27 feet	Dry & underwater	46,114.8	25,276.4	71,391.1
	60K + 399		Design 22 feet	Dry & underwater	224,768.2	54,851.4	279,619.7
	60K + 400		Existing	Not Required	-----	-----	-----
Escobar	@	60K + 950	Design 27 feet	Dry & underwater	142,660.2	26,252.0	168,912.2
	61K + 239		Design 22 feet	Dry & underwater	144,372.0	48,774.0	193,146.0
	61K + 240		Existing	Not Required	-----	-----	-----
Escobar	@	61K + 600	Design 27 feet	Underwater	201.8	12,064.7	12,266.5
	61K + 899		Design 22 feet	Underwater	894.7	28,281.2	29,175.9
	61K + 900		Existing	Not Required	-----	-----	-----
Escobar	@	62K + 000	Design 27 feet	Dry & underwater	10,833.7	14,260.5	25,094.2
(Luis Goyo)	62K + 199		Design 22 feet	Dry & underwater	16,763.9	23,008.7	39,772.6
	62K + 200		Existing	Not Required	-----	-----	-----
Cartagena	@	62K + 550	Design 27 feet	Underwater	1,990.2	26,780.5	28,770.7
(Tie-Up Viejo)	62K + 909		Design 22 feet	Underwater	3,018.6	44,543.0	47,561.6
	62K + 910		Existing	Not Required		-----	-----
Cartagena	@	63K + 050	Design 27 feet	Underwater		-	
	63K + 149		Design 22 feet	Underwater			
	63K + 150		Existing	Not Required	-----	-----	-----
Cartagena	@	63K + 327	Design 27 feet	Dry & underwater		-	
	63K + 725		Design 22 feet	Dry & underwater		-	
TOTAL VOLUME TO BE EXCAVATED FOR 27 FEET:					2,651,522.5	481,771.4	3,133,293.9
TOTAL VOLUME TO BE EXCAVATED FOR 22 FEET:					4,065,748.7	1,031,909.8	5,097,658.6

Note: Underwater Excavation: Includes dredging and some dry excavation

Dry & Underwater Excavation: Includes dredging and dry excavation required for the stabilization of the Gaillard Cut Slopes

Table 4b Excavation Volume Summary (East Bank)

CHANNEL DEEPENING PROJECT (EXCAVATION VOLUME, m3)

GAILLARD CUT - EAST SIDE

Sector	Station of Templates	Station West Side	Slope Condition	Excavation Type	Dry Exc. Volume	Underwater Exc. Volume	Total Exc. Volume
	50K + 780		Existing	Not Required	-----	-----	-----
Chagres	@	51K + 328	Design 27 feet	Underwater	134,872.56	132,923.80	267,796.36
(Northeast)	52K + 059		Design 22 feet	Underwater	158,718.11	168,404.11	327,122.22
	52K + 060		Existing	Not Required	-----	-----	-----
Chagres	@	53K + 371	Design 27 feet	Underwater	29,366.98	125,813.69	155,180.67
(Southeast)	53K + 549		Design 22 feet	Underwater	42,476.02	165,210.95	207,686.97
	53K + 550		Existing	Not Required	-----	-----	-----
Sardinilla	@	53K + 950	Design 27 feet	Underwater	15,793.12	71,387.94	87,181.06
	54K + 879		Design 22 feet	Dry & underwater	547,926.06	101,399.80	649,325.86
	54K + 880		Existing	Not Required	-----	-----	-----
Sardinilla	@	55K + 280	Design 27 feet	Dry & underwater	241,714.83	17,981.03	259,695.86
(North La Pita)	55K + 399		Design 22 feet	Dry & underwater	316,137.79	54,789.32	370,927.11
	55K + 400		Existing	Not Required	-----	-----	-----
La Pita	@	55K + 830	Design 27 feet	Dry & underwater	143,973.86	19,364.37	163,338.23
(Central)	55K + 999		Design 22 feet	Dry & underwater	382,287.18	62,142.13	444,429.31
	56K + 000		Existing	Not Required	518,982.78	-----	-----
Masambi	@	56K + 460	Design 27 feet	Dry & underwater	620,352.36	-82,644.43	537,707.93
(South La Pita)	56K + 559		Design 22 feet	Dry & underwater		679,862.14	679,862.14
	56K + 560		Existing	Not Required	-----	-----	-----
Summit	@	57K + 060	Design 27 feet	Underwater	549.63	8,982.14	9,531.77
	57K + 159		Design 22 feet	Underwater	6,064.20	46,223.28	52,287.48
	57K + 160		Existing	Not Required	-----	-----	-----
Summit	@	57K + 270	Design 27 feet	Underwater	0.00	2,631.00	2,631.00
	57K + 319		Design 22 feet	Underwater	2,545.59	13,449.06	15,994.65
	57K + 320		Existing	Not Required	-----	-----	-----
Summit	@	57K + 635	Design 27 feet	Underwater	0.00	8,679.00	8,679.00
	57K + 674		Design 22 feet	Underwater	1,278.00	33,255.02	34,533.02
	57K + 675		Existing	Not Required	-----	-----	-----
Summit	@	58K + 035	Design 27 feet	Dry & underwater	379,653.45	43,436.24	423,089.69

CHANNEL DEEPENING PROJECT (EXCAVATION VOLUME, m3)

GAILLARD CUT - EAST SIDE

Sector	Station of Templates	Station West Side	Slope Condition	Excavation Type	Dry Exc. Volume	Underwater Exc. Volume	Total Exc. Volume
(Northeast Culebra)	58K + 294		Design 22 feet	Dry & underwater	554,142.37	59,604.29	613,746.66
	58K + 295		Existing	Not Required	-----	-----	-----
Summit	@	58K + 520	Design 27 feet	Underwater	0.00	15,174.93	15,174.93
(Northeast Culebra)	59K + 599		Design 22 feet	Dry & underwater	170,722.17	46,928.30	217,650.47
	59K + 600		Existing	Not Required	-----	-----	-----
Culebra	@	59K + 668	Design 27 feet	Dry & underwater	625,055.01	2,278.58	627,333.59
(Southeast)	59K + 799		Design 22 feet	Dry & underwater	625,071.59	9,215.36	634,286.95
	59K + 800		Existing	Not Required	-----	-----	-----
Gold Hill	@	59K + 918	Design 27 feet	Underwater	2,736.35	21,715.63	24,451.98
	60K + 049		Design 22 feet	Underwater	3,267.78	29,757.48	33,025.26
	60K + 050		Existing	Not Required	-----	-----	-----
Cucaracha	@	60K + 244	Design 27 feet	Underwater	185.38	5,484.78	5,670.16
(Cucaracha Slide)	60K + 354		Design 22 feet	Dry & underwater	676,180.07	10,371.42	686,551.49
	60K + 355		Existing	Not Required	Remedial work being planned		
Cucaracha	@	60K + 412	Design 27 feet	Rock Anchor	Special stabilization work is required		
(Purple Rock)	60K + 499		Design 22 feet	Rock Anchor			
	60K + 500		Existing	Not Required	-----	-----	-----
Cucaracha	@	60K + 594	Design 27 feet	Dry & underwater	423,903.85	12,156.17	436,060.02
(South Extension)	60K + 694		Design 22 feet	Dry & underwater	424,411.51	16,524.38	440,935.89
	60K + 695		Existing	Not Required	-----	-----	-----
Cucaracha	@	60K + 747	Design 27 feet	Dry & underwater	95,398.63	3,335.57	98,734.20
(South Extension)	60K + 850		Design 22 feet	Dry & underwater	157,731.84	5,601.80	163,333.64
	61K + 420		Existing	Not Required	-----	-----	-----
Nitro	@	61K + 720	Design 27 feet	Underwater	22,423.20	32,693.31	55,116.51
	61K + 825		Design 22 feet	Underwater	27,542.42	40,233.12	67,775.54
	TOTAL VOLUME TO BE EXCAVATED FOR 27 FEET:				**2,735,979.21**	**441,393.75**	**3,177,372.96**
	TOTAL VOLUME TO BE EXCAVATED FOR 22 FEET:				**4,096,502.70**	**1,542,971.96**	**5,639,474.66**

Note: Underwater Excavation: Includes dredging and some dry excavation

Dry & Underwater Excavation: Includes dredging and dry excavation required for the stabilization of the Gailland Cut Slopes

6.0 References

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