APPENDIX E
SEEPAGE ANALYSIS

SEEPAGE ANALYSIS

In this appendix we provide an explanation of methods and soil parameters used in our analysis of seepage through and beneath the subject levee, as well as computer model printouts of our seepage analysis results.

Analysis Methods

Seepage analyses were performed using steady-state analysis procedures of the finite element program SEEP/W Version 7.12. This software was developed by GEO-SLOPE International, Ltd (2007) and can analyze two-dimensional planar or axi-symmetrical problems with isoparametric and higher-order finite elements. The program is able to work with multiple soil types having anisotropic hydraulic conductivity characteristics. Boundary conditions in steady-state analyses can be modeled as constant head, no-flow, constant flow, or variable based on head condition.

A fixed-head boundary condition set to the 100-year WSE was used along the vertical waterside edge, the boundary nodes of the waterside river bottom, and waterside slope of the levee. The nodes along the bottom of the model were modeled with a no-flow boundary condition. A fixed-head boundary condition set to the normal water surface elevation was used along the vertical landside edge, the boundary nodes on the landside river bottom, and landside slope of the levee. The elements on the top of the model extending from the landside levee hinge point to the normal water elevation on the landside slope are modeled as a potential seepage surface. These nodes are assigned a total flux boundary condition that is automatically adjusted by the computer program to a constant head boundary based on the iterative results of successive finite element runs. After each successive iteration, the calculated pressure head at each node is compared to the elevation head. If the pressure head is positive at the node, the node becomes a constant head node with head equal to the ground surface elevation, thus, allowing groundwater to seep from the surface.

Soil Parameters Used in Analysis

Hydraulic conductivity (also known as coefficient of permeability or simply permeability) values for the various soils in the analysis cross sections were selected using published empirical relationships between the soil type and the hydraulic conductivity such as those presented by Terzaghi and Peck (1967), Freeze and Cherry (1979), and Cedergren (1967). Correlation relationships based on grain size distribution as described in EM 1110-2-1913 (USACE 2000) and in NAVFAC DM-7.01 (NAVFAC 1986) were also used. Adjustments were made to the hydraulic conductivity of the sandy materials based on the percentage of fines (material passing No. 200 sieve) utilizing the Kozeny-Carman equation (Carrier 2003). Values from the ranges provided by those referenced above were assigned to the various zones as shown in Table E-1 below. The construction and compaction effort of the levee fill material are not known and thus the anisotropy of this material was assumed. The analyses were performed using a soil anisotropy ratio (k_v/k_h) of 0.25 for all naturally deposited layers and engineered/fill layers (e.g., levee fill).

Interpreting Seepage Results

In general, a cross section is said to be susceptible to levee failure by underseepage if the average gradient across the blanket layer is equal to or greater than about 0.80 (the critical gradient). This assumes a saturated unit weight of 112 pcf for the blanket soil layer. Applying a minimum factor of safety (FOS) of about 1.6, an acceptable gradient criterion of 0.5 was established. This criterion is based on observation of seepage conditions and comparison to average gradients calculated using USACE blanket theory. The average gradient is shown on the Total Head Contour plots as the ratio of the excess head above the blanket layer divided by the blanket layer thickness. The distribution of gradients can be represented in more detail by plotting gradient contours. Contours of the vertical component of gradients are presented on the Vertical Gradient Contour plots. While there is no widely accepted criterion for a local maximum gradient, in general, piping will initiate near a gradient of 0.85 regardless of the average gradient.

LIST OF ATTACHMENTS

The following plates are attached as part of this appendix and include graphical presentations of the seepage analyses with contours of total head at 1-foot intervals and vertical gradients at 0.05 intervals:

Plate E-1 Section C, 100-Year WSE – Constant Total Head Contours

Plate E-2 Section C, 100-Year WSE – Vertical Gradient Contours

Table E-1. Hydraulic Conductivity Values

Material Type	Soil Description	Kh (Kx in SEEP/W)		Kv/Kh (Ky/Kx Seep/w)	Resulting Kv (Ky in SEEP/W)	
		cm/s	ft/day		cm/s	ft/day
Low to Medium Plasticity CLAY	Clay core	10^{-6}	0.0028	1	10^{-6}	0.0028
	Clay fill	10^{-5}	0.028	1	10^{-5}	0.028
	Weathered clay blanket 3 ft thick	10^{-5}	0.028	0.25 - 100	10^{-3}	2.8
	Weathered clay blanket 4 to 10 ft thick	10^{-5}	0.028	0.25 - 10	10^{-4}	0.28
	Weathered clay blanket >10 ft thick	10^{-5}	0.028	0.25	$2.5x10^{-6}$	0.007
	Unweathered clay at depth	10^{-5}	0.028	0.1	10^{-6}	0.0028
SILT	Silt fill (mechanically placed)	10^{-4}	0.28	1	10^{-4}	0.28
	Silt fill (hydraulically placed)	$8x10^{-4}$	2.24	1	$8x10^{-4}$	2.24
	86 to 100% fines	$2x10^{-4}$	0.56	1	$2x10^{-4}$	0.56
	Silt with sand, 71 to 85% fines	$2x10^{-4}$	0.56	1	$2x10^{-4}$	0.56
	Sandy silt, 50 to 70% fines	$2x10^{-4}$	0.56	1	$2x10^{-4}$	0.56
SAND and SILTY SAND	Sand fill (mechanically placed)	--	--	1	--	--
	Sand fill (hydraulically placed)	--	--	0.125	--	--
	0 to 2% silt	10^{-2}	28	0.25	$2.5x10^{-3}$	7
	3 to 7% silt	$5x10^{-3}$	14	0.25	$1.25x10^{-3}$	3.5
	8 to 12% silt	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	13 to 27% silt	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	28 to 49% silt	$4x10^{-4}$	1.12	0.25	10^{-4}	0.28
SAND and CLAYEY SAND	Sand fill (mechanically placed)	--	--	1	--	
	Sand fill (hydraulically placed)	--	--	0.125	--	
	0 to 2% clay	$5x10^{-3}$	14	0.25	$1.25x10^{-3}$	3.5
	3 to 7% clay	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	8 to 12% clay	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	13 to 27% clay	$4x10^{-4}$	1.12	0.25	10^{-4}	0.28
	28 to 49% clay	--	--	0.25	--	--
GRAVEL	0 to 2% fines	$2.5x10^{-2}$	70	0.1	$2.5x10^{-3}$	7
	3 to 7% fines	$2.5x10^{-2}$	70	0.1	$2.5x10^{-3}$	7
	8 to 12% fines	$1.2x10^{-2}$	35	0.1	$1.2x10^{-3}$	3.5
	13 to 17% fines	$6x10^{-3}$	18	0.1	$6x10^{-4}$	1.8
	18 to 27% fines	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	28 to 49% fines	$4x10^{-4}$	1.12	0.25	10^{-4}	0.28

Material Type	Soil Description	Kh (Kx in SEEP/W)		Kv/Kh (Ky/Kx Seep/w)	Resulting Kv (Ky in SEEP/W)	
		cm/s	ft/day		cm/s	ft/day
GRAVEL with COBBLES and SAND	0 to 2% fines	$2x10^{-1}$	560	0.1	$2x10^{-2}$	56
	3 to 7% fines	$2x10^{-1}$	560	0.1	$2x10^{-2}$	56
	8 to 12% fines	10^{-1}	280	0.1	10^{-2}	28
	13 to 17% fines	10^{-2}	28	0.1	10^{-3}	2.8
	18 to 27% fines	10^{-3}	2.8	0.25	$2.5x10^{-4}$	0.7
	28 to 49% fines	$4x10^{-4}$	1.12	0.25	10^{-4}	0.28

Dad's Point Levee — Section C, Seepage Analysis w/ Constant Total Head Contours

File Name: Section C_Seepage_Steady State_100yr Flood.gsz
Last Saved Date: 1/13/2010
Analysis Type: SEEP/W
Analysis View: 2D

Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

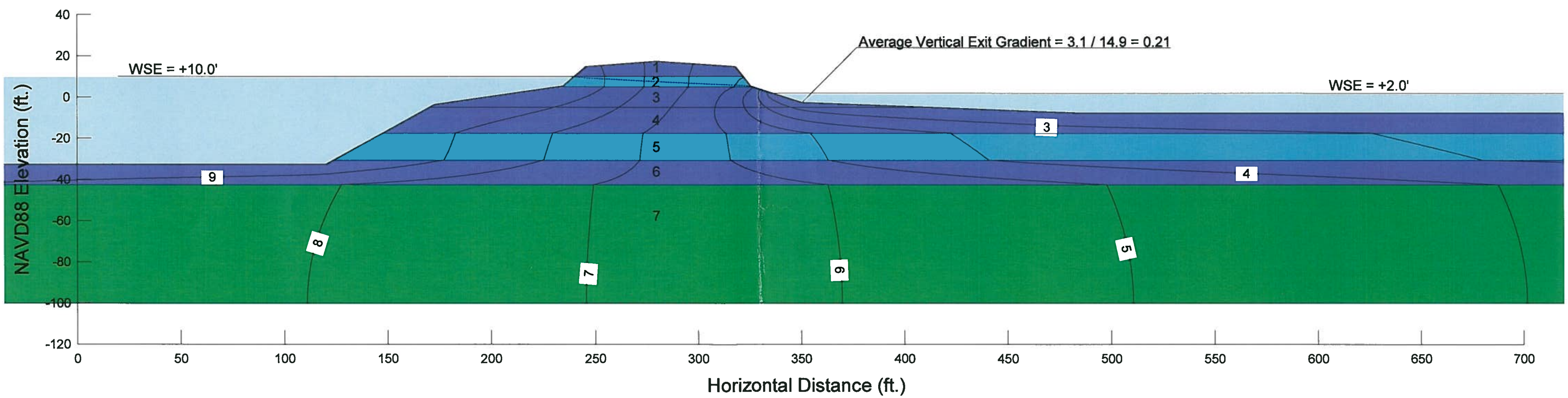
Material #1 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: Silt Ks= 0.28 ft/day (1e-4 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
Material #5 Hyd K Fn: Silt Ks= 0.28 ft/day (1e-4 cm/s) Ky/Kx Ratio: 0.25
Material #6 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
Material #7 Hyd K Fn: Sand w/ 13-27% CL or 28-49% ML, Ks=1.12 ft/day (4e-4 cm/s) Ky/Kx Ratio: 0.25

Top of Levee Elevation: +17.4 Feet (NAVD88)
Landside Toe Elevation: -2.6 Feet (NAVD88)
Landside Elevation 150 Feet From Toe: -7.6 Feet (NAVD88)

Waterside Water Surface Elevation: +10.0 Feet (NAVD88)
*Note: The water elevation used on the waterside of the model was equal to the 100-yr flood elevation.

Landside Water Surface Elevation: +2.0 Feet (NAVD88)
*Note: The water elevation used on the landside of the model was assumed as a 8 foot head differential from the waterside.

*Note: Boundary Conditions Along River Bottoms And Vertical Boundaries H = River Water Elevations.



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DATE:	9.28.09
DRAWN BY:	S. Wiesner
CHECKED BY:	R. Heinzen

Dad's Point Levee
Seepage Analysis

LEVEE EVALUATION
DAD'S POINT LEVEE CERTIFICATION
STOCKTON, CALIFORNIA

PLATE
E-1

Dad's Point Levee — Section C, Seepage Analysis w/ Vertical Gradient Contours

File Name: Section C_Seepage_Steady State_100yr Flood.gsz
Last Saved Date: 1/13/2010
Analysis Type: SEEP/W
Analysis View: 2D

Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
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Material #6 Hyd K Fn: Clay Ks=0.028 ft/day (1e-5 cm/s) Ky/Kx Ratio: 0.25
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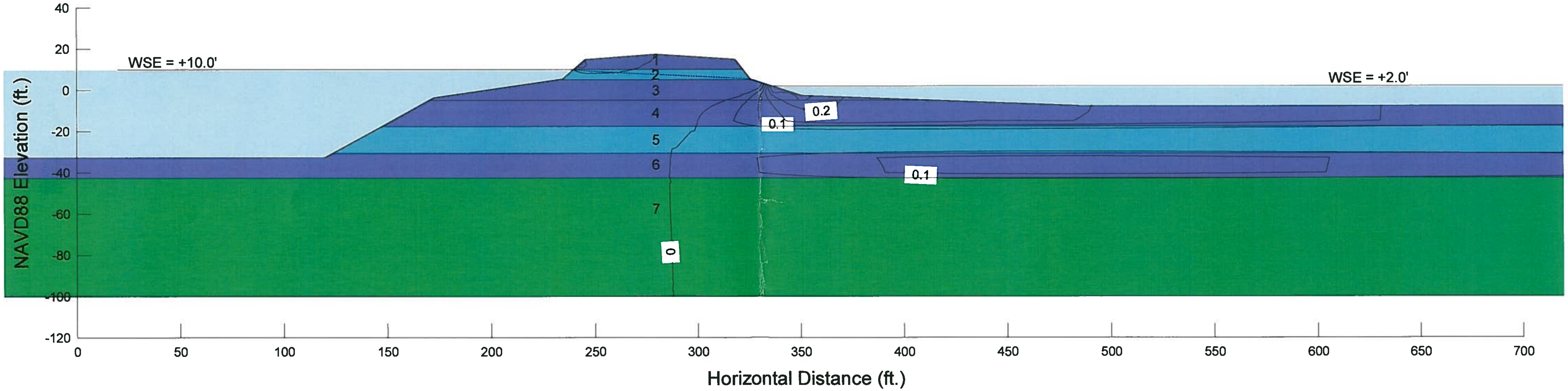

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PROJECT NO. 92459.G02	**Dad's Point Levee Seepage Analysis**		PLATE
DATE: 9.28.09			
DRAWN BY: S. Wiesner			**E-2**
CHECKED BY: R. Heinzen	LEVEE EVALUATION DAD'S POINT LEVEE CERTIFICATION STOCKTON, CALIFORNIA		