SUB-ATTACHMENT F

STABILITY ANALYSIS

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1. General Embankment and Foundation Conditions: To perform the stability analysis, the same typical levee section and foundation profile that was developed for the seepage analysis was used for the stability program. The foundation was divided into 3 zones. The foundation semi-impervious top blanket was modeled being 6 feet thick, the sand and gravel aquifer being 10 feet thick, and the clay deposit being 30 feet thick. The section also included the sand blanket and gravel toe drains located beneath the levee embankment.

2. Design Parameters:

a. Foundation Materials: Geotechnical design parameters used in the various analyses were based on blow count data and laboratory test results. Various studies and reports were used to assist in determining soil parameters. These reports provide correlations between strength properties of soils based on soil index properties and in-situ testing. The table below shows blow count data and the typical ranges of effective friction angles used in the stability analyses:

Zone/Stratum	Blow Counts (N)	Effective Angle of Internal Friction, ϕ',
Clayey Silty Sand, Sandy Clay Blanket	3 to 20, avg. range = 6 to 10	28° to 32°, avg.= 30°
Sand & Gravel Aquifer Layer	10 to 48, avg. range =15 to 20	32° to 36°, avg.= 34°
Lower lean to fat Clay	14 to 50+, avg. range = 20 to 30	See below lab test results

The lower clay deposit is part of the Potomac Formation; the clays are very stiff and are highly overconsolidated. Published shear strength data on the Potomac clays generally shows the clays to have high effective peak strengths; however, the residual shear strength can be significantly less than the peak strength due to saturation of the clay, shearing along previously sheared, or the soil being highly fractured. For this project, shear strength testing was performed on samples taken from the lower clay deposit. Two direct shear tests were performed. The first on an undisturbed sample, and the second test was performed on previously sheared samples from the first test. The samples were resheared along the same failure plane to determine the residual shear strength of the clay material. The test values (peak and residual) obtained for both tests are consistent with published data for the Potomac clay material. An unconfined compression test was also performed on a sample taken form one of the Shelby tubes. The results form the laboratory testing is shown on the following tables.

Sample	Depth	Material Class.	q_u (tsf)	Dry Density	Water content	PI	PL
DH-4B Shelby-1	22.0' – 24.0'	Fat Clay (CH)	1.48	95.5 pcf	25.3	26	24

Sample	Material Class.	Dry Density	Water content	PI	PL	Direct Shear Test	ϕ'
DH-4B Shelby-2 28.0' – 30.0'	Fat Clay (CH)	95.5 pcf	28.2	31	28	Undistrubed	30°
						Resheared	14°

b. Embankment Materials: The proposed design for the levee assumes a homogenous embankment, constructed primarily of select earth material from a borrow source obtained by the contractor. The select earth material should generally consist of impervious silty or sandy clays, clayey silts or clayey sands and gravels that contain at least 25% by weight passing the No. 200 mesh sieve and have a plasticity index greater than 5 but less than 30. At this phase of the project design, assumptions were made on the embankment's shear strength values, which were based on engineering judgment and experience with analysis of levee embankments with similar features and dimensions. In general the effective shear strength (ϕ') for compacted embankment materials can range between 28° and 36°. For this project, a ϕ'value of 34° with no cohesion (c=0) was used in the stability analysis. Design parameters for the drainage materials were selected to be within the normal range of shear strengths (ϕ'= 30° to 34°) for typical aggregates.

c. The table below shows the shear strength values used in the slope stability analysis:

Zone/Stratum	Unit Weights	Q	S		R	
	Moist (pcf)	c (psf)	ϕ (deg)	c (psf)	ϕ (deg)	c (psf)
Clayey Silty Sand, Sandy Clay Blanket	125		30°			
Sand & Gravel Aquifer	125		32°			
Lower lean to fat Clay	125	1000	11°		5°	1000
Impervious Emb Fill	125		34°			
Blanket Sand Drain	120		30°			
Gravel Toe Drain	125		32°			

3. Stability Analysis: For small levee embankment less than about 10 to 15 feet high, formal slope stability analyses are generally not performed. The maximum height of the proposed Huntington levee would be about 15 feet on the riverside and 13 feet on the landside; however, a majority of the landside levee embankment is less than 10 feet high due to the additional fill placed along the toe to provide cover for the pump station

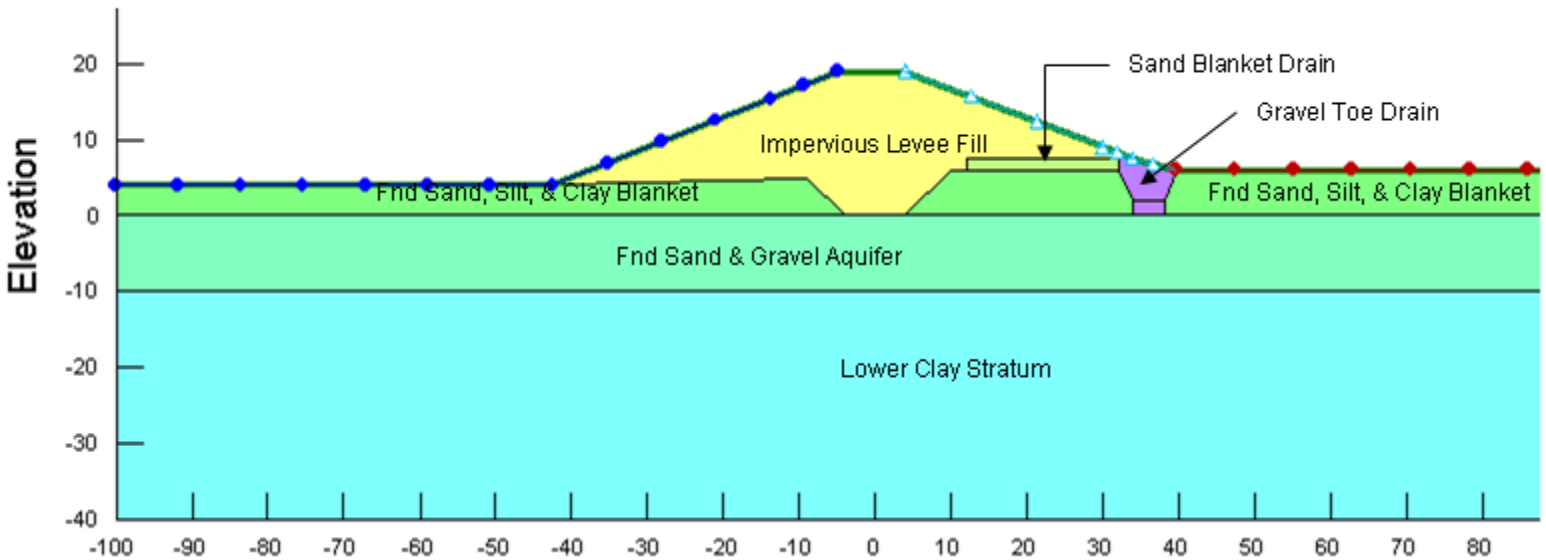
conduit. However, this fill was not included in the stability analysis section. Nevertheless, a stability analysis was performed using the same typical levee section and foundation profile that was developed for the seepage analysis. The same conditions (river and tailwater levels) modeled for the seepage analysis was used in the stability program. The slopes were analyzed in accordance with EM 1110-2-1913, "Design and Construction of Levees." The slope stability seepage program, SLOPE/W 2007, developed by GEO-Slope International was used to analyze stability of the embankment and foundation. The slope stability analyses were performed for the intermediate river stage, sudden drawdown, steady seepage, and end-of-construction conditions. The minimum factors of safety are 1.4 for intermediate river stage and steady seepage, 1.3 for end of construction, and 1.0 for sudden drawdown. In general, results from the stability analysis showed that the proposed embankment and foundation meet the factor-of-safety requirements as required in EM 1110-2-1913. Below is a summary of the results for each condition:

- Steady Steepage Condition: For the steady seepage condition, the pore pressure data generated by SEEPW program was used in the stability program. Water levels at both the top of protection and design water surface and tailwater levels at the ground surface and ponding level were evaluated. For the river level at the design water surface, all the factors of safety were above the required minimum factor of safety 1.4 for all the various tailwater and toe drain conditions. In addition, the extreme condition with the river at top of protection was also analysis and all the factors of safety were above 1.4, except one case where the factor of safety was 1.3. However for this extreme condition, it is considered that a factory of safety of 1.3 is acceptable. If the additional fill that will be used to cover the pump station conduit along the landside toe was added to the typical section, the factors of safety would significantly increase for all the loading cases.
- Sudden Drawdown Condition: For the sudden drawdown condition, a 2, stage analysis was performed. It was necessary to use only effective “drained” shear strength values for the embankment material since undrained shear strength values are unknown. However, based on the location of the trial arcs, it appears that the drained or effective shear strengths would provide conservative results. For the extreme drawdown case (from top of levee to top of ground) the factor-of-safety for drawdown exceeded the minimum required safety factor of 1.0.
- Intermediate River Stage Condition: Four different river stages were used to analyze the riverside slope for the intermediate river stage condition. All the factors of safety computed by the stability program exceeded the required minimum of 1.4.
- End-of-Construction Condition: Both the landside and riverside embankment have 2.5 horizontal on 1 vertical slope; however, since the riverside slope is slightly higher, it was used to analyze the end-of construction condition. The undrained shear strength (Q) for the lower clay material was used in the analysis. All the factors of safety computed by the stability program exceeded the required minimum of 1.3.

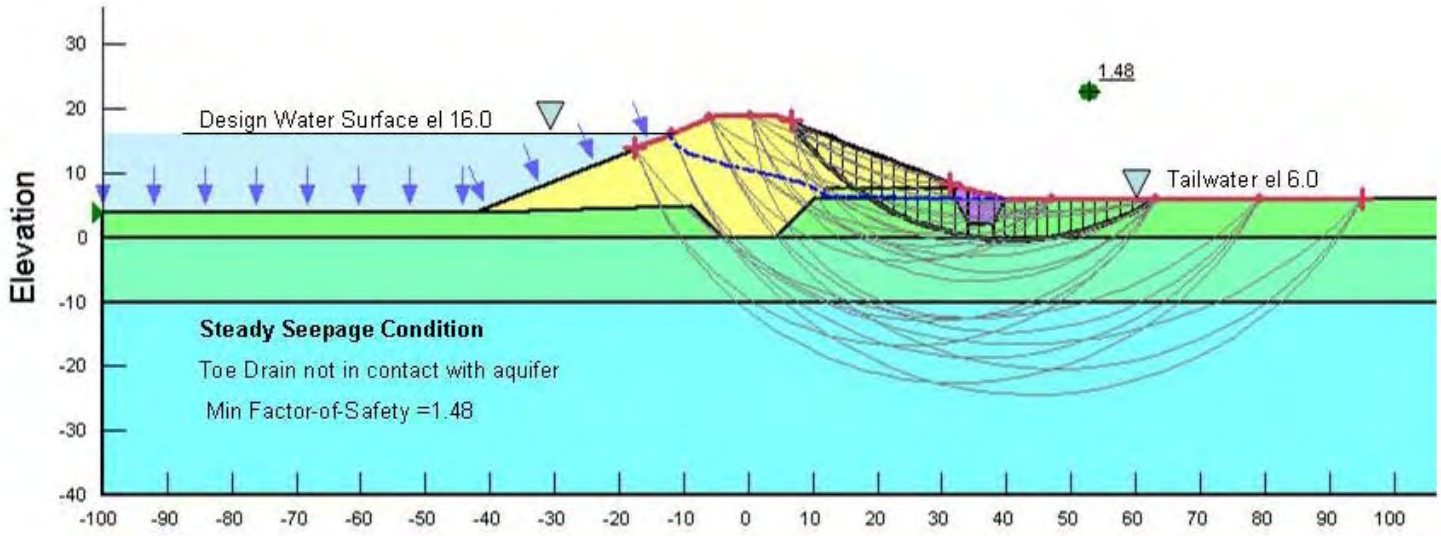
Summary plots of the critical failure surface are provided on the following pages.

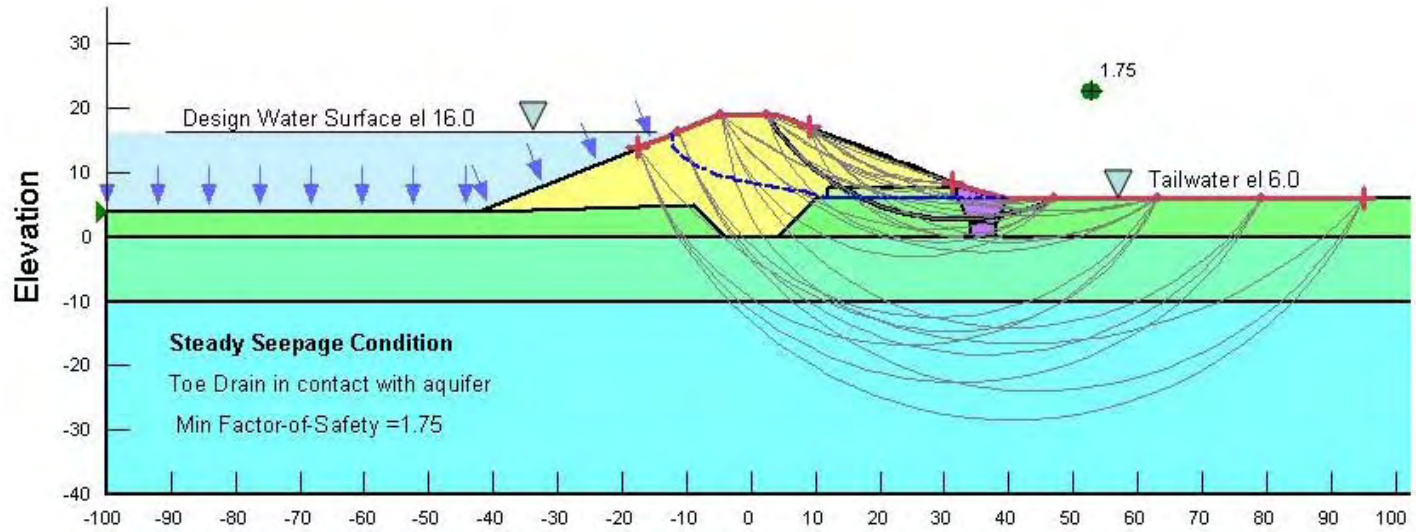
The table below shows the typical shear strength values used in the analysis:

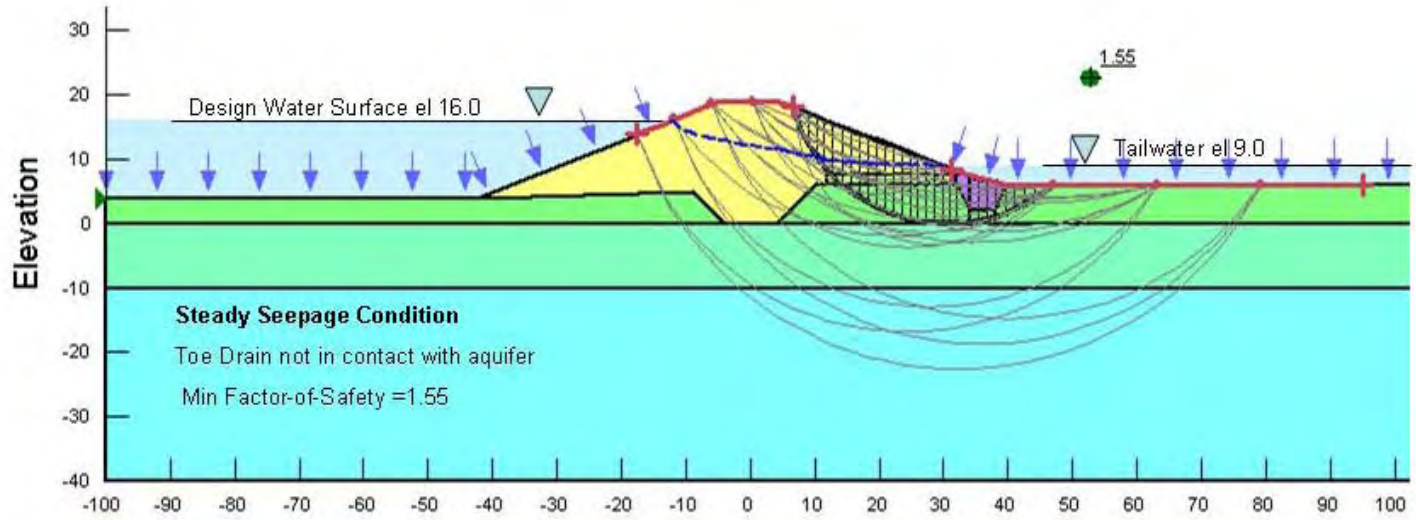
Zone/Stratum	Unit Weights	Q	S		R	
	Moist (pcf)	c (psf)	ϕ (deg)	c (psf)	ϕ (deg)	c (psf)
Clayey Silty Sand, Sandy Clay Blanket	125		30°			
Sand & Gravel Aquifer	125		32°			
Lower lean to fat Clay	125	1000	11°		5°	1000
Impervious Emb Fill	125		34°			
Blanket Sand Drain	120		30°			
Gravel Toe Drain	125		32°			

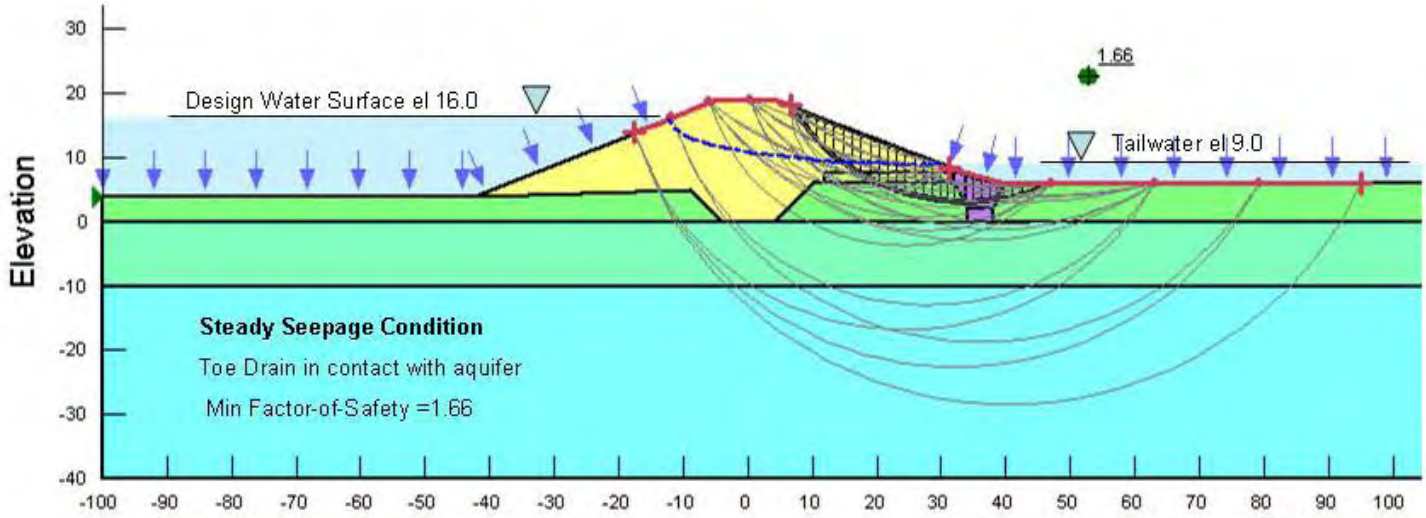


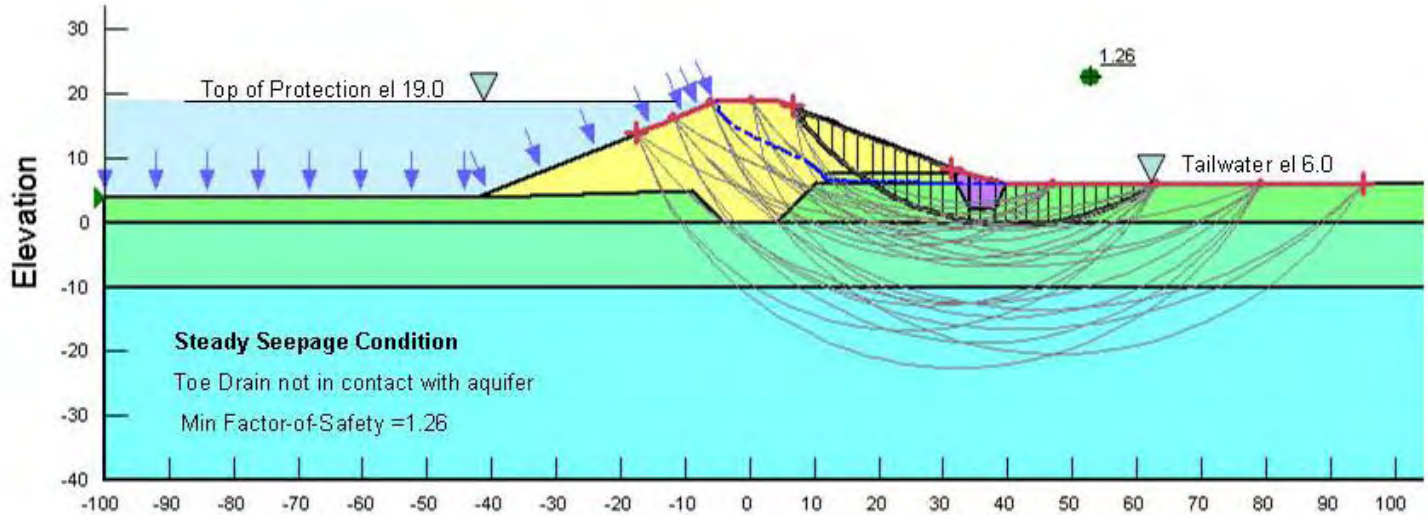
Typical Section

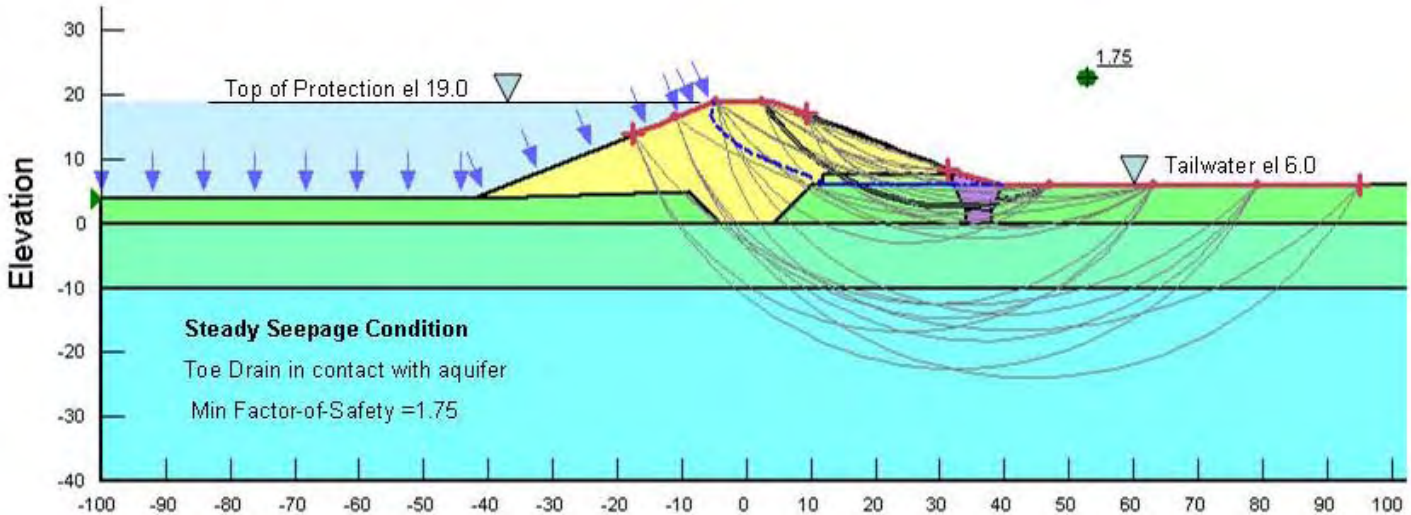

Elevation
Design Water Surface el 16.0
1.48
Tailwater el 6.0
Steady Seepage Condition
Toe Drain not in contact with aquifer
Min Factor-of-Safety =1.48

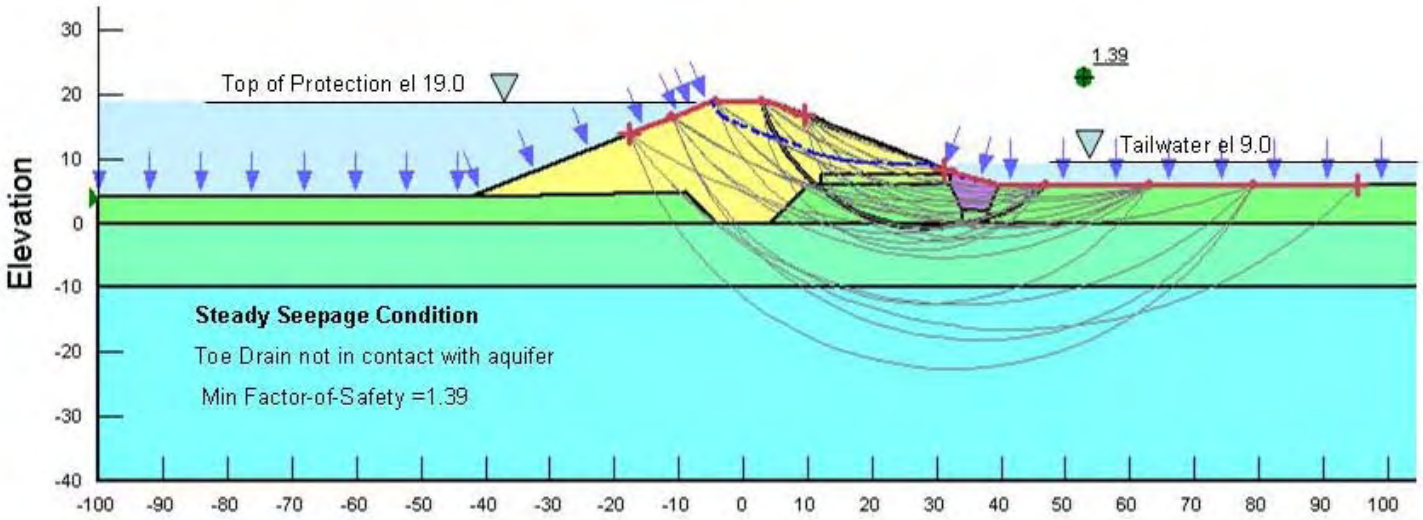

Elevation
Design Water Surface el 16.0
1.75
Tailwater el 6.0
Steady Seepage Condition
Toe Drain in contact with aquifer
Min Factor-of-Safety =1.75

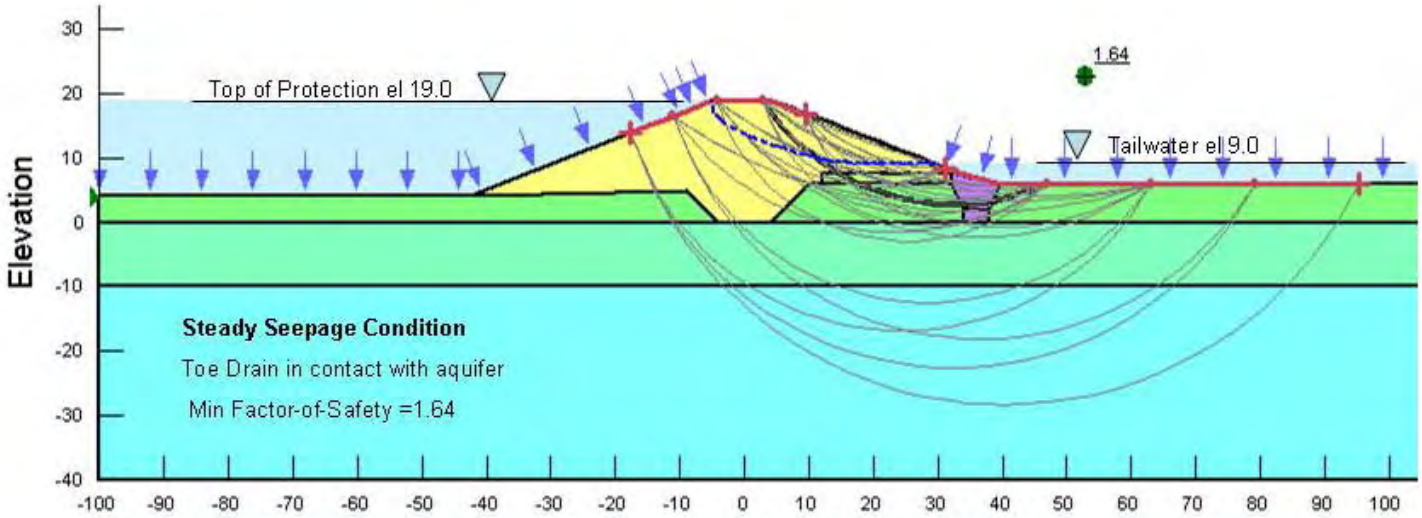

Elevation
Design Water Surface el 16.0
1.55
Tailwater el 9.0
Steady Seepage Condition
Toe Drain not in contact with aquifer
Min Factor-of-Safety =1.55

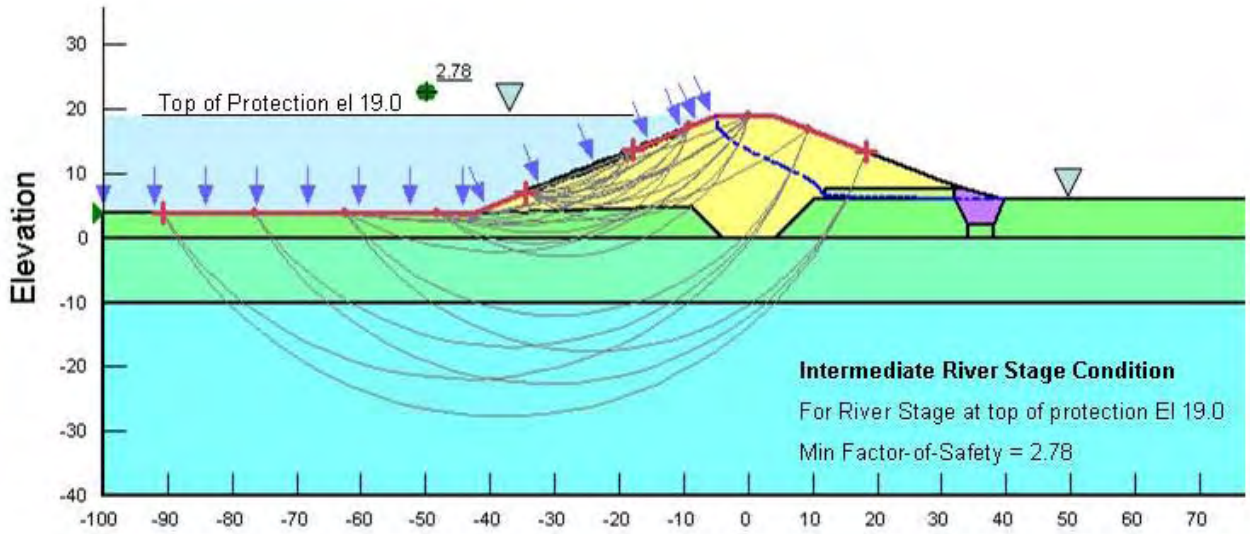

Elevation
Design Water Surface el 16.0
1.66
Tailwater el 9.0
Steady Seepage Condition
Toe Drain in contact with aquifer
Min Factor-of-Safety =1.66

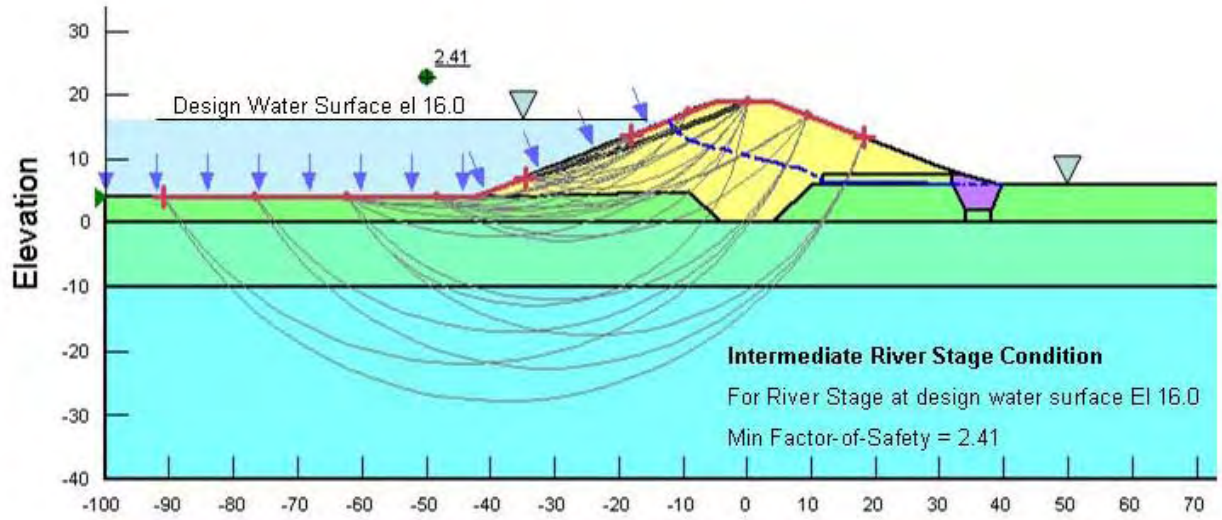

Top of Protection el 19.0
1.26
Tailwater el 6.0
Elevation
Steady Seepage Condition
Toe Drain not in contact with aquifer
Min Factor-of-Safety =1.26

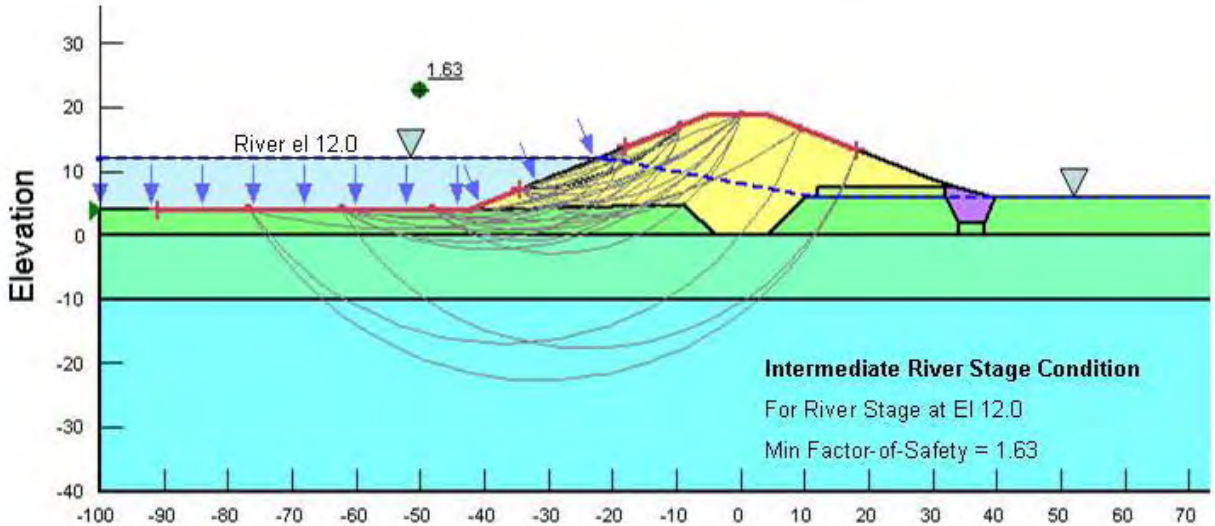

Top of Protection el 19.0
1.75
Tailwater el 6.0
Elevation
Steady Seepage Condition
Toe Drain in contact with aquifer
Min Factor-of-Safety =1.75

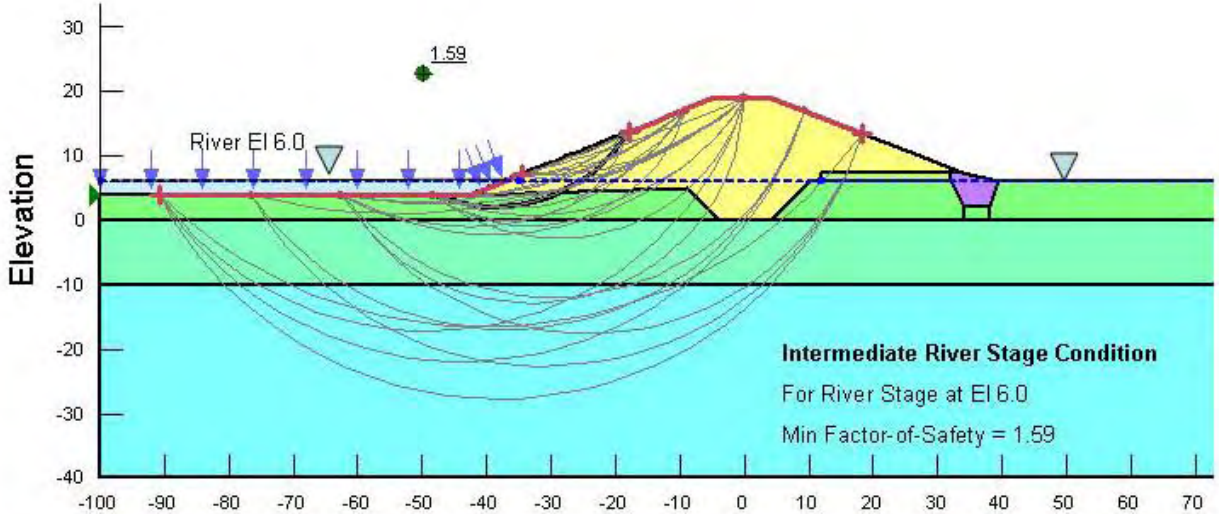

Top of Protection el 19.0
1.39
Tailwater el 9.0
Elevation
Steady Seepage Condition
Toe Drain not in contact with aquifer
Min Factor-of-Safety =1.39

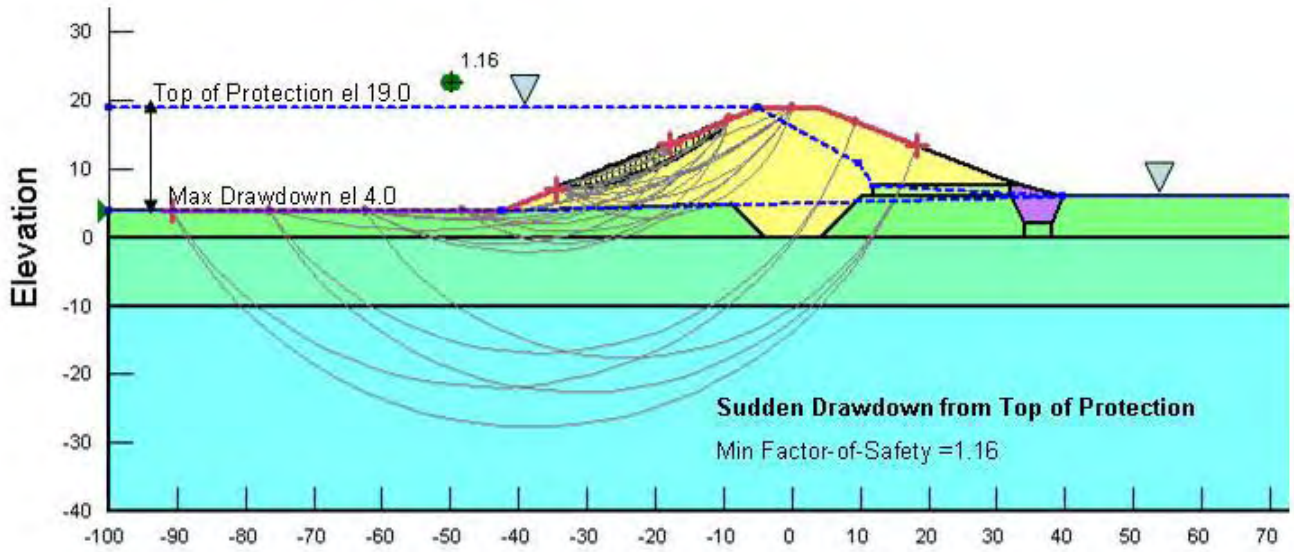

Top of Protection el 19.0
1.64
Tailwater el 9.0
Elevation
Steady Seepage Condition
Toe Drain in contact with aquifer
Min Factor-of-Safety =1.64

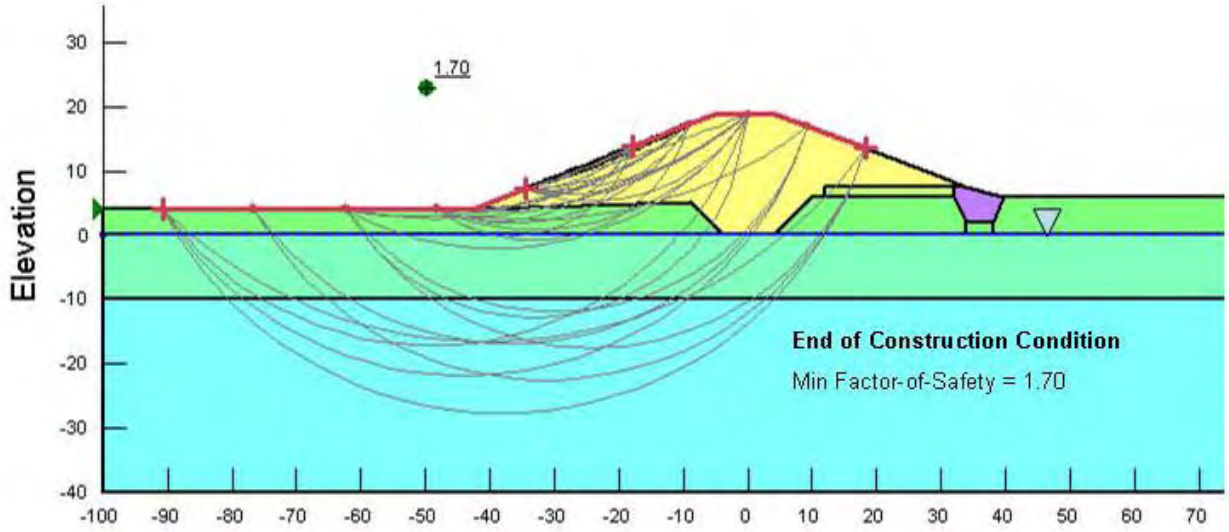

Elevation
Top of Protection el 19.0
2.78
Intermediate River Stage Condition
For River Stage at top of protection El 19.0
Min Factor-of-Safety = 2.78


Elevation
Design Water Surface el 16.0
2.41
Intermediate River Stage Condition
For River Stage at design water surface El 16.0
Min Factor-of-Safety = 2.41


1.63
River el 12.0
Elevation
Intermediate River Stage Condition
For River Stage at El 12.0
Min Factor-of-Safety = 1.63


1.59
River El 6.0
Elevation
Intermediate River Stage Condition
For River Stage at El 6.0
Min Factor-of-Safety = 1.59


1.16
Top of Protection el 19.0
Max Drawdown el 4.0
Elevation
Sudden Drawdown from Top of Protection
Min Factor-of-Safety =1.16


1.70
Elevation
End of Construction Condition
Min Factor-of-Safety = 1.70