UNDERSEEPAGE

1. General. The need for underseepage control is determined from a study of the thickness and characteristics of the natural blanket material, the thickness and permeability of the foundation sands, the effective seepage entrance and exit, and the maximum differential head on the levee created by the design water surface. Seepage enters the foundation sands beneath the levee through the bed of the river and through the foreshore blanket. This results in a hydraulic gradient and an artesian head at the base of blanket as the water flows from the riverward to the landward side of the levee. The pressures that develop landward of the levee during sustained flood stages may, unless controlled, cause heaving or rupture of the blanket in thin blanket areas resulting in a concentration of seepage flow and the formation of sand boils and potential levee failure. Relief wells, underseepage berms or other measures should be considered to control the effect of underseepage pressures in the permeable sands below the impervious blanket.

2. Guidance. Where applicable the seepage modeling techniques addressed within the appendices of EM 1110-2-1913, "Design and Construction of Levees" may be used by the designer. The techniques addressed are commonly used to determine the hydrostatic pressures landward of the levee and may also be used in design of underseepage berms and in calculating pressures to be used in structural uplift.

3. District Specific Guidance. The Kansas City District method of estimating the underseepage gradient and the required factors of safety are slightly different than the method and factors of safety presented in the EM 1110-2-1913 and are based on the conclusions of a Corps of Engineers, Missouri River Division Conference, held in Omaha in 27 November, 1962. The underseepage analysis and design recommendation are based on experience on the Missouri River during the flood of 1952. The procedure addressed is applicable when the impervious blanket is considered infinite in extent landward of the levee toe.

4. Tools. Groundwater model programs may be used for calculating underseepage and gradients, but the designer should confirm the model is applicable to the condition being modeled. Another tool, which may be used when addressing seepage issues, is the traditional flow net.

5. Calculations of the underseepage factors of safety. The factors of safety to be used in underseepage analysis are as follows:

5.1. The gradient (piping) factor of safety is defined as:

$$F_s = \frac{\gamma_b * z}{h * \gamma_w} = \frac{i_c}{i}$$

where:

F_S = gradient factor of safety
γ_b = buoyant weight of the saturated soil
γ_w = unit weight of water
z = thickness of impervious blanket
h = excessive piezometer head above ground surface acting on base of blanket
i = actual gradient (h/z)
i_c = critical gradient when flotation occurs, determined as follows:

$$i_c = \frac{\gamma_b}{\gamma_w}$$

The following factors of safety should be used:

$F_S \geq 1.1$ at the toe of levee with the river at the top of levee when evaluating for need for underseepage control.

$F_S \geq 1.5$ at the toe of the levee with the river at the design water surface (generally 3 feet below top of levee for urban levees). Designer should confirm actual design with the U.S. Army Corps of Engineers, Local Protection Section when designing underseepage control.

$F_S \geq 1.1$ at the toe of the underseepage berm with the river at the design water surface when designing underseepage control, for urban levees.

$F_S \geq 0.8$ at the toe of the long underseepage berm with the river at the design water surface when designing underseepage control, for agricultural levees.

$F_S \geq 1.5$ at the bottom of excavations (permanent or temporary) for excavations landward of the flood control projects, considering the river at the design elevation.

$F_S \geq 1.5$ at the mid-point between pressure relief wells in the instances when the underseepage is controlled by relief wells, considering the river at the design elevation.

$F_S \geq 1.5$ at the levee toe if the underseepage is not controlled by an underseepage berm, considering the river at the design elevation (a factor of safety of 1.1 should be obtainable approximately 200 feet landward of the levee).

If the geotechnical information obtained for the proposed project indicates different field conditions than the initial conditions used for the levee design, a back calculation will be necessary to determine the actual underseepage factors of safety. Any proposed construction should not worsen the existing condition of the levee and should be calculated based on the actual factors of safety obtained in back calculations. Different field conditions can occur if the blanket was eroded and the thickness reduced after flood events, if the distance from the riverside toe of the levee was reduced due to erosion of the riverbank, or the material in the blanket has been eroded and sand deposits replaced the natural impervious blanket after flood events.

5.2. Uplift Factor of Safety. In the special condition where the landward blanket is continuous, impervious, and relatively thick (greater than 10 feet), the designer should also check for uplift of the blanket in accordance with structural guidance for uplift of a structure or pipe. The gradient factor of safety should also be checked when checking for uplift.

5.3 Heave Factor of Safety in Excavations. At the bottom of temporary or permanent excavations, heave occurs under conditions of high hydraulic gradient, when the seepage force due to differential head equals the overlying total weight of soil. The factor of safety against heave ≥ 1.5 for river stage at the design elevation is required and is defined as follows.

$$F_s = \frac{\Sigma(\gamma_t * D_t)}{\gamma_w * (h + D_t)}$$

where:

F_S. = Factor of safety against heave at the bottom of the excavation

γ_t = Total unit weight of each soil layer below the excavation and above the pervious

D_t = Thickness of each soil layer below the excavation and above the sand

γ_w = Unit weight of water

h = Differential total head or net head at the analyzed location considering the river at the design elevation, above the existing top of ground in the excavation

6. Special Conditions. There is a special condition of basins and other permanent excavations constructed within the critical area landward of the levee. The seepage should be addressed both from river to basin or excavation and from basin or excavation to river.

6.1 Seepage from a permanent excavation landward of the flood protection structure (basin or ditch) should be considered in design. The factors of safety should be determined at the riverside toe of a levee considering the water elevation in the basin or ditch at the normal operation and the basin or ditch without impervious features. For this conditions, the following factors of safety are acceptable:

a. Piping (gradient) factor of safety: F_S = 1.5

b. Uplift factor of safety : Fs = 1.5

c. Heave factor of safety: F_S = 1.5

7. Kansas City District Method of Analysis. Figure UNDERSEEPAGE ANALYSIS shows a simplified cross section, with nomenclature and design data to be used in the underseepage analysis shown in the subsequent pages. The landward ground surface is generally assumed to be saturated and therefore used as the tailwater elevation. The permeability ratio represents the horizontal permeability of the pervious aquifer divided by the vertical permeability of the blanket material. The recommended basis for the selection of permeability ratios for use in the underseepage study is as follows:

Blanket Material	Assumed Permeability Ratio, K_f/K_b
SM	100
ML	200 - 400
ML-CL	400
CL	400 - 600
CH	800 - 1000

K_f = the horizontal permeability of the pervious substratum;
Kb = the vertical permeability of the blanket above the pervious substratum;

7.1 Seepage Quantities. The natural seepage per unit length of levee is determined using the equation:

$$Q = \$ * K_f * H$$

where:

Q = seepage per unit length of levee;
$\$$ = shape factor depending on the dimensions of the generalized cross section of the levee and foundation, the characteristics of the top stratum both riverward and landward of the levee, and the pervious substratum;

$$\$ = \frac{D_f}{L_1 + L_2 + L_e}$$

L_1 = effective length of the riverside blanket
L_2 = base width of the assumed impervious fill and natural blanket beneath it
L_e = distance from the landside toe of the assumed impervious section to the effective seepage exit
H = the net head on the levee.

8. Recommended references:

The following references contain details regarding COE requirements for the underseepage analysis within the critical area of a flood control project constructed by the COE.

8.1. EM 1110-2-1913, Design and Construction of Levees includes the following:

a. Necessary subsurface investigations and laboratory testing to obtain the geotechnical properties necessary for underseepage analyses.
b. Seepage control, including foundation underseepage and seepage through embankments.
c. Appendix B "Mathematical Analysis of Underseepage and substratum Pressure" establishes the method of underseepage analysis, the assumptions and the determination of factors involved in the analysis for different cases.

8.2. EM-1110-2-1901 “Seepage Analysis and Control for Dams”, includes the following:

a. Necessary subsurface investigation for determination of soil parameters for groundwater analysis.
b. Determination of permeability of soils in the foundation.
c. Seepage principles, including seepage forces, hydraulic gradients and uplift pressure.
d. Seepage conditions in the presence of relief wells, including well design.
e. Seepage control in earth foundation adjacent to structures, and remedial seepage control.

NOMENCLATURE AND EXPLANATIONS

(For Figure 1 UNDERSEEPAGE)

H	=	Total head on levee
D_{bR}	=	Thickness of natural blanket riverward of levee
D_{bL}	=	Thickness of natural blanket landward of levee
D_f	=	Thickness of natural pervious foundation
k_{bR}	=	Permeability coefficient in a vertical direction of the natural blanket riverward of levee
k_{bL}	=	Permeability coefficient in a vertical direction of the natural blanket landward of levee
k_f	=	Permeability coefficient of the pervious foundation
L_R	=	Actual length of the of the riverside natural blanket
L_L	=	Actual length of the of the landside natural blanket
C	=	Effective length of the pervious foundation of infinite length covered by a natural impervious blanket

$$C = \sqrt{D_f * D_b * \left(k_f / k_b\right)}$$

k_f/k_b	=	Permeability ratio between horizontal permeability of the permeable foundation and vertical permeability of the impervious natural blanket
L_1	=	Effective length of the riverside blanket

$$L_1 = C_r * \frac{e^{\left(2 * L_R / C_R\right)} - 1}{e^{\left(2 * L_R / C_R\right)} + 1}$$

L_2	=	Base width of the assumed impervious fill and natural blanket beneath it.
L_e	=	Distance from the landside toe of the assumed impervious section to the effective seepage exit

$L_e = C \quad when \quad L_L = \infty$ and Le = L_L when L_L < C

γ_s	=	Saturated unit weight of the natural blanket
γ_w	=	Unit weight of water
i_c	=	Critical or maximum upward seepage gradient through natural blanket

$$i_c = \frac{\gamma_s - \gamma_w}{\gamma_w}$$

h_o	=	Head above tailwater at landside levee toe

$$h_o = \frac{H * L_e}{L_1 + L_2 + L_e}$$

i_o = Upward seepage gradient through natural blanket

$$i_o = \frac{h_o}{D_{bL}}$$

F_{Si0} = Gradient factor of safety at the toe of the levee

$$F_{Sio} = \frac{i_c}{i_o}$$

W_T = Trial berm width
$W_{T/2}$ = One half width of the berm
$H_{(WT/2)}$ = Head above tailwater at midpoint of underseepage berm

$$H_{(W_{T/2})} = \frac{H * L_e}{((L_1 + L_2 + L_e) + W_{T/2})}$$

x = Location where uplift has to be calculated
h_x = Head above tailwater at location where uplift has to be determined

$$h_x = \frac{h_o}{e^{(x/x_L)}} \quad where \quad x_L = L_e$$

$H_{(WT)}$ = Head above tailwater at end of underseepage berm

$$H_{(WT)} = \frac{H_{(W_{T/2})}}{e^{(W_{T/2}/c)}}$$

$i_{(wT)}$ = Upward seepage gradient through natural blanket at the end of berm

$$i_{(WT)} = \frac{H_{(WT)}}{D_{bL}}$$

$FSi_{(WT)}$ = Gradient Factor of safety at the end of the berm
L = Distance from effective seepage entry to effective exit.
M = Slope of hydraulic grade line beneath levee