DIVR 1110-1-400
Change 2

DEPARTMENT OF THE ARMY
MISSISSIPPI VALLEY DIVISON, CORPS OF ENGINEERS
Vicksburg, Mississippi 39181-0080

CEMVD-ET-EG

Regulation
No. 1110-1-400 12 December 1998

Engineering and Design
SOIL MECHANICS DATA

1. This change to DIVR 1110-1-400, 5 Sep 67, revises section 8, Ground Water and Seepage.

2. The present DIVR 1110-1-400 should be revised as follows:

   a. Remove section 8, Part 6, Item 1

   b. Add section 8, Part 6, Item 1

3. File this change sheet in front of publication for reference purposes.

FOR THE COMMANDER:

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Engineering and Design, Soils Mechanics Design Data
SECTION 8 - GROUND WATER AND SEEPAGE
Part 6 - Landside Seepage Berms for Mississippi River and Major Tributary Levees
Item 1 - Design Procedures

1. Scope. This item describes the various design factors and procedures to be used in determining the need for underseepage protection to preserve the integrity of levees and presents the procedure for design of landside seepage berms for the Mississippi River Levees and levees of major tributaries within the Mississippi Alluvial Valley. This item also describes the procedure for documenting the results of these design studies. Although the design procedure was developed for the Mississippi River main line levees, it can also be used to design seepage berms in general, provided that proper design values are used. The criteria contained herein are applicable to levees that protect human life, regardless of the population density. Deviations from these criteria must be approved by the Mississippi Valley Division. These criteria are not intended to supercede criteria previously approved by the Office, Chief of Engineers, for sand levees and berms in the Rock Island District that protect entirely agricultural areas.

2. Design Procedure. Landside seepage berms will be designed using procedures set forth herein, which are based on procedures and nomenclature in WES TM No. 3-424, "Investigation of Underseepge and its Control, Lower Mississippi River Levees," October 1956. Nomenclature and design formulas are given on Plate 1.

3. Field and Office Investigations. Available seepage records will be reviewed to determine the severity of underseepage during high water; these observed conditions will be extrapolated to the project design flood flowline based on experience and judgement. Geologic and soil conditions along the levee will be evaluated from air photos, geologic maps, and borings. The presence of manmade features such as drainage ditches and borrow pits will be noted and their effects considered in design. Borings will be made as required to establish sufficient soils and geologic data for design. Any such borings should penetrate at least 5 feet into the clean sand substratum. Deep borings defining the thickness of the pervious aquifer should be included if at all practicable.

4. Design Values.

a. Where no riverside borrow pit exists, the distance from the landside levee toe to the point of effective seepage entry(s) will be determined as the base width of the levee (L_2) plus the effective length of blanket riverside of the levee (x_1). Values of x_1 will be determined from Table 1 based on the thickness and type of soil in the riverside topstratum (blanket) unless site specific permeability data indicate these values are inappropriate. Where a riverside borrow pit exists or is to be constructed, the x_1 distance to be used in the underseepage analysis should be the lesser of either the x_1 distance based on the thickness and type of top stratum neglecting the borrow pit or the x_1 distance based on the thickness and type of top stratum remaining in the bottom of the borrow pit plus the distance from the riverside levee toe to the borrow pit. The above is based on the assumption there is no other source of seepage entry nearer the levee. If a nearer source does exist, the distance to the nearer source should be used.

b. The effective thickness (d) and horizontal permeability (k_f) of the pervious substratum will be determined as follows. The thickness (d) is the total thickness of the principal pervious stratum between the bottom of the blanket and the bottom of the entrenched valley. It should be determined, if at all practicable, by deep borings which fully penetrate the pervious stratum or from a combination of shallow borings penetrating into the upper portion of the pervious substratum and the elevation of the bottom of the entrenched valley determined from seismic surveys or geologic reports. The average horizontal permeability (k_f) of the pervious substratum can be determined from a field pump test on a fully penetrating well or from the equation:

$$k_f = \frac{d_a k_a + d_b k_b + d_c k_c + d_n k_n}{d_a + d_b + d_c + d_n}$$

where the coefficient of horizontal permeability of each stratum is obtained from the permeability-grain-size correlation in Plate 2.

c. The effective thickness (z_{bL}) and permeability (k_{bL}) of the landside blanket must be determined so that the seepage exit length (x_3) can be computed. If the blanket is comprised of more than one stratum and the vertical permeability of each stratum is known, the thickness of each stratum of the blanket can be transformed into an equivalent thickness of material having the same vertical permeability as that for one of the strata as shown on Plate 3. The effective thickness (z_{bL}) of the blanket is the sum of the transformed thicknesses. As an example, consider a blanket composed of clay, silt, and silty sand strata. The thicknesses of the silt and silty sand strata can be transformed into equivalent thicknesses of material having the same permeability as the clay; the thicknesses of the clay and silt can be transformed into equivalent thicknesses of material having the same permeability as the silty sand; or the thicknessess of clay and silty sand can be transformed into equivalent thicknesses of material having the same permeability as the silt. Each of the above three transformations will result in the same z_{bl}/k_{bl} ratio and exit length. When making such transformations, the thickness transformation factor is the ratio of the vertical permeability of the material, after it has been transformed, to the vertical permeability of the material being transformed. The thickness for critical uplift (z_t) is equal to the total actual thickness of all strata overlying the base of the least pervious stratum added to the transformed thickness of any underlying more pervious top stratum materials (see Plate 3).

d. For seepage berm design, the landside blanket can be transformed using the transformation factors in Table 2. These transformation factors do not exactly agree with the ratios of permeability of silt and silty sand to that of clay, but will suffice for design purposes. Generally, the blanket will be transformed to a material with permeability equal to that of the predominant least pervious soil (clay or silt), with the permeability of the transformed material being obtained from Plate 4 unless site specific permeability data indicate these values are inappropriate. If the blanket consists of a single soil, it will not be transformed. Instead, the actual thickness will be used for z_{bl} and z_t. The values of k_{bl} on Plate 4 for thin clay blankets and for silty sand and silt blankets are the same as those in Table 3. The values of k_{bl} for thick clay blankets in Table 3 have been revised slightly. This revision was made to eliminate inconsistencies in dimensions of berms for thick clay blankets at large net heads. For convenience, values of z_{bl} and k_{bl} from Plate 4 are tabulated in Table 4.

e. The distance from the landside toe of the levee to the effective seepage exit (x_3) will be determined from the following blanket formulas:

where $L_3 = \infty$

$$x_3 = \frac{1}{c} = \sqrt{\frac{k_f z_{bL} d}{k_{bL}}}$$

where L_3 = finite distance to a block

$$x_3 = \frac{1}{c\tanh(cL_3)}$$

where L_3 = finite distance to an open exit

$$x_3 = \frac{\tanh(cL_3)}{c}$$

For cases where L_3 is infinite, k_f equals 1250 x 10^{-4} cm per sec, and d equals 100 ft, Plate 5 can be used to determine x_3. For cases where the top stratum is clay, L_3 is infinite and k_f equals 1250 x 10^{-4} cm per sec, Plate 6 can be used to determine x_3 for various values of d.

5. Design of Berm Section. The approach to designing seepage berms is outlined on plate 7 and described in detail below:

a. Landside blanket present. Where a landside blanket is present, the need for a landside seepage berm will be determined by computing the upward gradient at the landside toe of the levee (i_o) for the design project flow line using the equation:

$$i_0 = {}^{h_0}\!/_{z_t}$$

The head beneath the blanket at the landside levee toe (h_o) is computed from the equation:

$$h_0 = \frac{Hx_3}{s + x_3}$$

where H = design head on the levee.

(1) If the computed upward gradient at the landside toe of the levee is greater than 0.8, landside seepage berms will be designed using equations on Plate 1. The curves on Plate 8 may be used in the design of semipervious berms. The seepage berm will be designed so that the upward gradient through the blanket and berm at the landside toe of the levee equals 0.3, and the upward gradient at the landside toe of the berm equals 0.8. The thickness of the berm will then be increased 25 percent to allow for shrinkage of the berm, foundation settlement, and variations in values of the design factors. Of this 25 percent increase, approximately 15 percent is for normal variations in design factors associated with the required gradient of 0.3. The remaining 10 percent is for shrinkage and settlement. All berms will have a minimum net thickness of 5 feet at the levee toe, a thickness of about 2 feet at the berm crown, and a minimum width of 150 feet. If the computed dimensions exceed the above minimum dimensions, the berm will be built in accordance with the computed design except that the width of the berm generally will not exceed about 300 to 400 feet.

(2) If the computed upward gradient at the landside toe of the levee is between 0.5 and 0.8 without a berm, the minimum standard berm described above will be constructed. If the computed gradient is less than 0.5 but either observed seepage has been severe or seepage is expected to become severe and soften the landside portion of the levee at the design head, the minimum standard berm will be constructed.

b. No landside blanket. If there is no landside blanket present, a preliminary check of the need for a landside seepage berm will be based on Bligh's creep ratio, $c = \frac{x_1 + L_2}{H}$. If the levee is founded on very fine sand and the creep ratio is at least 18; or if on fine or medium sand and the creep ratio is at least 15; or if on coarse sand and the creep ratio is at least 12, no berm is required. If the creep ratio is less than the above minimum value, the need for a landside berm will be determined based on flow net construction. If the exit gradient at the toe of the levee exceeds 0.5, a berm will be constructed which meets the criteria described in preceding paragraph 5a. The head beneath the berm at the landside toe of the levee will be determined from the following equation:

$$h_0 = \frac{H(X + 0.43\overline{D})}{x_1 + L_2 + X + 0.43\overline{D}}$$

where

$$\overline{D} = d\sqrt{\frac{k_h}{k_v}}$$

which is the transformed thickness of the aquifer, L_2 is the base width of the levee, X is the berm width, and x_1 is the effective length of impervious blanket riverside of the levee. Where no riverside blanket exists, the value of x_1 will be taken as 0.43 $\overline{D}$. The quantity of seepage (Q_s) per unit length of levee beneath the levee will be determined from the following equation:

$$Q_s = \frac{k_f dH}{x_1 + L_2 + x + 0.43\overline{D}}$$

If the value of Q_s exceeds about 200 gpm per 100 ft of levee, a riverside blanket should be designed to reduce the quantity of seepage to the above amount. Procedures for designing riverside blankets are given in Part VI, WES TM No. 3-424.

c. Existing berm present. The following procedure and criteria will be used to evaluate the adequacy of existing seepage berms:

(1) Assume that the existing berm is not in place and compute the gradient at the landside toe of the levee without the berm.

(2) If the gradient at the landside toe of the levee, as computed in 5c(1) above, is 0.5 or less, enlargement of the existing berm is considered unnecessary. However, if this gradient is between 0.5 and 0.8, the gradient at the landside toe of the levee and at the toe of the existing berm should be computed with the existing berm in place and assumed to be semipervious. These gradients should then be

compared with an allowable gradient line which varies linearly from 0.3 at the levee toe to 0.8 at a distance of 150 feet landward of the levee toe. If the gradients computed with the existing berm in place are less than or equal to the values defined by the above allowable gradient line, the existing berm can be considered adequate. If the computed gradients with the existing berm in place exceed the allowable values, the existing berm should be enlarged to provide the minimum berm section.

(3) In instances where the gradient at the landside toe of the levee, as computed in 5c(1) above, is greater than 0.8, but the theoretical calculated berm section is less than the minimum berm section, the existing berm section should be checked using the allowable gradient line criteria indicated in paragraph 5c(2) above. If the existing berm satisfies these criteria, the existing berm can be considered adequate. If the existing berm does not satisfy these criteria, the minimum berm section should be provided. Where the computed gradient at the landside levee toe without the existing berm is greater than 0.8 and the theoretical calculated berm section is greater than the minimum berm section, the calculated berm width limited to 300 to 400 feet should be provided.

(4) In instances where an existing berm smaller than the minimum berm section is determined to be adequate based on the criteria in paragraphs 5c(2) and 5c(3) above, but a history of piping and/or heavy underseepage exists within or landward of the existing berm, the existing berm should be enlarged to the minimum berm section to preserve the integrity of the levee.

(5) In comparing an existing berm section to the minimum berm section or a theoretical calculated berm section, the existing berm thickness should be compared to the minimum or calculated berm thickness with no overbuild added.

d. The theoretical shape of the surface of a landside seepage berm is concave upward. The computed berm thickness ranges from a value of t at the levee toe to a value of zero at the berm toe. The thickness t' midway between the levee toe and berm toe can be determined from Plate 9. The theoretical berm surface has the following coordinates: $x = 0$, $y = t$; $x = X_{sp}/2$, $y = t'$; and $x = X_{sp}$, $t = 0$ (see Plate 9). Where wide, thick berms are required, consideration should be given to using a berm with a broken surface slope as shown on Plate 10 to more closely simulate the theoretical thickness and reduce the cost. Where this is done, the slope of the landward portion of the berm should not be flatter than 1V on 100H.

6. Other Considerations.

a. Landside ditches. Experience has indicated that ditches near the landside toe of levees or existing seepage berms have sometimes been subjected to high concentrations of seepage during highwater periods, and in some cases this has resulted in sand boils and piping in the ditch bottoms. When investigating the need for landside seepage berms it is also necessary to investigate possible seepage into any nearby landside ditches. As a general rule the upward gradient through the topstratum remaining under the ditch bottom should not exceed 0.5 if the ditch is adjacent to the levee toe and should not exceed 0.8 if the ditch is 150 feet from the levee toe. The gradient can vary linearly from 0.5 at the levee toe to 0.8 at a distance 150 feet from the toe. The gradient in the bottom of the ditch should be calculated assuming the water level is at the bottom of the ditch. In some cases it may be necessary to fill the ditches and relocate them a farther distance from the levee or berm toe. Large ditches resulting in high gradients should not be constructed or allowed immediately outside the 150 foot distance or immediately beyond the berm toe for berms wider than 150 feet. Practical maximum distances for ditch relocations should be based on specific site conditions.

b. Use of riverside blanket. For those reaches of levee where the pervious substratum is naturally exposed on the riverside of the levee or where riverside borrow pits expose pervious substratum material, riverside blankets should be considered as a means of increasing the seepage entrance distance thereby eliminating or reducing the required length of landside seepage berm. Design studies should be made for these reaches to ascertain whether riverside blankets exclusively or together with landside seepage berms would be feasible from an engineering and economic standpoint to help minimize landside right-of-way requirements. Procedures for designing riverside blankets are given in Part VI, WES TM No. 3-424.

c. In addition to the analysis for water at the project design flood flowline, levees with relatively low differential heads for which a small increase in head significantly increases exit gradients should also be evaluated for water to the top of the levee (net levee grade). If this evaluation indicates exit gradients would be increased sufficiently to create concern regarding the integrity of the levee before the levee is overtopped, additional seepage control measures should be provided.

7. Design Report. Underseepage investigations and berm designs will be completed in advance of plans and specifications for the proposed berms. The following data will be included in the design documentation:

a. An aerial photograph of the area along the levee to be protected by the berm to a scale of about 1 to 20,000 where available.

b. A map of the area showing available surface elevations, the proposed berm, existing levee and borrow pits, proposed extensions to existing borrow pits and/or new borrow pits, and the locations of all borings.

c. A soil profile along the landside toe of the levee stratified in conformance with geologic features similar to profiles contained in Volume 2, WES TM No. 3-424, "Investigations of Underseepage and Its Control, Lower Mississippi River Levees," and Volume 2, WES TM No. 3-430, "Investigation of Underseepage, Mississippi River Levees, Alton to Gale, Illinois."

d. Logs of borings in existing riverside borrow pits with the existing elevation of the borrow pit noted and logs of borings in proposed new borrow pits showing the proposed depth of borrow, and logs of all other borings not shown on the profile described in c above, all plotted to the same elevation scale.

e. A table of design values similar to LMV Form 282 showing all assumed and computed design values.

f. A concise design report citing history of seepage in the reach being studied, significant geologic and manmade features affecting the pattern and severity of underseepage, procedures used to design the berm, and factors considered in determining location and depth of borrow pits required to provide the material for the proposed berm.

g. Typical cross-sections of the levee and proposed seepage berms similar to those on Plate 78 of WES TM No. 3-430.

Table 1

Suggested Design Values of Effective Lengths and Vertical Permeability of Riverside Blankets

Soil Type	Blanket Thickness (ft)	Suggested Design Values* k_{br} (10^{-4}cm /sec)	x_1 (ft)
Sand	-----	---	250
Silty Sand	<5	7.0	300
	5 to 10	2.5	600
Silt and Sandy Silt	<5	2.0	400
	5 to 10	1.5	800
	>10	1.0	1200
Clay	<5	0.8	600
	5 to 10	0.5	1300
	10 to 15	0.2	2500
	>15	0.05	4000

*Use L_1 for x_1 where L_1 is less than x_1. (L_1 is the distance from the riverside toe of the levee to the riverside bank).

(From WES TM 3-424)

Table 2

Thickness Transformation Factors for Top Strata

Soil Type	Unified Soil Class. System	Transformation Factor
	Clay less than 5 ft in thickness	
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1
Sandy silt	Silt, sandy (ML)	3/4 to 1
Silty sand	Silty sand (SM)	1/5 if z* < 10 ft 0 if z* > 10 ft
Very fine sand	Fine sand	0
Alternating clay with silt strata with depth		1
	Clay more than 5 ft in thickness	
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1/2
Sandy silt	Silt, sandy (ML)	1/4 to 1/2 if z* < 10 ft 0 if z* > 10 ft
Silty sand	Silty sand (SM)	1/10 if z* < 10 ft 0 if z* > 10 ft
Very fine sand	Fine sand	0
Alternating clay and silt strata with depth		1

*z =.thickness of top stratum above material being transformed

(From WES TM 3-424)

Table 3

Suggested Design Values for Ratio of Permeability of Pervious Substratum to Landside Top Stratum and Permeability of Top Stratum

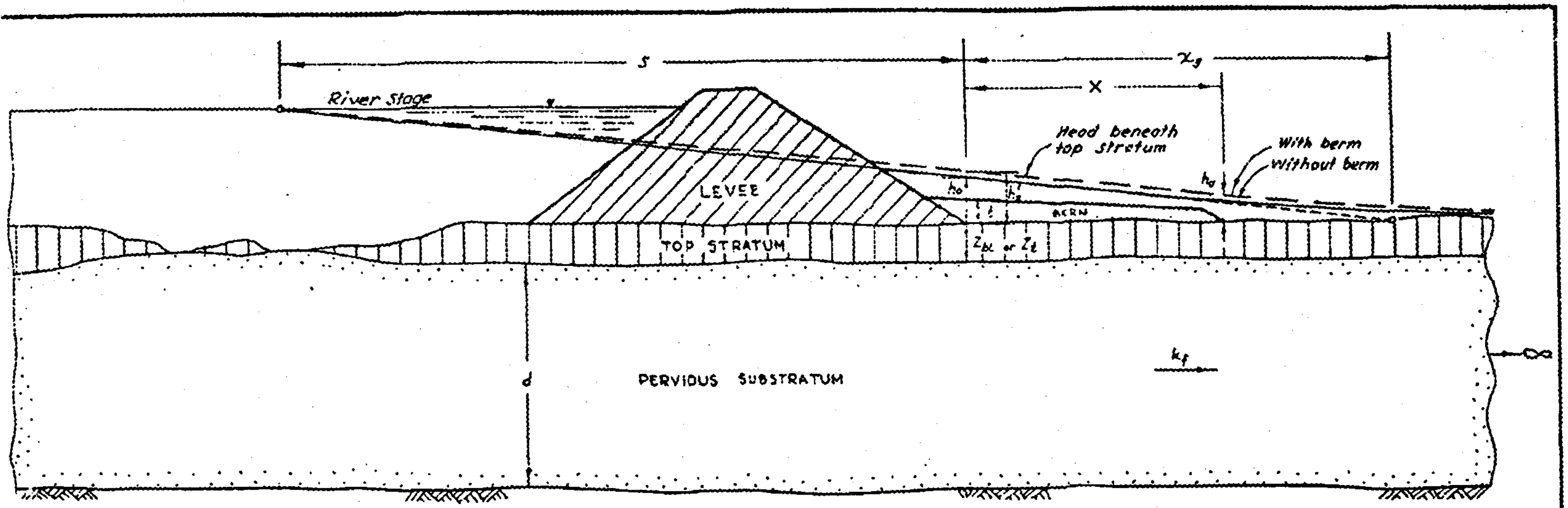
		Suggested Design Values	
Soil Type	Blanket Thickness (ft)	k_{bl} (10^{-4} cm/sec)	k_f / k_{bl}
Silty Sand	<5	10	125
	5 to 10	8	150
	>10	6	200
Silt and Sandy Silt	<5	5	250
	5 to 10	4	300
	10 to 15	3	400
	>15	2	600
Clay and Silty Clay	<5	4	250
	5 to 10	3	400
	10 to 15	1.5	800
	15 to 20	0.5	2500
	>20	0.08	15000

(From WES TM 3-424)

Table 4

Permeability of Landside Blanket

z_{bl}	k_{bl} (10^{-4} cm/sec)		
(Feet)	Clay	Silt	Silty Sand
1	4.56	5.70	10.50
2	4.30	5.40	10.10
3	4.06	5.10	9.80
4	3.80	4.80	9.40
5	3.57	4.50	9.00
6	3.30	4.25	8.60
7	3.10	4.00	8.30
8	2.88	3.80	8.00
9	2.66	3.60	7.80
10	2.45	3.40	7.55
11	2.25	3.23	7.30
12	2.08	3.10	7.10
13	1.89	2.95	6.95
14	1.72	2.81	6.80
15	1.57	2.70	6.60
16	1.41	2.60	6.50
17	1.28	2.50	6.40
18	1.14	2.40	6.20
19	1.01	2.30	6.10
20	0.90	2.22	6.00
21	0.78	2.14	5.85
22	0.69	2.05	5.80
23	0.60	1.98	5.65
24	0.52	1.90	5.60
25	0.45	1.83	5.45
26	0.38	1.78	5.40
27	0.31	1.71	5.30
28	0.25	1.66	5.20
29	0.20	1.60	5.15
30	0.15	1.56	5.10
>30	0.15		



NOTATIONS

$c = \sqrt{\frac{k_{bl}}{k_f z_{bl} d}}$

γ_z' = SUBMERGED UNIT WEIGHT OF TOP STRATUM

γ_t' = SUBMERGED UNIT WEIGHT OF BERM

γ_w = UNIT WEIGHT OF WATER

h_o = HEAD AT LANDSIDE TOE OF LEVEE WITHOUT BERM = $\frac{Hx_3}{S + x_3}$

h_o' = HEAD AT LANDSIDE TOE OF LEVEE WITH BERM

i_o = ALLOWABLE UPWARD GRADIENT AT LANDSIDE TOE OF LEVEE

i_1 = ALLOWABLE UPWARD GRADIENT AT TOE OF BERM

h_a = ALLOWABLE HEAD AT TOE OF BERM = $i_1 z_t$

X = REQUIRED BERM WIDTH

t = REQUIRED THICKNESS OF BERM AT TOE OF LEVEE

k_t = VERTICAL PERMEABILITY OF BERM

F = FACTOR OF SAFETY AGAINST UPLIFT AT TOE OF LEVEE

Q_s = FLOW INTO BERM PER FT OF LEVEE

FORMULAS

IMPERVIOUS BERM ($k_t = 0$)

$$X_I = x_3\left(\frac{H}{h_a} - 1\right) - S$$

$$h_o' = H\left(\frac{x_3 + X}{S + x_3 + X}\right)$$

$$t = \frac{h_o' - z_t\left(\frac{\gamma_z'}{F\gamma_w}\right)}{1 + \frac{\gamma_t'}{F\gamma_w}}$$

USE $F \geq 1.5$

SEMIPERVIOUS BERM ($k_t = k_{bl}$)

$$X_{sn} = \frac{-A + \sqrt{A^2 - 24(2 + r)\left(1 + Sc - \frac{H}{h_a}\right)}}{2c(2 + r)}$$

WHEREIN:

$$A = 6 + 3Sc(r + 1)$$

$$r = \frac{i_o}{i_1}$$

$$h_o' = h_a\left[1 + cX + \left(\frac{2 + r}{6}\right)(cX)^2\right]$$

$$t = \frac{h_o' - i_o z_t}{1 + i_o}$$

SAND BERM

$$X_s = \frac{1}{3}\left(X_p + 2X_{sn}\right)$$

$$h_o' = h_a\left[1 + cX + \left(\frac{2 + r}{6}\right)(cX)^2\right]$$

$$t = \frac{h_o' - z_t\left(\frac{\gamma_z'}{F\gamma_w}\right)}{1 + \frac{\gamma_t'}{F\gamma_w}}$$

PERVIOUS BERM WITH COLLECTOR

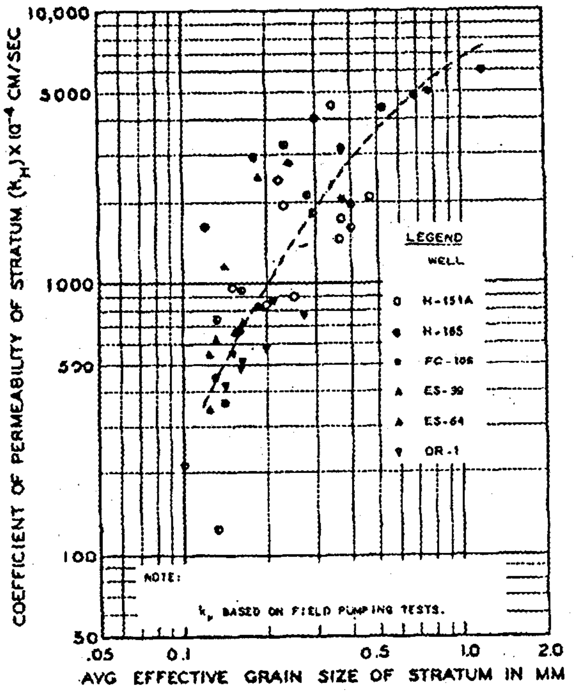
$$X_p = x_3 \log_e\left(\frac{h_o'}{h_a}\right)$$

$$h_o' = h_o = \frac{Hx_3}{S + x_3}$$

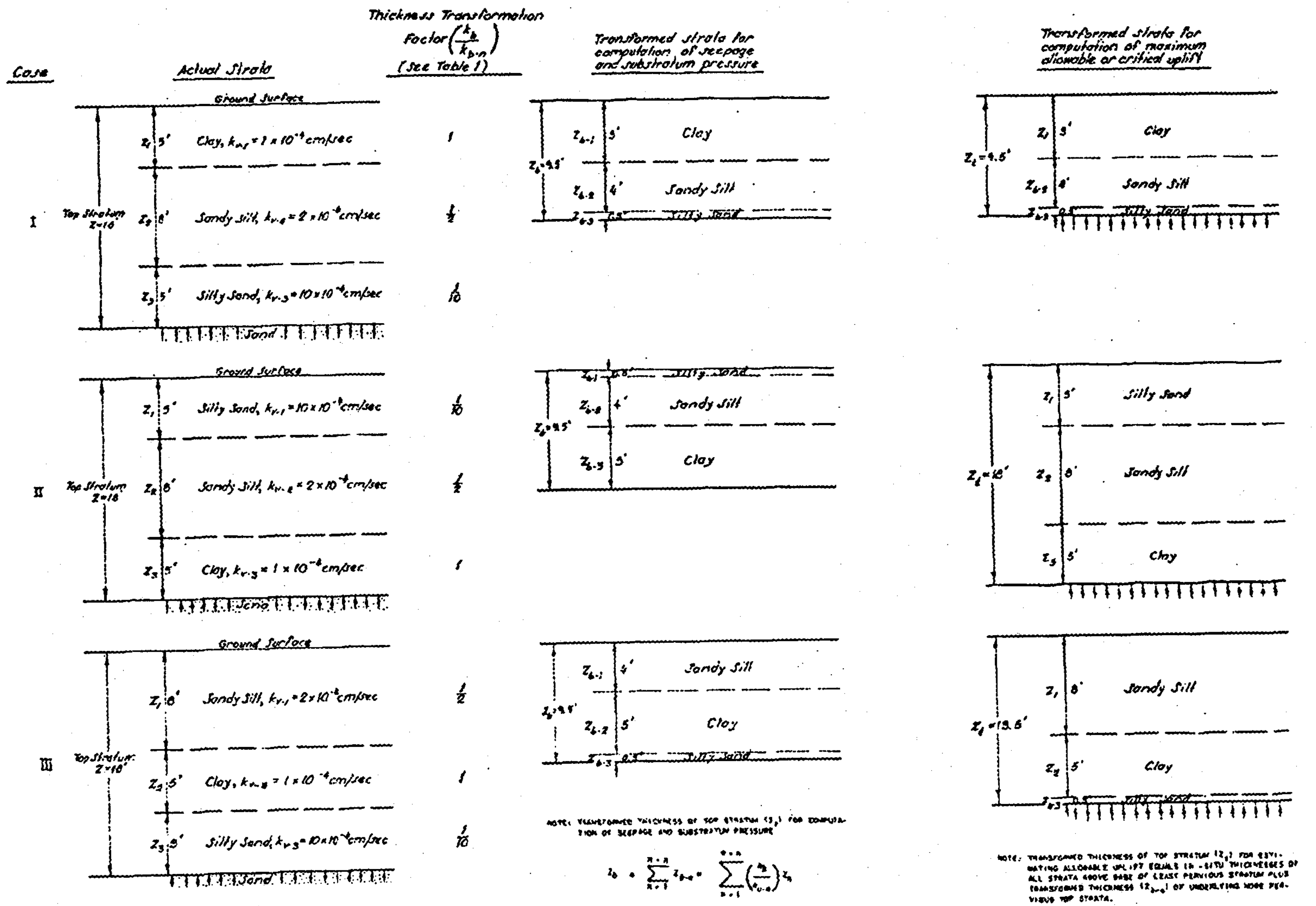
$$t = \frac{h_o' - z_t\left(\frac{\gamma_z'}{F\gamma_w}\right)}{1 + \frac{\gamma_t'}{F\gamma_w}}$$

$$Q_s = \frac{k_f d H}{S + x_3}\left(1 - e^{\frac{-X}{x_3}}\right)$$

Nomenclature and formulas for designing landside seepage berms on semipervious top stratum



In-situ horizontal permeability
vs effective grain size D_{10}

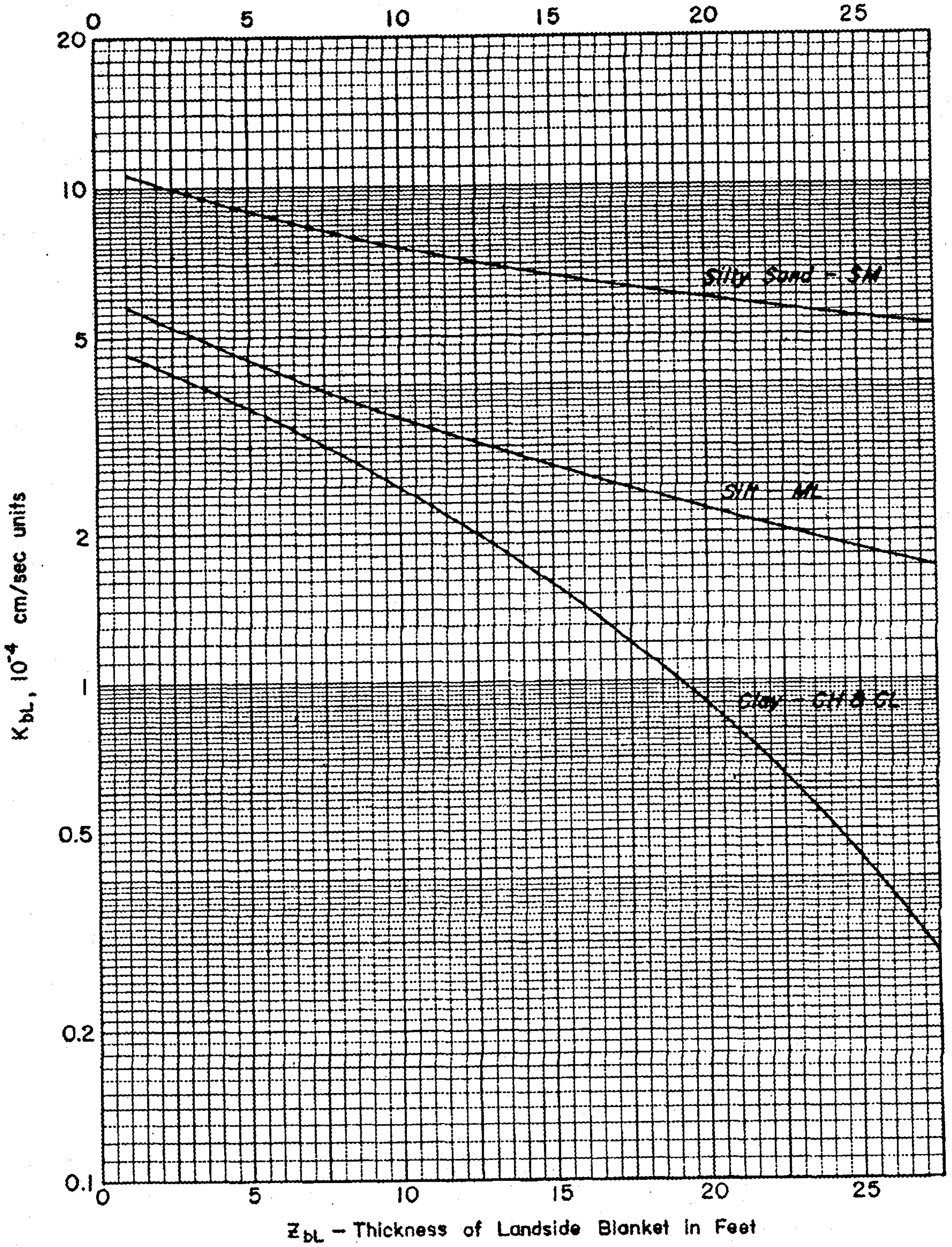


NOTE: TRANSFORMED THICKNESS OF TOP STRATUM (Z_b) FOR COMPUTATION OF SEEPAGE AND SUBSTRATUM PRESSURE

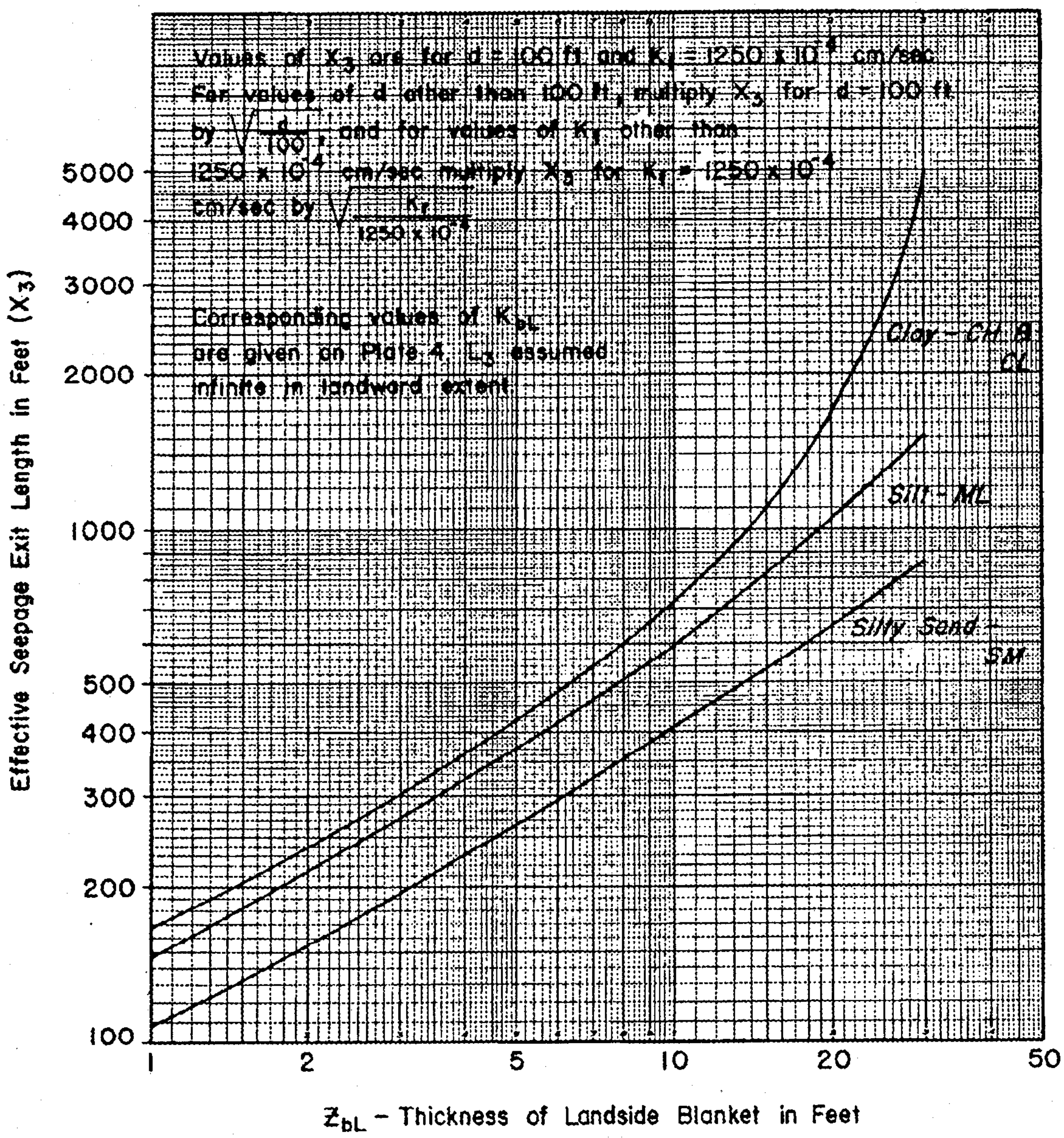
$$z_b = \sum_{n=1}^{n=n} z_{b-n} = \sum_{n=1}^{n=n} \left(\frac{k_b}{k_{v-n}}\right) z_n$$

NOTE: TRANSFORMED THICKNESS OF TOP STRATUM (Z_t) FOR ESTIMATING ALLOWABLE UPLIFT EQUALS IN-SITU THICKNESSES OF ALL STRATA ABOVE BASE OF LEAST PERVIOUS STRATUM PLUS TRANSFORMED THICKNESS (Z_{b-n}) OF UNDERLYING MORE PERVIOUS TOP STRATA.

Transformation of top strata



PERMEABILITY OF LANDSIDE BLANKET FOR DESIGN OF LANDSIDE SEEPAGE BERMS



Values of X_3 are for d = 100 ft and $K_f = 1250 \times 10^{-4}$ cm/sec. For values of d other than 100 ft, multiply X_3 for d = 100 ft by $\sqrt{\frac{d}{100}}$, and for values of K_f other than 1250×10^{-4} cm/sec multiply X_3 for $K_f = 1250 \times 10^{-4}$ cm/sec by $\sqrt{\frac{k_f}{1250 \times 10^{-4}}}$.

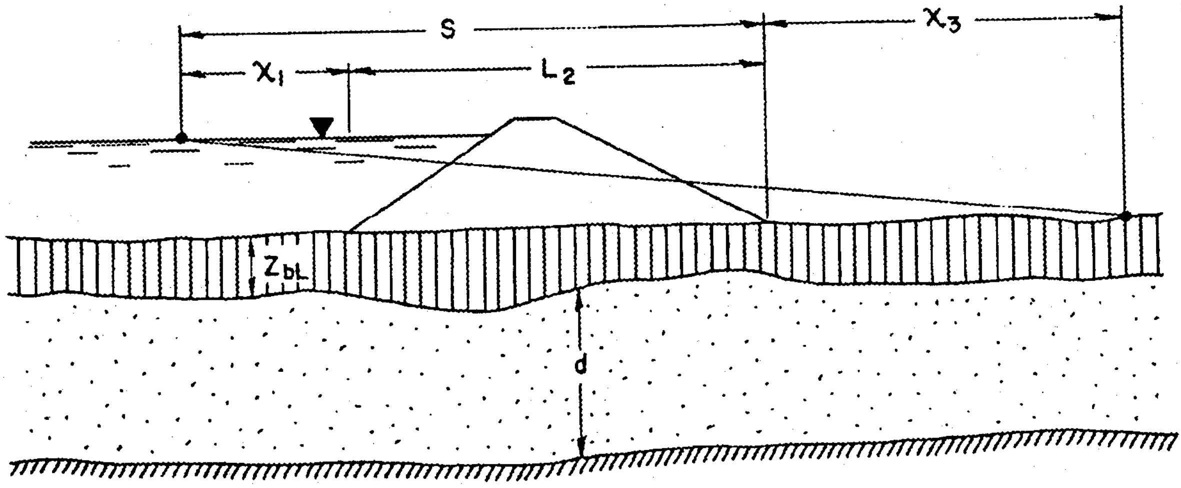
Corresponding values of k_{bL} are given on Plate 4. L_3 assumed infinite in landward extent.

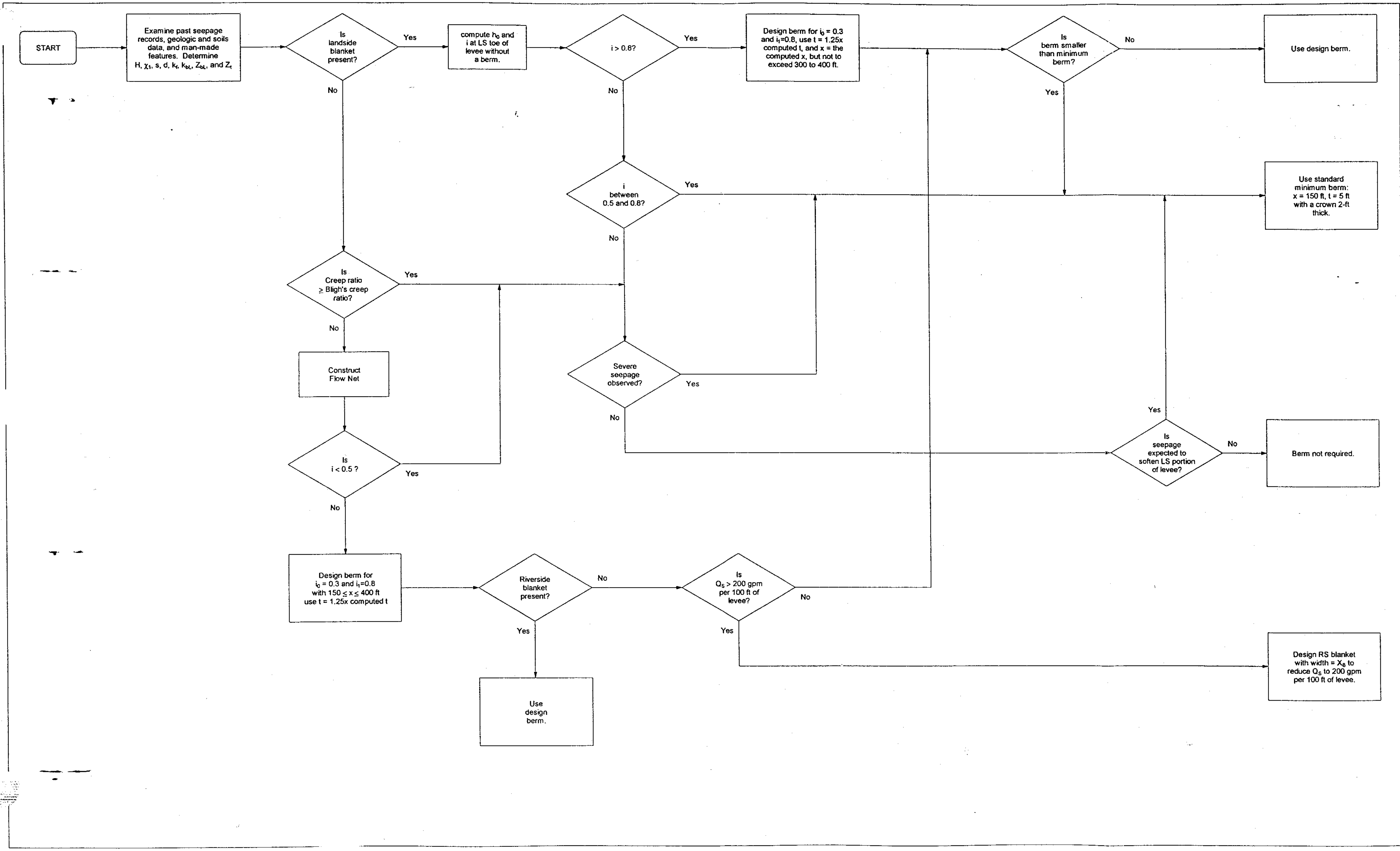
EFFECTIVE SEEPAGE EXIT LENGTH

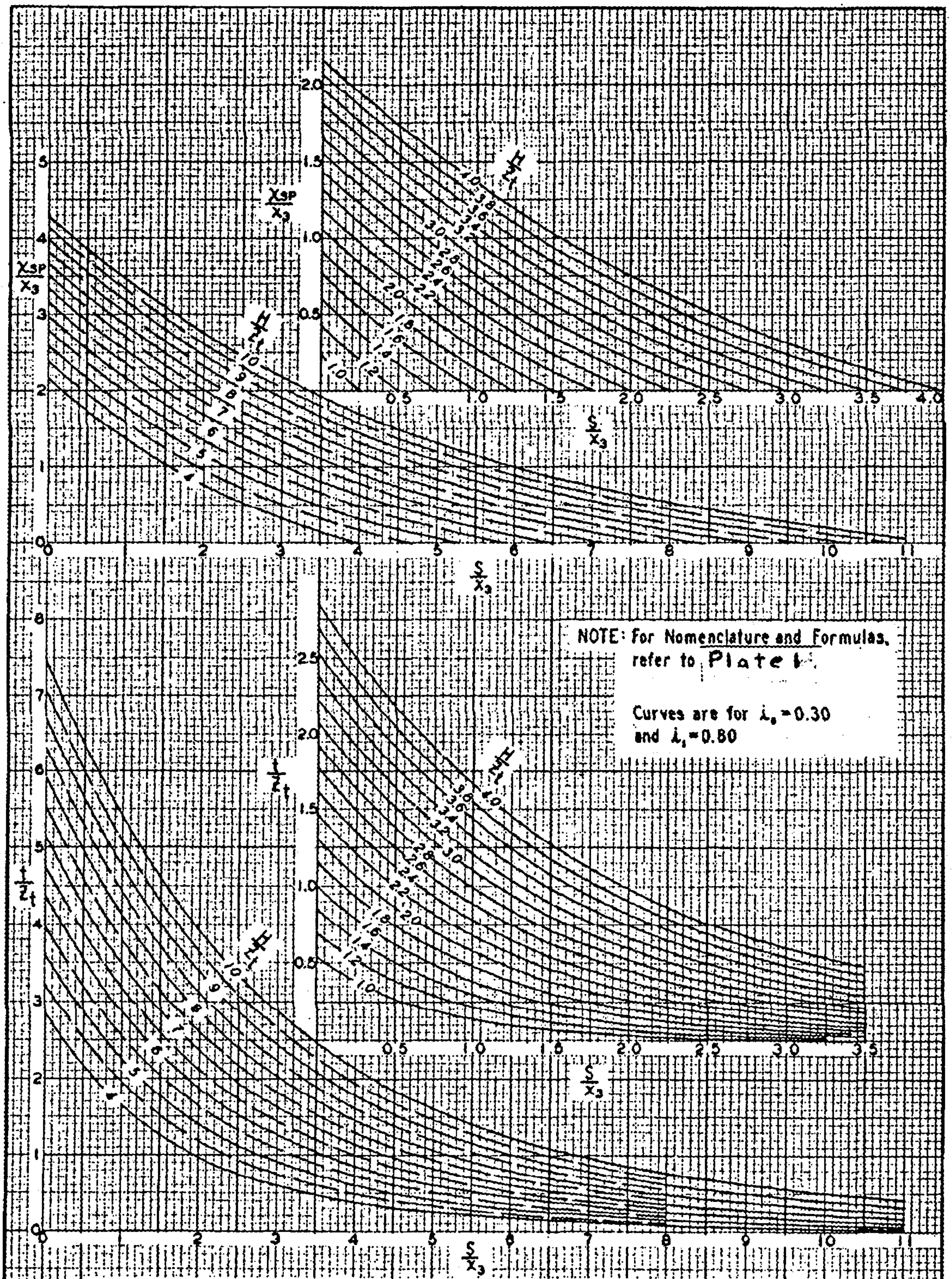
EFFECTIVE SEEPAGE EXIT LENGTH IN FEET

Z_{BL} FT	d= 80 FT	d= 90 FT	d= 100 FT	d= 110 FT	d= 120 FT	d= 130 FT	d= 140 FT	d= 150 FT
1	150	159	168	176	184	192	199	206
2	215	228	240	252	263	274	284	294
3	273	289	305	320	334	348	361	374
4	326	346	365	383	400	416	432	447
5	376	399	420	441	460	479	497	515
6	420	446	470	493	515	536	556	576
7	474	503	530	556	581	604	627	649
8	528	560	590	619	646	673	698	723
9	581	617	650	682	712	741	769	796
10	635	674	710	745	778	810	840	870
11	698	740	780	818	854	890	923	956
12	760	807	850	892	931	969	1,006	1,041
13	832	883	930	976	1,019	1,061	1,101	1,139
14	894	949	1,000	1,049	1,096	1,141	1,184	1,225
15	984	1,044	1,100	1,154	1,205	1,255	1,302	1,348
16	1,055	1,120	1,180	1,238	1,293	1,346	1,397	1,448
17	1,145	1,215	1,280	1,343	1,402	1,460	1,515	1,568
18	1,252	1,329	1,400	1,469	1,534	1,597	1,657	1,715
19	1,342	1,424	1,500	1,574	1,643	1,711	1,775	1,838
20	1,476	1,566	1,650	1,731	1,808	1,882	1,953	2,021
21	1,610	1,708	1,800	1,888	1,972	2,053	2,130	2,205
22	1,789	1,898	2,000	2,098	2,191	2,281	2,367	2,450
23	1,968	2,088	2,200	2,308	2,410	2,509	2,604	2,695
24	2,147	2,278	2,400	2,518	2,629	2,737	2,840	2,940
25	2,370	2,515	2,650	2,780	2,903	3,022	3,136	3,246
26	2,638	2,800	2,950	3,095	3,232	3,364	3,491	3,614
27	2,952	3,132	3,300	3,462	3,615	3,764	3,906	4,043
28	3,309	3,511	3,700	3,881	4,053	4,220	4,379	4,533
29	3,846	4,081	4,300	4,511	4,711	4,904	5,089	5,268
30	4,472	4,745	5,000	5,245	5,478	5,703	5,918	6,125

Note: Above values are for clay top stratum only. $k_f = 1250 \times 10^{-4}$ cm/sec, $L_3 = \infty$.



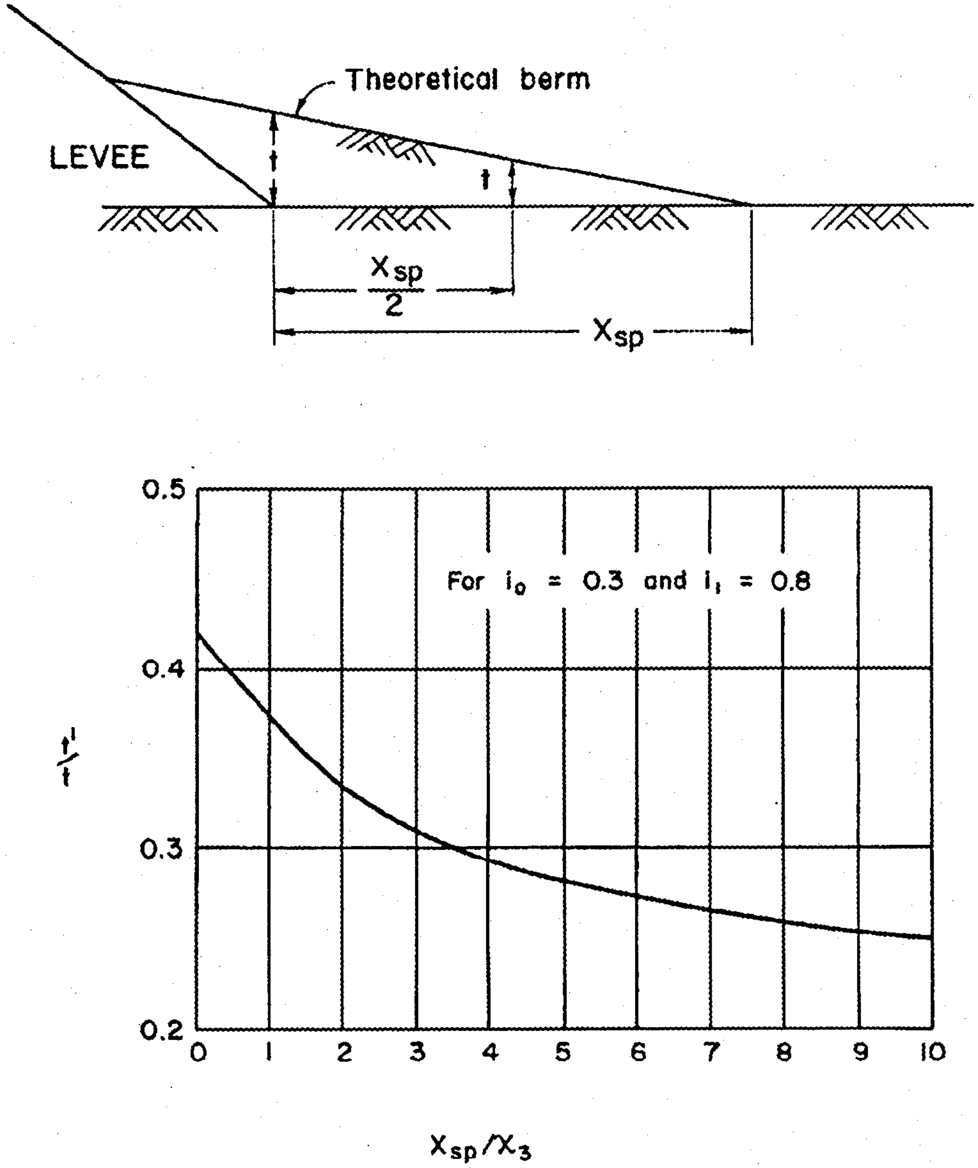

START
Examine past seepage records, geologic and soils data, and man-made features. Determine H, χ_1, s, d, k_f, k_{bL}, Z_{bL}, and Z_t
Is landside blanket present?
Yes
No
compute h_0 and i at LS toe of levee without a berm.
i > 0.8?
Yes
No
Design berm for $i_0 = 0.3$ and i_t=0.8, use t = 1.25x computed t, and x = the computed x, but not to exceed 300 to 400 ft.
Is berm smaller than minimum berm?
No
Yes
Use design berm.
i between 0.5 and 0.8?
Yes
No
Use standard minimum berm: x = 150 ft, t = 5 ft with a crown 2-ft thick.
Is Creep ratio ≥ Bligh's creep ratio?
Yes
No
Construct Flow Net
Severe seepage observed?
Yes
No
Is i < 0.5 ?
Yes
No
Is seepage expected to soften LS portion of levee?
Yes
No
Berm not required.
Design berm for i_0 = 0.3 and i_t=0.8 with 150 ≤ x ≤ 400 ft use t = 1.25x computed t
Riverside blanket present?
No
Yes
Use design berm.
Is Q_s > 200 gpm per 100 ft of levee?
No
Yes
Design RS blanket with width = X_B to reduce Q_S to 200 gpm per 100 ft of levee.



NOTE: For Nomenclature and Formulas, refer to Plate 1.

Curves are for $i_o = 0.30$ and $i_t = 0.80$

CURVES FOR DESIGN OF SEMI-PERVIOUS LANDSIDE SEEPAGE BERMS



THEORETICAL SHAPE OF SEMI-PERVIOUS LANDSIDE SEEPAGE BERM

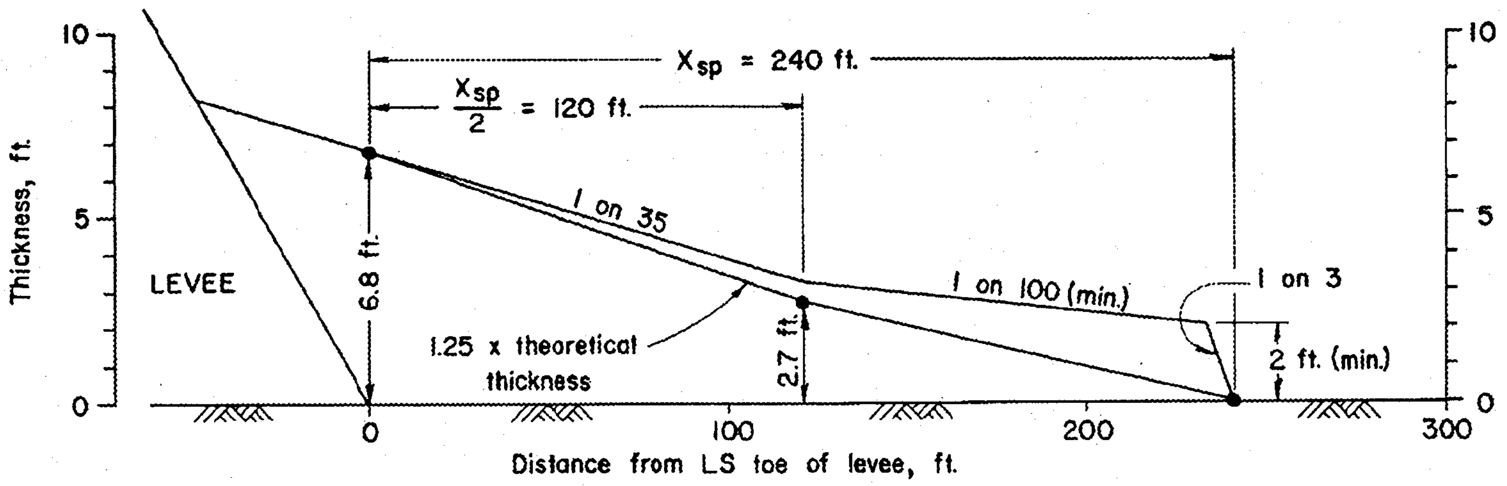
Assume: $H = 20$ ft., $s = 750$ ft., $d = 100$ ft., $k_f = 1250 \times 10^{-4}$ cm/sec, $z_{bL} = z_t = 8$ ft. of clay, and $k_{bL} = 2.9 \times 10^{-4}$ cm/sec with $L_3 = \infty$.

Problem: Design a berm for $i_o = 0.3$ and $i_1 = 0.8$

Procedure:

$$X_3 = \sqrt{\frac{k_f}{k_{bL}} z_{bL} d} = 585 \text{ ft.}$$

From Plate 1, $X_{sp} = 240$ ft. and $t = 5.4$ ft. Increasing t 25% for berm shrinkage, foundation settlement, and variations in design factors results in a thickness of 6.8 ft. $X_{sp}/X_3 = 240/585 = 0.41$. From plate 9, $t'/t = 0.4$ or $t' = 0.4 \times 6.8 = 2.7$ ft. including the 25% increase. These values of t and t' are plotted below together with a berm with broken surface slope which would suffice.



DESIGN OF SEMI-PERVIOUS BERM WITH BROKEN SURFACE SLOPE

Engineering and Design, Soil Mechanics Design Data
SECTION 8 - GROUND WATER AND SEEPAGE
Part 1 - Principles of Control of Ground Water and Seepage
Item 1 - Introduction

Introduction

1. Water-retaining flood-control and navigation structures are subject to seepage through, under, or around them. If uncontrolled, seepage may adversely affect the stability of the structure due to development of excessive uplift forces and loss of support from erosion. Thus, the seepage must be investigated in design and controlled where critical to insure the safety of the structure. Construction of structures frequently requires excavation below the water table into water bearing soils. In such excavations it is necessary to lower the water table below the slopes and bottom of the excavation to prevent slopes from sloughing and provide firm, stable surfaces for construction. Excavations for some structures may be underlain by a pervious stratum under artesian pressure, which, if not relieved, may rupture the bottom of the excavation causing sand boils and loss of foundation material.

2. When designing a water-retaining structure, the seepage problem expected after the structure is completed must be considered and the results of the seepage study and design of control measures reported in an appropriate portion of a feature design memorandum. The need for dewatering and/or pressure relief during construction also should be considered and reported in the memorandum.

3. This section contains procedures, equations, and a limited number of numerical examples to help the engineer accomplish the following:

a. Investigate the safety of structures with respect to seepage.

b. Design permanent drainage and seepage control measures to insure the safety of structures with respect to seepage.

c. Design construction dewatering and pressure relief systems for structure excavations.

d. Present the pertinent data and results of seepage analyses in design memoranda.

e. Prepare specifications which will help insure adequate dewatering facilities and proper installation and construction of seepage control measures.

4. The accuracy of seepage analyses and designs is affected by the accuracy of design assumptions and equations; reliability of permeability coefficients, stratum thicknesses, distance to source of seepage; seepage boundary conditions; and other factors. The designer must carefully examine and interpret all assumptions and field and laboratory data. Even then, conditions used in design probably will not coincide with those in the field. To allow for such deviations, an appropriate factor of safety must be used. The performance of important structures should be checked by installing and observing piezometers at potentially critical points.

Engineering and Design, Soil Mechanics Design Data
SECTION 8 - GROUND WATER AND SEEPAGE
Part 3 - Drainage Slots
Item 1 - Introduction

1. Many seepage problems can be solved by considering the flow from a source of seepage to a drainage slot. For example, where a drainage system consists of a relatively long gravel-filled trench, the trench can be treated as a drainage slot or a line sink. Also, an approximate solution for the drawdown produced by a line of closely spaced wells can be obtained by considering the well line equivalent to a line sink. This assumption is valid for wells having a spacing (a) not greater than about 6.5 times the effective well radius (r_w). In many cases a well system can be simulated by a slot and equations for flow to and drawdown caused by a slot are useful in evaluating flow to wells in complex systems.

2. The equations for flow to and drawdown from a slot presented in this part are based on the assumption that the slot and line source of seepage are infinite in length, and the flow per unit length of the slot is constant. Where a slot of finite length is a distance L from an infinite line source of seepage, the flow to the slot will be the same as if the slot were of infinite length except within a distance of about 0.5 L from each end of the slot. Near the ends of the slot the flow will be greater and the head reduction less than if the slot were of infinite length. Conditions near the ends of the slot can be evaluated from a plan flow net as described in this section. The equations also are based on the assumption that no hydraulic head loss occurs at the slot from the water entering it. Corrections to the water level in the slot and/or piezometric surface between the slot and source should be made after the hydraulic head loss is determined from data presented subsequently in this section.

Engineering and Design, Soil Mechanics Design Data
SECTION 8 - GROUND WATER AND SEEPAGE
Part 3 - Drainage Slots
Item 2 - Flow from Line Source of Seepage to Slot

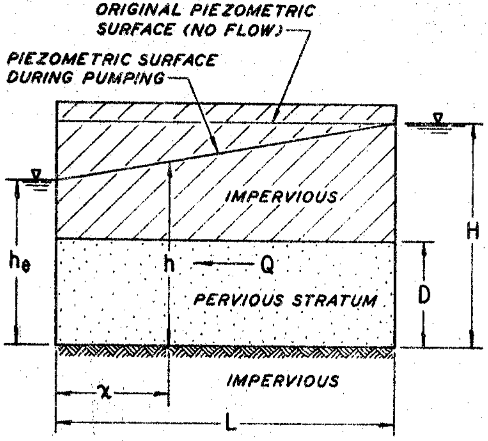
Fully penetrating slots

1. Equations for flow to and drawdown from a line source of seepage to a fully penetrating slot are shown for artesian conditions in Fig 1 of Plate 1, Item 2. In the artesian case, the piezometric surface in the pervious stratum is at or above the top of this stratum.

2. Fig 2 of Plate 1, Item 2, shows conditions for gravity or unconfined flow from a line source of seepage to a fully penetrating drainage slot. For the gravity case, the uppermost flow line or phreatic surface lies entirely below the top of the pervious stratum. Due to free discharge at the slot the phreatic surface at the slot will be at a height (h_s) above the water surface in the slot. The height (h_s) of free discharge can be computed from Fig 4 of Plate 1, Item 2. From Fig 4 it can be seen that h_s is small where the length of seepage path (L) is large compared to the head (H) and where the drawdown ($H-h_o$) at the slot is small.

3. When pumping from a well or drainage system it may be necessary to lower the ground water below the top of the pervious stratum. In such a case, if the head at the source is above the top of the pervious stratum the flow pattern is referred to as artesian-gravity flow. Conditions for this case are shown in Fig 3, Plate 1 of this item. The value of h_s can be obtained from Fig 4 of this plate using L_G for L and D for H.

4. A sample computation illustrating the use of Fig 4, Plate 1 is shown on Plate 2 for a gravity flow case. The computation is for computing the discharge required to lower the ground water beneath an excavation.



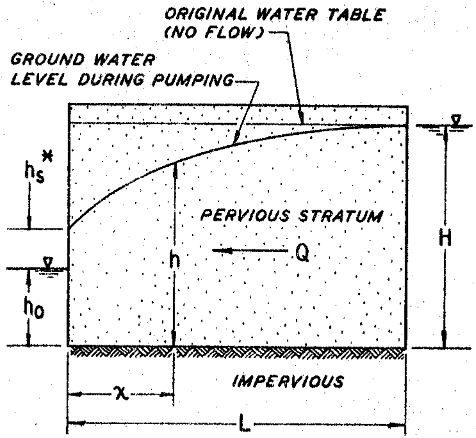
$$Q = \frac{kD}{L}(H - h_e) \qquad (2\text{-}1)$$

Q = FLOW PER UNIT LENGTH OF SLOT

$$h = \frac{Q\chi}{kD} + h_e \qquad (2\text{-}2)$$

$$H - h = \frac{Q}{kD}(L - \chi) = \frac{L - \chi}{L}(H - h_e) \qquad (2\text{-}3)$$

FIG. 1. ARTESIAN FLOW



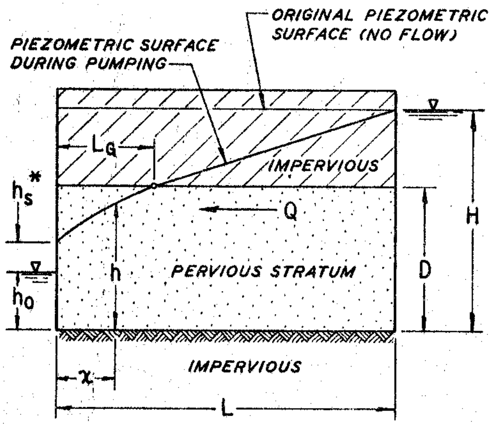
$$Q = \frac{k}{2L}(H^2 - h_0^2) \qquad (2\text{-}4)$$

$$h^2 = \frac{\chi}{L}\left[H^2 - (h_0 + h_s)^2\right] + (h_0 + h_s)^2 \qquad (2\text{-}5)$$

$$H^2 - h^2 = \frac{L - \chi}{L}\left[H^2 - (h_0 + h_s)^2\right] \qquad (2\text{-}6)$$

* SEE FIGURE 4

FIG. 2. GRAVITY FLOW



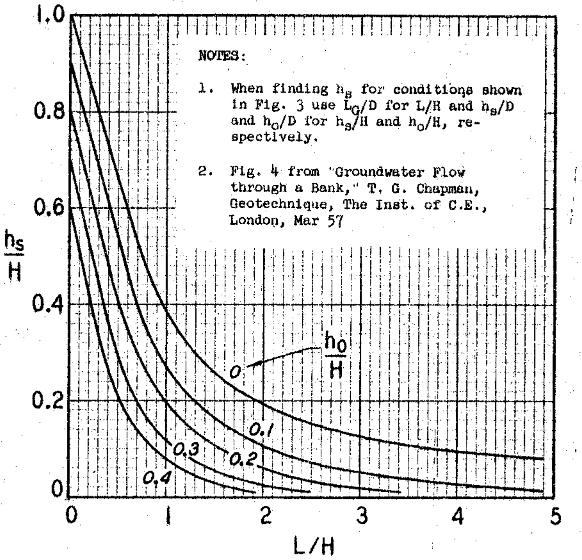
$$Q = \frac{k}{2L}(2DH - D^2 - h_0^2) \qquad (2\text{-}7)$$

$$L_G = \frac{L(D^2 - h_0^2)}{2DH - D^2 - h_0^2} \qquad (2\text{-}8)$$

$$\text{For } \chi \leqq L_G,\ h = \sqrt{\frac{\chi}{L_G}\left[D^2 - (h_0 + h_s)^2\right] + (h_0 + h_s)^2} \qquad (2\text{-}9)$$

$$\text{For } \chi \geqq L_G,\ h = \left(\frac{H - D}{L - L_G}\right)(\chi - L_G) + D \qquad (2\text{-}10)$$

FIG. 3. COMBINED ARTESIAN-GRAVITY FLOW

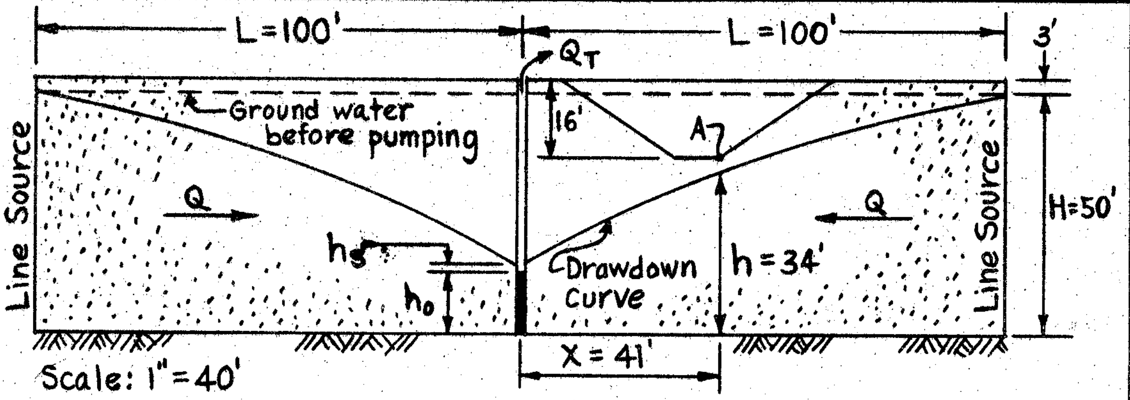


NOTES:

1. When finding h_s for conditions shown in Fig. 3 use L_G/D for L/H and h_s/D and h_0/D for h_s/H and h_0/H, respectively.
2. Fig. 4 from "Groundwater Flow through a Bank," T. G. Chapman, Geotechnique, The Inst. of C.E., London, Mar 57

FIG. 4. Correction factor for height of free discharge surface

FLOW FROM A LINE SOURCE OF SEEPAGE TO A FULLY PENETRATING SLOT OR SINK, BOTH OF INFINITE LENGTH



Problem: To determine the total flow Q_T required to lower ground water 3 feet below point A in a long excavation as shown above. Assume two parallel line sources of seepage.

Known: L = 100 ft, H = 50 ft, X = 41 ft, h = 34 ft, k = 0.1 ft/min.

Solution:

* 1) Solve for (h_o+h_s) in Eq. (2-5) on Plate 1 of this part & item: *

$$(34)^2 = \frac{41}{100}\left[(50)^2 - (h_o+h_s)^2\right] + (h_o+h_s)^2$$

h_o+h_s = 14.9 ft, say 15 ft

* 2) As Q is a function of h_o, h_o must be determined by successive trials from Fig. 4 on Plate 1 of this part and item by determining values of h_o and hs so that (h_o+h_s) = 15', with L/H = 2.0: *

h_o/H	h_s/H	h_o	h_s	h_o+h_s
0.20	0.06	10	3.0	13.0
0.26	0.04	13	2.0	15.0
0.30	0.03	15	1.5	16.5

Thus h_o = 13.0 ft, h_s = 2.0 ft

* 3) From Eq. (2 - 4) on Plate 1 of this part and item compute Q for h_o = 13.0 ft *

$$Q = \frac{0.1}{2(100)}\left[(50)^2 - (13)^2\right] = 1.16 \text{ cfm/foot of slot.}$$

The total flow per foot of slot = Q_T = 2Q = 2.32 cfm/ft

COMPUTATION OF GRAVITY FLOW TO A LONG, FULLY PENETRATING SLOT FROM TWO EQUALLY SPACED, PARALLEL LINE SOURCES.

Engineering and Design, Soil Mechanics Design Data
SECTION 8 - GROUND WATER AND SEEPAGE
Part 3 - Drainage Slots
Item 3 - Artesian Flow to a Slot Midway Between and Parallel to Two Line Sources of Seepage

1. Equations for flow and drawdown from two line sources of seepage to a fully or partially penetrating slot for artesian conditions are shown in Fig. 1 on Plate 1, Item 3.

2. Fig. 2 and 3 on Plate 1, Item 3 give the values of the factors (λ) and (f), respectively, to be used in the equations for head and discharge. The basic data used to determine these factors were obtained from a two-dimensional, electrical analogy model.

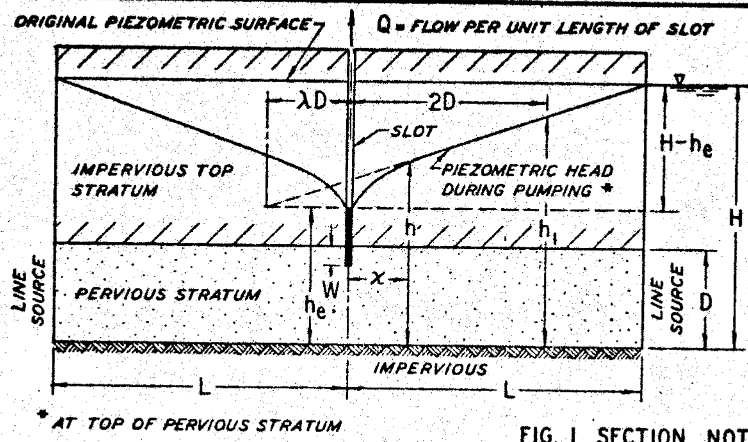
3. Bases for the development of the equations and factors are as follows: (Refer to Fig. 1 on Plate 1, Item 3.)

a. The extra length factor (λ) varies with slot penetration (W/D), increasing from zero at 100% slot penetration to infinity at 0% slot penetration. Fig. 2 on Plate 1, Item 3, gives this relationship, and is used to determine the value of (λ) for a given slot penetration to compute the extra length (λD). The extra length distance (λD) must be known to compute the flow (Q), Eq. (3-1), and the slope of the hydraulic grade line between $x = 2D$ and $x = L$.

b. Beyond a distance 2D from the slot, the equipotential lines are essentially vertical, indicating horizontal flow between the source and this point. Therefore the head (h) at any point between $x = 2D$ and $x = L$ will vary linearly from a value h_1 at $x = 2D$ to H at the source ($x = L$). The head (h_1) is computed from Eq. (3-2). The head (h) can be computed from Eq. (3-4) for any value of (x) between 2D and L.

c. Between the slot ($x = 0$) and $x = 2D$, the flow and equipotential lines are curved if the slot does not fully penetrate the pervious stratum due to the flow converging into the slot. In this region the head (h) at the top of the pervious stratum can be computed at any distance (x) from Eq. (3-3), after first determining the head factor (f) for the value of (x) from Fig. 3 on Plate 1, Item 3.

4. An example of the use of the equations and data on Plate 1, Item 3 is shown on Plate 2, Item 3. The computation is for the discharge required to lower the piezometric head beneath a shored excavation for a slot of given penetration.



* AT TOP OF PERVIOUS STRATUM

$$Q = \frac{2KD(H-h_e)}{L+\lambda D} \quad \text{(3-1)}$$

$$h_1 = \frac{D(\lambda+2)(H-h_e)}{L+\lambda D} + h_e \quad \text{(3-2)}$$

For $x \leq 2D$, $h = f(h_1 - h_e) + h_e$ (3-3)

For $2D \leq x \leq L$, $h = \frac{(h_1-h_e)(\lambda D + x)}{D(\lambda+2)} + h_e$ (3-4)

FIG. 1. SECTION, NOTATIONS AND EQUATIONS

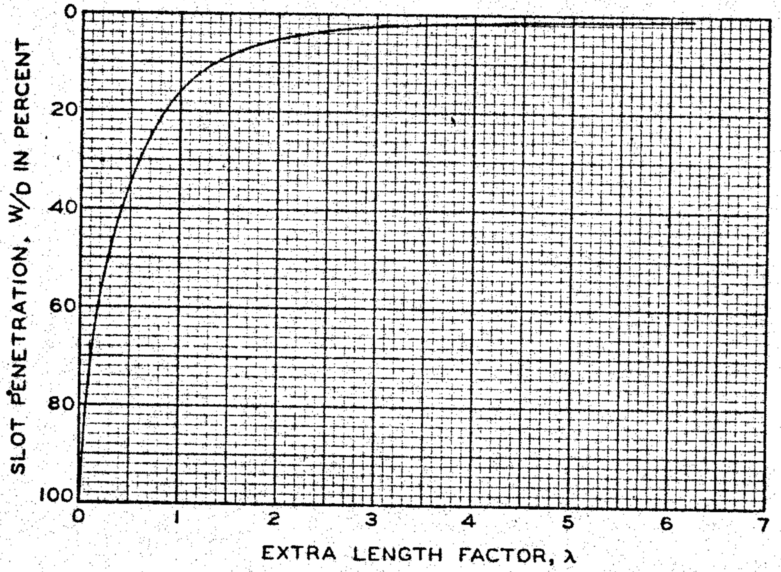


FIG. 2. EXTRA LENGTH FACTOR, λ

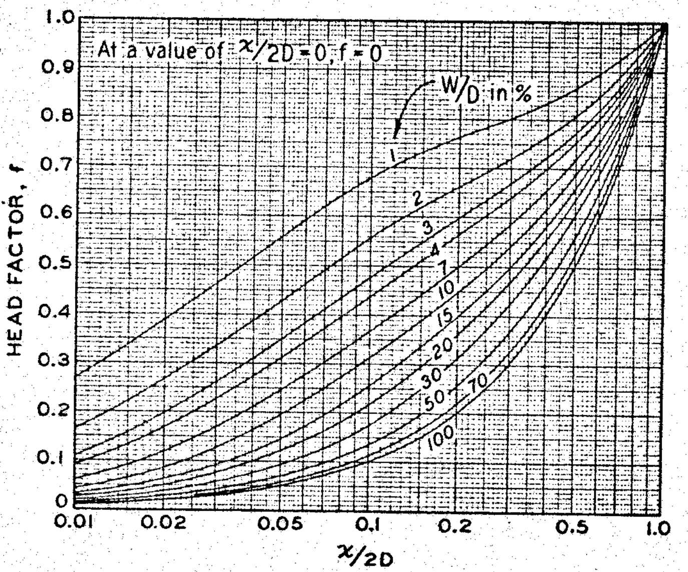
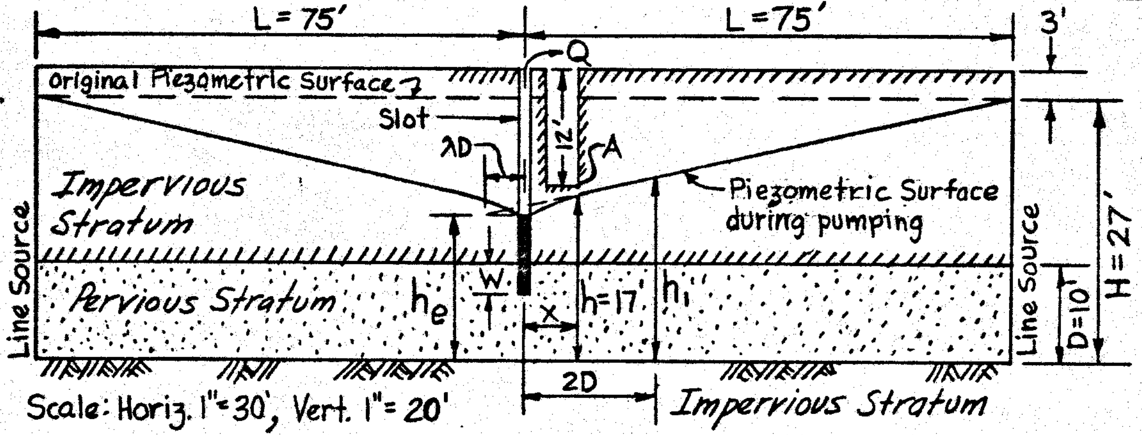


FIG. 3. HEAD FACTOR, f

ARTESIAN FLOW TO A SLOT MIDWAY BETWEEN AND PARALLEL TO TWO LINE SOURCES OF SEEPAGE



Problem: To determine the flow Q required to lower the piezometric head in the pervious stratum one foot below point A in a long, shored excavation as shown above.

Known: $L = 75$ ft, $H = 27$ ft, $D = 10$ ft, $W = 3$ ft, $x = 8$ ft,
$h = 17$ ft, $k = 0.02$ ft/min

Solution:

1) From Fig. 2 on Plate 1 of this part and item, obtain λ for $W/D = 0.30$. $\lambda = 0.59$

2) From Fig. 3 on Plate 1 of this part and item, obtain the head factor f for $W/D = 0.30$ and $x/2D = 0.40$. $f = 0.516$

3) Using Eq. (3-2) on Plate 1 of this part and item, obtain an expression for h_1 in terms of h_e

$$h_1 = \frac{10(0.59 + 2)(27 - he)}{75 + 0.59(10)} = 8.64 + 0.68\, h_e$$

4) As $x < 2D$, substitute the above expression for h_1 in Eq. (3-3) on Plate 1 of this part and item, which gives

$$17 = 0.516 \left[(8.64 + 0.68\, h_e) - h_e\right] + h_e$$
$$h_e = 15.1 \text{ ft}$$

5) From Eq. (3-1) on Plate 1 of this part and item, compute Q

$$Q = \frac{2(0.02)(10)(27 - 15.1)}{75 + 0.59(10)} = 0.058 \text{ cfm/ft of slot}$$

COMPUTATION OF ARTESIAN FLOW TO A LONG, PARTIALLY PENETRATING SLOT FROM TWO EQUALLY SPACED LINE SOURCES