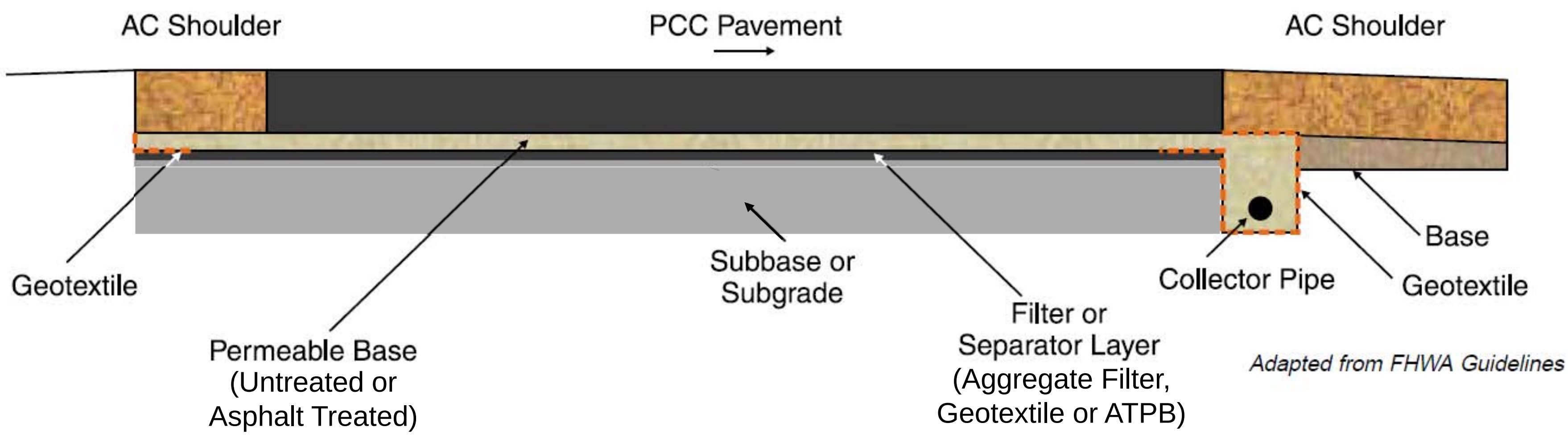
Subsurface Drainage Structures

Subsurface Drainage Structures



Source: "Making Edge Drains Work," *Better Roads*, January 2007

Permeability of Clean Sands

permeability
(cm/s)

effective
grain size
(mm)

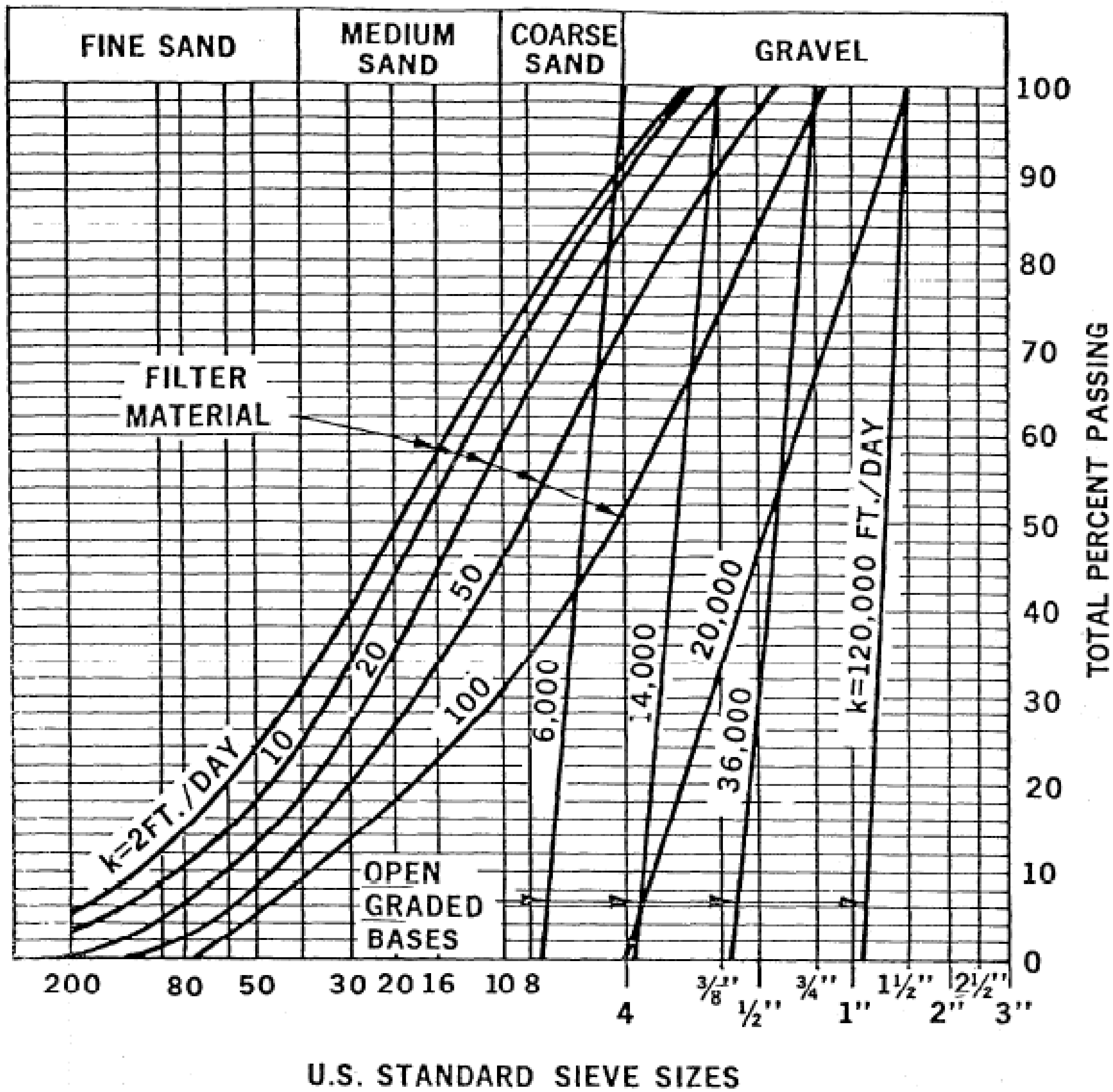
$$k = C_k D_{10}{}^2$$

Hazen's
coefficient
(0.8 - 1.2)

Permeability of Drainage Materials

$$k = (6.214 \times 10^5) \frac{{D_{10}}^{1.478} n^{6.654}}{{P_{200}}^{0.597}}$$

- k: permeability (ft/day)
- D_{10}: effective grain size (mm)
- n: porosity
- P_{200}: portion passing No. 200 sieve (%)



Source: Moulton (1990) "Highway Subdrainage Design," FHWA TS-80-224

Effective Porosity and Water Loss

$$n_e = n - \frac{\gamma_d w_c}{\gamma_w}$$

$$n = 1 - \frac{\gamma_d}{G_s \gamma_w} = \frac{G_s \gamma_w - \gamma_d}{G_s \gamma_w}$$

$$W_L = \frac{n_e}{n} \times 100\%$$

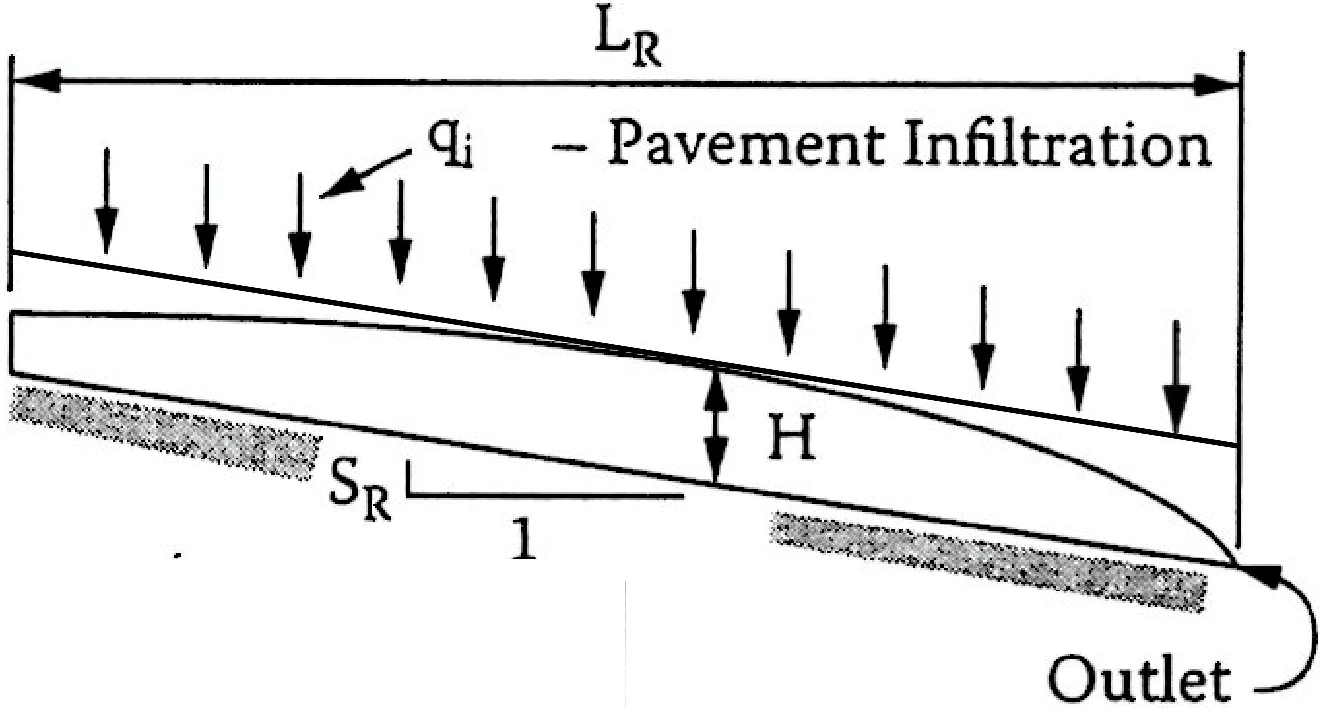
w_c = moisture content after draining

Water Loss Percentage

	< 2.5% Fines			5% Fines			> 5% Fines		
	Filler	Silt	Clay	Filler	Silt	Clay	Filler	Silt	Clay
Gravel	70	60	40	60	40	20	40	30	10
Sand	57	50	35	50	35	15	25	18	8

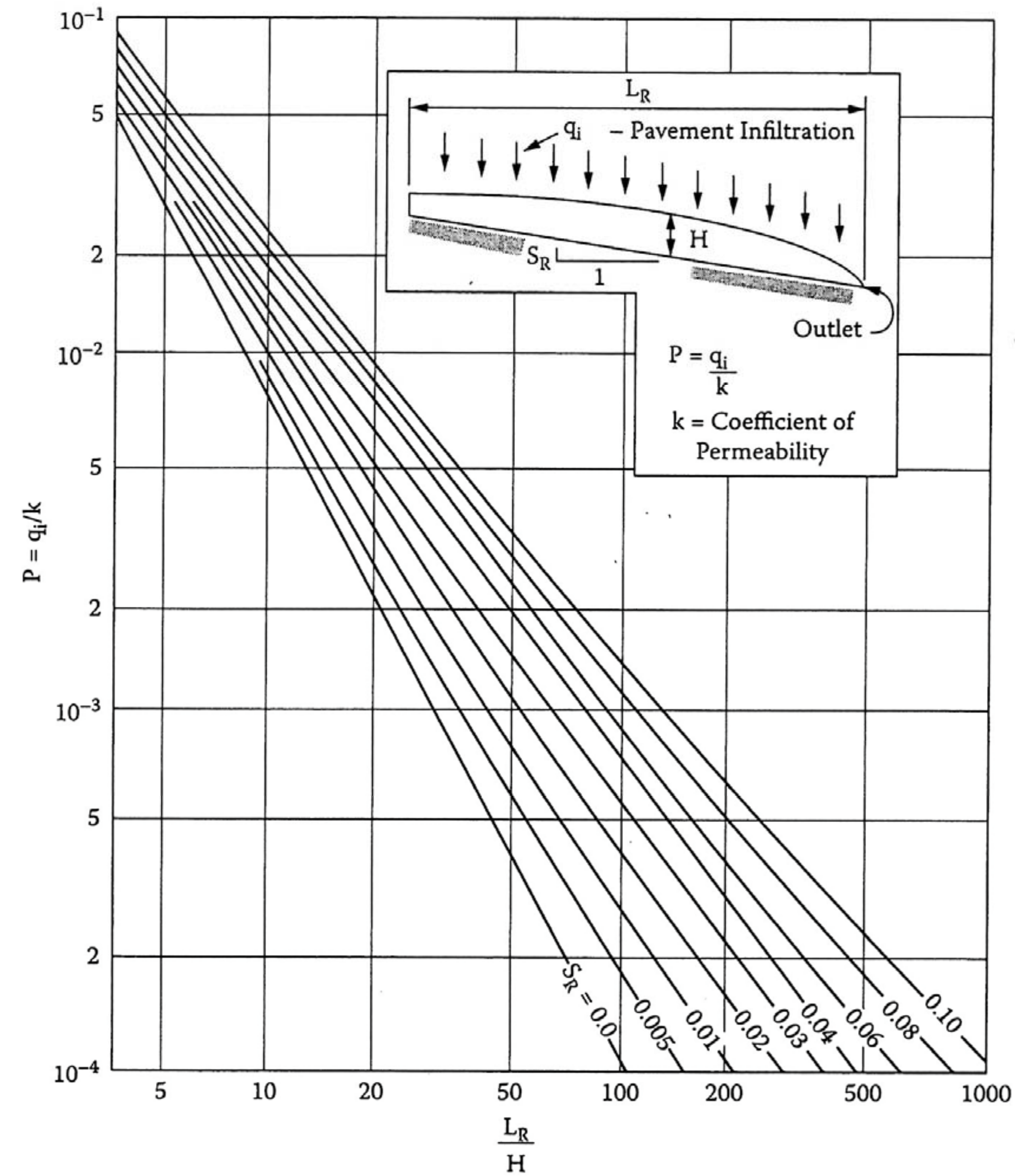
Source: FHWA (1992).

Maximum Depth of Flow



$$H_1 = \sqrt{\frac{q_i}{k} L_R} \left[\left(\frac{S}{\sqrt{\frac{4q_i}{k - S^2}}} \right) \left(\tan^{-1} \frac{S}{\sqrt{\frac{4q_i}{k - S^2}}} - \frac{\pi}{2} \right) \right] \quad (6.19)$$

Figure 6.14



L_R
q_i – Pavement Infiltration
H
S_R
1
Outlet
$P = \frac{q_i}{k}$
k = Coefficient of Permeability
$P = q_i/k$
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
10
20
50
100
200
500
1000
$\frac{L_R}{H}$
$S_R = 0.0$
0.005
0.01
0.02
0.03
0.04
0.06
0.08
0.10

Example 1 (Continued)

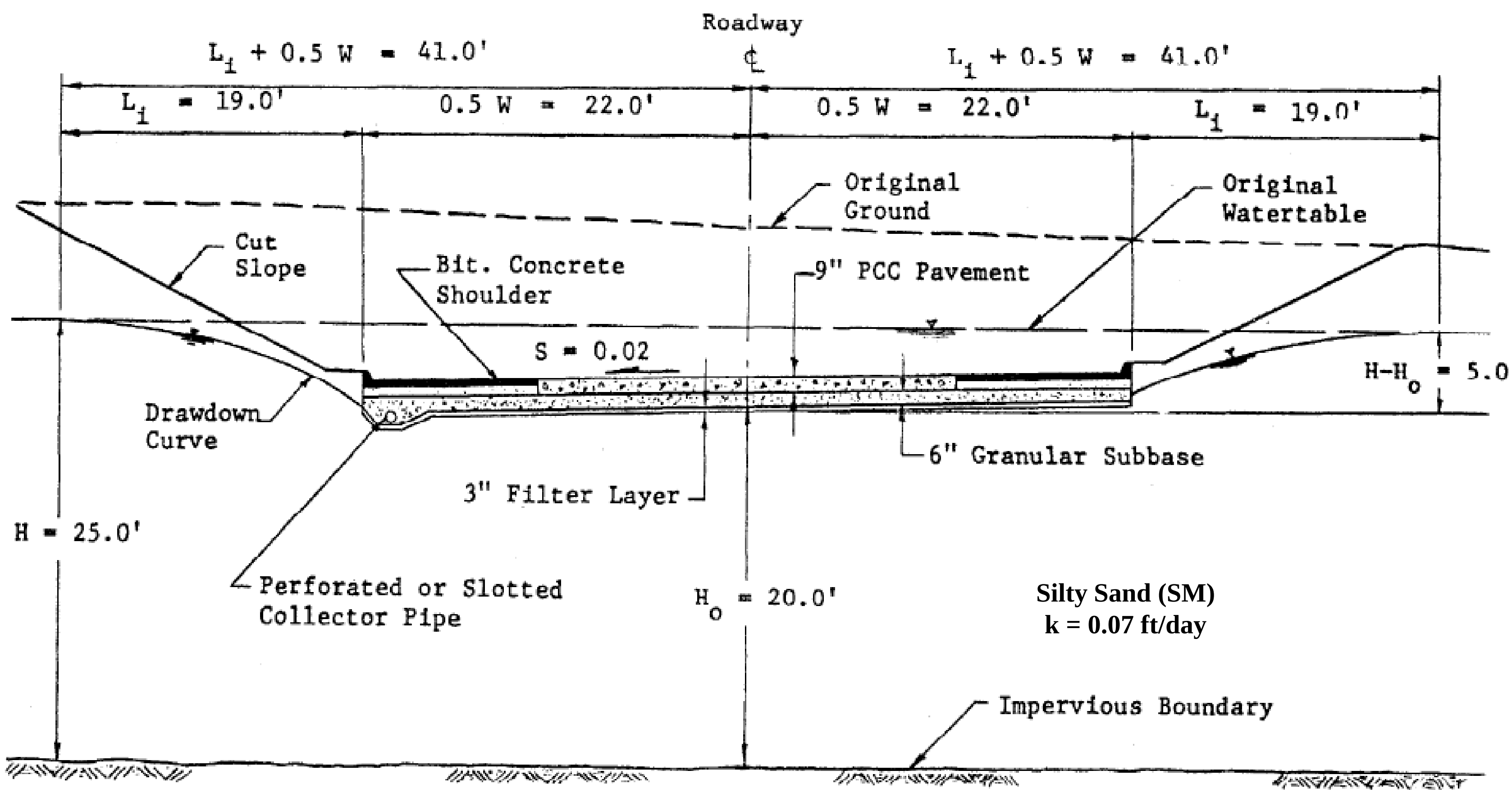
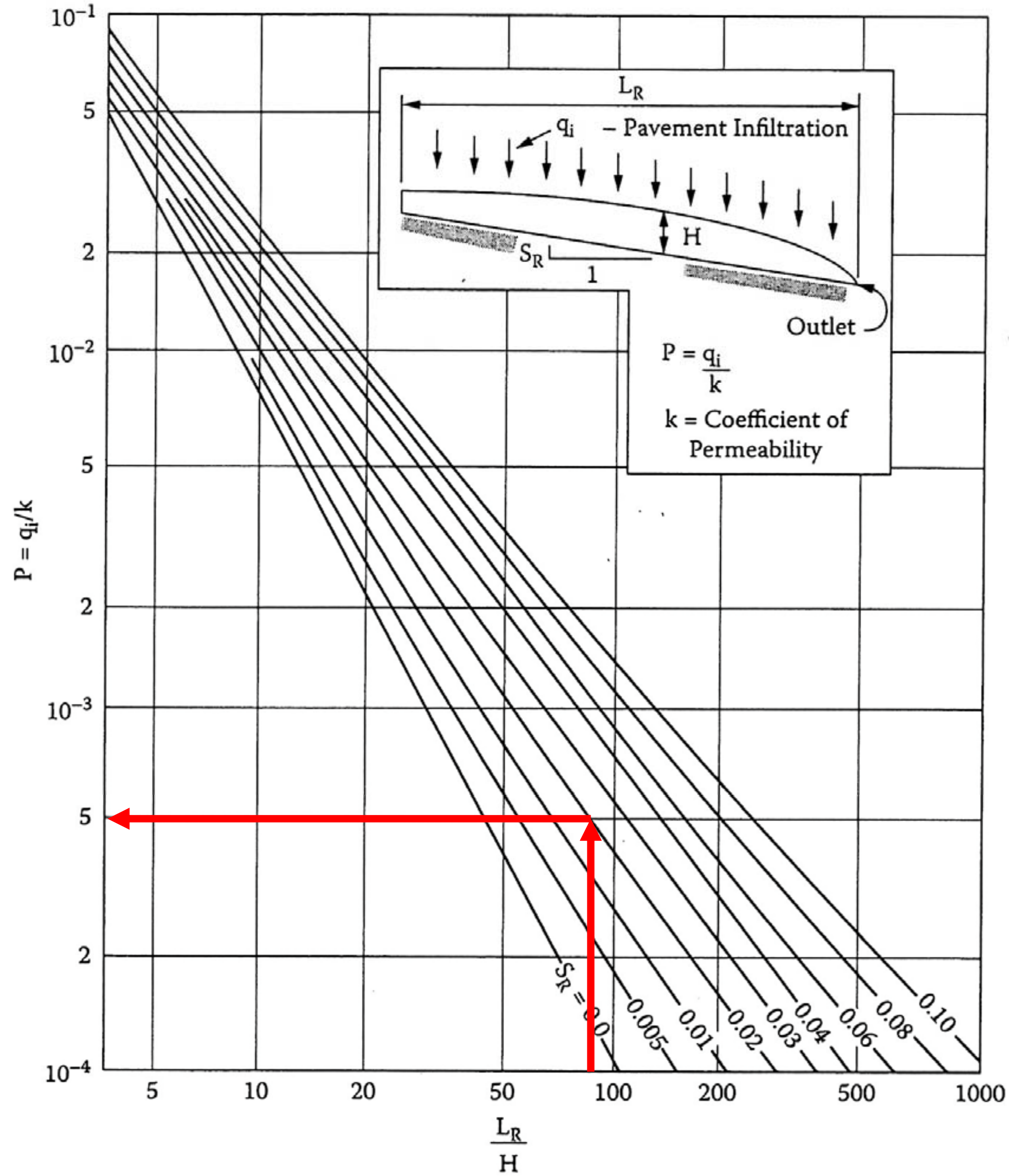
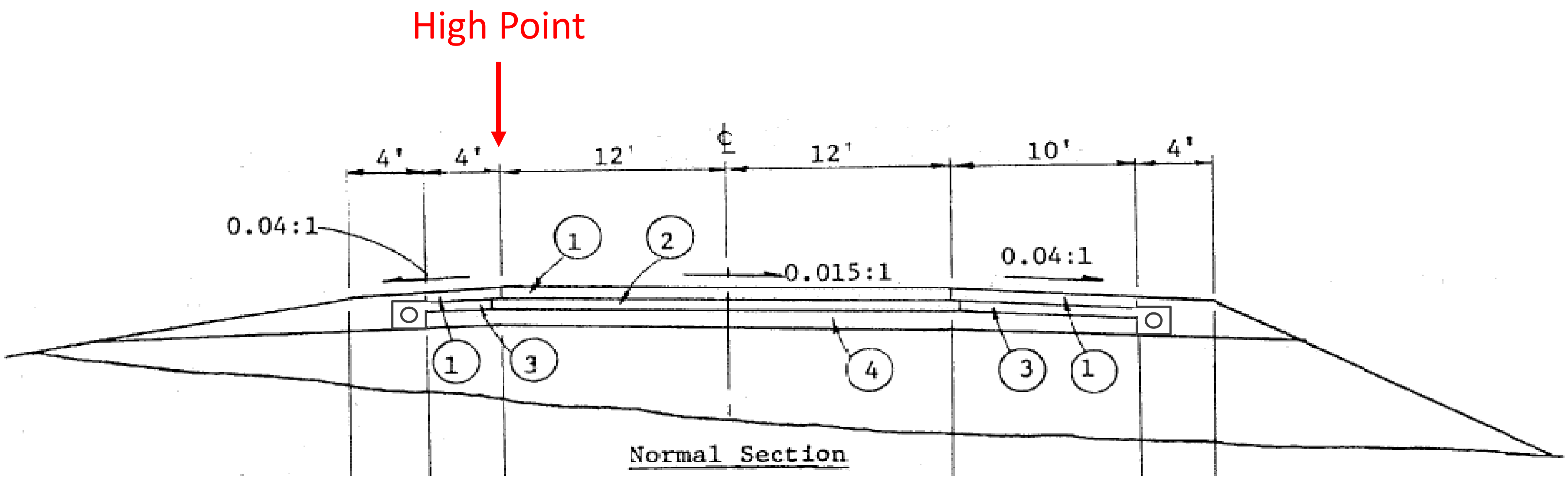


Figure 6.14



L_R
q_i
– Pavement Infiltration
H
S_R
1
Outlet
P = q_i / k
k = Coefficient of Permeability
P = q_i/k
10^-1
5
2
10^-2
5
2
10^-3
5
2
10^-4
5
10
20
50
100
200
500
1000
L_R / H
S_R = 0.0
0.005
0.01
0.02
0.03
0.04
0.06
0.08
0.10

Example 2 (Continued)



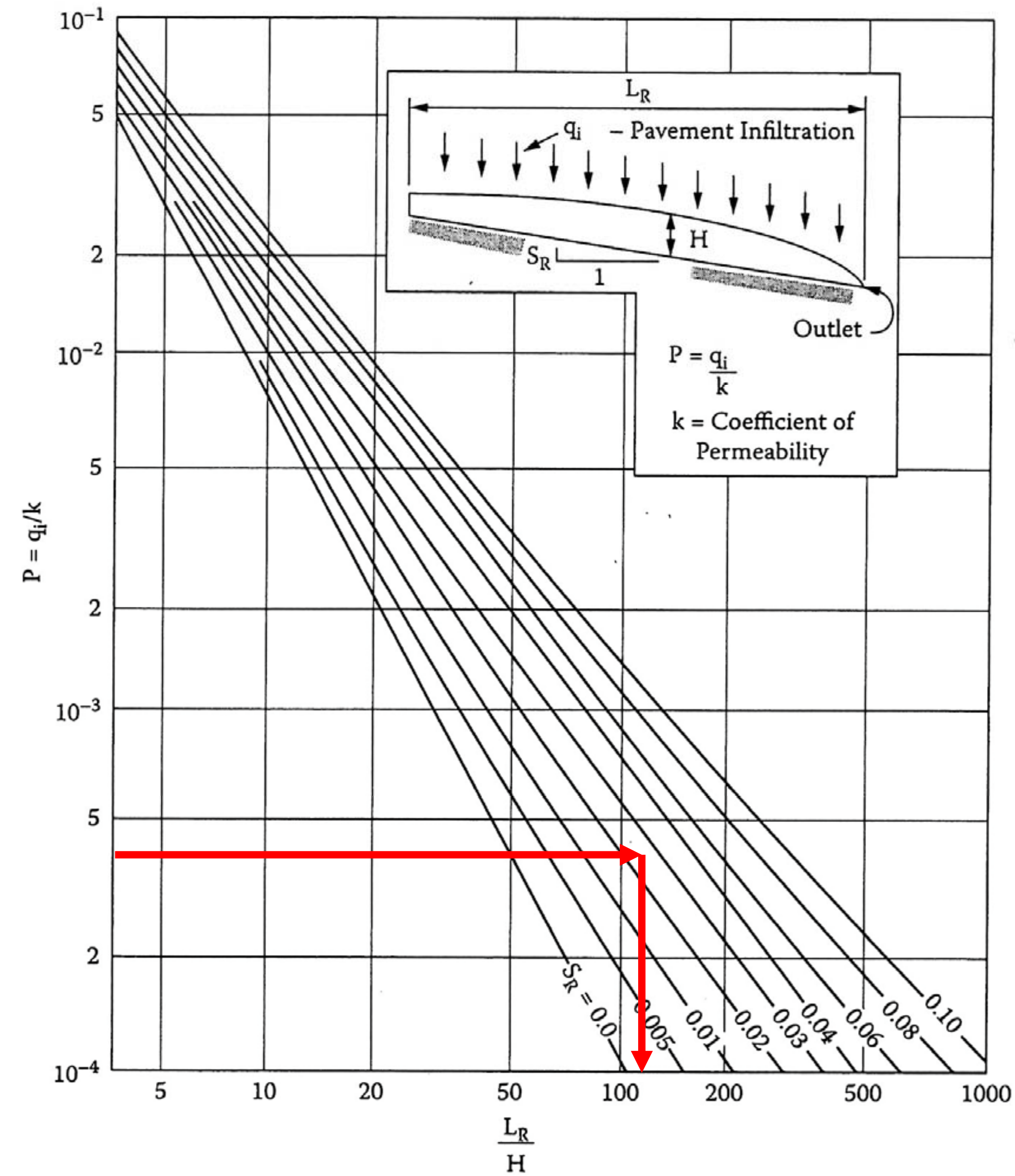
(1) - 6" Hot Mixed Asphaltic Concrete (3" Surf., 3" Binder)

(2) - 6" Cement Stablized Aggregate Base

(3) - 6" Aggregate Base

(4) -12" Dense Graded Aggregate Subbase

Figure 6.14



10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
$P = q_i/k$
5
10
20
50
100
200
500
1000
$\frac{L_R}{H}$
L_R
q_i – Pavement Infiltration
H
S_R
1
Outlet
$P = \frac{q_i}{k}$
k = Coefficient of Permeability
$S_R = 0.0$
0.005
0.01
0.02
0.03
0.04
0.06
0.08
0.10

Casagrande & Shannon

$$T = \frac{tkH}{n_e L_R{}^2} \quad , \quad S_l = \frac{H}{L_R S_R}$$

where: k = permeability of the drainage layer (ft/day)

n_e = effective porosity

H = height of the granular layer (ft)

L_R = length of the drainage path (ft)

S_R = slope of the drainage path (ft/ft)

t = time to drain a given percentage of the moisture (days)

Casagrande & Shannon

For $U \geq 0.5$

$$T = \left(1.2 - \frac{0.4}{\sqrt[3]{S_l}}\right)\left[S_l - S_l^{2}\ln\left(\frac{S_l + 1}{S_l}\right) + S_l \ln\frac{2S_l - 2US_l + 1}{(2 - 2U)(S_l + 1)}\right]$$

For $U \leq 0.5$

$$T = \left(1.2 - \frac{0.4}{\sqrt[3]{S_l}}\right)\left[2US_l - S_l^{2}\ln\left(\frac{S_l + 2U}{S_l}\right)\right]$$

Casagrande & Shannon

For U = 0.5

$$T = \left(1.2 - \frac{0.4}{\sqrt[3]{S_l}}\right)\left[S_l - S_l^{\,2}\ln\left(\frac{S_l + 1}{S_l}\right)\right] = \frac{tkH}{n_e L_R^{\,2}}$$

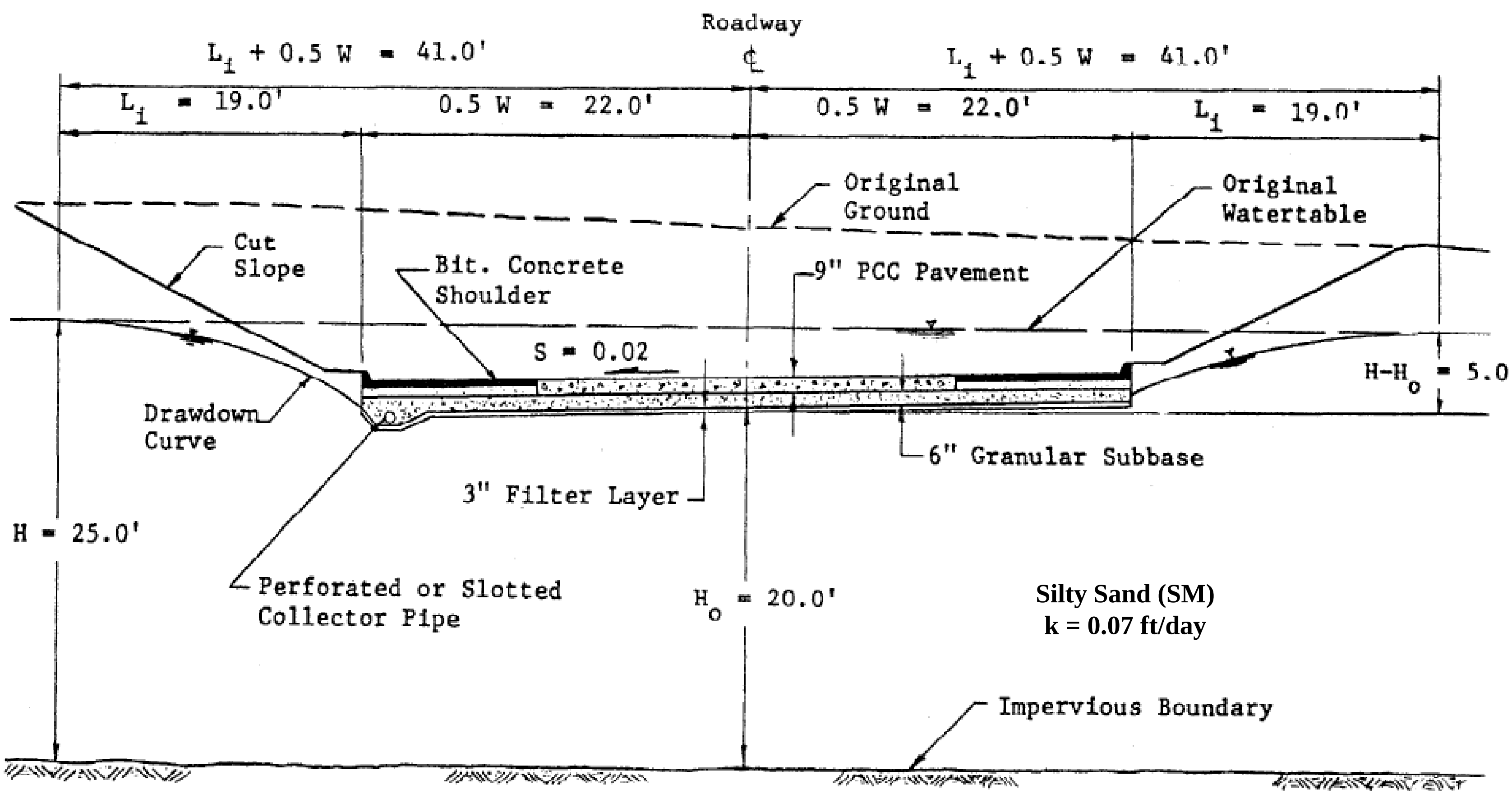
$$S_l = \frac{H}{L_R S_R}$$

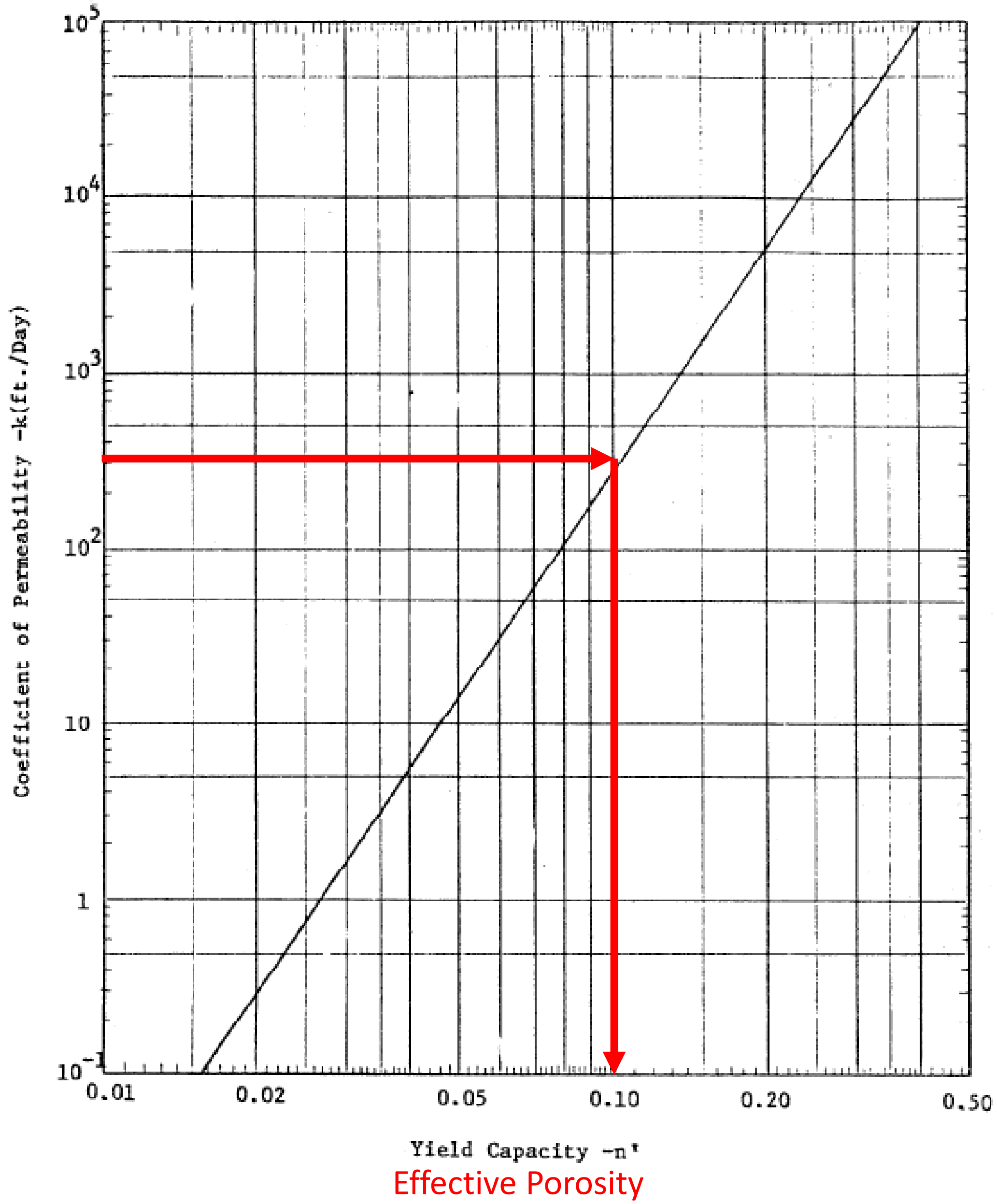
AASHTO Drainage Quality

Water removal time	Quality of drainage
2 h	Excellent
1 Day	Good
1 Week	Fair
1 Month	Poor
Water will not drain	Very poor

Figure 6.16 (Step 1)

Example 1 (Continued)



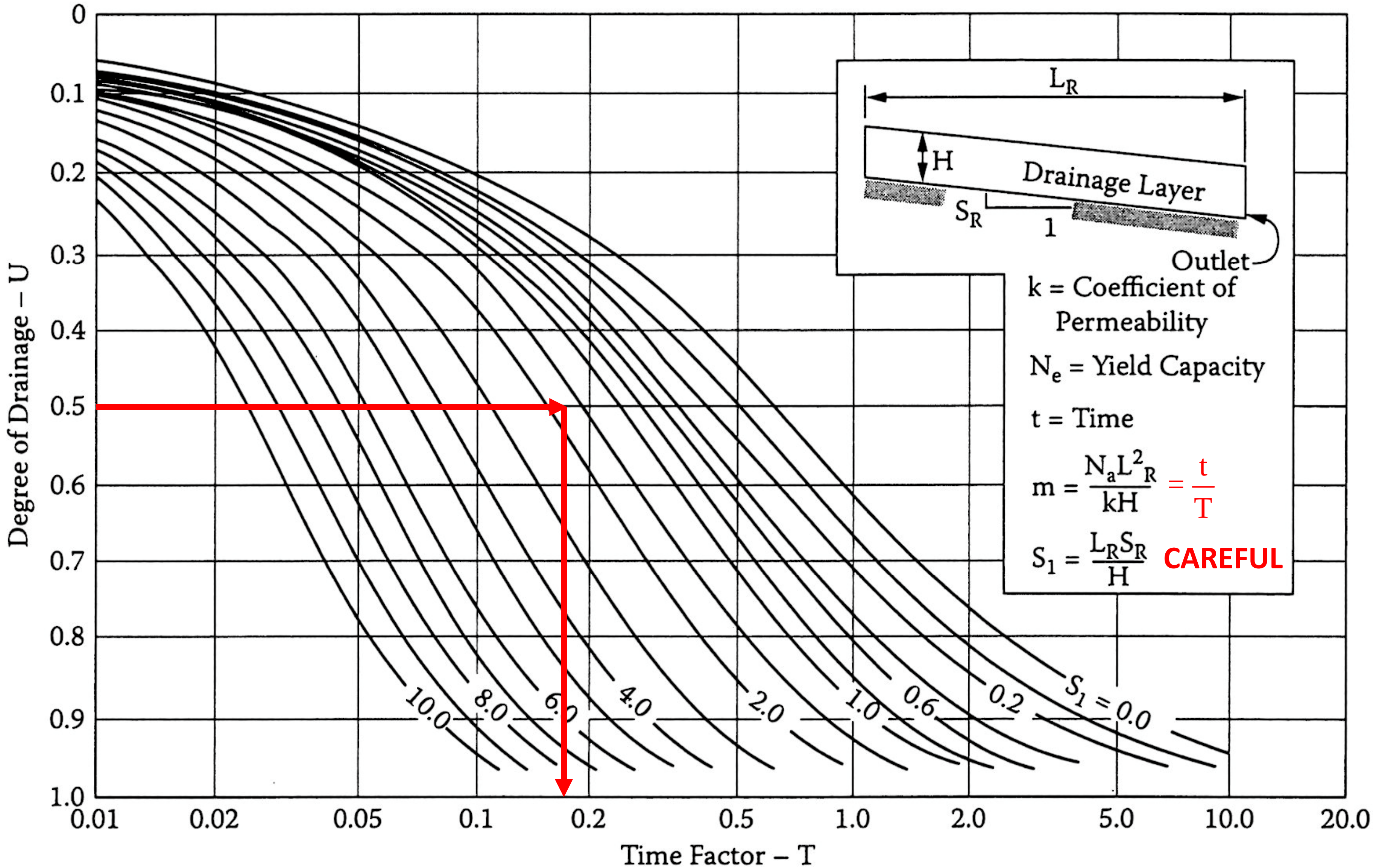


Source: Moulton (1990) "Highway Subdrainage Design," FHWA TS-80-224

Water Loss Percentage

	< 2.5% Fines			5% Fines			> 5% Fines		
	Filler	**Silt**	**Clay**	**Filler**	**Silt**	**Clay**	**Filler**	**Silt**	**Clay**
Gravel	70	60	40	60	40	20	40	30	10
Sand	57	50	35	50	35	15	25	18	8

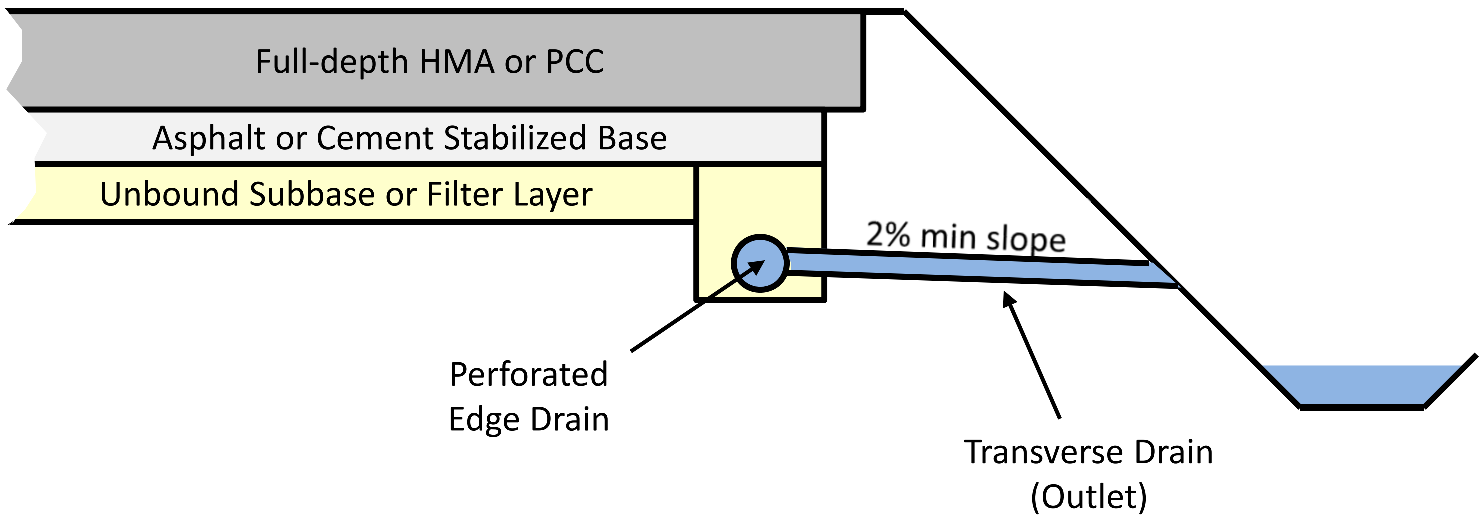
Source: FHWA (1992).



0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Degree of Drainage – U
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2.0
5.0
10.0
20.0
Time Factor – T
10.0
8.0
6.0
4.0
2.0
1.0
0.6
0.2
S1 = 0.0
LR
H
Drainage Layer
SR
1
Outlet
k = Coefficient of Permeability
Ne = Yield Capacity
t = Time
m = NaL2R / kH = t / T
S1 = LRSR / H
CAREFUL

Edge Drain Design

Edge Drain Design



After: TXDOT *Pavement Design Guide*

Design Flow Capacity

$$Q = Q_p L_o$$

Q = pipe flow capacity (ft^3/day or m^3/day)
Q_p = design discharge rate (ft^3/day/ft or m^3/day/m)
L_o = outlet spacing (ft or m)

Design Discharge Rate

(Based on Peak Flow)

$$Q_p = kS_xH$$ ← Blanket is full to the top

k = drainage layer permeability (ft/day or m/day)
S_x = drainage layer transverse slope (ft/ft or m/m)
H = drainage layer thickness (ft or m)

Design Discharge Rate

(Based on Infiltration Rate)

$$Q_p = q_i W$$

q_i = pavement infiltration (ft/day or m/day)
W = drainage layer width (ft or m)

Design Flow

$$q_n = q_i + \max\left(q_g, q_a, q_m\right)$$

Design Discharge Rate

(Based on Infiltration Rate + Groundwater Flow)

$$Q_p = q_n W + q_1 \longleftarrow$$

Groundwater flow from above the drain

q_n = design flow into drainage blanket (ft/day or m/day)
W = drainage layer width (ft or m)
q_1 = gravity drainage (ft/day or m/day)

Design Discharge Rate

(Based on Time to Drain)

$$Q_p = \frac{WHn_eU}{t}$$

W = drainage layer width (ft or m)
H = drainage layer thickness (ft or m)
n_e = drainage layer effective porosity
U = fraction of drainage occuring in time t
t = time for drainage U to be reached (days)

Manning's Equation

$$Q = \frac{K}{n} S^{1/2} R^{2/3} A$$

Q = flow capacity (ft^3/s or m^3/s)
K = conversion factor (1.4859 for English or 1 for metric)
n = Manning's roughness coefficient
S = channel slope (ft/ft or m/m)
R = hydraulic radius (ft or m)
A = cross-sectional area of flow (ft^2 or m^2)

Manning's Equation

$$Q = \frac{K}{n} S^{1/2} \left(\frac{D}{4}\right)^{2/3} \pi \left(\frac{D}{2}\right)^{2}$$

Q = flow capacity (ft^3/s or m^3/s)
K = conversion factor (1.4859 for English or 1 for metric)
n = Manning's roughness coefficient
S = edge drain slope (ft/ft or m/m)
D = pipe diameter (ft or m)

Manning’s Equation

$$Q = \frac{53.01}{n} S^{1/2} D^{8/3}$$

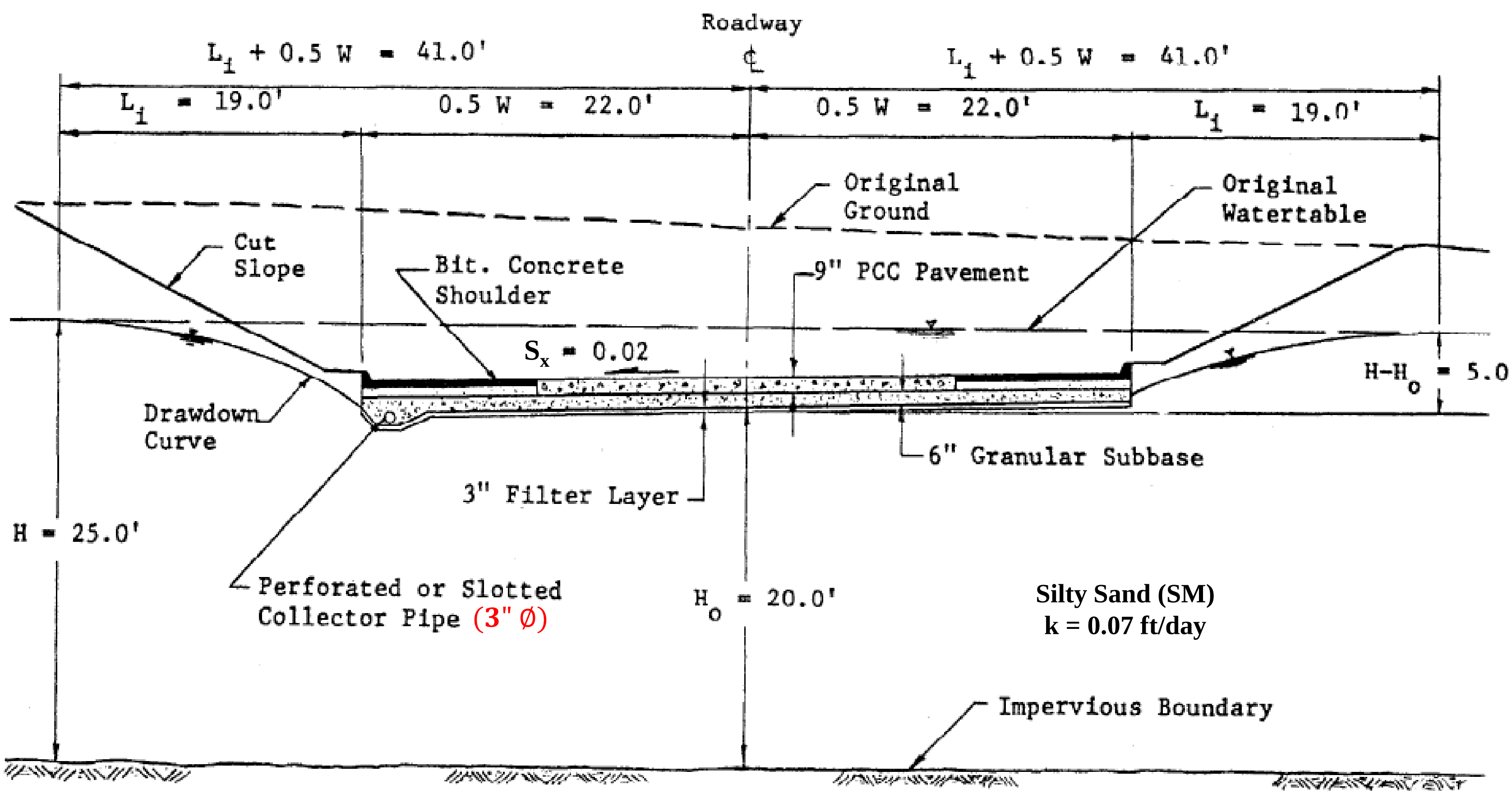
Q = flow capacity (ft^3/day)
n = Manning’s roughness coefficient
S = edge drain slope (ft/ft or m/m)
D = pipe diameter (in)

Typical Drain Pipe

Slotted Drain Pipe
n = 0.012

Corrugated Drain Pipe
n = 0.024

Example 1



Roadway
℄
L_i + 0.5 W = 41.0'
L_i + 0.5 W = 41.0'
L_i = 19.0'
0.5 W = 22.0'
0.5 W = 22.0'
L_i = 19.0'
Original Ground
Original Watertable
Cut Slope
Bit. Concrete Shoulder
9" PCC Pavement
S_x = 0.02
H-H_o = 5.0'
Drawdown Curve
6" Granular Subbase
3" Filter Layer
H = 25.0'
Perforated or Slotted Collector Pipe (3" Ø)
H_o = 20.0'
Silty Sand (SM)
k = 0.07 ft/day
Impervious Boundary