3.13.3 Cofferdam Seal Coat Design

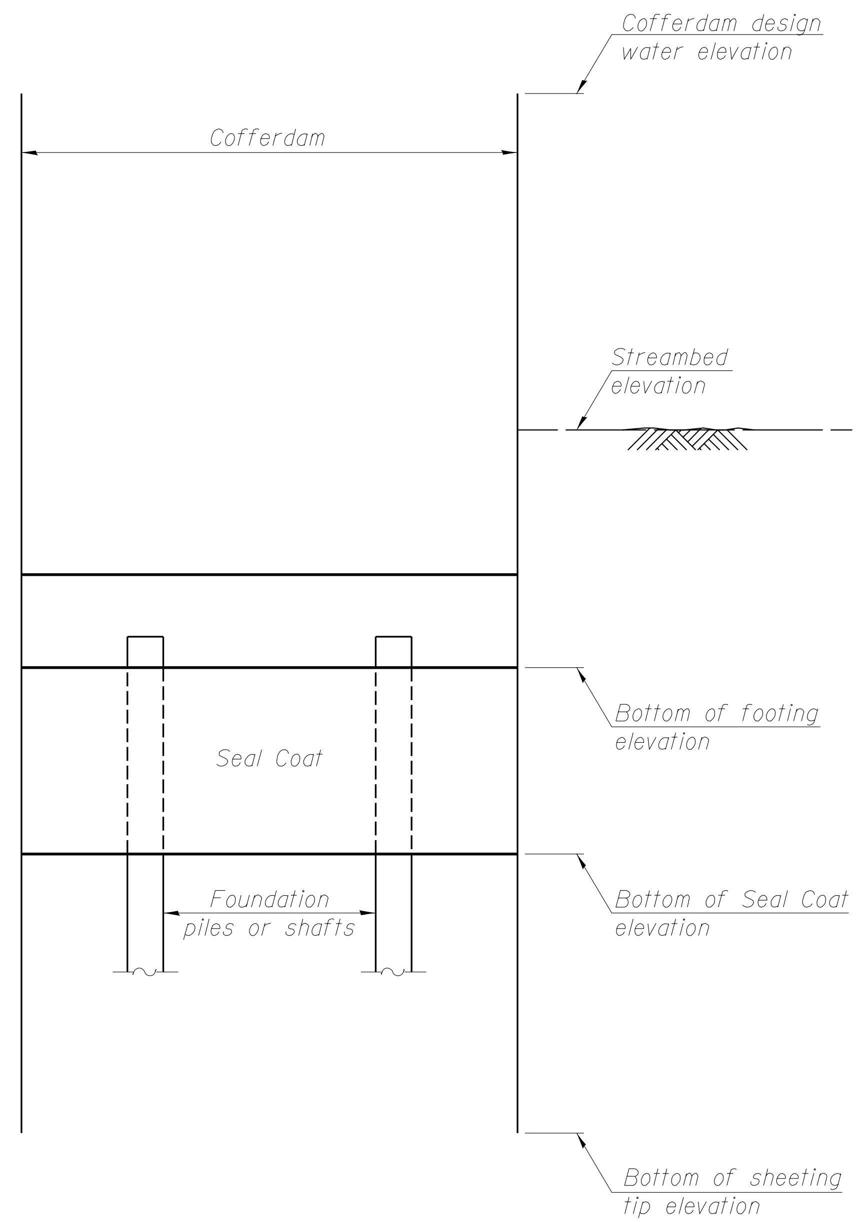
As defined in the Standard Specifications, cofferdams are watertight enclosures surrounding excavations. These enclosures normally consist of sheet piling driven around the perimeter of the excavation. A concrete seal coat and/or rings of wales placed within the sheet piling may also be required. A simple schematic for a cofferdam with seal coat is shown in the drawing below (Figure 3.13.3-1 repeated from the Bridge Manual).

Cofferdam seal coat concrete is used to provide a watertight seal at the bottom of the footing. It shall be Class SC Concrete, tremied underwater after piles, if used, have been driven. Seal coats shall be designed for a specified design water elevation on the outside of the cofferdam. For typical situations, this design water elevation shall be taken as 3 ft. above the Estimated Water Surface Elevation (EWSE). See Section 2.3.6.4.2 of the Bridge Manual for more information on the EWSE.

Cofferdam Seal Coat Design Procedure, Equations, and Outline

The design of a cofferdam seal coat consists of determining a concrete thickness that will be sufficient, in conjunction with other sources of resistance, to counteract the hydrostatic buoyant force produced at the bottom of the seal when the cofferdam is dewatered.

This design guide presents a relatively straightforward approach for seal coat design which produces reliable results for most typical situations. There are many possible failure mechanisms for seal coats. Detailed accounting for all of these during design can be cumbersome. For practicality, simplicity, and uniformity of design methodology, the Department advocates the approach detailed below. The basic method entails calculating minimum resistances for sheet piling and foundation piling separately and adding them to the weight of the cofferdam seal coat in order to determine a conservative total minimum resistance. This total minimum resistance shall be greater than the buoyancy force by a factor of safety of 1.2 as shown in the following equation:



SEAL COAT SCHEMATIC

$$F.S. = \frac{P_{sc} + P_{sp} + P_{fp}}{P_b} > 1.2$$

Where:

P_{sc} = weight of cofferdam seal coat (kips)

P_{sp} = cofferdam sheet piling resistance (kips)

P_{fp} = foundation piling resistance (kips)

P_b = hydrostatic buoyancy force (kips)

Determine Seal Coat Weight

When assuming a preliminary seal coat thickness, a reasonable estimate is between 0.2 and 0.4 times the hydrostatic head. Note, however, that the minimum seal coat thickness shall be three feet.

The weight of seal coat, P_{sc} (kips), is calculated as:

$$P_{sc} = t_{sc} \times A \times \gamma_c$$

Where:

t_{sc} = seal coat thickness (ft.)

A = inside cofferdam area (ft.^{2})

γ_c = unit weight of concrete, taken as 0.150 kcf

Determine Hydrostatic Buoyancy Force

The buoyant force produced at the bottom of the seal coat is calculated by finding the weight of displaced water inside the cofferdam. The hydrostatic head, H, of the cofferdam is the distance from 3 ft. above the EWSE to the bottom of the seal coat, in feet. The hydrostatic buoyancy force, P_b, in kips, is calculated as:

$P_b = H \times A \times \gamma_w$

Where γ_w is the unit weight of water, taken as 0.0624 $^{kips}/_{ft^3}$.

Determine Sheet Piling Resistance

Buoyant forces can cause two failure mechanisms for sheet piling. The sheet piling can either pull out of the soil or separate from the seal coat. The controlling resistance of the sheet piling, P_{sp} (kips), is the lesser of the two, as shown by the following equation:

$P_{sp} = P_{sh} + P_{shsoil}$ but not $> P_{shseal}$

Where:

P_{sh} = weight of sheet piling (kips)
P_{shsoil} = friction between sheet piling and soil (kips)
P_{shseal} = bond between the seal coat and sheet piling (kips)

Determine Weight of Sheet Piling

The weight of sheet piling, P_{sh} (kips), is found using the following equation:

$P_{sh} = L_{sh} \times COFF_p \times w_{sh}$

Where:

L_{sh} = length of sheet piling (ft.)
$COFF_p$ = perimeter of cofferdam sheet piling (ft.)
w_{sh} = weight of sheet piling, assumed to be 0.022 ksf

For preliminary estimation, assume that the sheet piling embedment is one-third of the hydrostatic head, making L_{sh} equal to $4H/3$. This length may be increased if required.

If necessary, the weight of any anticipated wales may be added to the weight of sheet piling. However, this is not recommended for typical situations.

Determine Sheet Piling Soil Friction

The friction between sheet piling and soil, P_{shsoil} (kips), is found using the following equation:

$$P_{shsoil} = L_{sh1} \times COFF_p \times FR_{soil}$$

Where:

L_{sh1} = assumed sheet piling embedment (ft.)

FR_{soil} = friction between the sheet piling and soil, taken as 0.150 ksf

For preliminary estimation, assume that L_{sh1} is $H/3$.

Determine Bond Between Seal Coat and Sheet Piling

The bond between the seal coat and sheet piling, P_{shseal} (kips), is taken as:

$$P_{shseal} = t_{sc} \times COFF_p \times FR_{shseal}$$

Where FR_{shseal} is the friction between sheet piling and seal coat, taken as 1.0 ksf assuming that the contact surface between the sheet piling and seal coat is free of mud.

Determine Foundation Piling Resistance

Foundation pile resistance is found assuming three possible modes of failure. Upon dewatering, all individual piles may pullout, piles around the perimeter may pullout, or piles may separate from the seal coat. The foundation piling resistance, P_{fp} (kips),is therefore taken as the least of:

i.) $P_p + P_{pilesoil}$

ii.) $P_p + P_{group} + P_{soil}$

iii.) $P_{pileseal}$

Where:

P_p = non-buoyant weight of piles less the hydrostatic pressure applied to the end of the piles (kips)

$P_{pilesoil}$ = soil friction/adhesion between all individual piles and soil (kips)

P_{group} = soil friction/adhesion between outside of the pile cluster and soil (kips)

P_{soil} = weight of soil mass when piles act as a cluster (kips)

$P_{pileseal}$ = bond between foundation piles and seal coat (kips)

Determine Weight of Piles

The non-buoyant weight of the piles, less the hydrostatic pressure applied to the end of the piles, P_p (kips), is defined as:

$$P_p = N \times [w_p \times L_p - (H + L_p - t_{sc}) \times \gamma_w \times A_p]$$

Where:

N = number of piles

w_p = non-buoyant weight of the unfilled pile per length unit length (k/ft.)

L_p = estimated pile length as shown on plans (ft.)

A_p = end bearing area of pile (ft.^{2})

Note that if the piles generate more buoyancy than they weigh, P_p will act in an upward direction.

Determine Soil Friction on Individual Piles

The soil friction on all individual piles, $P_{pilesoil}$ (kips), is defined as:

$$P_{pilesoil} = N \times SA_p \times FR_{pilesoil} \times (L_p - t_{sc})$$

Where:

SA_p = surface area of pile per unit length (ft.)

$FR_{pilesoil}$ = friction/adhesion between piles and soil, taken as 0.150 ksf

For HP piles, SA_p is defined as the box perimeter of the pile, taken as $2b_f + 2d$, where b_f is the flange width and d is the depth of the pile. For metal shell piles, SA_p is taken as the outside circumference of the pile.

Determine Soil Friction on Pile Cluster

The soil friction on the outside of the pile cluster, P_{group} (kips), is defined as:

$$P_{group} = (L_p - t_{sc}) \times FR_{pilesoil} \times GROUP_p$$

Where $GROUP_p$ is the outside perimeter of the pile group in feet.

Determine Weight of Soil Mass Contained in Pile Cluster

The weight of soil mass contained in the pile cluster, P_{soil} (kips), is defined as:

$$P_{soil} = (L_p - t_{sc}) \times A_s \times \gamma_s$$

Where:

A_s = area of soil engaged in pile cluster (ft.^{2})

γ_s = buoyant unit weight of soil, taken as 0.04 kcf

A_s is the area bounded by the outside perimeter of piles minus the area of the piles. The area of the piles is significant when concrete piles are used.

Determine Bond Between Foundation Piles and Seal Coat

The bond between foundation piles and seal coat, $P_{pileseal}$ (kips), is defined as:

$$P_{pileseal} = t_{sc} \times N \times SA_p \times FR_{pileseal}$$

Where $FR_{pileseal}$ is the friction between foundation piles and seal coat, taken conservatively as 1.0 ksf.

Cofferdam Seal Coat Design Example

Cofferdam Properties

Length of Cofferdam: 49 feet
Width of Cofferdam: 14 feet

Pile Type: 12 in. Metal Shells, weighing 22.6 lbs. per linear foot
Number of Piles: 45 piles
Estimated Pile Length: 60 ft.

Cofferdam Design Water Elevation: 749.40 ft.
(EWSE + 3 ft.)
Streambed Elevation: 746.00 ft.
Bottom of Footing Elevation: 727.30 ft.

Determine Seal Coat Weight

Assuming the seal coat thickness is 0.2 times the total hydrostatic head, the following algebraic equation must be satisfied:

$t_{sc} = 0.2 \times$ [Cofferdam Design Water Elevation – (Bottom of Footing Elevation – t_{sc})]

Solving the equation above results in t_{sc} = 5.53 ft. Assume a seal coat thickness of 5 ft. - 7 in. (5.58 ft.), P_{sc} is then found as follows:

$P_{sc} = t_{sc} \times A \times \gamma_c$

Where:

t_{sc} = 5.58 ft.
A = 49 ft. length $\times$ 14 ft. width = 686 ft.^{2}
γ_c = 0.150 kcf

P_{sc} = 5.58 ft. $\times$ 686 ft.^{2} $\times$ 0.150 kcf
= 574.2 kips

Determine Hydrostatic Buoyancy Force

$P_b = H \times A \times \gamma_w$

Where:

H = Cofferdam Design Water Elevation – Bottom of Seal Coat Elevation
= 749.40 ft. – (727.30 ft. – 5.58 ft.)
= 27.68 ft.

A = 686 ft.^{2}

γ_w = 0.0624 kcf

P_b = 27.68 ft. $\times$ 686 ft.^{2} $\times$ 0.0624 kcf
= 1184.9 kips

Determine Sheet Piling Resistance

$P_{sp} = P_{sh} + P_{shsoil}$ but not > P_{shseal}

Determine Weight of Sheet Piling

$P_{sh} = L_{sh} \times COFF_p \times w_{sh}$

Where:

L_{sh} = $4H/3$ = 4×27.68 ft.$/3$ = 36.9 ft.

$COFF_p$ = 2 $\times$ 49 ft. length + 2 $\times$ 14 ft. width = 126 ft.

w_{sh} = 0.022 ksf

P_{sh} = 36.9 ft. $\times$ 126 ft. $\times$ 0.022 ksf = 102.3 kips

Determine Sheet Piling Soil Friction

$P_{shsoil} = L_{sh1} \times COFF_p \times FR_{soil}$

Where:

L_{sh1} = H/3= 27.68 ft./3 = 9.23 ft.

FR_{soil} = 0.150 ksf

P_{shsoil} = 9.23 ft. × 126 ft. × 0.150 ksf = 174.4 kips

Determine Bond Between Seal Coat and Sheet Piling

$P_{shseal} = t_{sc} \times COFF_p \times FR_{shseal}$

Where FR_{shseal} = 1.0 ksf

P_{shseal} = 5.58 ft. × 126 ft. × 1.0 ksf = 703.1 kips

∴

P_{sp} = 102.3 k + 174.4 k = 276.7 kips but not > 703.1 kips

So,

P_{sp} = 276.7 kips

Determine Foundation Piling Resistance

P_{fp}, is taken as the least of:

i.) $P_p + P_{pilesoil}$

ii.) $P_p + P_{group} + P_{soil}$

iii.) $P_{pileseal}$

Determine Weight of Piles

$$P_p = N \times [w_p \times L_p - (H + L_p - t_{sc}) \times \gamma_w \times A_p]$$

Where:

N = 45 piles

w_p = 0.0226 k/ft.

L_p = 60 ft.

A_p = 0.79 ft.^{2}

P_p = 45 piles $\times$ [(0.0226 k/ft. $\times$ 60 ft. – (27.68 ft. + 60 ft. – 5.58 ft.) $\times$ 0.0624 kcf $\times$ 0.79 ft.^{2}] = -121.1 kips

Determine Soil Friction on Individual Piles

$$P_{pilesoil} = N \times SA_p \times FR_{pilesoil} \times (L_p - t_{sc})$$

Where:

SA_p = 3.14 ft.

$FR_{pilesoil}$ = 0.150 ksf

$P_{pilesoil}$ = 45 piles $\times$ 3.14 ft. $\times$ 0.150 ksf $\times$ (60 ft. – 5.58 ft.)
= 1153.4 kips

Determine Soil Friction on Pile Cluster

$$P_{group} = (L_p - t_{sc}) \times FR_{pilesoil} \times GROUP_p$$

Where $GROUP_p$ = 102 ft.

P_{group} = (60 ft. – 5.58 ft.) $\times$ 0.150 ksf $\times$ 102 ft.
= 832.6 kips

Determine Weight of Soil Mass Contained in Pile Cluster

$P_{soil} = (L_p - t_{sc}) \times A_s \times \gamma_s$

Where:

$A_s = 8 \text{ ft.} \times 43 \text{ ft.} - 45 \text{ piles} \times 0.79 \text{ ft.}^2 / \text{pile}$

$= 308.5 \text{ ft.}^2$

$\gamma_s = 0.04 \text{ kcf}$

$P_{soil} = (60 \text{ ft.} - 5.58 \text{ ft.}) \times 308.5 \text{ ft.}^2 \times 0.04 \text{ kcf}$

$= 671.5 \text{ kips}$

Determine Bond Between Foundation Piles and Seal Coat

$P_{pileseal} = t_{sc} \times N \times SA_p \times FR_{pileseal}$

$P_{pileseal} = 5.58 \text{ ft.} \times 45 \text{ piles} \times 3.14 \text{ ft.} \times 1.0 \text{ ksf}$

$= 788.5 \text{ kips}$

$\therefore$

$P_p + P_{pilesoil} = -121.1 \text{ k} + 1153.4 \text{ k}$

$= 1032.3 \text{ kips}$

$P_p + P_{group} + P_{soil} = -121.1 \text{ k} + 832.6 \text{ k} + 671.5 \text{ k}$

$= 1383.0 \text{ kips}$

$P_{pileseal} = 788.5 \text{ kips}$

So,

$P_{pileseal}$ controls, $P_{fp} = 788.5$ kips

Determine Factor of Safety

$$F.S. = \frac{P_{sc} + P_{sp} + P_{fp}}{P_b} > 1.2$$

$$= \frac{574.2 + 276.7 + 788.5}{1184.9}$$

$$= 1.38 > 1.2 \qquad \text{O.K.}$$

A 5 ft. - 7 in. seal coat is adequate for this location.