2.3.6.1.8 Bridge Scupper Placement

This design guide contains a procedural outline and example for scupper placement. See also Section 2.3.6.1.8 of the Bridge Manual for an overview of bridge scupper policies, procedures, and methods.

Bridge Scupper Placement Outline, Procedure, and Equations

Determine Distance from High Elevation to First Scupper

One variable affecting scupper location is longitudinal roadway slope. Since bridges are typically located on vertical curves for which the longitudinal slope varies, determination of scupper locations is typically an iterative process. This process is described below.

Step 1: Assume Longitudinal Slope at First Scupper Location

From the profile grade of the roadway, assume the longitudinal slope (S_1) at an arbitrary first scupper location intended to be a distance D_1 from the high point of the bridge. The arbitrary scupper location should be chosen based upon an assumed ideal location to intercept flow. However, locations may be altered as necessary to avoid conflicts with substructure units or traffic beneath the structure.

Step 2: Determine Flowrate from Drainage Area, Q_{D1},at First Scupper Location Using Assumed Slope

Using the assumed longitudinal slope at the arbitrary location, the following equation determines flowrate from the drainage area, Q_{D1} (cfs):

$$Q_{D1} \quad = \quad \frac{0.56z}{n} S_1^{1/2} d_{max}^{8/3}$$

Where:

n = Manning's coefficient, conservatively taken as 0.013 for concrete

S_1 = assumed longitudinal slope of roadway at first scupper location ≥ 0.005 (ft./ft.)

z = reciprocal of cross slope at scupper location

d_{max} = maximum allowable depth of flow at curb face (ft.), taken as T_{max}/z, where T_{max} is the maximum allowable gutter spread in feet. For roadway speeds less than 50 mph, T_{max} is taken as the shoulder width plus three feet. For speeds greater than or equal to 50 mph, T_{max} is taken as the shoulder width plus one foot.

Step 3: Determine Actual Location of First Scupper Using Flowrate Q_{D1}

Using the flowrate, Q_{D1}, the theoretical distance to the first scupper, D_1 (ft.), is calculated using the following equation:

$$D_1 = \frac{43560}{CIW} Q_{D1}$$

Where:

C = runoff coefficient, taken as 0.95 for concrete pavement
I = rainfall intensity, taken as 6 in./hr.
W = width of deck drained (ft.)

Step 4: Compare Actual Location to Initial Assumption and Verify That Assumption is Correct

Using the distance, D_1, and the profile grade, determine the longitudinal slope at the theoretical scupper location, and verify that the initial slope assumption is valid. If the assumed slope is valid, the theoretical scupper location is the actual scupper location. If the assumed slope is not valid, repeat Steps 1 through 4 as necessary until convergence.

Determine Distance from First Scupper to Second Scupper

The procedure used to determine the distance from the first drainage scupper to the second drainage scupper is similar to that used to find the distance from the high point to the first scupper. However, the total flow to the second scupper includes flow from the drainage area between the first and second scupper, and any flow that bypasses the first scupper. The bypass flow for any given scupper includes flow that is spread outside the limits of the scupper plus frontal flow that splashes over the scupper.

Step 1: Calculate Actual Depth of Flow at the Curb Face of the First Scupper

Using the actual Q_{D1} and S_1, determine the actual depth of flow at the curb face, d_1 (ft.), using the following equation:

$$d_1 = \left[\frac{Q_{D1}n}{0.56zS_1^{1/2}}\right]^{3/8}$$

Step 2: Calculate the Actual Gutter Flow Spread at First Scupper

Using the actual d_1, calculate the actual gutter flow spread, T_1 (ft.), using the following equation:

$$T_1 = d_1 z$$

Step 3: Calculate the Actual Gutter Velocity at the First Scupper

Calculate the actual gutter velocity, V_1 (ft./sec.), using the following equation:

$$V_1 = \frac{1.12}{n} S_1^{1/2} S_x^{2/3} T_1^{2/3}$$

Where:

S_x = cross slope (ft./ft.) = 1/z

Step 4: Calculate Frontal Flow Capture Fraction at the First Scupper

Calculate the frontal flow capture fraction, R_{f1}, using the following equation:

$$R_{f1} = 1 - 0.09(V_1 - V_0) \leq 1.0$$

Where:

V_0 = grate splash over velocity (ft./sec.) taken as:
5.8 for DS-12M10 scuppers

2.8 for DS-11, DS-12, and DS-33 scuppers

Step 5: Determine Bypass Flow at First Scupper Location

The bypass flow at the first scupper, Q_{b1} (cfs), is found using the following equation:

$$Q_{b1} = \frac{0.56z}{n} S_1^{1/2} d_1^{8/3} (1 - R_{f1}) + \frac{0.56z}{n} S_1^{1/2} d_{b1}^{8/3} (R_{f1})$$

Where:

d_{b1} = depth of flow (ft.) a distance w_d from face of curb at first scupper = $d_1\left(1 - \frac{w_d}{T_1}\right) = d_1 - \frac{w_d}{z}$

w_d = width of scupper (ft.)

Step 6: Calculate Longitudinal Slope at Assumed Second Scupper Location

Assume a distance, D_2 (ft.), between the first and second inlet and calculate the actual longitudinal slope, S_2 (ft./ft.), from the profile at the assumed location.

Step 7: Calculate Flowrate from Drainage Area at Second Scupper Location

Calculate the flowrate from the drainage area between the first and second scupper, Q_{D2} (cfs), using the following equation:

$$Q_{D2} = \frac{D_2 CIW}{43560}$$

Step 8: Calculate the Total Flowrate to the Second Scupper

The total flowrate approaching the second scupper, Q_{TOT2} (cfs), can be calculated using the following equation:

$$Q_{TOT2} = Q_{D2} + Q_{b1}$$

Step 9: Calculate Depth of Flow at the Curb Face of the Second Scupper

Using Q_{TOT2} and S_2, determine the depth of flow at the curb face, d_2 (ft.), using the following equation:

$$d_2 = \left[\frac{Q_{TOT2} n}{0.56 z S_2^{1/2}} \right]^{3/8}$$

Step 10: Verify D_2 Assumption

If d_2 is approximately equal to d_{max}, the initial assumption for D_2 is appropriate. If d_2 is less than d_{max}, assume a larger value of D_2 and repeat Steps 6 through 10. If d_2 is larger than d_{max}, assume a smaller value for D_2 and repeat Steps 6 through 10.

Determine Distance from Second Scupper to Subsequent Scupper

The procedure used to determine the distance from one drainage scupper to the next is similar to that used to find the distance from the first scupper to the second scupper. See the included example for further details.

Scupper Placement Example

Given the following data, determine if floor drains and/or drainage scuppers are required. If floor drains and/or drainage scuppers are required, determine their spacings.

Bridge Data

Crossing = Structure crosses a creek. Therefore, free fall scupper discharge allowable.
Bridge Width = 80 ft. (crown at centerline)
Shoulder Width = 4 ft. with a 2% cross slope
Design Speed = 55 mph
Bridge Length = 3 spans (125 ft., 150 ft., 125 ft.) 400 ft. bk. to bk. abutments
Scupper Width = 2 ft. (DS-12 scuppers are used)

Abutments = Integral (2 ft. – 6 in. wide)
Piers = Solid wall (3 ft. - 0 in. wide)
Skew = 0°

Curve Data

g_1 = +3.0%
g_2 = -3.0%
L = 800 ft.

Vertical curve is centered on bridge.

Constants

C = runoff coefficient = 0.95
I = rainfall intensity = 6 in./hr.
N = Manning's roughness coefficient = 0.013

Determine Distance from High Elevation to First Scupper

Step 1: Assume Longitudinal Slope at First Scupper Location

Assume a minimum longitudinal slope of 0.5% for the first scupper location.

Step 2: Determine Flowrate from Drainage Area, Q_{D1}, at First Scupper Location Using Assumed Slope

$$Q_{D1} = \frac{0.56z}{n} S_1^{1/2} d_{max}^{8/3}$$

$$z = \frac{1}{0.02} = 50$$

$$T_{max} = 4\text{ ft.} + 1\text{ ft.} = 5\text{ ft.}$$

$$d_{max} = \frac{T_{max}}{z} = \frac{5\text{ ft.}}{50} = 0.1\text{ ft.}$$

$$Q_{D1} = \frac{0.56 \times 50}{0.013} 0.005^{1/2} 0.1^{8/3} = 0.328 \text{ cfs}$$

Step 3: Determine Actual Location of First Scupper Using Flowrate Q_{D1}

$$D_1 = \frac{43560}{CIW} Q_{D1}$$

$$D_1 = \frac{43560}{(0.95 \times 6 \times 40)} \times 0.328 = 62.7 \text{ ft.}$$

Assume scupper placed at 60 ft. from the high point.

Step 4: Compare Actual Location to Initial Assumption and Verify That Assumption is Correct

Longitudinal slope at 60.0 ft. from high point = 0.45%. Minimum slope is 0.5%, therefore slope assumption is O.K.

Distance from centerline pier to high point = $150 \text{ ft.}/2 = 75 \text{ ft.}$

75 ft. – 60 ft. – 1.5 ft. = 13.5 ft. > 10 ft.

$\therefore$ Clearance between scupper and pier face O.K. and,

D_1 = 60 ft. (i.e. place first scupper 60 ft. from high point)

Determine Distance from First Scupper to Second Scupper

Step 1: Calculate Actual Depth of Flow at the Curb Face of the First Scupper

$$Q_{D1} = \frac{D_1 CIW}{43560} = \frac{60 \times 0.95 \times 6 \times 40}{43560} = 0.314 \text{ cfs}$$

$$d_1 = \left[\frac{Q_{D1} n}{0.56 z S_1^{1/2}}\right]^{3/8} = \left[\frac{0.314 \times 0.013}{0.56 \times 50 \times 0.005^{1/2}}\right]^{3/8} = 0.0984 \text{ ft.}$$

(Note that if S < 0.5 %, use S = 0.5 %)

Step 2: Calculate the Actual Gutter Flow Spread at First Scupper

$T_1 = z \times d_1 = 50 \times 0.0984 = 4.92$ ft.

Step 3: Calculate the Actual Gutter Velocity at the First Scupper

$$V_1 = \frac{1.12}{n} S_1^{1/2} S_x^{2/3} T_1^{2/3} = \frac{1.12}{0.013} 0.005^{1/2} 0.02^{2/3} 4.92^{2/3} = 1.298 \text{ ft./sec}.$$

Step 4: Calculate Frontal Flow Capture Fraction at the First Scupper

$R_{f1} = 1 - 0.09(V_1 - V_0) \leq 1.0$

V_0 = 2.8 ft./sec. for a DS-12 > V_1 = 1.298 ft./sec.

$\therefore R_{f1}$ = 1.0

Step 5: Determine Bypass Flow at First Scupper Location

$$d_{b1} = d_1 - \frac{w_d}{z} = 0.0984 - \frac{2}{50} = 0.0584 \text{ ft.}$$

$$Q_{b1} = \frac{0.56z}{n} S_1^{1/2} d_1^{8/3} (1 - R_{f1}) + \frac{0.56z}{n} S_1^{1/2} d_{b1}^{8/3} (R_{f1}) =$$
$$\frac{0.56 \times 50}{0.013} 0.005^{1/2} 0.0984^{8/3} (1 - 1) + \frac{0.56 \times 50}{0.013} 0.005^{1/2} 0.0584^{8/3} (1) = 0.0782 \text{ cfs}$$

Step 6: Calculate Longitudinal Slope at Assumed Second Scupper Location

Trial 1:

Assume D_2 = 50.0 ft.

Longitudinal slope at a distance 110 ft. (60 ft. + 50 ft.) from high point = 0.83%

Step 7: Calculate Flowrate from Drainage Area at Second Scupper Location

$$Q_{D2} = \frac{D_2CIW}{43560} = \frac{50 \times 0.95 \times 6 \times 40}{43560} = 0.2617 \text{ cfs}$$

Step 8: Calculate the Total Flowrate to the Second Scupper

$$Q_{TOT2} = Q_{D2} + Q_{b1} = 0.2617 + 0.0782 = 0.3399 \text{ cfs}$$

Step 9: Calculate Depth of Flow at the Curb Face of the Second Scupper

$$d_2 = \left[\frac{Q_{TOT2}n}{0.56zS_2^{1/2}}\right]^{3/8} = \left[\frac{0.3399 \times 0.013}{0.56 \times 50 \times 0.0083^{1/2}}\right]^{3/8} = 0.0921 \text{ ft.}$$

Step 10: Verify D_2 Assumption

D_2 = 0.0921 ft. is ± 8% less than d_{max} = 0.1 ft.

$\therefore$ Assume a larger value for D_2 and repeat Steps 6 through 10

Step 6 (2)

Trial 2:

Assume D_2 = 70.0 ft.

Longitudinal slope = 0.98%

Step 7 (2)

$$Q_{D2} = \frac{D_2CIW}{43560} = \frac{70 \times 0.95 \times 6 \times 40}{43560} = 0.3664 \text{ cfs}$$

Step 8 (2)

$$Q_{TOT2} = Q_{D2} + Q_{b1} = 0.3664 + 0.0782 = 0.4446 \text{ cfs}$$

Step 9 (2)

$$d_2 = \left[\frac{Q_{TOT2}n}{0.56zS_2^{1/2}}\right]^{3/8} = \left[\frac{0.4446 \times 0.013}{0.56 \times 50 \times 0.0098^{1/2}}\right]^{3/8} = 0.099 \text{ ft.}$$

Step 10 (2)

$d_2 \approx d_{max} = 0.1$ ft.

Distance from centerline pier to high point = $150 \text{ ft.}/2 = 75$ ft.

60 ft. + 70 ft. – 75 ft.. = 55 ft. into approach span of 125 ft.

$\therefore$ Clearance between scupper and pier face O.K. and,

D_2 = 70 ft. (i.e. place second scupper 70 ft. from first scupper or 130 ft. from high point)

Determine Distance from Second Scupper to Third Scupper

Step 1: Calculate Actual Depth of Flow at the Curb Face of the Second Scupper

d_2 = 0.099 ft.

Step 2: Calculate the Actual Gutter Flow Spread at Second Scupper

$T_2 = z \times d_2 = 50 \times 0.099 = 4.95$ ft.

Step 3: Calculate the Actual Gutter Velocity at the Second Scupper

$$V_2 = \frac{1.12}{n} S_2^{1/2} S_x^{2/3} T_2^{2/3} = \frac{1.12}{0.013} 0.0098^{1/2} 0.02^{2/3} 4.95^{2/3} = 1.825 \text{ ft./sec}.$$

Step 4: Calculate Frontal Flow Capture Fraction at the Second Scupper

$R_{f2} = 1 - 0.09(V_2 - V_0) \leq 1.0$

V_0 = 2.8 ft./sec. for a DS-12 > V_2 = 1.825 ft./sec.

$\therefore R_{f2}$ = 1.0

Step 5: Determine Bypass Flow at Second Scupper Location

$$d_{b2} = d_2 - \frac{w_d}{z} = 0.099 - \frac{2}{50} = 0.059 \text{ ft.}$$

$$Q_{b2} = \frac{0.56z}{n} S_2^{1/2} d_2^{8/3}\left(1 - R_{f2}\right) + \frac{0.56z}{n} S_2^{1/2} d_{b2}^{8/3}\left(R_{f2}\right) =$$

$$\frac{0.56 \times 50}{0.013} 0.0098^{1/2} 0.099^{8/3}\left(1-1\right) + \frac{0.56 \times 50}{0.013} 0.0098^{1/2} 0.059^{8/3}\left(1\right) = 0.112 \text{ cfs}$$

Step 6: Calculate Longitudinal Slope at Assumed Third Scupper Location

Trial 1:

Check if a third scupper is required before the end of the curbed 30 ft. approach pavement. End of approach pavement is 230 ft. from the high point on bridge.

230 ft. – 60 ft. – 70 ft. = 100 ft.

Assume D_3 = 100.0 ft.
Longitudinal slope at a distance 230 ft. from high point = 1.73%

Step 7: Calculate Flowrate from Drainage Area at Third Scupper Location

$$Q_{D3} = \frac{D_3 CIW}{43560} = \frac{100 \times 0.95 \times 6 \times 40}{43560} = 0.523 \text{ cfs}$$

Step 8: Calculate the Total Flowrate to the Third Scupper

$$Q_{TOT3} = Q_{D3} + Q_{b2} = 0.523 + 0.112 = 0.635 \text{ cfs}$$

Step 9: Calculate Depth of Flow at the Curb Face of the Third Scupper

$$d_3 = \left[\frac{Q_{TOT3} n}{0.56 z S_3^{1/2}}\right]^{3/8} = \left[\frac{0.635 \times 0.013}{0.56 \times 50 \times 0.0173^{1/2}}\right]^{3/8} = 0.101 \text{ ft.}$$

Step 10: Verify D_3 Assumption

$d_3 \approx d_{max} = 0.1\,\text{ft.}$

Since $d_3 \approx d_{max}$, either provide an additional scupper on the structure or provide a bridge approach pavement drain to reduce the amount of runoff exiting the approach pavement. For this example, an additional scupper will be provided on the structure and a bridge approach pavement drain will be omitted.

Step 6 (2)

Trial 2:

Since a scupper cannot be placed within 10 ft. of the abutment face:

Assume D_3 = 200 ft. – 2.5 ft. – 10 ft. – 130 ft. = 57.5 ft.
Longitudinal slope = 1.41%

Step 7 (2)

$$Q_{D3} = \frac{D_3 CIW}{43560} = \frac{57.5 \times 0.95 \times 6 \times 40}{43560} = 0.301\,\text{cfs}$$

Step 8 (2)

$$Q_{TOT3} = Q_{D3} + Q_{b2} = 0.301 + 0.112 = 0.413\ \text{cfs}$$

Step 9 (2)

$$d_3 = \left[\frac{Q_{TOT3}\,n}{0.56zS_3^{1/2}}\right]^{3/8} = \left[\frac{0.413 \times 0.013}{0.56 \times 50 \times 0.0141^{1/2}}\right]^{3/8} = 0.090\ \text{ft.}$$

Step 10 (2)

$d_3 < d_{max} = 0.1\,\text{ft.}$

$\therefore D_3$ = 57.5 ft. O.K. (i.e. place third scupper 57.5 ft. from second scupper or 187.5 ft. from high point)

Verify Need for Floor Drains When Longitudinal Slope < 0.3%

$$K = \frac{L}{|g_2 - g_1|} = \frac{800\text{ ft.}}{|-3-3|} = 133.33 < 167 \;\; \therefore \text{Floor drains not required}$$