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Erosion Prevention and Sediment Control Handbook

4.3.7 Stilling Basin



Source: TDEC

Definition and Purpose

Stilling basins are constructed riprap (typically conventional riprap) basins composed of a flat-bottom pool and an apron (Section 4.3.6). These permanent structures are located at drainage structure outfalls, where concentrated flows plunge into one end of the pool, forming a hydraulic jump at the other end against the apron. As a result, flow will generally be well dispersed as it leaves the basin, thereby preventing scour at the structure outlet and minimizing downstream erosion.

Appropriate Applications

This measure may be applied at drainage structure outlets where the velocity at the design discharge is 15 feet per second or greater. It may also be used at structures with lower outlet flow velocities where the required length of a riprap apron would be excessive or infeasible due to site conditions (TDOT).

Limitations and Maintenance

The use of this measure is not specifically limited; however, consider the available right-of-way area, the availability of materials, and the difficulties that could be encountered when implementing this measure on a project.

Additional permits that may be required include an ARAP, a Section 404 permit from USACE, a TVA 26a permit, or a local permit. If any additional permit is required, its conditions must be followed in conjunction with the CGP.



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

Planning and Design Considerations

In contrast to temporary EPSC measures, which are usually designed using lower peak flow rates (i.e., 2 year-24 hour or 5 year-24 hour), a stilling basin is considered a permanent structure and should be designed using the same flow rate used to design the drainage structure it is intended to serve (TDOT). The basin dimensions may be modified as required to match the configuration of the drainage structure end treatment.

The overall design process should match that of FHWA (2006), and designers are referred to that source for explicit design details. Eqn 25 may be used to compute the required depth of a riprap basin:

$$\frac{H1}{d_e} = 0.86 \times \left(\frac{D_{50}}{d_e}\right)^{-0.55} \times \left(\frac{V_o}{\sqrt{g \times d_e}}\right) - C_o \quad \text{(Eqn 25)}$$

where H1 is the dissipator pool depth (feet), d_e is the equivalent brink (outlet) depth (feet), and D_{50} is the median rock size by weight (feet), such that H1 divided by D_{50} is greater than or equal to two (Figure 4.3.7-A). Because of this H1: D_{50} ratio condition, designing riprap basin depth is an iterative approach. If the ideal D_{50} gradation is not available, round up to the next available size. Further, this equation contains a correction factor, C_o , which varies with tailwater depth (TW). Use Appendix B of FHWA (2006) if TW computations are required. C_o is computed by one of two sets of equations (Eqn 26 or Eqn 27) depending on whether a more conservative design is desired. In general, Eqn 26 will result in a basin depth one to two feet greater than Eqn 27; however, it will also allow a basin to be implemented in a greater number of scenarios and therefore may be more ideal for use.

$$\begin{array}{ll} C_o = 1.4 & TW:d_e < 0.75 \\ C_o = 4 \times (TW/d_e) - 1.6 & 0.75 < TW:d_e < 1 \end{array} \quad \text{(Eqn 26)}$$

$$\begin{array}{ll} C_o = 2.4 & TW:d_e > 1 \\ C_o = 2 & TW:d_e < 0.75 \\ C_o = 4 \times (TW/d_e) - 1 & 0.75 < TW:d_e < 1 \\ C_o = 3 & TW:d_e > 1 \end{array} \quad \text{(Eqn 27)}$$

Theoretically, the most efficient design would be to find the rock gradation such that the value of the H1: D_{50} ratio is as close to two as possible. For the majority of scenarios where a riprap stilling basin will be feasible, the value of H1 determined by Eqn 25 will be between one and a half and two and a half feet, regardless of the selected C_o (i.e., class A-1 conventional riprap will most commonly be used for stilling basins). Conventional riprap class B or C will be used to construct stilling basins only for comparatively large culvert installations. As a reminder, D_{50} size for class A-1, B, and C conventional riprap is approximately nine, 15, and 20 inches, respectively. For many smaller culverts, the value of H1 determined by Eqn 25 will be zero or negative, especially where the TW is more than approximately 85% of the equivalent depth at the culvert outfall. It is recommended that a



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

- Diameter of 60 inches
- Inlet elevation at 601.5 feet
- Outlet elevation at 600 feet
- Length of 100 feet
- Endwall is Type “U”

The channel downstream of the culvert is trapezoidal, having a bottom width of four feet, a depth of one and a half feet, 6H:1V side slopes, and a slope of 0.015 feet per foot. The Manning’s n value of the channel is 0.035. The stream carries a heavy load of sediments, small branches, and corn stalks.

Determine:

Whether the site is suitable for a stilling basin based on the culvert outlet hydraulics, tailwater depth, and debris load. If so, determine the proper class of conventional riprap and stilling basin dimensions.

Solution:

This site is a candidate for a riprap stilling basin because of the heavy debris load. Another type of dissipator might become clogged, thus reducing its effectiveness. Furthermore, it is judged that allowing a natural scour hole to form at this site could possibly have undesirable results. Other factors affecting whether a riprap basin would be suitable for this site will be investigated as the design progresses. As much as possible, the steps below follow the procedure provided in FHWA (2006).

Since the outlet velocity, V_o , is greater than 5 ft/sec, some form of erosion protection should be provided at the culvert outlet. In order to assess the suitability of a riprap stilling basin for the site, the following information is collected from the hydraulic analysis of the culvert:

- Brink depth, d_o , of 2.05 feet
- Outlet velocity, V_o , of 13.17 feet per second
- Tailwater depth, TW, of 1.55 feet
- Tailwater velocity, V_n , of 4.85 feet per second.

Step 1 – Find the TW: D_e ratio: The equivalent depth, d_e , at the culvert outfall is computed from Eqn 9-2 in TDOT:

$$d_e = \left(\frac{A_o}{2}\right)^{0.5} = \left(\frac{7.68}{2}\right)^{0.5} = 1.96 \text{ ft}$$

Step 2 – Find the appropriate C_o value: The C_o value is found using Eqn 26 or Eqn 27 based on the ratio of TW: d_e , which is 0.79.



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

The guidance herein indicates that a riprap apron should be used in place of a basin where the tailwater depth is greater than 75% of the brink depth. However, given the size of the pipe, high outflow velocity and a need to minimize the length of the riprap structure, it is decided to continue with the riprap basin design. If the computed basin depth, H1, is not at least twice the D₅₀ of the selected conventional riprap, a riprap apron will be specified for the site.

As mentioned, Eqn 26 is often more ideal and therefore implemented herein.

$$C_o = 4 \times \left(\frac{TW}{d_e}\right) - 1.6 = 4 \times \frac{1.55}{1.96} - 1.6 = 1.56$$

Step 3 – Determine proper stone size and basin depth: Because class A-1 conventional riprap (D₅₀ of 0.75 feet), is the most common class of riprap for a stilling basin, this is the first iterative input for Eqn 25:

$$\begin{aligned} \frac{h_1}{d_e} &= 0.86 \times \left(\frac{D_{50}}{d_e}\right)^{-0.55} \times \left(\frac{V_o}{\sqrt{g \times d_e}}\right) - C_o \\ \frac{h_1}{1.96} &= 0.86 \times \left(\frac{0.75}{1.96}\right)^{-0.55} \times \left(\frac{13.17}{\sqrt{32.2 \times 1.96}}\right) - 1.56 \\ H1 &= 1.62 \text{ feet.} \end{aligned}$$

Now that H1 is solved, ensure the ratio of H1:D₅₀ is greater than or equal to two.

$$H1:D_{50} = 1.62/0.75 = 2.16$$

Since this result is slightly greater than two, it is determined that a riprap stilling basin with class A-1 conventional riprap will provide an efficient design.

Step 4 – Determine all other basin dimensions: Once the basin depth has been determined, all other basin dimensions can be inferred from the standard drawing.

W1 refers to the width of the basin floor at the culvert outfall. This site will be provided with a Type “U” endwall, thus: W1= 5.0 feet.

L1 refers to the length of the pool portion of the basin. FHWA (2006) recommends this length be the greater of 10 times H1 or 3 times W1. Thus:

$$10 \times H1 = 10 \times 1.62 = 16.2 \text{ feet}$$

or

$$3 \times W1 = 3 \times 5 = 15.0 \text{ feet.}$$

So: L1 =17.0 feet (rounded).

L2 refers to the length of the apron portion of the basin. FHWA (2006) recommends this length be the greater of 5 times H1 or W1. Thus:

$$5 \times H1 = 5 \times 1.62 = 8.1 \text{ feet}$$

or



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

$$W1 = 5 \text{ feet.}$$

So: $L2 = 9.0$ feet (rounded).

The standard drawings require the elevation of the basin floor, including both the pool and the apron, to be below the natural stream elevation at the end of the apron. The fall in the stream over the length of the basin is computed as:

$$\text{Fall} = (L1 + L2) \times 0.015 = (17.0 + 9.0) \times 0.015 = 0.39 \text{ feet}$$

Occasionally, the designer may be presented with a situation in which the computed fall is very close to or even greater than $H1$. In that situation, it would be necessary to redesign the culvert with a lower outlet elevation and begin the riprap basin design again from Step 1. However, in this situation, since the computed fall is sufficiently less than $H1$, the design may proceed "as-is." Since the slopes at the upstream and downstream ends of the pool are 2:1, the length from the culvert outfall to the basin floor is $2 \times 1.62 = 3.24$ feet, and the length of the transition from the basin floor to the apron is $(1.62 - 0.39) \times 2 = 2.46$ feet. Thus, the length of the pool bottom is $17.0 - 3.24 - 2.46 = 11.3$ feet.

$W2$ refers to the width of the pool at the end of the apron. Since the floor expands at a 3:1 ratio on both sides, $W2$ is computed as:

$$W2 = W1 + (L1 + L2) \times (2/3) = 5 + (17 + 9) \times (2/3) = 22 \text{ feet}$$

$H2$ refers to the height at the top of the basin wall above the elevation of the culvert outfall. FHWA (2006) recommends the top of the basin should provide at least 1 foot of freeboard above the brink depth, do. Thus:

$$H2 = d_o + 1.0 = 2.05 + 1.0 = 3.1 \text{ feet (rounded)}$$

$W4$ refers to the width of the basin side slopes at the culvert outfall. Since the top of the basin is 3.1 feet above the outfall and the side slopes of the basin are 2:1,

$$W4 = 2 \times 3.1 = 6.2 \text{ feet}$$

$W5$ refers to the width of the basin side slopes above the floor of the pool. The top of the basin 4.8 feet above the floor of the pool, since the side slopes are also 2H:1V at this point:

$$W5 = 2 \times 4.8 = 9.6 \text{ feet}$$

$W6$ refers to the width of the basin side slopes above the floor of the apron. The distance to the top of the basin is equal to $H2$ plus the fall of the stream previously computed. Since the side slopes are still 2H:1V at this point:

$$W6 = (H2 + \text{Fall}) \times 2 = (3.1 + 0.39) \times 2 = 7 \text{ feet}$$



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

D1 refers to the thickness of the conventional riprap layer beneath the pool portion of the basin. The standard drawings indicate that the conventional riprap layer beneath the pool should be somewhat thicker than the conventional riprap layer beneath the apron. This varies from the recommendation in FHWA (2006), which indicates the riprap layer needs to be thicker only beneath the transition from the culvert outfall to the floor of the pool. Thus, the thickness criteria provided FHWA (2006) will be applied to the entire pool of the basin. Based on this approach, D1 will be the maximum of 3 times the median stone size, D_{50} , 2 times the maximum stone size, D_{max} , or the minimum thickness of the conventional riprap layer as specified in the Standard Specifications of 18 inches.

$$3 \times D_{50} = 3 \times 0.75 = 2.25 \text{ feet}$$

or

$$2 \times D_{max} = 2 \times 1.25 = 2.5 \text{ feet}$$

Thus, $D1 = 2.5$ feet.

D2 refers to the thickness of the conventional riprap layer beneath the apron portion of the basin. FHWA (2006) recommends that this layer be equal to the maximum of 2 times the median stone size, D_{50} , 1.5 times the maximum stone size, D_{max} , or the minimum thickness of the conventional riprap layer as specified in the Standard Specifications, as 18 inches.

$$2 \times D_{50} = 2 \times 0.75 = 1.50 \text{ feet}$$

or

$$1.5 \times D_{max} = 1.5 \times 1.25 = 1.9 \text{ feet}$$

This result may be rounded so that $D2 = 2.0$ feet

D3 and L4 refer respectively to the depth and length of a conventional riprap key, which is provided at the downstream end of the apron. The standard cut-off wall depth for a concrete structure is 3 feet. Furthermore, D3 and L4 should be approximately equal. Thus, the values of D3 and L4 will both be 3 feet.

Step 5 – Determine the transition dimensions: The width of the basin at the downstream end of the apron, $W2$, is 22 feet, which is greater than the natural channel bottom width of 4 feet. Thus, a transition will be provided to allow the basin cross-section at the downstream end of the apron to be warped to match the existing channel configuration. Thus, the following dimensions are determined for the transition.

$W3$ refers to the width of the transition at the downstream end. This should be equal to the existing channel width of 4 feet, therefore,

$$W3 = 4 \text{ feet.}$$



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

Erosion Prevention and Sediment Control Handbook

L5 refers to the length of the transition from the downstream end of the apron to the basin outlet. The TDOT standard drawings indicate that the transition should be at a rate of 3:1, so L5 is computed as:

$$L5 = (W2 - W3) \times (3/2) = (22 - 4) \times (3/2) = 27 \text{ feet.}$$

W7 refers to the width of the basin side slopes above the floor of the transition just downstream of the end of the apron. At this point, the top of the basin has already been transitioned from H2 computed in Step 5 to the height of the natural channel banks above the channel bed. This transition takes place over a distance, L3, which will be discussed below. At this site, the natural channel is 1.5 feet deep. Since the side slopes of the basin are still 2H:1V at this location,

$$W7 = 2 \times 1.5 = 3.0 \text{ feet.}$$

W8 refers to the width of the basin side slopes at the outlet from the transition. The side slopes of the basin are continuously warped from 2H:1V at the beginning of the transition to the natural channel side slopes at the end of the transition. Since the natural channel side slopes are 6H:1V and the channel depth is 1.5 feet,

$$W8 = 6 \times 1.5 = 9.0 \text{ feet.}$$

L3 refers to the length over which the top of the riprap basin transitions from H2 to the height of the natural stream bank. This transition occurs just upstream from the end of the apron and begins at the point where the top of the slope through the transition intersects the top of the basin above the apron. This length is computed from:

$$L3 = \frac{\left(\frac{W2}{2} + W6\right) - \left(\frac{W2}{2} + W7\right)}{\frac{1}{3} + \frac{\left(\frac{W2}{2} + W7\right) - \left(\frac{W3}{2} + W8\right)}{L5}} = \frac{\left(\frac{22}{2} + 7\right) - \left(\frac{22}{2} + 3\right)}{\frac{1}{3} + \frac{\left(\frac{22}{2} + 3\right) - \left(\frac{4}{2} + 9\right)}{27}} = 9 \text{ feet}$$

As described above, the height of the top of the basin above the apron is 3.1 feet, and the height of the channel bank is 1.5 feet. Thus, a transition of 1.6 feet will occur over the distance L3. This represents a slope of about 4.5H:1V. This slope will be adequate.

D4 refers to the thickness of the conventional riprap layer beneath the transition. This should be equal to the minimum layer thickness recommended for Class A1 conventional riprap, or 1.5 feet.

The following table and drawings summarize the results (in feet, unless otherwise specified) for this design example.



DWR – NPDES-SOP – G – 16 –Erosion Prevention and Sediment Control Handbook - 01092026

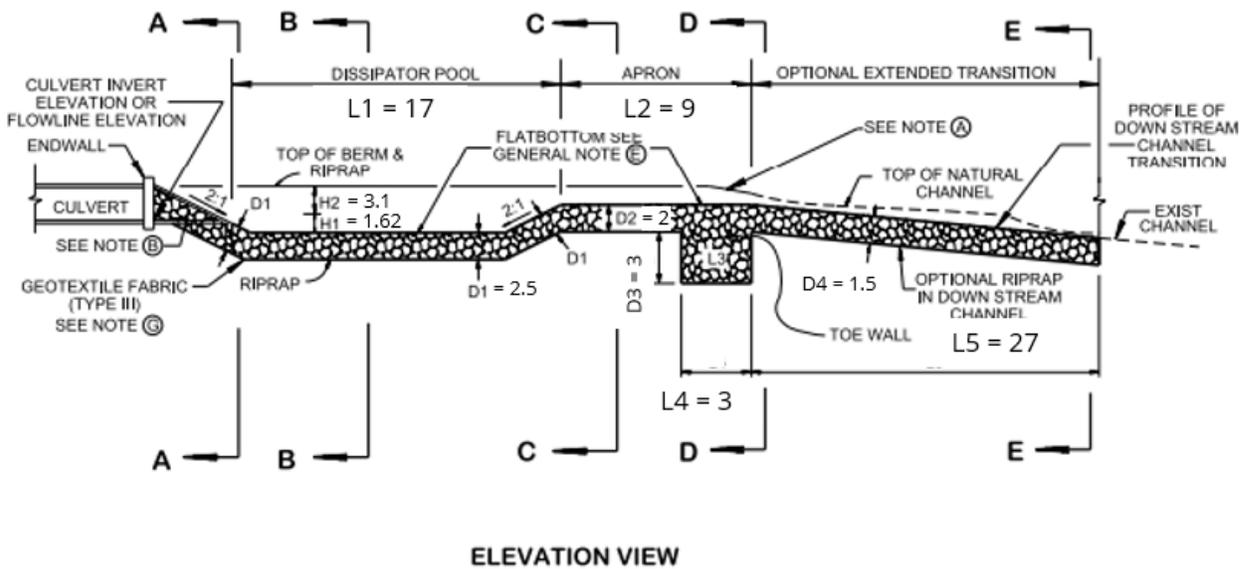
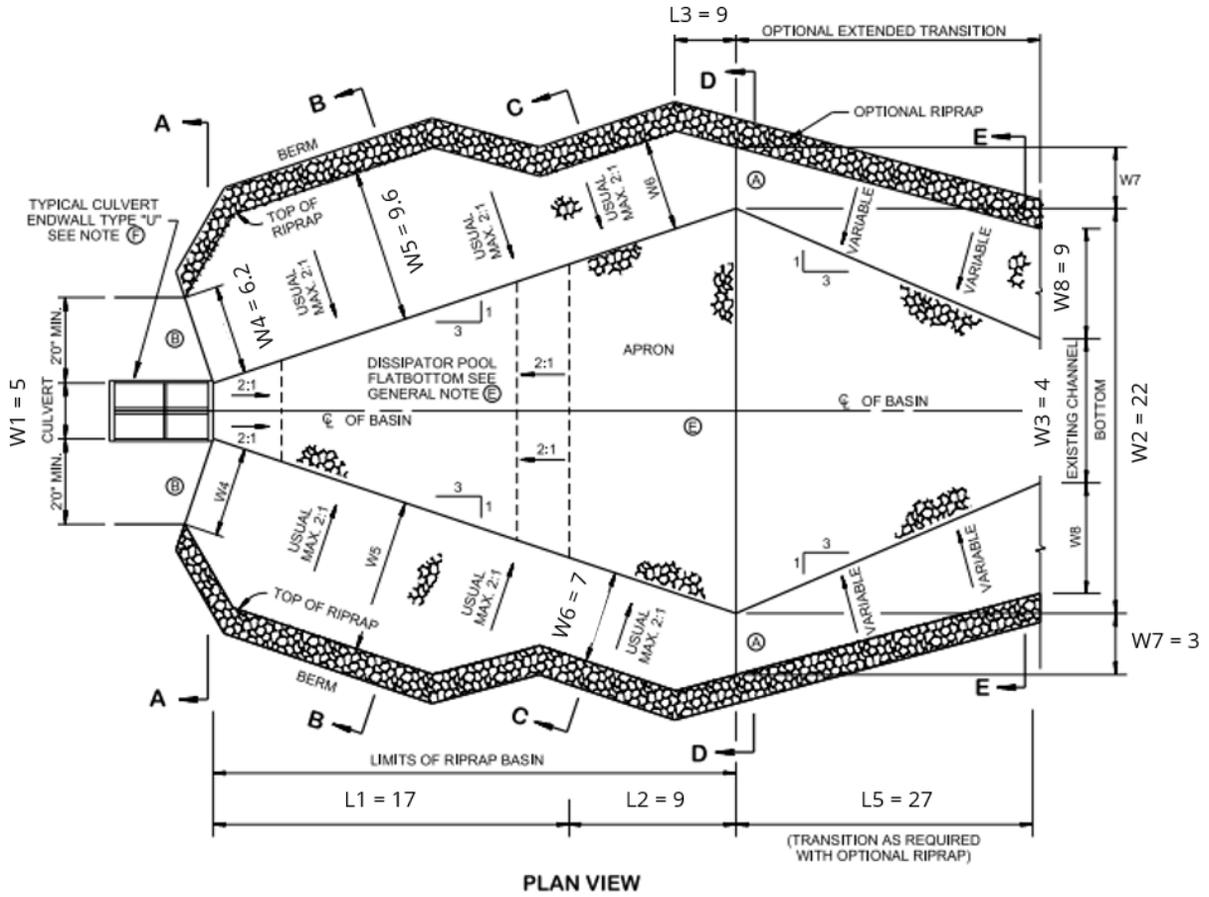
Erosion Prevention and Sediment Control Handbook

Dimension	Value
Station	1 + 90
Distance	62
Direction	Lt.
Culvert Size (in)	60
Culvert Length	100
W1	5
W2	22
W3	4
W4	6.2
W5	9.6
W6	7
W7	3
W8	9
H1	1.62
H2	3.1
L1	17
L2	9
L3	9
L4	3
L5	27
D1	2.5
D2	2
D3	3
D4	1.5



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Erosion Prevention and Sediment Control Handbook





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References

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