DESIGN PROCEDURES AND CRITERIA FOR TOEWALL DROP SPILLWAYS

Wisconsin Engineering Standard and Specifications for Grade Stabilization Structures (410) shall be followed to plan, design, and install toewall drop spillways.

The following design procedures and criteria will supplement Standard 410 and be applicable for fabricated corrugated aluminum and steel toewall drop spillways shown on Wisconsin Standard Drawing WI-301* and WI-302, and reinforced concrete toewall drop spillways shown on Standard Drawings series 3-L-7400.

Several materials and configurations may be used for these structures. Reinforced concrete, corrugated aluminum, and corrugated steel are commonly used materials. Concrete block is also an option. Structure drawings are available from the State Conservation Engineer. Structure configuration and dimensions vary with the material used; however, certain flow characteristics and velocity relationships must be met for any structure configuration used and are discussed in the design portion of this procedure.

These structures are to be placed on sites where the water table is at least two feet below the apron elevation. Type ‘a’ drainage, case B backfill, and loading conditions as shown in Table 4.1 of NEH, 11, Drop Spillways, was used for design purposes. All structures will withstand an equivalent fluid pressure of 60 $\#/ft^2/ft$ on headwalls and sidewalls. Foundation soils should have a bearing capacity of at least 2500 psf.

If site conditions differ from those stated above and on the standard drawings, a thorough design analysis is required by an engineer. Special design considerations may require the alteration of the structure apron (width, thickness, and steel placement).

Rock riprap apron protection is required on all toewall configurations. This feature will provide additional operational hydraulic stability. The riprap and apron length design used a tailwater depth of ¾ F and a nappe jet configuration at full capacity. A tailwater depth less than ¾ F could cause serious erosion downstream from the structure and possible structure failure.

The sizes and dimensions shown on the structure dimension charts should not be changed since they utilize standard dimensions for the types of materials used, and meet applicable hydraulic data. Structures proposed which do not conform to the dimensions shown on the structure dimension charts must be submitted to the State Conservation Engineer for approval.

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* Adapted from material developed by the Natural Resources Conservation Service in Indiana.

DESIGN AND INSTALLATION

1. From field survey and site analysis, determine the following:

   a. Overfall Height (F) - A plotted profile along the centerline of channel extending upstream and downstream from the structure is very helpful. The channel must be stable upstream and downstream from the structure. The applicable technical guide standards must be followed. Flow depth in the downstream channel, based on the design capacity of the structure, should not be less than ¾ of the overfall height, to provide backwater conditions at the structure outlet. Downstream channel protection must be provided and requires a special design if the backwater condition is not present. Flow analysis must be done for either a natural or a constructed outlet channel. If a bridge or culvert is located downstream, backwater from these must be evaluated to determine the tailwater on the toewall.

   b. Notch depth (H) - The notch depth indicated in the design tables will provide 0.25 to 0.5 feet of freeboard since capacity was determined by the formula

$$Q = \frac{3.1\ LH^{3/2}}{(1.14)}$$

   in accordance with procedures outlined in Section 11 of the National engineering Handbook.** Therefore, the design depth of the waterway upstream of the structure should not be deeper than the notch depth of the structure less 0.25 to 0.5 feet. The actual capacity through the notch for a given water depth can be obtained by the following formula:

$$Q = 3.1\ L\ H^{3/2}$$

   In the above formulas, Q = flow in cfs, L = length of weir, and H = depth of water above the weir crest measured at a distance of 3H or 4H from the weir.

   c. Notch Width (W) - the notch width selected should be approximately equal to the bottom width of the downstream channel.

   d. Riprap - The minimum rock requirements and extent of riprap is shown on the drawings.

   e. Soil pH - It must be greater than 4 and less than 9 for aluminum toewalls. It must be greater than 5 for steel toewalls.

** In some cases, the indicated capacity (Q) is less than that obtained by the formula because velocity through the downstream opening of the structure is limited to 5.0 feet per second.

$$\frac{Q}{F \times W} < 5$$

2. Determine the type of structure and complete the design using the attached charts.

   a. From the structure dimension chart for the overfall (F) required, select a structure with a capacity equal to or exceeding the Q required which most nearly fits the site conditions.

   b. Toewalls with 3 and 4 foot overfalls must have a spread footing to prevent over turning of the structure. On standard drawings, WI-301 or WI-302, select the correct sheet 3 by completing the equation:

$$\frac{W}{2} + B + 0.50$$

   The spread footing choice is based whether the result is greater than or less than 8 feet.

   c. Complete the construction plans by recording the structure dimensions, elevations, and quantities. Methods for computing some steel reinforcement lengths are shown on the standard drawings. Concrete and reinforcing steel quantities have been computed and are shown in the attached structure tables.

   d. Construction plans shall be provided as required to the owner, contractor, fabricator, and others as applicable.

<u>EXAMPLE</u>

Given: Watershed Area = 210 acres in Monroe County
Runoff Curve Number = 70
Site does not allow an emergency spillway
From Profile, Overfall to be Controlled = 3 feet
Flow Depth in Waterway Above Structure = 1.5 feet
Outlet Channel is stable with 6-foot bottom

Determine Structure Capacity - See Wisconsin Practice Standard 410, Grade Stabilization Structure, to determine required design capacity. No temporary storage, so use a full flow analysis. No emergency spillway - use 10-year, 24-hour design storm. (4.2 inches for Monroe County.)

Determine peak flow, 10-year, 24-hour discharge - see Engineering Field Handbook, Chapter 2, or Technical Release 55.

$$Q_{10} = 120 \text{ cfs}$$

Choose Aluminum Structure

Select a standard structure size from the structure dimension chart. For this example, use the chart on page 6-WI-6 and select the structure with an overfall (F) of 3.0 feet and a capacity (Q) of 120 cfs. Complete the structure data sheet with information from the structure data chart or by calculation. For this example:

F = 3.0 feet
H = 1.9 feet
W = 8 feet
B = 2.3 feet
L = 17.4 feet
A = 5.4 feet
S = 11.1 feet

Select spread footing size by computing:

$$\frac{W}{2} + B + 0.50 = \frac{8}{2} + 2.3 + 0.50 = 6.8$$

Since this is less than 8 feet, select the 4 foot spread footing standard drawing sheet 3.

The volume of concrete is 5.6 cubic yards and the reinforcement is 303 lineal feet or 202 pounds. This includes the volume of concrete and quantity of steel reinforcement for the required spread footing size. Lineal feet and pounds of steel shown in the tables will not be exactly the same as computed from the formulas as the result of rounding.

The remaining information for the construction plans can be calculated or depends on actual site conditions.

FABRICATED CORRUGATED ALUMINUM OR STEEL TOEWALL

Overfall Height (F) = 1.9 feet
Notch Depth (H) = 1.8 feet
Headwall Height (A) = 4.2 feet
Headwall Length (S) = 8.9 feet

Capacity Q (cfs)	Notch Width W (feet)	Leg Length B (feet)	Weir Length L (feet)	Concrete (cu yds)	#4 Bars Reinforcing Steel	
					Length (feet)	Weight (lbs)
65	7	1.6	14.2	4.1	163	109
75	8	0.7	14.2	4.2	173	116
95	10	0.7	17.4	5.1	232	155
110	12	0.7	20.6	6.2	298	199
130	14	0.8	23.8	7.4	375	251
150	16	0.8	27.0	8.7	458	306
170	18	0.8	30.2	10.2	549	367
190	20	0.8	33.4	11.8	647	432

FABRICATED CORRUGATED ALUMINUM OR STEEL TOEWALL

Overfall Height (F) = 3.0 feet
Notch Depth (H) = 1.9 feet
Headwall Height (A) = 5.4 feet
Headwall Length (S) = 11.1 feet

Capacity Q (cfs)	Notch Width W (feet)	Leg Length B (feet)	Weir Length L (feet)	Concrete (cu yds)	#4 Bars Reinforcing Steel	
					Length (feet)	Weight (lbs)
95	7	1.4	14.2	4.9	258	172
95	8	0.7	14.2	5.1	272	182
105	7	2.2	15.8	5.1	272	182
110	8	1.5	15.8	5.3	279	186
120	8	2.3	17.4	5.6	303	202
120	10	0.7	17.4	6.0	331	221
130	10	1.5	19.0	6.3	349	233
145	10	2.3	20.6	6.6	367	245
145	12	0.7	20.6	7.1	397	265
150	10	3.1	22.2	8.4	556	371
155	12	1.5	22.2	8.9	589	393
165	12	2.3	23.8	9.3	610	407
165	14	0.8	23.8	9.8	644	430
175	12	3.1	25.4	9.7	632	422
175	14	1.6	25.4	10.2	669	447
190	14	2.4	27.0	10.6	694	464
190	16	0.8	27.0	11.1	727	486
200	14	3.2	28.6	11.1	719	480
200	16	1.6	28.6	11.6	755	504

FABRICATED CORRUGATED ALUMINUM OR STEEL TOEWALL

Overfall Height (F) = 3.0 feet
Notch Depth (H) = 1.9 feet
Headwall Height (A) = 5.4 feet
Headwall Length (S) = 11.1 feet

Capacity Q (cfs)	Notch Width W (feet)	Leg Length B (feet)	Weir Length L (feet)	Concrete (cu yds)	#4 Bars Reinforcing Steel	
					Length (feet)	Weight (lbs)
210	14	4.0	30.2	11.5	744	497
210	16	2.4	30.2	12.1	783	523
210	18	0.8	30.2	12.6	818	546
220	16	3.2	31.8	12.6	811	542
220	18	1.6	31.8	13.1	849	567
235	16	4.0	33.4	13.0	839	560
235	18	2.4	33.4	13.7	880	588
235	20	0.8	33.4	14.2	916	612
245	18	3.2	35.0	14.2	911	609
245	20	1.7	35.0	14.9	955	638
255	18	4.0	36.6	14.7	943	630
255	20	2.5	36.6	15.5	990	661
270	18	4.8	38.3	15.3	974	651
270	20	3.3	38.3	16.0	1024	684
280	20	4.1	39.9	16.6	1058	707
290	20	4.9	41.5	17.2	1093	730
300	20	5.7	43.1	17.8	1127	753

FABRICATED CORRUGATED ALUMINUM OR STEEL TOEWALL

Overfall Height (F) = 4.0 feet
Notch Depth (H) = 2.1 feet
Headwall Height (A) = 6.6 feet
Headwall Length (S) = 13.4 feet

Capacity Q (cfs)	Notch Width W (feet)	Leg Length B (feet)	Weir Length L (feet)	Concrete (cu yds)	#4 Bars Reinforcing Steel	
					Length (feet)	Weight (lbs)
115	7	1.4	14.2	5.3	258	172
125	7	2.2	15.8	5.5	272	182
140	7	3.0	17.4	5.7	285	190
140	8	2.3	17.4	6.0	303	202
155	8	3.1	19.0	6.3	318	212
155	10	1.5	19.0	6.7	349	233
165	10	2.3	20.6	7.0	367	245
165	12	0.7	20.6	7.5	397	265
180	10	3.1	22.2	8.9	556	371
185	12	1.5	22.2	9.3	589	393
190	10	3.9	23.8	9.2	574	383
190	12	2.3	23.8	9.7	610	407
190	14	0.8	23.8	10.2	644	430
200	10	4.7	25.4	9.5	593	396
205	12	3.1	25.4	10.1	632	422
205	14	1.6	25.4	10.6	669	447
220	12	3.9	27.0	10.4	653	436
220	14	2.4	27.0	11.1	694	464
220	16	0.8	27.0	11.6	727	486
230	12	4.7	28.6	10.8	675	451
230	14	3.2	28.6	11.5	719	480
230	16	1.6	28.6	12.0	755	504
245	14	4.0	30.2	11.9	744	497
245	16	2.4	30.2	12.5	783	523
245	18	0.8	30.2	13.0	818	546
260	14	4.8	31.8	12.3	768	513
260	16	3.2	31.8	13.0	811	542
260	18	1.6	31.8	13.6	849	567

FABRICATED CORRUGATED ALUMINUM OR STEEL TOEWALL

Overfall Height (F) = 4.0 feet
Notch Depth (H) = 2.1 feet
Headwall Height (A) = 6.6 feet
Headwall Length (S) = 13.4 feet

Capacity Q (cfs)	Notch Width W (feet)	Leg Length B (feet)	Weir Length L (feet)	Concrete (cu yds)	#4 Bars Reinforcing Steel	
					Length (feet)	Weight (lbs)
270	14	5.6	33.4	12.7	793	530
270	16	4.0	33.4	13.5	839	560
270	18	2.4	33.4	14.1	880	588
270	20	0.8	33.4	14.6	916	612
285	16	4.8	35.0	13.9	867	579
285	18	3.2	35.0	14.6	911	609
285	20	1.7	35.0	15.3	955	638
300	16	5.6	36.6	14.4	895	598
300	18	4.0	36.6	15.1	943	630
300	20	2.5	36.6	15.9	990	661
310	16	6.4	38.3	14.9	923	617
310	18	4.8	38.3	15.7	974	651
310	20	3.3	38.3	16.5	1024	684
325	18	5.6	39.9	16.2	1003	670
325	20	4.1	39.9	17.0	1058	707
340	18	6.4	41.5	16.7	1036	692
340	20	4.9	41.5	17.6	1093	730
350	18	7.2	43.1	17.3	1067	713
350	20	5.7	43.1	18.2	1127	753
365	20	6.5	44.7	18.8	1162	776
380	20	7.3	46.3	19.4	1196	799
390	20	8.1	47.9	19.9	1230	822
400	20	8.9	49.5	20.5	1265	845

Pages 6-WI-11 through 6-WI-22 are reserved for future use.