AGRICULTURAL

MU Guide

Design criteria for bottom-withdrawal (lake-cleaning) spillway

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A pond or lake equipped with a bottom-withdrawal spillway will store the highest quality water possible for a reservoir in a given location. This is desirable when the reservoir will provide water for municipalities, livestock, households, fish production, recreation, field or orchard spraying, trickle irrigation, or other uses requiring high quality water. The bottom-withdrawal spillway discharges most of the muddy inflow, which decreases the sedimentation rate and increases the useful life of a water reservoir. The water discharged will have a higher sediment and nutrient content than water from conventional surface-withdrawal spillways.

For an introduction to the operation of a bottom-withdrawal spillway, see UMC Guide 1530, "Operation of a bottom-withdrawal (lake-cleaning) spillway."
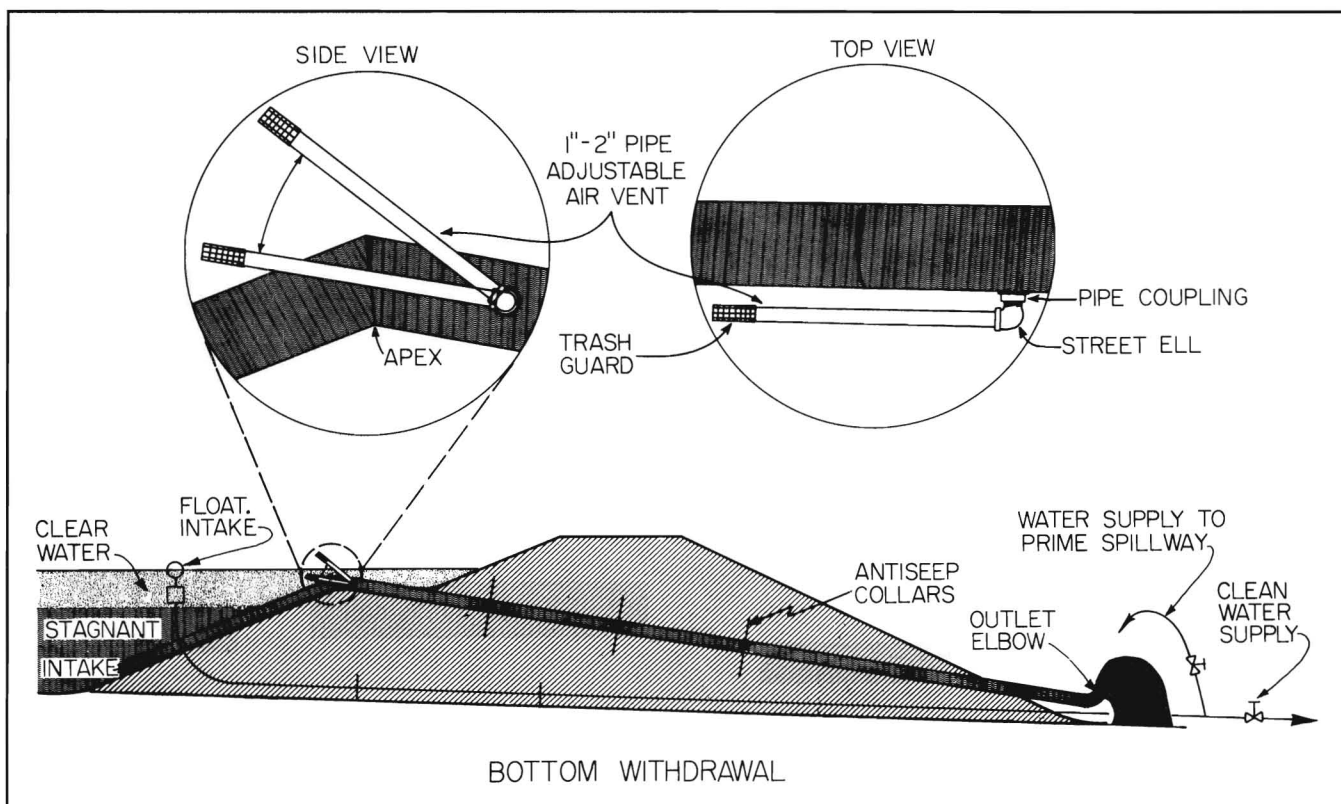

Figure 1. Cross-sectional view of a bottom-withdrawal spillway installation.
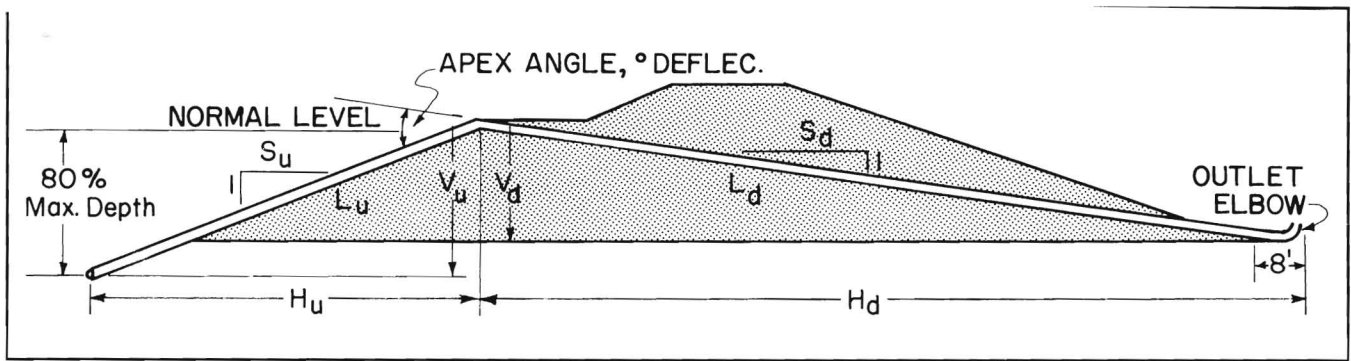
Figure 2. Cross-section of dam showing horizontal (H) and vertical (V) distances used to calculate the slopes of pipes (S) and the angle they form at the apex.

Similarities of the bottom-withdrawal spillway

Detention structures with the bottom-withdrawal spillway are designed similarly to those with canopy or hood inlet spillways. The cross-section and construction of the embankment are the same. The procedure for determining the length and diameter of the principal spillway pipe is similar. You use anti-seep collars to increase the path of seepage along the pipe by at least 10 percent (Refer to UMC Guide 1515, "Selecting materials for and installing principal spillways.")

Refer to the following UMC guides for guidance in the design of detention structures:

1516, "Emergency spillways, Part 1—Description."
1517, "Emergency spillways, Part 2— Design."
1518, "Estimating peak rates of runoff."
1519, "Effect of reservoir detention storage on spillway discharge."

Alternative design procedures are described in the Soil Conservation Service Engineering Field Manual. In Missouri, the Soil Conservation Service and the Cooperative Extension Service have a micro-computer program to design dams and spillways.

Uniqueness of the bottom-withdrawal spillway

As the name implies, the bottom-withdrawal spillway removes the excess water (caused by storm runoff) from the *bottom* of the pond (or lake). Locating the discharge pipe inlet below 80 percent of the normal-pool depth will usually preserve 96 percent of the clean water stored in the reservoir. Increasing the temporary storage volume (between the principal spillway and the emergency spillway) will decrease the loss of "clean" water through the emergency spillway.

The other advantage of having a deep intake is that few fish will be "lost" when it is located deeper than 8 feet because the deeper water is usually anoxic (without oxygen) during the warm months. This eliminates the need to "fence in the fish." In addition, inlet clogging from floating debris is no longer a problem.

The outlet elbow, also unique to this spillway design, enhances the operational versatility of the spillway. It serves as an airlock so siphoning begins at a lower water level. If the air vent is submerged, water turbulence in the pipe will entrain air and remove it from the pipe, causing siphoning until air enters the vent. Second, it serves as an excellent energy dissipator, preventing a deep "plunge pool," and, third, it aerates the anoxic bottom water as it leaves the spillway (See Figure 1).

Spillway design

You can proceed with spillway design after you have determined the water elevation, dam cross-section, and desired spillway discharge rate. Determine the required length of pipe graphically by plotting the dam cross-section and then scaling the length of pipe needed. An alternative method is to calculate the length, first by summing the net horizontal and vertical distances of each pipe, and then calculating the two diagonal lengths using the equation:
Total Length =
$$L_u + L_d = (H_u^2 + V_u^2)^{0.5} + (H_d^2 + V_d^2)^{0.5}$$
where L_u = length of pipe upstream (from the apex), L_d = length of pipe downstream, H_u and H_d are the horizontal distances of the upstream and downstream pipes, respectively, and V_u and V_d are, likewise, the vertical distances upstream and downstream, respectively (see Figure 2). The upstream and downstream pipes connect to form the apex (bend) angle. This angle, or bend in the pipe, should be calculated if you use a prefabricated miter bend. Compute the bend angle (at the apex) from the slopes of the two sections of pipe by the equation:
$$\text{Bend angle} = \tan^{-1}(V_u/H_u) + \tan^{-1}(V_d/H_d)$$
$$= \tan^{-1}(1/S_u) + \tan^{-1}(1/S_d)$$

To construct the miter bend, cut the pipe at one-half the bend angle, roll the cutoff piece 180 degrees and then weld the pieces back together to form the bend. This miter bend may vary from 27 to 35 degrees (deflection angle). For example, if the slope of the upstream pipe is 2.5 to 1 and the slope of the downstream pipe is 7 to 1 (through the dam), the bend angle would be 30 degrees (21.8 + 8.1). You would cut the ends of the pipe at 15 degrees to form the 30 degree miter bend. If you use plastic pipe, one or two 22.5 degree elbows can be used to obtain the proper angle.

Spillway discharge

The discharge through the spillway is affected by the pipe's diameter, length, and roughness, and minor losses such as entrance, miter bend, and discharge elbow losses. You can estimate the discharge from Tables 1 or 2. If you use the previous example and assume $V_u = V_d = 15$ feet, then $L_u = 37.5$ feet, $L_d = 105$ feet, and $L = 142.5$ feet. From Table 1, the discharge for a 6-inch smooth steel pipe ($n = 0.013$) with 15 feet of head would be 1.9 cfs (cubic feet per second) for 100 feet of pipe. The correction factor for 142.5 feet of pipe is 0.865 (by interpolation). Therefore, the discharge for 142.5 feet of 6-inch pipe is 1.9 x 0.865 = 1.64 cfs. If you need a larger discharge, you should select a larger pipe diameter. If you encounter conditions other than those assumed in Tables 1 and 2, you can compute the discharge by referring to the section, "Formulas for special cases."

Air vent

The primary purpose of the air vent is to stop the siphoning flow of the spillway when the water level reaches the desired level. The air vent can be fixed (for example, a hole in the apex of the pipe) or adjustable (for example, a short piece of pipe can be attached to the hole so that the pipe can rotate around the hole). The air vent is normally near the apex and above the normal pool level (see Figure 1). You can make the air vent movable by using a threaded elbow, a union and an elbow, a friction-fit plastic elbow, or flexible tubing that will not collapse under a partial vacuum.

The diameter of the air vent should be at least 1/14 (7 percent) of the spillway pipe diameter. Protect the air vent opening by attaching a screen to it or placing it in a screened enclosure to prevent plugging by leaves, nuts, or fish.

Modification of existing spillways

You can easily convert hood and canopy spillways into bottom-withdrawal spillways. First, survey the upstream slope of the dam, from the existing pipe to the deepest point, to determine the length of pipe needed. Check to see whether it can be straight or if it will require another bend.

Second, bring the appropriate amount of pipe to the site and assemble it near the water's edge. This pipe should be the same size as the existing pipe. If the same size is unavailable, use a slightly larger size if you can make the connection to the existing pipe.

Third, remove the existing hood or canopy and miter the existing pipe at the appropriate angle. If you add corrugated metal pipe to existing smooth or corrugated metal pipe, you can weld a short 2-foot section (mitered at the appropriate angle) to the existing pipe. To this short section, clamp the longer upstream section with a water-tight clamp. (An alternative method to join corrugated metal pipe to an existing corrugated metal pipe spillway follows: Cut the end off the existing pipe with a square cut to allow clamping on a prefabricated miter bend to position the apex as desired. The prefab miter bend may be re-galvanized for long life.)

Fourth, float the new section of pipe into place by temporarily plugging the intake end and rolling the pipe into the water. Don't allow the apex end to enter the water. Hold it near the existing pipe with a chain or cable. When the pipe is properly positioned, remove the temporary plug and allow the pipe to settle into place. Pull the apex into final position so you can weld or caulk it and clamp it to the existing pipe to make an airtight connection.

Fifth, complete the modification by adding the air vent and the outlet elbow.

Summary

New ponds, as well as existing ponds, can be easily equipped with a bottom-withdrawal spillway system. The design of this spillway is similar to that of other spillway pipes. First, determine the elevations and physical layout. Then determine the pipe diameter needed for the required flow capacity. You can convert existing hood and canopy spillways to bottom-withdrawal spillways. By installing bottom-withdrawal spillways, ponds and reservoirs will last longer and provide clean water for many years to come.

Table 1. Pipe flow rates in CFS

Using Bernoulli's equation: $Q = A(64.4H)^{0.5}/(1 + K_m + K_pL)^{0.5}$
Pipe flow for smooth steel pipe, n = 0.013, $K_m = K_e + K_b + K_{elbow} = 1.1$ and length = 100 feet.

H, Head in feet	Nominal diameter of pipe in inches												
	4	6	8	10	12	14	16	18	20	22	24	30	36
	Pipe diameter used in calculating flow rate												
	4	6	8	10	12	13.5	15.5	17.5	19.5	21.5	23.5	29.4	35.4
5	0.4	1.1	2.3	4	6	8	11	15	19	24	29	48	73
6	0.4	1.2	2.5	4	7	9	12	16	21	26	32	53	79
7	0.5	1.3	2.7	5	7	10	13	18	23	28	35	57	86
8	0.5	1.4	2.9	5	8	10	14	19	24	30	37	61	92
9	0.5	1.5	3.1	5	8	11	15	20	26	32	39	65	97
10	0.6	1.6	3.2	6	9	12	16	21	27	34	41	68	103
11	0.6	1.6	3.4	6	9	12	17	22	28	36	43	72	108
12	0.6	1.7	3.5	6	10	13	17	23	30	37	45	75	112
13	0.6	1.8	3.7	6	10	13	18	24	31	39	47	78	117
14	0.7	1.9	3.8	7	10	14	19	25	32	40	49	81	121
15	0.7	1.9	4.0	7	11	14	20	26	33	42	51	84	126
16	0.7	2.0	4.1	7	11	15	20	27	34	43	52	86	130
17	0.7	2.0	4.2	7	11	15	21	28	35	44	54	89	134
18	0.7	2.1	4.3	8	12	15	21	28	36	45	56	92	138
19	0.8	2.2	4.5	8	12	16	22	29	37	47	57	94	141
20	0.8	2.2	4.6	8	12	16	23	30	38	48	59	97	145
21	0.8	2.3	4.7	8	13	17	23	31	39	49	60	99	149
22	0.8	2.3	4.8	8	13	17	24	31	40	50	62	101	152
23	0.8	2.4	4.9	8	13	17	24	32	41	51	63	104	156
24	0.9	2.4	5.0	9	13	18	25	33	42	53	64	106	159
25	0.9	2.5	5.1	9	14	18	25	33	43	54	66	108	162
26	0.9	2.5	5.2	9	14	19	26	34	44	55	67	110	165
27	0.9	2.6	5.3	9	14	19	26	35	45	56	68	112	169
28	0.9	2.6	5.4	9	15	19	27	35	45	57	69	114	172
29	1.0	2.7	5.5	10	15	20	27	36	46	58	71	116	175
30	1.0	2.7	5.6	10	15	20	28	37	47	59	72	118	178

L, in feet	Correction factors for other pipe lengths												
50	1.33	1.29	1.25	1.22	1.19	1.18	1.16	1.14	1.13	1.12	1.11	1.09	1.07
60	1.24	1.21	1.18	1.16	1.15	1.14	1.12	1.11	1.10	1.09	1.09	1.07	1.06
70	1.16	1.14	1.13	1.12	1.10	1.10	1.09	1.08	1.07	1.07	1.06	1.05	1.04
80	1.10	1.09	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03	1.03
90	1.05	1.04	1.04	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01
100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
110	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99
120	0.92	0.93	0.94	0.94	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.97	0.97
130	0.89	0.90	0.91	0.91	0.92	0.93	0.93	0.94	0.94	0.94	0.95	0.96	0.96
140	0.86	0.87	0.88	0.89	0.90	0.90	0.91	0.92	0.92	0.93	0.93	0.94	0.95
150	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.91	0.91	0.92	0.93	0.94
160	0.81	0.82	0.84	0.85	0.86	0.87	0.87	0.88	0.89	0.90	0.90	0.92	0.93
170	0.79	0.80	0.82	0.83	0.84	0.85	0.86	0.87	0.87	0.88	0.89	0.91	0.92
180	0.77	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.91
190	0.75	0.76	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.86	0.88	0.90
200	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.87	0.89
210	0.72	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.86	0.88
220	0.70	0.72	0.73	0.75	0.76	0.77	0.79	0.80	0.81	0.82	0.83	0.85	0.87

Table 2. Pipe flow rates in CFS

Using Bernoulli's equation: $Q = A(64.4H)^{0.5}/(1 + K_m + K_pL)^{0.5}$

Pipe flow for corrugated pipe, $n = 0.025$, $K_m = K_e + K_b + K_{elbow} = 1.1$ and length = 100 feet.

H, Head in feet	Nominal diameter of pipe in inches									
	6	8	10	12	15	18	21	24	30	36
	Pipe diameter used in calculating flow rate									
	6	8	10	12	15	18	21	24	30	36
5	0.6	1.3	2	4	7	11	16	22	37	58
6	0.7	1.5	3	4	7	12	17	24	41	63
7	0.7	1.6	3	4	8	13	18	26	44	68
8	0.8	1.7	3	5	8	13	20	27	47	73
9	0.8	1.8	3	5	9	14	21	29	50	78
10	0.9	1.9	3	5	9	15	22	31	53	82
11	0.9	2.0	4	6	10	16	23	32	55	86
12	1.0	2.1	4	6	10	16	24	34	58	90
13	1.0	2.1	4	6	11	17	25	35	60	93
14	1.1	2.2	4	6	11	18	26	36	63	97
15	1.1	2.3	4	7	12	18	27	38	65	100
16	1.1	2.4	4	7	12	19	28	39	67	104
17	1.2	2.5	4	7	12	20	29	40	69	107
18	1.2	2.5	5	7	13	20	30	41	71	110
19	1.2	2.6	5	7	13	21	30	42	73	113
20	1.3	2.7	5	8	13	21	31	43	75	116
21	1.3	2.7	5	8	14	22	32	45	77	119
22	1.3	2.8	5	8	14	22	33	46	78	121
23	1.3	2.9	5	8	14	23	34	47	80	124
24	1.4	2.9	5	8	15	23	34	48	82	127
25	1.4	3.0	5	8	15	24	35	49	84	129
26	1.4	3.0	5	9	15	24	36	50	85	132
27	1.5	3.1	6	9	16	25	36	50	87	134
28	1.5	3.2	6	9	16	25	37	51	89	137
29	1.5	3.2	6	9	16	26	38	52	90	139
30	1.5	3.3	6	9	16	26	38	53	92	142

L, in feet	Correction factors for other pipe lengths									
50	1.37	1.35	1.33	1.32	1.29	1.27	1.25	1.23	1.20	1.18
60	1.26	1.25	1.24	1.23	1.21	1.20	1.19	1.17	1.15	1.14
70	1.18	1.17	1.16	1.16	1.15	1.14	1.13	1.12	1.11	1.10
80	1.11	1.10	1.10	1.10	1.09	1.09	1.08	1.08	1.07	1.06
90	1.05	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03
100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
110	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97
120	0.92	0.92	0.92	0.92	0.93	0.93	0.93	0.94	0.94	0.95
130	0.88	0.89	0.89	0.89	0.90	0.90	0.91	0.91	0.92	0.93
140	0.85	0.86	0.86	0.86	0.87	0.88	0.88	0.89	0.90	0.90
150	0.83	0.83	0.83	0.84	0.84	0.85	0.86	0.86	0.87	0.88
160	0.80	0.81	0.81	0.81	0.82	0.83	0.84	0.84	0.85	0.87
170	0.78	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.84	0.85
180	0.76	0.76	0.77	0.77	0.78	0.79	0.80	0.80	0.82	0.83
190	0.74	0.74	0.75	0.75	0.76	0.77	0.78	0.79	0.80	0.82
200	0.72	0.72	0.73	0.74	0.74	0.75	0.76	0.77	0.79	0.80
210	0.70	0.71	0.71	0.72	0.73	0.74	0.75	0.75	0.77	0.79
220	0.69	0.69	0.70	0.70	0.71	0.72	0.73	0.74	0.76	0.77

Formulas for special cases

For pipes with more than one miter bend or for a spillway with a bell-shaped entrance, you can more accurately calculate the discharge by using Bernoulli's equation:

$$Q = 8.025(A)(H)^{0.5}/(1 + K_m + K_pL)^{0.5}$$

where
- Q = discharge in cfs
- A = cross-sectional area of pipe in square feet = $((D_i)^2)/183.3$
- H = head causing flow, in feet
- K_m = sum of all minor pipe loss coefficients (Tables 1 and 2 assume $K_m = 1.1$)
- K_p = friction coefficient for the pipe (see Table 3)
- L = total length of pipe, in feet.

The minor pipe friction loss consists mainly of the entrance loss. Common entrance loss coefficients are shown in Figure 3. The most common entrance for bottom-withdrawal spillways will be the projecting pipe; the rounded entrance is most efficient.

If you used a well-rounded entrance in the above example instead of the projecting pipe, the discharge would increase 3 percent for a 6-inch pipe to 12 percent for a 24-inch pipe. Using a well-rounded entrance, instead of a projecting entrance, could permit the use of the next smaller pipe diameter.
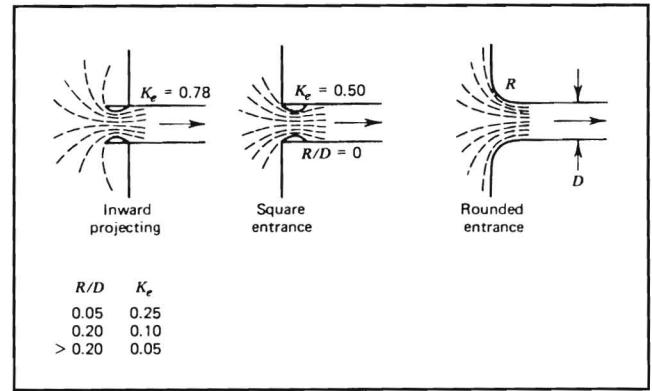

Figure 3. Entrance loss coefficients of pipe conduits.

Other minor friction losses in this spillway are caused by bends at the apex angle and the outlet elbow. Since this loss is dependent upon the roughness of the elbow or bend, it is easier (and more accurate) to calculate this loss as an equivalent length of pipe which is added to the actual total length of pipe before it is multiplied by K_p in the above equation.

The apex angle head losses are usually quite small since the angle will normally be from 27 to 35 degrees

Table 3. Head loss coefficient, K_p, for circular pipe flowing full

Pipe diam., inches	Flow Area, sq. ft.	Manning's Coefficient of Roughness, "n"		
		0.011	0.013	0.025
2	0.022	0.2443	0.3412	1.2617
4	0.087	0.0969	0.1354	0.5007
6	0.196	0.0565	0.0789	0.2916
8	0.349	0.0385	0.0537	0.1987
10	0.545	0.0286	0.0399	0.1476
12	0.785	0.0224	0.0313	0.1157
14	1.069	0.0182	0.0255	0.0942
16	1.396	0.0153	0.0213	0.0789
18	1.767	0.0130	0.0182	0.0674
20	2.182	0.0113	0.0158	0.0586
22	2.640	0.0100	0.0139	0.0516
24	3.142	0.0089	0.0124	0.0459
26	3.687	0.0080	0.0112	0.0413
28	4.276	0.0072	0.0101	0.0374
30	4.909	0.0066	0.0092	0.0341
32	5.585	0.0061	0.0085	0.0313
34	6.305	0.0056	0.0078	0.0289
36	7.069	0.0052	0.0072	0.0267

$$K_p = \frac{5087n^2}{D_i^{4/3}}$$

For intermediate pipe diameters, K_p values can be interpolated.
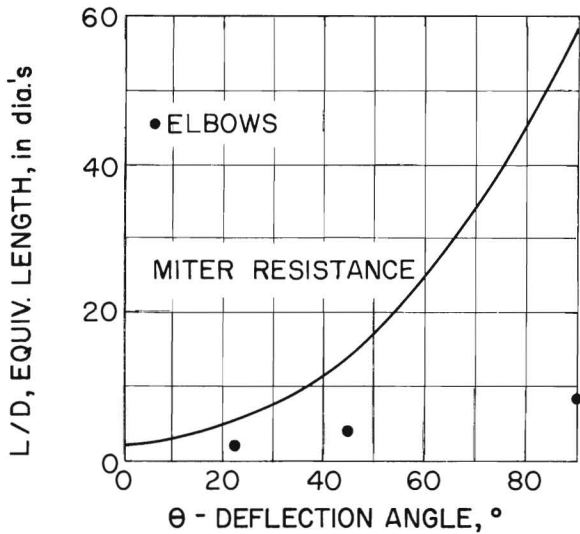
Figure 4. Resistance of miter bends and 22.5 degree, 45 degree, and 90 degree elbows.
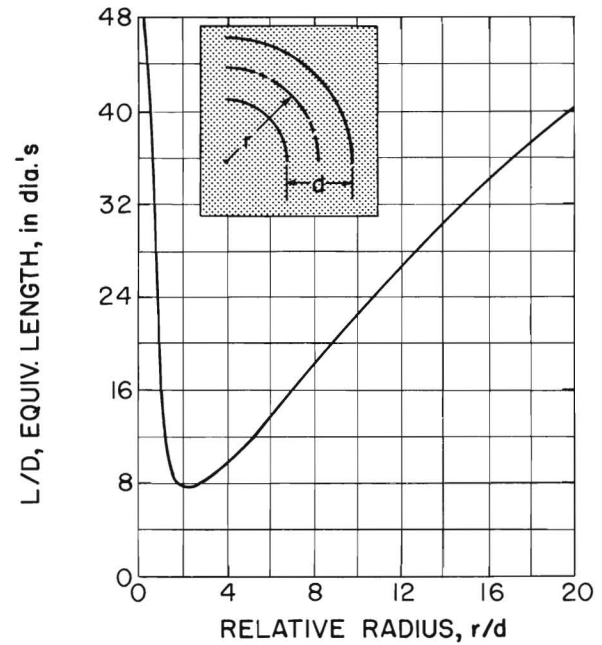

Figure 5. Resistance of 90 degree outlet elbows.

deflection. The losses (resistance), in equivalent length, for various deflection angles of single miter bends are given in Figure 4. The losses for elbows that might be used for the apex angle of plastic pipe are also shown.

You can treat the outlet elbow in a similar fashion. Figure 5 shows the equivalent length, L/D, for various radii of curvature. This chart applies to 90 degree elbows without any pipe attached downstream. You can keep the loss to a minimum if the relative radius, r/d, equals 2. The equivalent length, L/D, times the diameter in feet gives the equivalent length of pipe (in feet) to be added to the pipe's actual total length.

The head loss coefficients for circular pipes (see Table 3) are multiplied by the sum of the actual pipe length plus the equivalent lengths caused by bends in the pipe.

If you join two kinds of pipe with different "n values" to fabricate the spillway, compute the modified flow rate, Q_m in cfs, by the following equation:

$$Q_m = 8.025(A)(H)^{0.5}/(1 + K_m + K_{np}L_n + K_{op}L_o)^{0.5}$$

where n = subscript for new pipe
o = subscript for old pipe (existing pipe)

If the new pipe and the existing old pipe are different diameters (the new pipe should be larger, not smaller), the equation becomes:

$$Q_m = 8.025(A_n)(H)^{0.5}/((1 + K_{np}L_n) + (d_n/d_o)^4(K_m + K_{op}L_o))^{0.5}$$

where A_n = cross-sectional area of new pipe in sq. ft.
d_n = diameter of the new pipe in inches
d_o = diameter of the old pipe in inches

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