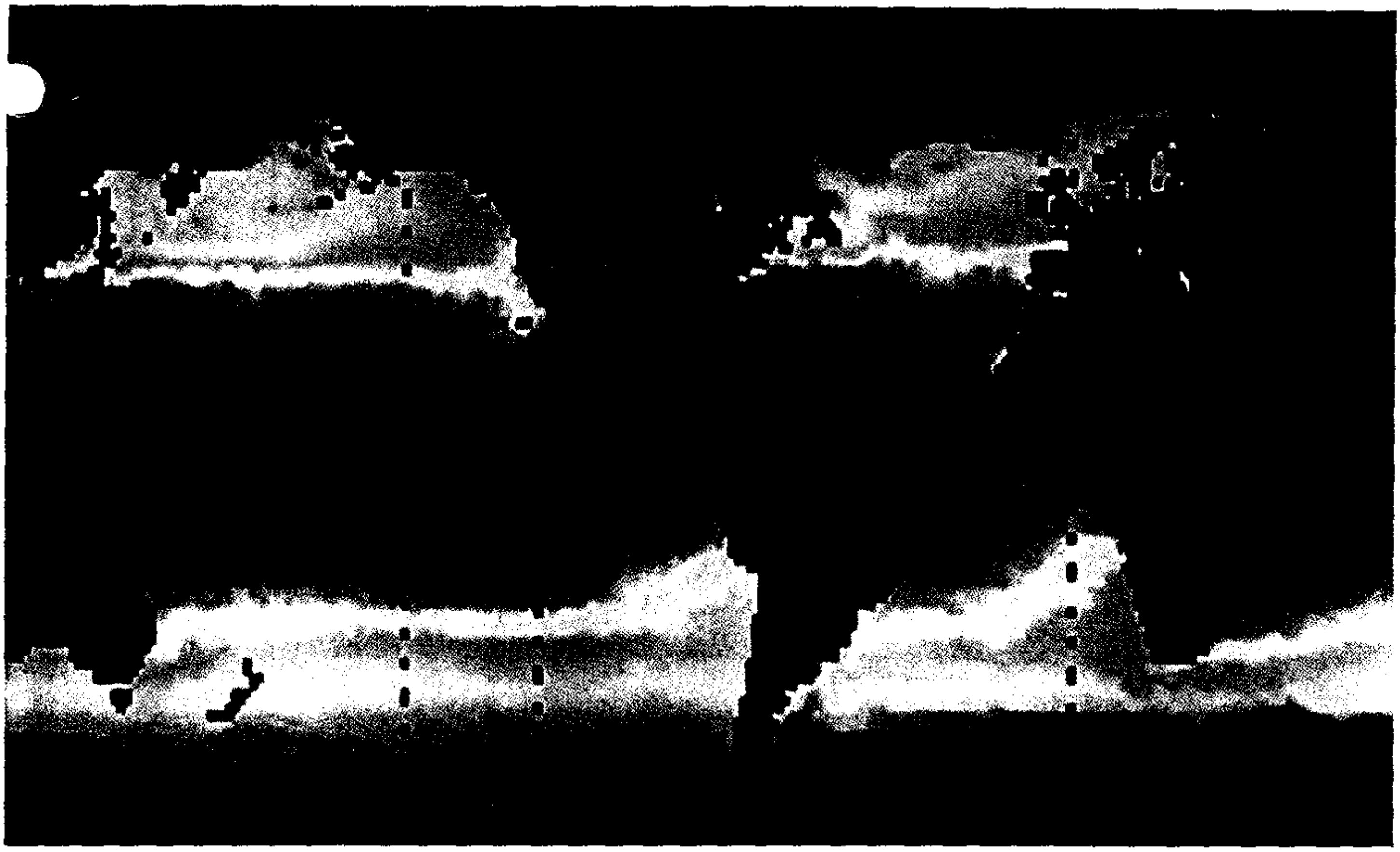

(image courtesy of FEMA El Nino Loss Reduction Center/ http://www.fema.gov/nwz97/elnino.htm)

Winter '97/'98: Year of the Great El Niño?

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EVALUATION OF ORIFICE FLOW PREDICTION EQUATIONS

By
Theodore V. Hromadka, Ph.D., Ph.D, P.E., P.H.
Principal Engineer
Exponent
Failure Analysis Associates

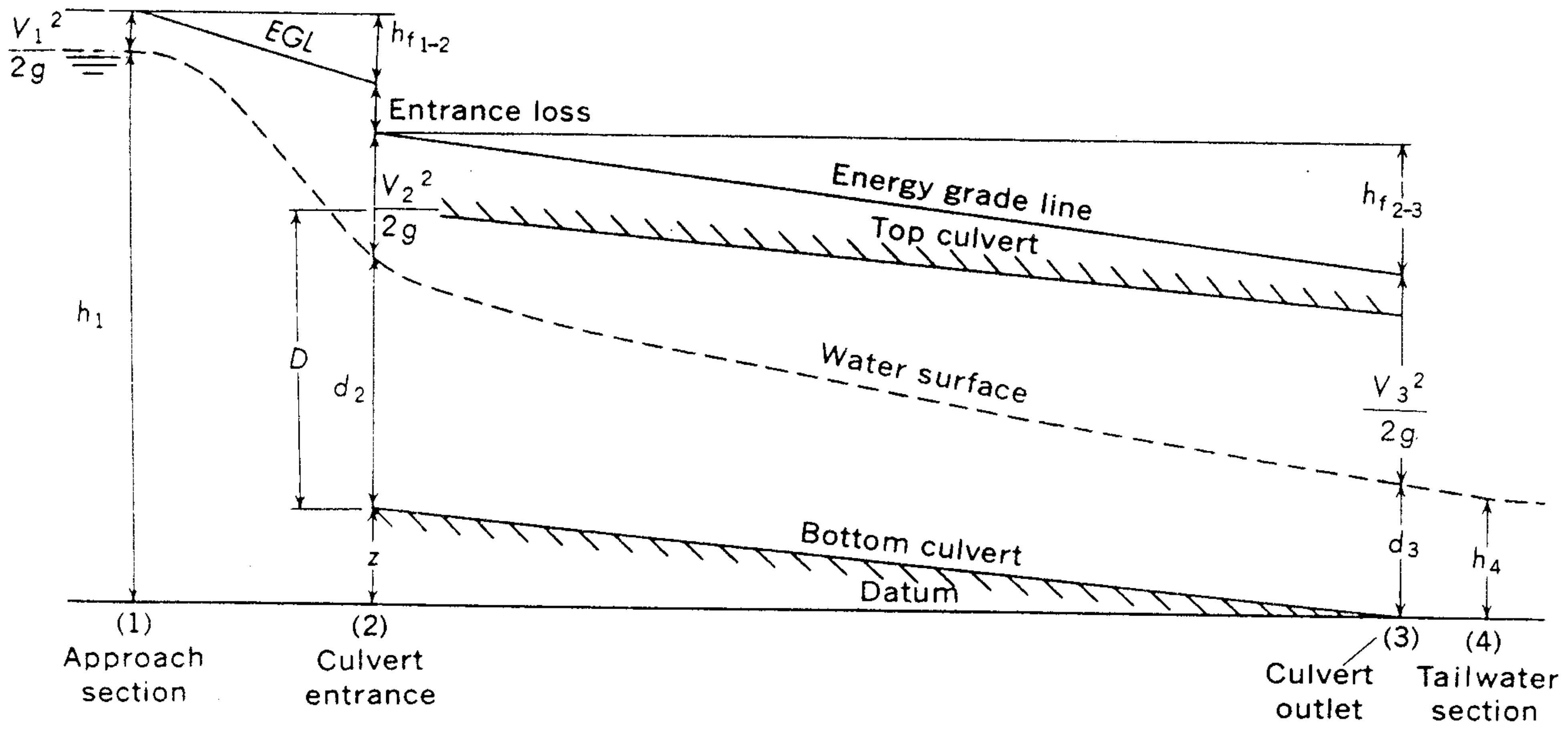
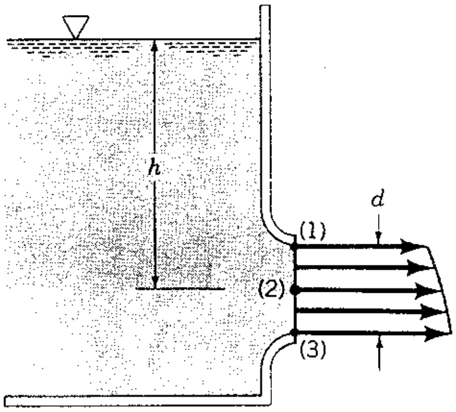


Figure 1.—Definition sketch of culvert flow. Note.—The loss of energy near the entrance is related to the sudden contraction and subsequent expansion of the live stream within the culvert barrel.

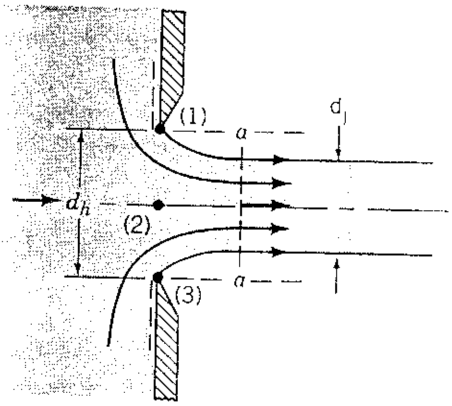


■ FIGURE 3.12 Horizontal flow from a tank.

For the horizontal nozzle of Fig. 3.12, the velocity of the fluid at the centerline, V_2, will be slightly greater than that at the top, V_1, and slightly less than that at the bottom, V_3, due to the differences in elevation. In general $d \ll h$ and we can safely use the centerline velocity as a reasonable "average velocity."

If the exit is not a smooth, well-contoured nozzle, but rather a flat plate as shown in Fig. 3.13, the diameter of the jet, d_j, will be less than the diameter of the hole, d_h. This phenomenon, called a *vena contracta* effect, is a result of the inability of the fluid to turn the sharp 90° corner indicated by the dotted lines in the figure.

Since the streamlines in the exit plane are curved ($\mathcal{R} < \infty$), the pressure across them is not constant. It would take an infinite pressure gradient across the streamlines to cause the fluid to turn a "sharp" corner ($\mathcal{R} = 0$). The highest pressure occurs along the centerline at (2) and the lowest pressure, $p_1 = p_3 = 0$, is at the edge of the jet. Thus, the assumption of uniform velocity with straight streamlines and constant pressure is not valid at the exit plane. It is valid, however, in the plane of the vena contracta, section a–a. The uniform velocity assumption is valid at this section provided $d_j \ll h$, as is discussed for the flow from the nozzle shown in Fig. 3.12.



■ FIGURE 3.13 Vena contracta effect for a sharp edged orifice.

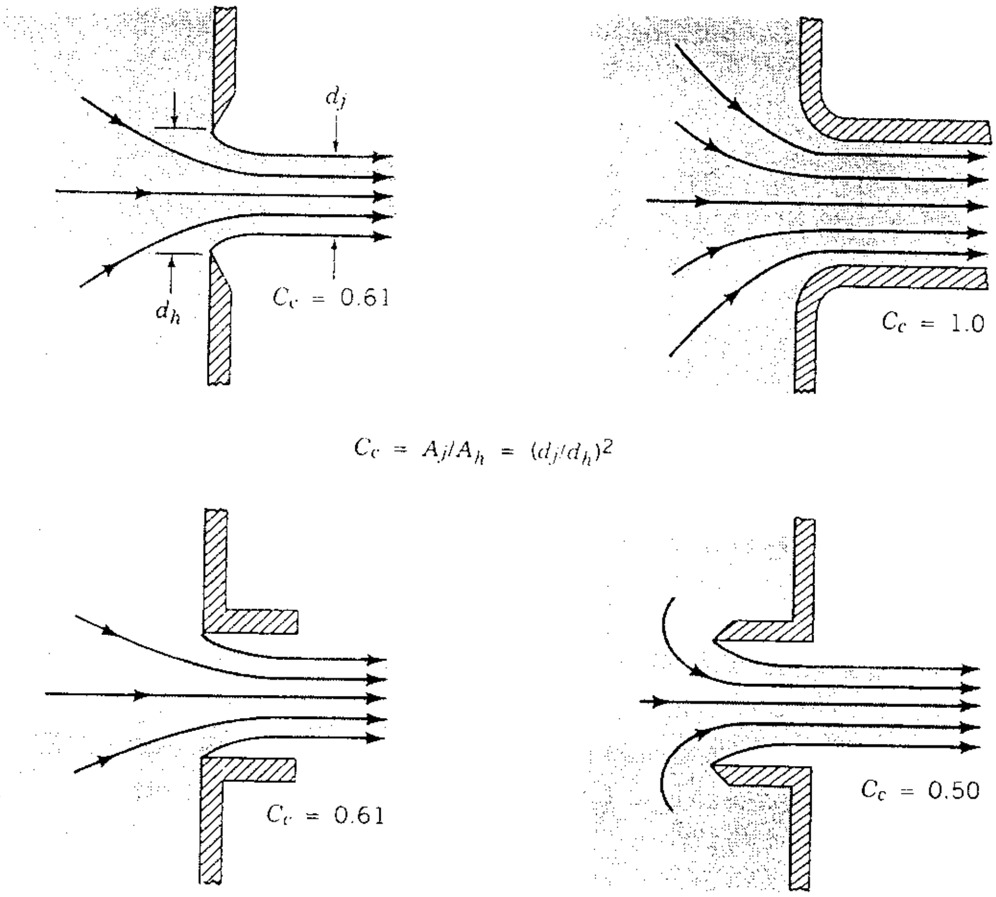


FIGURE 3.14 Typical flow patterns and contraction coefficients for various round exit configurations.

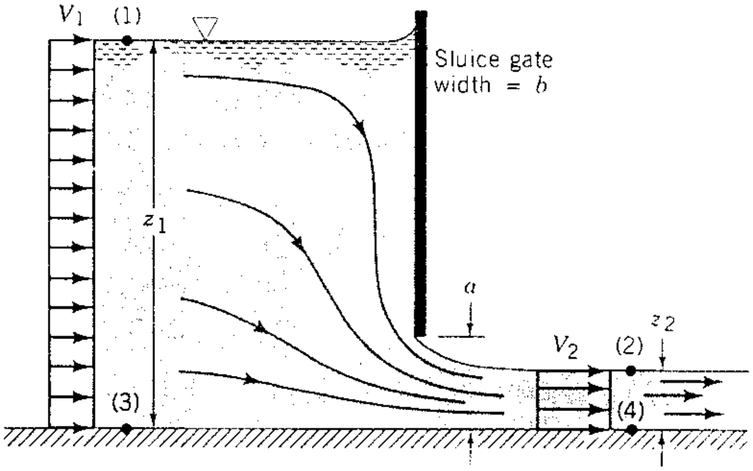
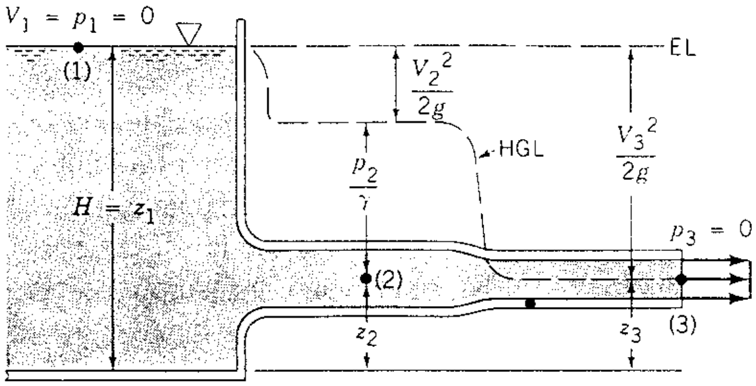


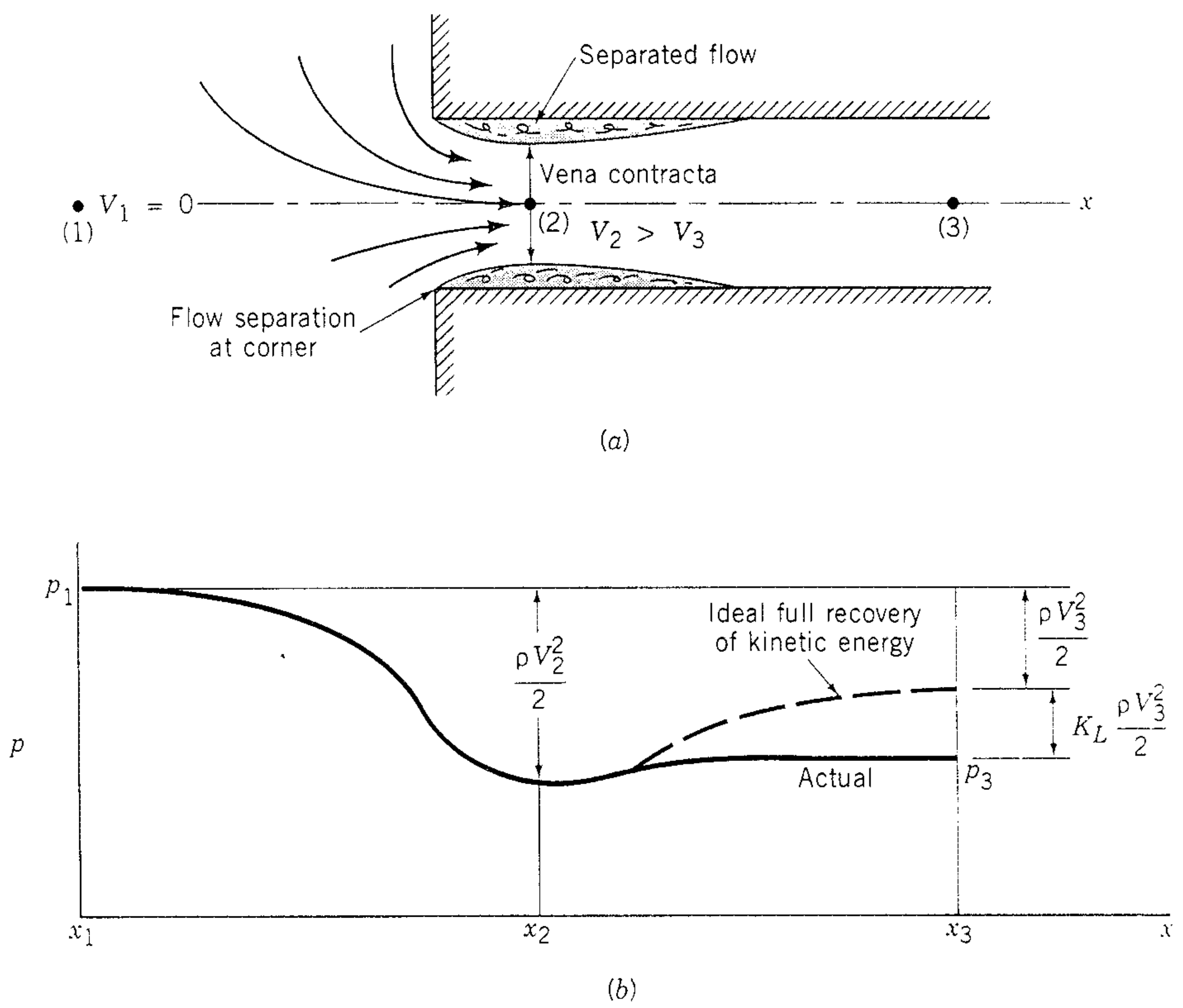
FIGURE 3.19 Sluice gate geometry.



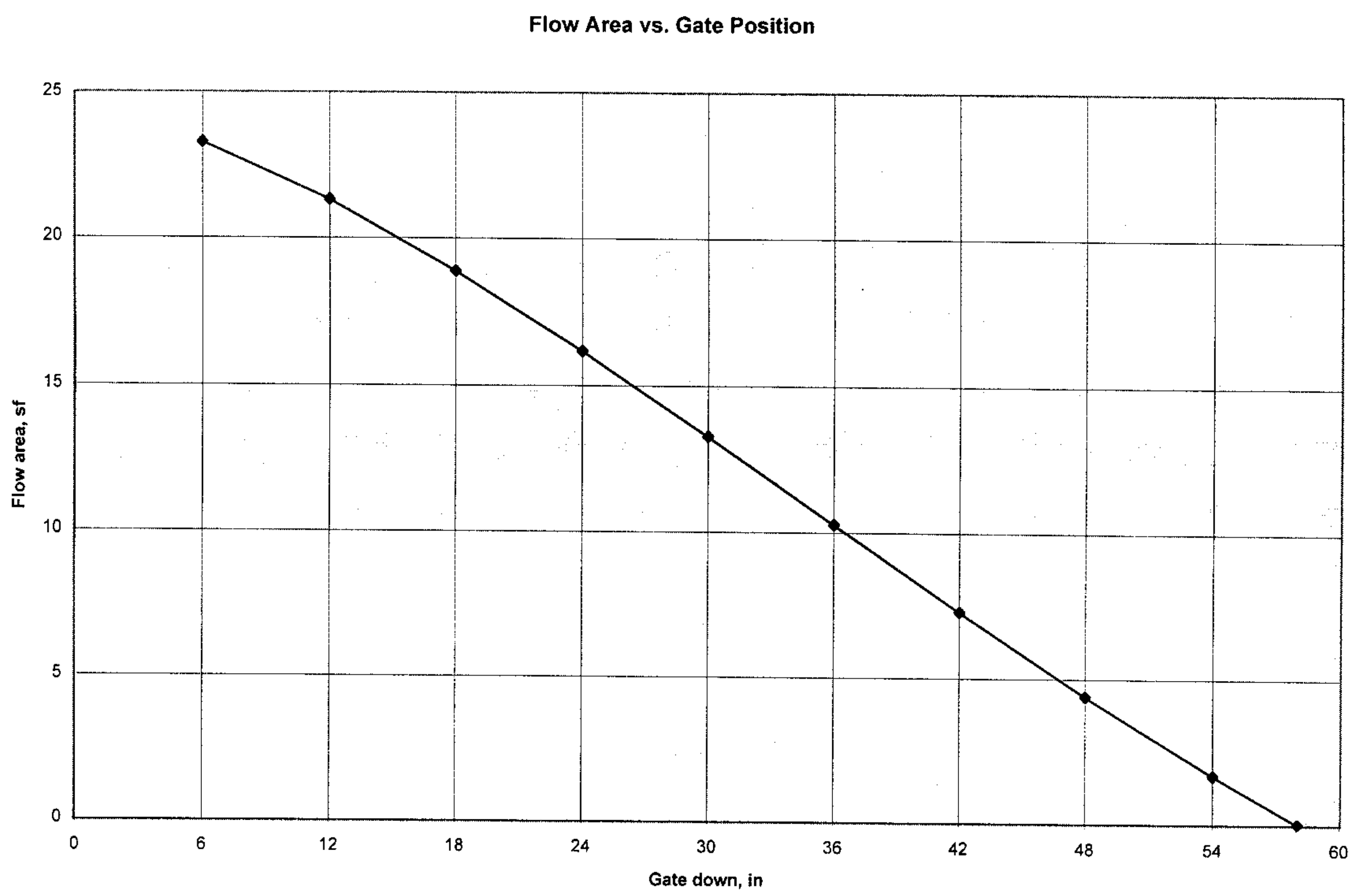
■ **FIGURE 3.22** The energy line and hydraulic grade line for flow from a tank.

A typical flow pattern for flow entering a pipe through a square-edged entrance is sketched in Fig. 8.26. As was discussed in Chapter 3, a vena contracta region may result because the fluid cannot turn a sharp right-angle corner. The flow is said to separate from the sharp corner. The maximum velocity at section (2) is greater than that in the pipe at section (3), and the pressure there is lower. If this high-speed fluid could slow down efficiently, the kinetic energy could be converted into pressure (the Bernoulli effect), and the ideal pressure distribution indicated in Fig. 8.26 would result. The head loss for the entrance would be essentially zero.

Such is not the case. Although a fluid may be accelerated very efficiently, it is very difficult to slow down (decelerate) a fluid efficiently. Thus, the extra kinetic energy of the fluid at section (2) is partially lost because of viscous dissipation, so that the pressure does not return to the ideal value. An entrance head loss (pressure drop) is produced as is indicated in Fig. 8.26. The majority of this loss is due to inertia effects that are eventually dissipated by the shear stresses within the fluid. Only a small portion of the loss is due to the wall shear stress within the entrance region. The net effect is that the loss coefficient for a square-edged entrance is approximately $K_L = 0.50$.



■ **FIGURE 8.26** **Flow pattern and pressure distribution for a sharp-edged entrance.**



Flow Area vs. Gate Position
Flow area, sf
25
20
15
10
5
0
0
6
12
18
24
30
36
42
48
54
60
Gate down, in

TABLE 8.22 Coefficient of discharge for pipe or box culverts set flush in a vertical headwall as a function of y_1/D and r/D or w/D, type 5 ɔw (Bodhaine, 1976)

	r/b, w/b, r/D, or w/D						
$(h_1 - z)/D$	0	0.02	0.04	0.06	0.08	0.10	0.14
1.4	0.44	0.46	0.49	0.50	0.50	0.51	0.51
1.5	0.46	0.49	0.52	0.53	0.53	0.54	0.54
1.6	0.47	0.51	0.54	0.55	0.55	0.56	0.56
1.7	0.48	0.52	0.55	0.57	0.57	0.57	0.57
1.8	0.49	0.54	0.57	0.58	0.58	0.58	0.58
1.9	0.50	0.55	0.58	0.59	0.60	0.60	0.60
2.0	0.51	0.56	0.59	0.60	0.61	0.61	0.62
2.5	0.54	0.59	0.62	0.64	0.64	0.65	0.66
3.0	0.55	0.61	0.64	0.66	0.67	0.69	0.70
3.5	0.57	0.62	0.65	0.67	0.69	0.70	0.71
4.0	0.58	0.63	0.66	0.68	0.70	0.71	0.72
5.0	0.59	0.64	0.67	0.69	0.71	0.72	0.73

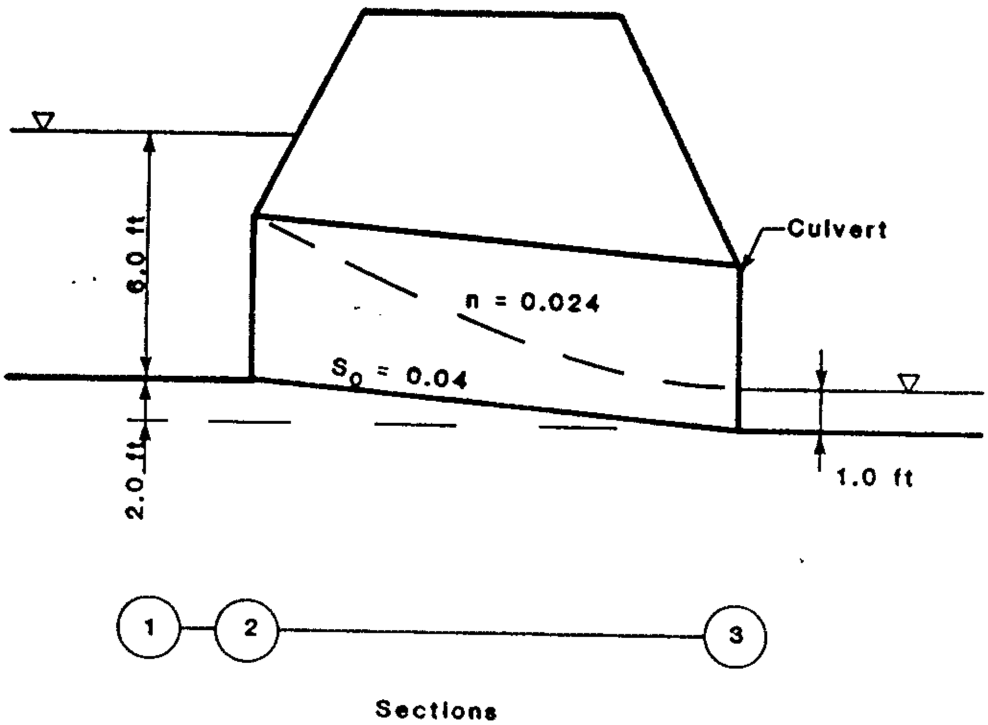
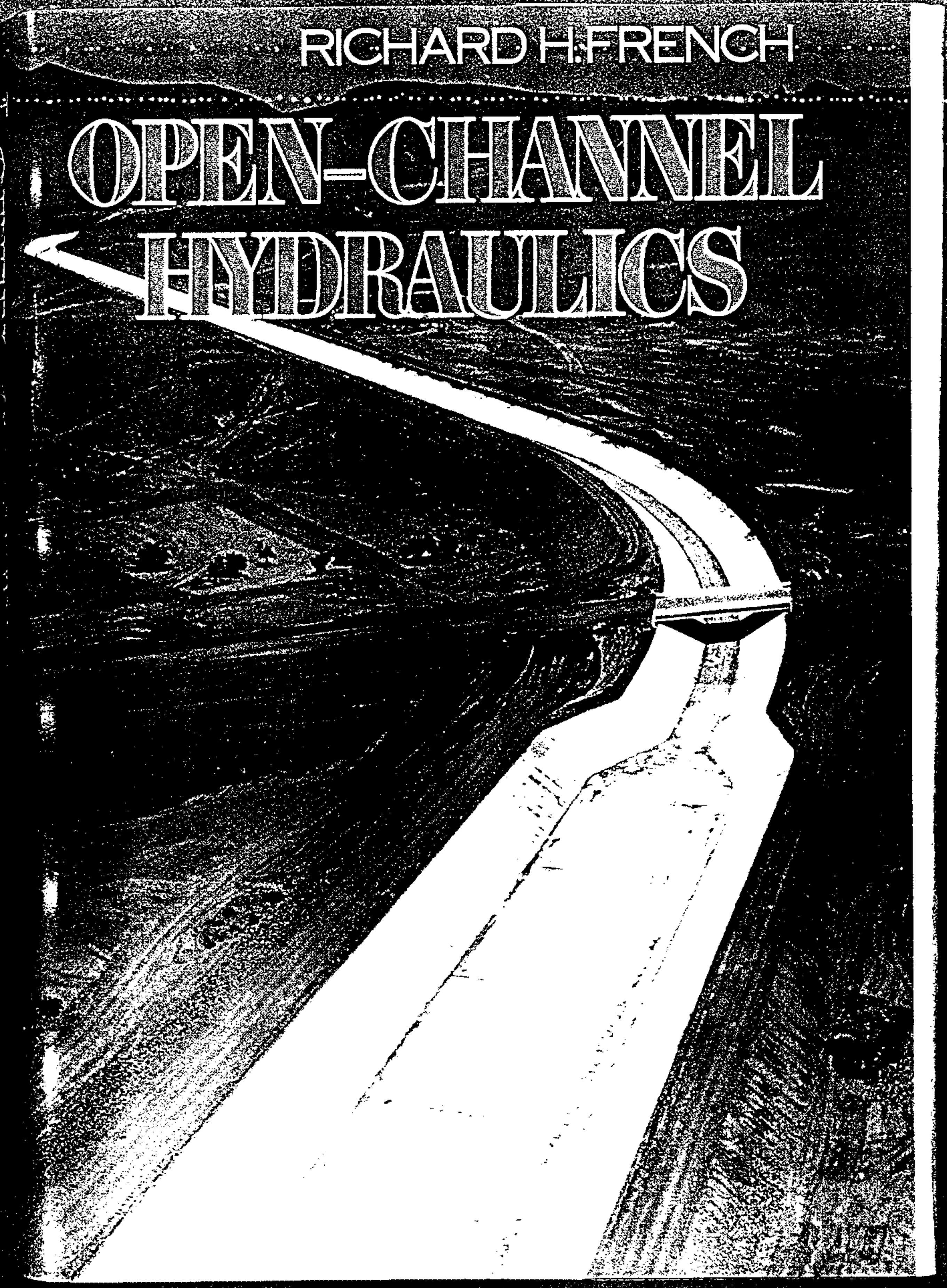


FIGURE 8.39 Schematic for Example 8.6.

RICHARD H. FRENCH

OPEN-CHANNEL HYDRAULICS



Accuracy of culvert computations

Under most field conditions, the computation of peak discharge through culverts should provide reliable results. The more ideal the field conditions, the more reliable the computed discharge will be.

In low-head flow very good results may be expected up to headwater-diameter ratios of 1.25 except where critical depth occurs between the approach section and the culvert entrance. Good results may be also expected for high-head flow when the type is definitely known and the headwater-diameter ratio is greater than 1.75. For type 6 flow, good results may always be expected.

Unusual culvert entrances

For culvert entrances of unusual shape, estimate the discharge coefficient on the basis of known values for the more common shapes (reentrant, sharp, 45-degree wingwalls). For the six types of flow discussed in this manual, this entrance coefficient can usually be estimated with sufficient accuracy. In high-head flow the entrance shape is very important because it may mean the difference between a culvert flowing full or partly full.

Remember that the effect of side contraction becomes negligible for flow types 4, 5, and 6 and that vertical contraction is very important.

Flow under high head

High-head flow will occur if the tailwater is below the crown at the outlet and the headwater-diameter ratio is equal to or greater than 1.5. This is an approximate criterion. The two types of flow under this category are 5 and 6.

The occurrence of type 5 flow requires a relatively square entrance that will cause contraction of the area of live flow to less than the area of the culvert barrel. In addition, the combination of barrel length, roughness, and bed slope must be such that the contracted jet will not expand to the full area of the barrel. If the water surface of the expanding flow comes in contact with the top of the culvert, type 6 flow will occur, because the passage of air to the culvert will be sealed off causing the culvert to flow full throughout its length. Under these conditions, the headwater surface drops, indicating a more efficient use of the culvert barrel.

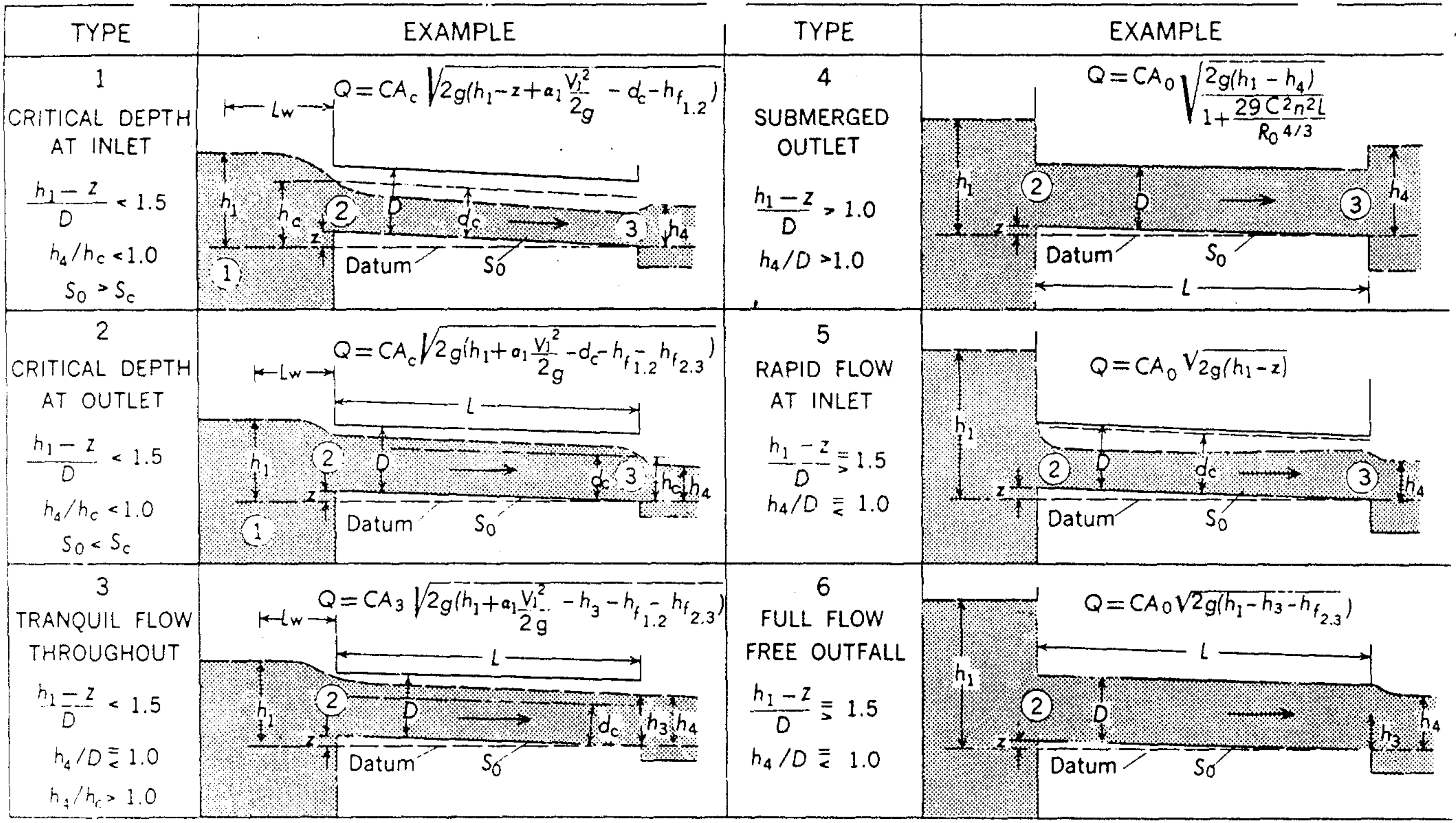


Figure 2.—Classification of culvert flow.

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A3

MEASUREMENT OF PEAK DISCHARGE AT CULVERTS BY INDIRECT METHODS

BOOK 3

APPLICATIONS OF HYDRAULICS

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A WATER RESOURCES TECHNICAL PUBLICATION

U.S. BUREAU OF RECLAMATION
DENVER, CO

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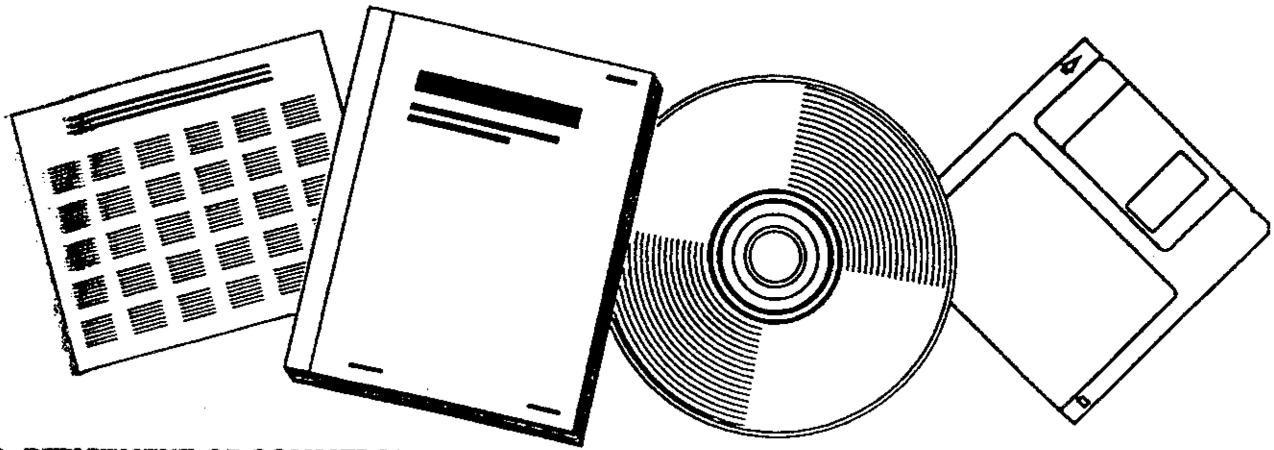

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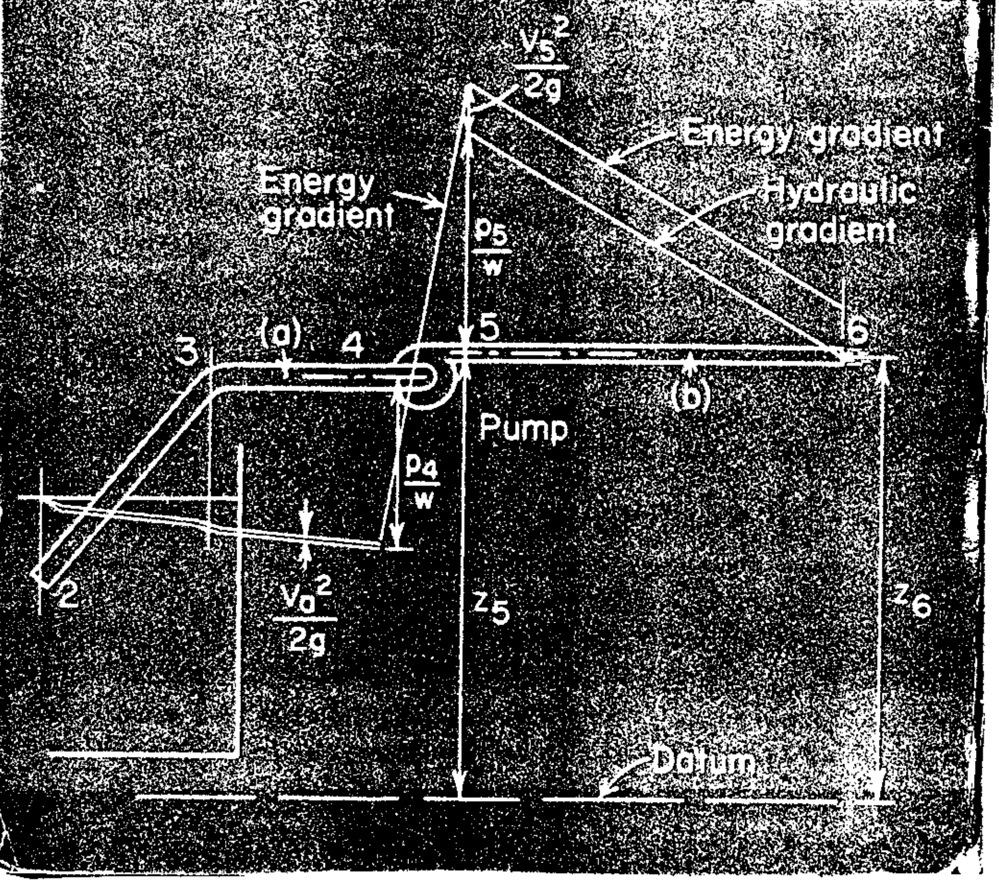
For the Solution of Hydraulic Engineering Problems

Sixth Edition



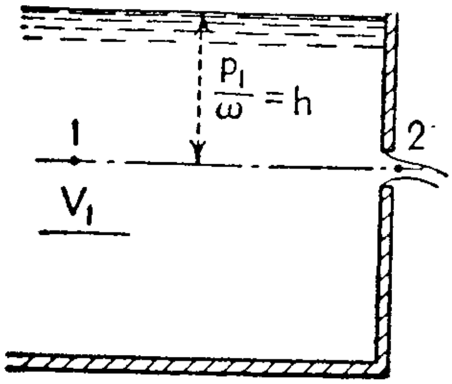


FIG. 4-1. Sharp-edged orifice.

Table 4-3. Smith's Coefficients of Discharge for Circular and Square Orifices with Full Contraction

Diameter of circular orifices, feet							Head, feet	Side of square orifices, feet						
0.02	0.04	0.07	0.1	0.2	0.6	1.0		0.02	0.04	0.07	0.1	0.2	0.6	1.0
.....	0.637	0.624	0.618				0.4	.....	0.643	0.628	0.621			
0.655	0.630	0.618	0.613	0.601	0.593		0.6	0.660	0.636	0.623	0.617	0.605	0.598	
0.648	0.626	0.615	0.610	0.601	0.594	0.590	0.8	0.652	0.631	0.620	0.615	0.605	0.600	0.597
0.644	0.623	0.612	0.608	0.600	0.595	0.591	1	0.648	0.628	0.618	0.613	0.605	0.601	0.599
0.637	0.618	0.608	0.605	0.600	0.596	0.593	1.5	0.641	0.622	0.614	0.610	0.605	0.602	0.601
0.632	0.614	0.606	0.604	0.599	0.597	0.595	2	0.637	0.619	0.612	0.608	0.605	0.604	0.602
0.629	0.612	0.605	0.603	0.599	0.598	0.596	2.5	0.634	0.617	0.610	0.607	0.605	0.604	0.602
0.627	0.611	0.604	0.603	0.599	0.598	0.597	3	0.632	0.616	0.609	0.607	0.605	0.604	0.603
0.623	0.609	0.603	0.602	0.599	0.597	0.596	4	0.628	0.614	0.608	0.606	0.605	0.603	0.602
0.618	0.607	0.602	0.600	0.598	0.597	0.596	6	0.623	0.612	0.607	0.605	0.604	0.603	0.602
0.614	0.605	0.601	0.600	0.598	0.596	0.596	8	0.619	0.610	0.606	0.605	0.604	0.603	0.602
0.611	0.603	0.599	0.598	0.597	0.596	0.595	10	0.616	0.608	0.605	0.604	0.603	0.602	0.601
0.601	0.599	0.597	0.596	0.596	0.596	0.594	20	0.606	0.604	0.602	0.602	0.602	0.601	0.600
0.596	0.595	0.594	0.594	0.594	0.594	0.593	50	0.602	0.601	0.601	0.600	0.600	0.599	0.599
0.593	0.592	0.592	0.592	0.592	0.592	0.592	100	0.599	0.598	0.598	0.598	0.598	0.598	0.598

Table 4-6. Miscellaneous Coefficients of Discharge for Various Sharp-edged Submerged Orifices

The two orifices experimented on by Ellis were horizontal. All other orifices were vertical.

Dimensions of orifice in feet	Authority	Head in feet							
		0.3	0.5	1.0	2.0	4.0	6.0	10.0	18.0
Circle, d = .05......	H. Smith	....	.599	.597	.595	.595			
Circle, d = .10......	H. Smith	.600	.600	.600	.599	.598			
Square, .05 by .05..	H. Smith	....	.609	.607	.605	.604			
Square, .10 by .10..	H. Smith	.607	.605	.604	.603	.604			
Rectangle, l = 3.0, d = .05.	H. Smith	....	.621	....	....	.620	.620	.618	
Circle, d = 1.0......	Ellis	....	....	....	.608	.602	.603	.600	.601
Square, 1.0 by 1.0..	Ellis	....	....	....	.601	.601	.603	.605	.606
Square, 4.0 by 4.0..	Stewart	.614							

Table 4-7. Coefficients of Discharge for Submerged Vertical Square Orifice with Rounded Corners

From experiments by Ellis

Dimensions of orifice in feet	Head in feet								
	3	4	5	6	8	10	12	14	18
Square, 1.0 by 1.0.......	.952	.948	.946	.945	.944	.943	.943	.944	.944

Table 4-4. Coefficients of Discharge for Rectangular Orifices 0.656 Ft Wide with Partially Suppressed Contraction

Description of contraction	Height, feet	Head, feet: 1	Head, feet: 3	Head, feet: 5
Complete contraction...	0.656	0.598	0.604	0.603
	0.328	0.616	0.615	0.611
	0.614	0.631	0.627	0.620
	0.098	0.632	0.628	0.623
	0.033	0.652	0.634	0.620
Suppressed at bottom only	0.656	0.620	0.624	0.625
	0.328	0.649	0.647	0.634
	0.164	0.671	0.668	0.666
	0.098	0.680	0.677	0.677
	0.033	0.710	0.705	0.696
Suppressed on both sides only.................	0.656	0.632	0.628	0.628
	0.328	0.637	0.630	0.630
	0.164	0.641	0.634	0.635
	0.098	0.653	0.643	0.639
	0.033	0.682	0.667	0.655
Suppressed at bottom and partly on one side..	0.656	0.633	0.636	0.637
	0.328	0.658	0.656	0.654
	0.164	0.676	0.673	0.672
	0.098	0.682	0.683	0.681
	0.033	0.708	0.705	0.695
Suppressed at bottom and partly on two sides.	0.656	0.678	0.664	0.663
	0.328	0.680	0.675	0.672
	0.164	0.687	0.680	0.673
	0.098	0.693	0.688	0.683
	0.033	0.708	0.705	0.698
Suppressed at bottom and two sides...............	0.656	0.690	0.677	0.672
Complete suppression.....	0.656	.....	0.950	

Table 4-5. Coefficients of Discharge of Various-shaped Orifices with Complete Contraction

Fanning's coefficients for vertical rectangular orifices 1 foot wide: Height of orifice, feet							Bovey's coefficients for various-shaped orifices, each 0.196 square inch in area								
0.125	0.25	0.5	1	2	4	Head, feet	Circle	Square: Sides vertical	Square: Diagonal vertical	Rectangle 4:1: Long sides vertical	Rectangle 4:1: Long sides horizontal	Rectangle 10:1: Long sides vertical	Rectangle 10:1: Long sides horizontal	Triangle
0.622	0.616	0.611	0.605	.....	.....	1	0.620	0.627	0.628	0.642	0.643	0.663	0.664	0.636
0.619	0.614	0.609	0.604	0.609	.....	2	0.613	0.620	0.628	0.634	0.636	0.650	0.651	0.628
0.614	0.610	0.607	0.603	0.606	0.608	4	0.608	0.616	0.618	0.628	0.629	0.641	0.642	0.623
0.610	0.608	0.604	0.601	0.604	0.605	6	0.607	0.614	0.616	0.626	0.627	0.637	0.637	0.620
0.608	0.606	0.603	0.601	0.603	0.604	8	0.606	0.613	0.614	0.623	0.625	0.634	0.635	0.619
0.606	0.604	0.602	0.601	0.602	0.603	10	0.605	0.612	0.613	0.622	0.624	0.632	0.633	0.618
0.607	0.603	0.601	0.601	0.602	0.603	15	0.604	0.610	0.611	0.620	0.622	0.630	0.630	0.617
[illegible]07	0.604	0.602	0.601	0.602	0.603	20	0.603	0.609	0.611	0.620	0.621	0.629	0.628	0.616
0.609	0.604	0.603	0.601	0.603	0.605	30								
0.614	0.607	0.605	0.602	0.606	0.609	50								