TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE CASPER, WYOMING SOIL CONSERVATION SERVICE

Engineering No. 15 February 24, 1976

Corrugated Metal Pipe Arch Hydraulic Properties

General

Enclosed is a set of graphs and tables for use in determining capacities of pipe arch culverts. Examples for the use of the graphs and tables are enclosed. Users are cautioned to use the proper method to fit their specific flow condition.

Culvert Capacity Sample Problem

Given: 13" x 22" arch CMP, length = 30 feet. Water surface 0.4 foot above top of pipe at inlet. Tailwater depth (TW) = 1.0 feet. Pipe slope = 0.01 ft./ft.

Find: Capacity of pipe.

Solution: Using inlet and outlet control tables:

1. Check inlet control with h = 0.4 ft. and 13" x 22" pipe. Select Q = 6.4 cfs from Table A. (Note: If inlet control governs, pipe length and slope will not affect Q.)
2. Check outlet control.
   H = fall from water surface at inlet to water surface at outlet. HW = 13" + 0.4 ft. = 1.08 + 0.4 = 1.48 ft. Fall in pipe = (0.010) (30) = 0.30 ft. H = 1.48 + 0.30 - 1.0 = 0.78 ft. Use 0.8 ft. Select Q = 5.6 cfs from Table B. This is less than Q = 6.4 for inlet control, therefore; outlet control governs. Q = 5.6 cfs.

Given: Same problem as above with pipe. S = 0.040.

Find: Capacity of pipe.

Solution: Using Tables A & B:
Inlet control Q = 6.4 cfs from first problem.
Check outlet control. Fall in pipe = (0.04)(30) = 1.20 ft.
H = 1.48 + 1.20 = 1.0 = 1.68 ft. Use 1.7 ft. Select Q = 8.2 cfs. This is greater than Q = 6.4 for inlet control, therefore; inlet control governs. Q = 6.4 cfs.

Full Pipe Flow Sample Problem

Given: 13" x 22" arch CMP, annular corrugations. Length = 50 ft. HW = 2.0 ft. Tailwater above outlet end of pipe. Projecting inlet. H = 0.6 ft.

Find: Capacity of pipe.

Solution: 1. Check inlet control.
h = 2.0 - 1.08 = 0.92 ft. Use 0.9 ft.
From Table A select Q = 8.3 cfs.

2. Check full pipe flow.

Ke = inlet loss = 0.9 (EFM Table 3-3, page 3-35)

Kp = 0.0768 (Table 2)

Kpl = (0.0768)(50) = 3.84

A = Area = 1.6 sq. ft. (Table 1)

$$V = \left[\frac{(64.4)(H)}{1 + Ke + Kpl}\right]^{\frac{1}{2}}$$

$$V = \left[\frac{(64.4)(0.6)}{1 + 0.9 + 3.84}\right]^{\frac{1}{2}} = \left[\frac{38.64}{5.74}\right]^{\frac{1}{2}} = \sqrt{6.73} = 2.6 \text{ fps.}$$

Q = VA = (2.6)(1.6) = 4.2 cfs.

Full pipe flow governs. <u>Q = 4.2 cfs</u>.

<u>Open Channel Flow Sample Problem</u>

Given: 13" x 22" arch CMP, water surface at both inlet and outlet is below top of pipe. Flow depth in pipe = 0.9 ft., S = 0.003.

Find: Capacity of pipe.

Solution: Using Table 1 and graph.

$\frac{d}{H}$ = 0.9/1.08 = 0.83 = 83%.

Cr = 1.22 (from graph)

Ca = 0.91 (from graph)

Full pipe area = 1.6 sq. ft. (from Table 1)

Flow area = (0.91)(1.6) = 1.46 ft.^{2}

Full pipe hydraulic radius = 0.340 (from Table 1)

Hydraulic radius = (1.22)(0.340) = 0.41 = r

$$V = \frac{(1.486)(r^{2/3})\ (S^{1/2})}{n}$$

$r = 0.41 \quad r^{2/3} = 0.552$ (Kings H.B.)

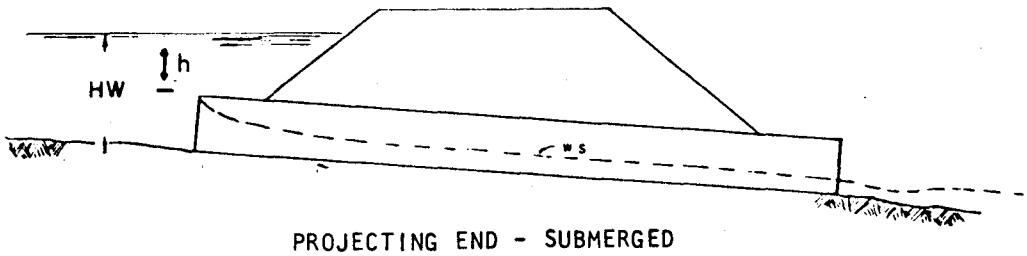
$S = 0.003 \quad S^{1/2} = 0.0316$ (Kings H.B.)

n = 0.025, annular corrugations

$$V = \frac{(1.486)(0.552)(0.0316)}{(0.025)} = 1.04 \text{ fps.}$$

Q = VA = (1.04)(1.46) = <u>1.5 cfs.</u>

INLET CONTROL



PROJECTING END - SUBMERGED

TABLE A

Culvert Capacity

Corrugated Metal Pipe-Arch Culverts
(capacity in cubic feet per second)

(h) Head above top of pipe entrance, ft.	Pipe Sizes (inches)						
	18"x11"	22"x13"	25"x16"	29"x18"	36"x22"	43"x27"	50"x31"
0.2	3.5	5.5	8.2	11.0	18.0	29.0	42.0
0.4	4.3	6.4	9.2	12.2	20.0	32.0	44.0
0.6	5.0	7.2	10.2	14.0	22.0	34.0	47.0
0.8	5.3	8.0	11.0	15.0	23.0	36.0	50.0
1.0	5.8	8.6	12.0	16.0	25.0	38.0	53.0
1.5	6.6	9.8	13.8	18.0	28.0	43.0	60.0
2.0	7.2	10.9	16.0	20.0	30.6	46.6	65.0
2.5	7.6	12.0	17.9	22.0	33.0	50.0	70.0
3.0	8.2	13.0	20.0	24.0	36.0	55.0	76.0
4.0	9.2	15.1	23.7	27.8	40.9	62.9	86.7

OUTLET CONTROL

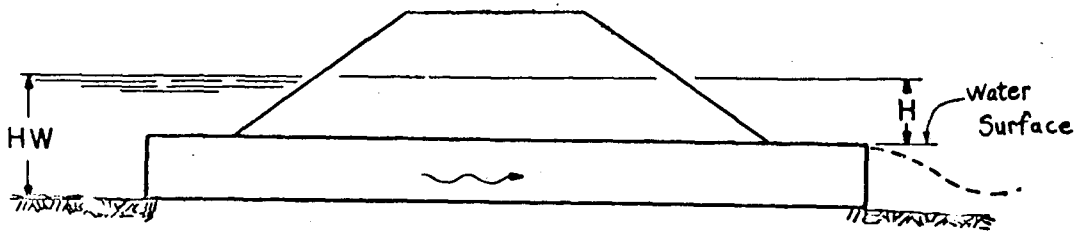


TABLE B

Culvert Capacity

Corrugated Metal Arch Pipe Culverts

(Capacity in cubic feet per second)

n = 0.025

Effect Head (feet)	18"x11" Pipe Length			22"x13" Pipe Length			25"x16" Pipe Length			29"x18" Pipe Length			36"x22" Pipe Length			43"x27" Pipe Length			50"x31" Pipe Length		
	20'	30'	40'	20'	30'	40'	20'	30'	40'	20'	30'	40'	20'	30'	40'	20'	30'	40'	20'	30'	40'
0.4	2.8	2.5	2.3	4.4	4.0	3.7	6.3	5.8	5.4	8.3	7.6	7.1	13.6	12.7	12.0	20.5	19.4	18.4	28.5	27.2	26.0
0.6	3.5	3.1	2.8	5.4	4.9	4.5	7.8	7.1	6.6	10.1	9.3	8.7	16.7	15.6	14.7	25.1	23.8	22.6	34.9	33.3	31.8
0.8	4.0	3.6	3.2	6.2	5.6	5.2	9.0	8.2	7.6	11.7	10.7	10.0	19.3	18.0	16.9	29.0	27.4	26.1	40.3	38.4	36.7
1.0	4.5	4.0	3.6	7.0	6.3	5.8	10.0	9.2	8.5	13.0	12.0	11.2	21.5	20.1	18.9	32.5	30.7	29.1	45.1	42.9	41.1
1.5	5.5	4.9	4.4	8.5	7.7	7.1	12.3	11.2	10.4	16.0	14.7	13.7	26.4	24.6	23.2	39.8	37.6	35.7	55.2	52.6	50.3
2.0	6.3	5.6	5.1	9.8	8.9	8.2	14.2	13.0	12.0	18.5	17.0	15.8	30.5	28.5	26.8	45.9	43.4	41.2	63.8	60.7	58.1
2.5	7.1	6.3	5.7	11.0	10.0	9.2	15.8	14.5	13.4	20.6	19.0	17.7	34.1	31.8	30.0	51.3	48.5	46.1	71.3	67.9	64.9
3.0	7.7	6.9	6.3	12.0	10.9	10.0	17.3	15.9	14.7	22.6	20.8	19.4	37.3	34.8	32.8	56.2	53.1	50.5	78.1	74.4	71.1
4.0	8.9	8.0	7.3	13.9	12.6	11.6	20.0	18.3	17.0	26.1	24.0	22.4	43.1	40.2	37.9	64.9	61.3	58.3	90.2	85.9	82.1

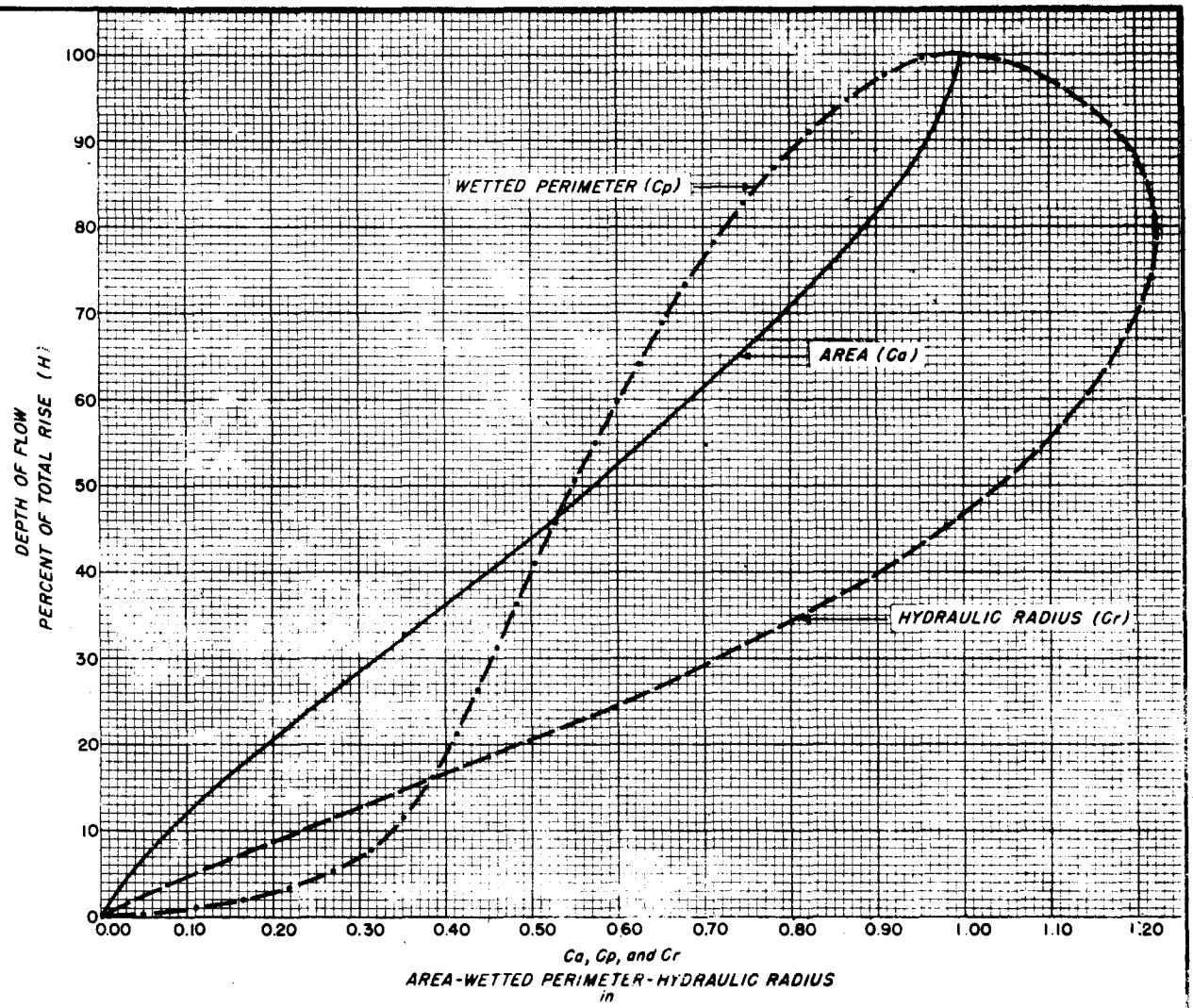


TABLE — I

HYDRAULIC FACTORS FOR
CORRUGATED METAL PIPE ARCHES AND MULTIPLATE PIPE ARCHES

Arch Number	Size (in.)	Rise (ft.)	Span (ft)	Area (sq.ft.)	Periphery (ft.)	Hydraulic Radius flowing full (ft.)	Round Pipe of Equal Periphery (in.)
			Pipe Arches				
1	11 x 18	0.92	1.50	1.1	3.93	0.280	15
2	13 x 22	1.08	1.83	1.6	4.71	0.340	18
3	16 x 25	1.33	2.08	2.2	5.50	0.400	21
4	18 x 29	1.50	2.42	2.8	6.28	0.446	24
5	22 x 36	1.83	3.00	4.4	7.85	0.561	30
6	27 x 43	2.25	3.58	6.4	9.42	0.679	36
7	31 x 50	2.58	4.16	8.7	11.00	0.791	42
8	36 x 58	3.00	4.83	11.4	12.57	0.907	48
9	40 x 65	3.33	5.42	14.3	14.14	1.011	54
10	44 x 72	3.67	6.00	17.6	15.71	1.120	60
			Multiplate Pipe Arches				
A	57 x 77	4.75	6.42	23.8	18.05	1.319	69 (approx.)
B	64 x 93	5.33	7.75	33.3	21.19	1.571	81 "
C	72 x 107	6.00	8.92	42.7	24.34	1.754	93 "
D	78 x 127	6.42	10.25	54.5	27.47	1.984	105 "
E	90 x 142	7.50	11.83	70.0	31.40	2.229	120 "
F	96 x 159	8.00	13.25	84.8	34.54	2.455	132 "
G	104 x 170	8.67	14.17	95.9	36.89	2.600	141 "
H	115 x 189	9.58	15.75	114.3	40.82	2.800	156 "

Method of determining the area, wetted perimeter and hydraulic radius of pipe arch and multiplate pipe arch culverts flowing partly full.

$$\frac{\text{depth of flow}}{\text{rise of pipe arch}} = \frac{d}{H} = \%\ \text{of total rise}$$

To determine the area, wetted perimeter, and hydraulic radius of an arch culvert flowing partly full, enter the graph with the % of total rise($\frac{d}{H}$) and obtain Ca, Cp, and Cr from their respective curves.

Then area = Ca x total area from Table I
Wetted perimeter = Cp x periphery from Table I
Hydraulic radius = Cr x hydraulic radius flowing full from Table I

HYDRAULIC FACTORS FOR CORRUGATED METAL PIPE ARCHES AND MULTIPLATE PIPE ARCHES

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ROBERT M. SALTER, CHIEF

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REFERENCE: Armco Drainage and Metal Products Inc.

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FULL PIPE FLOW

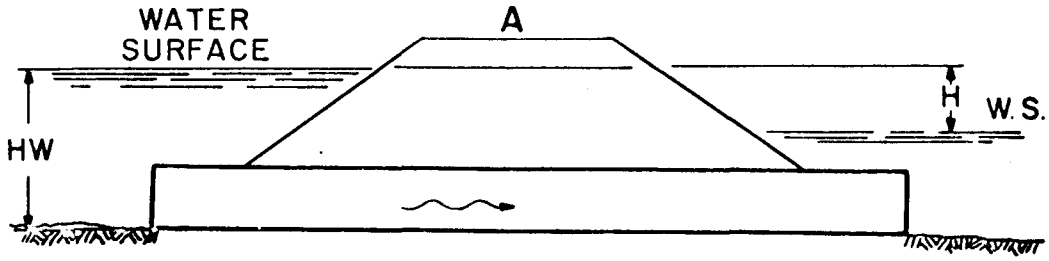

TABLE 2

Hydraulic Factors for Pipe-Arch

Round Pipe Equivalent	Arch Pipe Size	Area Sq. Ft.	Type of Corrugation	
			Annular Kp	Helical Kp
15"	11"x18"	1.1	0.09950	0.04600
18"	13"x22"	1.6	0.07681	0.03981
21"	16"x25"	2.2	0.06185	0.03958
24"	18"x29"	2.8	0.05348	0.04527
30"	22"x36"	4.4	0.03939	0.03939
36"	27"x43"	6.4	0.03054	0.03054
42"	31"x50"	8.7	0.02491	0.02491
48"	36"x58"	11.4	0.02076	0.02076
54"	40"x65"	14.3	0.01796	0.01796
60"	44"x72"	17.6	0.01567	0.01567

Mannings "n" for Helical CMP

$$K_p = \frac{29.164n^2}{r^{4/3}}$$

Diameter	"n"	Diameter	"n"
12"	0.016	21"	0.020
15"	0.017	24"	0.023
18"	0.018	30"+	0.025