Appendix C  PIPE FLOW DESIGN CHARTS

HDS-5, *Hydraulic Design of Highway Culverts* (FHWA, 1985) contains pipe design charts. Some of these charts have been reproduced in this appendix. An index of the design charts provided is given below, not all charts included in the FHWA manual are reproduced in this document.

Design curves were developed for common conduit shapes, sizes and inlet edge configurations constants using a set of design equations. The design equations used to develop the inlet control nomographs are based on the research conducted by the National Bureau of Standards (NBS) under the sponsorship of the Bureau of Public Roads (now the Federal Highway Administration). Seven progress reports were produced as a result of this research. These reports were one source of the equation coefficients and exponents, along with other references and unpublished FHWA notes on the development of the nomographs.

A constant slope value of 2 percent (0.02) was selected for the development of design curves. This is because the slope effect is small and the resultant headwater is conservatively high for sites with slopes exceeding 2 percent except for mitered inlets.

In formulating inlet and outlet control design nomographs, a certain degree of error is introduced into the design process. This error is due to the fact that the nomograph construction involves graphical fitting techniques resulting in scales which do not exactly match the equations. Checks by the authors and others indicate that all of the nomographs from HDS-5 (FHWA, 1985) have a precision of ± 10 percent of the equation values in terms of headwater (inlet control) or head loss (outlet control).

<table>
<thead>
<tr>
<th>Chart Number</th>
<th>Shape</th>
<th>Control Section</th>
<th>Material</th>
<th>Type</th>
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<tr>
<td>1</td>
<td>Circular</td>
<td>Inlet</td>
<td>Concrete</td>
<td>Beveled Ring Control</td>
</tr>
<tr>
<td>2</td>
<td>Circular</td>
<td>Inlet</td>
<td>Metal</td>
<td></td>
</tr>
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<td>3</td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>Circular</td>
<td>Critical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Circular</td>
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<td>Concrete</td>
<td>n = 0.012</td>
</tr>
<tr>
<td>6</td>
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<td>Outlet</td>
<td>Metal</td>
<td>n = 0.024</td>
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<td>7</td>
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<td>Metal</td>
<td>n = 0.0328 to 0.0302</td>
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<td></td>
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<td>9</td>
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<td>Concrete</td>
<td>Wingwalls 18° to 33.7° and 45°</td>
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<td>Concrete</td>
<td>90° Headwall, Beveled Edges</td>
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<td>Concrete</td>
<td>Skewed Headwalls, Beveled Edges</td>
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<td>12</td>
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<td>Flared Wingwalls, Normal and Skewed</td>
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<td>13</td>
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<td>Concrete</td>
<td>Offset Flared Wingwalls, Inlet Top beveled edge</td>
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<td>14</td>
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<td>34</td>
<td>Pipe Arch</td>
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<td>Metal</td>
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<td>35</td>
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<td>Inlet</td>
<td>Metal</td>
<td>18 in. Corner Radius</td>
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<td>Inlet</td>
<td>Metal</td>
<td>31 in. Corner Radius</td>
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<td>Critical</td>
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<td>Structural Plate</td>
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<td>Outlet</td>
<td>Metal</td>
<td>n = 0.024</td>
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<tr>
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<td>Outlet</td>
<td>Metal</td>
<td>18 in. Corner Radius</td>
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<tr>
<td>60</td>
<td>Roadway</td>
<td>Overtopping</td>
<td></td>
<td>Discharge Coefficients</td>
</tr>
</tbody>
</table>
Chart 1

Example:

\[ D = 42 \text{ inches (3.5 feet)} \]
\[ Q = 120 \text{ cfs} \]

- **HW** $\times$ $D$ in feet
- **(1)** 2.5 6.6
- **(2)** 2.1 7.4
- **(3)** 2.2 7.7

**Example:**

- **Headwater depth in diameters (HW/D):**
  - 6.0
  - 5.0
  - 4.0
  - 3.0
  - 2.0

- **Diameters (D) in inches:**
  - 12
  - 18
  - 24
  - 30
  - 36
  - 42
  - 48
  - 54
  - 60
  - 66

- **Discharge (Q) in cfs:**
  - 10,000
  - 6,000
  - 4,000
  - 3,000
  - 2,000
  - 1,000
  - 800
  - 600
  - 400
  - 300
  - 200
  - 100

**Entrance Type:**
- (1) Square edge with headwall
- (2) Groove end with headwall
- (3) Groove end projecting

**Headwater Scales 2.8**: Concrete Pipe Culverts with Inlet Control

Bureau of Public Roads Jan. 1943
Revised May 1964
**CHART 2**

**EXAMPLE**

\[ \frac{H}{D} = \frac{8}{4} \]

- (1) 1.0 3.4
- (2) 2.1 6.3
- (3) 2.2 6.6

\( \frac{H}{D} \) in feet

**EXAMPLE**

\[ \frac{Q}{C} = \frac{1000}{30} \]

- (1) 100 10
- (2) 200 20
- (3) 300 30
- (4) 400 40
- (5) 500 50
- (6) 600 60

**SCALE**

- (1) Headwell
- (2) Modified to conform to slope
- (3) Projecting

**ENTRANCE TYPE**

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through \( \frac{H}{D} \) and \( \frac{Q}{C} \) scales, or reverse as illustrated.

**HEADWATER DEPTH FOR C. M. PIPE CULVERTS WITH INLET CONTROL**

**BUREAU OF PUBLIC ROADS JAN. 1963**
CHART 3

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973
CHART 5

HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012
CHART 6

SUBMERGED OUTLET CULVERT FLOWING FULL

For outlet sworn not submerged, compute HW by methods described in the design procedure.

HEAD FOR STANDARD
C. M. PIPE CULVERTS
FLOWING FULL

n = 0.024
For outlet crown not submerged, compute HW by methods described in the design procedure.
**Chart 9**

**Example:**
- 3' x 3' Box, Q = 250 CFS
- Q/NB = 50 CFS/FT
- INLET H/W/D (FEET)
  - (1) 1.41 7.1
  - (2) 1.33 6.7

**Scale Entrance Type**
- (1) 45° Wingwall Flair with d = 0.043 D
- (2) 18° to 33.7° Wingwall Flair with d = 0.083 D

**Headwater Depth for Inlet Control**
- Rectangular Box Culverts
- Flared Wingwalls 18° to 33.7° & 45°
- With Beveled Edge at Top of Inlet
CHART 10

EXAMPLE

8' x 11' 9" 1/2 IN/FT BEVEL 2.09 10.4

INLET FACE-ALL EDGES:

1 IN/FT BEVELS 33.7° (1:1.5)
1/2 IN/FT BEVELS 45° (1:1)
3/4 INCH CHAMFERS

NOTE ON BEVELS

FACE DIMENSION OF ALL SIDE AND TOP BEVELS
SHALL NOT BE LESS THAN SHOWN TO OBTAIN BEVEL
TERMINATION IN ONE PLANE IN A RECTANGULAR BOX.
EITHER INCREASE # OR B, OR DECREASE THE BEVEL ANGLE.

FACE DIMENSIONS B AND # OF BEVELS ARE EACH RELATED TO
THE OPENING DIMENSION AT RIGHT ANGLES TO THE EDGE.

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS

90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973
EXAMPLE

B = 7 FT  D = 5 FT  Q = 1000 CF/S

EDGE & SKEW  HW  HW
3/4" CHAMFER  HW  feet
45°  2.81  12.8
30°  2.43  12.1
15°  2.36  11.8
VARIED BEVEL
10° TO 45°  2.07  10.3

CHART 11

BEVELED EDGES - TOP AND SIDES
3/4 INCH CHAMFER ALL EDGES

SKEW ANGLE  45°  30°  15°  10°  45°

HEADWATER DEPTH IN TERMS OF HEIGHT (HW/D)

HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKewed HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973
CHART 12

EXAMPLE

B = 7 FT, D = 5 FT, Q = 500 CFS

\( \frac{Q}{B} = 71.5 \)

INLET B WW HW HW
NORMAL

45° WW 2.18 10.9
18.4° WW 2.27 11.4
SKewed 15° 40°
18.4 OR MORE
WW 2.20 11.0

30° SKEW
NORMAL INLETS
WINGWALL FLARE - 45° 18.4° 18.4°

HEADWATER DEPTH IN TERMS OF HEIGHT (HW/D)

NOTE:
HEADWATER SCALE FOR SKEWED INLETS IS CONSTRUCTED FOR 30° SKEW AND 3:1 WINGWALL FLARE (18.4°)
ALSO A GOOD APPROXIMATION FOR ANY SKEW ANGLE FROM 15° TO 45° AND FOR GREATER FLARE ANGLES OF WINGWALLS.

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING

BUREAU OF PUBLIC ROADS
OFFICE OF R & D - AUGUST 1968
CHART 13

45° 1/2 IN./FT. 2.06 10.3
33.7° 1 IN./FT. 1.90 9.5
18.4° 1 IN./FT. 1.82 9.0

WINGWALL TOP EDGE HW
HW

EXAMPLE
B = 7 FT. D = 5 FT. Q = 600 C.F.S
D
B = 71.5

BEVEL ANGLE REQUIRED

TOP EDGE

ANGLE

45° 0.042
33.7° 0.083

EXAMPLE

HEIGHT OF BARREL (D) IN FEET

HEIGHT OF BARREL (D) IN FEET

DISCHARGE PER FOOT OF BARREL WIDTH (Q/D) CPS PER FOOT

DISCHARGE PER FOOT OF BARREL WIDTH (Q/D) CPS PER FOOT

WINGWALLS

FLARE ANGLE MIN. OFFSET

1:1
1:1.5
1:2
1:3

33.7°
33.7°
26.6°
18.4°

3/4 x B (FT.)
1' x B
1/4' x B
1/2' x B

USE 33.7° x 0.0083D TOP EDGE BEVEL AND READ HW ON SCALE FOR 18.4° WW

HEADWATER DEPTH IN TERMS OF HEIGHT (H/W)

HEADWATER DEPTH IN TERMS OF HEIGHT (H/W)

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
OFFSET FLARED WINGWALLS
AND BEVELED EDGE AT TOP OF INLET

BUREAU OF PUBLIC ROADS
OFFICE OF RB D AUGUST 1968
CHART 14

\[ d_c \text{ cannot exceed } D \]

CRITICAL DEPTH
RECTANGULAR SECTION

\[ d_c = 0.315 \sqrt{\frac{Q}{B}} \]

Bureau of Public Roads Jan 1963

CRITICAL DEPTH
RECTANGULAR SECTION
CHART 15

For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012
EXAMPLE
SIZE 12.9' x 8.3' Q=1000 CFS

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>HEADWALL</th>
<th>NO BEVL/BEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW/FT</td>
<td>11.8</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>11.6</td>
<td>10.1</td>
</tr>
</tbody>
</table>

CHART 35

TYPE OF INLET
90° HEADWALL:
33.7° x 0.100 BEVEL
NO BEVEL
PROJECTING

HEADWATER DEPTH IN TERMS OF ARCH RISE (HW/FT)

HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS

18-IN. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1968
# Chart 36

**Example**

<table>
<thead>
<tr>
<th>Size</th>
<th>17.4' x 11.5'</th>
<th>Q = 2500 CFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Headwall</td>
<td>No Bevel Bevel</td>
</tr>
<tr>
<td>HW /'</td>
<td>15.4</td>
<td>14.5</td>
</tr>
<tr>
<td>HW FT.</td>
<td>16.9</td>
<td>16.7</td>
</tr>
</tbody>
</table>

**Type of Inlet**

- 90° Headwall
  - 33.7" x 0.10 D Bevel
  - No Bevel
  - Projecting

**Discharge CFS**

- 6500
- 6000
- 5500
- 5000
- 4500
- 4000
- 3500
- 3000
- 2500
- 2000
- 1500
- 1000
- 500
- 300
- 200
- 100
- 50
- 30
- 20
- 10
- 5

**Headwater Depth in Terms of Arch Rise, HW /'**

- 4.0
- 3.5
- 3.0
- 2.0
- 1.5
- 1.0
- 0.9
- 0.8
- 0.7
- 0.6
- 0.5

**Pipe-Arch Size - Span x Rise (D), ft.**

- 20.6 x 13.2
- 19.9 x 12.9
- 19.3 x 12.3
- 17.4 x 11.5
- 15.8 x 10.7
- 14.4 x 10.0
- 13.3 x 9.4

**Embarkment Side Slope**

- Projecting Inlet with partial headwall for anchorage
- No Bevel
- 33.7° Bevel

**Headwater Depth for Inlet Control**

**Structural Plate Pipe-Arch Culverts**

- 31-in. radius corner plate
- Projecting or headwall inlet
- Headwall with or without edge bevel

**Bureau of Public Roads**

**Office of R&D July 1966**
Chart 37 can be used to approximate critical depth for comparably sized RCP-ARCH pipe.
Chart 38 can be used to approximate critical depth for comparably sized RCP-ARCH pipe.
For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR
STANDARD G. M. PIPE-ARCH CULVERTS
FLOWING FULL
n=0.024
CHART 40

For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR
STRUCTURAL PLATE
CORRUGATED METAL
PIPE ARCH CULVERTS
18 IN. CORNER RADIUS
FLOWING FULL

n = 0.0327 TO 0.0306

BUREAU OF PUBLIC ROADS JAN. 1963
CHART 60

\[ C_d = k_t C_r \]
\[ Q_r = C_d L H W_r^{1.5} \]

A) DISCHARGE COEFFICIENT FOR \( HW_r / L_r > 0.15 \)

B) DISCHARGE COEFFICIENT FOR \( HW_r / L_r \leq 0.15 \)

C) SUBMERGENCE FACTOR

DISCHARGE COEFFICIENTS
FOR ROADWAY OVERTOPPING