

APPENDIX A

This Appendix contains Culvert Design Charts and Nomographs taken from the AASHTO Model Drainage Manual, 1991.

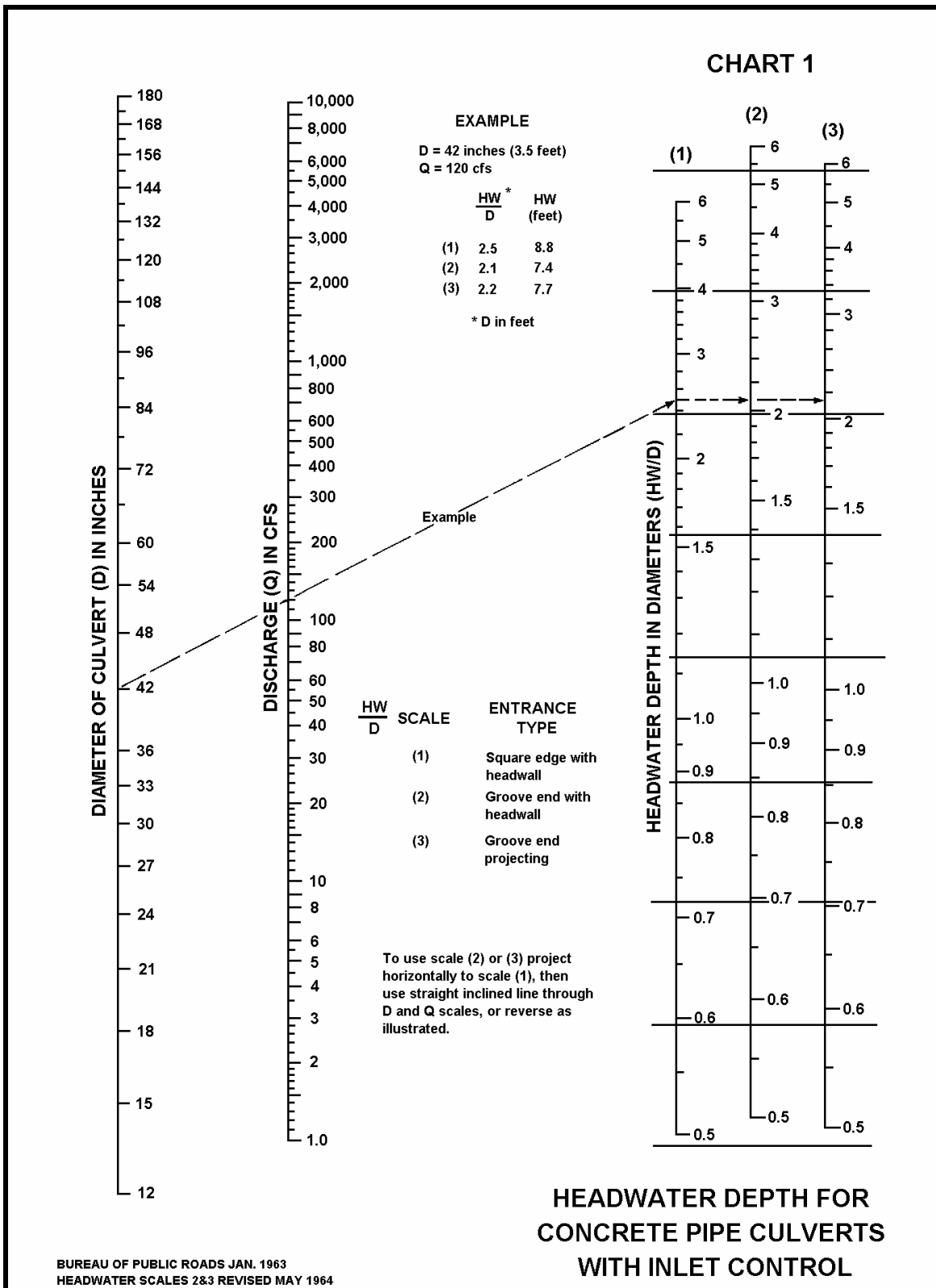
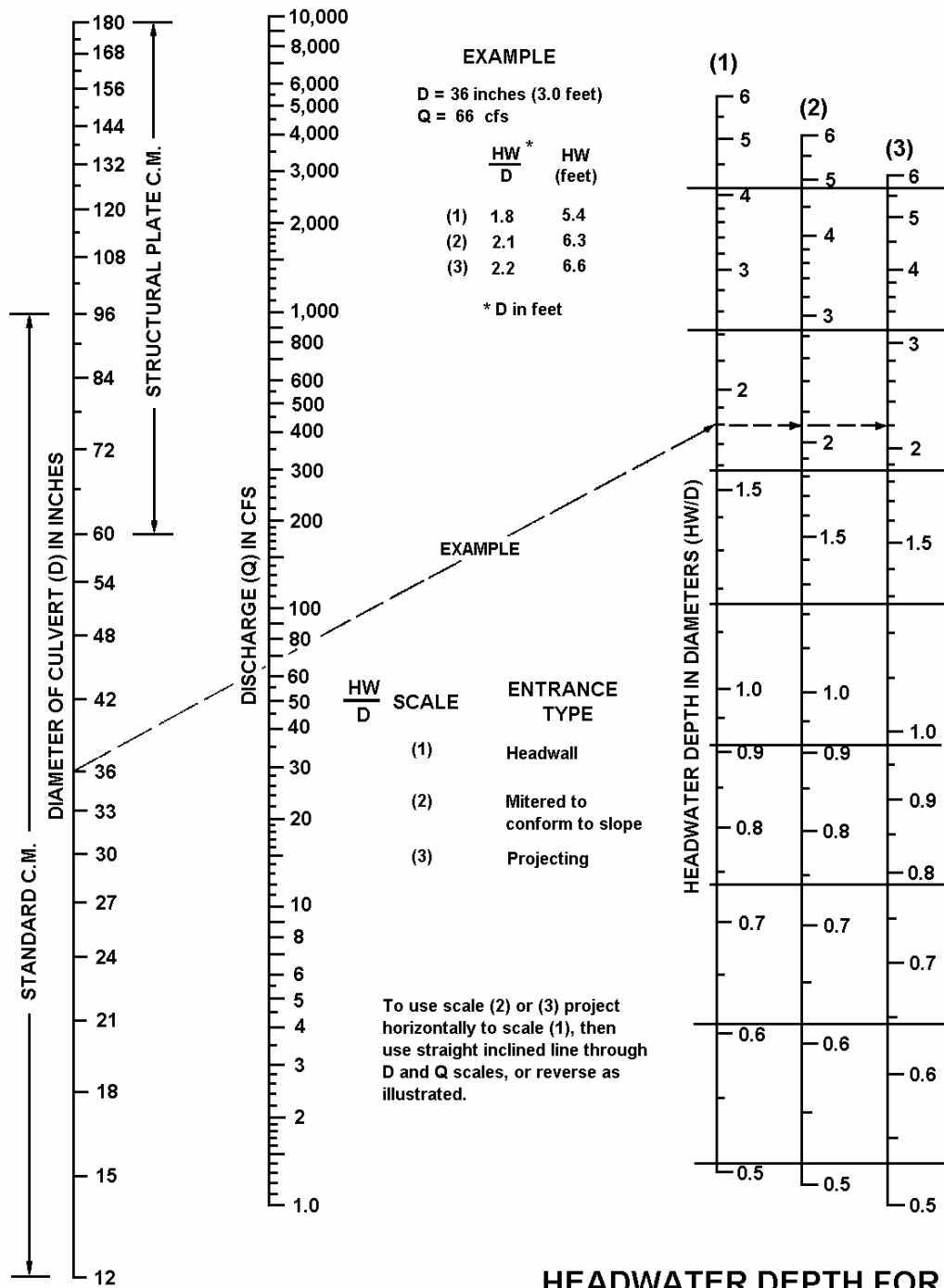




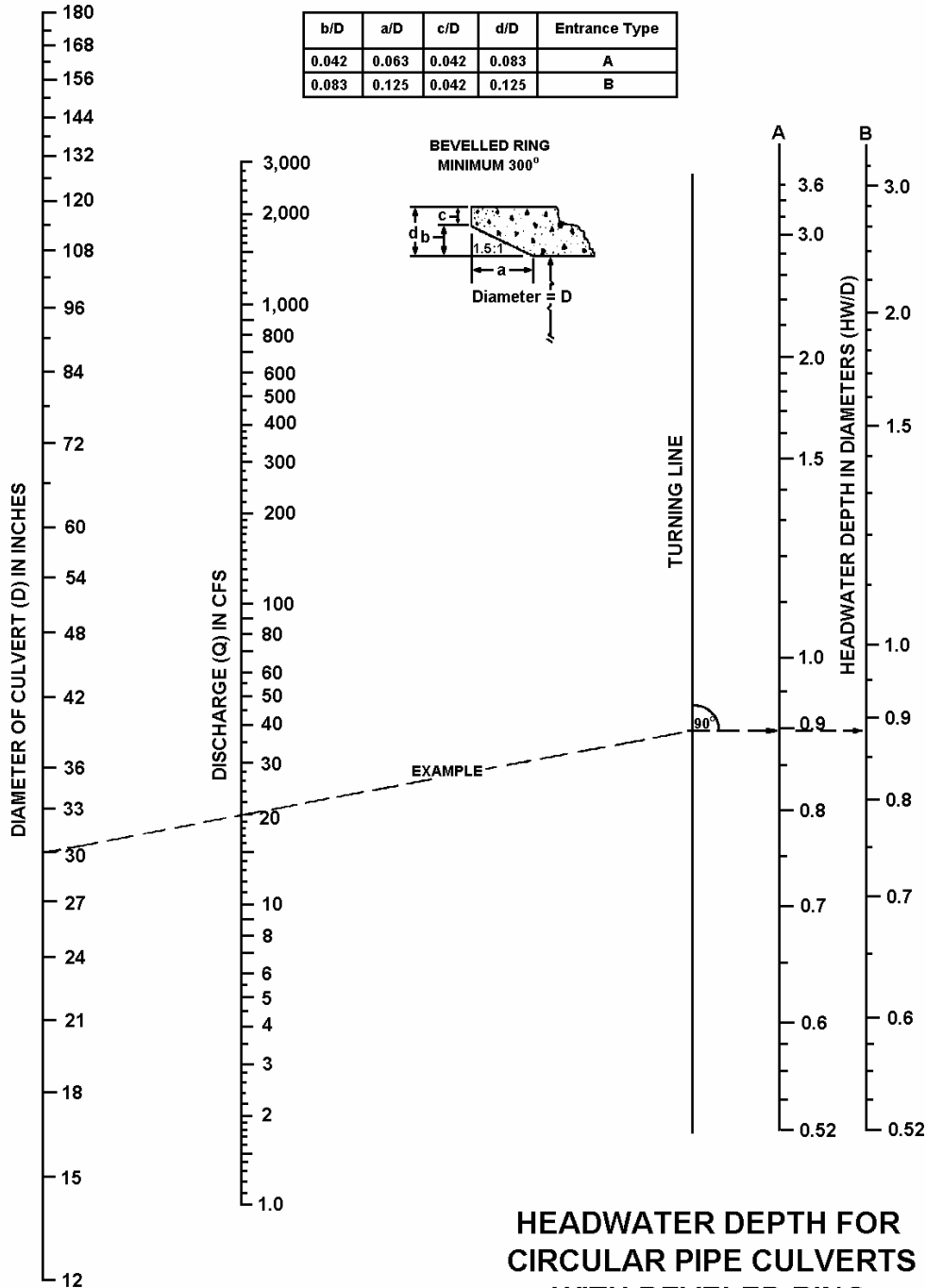
CHART 2



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

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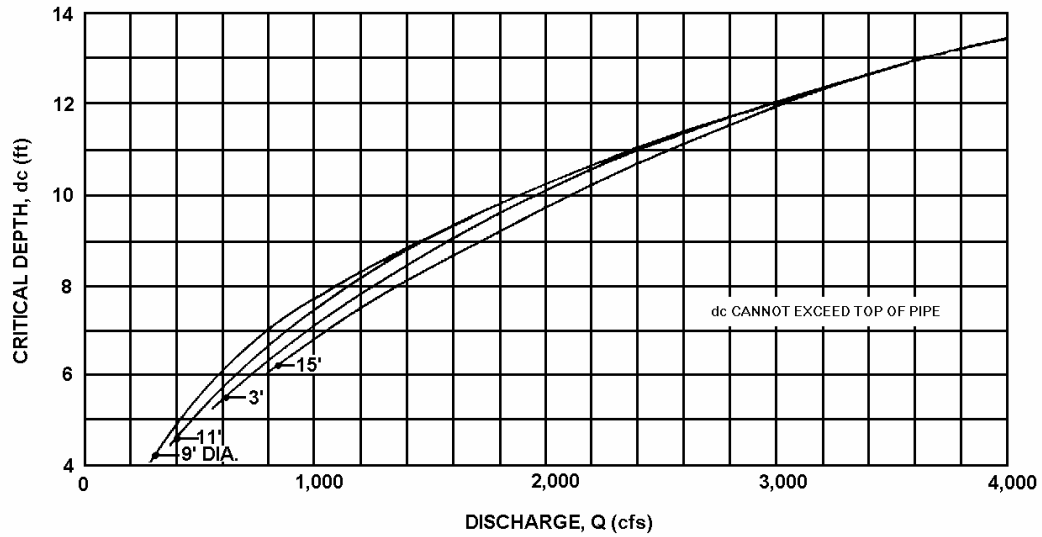
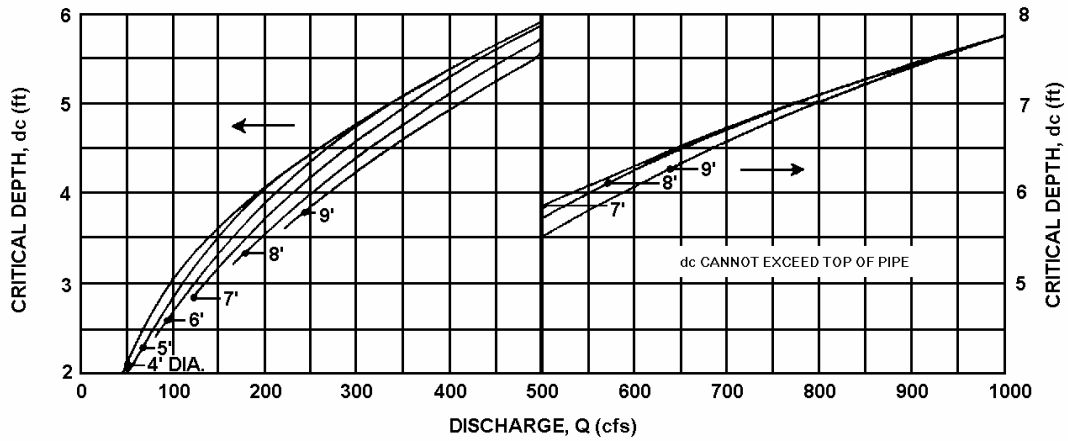
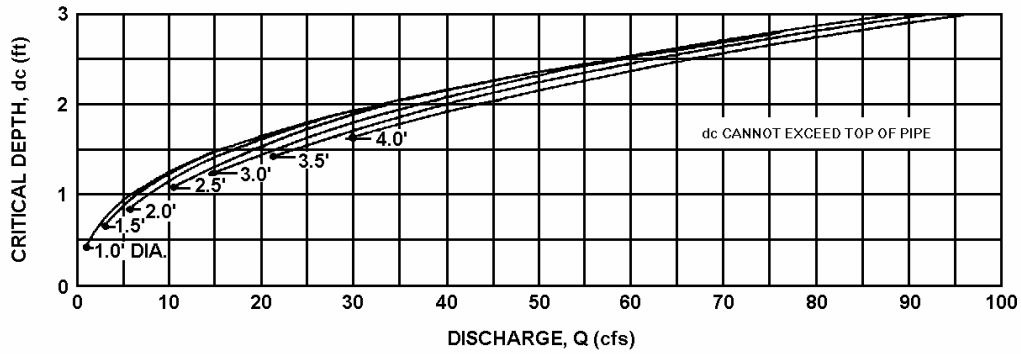
CHART 3



HEADWATER DEPTH FOR
CIRCULAR PIPE CULVERTS
WITH BEVELED RING
INLET CONTROL

FEDERAL HIGHWAY ADMINISTRATION MAY 1973

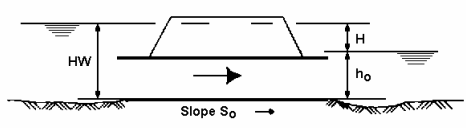
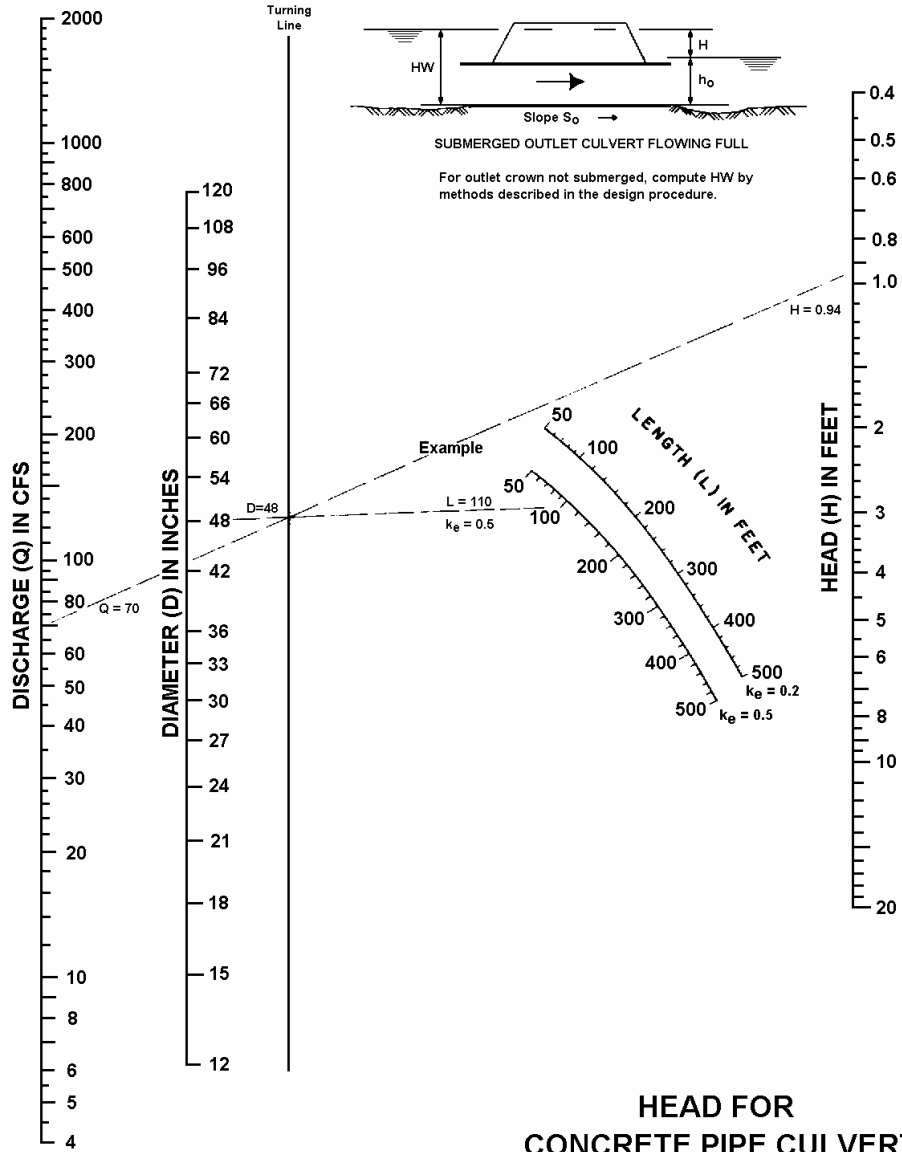
CHART 4



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CRITICAL DEPTH CIRCULAR PIPE

CHART 5



SUBMERGED OUTLET CULVERT FLOWING FULL
 For outlet crown not submerged, compute HW by methods described in the design procedure.

**HEAD FOR
 CONCRETE PIPE CULVERTS
 FLOWING FULL
 n = 0.012**

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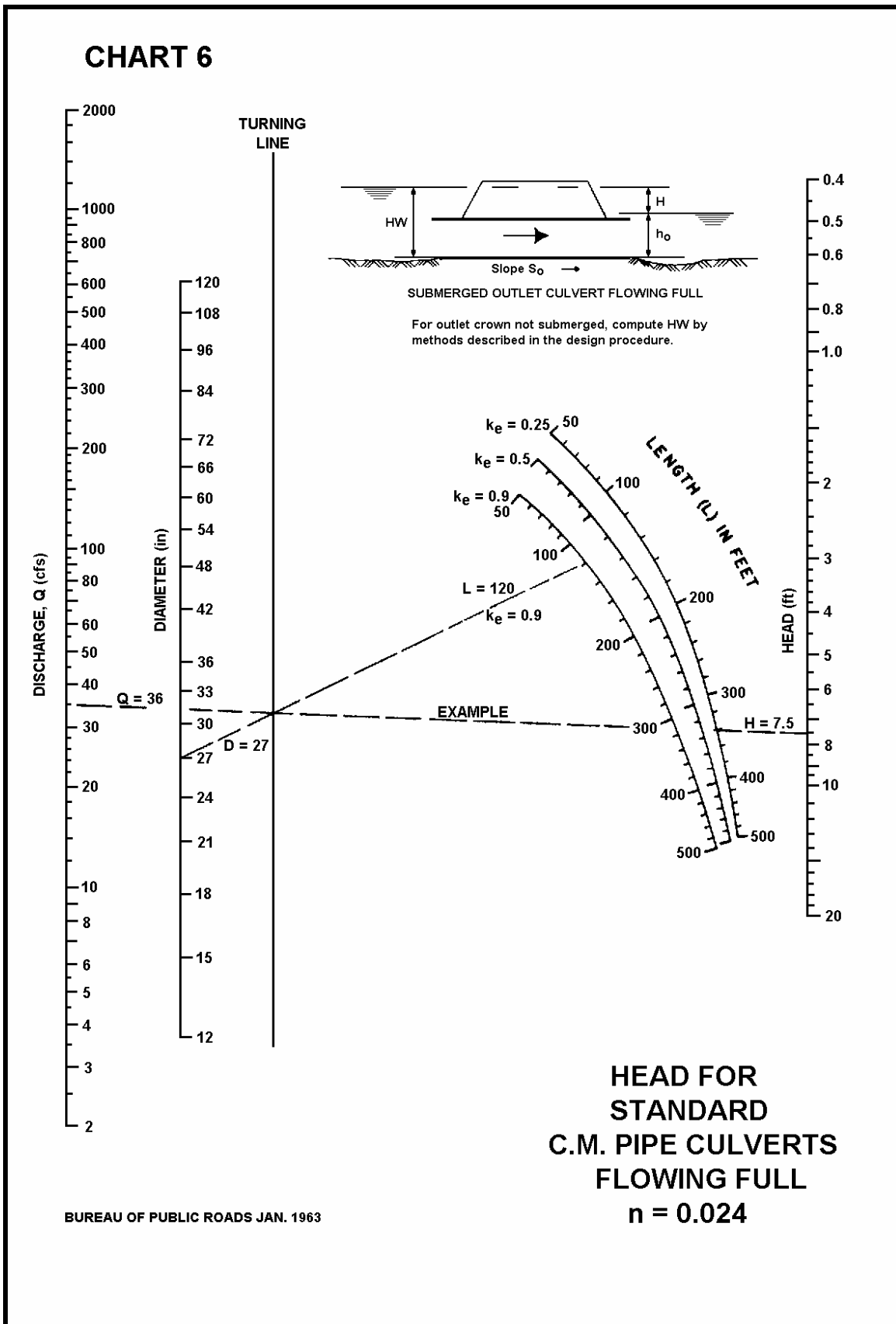
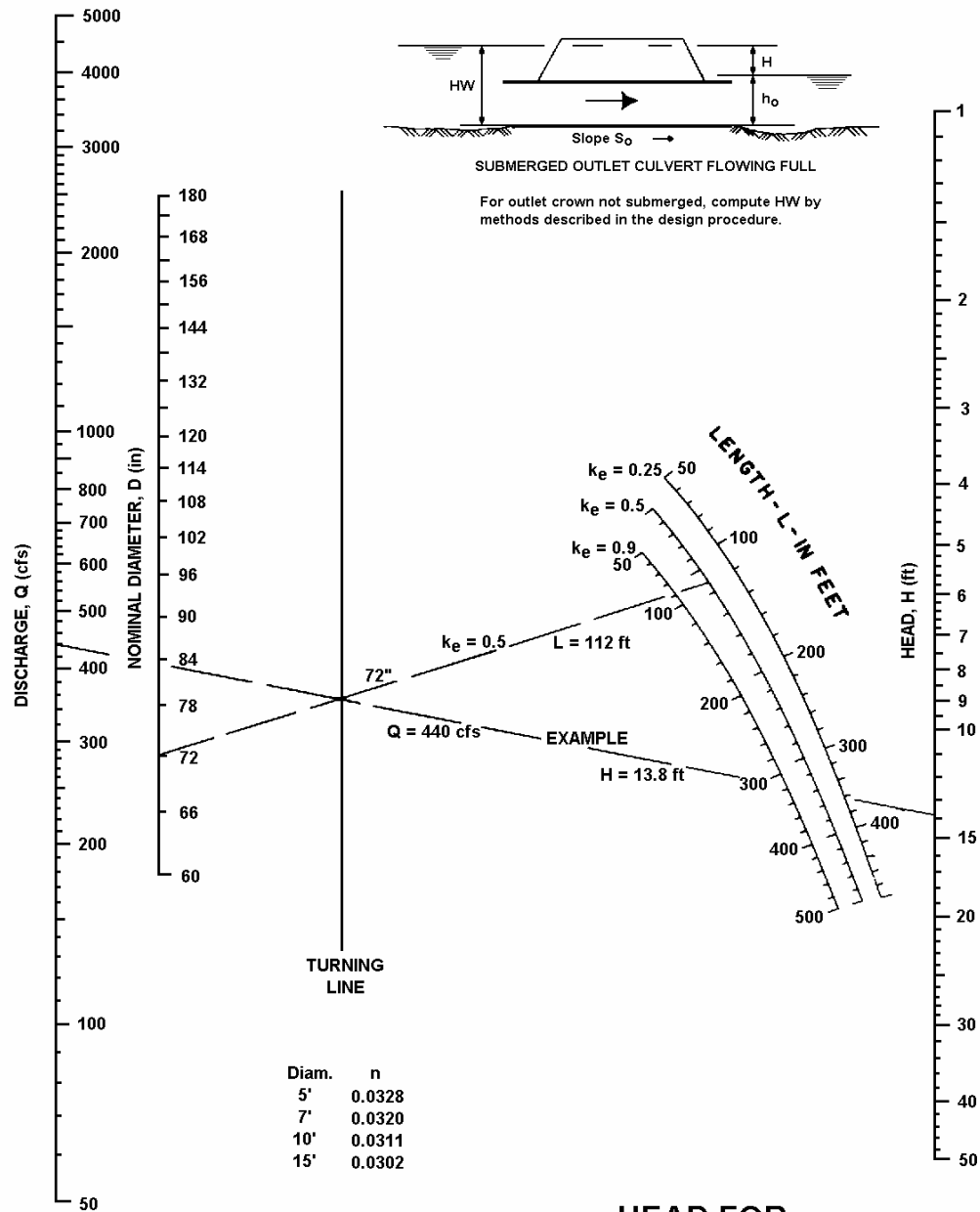


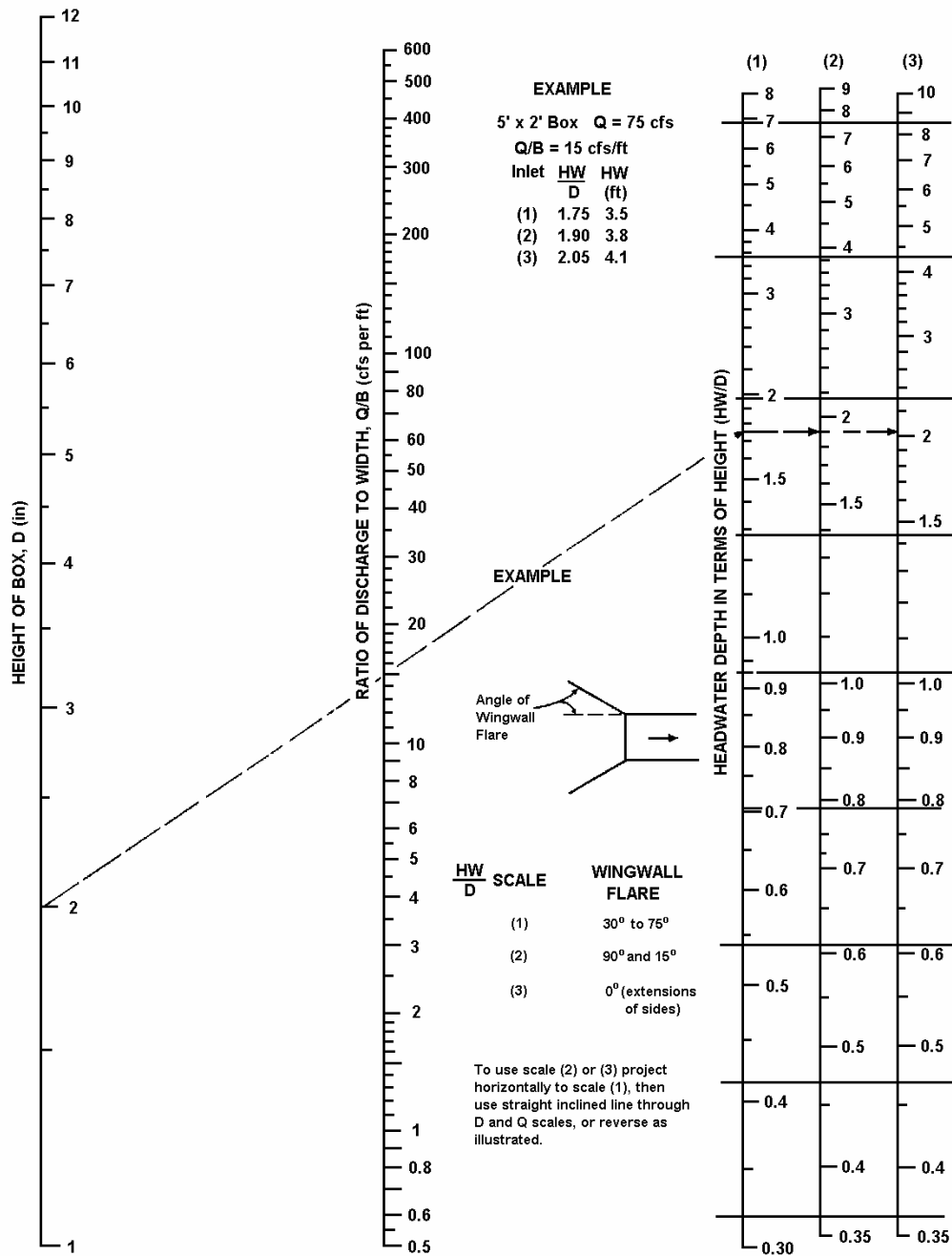
CHART 7



**HEAD FOR
 STRUCTURAL PLATE
 CORR. METAL PIPE CULVERTS
 FLOWING FULL
 n = 0.0328 TO 0.0302**

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CHART 8



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HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

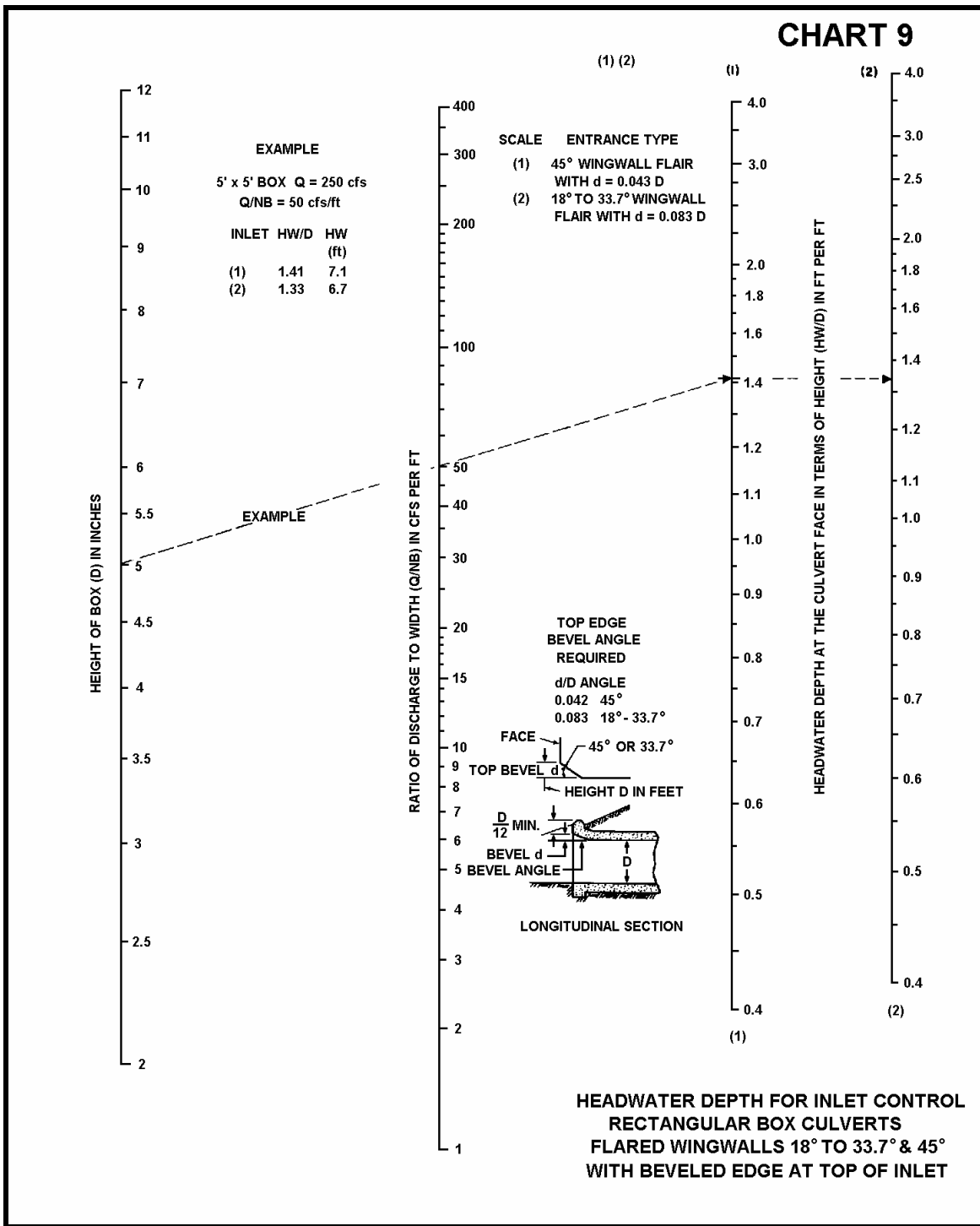


CHART 10

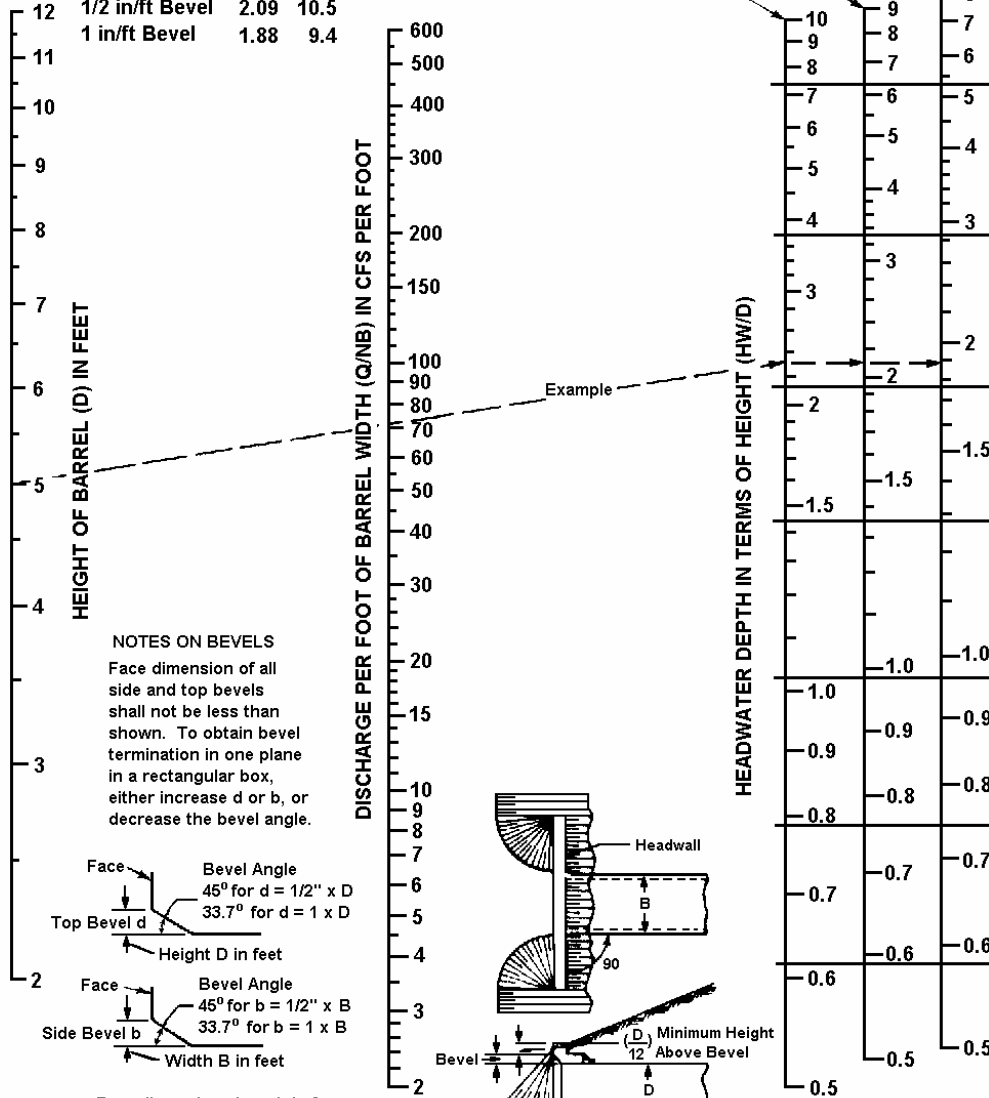
EXAMPLE

B = 7 ft D = 5 ft Q = 500 cfs $Q/NB = 71.5$

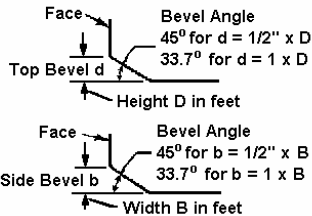
ALL EDGES	$\frac{HW}{D}$	HW (ft)
Chamfer 3/4"	2.31	11.5
1/2 in/ft Bevel	2.09	10.5
1 in/ft Bevel	1.88	9.4

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



NOTES 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 d or b, or decrease the bevel angle.



Face dimensions b and d 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

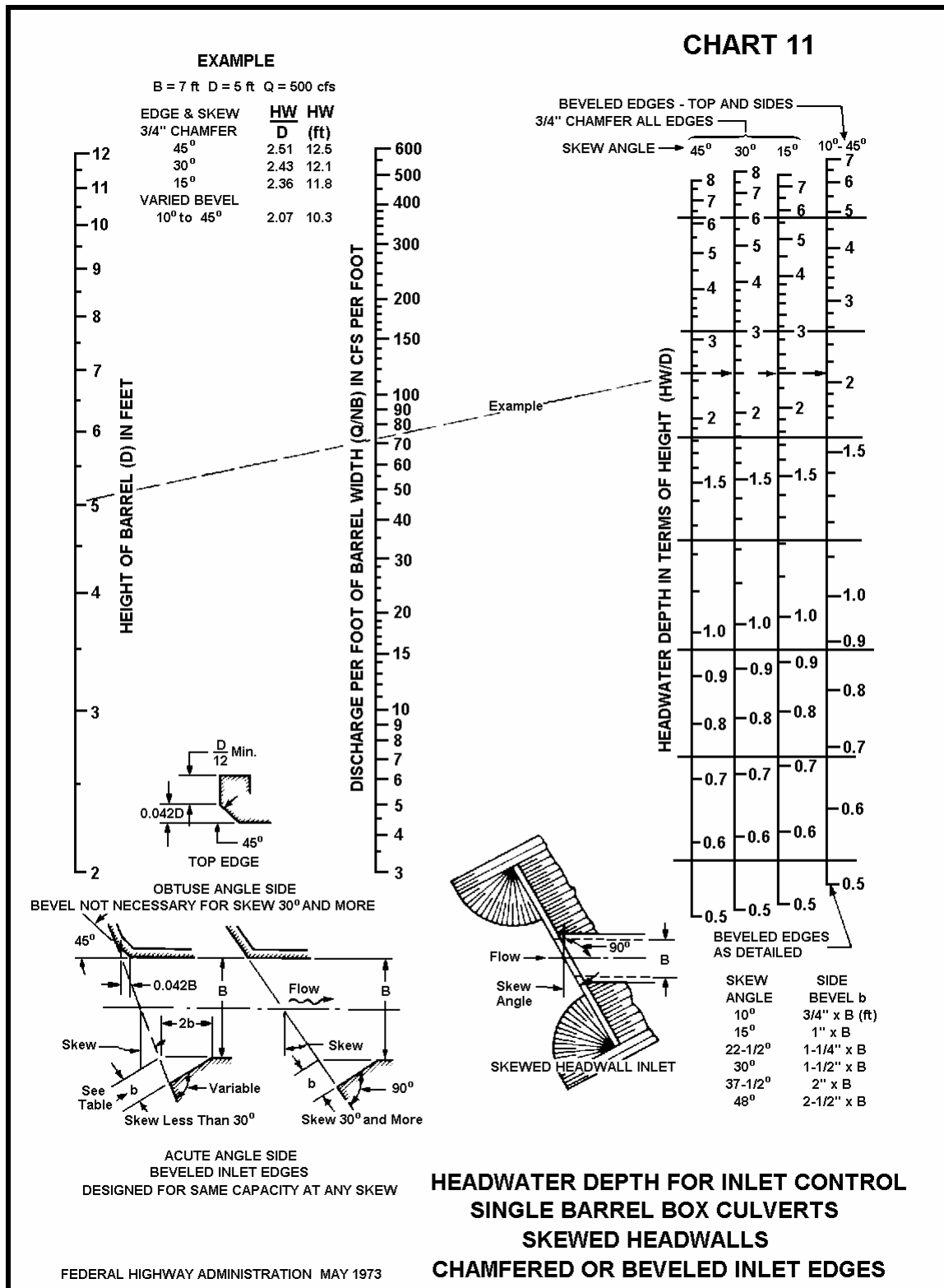
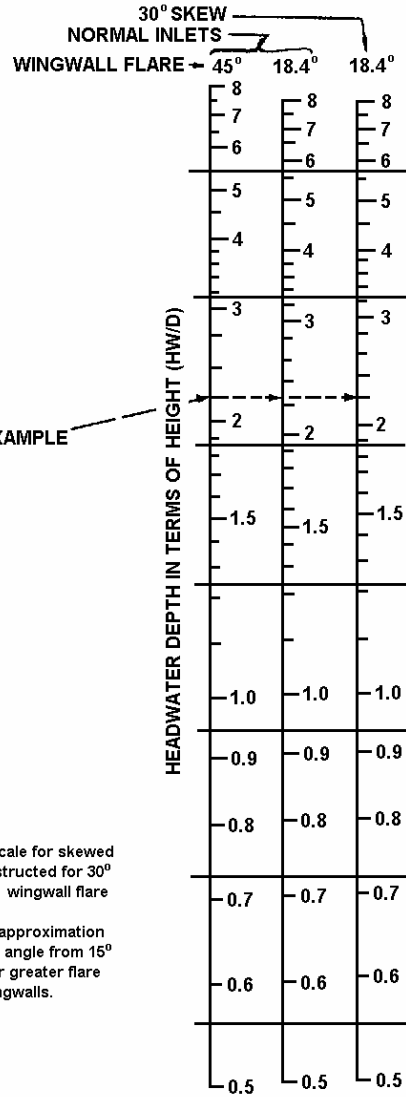
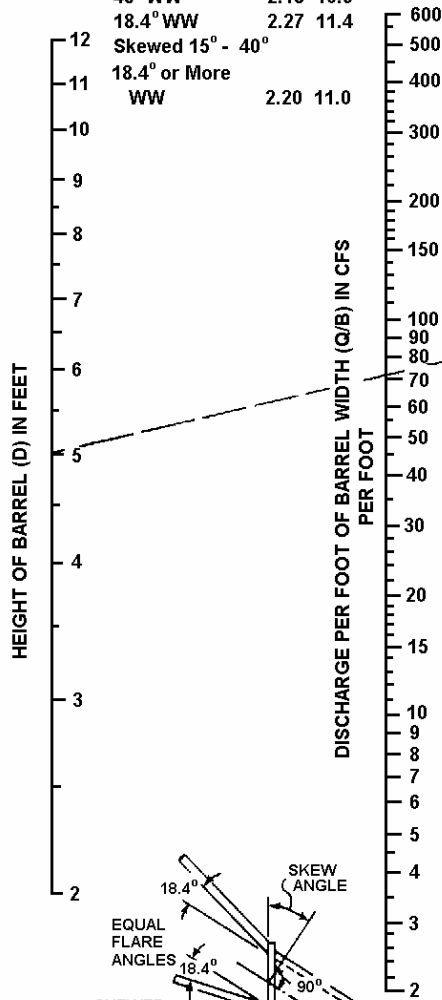


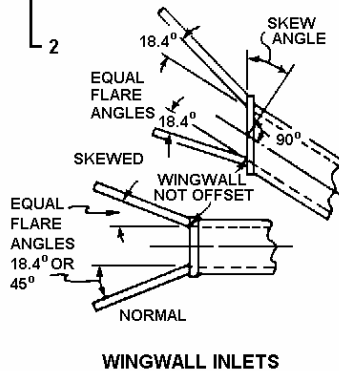
CHART 12

EXAMPLE
 B = 7 ft D = 5 ft Q = 500 cfs
 $\frac{Q}{B} = 71.5$

Inlet & WW	HW D	HW (ft)
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



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.



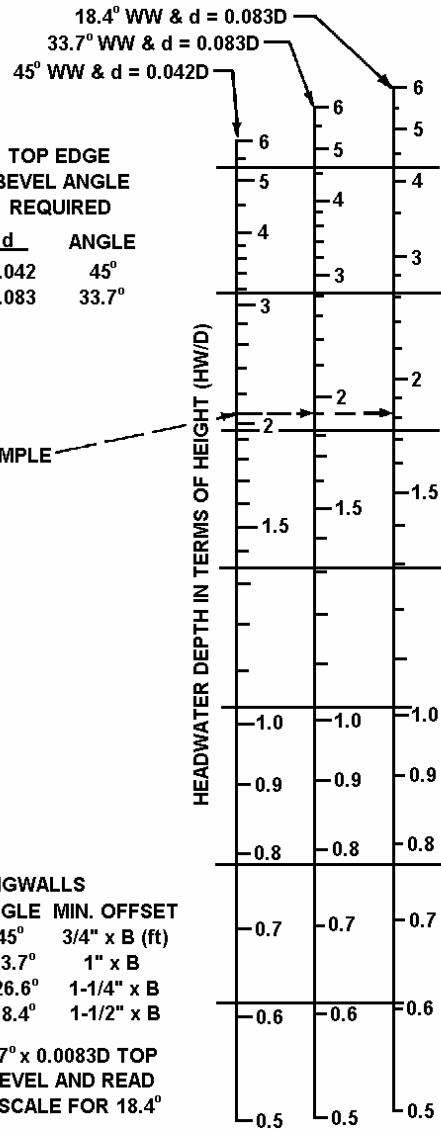
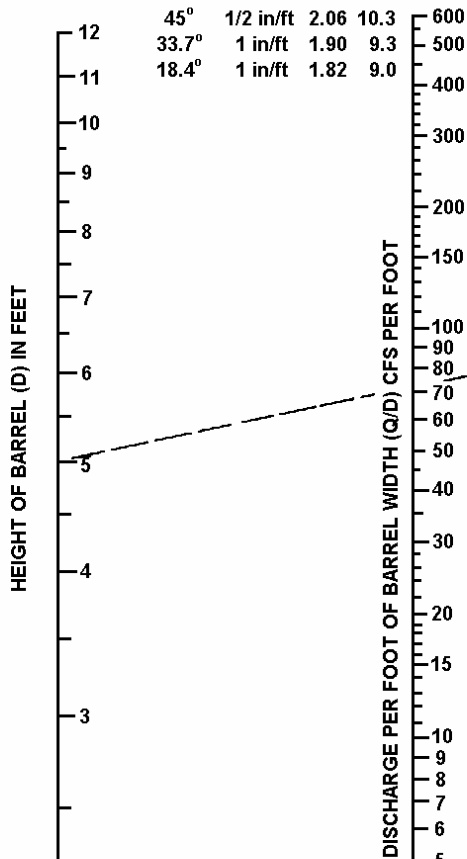
**HEADWATER DEPTH FOR INLET CONTROL
 RECTANGULAR BOX CULVERTS
 FLARED WINGWALLS
 NORMAL AND SKEWED INLETS
 3/4" CHAMFER AT TOP OF OPENING**

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 OFFICE OF R&D AUGUST 1968

CHART 13

EXAMPLE
 $B = 7 \text{ ft}$ $D = 5 \text{ ft}$ $Q = 600 \text{ cfs}$ $Q/B = 71.5$

WINGWALL TOP EDGE FLARE ANGLE	HW BEVEL	HW D (ft)
45°	1/2 in/ft	2.06 10.3
33.7°	1 in/ft	1.90 9.3
18.4°	1 in/ft	1.82 9.0



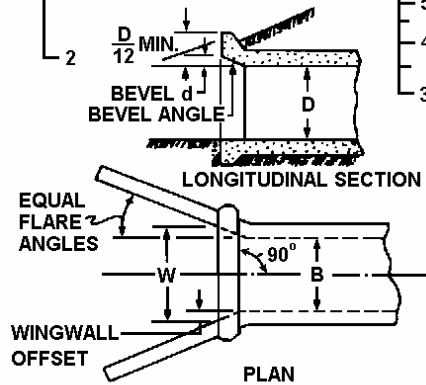
TOP EDGE BEVEL ANGLE REQUIRED

d	ANGLE
0.042	45°
0.083	33.7°

WINGWALLS

FLARE ANGLE	MIN. OFFSET
1:1 45°	3/4" x B (ft)
1:1.5 33.7°	1" x B
* 1:2 26.6°	1-1/4" x B
1:3 18.4°	1-1/2" x B

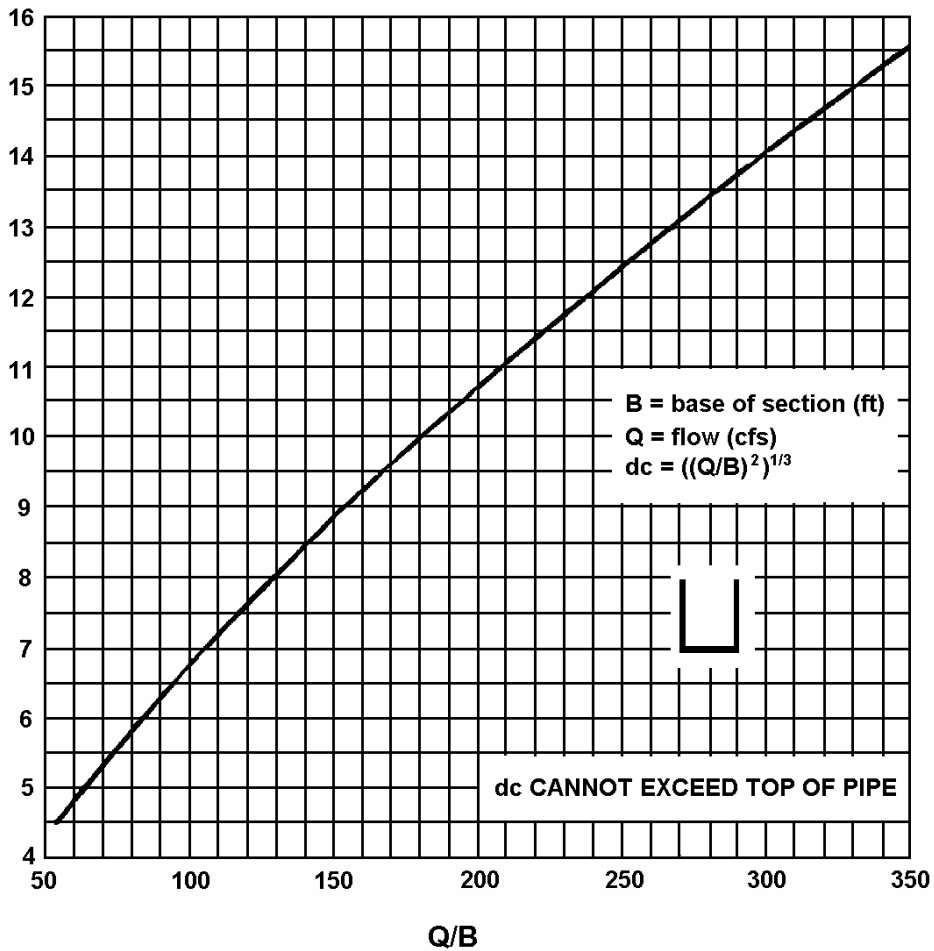
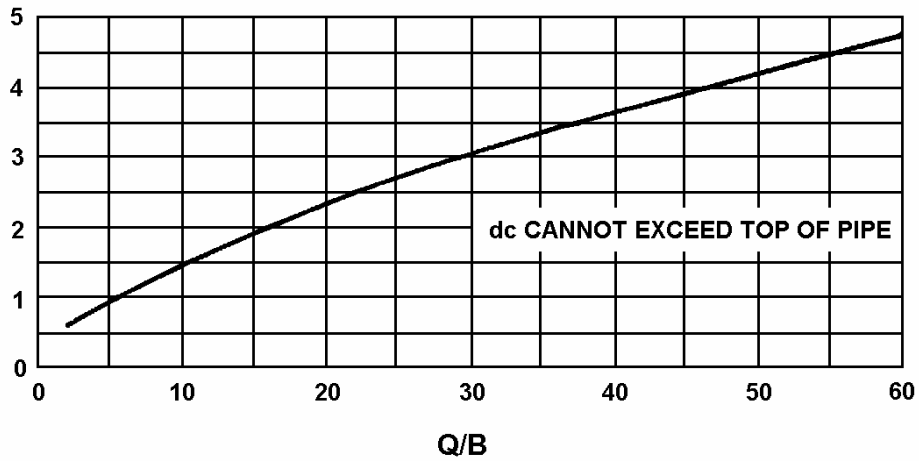
* USE 33.7° x 0.0083D TOP EDGE BEVEL AND READ HW ON SCALE FOR 18.4° WW



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

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 OFFICE OF R&D AUGUST 1968

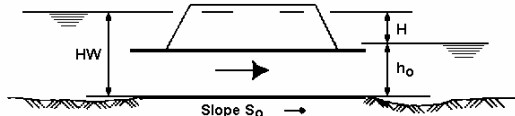
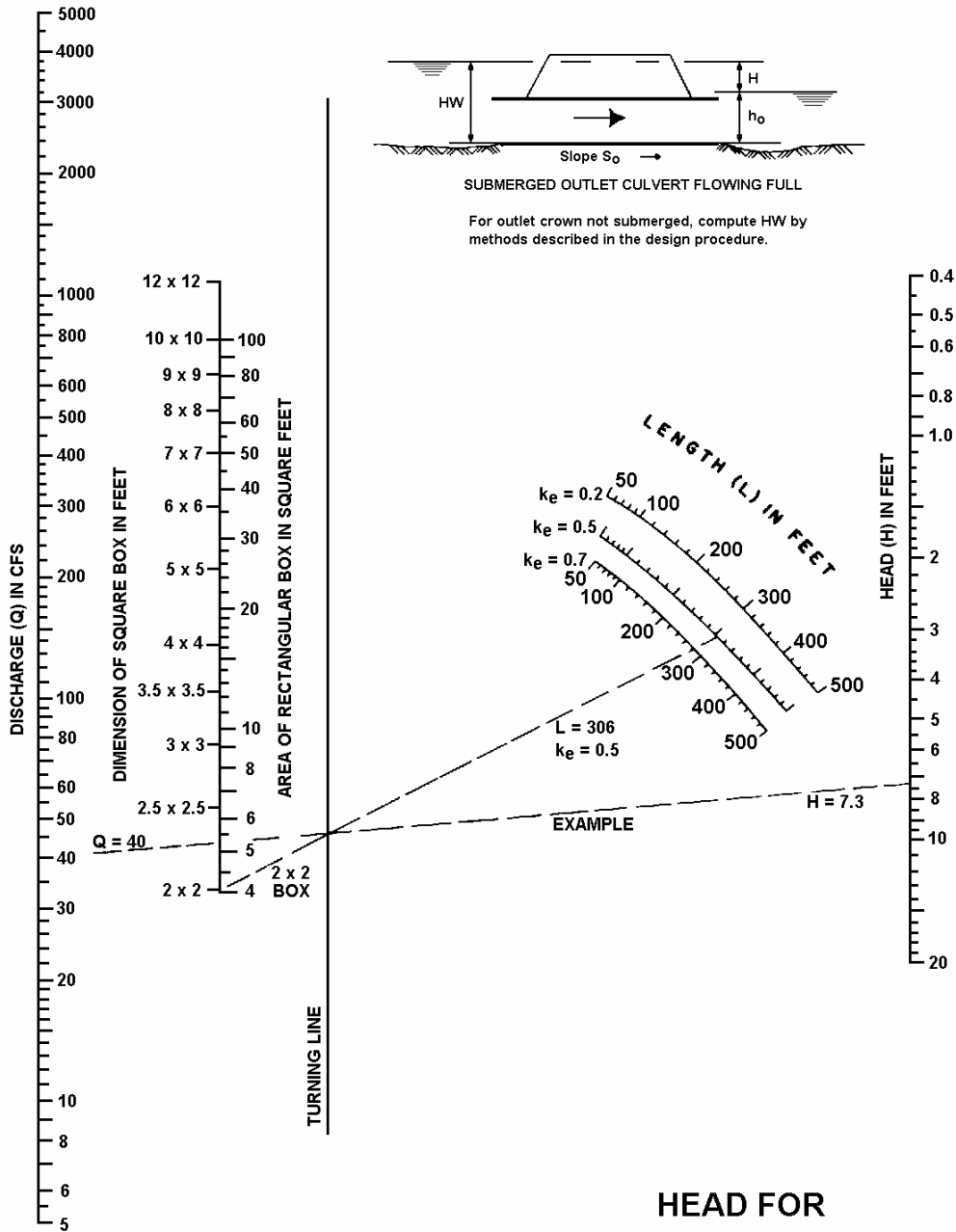
CHART 14



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**CRITICAL DEPTH
RECTANGULAR SECTION**

CHART 15

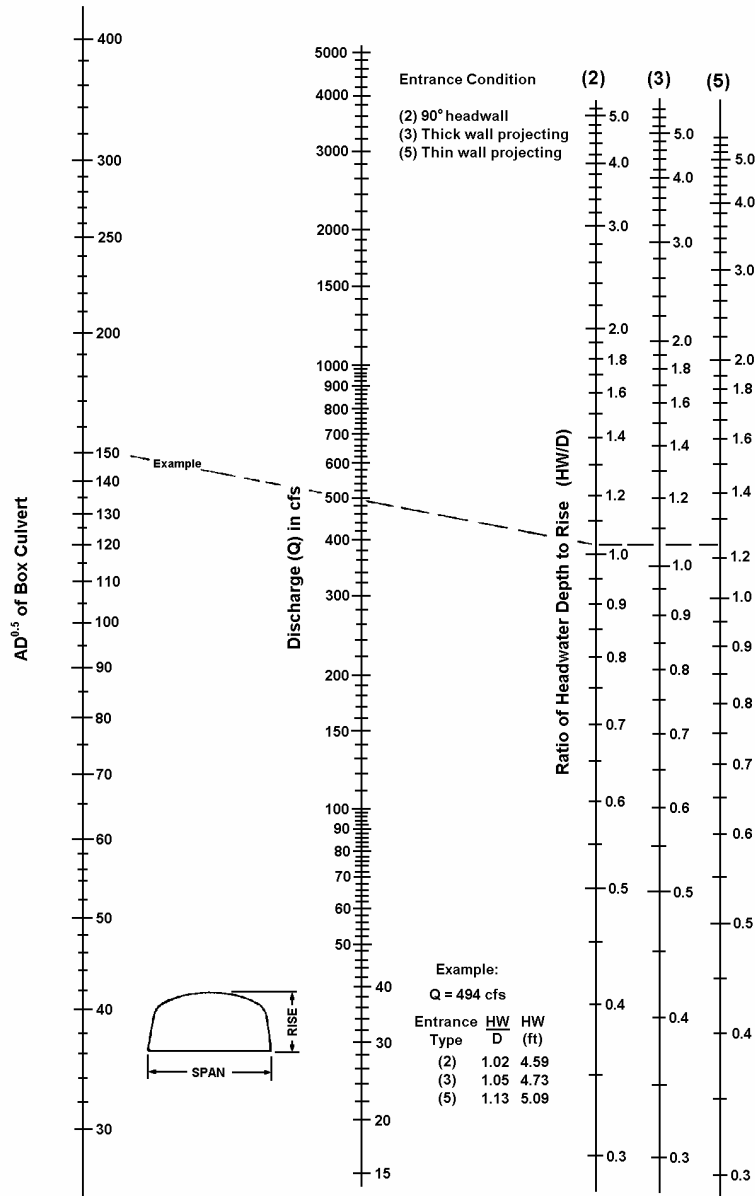


SUBMERGED OUTLET CULVERT FLOWING FULL

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

**HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
 $n = 0.012$**

CHART 16



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.

**HEADWATER DEPTH
FOR C.M. BOX CULVERTS
RISE/SPAN < 0.3
WITH INLET CONTROL**

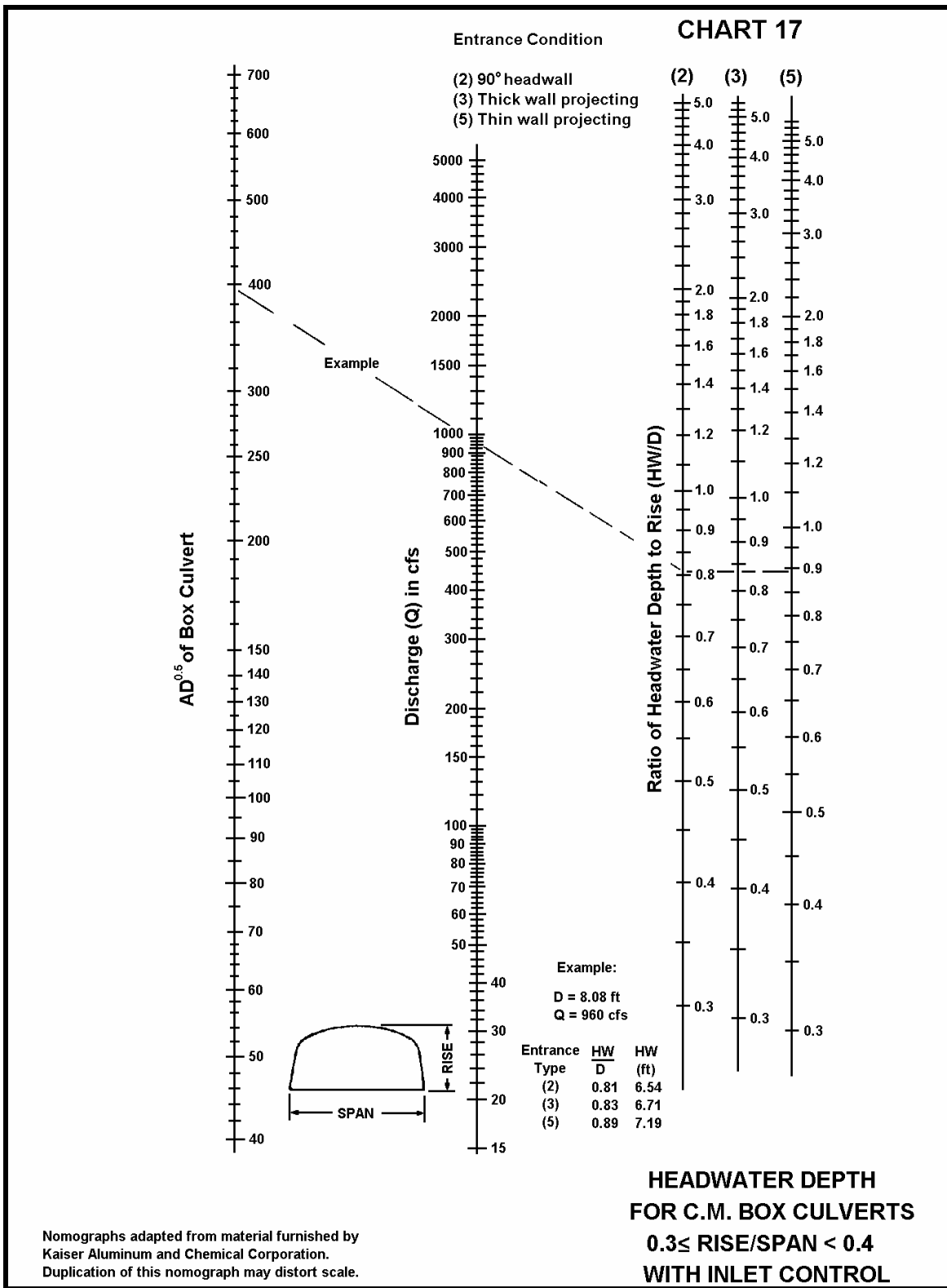
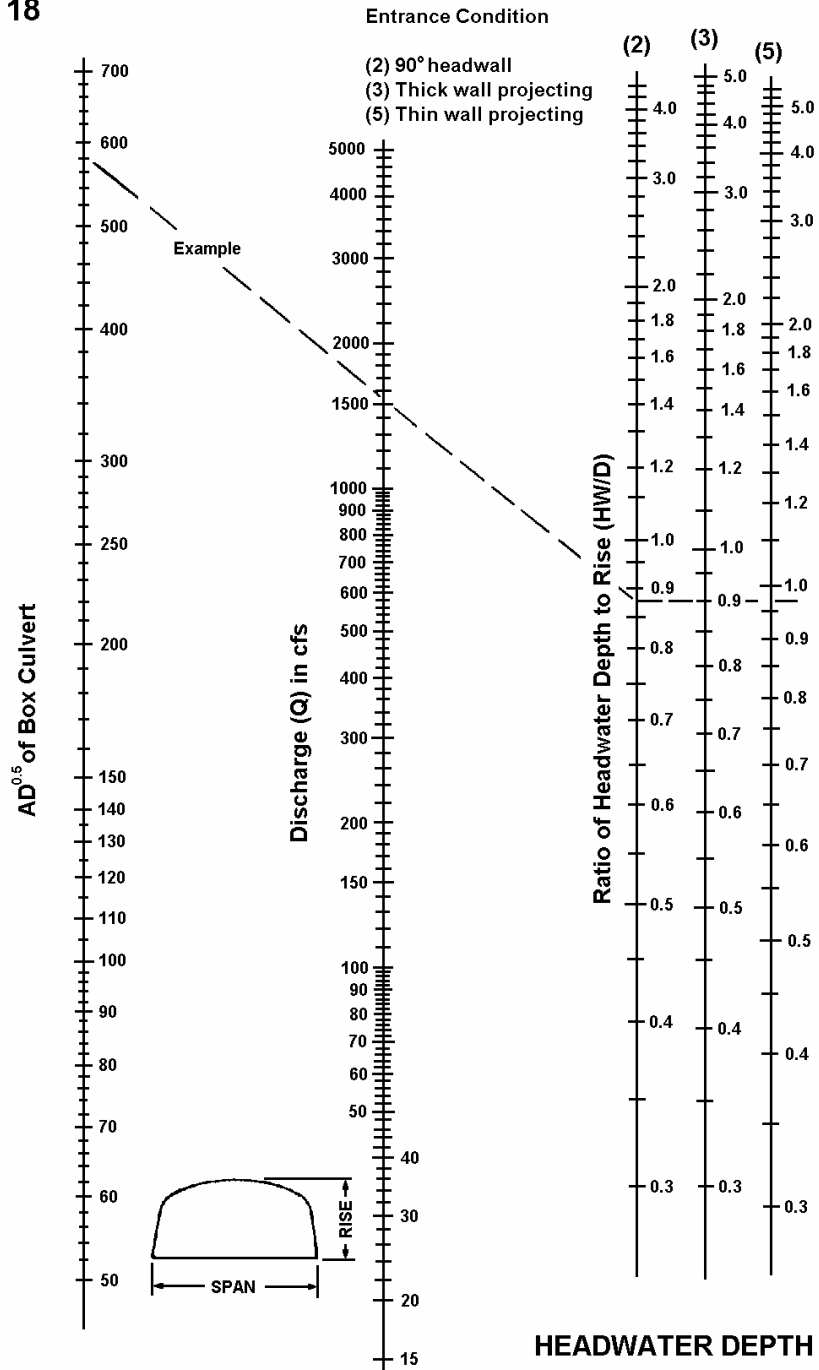
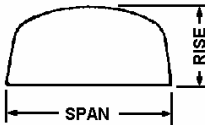


CHART 18



Example:
 D = 9.67 ft
 Q = 1520 cfs

Entrance Type	HW D	HW (ft)
(2)	0.88	8.51
(3)	0.90	9.38
(5)	0.97	9.38



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

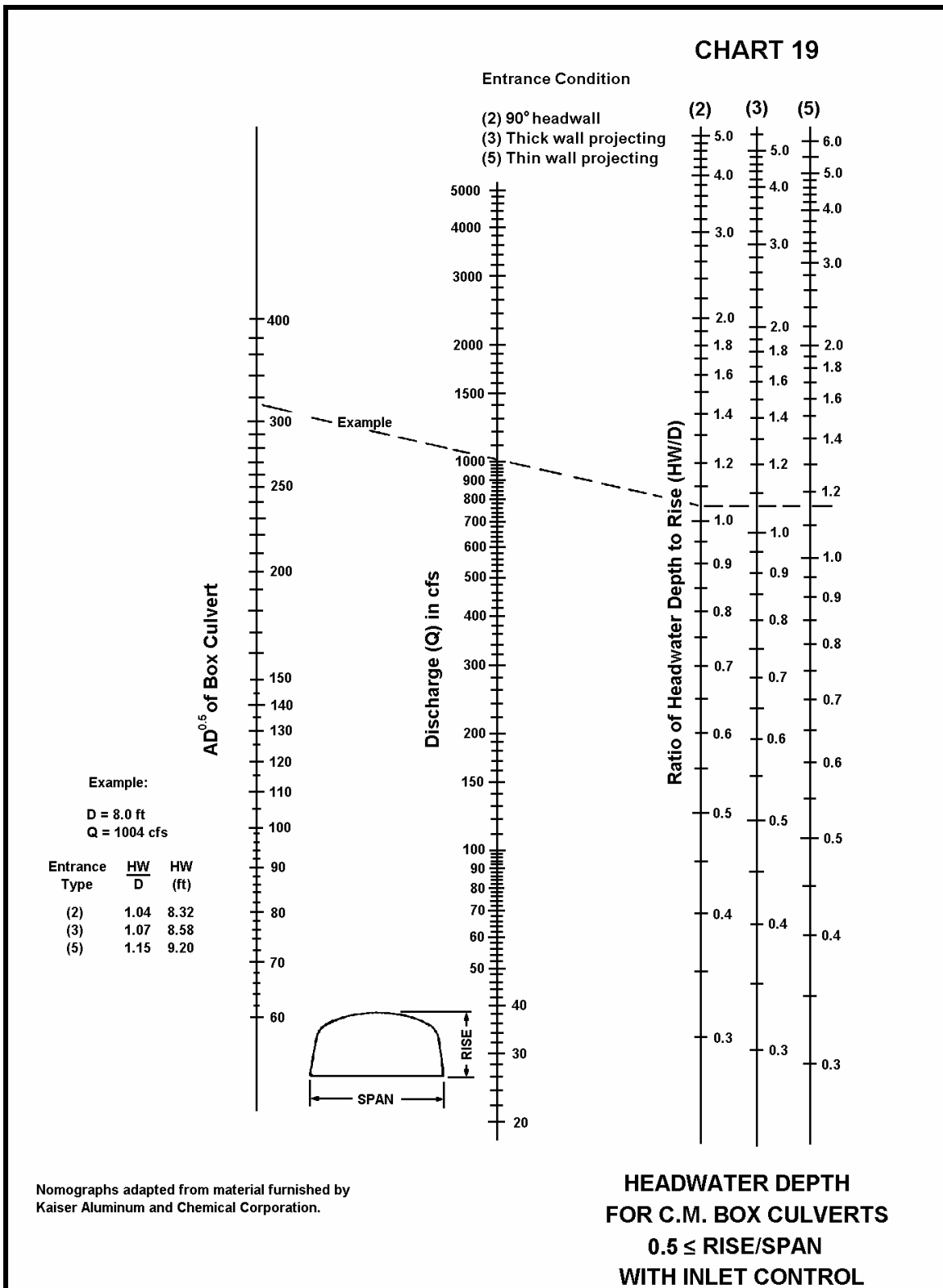
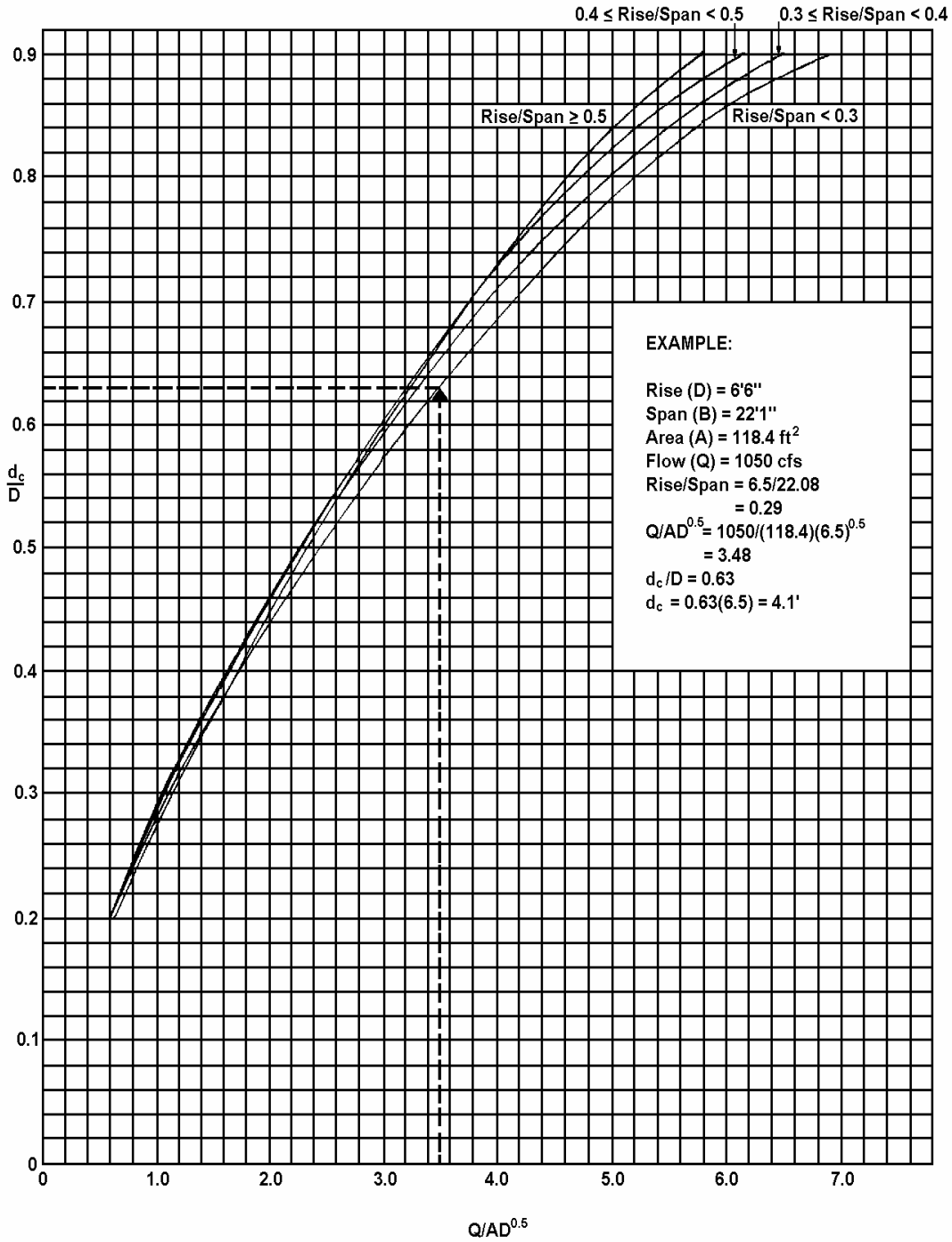


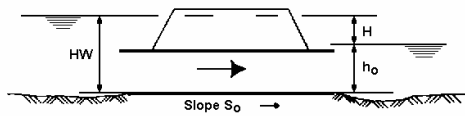
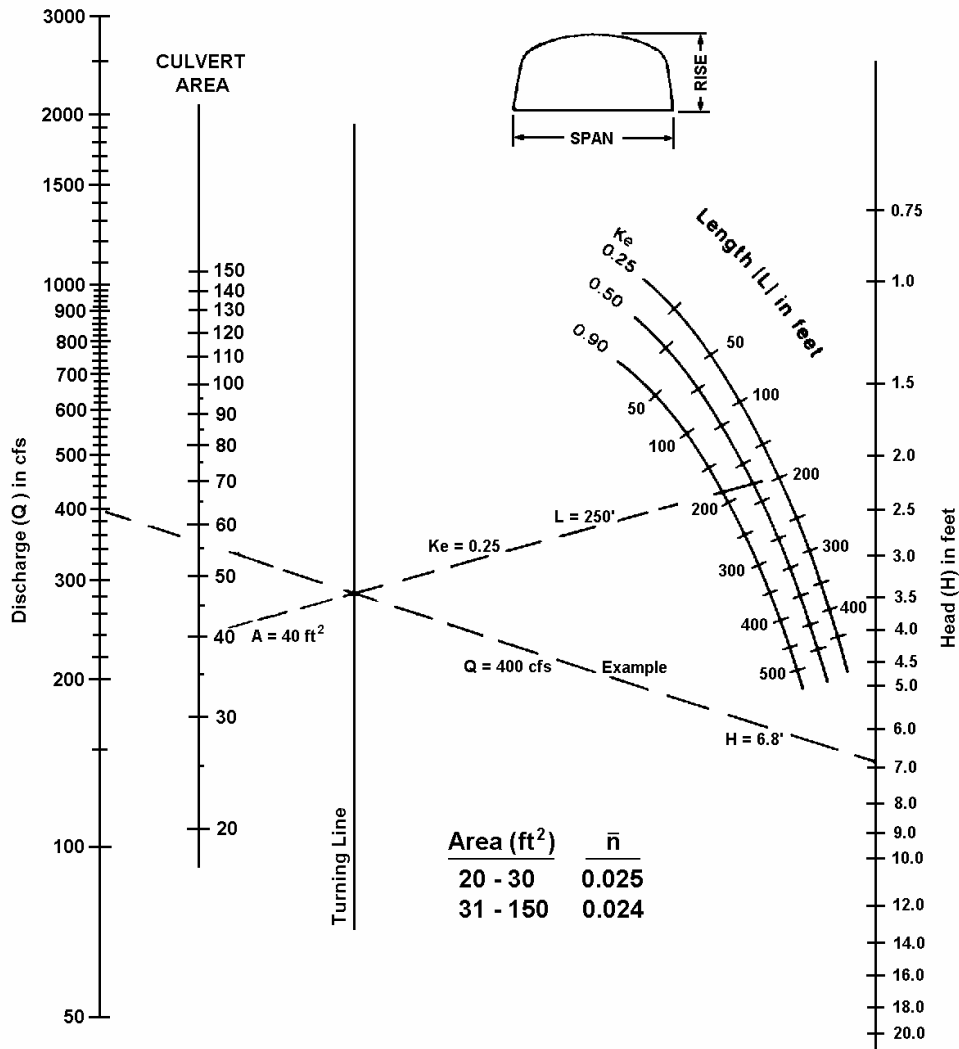


CHART 20



**DIMENSIONLESS CRITICAL DEPTH
 FOR C.M. BOX CULVERTS**

CHART 21



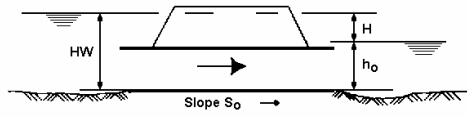
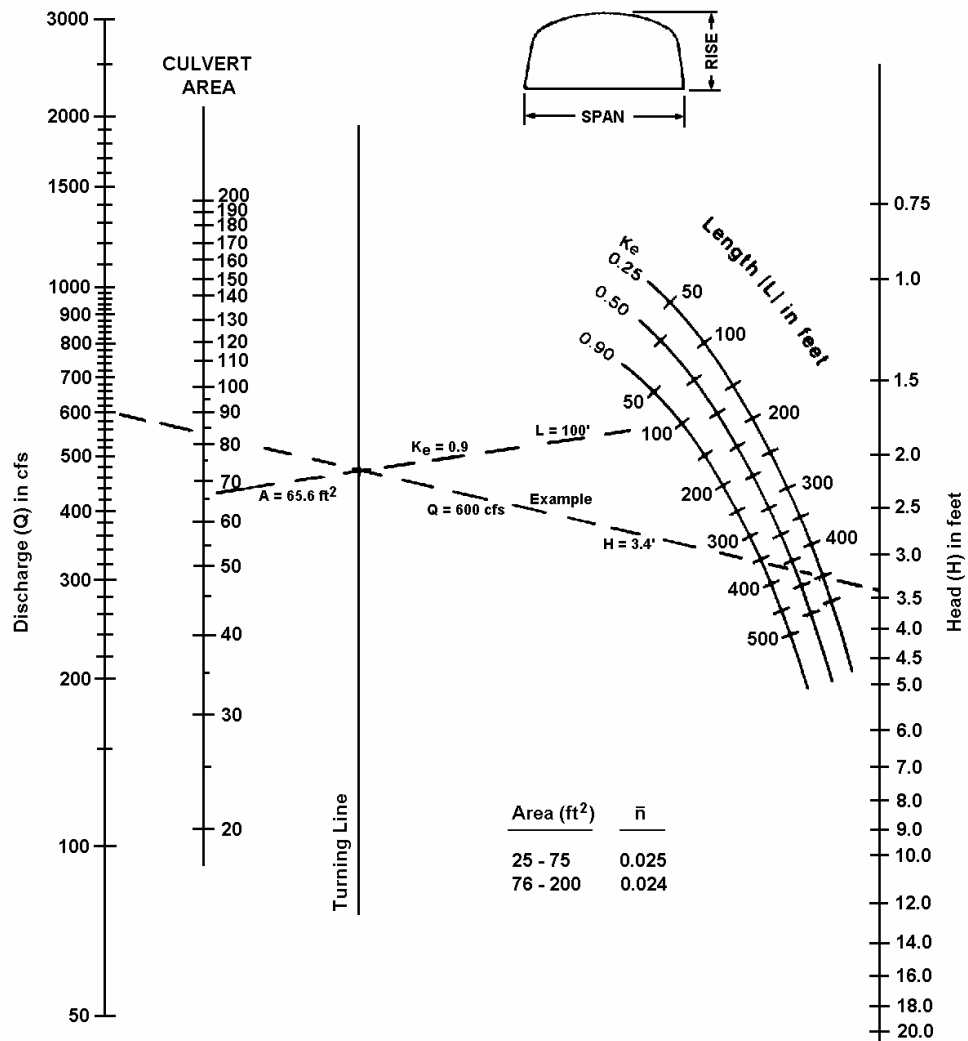
SUBMERGED OUTLET CULVERT FLOWING FULL

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

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
RISE/SPAN < 0.3**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 22



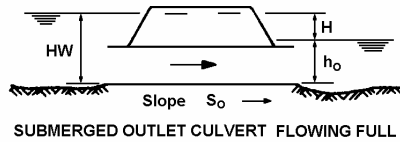
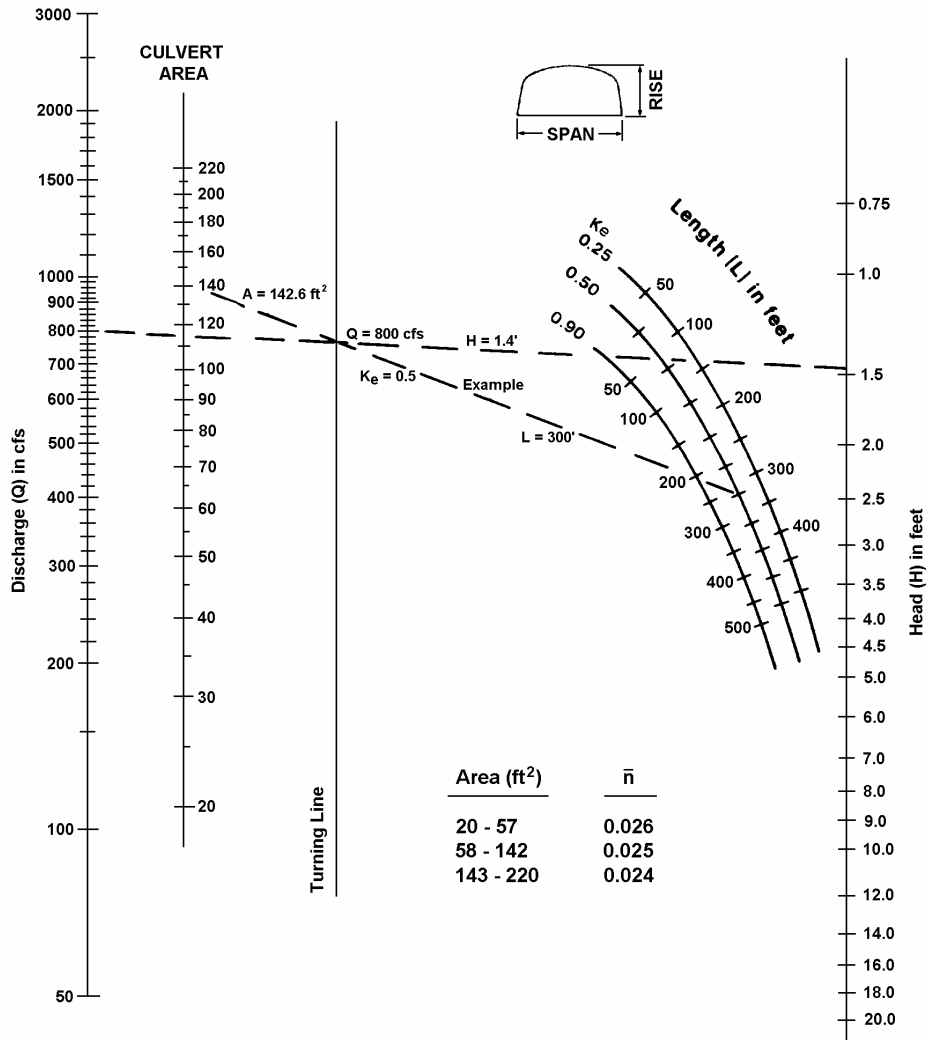
SUBMERGED OUTLET CULVERT FLOWING FULL

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

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.3 ≤ RISE/SPAN < 0.4**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

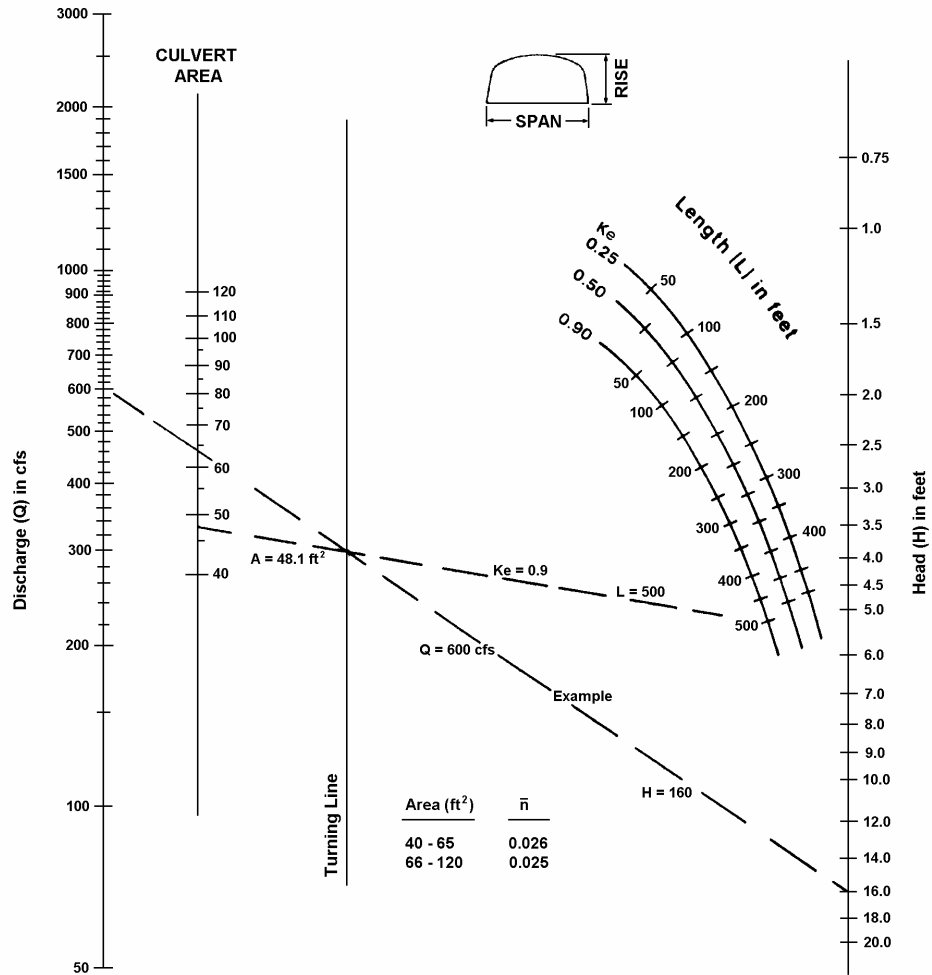
CHART 23



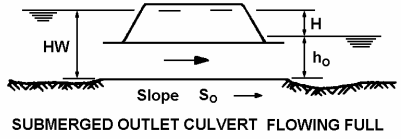
**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE/SPAN < 0.5**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 24



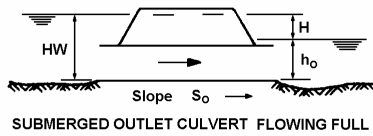
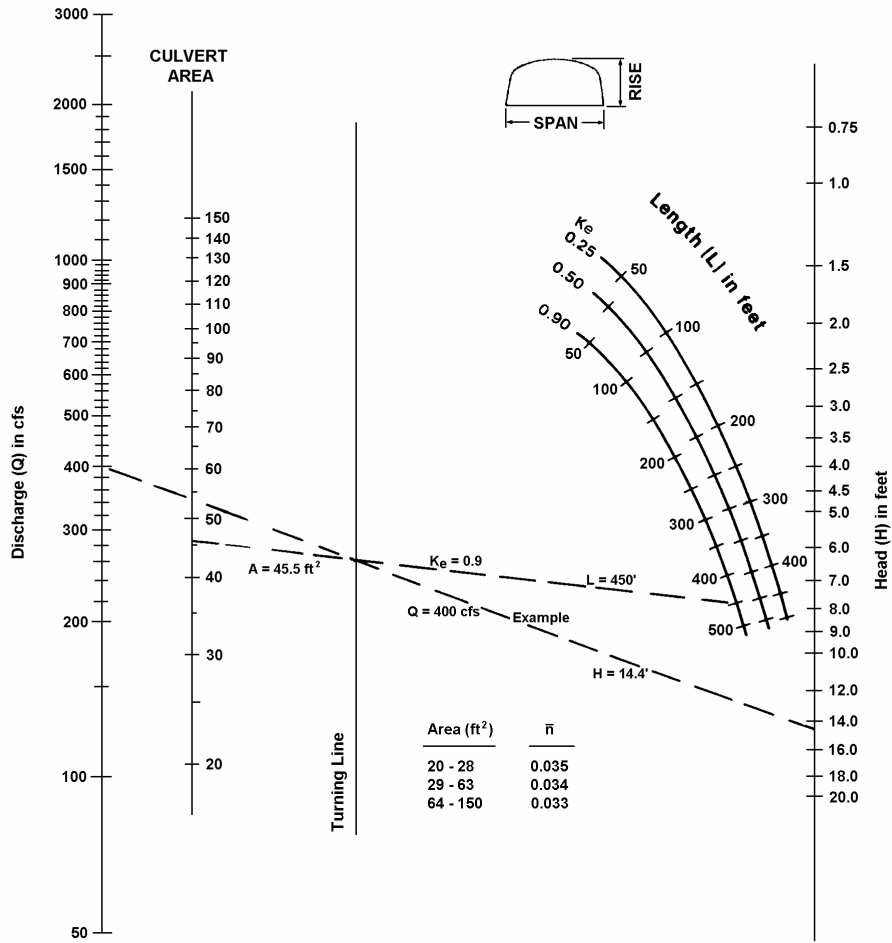
Area (ft ²)	\bar{n}
40 - 65	0.026
66 - 120	0.025



**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.5 ≤ RISE/SPAN**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 25

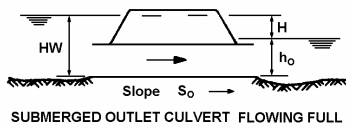
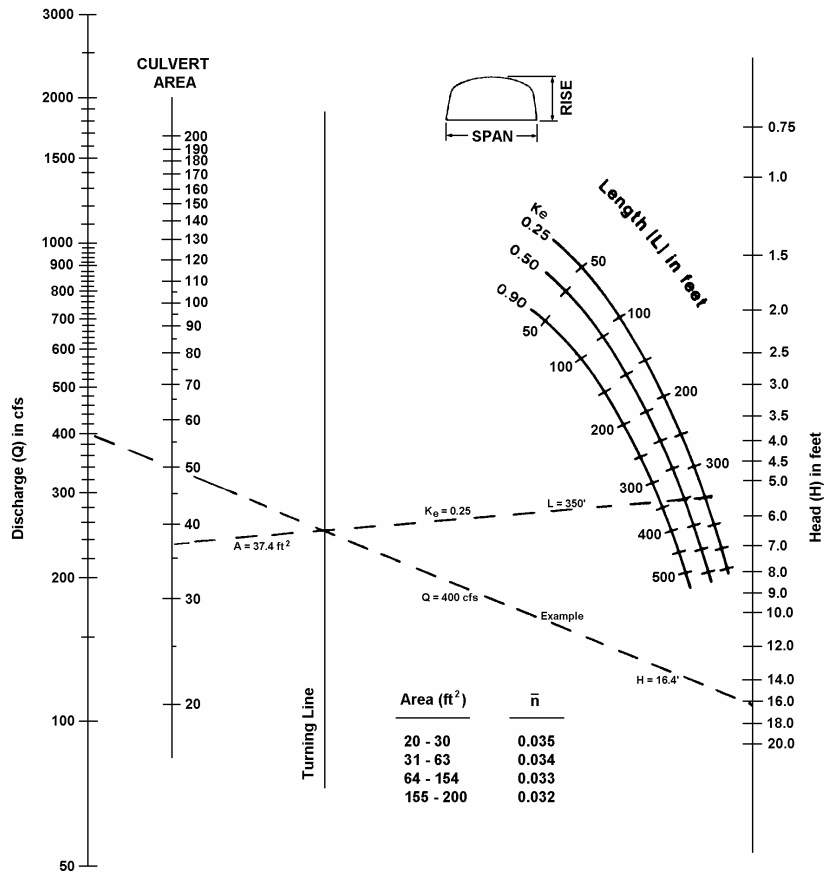


SUBMERGED OUTLET CULVERT FLOWING FULL

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.3 < RISE/SPAN**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 26

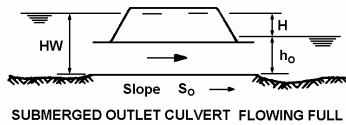
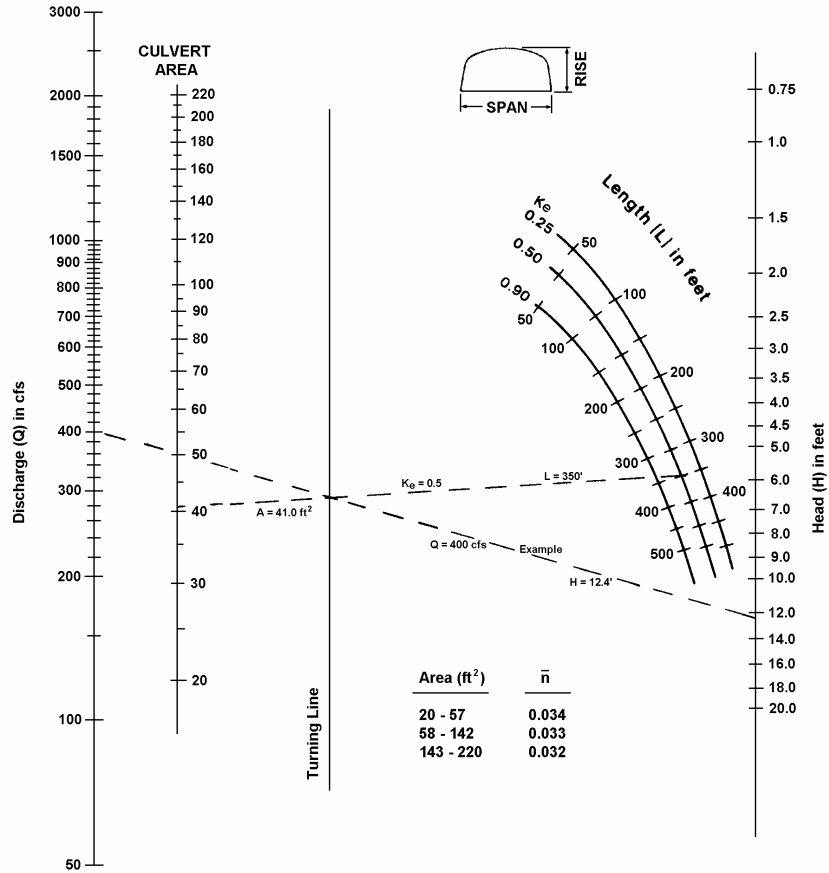


SUBMERGED OUTLET CULVERT FLOWING FULL

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
 $0.4 \leq \text{RISE}/\text{SPAN} < 0.5$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

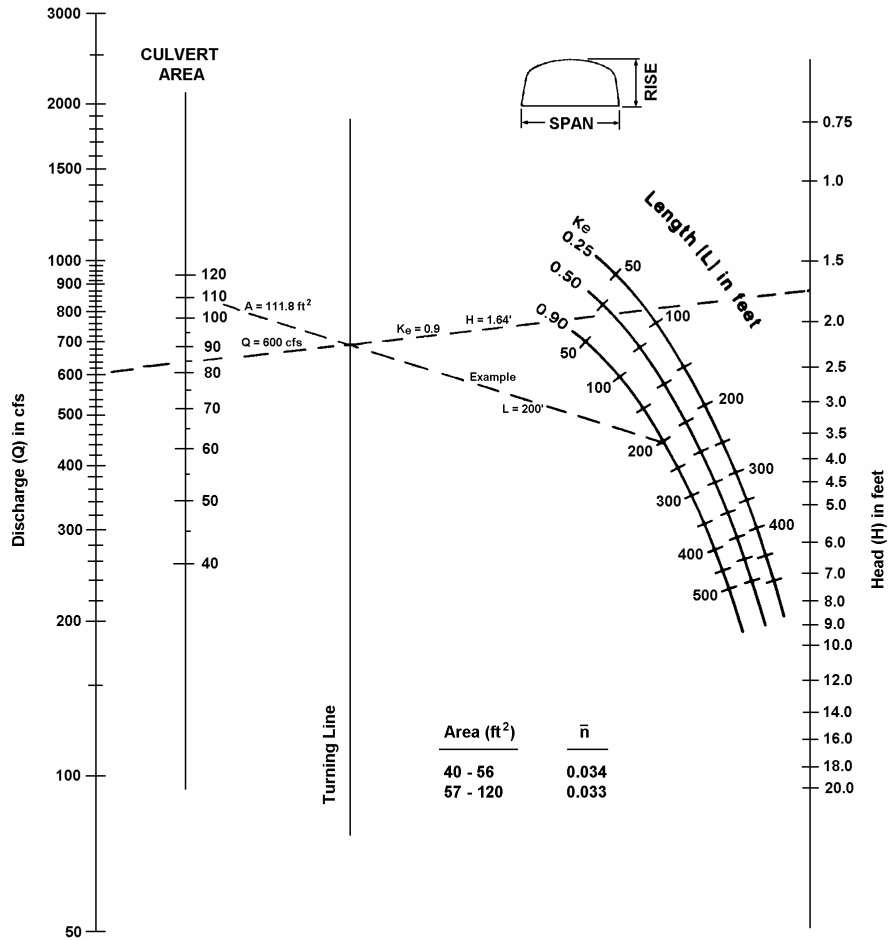
CHART 27



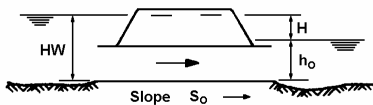
**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
 $0.4 \leq \text{RISE}/\text{SPAN} < 0.5$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 28



Area (ft ²)	\bar{n}
40 - 56	0.034
57 - 120	0.033

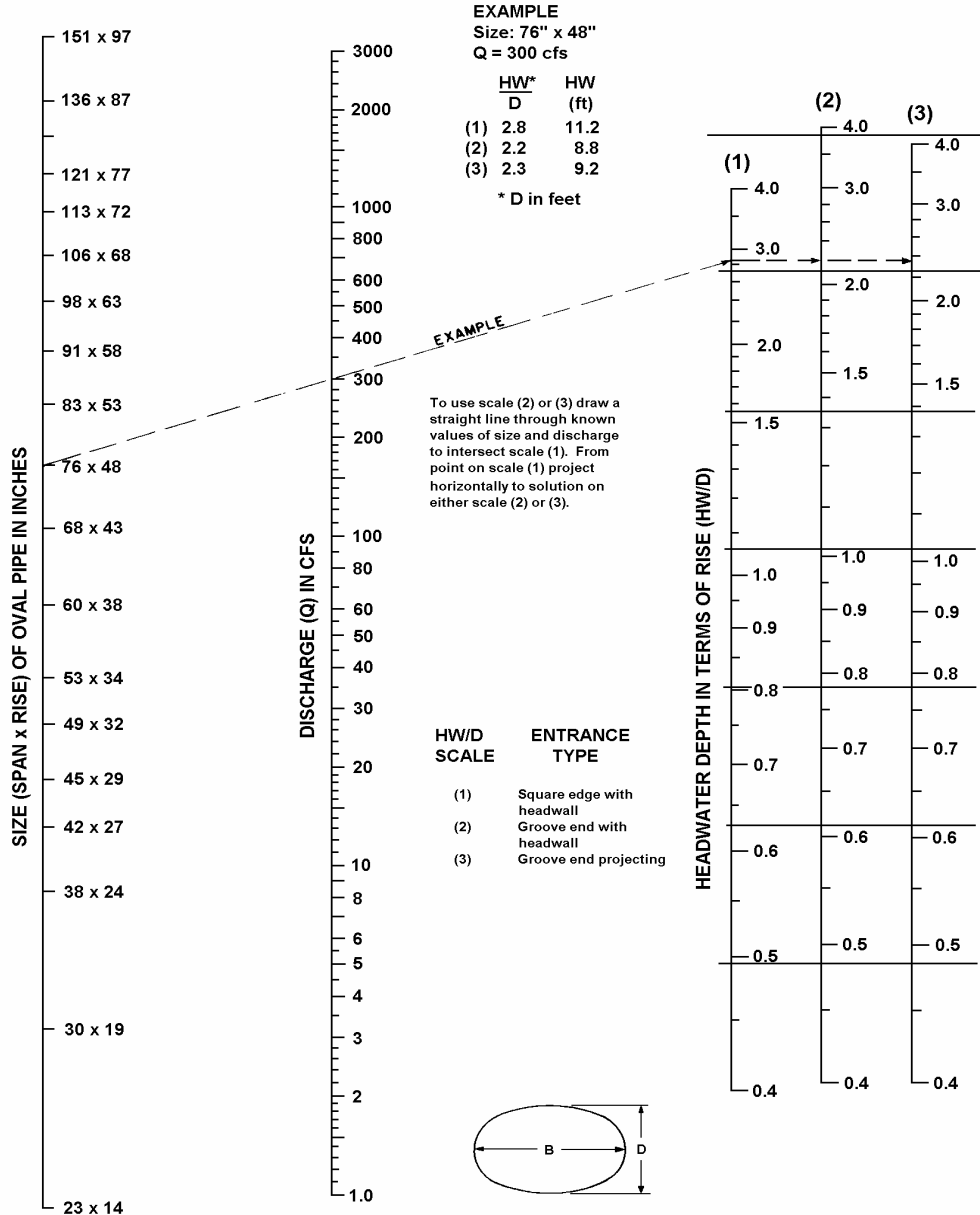


SUBMERGED OUTLET CULVERT FLOWING FULL

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.5 ≤ RISE/SPAN**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

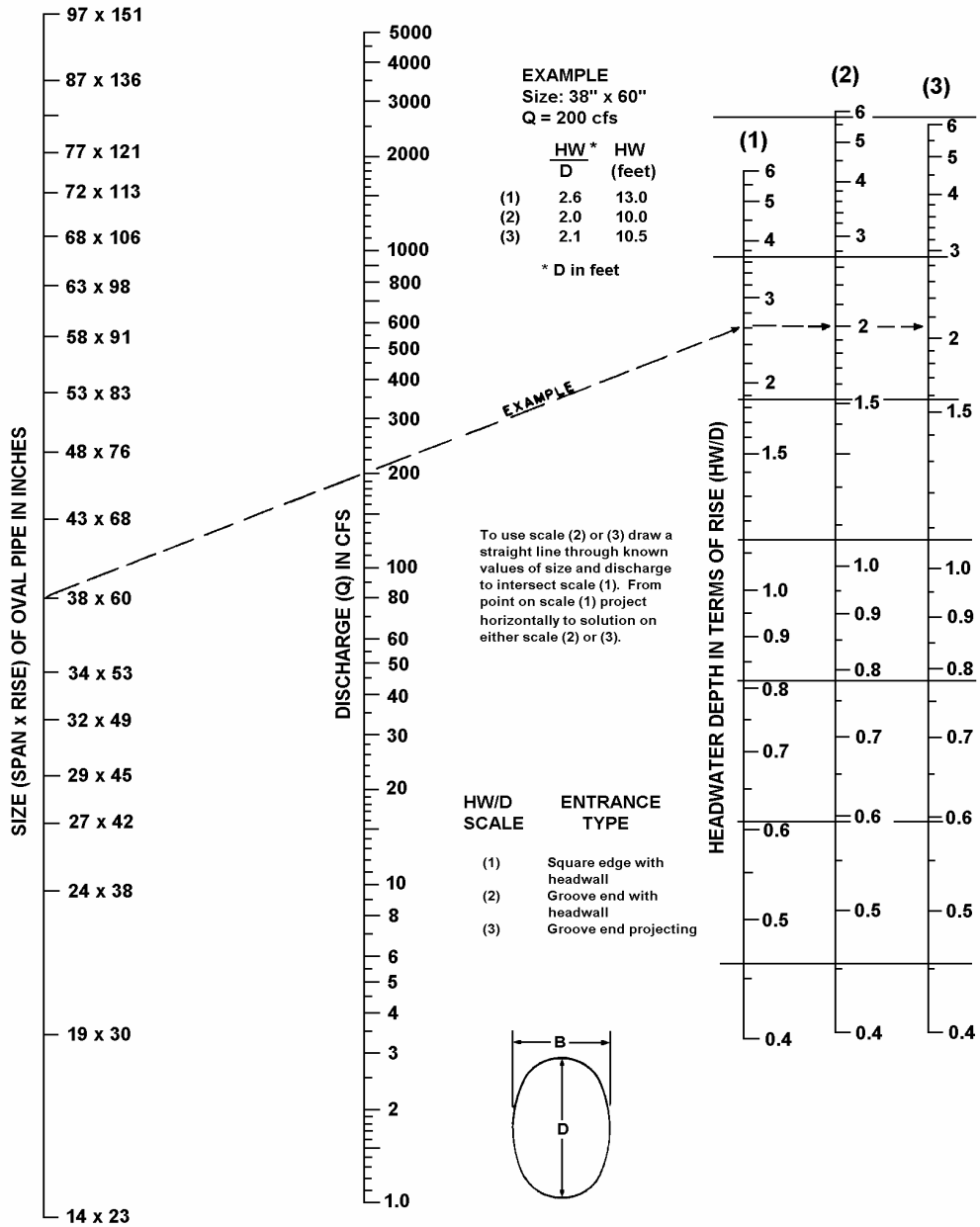
CHART 29



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HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

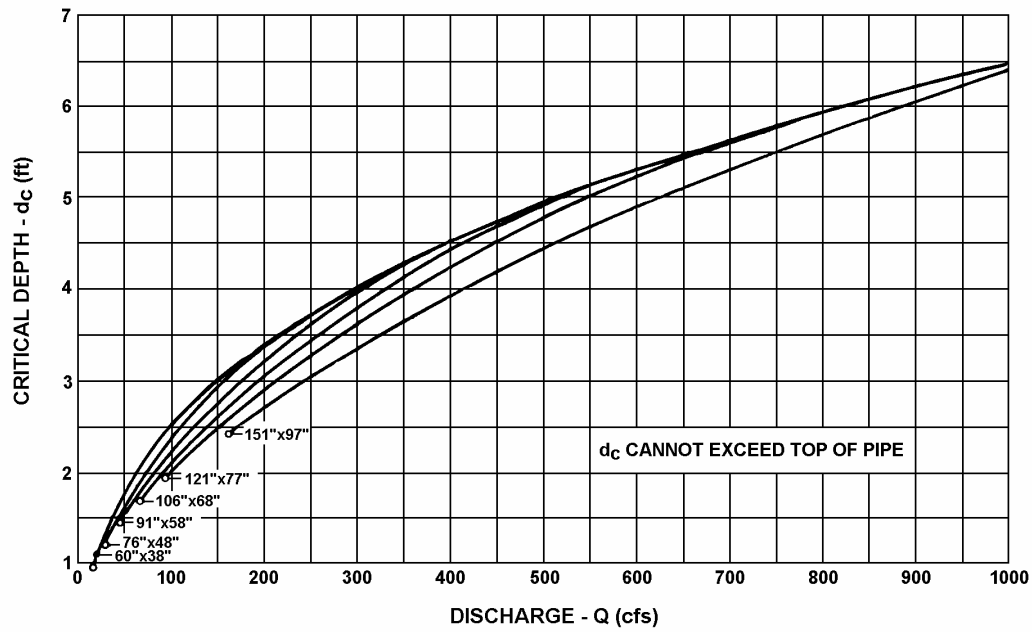
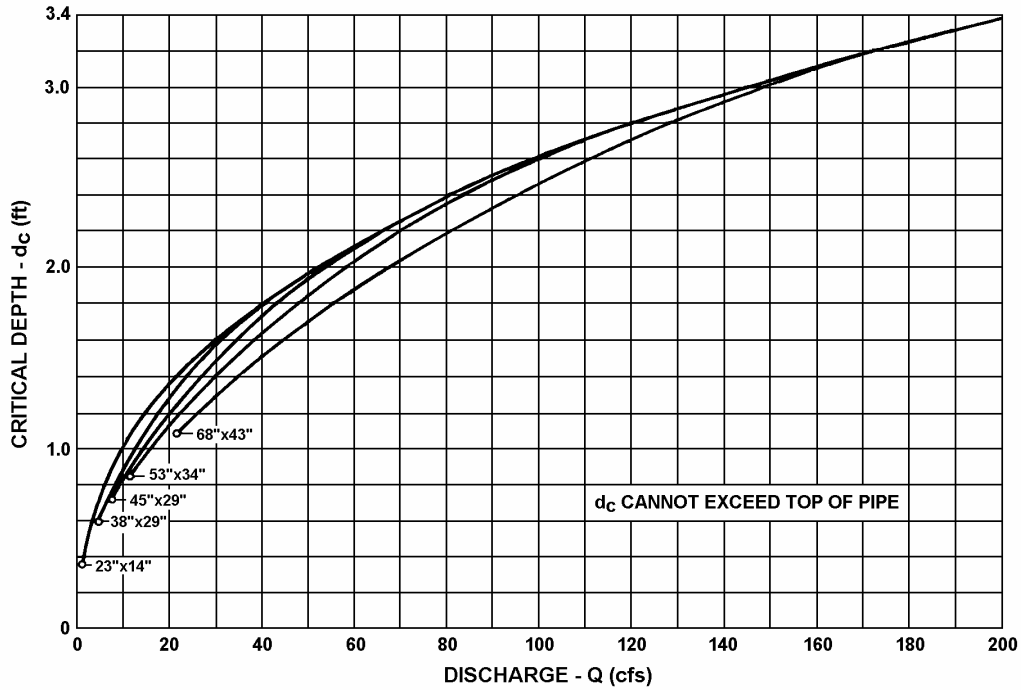
CHART 30



HEADWATER DEPTH FOR
 OVAL CONCRETE PIPE CULVERTS
 LONG AXIS VERTICAL
 WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

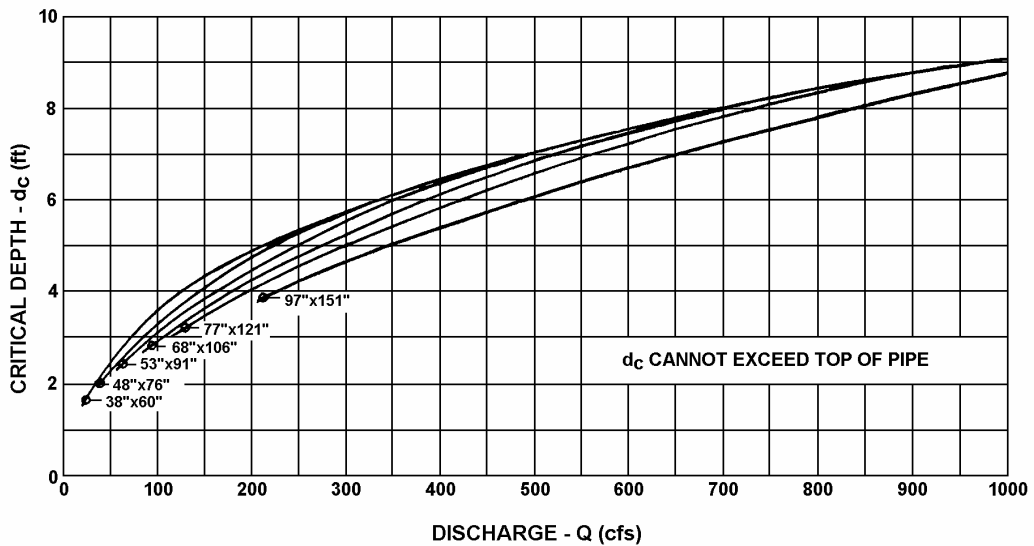
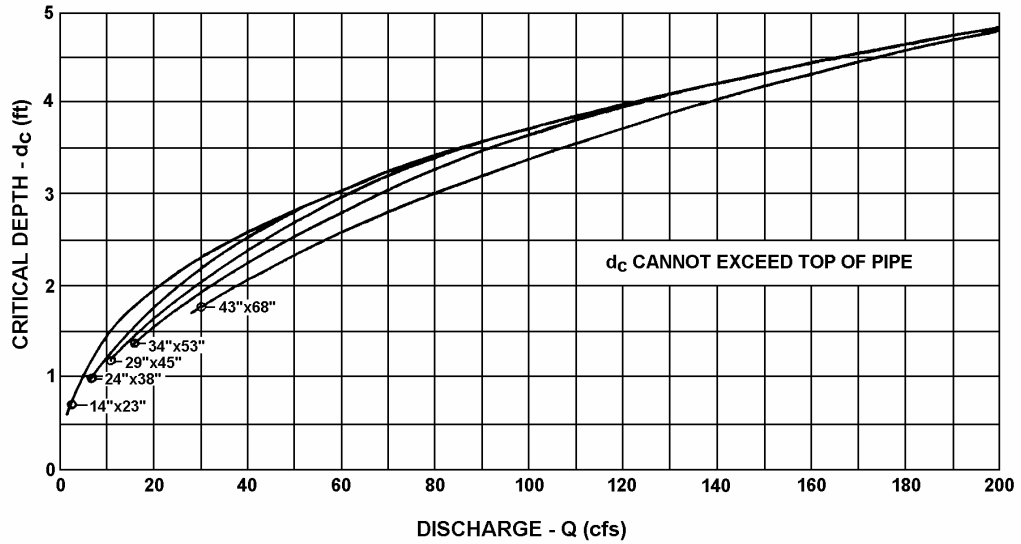
CHART 31



BUREAU OF PUBLIC ROADS JAN. 1964

**CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL**

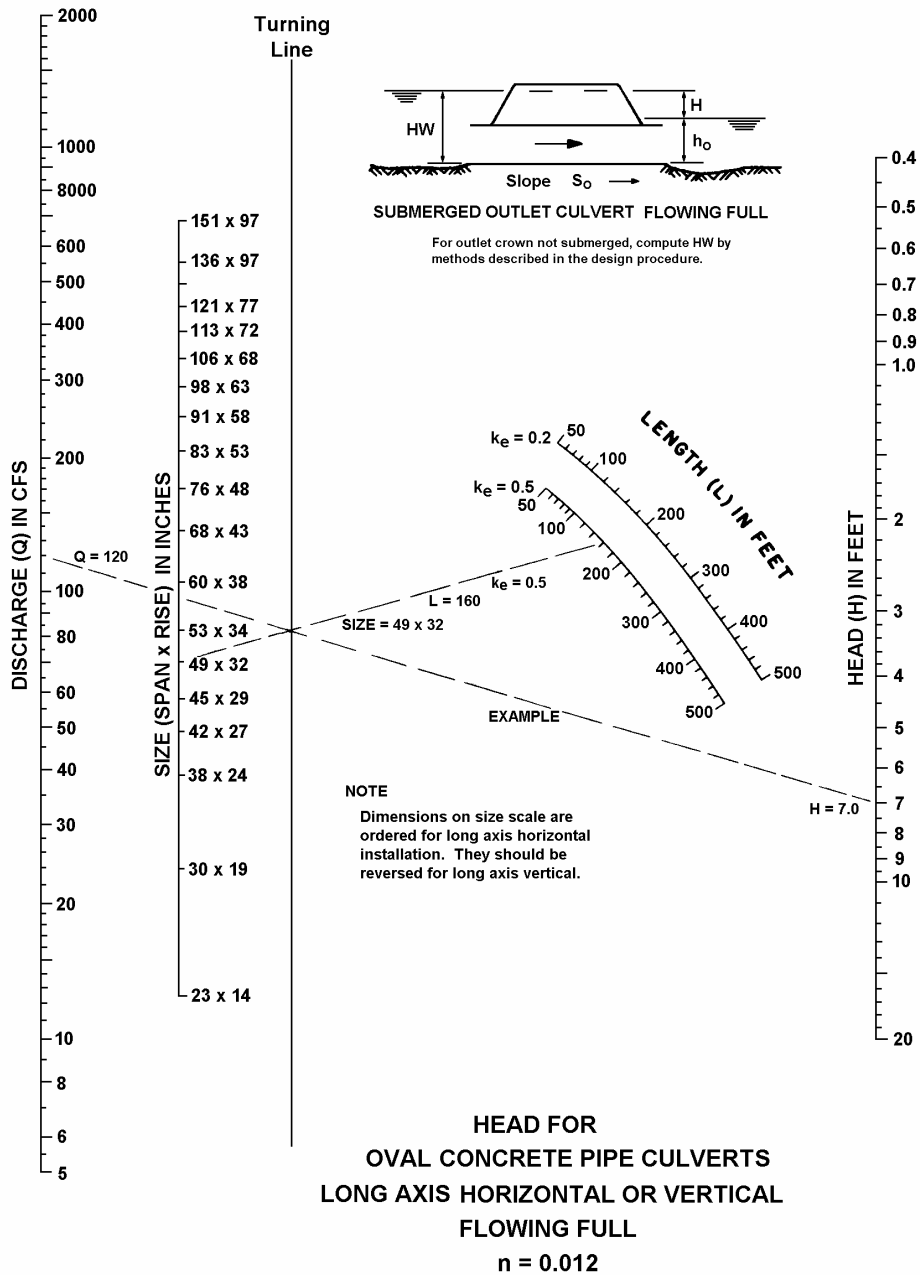
CHART 32



BUREAU OF PUBLIC ROADS JAN. 1964

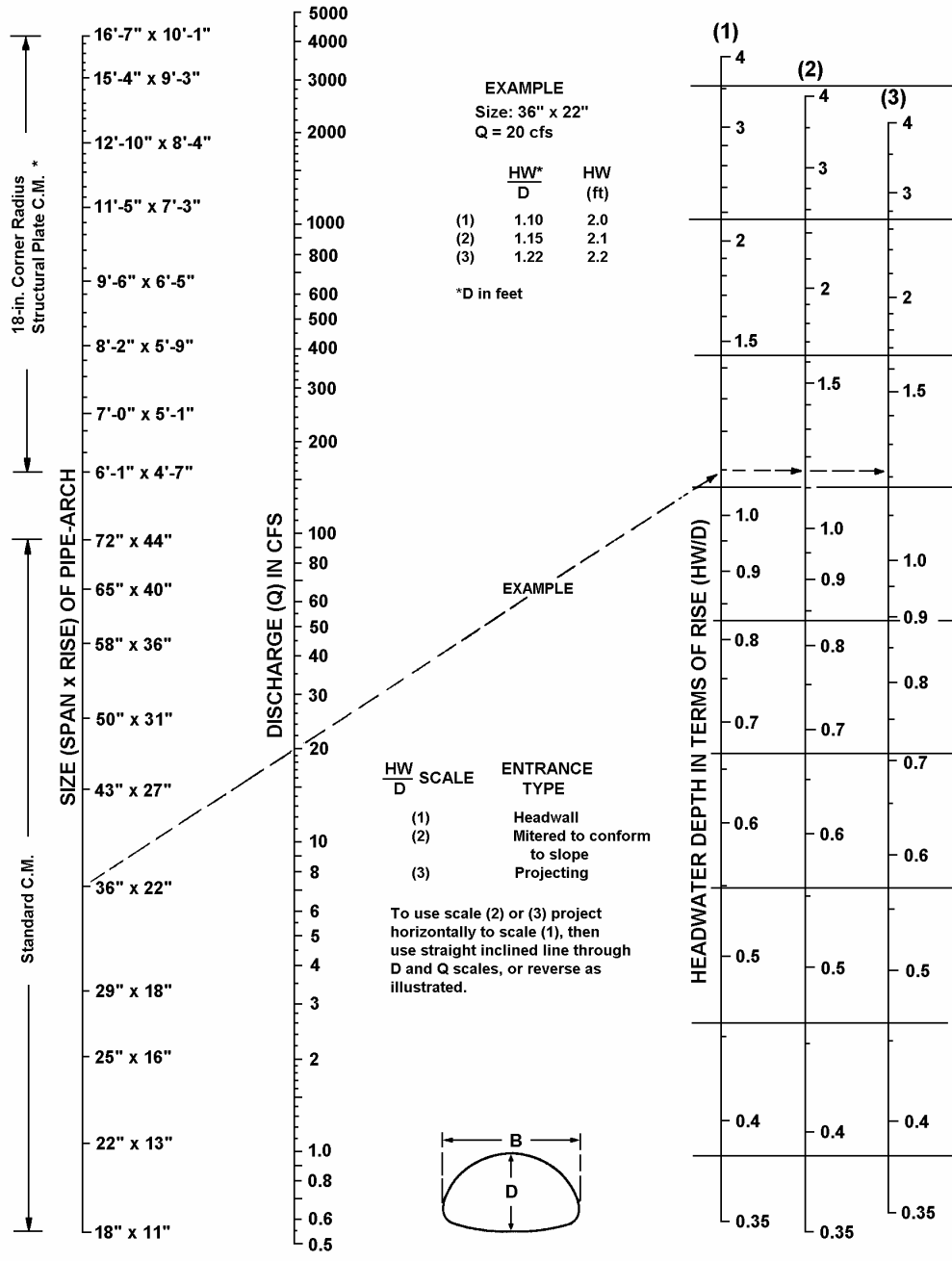
**CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL**

CHART 33



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CHART 34



* Additional sizes not dimensioned are listed in fabricator's catalog.

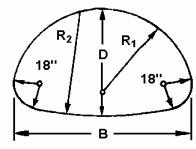
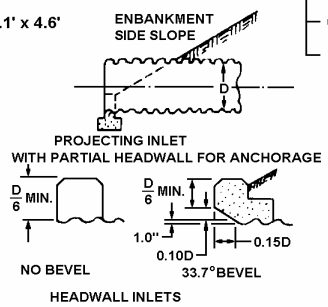
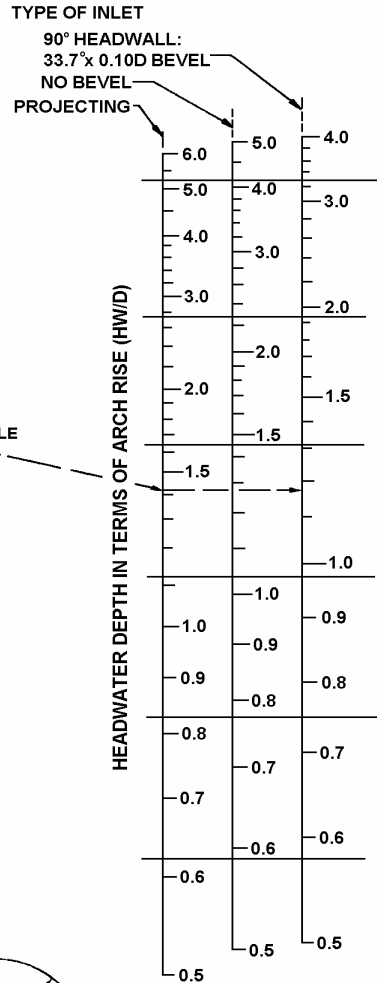
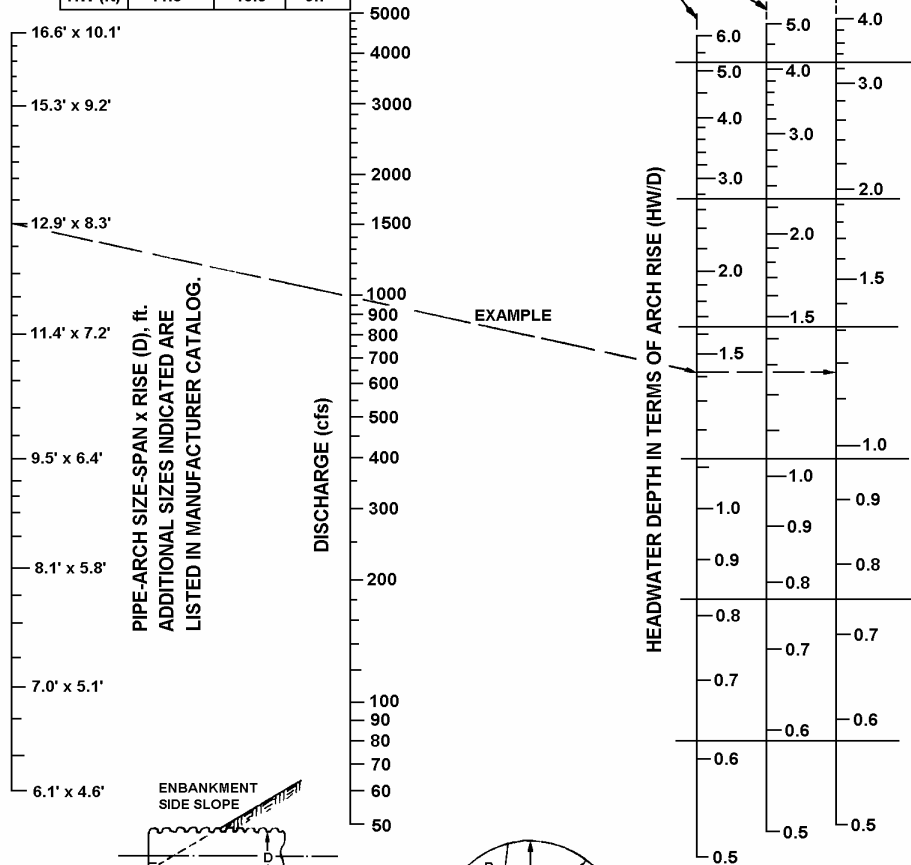
HEADWATER DEPTH FOR C.M. PIPE-ARCH CULVERTS WITH INLET CONTROL

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CHART 35

EXAMPLE
 SIZE 12.9' x 8.3' Q = 1000 cfs

	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW/D	1.42	1.27	1.17
HW (ft)	11.8	10.5	9.7



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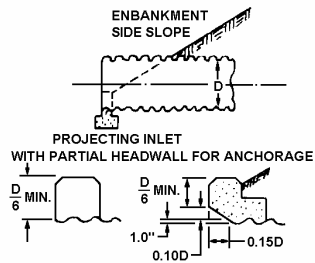
HEADWATER DEPTH FOR INLET CONTROLS
 STRUCTURAL PLATE PIPE-ARCH CULVERTS
 18 in. RADIUS CORNER PLATE
 PROJECTING OR HEADWALL INLET
 HEADWALL WITH OR WITHOUT EDGE BEVEL

CHART 36

EXAMPLE
 SIZE 17.4' x 11.5' Q = 2500 cfs

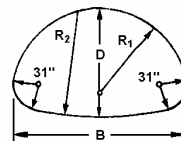
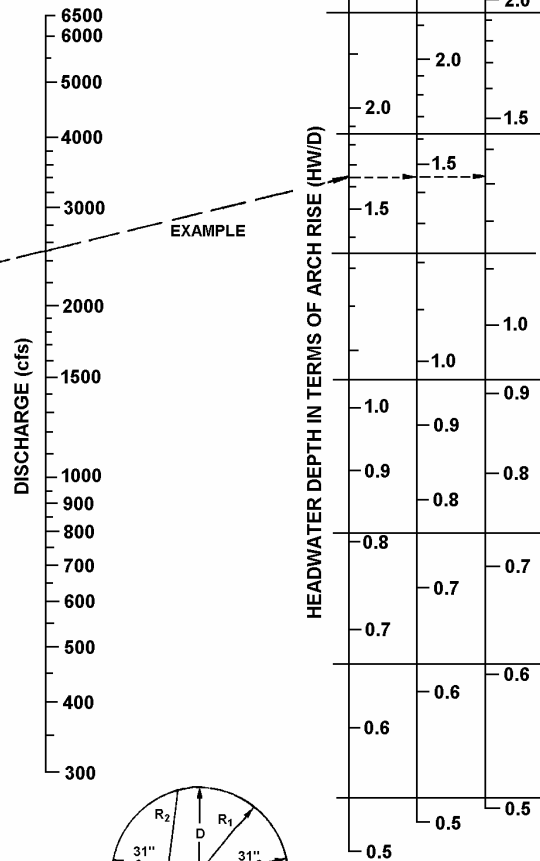
	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW/D	1.64	1.45	1.32
HW (ft)	18.9	16.7	15.2

- 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'
- PIPE-ARCH SIZE-SPAN x RISE (D), ft.
 ADDITIONAL SIZES INDICATED ARE LISTED IN MANUFACTURER CATALOG.



TYPE OF INLET

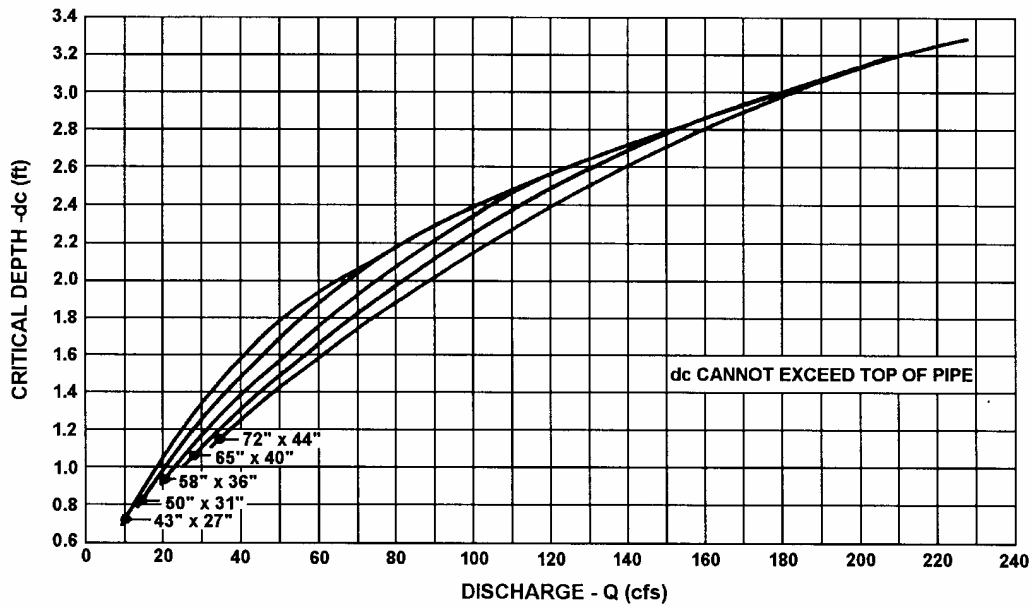
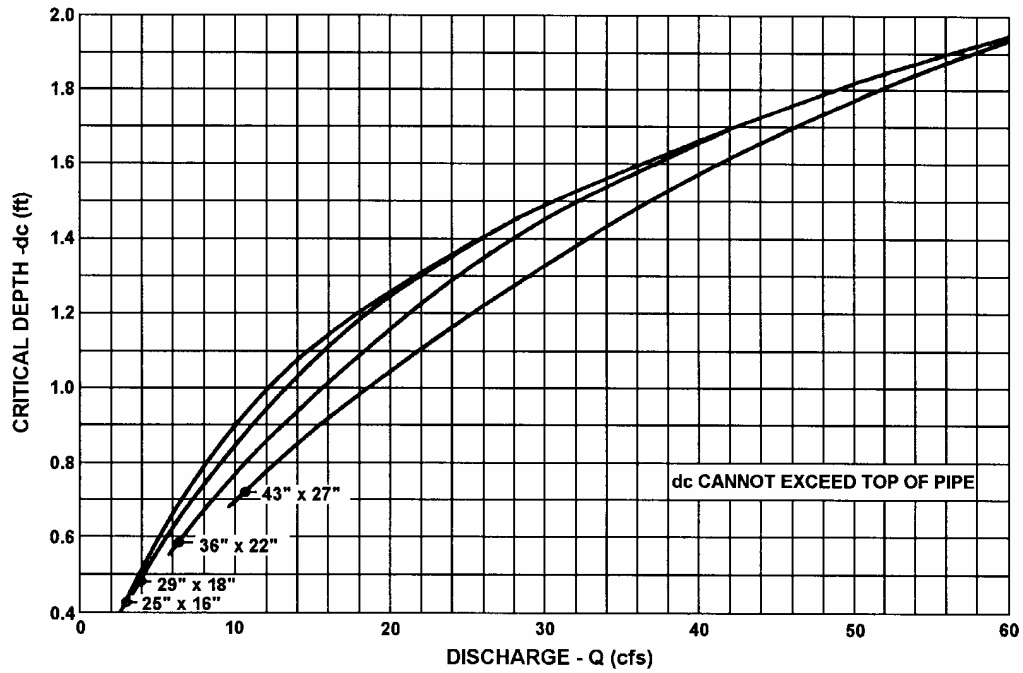
- 90° HEADWALL:
33.7' x 0.10D BEVEL
- NO BEVEL
- PROJECTING



BUREAU OF PUBLIC ROADS
 OFFICE OF R&D JULY 1966

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

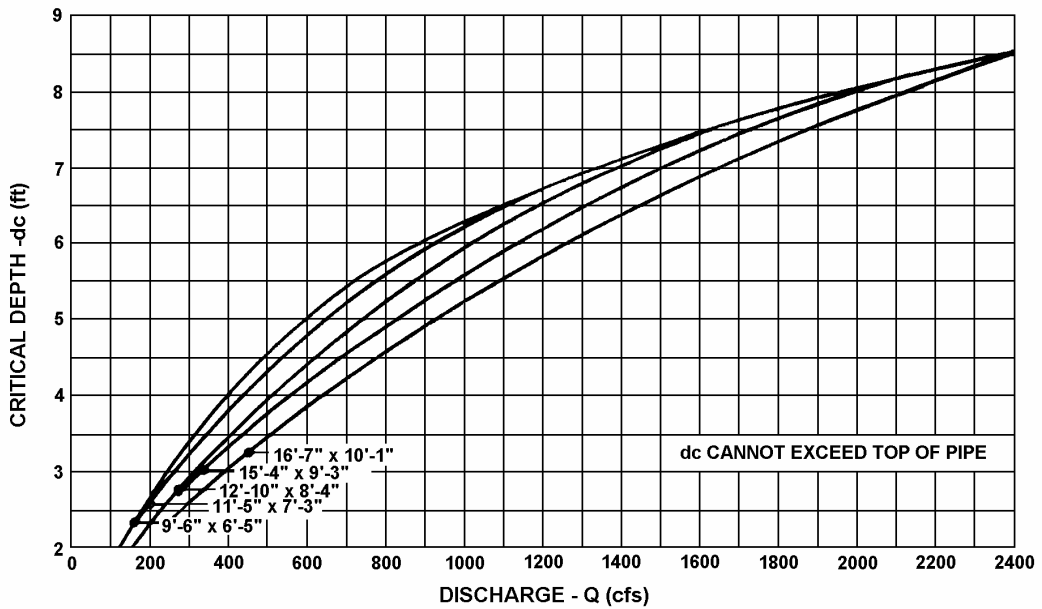
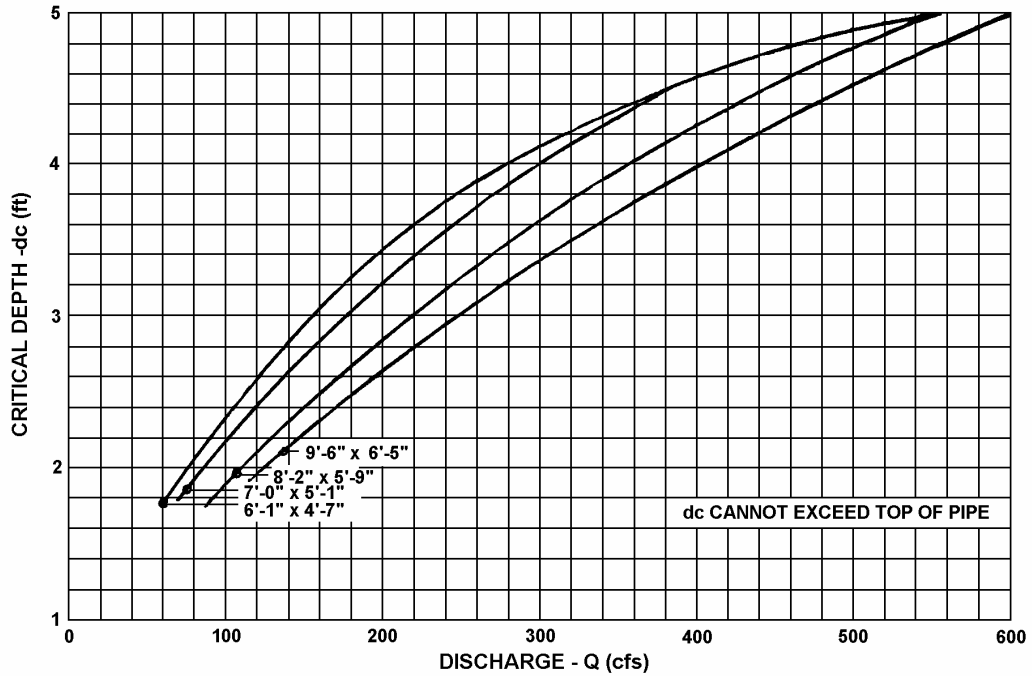
CHART 37



BUREAU OF PUBLIC ROADS
JAN. 1964

**CRITICAL DEPTH
STANDARD C.M. PIPE ARCH**

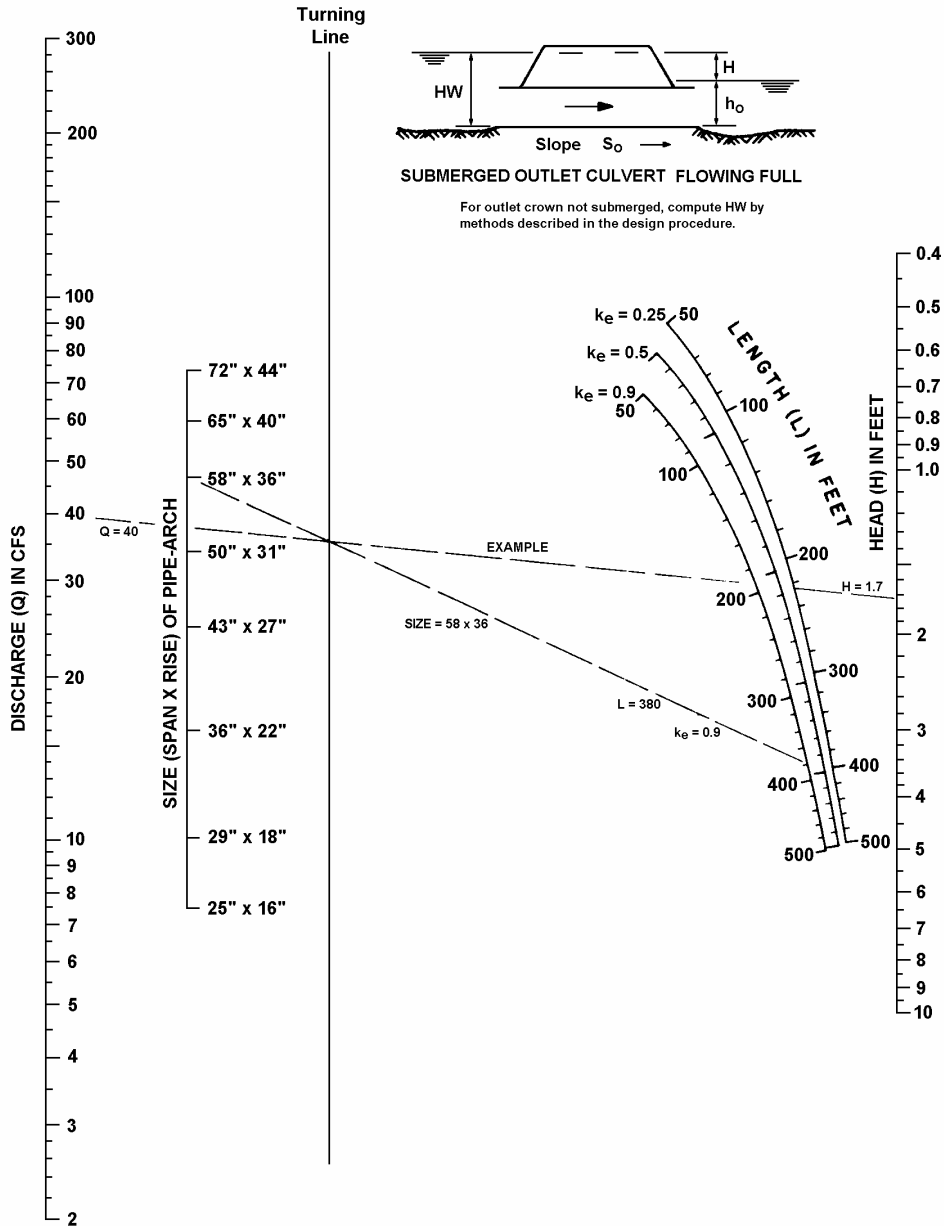
CHART 38



BUREAU OF PUBLIC ROADS
JAN. 1964

**CRITICAL DEPTH
STRUCTURAL PLATE
C.M. PIPE ARCH
18 in. CORNER RADIUS**

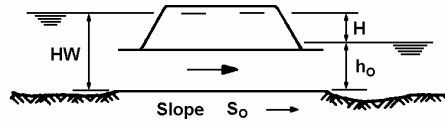
CHART 39



HEAD FOR
STANDARD C.M. PIPE-ARCH CULVERTS
FLOWING FULL
n = 0.024

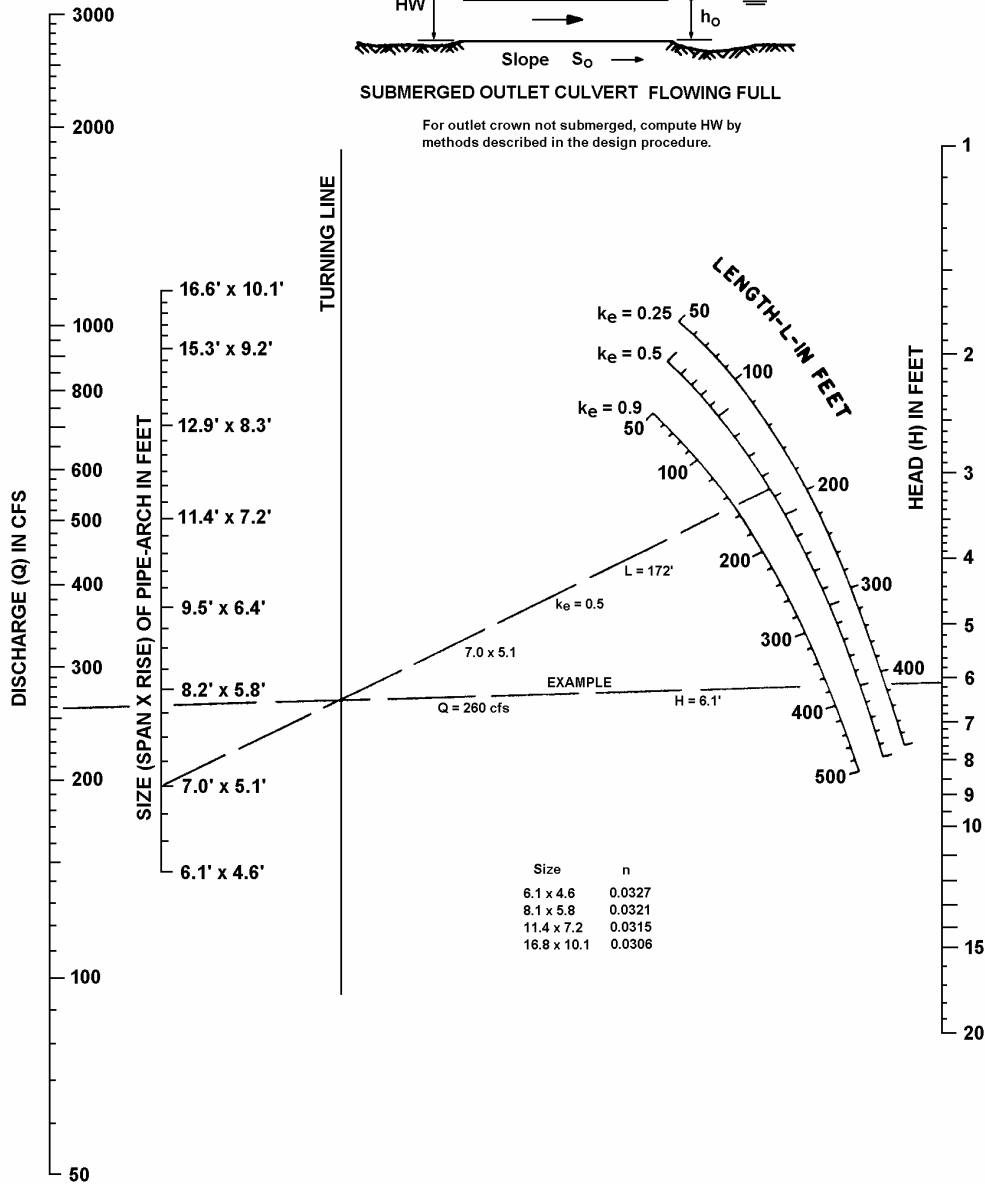
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 40



SUBMERGED OUTLET CULVERT FLOWING FULL

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



Size	n
6.1 x 4.6	0.0327
8.1 x 5.8	0.0321
11.4 x 7.2	0.0315
16.8 x 10.1	0.0306

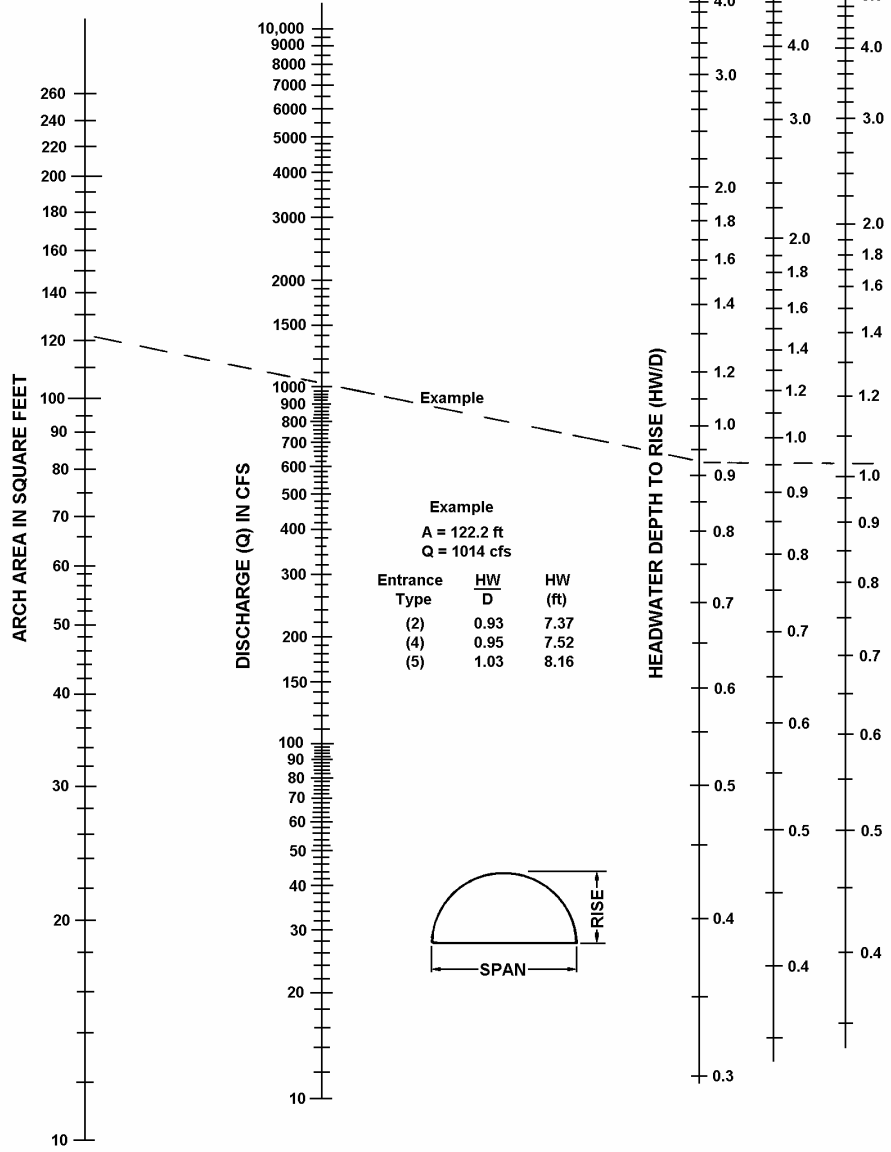
**HEAD FOR
STRUCTURAL PLATE
C.M. PIPE ARCH CULVERTS
18 in. CORNER RADIUS
FLOWING FULL
n = 0.0327 TO 0.0306**

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 41

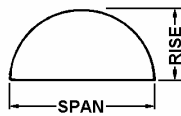
Entrance Conditions

- (2) 90° headwall.
- (4) Mitered to embankment.
- (5) Thin wall projecting corrugated metal.



Example
 A = 122.2 ft
 Q = 1014 cfs

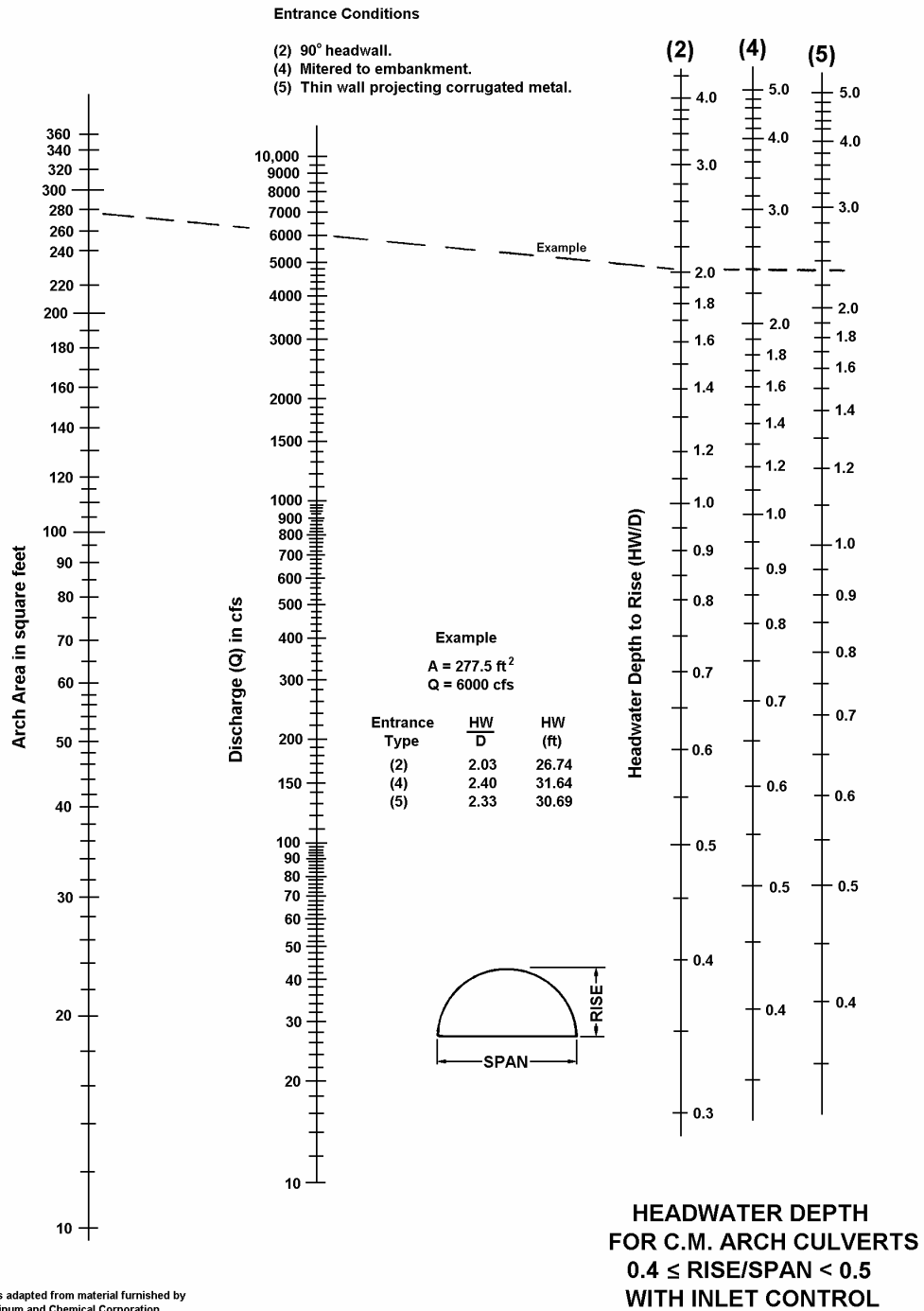
Entrance Type	HW/D	HW (ft)
(2)	0.93	7.37
(4)	0.95	7.52
(5)	1.03	8.16



HEADWATER DEPTH FOR C.M. ARCH CULVERTS
 $0.3 \leq \text{RISE}/\text{SPAN} < 0.4$
 WITH INLET CONTROL

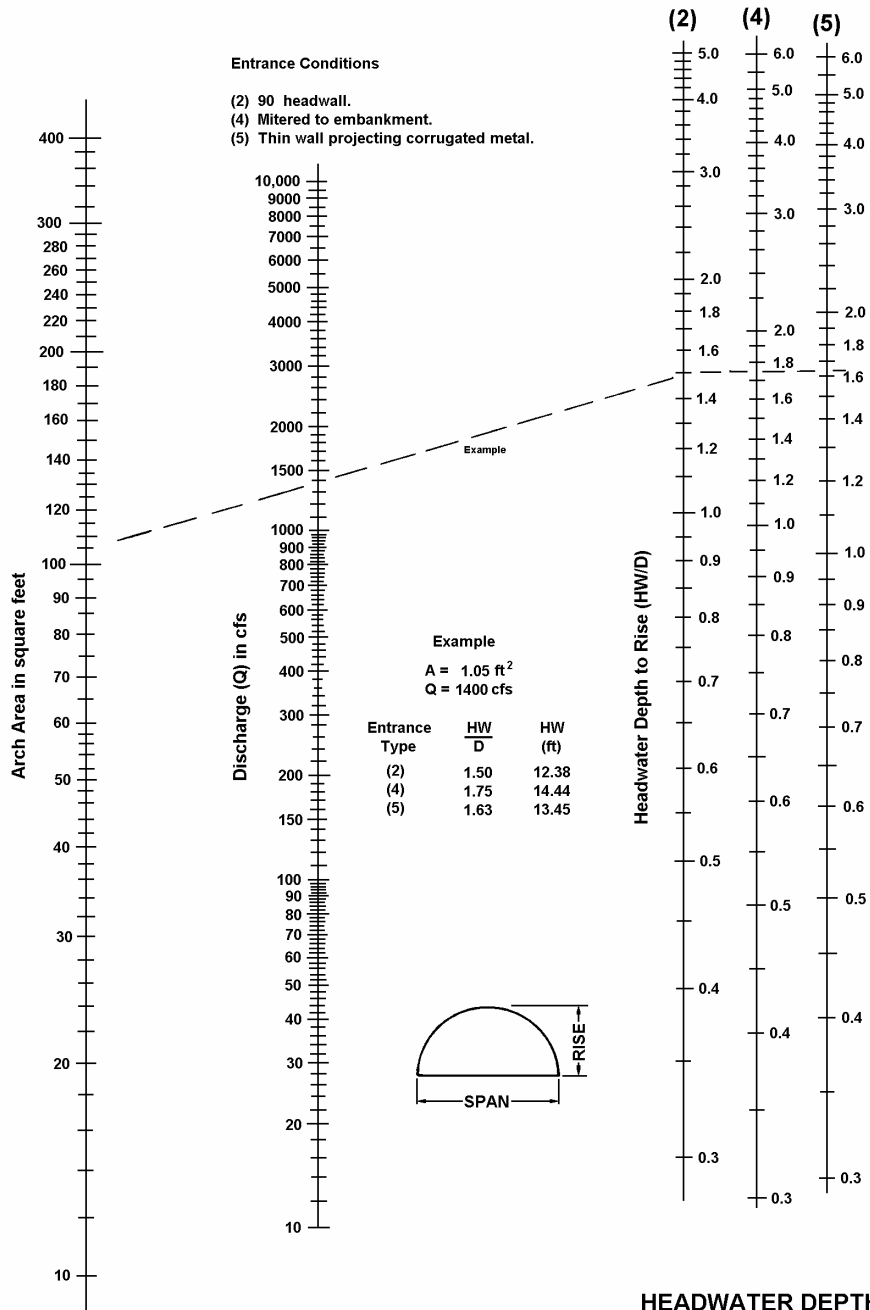
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 42



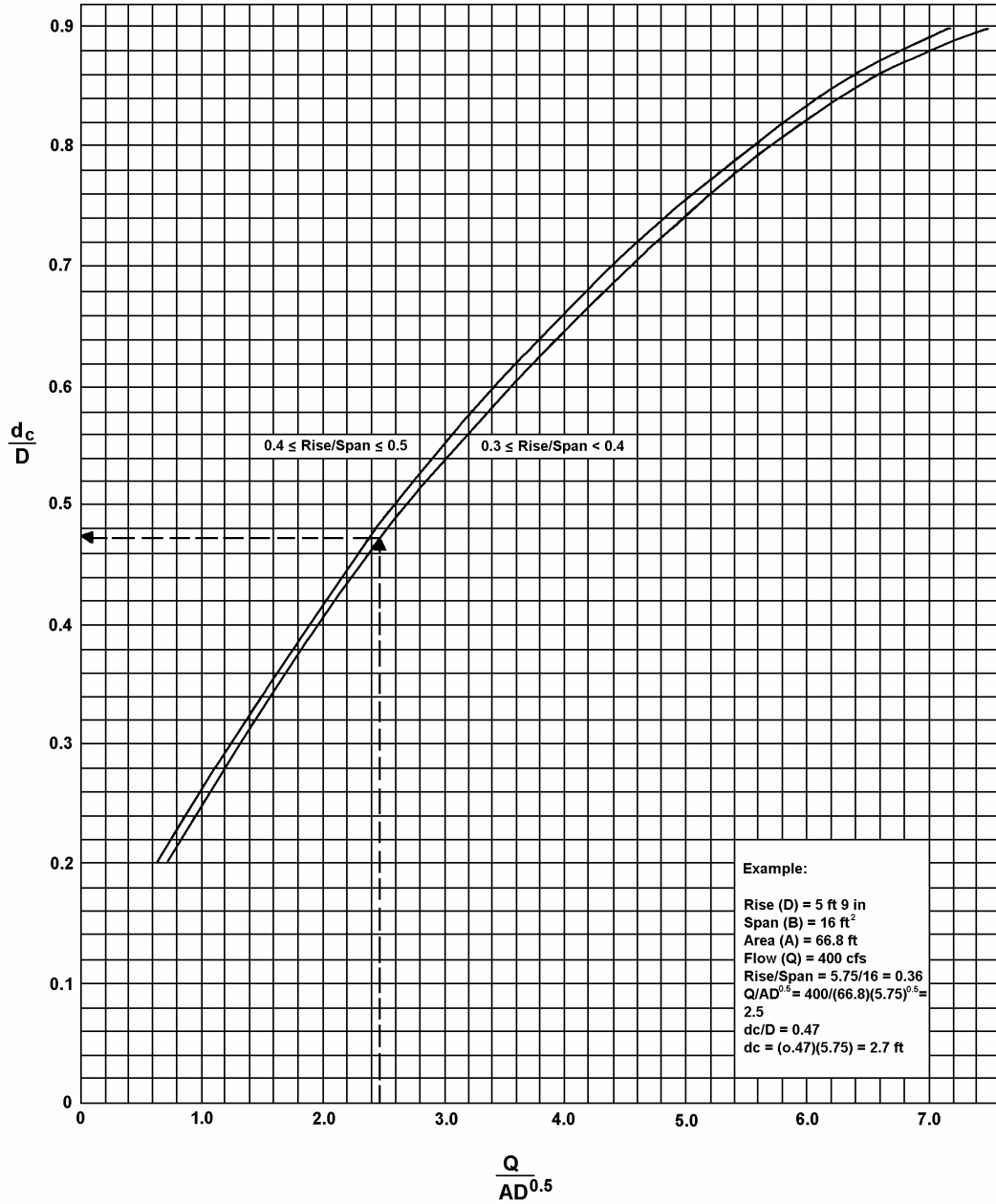
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 43



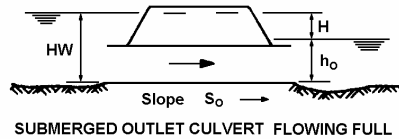
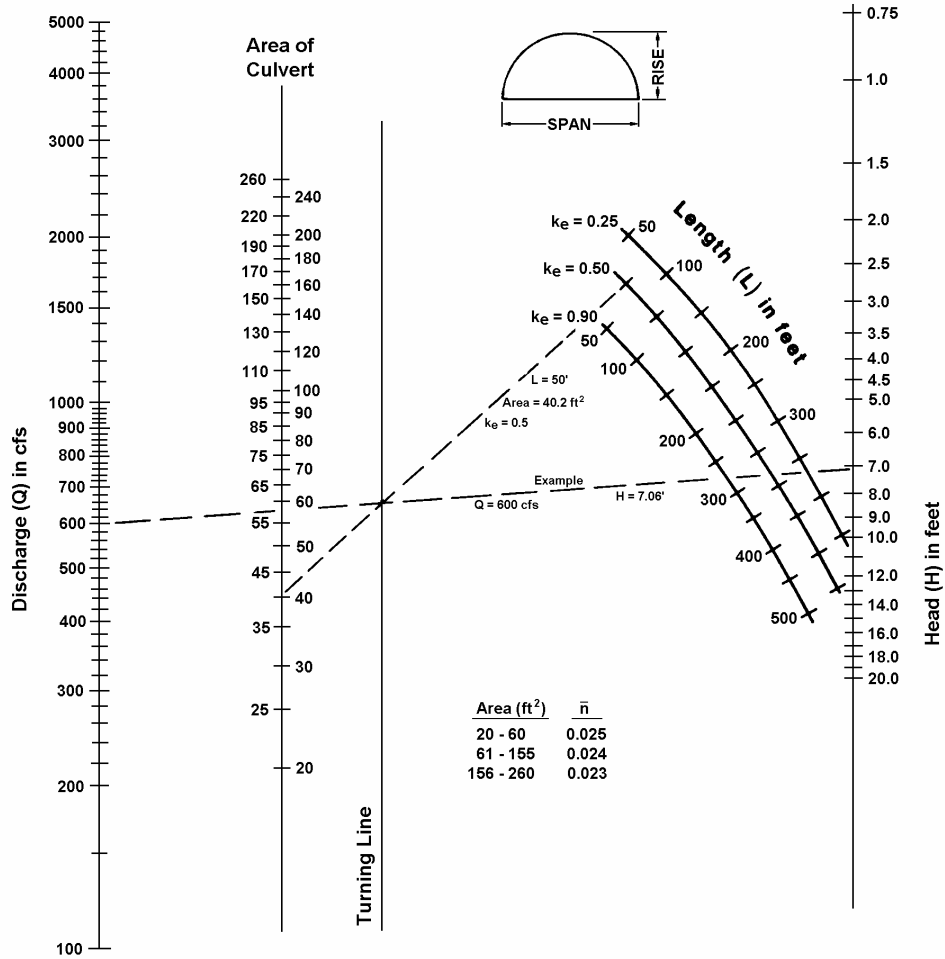
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 44



DIMENSIONLESS CRITICAL DEPTH CHART
FOR C.M. ARCH CULVERTS

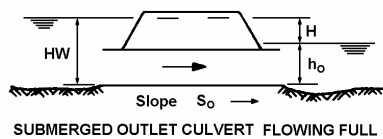
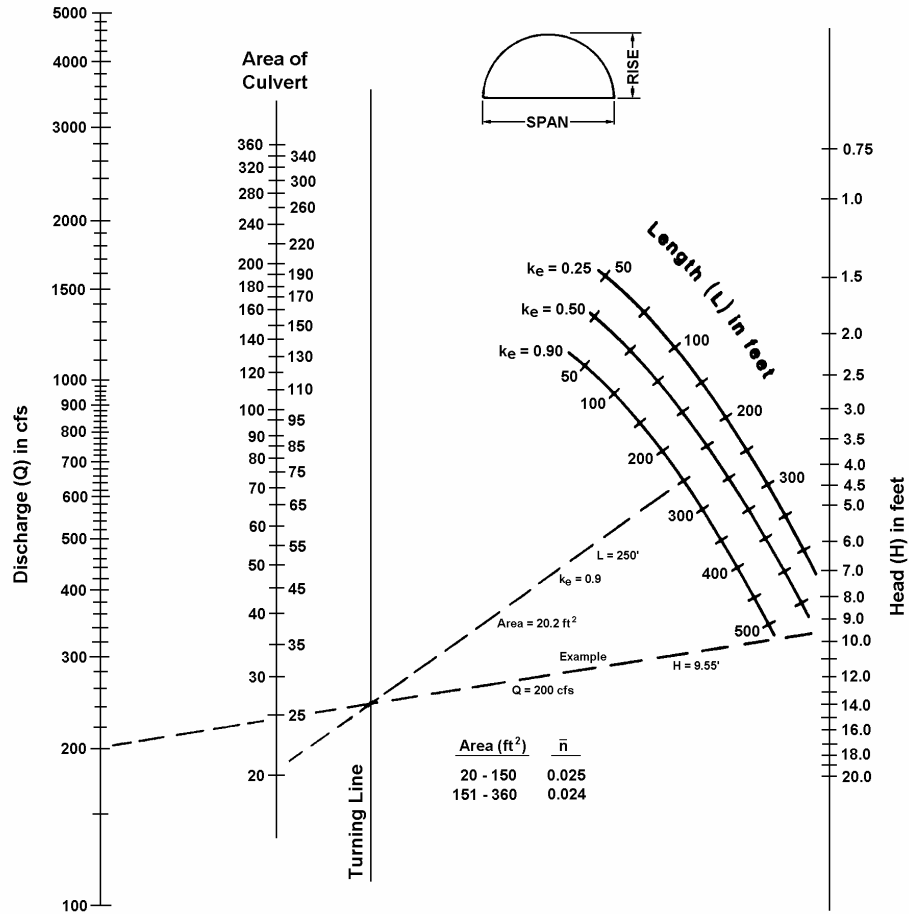
CHART 45



**HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
 $0.3 \leq \text{RISE}/\text{SPAN} < 0.4$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

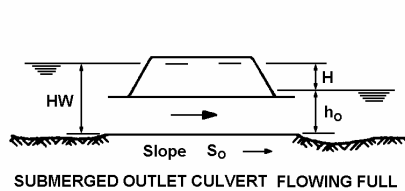
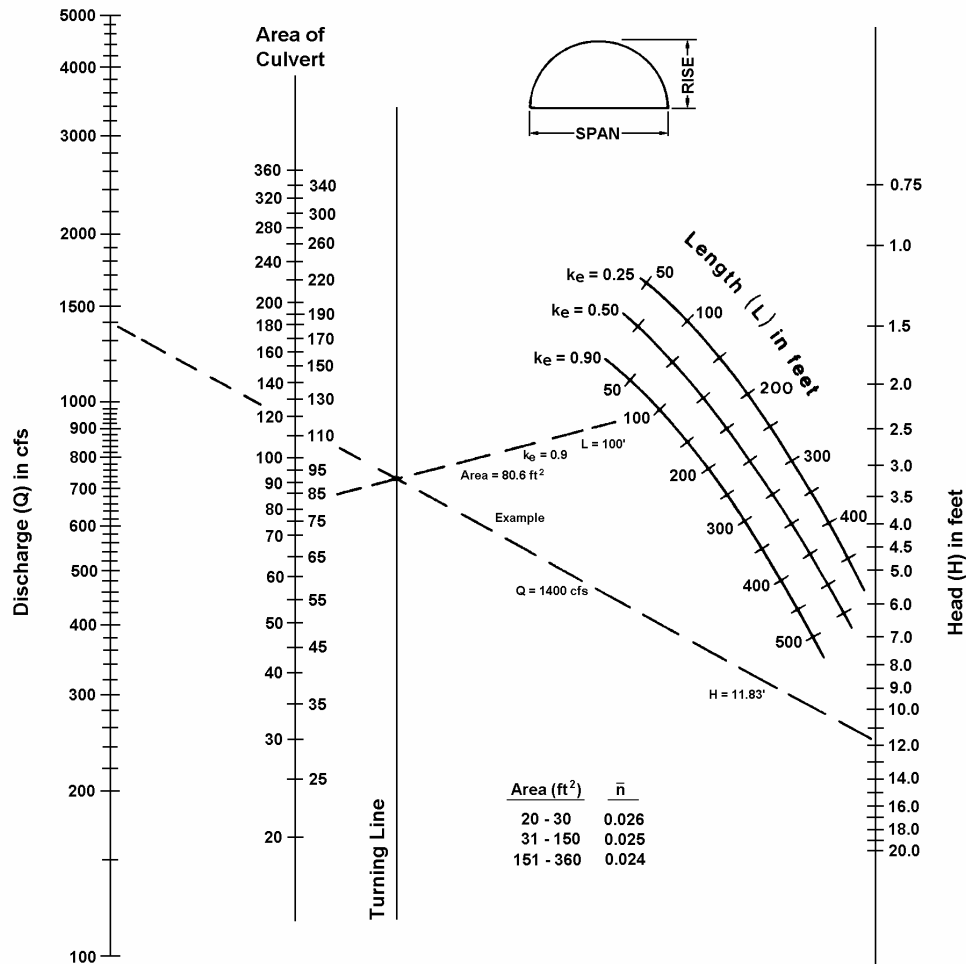
CHART 46



**HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
 $0.4 \leq \text{RISE}/\text{SPAN} < 0.5$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

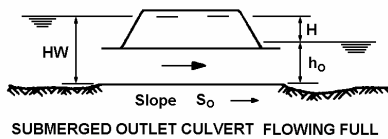
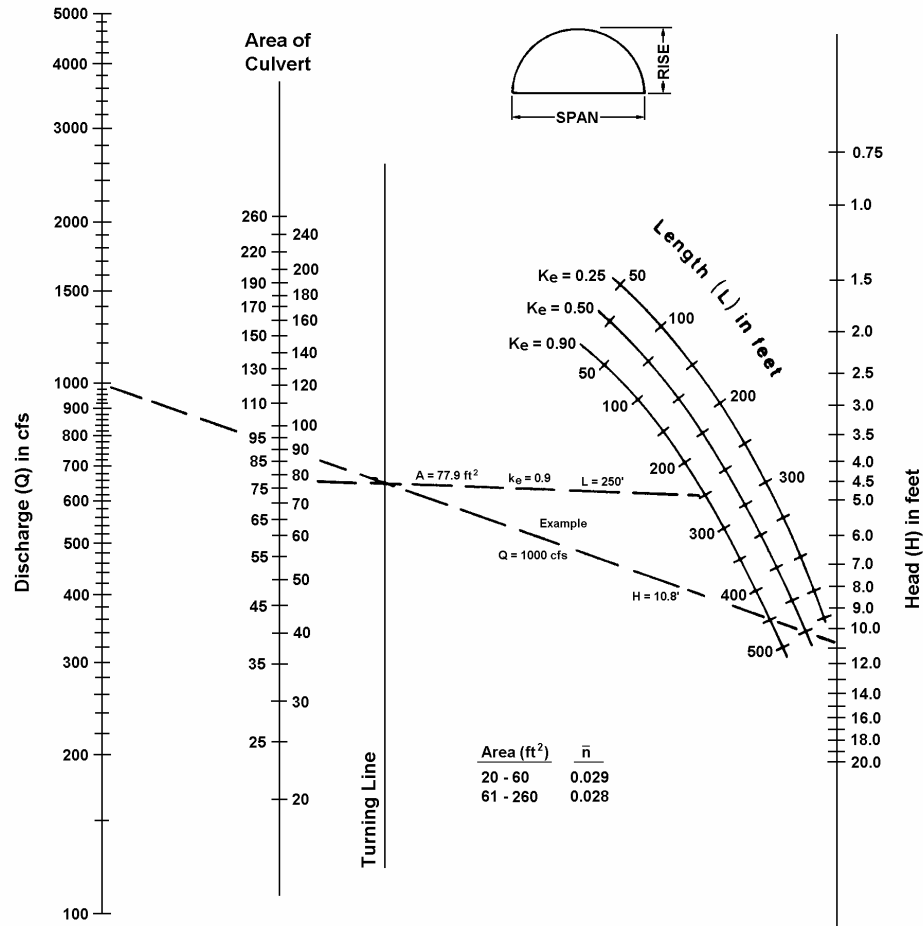
CHART 47



**HEAD FOR
 C.M. ARCH CULVERTS
 FLOWING FULL
 CONCRETE BOTTOM
 $0.5 \leq \text{RISE}/\text{SPAN}$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

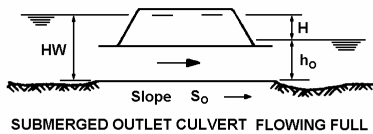
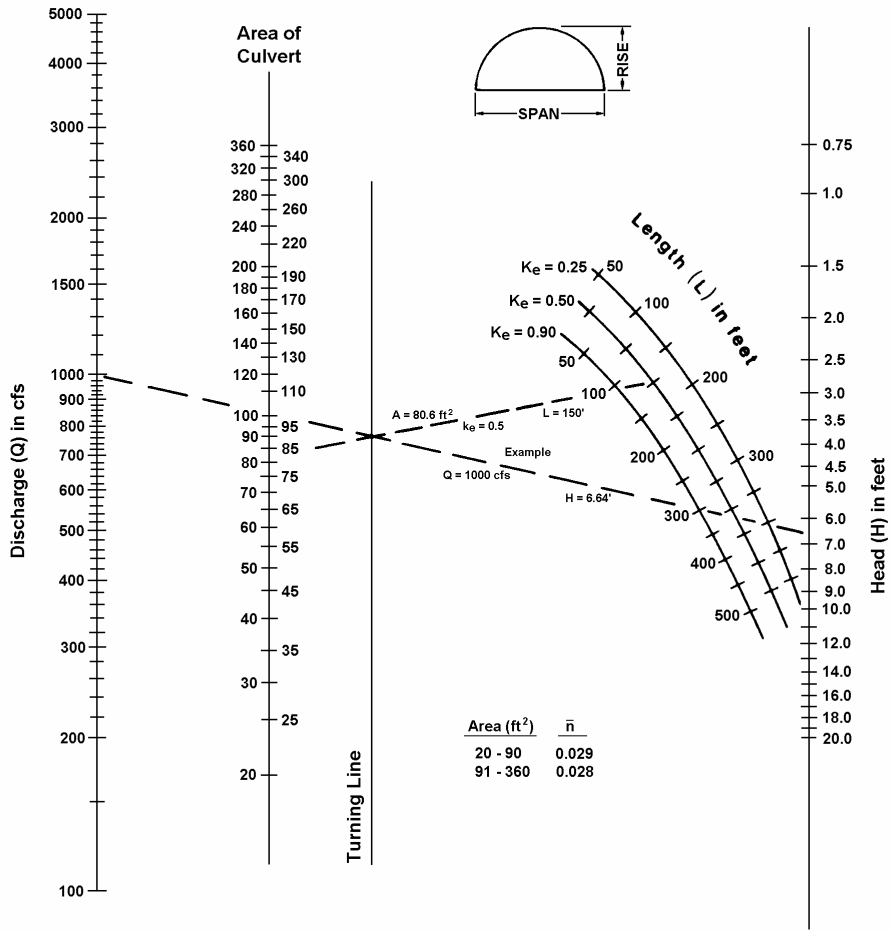
CHART 48



**HEAD FOR
 C.M. ARCH CULVERTS
 FLOWING FULL
 EARTH BOTTOM ($n_b = 0.022$)
 $0.3 \leq \text{RISE}/\text{SPAN} < 0.4$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

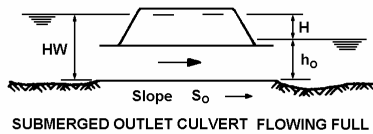
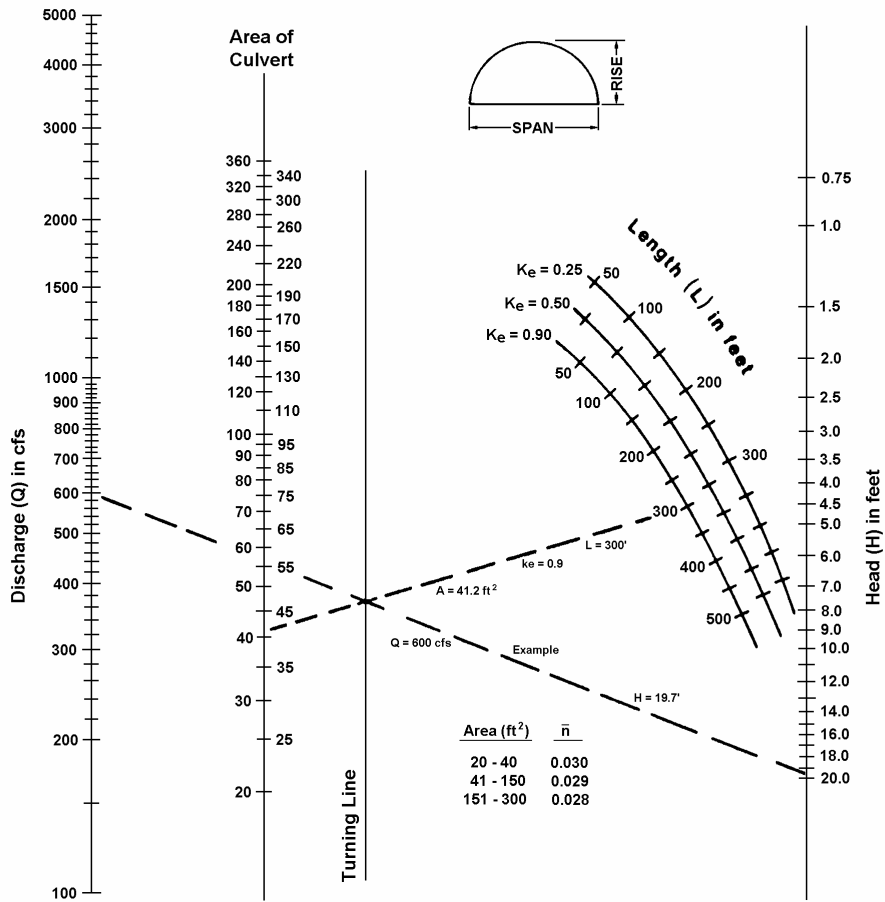
CHART 49



HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM ($n_b = 0.022$)
 $0.4 \leq \text{RISE}/\text{SPAN} < 0.5$

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 50



**HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM ($n_b = 0.022$)
 $0.5 \leq \text{RISE}/\text{SPAN}$**

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 51

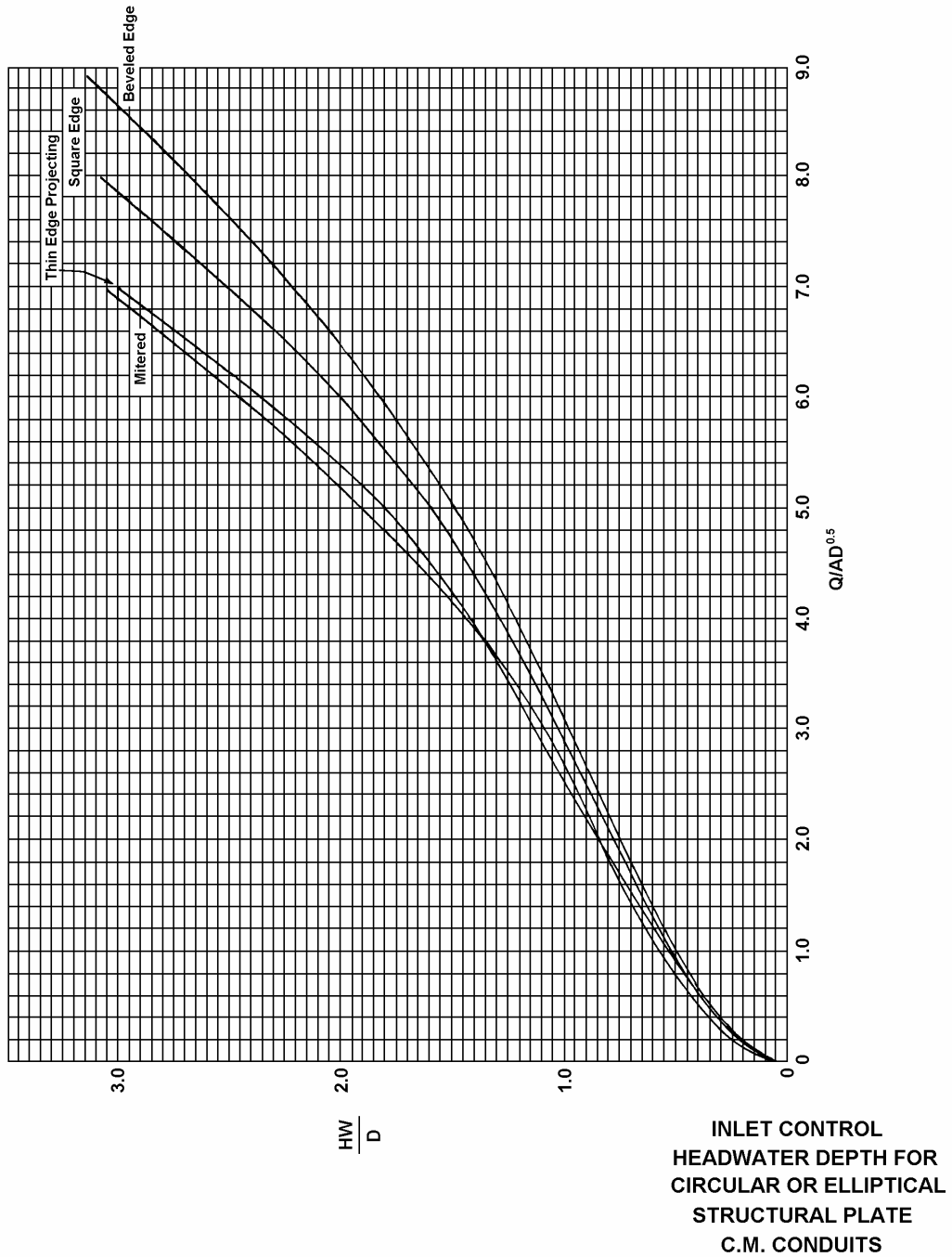
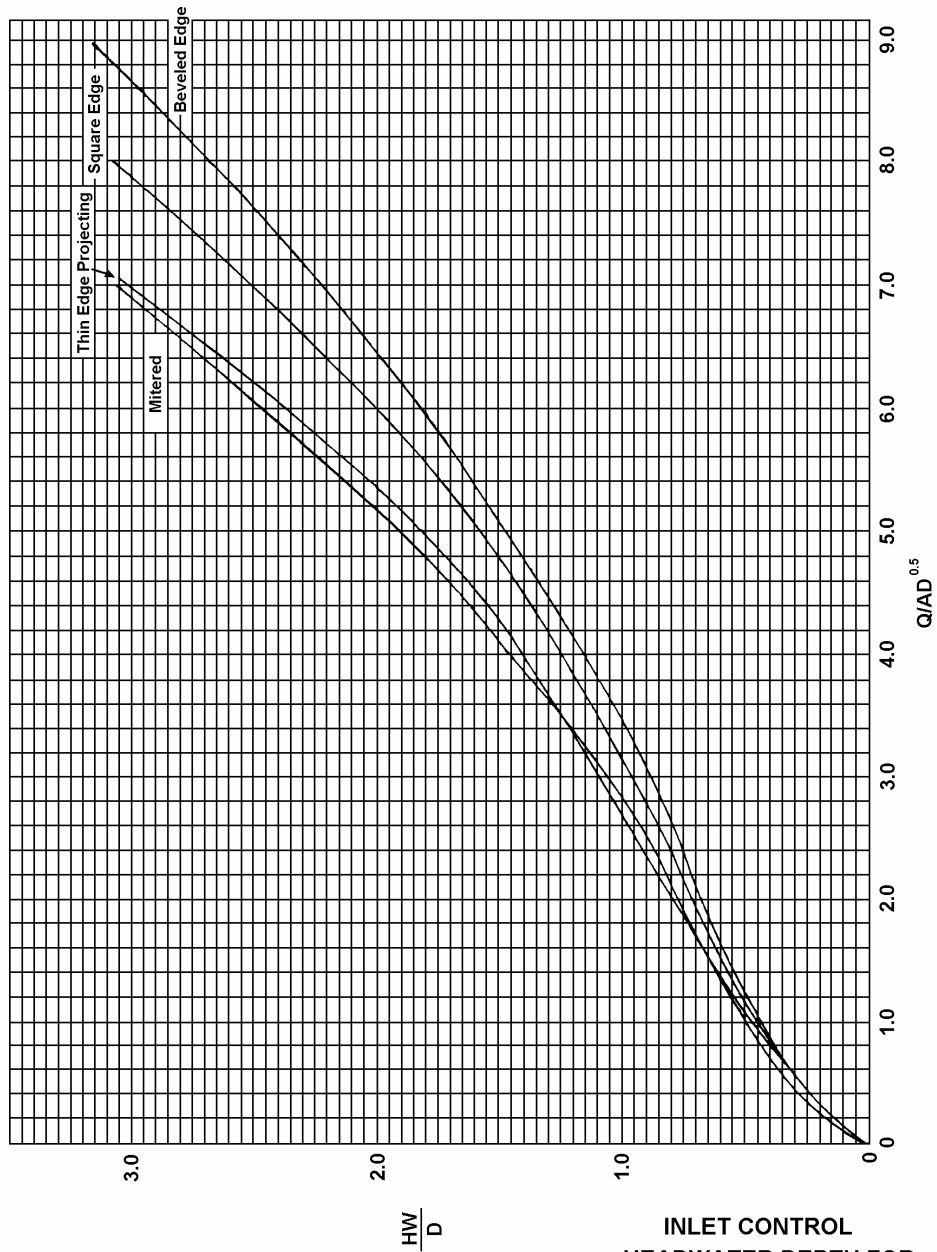
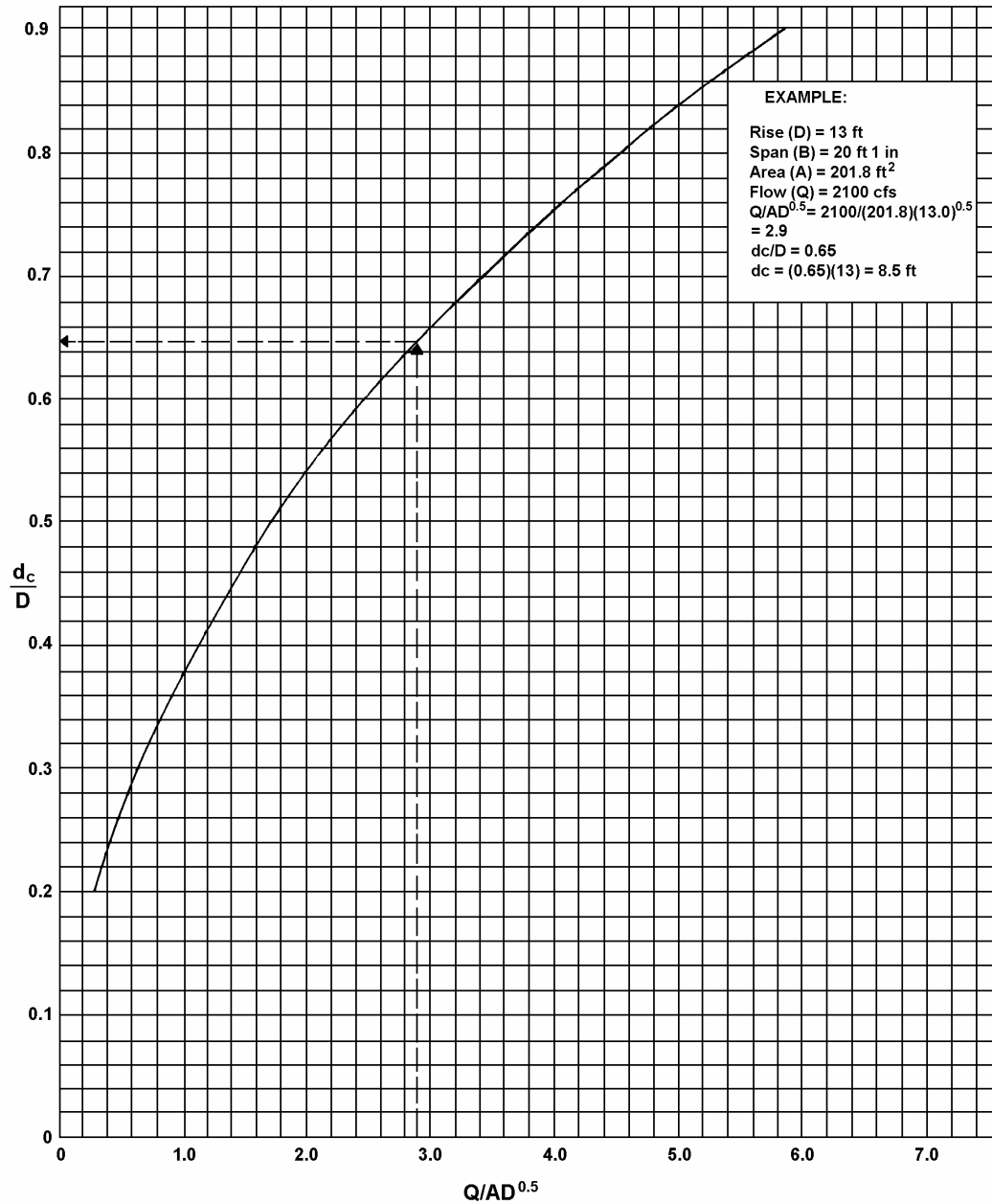


CHART 52



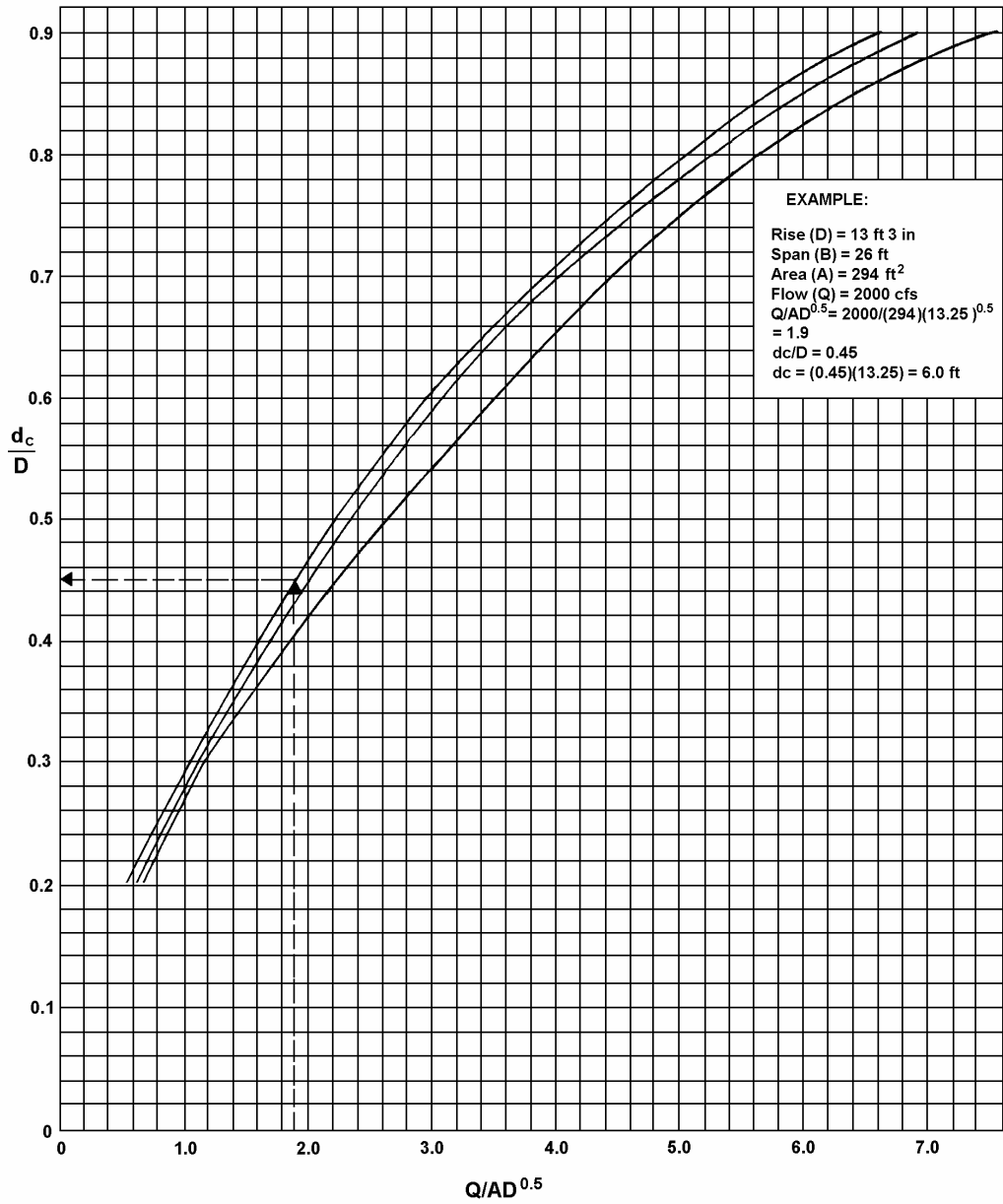
**INLET CONTROL
HEADWATER DEPTH FOR
HIGH AND LOW PROFILE
STRUCTURAL PLATE
C.M. ARCH**

CHART 53



**DIMENSIONLESS CRITICAL DEPTH CHART
 FOR STRUCTURAL PLATE
 ELLIPSE LONG AXIS HORIZONTAL**

CHART 54



**DIMENSIONLESS CRITICAL DEPTH CHART
 FOR STRUCTURAL PLATE
 LOW- AND HIGH-PROFILE ARCHES**

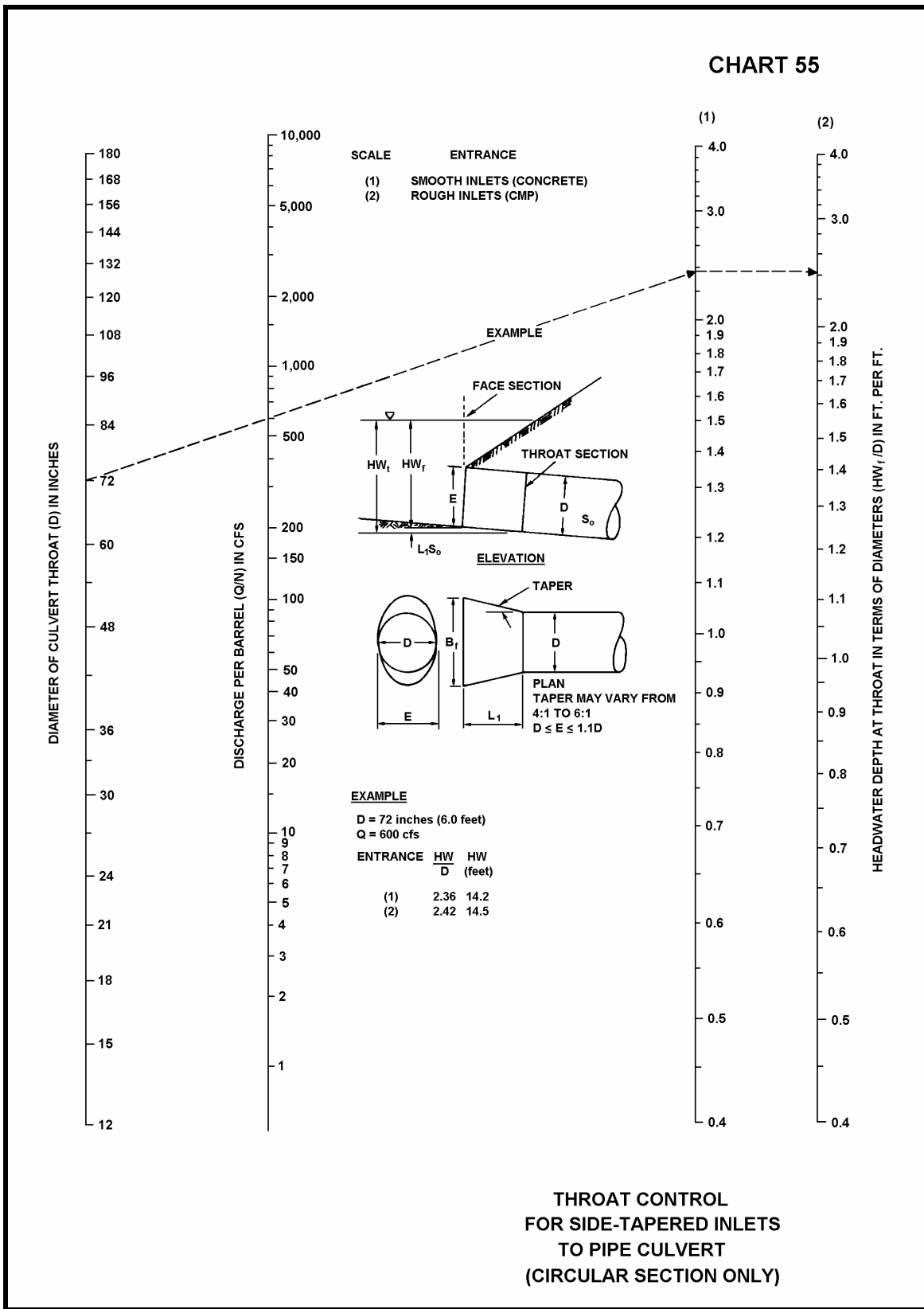
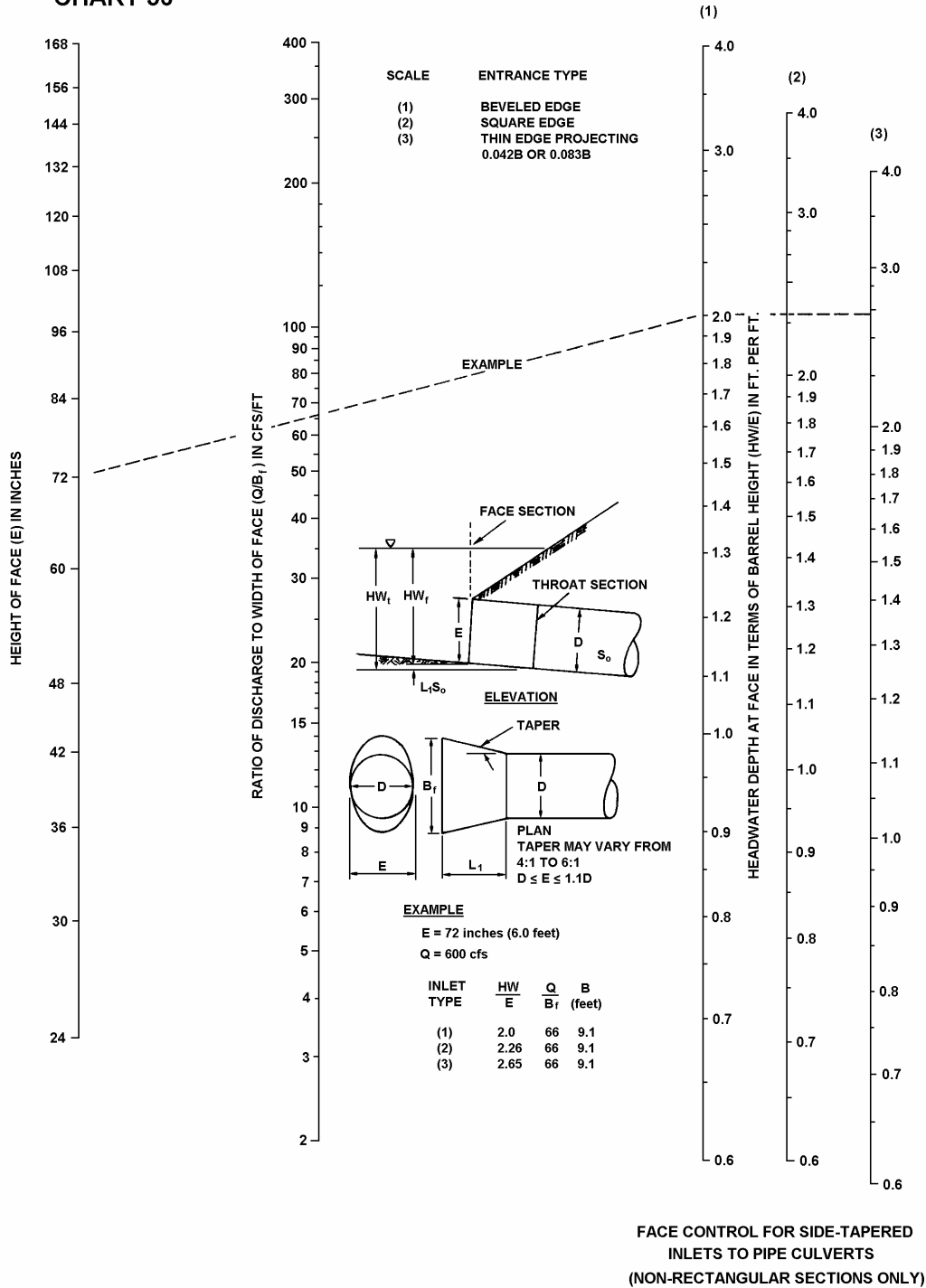
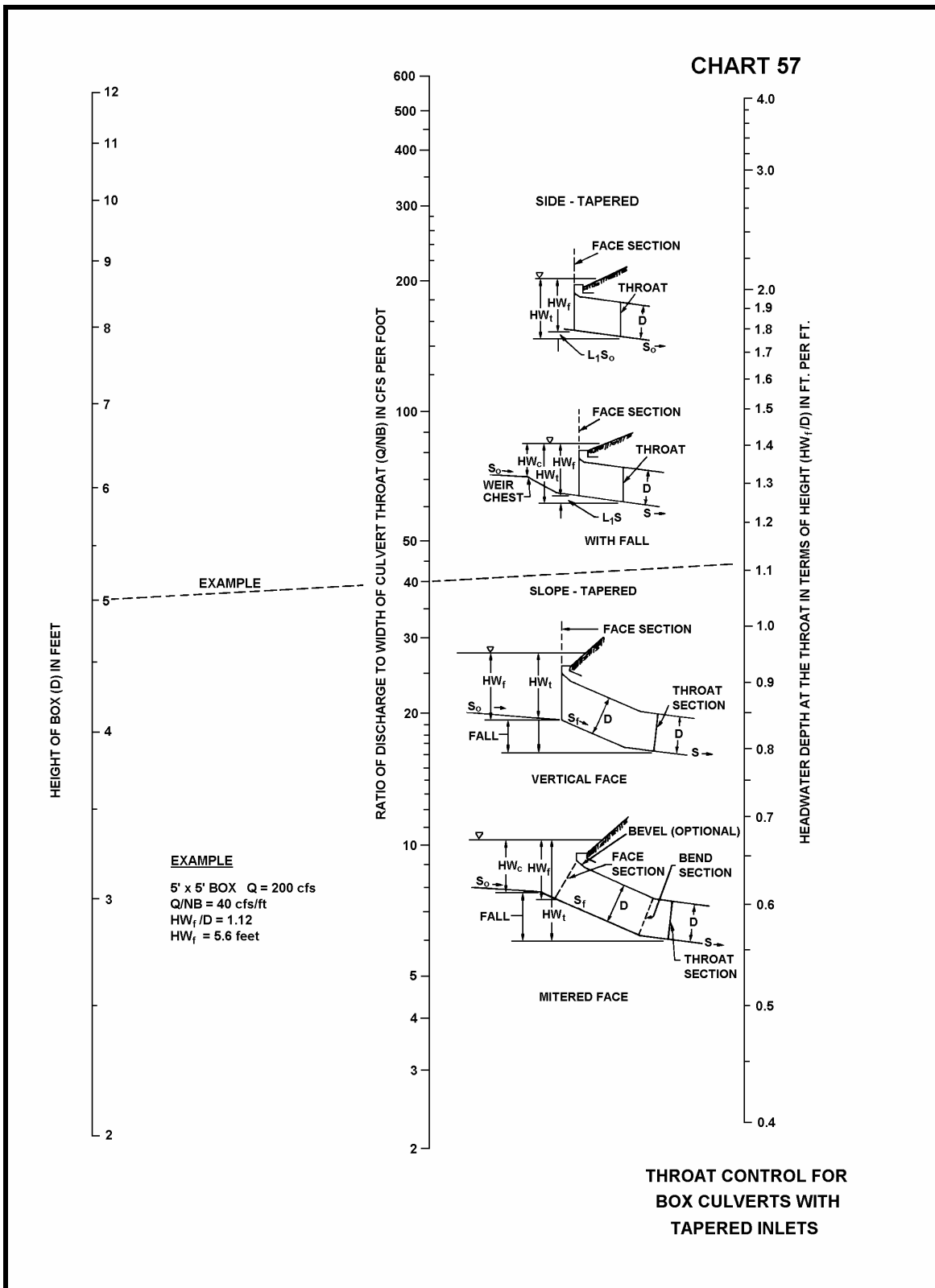
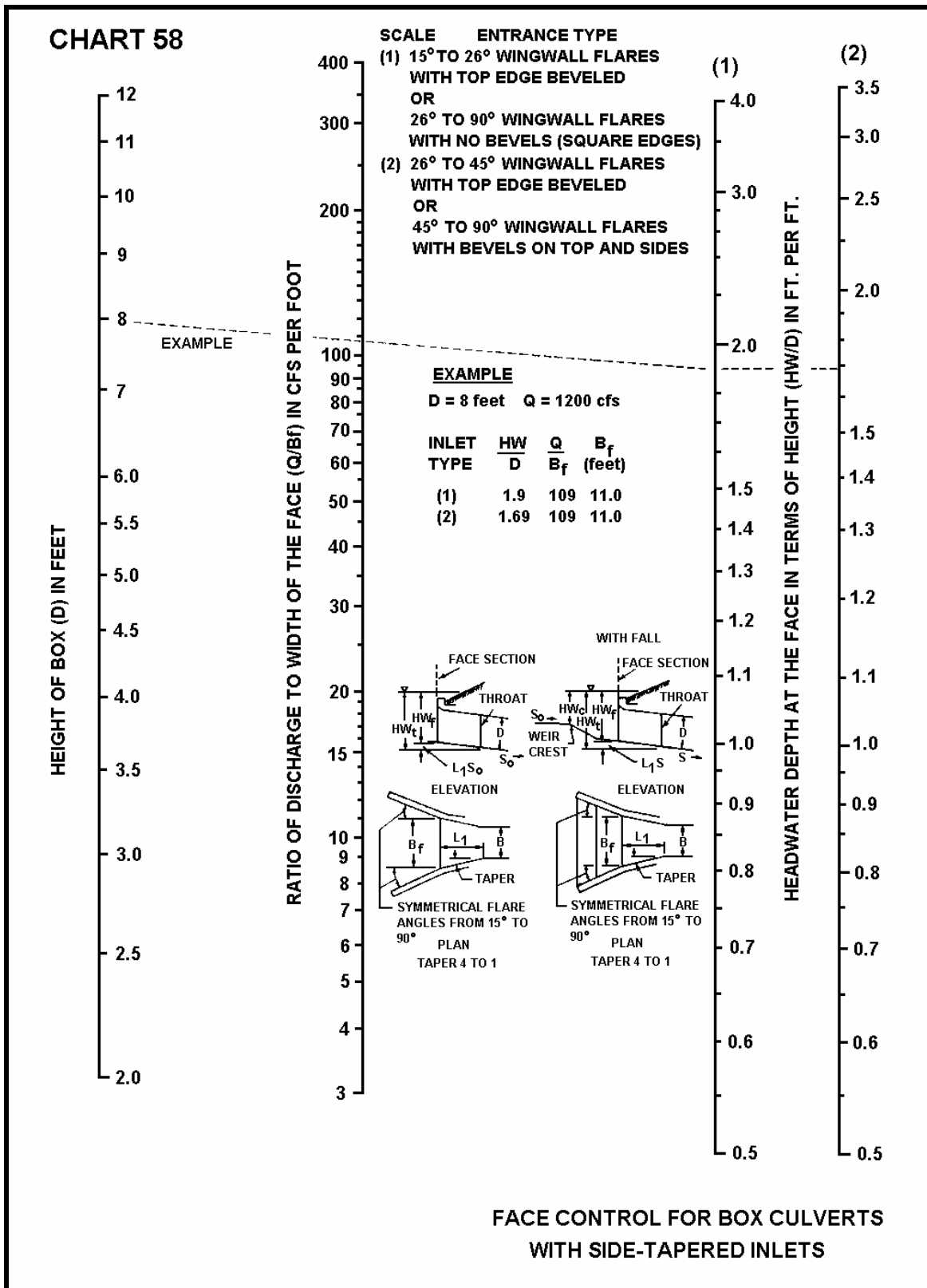


CHART 56







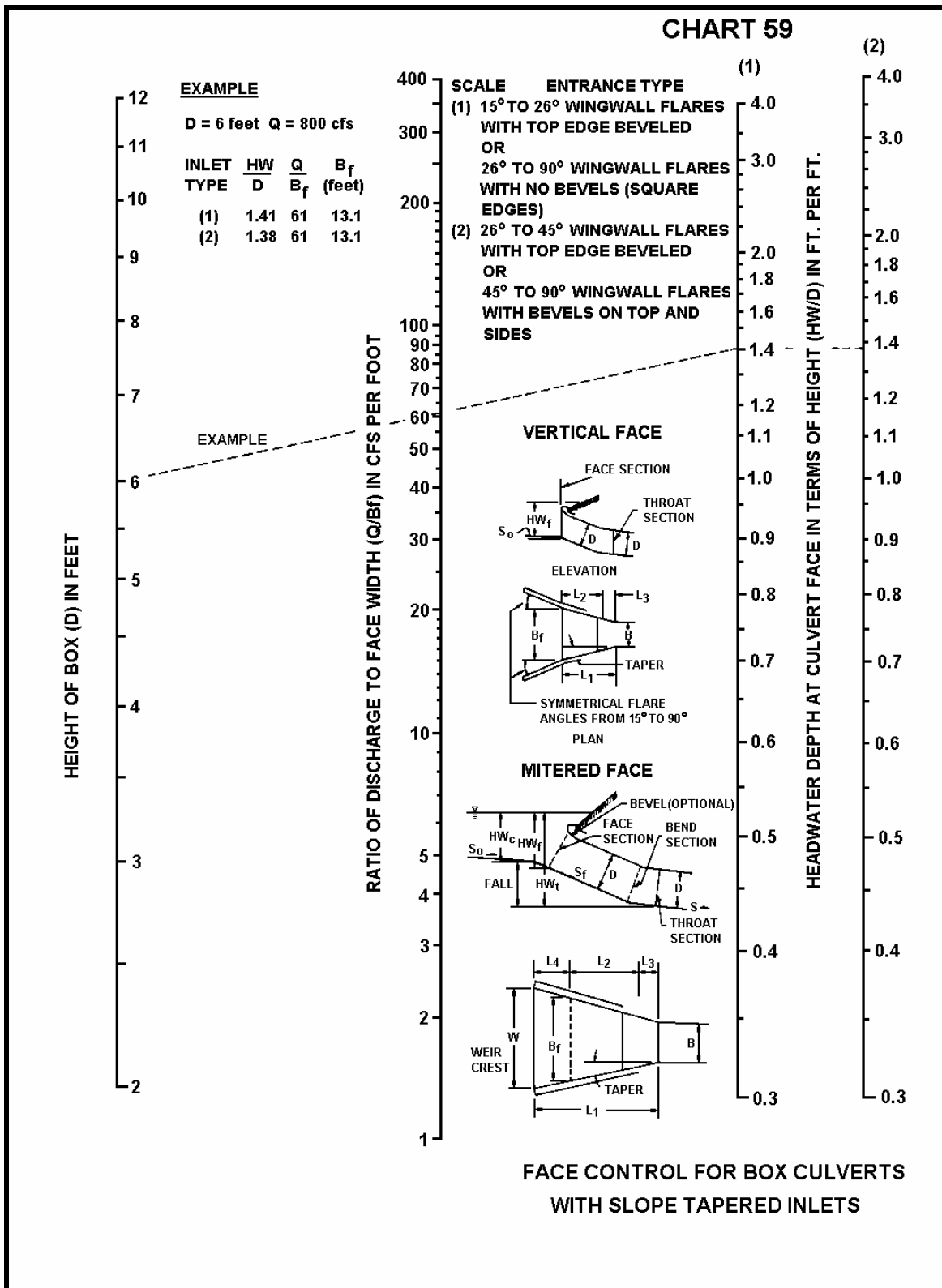
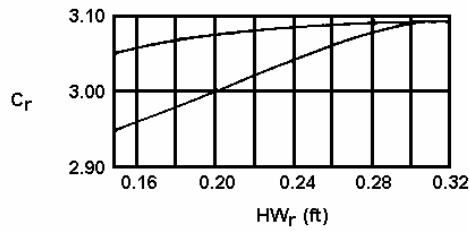
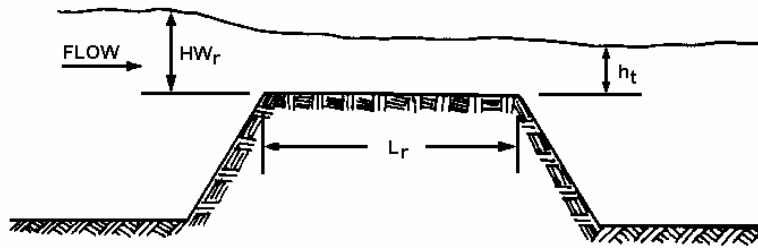
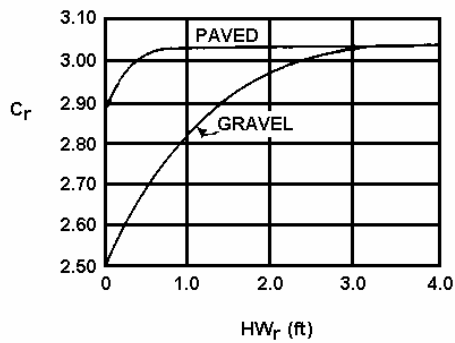


CHART 60



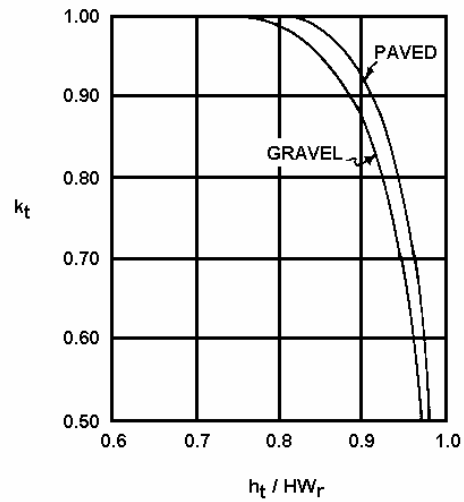
A) DISCHARGE COEFFICIENT FOR $HW_r / L_r > 0.15$



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

$$C_d = k_t C_r$$

$$Q_r = C_d L HW_r^{1.5}$$



C) SUBMERGENCE FACTOR

DISCHARGE COEFFICIENTS FOR ROADWAY OVERTOPPING



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