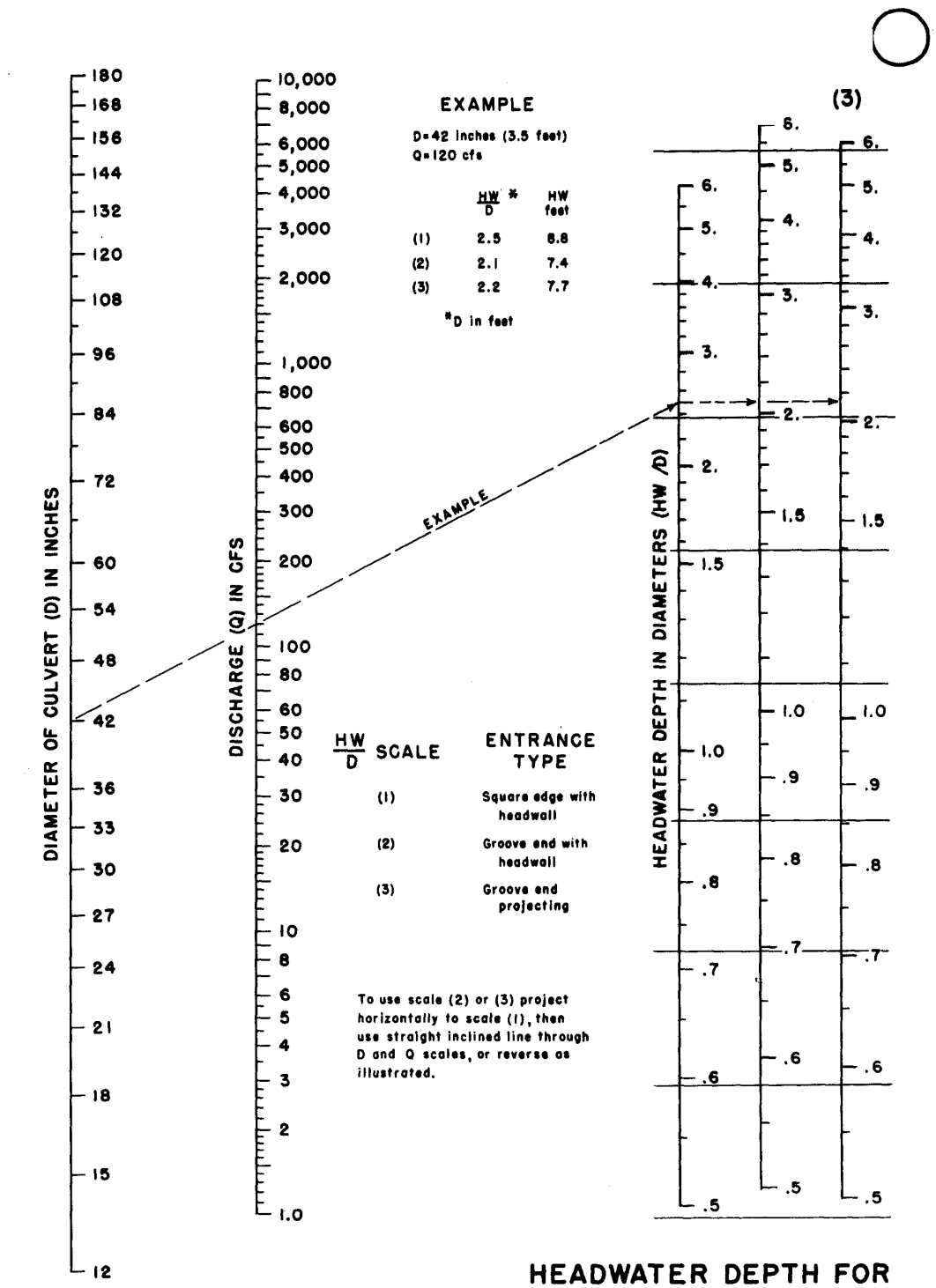
APPENDIX 9.D — DESIGN CHARTS

The following design charts are included in this Appendix.

Chart	Shape	Control Section	Material	Type
1	Circular	Inlet	Concrete	
2	Circular	Inlet	Metal	
3	Circular	Inlet	Metal	Beveled Ring Control
4	Circular	Critical		
5	Circular	Outlet	Concrete	n = 0.012
6	Circular	Outlet	Metal	n = 0.024
7	Circular	Outlet	Metal	n = 0.0328 to 0.0302
8	Box	Inlet	Concrete	
9	Box	Inlet	Concrete	Wingwalls 18° to 33.7^o and 45°
10	Box	Inlet	Concrete	90° Headwall, Beveled Edges
11	Box	Inlet	Concrete	Skewed Headwalls, Beveled Edges
12	Box	Inlet	Concrete	Flared Wingwalls, Normal and Skewed
13	Box	Inlet	Concrete	Offset Flared Wingwalls, Beveled Edge
14	Box	Critical		
15	Box	Outlet	Concrete	n = 0.012
16	Box	Inlet	Metal	Rise/Span < 0.3
17	Box	Inlet	Metal	0.3 ≤ Rise/Span < 0.4
18	Box	Inlet	Metal	0.4 ≤ Rise/Span < 0.5
19	Box	Inlet	Metal	Rise/Span ≥ 0.5
20	Box	Critical		
21	Box	Outlet	Metal	Concrete Bottom, Rise/Span < 0.3
22	Box	Outlet	Metal	Concrete Bottom, 0.3 ≤ Rise/Span < 0.4
23	Box	Outlet	Metal	Concrete Bottom, 0.4 ≤ Rise/Span < 0.5
24	Box	Outlet	Metal	Concrete Bottom, Rise/Span ≥ 0.5
25	Box	Outlet	Metal	Metal Bottom, Rise/Span < 0.3
26	Box	Outlet	Metal	Metal Bottom, 0.3 ≤ Rise/Span < 0.4
27	Box	Outlet	Metal	Metal Bottom, 0.4 ≤ Rise/Span < 0.5
28	Box	Outlet	Metal	Metal Bottom, Rise/Span > 0.5
29	Elliptical	Inlet	Concrete	Horizontal
30	Elliptical	Inlet	Concrete	Vertical
31	Elliptical	Critical	Concrete	Horizontal
32	Elliptical	Critical	Concrete	Vertical
33	Elliptical	Outlet	Concrete	Horizontal and Vertical
34	Pipe Arch	Inlet	Metal	
35	Pipe Arch	Inlet	Metal	457-mm Corner Radius
36	Pipe Arch	Inlet	Metal	787-mm Corner Radius
37	Pipe Arch	Critical		Standard
38	Pipe Arch	Critical		Structural Plate
39	Pipe Arch	Outlet	Metal	n = 0.024
40	Pipe Arch	Outlet	Metal	450-mm Corner Radius
41	Arch	Inlet	Metal	0.3 ≤ Rise/Span < 0.4
42	Arch	Inlet	Metal	0.4 ≤ Rise/Span < 0.5
43	Arch	Inlet	Metal	Rise/Span > 0.5
44	Arch	Critical		
45	Arch	Outlet	Metal	Concrete Bottom, 0.3 ≤ Rise/Span < 0.4
46	Arch	Outlet	Metal	Concrete Bottom, 0.4 ≤ Rise/Span < 0.5

Chart	Shape	Control Section	Material	Type
47	Arch	Outlet	Metal	Concrete Bottom, Rise/Span > 0.5
48	Arch	Outlet	Metal	Earth Bottom, 0.3 ≤ Rise/Span < 0.4
49	Arch	Outlet	Metal	Earth Bottom, 0.4 ≤ Rise/Span < 0.5
50	Arch	Outlet	Metal	Earth Bottom, Rise/Span > 0.5
51	Long Span	Inlet	Metal	Circular or Elliptical
52	Long Span	Inlet	Metal	High- and Low-Profile Arch
53	Long Span	Critical	Metal	Circular or Elliptical
54	Long Span	Critical	Metal	High and Low Profile
55	Circular	Inlet		Throat Control, Side Tapered
56	Circular	Inlet		Face Control, Side Tapered
57	Box	Inlet	Concrete	Throat Control, Side Tapered
58	Box	Inlet	Concrete	Face Control, Side Tapered
59	Box	Inlet	Concrete	Face Control, Slope Tapered
60	Box	Inlet	Concrete	Roadway Overtopping

CHART 1B

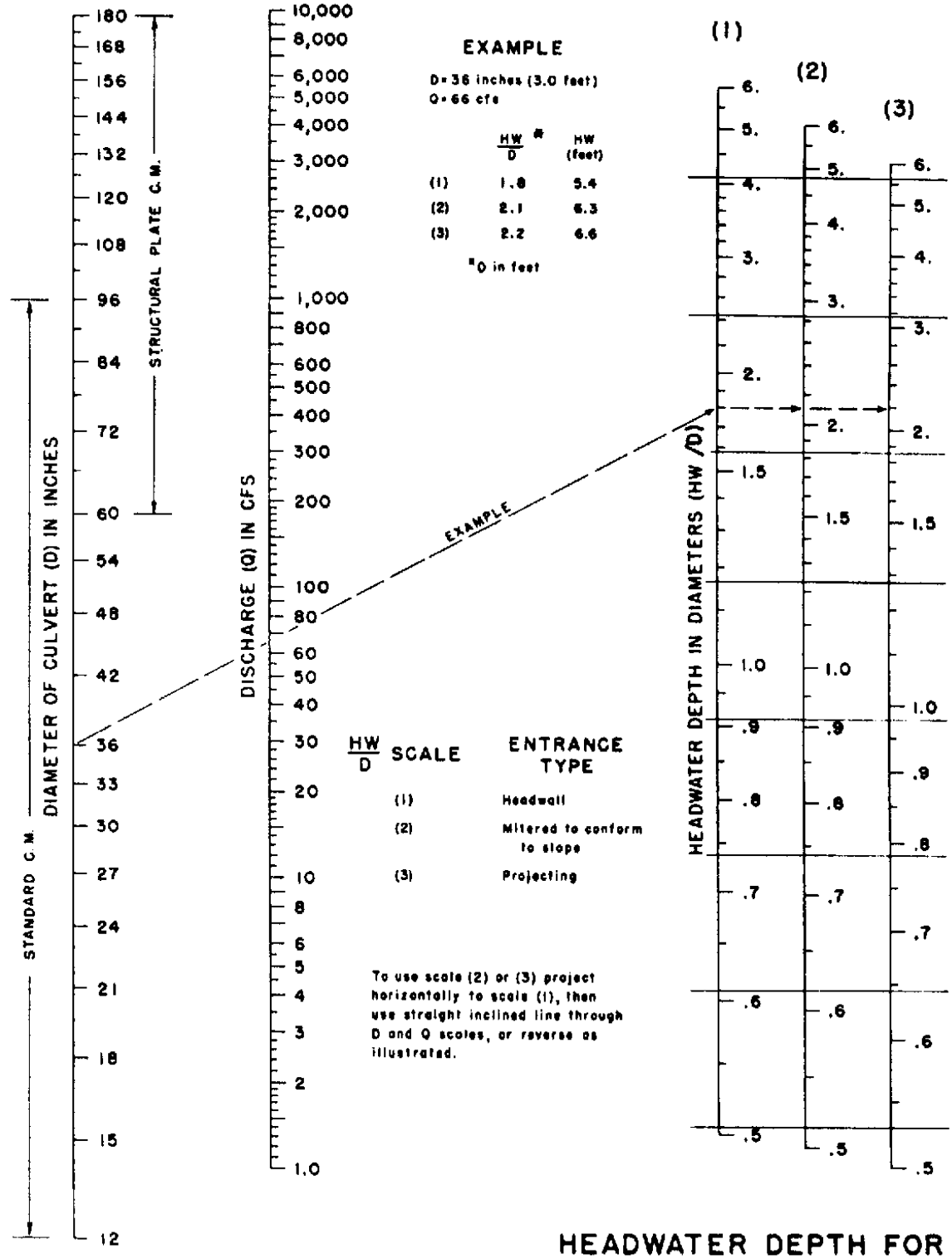


HEADWATER SCALES 2&3
REVISED MAY 1964

BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

CHART 2B

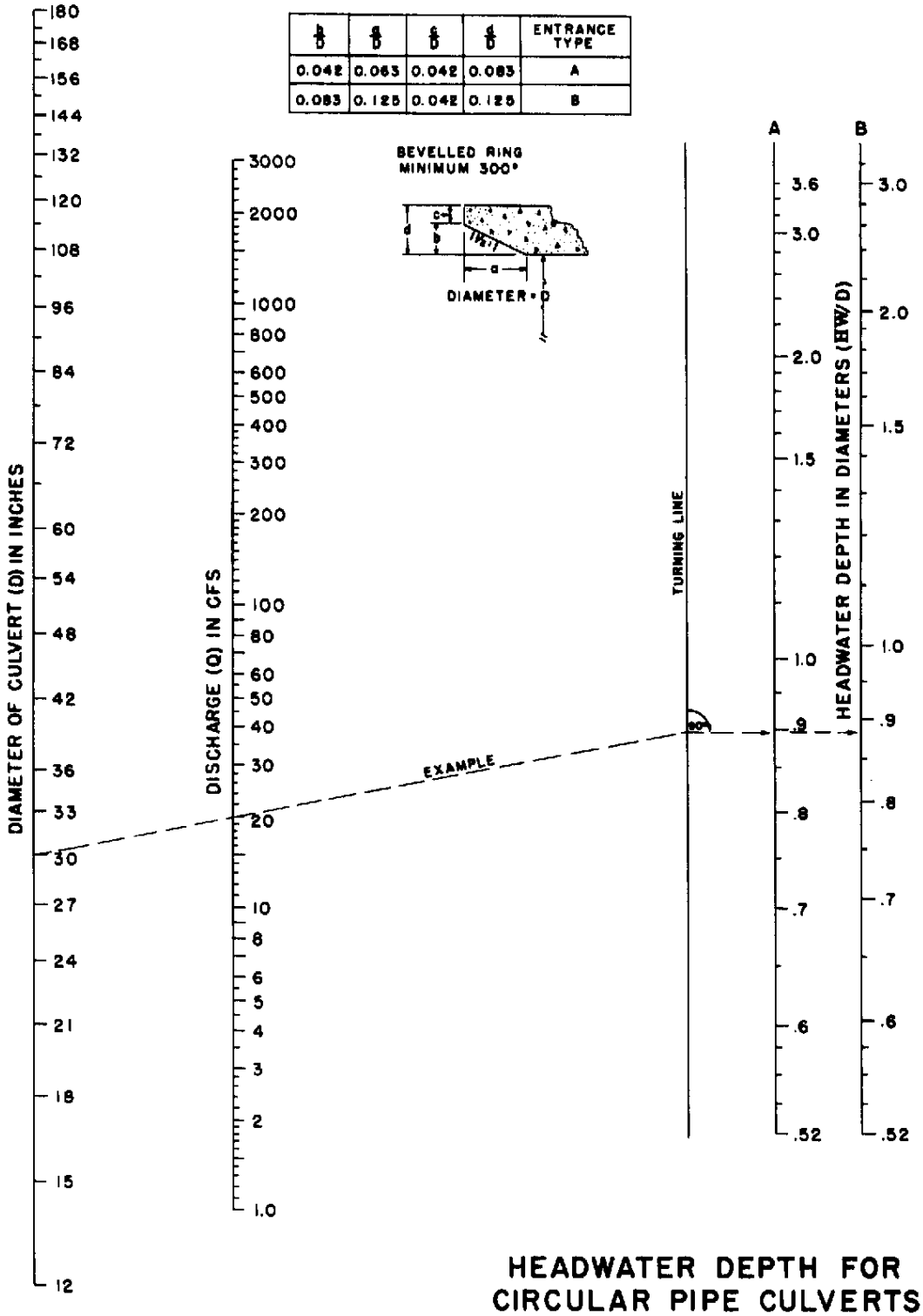


HEADWATER DEPTH FOR C. M. PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 3B

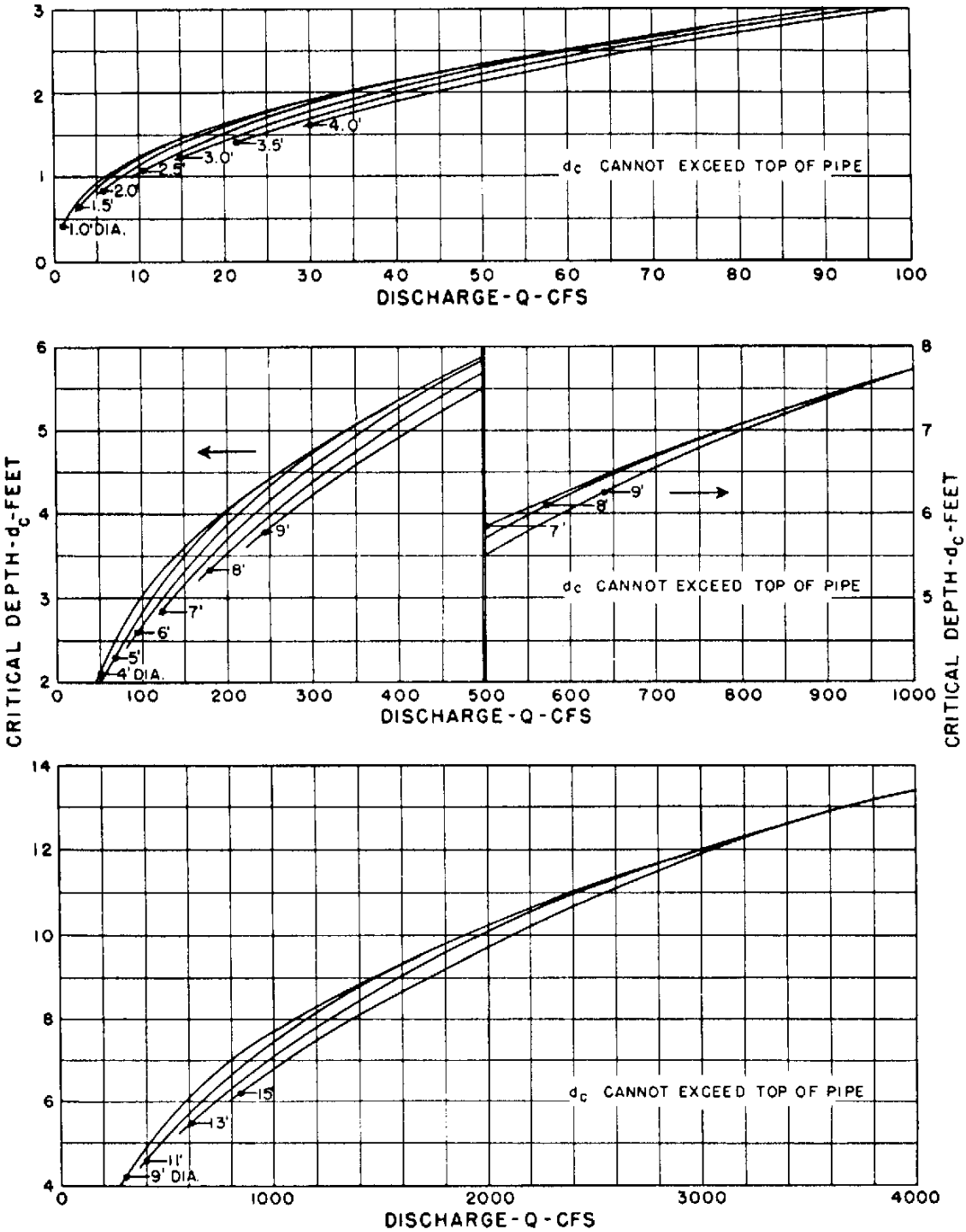
b/D	a/D	c/D	d/D	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B



HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

CHART 4B

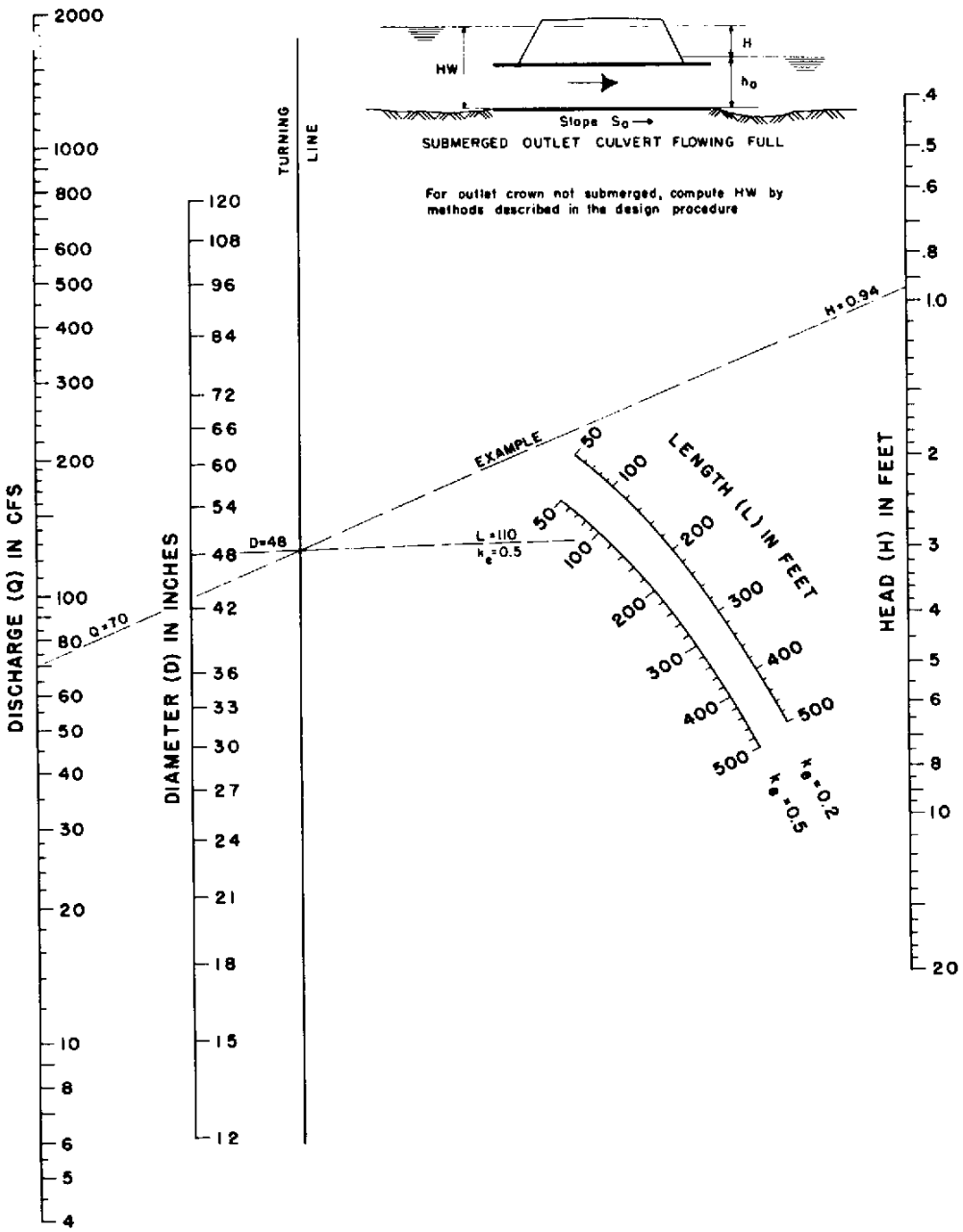


BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

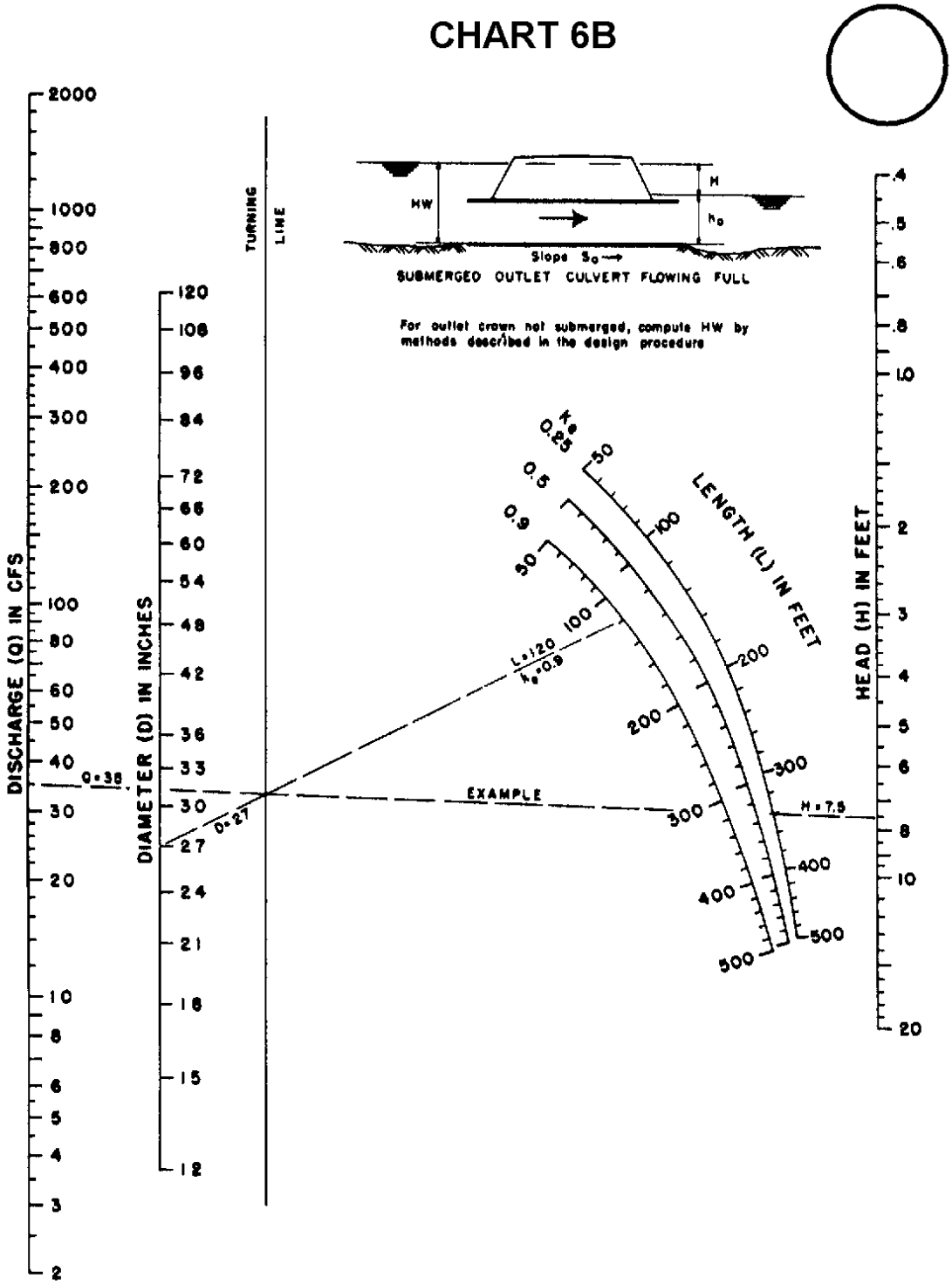
CHART 5B



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

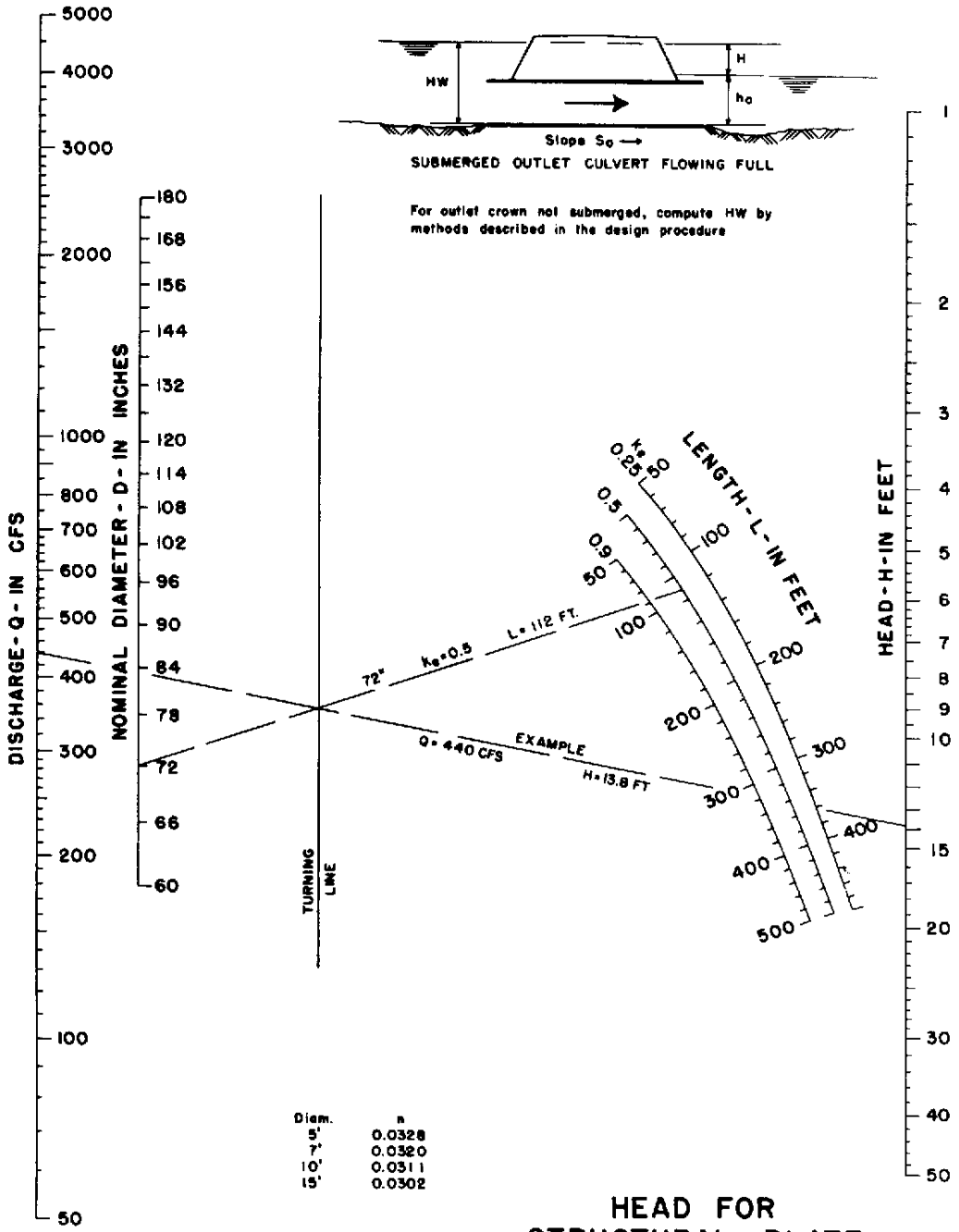
CHART 6B



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

BUREAU OF PUBLIC ROADS JAN. 1963

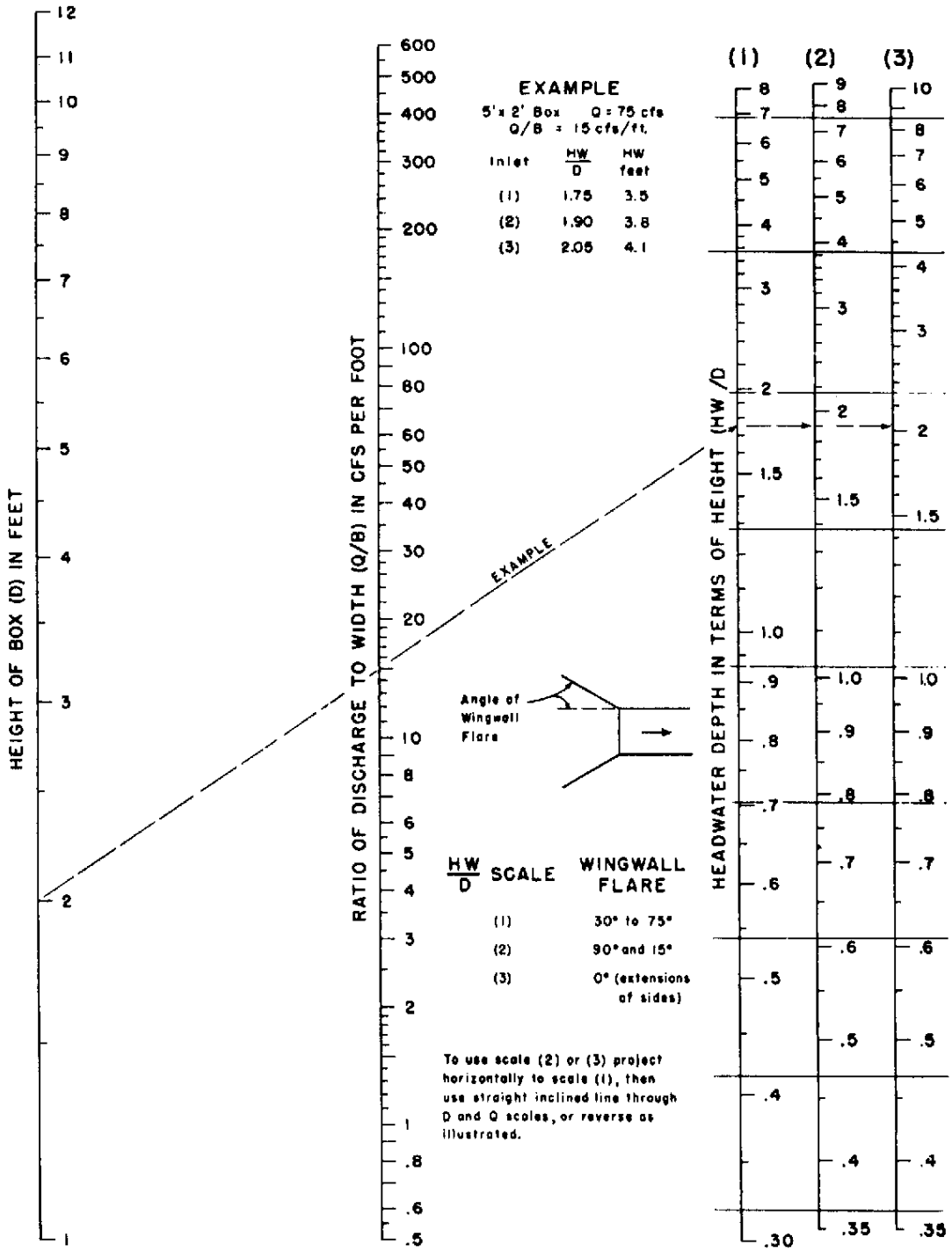
CHART 7B



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

BUREAU OF PUBLIC ROADS JAN. 1963

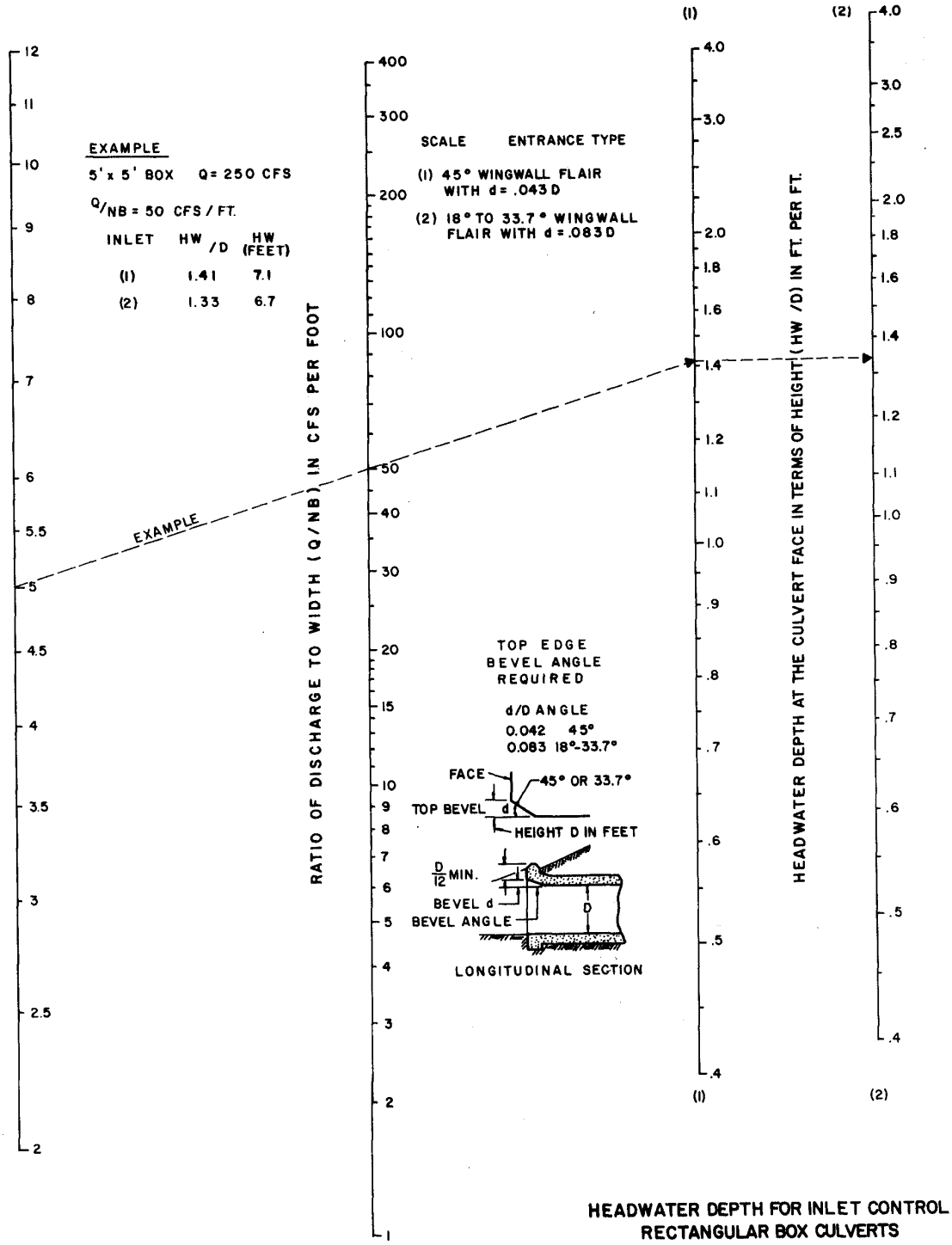
CHART 8B



HEADWATER DEPTH
FOR BOX CULVERTS
WITH INLET CONTROL

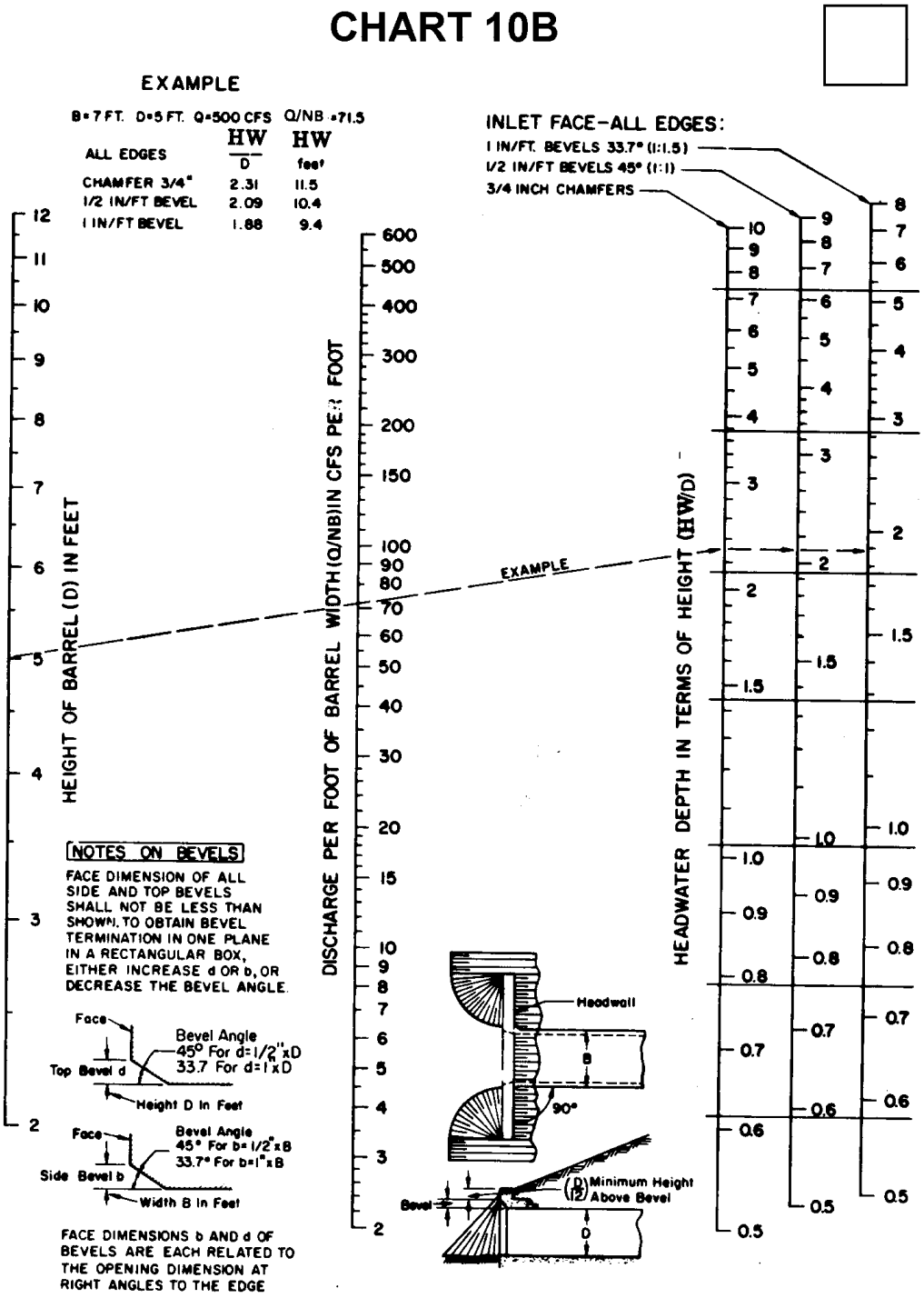
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 9B



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

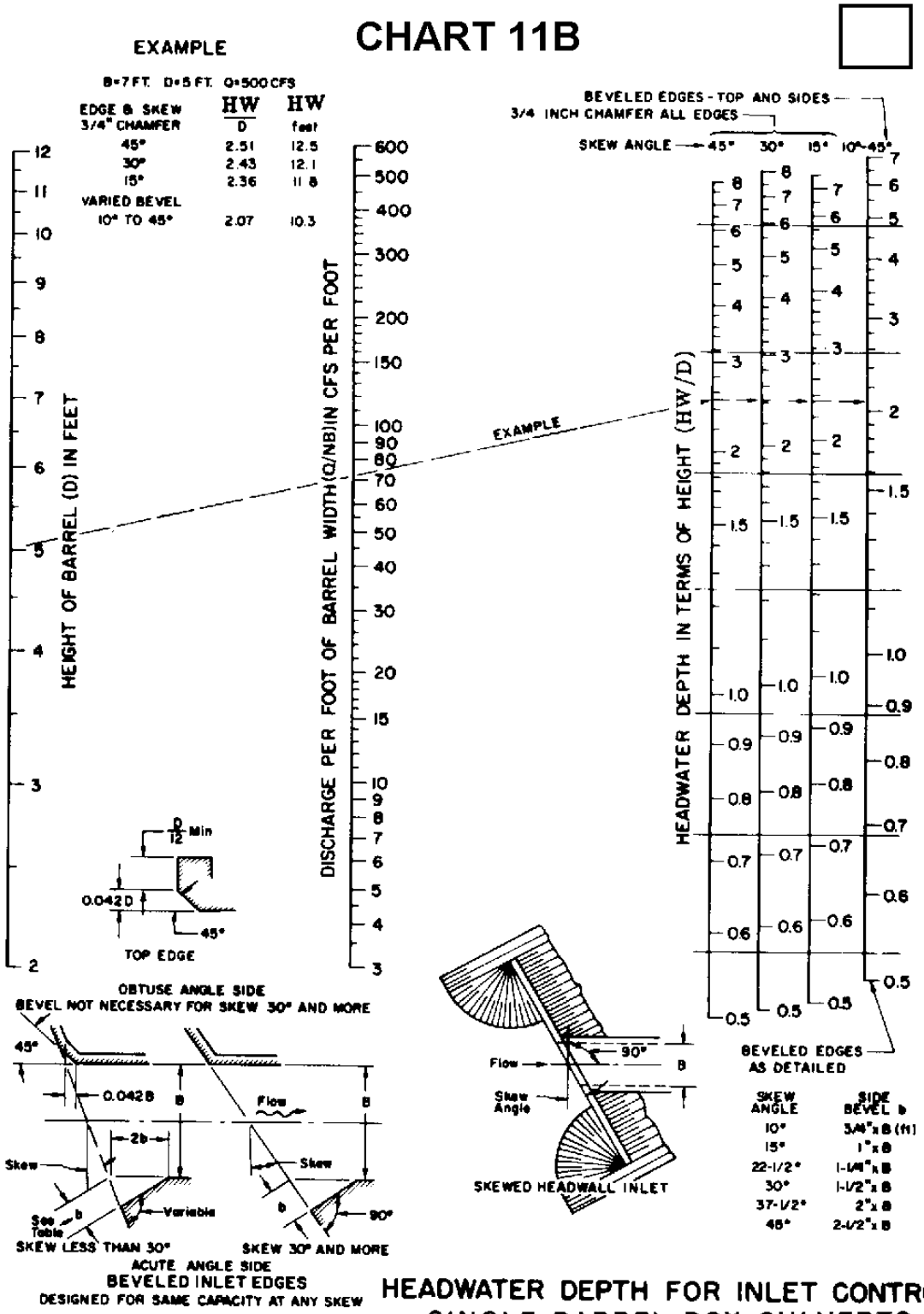
CHART 10B



HEADWATER DEPTH FOR INLET CONTROL RECTANGULAR BOX CULVERTS 90° HEADWALL CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

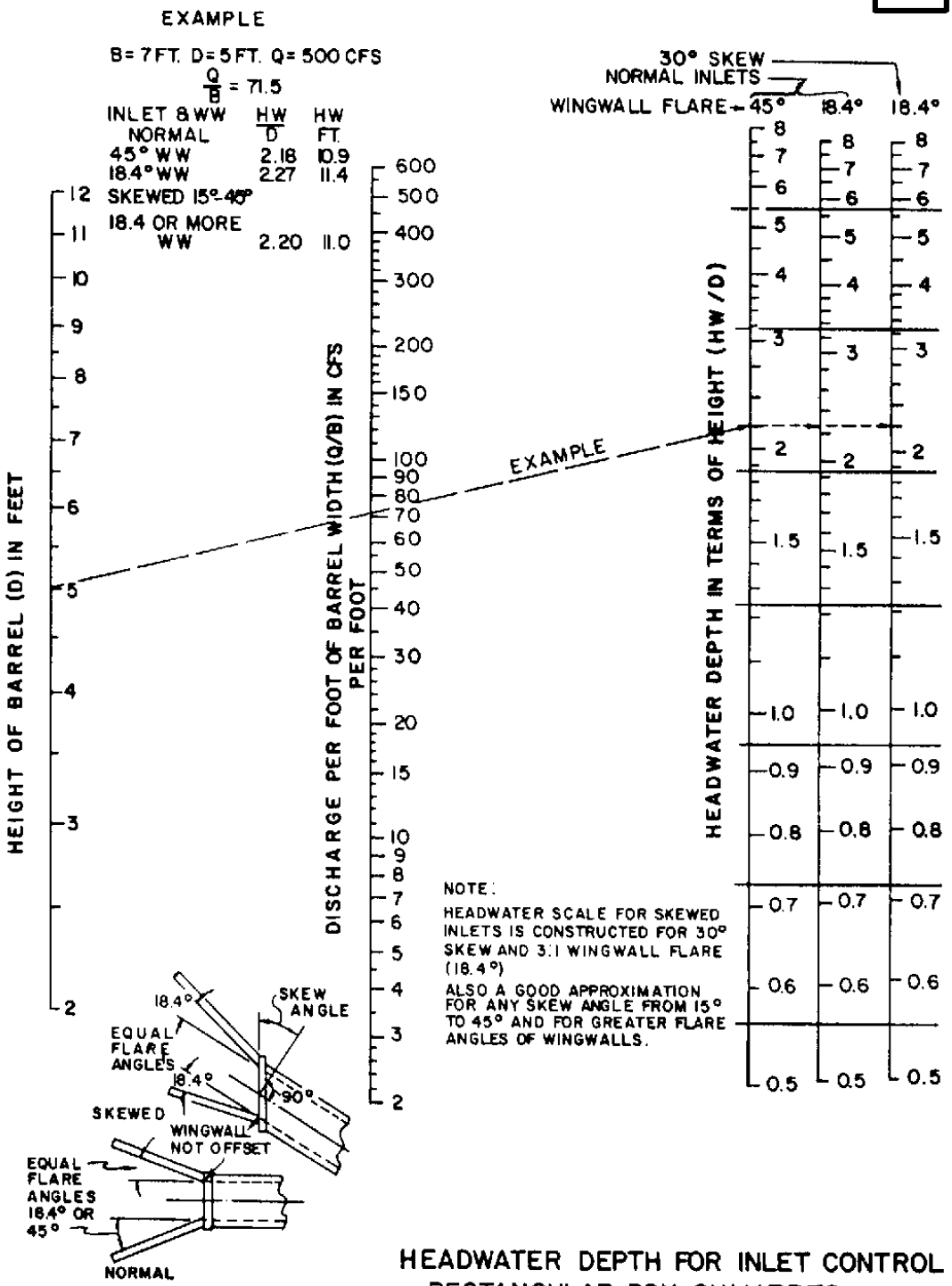
CHART 11B



FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

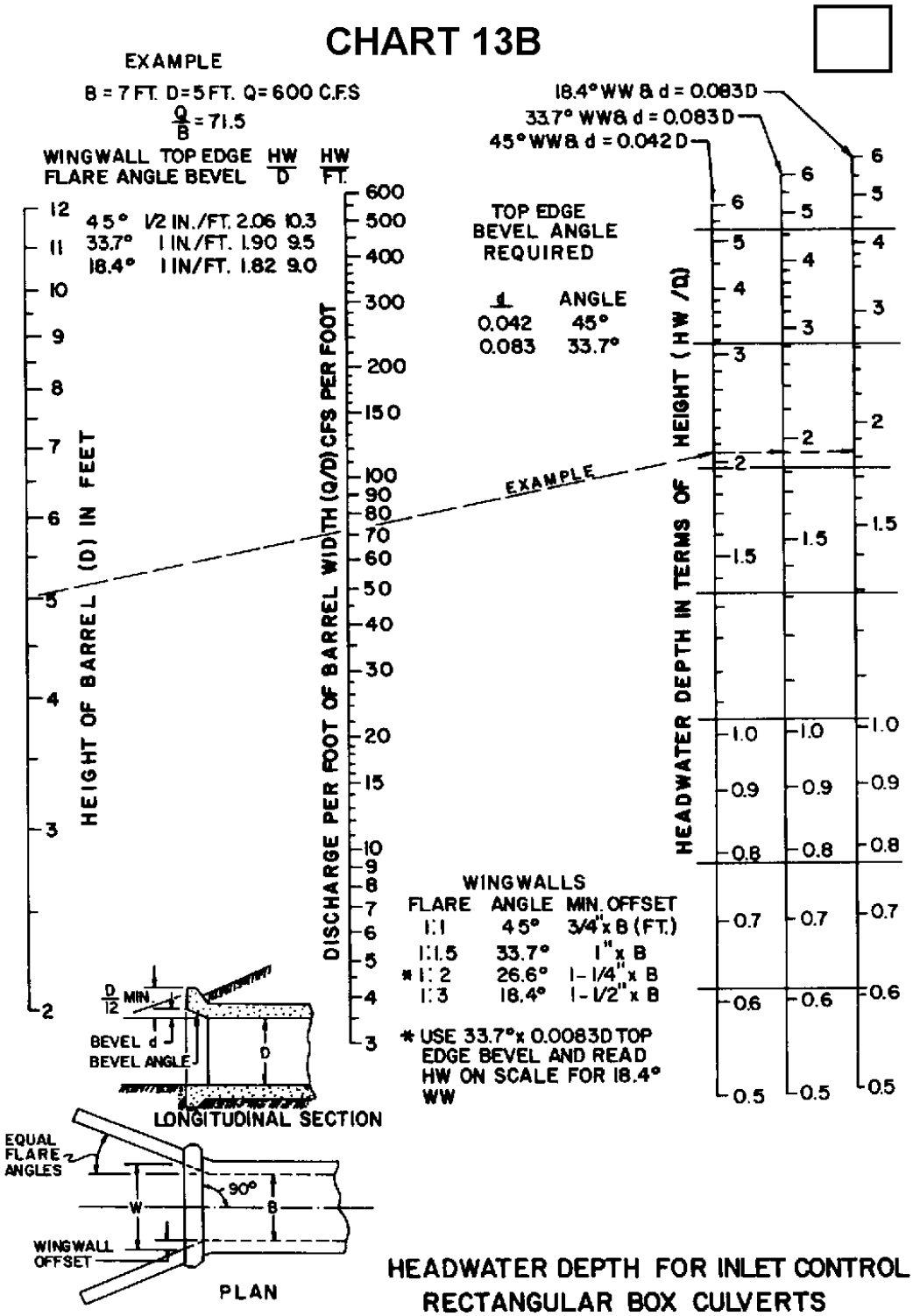
HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

CHART 12B



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

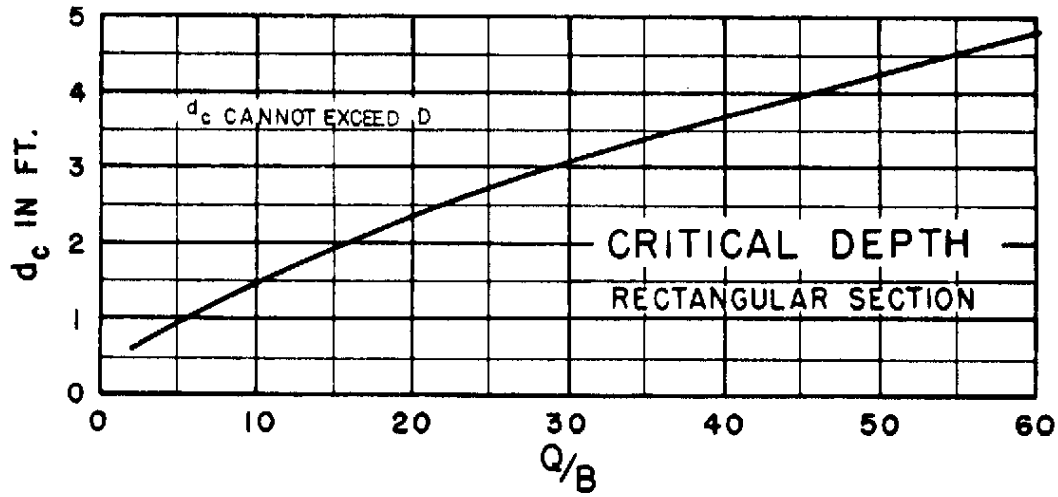
CHART 13B

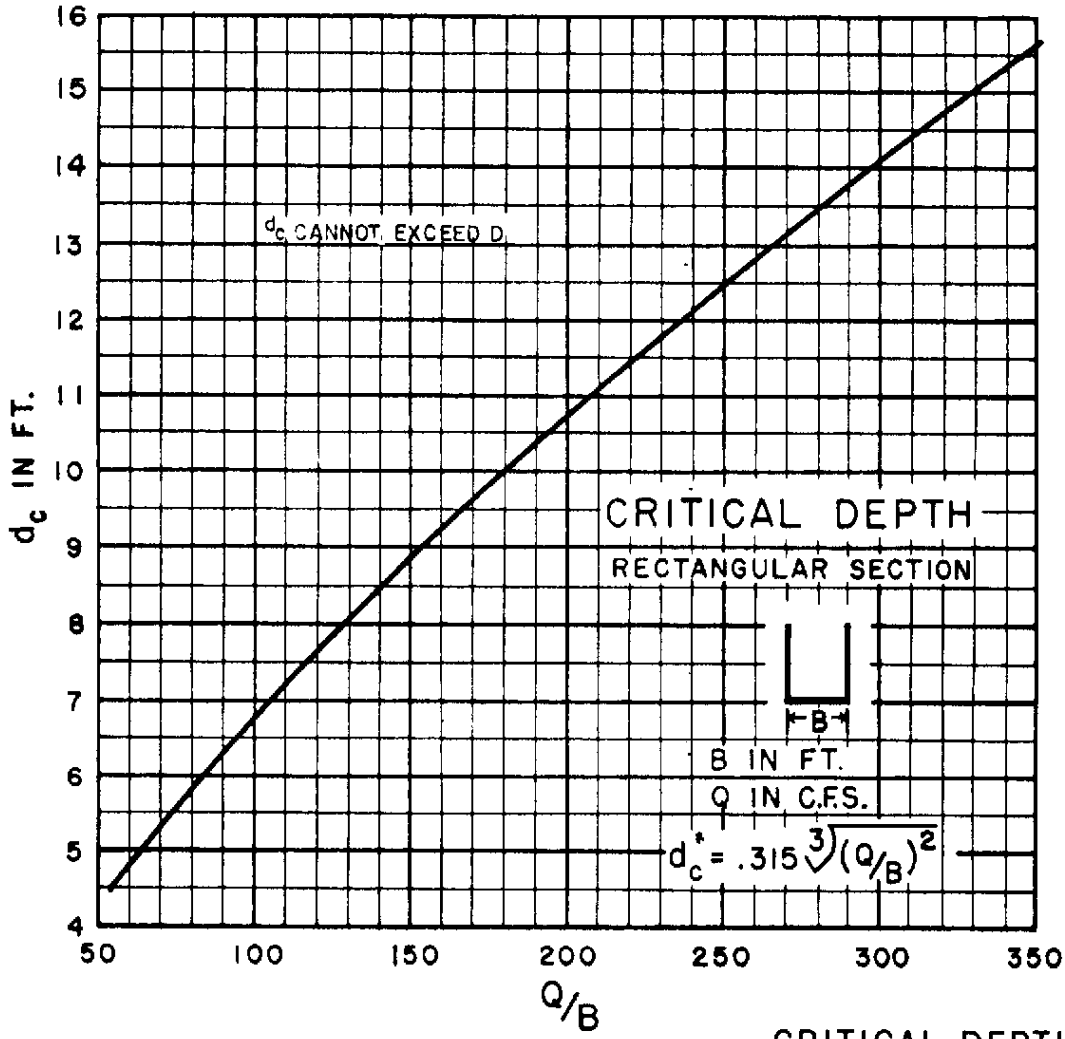


BUREAU OF PUBLIC ROADS
OFFICE OF R & D AUGUST 1968

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

CHART 14B

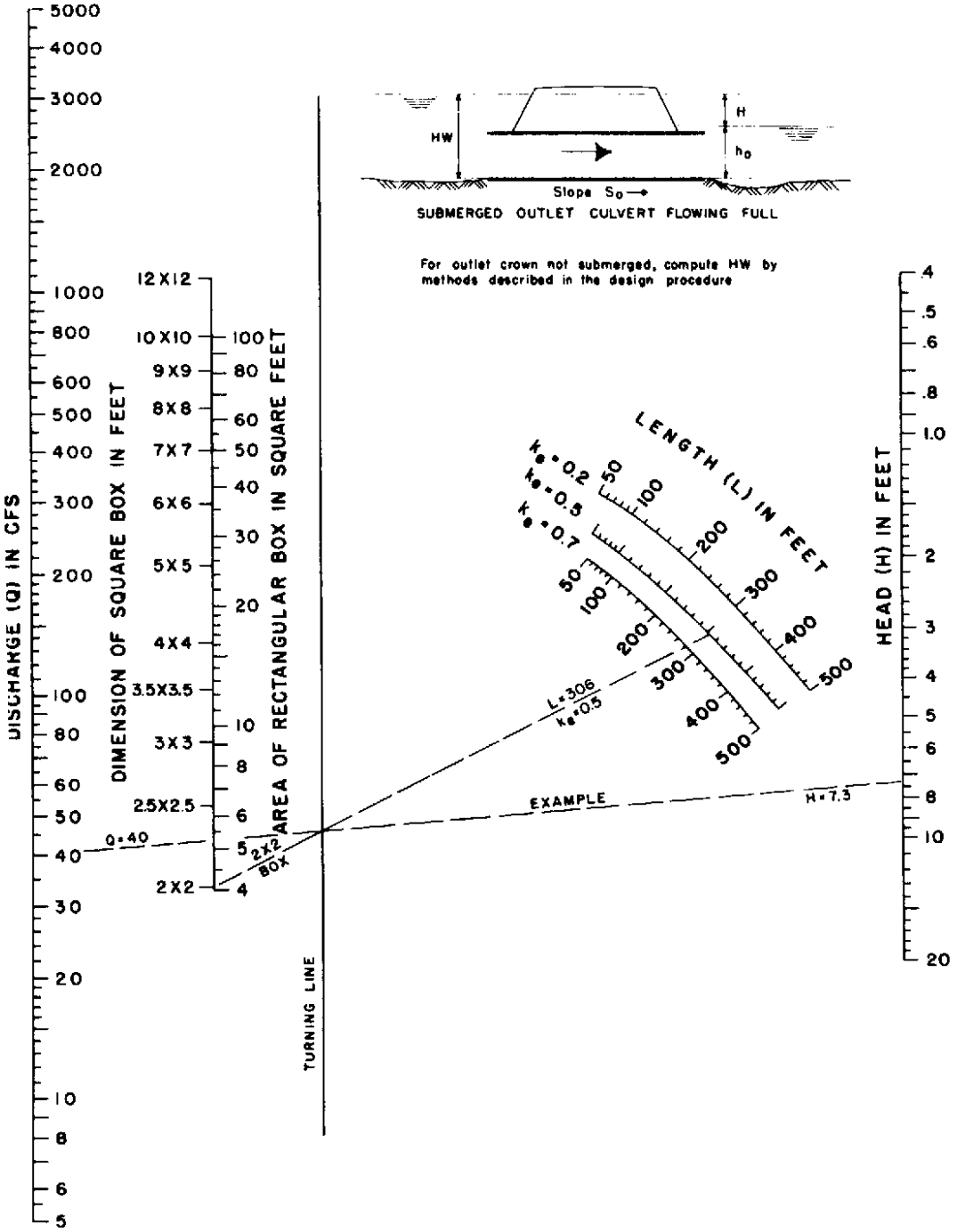




BUREAU OF PUBLIC ROADS JAN 1963

CRITICAL DEPTH
RECTANGULAR SECTION

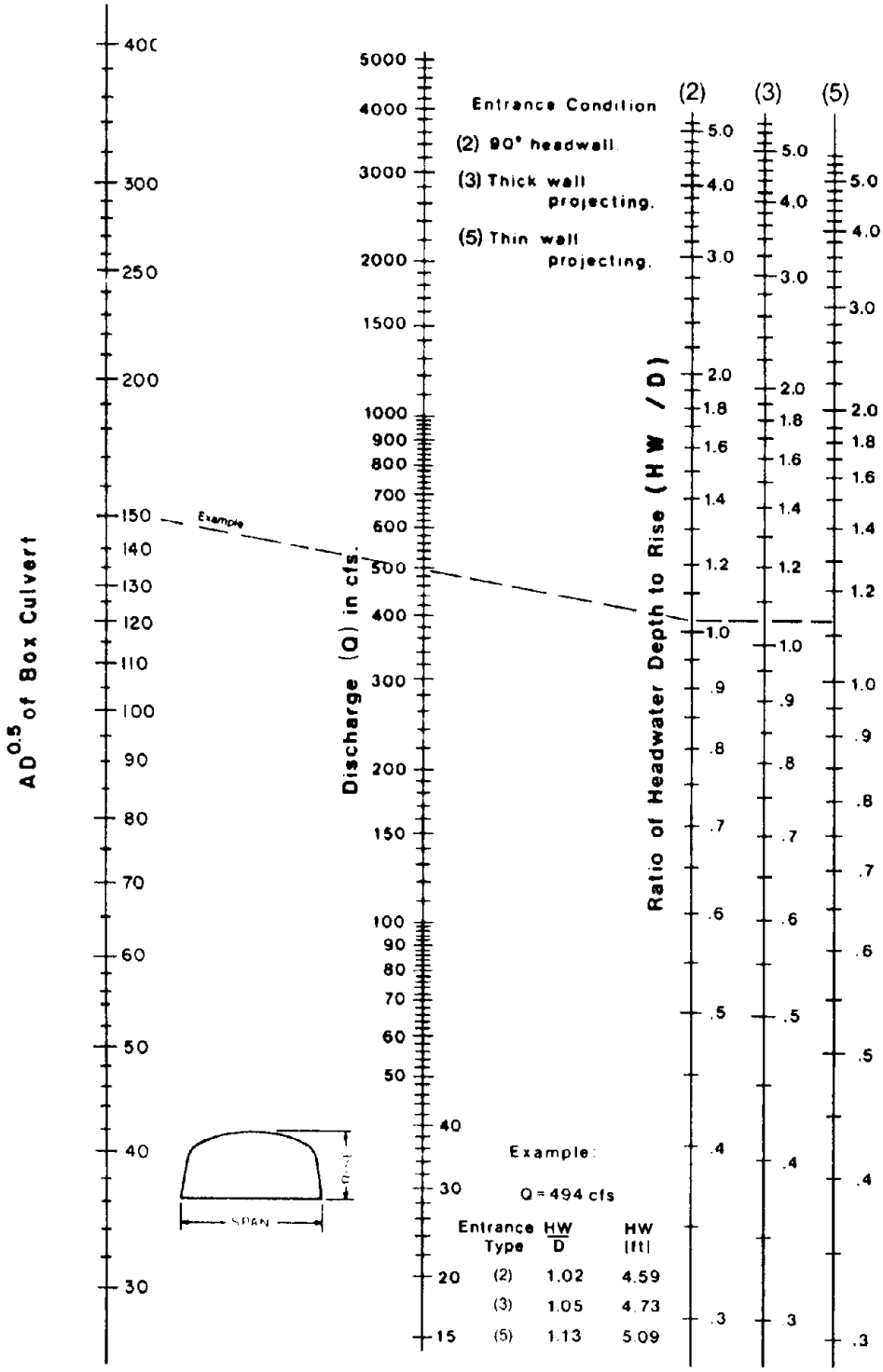
CHART 15B



HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012

AU OF PUBLIC ROADS JAN. 1963

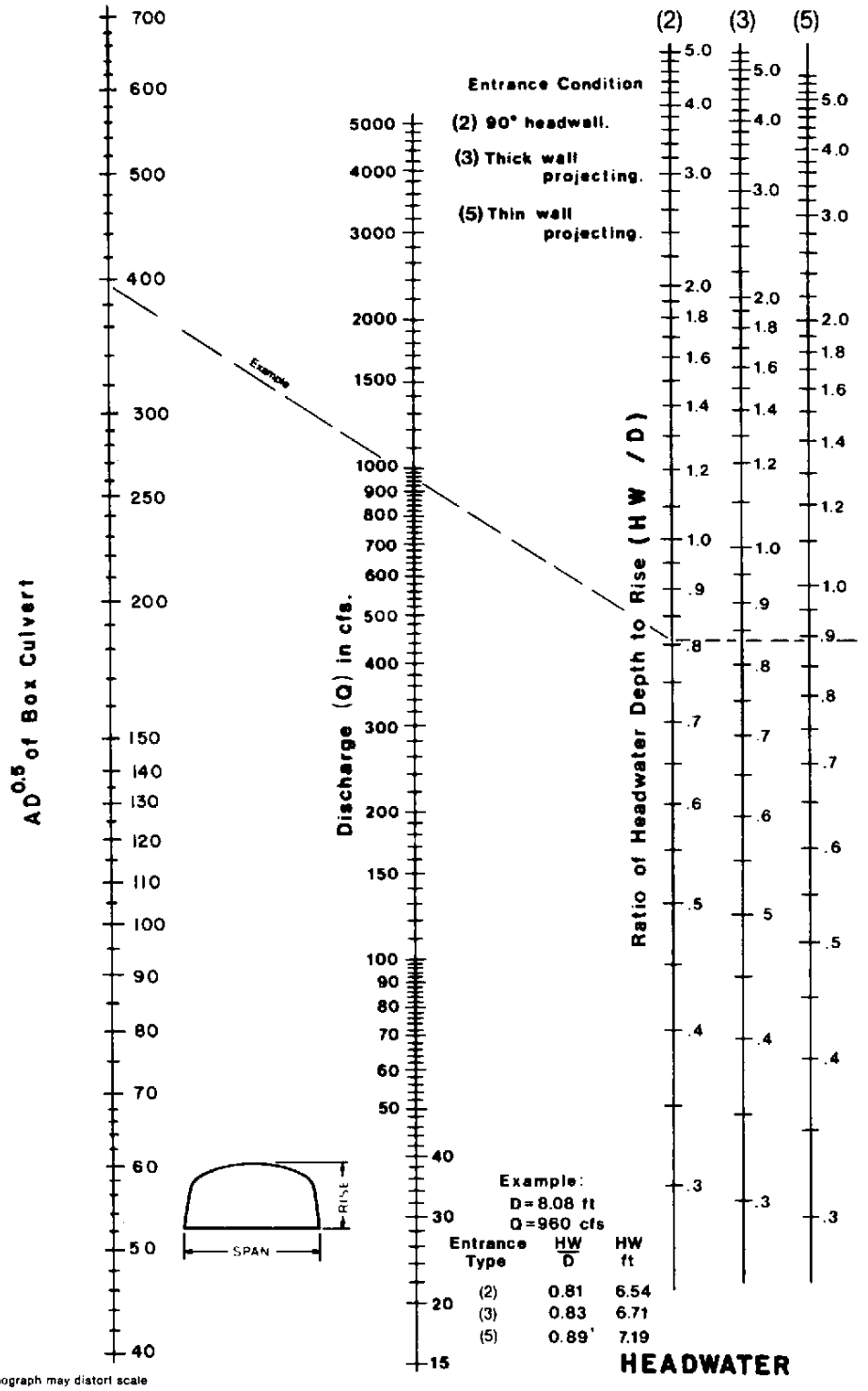
CHART 16B



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 17B



ication of this nomograph may distort scale

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

HEADWATER DEPTH FOR C.M. BOX CULVERTS

0.3 ≤ RISE / SPAN < 0.4

WITH INLET CONTROL

CHART 18B

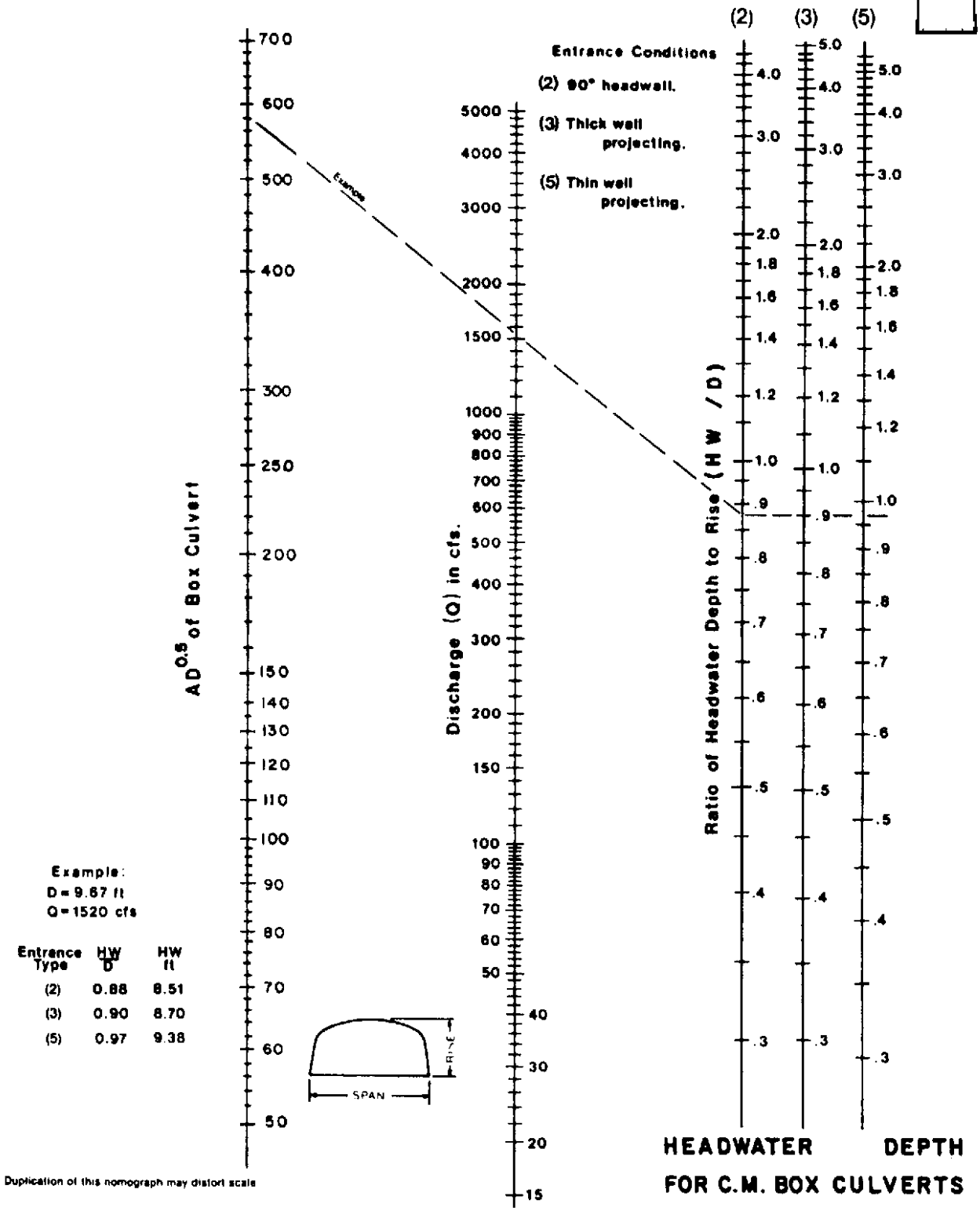
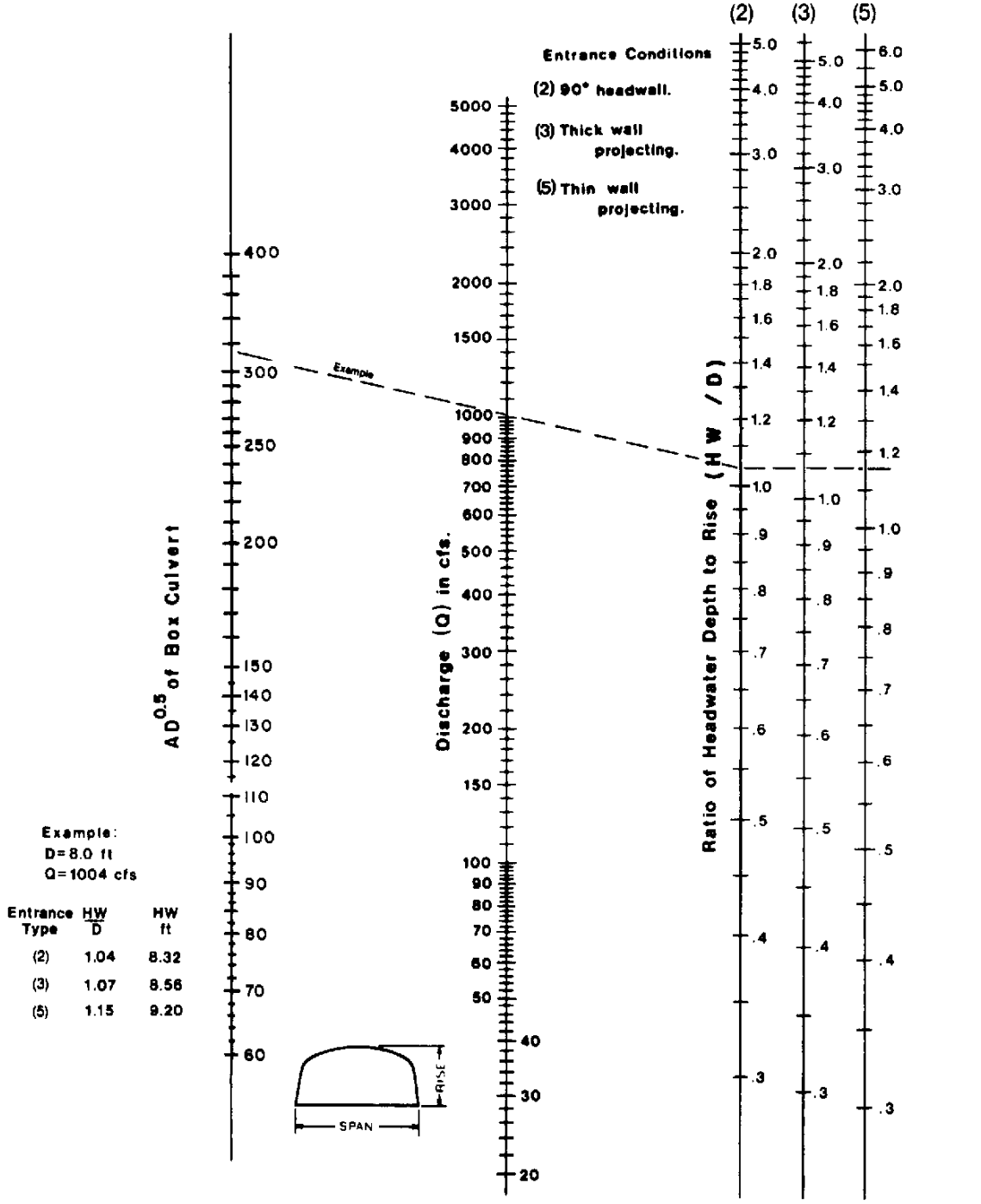

Entrance Conditions
(2) 90° headwall.
(3) Thick wall projecting.
(5) Thin wall projecting.
(2) (3) (5)
Example
AD^0.5 of Box Culvert
Discharge (Q) in cfs.
Ratio of Headwater Depth to Rise (HW / D)
RISE
SPAN
Example:
D = 9.67 ft
Q = 1520 cfs
Entrance Type | HW/D | HW ft
(2) | 0.88 | 8.51
(3) | 0.90 | 8.70
(5) | 0.97 | 9.38
Duplication of this nomograph may distort scale
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation
HEADWATER DEPTH
FOR C.M. BOX CULVERTS
0.4 ≤ RISE / SPAN < 0.5
WITH INLET CONTROL

CHART 19B



Example:
D=8.0 ft
Q=1004 cfs

Entrance Type	HW/D	HW ft
(2)	1.04	8.32
(3)	1.07	8.56
(5)	1.15	9.20

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

HEADWATER DEPTH FOR C.M. BOX CULVERTS
0.5 ≤ RISE / SPAN
WITH INLET CONTROL

CHART 20B

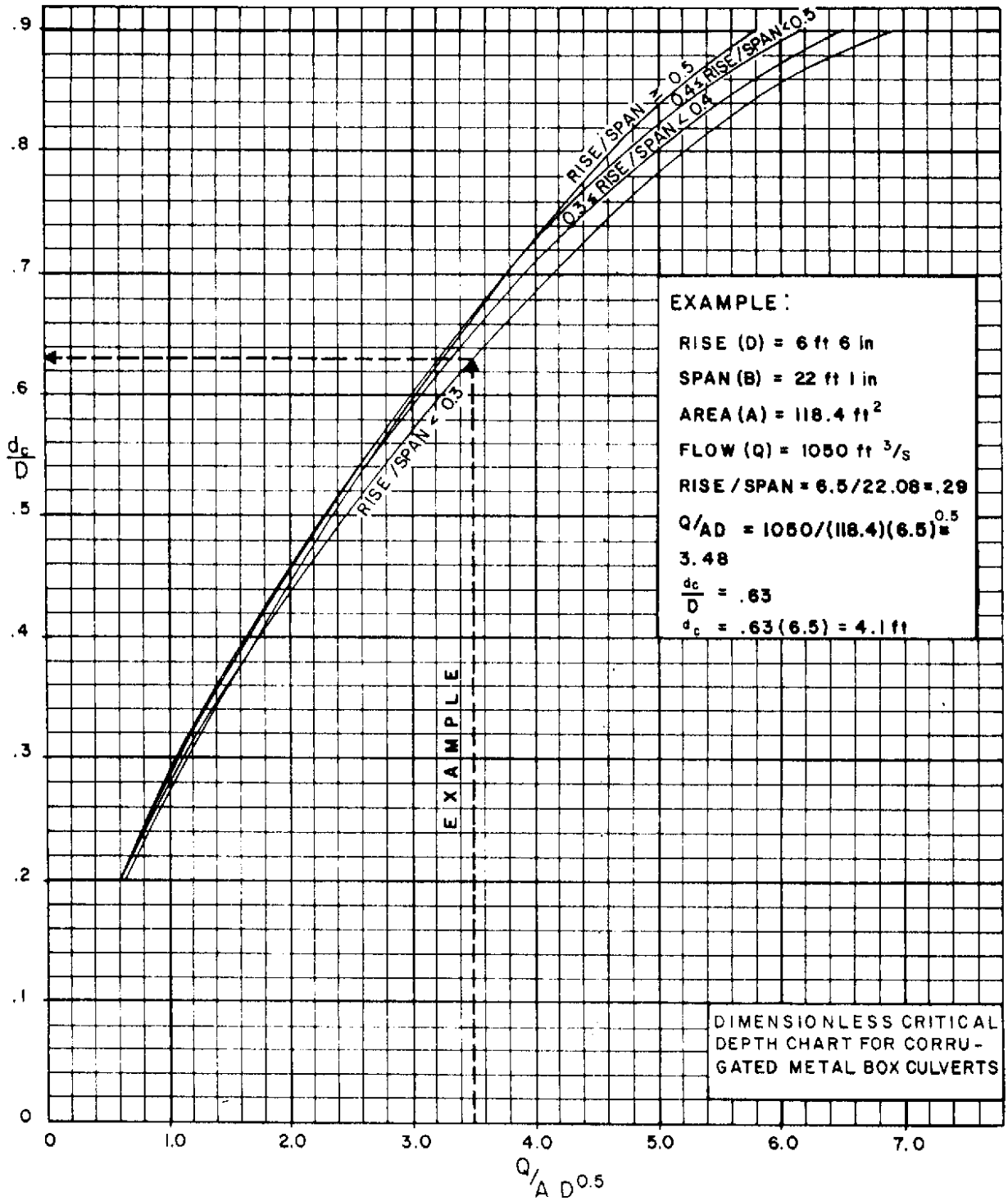
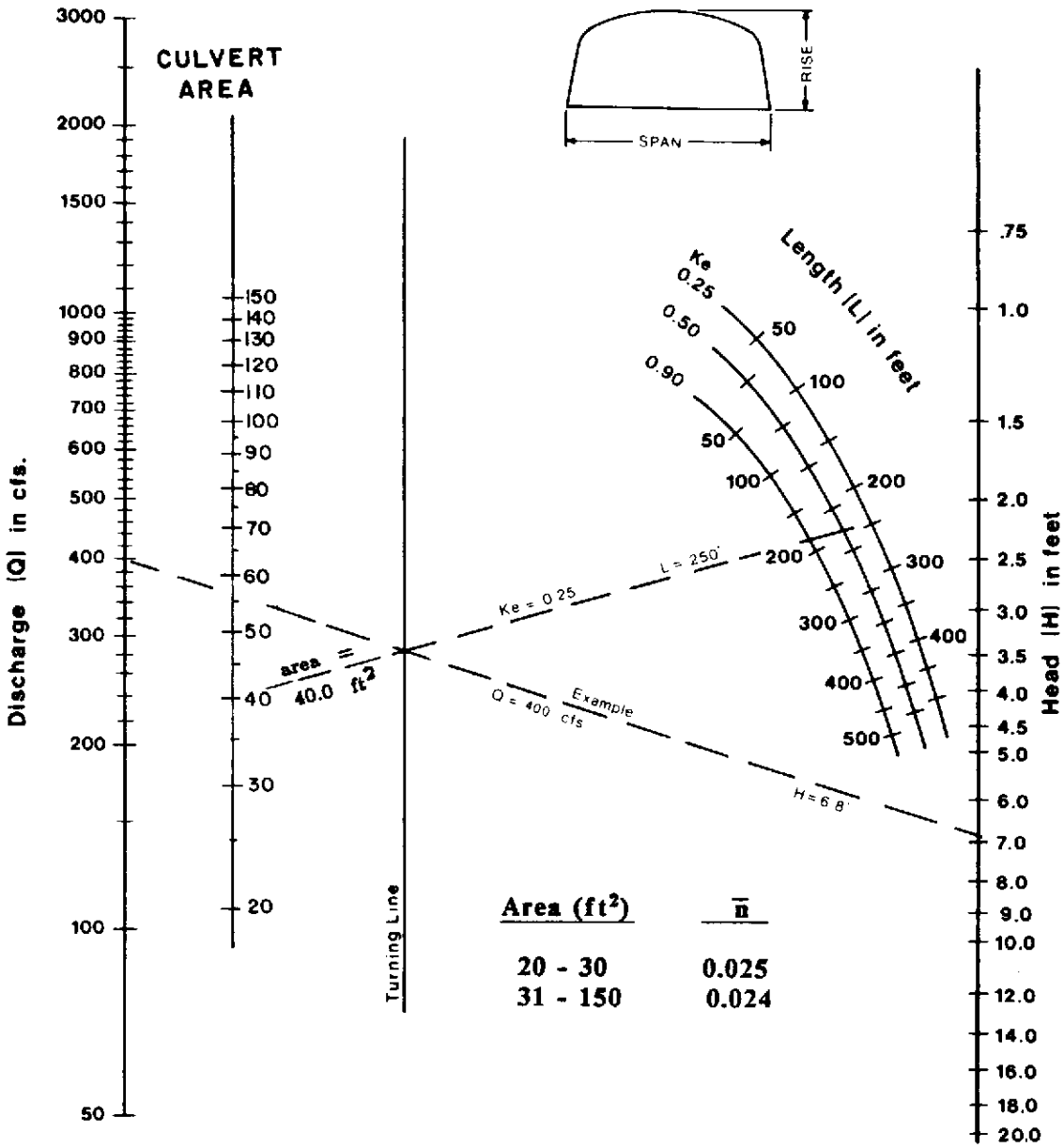
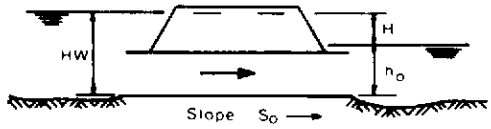

RISE/SPAN ≥ 0.5
0.43 ≤ RISE/SPAN < 0.5
0.33 ≤ RISE/SPAN < 0.4
RISE/SPAN < 0.3
EXAMPLE
EXAMPLE:
RISE (D) = 6 ft 6 in
SPAN (B) = 22 ft 1 in
AREA (A) = 118.4 ft²
FLOW (Q) = 1050 ft³/s
RISE / SPAN = 6.5/22.08 = .29
Q/AD^0.5 = 1050/(118.4)(6.5)^0.5 = 3.48
dc/D = .63
dc = .63(6.5) = 4.1 ft
DIMENSIONLESS CRITICAL DEPTH CHART FOR CORRUGATED METAL BOX CULVERTS
dc/D
Q/A D^0.5
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2.0
3.0
4.0
5.0
6.0
7.0

CHART 21B





SUBMERGED OUTLET CULVERT FLOWING FULL

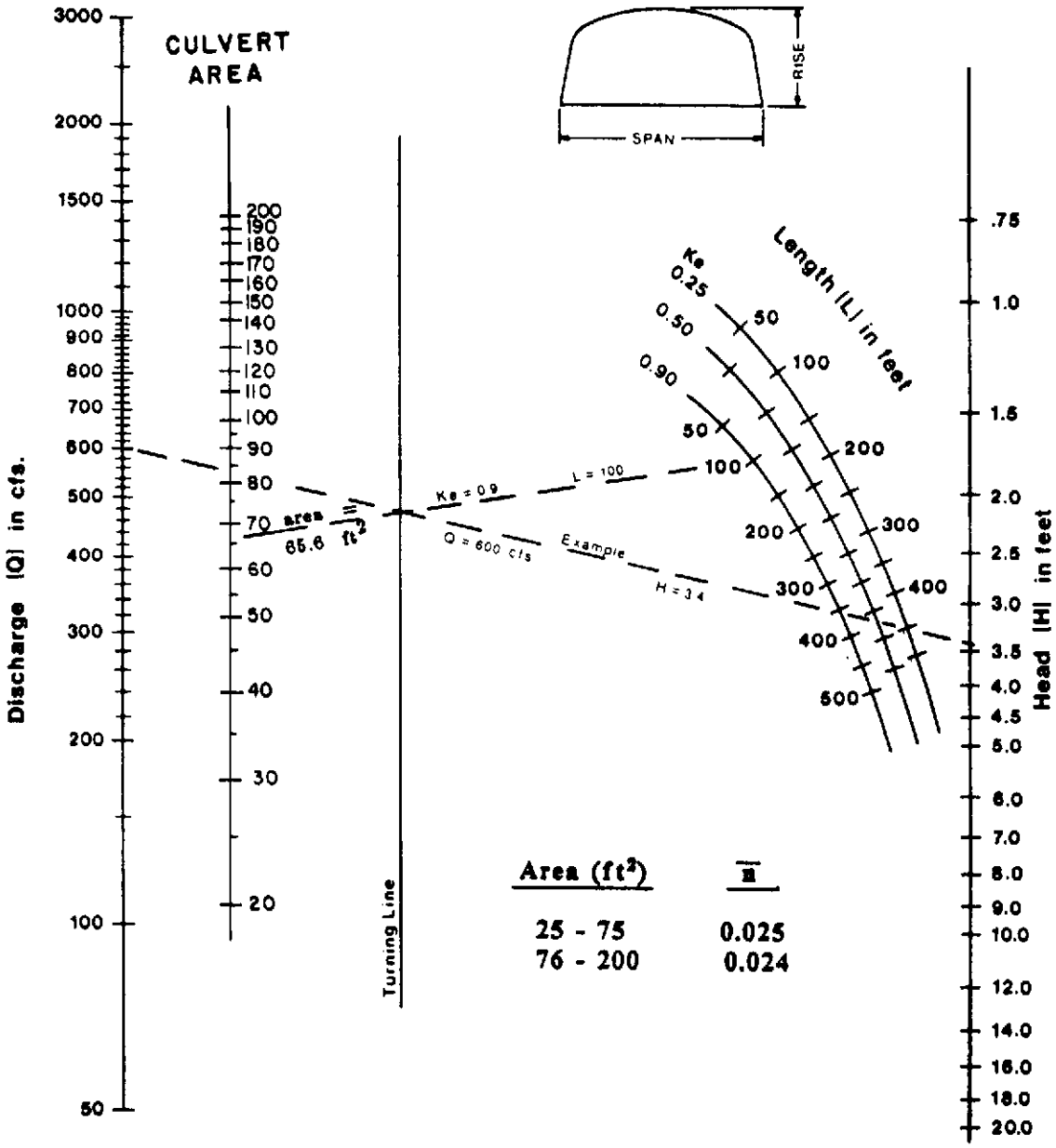
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM

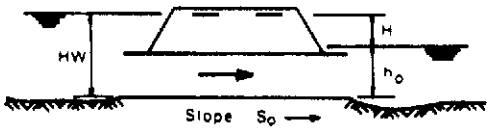
RISE/SPAN < 0.3

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 22B





SUBMERGED OUTLET CULVERT FLOWING FULL

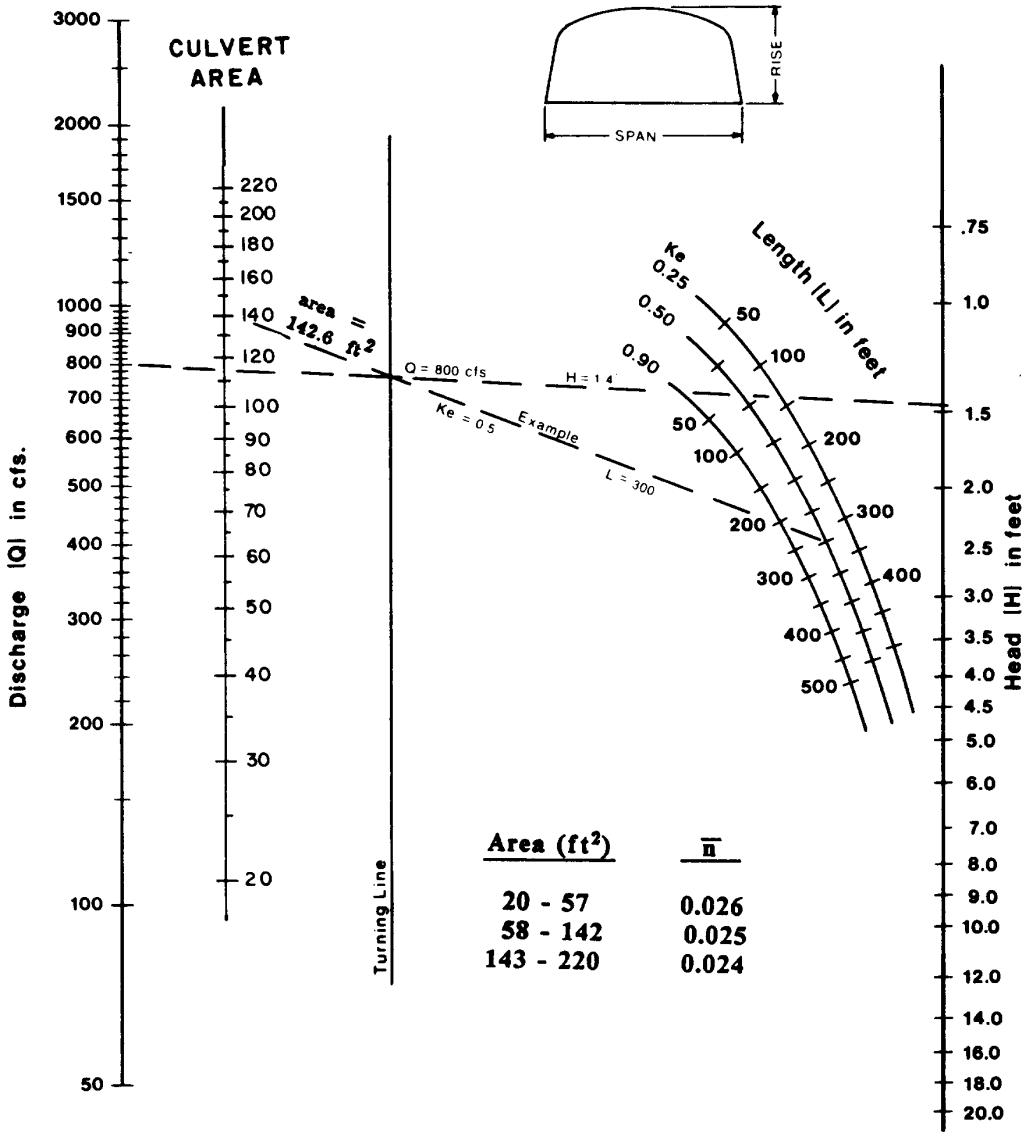
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM

0.3 ≤ RISE / SPAN < 0.4

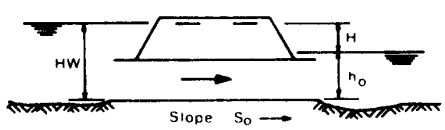
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 23B



Area (ft²)	n̄
20 - 57	0.026
58 - 142	0.025
143 - 220	0.024



SUBMERGED OUTLET CULVERT FLOWING FULL

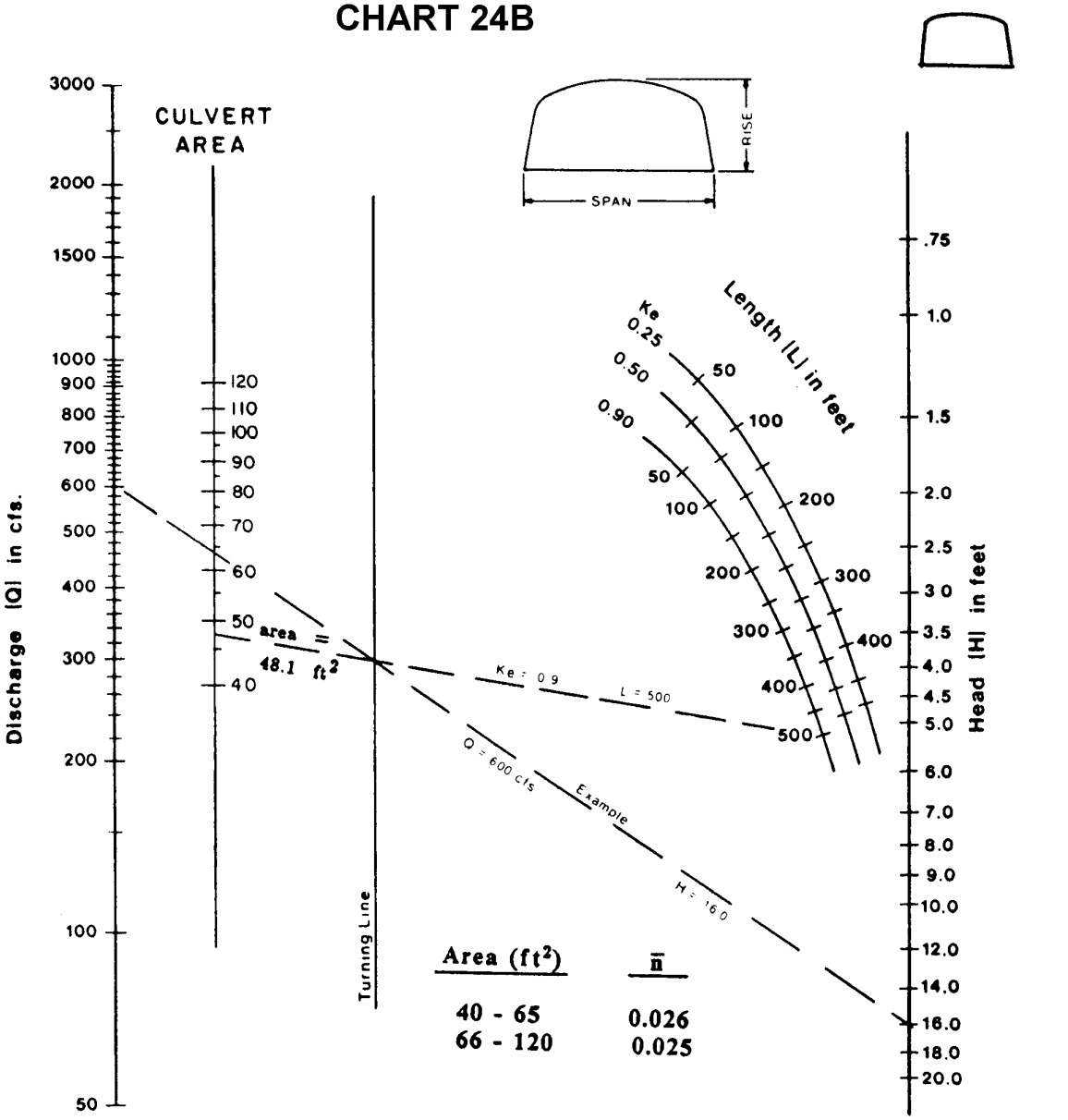
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM

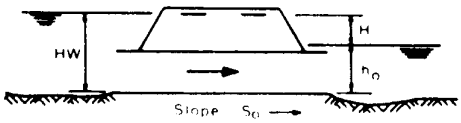
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 24B





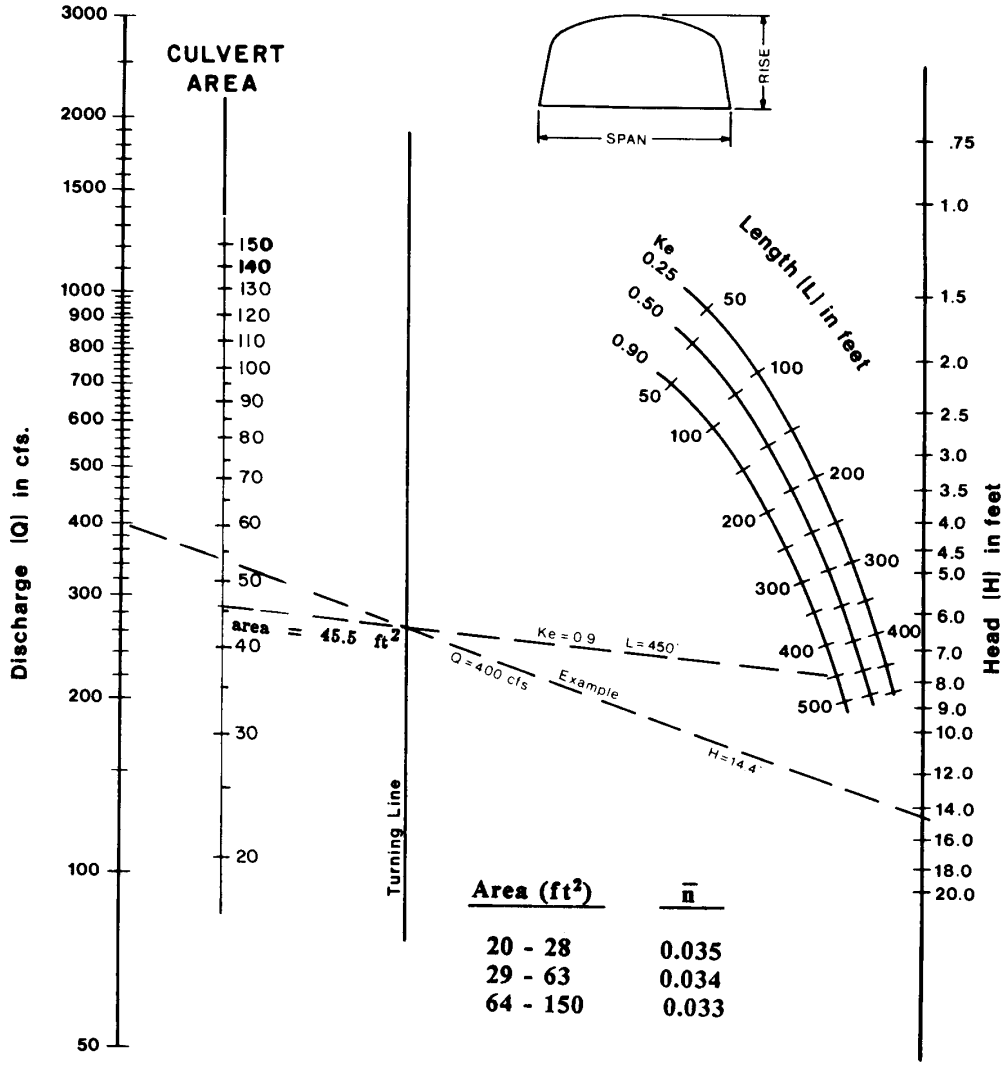
HEAD FOR
C. M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM

0.5 ≤ RISE / SPAN

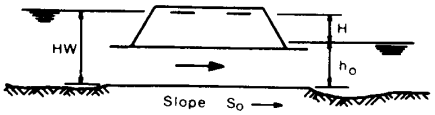
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 25B



Area (ft²)	n̄
20 - 28	0.035
29 - 63	0.034
64 - 150	0.033



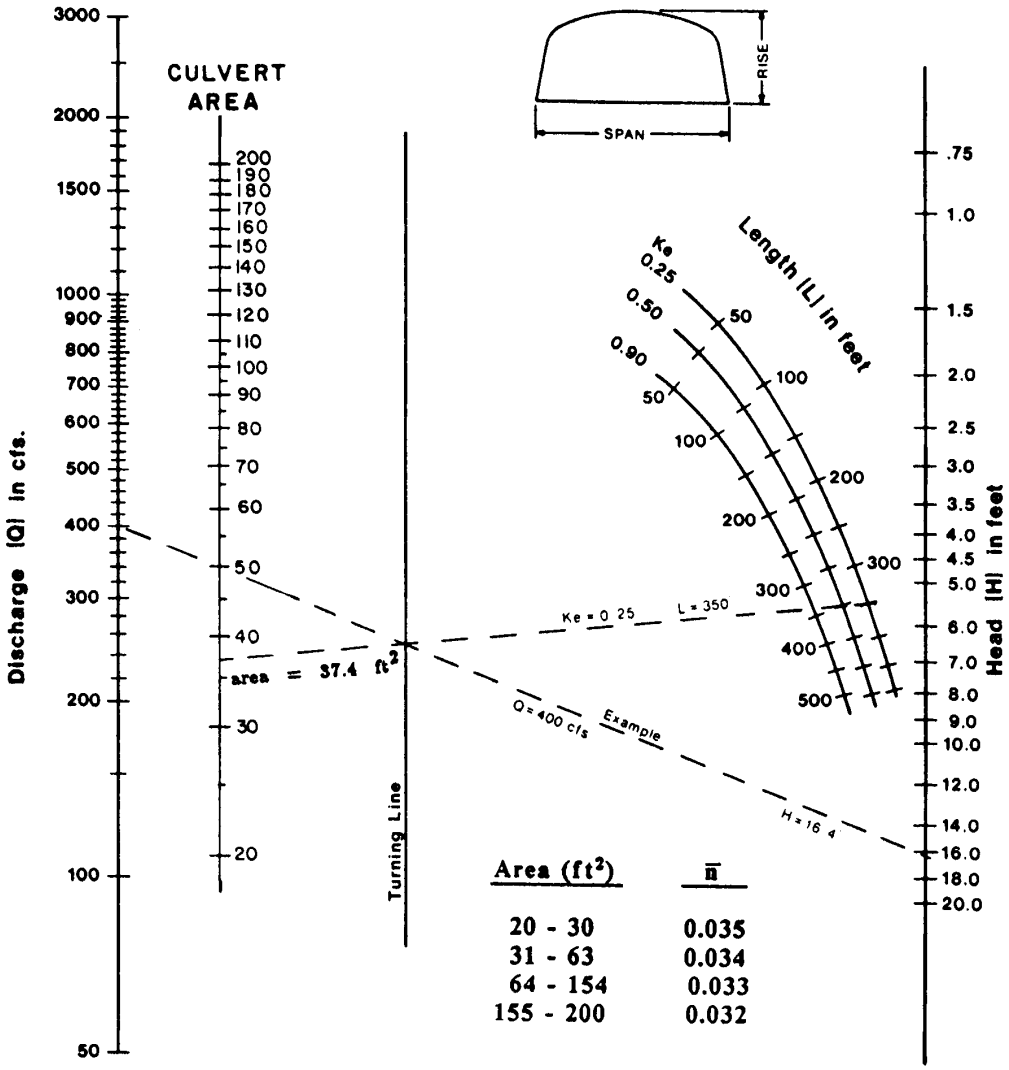
SUBMERGED OUTLET CULVERT FLOWING FULL

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

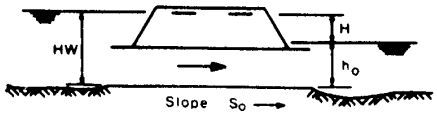
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 26B



Area (ft^2)	$\bar{n}$
20 - 30	0.035
31 - 63	0.034
64 - 154	0.033
155 - 200	0.032



SUBMERGED OUTLET CULVERT FLOWING FULL

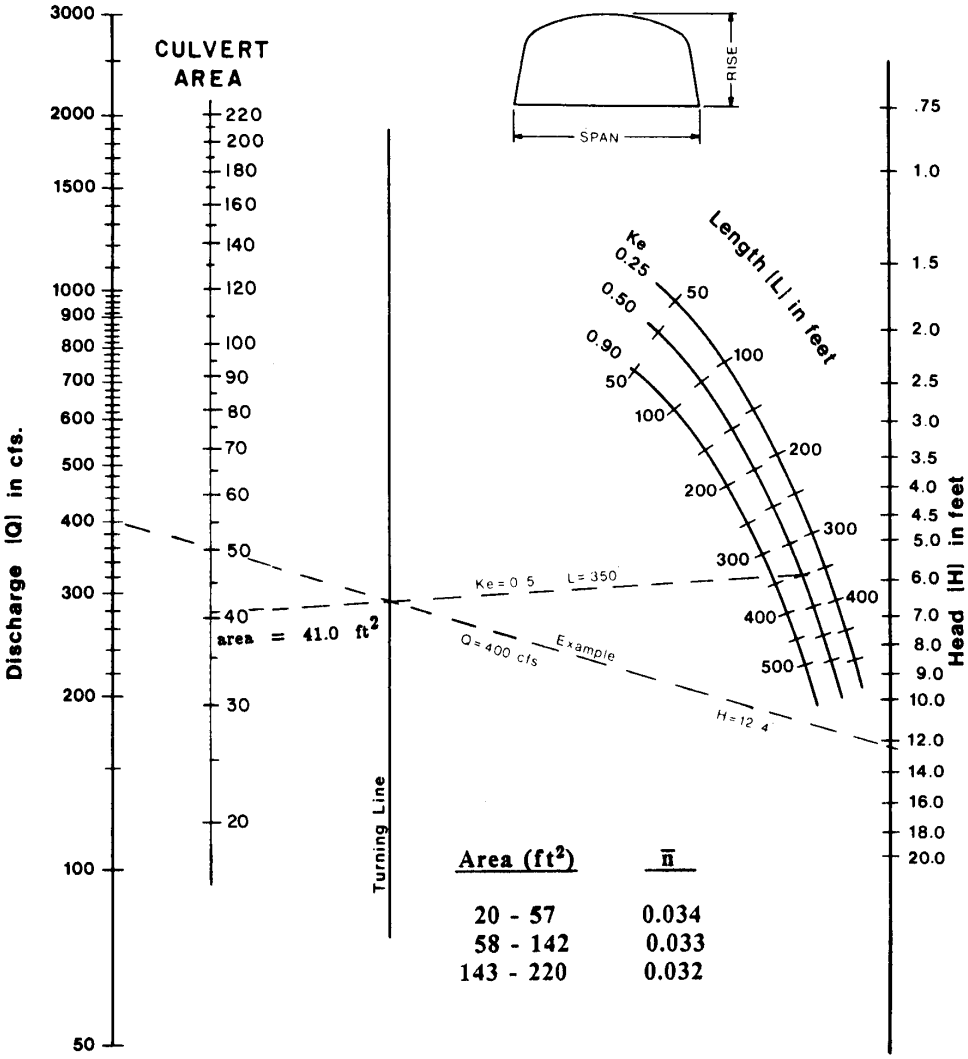
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM

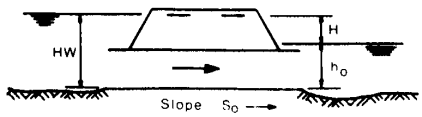
$0.3 \leq$ RISE/SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 27B





SUBMERGED OUTLET CULVERT FLOWING FULL

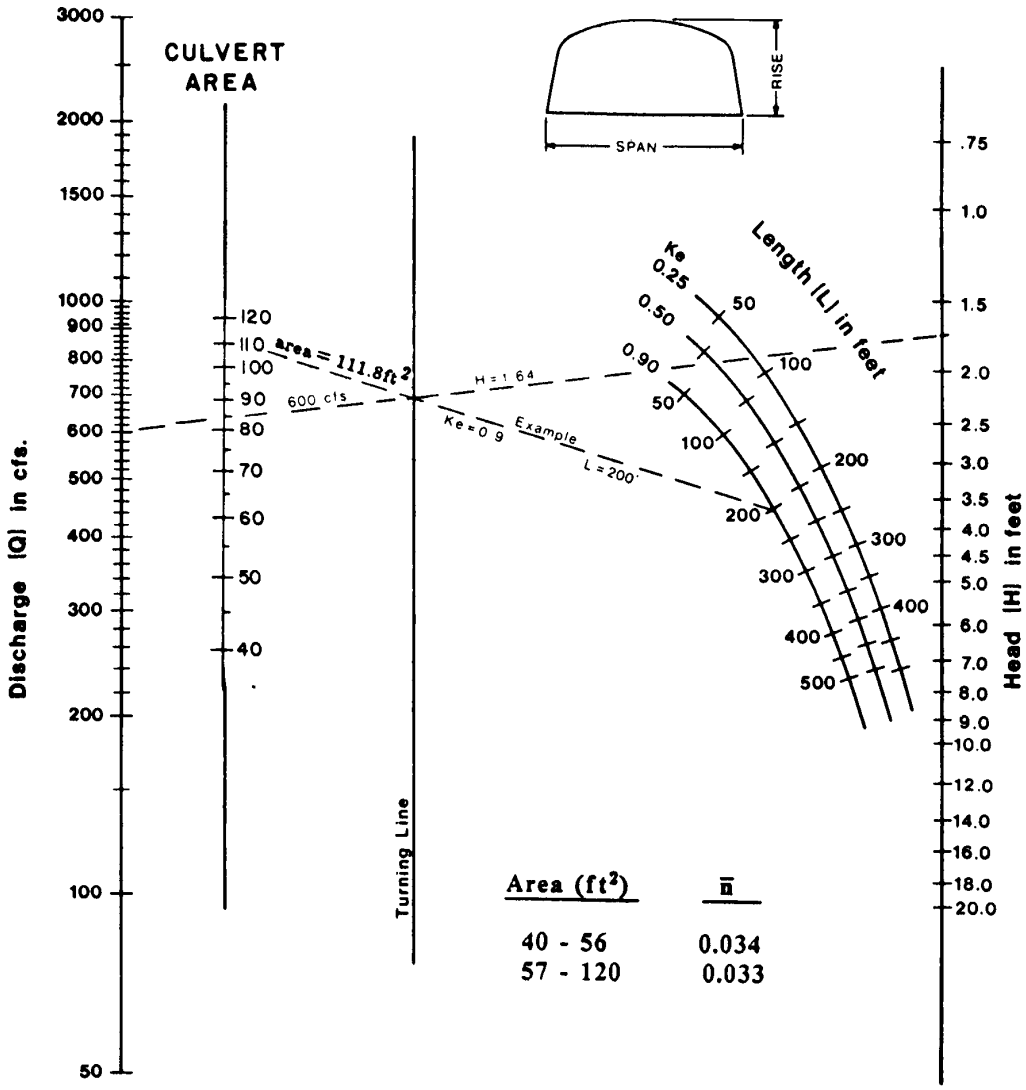
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM

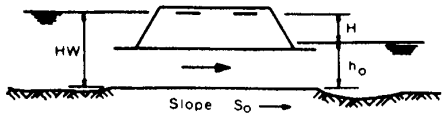
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 28B





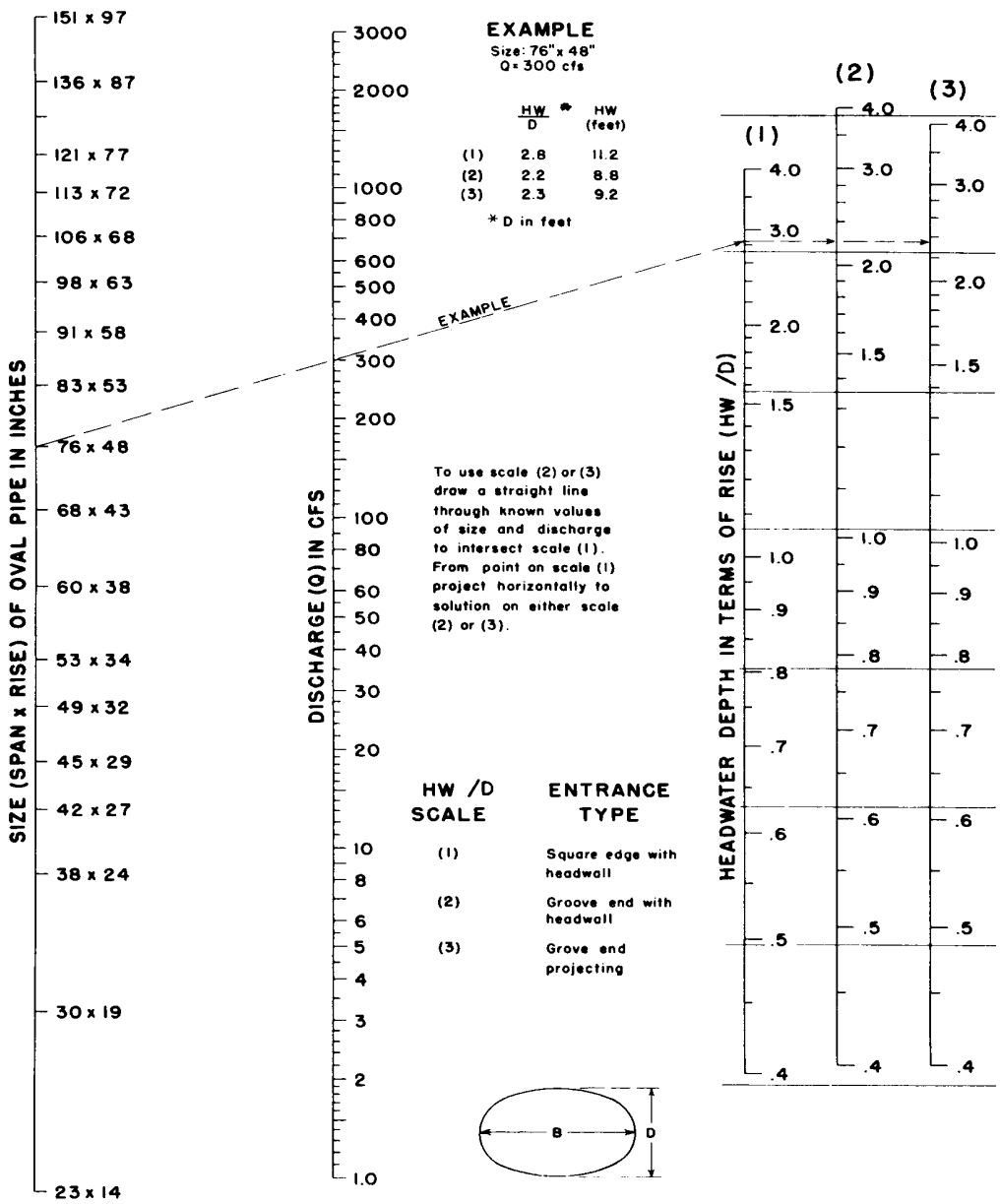
SUBMERGED OUTLET CULVERT FLOWING FULL

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

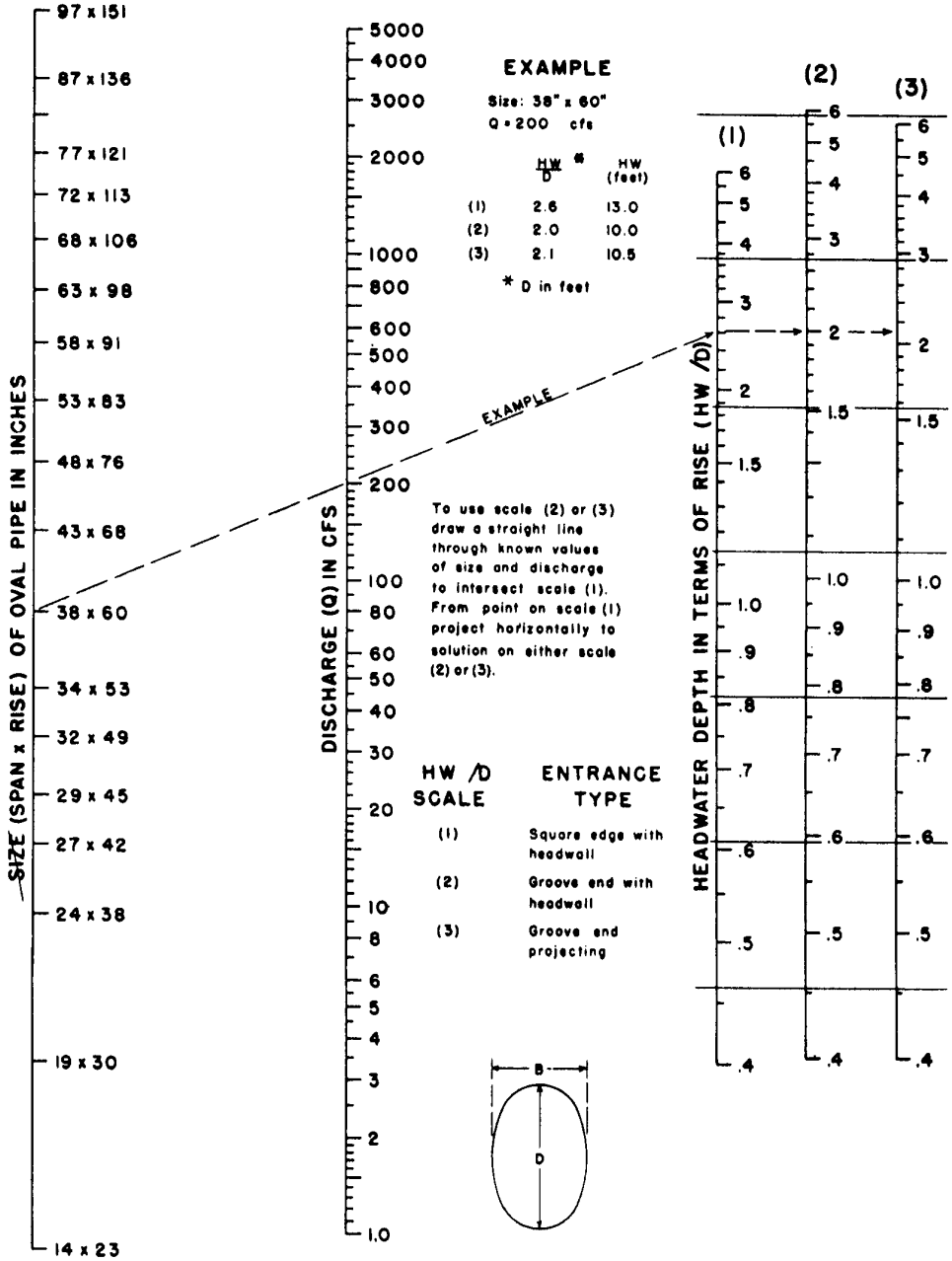
CHART 29B



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

BUREAU OF PUBLIC ROADS JAN. 1963

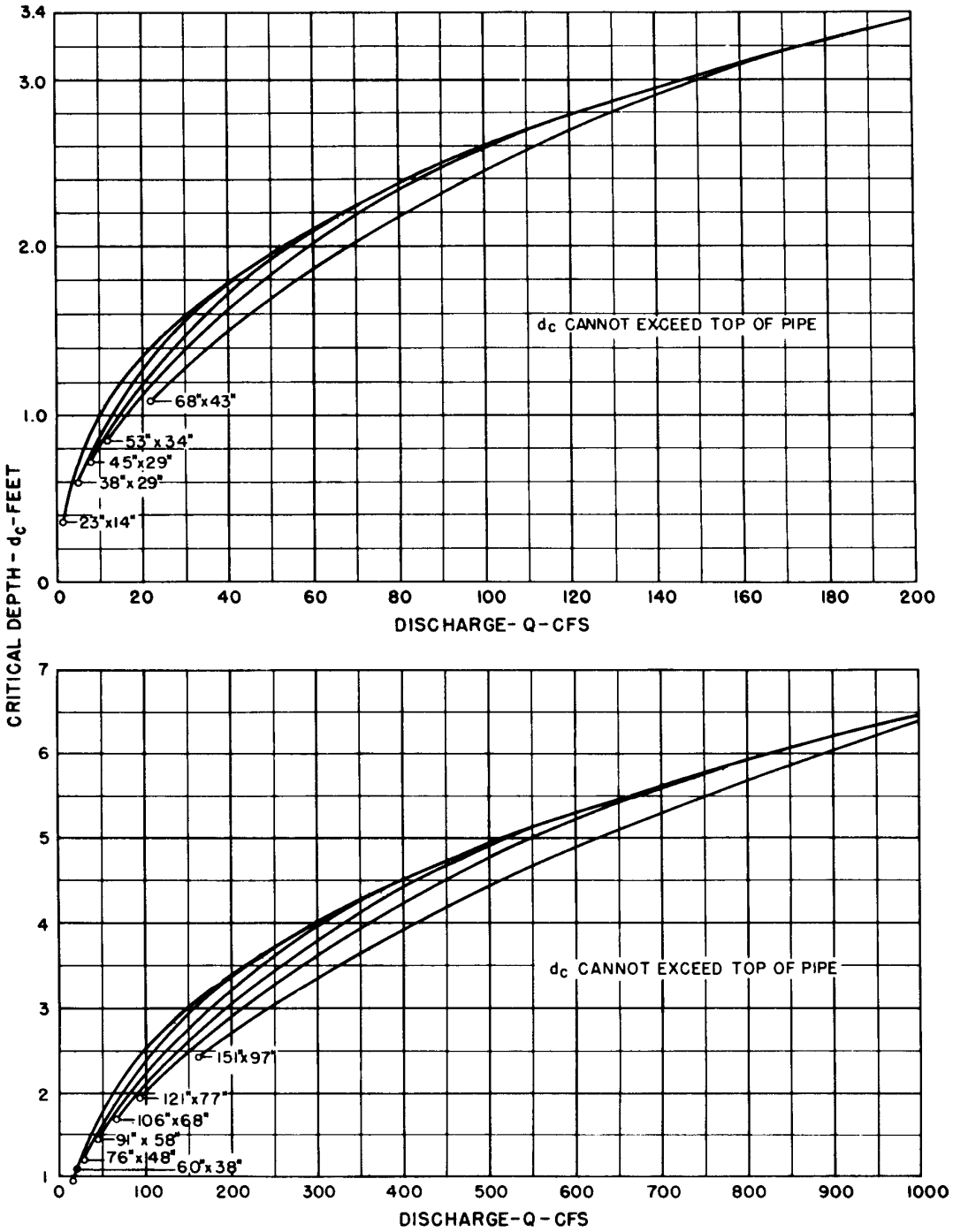
CHART 30B



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

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 31B

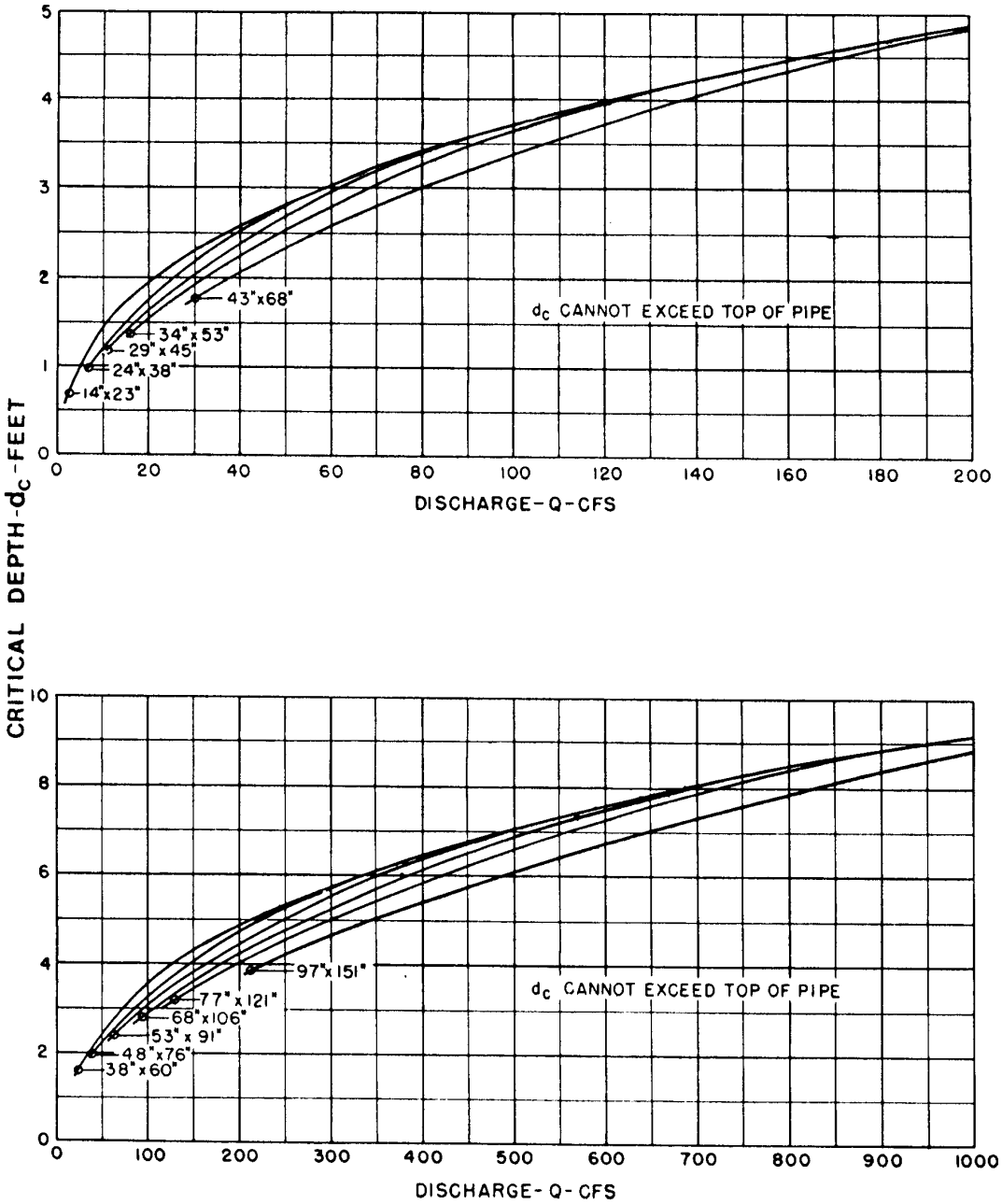


BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

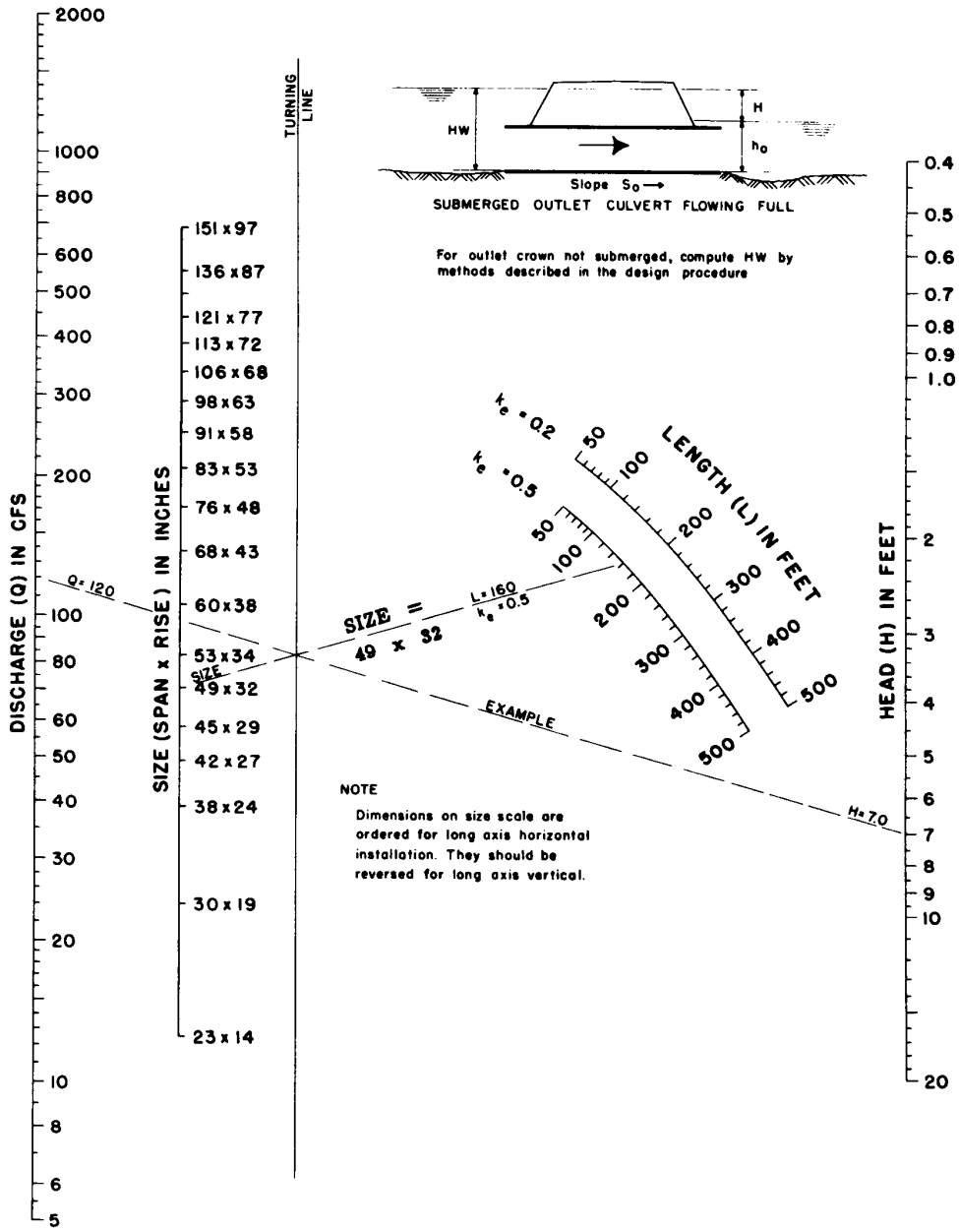
CHART 32B



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

CHART 33B

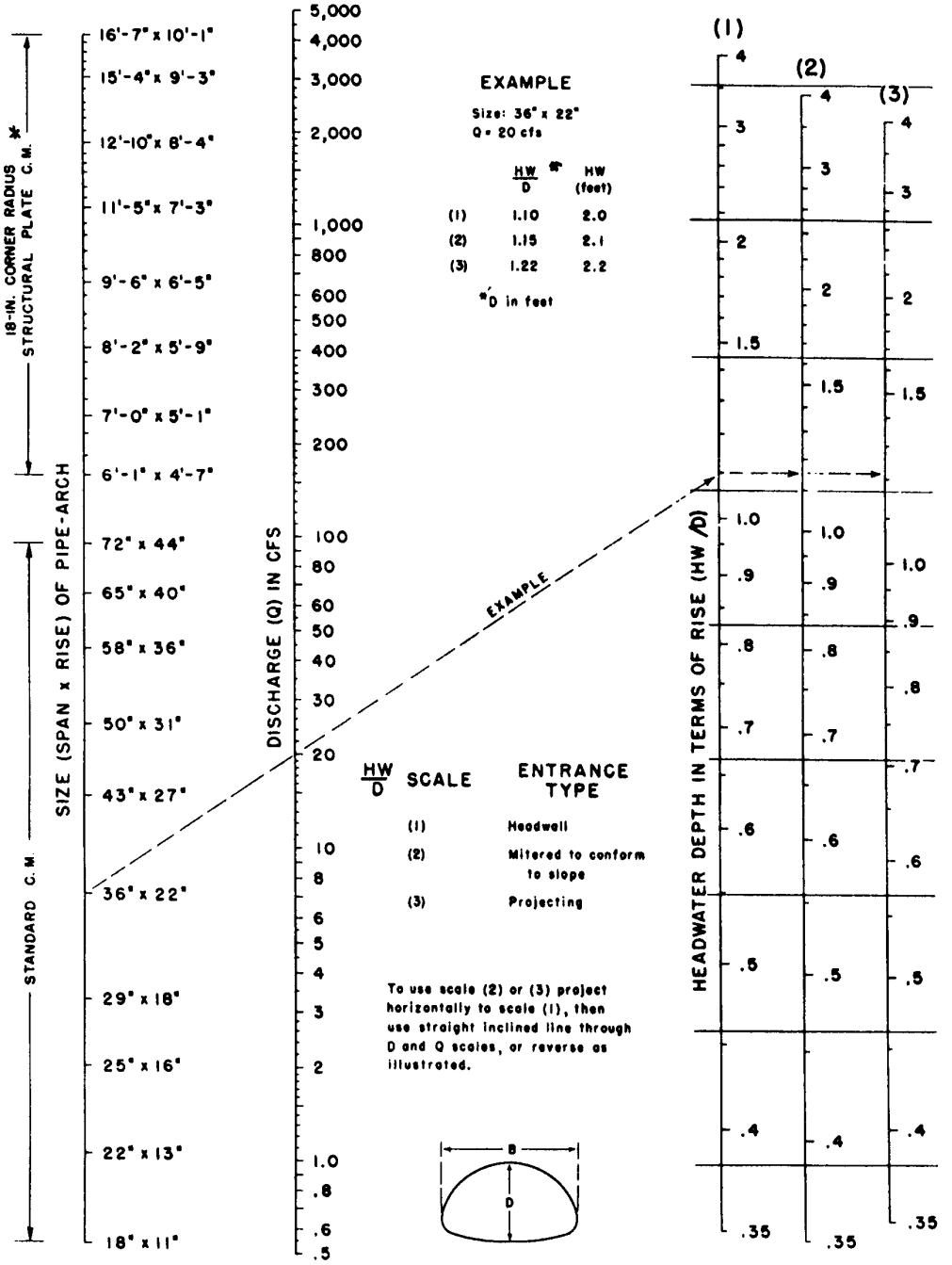


HEAD FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL OR VERTICAL FLOWING FULL

n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 34B

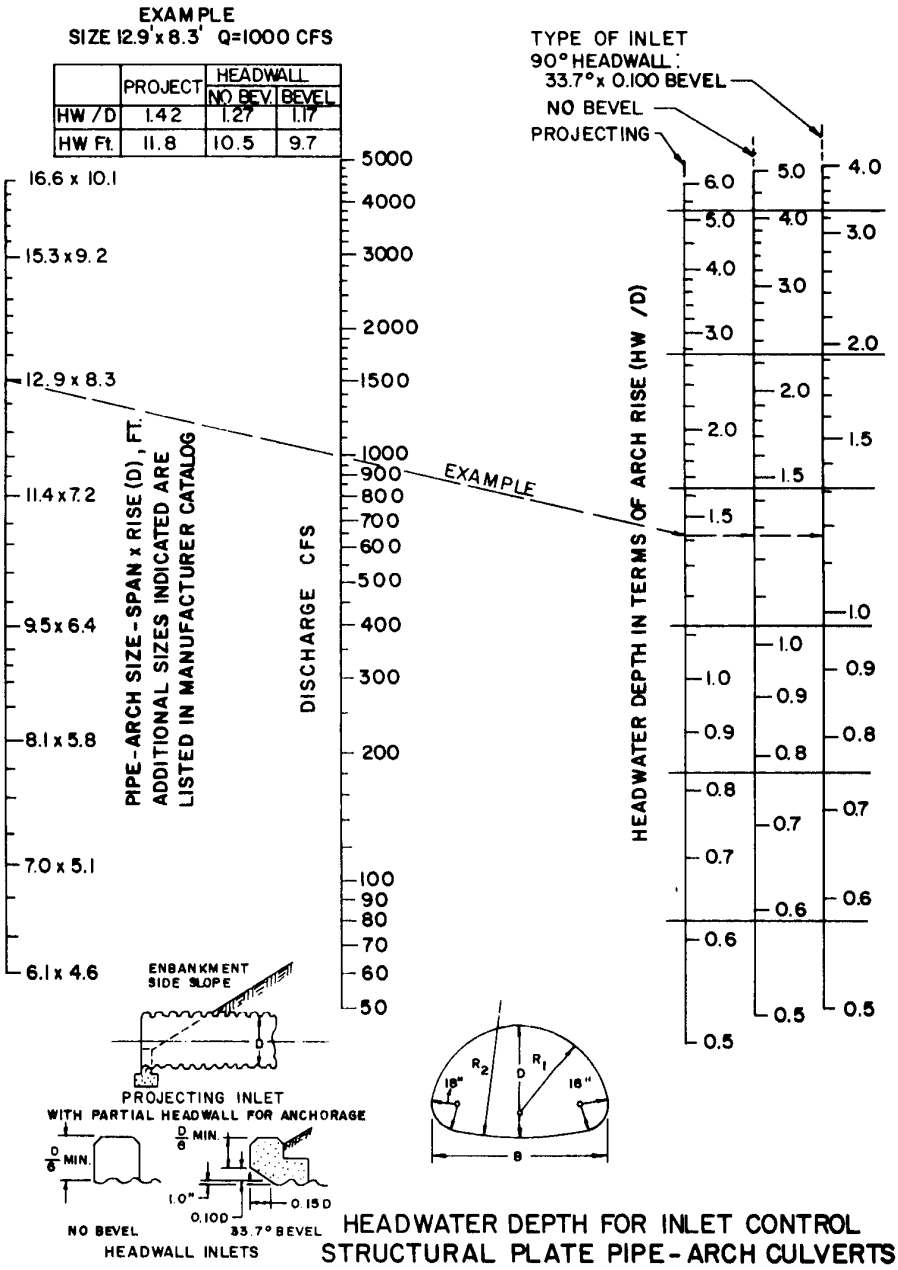


*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN. 1963

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

CHART 35B



HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS

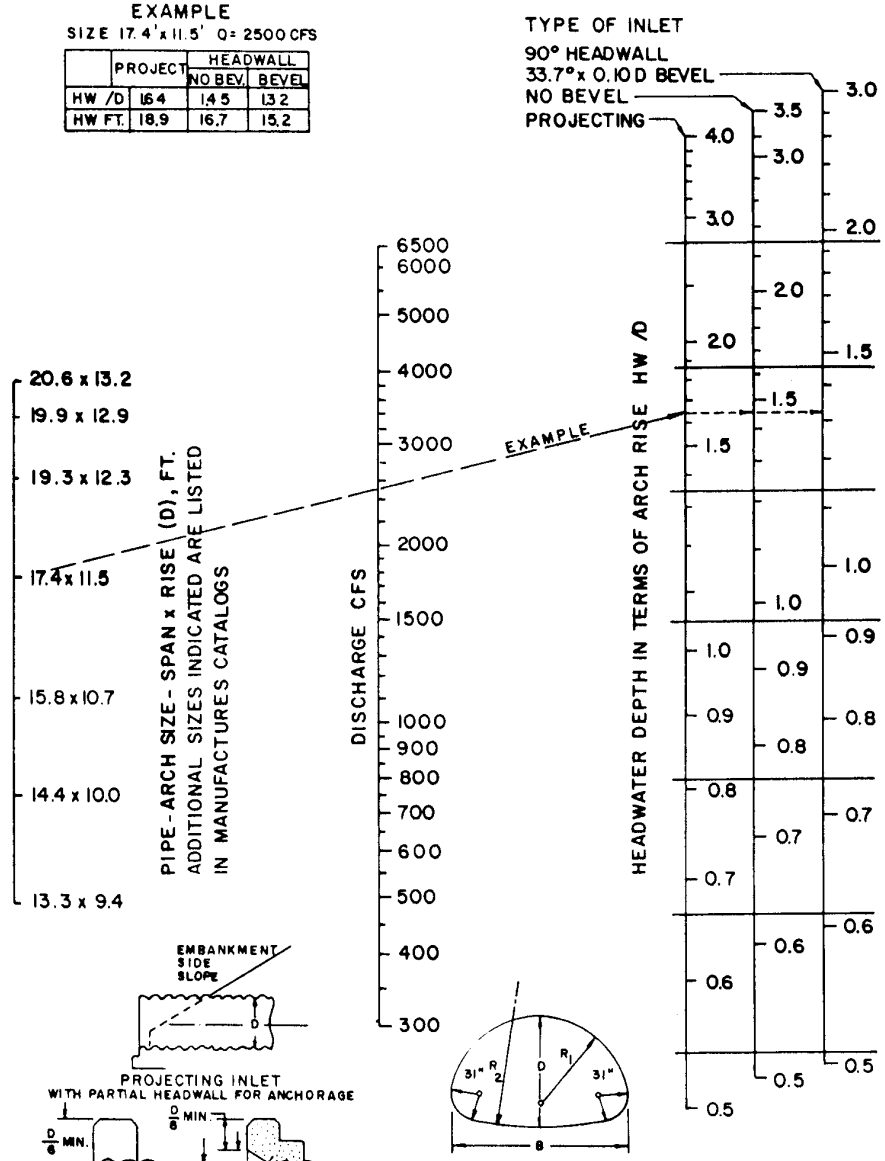
BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1968

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

CHART 36B

EXAMPLE
SIZE 17.4'x 11.5' Q= 2500 CFS

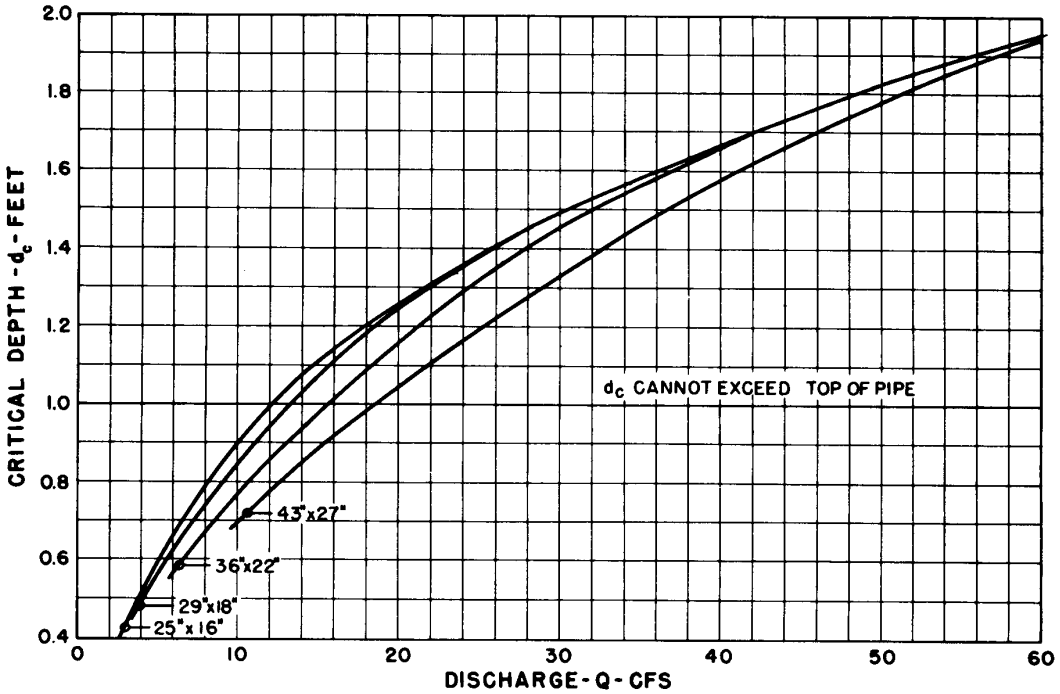
	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW /D	16.4	1.45	1.32
HW FT.	18.9	16.7	15.2

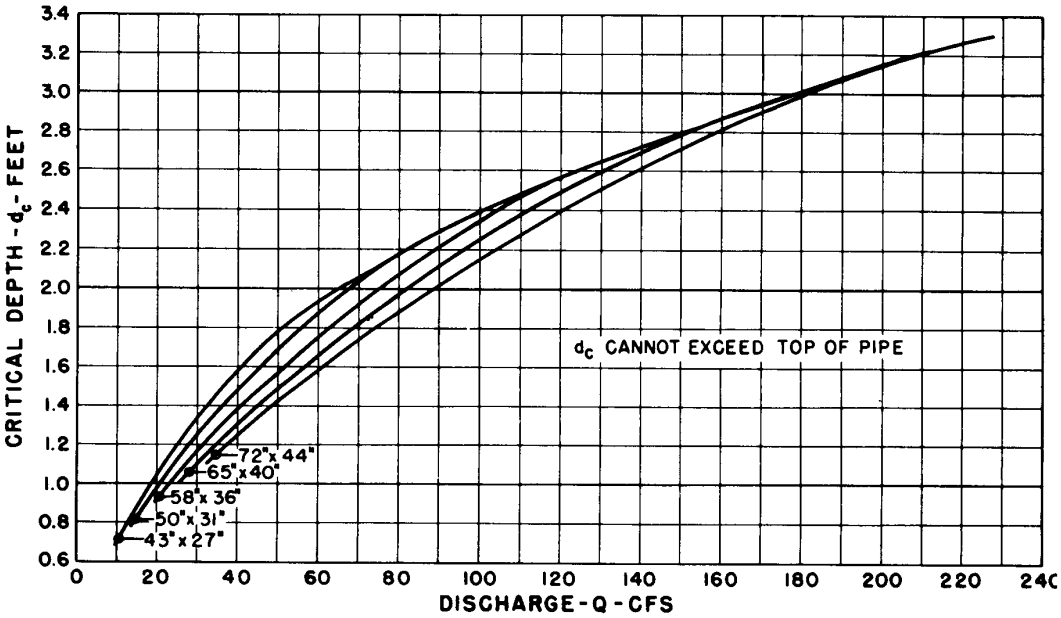


HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
31-IN. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1966

CHART 37B



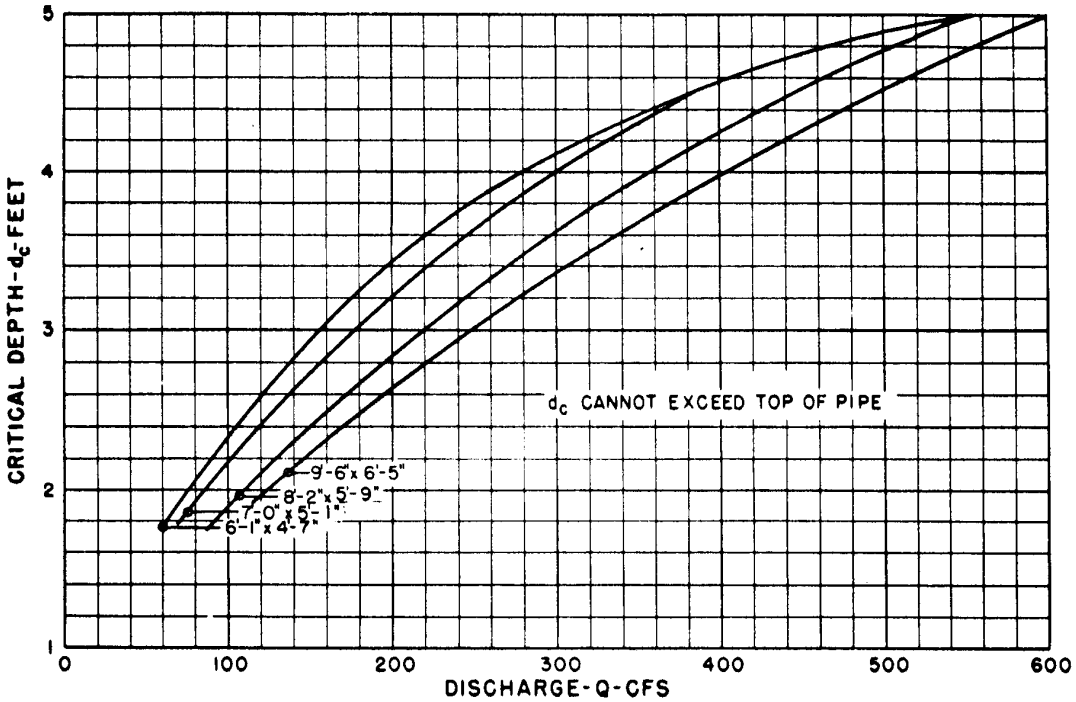


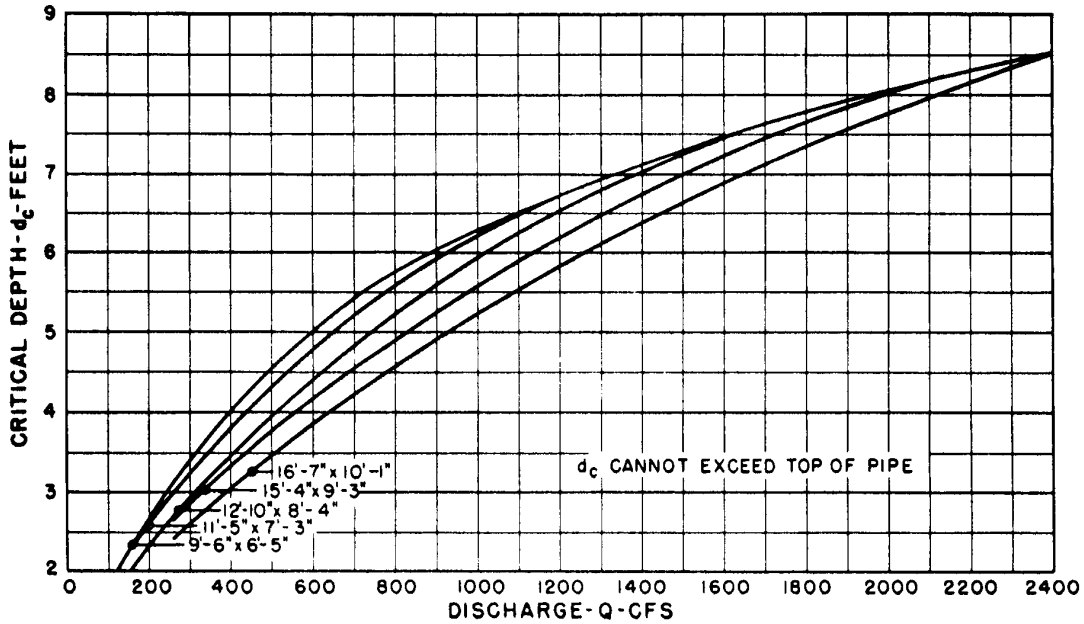
BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
STANDARD C.M. PIPE-ARCH

CHART 38B



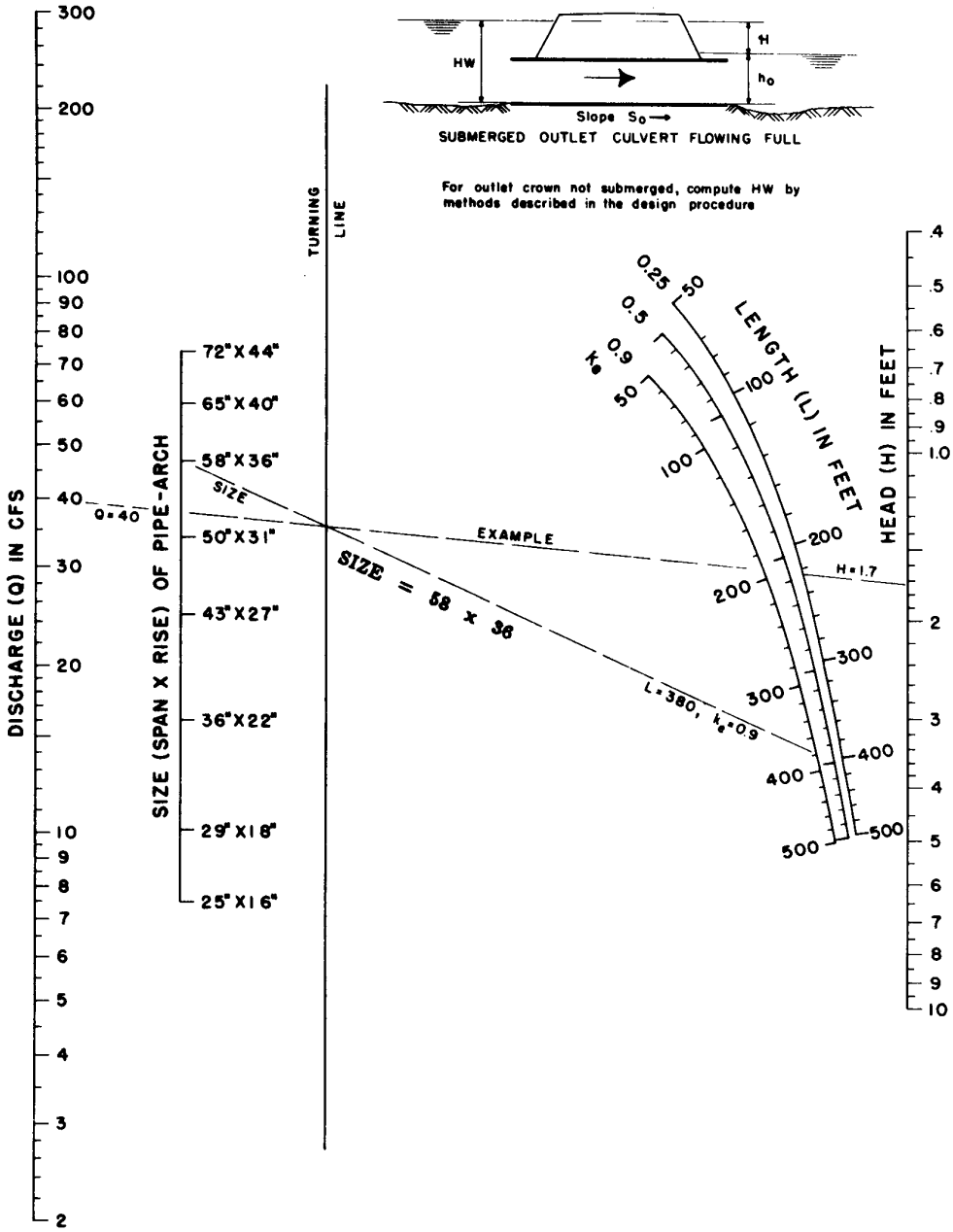


BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C. M. PIPE-ARCH
18 INCH CORNER RADIUS

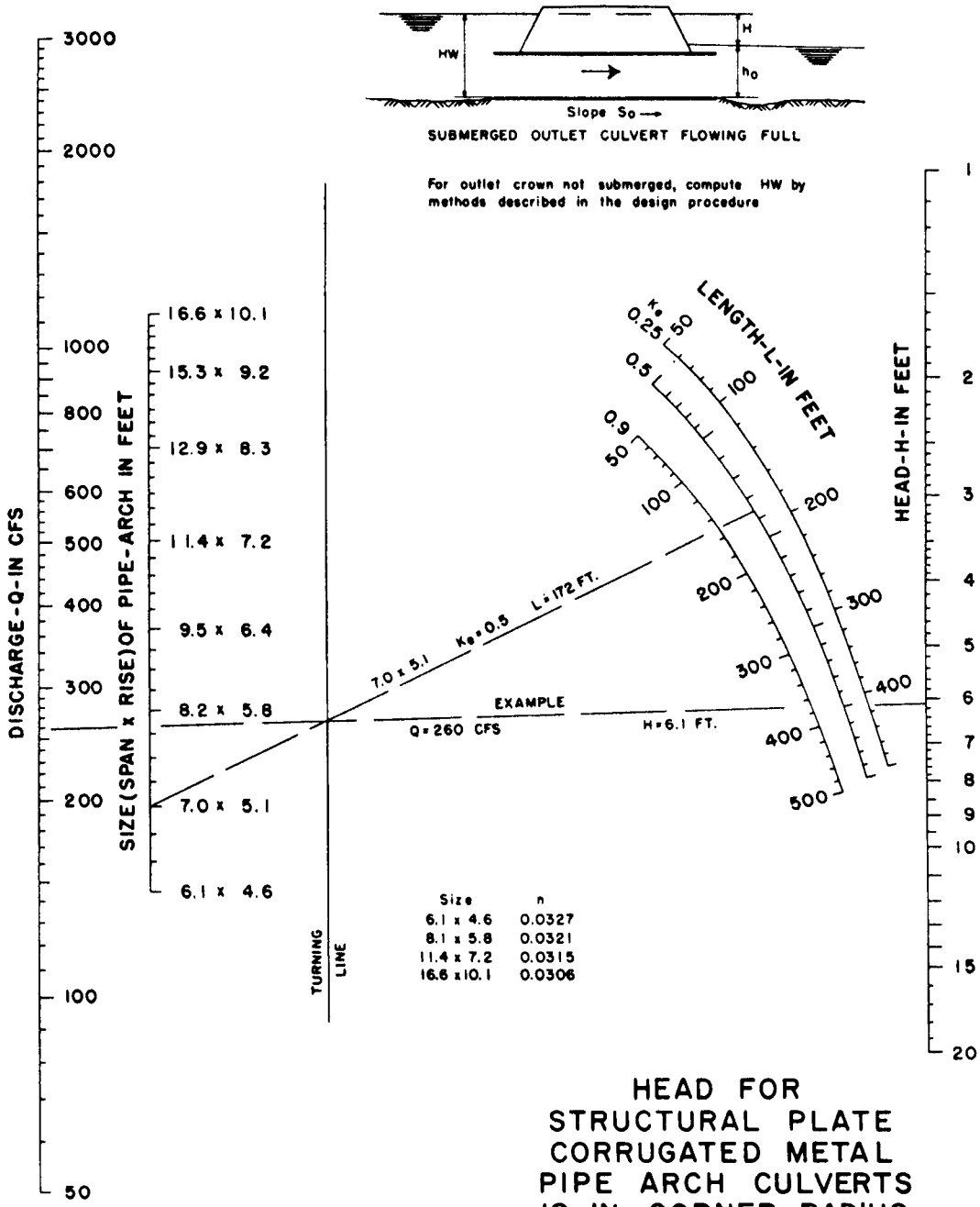
CHART 39B



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

BUREAU OF PUBLIC ROADS JAN. 1963

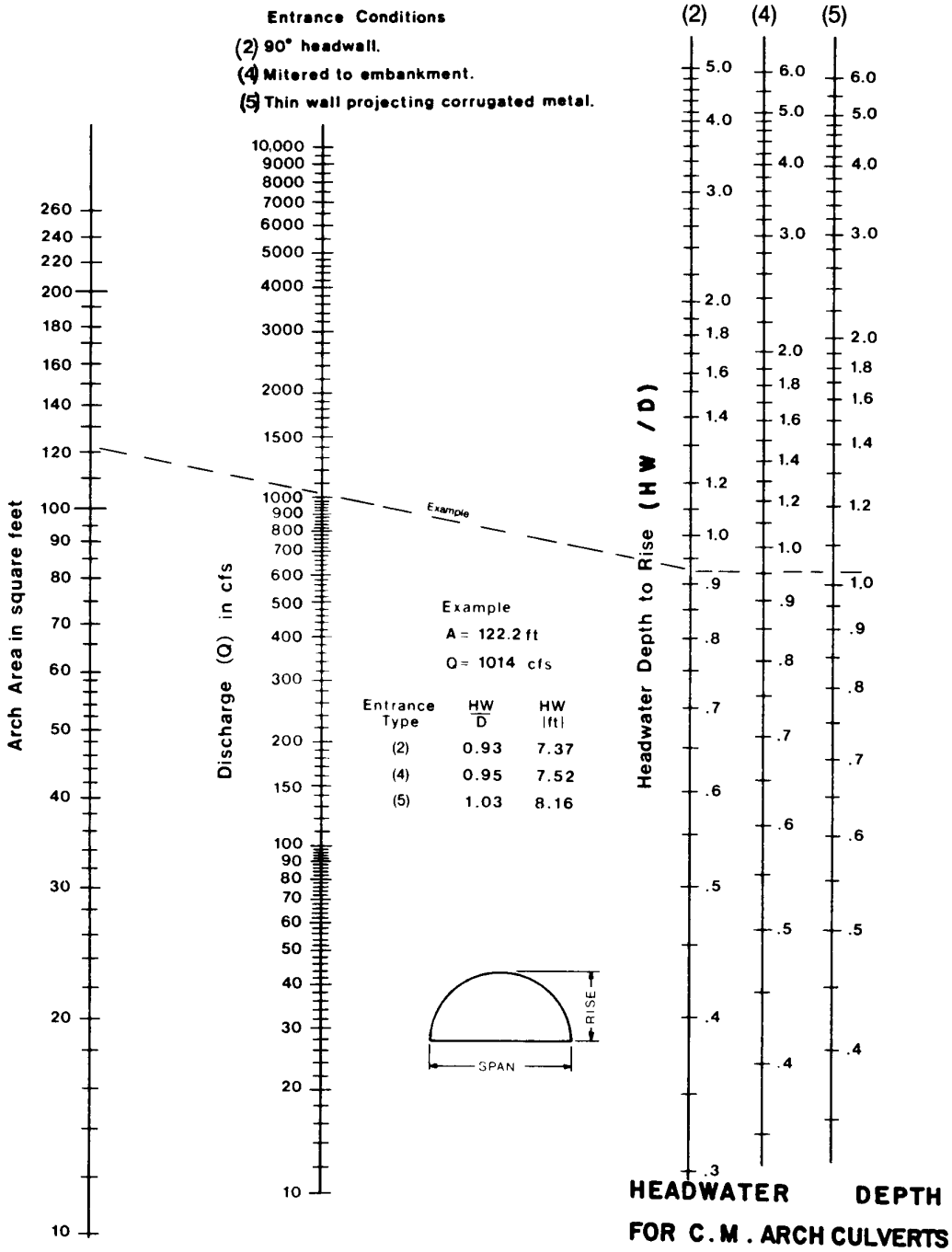
CHART 40B



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 41B



HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.3 ≤ RISE / SPAN < 0.4
WITH INLET CONTROL

Duplication of this nomograph may distort scale

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

CHART 42B

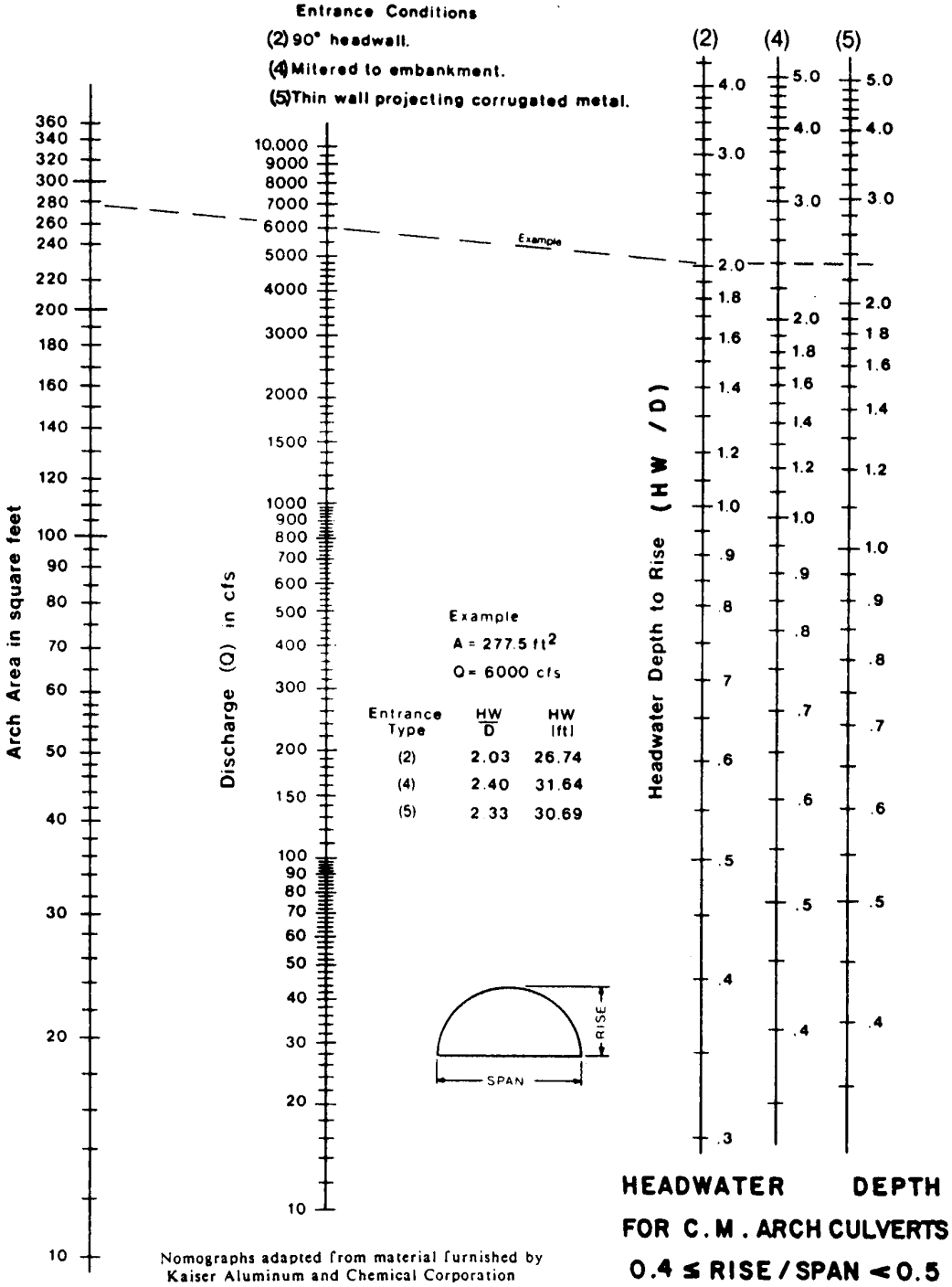
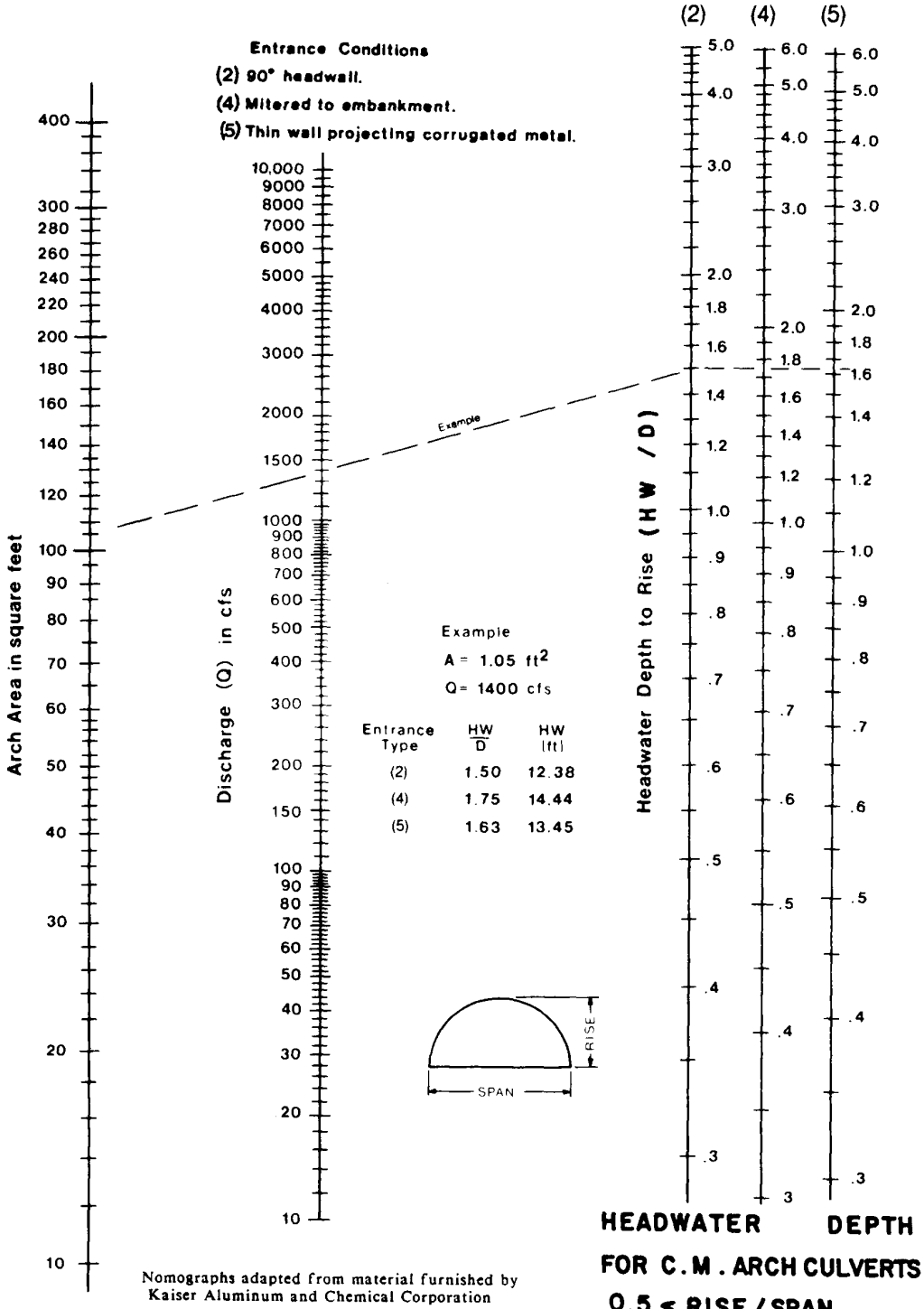

Entrance Conditions
(2) 90° headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.
Arch Area in square feet
Discharge (Q) in cfs
Headwater Depth to Rise (HW / D)
(2)
(4)
(5)
Example
Example
A = 277.5 ft²
Q = 6000 cfs
Entrance Type
HW/D
HW (ft)
(2) 2.03 26.74
(4) 2.40 31.64
(5) 2.33 30.69
RISE
SPAN
HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.4 ≤ RISE / SPAN < 0.5
WITH INLET CONTROL
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation
Duplication of this nomograph may distort scale

CHART 43B



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 44B

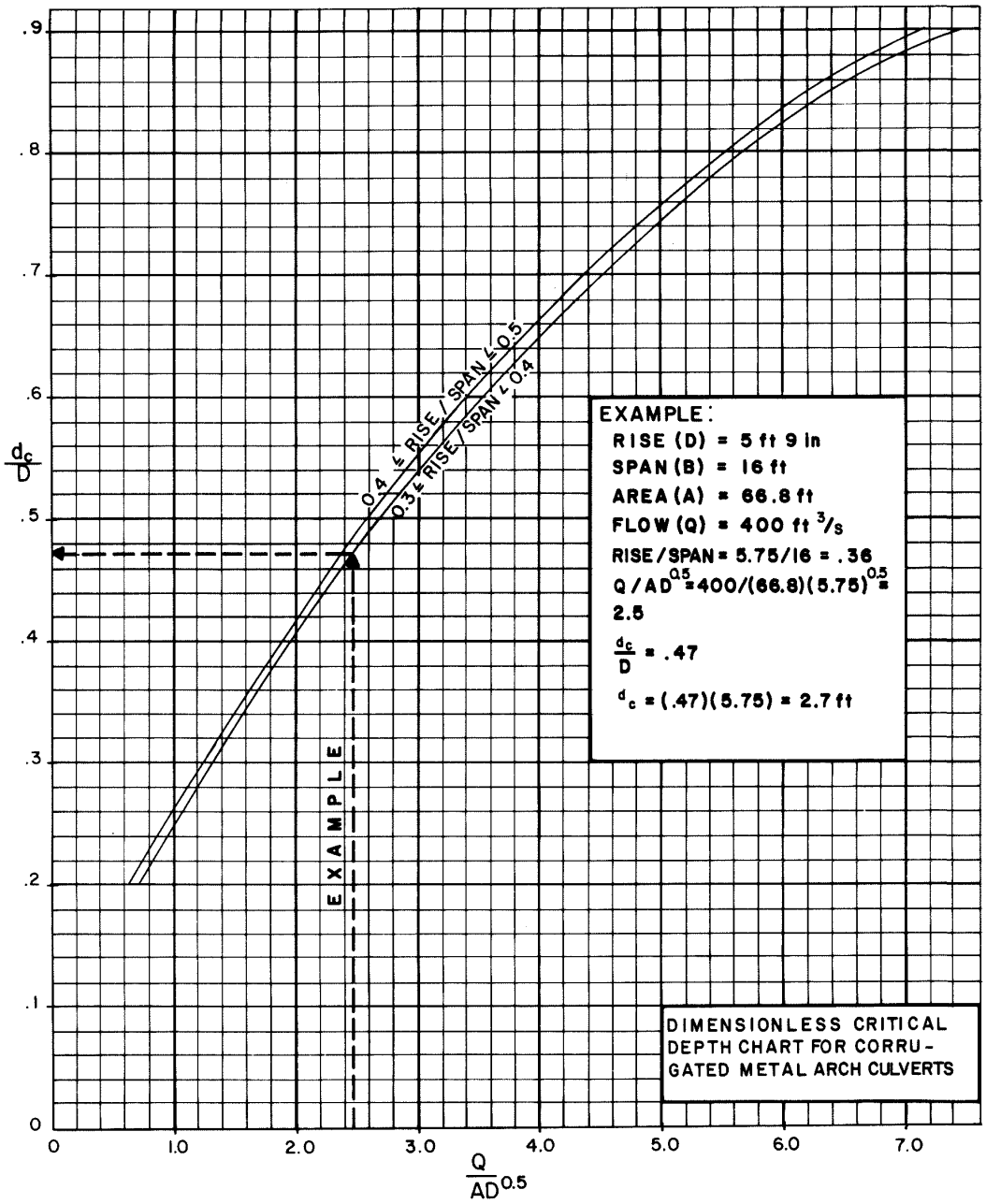
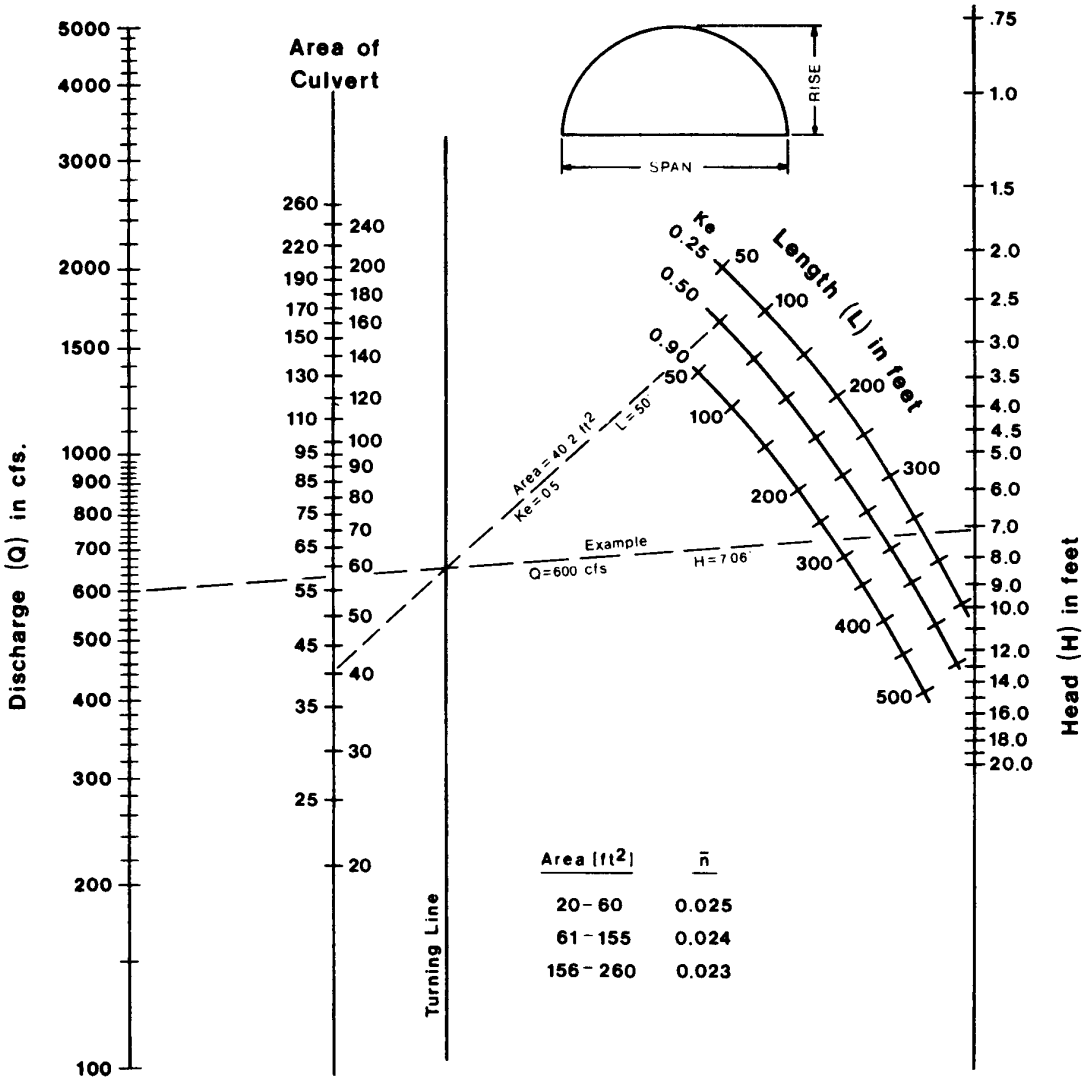
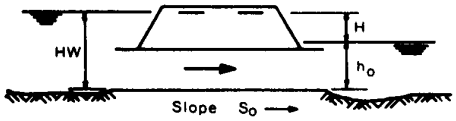

.9
.8
.7
.6
.5
.4
.3
.2
.1
0
$\frac{d_c}{D}$
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
$\frac{Q}{AD^{0.5}}$
0.4 ≤ RISE / SPAN ≤ 0.5
0.3 ≤ RISE / SPAN < 0.4
EXAMPLE
EXAMPLE:
RISE (D) = 5 ft 9 in
SPAN (B) = 16 ft
AREA (A) = 66.8 ft
FLOW (Q) = 400 ft ^{3}/s
RISE/SPAN = 5.75/16 = .36
$Q/AD^{0.5} = 400/(66.8)(5.75)^{0.5} =$
2.5
$\frac{d_c}{D}$ = .47
d_c = (.47)(5.75) = 2.7 ft
DIMENSIONLESS CRITICAL
DEPTH CHART FOR CORRU-
GATED METAL ARCH CULVERTS

CHART 45B





SUBMERGED OUTLET CULVERT FLOWING FULL

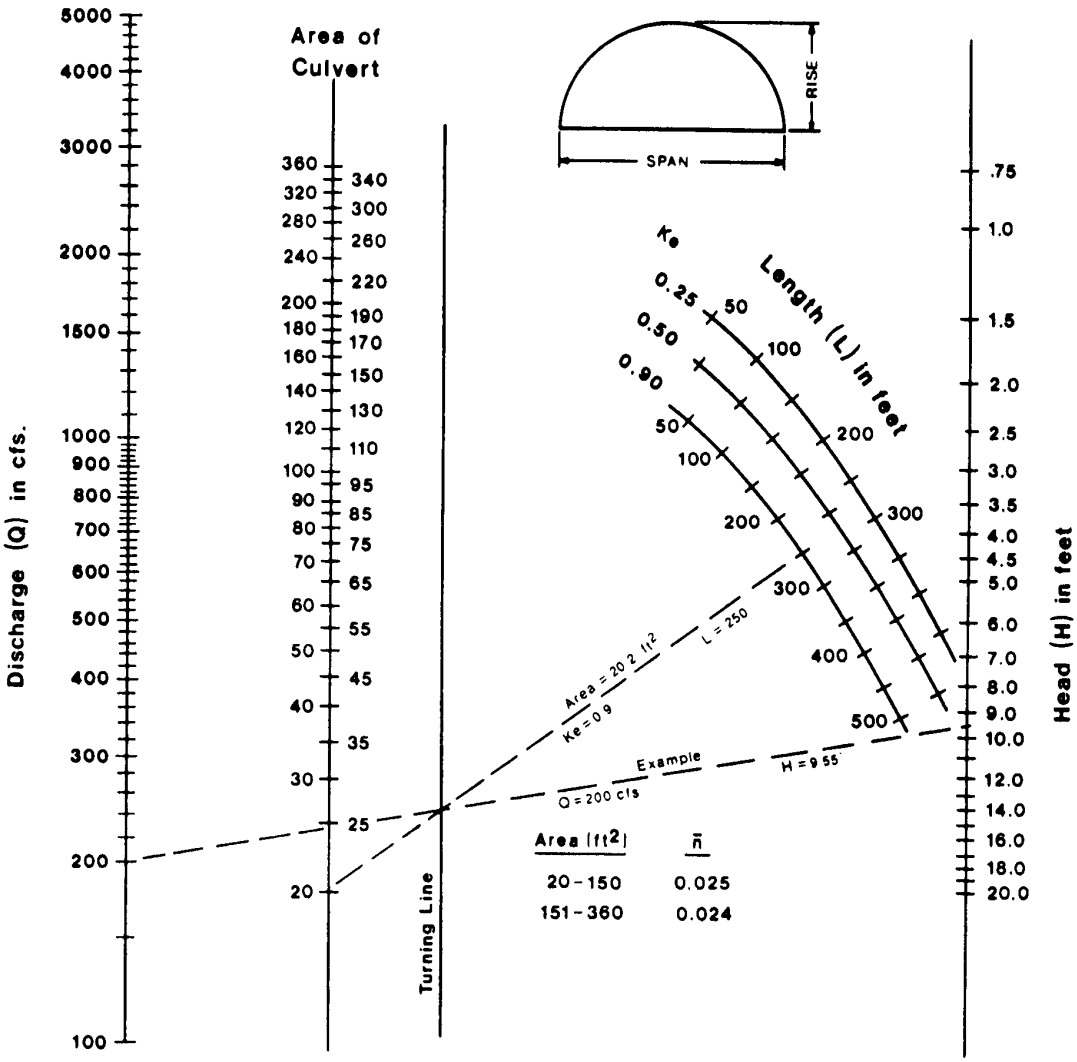
HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM

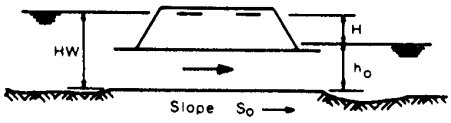
$0.3 \leq$ RISE / SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 46B





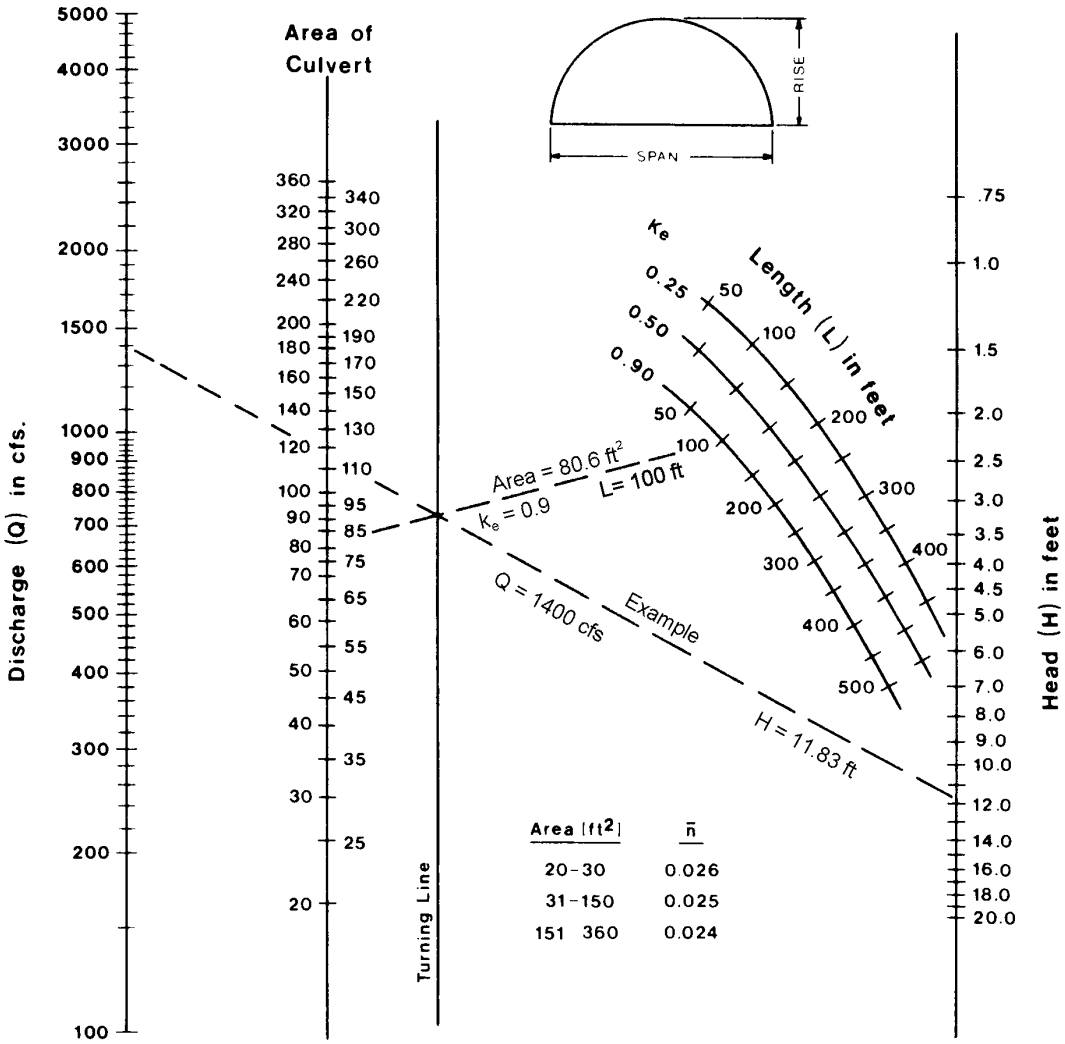
SUBMERGED OUTLET CULVERT FLOWING FULL

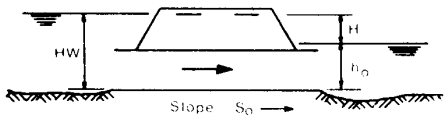
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE / SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 47B





SUBMERGED OUTLET CULVERT FLOWING FULL

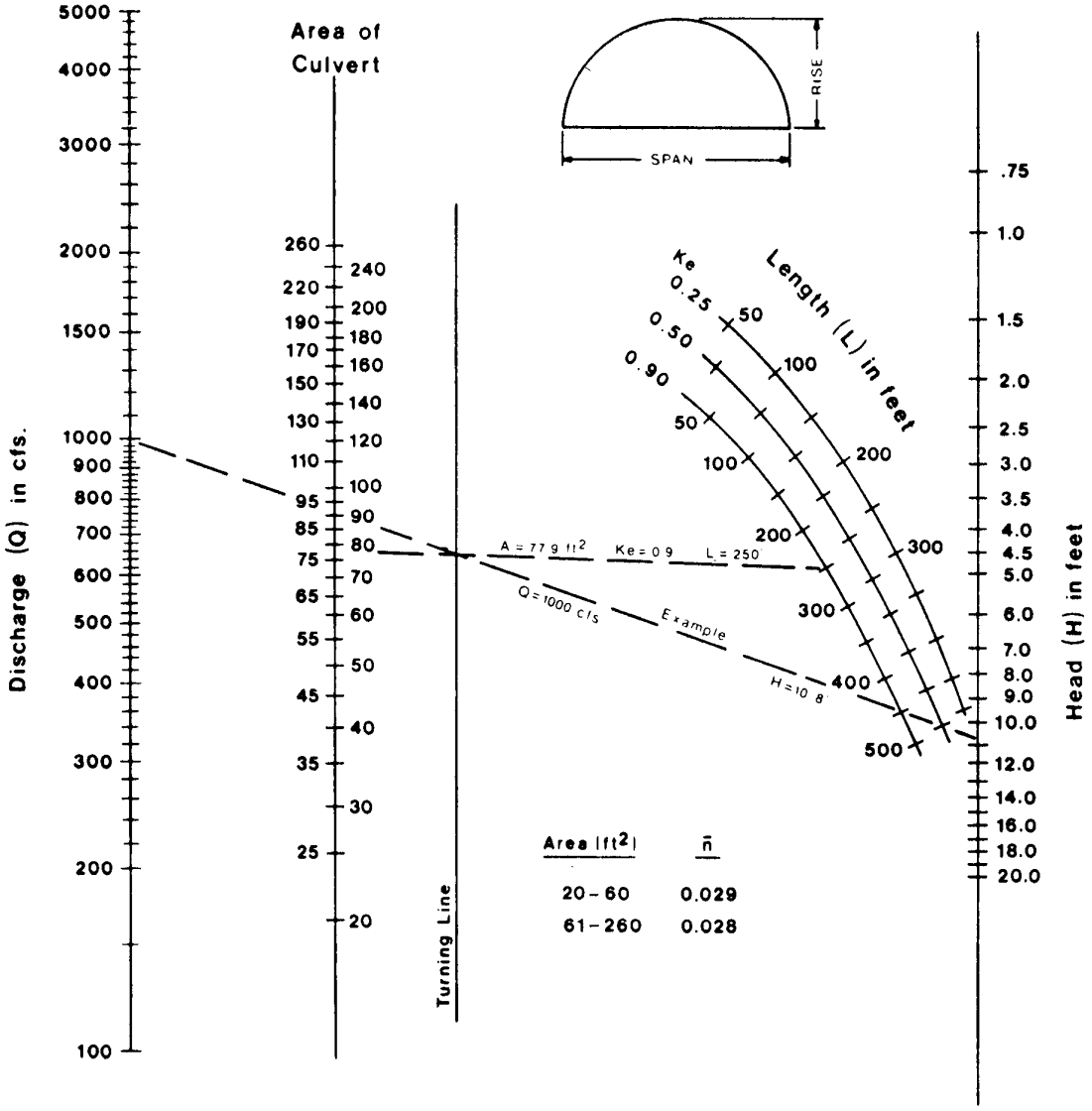
HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM

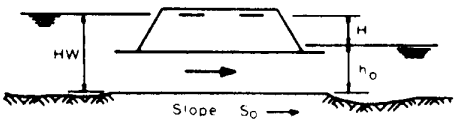
0.5 ≤ RISE / SPAN

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 48B





SUBMERGED OUTLET CULVERT FLOWING FULL

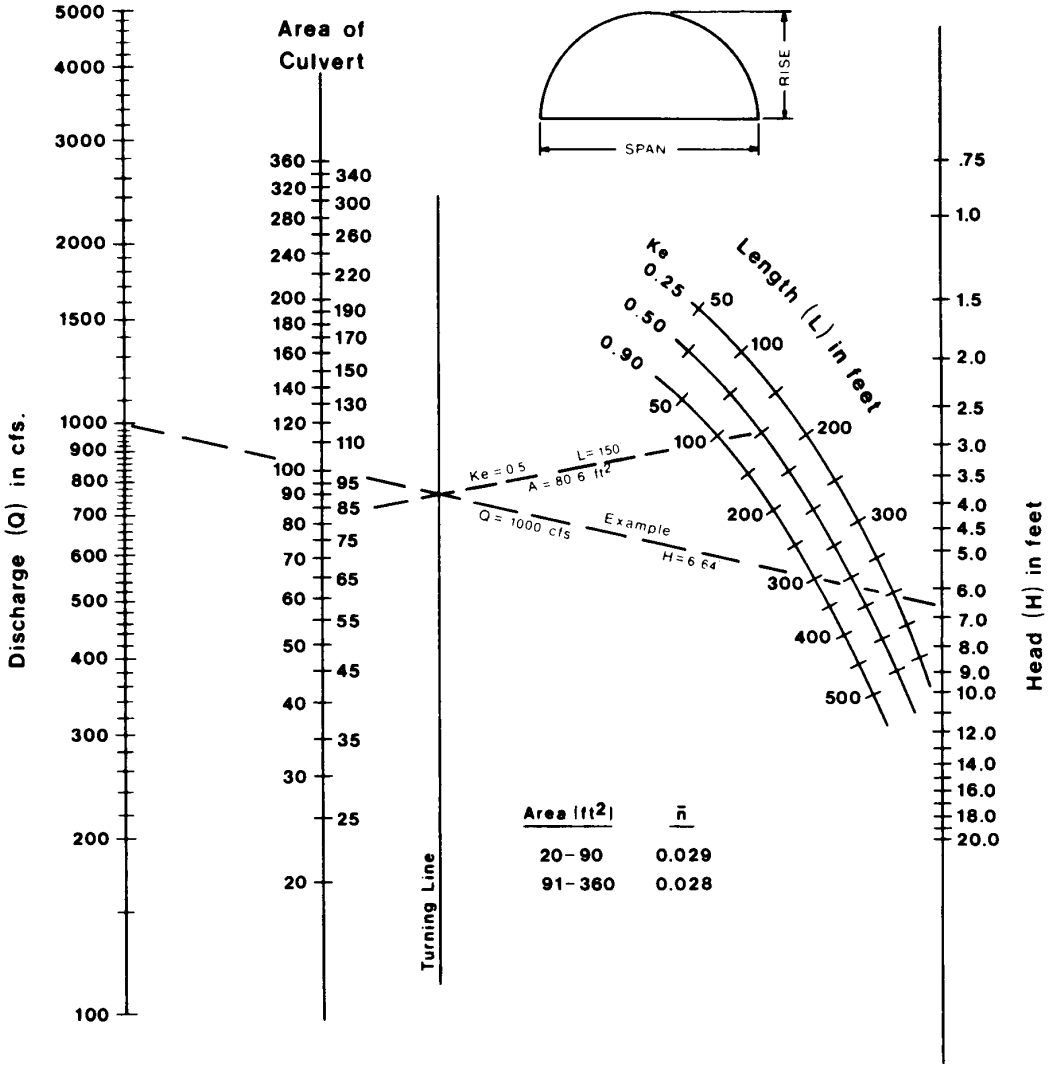
HEAD FOR C.M. ARCH CULVERTS FLOWING FULL EARTH BOTTOM (n_b = 0.022)

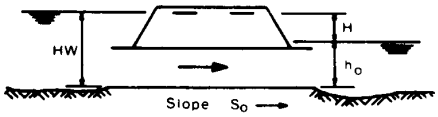
0.3 ≤ RISE / SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 49B





SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL

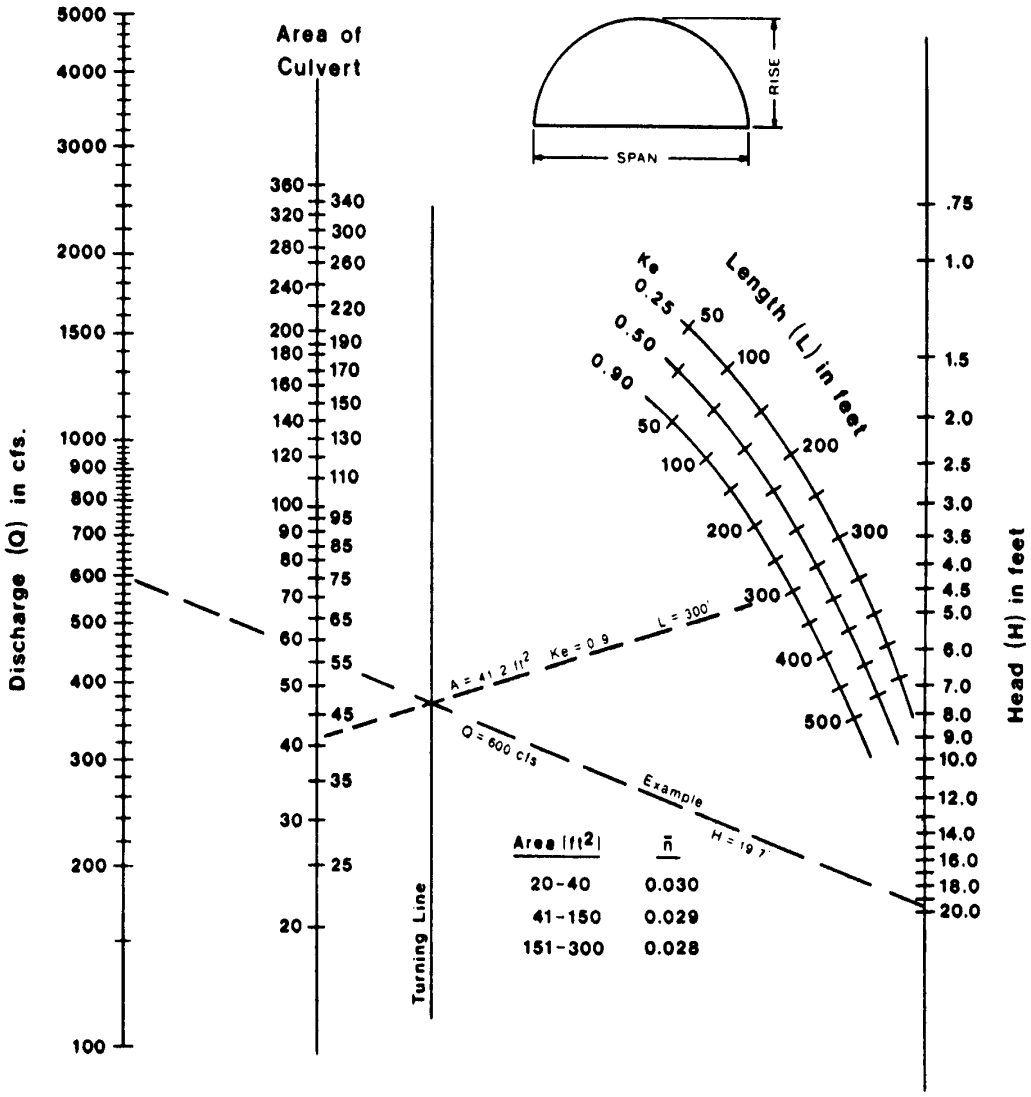
EARTH BOTTOM (n_b = 0.022)

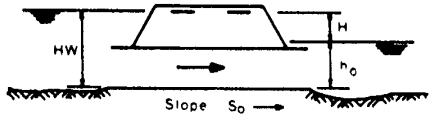
0.4 ≤ RISE / SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 50B





SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL EARTH BOTTOM (n_b = 0.022) 0.5 ≤ RISE / SPAN

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

CHART 51B
(English Units)

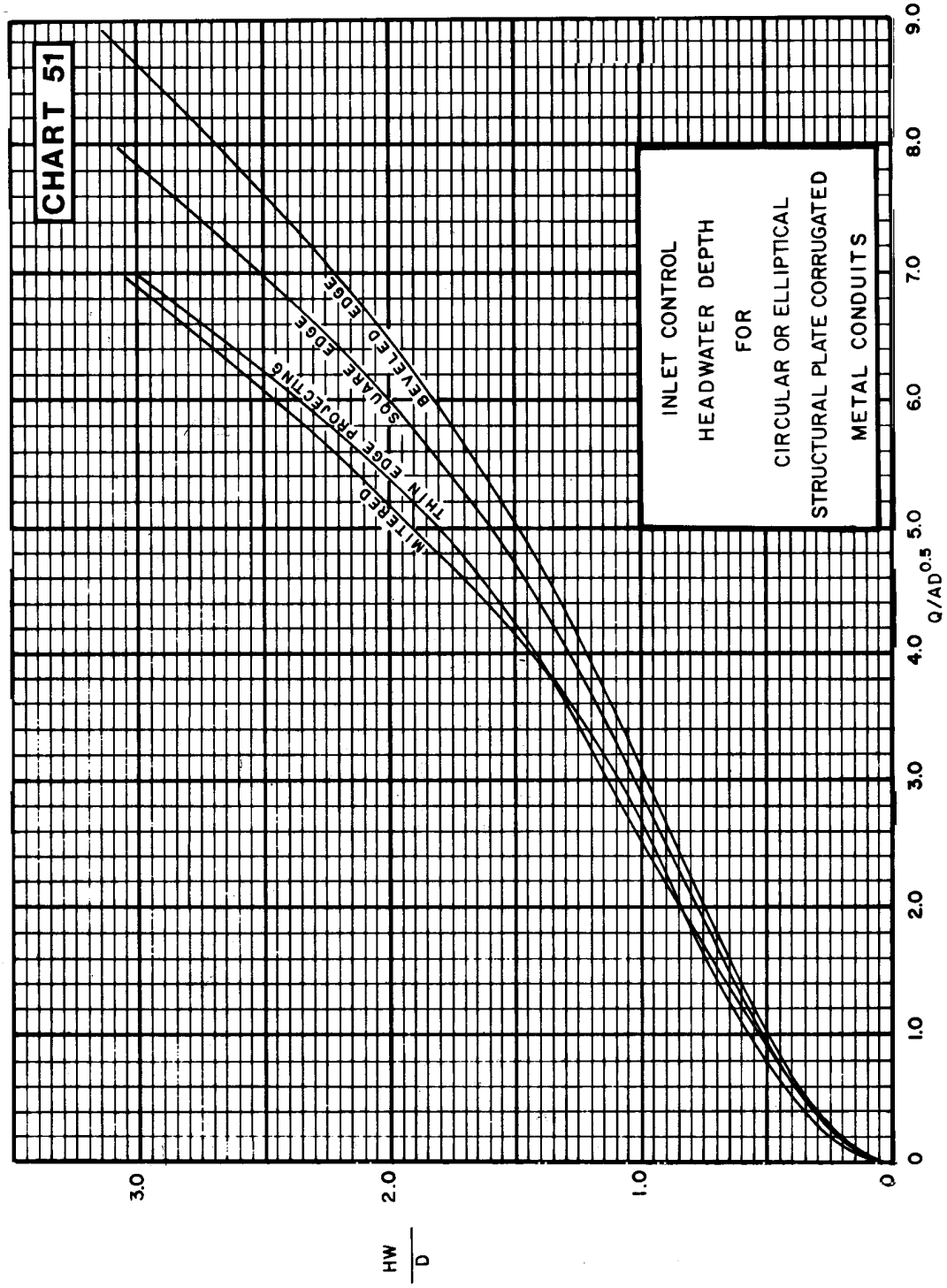


CHART 52B
(English Units)

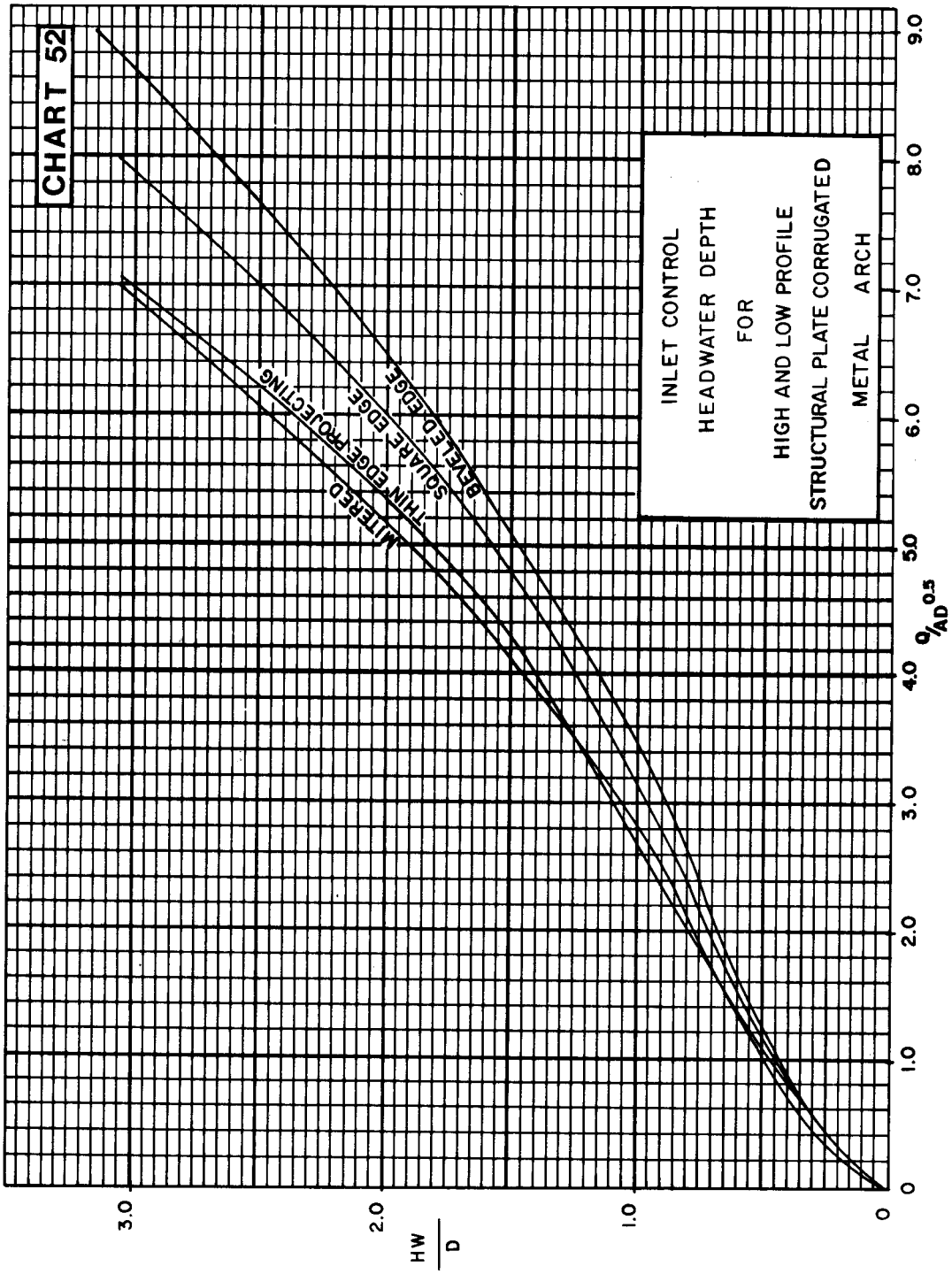
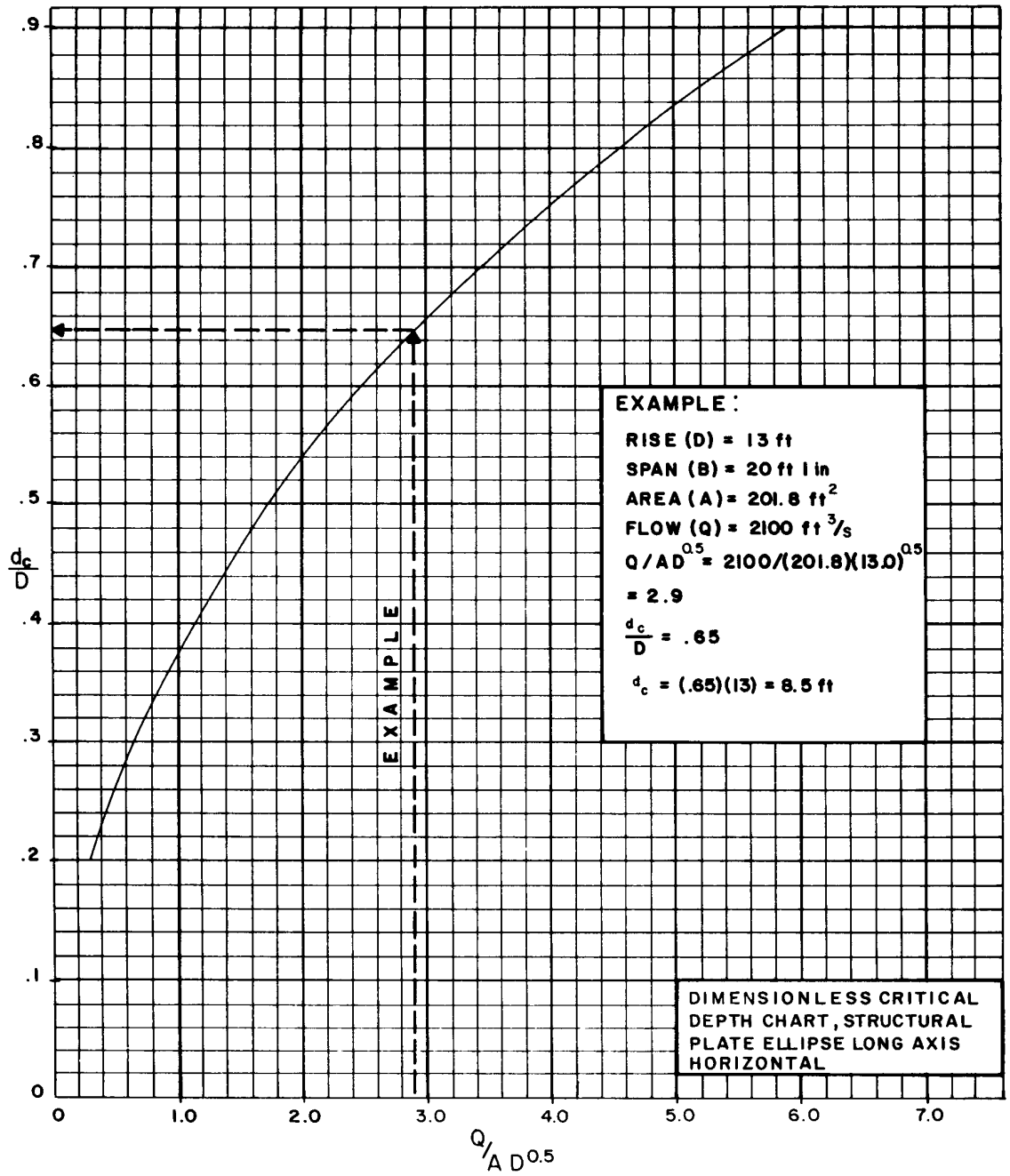


CHART 53B


.9
.8
.7
.6
.5
.4
.3
.2
.1
0
$\frac{d_c}{D}$
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
$Q/A\,D^{0.5}$
EXAMPLE
EXAMPLE:
RISE (D) = 13 ft
SPAN (B) = 20 ft 1 in
AREA (A) = 201.8 ft^2
FLOW (Q) = 2100 ft^3/s
$Q/AD^{0.5} = 2100/(201.8)(13.0)^{0.5}$
= 2.9
$\frac{d_c}{D}$ = .65
d_c = (.65)(13) = 8.5 ft
DIMENSIONLESS CRITICAL DEPTH CHART, STRUCTURAL PLATE ELLIPSE LONG AXIS HORIZONTAL

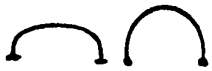


CHART 54B

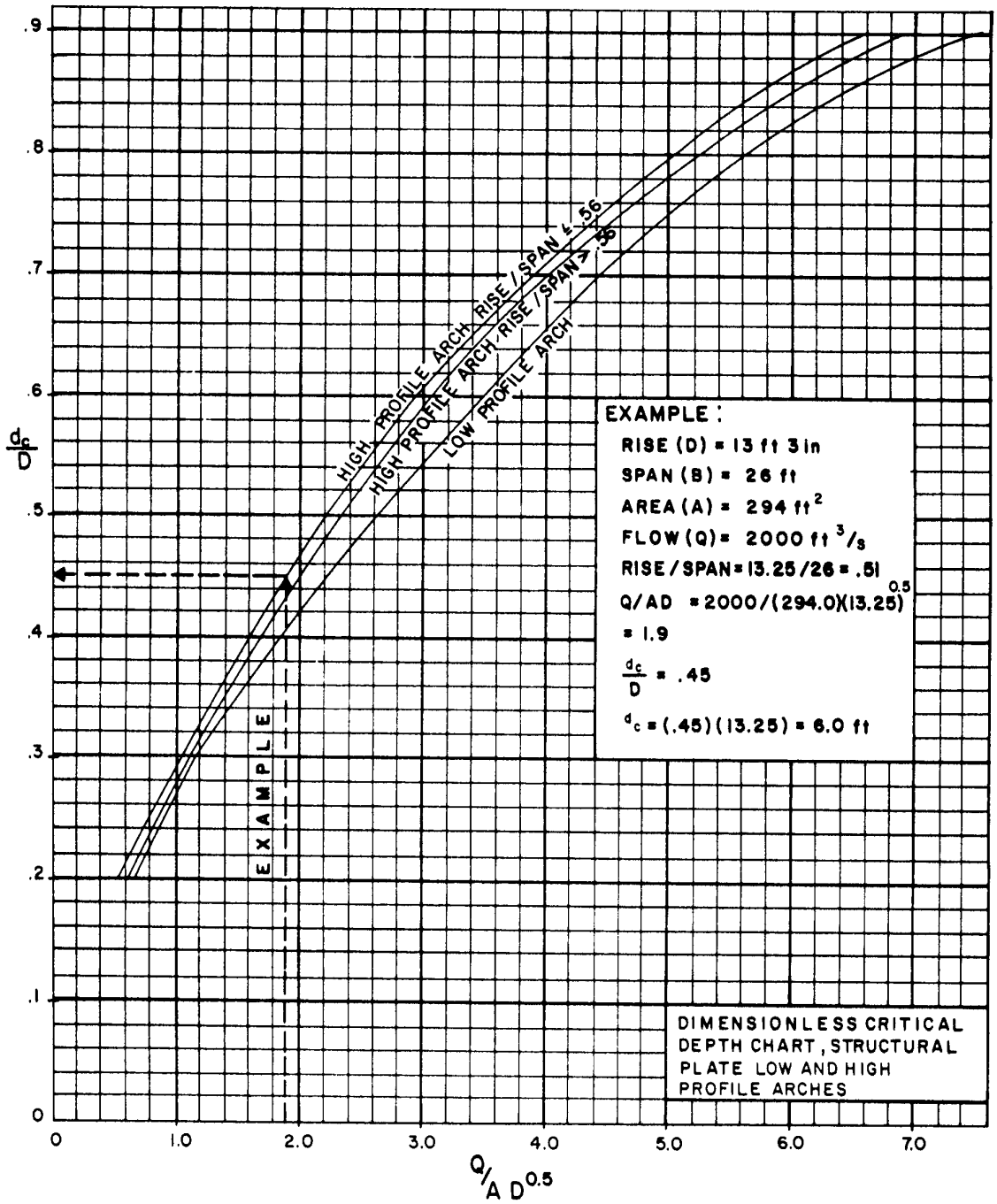
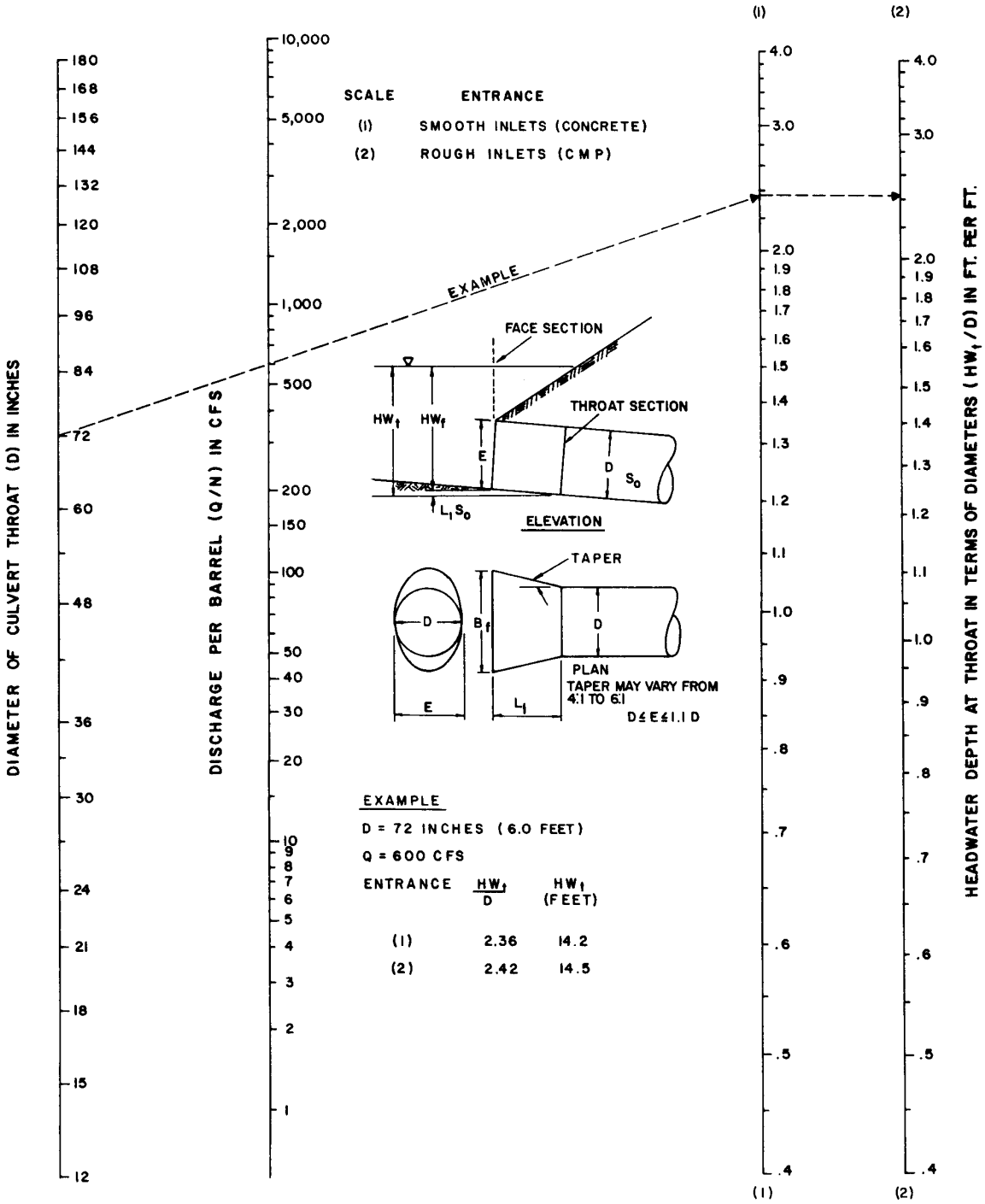
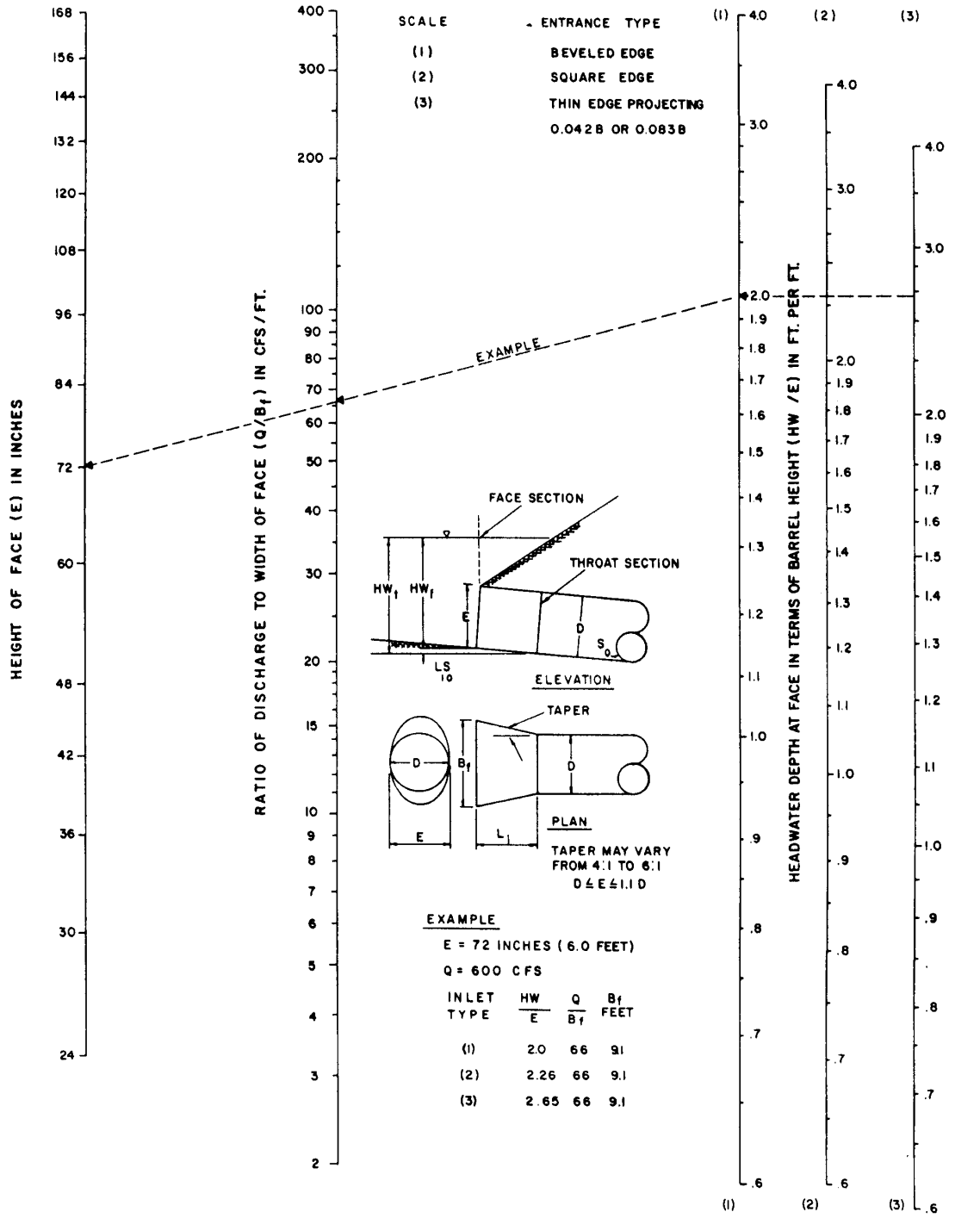

HIGH PROFILE ARCH RISE / SPAN ≤ .56
HIGH PROFILE ARCH RISE / SPAN > .56
LOW PROFILE ARCH
EXAMPLE
EXAMPLE :
RISE (D) = 13 ft 3 in
SPAN (B) = 26 ft
AREA (A) = 294 ft²
FLOW (Q) = 2000 ft³/s
RISE / SPAN = 13.25 / 26 = .51
Q/AD = 2000/(294.0)(13.25)^0.5
= 1.9
dc/D = .45
dc = (.45)(13.25) = 6.0 ft
DIMENSIONLESS CRITICAL DEPTH CHART, STRUCTURAL PLATE LOW AND HIGH PROFILE ARCHES
dc/D
Q/A D^0.5
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2.0
3.0
4.0
5.0
6.0
7.0

CHART 55B



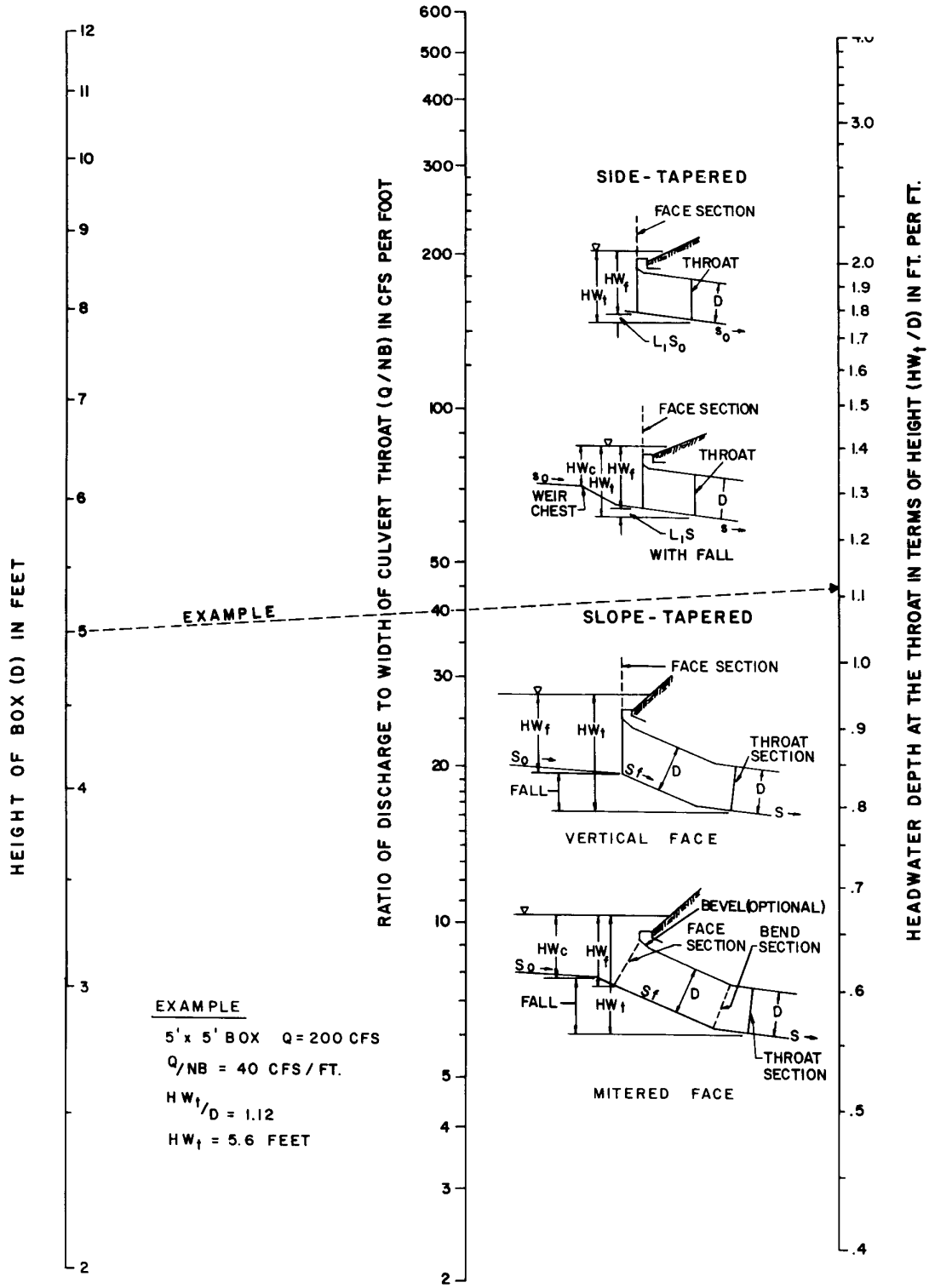
THROAT CONTROL
FOR SIDE-TAPERED INLETS TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

CHART 56B



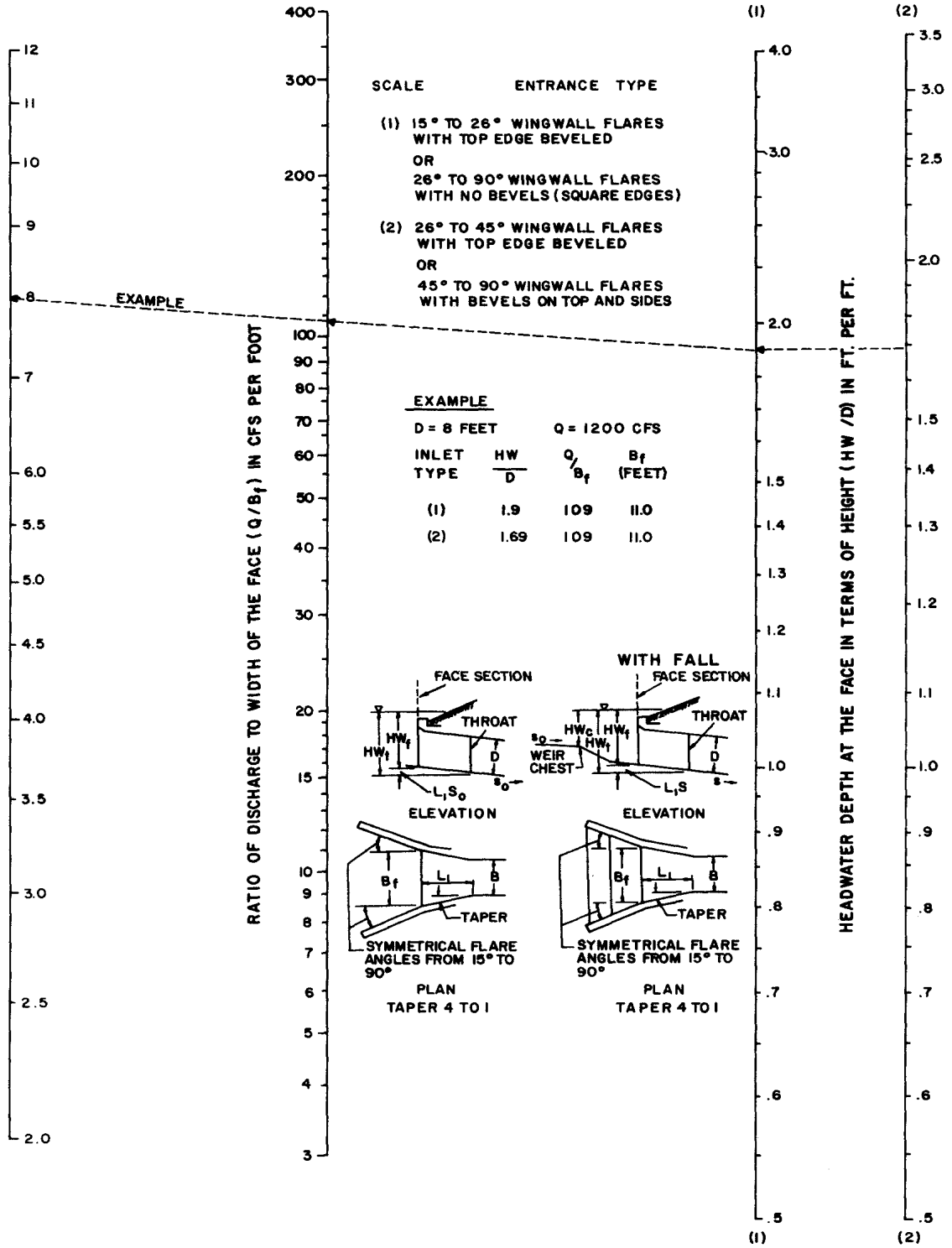
FACE CONTROL FOR SIDE-TAPERED INLETS TO PIPE CULVERTS (NON-RECTANGULAR SECTIONS ONLY)

CHART 57B



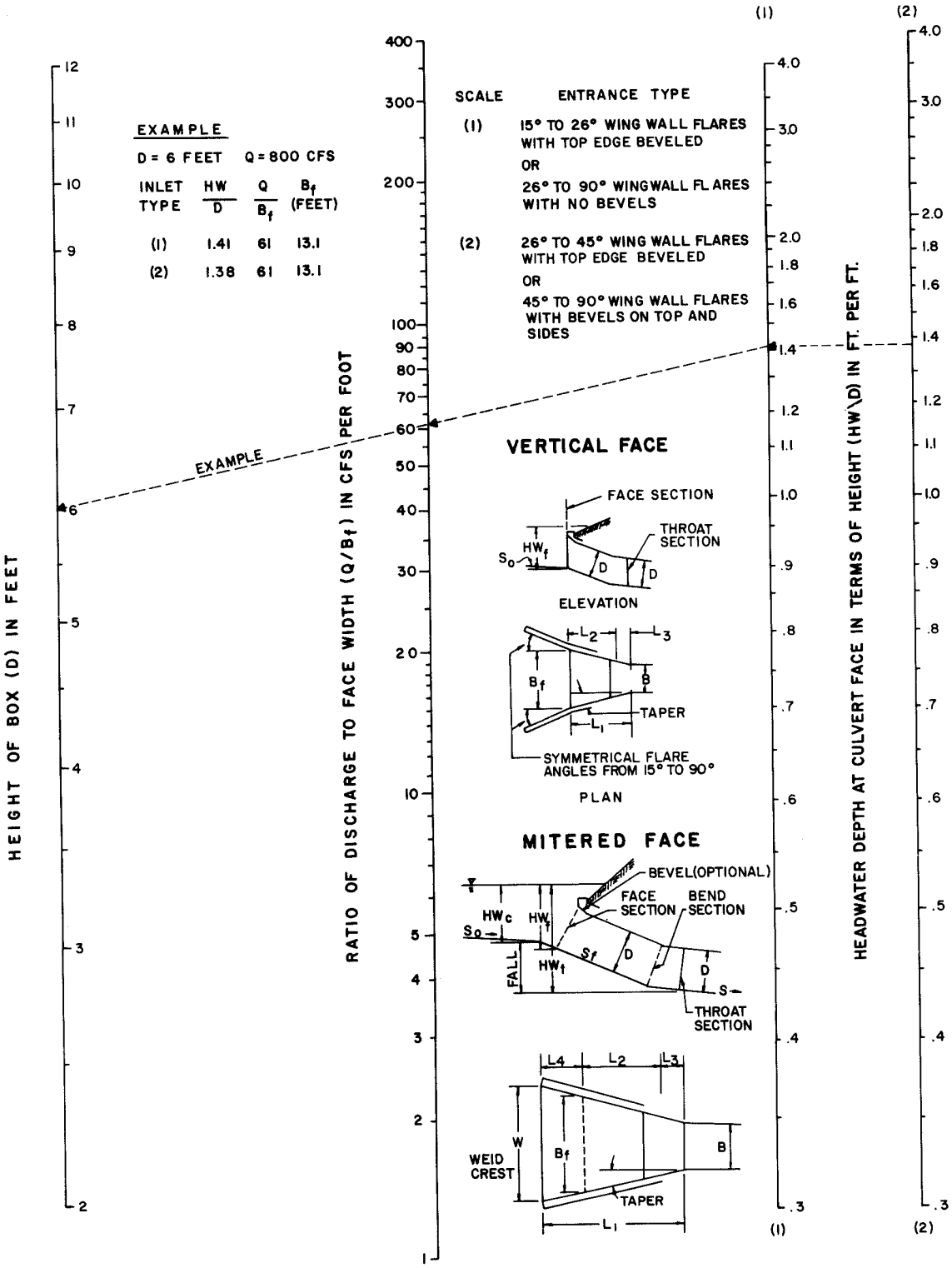
THROAT CONTROL FOR BOX CULVERTS WITH TAPERED INLETS

CHART 58B



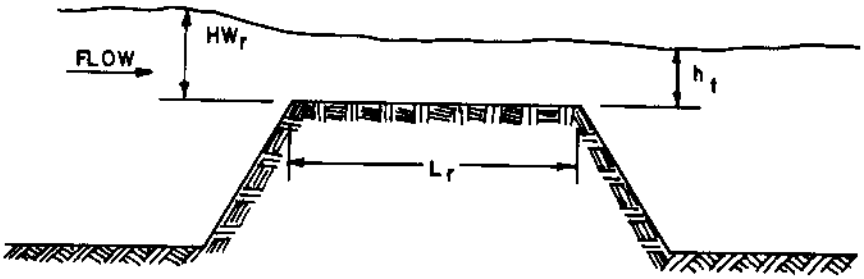
FACE CONTROL FOR BOX CULVERTS WITH SIDE TAPERED INLETS

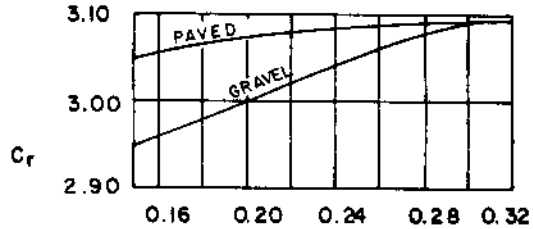
CHART 59B



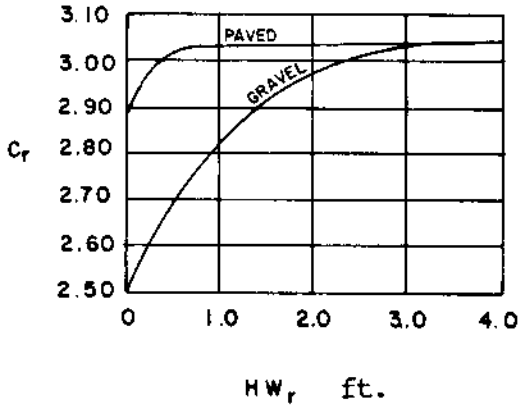
FACE CONTROL FOR BOX CULVERTS WITH SLOPE TAPERED INLETS

CHART 60B





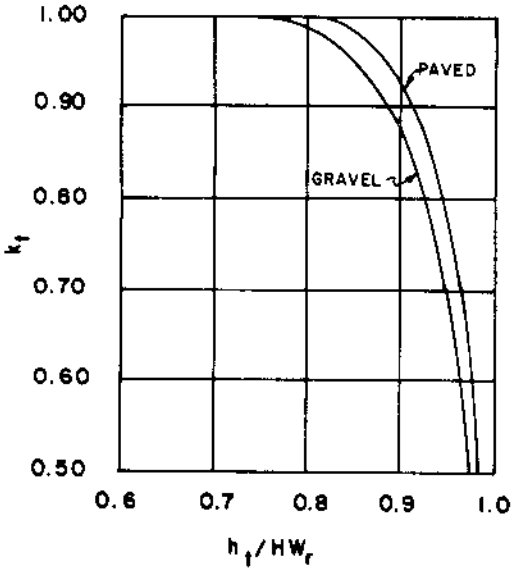
A) DISCHARGE COEFFICIENT FOR $HW_r / L_r > 0.15$



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

$$C_d = k_t C_r$$

$$Q_r = C_d \, L \, H \, W_r^{1.5}$$



C) SUBMERGENCE FACTOR

English Discharge Coefficients for Roadway Overtopping