DESIGN GUIDE MD #5

CULVERT STREAM CROSSINGS

CONSTRUCTION DETAILS
AND SPECIFICATIONS

NRCS Natural Resources Conservation Service

Maryland

May 2002

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SECTION I

GENERAL

This design guide is a technical resource prepared by the Maryland NRCS Engineering staff and is intended for use by the NRCS in Maryland and its partners. The intention of this guide is not to cover all types and sizes of culvert stream crossings, but only those most commonly used. Additional information, types and sizes of culvert pipes can be found in Hydraulic Design Series Number 5, Hydraulic Design of Highway Culverts by the Federal Highway Administration. Contact the local NRCS engineer for a copy of this information.

Section II contains a sample operation and maintenance plan for the culvert pipe stream crossings.

Section III contains the construction specifications to be used as part of the site-specific design. These construction specifications are to be used for all culvert pipe stream crossings. Add site specific construction specifications as needed.

Section IV contains nomographs to be used for sizing culvert pipes for inlet control and pipe flowing full (outlet control).

Section V contains the appropriate construction drawings for culvert pipe stream crossings.

To aid in the design process, the drawings, design guide text and specifications are available on the Maryland Home Page. No changes are allowed on these details without prior approval from the NRCS engineering staff.

PLANNING AND DESIGN CONSIDERATIONS

When planning a stream crossing different elements need to be considered. Several types of crossings are available and depending on the location, use and site constraints one type will be better than others will. Consider planned usage, livestock patterns (existing or planned), stability of the stream channel, and planned changes being made to the system. If the stream channel is not stable, measures will be needed to stabilize the channel. Imbricated riprap or riprap slope protection may be needed. Grade stabilization may also be required. If the stream channel is degrading, stabilization of the channel is critical. It is not enough to look only at the site when determining if channel degradation is occurring. The stream channel down stream of the crossing must be reviewed for active head cutting.

The size, shape, use and slope of the watershed will have a large impact on the type of crossing selected. Watersheds prone to flash flooding and high rates of runoff can damage culverts as well as other types of crossings. Under sized culverts will increase flooding of surrounding areas. Wooded watersheds in general contain large amount of debris, which during high flows can lodge in small culverts or other undersized structures causing increased flooding and damage to the crossing itself.

The frequency of use has a large influence on the type of crossing that will be suitable for a site. Crossings that are used frequently by livestock will be covered with manure. Ramps or fords, which slope toward the stream channel, will flush the manure into the stream. This should be avoided where practical. In addition manure can freeze on the slopes and cause hazards to livestock.

The topography of the crossing location is an important factor in deciding the type of structure to be used by considering its economical and technical aspects and purpose.

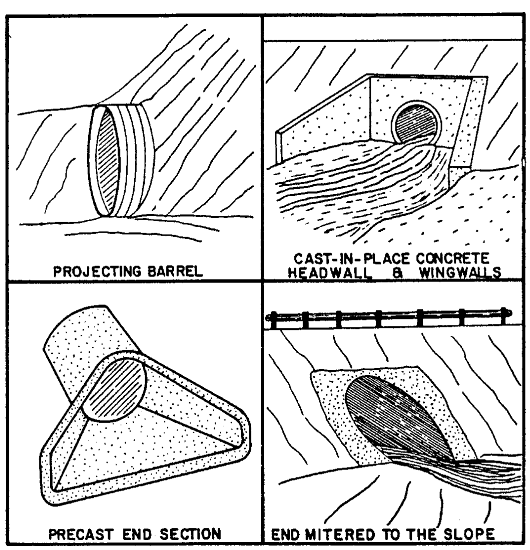
Ford stream crossings can be economical and suitable for the location when, banks are low and other alternatives limited, on large watersheds when bridges or culverts are impractical and when frequency of use and numbers of livestock are low. Banks that are high and steep cannot be easily graded and are not suited well for ramps or fords.

Bridges can be more practical when, the stream bed is deep and narrow, bank slope are steep, for larger and wooded watersheds, frequency of use and number of livestock are high, and when minimizing obstructions in the stream channel is important.

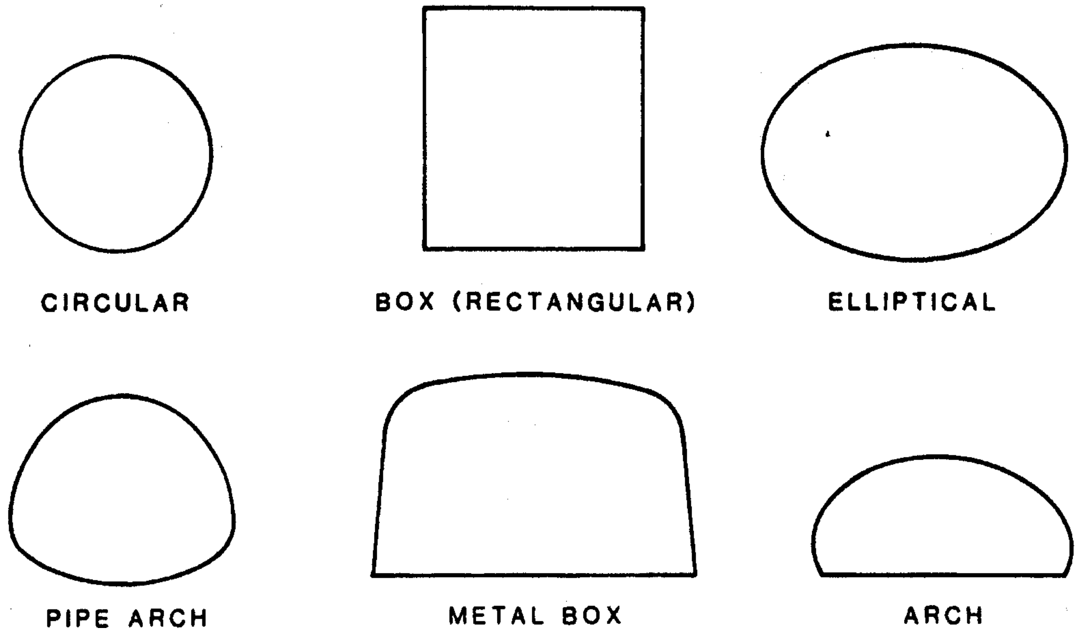
Culverts are mostly used for farm roads and driveways, livestock crossings and on small watersheds where minimal debris in the channel is anticipated. Small diameter culvert should be avoided. Large culverts and arches can be designed and function very similar to bridges.

CULVERT CHARACTERISTICS

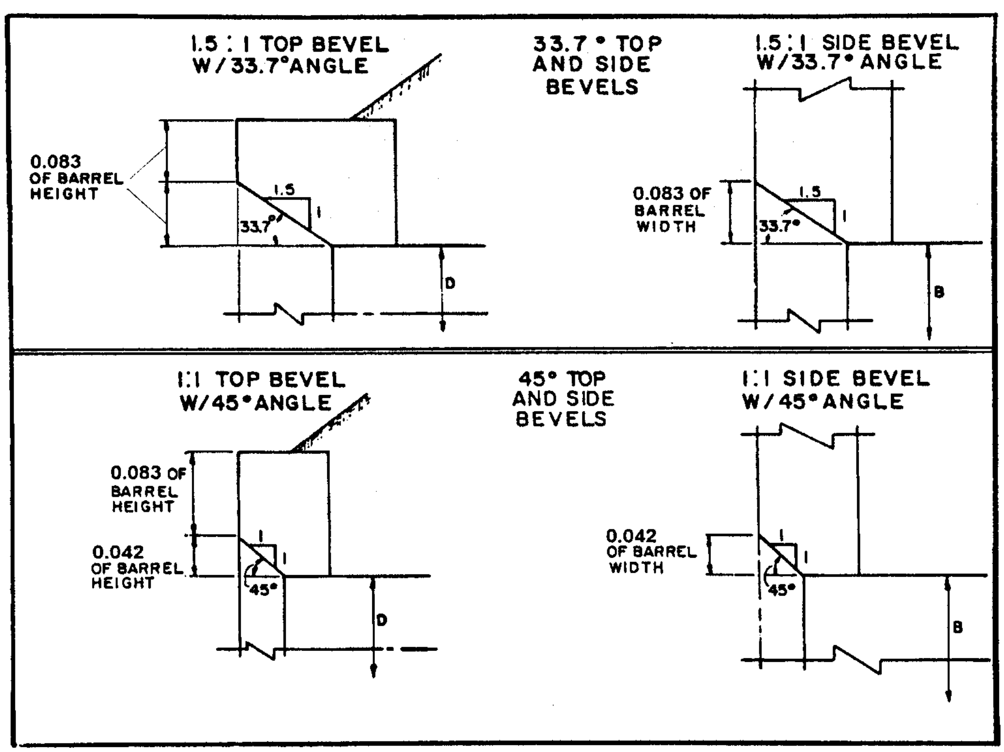
A culvert is a conduit placed within earthfill to carry stream flow. It is designed to safely carry designed flows without damage to the embankment or stream channel, be structurally adequate to carry loads from fill and traffic, be economically suitable for the intended purpose and be durable. Some of the common uses for culvert pipes include stream crossings from driveway to Interstate highways, livestock crossings, utility crossings, water conveyance, grade stabilization and manure transfer. Common shapes of and entrance and exit configurations of culvert pipes are shown below.



Common Inlet Types



Common Pipe Shapes



Beveled Edges

FLOW CHARACHTERISTICS

There are two major types of culvert flow. Flow with inlet control and flow with outlet control.

With inlet control the discharge will be dependent on the headwater elevation above the invert at the culvert entrance, the pipe size and shape, and the entrance edge. The culvert will always flow partially full when it is operating with inlet control. When under inlet control factors such as roughness and length or pipe, slope and outlet conditions will not effect the flow characteristics of the system, unless they are altered enough to reduce flow in the system to create outlet control. In all culvert designs headwater depth at the entrance of the culvert is an important factor in the culvert pipe flow capacity. Sketches of inlet control flow for both unsubmerged and submerged projecting entrances are shown in figures in 1A and 1B. Figure 1C shows a metered entrance flowing under a submerged condition with inlet control.

Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow, as the inlet opening will accept. With outlet control the discharge of the culvert pipe is affected by all hydraulic factors upstream and downstream of the outlet. These factors include headwater elevation, entrance geometry, pipe size length and slope, roughness of the pipe material and tail water conditions. Culverts that flow full operate with outlet control. However for flows that do not submerge the entrance, a culvert flowing partially full may operate with either inlet or outlet control if the tailwater depth is greater than critical depth in the pipe. It may cause the control to shift from inlet control to outlet control. Culverts flowing with outlet control can flow with the culvert barrel full or part full for part of the barrel length or for all of it see figure 2. If the entire cross section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow or flowing full, figures 2A and 2B. Two other common types of outlet control flow are shown in figures 2C and 2D.

HYDRAULICS OF CULVERTS

The economical design of a culvert usually calls for the smallest structure that will carry the design discharge for a fixed head on the inlet. A number of factors must be considered in determining a satisfactory size.

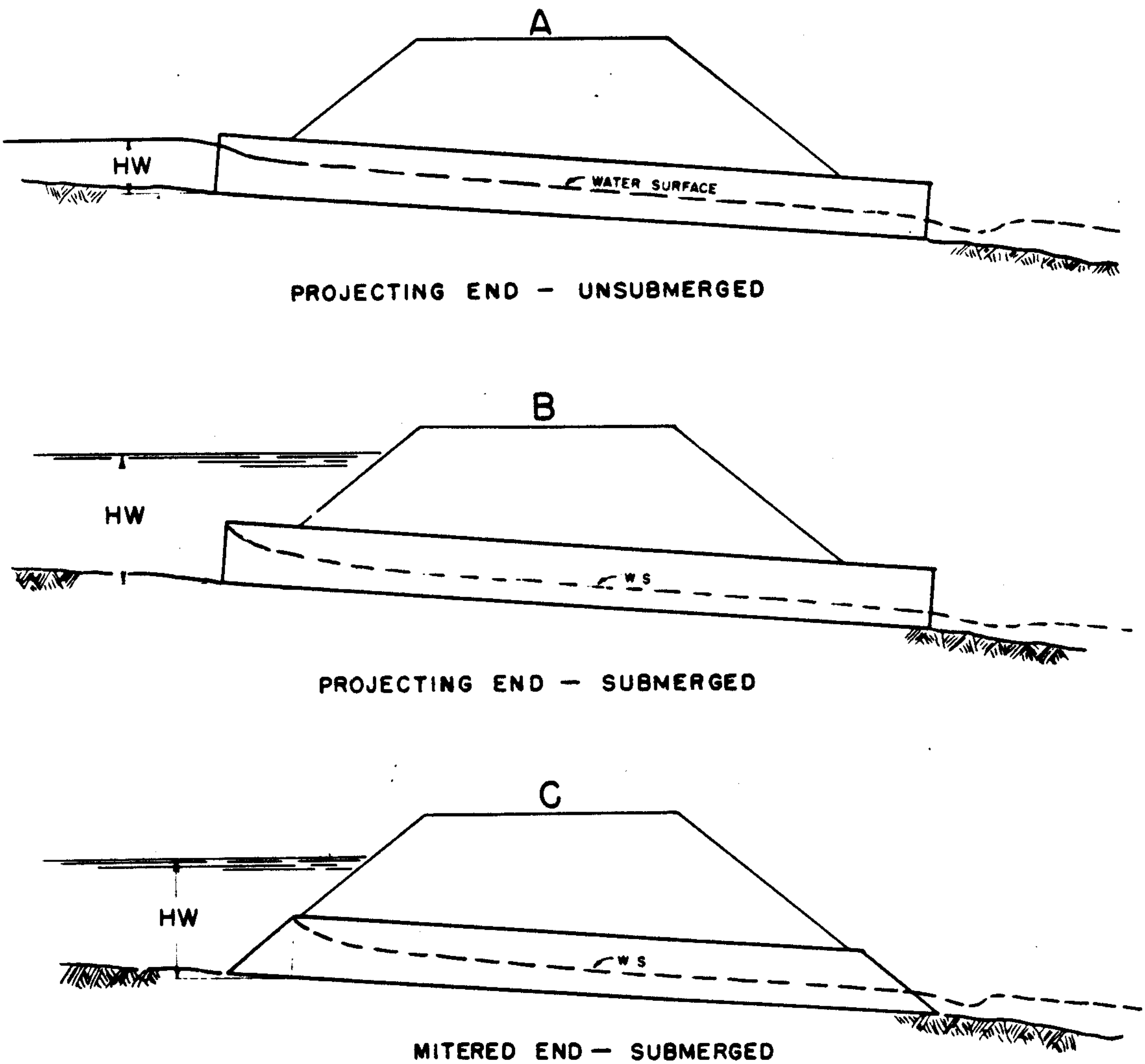
Roughness – A smooth pipe carries more water than a rough pipe, other factors being equal. A concrete pipe culvert flowing full may have a Manning coefficient of 0.010, while corrugated metal may have a Manning coefficient of 0.025. The concrete pipe flowing full carries two and one-half times as much water as the same size of corrugated metal.

Inlet Design – Culverts with an entrance treatment that directs water to it's opening such as a pipe mitered to the slope or flared end sections tend to flow full. Culverts with poorly designed inlets often do not flow full. Inlet design is particularly important in short culverts or long culverts on steep slopes. Inlet design is of lesser importance in long culverts on flat slopes.

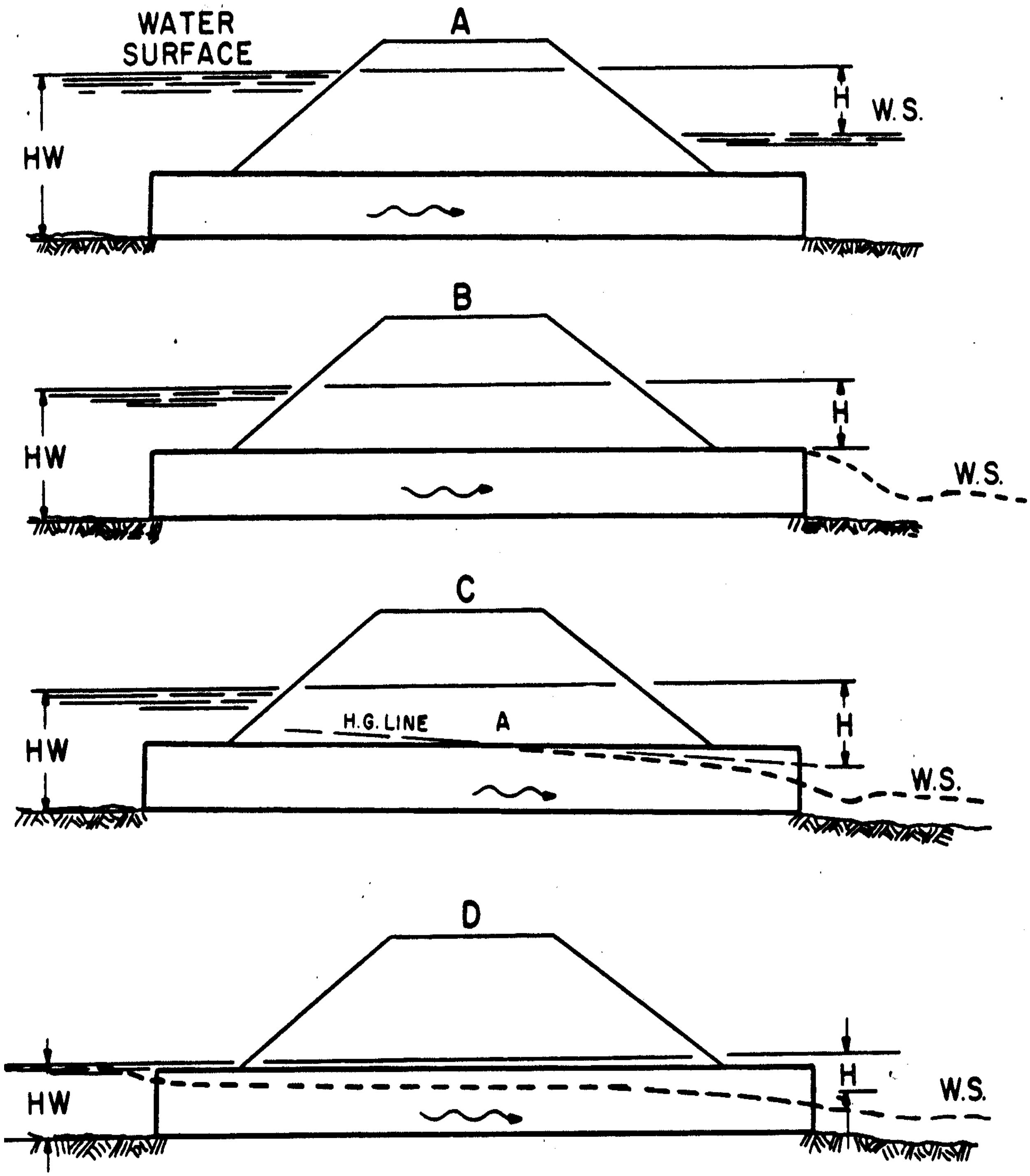
Slope – If a culvert flows full with a free outlet, the fall from the inlet to the outlet becomes available as additional head. Increasing the slope increases this head and also the resultant discharge. Slope is not important when the control section is at the inlet. Since the culvert does not flow full, an increase in slope causes an increase in velocity but a decrease in the depth of flow in the culvert barrel. There is no increase in the culvert discharge.

Length – The length will determine whether a culvert on a flat slope will flow full with a poorly designed inlet. Length is also a factor in culverts flowing full as the head loss due to friction increases with length.

The greatest economy will result from designs based on the culvert flowing full. This requires careful attention to the inlet design, the slope and the roughness.



Inlet Control
Figure 1



Outlet Control
Figure 2

TABLE 1 – ENTRANCE LOSS COEFFICIENTS

Outlet Control, Full or Partly Full, Entrance head loss $H_e = k_e (V^2/2g)$

Type of Structure and Design of Entrance	Coefficient k_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^o or 45^o bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^o or 45^o bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30^o to 75^o to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge	0.2
Wingwalls at 10^o to 25^o to barrel Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

*Note: "End Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design, have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

TABLE 2 – MANNINGS ROUGHNESS COEFFICIENTS

Manning's n for Natural Stream Channels
4/ (Surface width at flood stage less than 100 ft.)

1.	Fairly regular section:	
	a. Some grass and weeds, little or no brush	0.030 – 0.035
	b. Dense growth of weeds, depth of flow materially Greater than weed height	0.035 – 0.05
	c. Some weeds, light brush on banks	0.035 – 0.05
	d. Some weeds, heavy brush on banks	0.05 – 0.07
	e. Some weeds, dense willows on banks	0.06 – 0.08
	f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01 – 0.02
2.	Irregular sections, with pools, slight channel meander; increase values given above about	0.01 – 0.02
3.	Mountain streams, no vegetation in channel, banks usually keep, trees and brush along banks submerged at high stage:	
	a. Bottom of gravel, cobbles, and few boulders	0.04 – 0.05
	b. Bottom of cobbles, with large boulders	0.04 – 0.07

4/ From "Design Charts for Open Channel Flow".

MATERIALS

Common materials for culverts include corrugated metal pipe (CMP), structural steel plate, aluminum, smooth steel, reinforced concrete pipe (RCP), Poly Vinyl Chloride, and double wall High Density Polyethylene (HDPE). Steel pipes should be coated for protection against corrosion. Various coatings such as galvanized, aluminized, asphalt and polymers are also available.

PROCEDURE

Determine the crossing location; consider planned usage, livestock patterns, stability of the stream channel, and planned changes being made to the system including fences, feeding and watering facilities, buffers etc.

Determine if the stream channel is stable. Look downstream of the proposed crossing for active head cutting downstream of the site. If the stream channel is not stable, determine measures needed to stabilize the channel.

Survey the site. Take cross-sections as needed of the stream channel. A minimum of three cross-sections including one at the proposed crossing location and one upstream and downstream. Extend the cross-sections a minimum of 25 feet from the top of bank. Take a profile of the stream channel and extend the profile a minimum of 100 feet upstream and 100 feet downstream of the proposed crossing location.

As required in the conservation practice standard the culvert pipe must be submerged one foot below the stream bottom. This is to allow for partial filling of the pipe with soil and gravel to create a natural substrate for aquatic life. The minimum culvert pipe size shall be 30 inches. In some situations the channel depth at the proposed crossing location is low and only low head requirement can be met. Multiple pipes can be considered under these conditions. When multiple pipes are used the additional pipes need not be submerged below the stream bottom and the pipe sizes can be less than 30 inches in diameter. However careful consideration to the type and size of watershed is needed. If debris and sediment is anticipated the smaller pipe sizes should not be used.

Determine the design discharge. In general the design discharge for a stream crossing on a natural stream will be the channel shaping discharge which is estimated to be between the 1.5 and 2 year frequency discharge. This is commonly referred to as the bankfull discharge. The elevation of the bankfull discharge can be determined using field indicators. Then the bankfull discharge can be estimated using Manning's formula, with the average channel slope, the channel area at the bankfull elevation, and roughness coefficient for the stream channel. Since the bankfull elevation can be difficult to determine a simpler approach is to use the lesser of the 2-year frequency and the top of bank discharge.

There may be instances where a larger frequency design storm discharge is desired. An example is a stream crossing located in a channel used for flood control. It is desirable to pass through the pipe a discharge equal to the design discharge of the channel so that the crossing does not cause flooding.

Using the plotted cross sections determine the maximum headwater that can be achieved, pipe slope and length, and type of pipe desired.

Using the nomographs provided in section IV choose a pipe, or a combination of multiple pipes that will fit within the stream cross section and provide the desired discharge. Both inlet control and outlet control must be checked. The nomographs are written so they may be read in multiple directions. The Inlet control nomographs have three unknowns (pipe size, pipe discharge and HW/D) for a given type of pipe and entrance condition. Once any two of the unknowns are determined the last can be found. The nomographs for pipes flowing full (outlet control) are written with four unknowns (Pipe size, Discharge, Head and length of Pipe) for a given type of pipe and entrance condition. Once any three of the unknowns are determined the last can be found.

Specific nomographs for plastic pipe have not been developed however; the existing nomographs may be used for plastic pipe with reasonable accuracy. When checking inlet control for plastic pipe use "Headwater Depth for C.M. Pipe Culverts with Inlet Control". When checking for pipe flowing full (Outlet Control) use the nomograph for "Head for Concrete Pipe Culverts Flowing Full n=0.012).

The pipe sizing instructions included in the next section gives one method for determining required pipe sizes using the nomographs. Follow the procedure to check against inlet control and outlet control (Pipe flowing full). With moderate experience reading the nomographs in multiple directions will become evident.

The culvert pipe design sheet can be used to record the design information and also provides step by step instructions in determining a pipe size.

Construction details and specifications are provided in the design guide. These are to be used as part of a site-specific design. There will be no changes in the drawings or specifications without approval from the NRCS engineer.

PIPE SIZING INSTRUCTION FOR THE CULVERT PIPE DESIGN SHEET

The instructions given below show one methodology for the using the nomographs and culvert pipe design sheets.

Choose a type of pipe and entrance condition and record in block 1 of the Culvert Pipe Design Sheet.

Check Inlet Control

Choose a trial pipe size and record in block 3. In most cases a minimum pipe diameter of 30 inch will be required. The initial choosing of the pipe size is random and based on experience.

Determine the inlet HW from the site conditions and record in block 5. Divide the inlet HW (ft) by the pipe diameter (ft.) and record in block 4

Using the pipe size, HW/D and the Inlet Control nomographs charts 1-7 determine the pipe discharge (Q) and record in block 2. Compare the pipe discharge to that required for the design discharge. If the pipe discharge is low than a larger pipe, or multiple pipes will be required. To use nomograph start at right with HW/D and read horizontally to scale (1) then use a straight inclined line through the discharge scale to the pipe diameter scale. Read the discharge at inclined line intersect with discharge scale.

Check Outlet Control

From Table 1 determine entrance loss coefficient and record in block 6 under outlet control.

Using the nomographs for pipe flowing full (Outlet Control), pipe size, length of pipe and entrance loss, determine the required H for the outlet conditions. Draw inclined line from pipe scale to the pipe diameter. Mark where the inclined line intersects the turning line. Draw a line from the discharge scale line through the mark at the turning line to the required head (H) scale. Record H in block 7.

Record pipe diameter in block 8.

Multiply the pipe diameter (ft) by 0.75 and record in block 9.

Determine the tailwater (ft) over the barrel outlet invert from site conditions and record this in block 10.

Determine h_o and record in block 11. Use the greater of the tailwater over the invert of the barrel outlet or .75D.

Determine LS_o by multiplying the pipe length (ft) by the pipe slope (ft/ft) and record in block 12.

Find required HW for the outlet conditions by solving formula $HW = H + H_o – LS_o$ and record in block 13.

The greater of the required headwaters (HW) for the inlet or outlet conditions will govern. This is the controlling headwater, record in block 14. This is the minimum required HW for the given conditions and it will determine if the pipe is in inlet or outlet control.

Compute outlet velocity by dividing the pipe discharge (Q in cfs) by the area of the Pipe (A in ft^2).

DECISION RECORDING

There are many design options available that will effect the design, construction and operation and maintenance of the crossing. Many decisions are made in the field. Decisions are never recorded or are recorded on the CPA-6 and never discussed again, that is, until there is a problem. Recording of decisions and events is an important part of the design process. It is important that are recorded in the CPA-6 and the Operation and Maintenance Plan and construction plans are carefully reviewed with the landowner.

SECTION II

SAMPLE
OPERATION AND MAINTAINANCE PLAN
CULVERT PIPE STREAM CROSSING

Definition
A stabilized area to provide access across a stream for livestock, farm machinery or other vehicles.

Purpose
To provide a controlled crossing for livestock along with access for farm equipment. To control bank erosion, reduce sediment and enhance water quality.

Operation and Maintenance

This crossing is designed for livestock use and a maximum vehicular load of 15 ton gross vehicle weight.

The crossing shall be inspected at least twice annually. Provide maintenance or repairs as needed. Stone approaches shall be inspected and stone added as needed to maintain access areas.

Inspect the stream channel under and around the crossing, at least twice annually and after major storms, for obstructions. Remove any blockages of trash, sediment, or debris that could effect flow.

Fencing on the crossing and surrounding areas shall be maintained and repaired as needed.

If erosion is occurring around the pipe, riprap, earthfill or surrounding areas contact the Soil Conservation Office.

If pipes have become damaged or show noticeable signs of bending, corrosion, or other signs of damage discontinue use and contact the Soil Conservation Office.

If you have any questions or need assistance, call your District office at ____________.

I have reviewed and understand the operation and maintenance plan contained herein.

________________________________ __________ ______________________ _____

Landowner/Operator Date District Representative Date

SECTION III

CONSTRUCTION SPECIFICATIONS
CULVERT PIPE STREAM CROSSINGS

1. All materials and construction shall be in accordance with applicable NRCS standards and construction specifications.
2. Any changes in the plans or specifications must be approved by the engineer prior to being made. Changes are to be reviewed by the landowner for concurrence.
3. Pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unsuitable material is encountered; all such material shall be removed and replaced with suitable earth compacted to provide adequate support.
4. Steel pipe and its appurtenances shall be galvanized and fully bituminous coated and shall conform to the requirements of AASHTO specification M-190 Type A with watertight coupling bands. Coupling bands must be composed of the same material as the pipe.
5. Aluminum coated steel pipe and its appurtenances shall conform to the requirements of AASHTO specification M-274-79I. Coupling bands must be composed of the same material as the pipe.
6. Aluminum pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Coupling bands must be composed of the same material as the pipe.
7. All connections for metal pipe shall use a rubber or neoprene gasket when joining pipe sections. The end of each pipe shall be re-rolled an adequate number of corrugations to accommodate the bandwidth. The following type connections are acceptable for pipes less than 24 inches in diameter: flanges on both ends of the pipe with a circular 3/8 inch closed cell neoprene gasket, pre-punched to the flange bolt circle, sandwiched between adjacent flanges; a 12-inch wide standard lap type band with 12-inch wide by 3/8-inch thick closed cell circular neoprene gasket; and a 12-inch wide hugger type band with o-ring gaskets having a minimum diameter of 1/2 inch greater than the corrugation depth. Pipes 24 inches in diameter and larger shall be connected by a 24 inch long annular corrugated band using a minimum of 4 (four) rods and lugs, 2 on each connecting pipe end. A 24-inch wide by 3/8-inch thick closed cell circular neoprene gasket will be installed with 12 inches on the end of each pipe. Flanged joints with 3/8 inch closed cell gaskets the full width of the flange is also acceptable
8. Concrete pipe shall have a rubber gasket joint and shall meet ASTM specification C-76. Pipe shall be placed with the bell end upstream.
9. PVC pipe shall be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241. Coupling bands or joints must be composed of the same material as the pipe and be watertight.

10. Corrugated High Density Polyethylene (HDPE) pipe, couplings and fittings shall conform to the following: 4” – 10” inch pipe shall meet the requirements of AASHTO M252 Type S, and 12” through 24” inch shall meet the requirements of AASHTO M294 Type S. Coupling bands or joints must be composed of the same material as the pipe and be watertight.

11. Concrete shall have Type IA cement, compressive strength of 4,000 psi, and have 5% air entrainment.

12. Reinforcing steel shall conform to ASTM-A-615, Grade 60 steel. All reinforcing material shall be free of dirt, rust, scale, oil, paint or other coatings. The steel shall be accurately placed into position, as shown on the plans, and securely restrained and blocked into position prior to placement of concrete. Insertion of steel into fresh concrete is not permitted. Reinforcement steel shall have a minimum of 2 inches of concrete cover against all forms and 3 inches against soil, unless otherwise shown on the plans. All reinforcement steel splices shall overlap a minimum of 18 inches. Welded wire fabric shall conform to ASTM-A-185 and overlap a minimum of 2 squares.

13. Plasticizing and retarding admixture may be used with prior approval from the engineer and shall conform to ASTM specification C 1017.

14. Concrete shall be delivered to the site and discharged completely into the forms within 90 minutes after the introduction of cement to the aggregates. This time shall be reduced to 45 minutes when the atmospheric temperature is over 90^0 F. Set retarding admixtures may be used to increase mixing time, with prior approval from the engineer and shall conform to ASTM specification C 260.

15. All concrete for abutments shall be consolidated with internal type mechanical vibrators or by rodding.

16. Concrete shall not be placed when the daily minimum atmospheric temperature is less than 40^0 F unless facilities are provided to prevent the concrete from freezing. The concrete shall be kept at or above 40^0 F for a minimum of 7 days or the concrete shall be kept at or above 55^0 F for a minimum of 3 days. The use of accelerators or antifreeze compounds will not be allowed. The concrete shall be maintained at temperature below 90^0 F during mixing, conveying and placement.

17. Exposed surfaces of concrete shall be protected from the direct rays of the sun for at least the first 3 days. All concrete shall be kept continuously moist for at least 7 days after being placed. Moisture may be applied by spraying or sprinkling as necessary to prevent the concrete from drying. Concrete shall not be exposed to freezing during the curing period. Curing compounds may be used.

18. Compaction around structures shall be accomplished by placing fill in maximum 4-inch lifts and compacting by means of hand tampers or other manually directed compaction equipment. The technician shall determine if the moisture content is suitable for fill placement. The contractor shall make adjustments as directed by the technician. The method of compaction shall be approved prior to placement of fill material.

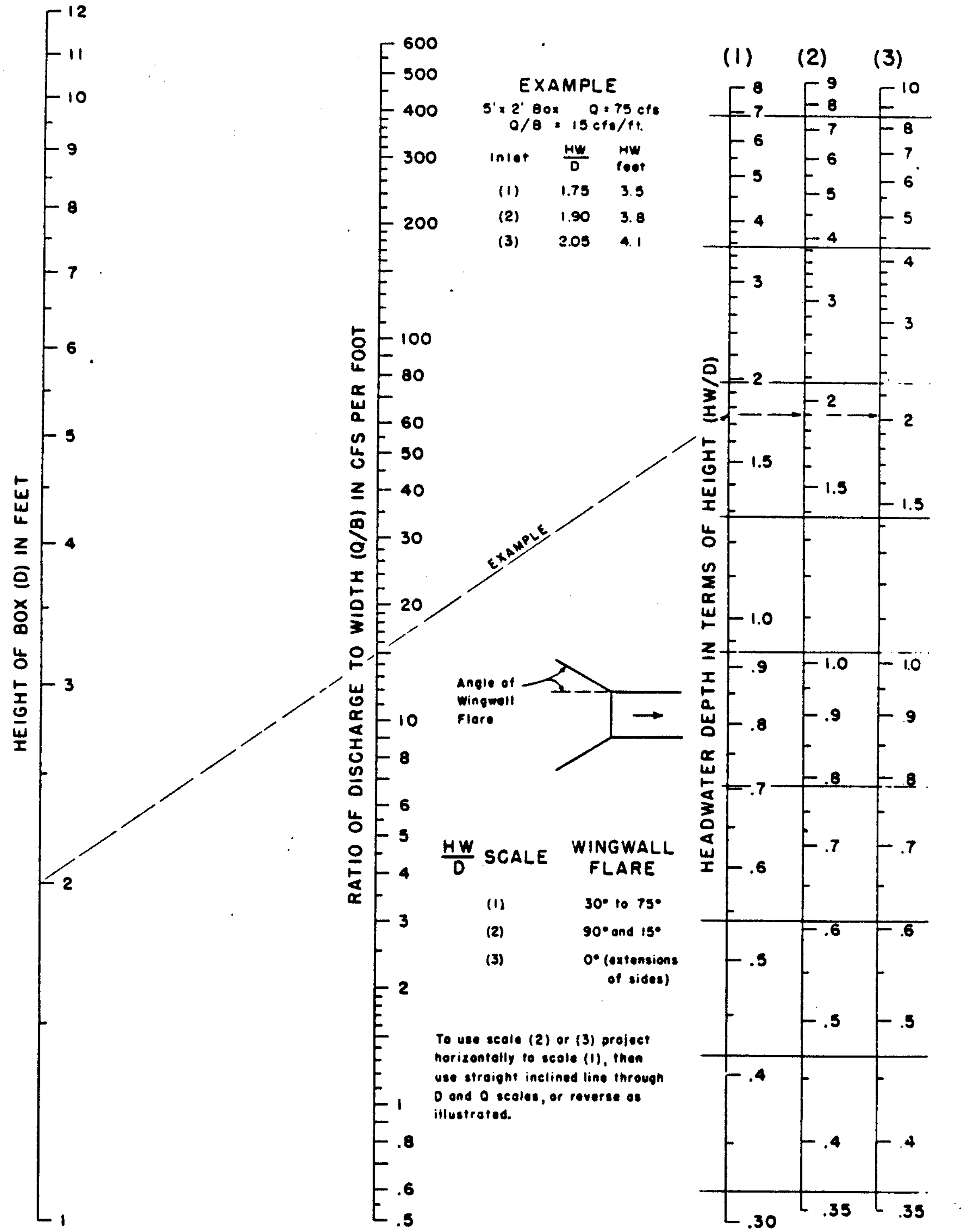
19. The Soil Conservation District makes no representation as to the existence or nonexistence of any utilities at the construction site. Shown on these construction drawings are those utilities, which have been identified. It is the responsibility of the landowners or operators and contractors to assure themselves that no hazard exists or damage will occur to utilities. Miss Utility should be contacted at 1 800-257-7777.

SECTION IV

Nomographs

Culvert Pipe Design Sheet

CHART 1



HEADWATER DEPTH
FOR BOX CULVERTS
WITH INLET CONTROL

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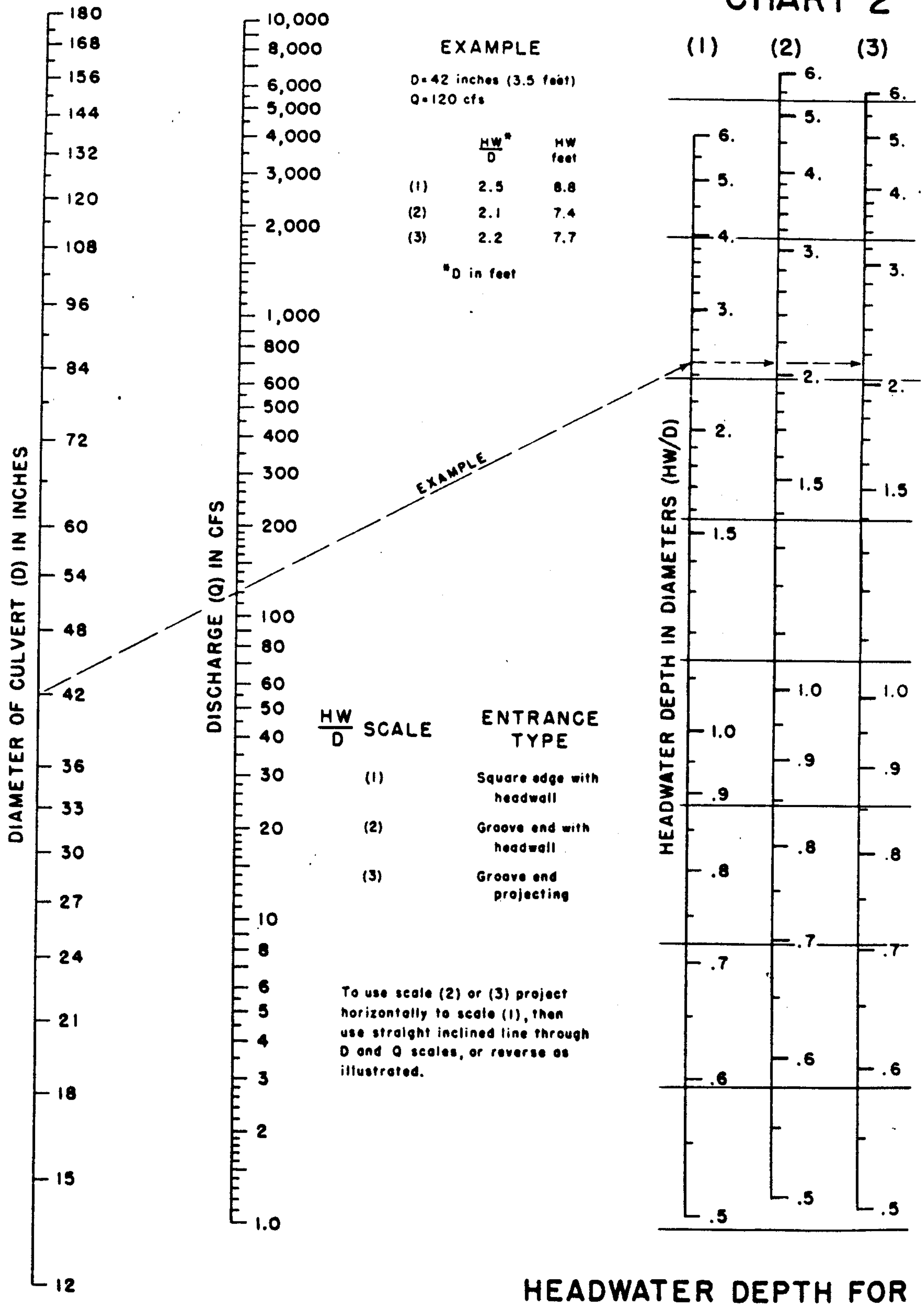
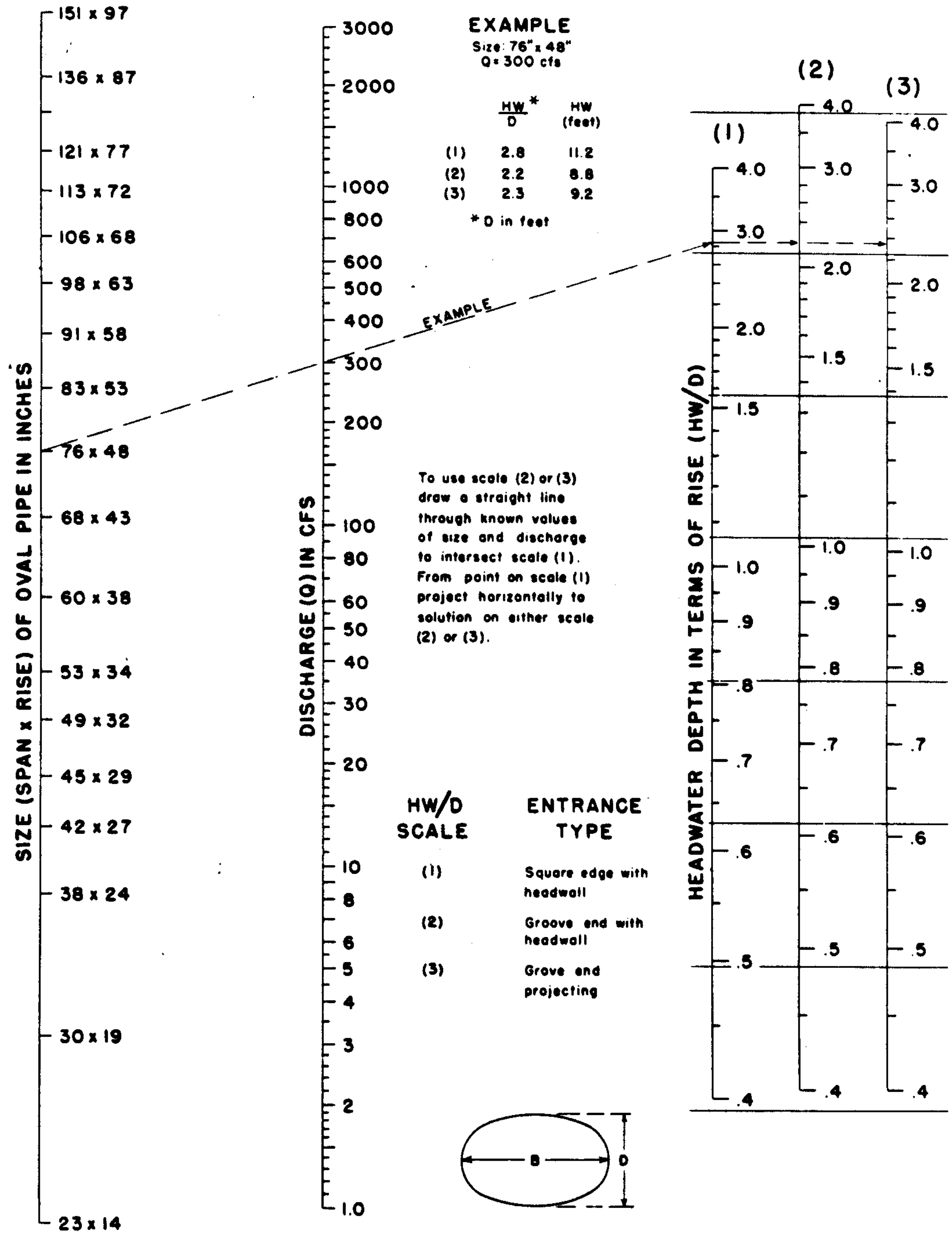
CHART 2



BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER SCALES 2&3
REVISED MAY 1964

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL



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

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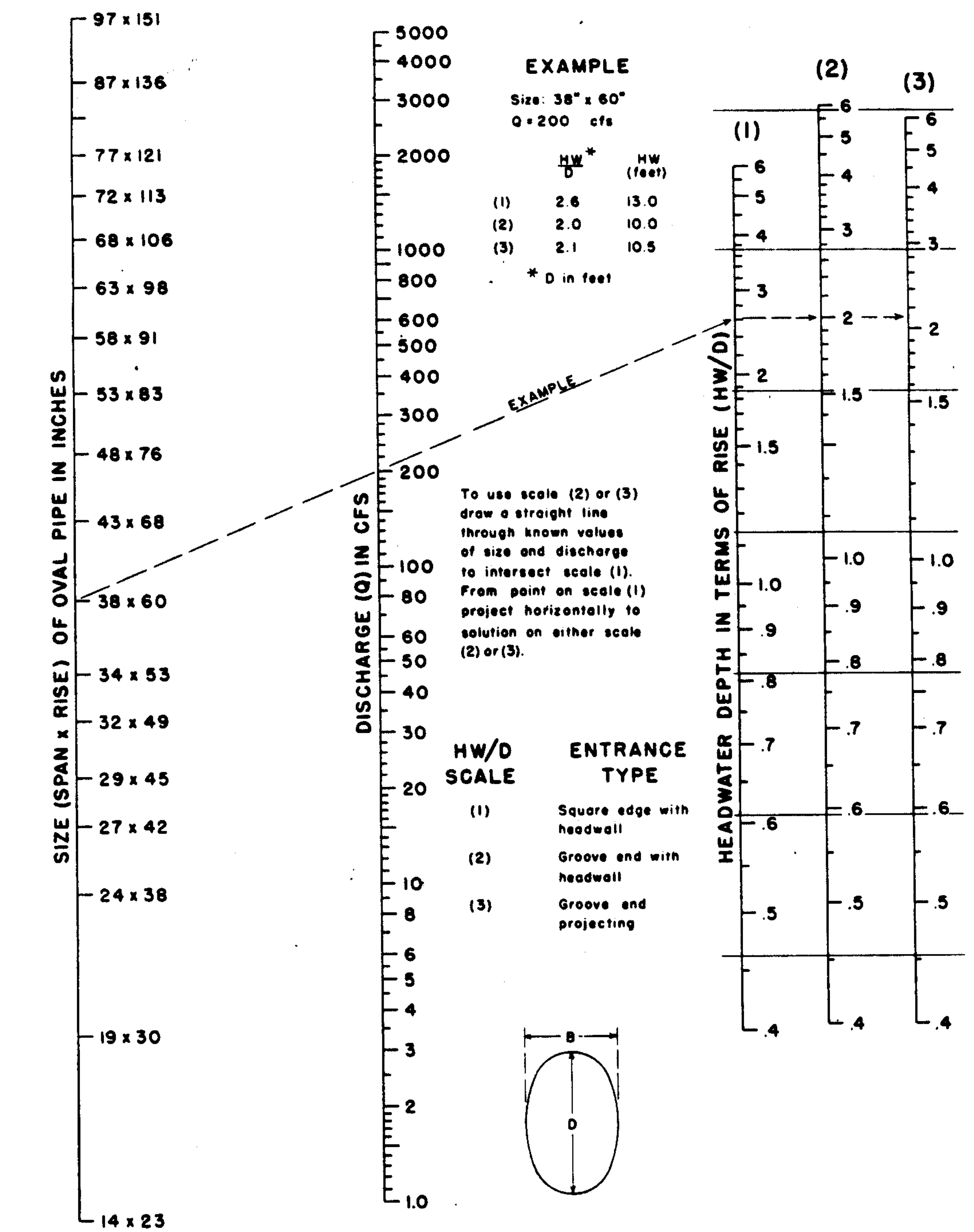
CHART 4



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

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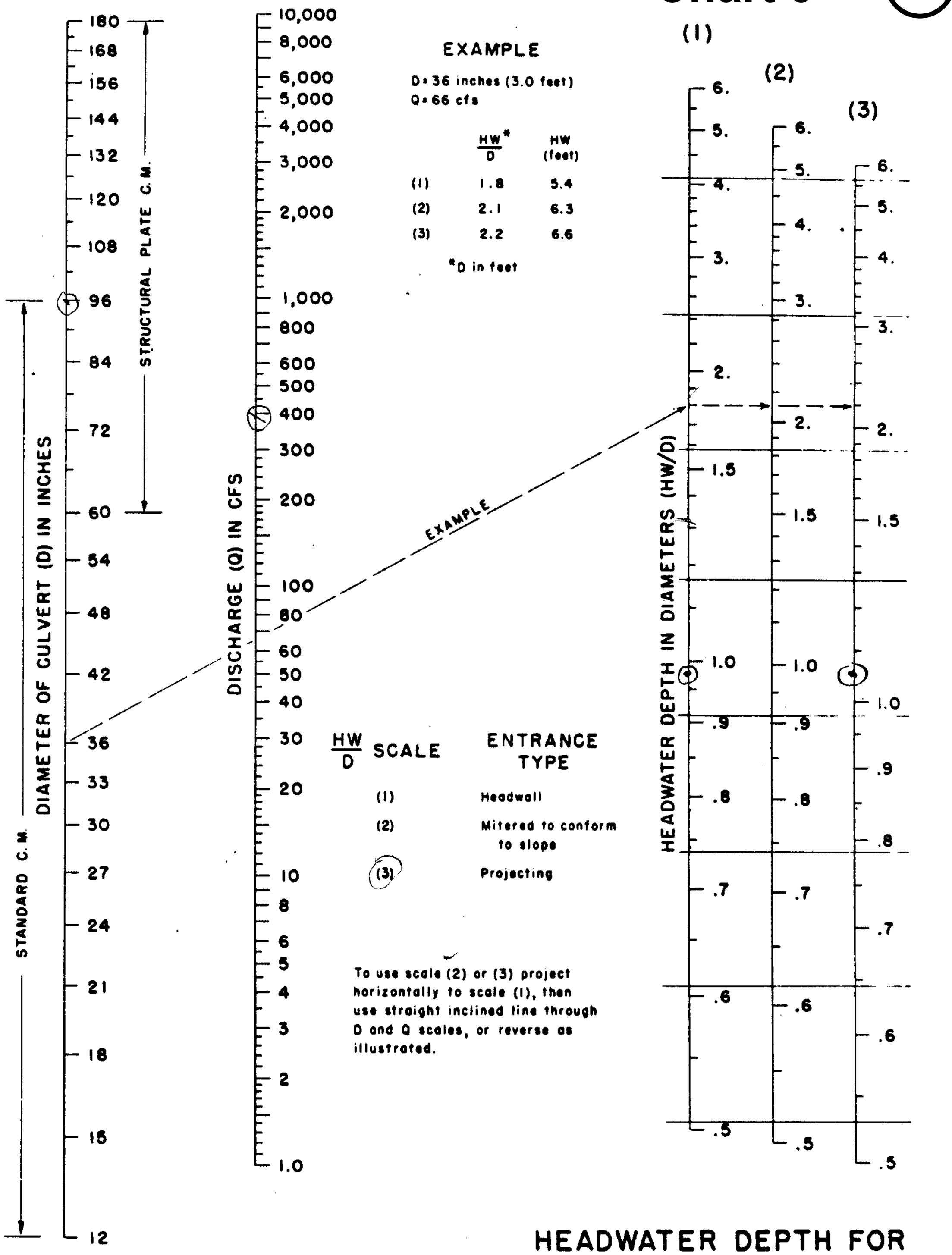
Chart 5



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

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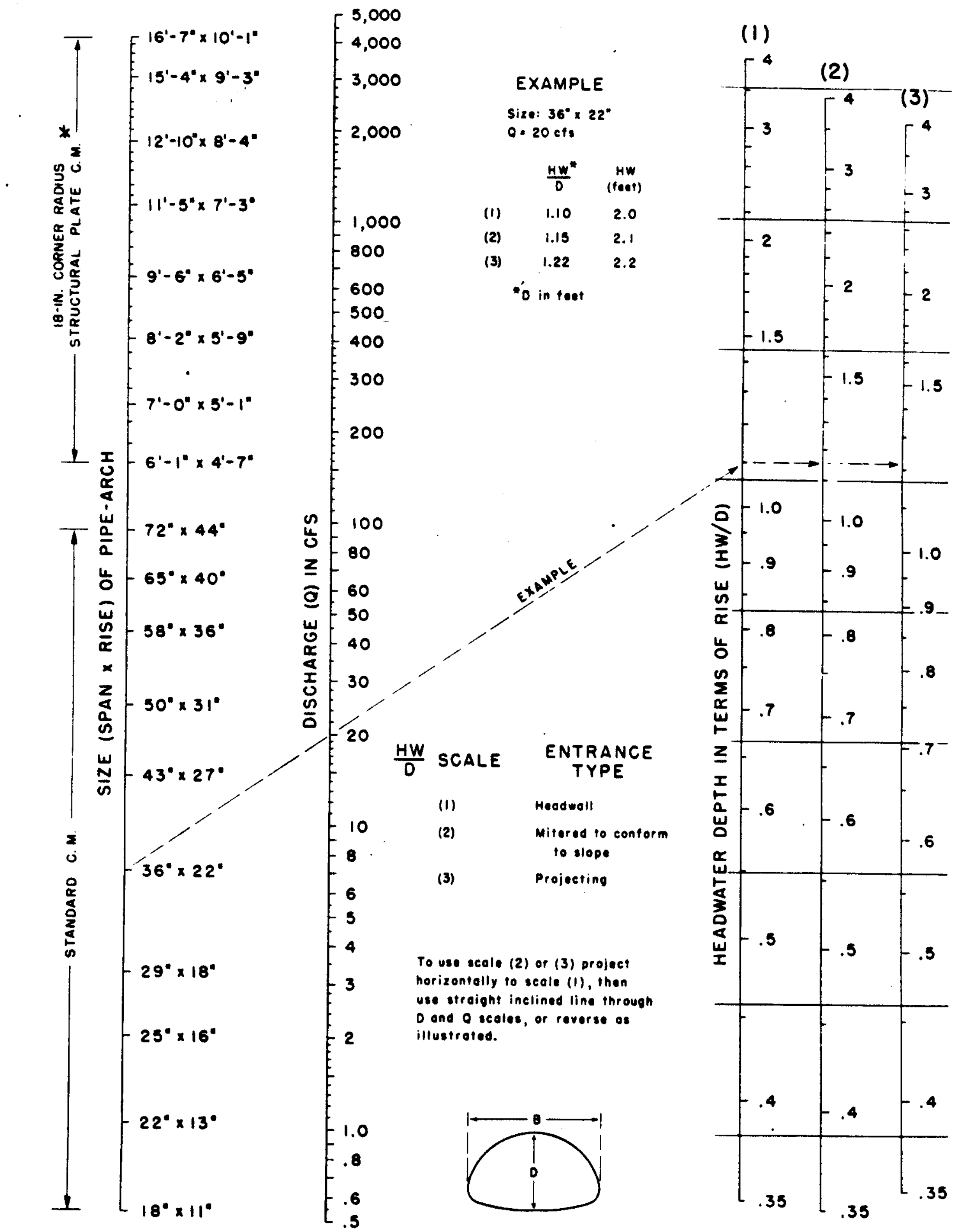
CHART 6

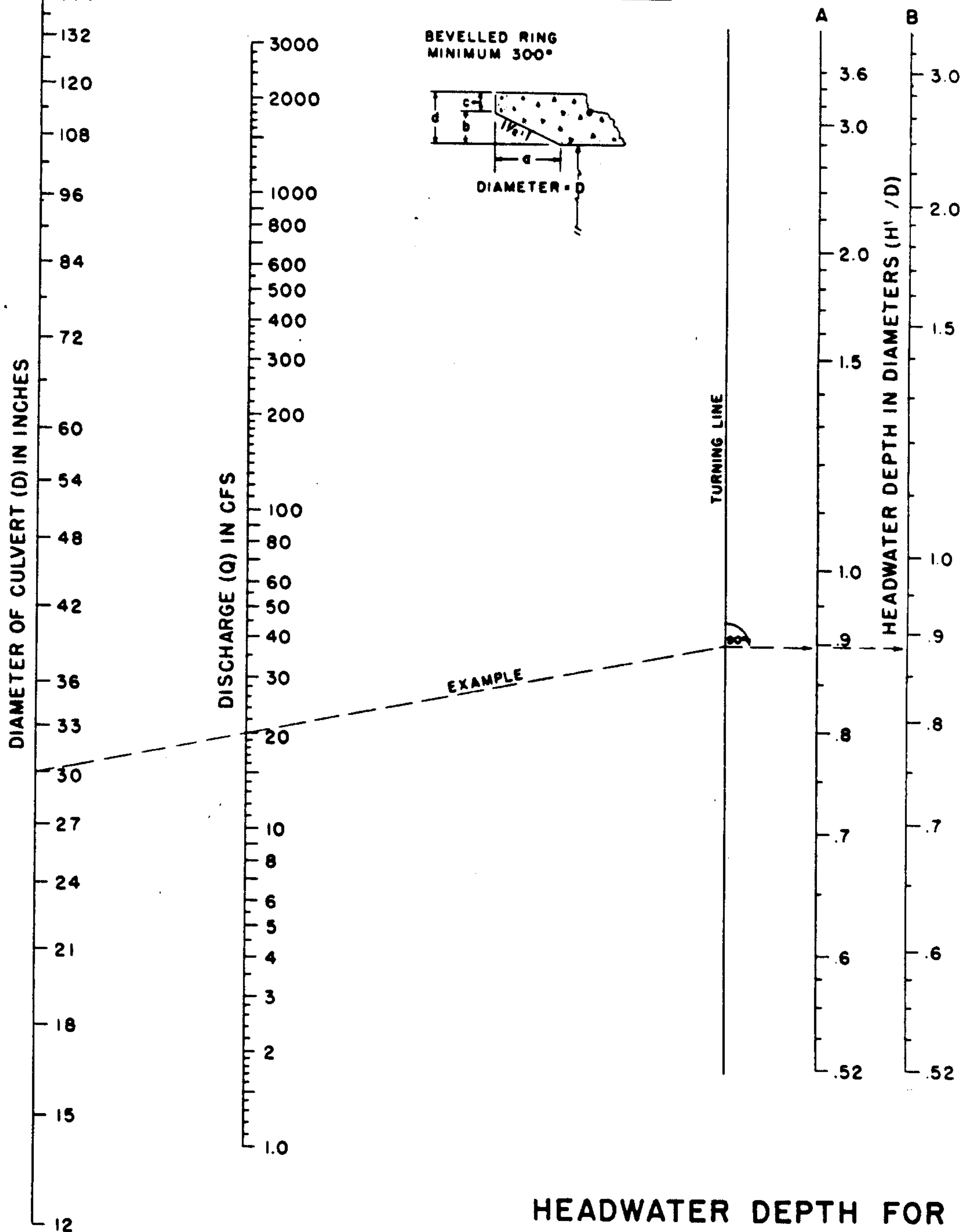


*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN. 1963

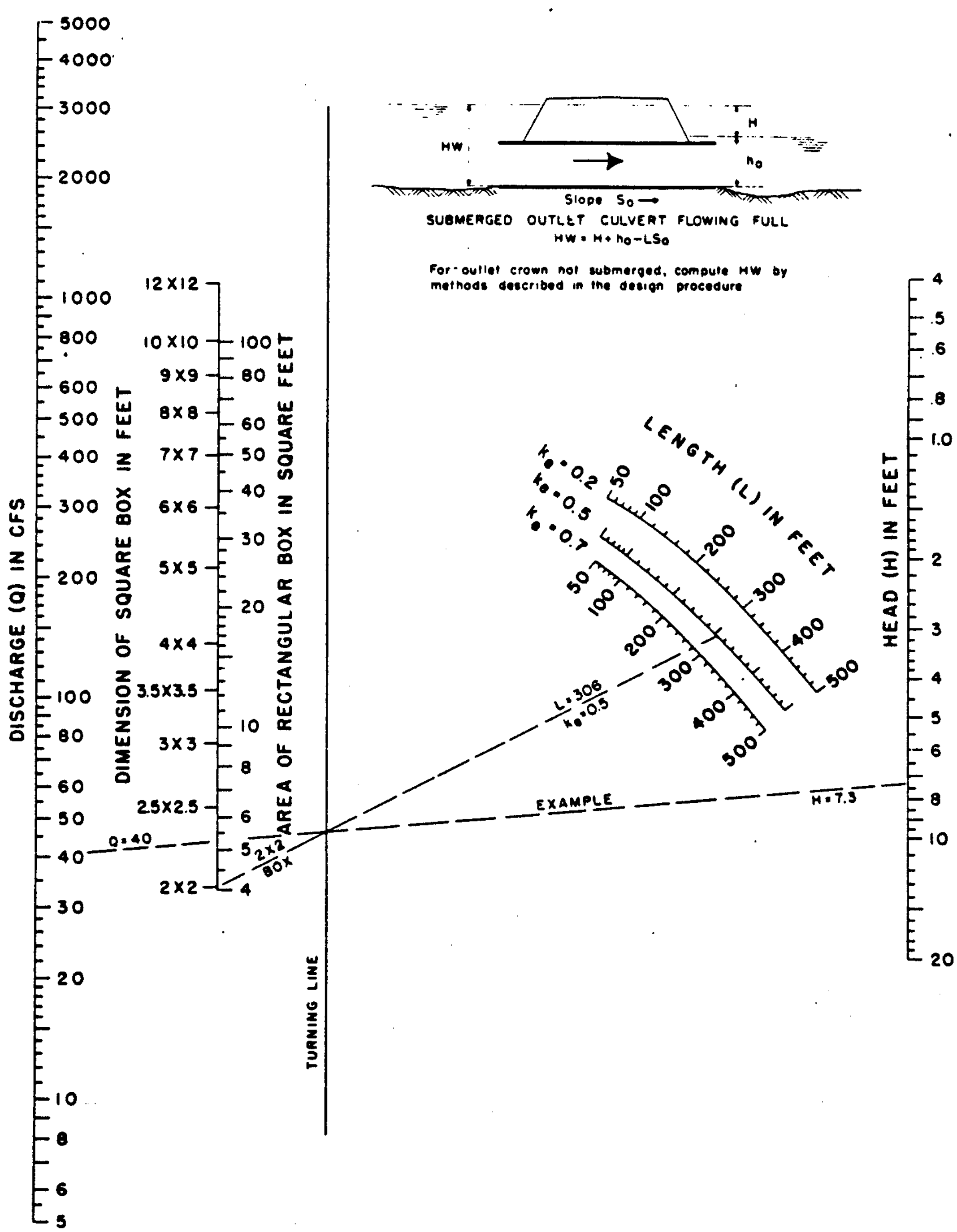
HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

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



FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL



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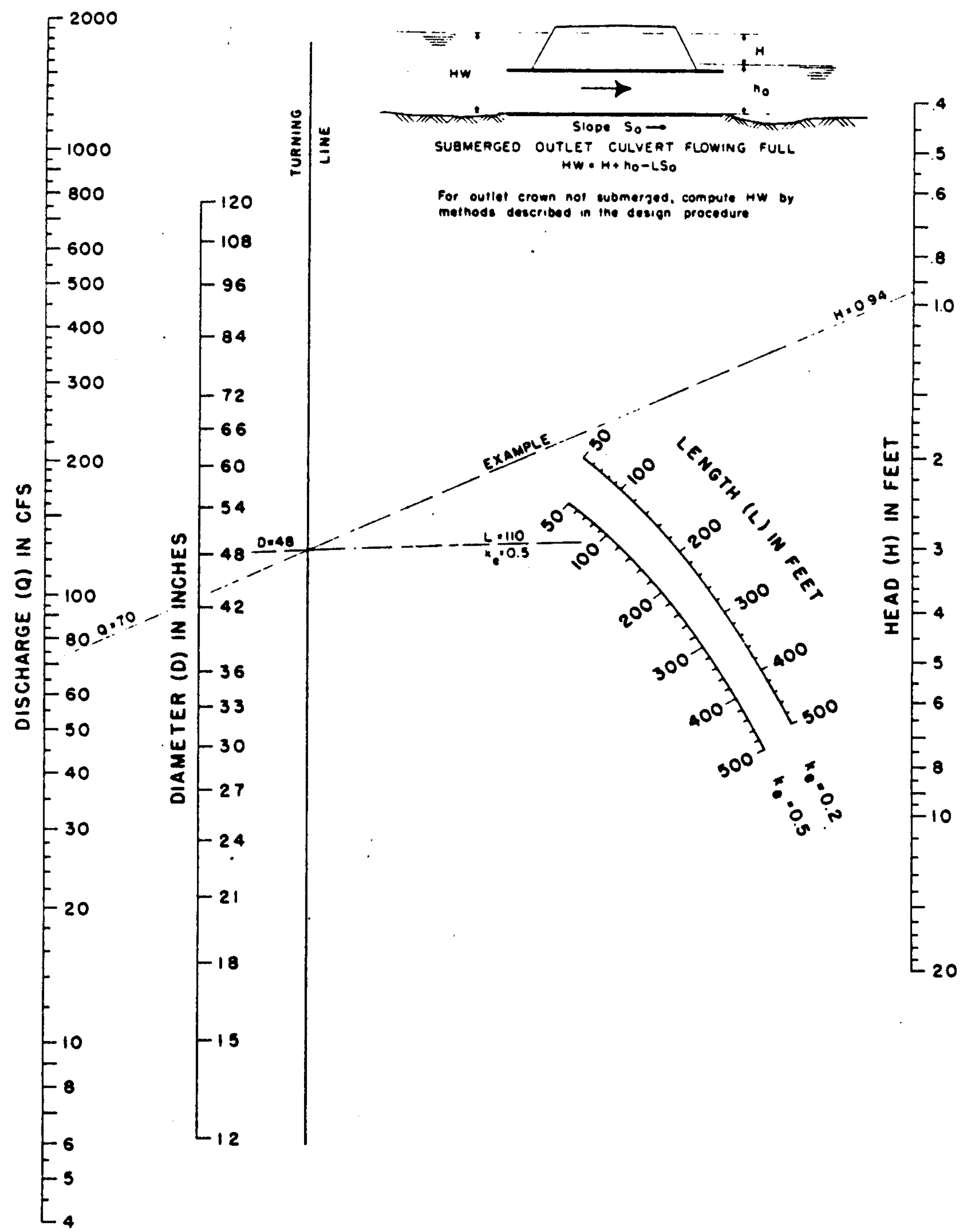
HEAD FOR CONCRETE BOX CULVERTS FLOWING FULL
n = 0.012



HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL
n = 0.012

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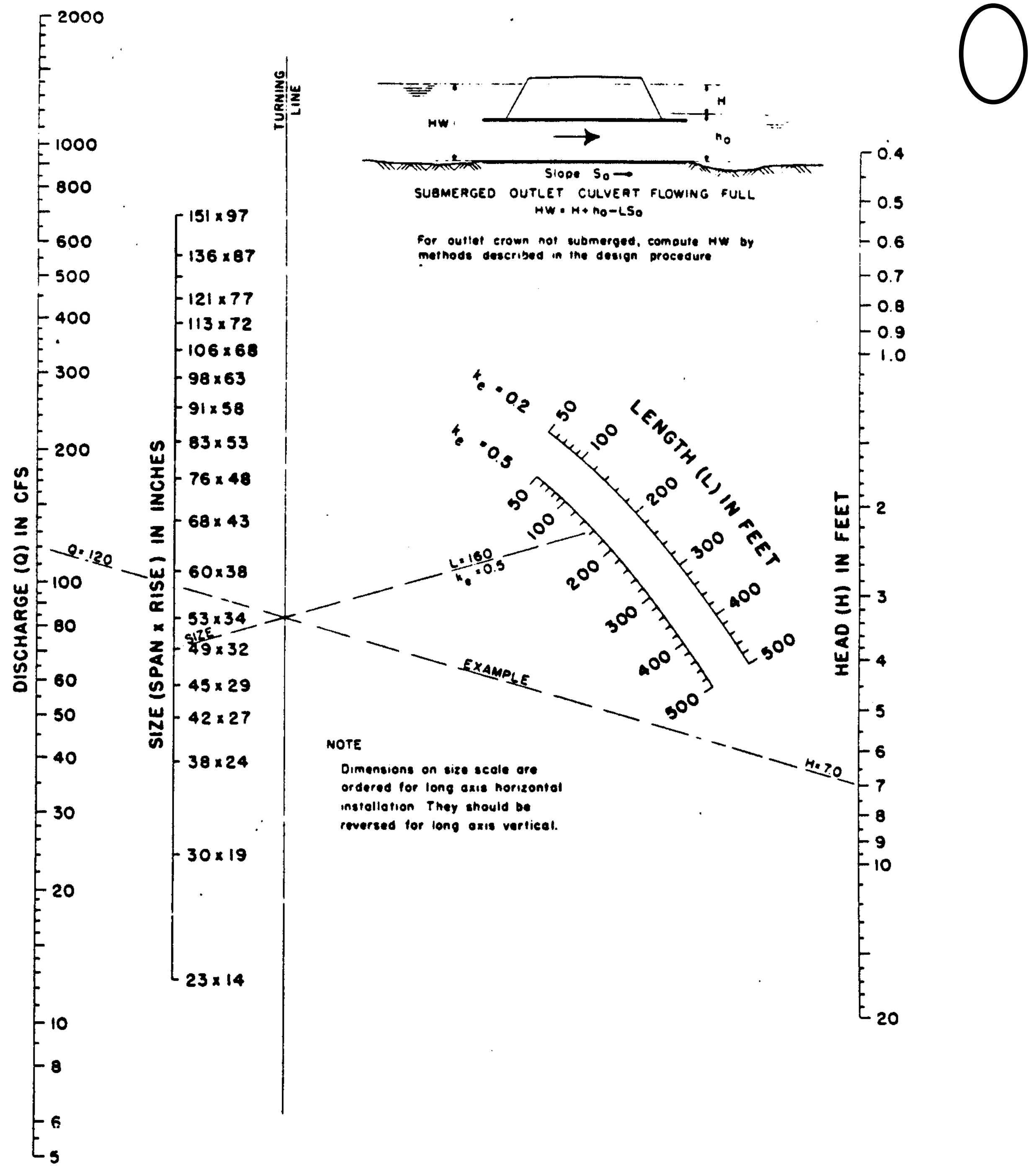
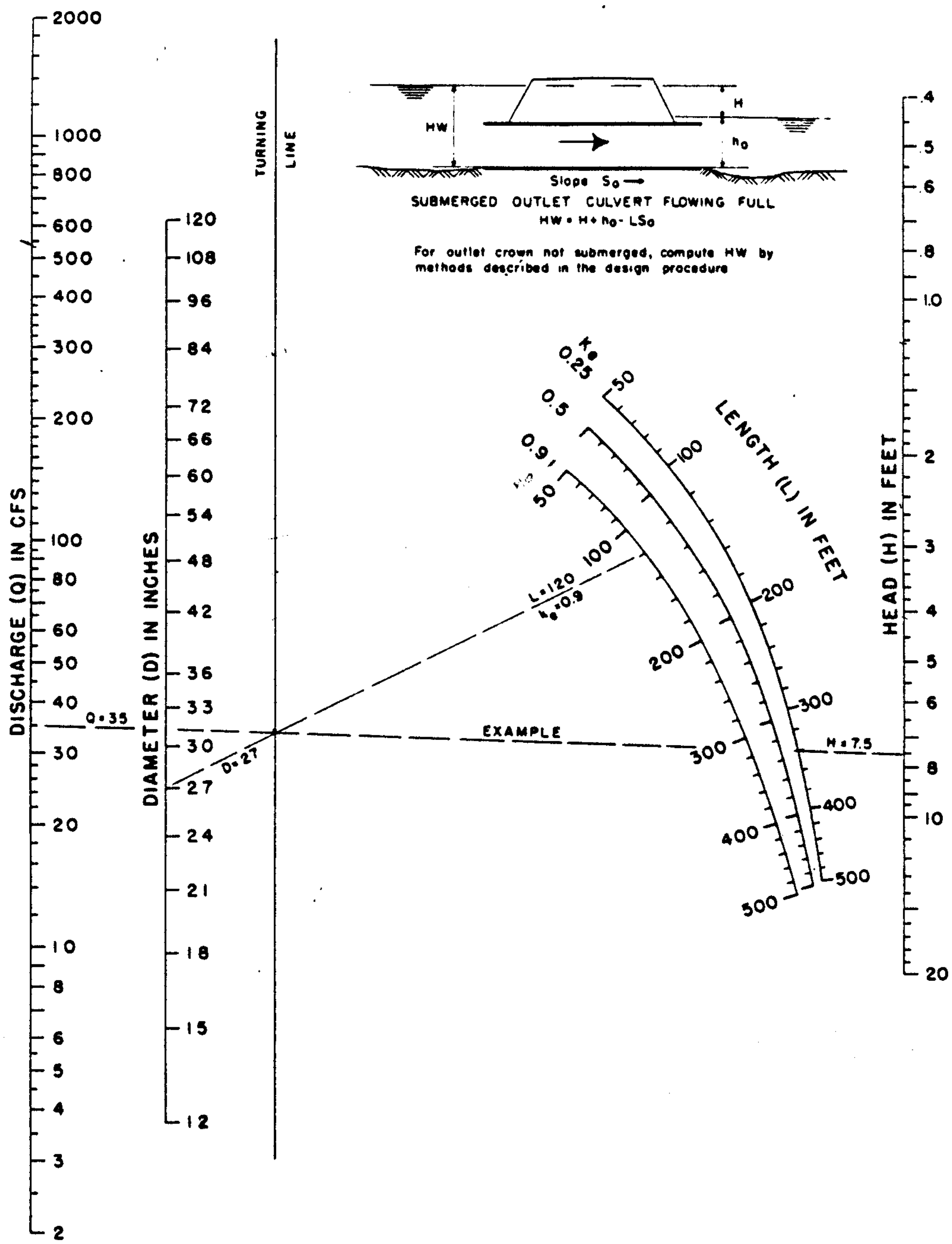
CHART 10



HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963



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

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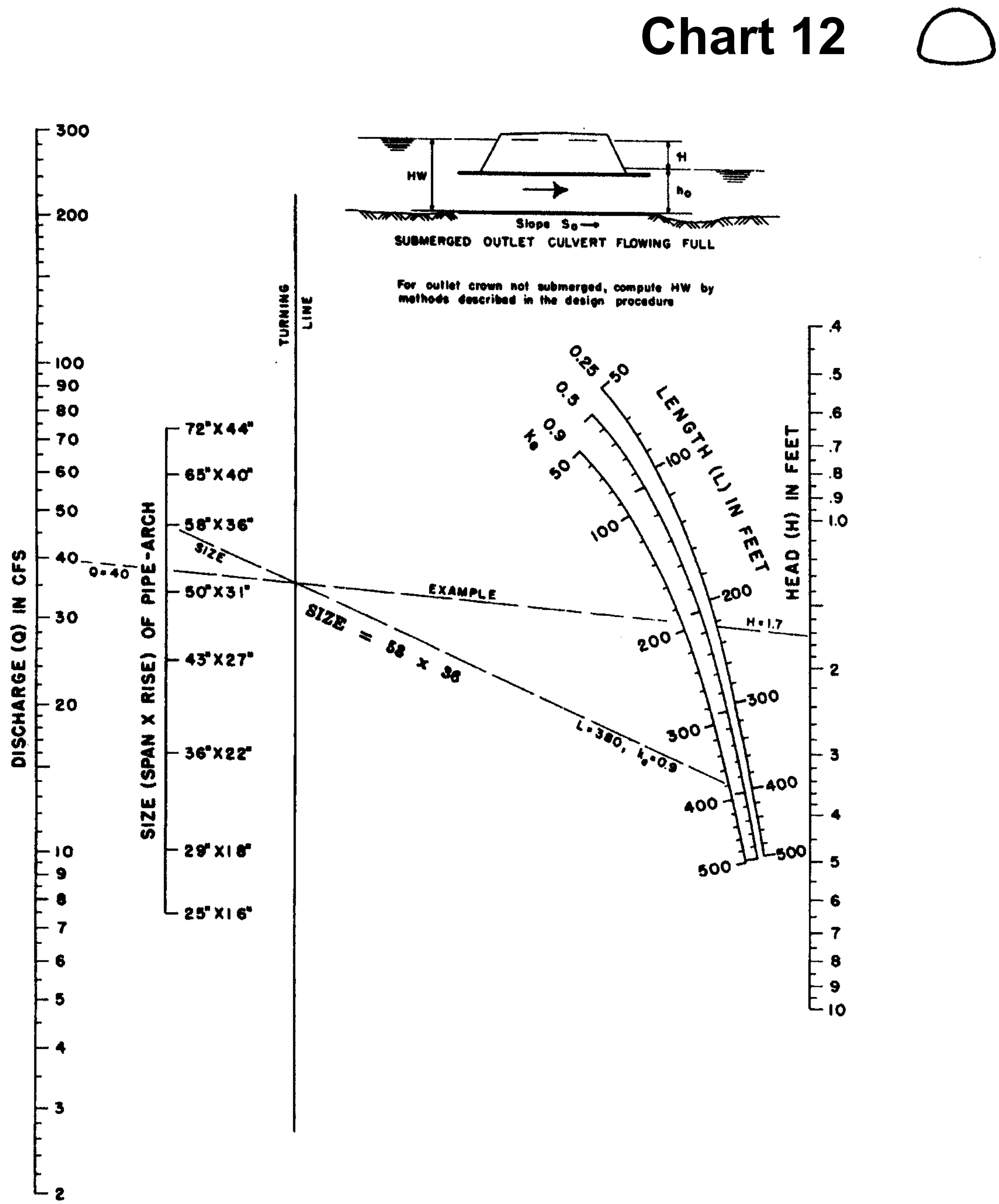
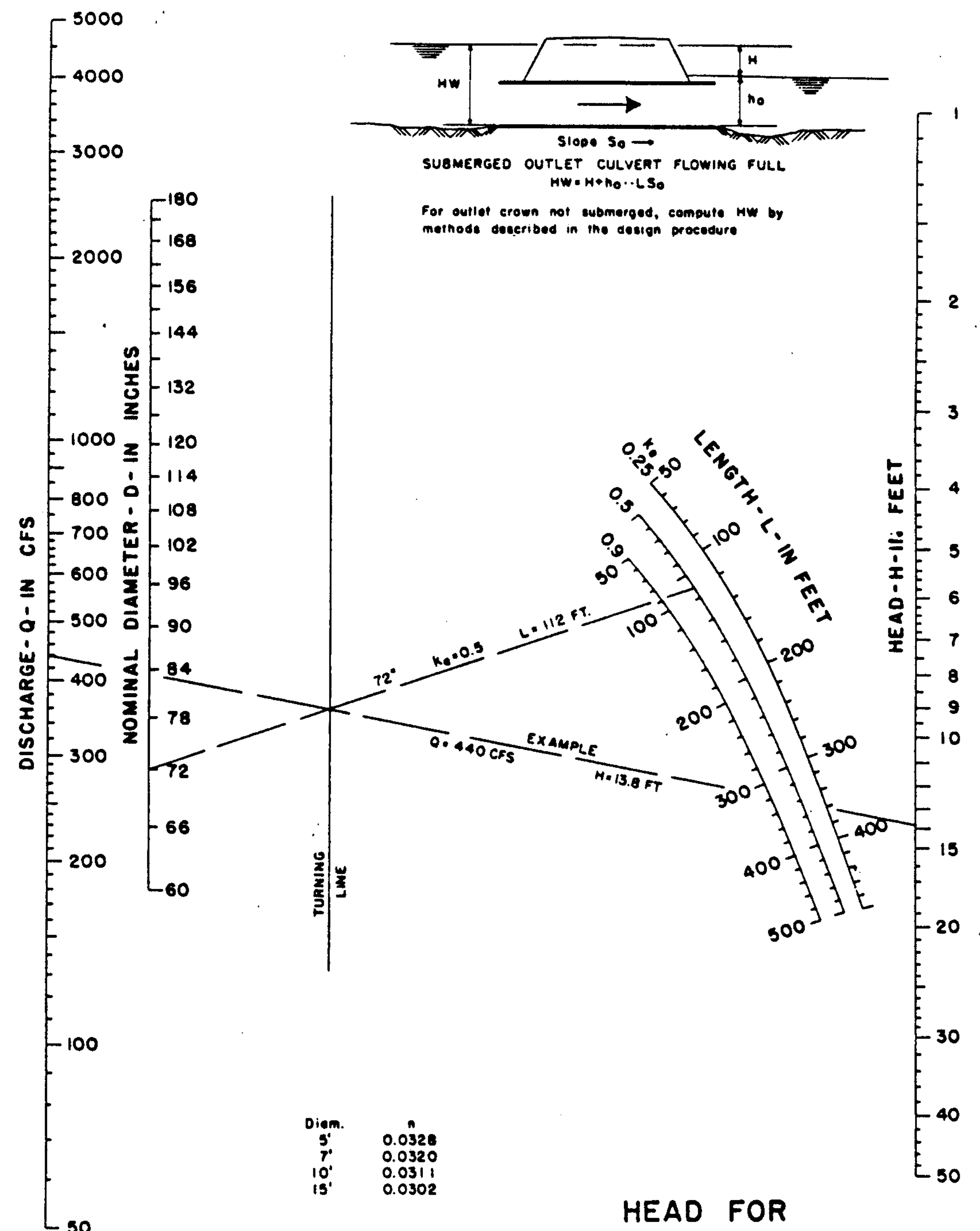
Chart 12



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

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 13

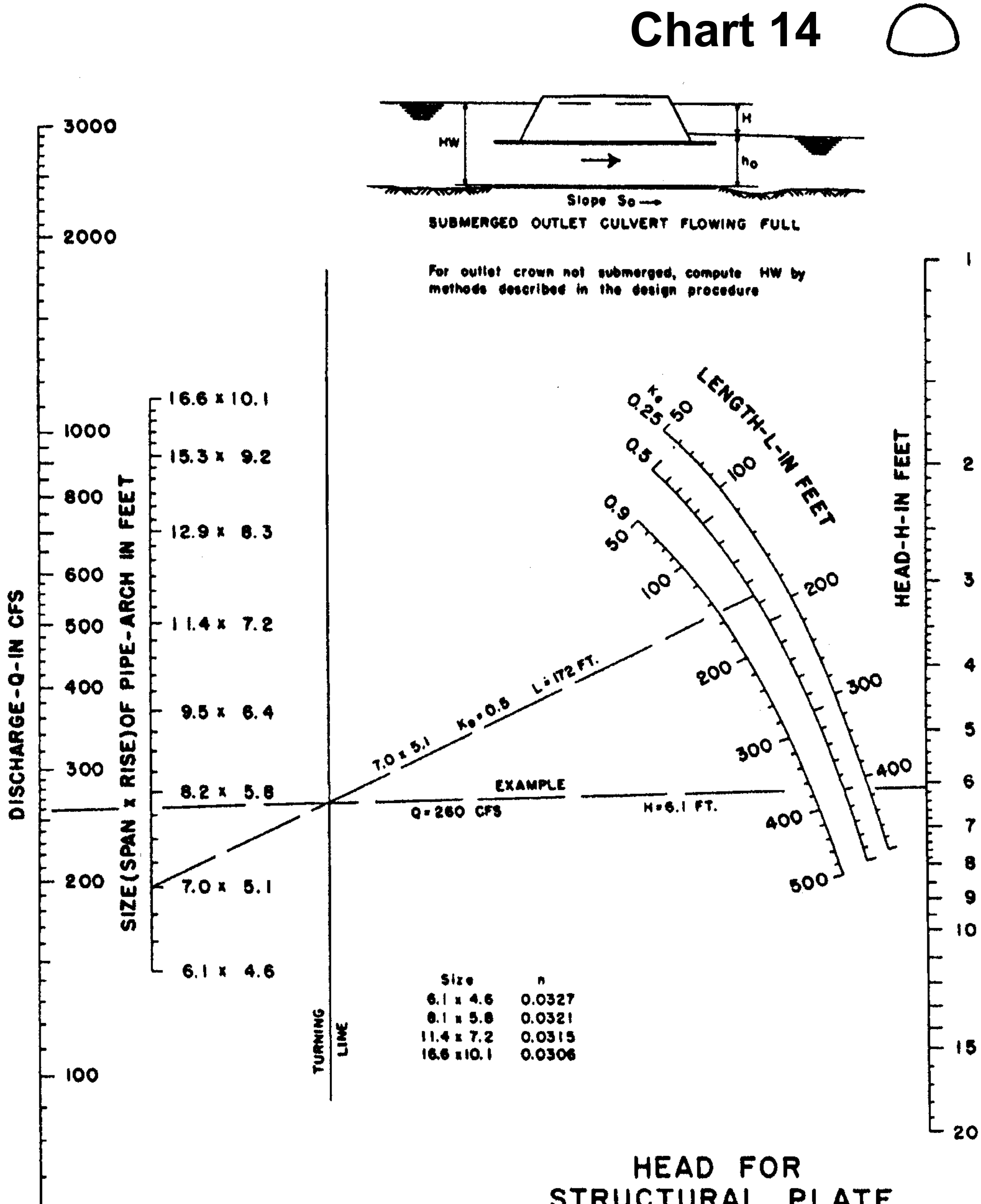


Diam.	n
5'	0.0328
7'	0.0320
10'	0.0311
15'	0.0302

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

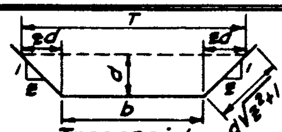
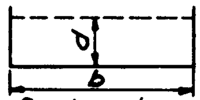
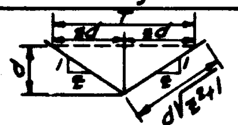
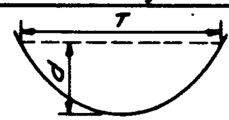
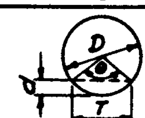
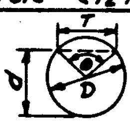
BUREAU OF PUBLIC ROADS JAN. 1963

Chart 14



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

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\dfrac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\dfrac{bd}{b+2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\dfrac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\dfrac{8d^2}{3T}$ 1/	$\dfrac{2dT^2}{3T^2+8d^2}$ 1/	$\dfrac{3a}{2d}$
 Circle - < ½ full 2/	$\dfrac{D^2}{8}\left(\dfrac{\pi\theta}{180}-\sin\theta\right)$	$\dfrac{\pi D\theta}{360}$	$\dfrac{45D}{\pi\theta}\left(\dfrac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\dfrac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle - > ½ full 3/	$\dfrac{D^2}{8}\left(2\pi-\dfrac{\pi\theta}{180}+\sin\theta\right)$	$\dfrac{\pi D(360-\theta)}{360}$	$\dfrac{45D}{\pi(360-\theta)}\left(2\pi-\dfrac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\dfrac{\theta}{2}$ or $2\sqrt{d(D-d)}$

1/ Satisfactory approximation for the interval $0 < \frac{d}{T} \leq 0.25$
When $d/T > 0.25$, use $p = \frac{1}{2}\sqrt{16d^2+T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

2/ $\theta = 4\sin^{-1}\sqrt{d/D}$
3/ $\theta = 4\cos^{-1}\sqrt{d/D}$
Insert θ in degrees in above equations

Exhibit 3-13 Elements of channel sections (Ref. NEH Section 5, ES-33)

CULVERT PIPE DESIGN SHEET

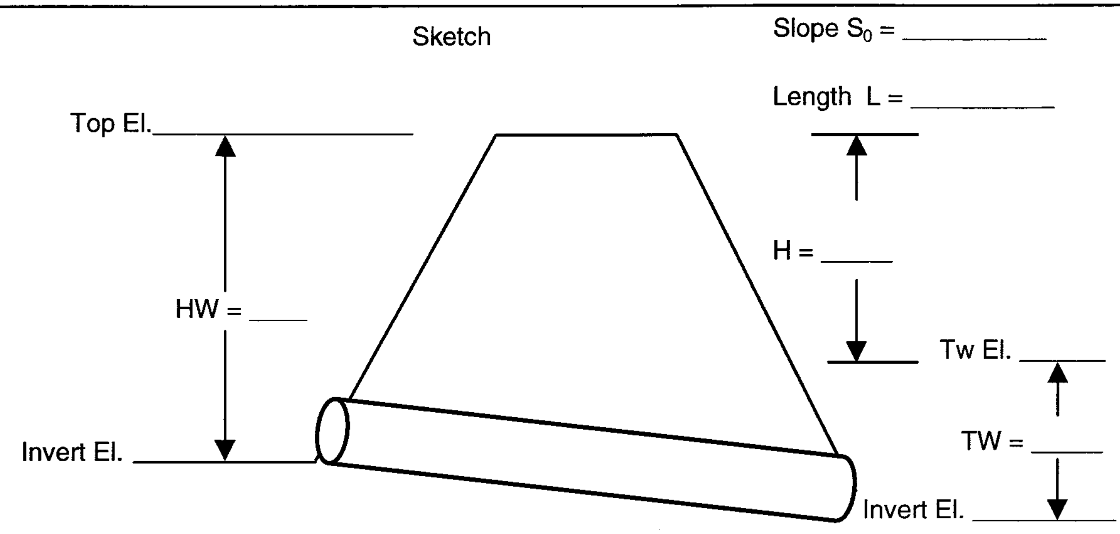
Landowner: ______________________

Designed By: ______________________

Date : ______________________

Design Discharge: ______________________

Sketch



Show whether concrete, CMP, Arch, Box Culvert, and whether projecting, headwall, mitered, etc.	Pipe Discharge, If multiple conduits, divide Q by number of conduits	Pick a Trial size - Diameter in (Inches)	Determine required H From Charts 1-7 Use Culvert type & Entrance type	Multiply - HW/D(ft) X Diameter(ft)	Entrances Loss (See Table 1)	From Charts 8-14 Need Pipe length, Ke, Q, Diameter Pipe	Pipe Diameter (Ft.)	0.75 X Pipe Diameter	Tail water over pipe invert	Use .75D or Tailwater Whichever is Greater	Multiply Length X Slope of Pipe	Solve Formula $HW = H + h_0 - LS_0$	Greater of HW for Inlet or Outlet Control	Compute by V = Q/A	
Culvert Description (Entrance Type)	Q	Size	Headwater Computations										Controlling HW	Outlet Velocity	Comments
			Inlet Control		Outlet Control $HW = H + h_0 - LS_0$										
			HW/D	HW	K_e	H	D	.75D	TW	h_0	LS_0	HW			

SECTION V

DESIGN EXAMPLE

Determine the culvert pipe size needed for the natural stream channel example given below.

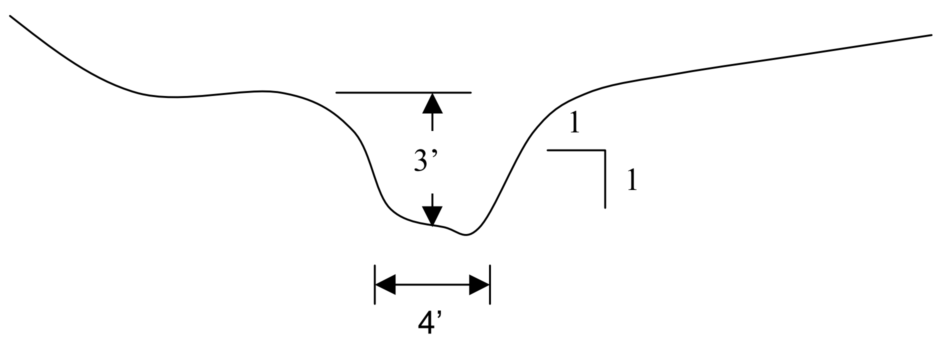
Given Data

2-year peak discharge in channel	48 cfs
Q – Design (Determined from top of bank capacity)	Calculate
Tail Water (Tw)	Free Outlet
Outlet Invert Elevation	22.0
Inlet Invert Elevation	23.0
Length of Pipe	25 feet
Type of Pipe	C.M.P.
Top of Fill El.	27.0
Entrance Type	Projecting
Channel Configuration	See below

The 2-year peak discharge in the natural stream channel is given (48 cfs). Determine the capacity of the channel at top of bank.

Determine the capacity of the stream channel at top of bank.

Typical cross section of the stream channel.



The stream channel has the average dimensions of 3 feet deep, 4 feet bottom width, 1:1 side slopes, trapezoidal in shape and has an n value of 0.05 and an average slope of 0.5 percent.

Calculate channel capacity at top of bank using Manning’s formula and the continuity equation.

Continuity Equation

$Q = A \times V$

Manning’s Equation

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

Therefore:

$Q = A \times 1.486/n \times (R)^{2/3} \times S^{1/2}$

Where:

n = Manning's Coefficient of Roughness (From Table 1 of other sources)
A = Cross Sectional Area of Flow in FT.^{2}
R = Hydraulic Radius = A/P
P = Wetted Perimeter
S = Slope in FT/FT

A = Cross Sectional Area in Ft^2 (See Exhibit 3-13 NEH Section 5)
Where b = Bottom width of channel in Ft.
d = Depth in Ft.
Z = Side Slope

$A = (b)(d) + (Z)(d)^2 = (4')(3') + (1)(3)^2 = 21.0 \text{ Ft}^2$

P = Wetted Perimeter
$P = b + 2d(Z^2 + 1)^{1/2}) = 4 + 2(3)(1^2 + 1)^{1/2}) = 12.49$

R = Hydraulic Radius
$R = A/P = 21.0/12.49 = 1.68$

$Q = A \times 1.486/n \times (R)^{2/3} \times S^{1/2}$

Where:
N = .05, R = 1.68, A = 21.0, S = .005
$Q = 21.0 \times (1.486/0.05) \times (1.68)^{2/3} \times (.005)^{1/2} = (21.0)(29.72)(1.42)(0.07)$
Q = 62 cfs

The capacity of the stream channel at the top of bank is 62 cfs. In accordance with the stream crossing standard, pass the lesser of the 2-year peak discharge or the channel capacity at top of bank. The 2-year peak discharge is 48 cfs, which is lesser than the channel capacity at top of bank (62 cfs). Size the culvert to pass 48 cfs.

Determine Pipe Size

Check Inlet Control. The channel depth is 3 feet and as required by the practice standard and state regulations the invert of the pipe will be submerged 1 foot below the stream bottom. Therefore the maximum headwater (HW) available for the inlet is 4 feet. In accordance with the practice standard the minimum (first) pipe diameter is 30 inch. By choice start with one 30-inch pipe, CMP with projecting inlet and record on blocks 1 and 3 as appropriate. Record the HW of 4 feet in block 5.

Calculate HW/D by dividing the HW (4 feet) by the pipe diameter (2.5 feet) and record (1.6) in block 4. Using the inlet control nomograph for corrugated metal pipe with a projecting inlet and using a pipe diameter of 30 inches, HW/D of 1.6, and HW of 4 feet the inlet pipe discharge is 32 cfs. Start by finding HW/D (1.6) on projecting entrance scale (3), read horizontally to scale 1, draw a straight inclined line from HW/D to pipe diameter (30 inches) scale. Where this line intersects the discharge scale is the pipe discharge (32 cfs). Record in block 3.

The discharge of the pipe for inlet control is 32 cfs, which is less than the 45-cfs required for the site. Given that site constraints will only allow a maximum head of 4 feet and a minimum amount of fill over the pipe (usually 12 – 18 inches) is required a larger circular pipe cannot be used.

In this example we will add a second pipe, however other options are available such as oval, arch or box pipe which can have higher discharge at lower heads.

Check Outlet Control. From table 1 determine the appropriate entrance loss coefficient and record in block 6. Determine the required head (H) for full pipe flow (outlet control). Using the corrugated metal pipe flowing full nomograph with and entrance loss of coefficient of 0.9, pipe diameter of 30 inches, pipe length of 25 feet and required discharge of 32 cfs the required head (H) for outlet control is 2 feet. Start by marking the pipe length (25 feet) on the Ke scale (0.9). Note since the minimum pipe length shown on the scale is 50 feet interpolate to a pipe length of 25 feet. Draw a line from this point through the turning line to the pipe diameter (30 inches) scale. From the discharge scale at 32 cfs draw a line through the intersect point on the turning line to the head (H) scale. Record the required head (2 feet) on block 7.

Calculate 0.75D ((0.75)(2.5 feet)) = 1.88 and record on line 9. From the site conditions determine the tailwater (TW) distance in feet above the culvert pipe outlet invert and record on block 10. In this example there is no tailwater.

Determine h_0 and record on block 11. Use the greater of 0.75D or tailwater. Solve LS_0 by multiplying the length of pipe (25 feet) by the pipe slope (0.04 ft/ft) and record (1 foot) in block 12.

Determine the required headwater (HW) for outlet control by solving $HW = H + h_0 - LS_0$. HW= 2 +1.88 – 1 = 2.88. Record in block 13.

Inlet or Outlet Control. The greater required headwater will determine if the culvert is in inlet or outlet control. In this example the HW required to pass 32 cfs at the inlet is 4 feet. The HW required to pass 32 cfs at the outlet (pipe flowing full) is 2.88 feet. The inlet requires a greater HW (4 feet) therefore the culvert pipe is in inlet control and will pass a discharge as designed of 32 cfs.

Adding a Second Pipe. One 30-inch diameter culvert pipe will pass 32 cfs. The site requires passing 48 cfs. In this example an additional pipe will be added to pass the difference not passed. The 30-inch pipe was submerged one foot below the stream bottom, as required. This is not required for the second pipe. Therefore the invert of the second pipe will be raised 1 foot, which decrease the available HW for the inlet condition from 4 feet to 3 feet.

Repeat the same procedure for the second pipe starting with an available headwater (HW) of 3 feet and a pipe diameter of 24 inches.

See the attached culvert pipe design sheet for the design example. The results are summarized below.

PIPE	PIPE SIZE	HW	HW/D	PIPE CAPACITY (cfs)
First Pipe	30 in.	4 ft.	1.6	32 (With 1’ submerged)
Second Pipe	24 in.	3 ft.	1.5	18

CULVERT PIPE DESIGN SHEET

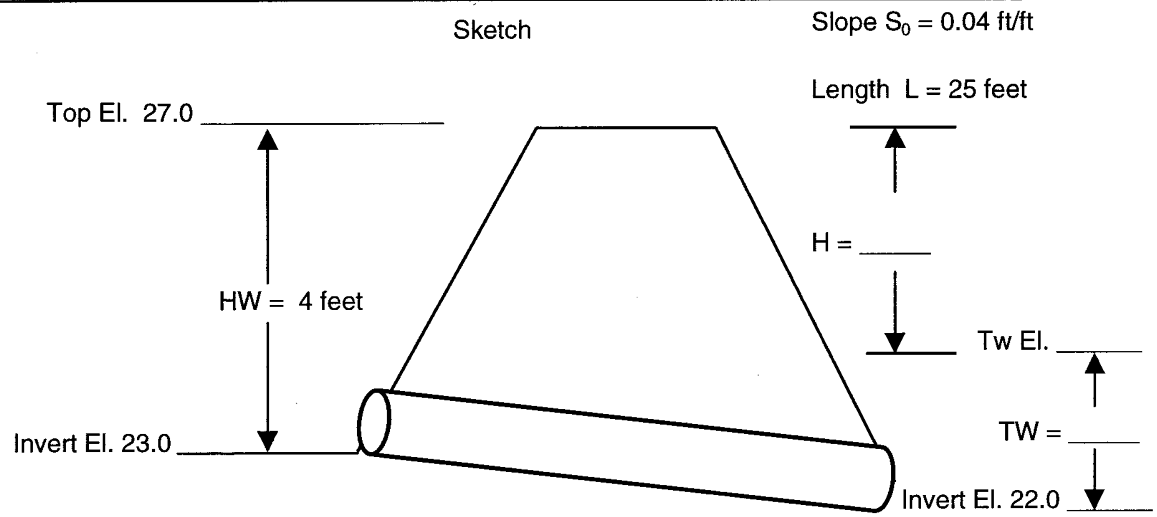
Landowner: Design Example

Designed By: Design Guide #5

Date : November, 2001

Design Discharge: 45 cfs

Sketch



Show whether concrete, CMP, Arch, Box Culvert, and whether projecting, headwall, mitered, etc.	Pipe Discharge, If multiple conduits, divide Q by number of conduits	Pick a Trial size - Diameter in (Inches)	Determine required H From Charts 1-7 Use Culvert type & Entrance type	Multiply - HW/D(ft) X Diameter(ft)	Entrances Loss (See Table 1)	From Charts 8-14 Need Pipe length, Ke, Q, Diameter Pipe	Pipe Diameter (Ft.)	0.75 X Pipe Diameter	Tail water over pipe invert	Use .75D or Tailwater Whichever is Greater	Multiply Length X Slope of Pipe	Solve Formula HW = H + h_0 - LS_0	Greater of HW for Inlet or Outlet Control	Compute by V = Q/A	
Culvert Description (Entrance Type)	Q	Size	Headwater Computations										Controlling HW	Outlet Velocity	Comments
			Inlet Control		Outlet Control HW = H + h_0 - LS_0										
			HW/D	HW	K_e	H	D	.75D	TW	h_0	LS_0	HW			
Pipe (1) CMP Projecting	32	30	1.6	4	0.9	2	2.5	1.88	-	1.88	1.0	2.88	4		Inlet Control
Pipe (2) CMP Projecting	18	24	1.5	3	0.9	1.7	2	1.5	-	1.5	1.0	2.2	3		Inlet Control, Pipe invert of this pipe raised 1 foot