CHAPTER 4

DESIGN OF CULVERTS

4.4 Design Procedures

4.4.1 Inlet and Outlet Control

Inlet Control – If the culvert is operating on a steep slope it is likely that the entrance geometry will control the headwater and the culvert will be on inlet control.

Outlet Control – If the culvert is operating on a mild slope, the outlet characteristics will probably control the flow and the culvert will be on outlet control.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information in inlet and outlet control see the Federal Highway Administration publication entitled – Hydraulic Design of Highway Culverts, HDS-5, 1985, and AASHTO Model Drainage Manual, 1998.

4.4.2 Procedures

There are two procedures for designing culverts: (1) the manual use of inlet and outlet control nomographs and (2) the use of a personal computer system such as HY8 – Culvert Analysis Microcomputer Program.

It is recommended that the HY8 computer model be used for culvert design. The personal computer system HYDRAIN uses the theoretical basis for the nomographs to size a culvert. In addition, this evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.

The following will outline the design procedures for use of the nomograph. The use of the computer model will follow the discussion on improved inlets. Other computer programs can be used if approved by City of Lawrenceville.

4.4.3 Nomographs

The use of nomographs requires a trial and error solution. The solution is quite easy and provides reliable designs for many applications. It should be remembered that velocity, hydrograph routing, roadway overtopping,

and outlet scour require additional, separate computations beyond what can be obtained from the nomographs.

Figures 4-1 and 4-2 show examples of an inlet control and outlet control nomograph that can be used to design concrete pipe culverts. For culvert designs not covered by these nomographs, refer to the complete set of nomographs given in Appendix B at the end of this chapter.

4.4.4 Steps in Design Procedure

The design procedure requires the use of inlet and outlet nomographs.

Step one:

List design data:

Q = discharge cfs)

L = culvert length (ft)

S = culvert slope (ft/ft)

TW = tailwater depth (ft)

V = velocity for trial diameter (ft/s)

K_e = inlet loss coefficient

Step two:

Determine tail culvert size by assuming a trial velocity 3 t0 5 ft/s and computing the culvert area, A = Q/V. Determine the culvert diameter (inches).

Step three

Find the actual HW for the trail size culvert for both inlet and outlet control.

- For <u>Inlet control</u>, enter inlet control nomograph with D and Q and find HW/D for the proper entrance type.

- Compute HW and, if too large or two small, try another culvert size before computing HW for outlet control.

- For outlet control enter the outlet control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter.

- To compute HW, connect the length scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from the equation:

$$HW = H + h_O - LS \qquad \textbf{(Eq 4.4.4-1)}$$

Where: h_O = ½ (critical depth + D), or tailwater depth, whichever is greater.

Step three:

Compare the computed headwaters and use the higher HW nomograph to determine if the culvert is under inlet or outlet control.

If <u>outlet control</u> governs and the HW is unacceptable, select a larger trial size and find another HW with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable HW by the inlet control nomographs, the inlet control for the larger pipe need not be checked.

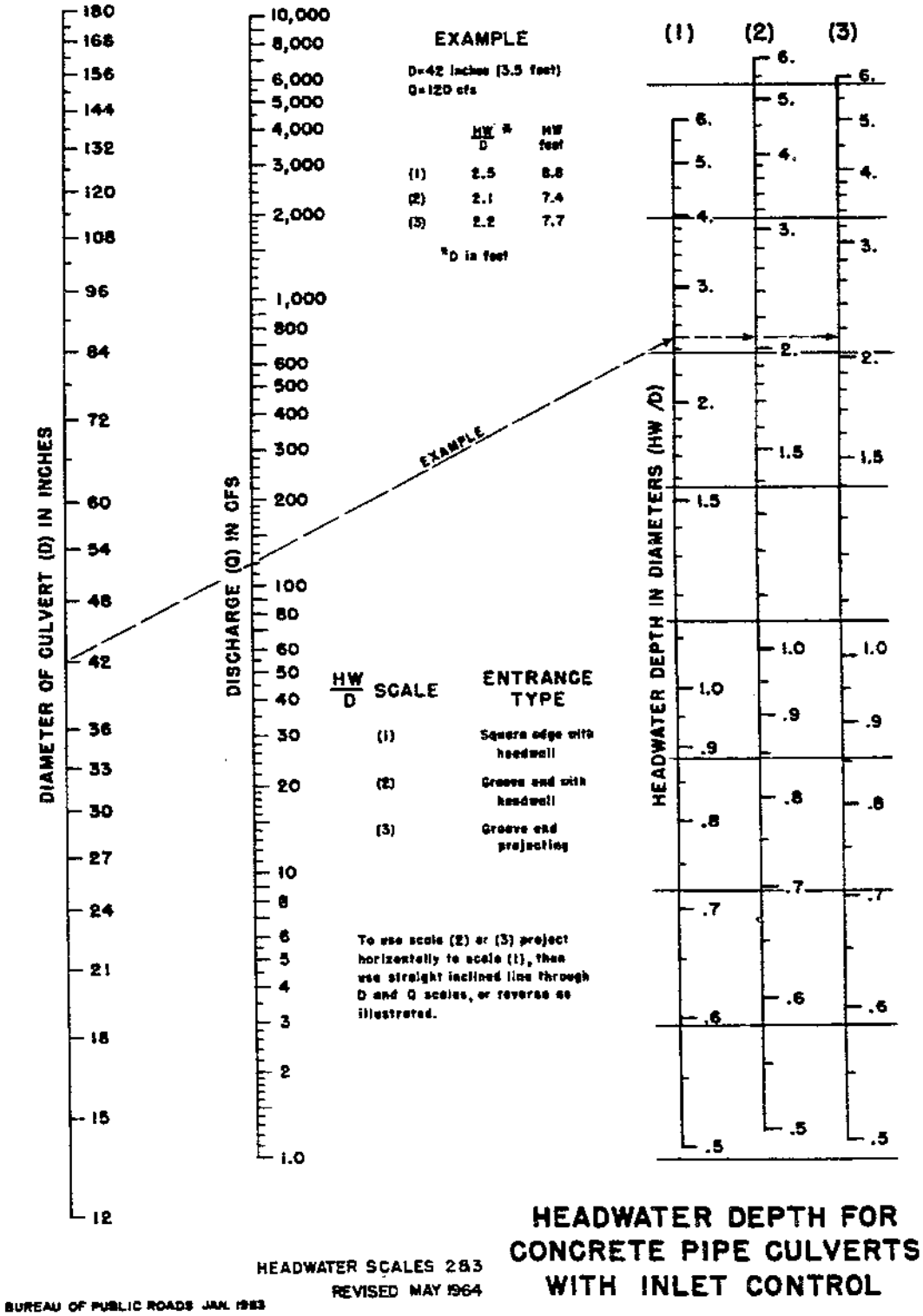
Step four:

Calculate exit velocity and expected streambed scour to determine if an energy dissipater is needed.

4.4.5 Performance Curves – Roadway Overtopping

A performance curve for any culvert can be obtain from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater vs. discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes. Such computations are made much easier by the computer program discussed in the next chapter of this manual.

Figure 4.4.5-1


DIAMETER OF CULVERT (D) IN INCHES
180
168
156
144
132
120
108
96
84
72
60
54
48
42
36
33
30
27
24
21
18
15
12
DISCHARGE (Q) IN CFS
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1.0
EXAMPLE
D=42 inches (3.5 feet)
Q=120 cfs
HW/D * HW feet
(1) 2.5 8.8
(2) 2.1 7.4
(3) 2.2 7.7
*D in feet
EXAMPLE
HW/D SCALE
ENTRANCE TYPE
(1) Square edge with headwall
(2) Groove end with headwall
(3) Groove end projecting
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.
(1)
(2)
(3)
HEADWATER DEPTH IN DIAMETERS (HW/D)
6.
5.
4.
3.
2.
1.5
1.0
.9
.8
.7
.6
.5
HEADWATER SCALES 2&3
REVISED MAY 1964
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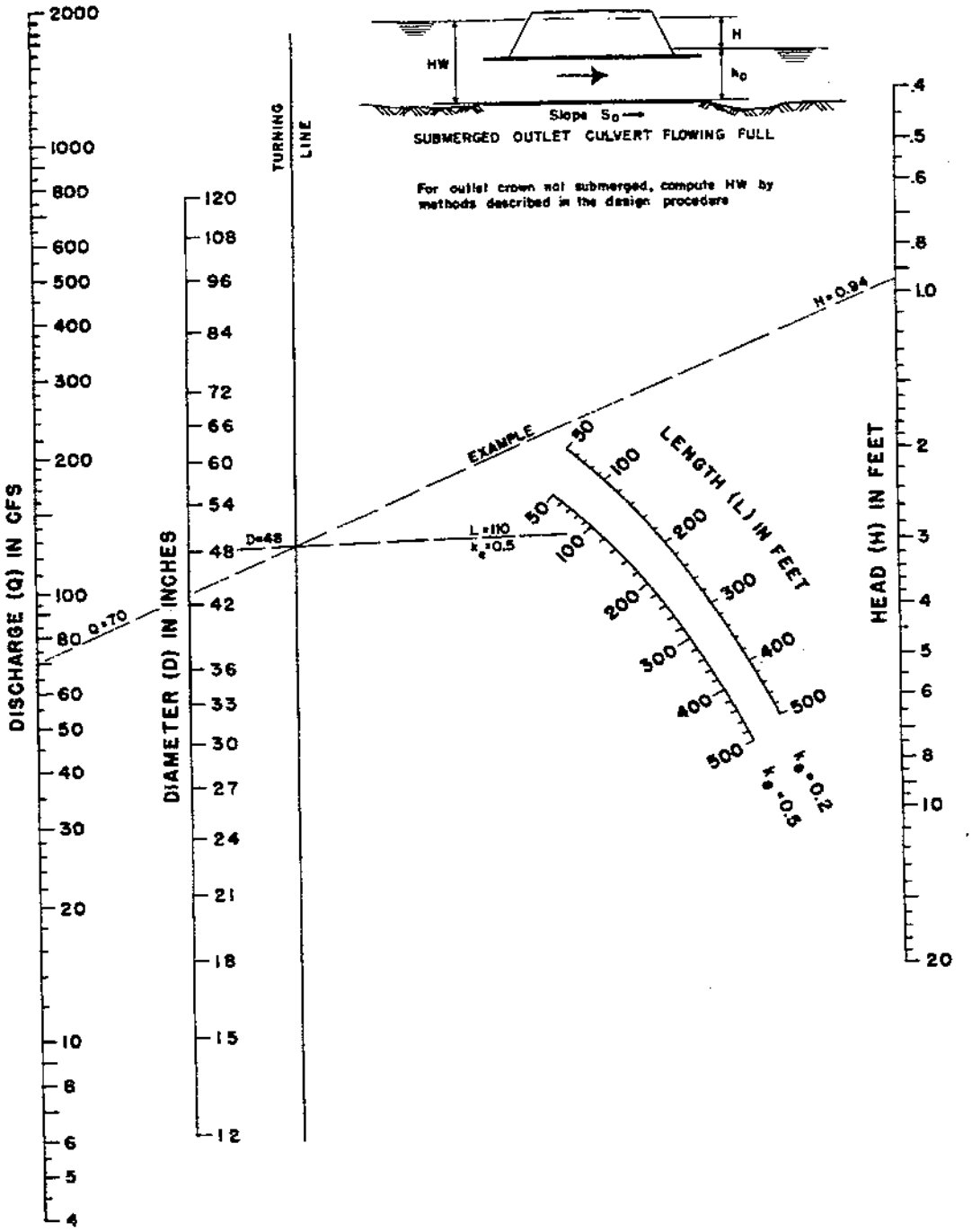
HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

Figure 4.4.5-2



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

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To complete the culvert design, roadway overtopping should be analyzed. A performance curve showing the culvert flow as well as the flow across the roadway is a useful analysis tool. Rather than using a trail and error procedure to determine the flow division between the overtopping flow and the culvert flow, an overall performance curve can be developed.

The overall performance curve can be determine as follows:

Step one:

Select a range of flow rates and determine the corresponding headwater elevations for the culvert flow alone. The flow rates should fall above the below the design discharge and cover the entire flow range of interest. Both inlet and outlet control headwaters should be calculated.

Step two:

The inlet and outlet control performance curves to define a single performance curve for the culvert.

Step three:

When the culvert headwater elevations exceed the roadway crest elevation, overtopping will begin. Calculate the equivalent upstream water surface depth above the roadway (crest of weir) for each selected flow rate. Use these water surface depths and equation 4.2 to calculate flow rates across the roadway.

$$Q = C_d L(HW)\text{^}1.5 \qquad \textbf{(Eq 4.4.5-2)}$$

Where:

Q = overtopping flow rate (ft^3/s)

C_d = overtopping discharge coefficient

L = length of roadway (ft)

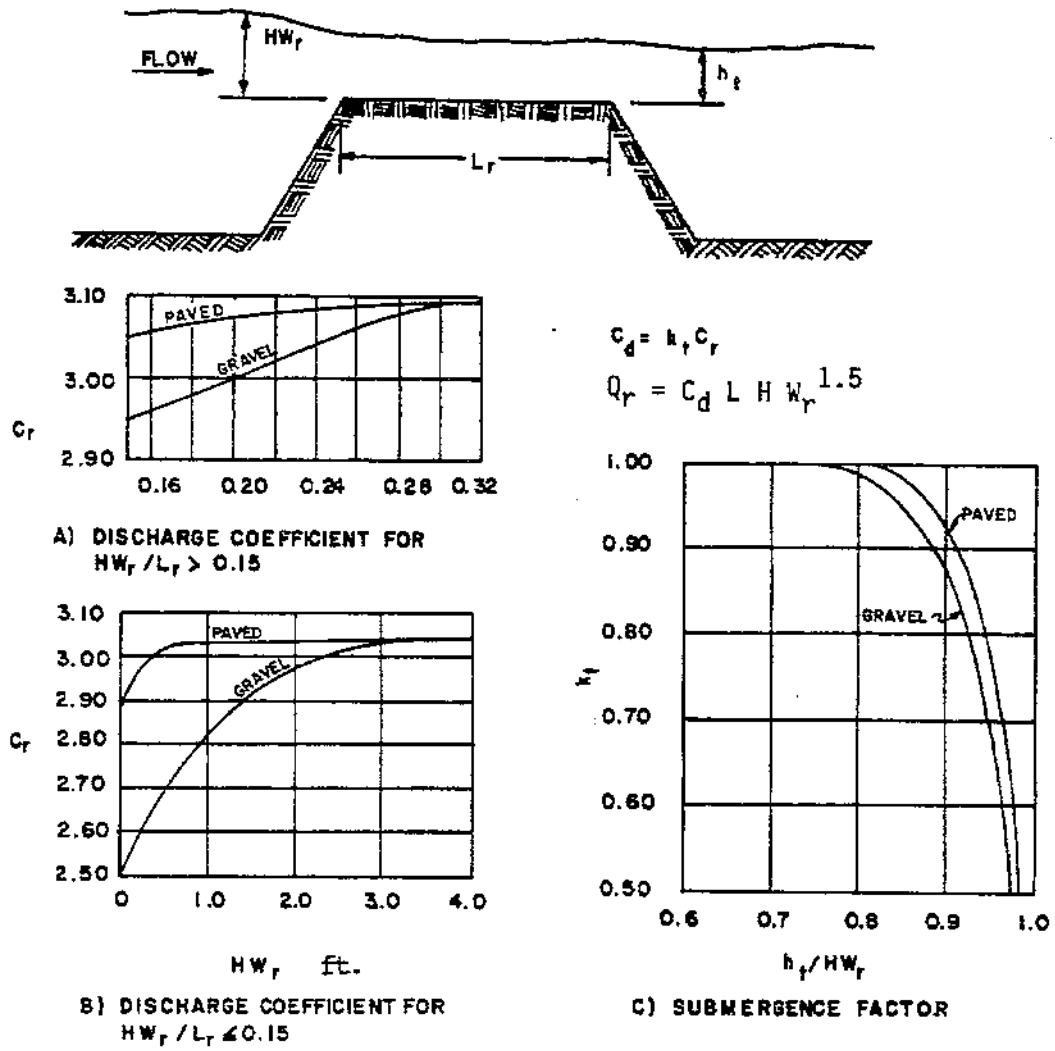
HW = upstream depth, measured from the roadway crest to the water surface upstream of weir drawdown (ft)

Note: See Figure 4.4.5-3 on the next page for guidance in determining a value for C_d. For more information on calculating overtopping flow rates see pages 39 – 42 in HDS No.5

Step four

Add the culvert flow and the roadway overtopping flow at the corresponding headwater elevations to obtain the overall culvert performance curve.

Figure 4.4.5-3
Discharge Coefficients for Roadway Overtopping



4.4.6 Storage Routing

A significant storage capacity behind a highway embankment attenuates a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert, and

its size, may be reduced considerably. If significant storage is anticipated behind a culvert, the design should be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. Routing procedures are outlined in Hydraulic Design of Highway Culverts, Section V – Storage Routing, HDS No. 5, Federal Highway Administration.

The storage should be taken into consideration only if the storage area will remain available for the life of the culvert as a result of purchase of ownership or right-of-way or an easement has been acquired.

END OF SECTION 4.4