8.11 Flood Routing Culvert Design

8.11.1 Introduction

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. It is possible that the findings from culvert analyses will be conservative if flood routing is not considered. Even if the selected allowable headwater is considered acceptable without flood routing, it is possible that costly over design of both the culvert and outlet protection may result, depending on the amount of temporary storage involved.

There are many ramifications listed below associated with altering the temporary upstream ponding caused by a culvert’s backwater. Culvert routing can be helpful in dealing with these ramifications.

- requirement for ownership or easement of upstream properties
- a perceived loss of a subjective safety factor
- credibility, both in court as well as in technical negotiations
- evaluating environmental concerns
- realistic assessments of potential flood hazards
- estimation of sediment problems

Flood Hazards

Potential flood hazards increase whenever a culvert increases the natural flood stage. Some of these hazards can conservatively be assessed without flood routing. However, some damages associated with culvert backwater are time dependent and thus require an estimate of depth versus duration of inundation. Some vegetation and commercial crops can tolerate longer periods of inundation than others, and to greater depths. Such considerations become even more important when litigation is involved.

Culvert Replacement Applications

Improved hydrology methods or changed watershed conditions are factors that can cause an older, existing culvert to be determined to be inadequate. A culvert analysis that relies on findings that ignore any available temporary storage may be misleading. A flood routing analysis may show that what was thought to be an inadequate existing culvert is, in fact, adequate.

Often existing culverts require replacement due to corrosion or abrasion. This can be very costly, particularly where a high fill is involved. A less costly alternative may be to place a smaller culvert with better entrance conditions and smoother pipe inside the existing culvert. A flood routing analysis may, where there is sufficient storage, demonstrate that this is acceptable in that no increase in flood hazard results.

Limitations

There are situations where culvert sizes and velocities obtained through flood routing will not differ significantly from those obtained by designing to the selected peak discharge and ignoring any temporary upstream storage.

This occurs when:

- there is no significant temporary pond storage available (as in deep incised channels)
- the culvert must pass the design discharge with no increase in the natural channel's flood stage
- runoff hydrographs last for long periods of time such as with snowmelt runoff

8.11.2 Routing Equations

In addition to the previous Design Equations (Section 8.6), the following routing equations shall be used. The basic flood routing equation is:

$$\mathbf{I - O = \Delta S/\Delta t \text{ or}} \qquad \mathbf{(8.13)}$$

$$\mathbf{2S_1/\Delta t - O_1 + I_1 + I_2 = 2S_2/\Delta t + O_2} \qquad \mathbf{(8.14)}$$

For a finite interval of time, Δt, equation 8.21 can be expressed by:

$$\mathbf{\Delta S = Q_i\Delta t - Q_0\Delta t} \qquad \mathbf{(8.15)}$$

From these equations:

$$\mathbf{(I_1 + I_2)/2 = \Delta S/\Delta t + O_1/2 + O_2/2} \qquad \mathbf{(8.16)}$$

Where:
- ΔS = $S_2 - S_1$
- S_1 = storage volume in the temporary pond at the beginning of the incremental time period Δt, m^3 (ft^3)
- S_2 = storage volume in the temporary pond at the end of the incremental time period Δt, m^3 (ft^3)
- Δt = incremental routing time interval selected to subdivide hydrograph into finite time elements, min
- I = average hydrograph inflow to the temporary pond during incremental time period Δt, m^3/s (ft^3/s)
- I_1 = instantaneous inflow to the temporary pond at the beginning of the incremental time period Δt, m^3/s (ft^3/s)
- I_2 = instantaneous inflow at the end of the time period Δt, m^3/s (ft^3/s)
- O = average outflow from the temporary pond during incremental time period Δt, m^3/s (ft^3/s)
- O_1 = instantaneous outflow at the beginning of the time period Δt, m^3/s (ft^3/s)
- O_2 = instantaneous outflow at the end of the time period Δt, m^3/s (ft^3/s)

8.11.3 Design Procedure

The design procedure for flood routing through a culvert is the same as for reservoir routing. The site data and roadway geometry are obtained (Data Collection Chapter) and the hydrology analysis completed to include estimating a hydrograph (Hydrology Chapter). Once this essential information is available, the culvert can be designed.

Flood routing through a culvert can be time consuming.

The designer should be familiar with the culvert flood routing design process. This familiarization is necessary in order to:

- recognize and test suspected software malfunctions
- circumvent any software limitations
- flood route manually where the software is limited
- understand and discuss culvert flood routing in a credible manner.

The steps are outlined in the Chapter 10, Storage Facilities.