Culvert Design

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1.0 INTRODUCTION AND OVERVIEW

The function of a culvert is to convey surface water across a highway, railroad, or other embankment. In addition to the hydraulic function, the culvert must carry construction, highway, railroad, or other traffic and earth loads. Therefore, culvert design involves both hydraulic and structural design considerations. The hydraulic aspects of culvert design are set forth in this chapter.

Culverts are available in a variety of sizes, shapes, and materials. These factors, along with several others, affect their capacity and overall performance. Sizes and shapes may vary from small circular pipes to extremely large arch sections that are sometimes used in place of bridges.

The most commonly used culvert shape is circular, but arches, boxes, and elliptical shapes are used, as well. Pipe arch, elliptical, and rectangular shapes are generally used in lieu of circular pipe where there is limited cover. Arch culverts have application in locations where less obstruction to a waterway is a desirable feature, and where foundations are adequate for structural support. Box culverts can be designed to pass large flows and to fit nearly any site condition. A box or rectangular culvert lends itself more readily than other shapes to low allowable headwater situations since the height may be decreased and the span increased to satisfy the location requirements.

The material selected for a culvert is dependent upon various factors, such as durability, structural strength, roughness, bedding condition, abrasion and corrosion resistance, and water tightness. The more common culvert materials used are concrete and steel (smooth and corrugated).

Another factor that significantly affects the performance of a culvert is its inlet configuration. The culvert inlet may consist of a culvert barrel projecting from the roadway fill or mitered to the embankment slope. Other inlets have headwalls, wingwalls, and apron slabs or standard end sections of concrete or metal.

A careful approach to culvert design is essential, both in new land development and retrofit situations, because culverts often significantly influence upstream and downstream flood risks, floodplain management and public safety (Photograph CU-1). Culverts can be designed to provide beneficial upstream conditions (Photograph CU-2) and to avoid negative visual impact (Photograph CU-3).

Photograph CU-1—Public safety considerations for long culverts should be accounted for with culvert designs such as with this collapsible trash rack at a park-like location.

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Photograph CU-2—Culverts can be designed to provide compatible upstream conditions for desirable wetland growth.

Photograph CU-3—Culverts can be integrated into the urban landscape without negative visual impact.

The information and references necessary to design culverts according to the procedure given in this chapter can be found in *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5 (FHWA 1985). Some of the charts and nomographs from that publication covering the more common

requirements are given in this chapter. Nomographs and charts covering the range of applications commonly encountered in urban drainage are contained in Section 11.0. For special cases and larger sizes, the FHWA publication should be used.

1.1 Required Design Information

The hydraulic design of a culvert essentially consists of an analysis of the required performance of the culvert to convey flow from one side of the roadway (or other kind of embankment, such as a railroad) to the other. The designer must select a design flood frequency, estimate the design discharge for that frequency, and set an allowable headwater elevation based on the selected design flood and headwater

considerations. These criteria are typically dictated by local requirements although state and federal standards will apply to relevant highway projects. The culvert size and type can be selected after the design discharge, controlling design headwater, slope, tailwater, and allowable outlet velocity have been determined.

The design of a culvert includes a determination of the following:

- Impacts of various culvert sizes and dimensions on upstream and downstream flood risks, including the implications of embankment overtopping.
- How will the proposed culvert/embankment fit into the relevant major drainageway master plan, and are there multipurpose objectives that should be satisfied?
- Alignment, grade, and length of culvert.
- Size, type, end treatment, headwater, and outlet velocity.
- Amount and type of cover.
- Public safety issues, including the key question of whether or not to include a safety/debris rack (Photograph CU-4).
- Pipe material.
- Type of coating (if required).
- Need for fish passage measures, in specialized cases.
- Need for protective measures against abrasion and corrosion.
- Need for specially designed inlets or outlets.
- Structural and geotechnical considerations, which are beyond the scope of this chapter.

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Photograph CU-4—Public safety features such as the rack at the entrance to an irrigation ditch and the railing on the wingwalls must be considered.

1.1.1 Discharge

The discharge used in culvert design is usually estimated on the basis of a preselected storm recurrence interval, and the culvert is designed to operate within acceptable limits of risk at that flow rate. The design recurrence interval should be based on the criteria set forth in the POLICY chapter of this *Manual*. Specifically, refer to Tables DP-1 through DP-3 for street overtopping criteria.

1.1.2 Headwater

Culverts generally constrict the natural stream flow, which causes a rise in the upstream water surface. The elevation of this water surface is termed *headwater elevation*, and the total flow depth in the stream measured from the culvert inlet invert is termed *headwater depth*.

In selecting the design headwater elevation, the designer should consider the following:

- Anticipated upstream and downstream flood risks, for a range of return frequency events.
- Damage to the culvert and the roadway.
- Traffic interruption.
- Hazard to human life and safety
- Headwater/Culvert Depth (HW/D) ratio.
- Low point in the roadway grade line.

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