Conduits, Culverts, and Pipes Part II

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Chapter 1: Introduction to Conduit, Culvert, and Pipe Design

Learning Objectives

By the end of this section, you will be able to:

- Identify the scope and applicability of this design manual for civil works projects.
- Evaluate pipe material selection based on project service life, product service life, and anticipated future costs in a life cycle design framework.
- Apply the key design principles for conduit shape, loading conditions, and essential joint and foundation requirements in dams and levees.

Executive Summary: Successful conduit, culvert, and pipe design relies on balancing minimum first cost with long-term performance (life cycle design). For major infrastructure, assume a 100-year project life. Select materials based on environmental factors, ensuring watertight and flexible joints are used in embankments to prevent piping.

1-1. Purpose and Scope

This manual provides guidance on the design and construction of conduits, culverts, and pipes. It also establishes the design procedures for:

- Trench and embankment earth loadings.
- Highway loadings.
- Railroad loadings.
- Surface concentrated loadings.
- Internal and external fluid pressures.

1-2. Applicability

This manual applies to HQUSACE elements and all USACE commands, districts, laboratories, and field operating activities that have civil works responsibilities.

1-3. References

The standard practice is to use the accepted design methods found in the references listed in Appendix A when this manual does not provide specific guidance on conduits, culverts, and pipes. Related publications are also compiled in Appendix A.

1-4. Life Cycle Design

a. General

When designing, base the selection of materials or products for conduits, culverts, or pipes on engineering requirements and life cycle performance. This process aims to balance the need to minimize first costs with ensuring reliable long-term performance and reasonable future maintenance costs.

b. Project Service Life

- Economic analyses used for project authorization typically project costs and benefits over a 50- or 75-year project life.
- Safety Constraint: For major infrastructure projects, designers must use a minimum project service life of 100 years when conducting life cycle design evaluations.

c. Product Service Life

The useful life of products varies significantly based on material and protective coatings. The product service life will likely be less than the project service life, and this differential must be explicitly accounted for in the life cycle design process.

Design Tip: You must investigate and document key environmental factors for each project and use them to select an appropriate product service life. Significant factors include soil pH and resistivity, water pH, presence of corrosive compounds (e.g., salts), erosion sediment, and flow velocity.

In general, concrete pipe is expected to provide a product service life approximately two times that of steel or aluminum.

Material	Expected Product Service Life	Key Failure/Corrosion Notes
Concrete	70 to 100 years	Most studies estimate 70-100 years. Of nine state highway departments, three listed the life as 100 years, five states stated between 70 and 100 years, and one state gave 50 years.
Steel	At least 50 years	Usually fails due to corrosion of the invert or exterior. Properly applied coatings can extend life to ≥ 50 years for most environments.

Aluminum	Not greater than 50 years	More affected by soil-side corrosion than invert corrosion. Long-term performance is difficult to predict, but the designer should not expect a product service life greater than 50 years.
Plastic	Not greater than 50 years	Performance history is limited; a designer should not expect a product service life of greater than 50 years. Different materials in this category have unique suitabilities/unsuitabilities.

d. Future Costs

The life cycle analysis must incorporate the initial construction cost plus future costs for maintenance, repair, and replacement over the project service life.

- Where certain future costs are identical (e.g., normal operation, inspection, and maintenance), they can be excluded from the comparative calculations.
- The primary focus is on costs for major repairs and replacement.
- If replacement is necessary, include all associated costs, such as constructing temporary levees or cofferdams, and accounting for disruptions to normal project operations.

1-5. Supportive Material

This manual includes several appendices to aid in design:

- Appendix B presents design examples for conduits, culverts, and pipes.
- Appendixes C and D provide outlines for evaluating and repairing existing systems, respectively.
- Appendix E is a conversion factor table for metric units.

Conduit materials are categorized by structural behavior:

- Rigid Conduits: Generally, concrete conduits.
- Flexible Conduits: Steel, ductile iron, aluminum, and plastic.

In flexible conduit design, vertical loads deflect the walls into the surrounding soils, developing the conduit's strength through soil-structure interaction. Therefore, control of backfill compaction around flexible conduits is critical to the design.

- Controlled backfill placement for either rigid or flexible conduits minimizes pipe deflection, maintains joint integrity, and reduces water piping.

1-6. Design Fundamentals

General

- Reinforced concrete conduits are used for medium and large dams.
- Precast pipes are used for small dams, urban levees, and other levees where public safety or substantial property damage is at risk.
- Corrugated metal pipes are acceptable for agricultural levees when the pipe diameter is 900 mm (36 in.) and the levee embankment is no higher than 4 m (12 ft) above the invert.
- Ancillary structures like inlet structures, intake towers, gate wells, and outlet structures should be constructed of cast-in-place reinforced concrete. Precast concrete or corrugated metal structures may be used in agricultural and rural levees.
- Culverts are typically used for roadway, railway, and runway crossings.

a. Shapes

Conduits are closed, shaped openings used to carry fluids through embankments.

- Conduit shape is determined by hydraulic design and installation conditions.
- Typical shapes include circular, rectangular, oblong, horseshoe, and square sections.
- Circular shapes are most common.
- Rectangular (box-shaped) conduits are generally used for large conduits through levees and for culverts carrying waterways under roads or railroads. Multiple cell configurations are commonly box shaped.

b. Loads

Conduit loadings include:

- Earth loads.
- Surface surcharge loads (e.g., reservoir pool water above finished grade).
- Vehicle loads.
- External hydrostatic pressures.
- Internal fluid pressures (determined by hydraulic design and a concern when greater than external pressures).

c. Materials

Construction materials include cast-in-place concrete, precast concrete, steel, ductile iron, aluminum, and plastic.

d. Joints

- Safety Constraint: Joints in conduits passing through dams and levees must be watertight and flexible to accommodate longitudinal and lateral movements.

- Joint integrity is critical because leaking joints lead to piping and premature failure of the conduit/embankment.
- Designers must control conduit deflections, settlements, and joint movements to maintain joint integrity.
- Improperly installed pipes can cause joint leakage, allowing soil fines to pass into the conduit or internal water to pass along the outside of the conduit (piping).

e. Foundation and Piping

The three common foundation problems are:

1. Water piping along the outside of the conduit.
2. Piping of soil into the conduit.
3. Migration of soil fines into a well-washed crushed rock foundation material.

- Soil migration problems often lead to sinkholes, which can cause embankment failure due to piping.
- Safety Constraint: In accordance with EM 1110-2-1913, a 450 mm (18 in.) annular thickness of drainage fill should be provided around the landside third of any conduit (Figure 1-1).
- This applies regardless of the conduit type used, where the landside zoning of the embankment or levee does not already provide such drainage.
- The drainage fill must include provisions for a landside outlet through a blind drain to the ground surface at the levee toe, connection with previous under seepage collection features, or an annular drainage fill outlet to the ground surface around a manhole structure.

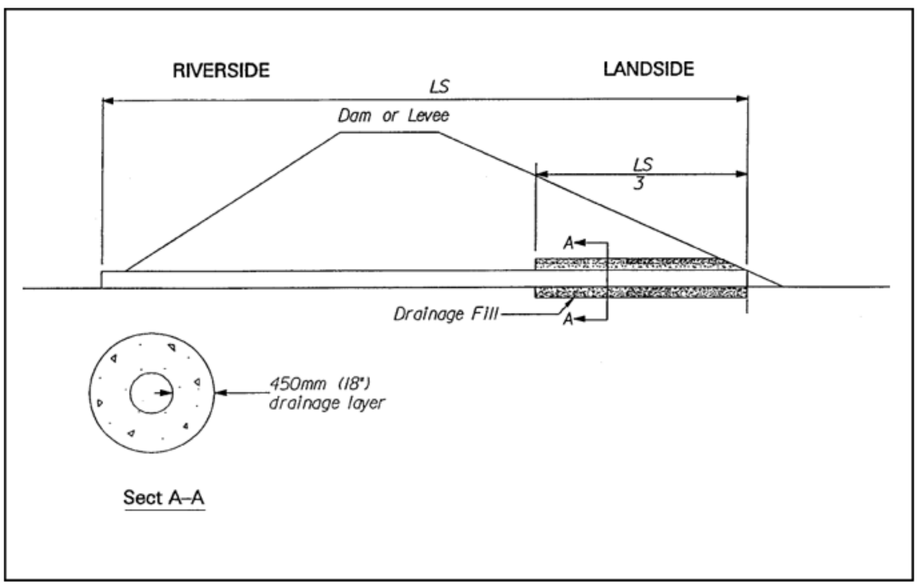

Figure 1-1. Drainage fill along conduit