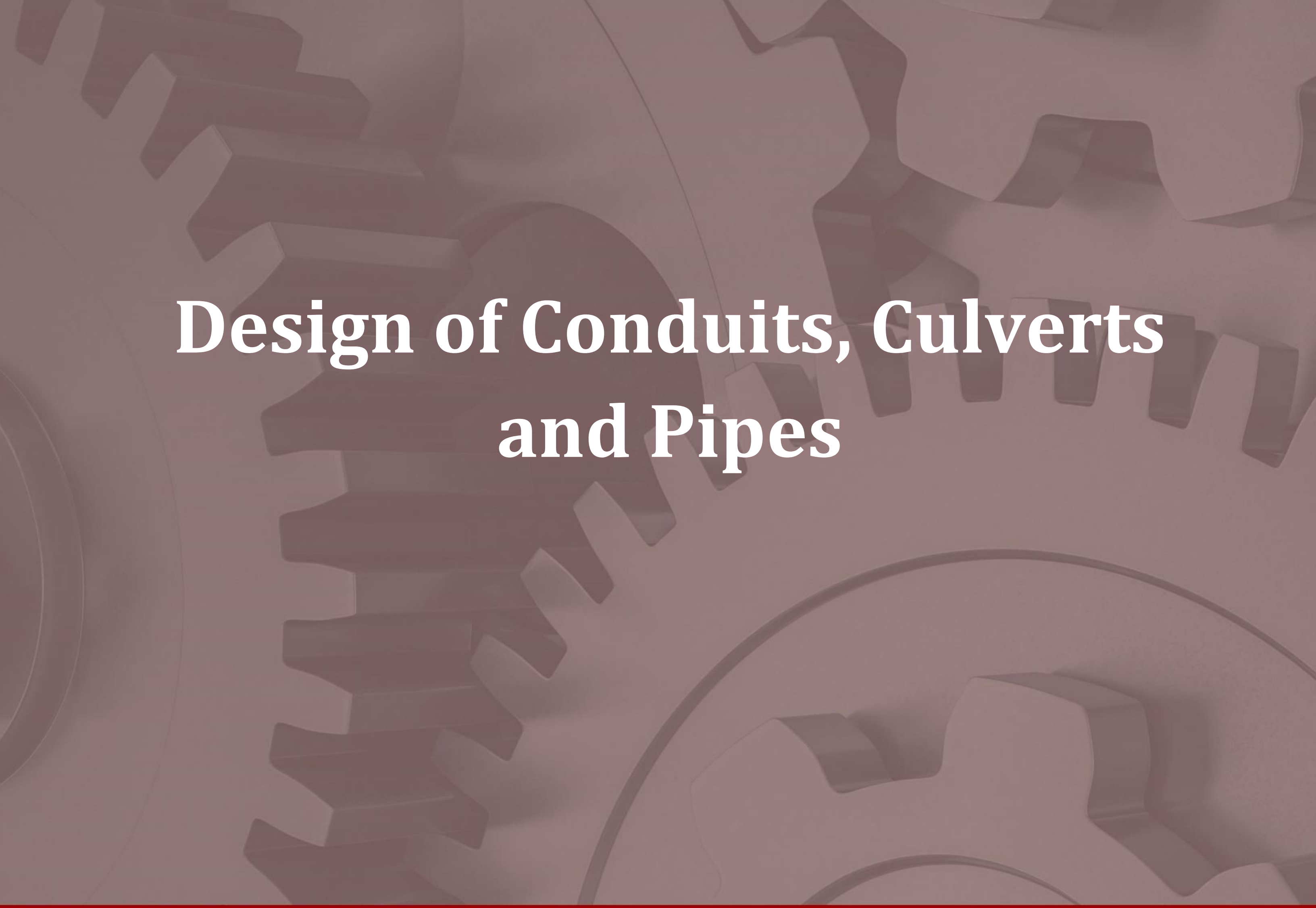

Design of Conduits, Culverts and Pipes

An Online Continuing Education Course for Engineers

Course Number: C-4042

Credit: 4 Hours / 4 PDH / 4 CPD

Design of Conduits, Culverts and Pipes

Chapter 1
Introduction

1-1. Purpose and Scope

This course provides (a) guidance on the design and construction of conduits, culverts, and pipes, and (b) design procedures for trench/embankment earth loadings, highway loadings, railroad loadings, surface concentrated loadings, and internal/external fluid pressures.

1-2. Life Cycle Design

a. General. During the design process, selection of materials or products for conduits, culverts, or pipes should be based on engineering requirements and life cycle performance. This balances the need to minimize first costs with the need for reliable long-term performance and reasonable future maintenance costs.

b. Project service life. Economic analysis used as a part of project authorization studies usually calculates costs and benefits projected for a 50- or 75-year project life. For major infrastructure projects, designers should use a minimum project service life of 100 years when considering life cycle design.

c. Product service life. Products made from different materials or with different protective coatings may exhibit markedly different useful lives. The service life of many products will be less than the project service life, and this must be considered in the life cycle design process. In general, concrete pipe can be expected to provide a product service life approximately two times that of steel or aluminum. However, each project has a unique environment, which may either increase or decrease product service life. Significant factors include soil pH and resistivity, water pH, presence of salts or other corrosive compounds, erosion sediment, and flow velocity. The designer should investigate and document key environmental factors and use them to select an appropriate product service life.

(1) Concrete. Most studies estimated product service life for concrete pipe to be between 70 and 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.

(2) Steel. Corrugated steel pipe usually fails due to corrosion of the invert or the exterior of the pipe. Properly applied coatings can extend the product life to at least 50 years for most environments.

(3) Aluminum. Aluminum pipe is usually affected more by soil-side corrosion than by corrosion of the invert. Long-term performance is difficult to predict because of a relatively short history of use, but the designer should not expect a product service life of greater than 50 years.

(4) Plastic. Many different materials fall under the general category of plastic. Each of these materials may have some unique applications where it is suitable or unsuitable. Performance history of plastic pipe is limited. A designer should not expect a product service life of greater than 50 years.

d. Future costs. The analysis should include the cost of initial construction and future costs for maintenance, repair, and replacement over the project service life. Where certain future costs are identical among all options, they will not affect the comparative results and may be excluded from the calculations. For example, costs might be identical for normal operation, inspection, and maintenance. In this case, the only future costs to consider are those for major repairs and replacement. Where replacement will be necessary during the project service life, the designer must include all costs for the replacement activities. This might include significant costs for construction of temporary levees or cofferdams, as well as significant disruptions in normal project operations.

1-3. General

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

a. Shapes. Conduits are closed shaped openings used to carry fluids through dams, levees, and other embankments. Conduit shapes are determined by hydraulic design and installation conditions. Typical shapes include circular, rectangular, oblong, horseshoe, and square sections. Circular shapes are most common. Rectangular or 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 account for earth loads, surface surcharge loads, vehicle loads, external hydrostatic pressures, and internal fluid pressures. Surface surcharge loads can be used to account for the reservoir pool water above a finished grade. Internal fluid pressure is determined by the hydraulic design of the conduit and is a concern when greater than the external pressures.

c. Materials. Construction includes cast-in-place concrete, precast concrete, steel, ductile iron, aluminum, and plastic. In general, concrete conduits are designed as rigid conduits, and the other materials are designed as flexible conduits. In flexible conduit design, the vertical loads deflect the conduit walls into the surrounding soils, thereby developing the strength of the conduit through soil-structure interaction. Therefore, control of the backfill compaction around flexible conduits is critical to the design. Controlled backfill placement for either type of conduit minimizes pipe deflection, maintains joint integrity, and reduces water piping.

d. Joints. Joints in conduits passing through dams and levees must be watertight and flexible to accommodate longitudinal and lateral movements. Because leaking joints will lead to piping and to the premature failure of the conduit and the embankment, designers need to control conduit deflections, conduit settlements, and joint movements. Maintaining joint integrity in conduits passing through dams and levees is critical. Improperly installed pipe causes joints to leak, allows soil fines to pass through the conduit joints into the conduit, or allows internal water to pass through the conduit joints and along the outside of the conduit (piping).

e. Foundation and piping. The three common foundation problems encountered in conduit design are water piping along the outside of the conduit, the piping of soil into the conduit, the migration of soil fines into a well-washed crushed rock foundation material. Soil migration problems often lead to sink holes, which can cause embankment failure due to piping. A 450-mm (18-in.) annular thickness of drainage fill should be provided around the land-side third of any conduit (Figure 1-1) regardless of type of conduit to be used, where the landside zoning of an embankment or levee does not provide for such drainage. For conduit installations with an embankment or levee foundation, the 450-mm (18-in.) annular thickness of drainage fill shall be provided and shall include provisions for a landside outlet through a blind drain to the ground surface at the levee toe, connection with pervious under-seepage collection features, or an annular drainage fill outlet to the ground surface around a manhole structure.

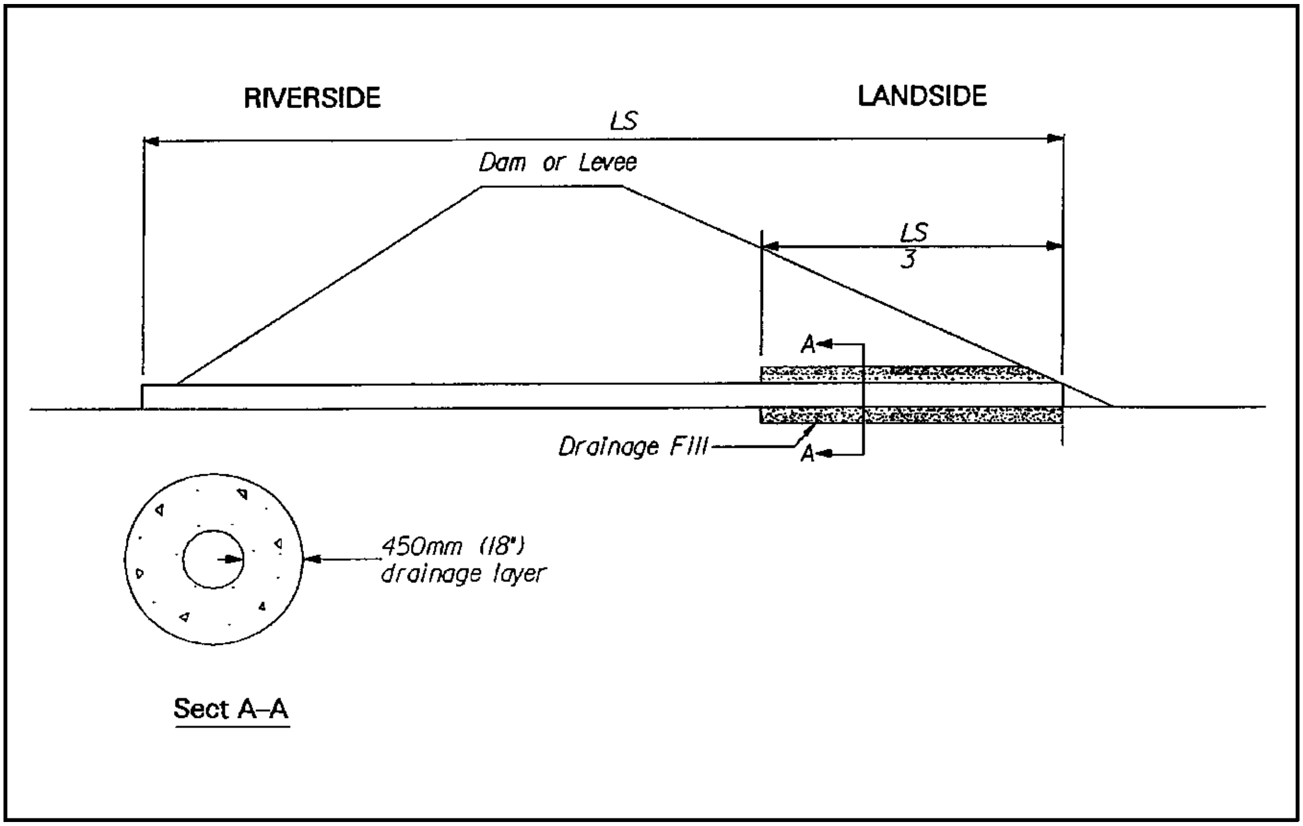

Figure 1-1. Drainage fill along conduit

Chapter 2

Cast-in-Place Conduits for Dams

2-1. General

The selection of the most economical conduit cross section must depend on the designer's judgment and the consideration of all design factors and site conditions for each application. For fills of moderate height, circular or rectangular openings will frequently be the most practicable because of the speed and economy obtainable in design and construction. For openings of less than about 5.6 m^2 (60 ft^2), a single rectangular box probably will be most economical for moderate fills up to about 18.3 m (60 ft). However, a rectangular conduit entrenched in rock to the top of the conduit may be economical for higher fills since the applied vertical load need be only the weight of the earth directly above with no increase for differential fill settlement. The ratio of height to width should be about 1.50 to accommodate the range of loading conditions economically. Where there is a battery of outlet gates, a multiple-box shape is sometimes economical where acceptable from a hydraulic standpoint.

a. Single conduits. For a single conduit of more than about 5.6-m^2 (60-ft^2) area and with a fill height over 18.3 m (60 ft), it will generally be found economical to use a section other than rectangular for the embankment loading (Condition III). The circular shapes are more adaptable to changes in loadings and stresses that may be caused by unequal fill or foundation settlement. For cases in which the projection loading condition applies, no material stress reduction results from the provision of a variable cross section. These structures should be formed as shown in Figure 2-1 and should be analyzed as a ring of uniform thickness. While these sections show variations in thickness in the lower half of the conduit due to forming and other construction expedients, such variations may be disregarded in the design without appreciable error.

b. Oblong sections. The oblong section shown in Figure 2-1 is formed by separating two semicircular sections by short straight vertical wall sections. The oblong section generally achieves maximum economy of materials by mobilizing more of the relieving fill pressure. The proportions should be selected carefully, and the tangent-length-to-radius ratio will usually be between 0.5 and 1.0. The conduit design should cover a range of possible loading conditions, from initial or construction condition to the long-time condition. Here also, a geologist or soils engineer should be consulted before final determination of the base shape of a conduit.

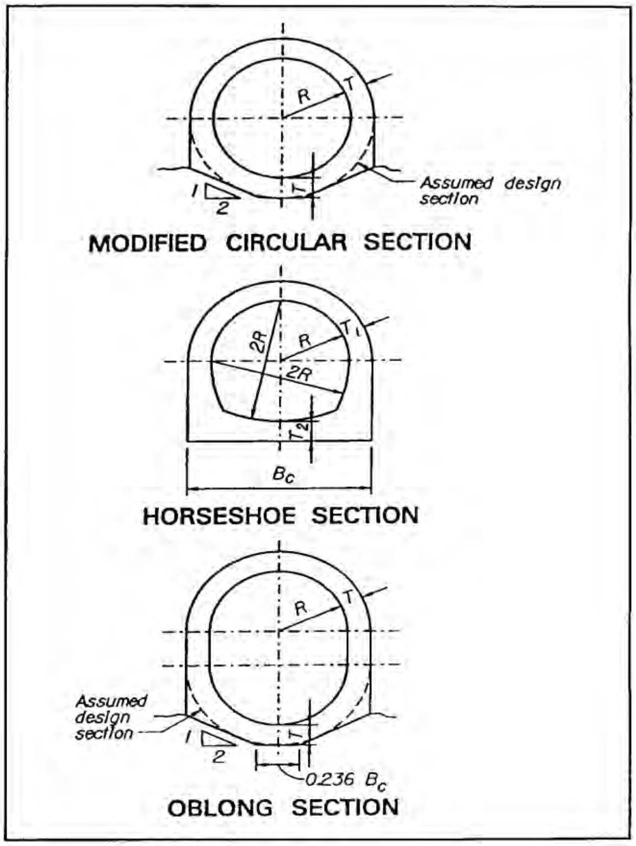

Figure 2-1. Typical cast-in-place conduits

c. Horseshoe sections. The "horseshoe" section in Figure 2-1 is generally less economical than the oblong and is therefore not often used. Its stress distribution is not as desirable as that of the circular or oblong section, and shear stirrups may be required in the base. It may be practicable, however, for some foundation conditions where the fill height is low.

d. Interbedded foundations. It may be difficult to shape the foundation excavation when in closely bedded, flat-lying shale, or when in rock with frequent shale interbeds. For this condition, it may be economical to excavate the foundation level and backfill to the desired shape with a low-cement-content concrete. A geotechnical engineer should be consulted to help develop the excavation plan. Excavation drawings should show the pay excavation lines and not the act excavation lines. For a cond designer should sho rather than the pa contractor should li excavation lines.

2-2. Materials

a. Concrete. Mini 28 MPa (4,000 psi) air

b. Reinforcement. Grade 400 MPa (60,000

2-3. Installation

Conduits through dams the soil or rock and, the design consideration. Wh foundation materials is should be used to maintain proper conduit grade. All foundation materials for cast-in-place conduits should be reviewed by a geotechnical engineer.

2-4. Loadings

Typical conduit loads are shown in Figure 2-2. The conduit supports the weight of the soil and water above the crown. Internal and external fluid pressures and lateral soil pressures may be assumed as uniform loads along the horizontal axis of the conduit when the fluid head or fill height above the crown is greater than twice the conduit diameter or span. Foundation pressures are assumed to act uniformly across the full width of cast-in-place conduits. Uplift pressures should be calculated as uniform pressure at the base of the conduit when checking flotation.

a. Groundwater and surcharge water. Because of the ratio of vertical to horizontal pressure, the most severe loading condition will generally occur when the reservoir is empty and the soil is in a natural drained condition. However, the following loads occur where there is groundwater and/or surcharge water.

l pressure. Use Equation 2-1 to cal pressure due to the weight of ined soil above the groundwater ight of the submerged soil below surface, and the weight of the e of water above the conduit, urcharge water above the fill

$$\ldots \gamma_w) H_s \qquad (2\text{-}1)$$

W = vertical pressure due to prism of soil above pipe, N/m^2 (psf)

γ = soil unit weight; d = dry, s = saturated, w = water, N/m^3 (pcf)

H = soil height; d = dry, s = saturated soil, m (ft)

H_w = water height above the point of interest, m (ft)

(2) Horizontal pressure. Horizontal pressure from the lateral earth pressure is obtained by using