Chapter 7

Durability and Service Life

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DURABILITY AND SERVICE LIFE

Durability of Drainage Pipes

Durability is the property to resist erosion, material degradation and subsequent loss of function due to environmental and/or other service conditions. Abrasion, chemical corrosion and electrochemical corrosion are the most common durability concerns for drainage pipes. Erosion of drainage pipes by changes in flow patterns also may include: impingement by suspended solid particles or gas bubbles striking the surface; turbulence at pipe entrances and sharp bends, as well as aggregate and sediment deposits. Although an unlikely event for culverts and storm drains, high pressure and sub-atmospheric pressures that may be associated with high velocity flows may cause cavitation.

Corrosive chemicals carried by the water expose the inverts of storm drain pipelines and culverts to corrosion-abrasion damage. The invert, host to both an electrolyte and varying concentrations of oxygen, may also be exposed to electrolytic corrosion.

In hostile environments, materials such as unprotected concrete and unprotected steel develop corrosion products that are more brittle and thus more vulnerable to bedload abrasion. As the corroded surface is stripped away, a fresh surface is exposed and new corrosion products form. If this cycle continues, eventual structural failure must be considered. Longevity of exposed pipes depends upon the qualities of the protective barriers. Palliative measures – such as protective coatings, linings and pavements – are at risk of being eroded, cracked or delaminated.

Corrosion

Chemical corrosion of buried pipelines and culverts may occur in the presence of soils and waters containing acids, alkalis, dissolved salts and organic industrial wastes. Surface water, ground water, sanitary effluent, acid rain, marine environments and mine drainage carry these contaminants. Some may occur in regions of high rainfall, others in arid locations. Sulfates, carbonates and chlorides degrade concrete – a process often accelerated in regions where freeze-thaw cycles leave the material open to deeper penetration by the offending elements. Vitrified clay and plastic pipes are largely inert. Zinc, aluminum, aluminum-zinc alloy metallic coatings, asphaltic coatings with and without fiber and polymer coatings offer metal pipes varying measures of protection against soil-side and water-side chemical and electrochemical corrosion.

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Electrochemical corrosion of metal pipelines and culverts may occur where oxygen starved and oxygen rich locations on, and in the vicinity of, the pipe respectively become anodes and cathodes. A potential difference will cause current flow through a circuit composed of an electrolyte (soil moisture in the vicinity of the pipe or liquid within), an anode (a region on the pipe giving up electrons), a cathode (a region on the pipe accepting electrons) and the pipe as a conductor. Loss of pipe material occurs at the anode. Stray direct current from a nearby electric railway or a cathodically protected utility is another source of potential difference. The degree of electrochemical degradation of corrugated steel pipe increases with lower pH and lower resistivity of soil and water. Reinforced concrete pipelines and culverts are also vulnerable to electrochemical corrosion. Permeable to moisture, concrete may serve as the electrolyte for highly anodic bare steel that can form where concrete cover has spalled off reinforcing bars. A potent corrosion cell may result.

Unlike metals, polyethylene pipes are non-conductors and are not vulnerable to galvanic corrosion associated with electrochemical attack. Polyethylene pipes are not degraded by pH extremes, aggressive salts or chemically induced corrosion. Unlike metals, HDPE pipes are non-conductors, insensitive to low soil resistivity, and therefore not subject to electrochemical corrosion. The Federal Lands Highway (FLH) policy is that plastic alternatives may be specified without regard to resistivity and pH of the site. The same is true for many states.

HDPE pipes are effective for drainage of hostile effluents, such as acid rain, acidic mine wastes, aggressive landfill leachates and effluents with high concentrations of road salts, fuels and motor oils. Laboratory studies indicate that only a negligible increase in abrasive wear of HDPE pipes may be expected when the pH drops from neutral (pH = 7) to medium-low acidic conditions (pH = 4). A reported field study showed that HDPE pipe is unaffected by acid mine run-off of pH ranging from 2.55 to 4.

Abrasion

Chemicals and abrasion are the most common durability concerns for drainage pipes, especially when the effluent flows at high velocities. In test after test, results show that it takes longer to abrade through polyethylene than concrete and metallic pipes. In fact, in testing in both the United States and Europe, polyethylene has demonstrated wear rates up to 10 times less than steel.

Abrasives – such as stones or debris – can result in a mechanical wearing away of the pipe. The extent of the problem depends on the type of abrasive, frequency that the material is in the pipe, velocity of the flow, and the type of the pipe material. The effect of abrasives may be seen in the pipe invert where exposure is most severe. Over time, abrasives can result in a loss of pipe strength or reduction in hydraulic quality as they gradually remove wall material.

Abrasion is a precursor to accelerated corrosion. The Federal Lands Highway Project Development Design Manual has defined measures of abrasion for typical flow conditions (rather than a particular design flood) as follows:

- nonabrasive – no bed load and very low velocities
- low abrasive – minor bed loads of sand and velocities less than 1.5 m/s (5 fps)
- moderate abrasive – moderate bed loads of sand and gravel and velocities between 1.5 and 4.5 m/s (5 and 15 fps)
- severe abrasive – heavy bed loads of sand, gravel and rock and velocities exceeding 4.5 m/s (15 fps)

The FLH design guide permits unrestricted use of HDPE and PVC for nonabrasive and low abrasive conditions. Many states permit the unrestricted use of plastic pipes for all abrasive environments.

Other Durability Items

Ultraviolet (UV) radiation and oxygen induce degradation in plastics that usually alter the material's physical and mechanical properties. The function of UV stabilizers is to inhibit the physical and chemical processes of UV-induced degradation. The most common UV stabilizer used in the polyethylene pipe industry is finely divided carbon black, which is the additive most effective in stopping these UV-induced reactions. However, colors with UV stabilizers, other than black, may be just as effective in inhibiting UV degradation.

The National Fire Protection Association (NFPA 704) rates polyethylene with a 1 (slow burning) in a scale from 0 to 4; higher ratings indicate increasing vulnerability. Polyethylene piping, in sizes up to and including 18 in. (457 mm) diameter has been used for 30 years in the natural gas industry without reported problems. Whereas prudence suggests that corrugated HDPE should be protected from exposure to major grass fires at drainage inlets and outlets, most states consider the risk insignificant or minimal. A Battelle study notes that the flammability of plastic pipe is a non-issue. Non-HDPE pipes typically have linings and coatings used for protection against corrosion and abrasion. Many of these coatings are also combustible. For all types of pipes, if exposure to fire is a considerable risk, there are numerous preventive measures that can be considered to prevent fire damage. Rip-rap or gravel around exposed ends, steel end sections or other methods can be used to keep grass or combustibles away from the pipe end.

Service Life

Control and disposal of surface water runoff during periods of abnormally high rainfall with associated floods require efficient and reliable systems of drainage of predictable longevity. Estimates of years of reliable low maintenance service, anticipated in the design phase, is dependent upon service experiences, choice of pipe materials, environmental considerations, regional construction practices and economic constraints.

The desired service life of a drainage system is specified by the agency of jurisdiction. A 50-year design life is generally the minimum specified; therefore a service life in excess of that brings further economies to the installation. The service life of corrugated HDPE pipe manufactured from today's materials is expected to exceed 100 years. Well-defined and timely maintenance is key to achieving the anticipated longevity. Inspection strategies vary. Rehabilitation or replacement is justified when it is unsafe, or uneconomical, to maintain elements of the drainage system in service. Trenchless methods of rehabilitating metal and concrete include sliplining, flexible tube lining and Portland cement mortar lining. The use of preformed linings of plastic are often followed with grouting of the annular space between the liner and the existing pipe.

Corrosion and abrasion damage to culverts and drainage pipelines is irreversible. Initial service life calculations must be inclusive of expectations of long-term durability, structural integrity and hydraulic capacity. When possible, useful service life may be extended by corrective measures. These costs must be weighed against costs of replacement. In cases of pipelines and culverts under high fills, addressing associated problems such as traffic interruption may be very costly.

Life Cycle Cost Analysis

Comparisons of design alternatives often employ the use of life cycle economic analyses. The life cycle cost of an alternative system or part of a system anticipates all the costs that are likely to occur over the service life. Included are costs of the initial investment, inspection as well as scheduled maintenance, repair, rehabilitation and/or replacement and disruption of services. Estimates are required for useful

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survival life, salvage credits, residual value, discount rate and time period of analysis. The likelihood of rural areas changing into urban areas and the associated needs for future increases in hydraulic capacity and accommodation of changes in aggressiveness of the effluent must be incorporated into life cycle analyses.

Predictions of useful service lives for cross drains, side drains, storm drains, under drains and sanitary sewers of all materials appear in a joint survey by the American Association of State Highway and Transportation Officials (AASHTO), the Associated General Contractors (AGC) and the American Road and Transportation Builders Association (ARTBA). FLH policy requires all permanent drainage pipe installations to be designed for a minimum of a 50-year maintenance-free service life – temporary installations excepted.

Alternatives with different costs are compared over the expected life of a project. Discount rates which include expectations of inflation are estimated – a risky process which will significantly influence the analysis. Low discount rates favor greater initial costs and lower future expenditures and vice versa. The lowest present worth estimate of alternatives is the most sound economic basis for selection.

The present worth of a cost "n" years after the initial investment is obtained by multiplying a present worth factor (PWF) by the estimated expenditure. With "i" defined as the discount rate:

$$PWF = 1/(1+i)^n \qquad \textbf{Equation 7-1}$$

Estimating a discount rate of 8%, what is the present worth of a $500,000 maintenance expenditure programmed to occur in 20 years? What is the present worth of this same expenditure if the discount rate is estimated to be 10%?

$i = 8\%$: $PWF = 1/(1+i)^n = 1/(1+.08)^{20} = 0.215$
Present Worth = $500,000(0.215) = $107,300

$i = 10\%$: $PWF = 1/(1+i)^n = 1/(1+.10)^{20} = 0.149$
Present Worth = $500,000(0.149) = $74,300

Note the impact of the discount rate on the outcome, the value of which should be consistent with the economic policies of the organization being served. Also, the estimated cost of maintenance "n" years into the future is sensitive to present approximations of the course of inflation.

Optional time periods for life cycle analyses include: desired service life, expected survival time to earliest rehabilitation or replacement, longest expectation of survival, time to anticipated capacity increase or any other period that is consistent with the physical and economic constraints of the owner of the facility. Refer to the work of T. J. Wonsiewicz (March 1990) for further discussion of discount rates and inflation.

Uncertainty of any of the alternatives may seriously skew the outcome of life cycle analyses. Experiences with pipes of different materials in local environments similar to the drainage facility of interest should be a major influence in the assignment of expected survival life.

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