American **Concrete Pipe** Association

LEAST COST ANALYSIS

HYDRAULIC EFFICIENCY

SELF-HEALING

CHOICE OF CLASSES

ENVIRONMENTALLY SAFE

LOCALLY AVAILABLE

FULL RANGE OF SIZES

STRENGTH

DURABILITY

VERSATILITY

STANDARD INSTALLATIONS

NON-FLAMMABLE

CORROSION RESISTANT

Start with the Math

The American Society of Civil Engineer's 2005 Report Card for America's Infrastructure estimates a $1.6 trillion investment will be needed over the next five years for infrastructure improvements across the United States. With increasingly tight budgets, public works officials are looking for ways to get the most for their dollar. Pipelines, culverts and related drainage facilities are vital components of our infrastructure, and like all engineering projects, decisions must be made regarding material and system selection. Material selection and development of appropriate design criteria are involved undertakings relating years of experience, usage and performance. The proper engineering design of any hydraulic structure requires consideration of many related fields including planning, hydraulics, installation, durability, maintenance and economics.

Durability and economics are generally not given proper attention and for many transportation or drainage projects, pipe materials or systems are selected on an initial (or capital) cost basis only. However, lower initial costs do not always result in the most economical product or system. To determine the best choice, the principles of economics must be applied through a Least Cost Analysis, (LCA), or Life Cycle Cost Analysis.

Local and state governments are increasingly including some type of LCA analysis in their material selection process. The importance of considering the service life of a project during the design phase has been heightened by the multitude of problems many authorities are facing as our infrastructure declines. In many instances, engineers and transportation officials have had to replace integral sections of infrastructure that have experienced premature degradation.

According to the U.S. Army Corps of Engineers, selection of all systems, components, and materials for Civil Works projects are based on their long-term performance, including a Least Cost Analysis. This design criterion is referred to as Regulation No. 1110-2-8159. The
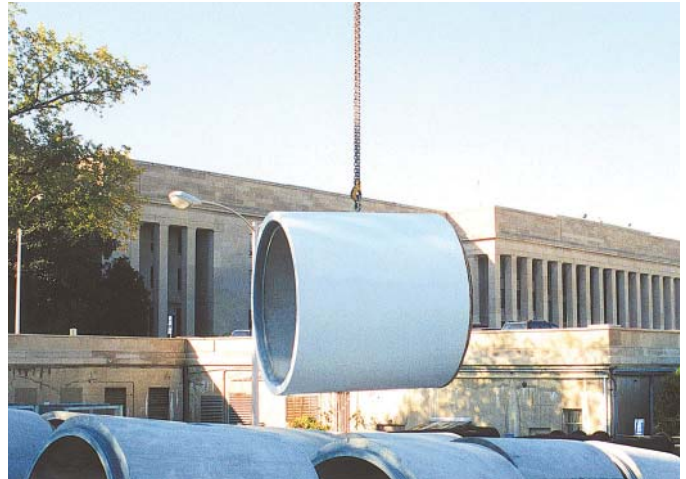
Reinforced concrete pipe used for storm water drainage system at the Pentagon.

cost consideration in a project must be based on the long-term performance of the material being used, not only on the initial cost. It is policy that engineers are responsible for implementing life cycle design concepts into the project development process.

Established by ASTM International

The American Society for Testing and Materials (ASTM) Committee C-13 on Concrete Pipe has developed and published ASTM C1131, *Standard of Practice for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer and Sanitary Sewer Systems.*

The least cost of a project is the lowest lump sum of money that would have to be set aside at the start of a project to cover all expenditures during the entire life cycle of the project. This amount is affected by both interest and inflation, and therefore must be analyzed to take these factors into account. Discounting costs transforms expenditures occurring at different times to a common unit of measurement. ASTM covers procedures for using LCA techniques to evaluate alternative pipeline materials, structures, or systems that satisfy the same functional requirement. The LCA technique is a well established economic principle used by economists and other professionals for decades to evaluate the present value constant dollar costs to install

and maintain alternative drainage systems including planning, engineering, construction, maintenance, rehabilitation and replacement and cost deductions for any residual value at the end of the proposed project design life. The decision maker, using the results of the LCA, can then readily identify the alternative with the lowest total cost based on the present value of all initial and future costs.

The American Concrete Pipe Association, (ACPA), has used ASTM C1131 to develop a comprehensive LCA practice, eliminating unreliable assumptions and resulting in a readily usable and accurate design aid. Information and design tools for this method are available from the ACPA through the *PipePac* software and *Design Data 25*.

In such analyses all factors affecting cost effectiveness must be evaluated. The *ASTM Standard Practice* includes the following factors:

- Project Design Life
- Material Service Life
- First Cost
- Interest (Discount) Rate
- Inflation Rate
- Maintenance Cost
- Rehabilitation Cost
- Replacement Cost (Direct & Indirect)
- Residual Value

First Cost – The first cost is only one of several factors that influence an economic analysis. When alternative materials have different life spans, first costs may underestimate the total cost of using different materials over the life of the project. It may be the least important factor if there are high maintenance costs or if the pipe material or system has to be replaced during the design life of the project. In fact, a study sponsored by FHWA and AASHTO found that, "Improvements with the lowest initial cost are often more costly in the long run than alternatives with higher initial costs, especially if costs of traffic delay during maintenance and rehabilitation activities in congested areas are considered."[10] Other important factors include the project design life and material service life.

Reinforced Concrete Pipe Replaces Failed HDPE Storm Drain Installation.

Project Design Life – The National Cooperative Highway Research Program Synthesis of Highway Practice titled *Durability of Drainage Pipe* defines service life as "the number of years of relatively maintenance free performance". Based on Synthesis recommendations, up to 50 years of relatively maintenance free performance should be required for culverts on secondary road facilities and up to 100 years for high profile facilities, such as primary and interstate highways and all storm and sanitary sewers.

Material Service Life – According to the U.S. Army Corps of Engineers reinforced concrete pipe has a service life of 70-100 years. Corrugated metal pipe may reach a 50-year service life in some environments with the use of coatings. The U.S. Army Corps of Engineers states that the long-term performance of aluminum pipe is difficult to measure due to a short history of use. Designers should not expect a material service life greater than 50 years.
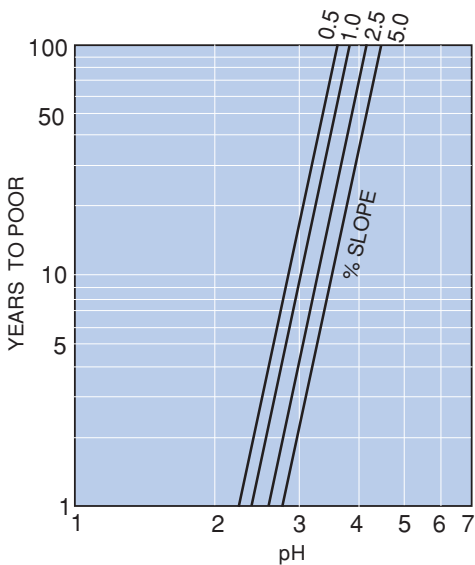
According to the U.S. Army Corps of Engineers designers and planners should likewise not expect a material service life greater than

50 years for plastic pipe. Plastic pipe is lightweight and flexible, but its service life greatly depends upon the installation and surrounding soil of the embankment, which will add to the installation cost of the pipe. Other factors that affect the service life of plastic pipe include flammability and ultraviolet sensitivity.

An extremely important report for the engineering profession is the Ohio Department of Transportation, (ODOT), publication "Culvert Durability Study." Field surveys were completed and an interim report presenting the data was published in 1972. The analysis of data and recommendations are presented in the final report published in 1982. The report evaluates the durability performance of both concrete and corrugated steel pipe under the same environmental conditions, and presents predictive equations and graphs for establishing service lives for both materials. The second issue of the American Concrete Pipe Association publication series, "Buried Facts," reviews the ODOT Report and presents the procedures for evaluating service lives.

Figure 1 is the predictive service life graph for concrete pipe which relates pH of the water and pipe slope to the number of years for the pipe to reach a poor condition. In evaluating pipe, the ODOT classification system rated
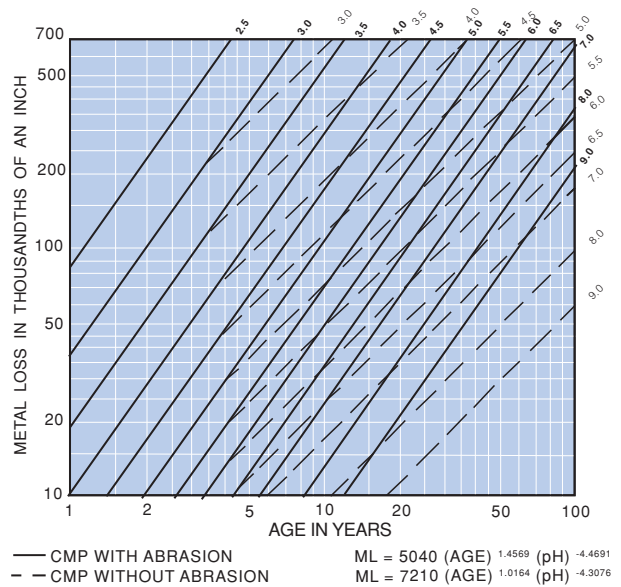
concrete pipe poor if there was significant loss of mortar and aggregate, and the concrete was in a softened condition. About 550 concrete culverts were inspected and only nine of them, less than 2%, were rated poor. These nine culverts were being repaired to provide additional service. As demonstrated, concrete can be expected to provide a service life in excess of 100 years for all environments with a pH value above 4.0.

Figure 2 is the predictive service life graph for plain galvanized corrugated steel pipe which calculates the amount of metal loss versus the pipe age, pH of the water, and potential for abrasion. The diagonal lines, representing the pH of the water, are solid when there is potential for abrasion and dashed when there is no potential for abrasion. In the 100 or even 50 years of required project service life, abrasion must be considered a strong possibility. For design purposes, the solid lines indicating a potential for abrasion should always be used.

Figure 2   Predicted Metal Loss for Corrugated Metal Pipe

As an example a 16 gage (0.064" thickness) in a neutral environment with a pH=7.0 and a potential for abrasion can be expected to provide a service life of 20 years. If the pH is lowered to 4.0 the expected service life decreases to 3 years.

Figure 1   Concrete Pipe Life

Figure 2   Predicted Metal Loss for Corrugated Metal Pipe

CMP WITH ABRASION $ML = 5040 \, (AGE)^{1.4569} \, (pH)^{-4.4691}$
CMP WITHOUT ABRASION $ML = 7210 \, (AGE)^{1.0164} \, (pH)^{-4.3076}$

Interest and Inflation Rates — To eliminate assumptions, it is not necessary to try to predict what interest rates or inflation rates will be in the future over a 20, 50 or 100 year period because the Least Cost Analysis is affected by the difference in the two rates. Based on substantial historical data, the two rates interact and influence each other and tend to move together resulting in a difference, or real interest rate, that remains relatively constant. The interest rate over a period of time will always be greater than the inflation rate, usually by 1 or 2 percentage points.

Table 1   Inflation/Interest Rate Factor

(i - I) Percent	$F = \left(\frac{1 + I}{1 + i}\right)$		
	Maximum	Mimimum	Average
1	0.9916	0.9905	0.991
2	0.9833	0.9811	0.982
3	0.9752	0.9720	0.974
4	0.9672	0.9630	0.965
5	0.9593	0.9641	0.957

Table 1 can be used to determine the appropriate inflation/interest rate factor, F, based on the desired difference of the inflation and interest rates. The table presents the maximum, minimum, and average values for the inflation/interest factor for inflation rates ranging from 4 to 18%, and the differentials between interest and inflation rates ranging from 1 to 5%.

The inflation/interest rate factor can then be used to calculate the Effective Cost (EC). The effective cost of a material is its total cost, in today's dollars, which includes first cost, any replacement costs during the project design life, and any residual value at the end of the project design life. Effective Cost can be calculated using the following equation:

$$EC = P\left[(1) + \left(\frac{1+I}{1+i}\right)^n\right]$$

Where:
P = Bid price
I = Inflation rate
i = Interest rate
n = Material life, years

Replacement Costs — Two types of costs should be considered to determine the total replacement cost of a culvert. First, the direct costs to the owner include planning, engineering, and construction. Many of these direct costs involved in replacement are not considered and are difficult to forecast. Among these costs are mobilization and demobilization, stream diversion, excavation, removal of existing pipe, backfill, pavement restoration, traffic control, safety, and other incidental costs.

The second factor, indirect costs, is also vital to accurately evaluate the total replacement cost, but is rarely considered due to the perceived difficulty in quantifying subjective factors such as road usage level and lost time. The cost of delay experienced by the user during the culvert's installation, D, can easily be computed based on:

$$D = AADT * t * d *(c_v * v_v * v_{of} + c_f * v_f)$$

Where:

AADT = Annual Average Daily Traffic of the roadway which the culvert is being installed
t = the average increase in delay or congestion the installation is causing to each vehicle per day, in hours
d = the number of days the project will take
c_v = the average rate of person-delay, in dollars per hour
v_v = the percentage of passenger vehicles traffic
v_{of} = the vehicle occupancy factor
c_f = the average rate of freight-delay, in dollars per hour
v_f = the percentage of truck traffic

Average Established Delay Costs as of 2005[11], in Dollars:
c_v = $18.62 per person-hour of delay
c_f = $52.86 per freight-hour of delay
Typical Traffic Assumptions:
v_v = 97% vehicle passenger traffic
v_f = 3% truck traffic
v_{of} =1.2 persons per vehicle

5

According to Dr. Joseph Perrin in his research of *The Economic Costs of Culvert Failures*[12] and the User Delay Cost equation above, a one-hour delay on a roadway carrying an Annual Average Daily Traffic of 20,000 vehicles costs the public over $450,000 every day. Indirect costs include traffic user costs, economic loss of business, and political implications and liability for the owner. While these costs are not directly absorbed by the owner, they should be considered in a Least Cost Analysis.

Example

Given: A culvert is to be installed under a primary road carrying an AADT of 10,000 vehicles and a design life of 100 years. When bids were opened, the bid price for concrete pipe was $500,000, and the bid price for HDPE pipe was $450,000.

The engineer selected a 100 – year service life for concrete pipe and a maximum 50 – year service life for HDPE pipe. He estimates lane closures to occur for 60 days and expects traffic delays of 30 minutes on average. He wants to compare the effective costs by the least cost analysis method, assuming a 2 percent difference between interest and inflation rates.

Find: The effective cost of the two alternates by least cost analysis method, and select the most economical pipe material.

Solution: The service life of the pipe is based on the U.S. Army Corps of Engineers guidelines. The effective cost, EC, for the concrete pipe is equal to the bid price, P, since it is not expected to be replaced during the project design life. Therefore:

$$EC_{Conc} = P_{Conc} = \$500,000$$

However, the HDPE pipe will need to be replaced at the end of n_{HDPE}, years to have a total service life equal to the project design life. The effective cost of the HDPE pipe is found by:

1. Direct Effective Cost:

$$EC_{HDPE} = P_{HDPE}\left[(1) + \left(\frac{1+I}{1+i}\right)^n\right]$$

From the equation above & the average value from Table 1:

$$DEC_{HDPE} = \$450,000\ [1+(0.982)^{50}]$$
$$DEC_{HDPE} = \$631,463$$

2. Indirect Effective Cost:

Cost of Delay:
$$D = AADT * t * d *(c_v * v_v * v_{of} + c_f * v_f)$$
$$D = 10,000*0.5*60*(18.62*0.97*1.2+52.86* 0.03)$$
$$D = \$6,977,844 \text{ when replaced in 50 years}$$

Discounting the costs back in today's dollars, and from Table 1:

$$IEC_{HDPE} = \$6,977,844(0.982)^{50}$$
$$IEC_{HDPE} = \$2,813,815$$

Answer: The direct effective cost to the owner of the HDPE pipe, $631,350, is 26 percent more than the effective cost of the concrete pipe. The effective cost to the public will be almost $7 million when the replacement is incurred and almost $3 million in comparative dollars today. Therefore, use concrete pipe.

Incorporation of Least Cost Analysis Procedures into Contract Documents

It is evident that a Least Cost Analysis is necessary when considering alternate materials with different service lives for capital projects. LCA should also be incorporated into contract documents and a procedure provided for evaluating bids for alternate materials. Table 2 can be used to incorporate LCA into the Instructions to Bidders portion of the specification.

The following outlines a procedure for evaluating the effective cost of bids by a least cost analysis that can be incorporated into the Instructions to Bidders portion of the specifications.

Evaluation of Bids

1. The design life of the project shall be _____ years.
2. Lowest responsive bids for each alternate will be compared for Effective Cost using least cost analysis, as described herein.
3. The service life of the alternate materials will be announced by the owner. Should a bidder on any of the alternates wish to have a service life longer than that assigned, he must submit to the owner, within 3 days of the date of bid opening, a written request containing documentation supporting the proposed service life, with a guarantee of the proposed service life. This request must be in a form satisfactory to the owner, and the guarantee must obligate the bidder and his successors to undertake repair or replacement of the alternate, should it not meet the service life guaranteed by the bidder. The owner is not obligated to accept any such proposed service life, but may elect to use his announced service life.
4. Replacement costs shall be calculated using a difference between interest and inflation of 2 percent.
5. The computation table shall be completed by following the appropriate steps, in order, for each alternate bid. The alternates will then be ranked in order of lowest effective cost.
6. The owner will take bids received under advisement and will announce as soon as possible the effective cost ranking of the lowest responsive alternate bid. The owner will be the sole judge as to which alternate is to be used in the award of the contract.

Table 2 Computation Table – Least Cost Analysis

Step / Alternatives: Longest Lived First.			
1. Project Design Life			
2. Assigned Service Life, n, yrs.			
3. Lowest Responsive Bid, P, Each Alternate			
4. Total Replacement Cost = $P\left[1+\left(\dfrac{1+1}{1+i}\right)^{n}+\left(\dfrac{1+1}{1+i}\right)^{2n}+...+\left(\dfrac{1+1}{1+i}\right)^{mn}\right]$			
5. Present Value, Residual Amount $P\left(\dfrac{n_L+n_S}{n_L}\right)\left(\dfrac{1+1}{1+i}\right)^{n_S}$			
6. Effective Cost (Step 3 + Step 4) or (Step 3 - Step 5)			

M = Total number of pipe replacements
n_L = Service life longer lived alternate, years
n_S = Service life shorter lived alternate, years

References

1. *ASTM C1131—Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer and Sanitary Sewer Systems*, American Standard for Testing and Materials International Standards, 2006.
2. *ASCE's Report Card*, retrieved from www.asce.org/reportcard on August 29, 2006.
3. *Buried Facts - Bid Evaluation by Least Cost Analysis,* American Concrete Pipe Association, February 1983.
4. *Consumer Price Index*, Bureau of Labor Statistics, All Urban Consumers, CPI-U.
5. *Current State of Life Cycle Design for Local Protection Structures*: A Literature Search, Civil Engineering Research Foundation, U.S. Army Corps of Engineers, April 20, 1992.
6. *Circular No. A-94, Office of Management and Budget*, retrieved from www.whitehouse.gov/omb/circulars/a094/a094.html on March 21, 2006.
7. *Design Data 25 – Life Cycle Cost Analysis*, American Concrete Pipe Association, 2002.
8. *Interest Rate and Inflation Rate Factors in Least Cost Analysis*, William Kerr, Ph.D., Barbara Ryan, and Arthur Young and Company, American Concrete Pipe Association.
9. *LCA (PipePac) Software*, American Concrete Pipe Association, Copyright 2003.
10. *Life Cycle Cost Analysis, Searching for Solutions, a Policy Discussion Series Number 12*, Gloria Jeff and Thomas J Ptak, FHWA. December 15, 1993.
11. *National Compensation Survey: Occupational Wages in the United States,* Department of Labor Statistics, United States Department of Labor, June 2005.
12. *The Economic Costs of Culvert Failures*, Joseph Perrin, Jr., November 2003.

For more information on Least Cost Analysis and other concrete pipe related topics, contact the American Concrete Pipe Association at www.concretepipe.org.