BID EVALUATION BY LEAST COST ANALYSIS

Selecting pipe materials best suited for service as a storm sewer, culvert, sanitary sewer, or small bridge replacement is of primary importance to the design engineer. Selection is based on hydraulic efficiency, structural integrity, durability and cost. Most engineers are well acquainted with hydraulic and structural design criteria, but the effect of product durability on the total cost may not be clearly understood. On many projects when alternate materials are bid, selection is too often based on first cost. However, the alternate with the lowest first cost may not be the most economical selection for the design life of the project. The most economical alternate must be determined through a least cost analysis.

LEAST COST ANALYSIS

A least cost analysis is an effective method of evaluating two alternative materials with different service lives for economic equivalence. The factors which affect the analysis are:

- Project design life
- Material life
- First cost
- Interest rate
- Inflation rate
- Replacement costs
- Residual value

First cost of a pipe material is important to the engineer and owner, but does not reveal the entire cost of the pipeline. If the service life of an alternate material is less than the project design life, future replacement costs must be considered. If the service life of an alternate material is greater than the project design life, residual value at the end of the project design life must be considered. Future replacement costs involve assumptions about inflation and interest rates. High and fluctuating inflation and interest rates have been with us for some time, and assumptions about their magnitude 25, 50, or 100 years hence are merely guesswork. The method of least cost analysis is designed to eliminate the least reliable aspects of the assumptions necessary to compare the effective costs of the alternative materials.

EFFECTIVE COST

Effective cost of an alternate 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. For each alternate material, therefore, three possible cases exist for determining effective cost:

- Case 1: Material life = Project design life
- Case 2: Material life < Project design life
- Case 3: Material life > Project design life

Case 1

When the alternate material life is equal to the project design life, its effective cost is simply the bid price:

$$EC = P \qquad (1)$$

where:

EC = Effective cost, dollars

P = Bid price, dollars

Case 2

When the alternate material life is less than the project design life, its effective cost is the bid price plus the present value total of all replacement costs adjusted for inflation:

$$EC = P + \sum \left[P \times \overline{IF} \times \overline{PVF} \right] \qquad (2)$$

where:

IF = inflation factor

PVF = present value factor

The inflation factor converts the current bid price to the future replacement cost:

$$\overline{IF} = (1 + I)^n \qquad (3)$$

where:

I = Inflation rate

n = material life, years

and the present value factor converts future replacement costs to today's dollars:

$$\overline{PVF} = \left(\frac{1}{1+i}\right)^n \qquad (4)$$

where

i = Interest rate

Substituting the terms from equations 3 and 4, and simplifying, equation 2 becomes:

$$EC = P\left[1 + \left(\frac{1+I}{1+i}\right)^n + \left(\frac{1+I}{1+i}\right)^{2n} \cdots + \left(\frac{1+I}{1+i}\right)^{mn}\right] \qquad (5)$$

where:

m = Total number of pipe replacements

This form of the equation is usable, but requires assumptions of future interest and inflation rates which could vary widely as have rates in the recent past. Calculations, however, reveal that the value of the interest factor times the present value factor is virtually constant for specific differences between the two rates. Utilizing a range of inflation rates from four through 18 percent, and differences between the interest and inflation rates of one through five percent, the maximum, minimum and average values of the interest factor times the inflation factor are shown in *Table 1*. Utilizing the average values, *Table 2* presents the combined interest/inflation rate factor raised to the n power for a number of service lives related to differences between the rates.

Table 1. Interest/Inflation Rate Factor.

(i - I) PERCENT	$\left(\frac{1+I}{1+i}\right)$		
	MAXIMUM	MINIMUM	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	0.9541	0.957

Case 3

When the alternate material life is greater than the project design life, its effective cost is the bid price minus the residual value remaining at the end of the project design life. Assuming a straight line depreciation, the effective cost of an alternate pipe material with residual value at the end of the project life is:

$$EC = P\left[1 - \left(\frac{n - n_p}{n}\right)\left(\frac{1+I}{1+i}\right)^{n_p}\right] \qquad (6)$$

where:

n_p = project design life, years

SELECTION OF FACTOR VALUES

Use of the effective cost equations requires selection of realistic values for the various factors. Guidance on the selection of appropriate values is presented in the following sections:

Project Design Life

While most agencies expect roadways to last a certain number of years, and embankments indefinitely, incidental construction, such as drainage pipe, is often specified with little regard for durability. Based on a review of published culvert surveys, the National Cooperative Highway Research Program Synthesis No. 50, "Durability of Drainage Pipe," defines service life as "the number of years of relatively maintenance-free performance," and further states "that a high level of maintenance may justify replacement before failure occurs."

The Synthesis offers guidelines to determine required project service lives for culverts under primary and secondary roads, with an appropriate safety factor. Based on these guide recommendations, *Table 3* presents the number of years of relatively maintenance free performance that should be required for culverts. As indicated, all sewers are classed as high type facilities, are located in urban areas with difficult construction requirements, and should be designed for 100 years of relatively maintenance-free performance.

Table 2. Combined Interest/Inflation Rate Factor to n Power.

$$\left(\frac{1+I}{1+i}\right)^n$$

i - I, %	n, years								
	20	25	30	40	50	60	75	80	90
1.0	0.835	0.798	0.762	0.697	0.636	0.581	0.508	0.485	0.443
2.0	0.695	0.635	0.580	0.484	0.403	0.336	0.256	0.234	0.195
3.0	0.590	0.518	0.454	0.349	0.268	0.206	0.139	0.122	0.093
4.0	0.490	0.410	0.343	0.240	0.168	0.118	0.069	0.058	0.041
5.0	0.415	0.333	0.268	0.172	0.111	0.072	0.037	0.030	0.019

Table 3. Project Design Life.

PROJECT	DESIGN LIFE
Culvert, primary road	100 years
Culvert, secondary road	50 years
Sewer, all projects	100 years

Material Service Life

Major specifying agencies, such as the Federal Highway Administration, Corps of Engineers, Soil Conservation Service, and most state departments of transportation have published reports on field and laboratory investigations to determine the durability of pipe materials and establish methods for predicting service life. This publication will consider only the findings and recommendations for concrete pipe and corrugated metal pipe. A preponderance of the investigations and published reports are on corrugated steel pipe, because this material has experienced critical durability problems in many culvert installations.

An extremely important report for the engineering profession is the Ohio Department of Transportation 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 pipe 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 Ohio Report, and presents the procedures for evaluating service lives.

A variety of soil, water, and bed load parameters were evaluated. It was found that embankment pH is neutral to alkaline throughout the state of Ohio, soil resistivities are very high, and water pH is also relatively neutral, except for a few counties where the pH is slightly acidic due to coal mine drainage. From the survey, it is apparent that environmental conditions are relatively neutral, and soils and water do not possess any characteristics which would contribute to premature deterioration of culverts. The Ohio predictive graphs for material service life, therefore, should be applicable or conservative for other areas.

Figure 1 is the predictive service life graph for conrete pipe, which relates pH and pipe slope to the number of years for the pipe to reach a poor condition. In evaluating pipe, the Ohio classification system rated concrete pipe poor if there was significant loss of mortar and aggregate, and the concrete was in softened condition. Only nine concrete culvert pipe were rated poor and these are being repaired to provide additional service. As evident, concrete pipe in a neutral environment can be expected to have a service life in excess of 1,000 years.

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

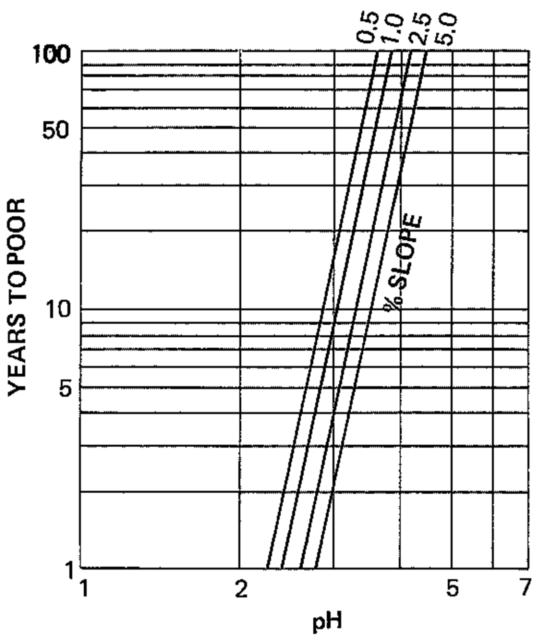
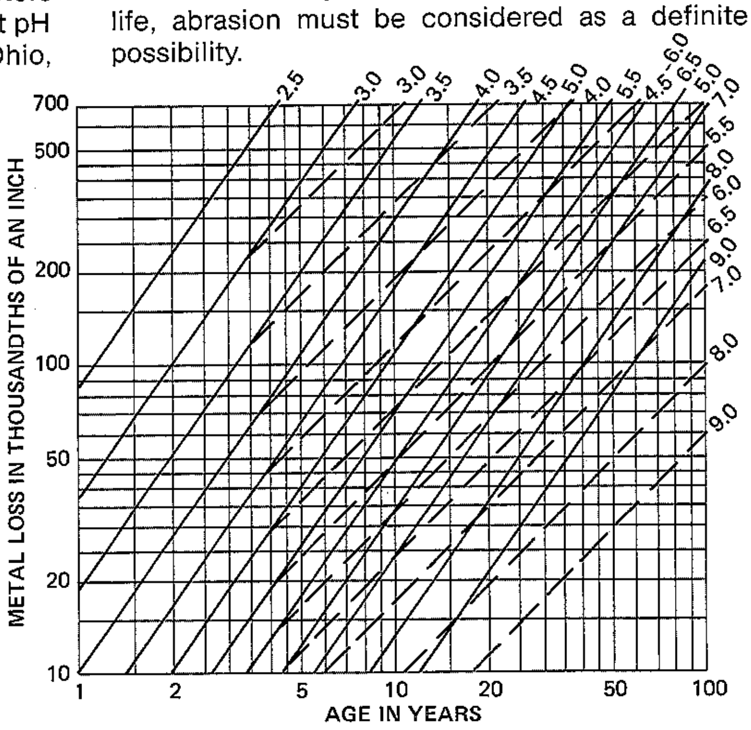


Figure 1. Concrete Pipe Life.



— CMP WITH ABRASION $ML = 5040\ (AGE)^{1.4569}\ (pH)^{-4.4691}$

– – CMP WITHOUT ABRASION $ML = 7210\ (AGE)^{1.0164}\ (pH)^{-4.3076}$

Figure 2. Predicted Metal Loss for Corrugated Metal Pipe.

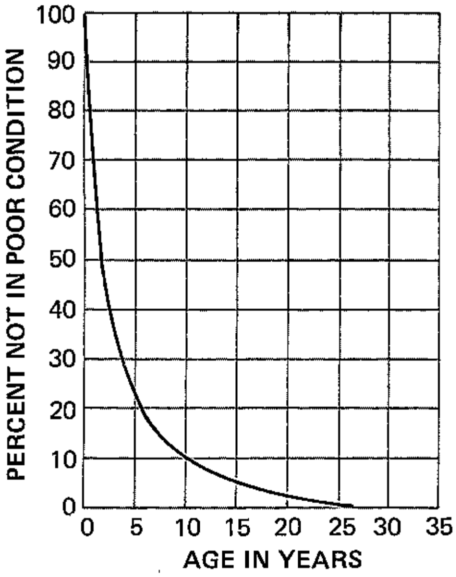


Figure 3. Bituminous Coatings.

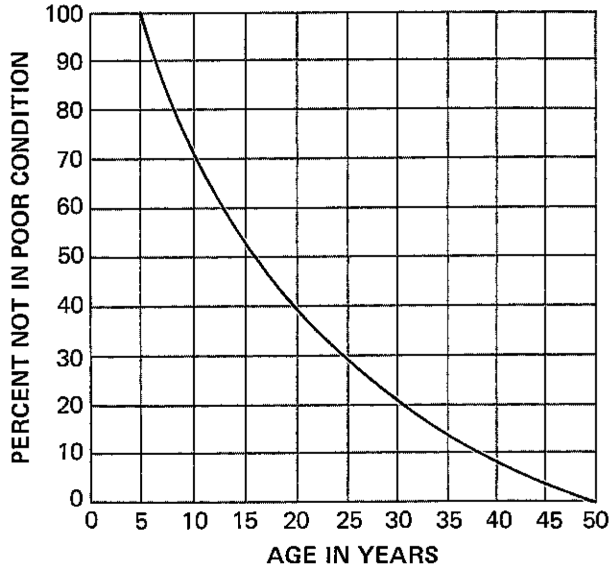


Figure 4. Bituminous Coatings with Paving.

Ohio also evaluated corrugated steel pipe coatings, and *Figures 3* and *4* are the predictive service life graphs for bituminous coatings, and bituminous coatings with paving respectively. In evaluating coatings, the Ohio classification system considered the rating good, even if the surface of interior coating was completely checked throughout, some of the interior coating was gone, or the paving was eroded to the top of the corrugations. The predictive graphs, therefore, are liberal, and Ohio assigns a 5 to 10 year service life to a bituminous coating with paving, and no service life to only a bituminous coating.

First Cost

First cost is simply the bid price for an alternate material. Historical data may be used to determine an appropriate value for pre-bid evaluations. If a least cost analysis is included in the bid documents as a basis for awarding the contract, then the actual bid price for the alternate materials would be used in the effective cost equations. Guidelines for using least cost analysis as a basis for contract award are included in the Appendix.

Interest/Inflation Rates

During the 1970's, the inflation rate fluctuated from below 5 percent a year to above 13 percent, yet interest rates generally led inflation by a few points. Considering that inflation is the devaluation of money by a certain percent each year, it stands to reason that the interest rate should equal or exceed the inflation rate. *Figure 5* compares the consumer price index and average prime interest rate during the 1970's, and indicates a difference of approximately 2 percent, which appears to be an appropriate value for present analyses.

Replacement Costs

The effective cost of alternate materials by the least cost analysis method has been developed considering only the cost, adjusted for inflation, of material replacement under initial project conditions of the shorter life material or the residual value of the longer life alternate. There are many costs involved in future total replacement which have not been considered and are difficult to estimate. Among these costs are mobilization and demobilization, stream diversion, excavation, removal of the existing pipe, backfill, pavement restoration, traffic control and safety, and other incidental costs. Recently, a bid was let to replace two corrugated metal culverts with concrete pipe under an interstate highway. Although the total bid was approximately $300,000, the cost of furnishing and installing the concrete pipe was only $50,000, one sixth of the total bid. The remaining quarter million dollars was for the additional incidental costs. Historical data should be analyzed to determine an appropriate relationship between material cost and total project cost, and this relationship should be applied to Case 2 alternate materials to determine realistic effective costs.

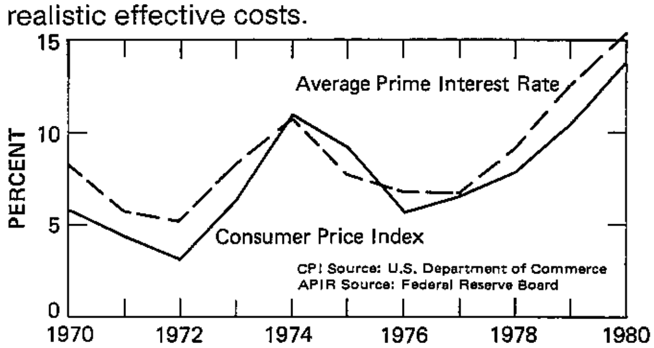


Figure 5. Comparison of Interest and Inflation Rates.

EXTENDING MATERIAL LIFE

As a result of many concerns, the Federal Highway Administration developed a technical advisory to provide guidance regarding the design of corrugated metal pipe for durability. The advisory states that products must be functionally equal for the project service life, if alternates are to be specified and bid, and provides for a way to extend the life of metal pipe by increasing the wall thickness. Using 16 gage galvanized steel pipe with a total metal thickness of 0.064 inches as the base, gage factors for the standard thicknesses of galvanized corrugated steel pipe are shown in *Table 4.* For example, an 8 gage galvanized steel pipe will have a service life of 2.8 times that of a 16 gage pipe installed under the same environmental conditions. If the service life of a 16 gage pipe is determined to be 20 years, then the service life of an 8 gage pipe would be 56 years.

Table 4. Gage Factors, Galvanized Corrugated Steel Pipe.

Gage	16	14	12	10	8
Thickness, in.	0.064	0.079	0.109	0.138	0.168
Factor	1.0	1.3	1.8	2.3	2.8

The service life of a corrugated steel pipe should not be extended when only a bituminous coating is applied. If a bituminous coating with paving is applied, then the service life could be extended five to 10 years. The bituminous coating with paving, however, will be effective for only the first five or 10 years of the project life, therefore, the hydraulic design should be based on the characteristics of a plain corrugated steel pipe. It is important, however, to check flow velocities with the hydraulic characteristics of a coated and paved pipe since high outlet velocities may be produced in the initial years when the coating and paving is still intact.

EXAMPLES

The following examples illustrate the selection of factor values and the use of the effective cost equations.

EXAMPLE 1

Given: A culvert is to be installed under interstate highway with a design life of 100 years. When bids are opened, the bid price for concrete pipe was $260,000, and the bid price for the bituminous coated corrugated 16 gage steel pipe was $195,000, 75 percent of the concrete price! The engineer selected a 100-year, n_C, service life for concrete pipe, and a 20-year service life, n_S, for the 16 gage bituminous coated corrugated steel pipe. A difference between interest and inflation rates of 2 percent is assumed.

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

Solution: 1. Since the service life of the concrete pipe equals the project design life, Case 1, the effective cost is found by Equation 1:

$$EC_c = P_c = \$260{,}000$$

2. Since the 16 gage steel pipe must be replaced at the end of n_S, $2n_S$, $3n_S$, and $4n_S$ years to have a total service life equal to the project design life, Case 2, the effective cost of the steel pipe is found by Equation 5:

$$EC_s = P_s\left[1 + \left(\frac{1+I}{1+i}\right)^{20} + \left(\frac{1+I}{1+i}\right)^{2(20)} + \left(\frac{1+I}{1+i}\right)^{3(20)} + \left(\frac{1+I}{1+i}\right)^{4(20)}\right]$$

Substituting the steel pipe bid price and the appropriate values from Table 2 for a 2 percent difference in rates.

$$EC_s = \$195{,}000\ (1 + 0.695 + 0.484 + 0.336 + 0.234)$$

$$EC_s = \$536{,}055$$

Answer: Since the total effective cost of the 16 gage bituminous coated corrugated steel pipe is 106 percent more than the total effective cost of the concrete pipe, use concrete pipe!

EXAMPLE 2

Given: A culvert is to be installed under a primary road with a design life of 50 years. When bids were opened, the bid price for concrete pipe was $260,000, and the bid price for a 10 gage bituminous coated and paved corrugated steel pipe was $213,200. The engineer selected a 100-year service life for concrete pipe and a 20-year service life for 16 gage plain corrugated steel pipe, and stated he would compare the effective costs by the least cost analysis method, assuming a 2 percent difference between interest and inflation rates.

Find: 1. The effective service life of the 10 gage steel pipe.
2. The effective cost of the two pipe materials.

Solution: 1. The service life of the 10 gage steel pipe is found by using the gage factor for 10 gage steel pipe from *Table 4.*

20 yrs. for 16 gage x 2.3 = 46 yrs.

Also, *Figure 2* shows that a 10 gage steel pipe has a 46 year service life with a water pH of approximately 8. The bituminous coating and paving could add another 4 years for a total of 50 years.

2. The effective cost for the 10 gage steel pipe is equal to the bid price since it is not expected to be replaced during the project design life, Case 1. Therefore:

$$EC_s = P_s = \$213{,}200$$

However, the concrete pipe will still have residual value at the end of 50 years, Case 3, and the effective cost is found by Equation 6:

$$EC_c = P_c\left[1 - \left(\frac{n_c - n_p}{n_c}\right)\left(\frac{1 + I}{1 + i}\right)^{n_p}\right]$$

Substituting the bid price for concrete pipe, the appropriate n values, and the appropriate values from *Table 2* for a 2 percent difference in rates:

$$EC_c = 260{,}000\left[1 - \left(\frac{100\text{-}50}{100}\right)(0.982)^{50}\right]$$

$$EC_c = 260{,}000\left[1 - (0.5)(0.403)\right]$$

$$EC_c = \$207{,}577$$

Answer: The effective cost of the concrete pipe, $207,577, is 2.5 percent less than the effective cost of the steel pipe. Use concrete pipe, as it will continue to function for at least 100 years.

APPENDIX
Incorporating Least Cost Analysis Procedures into Contract Documents

Life cycle cost analysis should be incorporated in contract documents and a procedure provided for evaluating bids for alternate materials. The following outlines a procedure for evaluating the effective cost of bids by a least cost analysis that can be incorporated into the Instruction 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 immediately after bids are opened. Should a low responsive 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 or assigns 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 bids. The owner will be the sole judge as to which alternate is to be used in the award of the contract.

Computation Table — Least Cost Analysis

Step \ Alternates: Longest Lived First.			
1. Project Design Life			
2. Assigned Service Life, n, yrs.			
3. Lowest Responsive Bid, P, each Alternate			
4. Total Replacement Cost = $P\left[1+\left(\frac{1+I}{1+i}\right)^{n}+\left(\frac{1+I}{1+i}\right)^{2n}+\ldots+\left(\frac{1+I}{1+i}\right)^{mn}\right]$			
5. Present Value, Residual Amount $P\left(\frac{n_L - n_s}{n_L}\right)\left(\frac{1+I}{1+i}\right)^{n_s}$			
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