Well points and wide trenches were necessary to install full bituminous coated and full paved CSP in this unstable ground.

CHAPTER 9 Value Engineering and Least Cost Analysis

This chapter deals with the important subject of cost efficiency. Today's engineer is turning to rational cost analysis in lieu of subjective selection of materials and designs. This requires both value engineering and least cost analysis. Value engineering is the critical first step to insure that correct alternates are used in the least cost analysis. Otherwise, the engineer may be comparing apples and oranges.

This manual offers guidelines for designing corrugated steel pipe systems that are structurally adequate, hydraulically efficient, durable and easily maintained. By following these guidelines, equal or superior performance can be realized through use of CSP products. Therefore, the basic techniques of value engineering are applicable. By allowing design and bid alternates, including the proper corrugated steel pipe system, savings on the order of 20% can frequently be realized. Alternative designs offer even more promise and savings of as much as 90% are possible compared to the costs of conventional designs. Thus, innovative use of corrugated steel pipe design techniques can offer truly substantial savings, with no sacrifice in either quality or performance.

VALUE ENGINEERING

A publication of the AASHTO-AGC-ARTBA entitled *"Guidelines for Value Engineering"* summarizes the basic processes as applied to street and highway construction. Value engineering provides a formalized approach which encourages creativity both during the design process and after the bid letting. During the design process it involves the consideration of both alternate products with equal performance and alternative designs. After bid award, it involves the substitution of different project plans together with revised design or materials to meet time constraints, material shortages, or other unforeseen occurrences which would affect either the completion date or quality of the finished product.

1) Cost reductions,
2) Product or process improvements, and
3) A detailed assessment of alternative means and materials both for construction and maintenance.

Value engineering is defined by the Society of American Value Engineering as: "The systematic application of recognized techniques which identify the function of a product or service, establish a value for that function and provide the necessary function reliably at the lowest overall cost." In all instances, the required function should be achieved at the lowest possible life cycle cost consistent with requirements for performance, maintainability, safety and aesthetics.

Barriers to cost effectiveness are listed as lack of information, wrong beliefs, habitual thinking, risk of personal loss, reluctance to seek advice, negative attitudes, over-specifying and poor human relations.

It is functionally oriented and consists of the systematic application of recognized techniques embodied in the job plan. It entails;

1) Identification of the function,
2) Placing a price tag on that function, and
3) Developing alternate means to accomplish the function without any sacrifice of necessary quality.

Many value engineering recommendations or decisions are borne of necessity involving perhaps the availability of equipment or material, or physical limitations of time and topography. These are the very reasons that it came into being and in these instances, the alternative selected should not be considered an inferior substitute. Such circumstances force us to restudy the function and if the appropriate job plan is carefully followed, the alternative selected should be equal if not better, and capable of functioning within the new limitations.

A value engineering analysis of standard plans can be very revealing and beneficial in most cases. This may be done as a team effort on all standards currently in use by an agency or it may be done on a project by project basis. Standard specifications should also be subjected to detailed analysis.

Designers are in some cases encouraged to be production oriented and to prepare completed plans as quickly as possible. However, time and effort are frequently well spent in applying the principles to individual project design.

Do local conditions indicate that receipt of bids on alternate designs is warranted? Do plans permit contractor selection of alternate designs and materials for specific bid items?

These questions may be very pertinent in ensuring the most efficient storm and sanitary sewer designs. Affording contractors an opportunity to

"O-Ring" being placed over the end of the pipe and recessed into the end corrugation.

CSP was a cost effective solution for the Newark Airport.

bid on alternates may result in a saving that was not previously evident. Permitting alternates may further encourage contractors and suppliers, who would not otherwise do so, to show interest in a proposal.

The utility of value engineering as a cost control technique has long been recognized by the Federal Government. It was first used by the Navy in 1954 and since then 14 Federal Agencies, including the U.S. Army Corps of Engineers have used these analyses in the design and/or construction of facilities. As an example, the 1970 Federal Aid Highway Act required that for projects where the Secretary deems it advisable, a value engineering or other cost reduction analysis must be conducted. In addition, the EPA developed a mandatory value engineering analysis requirement for its larger projects and is actively encouraging voluntary engineering studies on its other projects. Thus, these agencies obviously feel that the potential benefit resulting from such analysis far outweighs the cost incurred by the taxpayer in conducting them.

INCLUSION OF ALTERNATE MATERIALS IN A PROJECT INDUCES LOWER PRICES.

The following recommendations on alternate designs is reproduced in its entirety from a study by the Sub-Committee on Construction Costs of AASHTO-AGC-ARTBA.

ALTERNATE DESIGNS AND BIDS ON PIPE

a) Description of Proposal

In many cases the site conditions pertaining to pipe installations are such that alternative designs involving various pipe products will yield reasonably equivalent end results from the standpoint of serviceability. Moreover, in these cases no one pipe product is clearly less costly than the *others, particularly where all suitable products are allowed to compete. Therefore, it is proposed that wherever site conditions will permit, alternative designs be prepared for all types of pipe that can be expected to perform satisfactorily and are reasonably competitive in price and the least costly alternative be selected for use, with the costs being determined by the competitive bidding process.*

b) Examples or References

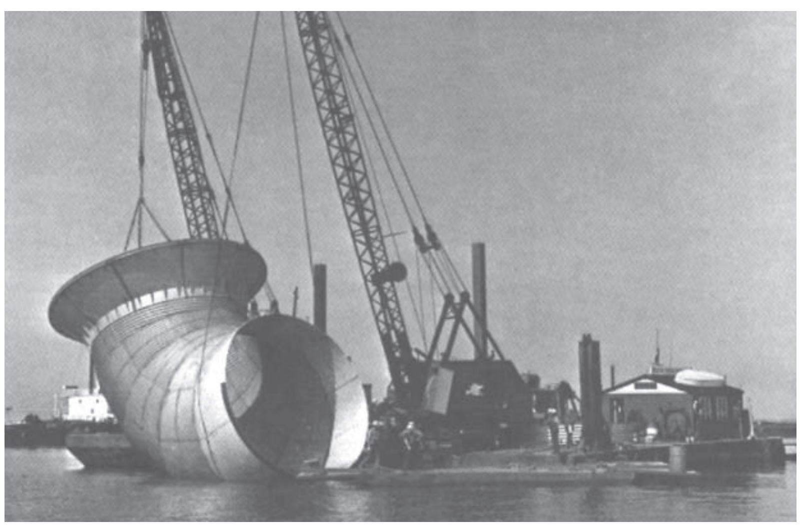
In the absence of unusual site conditions, alternative designs for a typical pipe culvert installation may provide for bituminous coated corrugated metal pipe and reinforced concrete pipe, with a size differential when required for hydraulic performance. In bidding the related construction work, bidders could be required to submit a bid for performing the work with the understanding that the successful bidder could furnish any one of the permitted types of pipe.

c) Recommendation for Implementation

The availability of competitive pipe products should be established on a statewide basis or on a regional basis within a state. Procedures should be instituted, where necessary, to assure that all suitable types of pipe are considered during the design of pipe installations. Any necessary changes in bidding procedures and construction specifications should also be instituted.

d) Advantages

Acceptance of this proposal should permit the greatest feasible amount of competition among pipe products. This will permit all related economic factors to operate freely in establishing the lowest prices for pipe installations.



Large 6000mm diameter "bellmouth inlet" for cooling water intake for thermal power project on floor of Lake Erie, is typical of widespread applications of design in steel to rigorous and difficult conditions, where rigid design would either be impractical, or prohibitively costly.

e) Precautions

Complex bidding procedures should not be necessary and should be avoided. In any case, bidders should be fully informed as to how the procedures are intended to operate. Care must be taken to avoid alternative designs in situations where choice of a single design is dictated by site conditions.

There are two basic ways to use value engineering: (1) at the design stage to determine the most cost effective material or design to specify without alternates, (2) to select the most cost effective bid submitted on alternates.

In the first case it is important to use value engineering principles when calculating estimates for various materials being considered. This means including in the estimates all the factors bidders would consider in their bids. Installation cost differences between concrete and corrugated steel pipe result from pipe dimensions, foundation and bedding, required equipment and speed of assembly. Table 9.1 is an actual example from a Northwest storm drain project.

Table 9.1 Value analysis (abbreviated)
Storm drain project – Northwest United States
475m of 1200mm diameter and 315m of 1800mm diameter

Principal factors	Corrugated steel pipe	Reinforced concrete pipe	
Material F.O.B. jobsite:			
1200mm diameter	$32,697	$ 56,052	
1800mm diameter	54,961	74,664	
Installation cost differences:*			
1200mm diameter		10,899	more
1800mm diameter		15,555	more
*For concrete pipe:			
Increased excavation quantities			
Increased amounts of select backfill and bedding material			
Heavier sections requiring heavier handling equipment			
Short sections requiring more handling time			
Breakage factors high – less material yield			
Total cost	$87,658	$157,170	

*Other items of consideration for Contractor, Engineer or Agency may include several of the following: prompt delivery as needed, minimum engineering and inspection costs, bad weather hazards, minimum interference with other phases of project, or business and residential areas, etc.

In the second case, where alternate bids are taken, it is important to clearly spell out in the plans and specifications the differences in pipe and trench dimensions for concrete and corrugated steel pipe. Foundation, bedding and minimum cover differences may also be significant. Construction time schedule differences could be a factor and should be required to be shown.

Cost Savings in Alternate Designs

ln addition to the savings resulting in allowing pipe alternates in conventional designs, alternative designs based on entirely different water management procedures can offer even more significant savings. Chapter 6 describes the design of storm water recharge systems which meet environmental requirements in force today, without the high cost of advanced waste water treatment systems. By using these techniques on a total system basis, smaller pipe sizes are required than for conventional systems and the cost of the pipe item itself can frequently be reduced.

Another example of an alternative design procedure is the principle of "inlet" control. Most current designs are based on a peak "Q" resulting from hydrologic, flood routing, and hydraulic considerations. Thus, the design is based on the peak discharge at the outlet end derived from the constituent contributions of the upstream network. Inlet control design analyzes the existing drainage system, calculates its capacity, and designs components that restrict the water reaching each part of the system to its rated peak capacity. Excess water is stored at the point of entry and released in a controlled manner after the peak discharge has passed.

An excellent example of the application of value engineering principles in a real situation is quoted in a paper by Thiel. Frequent basement flooding was occurring in areas with combined sewer systems in the Borough of York in Toronto, Canada. Earlier studies recommended separation of the storm and sanitary sewer systems and this conventional solution was proceeded with for about eight years with a budget of about $1 million/year. With rapid inflation, it became apparent that no adequate relief would be obtained within a reasonable time span without absorbing further enormous costs.

Mr. Thiel's firm was then engaged to seek alternative solutions to the problem. His task was to accommodate a 2 year design storm without causing surcharge above existing basement floors. As three of the four areas involved were located away from suitable storm water outlets, a system of relief sewers was rejected as unfeasible. By applying the principles of value engineering it was possible to show that application of the inlet control method with detention storage was the most cost effective solution by far.

Inlet control was achieved through the use of hydro-break regulators in the system, by either disconnecting downspouts or placing flow regulators in them and by sealing catch basins where positive drainage could be achieved. At low points, storm sewers were provided to carry the water to detention tanks. Storm water would thus be discharged into the combined sewer at a predetermined rate, thereby eliminating flood damage. The Borough was then presented with the following estimates to cover all work in the four areas for three different storm intensities;

2 Year Storm—$110,000
5 Year Storm—$285,000
10 Year Storm—$830,000

As a result, the Borough decided to proceed rapidly with providing protection against a 10 year storm, rather than the 2 year design envisaged, at a cost within one year's sewer separation budget.

Adequate, uniform compaction is the secret to building soil and steel structures.

LEAST COST ANALYSIS

Least cost analysis is a technique that compares differing series of expenditures by restating them in terms of the present worth of the expenditures. In this way, competing designs which have differing cost expenditures at different intervals can be compared and the least cost design on a present worth basis chosen.

The technique is familiar to most engineers and engineering students. Anticipated future costs are discounted by using a present worth discount table and restated in terms of today's costs. Once discounted, all the costs for one project design can be added together and fairly compared to all of the costs for a competing project design.

Least cost analysis is well suited for comparing the competing bids for storm sewer projects when pipe material alternates such as corrugated steel (CSP) and reinforced concrete (RCP) are specified.

The least cost equations are fairly straightforward. Tables can be used to determine the various present worth factors of competing projects or numerous computer programs and hand held calculators are available to solve these problems.

The real difficulty with the method is making unbiased assumptions which produce fair comparisons of the alternate bids. The assumptions include project design life, project residual values at the end of its design life, material service life, rehabilitation costs and inflation and interest rates.

Design Life

Before any life cycle cost comparisons of materials can be made, the basic project design life must be established. In the case of some agencies it is already a matter of policy. For example, a 50-year design life for primary

Trenches should be wide enough to permit proper tamping of backfill.

state highway culverts is common. The project design life has nothing directly to do with the various competitive materials available for the job. However, the least cost analysis of competitive materials is directly affected by the project design life.

There are two key factors that determine a proper project design life. One is probably obsolescence and the other is available funds. A design engineer may ignore these factors and select a design life based only on his intuitive sense of logic. This mistake is particularly easy to make in the culvert and storm sewer field. Buried structures create a spectre of excessive replacement costs; therefore, the tendency is to arbitrarily assign an excessive design life.

A rational determination of design life must consider obsolescence. How far in the future will the functional capacity be adequate? What is required in order to increase the capacity? Is a parallel line feasible? Does location dictate destruction of the old pipe to build a larger structure? All these questions and others must be considered and evaluated. Do you oversize now or not? If so, how much? It may require least cost analysis to evaluate the design capacity that is economically justified at this time to accommodate future requirements.

In addition to obsolescence in functional capacity, there is obsolescence in need. Will the basic facility be needed beyond some future date? The statistical probability that a specific facility will be totally abandoned after a certain period will set some upper limit of design life.

After rational study and economic analysis has determined a capacity (size), and a realistic design life for that capacity facility, there is still the question of available funds. Regardless of theoretical long-term economics, current resources will set practical limitations on building for future needs. Taxpayers and owners are not motivated to bear costs now which cannot possibly benefit them. This results in a limit on design life that could perhaps best be called political.

The result of these obsolescence and money factors is a practical limit on design life of 50 years for most public works projects. The taxpaying public can relate to a benefit to them in a 50 year life. Design lives exceeding 50 years are speculative at best.

Residual Values

The residual or salvage value of a facility is dependent upon some of the factors evaluated in establishing design life. If functional obsolescence determines design life, there may be no residual value in the facility beyond that point. For example: "The facility is a major storm drain in an urban area. The design life study established a 30 m^3/s capacity drain could be expected to meet flow requirements for 35 years. Available funds do not permit anything larger. At the end of the design life of 35 years, the existing structure must be replaced. It will not be possible or practical to add another line and the existing structure will be destroyed in the enlarging process."

This would be a case of zero residual or salvage value at the end of project design life. An objective look at current practice on replacement projects of drainage facilities to increase capacity shows there is little probability of any salvage value.

Material Life

After the design life of the facility (sewer, culvert) has been selected, the maintenance-free service life of the alternate pipe materials must be established. (Maintenance required of any type of pipe to maintain flow is not pertinent and is not the type referred to here.)

The validity of the least cost analysis will be no better than the estimated maintenance-free life (service life) selected. Unless this selection is given adequate effort and an objective evaluation, the least cost analysis will be only an exercise.

The average service life of various pipe materials varies with the environment, the effluent and the slope. Regional durability studies of culverts are available for most areas and can be used for storm drains, too. Additionally, numerous published reports by agencies and organizations (see bibliography) are available, and in conjunction with simple jobsite tests of the environment and effluent, can develop material service life appropriate for that region and application.

Rehab vs. Replacement

The end of average service life does not mean replacement of the pipe, as is often assumed in many life cycle articles. It does mean expenditure of funds at that time for pipe material maintenance. Currently there are several economical pipe rehab techniques being used. It is inevitable that easier and cheaper methods will be developed in the years between now and the end of a typical average service life period. For further information on pipe maintenance and rehabilitation see Chapter Eleven.

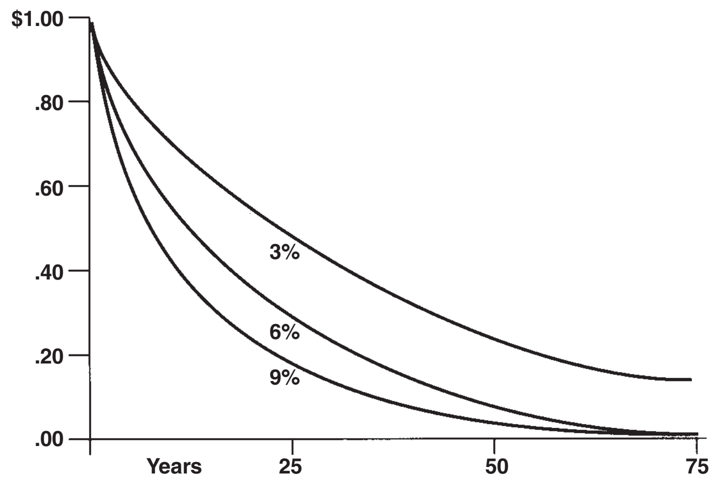
Interest & Inflation

The method of handling these two components probably contributes to most of the confusion in developing least cost comparisons. There are many articles and texts which go on at length about whether to inflate or not, by how much, and what should be used for interest rates. The logic for each seems coherent and yet, depending on the approach used, the calculations often result in completely different choices appearing to have the lowest cost. How can that be?

The answer lies in gaining an understanding of how the results are affected over a range of discount rates. In general, greater significance is given to future spending at low discount rates, and less significance at high discount rates, as shown in the following table and graph:

Present Value of $1.00 Expended at Various Intervals and Discount Rates

Year	Discount Rate 3%	6%	9%
0	1.00	1.00	1.00
25	.48	.23	.12
50	.23	.05	.01
75	.11	.01	.01



Present Value of $1.00 Expended at Various Intervals and Discount Rates

In contrast to the three times increase in discount rates from 3% to 9%, there is a 23 times *decrease* in the significance in the present values of expenditures occurring in year 50 (.23 vs. .01). Also, since present value factors behave exponentially, a 3 percentage point difference at higher rates (9% vs. 6%) has less of a present value significance than the same 3 percentage point difference at low rates (3% vs. 6%).

In practical terms, if an alternate were to require a future expenditure equal to the initial investment sometime between year 25 and 50, that expenditure would represent a much more significant portion of total present value at 3% discount rate, and much less at 9%.

Significance of Future Expenditure As % of Total Present Value		
Discount Rate	Year 25	Year 50
3%	32%	19%
9%	11%	1%

Generally, those who promote the recognition of inflation in least cost analysis wind up using relatively low discount rates, and those who exclude inflation use higher rates. So who is correct?

To Infate Or Not To Inflate

Recognition of inflation is a matter of policy. Strong arguments can be made for both techniques. As will be seen, the results of each approach require different interpretations.

In actual practice, both approaches are used. The U.S. Water Resources Council of the Department of the Interior in a report titled, *Economic and Environmental principles and Guidelines for Water and Related Land Resources Implementation Studies* (February 3, 1983), established evaluation principles to be followed by the Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority and the Soil Conservation Service for water resource project plans. The report states that all costs are to be a constant price level and at the same price level at the time of the analysis and as used for the computation of benefits (Section XII 2.12.4 [b] and [i]).

Similarly, Department of the Army Technical Manual, TM 5-802-1, Economic Studies for Military Design-Applications (December 31, 1986) indicates that the rate of inflation of the economy as a whole will be neglected in all least cost calculations. Although provisions are made to recognize differential cost growth (where particular costs or benefits are expected to change at rates different from the economy as a whole), it concludes that, in general, the differential growth rate will be assumed to be zero (Chap. 2-2.b. [7]-C).

Although the foregoing suggests inflation is not considered at the federal level, practice at the state level is mixed. Based on the 20 states and provinces who responded to the TRB's survey, Procedures For Selecting Pavement Design Alternatives (NCHRP 122) and who provided meaningful descriptions of their techniques, 8 states recognized inflation in their life cycle cost evaluations.

Opportunity Value or Cost of Money

The previously mentioned Department of the Army Technical Manual describes the "opportunity value" basis for evaluation. It states: (Chap. 2.-2.b.[4].) "The prescribed annual discount rate of 10 percent should be viewed as the minimum "real" rate of return—i.e., the net rate of return, over and above the rate of inflation—to be achieved by public sector investments. The Office of Management and Budget, at the recommendation of the Joint Economic Committees of Congress, has determined that withdrawal of investment capital from the private sector by taxation can be justified only when the capital is used to finance public sector investments for which the real rate of return is at least equal to that achievable on the average in the private sector (estimated to be 10 percent)."

This position is fairly close to that commonly used in industry. That is, money has value and the competing demands for its use exceed the supply. Using a minimum rate of return screens out the poorer prospects. At the same time, inflation is not expressly calculated since it is viewed that both costs and benefits are similarly influenced.

Another commonly held position is to use a discount rate that is related to the cost of borrowing. Typically, the interest rate associated with long-term federal, state or municipal securities is used. This approach makes the choice between alternatives only on the basis of the cost of borrowing. However, the cost of borrowing a given sum is not necessarily the best measure to determine whether an additional sum for a higher cost alternate is warranted.

The difference between "opportunity value" concept and the "cost of borrowing" concept is fundamental and requires the user to make a policy choice. As noted earlier, when the discount rates are high enough, there is generally little difference in the resulting answer for most drainage projects. In other words, if an agency has a 9% borrowing rate, it would come to the same choice of alternates as it would if it used the Department of Army's 10% discount rate.

Inflation

Those who do recognize inflation in their calculations generally are concerned that the savings from an alternate with a lower initial cost may not be sufficient to cover the actual costs incurred in the future. The common approach is to assume an inflation factor, project future costs and then discount the resulting cash flows to their present value. Some formulas require specific assumptions as to inflation and discount rates, others deal only with the differential. The end result is aimed at identifying the alternative with the lowest "real" cost.

Although the concept is sensible, its application can be troublesome. Especially for projects with long design lives. The first comes with rate selection. Aside from the basic choices of discount rates (opportunity or borrowing costs) what do you use for inflation? How do you apply it? Should a flat rate be used across the board or should different elements (e.g., labor, materials, energy) be treated independently? How do you predict it? If nothing else, the analysis becomes much more complex.

Another major problem is the determination of an acceptable "real" rate. Whereas most decision makers would be comfortable accepting a 9 or 10% return on their investment, how would they feel about accepting a 2% "real" rate of return? For that matter, how about $2^1/_2$ or 3 %? Simply put, most people do not have a practical feel for using "real" discount rates.

Rate Selection

For long life projects, rate selection should be a matter of policy similar to the basic choice between using opportunity costs as compared to borrowing costs. Historical trends are useful, but should be viewed for what they are-a guide. Certainly, recent history and economic projections should be given higher weighting than data from 3 or 4 decades in the past.

Above all, common sense should prevail. Some techniques being promoted sound logical, but don't make sense. One published approach recommends that inflation should be recognized and uses the differential rate approach. The calculation was based on the long-term relationship of municipal bond rates to the producer price index of .9953. If a long-term municipal bond rate of 8% is used in conjunction with this ratio, it implies a long-term inflation rate of 7.96%. By difference, the “real” value of money is only 0.04%. This just doesn’t make sense. No investor or taxpayer would agree to such a small value, real or otherwise.

Recommendations

Follow the general approach used by the Department of the Army and similarly, the Department of the Interior, using a 9% discount rate and excluding adjustments for future inflation.

For those who, by policy, must specifically identify inflation, a rate of 5% in conjunction with the 9% discount rate is recommended.

Mathematical formulae will not be presented here. They are readily available in numerous texts on the subject. Inexpensive hand held business financial calculators are recommended as they quickly handle the required computations.

The cost data used are intended to be realistic in their proportions, and represent typical competitive market conditions between corrugated steel pipe (CSP) and reinforced concrete pipe (RCP).

Base Information

The following data pertain to three alternative drainage structures intended to satisfy a 50 year design life requirement.

Alternative A:

Galvanized CSP with an initial cost of $195,000 and a projected service life of 40 years, followed by invert maintenance at 25% of initial cost ($48,750) to satisfy required design life.

Alternative B:

Asphalt coated CSP with initial cost of $214,500.

Alternative C:

Reinforced concrete pipe with an initial cost of $230,000.

Present Value

Of the three choices, only Alternative A needs to be analyzed to determine the present worth of the projected maintenance cost in year 40. The present value of Alternates B and C are equal to their first costs since there are no significant future expenditures.

In the case of A, at a discount rate of 9% the present value is as shown below:

Year	Current Dollars	Present Value at 9%	
		Factor	Amount
0 Initial Cost	$195,000	1.0000	$195,000
40 Rehab.	48,750	.0318	1,550
Total	$243,750		$196,550

This simple approach shows, for the assumptions used, that when ranked on a present value basis, Alternate A is the lowest cost alternate.

Average Annual Cost

This technique takes the present value calculation one step further. It is sometimes referred to as a “sinking fund” payment. In a way, it is similar to a mortgage payment. It represents the annual amount which would, over the project life, yield the total present value based on the stated discount rate. Accordingly, based on a 9% discount rate and a 50 year project design life:

	A	B	C
Total Current Cost	$243,750	$214,500	$230,000
Present Value at 9%	$196,550	$214,500	$230,000
Average Annual Cost (50 Years at 9%)	$ 17,930	$ 19,560	$ 20,980

Both the present value and average annual cost methods result in the same ranking of alternatives.

A potential error can occur if the material service life for each alternate is used to calculate the average annual cost. For the comparison to be fair, the project design life should always be used so that all competing alternates are on an equal footing.

Differential Cash Flow Comparisons

Although not widely used in engineering assessments, this technique is frequently used in private industry to evaluate capital expenditure decisions. Essentially, it compares the cash flow of competing alternatives, and solves for an interest rate. It is often referred to as a discounted cash flow analysis which results in an internal rate of return. The magnitude of the resulting interest rate is used to judge the relative attractiveness of spending a higher sum initially to avoid future expenditures. Expenditures which do not meet some specified minimum rate of return are usually avoided. Generally, cost of capital is considered to be at least 10%.

A comparison of Alternates A and C results in the following:

Cash Flow	C	A	Difference (C-A)
Year 0	$230,000	$195,000	$35,000
Year 40	—	48,750	(48,750)
Total	$230,000	$243,750	$(13,750)

The internal rate of return in this case is 0.83%, or less than 1%. This represents the discount rate at which the $48,7500 future expenditures avoided are equal to the $35,000 increased initial cost. Said another way, the added $35,000 investment to avoid a $48,750 future cost, results in less than a 1% return on investment. By any measure, a poor return.

Since the results of a discounted cash flow comparison can be directly interpreted as a return on investment percentage, it serves as a useful way to gauge the significance of difference in present value amounts.

Salvage Residual Value

The following information gives an indication of the effect of a broad range of salvage value assumptions.

Year	Alternate A	Alternate C Salvage At		
		10%	20%	30%
0	$195,000	$230,000	$230,000	$230,000
40 (a)	48,750	—	—	—
50 (b)	—	(23,000)	(46,000)	(69,000)
Total	$243,750	$207,000	$184,000	$161,000
Present Value				
at 9%	$196,600	$229,700	$229,400	$229,100
at 5% / 9%	205,900	226,400	222,900	219,400

(a) rehabilitation
(b) salvage value

Interest At	Sensitivity Present Value of Salvage as a % of Initial Cost — Salvage At 10%	20%	30%
9%	0.1%	0.3%	0.4%
5% / 9%	1.6%	3.1%	4.6%

Comment: The above shows that salvage value is not a significant factor. Even under the most extreme condition (30% of original cost) it represents a value which is less than 5% of the initial cost.

Rehabilitation Costs — Timing

This example shows the significance of the timing of future repair costs relative to the initial cost.

Year	Alternate A Invert Repair At Year	
	40	25
0	$195,000	$195,000
25	—	48,750
40	48,750	—
Total	$243,750	$243,750
Present Value		
at 9%	$196,600	$200,700
at 5% / 9%	205,900	214,100

Sensitivity Difference in Present Value As a % of Initial Cost	
Interest At	25 vs. 40 Years
9%	2.1%
5% / 9%	4.2%

Comment: Despite a significant acceleration in the assumption regarding invert repair, the effect on the present value is less than 5%

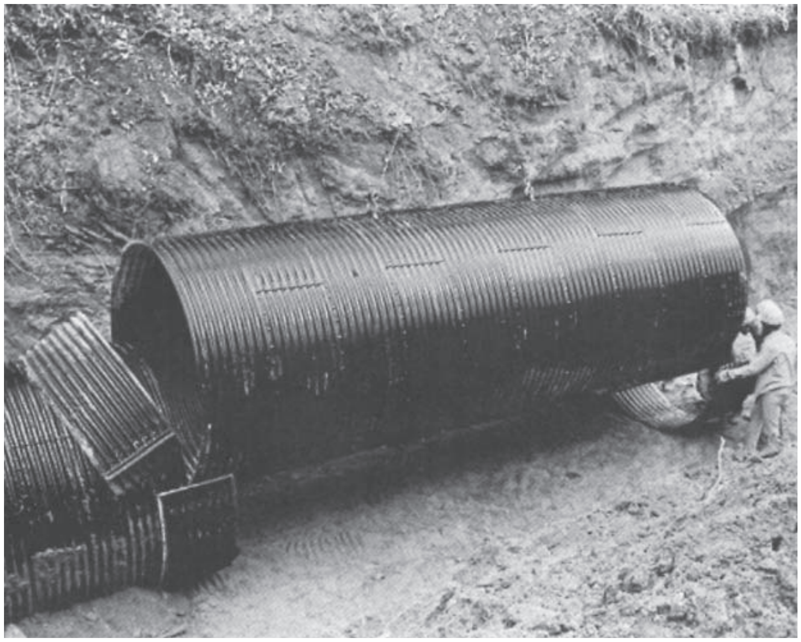
Rehabilitation Costs — Magnitude

This example portrays the significance of an increase in rehabilitation costs from the base assumption of 25% of original costs to 40%.

Year	Alternate A Invert Repair Costs At	
	25%	40%
0	$195,000	$195,000
40	48,750	78,000
Total	$243,750	$273,000
Present Value		
at 9%	$196,600	$197,500
at 5% / 9%	205,900	212,500

Sensitivity Difference in Present Value As a % of Initial Cost	
Interest At	40% vs. 25% Years
9%	0.5%
5% / 9%	3.4%

Comment: Similar to the previous example, even an exaggerated assumption on rehabilitation cost results in less than a 4% increase in present value relative to the initial cost.



Long lengths and simple mechanical joints are two of the cost saving features of CSP.

SUMMARY

Least cost analysis is an appropriate means for the selection of one design or material from the various alternatives. However, objective assumptions on the project design life and the estimated material service life are required. The analysis techniques currently being promoted are contradictory and the user must be on guard. This chapter has presented various techniques and the effects of the assumptions. The most crucial assumption is the basis for the proposed discount rate. Low rates should be rejected on a common sense basis. Additionally, the sensitivity calculations show that for long life drainage projects variations in design life, salvage value, rehabilitation costs and timing have only a small effect on total present value.

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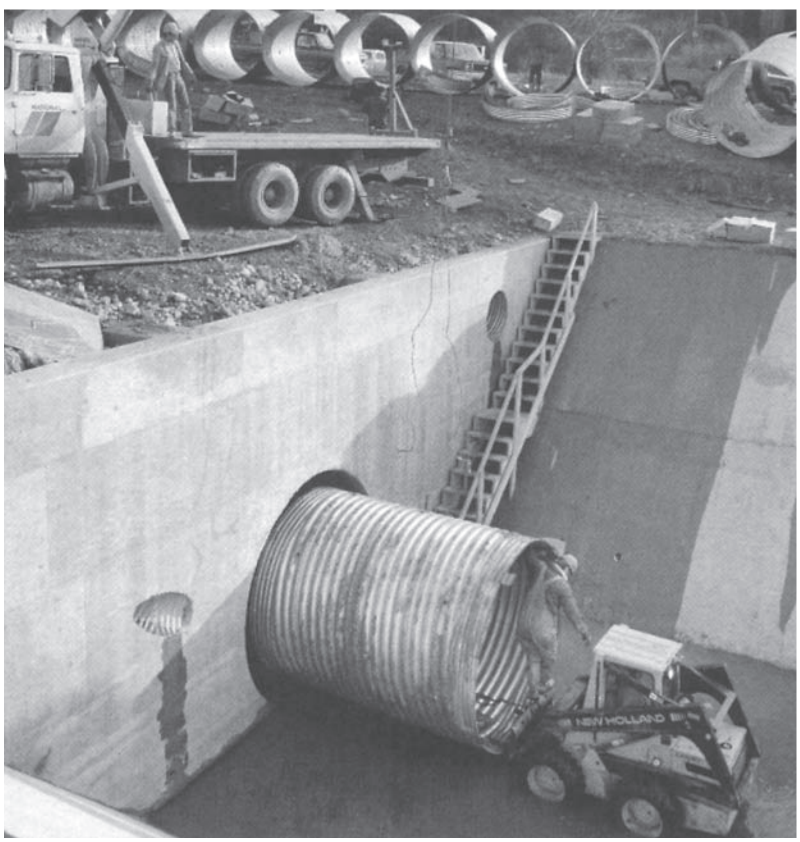

A rehabilitation technique called "Sliplining".
A 2400mm dia. CSP being sliplined into a 2800mm dia. failed concrete pipe.