COST ANALYSIS OF FAILURE FOR UNDERGROUND CONSTRUCTION

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Abstract:

Traditional performance for above ground structure is measured by stress in the material, so Performance limit is Strength. For buried structures performance is usually deformation. Deformation of flexible and rigid pipes, including leaks and excessive movement of the soil or structure, which leads to structural failure.

The cost of failure could be astounding, depending on damage and liabilities. Insurance cover or elimination of the probability any time period (the financial equality) is the cost of failure times the probability of failure.

The present paper shows what are the financial equivalents of failure? How to reduce failure to financial equivalent? Since the pipe wall strength is reduced by exceeding Performance limit, failure eventually occurs under a combination of internal and external forces. Therefore, whilst condition assessment is usually focussed on the pipe wall, water pressure, embedment support and external loading conditions are also important considerations.

The analysis found that the best choice for pipe material is by determined the probability of failure and calculate the cost of failure, through a periodic payment at the end of each year between different materials.

Key words:

Analysis failure, Probability of failure, techniques to estimate failure rate, financial equivalents for failure, Cost of Failure, cost of optimum system.

Introduction:

Performance Limits for buried pipes is deformation rather than stress. The more familiar performance Limits for the pipe is excessive deformation, which could cause leaks, or restrict flow capacity, like collapses due to internal vacuum, or external hydrostatic pressure. Bursting of the pipe due to internal pressure, is an noticeable case that deformation, beyond which the pipe cannot resist any increase in load this happened when stress σ,go behind strength S, A thickness / unit length , Di inside diameter.

$$\sigma = \frac{Pw(Di)}{2A} = S / Fs \tag{1}$$

Performance in soil-structure interaction is deformation as a function of loads, geometry and properties of materials. If performance were precisely equal to the performance limit, most of all installations would fail. To find probability of failure we should calculate the standard deviation, of normal distribution of data for enough failures.

Because delivery of the pipe to the job site is apart of installation process. Requirements for packing, stowing, restraining of the pipe during transit, unloading, and handling during the installation process are all important considerations, could damage the pipe.

On scrutiny, many buried pipes have failed but they still in continued service. Such as cracks in cast iron bell, concrete pipe and invert of steel pipes have been corroded or eroded. The (extenuating) factor is embedment soil which supports the conduit. One of the reasonable sequences in the design of buried pipes is money-making analysis, cost of alternatives then selecting optimum system.

Study Approach:

The Engineer is responsible for cost efficiency. Cost efficacy of any project is the extent to which the returns on investment outweigh the costs. Costs are money expenditures; but costs also include time, effort, overhead, insurance, warranty. Returns include money and reputation. All costs and returns must be reduced to financial equality. For analysis all financial equality must be reduced to the same basis. The present value of a project that is to continue forever by repeated replacements is called capitalized cost, $V\varpi$.

Taking into consideration more sophisticated techniques (present value **V**; (annually) payment **A**; future lump sum, **T**. life cycle costing n, interest rate, compounded at the end of each pay period i, Capitalized cost, $V\varpi$.) that consider the time value of money can also be used to evaluate the relative economics of alternative pipe materials. These techniques consider the installed cost of pipe in the calculation and future cash flow.

If a condition probability distribution can be estimated for a pipeline, it can be used as input to a physical/probabilistic failure model. By considering condition information together with pipe operating conditions, the probability of structural failure can be estimated and future failure rates can be forecast. Structural reliability modeling is commonly used for this purpose and requires the inputs given in Table 1

Table 1. Failure analysis output

Output	Structural reliability modeling
Asset failure rate	Yes
Asset risk function	Yes
Failure rate per pipe	Yes

Root of Equations

The interrelationships of money values, V, T, and A, for n periods at interest rate i compounded at the end of each period are as follows:

$$T = V(1+i)n \tag{2}$$

Consider each A of a series of periodic payments to be a separate V. For this analysis, let A be due at the beginning of each pay period. Then, evaluating and adding up the sums of all of the A's in the series, while working backward from the last A-payment to the first from one year past the last R,

<u>When A, is at the beginning of each pay period</u>

$$T = A(1+i)+ A(1+i)^{2+}A(1+i)^{3+} \ldots\ldots +A(1+i)^{n} \tag{3}$$

Multiplying both sides by (1+i),

$$T(1+i) = A(1+i)^{2} A(1+i)^{3+} \ldots\ldots +A(1+i)^{n+1} \tag{4}$$

Subtracting Equ. 2 from 3

$$Ti = A[(1+i)^{n+1} – (1+i)] \tag{5}$$

Eliminating T from 1 and 4

$$Vi(1+i)^{n} = A[(1+i)^{n+1} – (1+i)] \tag{6}$$

$$A = Vi(1+i)^{n} / [(1+i)^{n+1} – (1+i)] \tag{6-a}$$

$$V = A[(1+i)^{n+1} – (1+i)] / i(1+i)^{n} \tag{6-b}$$

$$V\varpi = A(I+1/i)$$

<u>When A, is at the end of each pay period</u>

$$Ti = A[(1+i)^{n} – 1] \tag{7}$$

$$Vi(1+i)^{n} = A[(1+i)^{n} – 1] \tag{8}$$

$$A = Vi(1+i)^{n} / [(1+i)^{n} – 1] \tag{8-a}$$

$$V = A[(1+i)^{n} – 1] / i(1+i)^{n} \tag{8-b}$$

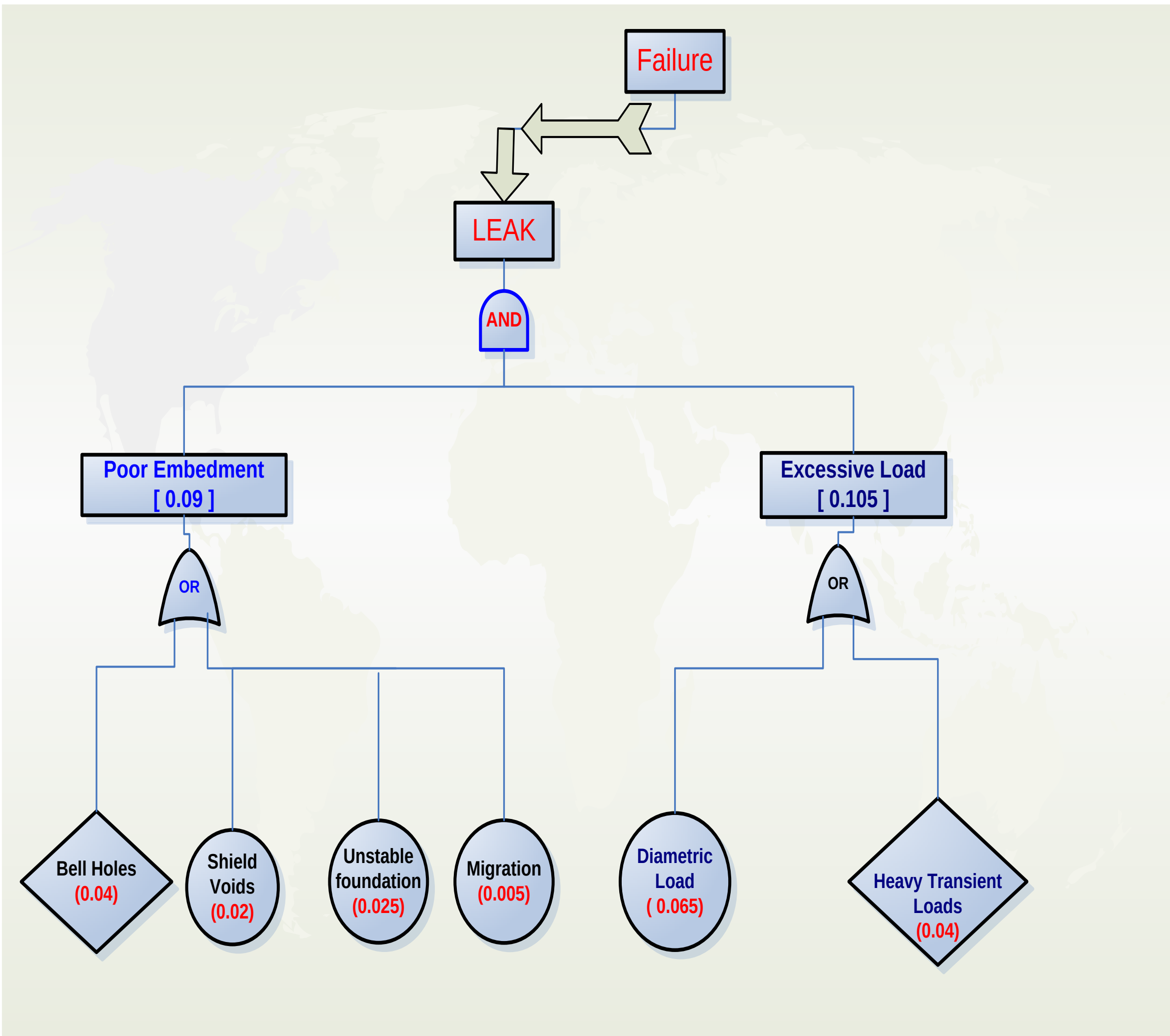
$$V\varpi = A(I+1/i)$$

Financial equal includes overhead and all direct costs such as purchases and installation. But financial equality also includes maintenance and the cost of risk. Risk includes public relations, insurance, and legal counsel, in addition to the cost of replacement

Economic Analysis of buried pipes:

Appropriate techniques for finding the financial equality of failure is system construction which is a logic steps that starts with failure and the causes of failure and determined and relate the probability of each reason to the probability of failure**(f_p).** Outputs from a structural reliability analysis that can be used to design rehabilitation plans are given in Table 1.

The condition assessment process stages are illustrated schematically in Fig. 1 and the input requirements and output of the various stages can be seen. Note how additional information (i.e. pipe type, pipe size, pipe age and soil type) is initially collected to plan a condition sampling strategy. Information on pipe operating loads is also required for the final failure analysis stage of the condition assessment process



Example (1)

Select the right material for a buried pipeline project length of line 50 km, pipe length 6 ms, DN 2000 mm, purchase of pipes is $(50,000,000). Installation cost is $ (5,000,000) per year at the end. Project will finish in 5 years. Liabilities for failure would be $(100,000,000).

In planning and design stage, engineer should identify possible alternatives pipe material by comparing between them. The best way to do that is the financial equality of (least costs) for all after dipping them to the same basis of financial equality which is equal annual payment A. So by calculating for all the alternatives pipe material the annual A, to pay off the project, first through the years until the pipeline is installed and finished, then the present value V, Second we calculate again the annual A, for life time of every pipe material, taking into consideration risk, cost of failure with interest rate, compounded 8 % at the end of each pay tear.

In figure (1) Probability of failure caused leak due to the following reasons are linked together with (and) gate, indicating that they have to be multiplied.

- Poor embedment
- Excessive load

Poor embedment Could be a result of

Bell holes or

Shields voids or

Unstable foundation or

Migration in the embedment

Either of them is adequate to be a reason for failure that is why they are linked to poor embedment through an (or) gate, and their percent of probabilities of failure cause leak **(f_p)** must be added together.

Bell Holes

Is a vital mistake but does not enlarge. If the contractor had (record), in bell holes, a probability might be enlarge. If not contained it and varied to determine their effect on the probability of failure. This could serve to evaluate the contractor's violation into the protection sector. Probability of failure **(f_p) would be (0.04) if** repair of a bell holes shows up in the bedding is one every 25 pipes.

Shield voids

Is a main error and enlarges. Probability of failure **(f_p) would be 0.02 if the** repair due to voids were not fill with the same materials and compact to the required densities, was found in one out of every 50 pipe.

Unstable Foundation

Is a vital mistake and enlarges. Probability of failure **(f_p) would be (0.025) if the** repair due to the foundation material which did not removed to the sufficient depth. Which should be done under the direction of a soils engineer and replaced was found in one out of every 40 pipe.

Migration

Is a critical mistake and enlarges. Field experience shows that migration can result in significant loss of pipe support. Probability of failure **(f_p) would be (0.005) if the** repair due to the unsuitable graded material where conditions may cause migration of fines and loss of pipe support was found in one out of every 200 pipe.

So by adding them together through the gate yielding a value of **(f_p) (0.04 + 0.02 + 0.025 + 0.005) = 0.09** Probability of failure of a poor embedment, **as shown in** Figure (1).

Excessive load

Excessive load could be a result of

Transient loads or

Diametric load or

Either of them is adequate to be a reason for failure that is why they are linked to, excessive load through (or) gate and their percent of probabilities of failure cause leak **(f_p)** must be added together.

Transient loads

Transient loads does not expand, and could be a result of a heavy truck or an military equipment passing over the pipe near to the axis, every 25 years the probability of any year is (0.04) as shown on transient loads.

Diametric load

In service, failure tends to occur where excessive ring deflection occurred before installation due to diametric load; this could be happened during transportation or storage of the pipes. Probability of failure **(f_p) would be 0.065 if the** repair due to excessive rings deflection was found in one out of every 15 pipe.

So by adding them together through the or gate yielding a value of **(f_p) (0.065 + 0.04) = 0.105** Probability of failure of a excessive load, **as shown in** Figure (1).

Cost of failure

A = year repayment of purchase cost + annual installation cost

Appling Eq. (8-a) V=50,000,000 in n = 5years at I = 8%

$$A = \$ 5,000,000 + \$ 50,000,000(0.08)(1.08)^{5} / \{(1.08)^{5} - 1\}$$
$$= \$ 17,522,823$$

Applying Eq. (8-b), present value V, for A =$17,522,823

$$V = \$ 69,963,550$$

Using life time for each pipe material (n) to compare through A

For every one of them when V = $ 69,963,550

For n = 50 (life time of the pipe material)

$$A = \$ 69,963,550 (0.08)(1.08)^{50} / \{(1.08)^{50} - 1\}$$
$$= \$ 5,719,021$$

For n = 30 (life time of the pipe material)

$$A = \$ 69,963,550 (0.08)(1.08)^{30} / \{(1.08)^{30} - 1\}$$
$$= \$ 6,214,683$$

For n = 20(life time of the pipe material)

$$A = \$ 69,963,550 (0.08)(1.08)^{20} / \{(1.08)^{20} - 1\}$$
$$= \$ 7,125,942$$

For n = 8 (if there is a failure)

$$A = \$ 69,963,550 (0.08)(1.08)^{8} / \{(1.08)^{8} - 1\}$$
$$= \$ 12,174,690$$

We can see from that the pipe with life time 50 years is the best choice

Discussion of results

- If the costs associated with pipe failure are known, then the failure rates in Fig. 1 could assist the development of long-term pipe replacement and rehabilitation strategies. Alternatively, as a useful intermediate step, the timings of subsequent condition assessment programs in each section of the pipeline could be scheduled.
- The Probability of failure in any pay period (year) is for Poor embedment and excessive load (f_p) = (0.09) times (0.105) = 0.00945 = 1/106 this means every one hundred and six pipe
- Elimination of the probability of failure

  = Cost of failure times the Probability of failure it will happen in any pay period (year)

  So if the cost of failure is

  = $ (100,000,000) * 0.00945 = $ 945,000 per year

The values of the selected assessment parameters mentioned above are calculated for pipe under selected conditions. The results calculated from the example given and shown in figure (1) highlight the importance of choosing the appropriate economic pipe materials, with least risk for failure and longer life time.

Summary and Conclusion

Limited to the conditions investigated in the present study and based on the obtained results, the following conclusions can be drawn:

- Future safety factors should include possibility of failure, and the cost of failure in addition to (risk and liability).
- Designers must allow for imperfection of construction, overloads, flawed materials.
- Engineers design buried pipes should take into consideration some assorted concerns, such as construction loads, installation techniques and soil availability. Environment,
- For planning and design, it is usual to compare (least costs) for all possible alternatives after dipping them to the same basis of financial equality, usually equal periodic payment, A. For marketing of a project. For settlement of claims, present value, V, is usually the best financial equality.
- Financial equality depends upon time and interest rates because the value of money is not constant.
- In the event of legal action, however, information upon which council directs legal proceedings must come from the engineer. Reduction to financial equivalent must come from the engineer.

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