A Methodology to Predict the Remaining Service Life of CSCPs

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ABSTRACT

Despite the fact that corrugated steel culvert pipe (CSCP) is widely used for stream crossings and drainage in many transportation systems in the US, historically, very little has been done regarding its condition assessment and planned maintenance. This research provides a methodology for developing a comprehensive plan for inspection, cleaning, condition assessment and prediction of remaining service of CSCP. Inspection frequency guidelines were developed based upon culvert size, age, importance and environmental factors, e.g., corrosion and erosion, bed load and pH. The CSCPs are classified into three levels according to increasing need for inspection, e.g., annual inspections are recommended for Level III. A four Condition State assessment system was developed based upon the CalTrans system, which includes quantifiable section losses, specific surface features, and a prescribed response associated with each condition state. A Markov deterioration model was used to predict the future Condition States and the probability of failure of new CSCP over a 30-year life for both urban and rural settings. The transition probabilities were based upon inspection data and corrosion case studies. The probability of failure ranged from 25 to 65 percent for the rural and urban areas respectively. Improvements to the model that will take into account the effects of maintenance and rehabilitation will be addressed in the next phase of the research project.

INTRODUCTION

Corrugated Steel Culvert Pipe (CSCP) serves as an inexpensive means for crossing streams and providing drainage along and across roadways, and thus are very important components of many transportation systems. CSCPs have been used for culverts and storm drains since their introduction to the North American market in the early 1900's.

The thicknesses of CSCP range from 0.052” (18 gage) to 0.168” (8 gage). There are different corrugation profiles available, but generally, 6”, 8”, and 10” pipes are produced with 1½”x1/4” corrugations; 12” through 48” Pipe with 2 2/3”x½”Corrugations; and large diameter pipe 54” through 144” with 3”x1” corrugations.

CSCPs are cheaper, more easily transported, and more easily assembled than other culvert pipes. The design flexibility of CSCP and its predictable mechanical properties allow the engineer to design a culvert, which will withstand heavy traffic loads and other site conditions that might occur during the life of the pipe.

Since its introduction to the construction industry, CSCP has undergone many revisions including its basic composition, corrugation pattern, and coating. Many state departments of transportation and independent engineering firms have conducted numerous durability studies to determine the life expectation of CSCP.

However, as with other pipe materials, corrosion protection is required for steel pipes to achieve their full-expected life. The coating for CSCP may be zinc coated steel; aluminum coated steel; zinc-aluminum coated steel; bituminous coated; and epoxy coated. Based on previous works performed by the Corrugated Steel Pipe Institute, the life expectancy of a protected and coated, and properly inspected and maintained CSCP is expected to be in excess of 100 years.

In June 1999 a significant change in financial reporting requirements for the more than 84,000 state and local governments in the US occurred when the Governmental Accounting Standards Board (GASB) approved the Statement No.34 (GASB 34): Basic Financial Statements—and Management’s Discussion and Analysis—for State and Local Governments. Among its many new provisions, GASB 34 requires that state and local governments report the value of their infrastructure assets, including roads, bridges, water, storm water and wastewater facilities, and dams (McNamee et al., 1999). Reporting the value of water, storm-water and wastewater facilities is a major challenge as they are below ground and inspection is a major problem.

The modified approach of GASB 34 allows governments to record the current costs of preserving eligible infrastructure in lieu of depreciation. To use this alternative approach, the government must use an asset management system or process that has the following components (McNamee et al., 1999):

- Maintains an up-to-date inventory of eligible infrastructure assets.
- Performs condition assessments of eligible infrastructure assets at least every three years, using a replicable basis of measurement and measurement scale.
- Summarizes the results, noting any factors that may influence trends in the information reported.
- Estimates each year the annual amount to maintain and preserve the eligible infrastructure assets at or above a prescribed level.

The above will lead to justification for funding a preventive maintenance program, which compares indirect and social costs due to the savings realized from preventing pipe and roadway collapses and the ensuing traffic delays (user costs) and expensive roadway repair. Please note that typically, only direct costs of damage to CSCP are considered in such analyses. However, indirect and social costs can easily exceed direct costs. Ignoring these costs can lead to less than optimal decisions. There are no clear, consistent guidelines as to what to include in each cost grouping, how these should be measured (especially Social/user costs), and how they should be captured. This leads to an inconsistent approach to life cycle costing, an incomplete analysis of the economic and social impacts of utility work and, potentially, underestimation of total costs. Without clear guidelines, utilities and regulators cannot make a complete and compelling argument for repair, rehabilitation and replacement of CSCP. The University of Utah is currently working on a TRB Report on the Economic Impact of Culvert Failures and expects to develop a consistent approach to life cycle costing.

PERFORMANCE OF CSCPs

There are a wide variety of problems that can occur with CSCP's. The National Cooperative Highway Research Program (NCHRP) has developed charts classifying these problems according to serviceability and strength-related criteria. The following are general types of culvert problems.

Serviceability-related problems:

- Scour and erosion of streambed and embankments
- Inadequate flow capacity
- Corrosion and abrasion of metal culverts
- Abrasion and deterioration of concrete and masonry culverts
- Sedimentation and blockage by debris
- Separation and/or drop-off of sections of modular culverts
- Inadequate length

Strength-related problems:

- Cracking of rigid culverts
- Undermining and loss of structural support
- Loss of the invert of culverts due to corrosion or abrasion
- Over-deflection and shape deformation of flexible culverts
- Stress cracking of plastic culverts

CSCPs are susceptible to internal and external corrosion once they are placed in the ground. Corrosion is an electrochemical phenomenon where a metal tends to return to its oxide state. An electric current flows from the metal through ions in the surrounding water or soil. The resistivity of a given soil or water is the simplest criterion for estimating it's relative corrosiveness and defines it's ability to serve as an electrolyte to conduct current. Values lower than 3,000 ohm.cm are considered corrosive, and those less than 1,000 ohm.cm are seen as very Corrosive. Other factors that affect resistivity include soil moisture content and compactness. Since resistivity is a function of temperature, frozen soils and water are much less corrosive than in their unfrozen state (Gory, 1998). Sandy soils that easily draw water away are non-corrosive; clay like soils that hold water have low resistivity and are corrosive (Gory, 1998). Additional environmental factors that play a significant role in corrosion are pH, oxygen level, acidity, and chloride and sulfates levels.

CSCP failures by wall thinning initiated at the inverts are mostly due to erosion and internal corrosion. The following were identified as major corrosion mechanisms:

- Stress corrosion cracking
- Corrosion fatigue
- Graphitization
- Tuberculation
- Pitting corrosion

The University of New Hampshire Technology Transfer Center finds that CSCP are subject to corrosion and abrasion, and have a shorter life span than other materials [DiBiaso, 2000]. Applied coatings (bituminous, asphaltic, etc.) do not improve the hydraulic characteristics of corrugated steel pipe. According to a Missouri DOT Durability Report (MR87-1), "coatings such as bituminous or polymer materials cannot be used to lower the coefficient of roughness for CSCP because the coating will be lost first, leaving the hydraulic conditions controlled by the uncoated CSCP."

The California Division of Highways conducted a comprehensive field study, where specially trained personnel evaluated over 7,000 CSCPs. It concluded that pH and conductivity of soil and water were the most important factors influencing the durability of CSCP [Beaton and Stratful, 1962].

After nearly 90 years of practical experience with CSCP installations, the pipe has a proven durability for use as culverts and storm drains. CSCP can be designed for field conditions by using galvanizing, asphalt coating, paved inverts and varying the metal thickness [CSPI, 1990].

According to New Jersey Department of Transportation (NJDOT), CSCP has been widely used in New Jersey for many years, both alongside and under roadways. Most CSCP that has been in place for 30 or more years has become deteriorated, especially at inverts. Corrosion and abrasion are the major causes of CSCP deterioration. Corrosion is a significant problem for underwater structures, particularly in environments where there are conditions that accelerate the process. Three dominant factors that cause deterioration of CSCP are soil chemistry, water chemistry, and abrasion resistance of sediments. The abrasion potential of an environment can be evaluated by measuring the slope of installation, the velocity of the flow, and the size of the abrasive materials in the culvert. Erosion of CSCP at the inverts can mechanically damage the invert surface.

MANAGEMENT OF CSCP

In response to the GASB 34 provisions, NJDOT initiated a major research study with NJIT to investigate the deterioration of CSCPs. The overall objectives of this research are to investigate causes of the deterioration of CSCP. Then to develop a plan for implementing an effective, statewide, preventative maintenance program for CSCP so that pipes can be repaired and rehabilitated before failure occurs, and to determine the best practice for using CSCP in new construction. This paper describes the initial results of this study, specifically, the results of a literature search; methods for inventorying, inspecting, and cleaning CSCP; means of assessing the condition of CSCP, estimating pipe deterioration rates, and predicting service life for pipes.

In addition, the research will investigate methodologies for determining the appropriate corrective action, i.e., to repair, rehabilitate or replace; study methods of record keeping and data storage; estimate the cost and recommend a preventative maintenance program for CSCP and best practice for use of CSCP in new construction. Consequently, design recommendations and guidelines will be formulated to develop a CSCP management strategy.

CULVERT INSPECTION AND INSPECTION FREQUENCY

The assessment of CSCP is a difficult exercise because culverts are usually substructures, submerged, or placed in a remote location. Comprehensive and properly documented inspections need to be carried out to determine whether culverts require repair, rehabilitation, or replacement.

The failure of a culvert under the westbound lane of I-70 near east Vail, CO during high runoff on June 1, 2003, suggested the need for regular inspection of highway culverts. This culvert failure caused the shutdown of 25-mile stretch of highway and 54 mile detour over two mountain passes for several weeks Culverts should be inspected on a routine basis to ensure that they are functioning properly. Presently, there is no standard or consistent methodology to inventory, inspect, and evaluate culverts in the field. Inspection of culverts is very important to ensure a successful pipe inspection program. Established standard guidelines must be put into place under which all inspectors should function so that data will be consistently collected. It is also necessary to schedule inspections on a regular basis.

Visual inspection is the most common method of culvert inspection. However, some departments of transportation and road authorities also make use of video cameras. Typically, visual inspection lacks consistency because multiple inspectors perform them. MnDOT [Ulteig Engineers, 2001] and City of Waterloo[Gallivan, 2002] utilized photographs and video cameras to enhance assessment. Other agencies are also considering purchasing video cameras after seeing benefits that were being derived. Other options include digital video and still photos. Digital video is the preferred option of NJDOT.

The Federal Highway Administration (FHWA) developed a comprehensive Culvert Inspection Manual. It describes in detail inspection procedures, guidelines and inspection frequency. FHWA required that inspections be performed once in every 3 years (Arnoult, 1986). NCHRP Synthesis 303 on Assessment and Rehabilitation of Existing Culverts also documents the following methods for inventorying, inspecting, and cleaning CSCP:

1. There is a need to establish a standard set of guidelines, under which all inspectors will inspect and consistently collect data.
2. NYSDOT and Connecticut DOT have comprehensive culvert inventory and inspection manuals that describe their culvert management program.
3. Most agencies cleanse their large diameter culverts between 2 – 3 year intervals.
4. There is need for a regular inspection schedule, similar to that provided in the National Bridge Inspection Standard [NBIS, 2001]. However, regular cycles are not followed by transportation agencies.

Major culverts should be scheduled for inspection at least every three years, but if the conditions are mild where the structure is located, inspection may be carried out every four years with FHWA approval. Although FHWA recommends that inspections be performed every 3 years, our research lead us to conclude that if a comprehensive inspection program is adopted, the frequency may vary from 1 to 10 years based on the hydraulics, location and importance of CSCPs. Some critical CSCPs, e.g., those crossing major highways and connected to upstream or downstream hydraulic structures that are not owned and maintained by DOTs may need to be inspected more frequently, even annually. While others, e.g., small diameter new CSCPs running along the highways that are not in highly erodable or corrosive environments may be inspected with much less frequency. NJIT proposed a new inspection frequency for CSCPs in NJ that is shown in Table 1. Culverts are categorized into three levels based on the following factors, i.e., corrosion and erosion, bed load, pH, and culvert size, age and importance.

Table 1. Proposed CSCP Inspection Frequency

Rating Level	I	II	III
Inspection Frequency	10yrs	3 yrs	1 yrs
Basis for Time Interval	Self-cleaning design (10-year flood) for small diameter CSCPs	FHWA Guidelines	Reported Problems
Physiological Features	Free of corrosion and debris	Evidence of corrosion and/or debris	Reported clogging or collapse
Sediment	Low Abrasion	Moderate Abrasion	Severe Abrasion
-Bed Loads	Soil	Sand and Gravel	Gravel and rock
-Water Velocity	V < 1.5 m/s	1.5 < V < 5 m/s	V > 5 m/s
pH	5.8 < pH <8.0	5.0 < pH < 5.8	pH < 5.0
Location: Corrosion/ Erosion - (Historical Data)	Low or none	Medium	High
Pipe Age	10 yrs	15 yrs	30 yrs

Culverts rated as Level I are considered to be working fine, while those rated as Level III require urgent attention. Corrosion is a major cause of deterioration of culverts; hence culverts exhibiting excessive corrosion require urgent attention. Acidity of the environment in which culverts are located also plays a dominant role in the deterioration process of culverts; hence culverts in high acidity environments deteriorate at a faster rate and hence need to be inspected more frequently. Culverts, like other infrastructure, generally deteriorate at a faster rate with age, and hence require more frequent inspections with increasing pipe age, i.e., as they approach their design service life.

The most stringent inspection schedule should be selected based on the selection criteria in Table 1. For example, all large diameter CSCPs crossing major highways should be by default rated as Level II or III. We were unable to express the bed load, which is a measure of culvert erosion, in terms of a more tangible parameter. Hence, bed load should be selected after visiting the location of CSCP and examining the surrounding soil. If it is sandy select a medium value. Silt or clay, select the lowest value, and gravelly select a high value. A computer program was developed at NJIT to select the inspection frequency of a given culvert based on the criteria shown in Table 1.

CULVERT CLEANING

There are various equipment and methods commercially available today for cleaning culverts. Table 2 provides a list of all the available methods for CSCP cleaning with the advantages and disadvantages of each method. The types of equipment and methods to be used depend the degree of movement and versatility required, video inspection of a problematic section or entire system. The video inspection systems can also identify offset joints, broken pipes, protruding laterals, off grade pipes, leaking joints, recessed taps, cracked pipes, blockages, corrosion, root infiltration, obstructions and collapsed pipes. These systems

Table 2. Pipe cleaning methods

CLEANING METHOD	*ADVANTAGES*	*DISADVANTAGES*
Vacuum Pump	**Capable of removing stones, bricks, leaves, and sediment deposits**	**Limited to working depth of 6m**
Water Jet Spray	**Effective in cleaning pipes that require high pressure and general cleaning**	**Cannot be used to clean culverts due to the damage to protective coatings.**
Buckle Line	**Easily available and can be used for general cleaning and sediments removal**	**Limited to large pipes of over 48 inches diameter or width.**
Compressed Air Jet	**Effective in removing debris from vertical walls**	**Normal working depth limited to 20m (75ft).**
Fire Hose Flushing	**Effective in removing light materials from the wall and for general removal of light materials**	**Limited to light to light sediments and materials**
Sewer Jet Flushes	**Effective in cleaning area with light grease problem, sand and gravel infiltration and general cleaning.**	**Much more expensive than other methods.**

can also inspect clean-outs, drain lines, service laterals, vent stacks, floor drains, and water lines. The aim is to free culvert from debris and normal flow of water.

CONDITION ASSESSMENT

Aktan et. al 1996, describes condition assessment as a process which can be summarized in the following steps:

1. Measure the extent of damage/deterioration.
2. Determine the effect of that damage/deterioration on the condition of facility.
3. Set the scale of parameters that describes the condition of the facility as a whole.
4. Compare the existing damage/deterioration with previous records of condition assessment.

AASHTO specified a simple condition rating process that describes three to five classes of conditions. The condition states were designed to be consistent and repeatable if used by certified inspectors. Below is a definition of condition states of painted steel girder (Sobanjo, 2001):

1. There is no evidence of corrosion, and the paint system is sound and functioning as intended to protect the metal surface.
2. There is little or no active corrosion. Surface corrosion has formed or is forming. The paint system may be chalking, peeling, curling or showing other evidence of paint system distress, but there is no exposure of metal.
3. Surface corrosion is prevalent. There may be exposed metal but there is no active corrosion, which is causing loss of metal section.
4. Corrosion may be present but any section loss due to active corrosion does not yet warrant structural review.
5. Corrosion has caused section loss and is sufficient to warrant structural review to ascertain the impact on the ultimate strength and/serviceability of the structure.

The Tennessee Department of Transportation (TDOT) uses a 10-point scale to define different condition states of Culverts, which in authors' opinion is quite complex for CSCP (TDOT 2003). The California Department of Transportation (CalTrans) defines condition states of steel bridge and culverts and other steel structures in terms of the section and proposed some feasible actions as follows:

Condition State 1: There is no evidence of active corrosion of the structure with any measurable section loss.
Suggested corrective action: Do nothing

Condition State 2: Surface or freckled rust has formed or is forming on the structure, flaking, minor section loss less than or equal to 10% of thickness.
Suggested corrective action: Clean and paint

Condition State 3: Flaking and swelling with surface pitting but any section loss due to active corrosion is measurable and does not affect the strength or serviceability of the structure. Section loss is between 10 to 30 % of thickness.
Suggested corrective action: Clean and paint or re-lining.

Condition State 4: Corrosion is advanced and heavy section loss to warrant analysis to ascertain the impact on the ultimate strength and/or serviceability of the structure. Section loss is greater than 30% of section thickness.
Suggested corrective action: Re-lining or replacement of structure.

With the above quantifiable section losses associated with each condition, the authors decided to recommend the Condition States used by Caltrans for NJDOT and to predict remaining service life of CSCP based on the above. NJIT is now in the process of negotiating with a vendor using digital cameras for culvert inspection to develop automated condition assessment system using the color, texture and the corrosion features of digital pictures.

MARKOV DETERIORATION MODEL

In order to predict the remaining service life one needs the corrosion rate with the age. There is very little measured data on corrosion of CSCP. Extensive search for data reviled that corrosion rate increase with the age if the surface is free of rust. However, the rust build-up decreases the corrosion rate. Hence it was concluded that it is reasonable to assume a uniform corrosion rate for CSCP with the age. The best usable data for remaining service life prediction comes from an ASTM (American Society for Testing and Materials) study of corrosion of carbon steel from 1960 to 1964 at 46 locations, including 14 locations in other countries. The specification of the carbon steel specimen used for this study is comparable to that defined by ASTM A242. The locations ranged from tropical to polar, industrial to rural, and marine to arid. Based on the above data, 3.0 mil/year recorded at Bayonne, NJ (Boyer and Gall, 1985) was selected as the worst case and 1.5 mil/year recorded at rural environment (Boyer and Gall, 1985) was selected as the mildest corrosion rate for our research.

The Markov model can be used to predict future Condition State of any system given the present state and the past states have no influence on the future state. This property is called the Markov property, and systems having this property are called Markov chains. In Markov process, the state probabilities (probability of CSCP be in a particular state) and the transition probabilities (probability that CSCP will deteriorate to a worse state) are used to predict the future condition of the infrastructure (Deshmukh and Sanford-Bernhardt, 2000).

Sobanjo, 2001 elaborated an attempt to develop Markov deterioration model bridges, but he used data from surveys to develop the transitional probabilities. Inspection data (which is subjective) can be used in estimating the transition probabilities for the chain process, but there is very little historical data. Hence the transitional probabilities for each condition state is computed using the half life of CSCP and the number of years it takes to deteriorate to that state. Hence the following was computed:

Condition State 1: Assuming the average corrosion rate of 3mil/year and gauge 18 (.052"), the number of years to reduce the section by 50% is approximately 8.7 years. Hence the transition probability P(1,1) that the system will remain in this state (Condition State 1) after one year is computed from the following equation.

$$(P(1,1))^{8.7} = 50\% \tag{1}$$

Hence P(1,1) is 92.3%. Therefore, the probability that CSCP will deteriorate to Condition State 2, P(1,2), is 7.7% (100.0% -92.3%) since sum of the two probabilities is 100%. Since Condition States 3 and 4 can not be reached from Condition States 1 after one year, hence P(1,3) = P(1,4) = 0.

Condition State 2: This is computed relative to P(1,1) in a similar way as above. Condition State 2 occurs when the section loss is 10%. Assuming the average corrosion rate of 3mil/year and gauge 18 (.052"), numbers of years to reduce the section by 10% is approximately 1.7 years. Hence assuming a similar distribution the transition probability P(2,2) that the system will remain in this state (Condition State 2) after one year is computed from the following equation.

$$P(2,2) = (0.9)^{1/1.7} \text{ x } P(1,1)/100\% \tag{2}$$

Hence P(2,2) is 86.7%. Therefore, the probability that CSCP will deteriorate to Condition State 2 P(2,3) is 13.3% (100.0% - 86.7%) since sum of the two probabilities is 100%. Since Condition States 4 cannot be reached from Condition States 2 after one year, hence P(2,4) = 0. Also, since there is no cleaning or rehabilitation can not move to Condition States 1 from Condition States 2 after one year, hence P(2,1) = 0.

Condition State 3: This is also computed in a similar way as above. Condition State 3 occurs when the section loss is 30%. Assuming the average corrosion rate of 3mil/year and gauge 18 (.052"), numbers of years to reduce the section by 30% is approximately 5.2 years. Hence assuming a similar distribution the transition probability P(3,3) that the system will remain in this state (Condition State 2) after one year is computed from the following equation.

$$P(3,3) = (0.7)^{1/5.2} \text{ x } P(2,2)/ (0.9)^{1/1.7} \tag{3}$$

Hence P(3,3) is 86.2%. Therefore, the probability that CSCP will deteriorate to Condition State 4 P(3,4) is 13.8% (i.e., 100.0% - 86.2%) since sum of the two probabilities is 100%. Since there is no cleaning or rehabilitation can not move to Condition States 1 and 2 from Condition States 3 after one year, hence P(3,1) = P(3,2) = 0.

Condition State 4: This condition is failure state hence P(4,4) is 100%. This is known as the absorbing state from the Markov chain theory. Since there is no cleaning or rehabilitation can not move to Condition States 1, 2 and 3 from Condition States 4 after one year, hence P(4,1) = P(4,2) = P(4,3) =0.

The results of the above computations are summarized in Table 3. Based on these transition probabilities, the future condition of the culvert system over a 30-year span can be predicted. A similar calculation can be performed for CSCPs in rural environments with a corrosion rate of 1.5mil/year and corresponding transition probabilities. It should be noted that these calculations were developed on the theory that there is no corrective or maintenance action (cleaning, repainting, rehabilitation, or replacement) over this time period.

Table 3. Transition Probability Matrix

	To Condition State			
From Condition state	1 (New)	2	3	4 (Failure)
1 (New)	0.0	92.3	7.7	0.0
2	0.0	86.7	13.3	0.0
3	0.0	0.0	86.2	13.8
4(Failure)	0.0	0.0	0.0	100.0

The predicted future performance of new CSCP under rural and urban settings with time is shown in Figure 1.

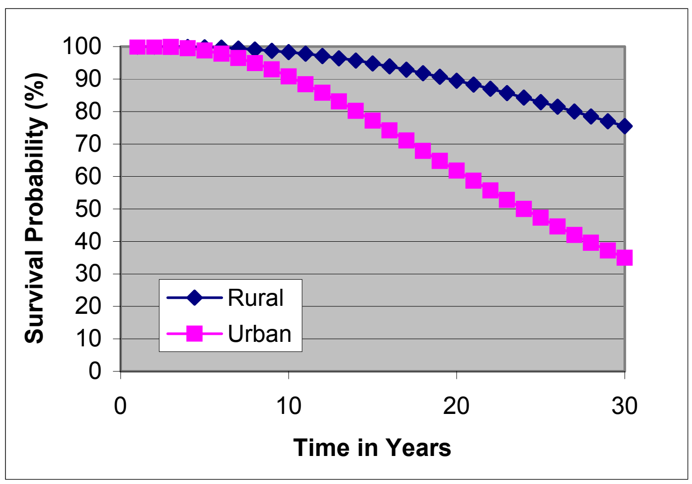

Fig. 1 Survival probability of CSCPs with time and environment.

It shows that CSCP in an urban area has a 65% probability of failure after 30 years, if no corrective or maintenance action is performed, while CSCP in a rural environment has a 25% probability of failure. If corrective or maintenance action is carried out, then the Condition State is improved, and the above model will no longer be applicable. During the second phase of this project it proposed to expand the above model to include the impact of cleaning or rehabilitation on service life. With cleaning or rehabilitation of CSCPs the Condition State will improve.

PREDICTION OF REMAINING SERVICE LIFE

If the current condition is known, then using the Markov deterioration model one can predict the remaining service life of a CSCP. If the Condition State of CSCP in year n is x, then the distribution of a CSCP reaching Condition State y in year n+1 (or in an additional year) is given be the following equation (Hoel et al., 1972).

$$P_x(T_y = n+1) = \sum_{z \neq y} \left\{ P(x,z) P_z(T_y = n) \right\} \quad (4)$$

Please note that z can take all the values except y. If y is assumed as the failure state and there are for Condition States then z=1, 2 or 3. T is the time in years and P(x,z) vales are those computed before. Assuming a current Condition State, equation 4 can be iteratively used to find the number of years for a given probability of a CSCP failure. A computer program was developed at NJIT for this purpose and from this program the number of years for 95% probability of a CSCP failure from Condition States 1, 2 and 3 were found to be 57, 32 and 20 years respectively.

During the second phase of this project it proposed to expand the above model to include the impact of cleaning or rehabilitation on service life. With cleaning or rehabilitation of CSCPs the Condition State will improve and affect the probability of survival. Quantifying these types of improvements is critical to long-term planning and asset management.

SUMMARY AND CONCLUSIONS

New inspection frequency guidelines for CSCPs in NJ were proposed, where the CSCPs are rated at three levels. The rating categories are based on the following factors, i.e., corrosion and erosion, bed load, pH, and culvert size, age and importance, and are ranked according to increasing need, e.g., annual inspections recommended for Category III.

Condition state assessment according to the CalTrans system, which defines four condition states of culverts, is recommended for use in NJ. The CalTrans condition states have quantifiable section losses, specific surface features, and a prescribed response associated with each condition state. The four condition states are ranked in terms of increasing deterioration, and the response range from “Do nothing” to “Re-lining or replacement”.

A Markov deterioration model was used to predict the future Condition State of new CSCP in urban and rural settings. The transition probabilities were based upon inspection data and corrosion studies. The model was extended to predict the future condition of new CSCP in both settings over a 30-year life. The probability of a failure ranged from 25 to 65 percent for the rural and urban areas respectively. However, it should be noted that the current model does not take into account the effects of maintenance or rehabilitation. These improvements will be addressed in the next phase of the project. The above provides a methodology for developing a comprehensive plan for inspection, cleaning, condition assessment and prediction of remaining service of CSCP.

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