Best Practices for Assessing Culvert Health and Determining Appropriate Rehabilitation Methods

South Carolina Department of Transportation

CLEMSON UNIVERSITY

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PROJECT SUMMARY

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Overview

Several culvert structures in the United States are in a deteriorated state needing immediate attention to prioritize critical culverts and rehabilitate them in a timely and economical manner. The overarching goal of this study is to provide technical guidance to SCDOT in effectively managing their culvert infrastructure. This study identified best practices for effectively inspecting deteriorating culvert infrastructures and choosing appropriate rehabilitation methods. The synthesis of literature on best practices for culvert rehabilitation is formulated into a simple decision-making architecture using the principles of analytical hierarchy procedure (AHP). Specifically, a Microsoft Excel-based Culvert Renewal Selection Tool (CREST) is developed to assist SCDOT in shortlisting suitable construction methods for the renewal of failing culverts. Furthermore, a multinomial logistic regression (MLR) model as well as an artificial neural network (ANN) model is developed to predict the condition scores of a culvert based on historic inspection data recorded into SCDOT's culvert inspection database. A simple analytical hierarchical procedure (AHP) is used to subsequently prioritize critical culvert structures based on their condition scores evaluated on various defect categories. The prioritization model has been demonstrated using the inspection data available in the SCDOT's culvert inventory database.

Results and Key Findings

Culvert inspection: Several advanced condition assessment techniques are currently available for inspecting culvert structures. They include but not limited to CCTV, Sonar, Laser, Ultrasonic, Infrared Thermography, and Ground Penetration Radar. While some of these techniques are matured to sophisticated commercialization, some are yet to be thoroughly evaluated. The suitability of these techniques largely depends on the anticipated defect types, culvert material, size, and surround soil characteristics. Besides technology maturity, high cost is another reason for why these techniques are currently not popularly employed by DOTs.

Deterioration prediction: Condition assessment scores of culvert structures are predicted using MLR and ANNs based on 5,181 culvert inspection entries in the SCDOT's inventory database. While condition assessment categories such as cracking, separation, corrosion, alignment, scour, sedimentation, vegetation, erosion, blockage, and piping are used as prediction output variables, culvert material, shape, dimensions, number of barrels, inlet and outlet end type, end treatment, apron type, temperature, precipitation, pH, and runoff coefficient are used as input variables. While ANN performed better for reinforced concrete pipe (RCP), corrugated metal pipe (CMP), masonry and other culvert materials, LRM fared better for corrugated aluminum pipe (CAP) and high-density polyethylene (HDPE) culverts. The four environmental variables (i.e., temperature, precipitation, pH, and runoff coefficient) were found to be negatively correlated to various culvert condition categories. The prediction models produced are found to have a coefficient of determination ranging between 0.25 (for poorly correlated models) to 0.8 (for better correlated models) based on comparisons with the actual culvert score.

Risk-based prioritization: The prioritization model is mainly informed by the assessment scores from the SCDOT's culvert inventory database and defect weightings derived from a survey conducted as part of this project. The prioritization model is demonstrated on inspection scores of about 5,000 RCP and 225 CMP culverts available in the SCDOT's culvert inventory database. It was determined that about 61.3% of RCP culverts measured by length (≈ 55.1 miles) are at no risk and only about 4% measured by length (≈ 1.42 miles) are found to have reasonable failure risk estimates. Similarly, about 39% of CMP culverts measured by length (≈1.7 miles) are determined to be at no risk and 60.8% of CMP culverts measured by length (≈2.4 miles) have some level of risk.

Culvert renewal planning: The CREST model comprises a variety of renewal techniques including open-cut, internal and robotic grouting, internal and robotic shotcreting, sliplining, cured in place pipe lining, centrifugally cast concrete pipe lining, fold and form lining, spiral-wound lining, and pipe bursting. These renewal techniques are evaluated based on cost, expected design life, capacity reduction, traffic impact, and environmental impact after being categorized into non-structural, semi-structural, and full structural groups. It has been determined that a variety of grouting techniques are suitable for addressing minor to moderate non-structural cracks and joint in/exfiltration issues, while shotcreting is suitable for minor to moderate non-structural and semi-structural invert deterioration issues. Cured-in-place-pipe (CIPP) lining, fold and form lining, or spiral wound lining were found to be suitable options for a variety of other semi-structural renewal needs. CIPP, slip-lining, spiral wound lining SWL, pipe bursting, or open-cut methods were found to be suitable options for a variety of full structural renewal needs. Furthermore, twenty six real world case studies are documented to validate the CREST model and it is found that CREST's prediction matched the actually employed renewal methods in 50% of the cases while the overall average accuracy measured using a validation score is 80%.

Conclusions and Study Limitations

The findings of this study provide preliminary guidance to the management of culvert infrastructure by maintenance departments at state and district levels. Specifically, the models developed for deterioration prediction, risk-based prioritization, and renewal selection would aid in effective short-term and long-term planning of deteriorating culvert infrastructure. Major limitations of this study that may be addressed in the future include: (a) the lack of age data to be included in the deterioration prediction modeling which could have helped with the accuracy of the model; (b) the limited number of survey responses that informed the defect-weightings used in the risk-based prioritization model; also the lack of consideration of the inlet and outlet structures as part of the failure risk assessment; (c) the performance evaluation of various culvert renewal techniques, which is an integral part of the decision making tool, is purely informed by the synthesis of published literature after reasonable interpretations were made; an objective performance evaluation informed by consistently documented renewal project case studies would have improved the quality of CREST's decision making.

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