Problem

The Ohio Department of Transportation (ODOT) estimates there are over 100,000 culvert structures associated with Ohio’s primary and general highways. Some of these culverts have reached the end of their defined service life, and there have been a few cases of culvert failure in recent years. While there are mandatory annual inspections of all bridges with a span of at least 10 ft (3.0 m), previously a mandatory inspection program for culverts was not required.

Beginning in 2003 with ODOT’s new Culvert Management Manual culverts with spans between 1 ft (0.3 m) and 10 ft (3 m) are to be inspected once every five years. The 2003 Culvert Management Manual introduced a new and more detailed culvert inspection rating system, which needs to be independently validated.

ODOT conducted a comprehensive culvert durability study in 1982; since then new coatings and new pipe materials have been used for culverts. The wide variety of materials can lead to failure mechanisms that did not exist 20 years ago. Loss of culvert integrity could result in temporary roadway closure and considerable remediation costs; total collapse of culverts could pose a major safety risk to motorists.

ODOT is facing a large number of aging infrastructures with limited amounts of available funding. Detailed information on new innovative techniques for repairing and replacing aging culverts will be highly beneficial to ODOT and can be tied into the “better, smarter, faster bridge” strategic initiative.

Objectives

This project was contracted to the Ohio Research Institute for Transportation and the Environment (ORITE) at Ohio University with the primary objective of reducing the risk of structural failure of short-span culverts serving major highways in Ohio. This objective was to be met by performing the following tasks:
(1) Review the culvert inspection policies and procedures of other DOTs and the FHWA.
(2) Review ODOT procedures for assessing culvert durability based on field data and maintenance records.
(3) Develop a new rating system and use it and the most recent (2003) ODOT rating systems to perform field
inspections of designated high-priority culverts.  
(4) Conduct a risk assessment of the culvert inventory based on culvert characteristics and data collected.  
(5) Evaluate and recommend the best maintenance and remedial measures for culverts. Review new innovative techniques for culvert rehabilitation and replacement.

Description

The study included a literature review and a nationwide survey of other state DOTs to determine their policies for culvert inspections. Seventy-four percent of the states responded.

A list of highway culverts recommended for inspection was requested from all ODOT districts, with Districts 1, 2, 5, 6, 8, 9, 10, and 12 responding. Of one hundred ten culvert structures reported by these districts, sixty were selected for field inspections: 25 were metal, 25 were concrete, and 10 were thermoplastic. These culverts were inspected and photographed over a 14 month period from April 2003 to June 2004.

ODOT’s new 2003 Culvert Management Manual was verified by using the ODOT inspection procedure on the selected culverts. In addition, an inspection procedure devised by ORITE was implemented using field inspection data sheets developed for this project. Both the ODOT and ORITE proposed inspection schemes used a 0 to 9 point scale instead of the 1990 ODOT 4-point scale (good, fair, poor, critical). The ODOT inspection scheme considers 16 items, while the ORITE proposed scheme includes 30-33 items covering the status of the culvert material, headwall, channel, roadway surface, and embankment.

Enough data were collected to perform linear and nonlinear multi-variable regression analyses in the course of developing a risk assessment methodology. The statistical tests were used to identify key parameters affecting culvert performance. ODOT equations were applied to estimate material durability. Culverts were given adjusted overall rating (AOR) scores in the ODOT and proposed rating systems, and these were used to develop a risk assessment method and to determine maintenance immediacy and course of action based on the NCHRP 251 report.

Jobes Henderson & Associates evaluated and recommended the best available technologies for culvert repair and rehabilitation. Tables presenting guidelines for selecting proper rehabilitation or replacement methods were developed. Also, recommended specifications and drawing details were provided in one of the appendices.

Conclusions & Recommendations

The nationwide survey results indicated that 60% of state DOTs have developed culvert inspection policies; 48% of those specify a 1-2 year inspection cycle and 16% specify a 3-5 year cycle. Most of the states that inspect culverts have applied numerical rating systems. Five states (12.5%) besides Ohio have developed culvert inspection manuals. Only five other states have developed their own culvert risk assessment procedure.

Environmental data collected at the 60 selected culvert sites largely verified the state pH and flow abrasiveness maps produced by the 1982 ODOT culvert durability study. The inspection results also provided an overall picture of how each major type of culvert tends to age in Ohio.

None of the concrete culverts had serious alignment problems, and the roadway surfaces over them showed no settlement problems. The service life of concrete culverts appeared to be limited to 70 to 80 years. Overall ODOT ratings were very similar between cast-in-place concrete box culverts and reinforced concrete circular or elliptical pipe culverts. The most frequently encountered conditions were deteriorated headwalls, deterioration of concrete in the crown region or top slab and inlet walls, and transverse shear cracks on abutment walls.

No serious alignment problems were found at most metal culvert sites. No stress cracks were detected at the bolt lines inside any of the metal culverts. The service life of metal culverts appears to be limited to 60 to 65 years. The lowest average ODOT rating was associated with general material condition, and the next lowest was associated with culvert shape. Material deterioration was of greatest concern for the invert region. The inlet end section was generally rated no worse than the outlet end section of metal culverts. The most frequently encountered conditions were perforated invert, perforations at the flow line, scour hole at inlet or outlet end, and movement of the concrete headwalls. The main location of perforation was at the invert for culverts in District 10 and at the flow line for culverts located elsewhere.

The case of culvert NOB-145-3.59 showed that a thermoplastic pipe culvert can provide satisfactory performance for many years in severe service conditions with low pH, abrasive flow, and shallow cover. The ratings showed that the springline is potentially the region where the first sign of structural distress may develop.

The statistical analysis of data for concrete culverts indicated that age and pH were significant variables in both the ODOT and proposed rating systems. Flow abrasiveness was also a significant factor in the ODOT rating system. The linear regression model based on the
ODOT rating system detected more significant variables and had a higher adjusted R² value than the proposed system, even though the latter had more details. The adjusted R² values were 0.45 for the ODOT system and 0.39 for the proposed system. These adjusted R² values indicate a low correlation. If the sample size of 25 was enlarged the level of accuracy and number of details found in the analysis would increase.

The statistical analysis of the metal culverts indicated that age, rise, and culvert types were significant variables for both rating systems. Flow abrasiveness, pH, and flow velocity were also significant variables in the proposed rating system. The proposed rating system detected more significant variables and had a higher adjusted R². The adjusted R² values were 0.43 for the ODOT system and 0.75 for the proposed system.

Because the sample size of thermoplastic culverts was limited to 10 and because their average age was only about 5 years, very limited statistical analysis could be performed.

The ODOT durability equations for metal culverts predicted the inspection ratings relatively closely compared to the values determined in the field under both rating systems; only one isolated case was inconsistent. Thus, the ODOT durability evaluation procedure for metal culverts appears to be reasonably accurate.

The risk assessment methodology was developed based on field inspection data and statistical analysis of both rating systems. The method involves adjusting the overall culvert rating score by applying rating modifiers to account for culvert age, pH of drainage water, abrasiveness of flow, and height of soil cover to culvert rise ratio. The 1982 NCHRP Report 251 was adopted to relate the adjusted overall culvert rating to the recommended course of action.

The adjusted overall rating (AOR) scores for the concrete culverts under the ODOT system were between 2 and 6. One concrete culvert was rated 2, requiring the highest priority maintenance immediacy of action, and two were rated 3, requiring high priority maintenance immediacies of action. The rest of the metal culverts scored between 4 and 6, with associated maintenance immediacies of action between “priority for current season” and “add to scheduled work by end of next season”.

Similar results were obtained using the proposed rating system for both concrete and metal culverts, supporting the conclusion that ODOT’s rating systems for these culverts are basically sound but can be improved further by adopting additional elements in the ORITE proposed system.

The adjusted overall rating (AOR) scores for the thermoplastic pipe culverts under the ODOT system were between 6 and 9, with associated maintenance immediacies of actions between 6, “add to scheduled work by end of next season”, and 9, “no repairs needed”. Using the proposed system the overall ratings ranged from 5 to 9, with the maintenance immediacies of action between 5, “place in current schedule at first reasonable opportunity”, and 9, “no repairs needed”.

The best culvert rehabilitation option will depend on what is appropriate structurally, hydraulically, environmentally, and fiscally for that culvert. Of the several culvert rehabilitation techniques studied, the following appear to have the most promise for regular use: slip-lining, cured-in-place pipe (CIPP), invert replacement using concrete or gunite, filling voids, and repairing sleeves for localized problems. CIPP should be considered if slip-lining will decrease hydraulic capacity too much or if the culvert changes direction and does not allow installation of a liner pipe. Invert replacement has been used successfully and is very cost effective if done properly; invert problems are common in Ohio, especially in low pH areas. Filling voids can be a stand-alone treatment or combined with slip-lining, CIPP, or invert replacement. Repair sleeves are preventative maintenance that can save money by repairing minor joint problems before more costly treatments are necessary. Manufacturers could train ODOT staff on installation procedures as part of their Highway Technician Training Program.

The cone penetration test (CPT) can be a useful tool for evaluating the quality of backfill soil, easily identifying weak or loose soil and voids near the culvert.

### Implementation Potential

The drainage water pH contour map from the 1982 ODOT culvert durability study can still be used for evaluating the pH of drainage flow in Ohio.

The 1982 ODOT culvert durability formulas the metal culverts can still be used, provided the 0-9 score on the new scale is converted to an equivalent value on the old 1-4 scale.
The culvert age, cover height-to-culvert rise ratio, and environmental conditions such as pH and abrasiveness of drainage flow should be factored into determining the frequency of field culvert inspection. Culverts that are older, serve in low-pH or abrasive flow regions, or have low height-to-rise ratios should be inspected more frequently.

The 2003 ODOT rating system for all three types of culverts is basically sound. Possible improvements include evaluating each end independently of the main barrel, evaluating material condition on the top, sides, and invert independently, and providing clear instructions for rating the headwalls at inlet and outlet independently. Additionally, for metal culverts, a rating for protective coating should be added, as well as a rating for invert paving based on that used in the 1990 ODOT Culvert Inspection Manual. For thermoplastic pipe culverts, additional inspection points should include addressing the degree of wall cracking and using vertical deflection exclusively to evaluate the culvert shape.

Once a set of culverts is identified as requiring remedial work in any ODOT districts, the adjusted overall rating (AOR) method presented in this report should be utilized to prioritize the work schedule among the list. The lower AOR score is, the higher the priority for repairs/replacement.

Installation quality of any culverts larger than 36 inches (0.9 m) in diameter/rise at state highway project sites should be monitored and documented more closely by both contractors and state DOT personnel.

During the initial backfilling of flexible (metal, thermoplastic) culvert, the soil stiffness gauge (SSG) should be used, in stead of the conventional nuclear moisture/density gauge. This is because stiffness is a better indicator of the backfill soil than dry density.

The current list of potential maintenance and repair items is not specific enough to convey exactly what type of maintenance or repair actions are required. ODOT should revise the list to include detailed items such as invert paving, bracing, extension, CIPP, and so on. Drawings detailing the rehabilitation alternatives should become part of the ODOT Culvert Management Manual and Maintenance Manual.

A few ODOT districts have acquired personnel to conduct field inspections of highway culverts using the new ODOT rating system. It is recommended that these personnel also apply the proposed culvert risk assessment method. As additional field inspection data are obtained, these data can be incorporated into the statistical analysis.

Innovative in-situ test methods such as the cone penetration test (CPT) to determine the quality of backfill soil should become an integral part of the overall investigation efforts at any culvert site where the performance has not been satisfactory and the cause is unknown.