**General Literature Search for ORIL Research Idea Submission (November 2014-2015)**

**Structural Benefit of Concrete Paving of Steel Culvert Inverts**

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Ohio Department of Transportation

Structural Benefit of Concrete Paving of Steel Culvert Inverts

*Prepared for*

*Ohio’s Research Initiative for Locals (ORIL)*

*November 2014*

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*Transportation Literature Searches are prepared for ODOT staff to identify completed research and other authoritative information in an area of interest. The citations below are representative, rather than exhaustive of available English-language studies and other pertinent information on the topic. Primary online resources for the literature search TRID Online, TRB‘s Research in Progress (RiP), and Practice-Ready Papers databases, WorldCat, ASCE, the National Transportation Library (NTL) catalog, and other academic, engineering and scientific databases as available.*

***Keywords (singly/combinations****): Steel culverts, culvert pipe, pipe arches, reinforced concrete, corrosion, tunnel lining, rehabilitation, soil structure interaction, bridges and culverts, corrugated pipe culverts, steel pipe, paved inverts, culvert lining, culvert inspection, culvert performance*

***Citations:*** *Links to online copies of cited literature are provided when available. If you are interested in full reports/articles lacking a web link, please contact me and I will obtain the full report/article if possible.*

***Research idea:*** *Many steel culverts have their steel bottom or lower radiuses on pipe arches corroded to the point where holes in the steel and the section are very thin. This allows water to flow under the steel culvert, causing erosion and scour and weakens the structural integrity of the culvert. Many counties pour a concrete floor in the bottom of the culvert about six inches thick and shape the concrete to rise up the sides of the culvert one to two inches. This seals the holes to prevent water from flowing under the culvert but the question arises about the structural integrity.*

*Research could include documenting existing culverts where concrete has been added to the bottom, field testing them for deformation/deflective, and documenting the results. Also a lab study is suggested for additional tests.*

***Summary:*** *Typical rehabilitation or repair measures undertaken with culverts include the following: Install a reinforced concrete invert to repair or replace a deteriorated invert in a corrugated metal culvert pipe; there are situations where the damage or deterioration to the culvert is limited to the invert. The remainder of the culvert is in good shape and is in satisfactory structural condition. The culvert is sometimes salvaged by adding a reinforced concrete floor. This research is important because it could prevent weak culverts from being overlooked, and as a result affect the safety of the public in Ohio’s cities, counties, and townships.*

*After a thorough review of transportation databases, very few research reports were located that mention steel culverts with poured concrete floors as a rehabilitation technique. The majority of the research located focuses on fully lined steel pipe/culverts, and methods of predicting remaining service life of the culvert. All studies that were close to the research idea have been included. It is suggested that the reference or bibliography section of the research reports be reviewed for additional resources of value to the research going forward.*

**Corrugated Metal Pipe Culvert Performance. Final Report.**

Culvert examinations were conducted in ten counties across the state of Kansas. A total of 103 corrugated metal pipes (CMPs) and a smaller number of concrete crossroad pipes were examined. Of the 103 CMPs, 36% were rusty, with 24.3% heavily rusted or otherwise seriously compromised. Only one CMP had damage adequate to be classified as failed. The only problems noted on the reinforced concrete boxes (RCBs) and pipes (CPs) were caused by faulty installation or improper grades. No CP or RCB failures were found at the limited number of locations observed. However, District engineers indicated that erosion caused displacement of CP end sections was a significant problem. It was concluded that, within the next 10 to 15 years, over 50% of the CMPs examined will be rust perforated and some of them possibly collapsed. Although without proof, the rust was probably caused by some form of strong acidic drainage which etched the zinc film away from the pipe surface. There is an abundance of agricultural chemicals available which may react with this galvanized layer, and these chemicals are probably used on adjacent or nearby farm land. Silting and poor drainage at some locations may have contributed to the early severe rusting of the CMPs. Even under ideal installation and maintenance conditions, an estimated 11% of the pipes would still show rusting. It is recommended that an increased emphasis on the design, installation and maintenance of crossroad structures should be promoted. Also, a method of maintenance repair, i.e., slip liners or **invert paving**, should be developed and implemented to extend the life of the severely rusted CMPs.

Kansas Department of Transportation

Docking State Office Building  
Topeka, KS 66612 USA

Federal Highway Administration

1200 New Jersey Avenue, SE  
Washington, DC 20590 USA

16p.

1989

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**Culvert Repair Best Practices, Specifications and Special Provisions – Best Practices Guidelines**

<http://www.lrrb.org/media/reports/201401.pdf>

This document contains the results of Task D, Best Practices Guidelines for the Culvert Repair Best Practices, Specifications and Special Provisions Guidelines Project. These guidelines will provide guidance to Minnesota Department of Transportation (MnDOT) engineers in making better decisions on culvert repairs. New materials specifications, special provisions, and standard details will ensure adherence to standardized practices and increase the effectiveness and longevity of repairs. Focus is on repair of centerline culverts of 24 inches to 72 inches in diameter. This Task D document contains the best practices guidelines for replacement, rehabilitation and repair methods for **deteriorating culverts**. An overview of replacement methods is provided. Rehabilitation and repair methods are discussed in more detail. The methods discussed are the most common culvert rehabilitation and repair methods identified during governmental and industry surveys conducted during Tasks A and B. The final list for inclusion in this guideline was chosen by the authors and the Technical Advisory Panel (TAP). Special provisions and standard details were prepared for the following methods: **paved invert**, cured-in-place pipe liner (CIPP), slip lining culvert pipe, centrifugally cast concrete culvert lining, spall repair, joint repair, and void filling outside the culvert.

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395 John Ireland Boulevard  
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94p

2014

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**Experimental Examination of Deteriorated and Rehabilitated Corrugated Metal Culverts Subjected to Service Load**



Many culverts in North America are in various states of deterioration resulting in diminished structural and/or hydraulic capacities. A culvert’s failure could result in road subsidence or even collapse, leading to serious consequences for vehicular traffic and public safety. The goal of this research is to establish distress and failure mechanisms for **rehabilitated culverts** made from corrugated metal and concrete pipes, as well as liner-culvert-soil interaction mechanisms, in support of the development of sound design methodologies for these repairs. A series of tests were performed on deteriorated 24-inch metal culverts prior to and following rehabilitation using various trenchless lining methods. This research employed either exhumed deteriorated corrugated metal pipe culverts or corrugated metal pipes deteriorated mechanically by **removing 25 percent of the metal within a pre-determined arc along the** **lower half of the culvert**. Culvert specimens were carefully bedded, backfilled, and compacted in soil within a test chamber, and then loaded using a pneumatic loading system to simulate deep burial conditions. Deformation and strains were measured at multiple locations around the circumference of the culvert’s structure during application of load, while earth pressure cells recorded stresses in the embedment zone. The deformed culvert was then rehabilitated using a cured-in-place liner, a slip liner, or a spiral-wound liner, and external load was re-applied. Numerical simulation of culvert was also performed using ANSYS. Responses of the deteriorated and rehabilitated soil-pipe systems were recorded and compared. The results revealed that the degree of compaction of the bedding materials plays a critical role in determining the stress distributed on the culvert.

Alam, Shaurav

Sayem, Sarkar

Aaron, Steven

Pierce, Jacob

Allouche, Erez N.

McKim, Robert

13p.

2014

[Transportation Research Board 93rd Annual Meeting](http://trid.trb.org/results.aspx?q=&datein=all&serial=%22Transportation%20Research%20Board%2093rd%20Annual%20Meeting%22)

Location: Washington DC  
Date: 2014-1-12 to 2014-1-16

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**Rehabilitation of Large Diameter Steel Culverts. Final Report.**

Most of the large culverts in Maine are galvanized steel structural plate pipes and many of these are nearing the end of their service lives. In the past, these culverts have usually been replaced with new structural plate pipes. **Rehabilitating culverts** in place instead of constructing new pipes would save inconvenience and danger to the public during construction as well as construction costs. This study investigated the feasibility of rehabilitating structural plate pipes as well as alternative designs and materials for new or replacement culverts that would economically offer extended service lives and thus reduce the future need for culvert replacement. The study involved a literature search and a survey of state departments of transportation as well as receiving information from trade associations, suppliers, and contractors engaged in culvert rehabilitation. Using this information and current construction costs and estimated service lives, the economic feasibility of various rehabilitation methods and alternatives for new construction of large culverts were evaluated. Recommendations based on the material prices, construction costs, and expected service lives used in the study are as follows. If possible, pipes should be rehabilitated by lining the **inverts with reinforced concrete**. If the cross sectional shape of the existing culvert is distorted or corroded to the extent that the culvert cannot continue to support the applied loads, the culvert should be rehabilitated by slip forming. When rehabilitation is not practical because of advanced pipe deterioration, reduced **hydraulic capacity** or increased elevation of the invert, the pipe should be replaced with an aluminum structural plate pipe or aluminum structural plate arch. These recommendations are valid only for the material prices, construction costs, and service lives used in the economic analysis. The designs for rehabilitating or replacing deteriorated culverts in the future should be based on similar analyses incorporating the best current estimates for costs and service lives.

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Maine Department of Transportation

Technical Services Division, 16 State House Station  
Augusta, ME 04333 USA

123p.

1994-12

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**Condition and Corrosion Survey on Corrugated Steel Storm Sewer and Culvert Pipe. Second Interim Report.**

In 1986 the National Corrugated Steel Pipe Association undertook a five year program to gather service life information on 125 to 135 Corrugated Steel Pipe (CSP) installations. To facilitate this endeavor, Corrpro Companies, Incorporated was retained to develop a detailed program of inspection, testing and evaluation. The first report, published in 1987, reviewed data on 21 sites. This second report provides data on 32 additional sites. From an interior corrosion standpoint, site data indicate that typically, significant **interior corrosion is limited to the invert** of the pipe. This is generally a corrosion/erosion phenomena affected by bed loading, flow velocity and flow frequency as well as site chemistry. This study and others indicate that concerns for premature invert loss can be alleviated by **paving the invert**. Pavements such as asphalt or concrete not only provide corrosion protection but also protect the invert from abrasive bed loads. To date, the data collected indicate CSP installation can be designed for a useful service life of 100 years in varying site conditions. This second report uses data from 18 sites which were not coated to address unprotected exterior galvanized coating life. It provides an initial means of (1) predicting the probable life of unprotected exterior galvanized coatings, and (2) estimating the current condition of the external galvanized coating on in-service pipes.

Corrpro Companies, Incorporated

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National Corrugated Steel Pipe Association

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Washington, DC 20006 USA

1988

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**Use of CANDE and Design Codes to Assess Stability of Deteriorated Metal Culverts**



Three design cases are used to study the effects of corrosion, burial depth, and staged construction on the capacity of **steel culverts.** The finite element packages CANDE and ABAQUS are used to perform the numerical investigation. The results of these numerical models are compared to current and proposed design methods to determine which approach gives the most conservative estimation of thrust force for both new and corroded culverts. Simple ring compression theory (springline thrust equal to half the soil prism load) produced thrusts that were 42%, 16% and 7% lower than those based on “staged construction” finite element analysis for the 4m diameter example culvert buried 1.5m, 3m, and 10m respectively. The American Association of State Highway and Transportation Officials (AASHTO), Canadian, and proposed design equations all underestimated thrust compared to those finite element results (by 46%, 22% and 24% respectively for 4m diameter culvert at 1.5m burial depth, and with 12.5% wall thickness remaining). Thrust forces obtained using CANDE were slightly lower than those produced by ABAQUS, and it appears that CANDE can be used to estimate thrust forces after corrosion, even though the CANDE analysis featured uniform wall loss around the whole pipe circumference and ABAQUS was used to model wall loss across the **invert** only.

18p.

2012

[Transportation Research Board 91st Annual Meeting](http://trid.trb.org/results.aspx?q=&datein=all&serial=%22Transportation%20Research%20Board%2091st%20Annual%20Meeting%22)

Location: Washington DC  
Date: 2012-1-22 to 2012-1-26

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**Condition Assessment of Highway Culverts and Determination of Performance Measures. Volume 1: Final Report**

[**http://utah.ptfs.com/awwe...chive?type=file&item=45723**](http://utah.ptfs.com/awweb/awarchive?type=file&item=45723)

The Utah Department of Transportation (UDOT) installed and manages over 47,000 culverts but has no comprehensive, quantitative method for evaluating the performance of these culverts. UDOT contracted with Simpson Gumpertz & Heger Inc. to 1) determine the condition of highway culverts with spans from 2 feet to 5 feet, 2) develop a system of culvert performance measures, 3) support UDOT in modifying and populating a culvert inventory and inspection database, and 4) recommend implementation of performance measures for future UDOT procedures. 272 culverts were inspected under this contract. Culvert barrel materials consisted primarily of steel, concrete, and polyethylene. Most inspected culverts had barrel span less than five feet. Culvert inspections were conducted in all UDOT Maintenance regions, in all major surface and deep soil zones, and at most elevations. UDOT culverts are performing well overall. Inspection results indicate no significant performance differential between the different barrel materials. Available data includes many concrete and metal barrels that were installed before thermoplastic barrels were used, that is, thermoplastic barrels have a shorter service life history for comparison. The problems unique to each type of culvert pipe material are discussed. Performance measures were adopted from available references and further developed to assist in assessing both the waterway and the barrel condition of each culvert installation. Inspection results were used to determine **performance ratings for culvert structural and hydraulic condition**. A rating modifier for culvert importance (Importance Modifier) is proposed as a method to reduce the number of culverts that require routine monitoring and to prioritize culvert maintenance. The numeric performance ratings give equal consideration to all culvert barrel materials. This project also evaluated, modified, and used the UDOT Culvert Database, which is composed of a database with inventory and inspection datasets and a Form program used to interface with the database. Through a cooperative effort with Utah State University the database and Form Program were upgraded to improve functionality and usability for this project. This project also provides recommendations to improve UDOT culvert installation and maintenance procedures. The UDOT Culvert Database was also evaluated and recommendations are provided to make the Database usable by UDOT maintenance personnel for future work. References are provided to assess the different expected service life of various metal culverts and coatings.

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130p

2004

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**A Comparative Study of Aluminum and Steel Culverts**

<http://www.virginiadot.org/vtrc/main/online_reports/pdf/70-r38.pdf>

Virginia Highway Research Council

Virginia Department of Highways

University of Virginia

Charlottesville, Virginia

May 1971

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**Synthesis of Information Related to Highway Problems. Topic 45-01. Service Life of Culverts**

Research in Progress Project 37754

[**http://apps.trb.org/cmsfe...Display.asp?ProjectID=3578**](http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3578)

This study will update Synthesis 254, Service Life of Drainage Pipe (1996), which in turn updated National Cooperative Highway Research Program (NCHRP) Synthesis 50, Durability of Drainage Pipe (1978). The culvert industry and research community has produced in the last 15 years significant developments in plastic pipe, fiber-reinforced concrete pipe, polymeric-coated metal pipe, recycled materials, larger and more diverse structures, and sophisticated analytical soil-structure interaction modeling. As such, there is a growing need for a new study of the service life of culverts. For the purposes of this study, service life is the time duration during which a culvert is expected to provide the desired function with a specified level of maintenance established at the design or retrofit stage. The selection of alternate culvert or materials for a particular site is based on the material's ability to satisfy the requirements of five selection criteria: (1) Structural design, (2) Hydraulic design, (3) Environmental and site considerations, (4) Joint performance, and (5) Service life (durability). Significant published works provide guidance for the first three criteria and NCHRP Project 15-38 and American Association of State Highway and Transportation Officials (AASHTO) 20-07 Task 347 address joint performance. Service life is the remaining criterion that will be addressed by this synthesis study. No consensus exists among the state departments of transportation (DOTs) on the definition of service life and/or the required time frame of service. Predictive models are often parameterized to specific geographic and environmental considerations. Design service lives range from 15 to 100 years based most often on site conditions, traffic volume, or functional classification of roadways. Material service life models developed for different pipe materials are inconsistent and do not relate to limit state (failure mode) or **service distresses adversely affecting both structural** and hydraulic performance, including cold-weather induced distresses. The following information will be gathered and synthesized: (1) the required service life for the culvert in varying conditions, including the basis for determining the service life (e.g. average daily traffic (ADT), accessibility, cost of future repair) and any additional design parameters based on the service life. (e.g. oversizing for slip-lining). This will include considerations of maintenance. (2) The conditions constituting the end of useful service life for various culvert installations, including but not limited to materials, soil/backfill properties, hydraulic performance, and appurtenances. (3) The time for a particular material to reach the end of its useful service life, and (4) Information on the how the following are correlated and/or implemented- a. Material service life, and b. **Culvert failure limit** states This synthesis final report will do the following: (1) Update NCHRP Synthesis 254, Service Life of Drainage Pipe; (2) Build upon the significant start of AASHTO 20-07 Task 264, Guidance for Design and Selection of Pipes; (3) Review AASHTO/DOT, TRB/NCRHP, industry, and other published literature for methodologies used to establish service life and material service life; (4) Provide definitions of the end of useful service life for culvert materials in a rational and implementable form; (5) Provide a catalog of models for determining service life of culvert materials; (6) Provide an example of how the material in the report might be used to predict service life of a hypothetical culvert selection; and (7) Identify gaps in knowledge and future research needs, which may include preparation of a formal NCHRP research problem statement. Information will be gathered by literature review and survey of state transportation agencies, including Canadian provinces (See NCHRP 10-86 for possible survey recipients). An initial screening survey will be sent to the AASHTO Highway Subcommittee on Maintenance to determine who are the most appropriate recipients of the survey (100% response is required).

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American Association of State Highway & Transportation Officials

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National Cooperative Highway Research Program (NCHRP) Synthesis

Transportation Research Board  
500 Fifth Street, NW  
Washington, DC 20001

Start Date: 2013-11-02

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**Finite Element Study of Stability of Corroded Metal Culverts**



The development and the use of finite element analyses in the 1970s and 1980s changed the nature of culvert assessment because they permitted consideration of the geometrical and material details of the burial condition, as well as the construction process, culvert geometry, and earth and vehicle loads. While these procedures have been used to study a wide range of new culvert and pipe structures, there has been little consideration of the structural deterioration that is precipitating most current infrastructure investments. This study therefore examines the **influence of corrosion on the stability of corrugated steel culverts**. Corrosion in the lower half of the structure is considered, including a range of losses in wall thickness and lateral extents. Changes in the factor of safety against yield are assessed as corrosion develops, as are changes in culvert resistance to buckling failure. For the five specific design cases considered, the governing design criterion was stability against yield, and the factor of safety against yield was found to decrease almost in proportion to wall thickness (when maximum wall thrust within the corroded zone was considered). This decrease occurred because the corroded metal culverts experienced little change in the distributions of thrust or moment as a result of local losses in wall thickness. While the results presented are purely theoretical, they provide a starting point for an appreciation of the influence of metal culvert deterioration and can guide future research, including physical test programs.

El-Taher, Mohamed

Moore, Ian D.

P.157-166

2008

[Transportation Research Record: Journal of the Transportation Research Board](http://trid.trb.org/results.aspx?q=&serial=%22Transportation%20Research%20Record%3A%20Journal%20of%20the%20Transportation%20Research%20Board%22)

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