NBDTI Implementation of a Culvert Rehabilitation Program to Address a Deteriorating Inventory

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Abstract

The New Brunswick Department of Transportation and Infrastructure (NBDTI) highway network contains over 3400 culverts greater than 1.2 m in diameter. This inventory exhibits similar condition issues to the rest of North America, possibly more urgent due to harsh water conditions, multiple freeze thaw cycles and relatively low maintenance budgets. Recent analysis has suggested that approximately 40% of the large culvert inventory is expected to require replacement or rehabilitation within the next 10 years (Northmore, A., 2021).

As part of the Department's strategy to address this backlog of deteriorating culverts, a rehabilitation program was implemented in 2021. The goal is to defer the high costs of conventional excavations and replacements, especially in deep fill embankments and high traffic roads.

Although select culvert rehabilitations were carried-out in the past, the allocation of incremental funding toward rehabilitations ensures that these projects are not in competition with priority culvert replacements for budget.

Since implementation of the program in 2021, twenty-five sites, ranging in size between 1.0 m and 3.35 m have been rehabilitated using a mix of conventional and trial methods including slip lining, concrete invert lining and point repairs, and spray-applied geopolymer and shotcrete.

This paper includes details on the following:

- Background
- Identification of potential rehabilitation candidates
- Renewal option selection
- Design
- Construction
- Results
- Lessons learned

In addition to sharing the results of NBDTI's Culvert Rehabilitation Program, the Department aims to generate further discussion with other jurisdictions on their experience with culvert rehabilitations and emerging methods.

Background

Beginning in the 1960s, NBDTI began to install steel (CSP and SPCSP) and reinforced concrete pipes on a larger scale. In the 1980s, inverts of the steel pipes were already showing signs of corrosion, and it was becoming evident that their service life would be shorter than originally expected.

The Department began to rehabilitate bridge-sized (diameter >/= 3m) Structural Plate CSPs by placing new reinforced concrete inverts. This was done using its own construction staff when resources were available.

From 2006-2012, a program was carried-out involving the rehabilitation of 10-15 bridge-sized SPCSPs per year using the public tendering process to engage contractors. Although this program was phased out, the Department continued to rehabilitate culverts, albeit at a reduced frequency of 1-2 sites per year, and with more of a focus on "Large Culverts" (1.2m < diameter < 3m) throughout the 2010s.

In 2021, it was decided that incremental funding should again be allocated to culvert rehabilitation projects on an annual basis. The goal is to address minor deterioration, such as rusting and deformation, while rehabilitation is still feasible. This prevents the need for costly excavation and replacement, especially at sites underneath high-fill embankments and high-traffic roadways.

Identification of Potential Rehabilitation Candidates

Screening of Culverts for Prioritization

With over 3400 buried structures of various types that exist on New Brunswick highways, the development of a culvert rehabilitation program required a methodology that would identify candidate culverts representing good value, and the best use of the limited funds available. NBDTI's overall culvert inventory database, BRDG, was utilized as a starting point to review culvert assets for their suitability as potential candidate culverts. Culverts in the inventory are organized into *Large Culvert* category (diameter 1200mm - 3000mm) and *Bridge Size Culvert* category (diameter > 3000mm).

Relevant data for all Buried Structures (Large Culverts and Bridge Size Culverts), were extracted from BRDG, and Microsoft Excel spreadsheets were used to sort, screen & filter selected assets, based on key characteristics.

To date, focus has been given to culverts with reserve hydraulic capacity, crossing important roadways with high traffic, under deep fills, particularly in situations where road closure would have significant impacts.

Recognizing some key characteristics are not readily available in BRDG (ie. hydraulic capacity), a long list of candidates was first created from the other criteria, and hydraulic analyses of these are being conducted on an ongoing basis. When hydraulic performance is determined, any assets having reserve hydraulic capacity can then be prioritized and ranked for the culvert rehabilitation program. Pre-design activities are then conducted on the highest ranked candidates to fulfill the program.

Prioritization and Ranking of Candidate Culverts

Similar to how an existing ranking system is used by NBDTI Design Branch to prioritize bridges and culverts for renewal under the regular Capital Program, a need arose to develop a prioritization tool specifically for the culvert rehabilitation program. A ranking system was developed that assigns priority points to a subject culvert based on objective review of its key characteristics and surrounding environment. The prioritization review is usually undertaken by a small team of members of the Design

Branch Hydraulic Unit, where a group of candidates are assessed and there is consensus among the review team in how the points are assigned for each culvert. A rehab prioritization meeting involves reviewing the findings of the hydraulic analysis, the most recent regular inspection report & photographs, as well as other mapping data that is readily available. Characteristics that are considered for assignment of priority points include:

- Structural Condition (degree and extent of deterioration, deformation, joint separation)
- Height of Fill
- Hydraulic Capacity & Freeboard
- Aquatic Indicators (ie. existing crossing appears to provide fish passage, existing crossing does not appear likely to require fish passage)
- Property Requirements (are additional lands likely to be required for temporary and/or permanent works)
- Roadway Importance (Daily Traffic Volume, Off-site detour requirements for a full closure scenario, vital routes, strategic corridors)

Renewal Option Selection

At the stage when a culvert asset is selected from the priority list to be advanced, a pre-design phase is initiated. The goal of pre-design is to identify multiple feasible approaches to rehabilitation, which can be compared across key evaluation criteria. This work involves conducting site visits, collecting site data, conducting detailed structural condition reviews, determining construction access and temporary water control strategies, and initiating discussions with regulators. The outcome of pre-design is to select the best suited rehabilitation method(s) to proceed into the detailed design, and preparation of tender documents.

To date, NBDTI has rehabilitated culverts using the following traditional and trial methods:

- Concrete Invert Installation
- Slip Lining
- Pipe end replacement
- Cured-in-place pipe
- Spray Applied Methods
    - Shotcrete
    - Geopolymer Mortar
- Localized Point Repairs

A recommendation for the preferred feasible rehabilitation approach is usually derived from comparing the alternatives to the following key criteria:

- Capital Cost Requirements
- Durability, Expected Service Life
- Life Cycle Cost
- Hydraulic Performance
- Fish Passage Requirements
- Property Impacts
- Traffic Impacts
- Anticipated Construction Duration
- Risks to Cost or Schedule

Design

Detailed design and tender package preparation for the preferred alternative involves depicting the required temporary and permanent work activities and culvert features on a set of Plans, as well as defining the work requirements by Item in the format of a Unit Price Contract. Many work activities that are included on a culvert rehabilitation project are contained within the DTI's Standard Specifications for Highway Construction, however some specialized items require development of particular specifications, for use in one project, or for use in a subset of culvert rehabilitation projects.

The plans produced during detailed design phase are utilized to identify and secure additional lands required, obtain relevant permits, depict areas not to be disturbed by work activities, undertake tree clearing and utility moves in advance of tender, and to facilitate the calculation of quantities in developing a detailed cost estimate as well as to define quantities used in the tender package for advertisement.

Detailed submittals, including design and installation of pipe rehabilitation products are often a requirement of the construction contract, for example pipe liners, spray-applied liners.

Construction

The Department commonly issues construction tenders for culvert rehabilitation projects using a Design-Bid-Build procurement method, the following exceptions:

- The 2021 Geopolymer Pilot Project was a partnership with Northern Construction – a New Brunswick company that submitted an unsolicited proposal to the Department to rehabilitate five culverts using a spray-on geopolymer product.
- Concrete invert installations installed by Department staff, discussed previously in *Background* section.

Each tender typically only includes one site, with two exceptions where tenders were issued which bundled two sites that are near one another – GB10/GB11 and NE07/NE11 in 2022.

Between 2021 and 2023, an average of three bids were submitted for each tender by contractors based in New Brunswick and Nova Scotia. Of the four sites tendered in 2024, there was an average of 5-6 bids submitted which suggests a positive trend of industry interest in rehabilitation projects.

Beginning with the geopolymer pilot project in 2021, a consultant was engaged to conduct third party quality control testing of the mixed geopolymer material on-site and in their lab (Profit et al., 2022).

Quality Assurance consisted of site visits by NBDTI staff to measure material thickness, monitor presence of cracking, quality of material application and other notable post-construction observations. It was found that at some sites, design thickness was not consistently achieved. The Contractor returned to these sites the following year to perform additional applications of the product to meet the design thickness within the entire pipes.

Results

Since inception of the program in 2021, twenty-five culvert sites have been rehabilitated and are shown in Figure 1 and Table 1 below.

Figure 1. Locations of Completed Culvert Rehabilitations (2021-2024)

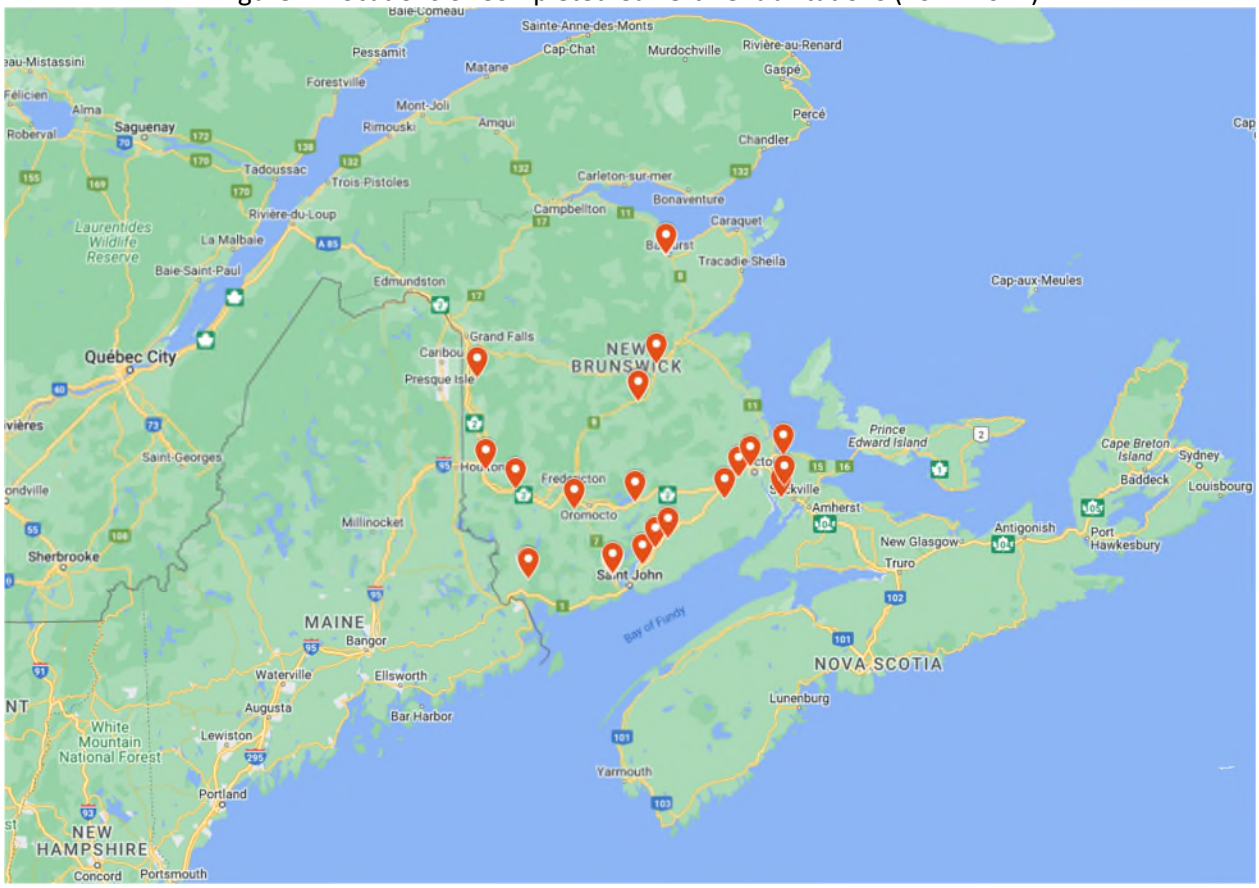

Table 1. Completed Culvert Rehabilitations (2021-2024)

Asset	Name	Program Year	Pipe Size (mm)	Pipe Type	Method of Rehab
DE03	Route 127 Culvert No. 2	2021	1500	CSP	Geopolymer Spray Liner
LR03	Route 119 Culvert No. 3	2021	1500	CSP	Geopolymer Spray Liner
LX11	Route 102 Culvert No. 1	2021	1700	CSP	Slip Liner
ND07	Route 8 Culvert No. 11	2021	1400	CSP	Geopolymer Spray Liner
NE12	Route 8 Culvert No. 9	2021	1350	CSP	Geopolymer Spray Liner
QC17	Mill Cove Road Culvert No. 1	2021	1600	CSP	Geopolymer Spray Liner
YT16	Hawkshaw Bridge Road Culvert No. 1	2021	1500	SPCSP	Slip Liner
GB10	Carters Brook Culvert No. 2	2022	1350	SPCSP	Slip Liner
GB11	Carters Brook Culvert No. 3	2022	1500	SPCSP	Slip Liner
LX08	Route 7 Culvert No. 11	2022	1600 x 1000	CSP Arch	Geopolymer Spray Liner
NE07	Route 8 Culvert No. 5	2022	1800	CSP	Geopolymer Spray Liner
NE11	Route 8 Culvert No. 8	2022	1350	CSP	Geopolymer Spray Liner
VP07	Route 109 Culvert No. 2	2022	1830 x 1780	Concrete Arch	Slip Liner
WD10	Breau Creek Upper Branch Culvert No. 1	2022	2700	SPCSP	Slip Liner
C144	Carr (Mark) Route 655	2023	3350	CSP	Slip Liner
CN09	Route 105 Culvert No. 9	2023	1500	CSP	Geopolymer Spray Liner
DE02	Route 127 Culvert No. 1	2023	2200	CSP	Geopolymer Spray Liner
L770	Long Lake Outlet No. 1	2023	3670	SPCSP	Concrete Invert
LN01	Fraser Road Culvert	2023	1800	SPCSP	Slip Liner
LN14	Tributary to Moosehorn Creek Culvert No. 1	2023	1800	CSP	Slip Liner
WU25	Route 15 Culvert No. 6	2023	1350	CSP	Geopolymer Spray Liner
AC02	Route 112 Culvert No. 2	2024	1450 x 1400	Concrete Arch	Concrete Repairs
WD13	Robbs Brook Culvert No. 1	2024	1500 x 1500	Concrete Arch	Slip Liner
WM25	Route 2 Culvert No. 6	2024	1800	CSP	Slip Liner
WT25	Route 905 Culvert No. 1	2024	1560 x 1450	Concrete Arch	Concrete Repairs

Lessons Learned

Temporary Water Control

A significant challenge that is present in every project is to successfully divert water from the host structure. In some cases, the watercourse is easily diverted by pumping, however this is not always feasible or preferred. On lower traffic roadways, it is typically acceptable to dig a trench across the road and install a pipe casing for pump discharge hoses protect it from the weight of traffic. However, on busy highways, where the goal is to avoid disruptions to traffic altogether, other solutions have been employed, including directional drilling, intermittent pumping through hoses installed in the host structure, and conducting some of the work within the streamflow.

Directional drilling, shown in Figure 2, was used at two sites to provide a conduit for water diversion. At the first site, YT16, the Department engaged a drilling contractor to conduct the work and install the conduit prior to tendering the rehabilitation project. The lowest bid submittal for the Temporary Water Control (TWC) item was 37% lower than the design engineer's estimate.

At the second site, WU25, the TWC method was specified to be at the discretion of the Contractor. The two bids submitted for the TWC Item were 250% and 381% higher than the engineer's estimate.

Although there may be other factors that influenced these varied bid results, including the difference in timing (2021 vs. 2023), associated inflation, and the urgency of the work to be completed, the Department will consider this on future sites where directional drilling is seen as the most feasible, or only, TWC method.

Directional drilling during the design phase and prior to issuing a tender for rehabilitation work leads to a more flexible schedule for the drilling contractor and less uncertainty for bidders on how they will address TWC. In contrast, when TWC installation is left to the general contractor, and directional drilling is the only feasible option, the work is often requested with a quick turnaround and during construction season.

Figure 2. YT16 – Pipe Casing Installed by Directional Drilling for Temporary Water Diversion

Another TWC method that began to be used for slip lining work in 2022 was the use of intermittent pumping through the host structure while it is being cleaned of debris and repaired. The watercourse is then returned through the host culvert while the liner pipe is inserted within the streamflow. Finally, the watercourse is directed through the liner pipe while the annular space is being filled with controlled low strength material (CLSM). This method is only viable at culverts conveying smaller watersheds where the flow does not pose a safety risk to workers. Careful attention must be given to ensure the joints between liner pipe sections are watertight to prevent infiltration into the annular space and curing CLSM.

Geopolymer

In general, the main issues are related to control of water infiltration and proper curing of the material (Profit et al., 2022). These issues persisted during the 2023 season.

With geopolymer application using an automated spin caster, it has been necessary to divert the watercourse flow outside of the host culvert and around the site. One exception to this was on site QC17 where the flow was directed through a 4" ABS pipe placed along the invert of the host pipe and eventually covered with geopolymer, plugged and left in place after project completion. Although this is possible for particularly low flow diversions, it is not preferred due to the protrusion in the invert that remains upon completion. This method is shown in Figures 3 and 4 below:

Figure 3. QC17 - Hand spraying over ABS water diversion pipe

Figure 4. QC17 - Invert protrusion above location of ABS diversion

The challenges encountered with application of the geopolymer product have resulted in changing the planned rehabilitation method for an upcoming 2024 rehabilitation site, WM25. This 1.8m diameter CSP is over 100 m in length and conveys a watercourse under four lanes of the Trans Canada Highway (Route 2) and on- and off-ramps in Moncton - one of the busiest sections of highway in New Brunswick with an AADT of over 30,000 vehicles per day. It was decided that slip lining this pipe would carry less risk of construction setbacks and result in a longer service life extension than geopolymer.

It is understood that issues experienced thus far with geopolymer rehabilitations are not necessarily results of the product itself. It is to be expected that a learning curve would exist for contractors to adjust to new products, equipment, and application methods. Geopolymer remains a product that the Department will consider for use on future sites where watercourse diversion is easily addressed, where the condition does not allow for groundwater infiltration, where fish passage requirements can be achieved with roughness elements embedded in geopolymer rather than the need for standard weirs in a liner pipe, and/or where hydraulic capacity is limited to the point where slip lining is not feasible.

Lessons learned during the application of geopolymer are described in further detail in the 2022 paper cited at the beginning of this subsection.

Slip Lining

The main limitation to slip lining is that it reduces the hydraulic capacity of the existing pipe more significantly than spray-on products. This is mainly a consideration during the planning and design process. The Department has been able to address this issue on numerous sites by adding larger pipe extensions at the inlet to funnel the flow into the remaining smaller sections of pipe. This tactic, which is more effective for higher slope conditions, was used at over half (6 of 11) slip lining sites.

On a typical slip lining project, CLSM is placed within the annular space between the host and liner pipes. Culverts on steeper slopes are especially susceptible to over grouting. The material flows relatively quickly on higher slopes, with the outlet end receiving higher than expected lift heights.

One instance of over grouting was experienced in 2021 at site YT16, a 90m long, 1.5m diameter SPCSP with a slope of 11% that was being slip lined with a 1.25m diameter Corrugated Aluminum Pipe (CAP). This resulted in one of the sections of CAP collapsing under the pressure. added approximately 10 days to the project duration and was a costly repair for the contractor.

Figure 5. YT16 - Collapse of CAP Section due to Over Grouting – September 2021

The collapsed portion of the CAP needed to be cut with a mini grinder and removed. The cured CLSM was then hammered out before a new section of pipe was welded back to the remaining intact sections.

Figure 6 – YT16 - Repaired CAP - October 2021

Conclusion

Based on results of the culvert rehabilitation program over the past four construction seasons, the Department plans to continue conducting rehabilitations at suitable sites. The cost savings and avoidance of major impacts to industry and the travelling public make rehabilitation the preferred option for management of the culvert inventory when conditions permit.

There are currently six culvert sites planned for rehabilitation in 2025 while sixty-three additional sites have been inspected, analyzed hydraulically, and deemed suitable for rehabilitation. As industry adapts to the program, it is expected that the Department could increase the number of rehabilitation projects each year.

As with any asset management program, it can be a challenge to earmark funding for rehabilitation work when urgent replacement projects regularly arise and create a need for difficult decisions to divert funds. However, since one of the intended results of the program is to encourage more interest and competition from local contractors, the Department has a responsibility to ensure that rehabilitations continue to be pursued as an important piece of the overall capital program. Other jurisdictions facing similar challenges with aging infrastructure will continue to be consulted to learn from past projects and employ best practices.

References

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