Innovative Culvert Asset Management and Relining

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ABSTRACT
The Saskatchewan Ministry of Highways and Infrastructure (SMHI) is responsible for approximately 65,000 culverts that provide critical drainage and water control for the provincial highway network. Unfortunately, a high percentage of these culverts are well past their design life. The majority of existing culverts in the province are corrugated steel pipe (CSP). Under normal field state conditions, CSP culverts have a design life of approximately 30 years.

This paper summarizes a pro-active culvert asset management approach as well as a preventative failure lining system that significantly improves the cost effectiveness of culvert remediation and/or replacement. This paper provides a summary of innovative culvert rehabilitations conducted in Saskatchewan that used Snap-Tite® High Density Polyethylene (HDPE) culvert liners.

Multiple advantages were realized by using an HDPE liner to rehabilitate aging culverts: construction was performed in the winter and was efficient and easy; Snap-Tite® culvert liners were easy to manoeuvre and assemble; no expensive or specialized equipment was needed to install the culvert liners onsite; and grout can be used to fill voids in the granular backfill material around the CSP culvert. In addition, Snap-Tite® culvert liners are applicable to all types of existing culvert materials including corrugated steel pipes and concrete pipes and the structural integrity of the culvert in increase and flow rate capacity is increased.

(215 words)

INTRODUCTION

The Saskatchewan Ministry of Highways and Infrastructure is responsible for approximately 65,000 culverts that provide critical drainage and water control for the provincial highway network. At present, it is estimated that 70 percent of the in-service culverts in the Ministry's inventory are at or past their design life. The majority of existing culverts in the province are corrugated steel pipe (CSP).

Under normal field state conditions, CSP culverts have a design life of approximately 30 years (3, 5). Besides plugging and/or washing out, culvert performance deterioration is a result of many factors. For instance, humidity and moisture combined with freeze thaw conditions accelerate corrosion, typically at the invert of the culvert. Also, reduced invert strength causes the culvert to scour and fail in demanding flow conditions. In addition, the culvert CSP connection can corrode or pull apart, allowing subbase and base cover materials to enter the pipe resulting in cavitations of the structure and a reduction in culvert flow capacity. CSP, by nature, uniformly anchors to the surrounding soil. As the soil subgrade settles and widens, and as freeze-thaw action takes place, it is hypothesized that the lateral strains are sufficient to pull CSP and concrete pipes apart at the joints (6). Once apart, water flow will create voids along the outside bedding of the pipe.

Figure 1 shows a typical road minor top cavitation as a result of a culvert joint separation failure and the corresponding crown material loss and settlement. Culvert failure can occur in conjunction with conditions that overwhelm the existing capacity and/or structural integrity of the culvert. The Saskatchewan Ministry of Highways and Infrastructure has surveillance protocol in place to monitor and mitigate any potential safety concerns with regards to culverts.

Traditional culvert remediation and/or replacement methods include full depth excavation and replacement, ram jacking steel pipe outside or inside existing pipe, and boring or tunnelling a new culvert. However, full depth excavation and replacement with a new CSP pipe involves significant cost and delays to traffic. The use of high density polyethylene (HDPE) pipe to remediate and line failed culverts is increasing as a highly cost effective solution for CSP culvert remediation. Snap-Tite® is a culvert relining product that can significantly improve the cost effectiveness of culvert remediation and/or replacement.

Three CSP culverts in need of rehabilitation were selected as candidates for relining in October 2009. The solution involved rehabilitating existing culverts with grout in-place HDPE pipe, specifically designed for the purpose of relining culverts. The three culverts were rehabilitated in with an HDPE culvert liner and were located in Saskatchewan on Control Section (C.S.) 16-16 at km 1.400, km 10.950, and km 11.400. Figure 2 through Figure 4 illustrates photos of the existing culverts taken during a culvert inspection in October 2009, as detailed below. Figure 2 shows the CSP culvert at km 1.400 (diameter of 600 mm). Figure 3 shows the CSP culvert at km 10.950 (diameter of 600 mm). Figure 4 shows the CSP culvert at km 11.970 (diameter of 600 mm).

OBJECTIVE

This paper summarizes the use of Snap-Tite® HDPE pipe liners in three culvert rehabilitation in Saskatchewan. The objective of this culvert rehabilitation project was to pilot the use of Snap-Tite® high density polyethylene (HDPE) pipe to reline in-service CSP culverts.

SNAP-TITE® HDPE PIPE BACKGROUND

Snap-Tite® HDPE pipes are engineered to reline culverts. Snap-Tite® is a culvert relining product that can significantly improve the cost effectiveness of culvert remediation and/or replacement. Snap-Tite® is a product that has been specifically engineered for use as a culvert relining material. Figure 5 presents a photo of the unique Snap-Tite® joint design. Snap-Tite® technology has the following benefits (1, 2, 3):

- Tested to meet AASHTO Standard M326 for culvert lining;
- Long design life (over 100 years) in buried installations;
- Smooth wall interior for high flow capacity;
- Smooth wall exterior to resist induced tensile loading;
- Engineered mechanical joint system that provides high strength, non-separable joint; and
- Ability to grout existing voids in the road structure and cover material.

Snap-Tite® relining has several benefits to SMHI including a lower cost than traditional full replacement, no disruption to traffic during relining, elimination of field welding, and improved flow characteristics and serviceability associated with a smooth pipe culvert system (1). In addition, Snap-Tite® liners can be installed in the winter season – outside of the regular construction season. The Snap-Tite® HDPE liner is inserted, coupled, and grouted in place. The ability to utilize self-sealing joints that snap together significantly reduces time for installation in the field. Grouting materials provide an effective and efficient method of sealing HDPE liners in-place and ensure continued culvert flow capacity.

This pilot project has realized numerous advantages to using Snap-Tite® culvert liners to rehabilitate existing aged CSP culverts. These advantages are documented in the Snap-Tite® Manual and online (1, 5) in addition to many published papers (2, 3, 4, 6, 8,). This chapter summarizes the advantages of Snap-Tite® culvert liners.

Snap-Tite® HDPE Material and Structural Design

Snap-Tite® culvert liners are made of HDPE material and are a thick-walled rigid pipe that increases the structural integrity of the culvert (2). The walls of the HDPE pipe are smooth; this increases the flow rate despite the reduced size of the culvert liner (1, 4). As the Snap-Tite® pipe is smooth walled, flow rate capacity of the pipe increases by up to 30 percent, despite a reduced diameter (1). The smooth wall design also results in the culvert being less likely to plug with debris or dirt (1).

Manning's formula is used to estimate flow of the Snap-Tite® culver liner. Manning's 'n' of a corrugated steel pipe is 0.024 while Manning's 'n' of a Snap-Tite® liner is 0.00914 (1). To illustrate the three pilot CSP culverts installed in C.S. 16-16 were 600 mm in diameter. Based on Snap-Tite® manual, a Snap-Tite® culvert liner of 500 mm diameter would improve the flow by 135 percent (1).

Ease of Construction and Overall Installation

Relining the CSP culverts on C.S. 16-16 was found to be efficient, easy, and safe to perform for the following reasons:

- There was no road closure.
- There was no need to excavate the entire road structure to access the existing culvert.
- There was minimal disruption to traffic; the shoulder of the road was closed and speed reductions were sign posted.
- The relining was performed during the winter month of February.
- The Snap-Tite® liner uses a patented locking joint design that was easily assembled on site.
- There was no need for pipe fuse welding equipment.
- Installation time was reduced.
- Snap-Tite® material weighs significantly less than CSP material and was easy to handle.
- No expensive or specialized equipment was needed to install the culvert liners.

Grouting the Annular Space

The installation grout consisted of a cellular concrete that was pumped into the annular void between the Snap-Tite® liner and the existing CSP culvert. The grout provides the following advantages:

- Grout can be used to fill voids in the granular backfill material around the CSP culvert (1, 2, 4).
- The grout increases the structural integrity of the culvert and liner system (2).
- Cellular concrete grout has a low density which allows it to flow into the voids within the granular backfill (4, 7).
- Cellular concrete grout has a compressive strength of up to 5 MPa (7).

During the grouting process on C.S. 16-16, it was found that more grout was used for each of the three culverts than initially calculated expected. This was particularly the case for the CSP culvert at km 10.950 where the grout expelled from the backfill surrounding the CSP culvert; twice as much grout was used than anticipated. The existing CSP culvert at km 10.950 had been very corroded and had localized voids, similar to the schematic illustrated in Figure 6. In this case, there were voids within the backfill and the grout filled these voids. The timely rehabilitation of culverts improved the structure surrounding the culvert and mitigates the risk of a severe structural failure in the foreseeable future (2).

Extended Service Life and Cost Effectiveness

Snap-Tite® culvert liners have water tight joints and a near indefinite service life (1). Although there has been debate over the expected service life of HDPE pipe, literature suggests that these pipes have a service life of at least 50 years and possibly exceeding 100 years (8). Snap-Tite® culvert liners are a cost effective alternative to the conventional culvert rehabilitation methods previously mentioned.

PILOT CULVERT RELINING CASE STUDY CONSTRUCTION SUMMARY

This section summarizes the CSP culvert relining procedure implemented on C.S. 16-16 using Snap-Tite® culvert liners. The overall procedure is summarized below and illustrated Figure 7.

1. Cleaning the existing culvert of debris and dirt.
2. Remediation of any culvert distortion or damaged areas as required.
3. Insertion of HDPE liner to reline the CSP culvert.
4. Preparation of liner and culvert ends for grouting.
5. Trimming of Snap-Tite® culvert liner end.
6. Grouting of liner into place.

Initially, each existing CSP culvert was inspected for obstructions, debris, and dirt. As pictured in Figure 7 a), dirt and debris was removed as necessary from the existing CSP culvert using a hydro-vac machine. If the existing CSP culvert was already clean, hydro-vac cleaning was not required. As pictured in Figure 7 b), the damaged ends of the existing CSP culvert were removed to allow for the Snap-Tite® culvert liner to be inserted.

Figure 7 c) shows one of the HDPE culvert liners inserted into the CSP culvert with the second Snap-Tite® culvert liner positioned against the first liner. Figure 7 d) shows the Snap-Tite® culvert liners aligned and Figure 7 e) shows the lubrication of the end of the Snap-Tite® culvert liner.

Figure 7 f) shows the Snap-Tite® culvert liner being inserted into the existing CSP culvert. The liner was pushed into the CSP culvert until it was completely lined. When the culvert was completely lined, the ends of the culvert were sealed using a cement grout and pipes were inserted to drain water, vent air, and allow for the installation of grout, as pictured in Figure 7 g). The ends of the Snap-Tite® culvert liner were trimmed as seen in Figure 7 h). The annular space between the CSP culvert and the Snap-Tite® culvert liner was then grouted, as pictured in Figure 7 i). Figure 7 j) shows the Snap-Tite® lined culvert with grouting in place.

Grouting Details

Cellular concrete is a construction material composed of cement, water, foam, sand, and air; this makes for a very low density material. Cellular concrete has been used in numerous construction applications including frost protection, insulation, grouting, and underground void filling because of its reasonable cost and high flow rate (2, 7). Cellular concrete has a high air content which contributes significantly to its heat generation during the hydration reaction. As heat is generated, the reaction increases and additional heat is generated. Cellular concrete is often placed in cold temperatures due to this ability to generate heat within itself (7). Cellular concrete has been placed as an insulating backfill material and achieved its compressive strength within 3 days in the field in temperature ranging from -15°C to -25°C (7). Cellular concrete offers advantages in cold winter climates: it is strong, fire resistant, durable, and easy to apply (7).

The grout used to fill the annular space between the CSP culvert and the Snap-Tite® liner was a cellular concrete culvert lining grout. A 3.0 MPa cellular concrete mix design was selected to ensure high strength, an easy flow, and easy to pump materials. Cellular concrete grout was applied when the winter temperature varied from -5°C to -10°C. It was found that the grout was easy to apply to the confined space between the CSP culvert and the HDPE culvert liner by low pressure pumping.

C.S. 16-16 CULVERT RELINING DETAILS

This section provides a description of the culvert relining details at each culvert remediation location. The culverts relined on C.S. 16-16 as part of this pilot case study included:

- CSP culvert at km 1.400 (diameter of 600 mm).
- CSP culvert at km 10.950 (diameter of 600 mm).
- CSP culvert at km 11.970 (diameter of 600 mm).

C.S.16-16: km 1.400

The existing CSP culvert located on C.S. 16-16 at km 1.400 had an average diameter of 600 mm. It was approximately 34 m in length. The existing CSP culvert was significantly plugged with mud and debris and its end was partially submerged, as pictured in Figure 8 a) and b). Before relining with the Snap-Tite® culvert liner, the CSP culvert was cleaned out using the hydro-vac machine, as pictured in Figure 8 c). It was found that the hydro-vac machine cleaned the culvert out sufficiently and effectively. The Snap-Tite® culvert liner used in the rehabilitation was 500 mm in diameter. Based on the area of the annular space between the CSP culvert and the Snap-Tite® liner as well as the length of the culvert, the estimated volume of grout required was 3.6 m^3. However, the volume of grout used in the field to fill the annular space was 4.8 m^3. Therefore, it is approximated that 1.2 m^3 of grout was expelled into the void spaces in the backfill of this culvert.

C.S.16-16: km 10.950

The existing CSP culvert located on C.S. 16-16 at km 10.950 had an average diameter of 600 mm. It was approximately 34 m in length. The Snap-Tite® culvert liner used in the rehabilitation was 500 mm in diameter. Based on the area of the annular space between the CSP culvert and the Snap-Tite® liner as well as the length of the culvert, the estimated volume of grout required was 3.6 m^3. However, upon initial grouting it was visible that grout was expelling out backfill around the CSP culvert, as seen in Figure 9. An initial volume of 3.1 m^3 of grout was left to set. Upon allowing time for partial setting, an additional 2.3 m^3 of grout was pumped into the annular space and backfill voids.

The total volume of grout required for the culvert rehabilitation at km 10.950 was 5.4 m^3. Therefore, it is approximated that 1.8 m^3 of grout was expelled into the void spaces in the backfill of this culvert (based on an estimated 3.6 m^3 required).

C.S.16-16: km 11.970

The existing CSP culvert located on C.S. 16-16 at km 11.970 had an average diameter of 600 mm. It was 34 m in length. Figure 10 shows the installation of the Snap-Tite® line at this location. The Snap-Tite® culvert liner used in the rehabilitation was 500 mm in diameter. Based on the area of the annular space between the CSP culvert and the Snap-Tite® liner as well as the length of the culvert, the estimated volume of grout required was 3.6 m^3. However, the volume of grout used in the field to fill the annular space was 4.7 m^3. Therefore, it is approximated that 1.1 m^3 of grout was expelled into the void spaces in the backfill of this culvert.

PILOT CULVERT RELINING CASE STUDY ECONOMIC ANALYSIS

A review of SMHI culvert tenders in 2009 and 2010 was conducted for similar diameter pipes to those rehabilitated in the pilot case study. The results are summarized per meter length of pipe in Table 1. As seen in Table 1, the cost of traditional culvert remediation methods ranges from $1,200 to $1,800 per meter, depending on the method used. This averages approximately $1,600 per meter. In the event of total road and culvert structural failure, the resulting impact can easily be upwards of millions of dollars in damage.

In comparison, a Snap-Tite® culvert liner costs approximately $1,000 per meter. The installation of a Snap-Tite® culvert liner 500 mm in diameter (installed in a 600 mm diameter CSP culvert) and 34 meters in length costs approximately $34,000. A traditional culvert replacement would have cost between $50,000 and $60,000. This accounts for savings of at least 40 percent by using Snap-Tite® culvert liners versus traditional culvert remediation techniques.

The Snap-Tite® culvert liner will see some reduction in cost as economies of scale are realized. It is feasible to estimate a cost savings of at least 20 percent, up to 80 percent, when using a Snap-Tite® culvert liner in lieu of traditional culvert remediation techniques. For example, the Utah Department of Transportation found that HDPE liners were the most cost effective culvert rehabilitation method used in Utah (2). Given the large number of culverts expected to need replacement in the next several years in Saskatchewan, by economies of scale, a reduction of at least 40 percent could be realized in the cost or rehabilitating culverts affords the opportunity for significant savings per year in high priority corridors where several hundred culverts are in need of rehabilitation or replacement.

SUMMARY

The Saskatchewan Ministry of Highways and Infrastructure has piloted the installation of Snap-Tite® culvert liners in three CSP culverts on C.S. 16-16. Snap-Tite® culvert liners, when installed in a 600 mm diameter CSP culvert of 34 m in length, costs $34,000 whereas a traditional culvert replacement would have cost between $50,000 and $60,000. This accounts for

savings of at least 40 percent by using Snap-Tite® culvert liner technology versus traditional culvert remediation techniques.

This piloted project realized the following benefits with regards to using Snap-Tite® culvert liners to rehabilitate deteriorated and failing culverts in Saskatchewan:

- Snap-Tite® culvert liners are a rigid pipe made of HDPE material that increases the structural integrity of the culvert.
- Despite the reduced diameter of the HDPE pipe, flow rate capacity is increased.
- Overall, relining the CSP culverts with Snap-Tite® culvert liners was efficient, easy, and safe. No road closure was necessary, there was minimal disruption to traffic, no excavation was required, and no expensive or specialized equipment was needed to install the culvert liners onsite.
- Snap-Tite® culvert liners were easy to manoeuvre and assemble.
- Construction was performed in the winter.
- Grout can be used to fill voids in the granular backfill material around the CSP culvert.
- The cellular concrete grout used to fill the annular space between the CSP culvert and the Snap-Tite® liner filled the voids within the granular backfill.

Culvert relining, as compared with a conventional excavate and replace approach has been shown to be very cost effective, typically reducing the costs of the full replacement by a minimum of 20 percent and up to 80 percent. Given the large number of culverts expected to need replacement in the next several years, by economies of scale, a reduction of at least 40 percent could be realized in the cost or rehabilitating culverts affords the opportunity for significant savings per year in high priority corridors where several hundred culverts are in need of rehabilitation or replacement.

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LIST OF TABLES

Table 1 Cost Summary of Culvert Tenders

Type of Culvert Remediation	Approximate Price Per Meter	Total for a 34 m Long CSP Culvert
Excavation and Replacement	$1,500 to $1,800	$51,000 to $61,000
Inside Steel Lining	$1,500 to $1,700	$51,000 to $58,000
Outside Steel Lining by Ramming/Jacking	$1,200 to $1,500	$41,000 to $51,000
Boring/Tunnelling	$1,500 to $1,700	$51,000 to $58,000
Snap-Tite® Culvert Liner	Less than $1,000	Less than $34,000

LIST OF FIGURES

Figure 1 Surface cavitation as a result of culvert joint failure

a) Culvert end (km 1.400) b) Culvert interior (km 1.400)

Figure 2 CSP culvert at km 1.400 (diameter of 600 mm)

Figure 3 CSP culvert at km 10.950 (diameter of 600 mm)

a) Culvert end (km 11.970) b) Culvert interior (km 11.970)

Figure 4 CSP culvert at km 11.970 (diameter of 600 mm)

Figure 5 Snap-Tite® joint design

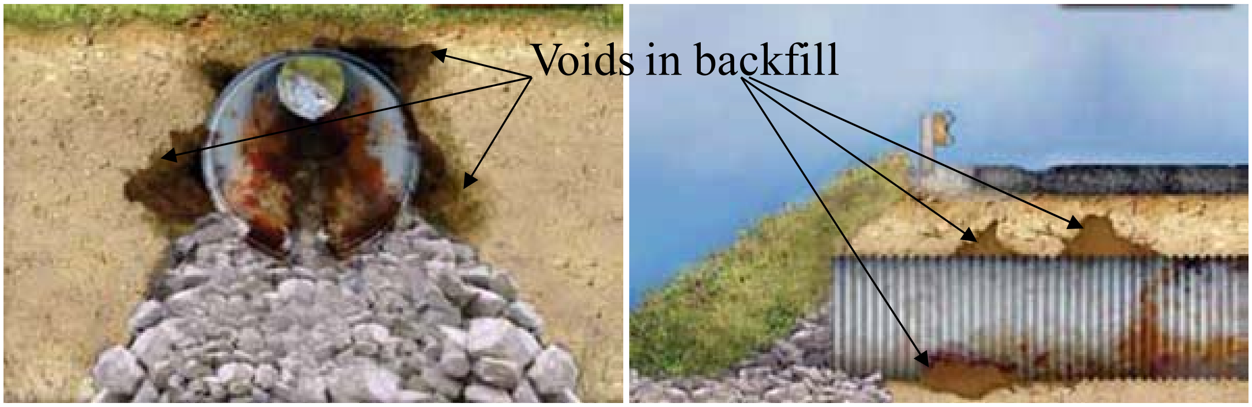

Figure 6 Schematic of Voids in Culvert's Backfill Material (1)

a) Cleaning Existing Culvert

b) Removal of Damaged Culvert End

c) Insertion of HDPE Liner

d) Aligning Sections of HDPE Liner

Figure 7 Installation Process of Snap-Tite® culvert liners (continued next page)

e) Lubricating of the Liner Joint and Gasket **f) Insertion of Sections of Snap-Tite® Liner**

g) Dry Packing Ends/Installing Grout Tubes **h)Trimmed End of Snap-Tite® Liner**

i) Grouting HDPE Liner into Place **j) Culvert with Grouting Complete**

Figure 7 Installation Process of Snap-Tite® culvert liners

a) Culvert end submerged **b) Culvert plugged with debris** **c) Cleaning culvert**

Figure 8 CSP Culvert at km 1.400

Figure 9 Grout Expelled Out of the Backfill at km 10.950

Figure 10 Installation of Snap-Tite® Liner at km 11.970