Advantage

Restricted to FERIC Members and Partners Vol. 6 No. 15 June 2005

Contents

Author
Clayton T. Gillies,
Western Division

Replacing wooden-box culverts with aluminum arch culverts: two case studies

Abstract

The Forest Engineering Research Institute of Canada (FERIC) monitored and documented the installation of aluminum arch culverts replacing wooden-box culverts at two sites. Detailed installation procedures and costs for the projects are presented in this report, as well as comparisons with alternative replacement structures and implementation suggestions for future installations.

Keywords

Stream crossing, Water crossing, Aluminum arch culvert, Fish habitat.

Introduction

Preservation of water quality, fish habitat, and riparian attributes are important goals for forest managers when installing or replacing crossings over fish-bearing streams. FERIC monitored the installation of two aluminum Dur-A-Span™ Forestry Arches[1] by Tolko Industries Ltd.[2] in its Kelowna woodlands operation. The first arch was installed along Barton Road and the second arch was installed along Esperon Road. The aluminum arches were replacements for two wooden-box culverts, which were 15 to 20 years old and nearing the end of their effective lives.

This report describes the installation procedures for the first arch at Barton Road in detail and highlights installation differences with the second arch at Esperon Road. The report also presents the estimated cost of each installation, a comparison with alternative structures, and suggestions for implementation of future arch culverts.

Objectives

The purpose of this study was to provide FERIC's members and partners with information about the procedures and costs of installing arch culverts.

Background and site description

Barton and Esperon Roads are located within Tolko's Kelowna operating area (Figure 1). The two wooden box culverts were temporary structures and frequently inspected, and were replaced due to their age and condition. The life of wooden structures is somewhat uncertain, and can vary depending on the strength of the timber used and the rate of decay. Tolko believed that by replacing the two structures with permanent aluminum arch culverts, the frequency of inspections could be reduced and the life of the new structures could be more readily predicted.

At the Barton site, the natural stream's width ranged from 61 to 68 cm, and had an average channel depth of 39 cm. A localized section of the stream near the outlet of the wooden-box culvert was 124 cm wide. The stream is classified as S4[3] and flows into

[1] The Dur-A-Span™ Forestry Arch (aluminum structural plate) is a product of Atlantic Industries Limited.

[2] Riverside Forest Products Limited at the time of study.

[3] S4 stream classification refers to fish and/or community watershed streams which are less than 1.5 m wide on average (BCMOF and BC Environment 1998).

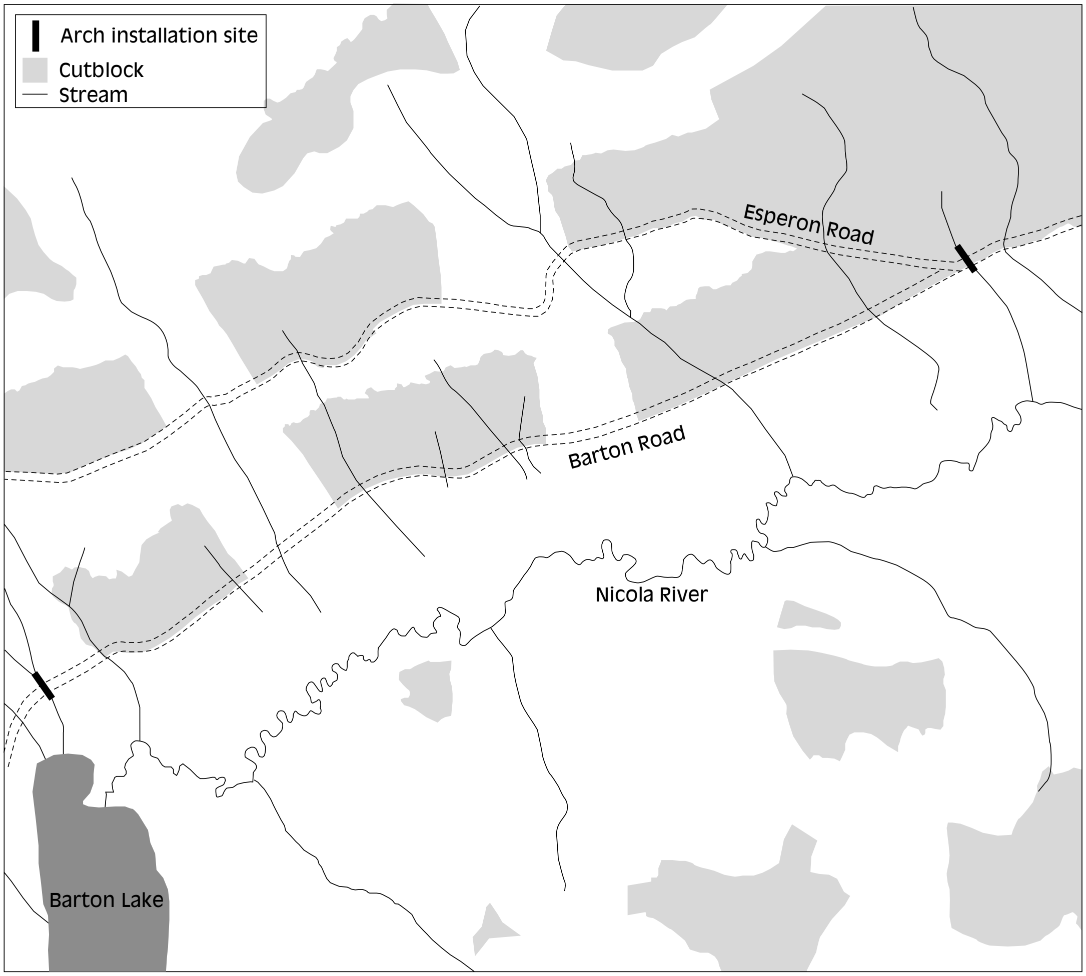

Figure 1. Location of arch culverts on Barton and Esperon Roads.

Barton Lake approximately 300 m downstream of the crossing. Barton Lake connects directly to the Nicola River. Fish were not observed at this site, but due to the gentle gradient (approximately 5%) and absence of obvious barriers between Barton Lake and the crossing location, rainbow trout are presumed to utilize this reach of the stream. Sand and gravel were deposited upstream of the crossing, providing evidence of streambank overflow. The stream gradient immediately upstream and downstream of the crossing was approximately 6%. The stream was barely flowing during the installation period in August. The inlet of the wooden-box culvert measured 78 cm wide and 55 cm high, and the outlet measured 88 cm wide and 43 cm high. The depth of the fill over the wooden-box culvert at the road centreline was approximately 1.8 m (Figure 2).

At the Esperon site, the natural stream's width ranged from 87 to 104 cm, and channel depths ranged from 30 to 71 cm. The stream is classified as S4 and flows into Nicola River approximately 600 m downstream. Fish had been observed at this site and were presumed to be rainbow trout. The stream travels through an old clearcut upstream of the crossing location.

Forest Engineering Research Institute of Canada (FERIC)

Find us Online! www.feric.ca

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9

(514) 694-1140
(514) 694-4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4

(604) 228-1555
(604) 228-0999
admin@vcr.feric.ca

ISSN 1493-3381

Although the stream was not flowing during the installation period, there were isolated pools of water present along the stream channel. Ponded water had also accumulated at the inlet and outlet of the wooden-box culvert. The stream gradient immediately upstream and downstream of the crossing was approximately 1%. The inlet of the wooden-box culvert measured 90 cm wide and 58 cm high, and the outlet was 135 cm wide and 75 cm high. The depth of the fill over the wooden-box culvert at the road centreline was approximately 65 cm.

Figure 2. Inlet of Barton Road wooden-box culvert.

Figure 3. Stockpiled aggregate showing one load of riprap on either end of the crushed rock.

Planning and design

The locations were surveyed to produce plan and profile views of the construction sites which were the bases of installation designs. Site attributes shown on each of the designs included the stream channel, toe of the road fill, edge of running surface, and fill slope angle. The proposed arch culverts were superimposed on the designs, which showed the length of the culvert required for the existing fill slope angle and depth of fill. Average gradient of the natural stream channel was given for each site. The aluminum arches had the same orientations to their respective roads as the wooden-box culverts they replaced. The installations were scheduled for the in-stream work window or "fish window" for the local area and fish species.[4] The culverts were sized to accommodate the natural stream width at each site, and to allow passage of a 100-year (Q100) flood event.

Owing to the deeper fill, the design for the Barton Road arch specified wider footings and a longer culvert length than those for the Esperon Road arch.

Riprap and crushed aggregate were hauled and stockpiled at the installation sites prior to starting the installations (Figure 3) to avoid delays. First, two loads (24 m^3) of crushed aggregate were delivered by a clamshell dump truck; round-trip delivery time was 1 hour per load. Next, two loads (18 m^3) of riprap were delivered by a tandem dump truck with a heavy duty box; round-trip delivery time was 30 minutes per load. The delivered riprap varied in size; one load contained small (18 to 42 cm) riprap, while the second load contained large (72 to 95 cm) riprap. The tandem dump truck placed one load of riprap at each end of the delivered crushed aggregate.

A lowbed delivered both arches (pre-assembled) in one trip the day before the installations began. A John Deere 200 LC excavator with clean-up bucket and live thumb unloaded the arches, which were fitted with lifting eyes along the top to aid in lifting and moving (Figure 4). The Barton Road arch was placed along the road right-of-way beside the installation site, while the Esperon Road arch was loaded onto a small trailer for a 3.5-km move with a pick-up truck when needed.

[4] The preferred window for in-stream work by fish species and by geographical area is found in DFO et al. 1993. This work window is generally considered to be the period of least risk for the fish species present.

Materials and equipment

The two Dur-A-Span™ Forestry Arches had the same span (width) and rise (1220 and 610 mm, respectively, with an end area of 0.58 m^2), but different lengths and footing dimensions. The Barton Road arch was 13.7 m long with 43-cm-wide footings, and the Esperon Road arch was 11.0 m long with 31-cm-wide footings. The footings were not continuous along the length of either arch; the space between each section of footing was approximately 10 cm. Wider footings were chosen for the Barton Road site owing to the deeper fill. The arches weighed 38 kg/m, and the corrugation profile was 64 mm deep and 230 mm wide (Figure 5). The footings were designed for a surface with 200-kPa bearing capacity. The arches are designed to an L100 rating (approximately 91 tonnes gross vehicle weight), with a minimum compacted cover of 600 mm.


Figure 4. Lifting arch off delivery truck in preparation for placement on small trailer.


Figure 5. Corrugated aluminum arch and footings showing the corrugation profile and gap between the footing sections.

The equipment used during the installation included a John Deere 200 LC Logger 20-tonne excavator with clean-up bucket, live thumb, and boom reach of approximately 8.5 m; a 3.7-kW gas-powered Honda pressure pump with hoses; sandbags and plastic for dam; and a 4.1-kW, 86-kg gas-powered Wacker vibrating plate compactor. Other tools and supplies were a clinometer, loggers tape, and spray paint.

Site preparation

Site preparation consisted of dewatering the sites and removing the wooden-box culverts.

Dewatering

A dam consisting of three rows of sandbags was built immediately upstream of the wooden-box culvert. Plastic sheeting was laid in front of the sandbags on the upstream side. At the Barton Road site the flow in the stream was minimal, and the accumulated water behind the dam had to be pumped only once during the installation. The water was pumped onto the forest floor, away from the stream channel approximately 20 m downstream from the crossing site.

At the Esperon Road site, a natural pool at the inlet was pumped free of water, and two sumps, one at either end of the wooden-box culvert, were then excavated to collect seepage flow. The sumps had to be pumped out once during the installation. Again, all pumped water was delivered onto the forest floor, away from the stream channel approximately 20 m downstream of the crossing.

Wooden-box culvert removal

The excavator removed as much of the fill over the log stringers as possible to keep the road fill from entering the stream channel, and then removed the stringers (Figure 6). Finally, the excavator pulled out the sill logs and dug out the mud sills. The culvert logs were then placed randomly in the right-of-way below the road, to serve as downed large woody debris. Complete removal of the old wooden-box culverts took 1.5 hours at each site.

Installation

Each installation took one day including the removal of the existing wooden-box culvert, and the two installations were done on consecutive days. The installation consisted of eight steps: excavation; bed preparation; arch placement; backfilling; armouring footings; armouring fill slopes; re-connecting the stream channel; and building the road up to grade.

Excavation

The excavator prepared each site to a cleared width of approximately 3.2 m at the base of the excavated trench to allow nearly 1 m on either side of the arch for compacted fill. The width of the trench at the road surface was approximately 6 m. The excavations at both sites were about 1.7 m deep. The excavation depth at the Barton Road site was determined by the depth of road fill and existing structure. At the Esperon Road site, the trench was excavated below streambed level to find a better bearing surface than was present at the original level. Soil conditions beneath the original streambed did not appear to improve with deeper excavation (Figure 7) so additional bed preparation was necessary. Excavating and preparing the trenches took about 2 hours at each site.

Bed preparation

After excavating the Barton Road trench, the excavator pressed down on the base of the trench with the backside of its bucket to determine if the soil's bearing capacity was adequate to support the arch. A small amount of crushed aggregate had to be spread and compacted with the plate compactor in a soft spot near the outlet.

Bed preparation at the Esperon Road site was more complex owing to the poor subsurface conditions. After the trench was excavated below the streambed level, riprap was placed in the trench (Figure 8) and topped with crushed aggregate to provide an adequate foundation for the arch. A line was painted along the sides of the excavation to mark the height of the aggregate lifts. Finally, some of the excavated soil was spread over the crushed aggregate and compacted with the excavator's bucket (Figure 9).

Once the bed was compacted the crew marked the centreline and footing lines where the arch was to be positioned, and staked the

Figure 6. Excavator removing final stringers from over the sill logs.

Figure 7. Excavated trench at Esperon Road site.

Figure 8. The Esperon Road site showing first lift of large riprap before topping with crushed aggregate. Arrow indicates design height of fill.

inlet and outlet positions. In preparation for armouring the footings, small riprap (18 to 27 cm) was hand-picked from the stockpile, placed in the excavator's bucket, and windrowed along the centreline (Figure 10).

Arch placement

The installation crew first ensured that the arch inlet and outlet ends, which were defined by the overlapping pattern of the culvert sections, were properly aligned with the stream. The excavator lifted the arch by the two stock lifting eyes and positioned it so that it straddled the windrowed armouring material (Figure 11). The workers were able to move the arch into proper position while it was suspended. The final placement was made easier by marking the site for the footings.

Figure 9. Compacting the final lift with the excavator bucket.

Figure 10. Windrowed riprap along culvert centreline. The white dashed lines show where paint lines would indicate the location for one side of the arch's footings.

Figure 11. Excavator and workers orienting arch for final placement.

Backfilling

Backfilling began when the arch was in place but before armouring the footings on the inside. Drier material removed from the original excavation was used for fill. Some of the stockpiled crushed aggregate was also used as backfill.

The excavator alternated backfill placement from one side of the arch to the other, in lifts of approximately 30–40 cm deep before compaction. A vibrating plate compactor was used to compact the backfill between lifts.

At the Esperon Road site, some of the original excavated material was too wet to re-use as backfill. As a result, some of the stockpiled crushed aggregate and material from the road edge and surface were used for backfill. This was feasible because the road at this site was wider than the minimum target road width of 7 m. The excavator also removed some road fill from an area approximately 10 m away from the crossing. This created a shallow dip in the road that also drained road-surface runoff away from the stream.

Armouring footings

The windrowed aggregate along the centreline of the arch was used to armour the footings. To place the aggregate on the footings, a worker lay on a sheet of plywood and placed the rocks by hand on the footings. The worker continually moved the sheet of plywood forward as the footings within reach were covered. This aggregate placement was done in one direction for the entire length of the culvert. The armouring of the footings took 12 minutes at the Barton Road site and 38 minutes at the Esperon Road site.

Armouring fill slopes

The excavator placed riprap on the fill slopes at the inlet and outlet areas of the arch. Larger riprap was placed near the base of the fill slope and next to the arch, while smaller riprap was placed near the top of the fill slope (Figure 12). The purpose of the armouring was to direct high flows into the arch while providing scour protection to the inlet and outlet areas, and also to prevent road material from sloughing into the stream.

Re-connecting the stream channel

At the Barton Road site, the dam was dismantled carefully, and the plastic sheeting and sandbags were saved for future re-use. Stream flow was minimal so no water flowed through the arch. At the Esperon Road site, the sumps were infilled with backfill material and the stream channel was blended together over the sump area. At this site as well, stream flow was minimal and no water was observed flowing through the arch.

Road grade

The excavator built the road up to grade using the remaining material onsite, leaving the lowest area 5 to 10 m away from the culvert to direct surface runoff away from the stream channel. The road at the Barton site was re-built to the original profile which directed surface runoff away from the stream (Figure 12). The depth of fill over the arch at this site was approximately 180 cm at the road centreline, or the same as over the original wooden-box culvert.

The original road grade at the Esperon site was flat at the stream crossing, so the road was raised slightly at the arch to direct road runoff away from the stream (Figure 13). The depth of fill over the arch at this site was 84 cm at the road centreline, or 19 cm deeper than over the original wooden-box culvert.

Figure 12. Inlet of arch showing placement of large and small riprap on fill slopes around the arch.

Figure 13. Outlet of arch at Esperon Road site showing fill height above arch and the low areas on either side of the arch along the road.

Project costs

FERIC's estimate of project costs are shown in Table 1. A two-person crew completed the site survey for each crossing in 2 hours, and an additional 2 hours for one person was required to produce the plan and profile views/design for a crossing. The purchase and delivery of the arch culvert represented 74% of the final installed cost at the Barton Road site and 66% for the Esperon Road site, compared to 50% in a previously reported case study (Gillies 2002). The cost to drill and blast the aggregate riprap was $\$8/m^3$, while the crushed aggregate was more expensive at \$4 500 per day producing 400 m^3 ($\$11.25/m^3$). The cost for loading the aggregate into the delivery trucks is incorporated into these production costs.

Aluminum can be sold as scrap for \$1.10/kg to \$1.40/kg (\$0.50 to \$0.65 per lb.) depending on quality. Therefore, a 520-kg aluminum arch has a potential salvage value of \$570 to \$730 not including removal or

Table 1. Estimated project costs – Barton and Esperon sites

Cost category	Barton Road Quantity	Barton Road Unit cost ($)	Barton Road Total cost ($)	Esperon Road Quantity	Esperon Road Unit cost ($)	Esperon Road Total cost ($)
Materials						
aluminum arch	13.7 m	469 [a]	6 425	11.0 m	409	4 499
crushed aggregate for bedding/backfill	24.4 m^3	11.25	275	24.4 m^3	11.25	275
riprap for armouring	18.4 m^3	8	147	18.4 m^3	8	147
Equipment						
excavator @ 20 t	8.75 hours	126.54 [b]	1 107	9.0 hours	126.54 [b]	1 139
tandem dump truck@ 9.2 m^3	1 hours	77.90 [b]	78	1 hour	77.90 [b]	78
clamshell dump truck @ 12.2 m^3	2 hours	85.50 [b]	171	2 hour	85.50 [b]	171
freight (delivery of arch)	2.5 hours	100	250	2.5 hours	100	250
compactor	1 day	52 [c]	52	1 day	52 [c]	52
pump and hoses	1 day	93.15 [c]	93	1 day	93.15 [c]	93
Labour						
site survey	4 hours	30.64	123	4 hours	30.64	123
site plan/design	2 hours	30.64	61	2 hours	30.64	61
site preparation and installation	9 hours	30.64	276	10 hours	30.64	306
tow trailer with culvert [d]				1 hour	30.64	31
Total			9 058			7 225

[a] This cost represents aluminum arch with wide footings.
[b] Based on FERIC standard costing methodology for given weight class/volume capacity of machine.
[c] Based on 2001–2002 Equipment Rental Rate Guide (B.C. Road Builders and Heavy Construction Association 2001).
[d] No cost has been allocated for the pickup truck used to tow the Esperon arch to the installation site.

transport. By comparison, steel has a salvage value of \$0.02/kg to \$0.08/kg (\$0.01 to \$0.04 per lb.).

Both installations were completed in one day. The shallow excavation and the re-use of the excavated material as backfill contributed to cost savings. Pre-delivered aggregate with short round trips during delivery also proved favourable to the final installed cost. The on-site foresters considered these installations straightforward and easy, and hence the costs of the installations should be considered at the low end of typical.

Alternative crossing structures

When choosing a stream crossing structure, the choice of crossing structure is influenced by a variety of factors such as site and stream conditions, life expectancy, cost of the product, and local experience. The following section discusses some of the costs and considerations involved in choosing between an arch, an embedded culvert, or a short-span bridge, and compares the arch to alternative stream crossing structures.[5]

Embedded closed-bottom culverts

All closed-bottom structures placed along fish-bearing streams must be installed during the preferred in-stream work window and sized so as to not restrict the stream as it enters the culvert. Pipe-arch culverts used to cross fish-bearing streams should be infilled (embedded) with material to 20% of their rise, while round culverts should be infilled to 40% of their diameter. Two FERIC case studies of embedded culverts illustrate the cost implications of this alternative compared

[5] No comparison is given to a wooden-box culvert, as one of the main objectives in replacing these structures was to install permanent structures with longer life expectancy and a less frequent inspection schedule.

to the use of arch culverts. First, a 90-cm-wide stream was crossed using a pipe-arch with a span of 1390 mm and a rise of 970 mm which was purchased and delivered for a cost of $2 166, and infilled and installed for a total cost of $13 131 (Gillies 2003). Although the cost of the pipe arch was considerably less than the aluminum arch at the Barton Road site, the final cost of the infilled pipe arch was 45% ($4 073) more than that of the installed aluminum arch, mostly owing to the infilling requirements. Second, a 1.3-m-wide stream was crossed using a round culvert with a diameter of 1600 mm which was purchased and delivered for a cost of $2 330, and infilled and installed for a total cost of $12 070 (Gillies 2003). Again, although the cost of the round culvert was less than the aluminum arch, the final installed cost was 33% ($3 012) more than that of the final installed aluminum arch at the Barton Road site.

Open-bottom steel arches

Steel multi-plate arches are available in sizes comparable to the aluminum arches and can be delivered pre-assembled. Typical dimensions range from spans of 800 to 1800 mm and corresponding rises of 400 to 900 mm. Steel arches can accommodate a live load rating of L100 with a minimum compacted cover of 400 to 600 mm, depending on size chosen, and are designed for a surface with 200-kPa bearing capacity. Steel arches weigh more than aluminum (87 to 144 kg/m for the above dimensions). Depending on the length of the structure and the corresponding weight, a larger excavator may be needed to lift and place a steel arch than for an aluminum arch. For a cost comparison, a typical pre-assembled steel arch with a 1200-mm span, a 600-mm rise, and a 13.7-m length would cost approximately $6 420 (not delivered). This purchase price is the same as the aluminum arch but the potential salvage value would be less. A headwall can be used with steel arches at a cost of $1 600 each, depending on size. When utilized, the headwall can shorten the length of arch required and lessen the need for armouring the inlets and outlets.

Short-span bridges

Bridges used to cross small fish-bearing streams (S3 and S4) can typically be installed without any in-stream work activity and therefore are not constrained by the in-stream work window.[6] However, because of their costs, clear-span structures are better suited for larger streams. For example, FERIC collected information for the installation of a 6.6-m concrete slab-girder bridge on pre-cast concrete pads and lock-block abutments on a 2-m-wide stream (Gillies 2004). The bridge was purchased and delivered for a cost of $16 000, and the final installation cost was $39 500 (including design, supervision, environmental monitoring, heavy equipment, and supplies).

Conclusions and implementation

In 2002, Tolko Industries Ltd., Kelowna woodlands operation replaced two wooden-box culverts with Dur-A-Span™ Forestry Arch aluminum culverts. By choosing aluminum arches it was expected that the frequency of inspections could be reduced and the life of the new structures could be more reliably predicted. The two arch culverts were installed during the preferred in-stream work window for a total cost of $9 058 at the Barton Road site and $7 225 at the Esperon Road site. The purchase and delivery cost for the arch culverts represented 74% and 66% of the total installation cost at the Barton Road site and Esperon Road site, respectively. Aggregate was pre-delivered to the construction sites. At each site, the stream was dewatered, the existing structure removed, the arch installed, and road re-built to grade in one day. Contributing factors to the low installation costs were the shallow

---

[6] Any activities conducted within the stream channel would need to be conducted during the in-stream work window, unless authorized by Fisheries and Oceans Canada.

depth of excavation, the re-use of excavated material as backfill, and the limited effort required to dewater these sites.

Embedded closed-bottom pipe arches or round culverts, and steel multi-plate arches, would also have been feasible alternatives for these crossings. Closed-bottom culverts are less expensive, but installation costs may be higher because of the need for additional excavation and infilling required on fish-bearing streams. A steel arch costs the same as aluminum but is heavier and therefore might require a larger excavator to lift it into place or require on-site assembly. Short-span bridges are technically feasible, but not necessarily economical.

Some points to consider when planning stream crossings:

- Aluminum arch culverts are well suited to small fish-bearing streams. Tolko chose to use aluminum arches because their spans (1220 mm) matched well with the stream dimensions and thus would not constrict the stream flow. The use of arches also eliminated the need for infilling, as compared to closed-bottom culverts which require infilling.
- On higher energy streams, the use of an arch may not be as desirable due to the potential for the stream to scour below the footings. For higher energy streams, the footings should be aggressively armoured or placed outside of the flowing channel to help mitigate the potential for scour.
- Delivering all materials (e.g., culverts, aggregate, and riprap) to the site prior to installation allows for the installation to continue without interruption. Aggregate should be placed as close to the installation site as possible, while making sure to leave room for storing excavated material from the installation site.
- Preparing the site plan and subsequent designs for these installations was straightforward. It could be anticipated that more time and detail would be needed for larger arch installations or for installations on new road headings. When replacing stream crossing structures, the stream's orientation through the road has already been established and dictates the placement of the new structure, unless the new structure is to be placed in a new position/location to help rectify a poorly aligned/located structure. With a new crossing the arch's orientation should be carefully considered and planned.
- Planning in-stream work within the fish-window was beneficial to the proponent of the project as there was no need for authorization from Fisheries and Oceans Canada to work outside of the fish-window, thus eliminating additional applications and delays. Also, by working during these times the weather is predominantly dry and the stream contained low flows, therefore reducing additional construction tasks.
- The stringers, sill logs, and mud sills from the original wooden-box culverts were distributed along the roadside, downstream of the crossing, to serve as a source of large woody debris, thereby eliminating the need for hauling the material to a disposal site. Also, placing the debris on the downstream side ensures that it cannot block the culvert or deflect flows away from the culvert inlet.
- Minimal time and effort to dewater the stream because of extremely low flows; shallow excavation depth; re-use of excavated material; and short haul distances for the aggregate contributed to the low cost of installation. Other contributing factors included the decision to deliver aggregate prior to installation; delivering the arches pre-assembled and in one trip; assigning appropriate-sized equipment for the job; and producing simple site plans and designs with an appropriate level of detail.

- Both installations described here required excavation of the existing streambed and preparation of the arch footing area to achieve adequate load-bearing capacity for the arch. If the stream channel could not be disturbed, an oversized arch or small bridge would be required.

References

B.C. Road Builders and Heavy Construction Association. 2001. Equipment rental rate guide. Richmond, B.C. 130 pp.

British Columbia Ministry of Forests (BCMOF); BC Environment. 1998. Forest practices code of British Columbia: Fish-stream identification guidebook (2nd ed.). Victoria, B.C. 70 pp.

Department of Fisheries and Oceans Canada (DFO); B.C. Ministry of Environment, Lands and Parks; B.C. Environment. 1993. Land development guidelines for the protection of aquatic habitat. Vancouver, B.C. 128 pp.

Gillies, C. 2002. Installation of an aluminum open-bottom arch culvert. FERIC, Vancouver, B.C. Advantage Report Vol. 3 No. 16. 7 pp.

Gillies, C.T. 2003. Closed-bottom corrugated-steel embedded culverts in British Columbia: overview of twelve sites. FERIC, Vancouver, B.C. Advantage Report Vol. 4 No. 29. 31 pp.

Gillies, C.T. 2004. Closed-bottom corrugated-steel embedded culverts in British Columbia: overview of seven sites. FERIC, Vancouver, B.C. Advantage Report Vol. 5 No. 31. 19 pp.

Acknowledgements

The author expresses his appreciation to Gary Forster formerly of Riverside Forest Products Limited in Kelowna, and Ted Swab of Tolko Industries Ltd. (Riverside Forest Products Limited at the time of study). FERIC staff is also acknowledged for report reviews, graphics and layout work, and final edit.