Advantage

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Contents

Installation of an embedded pipe culvert: Stuart Lake tributary

Abstract

The Forest Engineering Research Institute of Canada (FERIC) monitored and documented the installation of an embedded corrugated-steel pipe culvert as a replacement structure for a temporary concrete-slab bridge. Detailed installation procedures and total costs (including planning) for the project are presented. Suggestions for implementation of future embedded culverts are given.

Keywords

Stream crossing, Streambed, Water crossing, Embedded pipe culvert, Corrugated steel pipe culvert, Fish habitat.

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Introduction

Water quality, fish habitat, and fish passage need to be considered when planning forest operations. Stream crossings on forest roads should maintain water quality, protect fish and fish habitat, and provide safe fish passage. In British Columbia, marginal, important, and critical fish habitat must be identified and treated appropriately (BCMOF et al. 2002). In the past, closed-bottom structures have generally not incorporated streambed substrate through their length. A carefully-installed embedded pipe culvert will include streambed substrate and be a cost-effective way to meet stream-crossing objectives at appropriate sites. To document the installation of embedded pipe culverts, the B.C. Ministry of Forests (BCMOF), Resource Tenures and Engineering Branch, contracted FERIC to monitor and report on selected pilot projects.

FERIC worked with Riverside Forest Products Limited and the BCMOF, and monitored the installation of an embedded corrugated-steel pipe culvert (CSP). The installation was carried out within Riverside's Kelowna woodlands operation in September/October during the preferred instream work window for the identified fish species (DFO et al. 1993). This report describes the installation procedures and presents the estimated cost of the project. Suggestions for implementation of future embedded culverts are given.

Figure 1. View of stream crossing, showing newly built road and temporary structure.

Site description

Prior to the installation of the embedded culvert in the newly-built spur road, a temporary bridge composed of two concrete slabs had been installed at the crossing site to provide access for road construction (Figure 1). The unnamed stream, with an S3 classification,[1] is considered to be fish bearing because it flows into Stuart Lake (approximately 400 m away) and does not contain any known fish

[1] S3 stream classification refers to fish and/or community watershed streams which are 1.5 to 5 m wide (BCMOF and BC Environment 1998).

barriers. Stuart Lake contains eastern brook trout (stocked) and rainbow trout. At the road crossing, the stream's well-defined channel is 1.3–1.7 m wide with a gradient of 4–6%.

Planning and design

To develop the design for the crossing, the site and stream were surveyed to produce a site plan and site profiles. The surveys were completed prior to any road construction work at the site by BCMOF, Kamloops Forest Region's Engineering Section, using a total station instrument. The stream survey extended at least 35 m on either side of the installation site. Elevation benchmarks and horizontal references were established for construction reference. The site plan consisted of a map of the area with 0.5 m contours, showing the ground topography and existing conditions. The stream thalweg profile and stream cross-sections were also developed from the survey information. The stream profile is a critical requirement for the design as it is used to determine the proposed streambed elevation and gradient, and the culvert elevation and gradient.

The design was developed following a site review, utilizing the site plan, profiles, and cross-sections.[2] During this review, the stream's width was measured at numerous locations, and averaged 1.7 m. Stream crossing design drawings were developed and submitted, and approval was obtained from the B.C. Ministry of Water, Land and Air Protection. Information on the design drawings include:

- stream data (width, grade, riparian class)
- design flood event volume (1.3 m^3/s)
- plan and profiles (culvert and road)
- construction referencing (vertical and horizontal)
- materials specifications
- installation specifications
- other details (riprap specifications, weir specifications, etc.)

Five drawings resulted from the design process.[3] The design drawings showed the proposed embedded-culvert superimposed on the site plan and profiles. The proposed location of the culvert was referenced to the benchmark and horizontal reference stakes. Drawings showed the proposed culvert in plan, section, and profile view; a downstream weir in three views; and the proposed road centreline in profile view.

Materials and equipment

The CSP was 17 m long, 1.8 m in diameter, and 3.5 mm thick (10 gauge), and had a corrugation profile of 68 by 13. The culvert was supplied by Atlantic Industries Limited. The design specifications included:

- Design live load BCMOF L-75 (approximately 68 tonnes gross vehicle weight).
- Backfill material within 30 cm of the CSP shall be 75-mm minus.
- The CSP shall be installed using appropriate mechanical vibratory compaction in lifts of a maximum 30 cm height.

Equipment and supplies used during the installation included:

- Heavy equipment: Hitachi EX270 LC excavator with digging bucket and live thumb, Hitachi EX200 LC excavator with digging bucket and live thumb, Caterpillar D7R XR crawler tractor,

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2 Design drawings were developed by Brian Chow, M.Eng., P.Eng., BCMOF, Resource Tenures and Engineering Branch, and E.George Robison, Ph.D. (forest hydrology), Watersheds Northwest Inc., Oregon, USA.

3 Copies of design drawings can be obtained from Brian Chow, BCMOF, Victoria, B.C.

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Caterpillar D300 D articulating dump truck, and a belly-dump tandem truck.
- Survey equipment: level with tripod, rod, and nylon measurement tape.
- Dewatering equipment: sandbags, plastic bags, plastic roll, 25 m of plastic diversion pipe (18 cm diameter), 2.6-kW Honda volume pump, and 3.7-kW Honda pressure pump.
- Embedding equipment: wheelbarrows and Kubota K008 mini-excavator.
- Hand tools and other items: plate compactor, rake, shovel, lifting chains, spray paint, measuring tape, knife, and non-woven geotextile fabric.

Culvert backfill material was retained from the original excavation, while armouring and a portion of embedding material were imported and stockpiled on-site. The backfill material was a mix of sand and 20-mm minus material. Large riprap (approximately 90-cm diameter) was used to armour the inlet and outlet areas of the CSP. The riprap was placed in four piles close to the intended armouring location. The imported embedding material was predominantly a mix of sand and 76-mm minus aggregate; larger 30-cm minus was used during additional work following the installation. The remaining embedding material was from the original streambed.

Site preparation

The site preparation included three steps: stream diversion, removal of temporary structure, and field referencing.

Stream diversion

The stream was dewatered and the temporary crossing structure was removed prior to the CSP installation. The excavator prepared a trench for the gravity-fed diversion pipe. The trench was positioned on the bush side of the stream (as opposed to town side), approximately 1 m from the proposed excavation for the CSP, to avoid the heavy equipment used during the installation. The diversion pipe was laid in the trench by hand (Figure 2), with the inlet at the diversion dam and the outlet approximately 10 m downstream of the construction site. The dam was built by hand using sandbags and plastic bags. After the trench was completed, the diversion pipe was placed through the dam wall, with the sandbags placed on top of the pipe. Plastic sheeting was used to further seal the dam. Once the dam and pipe were in place, the site was dewatered.

Removal of temporary structure

Each concrete slab was removed by placing a chain around it, lifting it with the excavator (Figure 3), and moving it aside. The log abutments were also removed. The stream could not be crossed once the temporary structure was removed.

Field referencing

The design drawings showed the location of the proposed culvert relative to the horizontal reference stakes established during the detailed site survey. Centreline stakes, both downstream and upstream, were established by measuring from the horizontal field reference stakes as detailed in the design drawings. A direct line between centreline stakes helped establish the proposed location of the culvert.

Figure 2. Diversion pipe laid in a trench on the bush side of the temporary structure.

Figure 3. Temporary structure being dismantled.

Installation

Installation is described here in eight steps: seepage management, excavation, placement, backfilling, embedding, weir construction, armouring, and dismantling and reconnecting.

Seepage management

Two gasoline-fuelled water pumps were used during the installation to further dewater the site. One pump removed water from the dam and delivered it downstream of the installation area. The second removed sediment-laden water from a downstream sump, and spread it out onto the forest floor. The gravity-fed diversion pipe continued to function during the installation.

Excavation

The installation crew consisted of the excavator operator, two forest workers, and a foreman. A surveyor and helper used a level on a tripod, a rod, and a measuring tape to guide the elevation of the new structure. Once the level was set up and the initial reading had been taken on a chosen bench-mark, the level was not moved. As the excavation proceeded, measurements were made to establish the final invert (bottom of culvert) depth at the inlet and outlet, as well as depths along the length of the excavated trench to help establish the gradient (Figure 4). Shovels and rakes were used to smooth any small mounds within the trench.

Figure 4. A surveyor and helper took measurements within the excavated trench.

Figure 5. The excavator placed the CSP into the excavated trench.

The excavator worked from the town side of the stream during the installation, and started at the downstream end of the trench, working up the stream. The excavated material was hauled 40–50 m using an articulated dump truck. The final excavated area was 3.6–3.8 m wide and 20–22 m long. Three to five metres of the excavated length at the outlet end will function as a new stream channel.

Placement

When the excavation was complete, two logs were placed in the road fill adjacent to the trench to act as a stable working pad while the CSP was placed. The excavator then used two sets of chains to lift the CSP, and move it approximately 75 m from its delivery point to the installation site, and lower it into place (Figure 5). Final placement was established by checking the distance to the outlet from a reference stake. The gradient of the CSP was measured before the lifting chains were removed.

Backfilling

Culvert backfilling started by placing fill material on either side of the CSP. Shovels were used to help move material into place below the haunches on both sides of the CSP. Compacting at this point entailed the workers stepping on the fill and pounding on it with their boots, as there was not enough room to run the compactor in this narrow area below the CSP. As backfilling continued, material was raked flat on either side of the CSP and the plate compactor was used in a series of lifts (Figure 6). The excavator moved the compactor from one side of the CSP to the other during the numerous lifts. Compacting the lifts continued until half of the pipe was backfilled, and then the embedding material was placed in the CSP.

Once the embedded material had reached the specified height within the CSP, the crew completed the culvert backfilling. Compaction of the backfilling lifts continued until the pipe was completely covered. A crawler tractor was used to place the final fill and to build the road up to the final grade. Approximately 1.3 m of fill was placed over the top of the CSP, a gain of 1 m in road height from the pre-installation location. The CSP was installed at a slope of 6.4% and the simulated streambed through the culvert measured 5.8%, matching the natural stream gradient.

Figure 6. A plate compactor was used to compact backfill lifts on either side of the CSP.

Figure 7. A Kubota K008 mini-excavator spreads material within the CSP.

Embedding

The inside of the CSP was filled to a height of 72 cm (40% of CSP diameter) using the original streambed material and the stockpiled 76-mm minus aggregate. As a guide, the desired height of the embedding material was measured and marked with spray paint on the inside of the CSP.

Initially a Kubota K008 rubber-tracked mini-excavator was used (Figure 7). The Kubota reversed into the CSP and used its excavating blade to drag, and a rear-mounted stabilizing blade to push, embedding material through the CSP, filling the outlet end first. The Hitachi excavator placed the embedding material at the inlet, and transferred material to the Kubota as needed. The Kubota was not able to spread it to the required height because the machine could not work inside the CSP once the material had reached 40–50 cm depth.

Two wheelbarrows were used to finish the embedding. The Kubota was positioned outside of the CSP, filling one wheelbarrow with material while the other delivered it within the CSP. The workers dumped the wheelbarrows and positioned the material with shovels.

Weir construction

The weir was built 2.4 m downstream from the outlet of the CSP although the engineered drawings prescribed a distance of 3.6 m. The weir was built using riprap and 76-mm minus material. First, the riprap was placed across the width of the channel. Then, smaller material was placed on either side of the riprap. Shovels were used to direct the smaller material from the bucket of the excavator into place.

As the weir was constructed, smaller riprap and 76-mm minus material were also spread within the newly-created section of stream channel at the culvert's downstream end. The new channel was blended into the existing channel within 3 m of the weir.

Armouring

The fill slope was re-graded and pulled back in some places in preparation for the riprap. Non-woven geotextile was placed on the fill on both sides and over the top of the CSP where the riprap was to be placed. The geotextile will reduce the migration of fine material from the road fill into the stream. The excavator then armoured the inlet and outlet of the CSP, extending the riprap over the top of the CSP and up the ditchline on the town side (Figure 8). The operator was careful to interlock the riprap.

Figure 8. Riprap armouring at outlet and final road grade showing fill height over the embedded CSP.

Dismantling and reconnecting

The pumps were turned off, and the dam and diversion pipe were dismantled by hand, thereby allowing the stream to run through the embedded CSP. Sediment-laden water was washed through the CSP during the initial creek reconnection. The stream had a very low flow at this time of year. At first, portions of the streamflow were below the simulated streambed surface.

Additional work

Additional work was considered necessary to improve the embedding material inside the CSP, specifically to bring the stream flow up to the surface of the simulated streambed and increase the amount of larger coarse material. The weir was also moved further from the outlet of the CSP.

Additional coarse embedding material was delivered by a belly-dump truck. A Hitachi EX200 LC moved this material to the culvert site and reconstructed the weir approximately 4.5 m from the outlet of the CSP, closer to the prescribed location. Material, 76-mm minus and 30-cm minus, was also placed inside the CSP using wheelbarrows. To help fill the voids and bring the streamflow up to the surface, the plate compactor was used inside the CSP. A low-flow channel to concentrate the flow was created by hand and functioned well (Figure 9). Exposed soil on cut and fill slopes will be grass seeded to establish vegetation and minimize sediment movement.

Figure 9. Simulated streambed within CSP, showing range of material sizes and a low-flow channel.

Project costs

FERIC's estimate of project costs is shown in Table 1. The purchase and delivery of the CSP accounted for 27% of the overall installation cost. The additional work for the embedding material inside the CSP and moving the weir accounted for approximately 12 hours of labour, 7 hours of the Hitachi EX200 excavator time, one day of compactor rental, one day of supervision, and the delivery cost of the additional 76-mm minus and 30-cm minus aggregate, for a cost of $2 100. The total estimated project cost is $17 700.

Conclusions and implementation

The CSP was installed and embedded during the preferred instream work window for the resident fish species, at a total cost of $17 700. The purchase and delivery cost of the CSP accounted for one-quarter of the overall installation cost.

The installation site was dewatered using a gravity-fed diversion pipe and water pumps. A surveyor and helper measured the precise depth of excavation during the installation to ensure culvert placement. The CSP was filled with material to a height of 72 cm (40% of CSP diameter) using a mini-excavator and wheelbarrows. Culvert backfill lifts were spread and then compacted using a plate compactor. A crawler tractor completed the road to grade over the CSP.

A rock weir was constructed downstream of the CSP to help retain substrate within the culvert, and to provide a back-watering mechanism and pool area. The initial release of water through the CSP resulted in subsur-

Table 1. Estimated project costs [a]

Cost category	Quantity (no.)	Units	Unit cost ($)	Total cost ($) [b]
Materials				
corrugated steel pipe culvert (1.8 m diameter)	17	m	253.38	4 307
76-mm minus aggregate and sand (delivered)	15	m^3	4.25	64
riprap (delivered)	70	m^3	28.00	1 960
30-cm minus aggregate (delivered)	20	m^3	36.58	732
geotextile	100	m^2	1.35	135
Equipment				
excavator (25–30 t) (Hitachi EX270 LC)				
site preparation and CSP installation	13	hours	143.55 [c]	1 866
excavator (20–25 t) (Hitachi EX200)				
additional streambed/weir work	7	hours	126.50 [c]	886
excavator (1 t) (Kubota K088)				
infill CSP	9	hours	50.00 [c]	450
articulated dump truck (10.7 m^3 capacity) (Caterpillar D300D)				
on-site rock relocation/endhaul	5	hours	135.00 [c]	675
crawler tractor (25–30 t) (Caterpillar D7)	9	hours	152.04 [c]	1 368
freight (delivery of CSP)	5	hours	90.00	450
compactor rental	3	days	50.00	150
pumps and hoses	2	days	50.00	100
Labour				
site plan survey & drawings	1	crew	600.00 [d]	600
design drawing drafting	1	set	600.00	600
on-site surveyor and helper	1	crew	600.00	600
site preparation and installation	41.5	hours	30.03 [e]	1 246
Supervision - foreman	3	days	500.00 [f]	1500
Total				17 689

[a] These costs do not include crew transportation, profit, and office overhead, and may not represent the actual costs incurred for the study site. No cost has been associated with the ownership of the diversion pipe, nor mobilization or demobilization of heavy equipment.
[b] Rounded to the nearest dollar.
[c] Hourly rate for equipment includes operator.
[d] Estimated as site plan developed and provided by BCMOF, Kamloops Forest Region.
[e] IWA labour rates effective July 1/01, including 38% wage benefit loading.
[f] Day rate, including wage and benefit loading, is estimated by FERIC.

face flow through the simulated streambed. Additional work within the pipe addressed this issue, and created a flow on top of the streambed, specifically within the constructed low-flow channel.

As experience and innovation develop with installation of closed bottom embedded culverts for small fish streams, efficiencies should allow this approach to be an economic alternative.

Observations were made on-site which may be useful during future installations:

- In order to appropriately design a culvert crossing, the configuration of the proposed road must be known in relation to the proposed culvert. The road width, fill slopes and height, location, and alignment will all affect the required length of the culvert.
- The detailed site plans and design drawings made the requirements of the installation clear and provided example drawings for training purposes and agency approvals. Locating the new culvert was facilitated by the design drawings.
- Specifications for embedding materials should be clearly stated in the design, and should include the size and gradation of preferred material. Unless streambed

(or other local) material is specifically sampled and found to be of suitable size, gradation and volume, it may be preferable to deliver suitable material to the site.

- Voids in the embedding material must be filled to achieve streamflow on the simulated streambed surface. This is especially critical during low flows in order to permit fish passage. Vibratory techniques (plate compactor) or a well-graded mix of streambed material can reduce the voids. Spreading and hosing in of sand and gravel material to 'seal' the streambed can also help bring the water flow to the surface.
- As-built drawings were produced by noting final elevations and modifications on the accepted design drawings. The as-built drawings serve to document conformance to the original design and can be used for monitoring purposes.
- The use of the mini-excavator was experimental, and it was not very efficient during this project. The wheelbarrows were more effective at importing materials into the culvert. The close working space means equipment used to bring streambed material into the culvert must be carefully selected. A powered wheelbarrow has been used successfully in other installations.
- When using wheelbarrows to fill the CSP, the length of their handles should be considered. If the handles are too long, they will hit the top of the CSP when the wheelbarrow is tipped forward to dump the substrate. This becomes more important as the depth of substrate increases. Alternatively, wheelbarrows can be tipped sideways.
- Having the proper array of equipment on-site can increase efficiencies during the project. The crawler tractor was efficient in moving large amounts of fill material over the CSP and building the road up to grade. As well, using the articulated dump truck to move excavated material to and from the endhaul site saved time. An excavator with a live thumb is necessary for placing the riprap. All of the heavy equipment required for this project was available at a nearby road heading, so no mobilization costs were charged to the culvert installation. Costs to mobilize equipment (if not on-site) must be included when determining efficiencies to be gained.
- When preparing the simulated streambed within the CSP, it is important to create a low-flow channel. Without the low-flow channel, the water depth may be too shallow for fish passage.

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