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Installation of an embedded pipe culvert: Lewis Lake tributary

Abstract

The Forest Engineering Research Institute of Canada (FERIC) monitored and documented the installation of a closed-bottom corrugated-steel embedded pipe culvert on a newly built section of forest road near Powell River, B.C. Detailed installation procedures and cost information are presented. Suggestions for implementation of future embedded culverts are given.

Keywords

Stream crossing, 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, constructing, and maintaining stream crossings on forest roads. In British Columbia, fish habitat within the stream must be identified and considered when choosing a stream-crossing structure (BCMOF 2002). Also, Section 35 of the Fisheries Act contains habitat protection provisions, prohibiting the harmful alteration, disruption, or destruction (HADD) of fish habitat, unless authorized, and Sections 22 and 26 prohibit any obstructions to fish migration (DJC 1985).

Embedded culverts are one option for achieving stream-crossing objectives, and providing that efficiencies are promoted they can be cost-effective.[1] A properly designed and installed embedded culvert will include a simulated streambed through its length and offer continuous connectivity of the bedload in the stream channel. Fisheries agency approval or authorization for a HADD is not required if the following conditions are met: the installation is done during the preferred in-stream work window (period of least risk/fish window), the fish habitat is assessed as "Marginal",[2] the average stream width is less than 2.5 m, and the gradient of the stream channel is less than 6% (BCMOF 2002).

In August of 2002, FERIC documented the installation of a closed-bottom corrugated-steel embedded pipe culvert on Weyerhaeuser Company Limited's Stillwater Timberlands Operation in coastal British Columbia. This report describes the installation procedures and presents the estimated cost of the project. Suggestions for implementation of future embedded culverts are given.

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[1] An embedded culvert differs from a typical water-passing culvert in that it is purposefully installed below the streambed level and filled with aggregate through the length of the culvert, up to the natural streambed level. Typical target infill depths are: round culverts filled to 40% of diameter, and pipe arch culverts filled to 20% of their rise. When filled to these infill depths, round culverts have 63% and pipe arches have 83% of the original cross-sectional area remaining for water flow.

[2] The definitions and indicators for "Marginal", "Important", and "Critical" fish habitat are given in BCMOF 2002. "Marginal" habitat has low productive capacity and contributes marginally to fish production. This can be indicated by the absence of suitable spawning habitat, and/or habitat with low rearing potential.

Objectives

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

Site description

The embedded culvert was installed across a tributary stream to Lewis Lake located on the Spring Lake Mainline Road. The crossing location had only the right-of-way felled when FERIC arrived, and no existing stream-crossing structure was in place. Lewis Lake contains cutthroat trout, dolly varden, and rainbow trout[3] and is approximately 400 m downstream from the crossing. The tributary was inventoried for fish prior to the culvert installation. Cutthroat trout were found below the crossing location, but no fish were recorded upstream (FishFor Contracting Ltd. 2002).

The stream at the crossing site had a well-defined channel and an average width of 1.6 m. The substrate was comprised of silt and sand, with small areas containing clean gravels. Small and large woody debris were abundant both upstream and downstream of the crossing location. The stream gradient at the crossing was 5–6%. The fish habitat at the crossing location was classified as "Marginal" (FishFor Contracting Ltd. 2002). The drainage area above the crossing site is 35 ha and the estimated 100 year high-water stream-flow event (Q100)[4] is 4.9 m^3/s.[5]

Stream flow was minimal prior to and during the installation. The natural stream channel had numerous stretches devoid of surface flow and pools of water were isolated from one another due to the lack of surface water. Fish were observed in a few isolated pools downstream of the installation site.

Planning and design

To develop the design for the crossing, StoneCroft Project Engineering of Black Creek, B.C. completed a stream profile and a site survey using a transit level and rod before the right-of-way was felled. A benchmark was located on a tree outside of the right-of-way on the upstream side of the road. The detailed designs specified the use of a 2.7-m-diameter embedded culvert along the tributary stream. The design drawings included the proposed culvert being shown on the site plan, both in plan and profile view. This overlay showed the culvert with respect to the tagged centreline of the unbuilt road, stream channel, contours, and benchmark. The design elevations for the invert (bottom) at the inlet and outlet of the culvert were also indicated.

Materials and equipment

The culvert, supplied by Armtec Limited, was delivered in two sections, each 7 m long, 2.7 m in diameter, and 3.5 mm thick (10 gauge). The corrugation profile measured 125 mm by 25 mm. The inlet section was prepared with a step-bevel. The two sections were joined using one Huggar Band 500 coupler. The coupler was comprised of three pieces, joined together by six bolts at each connection. The installation designs included:

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3 Source for fish species information is Fish Wizard found at http://pisces.env.gov.bc.ca.

4 Q100 refers to the predicted discharge (Q,m^3/s) for an event which on average occurs once during the specified interval (100 years).

5 Brad Beaton, StoneCroft Project Engineering, personal communication, June 2003.

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- Live load rating of BCMOF L-165 truck (approximately 150 tonnes gross vehicle weight).
- Inlet of culvert bevelled at a slope of 1:1.
- The use of non-woven geotextile as a "seal" near the outlet end of the culvert.
- A minimum of 70 cm of fill covering the culvert along the road's running surface.

Equipment and supplies used during the installation included:

- Heavy equipment: John Deere 330 LC excavator (primary) with digging bucket and live thumb, Hitachi EX270 LC excavator (secondary) with digging bucket and live thumb, Bell B25B six-wheeled articulating dump truck.
- Survey equipment: one set of installation designs, level on a tripod, rod, nylon measuring tape, and spray paint.
- De-watering/seepage management equipment: 3.0-kW Mitsubishi volume pump (620 L/min), three lengths of 15-m hose, and a plastic bucket for intake of pump.
- Infilling equipment: self-dumping, tracked skid-steer 4.1-kW Kubota KC50 wheelbarrow, with maximum designed carrying load of 700 kg. Bucket area is 80 cm wide, 125 cm long, and 34 cm deep (0.34 m^3). The width of the wheelbarrow, measured from the outside of the tracks, is 81 cm.
- Other items: 534-kg plate compactor (86 cm long by 55 cm wide), electrical impact gun, and non-woven geotextile.
- Miscellaneous hand tools: shovels, rake, and knife.

The material excavated from the stream channel was endhauled to a spoil site. Culvert bedding, backfill, and infill material were all produced from a nearby cutbank. The material in the cutbank was "weathered/rotten rock" which was easily ripped using the secondary excavator's digging bucket. The ripped cutbank material was predominantly coarse sand with few cobbles. The riprap was salvaged nearby and also blasted from a nearby bedrock outcrop, and ranged in size from 39 to 112 cm.

Site preparation

A pre-construction meeting was held on-site outlining the environmental and safety concerns of the project. The site preparation is described in the following three steps:

Preparing road access

The right-of-way at the stream-crossing site was manually felled one day prior to the embedded culvert installation. The primary excavator prepared access to the crossing site for the articulated truck by clearing the right-of-way, and building a corduroy trail with unmerchantable stems (Figure 1).

Stockpiling aggregate

In preparation for the use of aggregate (riprap, bedding, backfill, and infill) during the culvert installation, the truck, loaded by the secondary excavator, stockpiled riprap close to the stream crossing. The initial stock-piles were comprised of riprap. Bedding, backfill, and infill material (Figure 2) were produced from a nearby cutbank and delivered during the installation.

Figure 1. Excavator smoothing the surface of the corduroy trail.

Figure 2. Material for bedding, backfill, and infill was predominantly coarse sand.

Field referencing

Using the design drawings and the established benchmark for reference, the location of the proposed inlet was marked with a stake. The stake and the designed outlet location were marked with spray paint for visibility.

Installation

The installation crew consisted of the primary excavator operator, the secondary excavator operator, the truck driver, an environmental monitor, and a forest worker. Two fish habitat/biology specialists from FishFor Contracting Ltd. of Port McNeill were on-site to give advice during the construction of the simulated streambed. The installation procedure is described in the following nine steps:

Seepage/water management

The primary excavator prepared a sump at the downstream end of the installation site with the excavated soil endhauled to a spoil site approximately 2 km away. The sump collected seepage and stream flow during the installation of the embedded culvert. The sediment-laden water was pumped into the forest approximately 30 m away from the stream, for filtering through the forest floor.

Excavation

The primary excavator prepared a site approximately 6 m wide and 1.5 m deep. The excavated material was not considered appropriate for re-use as backfill or infill material. Therefore, it was loaded directly onto the articulated truck and hauled to the spoil site. The environmental monitor used a construction level and rod to check the depth of excavation against the design elevations (relative to the field benchmark) for the invert at the inlet and outlet of the culvert. This ensured the culvert was installed at the design gradient.

Figure 3. Prepared excavation showing the use of riprap at either end, a layer of bedding material through the length, and geotextile before being cut. Dashed line shows approximate cut line.

Bed preparation

The bottom, or bed, of the excavated trench was prepared for the placement of the culvert. Riprap was placed at each end of the excavation and pounded into the soil with the bucket of the excavator. The purpose of the riprap was to support the culvert at each end and minimize settling and movement over time. Elevations were checked after the riprap had been placed. The truck delivered a load of coarse sand for bedding material and the excavator spread this material over the placed riprap and along the length of the prepared excavation.

A section of non-woven geotextile (approximately 6 m by 4 m) was placed near the outlet area of the prepared excavation (Figure 3). The purpose of the geotextile was to act as a barrier to fine soil movement along the outside edges of the culvert. The geotextile was cut near its centre, parallel to the stream, in preparation for raising and tying it around the culvert. The cut did not extend all the way through the length of the geotextile; the geotextile was in one piece.

Placement and coupling

The primary excavator unloaded the culvert approximately 150 m away from the crossing location and walked each section of the culvert to the installation site. At first, the excavator lifted a culvert section using chains, but the culvert was not held securely by the chains so this method was abandoned in favour of lifting straps (Figure 4). By placing the straps completely around the culvert at either end, the risk of bending or damaging the culvert was reduced. Once the inlet section was properly positioned in the prepared excavation, the second section of the culvert was brought to the site.

The excavator lifted one end of the placed culvert section so that one of the three sections of the coupler could be placed below the culvert. The remaining two sections of the coupler were joined loosely together (Figure 5) and placed on top of the first culvert section. The excavator used one lifting strap to lift and drag the second section of the culvert towards the first section (Figure 6). The second lifting strap was left fastened to the outlet end of the culvert and re-attached to the excavator during final alignment. Once the two culvert sections were abutted and aligned, the coupler was bolted together. An impact gun worked well to tighten shorter bolts around the coupler. A deep socket attachment was not available for the longer bolts so these were tightened by hand. Securing the two culvert sections together with the coupler took approximately 1.5 h.

Figure 4. Lifting straps were used to carry the inlet section of the culvert.

Figure 5. Two sections of the three-piece coupler being loosely joined together.

Figure 6. Second section of the culvert being dragged towards the first section using a single lifting strap. Notice the section of the coupler below the culvert.

Backfilling

Backfilling of the entire culvert length started once the coupler was secured and the geotextile was lifted and tied together over the top of the culvert. The excavator delivered coarse sand from the nearby cutbank to both sides of the culvert for use as backfill material. The excavator operator could not see below the far side of the culvert, so a helper used hand signals to indicate where the operator should place and deliver material along the far side of the culvert. The excavator was nearly at its maximum reach when delivering backfill material to that location.

In Weyerhaeuser's experience, two excavators are preferred for installation of round culverts 3000 mm and greater. This eliminates lifting and placement constraints, and aids delivery of backfill material to both sides of the culvert, because a single excavator has difficulty placing backfill material on the far side of a 3000-mm-plus culvert installation. A second excavator situated on the far side eliminates this problem. However, two excavators increase the final installation cost of an embedded culvert.

The initial backfill lifts were forced below the culvert (haunch area) by using the hose to direct pumped sump water (Figure 7). The forest worker compacted the backfill material in this area with her boots. The backfill lifts near and above the haunch area were compacted using a single 534-kg plate compactor. Pre-compacted lifts were approximately 30 to 40 cm deep. Each delivered lift was raked flat in preparation for compaction by the plate compactor. The excavator lifted the plate compactor from one side of the culvert to the other, as needed (Figure 8).

Figure 7. Forest worker using pumped water to force backfill material below the haunch of the culvert.

Figure 8. Forest worker attaching plate compactor to excavator's bucket hook in preparation for lifting it to the other side of the culvert. Notice the geotextile tied over the top of the culvert.

Figure 9. Wheelbarrow delivering infill material near the inlet of the culvert.

The excavator gathered and placed riprap while the backfill was raked and compacted. The inlet was almost completely armoured with riprap by the time infill material was placed within the culvert.

Infilling

The delivery of infill material started once the backfilling and compaction were completed. A motorized tracked self-dumping wheelbarrow delivered material within the culvert (Figure 9). The wheelbarrow was placed in the inlet area (staging area) by the excavator, which then loaded the wheelbarrow. The wheelbarrow delivered the first layer of infill material starting at the inlet and worked its way towards the outlet. This allowed the wheelbarrow to deliver material in front of itself while creating a flat travel surface. This layer was approximately 30 cm deep. Once the initial layer was completed, the wheelbarrow delivered material to the desired height starting at the outlet and working back towards the inlet. The culvert was filled to 40% of its diameter (108 cm deep) during the second pass.

Detailed timing showed that it took 2.0 min for the wheelbarrow to be loaded, travel approximately 13 m (maximum distance was 14 m), dump the load, and travel backwards out of the culvert to the staging area. This cycle time became shorter as the distance travelled became shorter. The culvert was filled to target depth in 3.2 h with approximately 30 m^3 of material delivered in 88 loads. The powered wheelbarrow was a very efficient way to fill the culvert.

The final delivery of material was typically on top of an area 30% filled (189 cm clearance), while the height of the wheelbarrow's bucket when tipped forward during dumping was 168 cm. There was sufficient room inside the culvert to allow the wheelbarrow to deliver material to the target infill depth.

Simulated streambed enhancement

Once the infilling of the culvert was completed, the simulated streambed was prepared. FishFor Contracting Ltd. was on site to guide this stage of the installation process. The powered wheelbarrow delivered large aggregate for placement along the surface of the simulated streambed. The excavator placed some of the larger aggregate at the staging area, which was rolled a short distance for use within the culvert near the inlet.

The larger aggregate was used to build rock spurs and for random placement, both within the culvert. The placement of the larger aggregate was all done by hand. Shovels and rakes were used to move material and to dig a shallow meandering low-flow channel. The rock spurs projected towards the centre of the culvert from alternating sides to create a meandering channel during low water flows (Figure 10). The spurs and the randomly placed aggregate offer areas of lower water velocity (velocity shadows), which serve as resting areas for fish passing through the culvert.

The pump and hose were used to deliver sump water to the surface of the simulated streambed. This "washing" of the surface showed that water would flow along the surface, and also promoted subsurface voids to become filled with sand and fines.

The excavator delivered some infill material to the surface of the staging area and in the same area placed large woody debris along the streambed surface. The staging area was "washed" with pumped water (Figure 11). After the initial washing phase, the hose was positioned near the inlet and left alone, allowing pumped water to continue flowing through the culvert.

The width of the simulated streambed within the culvert averaged 2.6 m, which was greater than the average stream width (1.6 m). The natural stream was not constricted as it entered or travelled through the culvert.

Armouring

Riprap was delivered near the inlet and outlet of the culvert. The excavator started at the inlet area, allowing the sump at the outlet to continue to function until the end of the installation. Armouring had been started during the infilling of the culvert. The excavator armoured the fillslopes adjacent to and over the top of the culvert. Single pieces of riprap were placed along the streambank where needed. The riprap ranged in size from 45 to 110 cm. The outlet area was also armoured and had large woody debris placed in a similar manner as at the inlet.

Stream channel blending/ reconnecting

In preparation for armouring the outlet area, the sump was pumped dry and filled with large aggregate. Coarse sand was spread over the surface of the filled sump area. The source of pumped water (the sump) was no longer present and therefore the coarse sand could not be washed into the surface. The natural stream flow was minimal during these final stages of the installation and sufficient water was not available for washing the surface. However, the sump area became saturated with stream flow over time. The simulated streambed blended into the existing stream channel within 3.7 m of the outlet of the culvert.

Figure 10. Final simulated streambed surface showing meandering low-flow channel between rock spurs.

Figure 11. "Washing" the staging area near the inlet of the culvert. Note the large woody debris.

Road and grade work

The excavator built the road up to its final grade. Fill material was delivered by the truck and the excavator used a log to prepare a flat surface. The road length associated with the installation extended approximately 15 m on either side of the culvert. The finished road width measured between 6.0 and 6.1 m. The final road grade was prepared with the lowest area away from the culvert location, to keep road surface runoff from directly entering the stream.

The survey equipment was used during this time to check the gradient of the installed culvert, which measured 6.7%. The height of fill above the culvert was 98 cm (Figure 12). The gradient of the simulated streambed through the culvert was 6.8%.

Figure 12. Excavator preparing road surface above the installed embedded culvert.

Project costs

FERIC's estimate of project costs is shown in Table 1. The purchase and delivery of the culvert accounted for one-third of the total installation cost. Two other FERIC studies of embedded culvert installations estimated the purchase and delivery cost to account for 23% and 27% of the total installation cost (Gillies 2002a,b).

The aggregate produced and delivered during the installation included 20 loads of backfill (240 m^3), 3 loads of infill material (36 m^3), and 7 loads of riprap (84 m^3).

Five calendar days were required to complete the installation. Not all the time during the five days was allocated to the embedded culvert installation. The first day required 5 h of the environmental monitor's time (project start-up, pre-construction

Table 1. Estimated project time and costs [a]

Cost category	Quantity (no.)	Units	Unit cost ($)	Total cost ($) [b]
Materials				
corrugated steel pipe culvert (2.7 m diameter) (delivered)	14	m	705.36	9875
geotextile	24	m^2	1.35	32
Equipment				
primary excavator (35–40 t) (John Deere 330 LC)				
site preparation and installation	38	hours	148.21 [c]	5632
secondary excavator (25–30 t) (Hitachi EX270 LC)				
aggregate production	18	hours	131.77 [c]	2372
articulated truck (12 m3) (Bell B25B)				
endhaul, aggregate and riprap delivery	33	hours	126.90 [c]	4188
compactor rental	1	week	450.00	450
powered wheelbarrow (rental)	1	week	450.00	450
pump and hoses (rental)	1	week	300.00	300
Labour				
stream profile and site survey	1	crew	600.00	600
engineering (site plans/designs, certification)	1	set	2000.00	2000
habitat assessment	1	crew	1800.00	1800
environmental monitor/site supervisor	41	hours	31.71 [d]	1300
forest worker	18	hours	30.62 [d]	551
Total				29 550

[a] Time presented is for productive time only. 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 mobilization or demobilization of heavy equipment.
[b] Rounded to nearest dollar.
[c] Hourly rate for equipment includes operator.
[d] IWA labour rates effective June 15, 2002, including 38% wage benefit loading.

tailgate meeting, etc.) and 2.5 h of the primary excavator's time (when clearing felled stems 15 m to either side of the stream crossing). A 1.5 h delay occurred during the last day of the installation to blast a rock outcrop. The secondary excavator was used for two days, and the forest worker was on-site for three partial days. No time was allocated for the professional advice from FishFor Contracting Ltd., as they were nearby for other duties. In this case, the fee for their professional advice is included in the habitat assessment.

Conclusions and implementation

An embedded culvert was installed as a new crossing during an instream work window on a stream containing resident fish. The total cost of the installed culvert, including field surveys and designs, habitat assessment, and aggregate production and delivery was $29 600. The purchase and delivery cost of the culvert accounted for one-third of the overall installation cost.

The 2.7-m-diameter, 14-m-long culvert was installed using one 35–40 t excavator. (A larger culvert would have required the use of two excavators, which would have increased the total cost of installation.)

The backfill, bedding, and infill materials were produced from a nearby cutbank using a second excavator. The coarse sand prepared from the cutbank was an excellent material for use during the installation. Riprap was salvaged along the newly built road, and from a nearby blasted rock outcrop.

A powered wheelbarrow delivered approximately 30 m^3 of material within the culvert in 3.2 h. The powered wheelbarrow was very efficient at delivering infill material to a culvert of this diameter.

The stream had a minimal flow during the mid-summer installation (fish window) and therefore the risk for sediment transport was low. Downstream pools were isolated from one another due to the lack of surface flow.

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

- A benchmark was established during the site survey, and eventually used during the culvert installation to locate the desired position of the inlet. A semi-permanent benchmark is necessary to install a culvert according to a prepared design.
- A prepared design can greatly enhance the ease with which an embedded culvert is installed. Critical aspects of the design are the established inverts of the inlet and outlet which are directly correlated to the depth of excavation.
- Because of the extremely low flows during the installation period, water for use during installation was scarce. Water was needed for jetting backfill material under the haunches of the culvert, and washing the surface of the simulated streambed. Once the downstream sump was filled with aggregate, water was not available for washing this area. Before the sump was filled, water from the sump could have been pumped and saved in containers for final use.
- Subsurface flow within the culvert is a common concern when embedding culverts. The aggregate produced from the cutbank was an excellent material for the simulated streambed. The streamflow was along the surface of the simulated streambed, suggesting that any voids below the surface were filled during the "washing."
- Rock spurs were built along the surface of the simulated streambed to promote a meandering channel through the culvert and to offer velocity shadows for fish passage through the culvert during high flows.

- A low-flow channel was built along the surface of the simulated streambed, following the meander between the rock spurs to concentrate the streamflow and allow fish passage during low flows.
- The powered wheelbarrow did not have any constraints when dumping inside the culvert. The smallest diameter culvert that would allow this machine to dump on top of an area already 30% full would be 2.4 m. A 2.0-m-diameter culvert could have material delivered into it, but shovels would be required to pile the material higher within the culvert to reach the target (40% diameter) infill depth.
- Appropriate lifting straps should be used to lift large culverts during delivery and installation. In this case, chains were used at first to lift and move the culvert but did not offer the proper support during lifting, so a short delay occurred while waiting for a set of straps to arrive.
- Large woody debris placed near or within a culvert should not interfere with the hydraulic capacity of the culvert. Large boulder placement should be considered as well.
- Gillies (2003) has prepared an overview of twelve closed-bottom corrugated-steel embedded culvert installations which may be useful for potential users of these structures to gain additional information.

References

British Columbia Ministry of Forests (BCMOF). 2002. Forest practices code of British Columbia: Fish-stream crossing guidebook. Victoria, B.C. 68 pp.

Department of Justice Canada (DJC). 1985. Fisheries Act, Chapter F-14. Ottawa, Ont.

FishFor Contracting Ltd. 2002. Habitat assessment for the proposed culvert installation in stream 17 - Spring Lake Main, Lois Lake watershed. Prepared for Weyerhaeuser Company Limited, Stillwater Timberlands. Powell River, B.C. 39 pp.

Gillies, C. 2002a. Installation of an embedded pipe culvert: Stuart Lake tributary. FERIC, Vancouver, B.C. Advantage Report Vol. 3 No. 40. 8 pp.

Gillies, C.T. 2002b. Installation of an embedded pipe culvert: Hotfish Creek. FERIC, Vancouver, B.C. Advantage Report Vol. 3 No. 38. 11 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.

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