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Installation of an embedded pipe culvert: Hotfish Creek

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 perched culvert. 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.

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 monitored the installation of an embedded corrugated-steel pipe culvert (CSP), as a replacement for an existing perched CSP. The installation was done under contract to the BCMOF, 100 Mile House Forest District, Small Business Forest Enterprise Program by a contractor that had previous experience with open-bottom culverts. The installation works were carried out in October during the preferred instream works 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.

Site description

The site of the culvert is approximately 70 km northeast of 100 Mile House on the Spanish/Art Creek Forest Service Road (Figure 1). Hotfish Creek, with an S3 classifiication,[1] contains rainbow trout and has no known fish barriers downstream of the culvert site to Hotfish Lake. At the road crossing, the stream passed through a 0.9-m diameter, 20 m long CSP (composed of three sections). The existing CSP had been installed during road construction in 1989, and was not embedded. The outlet was perched with an 18–21-cm drop, creating a barrier to 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).

Figure 1. View of installation site before construction. Arrow indicates where existing CSP passes through the road.

Figure 2. Outlet of the existing CSP showing the fish barrier and fish traps placed in the plunge-pool.

passage (Figure 2). At the road crossing, the stream had a well-defined channel both up and downstream, 1.6–1.8 m wide with a gradient of 4–6%. The road's horizontal and vertical alignment changed at the crossing. The road surface width was approximately 7 m, and 1.7 m of road fill covered the top of the CSP.

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 by BCMOF, Cariboo Forest Region, Engineering Section, using a total station instrument. The stream survey extended at least 35 m on either side of the installation site, and the roadway was surveyed for 75 m on either side. Adjacent areas which could influence the design were also included in the survey. 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, road centreline 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 1.8 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 in 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 specs, weir specs, 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 new embedded culvert was referenced to the benchmark and horizontal reference stakes. Drawings showed the

[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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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, supplied by Atlantic Industries Limited, was delivered in three sections, each 7 m long, 2.0 m in diameter, and 2.8 mm thick (12 gauge). The sections were joined using two fully corrugated (annular) couplers. Each coupler was comprised of two pieces (top and bottom sections), joined together using five bolts on each side. The design specifications included:

- Design live load rating of 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 EX200 LC with bucket and live thumb, and a Pacific P9 dump truck with trailer.
- Survey equipment: level with tripod, rod, nylon measuring tape, and string.
- Dewatering equipment: 57-cm diameter spiral corrugated plastic diversion pipe (6 sections and 5 collars totaling 40 m), sandbags, sand, 2.8-kW Honda volume pump, and 3.0-kW Shindaiwa volume pump.
- Fish/water quality protection supplies: 6.3-mm wire mesh, woven geotextile, fish/minnow traps, rebar stakes, wooden stakes, and staples.
- Embedding equipment: wheelbarrows and shovels.
- Hand tools and other items: jumping-jack compactor, tape measure, woven geotextile, lifting chains, ratchet, C-clamp, spray paint, and knife.

Culvert backfill material was obtained from the original excavation and from the road banks near the installation site. Sand and gravel, and coarser cobbles and boulders were imported and stockpiled separately on-site for use as embedding material inside the culvert. The coarse material had been screened and washed, while the sand and gravel were pit-run. Large riprap (approximately 90-cm diameter) was obtained on-site and stockpiled on both sides of the existing CSP.

Site preparation

The site preparation included five steps: fish isolation/salvage, stream diversion, culvert delivery, field referencing, and removal of existing culvert.

Fish isolation/salvage

Wire-mesh fish screens were installed above and below the existing CSP to prevent fish from entering the installation site. The screens were supported with sections of rebar, and secured along the channel bottom with large rocks. On the downstream side, a silt fence was placed upstream of the wire-mesh screen. The silt fence was made of geotextile stapled to wooden stakes. Baited fish traps (minnow traps) were set between the two wire-mesh screens at the outlet plunge pool and at the inlet area to capture any fish present (Figure 2). Some fish were captured and relocated to the downstream side of the installation site.

Stream diversion

The excavator prepared a trench for the gravity-fed diversion pipe, positioned on the bush side of the stream 2–3 m from the installation site. The excavator placed five pipe sections in the prepared trench and they were joined using screw-on couplers. A diversion dam was built upstream using sandbags and sand to channel the flow into the pipe. The pipe was covered with fill to anchor it and allow the excavator to cross if necessary. After the fill was placed, the sixth length of pipe was added at the outlet to improve the delivery of water to the stream, specifically to keep the water from flowing along the bank before re-entering the stream. The excavator lifted the outlet end of the pipe while the coupler and additional section were attached (Figure 3).

Culvert delivery

The three sections of 2.0-m CSP were delivered on two trucks and a trailer. The excavator used chains to lift each section of CSP, placing them in a clearing at a road junction 350 m from the installation site until needed.

Field referencing

The culvert design drawings showed the vertical and horizontal location of the culvert in relation to field references established during the site survey. Culvert centreline stakes, both downstream and upstream, were established by measuring from the horizontal field reference stakes as detailed in the design drawings. Additional stakes and spray paint marked the culvert centreline, inlet, and outlet positions on the ground, and a stringline was established along the centreline. Offset lines, 1.5 m on either side of the centreline, were painted on the ground to mark the width of the required excavation.

Figure 3. Forest worker preparing diversion pipe (being lifted by excavator) in preparation for adding an additional section.

Figure 4. Excavator removing coupler between two sections of the existing 900-mm CSP. Notice one section has been removed already.

The reference points and lines for locating the culvert were periodically checked to ensure location and alignment. An elevation benchmark was referenced periodically with the construction level to help monitor the depth of excavation.

Removal of existing culvert

The excavator worked from the town side of the stream during the entire installation process, starting at the upstream end. As the old CSP was excavated, the material was piled on-site for re-use. The entire length of the culvert was uncovered before each section was removed (Figure 4) and stored 20 m away.

Installation

Installation is presented in nine steps: seepage management, excavation, placement and coupling, backfilling, embedding, armouring, splash-pad construction, stream channel blending, dismantling and reconnecting.

Seepage management

Two gasoline-fuelled water pumps helped to manage seepage into the excavation site. One pump removed sediment-laden water from a downstream sump (existing plunge pool area) and spread it onto the forest floor, while the other was used for various tasks.

Excavation

The installation crew consisted of the excavator operator, a forest worker, a surveyor, and a foreman. Seven additional people were on-site for one day to help install the material inside the CSP.

Once the old CSP was removed, the excavator continued to excavate for the installation. The surveyor and forest worker used a level on a tripod, a rod and a tape measure to guide the elevation of the new structure. As the excavation proceeded, measurements were taken to establish the final invert (bottom of culvert) depth at the inlet and outlet, as well as depths through the length of the excavated trench to help establish the gradient (Figure 5). Depths were checked often until the final excavation was established.

Figure 5. Surveyor checking depth of excavation along the length of the prepared trench.

Placement and coupling

The first section of the CSP was placed in the prepared trench, starting at the inlet. Sections had been labelled during a dry run coupling before delivery to show the order of placement. Final placement was established by checking the distance from an upstream centreline stake to the inlet. Once the first section of CSP was placed, a coupler was prepared. The excavator used the edge of its bucket to lift the CSP, allowing the bottom piece of the coupler to be positioned underneath it (Figure 6). The top section of the coupler was then placed on top of the first section of CSP in preparation for final placement and tightening. The second section of CSP was then placed in the trench abutting the first section (Figure 7).

Figure 6. Excavator lifting one end of the CSP while forest workers place the bottom side of a coupler under it.

Some minor adjustments to the placement of the first two sections of CSP were made to ensure the tightest fit possible before the coupler was tightened. A C-clamp held the top and bottom flanges of the coupler together and five bolts were threaded through the holes in the metal plate. The couplers were then tightened on both sides of the CSP. The second coupler and third section of CSP were prepared and placed in the same manner; again alignment was checked before securing the coupler. Each coupler took approximately 45 minutes to secure.

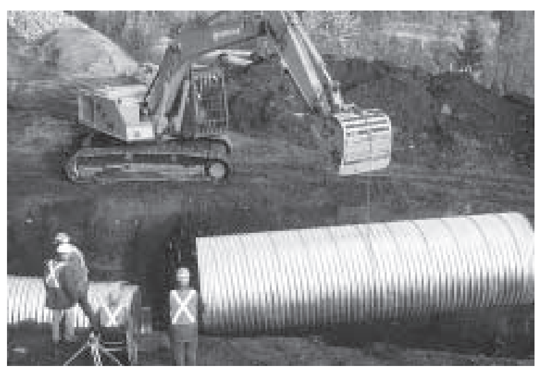

Figure 7. Excavator lowering second section of CSP into place. Notice bottom section of coupler in place below the stationary section of CSP.

Backfilling

Backfilling and embedding started once all the sections of the CSP were in place and the two couplers were secured. It was snowing at the time and the excavated fill material, to be re-used as backfill, became wet. Drier portions of this fill material were placed on both sides of the CSP in 30–40-cm lifts, with each lift compacted using a single jumping-jack compactor (Figure 8). The excavator moved the compactor from one side of the CSP to the other. Backfill lifts and compaction continued until the CSP was half

Figure 8. Jumping-jack compactor. Notice the swath to the left of the forest worker (arrow) compacted during one pass.

covered with backfill material, and then the embedding material was placed in the CSP.

Once the embedding was essentially complete, the culvert backfilling continued. The snow had continued, and the fine-textured material from the original excavation became too wet to use. The excavator retrieved dry material from the road bank, forwarded it to the installation site, and cleared the road of the saturated material. This additional work slowed the operation.

Embedding

The inside of the CSP was filled to a depth of 80 cm (40% of CSP diameter) using the stockpiled sand, gravel, cobbles, and boulders. A fill-height line was spray painted inside the CSP to show the target depth. A wooden stick was also cut to the appropriate length (120 cm) to measure down from the roof of the culvert at its center.

A crew of seven was used for the embedding portion of the operation. The excavator brought material from the stockpiles to the inlet of the culvert, and lowered the bucket close to the wheelbarrows. The crew used shovels to guide the material into the wheelbarrows (Figure 9), and delivered it to the outlet end first (working back towards the inlet). Two wheelbarrows were used and 2–3 men worked inside the CSP with shovels to create the simulated streambed. At the beginning, loads of finer sand and gravel were delivered alternately with loads of the coarser cobbles and boulders. The materials were mixed with shovels and by hand inside the culvert (Figure 10). Later in the process, fine and coarse materials were mixed using the excavator bucket before being loaded into the wheelbarrows. Dumping the wheelbarrows in front of the previously placed material was easier than trying to ramp up to the top of the finished surface.

A pump and hose were used to wash the sand and gravel into the embedding material, filling the voids. Additional sand and gravel were added and the washing continued until water remained on the surface, in effect sealing the streambed. (When the voids are filled with sand and gravel the water flows over the simulated streambed and not subsurface.) During the washing process, a sump at the end of the culvert was maintained to prevent sediment-laden water from entering the stream. The water was pumped onto the forest floor, away from the stream.

The excavator delivered boulders (40–50 cm diameter) to both ends of the CSP, and these were rolled into the culvert and placed at various locations. The boulders offer heterogeneity to the substrate as well as microhabitat and waterflow variations. The pump remained running and the hose was secured with rocks to continue delivering water to saturate the embedding material while other activities were conducted. The embedding crew worked one full day to install the material into the CSP.

Figure 9. Embedding crew filling wheelbarrows at inlet end of CSP. (Photo courtesy of Brian Chow, BCMOF.)

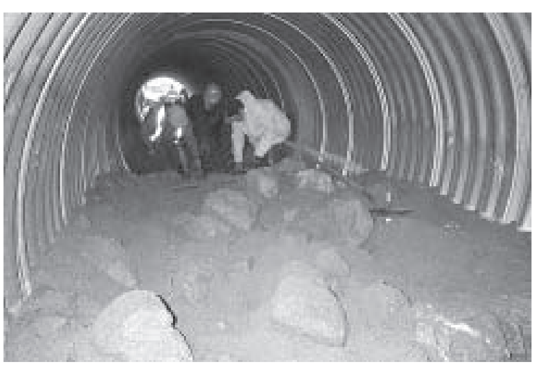

Figure 10. Forest workers mixing material within the CSP. Note fill-height line spray pointed inside CSP. (Photo courtesy of Brian Chow, BCMOF.)

Armouring

Once the CSP was covered with fill, the excavator prepared the inlet and outlet fill slopes for placement of riprap as armouring. First, woven geotextile was placed on the fill adjacent to the culvert. The geotextile will reduce the migration of fine material from the road fill into the stream. The fill slope was re-graded and pulled back in some places in preparation for the riprap. The excavator then armoured around the inlet and outlet of the CSP, extending the riprap over the top of the pipe.

Splash-pad construction

A splash-pad was constructed instead of the rock weir planned in the design.[4] The excavation at the outlet, beyond the end of the culvert, was backfilled to streambed level with coarse cobble and boulder materials. Fines were added to fill the voids and seal the material to keep the water flow on the surface. The resulting splash-pad will function as a slight back-watering mechanism and prevent scouring and erosion in this area (Figure 11).

Stream channel blending

While the excavator worked near the streambed at the inlet shaping the slope and placing riprap, coarse cobble material was spread within the stream channel to blend the new and existing channels. At the inlet, the newly constructed channel was 10 m long and 6–7 m wide.

Dismantling and reconnecting

The diversion dam was dismantled by hand, initially releasing only a portion of the stream flow. The water percolated into the blended streambed as it reached the inlet area of the CSP. The excavator placed a bucket of sand and gravel at the inlet area, and this material was washed into the streambed. Eventually the inlet area became sealed and the water flow rose to the surface. The flow through the newly-constructed streambed channel was on the surface and flowing clear(Figure 12). The pump at the down-stream sump area removed sediment-laden water onto the forest floor during this time.

Once the dam was completely dismantled, the excavator uncovered the diversion pipe and lifted it out of its trench. Pipe sections were moved along the road where they were uncoupled and loaded onto a trailer.

Figure 11. Final installation at downstream side of CSP showing riprap armouring and location of splash-pad (arrow).

Figure 12. Final simulated streambed within the CSP, showing range of material sizes and streamflow spread across the width of the streambed.

Road and grade work

After the culvert installation was completed, the road grade was re-established. The fill material was excavated from the road bank, where the material was drier than the stockpiled material. Excavating and delivering it to the site took considerable time. A 35-m long section of geotextile (5-m wide) was laid on top of the road section above the CSP, on approximately 1.7 m of fill, to separate the wet underlying material from the drier final lifts.

As the excavator placed fill over the geotextile, the surveyor used the level and rod to check the precise height. The finished grade added another 80 cm of fill, resulting in 2.5 m of fill as specified by the design drawings. The surveyor also checked CSP and streambed gradients at this time. The CSP was installed at a slope of 5.9% and the simulated streambed through the culvert measured 5.6% gradient, matching the natural stream gradient well.

4 The change was approved on-site by the BCMOF designer.

Forty metres of road were re-built to a width of 6.5 m. The road height was 1.5 m higher than the pre-installation location.

The excavator travelled over the re-built road section several times to firm the fill. Final placement of riprap armouring was done once the road work was finished. Fill slopes were graded to a final slope of 1.7:1 (Figure 13). Exposed soil on cut and fill slopes will be grass seeded to establish vegetation and minimize sediment movement. The pump was removed from the down-stream sump area, and the wire-mesh fish screens and silt fence were removed. The excavator filled the bank excavation with the saturated material from the original excavation.

Figure 13. Excavator grading the final road fill at inlet of embedded CSP. Notice the final placement of the riprap armouring.

Project costs

FERIC's estimate of project costs is shown in Table 1. The purchase and delivery cost of the CSP accounted for approximately one-quarter (23%) of the overall installation cost. Installation of the diversion pipe accounted for 34.5 hours of the labour included for the site preparation and installation, and 11.5 hours of the excavator's time. The additional work created by the wet weather (preparing saturated road surface and excavating/forwarding dry material) accounted for approximately 10 h of the excavator's time. The total estimated cost of the installation is $28 800.

Conclusions and implementation

An embedded pipe culvert was selected by the BCMOF as a replacement for 20-m long corrugated steel pipe culvert along a creek with resident fish. The existing CSP was elevated at the outlet creating a barrier to fish passage. The replacement CSP was installed and embedded during the preferred instream work window for the fish species for a total cost of $28 800. The delivered CSP accounted for one-quarter of the total installation cost.

During the installation, the site was dewatered using both a gravity-fed diversion pipe and water pumps. A surveyor on-site measured the precise depth of excavation and checked the final levels for the CSP and simulated streambed surface. The CSP was filled to a height of 80 cm (40% of diameter) with material of various sizes. Wheelbarrows transported the embedding material into the pipe, and shovels were used to build the simulated streambed. The excavator built the road to final grade. A splash-pad, built downstream of the CSP, will function as a back-watering mechanism and pool area, and help to prevent scouring and erosion in this area.

When the streamflow was released into the inlet area, it percolated below the surface. Additional sand and gravel filled the voids and the water flowed on top of the newly constructed stream channel. Washing the embedding material to fill the voids was an effective technique, as it sealed the streambed and water then flowed on the surface. Boulders were placed throughout the CSP to provide flow and habitat diversity.

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

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

- 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.

Table 1. Estimated project costs [a]

Cost category	Quantity (no.)	Units	Unit cost ($)	Total cost ($) [b]
Materials				
corrugated steel pipe culvert (2.0 m diameter) (delivered)	21	m	314.9	6 613
23-cm minus aggregate (delivered)	52	m^3	41.13	2 139
sand (delivered)	28	m^3	29.61	829
geotextile	275	m^2	1.35	371
Equipment				
excavator (20 - 25 t) (Hitachi EX200)				
site preparation and installation	65.5	hours	132.00 [c]	8 646
compactor rental	2	days	50.00	100
pumps and hoses	5	days	50.00	250
Labour				
planning site survey	1	crew	600.00 [d]	600
design drawing drafting	1	set	600.00	600
fish salvage	1	crew	500.00	500
embedding crews	7	person	250.00	1 750
site preparation and installation	88.5	hours	30.03 [e]	2 658
surveyor during construction	40.5	hours	30.03 [e]	1 216
Supervision - foreman	5	days	500.00 [f]	2 500
Total				28 772

[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 nearest dollar.
[c] Hourly rate for excavator includes operator.
[d] Estimated as works provided by BCMOF.
[e] IWA labour rates effective July 1/01, including 38% wage benefit loading.
[f] Day rate, including wage and benefit loading, are estimated by FERIC.

- Specifications for embedding materials should be clearly stated in the design, and should include the size and gradation of preferred material.
- 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.
- Prior to being delivered to the site, the three sections of CSP were aligned and joined together with the couplers at the manufacturing plant. The abutting sides were spray painted with the same letters. The three sections would then be placed in the same order in the field, and unforeseen complications would be avoided.
- Good planning of the construction site will increase efficiency. The materials should be delivered as close as possible to the installation site, and by trucks that can also unload them. In contrast, the three sections of 2.0 m CSP were delivered 350 m from the installation site. The excavator on-site unloaded the sections from the trucks and trailer and walked them, one by one, to the stream crossing, utilizing approximately 1.5 hours. The embedding materials were also stored away from the excavation and were ferried by the excavator.

- If the backfill/embedding materials can be delivered while the material is being placed, site disturbance caused by stockpiling in the vicinity of the stream crossing will be reduced. Stockpiling on site prior to the actual installation date may require vegetation to be removed adjacent to the work site; loss of riparian vegetation should be minimized.
- Longer sections of culvert would reduce on-site assemble time, but may require alternate transportation arrangements. Shorter segments may facilitate future removal.
- When piling excavated material for re-use as backfill, the pile should be well peaked to shed precipitation. Care should be taken to keep excavated fine-grained soils dry; tarps could be used when the probability of precipitation is high. In this installation, alternative dry material was nearby, but time was required to excavate it from the road bank and bring it to the site.
- Compacting backfill lifts to the specified densities is necessary but it is time consuming. Using two compactors, one on either side of the CSP, would allow both sides to be compacted simultaneously, and would avoid moving a compactor from side to side. Jumping jack compactors are well suited to compacting the haunch area and fill immediately adjacent to the CSPs, while vibratory plate compactors are well suited to the backfill area away from the haunches. Regardless of the type of compactor used, specified densities must be achieved.
- 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 where there is insufficient vertical clearance. A powered wheelbarrow has been used successfully in other installations.
- The sections of diversion pipe were heavy and required the excavator to lift and move them. The heavy-duty pipe chosen may not have been necessary at this location. A smaller and/or lighter diversion pipe would have been easier and faster to handle.
- Steeper fill slopes should be aggressively revegetated to prevent sediment movement into the stream. Additional riprap armouring of the fill slopes above and adjacent to the CSP would have given added protection at this site.
- The installation of an embedded CSP differs from that of a conventional closed bottom culvert in two respects: the excavation is deeper and material is imported into the culvert. The additional excavating was estimated to take one-half day, and the importation of embedding material took a full day.

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