Title

Design and construction of aquatic organism passage at road-stream crossings: construction challenges and case studies of stream simulation structures for aquatic organism passage

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DESIGN AND CONSTRUCTION OF AQUATIC ORGANISM PASSAGE AT ROAD-STREAM CROSSINGS

CONSTRUCTION CHALLENGES AND CASE STUDIES OF STREAM SIMULATION STRUCTURES FOR AQUATIC ORGANISM PASSAGE

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Abstract: This paper presents guidance for constructing stream simulation structures capable of passing most aquatic organisms, amphibian and some terrestrial species. Bridges are not addressed specifically in this document but many of the construction details, including the stream simulation bed, apply to bridges. To simulate a stream the structure must have been designed to fit well with and have minimal impact on stream dynamics and processes. Traditional construction methods are used for both embedded pipe and open bottom arch construction. In chronological order, the primary structure construction steps include prework meetings, surveys, traffic controls, dewatering, erosion control, clearing, excavation, foundations, bedding, pipe assembly, backfill and embankments, and rewatering. The single most important and unique detail to stream simulation structures is the simulated streambed inside the embedded pipe or open bottom arch. The bed is typically shaped to have a low water channel, margins, and banks and may include other large rocks added to simulate streambed roughness, stable banks and step pool. Bed construction requires unique effort and a combination of machinery and skilled hand labor to fit and arrange pieces to match the design interlock well and be durable. Protection of the aquatic environment is emphasized through minimizing turbidity and sedimentation. Additional aquatic organism protection can include collection and transport of species from the dewatered area, slow rewatering to avoid stranding, limiting toxic substances and noise, and reducing blasting effects. Communication among designers and contract administrators is emphasized to improve understanding of design objectives, maintaining a feedback loop to address site problems and transferring wisdom gained from the project's construction.

Background

There has been an accelerated effort made to remove stream barriers at stream crossings since the mid '90's. Various design philosophies have been tried and refined. Many constructed fish passage projects met stated project goals, yet many did not allow migration of aquatic organisms other than adult fish. It became clear that weak swimming species or life stages of fish, eels, and amphibians were unable to negotiate some fish passage structures. Flood events demonstrated the need to pass sediment and debris on many sites and indicated the need for channel-wide and larger pipe widths to allow streams to function naturally. As a result of these observations and organized monitoring efforts, various sources began refining design methods. Washington Department of Fish and Wildlife published *Design of Road Culvert for Fish Passage* in May 2003. This document serves as the guide to many US Forest Service projects in the northwest.

Stream simulation is a design method that creates a streambed inside a structure that has most of the key channel characteristics of the adjacent channel (Gubernick and Bates, this volume). Key features may include banks, margins, a low water channel, boulder fields, steps, or clusters of large rocks. Because the structure looks like the adjacent stream, it is presumed to pass aquatic species present and possibly some amphibian and terrestrial species.

Introduction

Construction of stream simulation structures involves many techniques and materials common to other culvert and open bottom arch projects. Other techniques and materials are unique and require extra care on the part of the contractor. If both standard and unique aspects are executed well, the result will be an effective, durable structure capable of passing many aquatic species. The project will have minimized damage to riparian and aquatic habitat and will have negligible impacts in the future.

Construction Sequence

The following table provides a general outline of a stream simulation construction project along with the primary concerns about construction for each stage. Project details will vary with site location, topography, soils, road width, and traffic, etc. On larger, multiple-lane highway projects items such as traffic bypass construction, traffic control, and dewatering details can become major contract items. Traffic control, bypass roads, and road travel way reconstruction are not covered in this document.

The format of this document follows the process described in table 1. The sequence of events and some details may change from project to project. Included are common practices and challenges. The report concludes with case study examples. Many typical construction aspects of culvert construction are not covered in this document. The reader is referred to the National Corrugated Steel Pipe Internet site www.ncspa.org/tech.htm, and manufacturer's literature for the specified project pipe.

Table 1
Contract Work Items and Primary Concerns

WORK ITEM	PRIMARY CONCERN
Prework meetings with the contractor	Communication, orientation
Construction Surveys	Verification, aid construction, quality assurance.
Traffic Controls at Stream Crossings	Safety, public relations, roadway stability, structure integrity
Dewatering	Constructability, turbidity, protect aquatic species
Erosion & Sedimentation Control	Turbidity and sedimentation, protect aquatic species
Clearing	Erosion, material conservation
Excavation	Sedimentation, turbidity, blasting effects
Foundations	Structural, concrete in stream effects.
Bedding	Structural, gradation
Pipe Assembly	Structural
Backfill and Embankments	Structural, compaction, gradation, erosion, sedimentation
Streambed Materials, Construction	Meet aquatic species passage needs, details, permeability
Rewatering	Protect aquatic species

Prework Meetings and Other Considerations

There are subjects that can be emphasized to help smooth administration of a successful project. For example, explain any project objectives not obvious in other contract language such as meeting specific stream entry permit requirements or public concerns. These may be qualitative items not described specifically in specifications, drawings, or the contract language. Try to make contract language as clear as possible. Items that should be specifically addressed at the prework meeting include:

Protection of Water Quality – Prevention of direct runoff of sediment containing water into streams, proactive prevention of erosion, qualitative design expectations relating to construction area drainage and treatment, preparation and protection of the site from potential storms during the work period.

Protection of Habitat – Preservation of riparian habitat, minimization of damage to existing vegetation, preservation and use of cleared large wood with stumps.

Dewatering Method Performance - Expectations of erosion control methods, sediment trapping and turbidity treatment of runoff, expectations of possible subsurface flow in the excavation and the method for handling it, including payment method. Capture and rescue of aquatic organisms may be an important part of dewatering that could be the responsibility of the contractor. Discuss expectation and coordination with other specialists (fish biologist).

Quality of Stream Bed Simulation Rock Placement – Emphasize that the intent is to reconnect the channel and create as natural a channel inside the pipe as possible. Photos of the site showing stream segments with similar channels to what is in the contact plans can be helpful. Discuss the proposed method of placing of bed material; this often requires hand labor and specialized equipment. The quality of labor and effort put into fitting and interlocking individual pieces of rocks together can have a substantial effect on their durability. Material dimensions, gradation, and permeability are vital to the simulated streambed's performance. Special specification and pay items are vital to describe and administer this area of work. These items may be a minor cost item in the overall contract, but they have a major impact on the effectiveness of the structure.

Surveys

The original site survey should have at least three durable reference points for location of all other site features and establishing additional references. Remote projects that are surveyed, then delayed for years, may lose reference points to vandalism, storm events or road maintenance activity. Site topography may also change, especially in stream channels due to flood events. Lost references have to be replaced. Existing culvert inverts and drill holes can be useful project references.

Preconstruction Survey

An early review of project plans in the field with the contract administrators and designers can help prevent surprises later on by answering specific questions and verifying that the design still fits if some site changes have occurred.

Enough references and data points should be surveyed to be able to locate the structure and reestablish the road surface and embankment geometry. Assure the road surface is adequately described by existing survey information; otherwise, survey additional points to assure that super elevation, vertical curves, curve widening, or any other critical geometric elements can be reestablished. A straight road segment is easy to recreate with a minimum of survey data, but others such as a super-elevated "S" curve are not.

Examine site plans and design elevations carefully. The project site may not seem to match the site plan or stream profile. If survey points near the existing or new structure are not marked and the channel is very rough, this may lead to confusion and uncertainty as to design elevations and assumptions. A stream classification system may be helpful in describing channel conditions. This could be due to the software used to generate the contour map. Rough channels can be confusing unless you know exactly what points were surveyed in the channel. The "stream channel elevation" used to design the new structure invert can vary a foot or even more depending on where the survey rod was placed originally. Was it held on top of a boulder or between boulders? Are boulders dominant? Do they seem to define elevation more than the spaces between boulders? Some additional surveying may be needed. The designer and administrator should communicate and verify design assumptions on the ground and during the contract as necessary to reduce potential questions such as these, and to prevent inappropriate "last minute" changes during construction. This is especially important when the decision affects the new structure elevation, orientation or gradient. Figure 1 shows areas where some confusion may arise during construction surveys over contract drawings, survey points, elevations and design assumptions.

Construction Surveys
Additional surveys by the contract administrator may be helpful before excavation to help locate any additional specific features or objects not in the contract drawings or original survey. Surveys performed during construction to determine specific locations of the structure and details are extremely important and are in a larger sense verifying that the design meets the site geometry. Contractor survey accuracy should be checked. Contract administrator should be skilled in survey methods and able to verify contractor surveys. Survey errors can lead to costly construction mistakes and, therefore, should be caught as soon as possible. For instance, if the structure is placed at the wrong elevation, when the stream channel is constructed and reconnected to the adjacent channel, slopes into or out of the pipe may cause channel scour or passage problems that are difficult to mitigate. A structure placed in the wrong location may create road alignment problems later on.

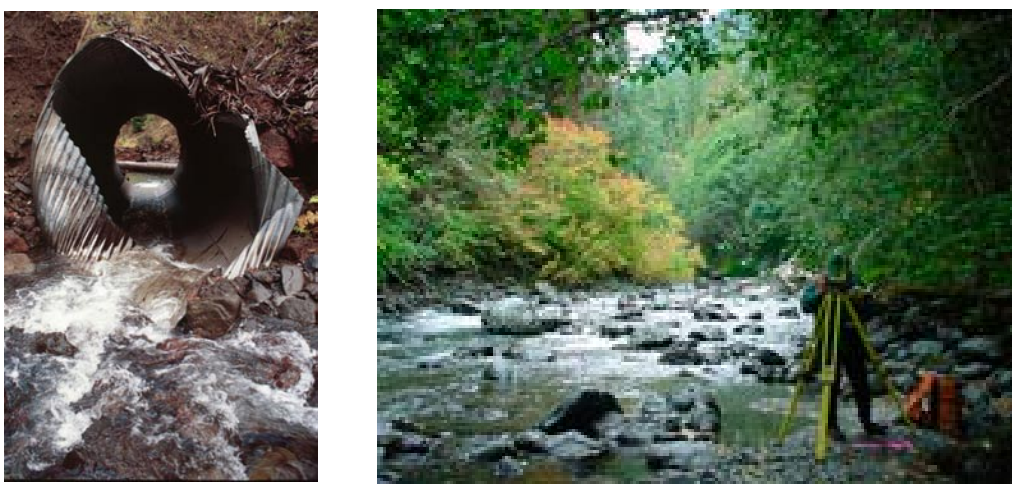


Fig. 1. Possible confusing survey areas - folded pipe invert, high relief boulder stream.

Traffic Controls at Stream Crossings

The contract will have provisions for blocking, diverting or accommodating traffic during construction. If traffic must be allowed over the site, a separate bypass road may be required, often having the secondary function of creating a draw down pool for dewatering purposes. Dewatering is normally provided before this bypass road is constructed to reduce stream impacts. Other sites, such as double lane or wider roads may be better suited to allowing traffic to drive the road while one half of the structure is constructed. Traffic is then switched to the reconstructed side, and the remaining structure is completed. This option may require the use of a retaining wall to help support traffic during construction. These features are described in detail in the contract. Sites with high speed, or high volumes of traffic during any phase of construction should be well marked with traffic control signs, lights and/or personnel. Concern for safety at remote sites may require similar traffic controls, especially where weekend traffic or hunting seasons overlap with construction seasons and the roadway changes abruptly due to construction. Traffic controls must be maintained diligently. Accommodating traffic has a higher degree of risk for everyone.

Dewatering

Protecting aquatic organisms during dewatering should be considered for every project. Aquatic organisms can be removed by setting up block nets above and below the project. Organisms can be moved by techniques such as "herding," gentle electro shocking, or netting. During dewatering, water should drop slowly in the stream to avoid stranding organisms. A fish biologist should guide this effort and generally would be on hand to perform this work. The contractor should not perform this work without consent by the contracting officer. Handling endangered species is prohibited without specific permission by applicable governing agencies, such as NOAA Fisheries or US Fish and Wildlife Service.

Other guidelines and restrictions on dewatering methods may include some of the following:

- In-stream work periods limiting time the stream may be dewatered.
- Restricted work area due to property boundaries or utilities.
- Permits restricting stream channel modification.
- Requirements to capture and preserve aquatic species before and during dewatering
- Requirements to allow slow re-watering of the stream to protect aquatic organisms when the dewatering system is removed.
- Dewatering features should be reliable and able to withstand stream flows and storm events throughout the construction period without failing or causing contaminated water to enter the stream.

Minimize the time the stream is dewatered to lessen impacts on aquatic species. Dewatering can be delayed until excavation is very close to the stream bottom. Footing can be precast; pipes can be preassembled; and bedding, stream simulation rock and backfill can be stockpiled close by. This may reduce stream-dewatering time from months to weeks to days, depending on the structure and contractor ingenuity. Some sites may lend themselves to maintaining stream flow by diverting the stream into developing flood plain channels, by having the room to construct open bottom foundations outside the existing culvert edges, or by dewatering the foundation areas with cofferdams while maintaining stream flow.

Dewatering can be a complex design problem for the contractor to solve in an effective and acceptable manner. It requires capturing stream surface flow, diverting and carrying it away from construction activity, and releasing it downstream. In addition, subsurface water in excavations requires capture, transport, treatment and release. Details of the system may be specified in the contract, but unique site conditions, especially with inter gravel flow, will require adjustments or additions to many designs. Figure 2 shows an example drawing of a dewatering scheme for a stream diverted through the work area. It is usually more convenient for the contractor to divert the flow around the primary work area.

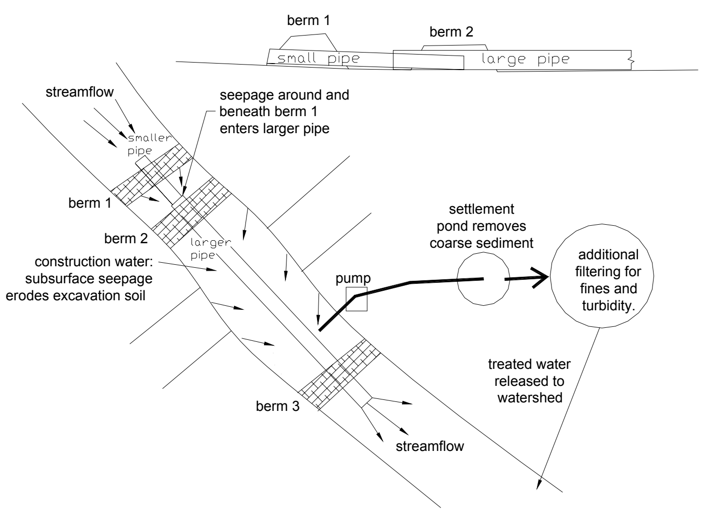


Fig. 2. Conceptual sketch of a complete dewatering system.

Capturing Stream Flow

Surface water is usually collected by constructing a low elevation dam or cofferdam across the streambed. The pooled water is then diverted into a transport pipe or channel. Some regulations require the use of sandbags with clean fill instead of local fill material to construct diversion dams. The pooled water creates increased hydraulic pressure on the surrounding channel and frequently forces some surface water beneath or around the dam. Plastic or membrane lining can be placed on the upstream dam edge and the upstream channel bottom for 10's of feet will help capture surface water and reduce leakage around the dam. A second dam may be placed a short distance downstream to collect water that seeps by the first dam. When a pipe transport system is used, the first dam's pipe may be fed into a larger pipe in the second dam. This leaves an annular opening capable of collecting water behind the second dam. The designer may have specific reasons for designing a detailed dewatering plan instead of asking the contractor for a dewatering plan for approval. Knowledge of good practices combined with experience can help facilitate construction and prevent turbidity problems.

Commercial cofferdams may provide a better solution, especially for larger projects. Water-filled cofferdams are flexible bladders that conform to the ground to form a seal. There are some limitations on their use that can be found on the Internet site www.waterstructures.com/.

Driven pile cofferdams are complex engineered retaining walls that may be suitable in some locations. They have more impact on streams especially when removed. They may also help control groundwater leakage into the project excavation. Pile driving may be prohibited during part or all of the in-stream work period. Useful information may be found at the Internet site www.corusconstruction.com/piling/Cofferdams/.

On small projects that can be constructed very quickly, the entire project dewatering system may simply consist of pumps. If a draw down pool exists upstream or can be constructed, the project may be dewatered easily. Pumps may need to run 24 hours a day and be maintained during that time. A backup pump should be available in case of breakdown. Siphoning may take over if enough flow capacity can be reliably maintained.

Fig. 3. Dewater only part of the stream to maintain aquatic organism passage.

Water Transport

Pipe(s) should be designed to carry expected storm-generated flows during the construction period. Failure to do so can lead to overtopping or failure of the diversion dam. Maintain pipe inlets to prevent plugging by leaf and small wood debris. Water from the diversion can be transported by gravity or by siphoning with pipes placed through the construction area or adjacent to it. Placing the transport pipe away from the excavation can dry work areas and aid work processes. If diversion pipe joints leak, they contribute water to the construction area drainage, adding to the volume of water requiring treatment. If pipes are placed in the fill or on excavation benches, leaks may cause fill instability, endangering workers in the excavation area below. The use of pipes with sealed joints is recommended. Various O-ring, sleeve and strip gaskets are available for this purpose.

Some projects may have an adjacent channel in a floodplain, abandoned channel or one formed with a cofferdam that can be used for water transport. These have the advantage of possibly providing aquatic species passage during construction. Channels may have to be lined to prevent erosion and seepage into the construction site.

Water from pipes or channels is usually released as close to the project as practical to minimize the area of channel area dewatered by the project. The outlet area should be chosen or modified to dissipate any excess energy created by any steeper gradient, or higher outlet flow. Outlet drops should be avoided. A pool area may be available where the outlet can be placed and submerged to dissipate energy.

Construction Water

The construction area for the structure is excavated below the surface of the stream channel. Groundwater is frequently intersected near the channel elevation in perennial and intermittent streams. Subsurface water discharge can vary with weather and can be large, matching or exceeding surface flows especially during storm events. During excavation and pipe removal, sediment mixes with construction area runoff and ground water, elevating suspended sediment to unacceptable levels for release into the stream. Even foot traffic can generate high turbidity levels just by walking though loose soil where water is flowing or standing. The excavation surface can be covered with a geotextile (optional) and a thin layer of clean well-drained crushed rock such as 1/2" – 2" diameter drain rock (see Stream Turbidity section).

Capturing subsurface flow inside the excavation requires care and sometimes artful ditching and piping. Narrow excavations leave little room for constructing ditches outside of footings or embedded pipe edges. Water can be collected in a depression or a natural outlet pond at the downstream end of the excavation. A pumping or siphoning system should always be in place to remove groundwater from the construction and excavation area. Multiple pumps may be required to keep the construction area drained during storm events. A backup pump should be available. Failure to remove water fast enough can cause the excavation to flood. If the downstream dam is overtopped, the resulting damage to downstream habitat and organisms can be severe. Downstream construction water containment dams can leak through channel edges below the dam. The upstream channel and dam edge should be lined with an impermeable membrane or thick plastic to minimize seepage.

All water containing suspended sediment must be treated. Oil-absorbing booms should also be on hand in case of hydraulic hose leaks. Obviously, equipment should be washed thoroughly to remove oil and grease. Equipment may also require washing to remove invasive plants seeds and aquatic diseases.

Stream Turbidity

Subsurface water and construction water should be pumped to a holding pond to settle fines before returning it to the stream (see figure 2). The importance of preventing erosion, and elevated turbidity levels in streams, is due to the negative effects on aquatic organisms and their habitat. Fine sediments generated from a project are detrimental to incubating fish eggs because blockage of interstitial spaces by silt prevents oxygenated water from reaching the eggs, adversely affecting the removal of waste metabolites. Although construction may not occur during these times, sediment may become mobile later, causing damage during critical periods. High silt loads may also inhibit larval, juvenile and adult behavior, migration, or spawning. Siltation, substrate disturbances and increased turbidity also affect the invertebrate food sources of anadromous fishes. Figure 4 illustrates the effect of construction-generated sediment reaching the stream and covering streambed gravels.

Fig. 4. Construction-generated sediment effects on streambed, before and after excavation.

Many major statutes may apply to stream simulation projects and contain language specifying allowable turbidity levels including: Anadromous Fish Conservation Act, Clean Water Act, Endangered Species Act, Fish and Wildlife Coordination Act, Magnuson Fishery Conservation and Management Act, National Environmental Policy Act, and the Rivers and Harbors Act of 1899 (Buck 1995).

It may be wise to attempt to separate clean subsurface water from water with suspended sediment in the construction area to reduce the volume of water to treat. Sand-sized particles can be settled out of suspension by reducing water velocity. Water can be transported to a settling pond, portable water storage pools or by passing through other types of filtration units, vegetated swales, or constructed wetlands. Finally, there are confined areas where treatment of suspended sediment is not possible in the adjacent riparian areas. In these cases water may have to be transported out of the immediate project area to be treated or released into a suitable filter area such as a permanent settlement pond, constructed wetland, or well-vegetated areas. Project permits may limit the upper level of turbidity allowed in the stream. Limits are sometimes set for a specific time period, such as < 50 NTU instantaneously or < 25 NTU for a 10-day average.

Turbidity is expressed in a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles. The scattering of light increases with a greater suspended load. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but may also be measured in Jackson Turbidity Units (JTU). The velocity of the water resource largely determines the composition of the suspended load. Suspended loads are carried in both the gentle and fast currents of flowing waters. The suspended load usually consists of grains less than 0.5 mm in diameter including sand, silt and clay sediment classes. (Schmitten 1996).

Option - Use of Natural Flocculants for Treatment of Turbidity
Chitosan (pronounced ky-toe-san), a natural polysaccharide derived from crab and shrimp shells, is an effective flocculate to remove suspended sediment by causing particles to settle out of the water column. Chitosan has been tested for effectiveness of sediment removal and fish lethality in the laboratory. It is approved for drinking water treatment and industrial wastewater treatment. There is uncertainly about how it reacts when applied to a natural stream system. Little is known about the fate of the residual product or its effects to stream biota. In addition, little is known about the consequences of settling sediment by flocculation in downstream reaches from in-situ application. (Oregon DOT 2003; McPherson 2002)

Erosion Control of Slopes and Embankments

Provide erosion control at the beginning of the project to protect the stream, riparian areas, wetland and other important areas near the project. The erosion control system should be in place before excavation begins, dewatering systems are constructed, equipment access and traffic bypass roads are constructed, and sufficient erosion controls and measures are provided.

When excavation begins, the protective soil cover of organic debris, roots, and vegetation is removed, exposing it to wind and water erosion. As excavation removes pockets of soil, slopes are temporarily steepened which can lead to collapse of soil pockets that may fall into flowing water. It is generally wise to install the dewatering system before excavation begins to prevent excavation materials from dropping into live streams.

The system used should reflect the soil's vulnerability to erosion. Soil erosion is a function of particle size, gradation, character of the fines, chemistry, moisture content, slope, and erosive force. Sources of erosive force to consider are usually rainfall, wind and gravity. Mass wasting can become problematic if excavations or temporary embankments are over steepened.

The length of time a project takes affects the erosion control methods used. During single season construction projects, brief storms may be the largest risk to site erosion. In some areas of the country, the construction season may occur during periods of very intense rainstorms, with the potential to cause considerable erosion of freshly exposed soil. Increases in surface and subsurface flow may overwhelm dewatering and drainage systems.

Multiple-year projects experience a full cycle of seasons and may include multiple rainstorms, wind, snow, ice and drought. This can make some common erosion control methods unsuitable. Probably the best method to protect multi-year projects is to establish grass or some other dense annual groundcover. In arid areas, a thin layer of aggregate may be sufficient to reduce erosion.

Some projects may consist of removing a culvert and embankment the first year, then letting the stream adjust through the next season before reconstructing the site. Protection of exposed soils should be carefully considered. Stabilization may be undesirable at some sites, but necessary at others to prevent uncontrolled head cutting or destructive bank erosion. It may be possible to use on-site material, such as trees, brush, and large rocks, to provide some stabilizing structures.

Erosion Prevention Methods
Generally, slopes should be protected as excavation or embankment construction is completed. Preventing erosion means preventing soil particles from becoming dislodged. Some products are called erosion control even though they allow some erosion that can be trapped near its source. An example is straw mulch. If it doesn't cover nearly 100 percent of the surface area, some rainfall will fall between pieces of straw and dislodge soil. A 100 percent effective erosion control method would be to cover the vulnerable area with an impermeable membrane or a layer of non-erodable material on a moderate slope, such as a clean, coarse gravel layer. Areas to protect with more reliable methods are long sloping surfaces leading directly to live

streams, such as a road embankment. Other critical areas are wetlands, rare and endangered sensitive plant locations, private land, utility corridors and archeological sites.

The type and effectiveness of the product should be based on the vulnerability of the soil in the environment. Steep slopes with loose fine sand may require 100 percent effective methods. Common effective erosion protection materials are straw mulch, hydraulically applied mulch grass seed, and erosion control fabrics. The contract may call for live vegetation, such as willow starts, in various configurations to quickly obtain root strength, shade and cover particularly in riparian zones, wetlands and along banks. Many rural forest projects can be left to "self seed." Native grass is commonly used to provide short-term erosion control until other natural seeding takes place and is established. Planting may have to be delayed until a suitable season arrives for successful germination.

Stockpiles may need to be covered with an impermeable membrane to prevent rainfall and wind erosion. Runoff from covered stockpile areas and larger drainage areas should be gathered and directed toward a suitable release point where it can be dispersed. Large openings may generate large amounts of dust and drainage. Reduce erosion by providing an effective frequent drainage system and a surface cover such as grass, mulch or gravel. Permanent waste areas may require more extensive planting, mulching and sometimes irrigation systems to establish permanent vegetation cover. More extensive landscape plantings are common on urban area highway projects and may include a complete landscape plan with mulch, groundcovers, shrubs and trees.

Excavation style and technique can affect the amount of sediment generated from the project. If the excavated slope angle during fill removal is too steep it may lead to shallow soil failures which fall into the excavation area or slide toward the live stream. Some excavation slopes are vulnerable to erosion and may benefit from a cover when not being worked on. Covering slopes may slow drying of embankments. Erosion of excavated slopes can become the largest source of sediments on some projects. Preventive erosion costs may be less than the costs of providing removal of that same suspended sediment for construction drainage. Loading and hauling excavated materials on the project can leave considerable amounts of fines on the road surface, which may wash into live streams. These areas should either be kept clean or a system of drainage and sediment trapping should be employed to protect the stream.

Sediment Trapping

The purpose of sediment trapping is to capture sediment that has already been dislodged and mobilized by rain or wind or gravity. The conventional methods of sediment trapping consist of silt fence installation around the entire work area. It may extend along some haul routes and surround stockpiles and waste areas. Other mechanical means of sediment trapping include berms, straw bales, wood shaving bundles, brush piles, vegetated swales, and use of vegetated areas with extensive groundcover capable of trapping sediment. Rain-generated sediment may be collected and treated with excavation water or other suitable filter systems.

Sediment collection ponds at the downstream end of the excavation may accumulate enough sediment to require removal to maintain adequate storage capacity. Consideration should be given to maintaining access to the pond during construction. Sediment may have to be loaded and transported to a suitable location for disposal. Since this sediment is usually saturated as well, it may drip from the bucket and risk entering a live stream. Determine how to transport this to a waste site with a suitable method (sealed container) ahead of time. This can be difficult in confined areas.

Clearing

After erosion prevention and sediment trapping systems are in place, clearing and grubbing proceeds. If sediment-trapping systems such as silt fences are damaged during clearing, they should be immediately repaired. When the contract calls for in-stream wood structures, tree removal from embankments may require leaving the stump attached. Other wood debris may be conserved and used as an additional erosion control feature on new embankments or riparian areas when the project is near completion. Clearing should be minimized and care should be taken to retaining vegetation for stream shade. Clearing limits should be outlined in the contract but flagged in the field.

Excavation

If excavation slope angles, bottom width and depth are not specified in the contract, the excavation will tend to be as narrow and steep as possible since this is an area of potential cost savings to the contractor. This can result in inconvenient and unsafe working conditions. Excavation slopes can ravel or fail creating excavation area drainage problems or damage to completed work. Large embankment or excavation slope failures may be capable of entering live stream areas.

Slope angle is a matter of safety and is regulated by the Department of Labor, Occupational Safety and Health Administration (OSHA). OSHA regulates maximum slopes and configurations for trenches and excavations up to 20 feet in depth. A registered professional engineer must design excavations with depths greater than 20 feet. The Department of Labor recognizes excavating as one of the most hazardous construction operations. Revised OSHA Subpart P, *Excavations,* of 29 CFR 1926.650, .651 and .652 make the standard easier to understand, permit the use of performance criteria where possible, and provide construction employers with options when classifying soil and selecting employee protection methods. Contract administrators should be familiar with this document.

The OSHA manual displays common hazards that may be encountered at stream crossing excavations. Inspectors should be aware of these features. OSHA provides maximum excavation slope angles for five categories of soil and various benching and trenching options. The Internet site is: http://www.osha-slc.gov/dts/osta/otm/otm_v/otm_v_2.html. A slope stability specialist should be consulted when unusual conditions arise. Figure 5 illustrates are common slope stability problems associated with excavation from the OSHA Excavation manual.

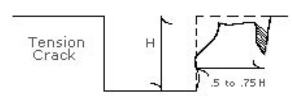
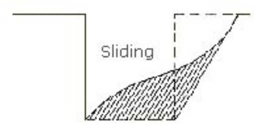
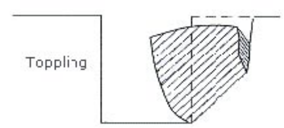
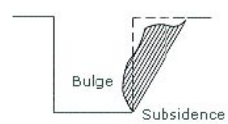
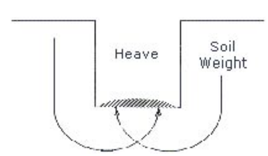
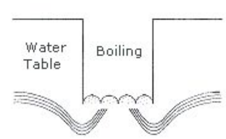
TENSION CRACKS. Tension cracks usually form at a horizontal distance of 0.5 to 0.75 times the depth of the trench, measured from the top of the vertical face of the trench. See the accompanying drawing for additional details.	TENSION CRACK 
SLIDING or sloughing may occur as a result of tension cracks, as illustrated below.	SLIDING 
TOPPLING. In addition to sliding, tension cracks can cause toppling. Toppling occurs when the trench's vertical face shears along the tension crack line and topples into the excavation.	TOPPLING 
SUBSIDENCE AND BULGING. An unsupported excavation can create an unbalanced stress in the soil, which, in turn, causes subsidence at the surface and bulging of the vertical face of the trench. If uncorrected, this condition can cause face failure and entrapment of workers in the trench.	SUBSIDENCE AND BULGING 
HEAVING OR SQUEEZING. Bottom heaving or squeezing is caused by the downward pressure created by the weight of adjoining soil. This pressure causes a bulge in the bottom of the cut, as illustrated in the drawing above. Heaving and squeezing can occur even when shoring or shielding has been properly installed.	HEAVING OR SQUEEZING 
BOILING is evidenced by an upward water flow into the bottom of the cut. A high water table is one of the causes of boiling. Boiling produces a "quick" condition in the bottom of the cut, and can occur even when shoring or trench boxes are used.	BOILING 

Fig. 5. Common slope stability problems associated with excavation from the OSHA Excavation manual.

Conserving Streambed Deposits

Once the existing pipe is removed, the excavation is normally deepened to the new pipe embedment or foundation depth. The excavated material may appear "dirtier" than other streambed material but is often stream sediments covered with fines from excavation. The material should not be substituted for imported streambed simulation rock unless approved by the designer since it may not represent the gradation of other streambed sediments and may lack the armor needed for streambed simulation material. Excavated material is often wet and should be dried to facilitate compaction in the structure. Place this material in a separate stockpile and protect it from contamination from other excavation.

Foundation Area Preparation
The excavation may intercept groundwater as general seepage, piping or "subsurface streams." This can cover the excavation bottom making it difficult to see the foundation bed area. Excavation normally begins downstream of the structure, extending upstream to facilitate subsurface drainage away from the work area and avoid pooling. The foundation area should be kept relatively dry to allow foundation areas to be seen, and shaped. As the bottom of the excavation is reached, a survey check should verify the proper depth has been reached. Measure twice and excavate once. A simple drive probe of rebar or pipe may be useful in prodding for bedrock, or estimating the soil consistency.

When the excavation is ready for foundation work, consideration should be given to covering the bed with either pipe bedding or "drain rock." This will keep excavation drainage much cleaner, improving mobility and working conditions.

Bedrock
When bedrock is encountered where the foundation is to be formed, the bedrock should be removed or the design should be modified to fit. The designer should always be consulted before making field adjustments to foundations since changes can affect streambed simulation, structural integrity and can lead to project failures. The designer and interdisciplinary team must be proactively involved during this phase of construction in case some condition arises which affects the foundation stability, or position. The site should be made to fit the design; otherwise, the designers should determine a new solution for the changed conditions in a timely manner.

Blasting Near Wildlife and Aquatic Species
Blasting may be desired when bedrock is countered. It can be prohibited for various reasons in some areas, or during part of the year. Nesting birds may require protection during specific periods. Time periods and concerns should be listed in project NEPA documents. If a wildlife biologist surveys the specific site and finds no species of concern, it may be possible to blast during normally restricted times. Blasting in or near water may be prohibited to protect aquatic species such as fish. Dewatered sites may be only partially hydraulically disconnected from the adjacent stream due to construction area drainage, or subsurface water in bedrock joints. Fish near blast sites may be injured as a result of swim bladder rupture, tissue and organ damage or internal bleeding. The damage to fish depends on size of charge, distance to fish, depth of water, substrate type and the size and species of fish (US Army Corps of Engineers 1995).

Some suggested blasting mitigation practices include (Golder Associates /Alberta Transportation, unknown):

- Limit the charge size and detonation velocity
- Prohibit explosives capable of producing an instantaneous pressure change greater than 100 kPa (14.5 psi) in the swim bladder of a nearby fish
- Prohibit explosives that produce peak particle velocity greater than 13mm/s in a spawning bed during incubation.

Table 2
Setback distance from detonation center to fish habitat to achieve 100 kPa standard

Weight of explosive charge (Kg)	0.5	1	2	5	10	25	50	100
Setback: Rock (m)	5	7	10	15	20	35	50	70
Frozen Soil (m)	5	6	9	14	20	31	45	62
Ice (m)	5	6	8	13	18	30	40	55
Saturated Soil (m)	4	6	6	12	18	28	40	55
Unsaturated soil (m)	3	4	5	10	12	20	28	40

Table 3
Setback from detonation center to spawning habitat to achieve 13 mm/s standard

Weight of explosive charge (kg)	0.5	1	5	10	25	50	100
Setback Distance (m)	15	20	45	65	100	143	200

Other blasting considerations include:

- Increase the delay between charges to 25 milliseconds or more
- Perform blasting work during non-critical or less sensitive time periods for fish
- Keep fish out of the blast area by electro shocking and surround the area with block nets
- Fill (stem) blast holes flush and consider using blasting mats to minimize blast debris scatter
- Ammonium nitrate-fuel mixture (ANFO) should be prohibited in or near water due to the production of toxic by-products (ammonia)

These specifications should be listed in the contract. Blasting details should be submitted by the contractor and checked for compliance by a knowledgeable blasting engineer.

Foundations

The foundation preparation area extends beneath footings, the area directly beneath pipes and an area to the side of the structure that supports backfill. The width of fill to either side of large multi-span structures can be quite wide and is based on structural considerations of soil/structure interaction. This width should be shown in the contract drawings. The foundation area should be approved by the foundation engineer before proceeding with construction. Concrete foundation may be founded on soil or rock. Metal footings require a bedding material beneath for even support. The AASHTO Soil-Corrugated Metal Structure Interaction System Chapter 12.1.6.3 states: "…It is undesirable to make a metal arch relatively unyielding or fixed compared with the adjacent side fill…Where poor materials are encountered, consideration should be given to removing some or all of the poor material and replacing it with acceptable material." Thus when bedrock is found under part or all of the foundation, it may be desirable to place a soil cushion over the rock to allow more even settlement of the footing and to reduce drag forces from settlement of the adjacent fill material. The structure thickness may be designed to accommodate drag forces and cushioning may not be necessary. Consult the designer before taking any actions not provided for in the contract. It is important to limit settlement to avoid adversely affecting line, grade, and structural shape.

The contract administrator must have a fundamental knowledge of soil types and be able to judge whether a material is suitable. Local experience is invaluable. General advice is to avoid fine-grained soils that are wet and soft to the touch. Wet granular soils may be suitable. Familiarity with the anticipated foundation bearing capacity is also important. A hammer driven probe can be used to find deeper layers of firm material or bedrock and to estimate soil consistency. Commercially available hand-held soil penetrating or shearing devices can be used to test undisturbed soil for shear strength to compare with design assumptions.

Settlement Beneath Foundations

Controlling settlement of the foundation area assures adequate backfill support and helps to maintain the constructed road surface shape. Compaction of this area, the condition of the soil during compaction, and the soil's properties control the potential settlement in this zone. If very soft materials are present, such as wet clay, silt of other soft plastic fine-grained soils, they should be replaced with structural backfill to improve compaction and limit settlement. Structural backfill should be a well-graded, dense material resistant to piping. The area directly beneath the structure should be compacted slightly softer than the embankment backfill to provide slightly more settlement, which will reduce settlement-caused stress on the pipe structure.

Concrete Footings

Constructing forms for concrete footings is a relatively time consuming part of the construction process. Each forming and concrete pouring sequence may take from a few days to a week or more. Massive rectangular footings are often used on smaller projects to speed foundation construction. Contractors may request changing footings from a footing and stem wall to a single rectangular footing of equal height and width. This is generally not a problem. Any foundation changes should be made or checked and approved by the designer or another foundation engineer. Survey accuracy is vital to obtaining parallel, equal elevation footings spaced properly for the arch dimensions. The structure can be attached to the top of the foundation using either a grouted slot or a bolted metal channel connection set at the proper angle. The grouted slot attachment is generally easier to use and more forgiving of minor errors.

The concrete pour is not always a flawless activity. Pump trucks can plug, concrete can spill, forms can be damaged, concrete can arrive early or late, cold joints can form. An experienced concrete contract administrator should always be present during pours. Protect streams from concrete. Concrete and related products that mix with water and enter live streams can kill fish in minutes because of high alkaline pH levels that are corrosive to fish gills.

Special concrete placement methods may be necessary when standing or running water is present in or adjacent to forms. If it is not possible to remove standing water from the form, it can be displaced. If running water is present, it can be plugged with concrete at the source. Regardless of the concrete placement method, when water is present, the concrete should be placed as gently as possible to avoid mixing and dilution with standing or running water. The pump hose should touch existing wet concrete, or with any method, be released as close as possible to existing wet concrete. Assure that water does not pond on the excavation side of forms where it can be forced through concrete joints washing away concrete and exposing reinforcing steel. Figure 6 illustrates the proper technique to pour concrete near flowing water.

Fig. 6. Concrete is being placed to seal off water at upstream end of form first.

Concrete forms can be stripped as soon as the cured concrete can support its own weight. Backfilling should wait until minimum strength is achieved in the concrete. Concrete test cylinders taken during the pour can be tested at intervals to determine when sufficient strength is reached. Accelerating the cure time with additives may be economical for the contractor. With massive footings it may be possible to place streambed simulation rock (interior) and backfill (exterior) on the other side of the footing in simultaneous lifts earlier. The design engineer should be consulted first. With high strength concrete or accelerators, a weekend may be sufficient for curing.

Metal Footings

When metal footings are used for open bottom arches, it may be possible to place some stream simulation material between the footings before full pipe assembly. Take special care to avoid displacing footings, which makes the remaining assembly very difficult.

Bedding

Bedding material and preparation are critical to both pipe performance and service life. Bedding helps maintain proper pipe elevation, eliminate undesirable stresses and ensures good hydraulic performance by minimizing flow around the pipe. Improper bedding beneath pipes can lead to loss of surface flow during periods of low water, preventing passage of aquatic species though the structure.

There are three general methods for placing bedding beneath a pipe. One method is to shape the bedding to conform to the pipe shape before placing the pipe in position. The second method is to carefully tamp a select granular material beneath the haunches to achieve a well-compacted condition (figure 7). Long span structures required intimate contact between invert and underlying soil for proper soil-structure interaction and stability. The third method uses a low strength concrete mix that is poured into position. The pipe must be secure against displacement or flotation prior to placing flowable concrete mixes. Placement of a minor amount of streambed simulation rock in the culvert for this purpose may work, but care must to taken to avoid deformation of the pipe. No machinery should be allowed in the pipe, but material can be placed by bucket or hand. Table 4 shows two sample mix designs for low strength concrete mixes.

Table 4
Examples of low strength concrete mixes

Special Pipe Embedment Material	Flowable Mortar	Controlled Low Strength Material (CLSM)
Cement	100 lbs	50 lbs
Fly ash	300 lbs	250 lbs
Fine Aggregate	2600 lbs	2910 lbs
Water, approximate	70 gallons	60 gallons
Compressive Strength at 28 days	100-200 psi	50 psi

Pipe Assembly

Non-multi-plate pipes require proper joints coupling and waterproofing gaskets to prevent water loss and backfill piping. Water loss during dry conditions can prevent aquatic species passage. Long-span multi-plate structures have special assembly requirements to maintain shape and may require a shape engineer from the manufacturer to guide assembly and backfill operations.

Backfill and Embankments

For embedded pipes, backfilling can begin when bedding is completed and the structure is placed. For open bottom arches with poured in-place footings, backfilling can occur as soon as footings can withstand backfill forces. Backfill should be placed in 6 to 8-inch lifts and brought up at the same rate and time on both footings. Machine compaction is used in wide areas and hand-operated equipment used in confined areas and against the structure. Many existing pipes show some signs of damage from construction handling or backfill operations. Assure that the minimum compacted cover height exists above the pipe before allowing traffic across. Where pipe cover is shallow, construction equipment may require more cover than the finished elevation of the road. A temporary cover may be necessary.

Fig.7. Hand tamping bedding with a pneumatic tamper.

Fig. 8. Placing flowing mortar bedding. Photos courtesy of Contech CPI

Stream Bed Simulation Materials

The most important detail of a stream simulation project is the simulated streambed. It requires the most care to produce a quality product that simulates the stream. It will be home to aquatic organisms traveling through and perhaps even living inside for a period of time. Specifications and drawings should describe the specific bed features.

Streambed Simulation Rock

Streambed simulation rock is the main material used in the structure. It is designed to match the gradation of streambed materials or to be slightly different if the structure requires a different gradient. Using stream simulation design guidelines, a well-graded mix of coarse to fine materials matching the stream is chosen to produce a dense, low permeability, well-interlocked bed. It should be specified in the contract and include details of gradation, placement shape and compaction method. When placed, the bed will have roughness, bed shape characteristics and a variety of hydraulic conditions similar to the natural channels. The bed is shaped to form a low water channel, rising toward the edge of the structure. The slope may flatten before the edge to form a bank line.

Obtaining stream simulation material may take extra effort. Materials often have to be gathered from a variety of material sources of boulders, cobbles, gravels, sands and "soil." Finer sizes of mix, such as 2-inch and smaller, may be available commercially. Table 5 provides a streambed simulation mix for a theoretical cobble and boulder dominated project stream.

Table 5
Project specification

% Passing	Sieve Size	% Within Size Range
D100	= 750mm	16% from 300mm to 750mm
D84	= 300mm	34% from 120mm to 300mm
D50	= 120mm	34% from 48mm to 120mm
D16	= 48mm	16% from 0mm to 48mm

The contractor and contract administrator should work together to determine a practical way to produce the specified mix as accurately as possible. Table 6 shows a practical recipe to produce the specified mix using locally available material gradations.

Table 6
Project recipe

Material Volume	Size and Source
2 loads of boulders	300mm to 750mm boulders from quarry
4 loads of cobble to boulder	125mm to 300mm shot rock from quarry
4 loads of gravels to cobble	50mm to 150mm mix of landscaping "river rock"
1 load of gravel to sand	50mm minus base rock or "river rock"
1 load of soil	bank soil from project site

Gradation requirements should be achieved and verified by weighing or measuring recipe components carefully. Evenly filled bucket loads are accurate enough. The bed material must be mixed well to provide good interlocking. Mixing may be done on site or remotely. Transport can cause mixed materials to separate some, but the remote mixing and transport may still produce a better product than mixing material on site.

Additional Large Rocks
Large rocks are sometimes added to simulate stream roughness elements or stable channel features found in the adjacent channel. They may be used to simulate stream banks, step-pool steps, and boulder fields. Large rocks may also be used to simulate effects of wood, bedrock, or colluvium. In the contract, the size, number and perhaps shape of the rocks will be specified. Large rocks may be available on site from existing structure riprap, embankment fill, or road maintenance debris storage.

Constructing the Simulated Streambed

The contract drawings should show the streambed in plan and profile views. The details may include:

- A shaped bed with banks and a low water channel
- Reinforced bank areas
- Across-channel steps
- Fields and clusters of large rocks

A study of adjacent streambeds, or the project reference can provide additional visual clues for how rough the surface may look, the orientation of interlocked step-pool steps, orientation of shaped particles and overall channel shape. The shape may appear rougher than the drawing. Drawings simplify the complex shape into representative dimensions for quantity and payment in the contact. Figure 9 shows a sample construction drawing with details for shaping the bed and constructing simple step pools. Specific details should be based on the specific project site, size and depth of streambed materials, and gradient.

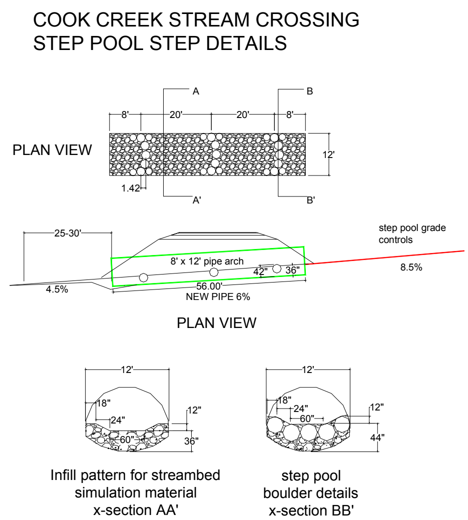


Fig. 9. Step pool and bed shaping details.

Placing Streambed Simulation Materials

Placing streambed materials within an open bottom arch is relatively easy since the material can be placed before the overhead arch is in place. An excavator is usually used to place bed materials. A variety of equipment can be used to compact the bed in thin layers. The backfill and streambed materials should be brought up to the same level at the same time. It is difficult to compact bed materials tightly against a concrete footing with an excavator. Smaller equipment can do more detailed work, but handwork should be used to perform final filling of voids along the footing wall and bed material. This material should be placed, tamped or washed into voids until they are filled before placing the next lift. Washing finer material into the voids with a hose is particularly effective. Proper gradation of bed material and thorough mixing of fines throughout will make this process easier and will take less time and may make it unnecessary. After placing the bed material, the shape of the bed can be made with an excavator bucket, blade, or backhoe. On small projects, hand labor may be any efficient shaping method. Large rock can be incorporated into the upper lifts. Carefully tamp material around large rock features to provide good interlocking and low permeability.

Many embedded pipes are relatively small. Most are non-multi-plate pipes with a maximum span of 12' for round and 14' wide for pipe arch shapes. Small equipment, such as rubber tired loaders (i.e., Bobcat), garden sized tractor-trailers, small dozers run on a cushion of previously placed bed material, or hand labor, can be used to place bed materials. Hand labor is typically underutilized. There is no exhaust to breath. The bed material can be loaded by machine into a two-wheel wheelbarrow, carried downhill and end dumped. As with any embedded pipe filling method, once dumped, the material must be spread by machine or by hand. Machines may be partially used for spreading but can be difficult to use in confined spaces. Hand labor is required to fill void spaces. It is best to place material in lifts and compact with wheels, hand held vibratory compaction equipment or rollers. Fill the voids by hand or by washing between lifts. Placing lifts one at a time through the entire pipe slowly reduces the headroom available. If this is detrimental to construction, the bed can be placed in layers that slope downward toward the inlet (filling end). This may facilitate placing large rocks as well. Figure 10 shows hand labor filling a pipe with a wheelbarrow. Figure 11 shows an excavator placing and mixing streambed material.

Fig. 10. Hand Labor – 1 day to place 45 CY.

Fig. 11. Machine Labor – 4 day to place 600 CY.

Larger multi-plate embedded pipes may allow larger equipment inside to facilitate bed placement. Larger equipment may cause bedding support problems unless bedding is of very high quality. Low strength concrete mixes are suggested if large equipment will be inside the pipe. It is typically not practical to place bed material before assembling the upper half of embedded pipes, though occasionally attempts are made such as cutting a one piece pipe in half, welding flanges to each half, filling, then bolting the two together. The wide flanges allow for some misalignment during connection.

Care should be taken to avoid damage to galvanized coating in steel pipes during bed placement. Pushing material on the metal surface can remove galvanizing, shortening the life of the structure. End dumping is preferred. Rubber tired equipment is strongly recommended. Overfilling of buckets should be avoided and spilled pieces should be removed from the travel path. A cushioning bed of streambed material should be placed in front of a tracked vehicle to avoid metal damage. Regardless of the haul method used, placement of the material is important to achieve density and low permeability. Hand labor is necessary to shape finer bed form details, especially in confined areas. Hand labor is also very useful at plugging voids left during filling between larger pieces of bed or between the bed and the culvert or foundation edge. Finer material, such as ¾"-minus can be packed and tamped into voids to seal the bed. It should be placed between lifts. With large bed material, thick lifts can be difficult to compact as particles lock together without fully seating themselves. The stream will add mobile fines to the bed surface in the future, but this is often not a reliable method of sealing the bed in the first year. When the bed is not sealed, low water flow will diminish or disappear. It can take years to seal the bed unless considerable fine sediments are transported during normal flows. Placing large rocks involves embedding them in smaller bed materials. Machinery is required to move large rocks. Large rocks in step-pool steps, along banks or in clusters should be oriented, fit and packed with finer material by hand for a good fit. This is a qualitative aspect of construction that benefits from natural talent and is difficult to enforce. Figure 12 demonstrates the difference between loose well-interlocked rock placements.

Fig. 12. Views of loose rock on left and tightly fit rock on the right.

Some channel length is usually reconstructed to connect the stream simulation project with the adjacent stream channel. This work requires the same level of concern as the structure including compaction in layers, machine and hand labor to reduce permeability, interlocking, and shaping of the bed material.

It is always beneficial to "kick a few rocks around" to improve the streambed after diverting the stream back through the pipe. The stream will erode fines, shift material around, and may be subsurface in some poorly sealed areas. This work should be part of a special specification in the contract. A few cubic yards of ¾" -

minus hand placed in these zones of vulnerability and tamped into voids can provide good passage conditions faster than if left to nature. Figure 13 shows a finished project with features of wide banks, margins, and a low-water meandering channel, inside an embedded pipe.

Fig. 13. A completed stream simulation project with bed simulation features.

Rewatering

Special attention is required when removing dewatering structures to avoid excess turbidity. In addition, pooled areas both upstream and downstream will have allowed movement of aquatic organisms into areas that may be drained as the diversion is removed. Provide protection by slowly lowering water in pooled areas to encourage movement into new habitat areas. Species may become stranded and need help moving to suitable habitat. Total breaching may be appropriate on some projects. It is normal for some fine sediment to be washed out of the streambed simulation materials during stream rewatering. Normally this will be greatly reduced in less than 24 hours.

Summary

Construction of stream simulation projects requires good design coupled with skilled contract administration and the cooperation of the contractor. Some semi-skilled hand labor is necessary for construction of the streambed features most valuable to the project. Protection of aquatic habitat and species can be a major emphasis and potentially troublesome task during a project. Good communication between designers, contractors, and contract administrators is necessary to make appropriate changes within the scope and objectives of the project. Projects that are not constructed as designed often suffer the consequences. Through the continued open communication of designers, contract administrators and contractors, project designs and contract details can be refined, wisdom can be shared and future project planning can be improved to aid future projects.

Construction Case Examples

The following photos demonstrate some of the problems that can be found during and after construction. All of these may have been prevented with good contract administration and the help of the designer.

Embedded pipe design. Engineer gave permission to County construction crew to eliminate bed material. The assumption was streambed material would be deposited into pipe by the stream. After two winters, pipe has minimal sediment stored, and there is a steep cascade at the pipe entrance, a barrier to many species and life stages of organisms.

- *Predicting sediment transport requires specialized skills.*
- *Sediment that washes into pipe can also easily wash back out.*
- *Recommend placing stream bed in pipe– base on stream reference reach*

Fig. 14. Design/Construction Problem – eliminated streambed material.

Survey error lead to inlet being placed 2' lower than meadow. Head cut traveled upstream draining wet meadow.

- *Sandy loam soil is easily eroded by stream flow.*
- *Channel erodes around wood leaving it stranded.*
- *Pipe invert elevation controls incision depth.*
- *Administration lacked survey quality assurance. Could have been presented.*
- *Site visit by designer during construction may have caught the error before project completion.*

Fig. 15. Administration Problem - Survey error leads to wrong inlet elevation.

Embedded pipe design, 6% gradient, 120% of bank full width structure. Streambed material partially scoured out during a 100-yr storm. Downstream pool area is filled with fine sediment. Water is subsurface my mid summer. Pipe has not refilled after 7 years. Streambed material gradation remaining in pipe is 25% smaller than average cobble/gravel size in upper stream channel.

- *Streambed material scoured because of small size and may have been too thin to develop good interlocking.*
- *Recommend – Construct a new bed based on a stream channel reference reach.*

Fig. 16. Design Problem – Scour resistance of undersized streambed simulation material.

Contract called for "streambed gravel." What went wrong here could happen as a result of: the design or errors in translating into the contract documents, inadequate administration of the contract or misinterpretation by the contractor.

- *Be specific in the contract. Describe streambed material and gradation.*
- *Communicate objective of having the structure streambed look like the channel streambed.*
- *Recommend – Try to remove undersized material and replace with streambed simulation design material.*

Fig. 16. Construction Problem – Supply of incorrect streambed: contract or administration?

Surprise #1:
An extra pipe and wood debris is found beneath existing pipe. It was apparently damaged in a past flood event, smashed and left in place. The pipe and debris extend beneath embankment near inlet. Excavation had to be widened to remove debris. Extra days of work create additional turbidity to treat.

- *Design change*
- *Remove extra debris*

Surprise #2:
Excavation is 6 feet below existing streambed. Multiple past debris slides can be seen in excavation. Abundant groundwater and subsurface streams flood the excavation during summer rainstorms. Dewatering and treatment of turbidity depended on settlement ponds and riparian vegetation filters to remove sediment Filtering capacity was inadequate during storm events. Excavation water should have been transported out of the narrow confined valley to a better filtering area.

- *Design change*
- *Develop and use a better treatment plan*

Surprise #3:
Large boulders were found in the foundation area. This 6' diameter boulder is too heavy to move by the excavator and blasting could dislodge the larger boulder overhead. The foundation design was modified to incorporate the boulder into the concrete footing and stem wall. Holes were drilled into the boulder. Rebar was grouted in holes and connected to foundation steel. Overall dimensions of the footing are massive compared to the boulder.

- *Design change*
- *Modify footing details near boulder*

Fig. 17. Illustrates several "surprises" found during the contract.

Surprise #4
You wake up one morning with a "funny feeling". So you drive out to the project site just because…and you find the contractor got up early too! Give notice of non-compliance!

- *No pumps are running: he is generating very high turbidity levels, water is overtopping the dam, releasing sediment directly into the stream, possible petrochemical pollution.*
- *This is a violation of a basic project objective of protecting aquatic species and habitat.*

Surprise #5

- Pipe lacks any banks or roughness characteristics like it's boulder channel.
- Place materials as shown on drawings.

Fig. 17. (con't) Illustrates several "surprises" found during the contract.

Biological Sketch: David Kim Johansen is a geotechnical engineer and geologist for the Northwest Region of the United State Forest Service. He is a Geotechnical Engineer, Geologist, P.E. who has been with the USDA Forest Service 23 years working in Willamette, Siuslaw, and Gifford Pinchot National Forests. He has been a landscape laborer and foreman 11 years. His primary duties include geotechnical engineering, aquatic organism passage designs, inspections, training, and monitoring.

References

AASHTO Specifications for Highway Bridges.

Buck, E.H. 1995. Summaries of major laws implemented by the National Marine Fisheries Service. CRS Report for Congress. Congressional Research Service, Library of Congress, March 24, 1995.

Contech Construction Products, Technical Bulletins, No. 1-6.

Golder Associates/Alberta Transportation MC Factsheet, Blasting Mitigation Construction Practices.

Macpherson, J., LeMaster, M., Jack, A., and Kilander, A. Tohoe Key Marina Project Review, World Dredging Mining and Construction, December 2002, pages 8-14.

National Corrugated Steel Pipe Association, Installation Manual.

Oregon Department of Transportation, FY 2004 Research Problem Statement, 04RD9-Assessing Effects of Using Natural Flocculants to Manage Turbidity, 2004.

Rolland A. Schmitten, Assistant Administrator for Fisheries, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, National Gravel Extraction Policy, 1996.

United States Department of Labor, Occupational and Safety and Health Administration, OSHA Technical Manual Section V, Chapter 2.

Wilmington District, United States Corps of Engineers, Assessment of Impacts Associated with Rock Blasting, 1995.