A Brief Discussion on Permanent Footings
for Open Bottom Arch Crossings on Small, Fish Bearing Streams

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With the development of modern materials for use in open bottom arch stream crossings, there is a need to revisit how such installations may be achieved. The footings (both the footing materials and the installation procedures) required for the old culvert technology (galvanized steel or concrete arches) are no longer always appropriate. Modern composite materials behave differently and have different footing requirements. As it happens, the footing requirements for more modern and flexible arches can be less onerous to construct, do more to protect fish habitat, and last longer. Thankfully, there are a number of well know engineering (physical) principles that can help to explain how new arch materials can be used to their best advantage. Further to that, there are other established principles that explain how the use of concrete footings may not be the most environmentally satisfactory choice.

Structural Issues with Concrete Footings:

Before discussing the design, installation and materials for footings, it is important to understand the differences between older (less elastic) materials and some newer (more elastic) materials. These materials perform very differently within the soil prism and under dynamic loads. The difference largely comes down to a fundamental structural engineering principle which is that ***"stiffer elements will attract greater proportions of shared load than those that are more flexible"***.

Older arch technology (particularly the footings) is based upon materials that are very strong in compression but are not very elastic. This means that they function very well as long as there are no bending or twisting moments applied to them. However, excessive stiffness can be a serious liability when forces other than strict compression enter the equation. This happens with great regularity in stream banks and streambeds where substrates can be highly variable and loading is highly dynamic (eg. fast moving fully loaded log trucks and very heavy equipment). If inelastic materials (eg. concrete) are allowed to bend or twist, then they will break. In so doing they may crack a concrete arch or tear and separate a steel arch and thus render the entire crossing dysfunctional. This is a common problem and has created the necessary practice of extremely stiff, heavy and expensive footings for both concrete and steel arches.

Flexible composite arches (or for that matter many flexible culverts and pipes) are both strong in compression and high in elasticity or more importantly, viscoelasticity. This means that they are thoroughly capable of being designed to carry extreme loads (just as with steel). However, in addition to that, they have to ability to transfer a good deal of their load to surrounding, stiffer substrates (i.e. the soil prism). With regard to buried arch and pipe structures, this manifests itself as the phenomenon know as ***soil arching***. When confronted with a shifting soil prism, a stiffer arch installation (steel and concrete) will respond by accepting a greater proportion of the shared load between the soil and the stiffer structure. A soil arch composite relationship cannot be formed when the structure is stiffer than the substrate. Thus, if there is any movement or inconsistency in the substrate surrounding the culvert, the flexible structure with a compliant footing will survive while the inflexible structure with a concrete footing may fail (i.e. "you may bend the sapling, but not the tree"). Failure of steel or concrete arches with concrete footings after slumping, frost heaving, scouring or other movements in the soil prism are very common and well recorded. With this in mind, it is important to consider the less invasive, less expensive and less problematic flexible arches with compliant footings.

Environmental Issues with Concrete Footings:

There are a number of problems with concrete footings on fish bearing streams that result from both installation procedures and from the completed structures.

The installation process itself is problematic with concrete footings. In order to install a concrete footing, there is no other way than to excavate and remove the soil substrate to accept the footing. This both disturbs the integrity of the native soil prism and disturbs the stream bank and often the stream bed. In addition, diversions are often required which simply add to the sedimentation and general disturbance of the fish bearing stream. Stream bank disturbance affects the stream itself by removing riparian vegetation and exposing soil to erode and infiltrate the stream (sedimentation). This is harmful to both fish and other aquatic species and mitigation procedures are often required to attempt to counteract the effects of sedimentation. The same problem occurs again when a concrete footing must be removed after a road deactivation or to replace a damaged crossing. In addition to this, excavation of a poorly drained streambank in an area comprised of silts or clays often results in liquefaction and a complete loss of control of the soil prism at the crossing. This can and often has been a major issue that causes extreme damage to downstream fisheries. It seems appropriate that these issues of stream bank and streambed damage with subsequent sedimentation should be avoided rather than invited.

Once installed, a number of other problems begin to manifest themselves over time. Concrete footings are much harder than the surrounding substrate (unless it is solid rock). A fundamental principle of erosion is that any eroding agent (wind, water, or other) will remove the soft parts first and leave the hard parts behind. This principle accounts for one of the most difficult problems that we are faced with when using concrete footings buried at or below normal stream flow levels.

Scouring

Scour (for the purposes of culverts) is the removal, by hydrodynamic forces, of granular bed material in the vicinity of structures that project into the water of a river or stream. Scour is just a more specific form of erosion. In streams and rivers, a major cause of scour is when the water seeks continually to fill the void created on the downstream end of a hard footing that is installed in and below the normal bank full flow zone. This sets up a vortex that then undermines the structure. It erodes the soft parts away and leaves the hard part (the footing) perched without a substrate to support it. If you are installing a culvert over a stream or river, and you place your concrete footings within the zone of "normal" stream flow, then scouring will take place and has the opportunity to do so year round. Water is one of the more powerful eroding agents and so scour is an issue whenever one builds hard and un-erodible structures **in or very near to streams**.

Another problem that can be exacerbated by the installation of concrete footings is frost heave. Frost heaving is a phenomenon that depends upon certain conditions in order to occur. These conditions are often set up when a native soil prism is disturbed and lensing is encouraged. As with scouring, frost heaving is less likely to occur if the conditions for it are not enhanced by our activities. Generally speaking, less disturbance of the natural substrate will reduce the potential for frost heaving. With concrete footings, frost heaving can force bending and twisting moments upon the structure and thus cause it to fail.

Compliant Footings:

Compliant footings such as logs, treated timbers, heavy plastic pipe (eg. double walled, corrugated HDPE) or even flexible steel pipe, have several major advantages for use in small, fish bearing stream crossings. The ability of compliant footings to adapt to changes in the substrate and even to simple irregularities of a stream bank, combined with the flexible (viscoelastic) nature of composite arches such as Enviro-Span, creates an extremely versatile, strong, clean and long lived system. Minor changes in alignment of the crossing over time caused by soil movement have no effect on the durability and strength of a composite arch. A compliant footing will adapt to such stresses and will thus not break. Also, the strong composite Enviro-Span arch will flex with the compliant footing and allow much of the changing stresses to be shouldered by the stiffer and less yielding soils that surround it. That is to say, it will share its load with the soil instead of attracting greater portions of the load as with a stiffer material such as steel or concrete. Composite arches with compliant footings form a composite structure with the substrate in which they are buried. Stiffer, old arch culvert technology with concrete footings will simply not do this.

Further to this, compliant footings can be placed at or near the surface of the substrate with little or no disturbance required. Because the footings are compliant, they do not require the preparation of a perfect foundation. This means that do not have to be buried below the streambed depth in order to be stable. In addition, the composite Enviro-Span arch has elbow modules that allow it to follow the stream course without reconfiguring the channel. With these two features, one can perch the arch above the normal bankful line and thus avoid setting up the conditions for scouring. The stream remains in its completely natural condition without any massively invasive procedures. The ability to leave the substrate around the stream undisturbed also reduces the potential for frost lensing/heaving. It should be noted that there are many of these crossings in place across North America at this time and that some of the prototypes have been operational for as long as nine years now. **There have been no reported issues associated with any of these installations in all of that time.** In addition, these crossings are installed in fully operational, logging, mining and oil & gas extraction roads in the extreme climate conditions of northern Canada. They have been in use under high cycles, multiple seasons and the full force of loaded log trucks, oil rigs and ultra-class mining trucks. They are extremely tough, durable and non-invasive.

Since the footings can be established without significant excavation, there will be no sedimentation during installation. Also, since no major excavation and concrete pouring or placement is required, no stream diversions are required. An Enviro-Span composite arch can be installed all from one side of the stream without requiring any machine crossings at any time. A view of the YouTube posted video http://www.youtube.com/watch?v=bfSsIFoJqcQ demonstrates just how non-invasive and gentle this system is. Photos from this video (below) also illustrate the procedure. There is nothing that the old school arch culvert technology can do to come close to the environmental sensitivity, safety, strength, durability and longevity of these composite arches.

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It would be a significant blow to the advancement of stream crossing technology and improved protection of fish habitat to allow interference with the use of composite arches with compliant footings. Such a thing could happen inadvertently if policies were developed that specified only the use of traditional systems in traditional applications. One example would be any insistence upon the use of concrete footings in particular or deeply buried footings in general for arch culverts. While such a policy might be appropriate for the proper installation of old technology (i.e. corrugated steel) arches, it would only serve to reduce the significant advantages and improvements to fisheries that can be provided by composite arches with compliant footings.

Visco-elastic culvert materials combined with compliant footing materials render the most durable installations acheivable for small stream crossings.

Spray Lake Sawmills, Zero Disturbance Stream Crossing with an Enviro Span Modular Culvert System

Completed Thurs. 16 Aug. 2012 (Powderface Trail,Jumping Pound area)

About the author: Ron W. Hammerstedt, B.Sc.F., RPF. has been a Registered Professional Forester for the past 30 years. His career has been characterized by an unconventional and very successful approach to natural resource stewardship that has led to award winning innovations and operational improvements in large scale forest management systems.

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