Failing Culverts – Structural Problems & Economic Considerations

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Introduction

When we hear the word infrastructure, most of us think of roads and bridges. However, supporting those roads and bridges are countless drainage structures, most of which can be classified as culverts, that are failing or working beyond capacity. These culverts carry surface drainage - rainwater - from one side of the road or highway to the other. They are sized based on very specific data concerning rain events. In addition to the single rain event criteria, there are other considerations. In northern areas subject to snow accumulation, sudden snowmelt can dramatically impact the storm water runoff calculations. Even the likelihood of a hurricane must be taken into consideration in certain locations. The culvert infrastructure is critical to not only preventing flooding of our communities during normal and extreme weather conditions but is integral to proper road and highway maintenance.

This paper discusses why there is an increasing interest in rebuilding infrastructure and preventing catastrophic culvert failures. It is essential to realize that any attempts to rebuild or repair culverts must address the ***composite structure*** that exists within the soil and pipe environment. Additionally, culvert repair or replacement must also address culvert flow capacity issues, as most culverts will need to handle increased flows during their lifetimes. There are several alternative methods one may consider for culvert repair and replacement; however, as discussed here, open cut replacement and tunneling are structurally superior. The point is made here that from an economic viewpoint, when the issues of soil and pipe composite structure and culvert flow capacity are considered, tunneling is probably the best long term and economic solution.

Structural Considerations

Flow calculations are made for the amount of water that must be drained. To properly size the culvert, flow calculations require not only the volume but also the time it takes to drain the volume. The existing pipe is sized for a predicted maximum flow based on the best data available at the time of construction. Flow is the amount of water that passes a specific point during a specific duration in time and is commonly presented as cubic feet per second. If the pipe is too small, then the time it takes for the area to drain is simply extended. This causes flooding issues when there is a heavy rain. We hear of fifty year and one hundred year storms. These are benchmarks in the data that the drainage engineer uses for the volume estimate to size the original pipe. The time considered is a combination of the duration of the rain event and that resulting from the speed at which the storm water travels over the land and in channels to get to the culvert. The volume does not really change. The time does change as manmade features accelerate the speed that the volume moves across a drainage area.

Now we all know that when an area is developed, streets and houses are constructed, and commercial buildings are developed with parking lots. The families move into the new homes and everyone is happy. Let's look at what really happens - the dirt surface that absorbed or slowed down the flow of a great deal of the rain that fell or the snow that melted is now paved or covered with a structure with roof drainage. The paving improvements and roofs are sloped toward a catch basin or other drainage structure. The increased rainwater that has been captured has to go somewhere and because it has been captured and concentrated into drainage structures, the same amount of water gets to the culvert much faster. The result is that the new flow is higher and accumulates over a shorter period than the original design. If there is a road or highway to cross, it will cross the road through a culvert. The culvert now must carry the same amount of water but over a much shorter time. However, the culvert can only take the designed flow or a designed amount of water over a specified length of time.

The development upstream is an extremely important and is sometimes an overriding detail. As was mentioned earlier, when the pipe is no longer large enough to carry the new increased flows caused by the upstream development, it takes longer for the water to pass through the pipe. It will all pass if given enough time. This increased time has some far reaching effects both in flooding upstream of the culvert and on the structural integrity of the culvert.

Let's talk about the existing pipes used for culverts. Corrugated metal pipes (CMP) were first used around 1900. In the 1930s a university professor by the name of Spangler went to work testing and theorizing ways to design and install CMP properly to insure that the metal culverts would stay in service throughout their design life. There is a great deal of CMP under our roads and highways. One of the best attributes of CMP is that it is not flammable and therefore not vulnerable to grass fires or vandalism.

Because of Spangler's work, thin flexible pipe can be used in conjunction with the ground around the pipe to create a very cost effective, strong and dependable composite structure. A ***composite structure*** means that all loads are supported by the combination of the flexible metal structure *and* the surrounding engineered soil. This use of the soil interaction with the pipe depends on installing engineered select compacted soil around the pipe *and* the ability for the flexible metal section to retain the soil in place. For that reason, most of the thin flexible pipe that exists underground is surrounded by granular material such as sand or gravel. For the reader who is not a soil expert - sand and gravel is easy to level in layers and compact as the pipe is being buried and is not generally susceptible to frost. Water will pass easily through this material.

Existing concrete pipes are stronger than the flexible metal pipe. Concrete pipes are thick walled and rigid. They do not require the same soil structure interaction as the thin flexible pipes to support the same load. For that reason, "native material" can sometimes be used as bedding instead of sand and gravel. Native material, when it's compacted, is very effective in resisting groundwater movement along the concrete pipe.

There is usually only one reason that a specific culvert gets the attention of the owner (the State DOT or the City or County maintenance staff) and that is because there is a failure of some kind:

- There is excessive backup on the upstream end – flooding,

- The ability of the pipe to carry water is diminished - it's beginning to cave in or close up,
- The road above is settling over the path of the existing pipe,
- The headwall is beginning to move away from the existing pipe at the downstream end,
- The backfill material around the pipe at the down stream end is beginning to "unravel",
- Or, the culvert and the road have washed out during a heavy rain event or snowmelt runoff.

Culvert failures are seldom small and easy to fix. (source for this photo - unknown)

The first thing that must take place is obvious - the existing pipe must be visited and inspected. If it is concrete pipe, the potential problems are limited to the pipe structure. The pipe is almost always structurally sound and safe for a workman to enter. The same cannot be said for flexible pipes like CMP. Corrugated metal deteriorates with age. The galvanizing is normally worn away on the invert (the lowest point) and the metal rusts and eventually disappears (sometimes disappearing and sometimes simply buckling upward). In some pipe configurations, the spiral joints rust. When the invert rusts, there are two things that happen. First, the bedding and backfill under and around the pipe is no longer supported and is thus allowed to enter the stream of water, and the water washes away any material that can be dislodged. Secondly - because part the circumference or “hoop” is gone, the “hoop strength” of the pipe is no longer able to retain the soil in the position and engineered condition necessary for a stable composite structure. This affects the ability of the soil and flexible metal pipe composite structure to resist the weight above and the circumference of the pipe begins to change - it closes in where the invert used to be and gets smaller. In both of these scenarios, the soil in close proximity of the pipe is now moving, and when it moves it loses its compaction. In other words, large and uncontrolled voids develop between the soil particles where there were no voids before the pipe deteriorated.

Unlike concrete pipe, soil movement must be considered for CMP culverts, as the soil is a critical structural element of the composite culvert structure. Without the soil, the culvert will collapse, often catastrophically (very quickly - possibly in a matter of minutes). Once the ground has lost its compaction, the flexible pipe is no longer structurally sound. The pipe will normally show evidence of this structural failure mode. The pipe will show sags. The invert or what's left of the invert will begin to buckle upward. When these indicators are present the pipe is unsafe to enter.

Beyond the safety issue, the now unstable pipe is especially vulnerable to smaller and smaller additional loading such as flow from a heavy rain. As was mentioned earlier, as the community upstream from the pipe develops, the flow increases. As the pipe deteriorates and the pipe begins to close up, it cannot carry the flows it was originally designed to handle. When these two phenomenon come together, we will see slower draining at the inlet of the pipe. The puddle or lake that is temporarily formed causes pressure at the inlet of the pipe. This pressure is called hydrostatic pressure and it exerts itself on the ground around the pipe as well as on the inlet of the pipe.

If hydrostatic pressure is allowed to form around the pipe on the upstream end, the pressure will result in water seeping through the uncompacted granular material near the pipe. Water flowing through the ground will in time carry and move the fines of the soil and a washout will occur. This phenomenon can be seen in less catastrophic terms when the earth around the downstream end of the pipe seems to be disappearing or when the outlet headwall moves for no apparent reason.

In today's harsh economic environment, there is increasing pressure to simply line the old pipe. Another fix sometimes employed is to pour a concrete floor on the deteriorated invert to replace the eroded or lost pipe structure. However, if the soil around the thin flexible pipe has lost compaction, there are only two ways to fix the problem. The pipe can be replaced by open cut construction or it can be tunneled. Both solutions result in removal or modification of the unknown amount of uncompacted material. At this time, there are two design approaches that may be considered: flexible and rigid pipe. A flexible pipe design approach requires reestablishing a controlled backfill for a specified distance around a lower cost flexible structure. A rigid design approach is to create a new pipe section that does not need to be dependent on the surrounding soil for carrying the required loads.

There are many situations where the existing flow has not increased dramatically and the existing culvert size is sufficient. Sliplining would appear to be a very cost effective way to deal with the deteriorated culvert. However, sliplining with a new pipe and grouting the annulus once the old pipe has been breeched and soil lost cannot change the soil conditions around the old pipe, namely - uncompacted material that can no longer be relied on to support the pipe. Thus, the new pipe must be designed to fully support all ground and traffic loads and can no longer take advantage of the soil for carrying some of the load. This uncompacted material affects not only the structural integrity of the old composite pipe system but also affects the ongoing resistance to washout caused by groundwater movement from the upstream end. In other words, the newly slip lined pipe might be washed away by the failure of the embankment to hold back the groundwater migration allowed by the uncompacted bedding material (sand and gravel) near the old pipe. The uncompacted material around the old pipe is actually a progressive failure that will grow with time. The sliplining effort did not address this inherent progressive failure.

In situations where the existing pipe is undersized because of development upstream, a larger pipe must be installed. This can be readily accomplished by open cut or tunneling.

We have been hearing a lot of talk about climate change. It seems that areas that normally get a lot of rain, don't get as much. In areas that normally don't get much rain, it seems that the opposite is true. One thing is for sure, the weather keeps changing. And we need to simply look around to see how vulnerable we all are to Mother Nature.

The need to address infrastructure in the US and Canada has gained political strength. Noteworthy is the high failure rate of flexible pipe culverts, most of which are corrugated metal, under our federal, state, and local highways. Some recent failures have been catastrophic as highways collapse without warning, and most occur in high traffic volume areas. With today's economic realities, it is more important than ever to closely scrutinize these failures and develop long term, cost effective, site appropriate, solutions.

Ultimately, the majority of culvert failures are due to corrosion and the degradation of the soil-pipe structure. The only fix for a failing conduit that is to continue to be supported by a granular structure is replacement of the failed granular material. However, the excavation and time required to reconstruct this engineered composite structure is time that the road will be out of service. This is often not a politically acceptable solution in urban areas. A viable solution is to use a rigid pipe design that can be installed without taking the road out of service to modify the surrounding fill.

Economic Considerations

Now comes the challenge – money to fix these community assets is always scarce.

Many culverts, whether they are federal, state, or local, are located in high traffic areas or in deeper fills. Rehabilitation of these culverts has become a national problem, as there are few alternatives that do not impact traffic flow and local commerce and incur large social costs. Traditional tunneling methods have been found to be an economical and effective method of removal and replacement of theses failing culverts as they can address both the damaged surrounding soil in a limited area and the need to have a highly engineered fill composite for the final structure. This alternative also allows the owner to upsize the existing capacity. Tunneling combined with the use of rigid pipe allows for the replacement of the existing pipe without upsetting any other existing utilities or the need to reconstitute or replace the failed engineered fill system. Tunneling also minimizes the social costs associated with installation of the culvert.

Conclusion

This geotechnical perspective has shown that there are several elements or mechanisms of pipe failure that work in concert to affect the total failure of the culvert. There is no more cost effective solution to these challenges than to "fix it" properly with a low social cost of installation, the longest design life, and a low maintenance solution. Tunneling creates a new structure with a new long design life material and a very long life expectancy.

Please view the following Video clip on U-tube -
http://www.youtube.com/watch?v=p_uqPR4Ir5o

The video is a good example of when a drainage pipe cannot handle the flow, the water begins to migrate along the outside wall of the pipe and soon washes away the bedding and the road.