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Case Study of the Replacement of Corrugated Metal Pipe (CMP) Culverts using Pipe Bursting

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ABSTRACT

Culverts are very critical to drainage and transportation of fluids under highways. State Departments of Transportation maintain thousands of these culverts under highways, road and freeways. The Ohio Department of Transportation alone maintains over 85,000 culverts under Ohio's priority and general highways. Through regular inspections and condition assessment of these culverts, a course of action ranging from routine maintenance to replacement is recommended. Pipe bursting is a viable alternative to replace deteriorated culverts. However, a high percentage of these culverts are made of corrugated metal pipes which are challenging to burst because the ridges tend to fold under the compression stress making it difficult, and often times, impossible to burst. The research team at Bowling Green State University (BGSU) in collaboration with two pipe bursting manufacturers (TT Technologies and Hammerhead) conducted pipe bursting research tests aimed at finding solutions to bursting corrugated metal pipes. This paper provides an overview of the pipe bursting operations through which four corrugated metal pipe culverts (12", 18", and 24" in diameter) were successfully replaced through this collaborative effort.

INTRODUCTION

The State Departments of Transportation (DOTs) are responsible for a large number of highway assets including culverts, which are important drainage structures under roads. The main purpose of these culverts is to transport water or fluid from one side of the highway to the other. During the industrial growth in the 1950s, culvert construction became necessary as a result of the freeway construction projects initiated in United States through the Federal-Aid Highway Act of 1956 (Camp, Boyce, & Tenbusch, 2010). Corrugated pipe, and in particular, corrugated metal pipe (CMP), was generally the material of choice on these low bid projects because of the relative low cost for a given strength of the pipe. The corrugations add strength to the pipe while permitting a reduction in wall metal thickness resulting in lower pipe material cost per foot of pipe (Tenbusch, Dorwart, & Tenbusch, 2009). Many of these culverts were designed for a 50-year life cycle, which is now ending (Camp, Boyce, & Tenbusch, 2010). For these assets to continue to perform their intended function and meet future demands, they have to be replaced or rehabilitated.

As underground structures, culverts are less noticeable and are often ignored until a catastrophic failure occurs (Gee, 2007). These failures lead to temporarily roadway closure, disruption of traffic flow, and considerable re-installation costs. A complete collapse of the culvert may result in the collapse of the roadway posing a major safety risk or hazard to motorists. With factors such as aging and deteriorating national infrastructure, increasing congestion, highway safety challenges, and limited funds, state departments of transportation are looking for innovative ways to manage their transportation assets (Gee, 2007). Consequently, the selection of economic alternatives to replace deteriorated culverts has become an important aspect of managing these assets.

Open-cut, which is the traditional method for culvert rehabilitation, is an expensive alternative for deep installations due to the massive excavation and need for shoring. Apart from the direct cost, there are social costs such as traffic disruption, road closures, business interruptions, noise pollution, environmental impact, and reduced safety for both workers and road users associated with open-cut. Trenchless rehabilitation methods such as cured-in-place pipe, slip lining, fold and form and other relining techniques have the disadvantage of reducing the internal diameter of the existing pipe and hence not applicable where there is the need to increase the diameter and flow of the existing pipe.

Pipe bursting provides an innovative and practical alternative to open cut without the disturbance and the cost of excavating a trench (Atalah, 2008). Pipe bursting has several advantages over the traditional open-cut method; it is much faster, more efficient, and less expensive especially in gravity applications due to their deeper depths. Pipe bursting is the only trenchless rehabilitation method that can replace an existing pipe with an entirely new pipe resulting in total replacement of the existing deteriorated pipe (Lueke, 1999). Pipe bursting also has the advantage of maintaining or increasing the flow capacity of the existing deteriorated pipeline by increasing the diameter of the replacement pipe. Pipe bursting has been used to replace almost all types of pipes including lightly reinforced concrete pipes, ductile iron pipes, clay pipes, steel pipes, vitrified clay pipes (VCP), cast iron, plain concrete, asbestos and some plastics. However, corrugated metal pipe (CMP) is not considered a good candidate for pipe bursting because the ridges of CMP fold like an accordion under compression thickening the wall and making it almost impossible to burst or slit or split.

The Ohio Department of Transportation (ODOT), alone maintains over 85,000 culverts and about 20% (17,500) of these culverts are corrugated metal pipes (ODOT Culvert Database, 2014). Considering the large number of existing CMP culverts and the continual use of CMP for culverts, it is essential to expand the pipe bursting applications to these culverts, which will in turn provide an alternative rehabilitation method for municipalities and transportation agencies.

To determine the system and tools for successful bursting of corrugated metal pipes, field tests were conducted that involved the replacement of actual culverts under existing roads. The two pipe bursting manufacturers, TT Technologies and Hammerhead, contributed their bursting equipment and technicians. These tests provided the opportunity for the manufacturers to investigate different accessories, designs, and system configurations to successfully burst corrugated metal pipes.

Through the collaboration of ODOT, the manufacturers, and the research team from BGSU, four CMP culverts were successfully replaced using pipe bursting. The pipe bursting tests were done in ODOT's Districts 2, 5, and 10. All the pipes were replaced with high density polyethylene (HDPE) DR 17 pipes which were delivered and fused on site. The District 10 test was done with a pneumatic bursting system, while the District 5 and 2 tests were done with a static bursting system.

PIPE BURSTING

Pipe bursting is a pipe replacement technique where the existing pipe is broken by brittle fracture, using force from within, applied mechanically, and its fragments are forced into the surrounding ground. As the existing pipe is broken, the new pipe is either pulled or jacked into place (NASTT, 2013). The breaking of the old pipe and installation of the new pipe are done concurrently. The new pipe can be of equal or larger diameter than the existing pipe and will follow the same alignment as the existing pipe.

There are two main pipe bursting systems which are classified based on the type of bursting head used as shown in Figure 1:

- Pneumatic pipe bursting, which uses pulsating air pressure to drive the head forward and burst the old pipe. A pulling device (winch) guides the head via a constant tension cable.
- Static pull, where a static head with no moving internal parts is used. The head is simply pulled through the pipe by a heavy-duty pulling device via a segmented drill rod assembly or heavy anchor chain (Atalah, 2008).

For this research, the pneumatic and static systems were selected by the manufactures based on their experience with them. The bursting heads used in conjunction with the systems were designed by the manufacturers for bursting CMP.

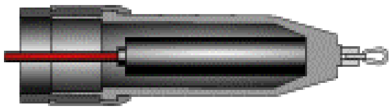
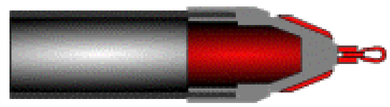
Pneumatic head	Static head
	

Figure 1: Bursting heads for the different PB systems

TEST DONE USING THE PNEUMATIC BURSTING SYSTEM

After visiting the culvert sites, Hammerhead Trenchless Equipment selected the pneumatic system to replace one corrugated metal culvert in ODOT's district 10. The existing culvert was a 24 inch corrugated metal pipe, 100 feet long and 8 feet deep. It was replaced with a 24 inch HDPE pipe 100 feet long. The '16 (400) AR' pneumatic bursting tool and the 'HG12' winch, shown in Figure 2, were used for this burst. The winch was thrust against a steel plate which was supported by two I-beams driven into the soil as shown in Figure 2. The bursting tool was placed inside the HDPE pipe and the expander bolted onto the pipe as shown in Figure 3. A pilot with a blade designed to cut the corrugated pipe (shown in Figure 4) was placed in front of the expander to cut the CMP and hold the pipe in place to prevent it from collapsing.

Figure 2: Winch Setup for pneumatic bursting

Figure 3: Front-end expander bolted to HDPE pipe with bursting tool inside the pipe

Figure 4: Pilot with cutting blade

The steel plate was offset (by about 20 feet) from the existing culvert in the pulling pit to allow enough room for the pilot and expander to fully exit the existing pipe. The I-beams were driven into the ground behind the steel plate offering a surface for the winch to thrust against. However, because of this setting there was insufficient soil behind the steel plate to create the needed passive resistance. During bursting, the pulling force from the winch forced the I-beams and steel plate to tilt out of position. The steel plate and the I-beams were driven further into the ground to provide extra stability and held back by the excavator for additional support as shown in Figure 5. The entire culvert replacement work including setup and bursting took 10 hours. The actual bursting (installation) operation took 2 hours 20 minutes. The rate of burst was about 2 minutes per foot of pipe installed. The maximum pulling force from the winch was 12 tons and the air pressure from the compressor averaged 1000 psi for the burst.

Figure 5: Setup with excavator supporting the I beams and steel plate

The CMP was replaced successfully. However, The final few feet (estimated to be between 15 to 20 feet) of existing corrugated pipe folded onto the bursting head forming a 'ball' on the expander that was not cut, as it should be, by the bursting tool and was pulled into the pulling pit as shown in Figure 6. When bursting pipes longer than the 100ft that were burst in this case, the balling action may be very problematic.

Figure 6: Folded CMP pushed out

TESTS DONE USING THE STATIC BURSTING SYSTEM

The static pipe bursting system was used to replace two culverts in ODOT's District 5 and one in District 2. TT Technologies selected the Grundoburst 1250G to replace these three culverts with their details shown in Table 1. The setup for the static puling system is shown in Figures 7a and 7b.

Table 1: Culverts replaced using static pipe bursting

ODOT's District		Existing pipe	New pipe
5	Test 1	18" CMP pipe, 105' long	18" HDPE pipe, 120' long
5	Test 2	12" CMP pipe, 90' long	16" HDPE pipe, 100' long
2	Test 3	24" CMP pipe, 80' long	24" HDPE pipe, 120' long

Figure 7a: System setup for static bursting

Figure 7b: System setup for static bursting

The bursting head, designed with a blade to cut the CMP ahead of the expander, was attached to the expander which was then bolted to the HDPE pipe as shown in Figure 8. Rods were driven through the CMP and connected to the bursting head to be pulled back, bursting the existing pipe while simultaneously installing the new HDPE pipe.

The duration of Test 1 in ODOT's district 5 was 14 hours 20 minutes with the actual bursting (installation) taking 45 minutes. The bursting rate was 0.4 minutes (24 seconds) per foot of pipe installed.

The duration of the second test in ODOT's district 5 was 12 hours 40 minutes with the actual bursting (installation) taking 35 minutes. The bursting rate was 0.4 minutes (24 seconds) per foot of pipe installed. The duration for the replacement in ODOT's district 2 was 14 hours 30 minutes with the actual bursting (installation) taking 30 minutes. The bursting rate was 0.25 minutes (15 seconds) per foot of pipe installed. And while all the bursts were successful, the last section of the existing CMP (about 10 to 15 feet) was always pushed out unburst as shown in Figure 9. This last section of the pipe would ball-up on the bursting head and get pushed out, unburst.

Figure 8: Bolting expander with bursting head on HDPE pipe

Figure 9: Folded CMP on bursting head

OBSERVATION

Part of the existing corrugated pipe folded onto the bursting head forming a 'ball' on the expander and was pulled into the pulling pit. This was the final few feet (estimated to be between 10 to 20 feet) of the existing corrugated pipe which was not cut by the bursting head. There are two reasons that we can attribute to this:

1. The friction between the soil and final few feet of the corrugated pipe does not offer enough resistance to hold the pipe in place for the cutting edge to cut it. The path of least resistance is the movement of the final segment out the pulling pit, and
2. The existing CMP balls-up gradually over the drive and during the final few feet, the ridges have folded to the extent that the cutting edge is incapable of cutting the pipe. With increased force, the pipe is pulled out.

The balling effect of the CMP creates an overcut (bigger than the expander) around the installed pipe. This overcut is reasonably expected to get bigger for longer runs of installation. Pipe bursting is used successfully and routinely to replace pipes up to 500 feet in length. However, the CMP culverts tested were up to 120 feet long. From the field observations and conversations with the manufacturers, the research team reasonably concluded that pipe bursting systems can be used to burst similar CMP culverts up to 150 feet long. Further research is required to investigate the ability of the systems to replace longer runs of CMP culverts and to develop a more capable system to cut the CMP without excessive balling effect and overcut. It was also observed that the pneumatic burst took longer time than the static bursts.

After tracking all the man and equipment hours and the cost of material for the pipe bursting tests and similar open cut jobs in terms of diameter and length of pipe installed, the following conclusions can be made:

- The average direct cost per linear foot for the 18 inch bursting jobs was $130 and that of the open cut was $151. This represents a cost savings of 14% by using pipe bursting.
- The average direct cost per linear foot for the 24 inch bursting jobs was $159 and that of the open cut was $195 as shown in Figure 10. This represents a cost savings of 18% by using pipe bursting; the savings are expected to increase as the pipe gets deeper.

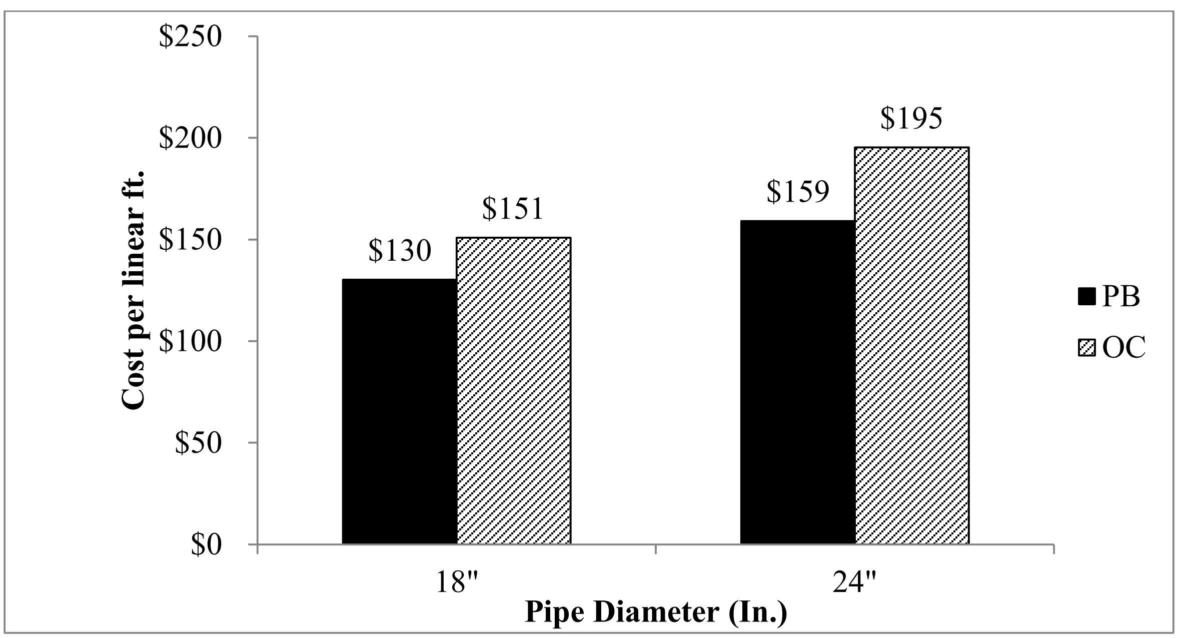


Figure 10: Direct cost comparison for pipe bursting versus open-cut

The lengths of all the culverts used in the comparison range between 100 and 120 feet. It is important to state that the culverts replaced using pipe bursting in this analysis were, on average, at a greater depth than those replaced using open cut. The cost disparity would have been greater had the culverts that were replaced using open cut been at the same depth as those replaced using pipe bursting. The depth of the culverts replaced using pipe bursting ranged from 8 to 18 feet while those replaced using open-cut ranged from 5 to 10 feet.

The total passenger car-delay hours for pipe bursting versus open-cut ranged from 75 hours to 249 hours for pipe bursting and 149 hours to 1,307 hours for open-cut. The passenger car-delay hours for the pipe bursting jobs were 50% to 81% lower than that for open cut jobs.

CONCLUSION

Based on the pipe bursting tests conducted, the research team concluded that:

- Pipe bursting (both pneumatic and static) is a viable technique for the replacement of CMP culverts.
- For this application, the static system seemed to work better and more efficient than the pneumatic system.

For this research, direct cost savings of at least 14% are achievable by using pipe bursting; the savings will increase as the pipe gets deeper. The benefit of pipe bursting goes beyond cost savings. The pipe bursting tests were completed in 1.5 days on average while the open cut jobs were completed in 3 days. While only one lane was closed during pipe bursting, the road was completely closed for open cut jobs.

RECOMMENDATIONS

- The research team recommends the use of the static bursting system to replace corrugated metal culverts up to 120 feet in length.
- The following measures can help reduce the risk of failure:
  - Ensure the bursting head is concentric with the old pipe (CMP)
  - Ensure that the cutting blade on the pilot is appropriately positioned to effectively cut the CMP. It is preferable to set the blade at the weakest point of the pipe (usually the bottom).
- The balling effect, should it occur, could overcut the soil around the pipe, creating a void in the ground. This void should be grouted to avoid potential settlement and damage the nearby utilities and pavement.
- It is recommended that further study be conducted on this topic to establish the viability of bursting corrugated metal pipes longer than 120 feet.

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