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Pipe Bursting as a Viable Alternative for Replacing Corrugated Metal Pipe Culverts.

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***Abstract*— The integrity of our roads is partly dependent on how effectively we drain the surface water and not allow it to percolate through the road structures and undermine their integrity. Culverts are critical to transporting the surface water under our pavements and must be maintained, repaired, renewed, and replaced as needed. Pipe bursting is a competitive alternative to the conventional open-cut method for replacing culverts. Pipe bursting can install a culvert of equal or larger diameter than the existing one at the same horizontal alignment as the existing pipe. In favorable conditions, pipe bursting is less expensive than open cut, and provides other benefits in terms of indirect cost savings including less impact on traffic, less impact on the environment, and higher safety for both workers and the public. However, bursting corrugated metal pipe (CMP) has been challenging and risky because the ridges fold under compression, thickening the wall, and making it almost impossible to burst or split. This paper explores the viability of bursting CMP through case studies of CMP culverts replaced using both the pneumatic and static pipe bursting systems.**

***Keywords*— Pipe Bursting, Corrugated Metal Pipe, Culverts, Trenchless, Pneumatic Bursting, Static Bursting, Open-cut.**

I. INTRODUCTION

A culvert is a conduit used to transport surface water under a pavement, railway or any other form of embankment or levee. Culverts are available in different shapes and sizes and can be made of a variety of materials including steel, concrete, polyvinyl chloride (PVC), high-density polyethylene (HDPE), ductile iron, corrugated metal, and clay. The most common culvert pipes are corrugated metal (CMP), concrete, and plastic (HDPE and PVC). Selection of the appropriate culvert shape, configuration and material depends on the roadway profile, channel characteristics, flood damage evaluations, construction and maintenance costs, and estimates of service life (Schall, Thompson, Zerges, Kilgore, & Morris, 2012).

Culvert construction in the United States became increasingly necessary with the interstate highway construction projects initiated under the Eisenhower administration (1953-1961).

Many of these culverts, designed for a 50-year life cycle, are either nearing or have exceeded their design life (Camp, Boyce, & Tenbusch, 2010). Historically, corrugated metal pipe was widely used to provide drainage for roadways and other embankments primarily because it is cheaper, easier to transport, and easier to assemble than other culvert pipes (Meegoda & Juliano, 2009). However, once installed in the ground, CMPs are susceptible to corrosion on both the internal surface and the external surface that is in contact with the soil. About 21% of the total culverts maintained by Ohio Department of Transportation (ODOT) are made of CMP (Adamtey, 2016). Assuming Ohio is representative of the 50 states, there may be tens of thousands of corrugated metal culverts across the United States.

Culverts need to be routinely maintained through cleaning and debris removal. These routine culvert maintenance activities help detect and address specific problems as they occur. It is also standard practice for utility owners to routinely inspect their culverts and based on the condition assessment, make a determination on whether they need to be repaired, renewed, or replaced (Masada, Sargand, Tarawneh, Mitchell, & Gruver, 2007). Culvert repair measures - including patching, sealing, localized grouting, and use of interior seals - are effective when there are minor defects like cracks, spalling, and misaligned joints. When repair action is insufficient to bring the culvert back to satisfactory working condition, the culvert must either be renewed or replaced. While renewal methods form a new pipe within the existing one, replacement procedures involve complete elimination of the existing culvert. The available renewal methods include cured-in-place pipe (CIPP), fold and form, sliplining, spray-in-place pipe (SIPP), spirally wound liner, and shotcrete. Applicable replacement methods include open cut, horizontal auger boring (HAB), horizontal directional drilling (HDD), pipe bursting, pipe jacking, and pipe ramming (ASCE, 2017).

Pipe bursting is a well-established trenchless method that provides an innovative and practical alternative to the conventional open-cut method without the disturbance and the cost of excavating a trench (Atalah, 2008).

Despite the growth of pipe bursting, CMP has been identified as unsuitable or not a good candidate for conventional pipe bursting (IPBA, 2012). Bursting CMP has been challenging and risky because the ridges fold under compression, thickening the wall and making it almost impossible to burst or split.

The vast number of CMP culverts that need to be replaced and the need to replace them using systems that are more economical, functional, and environmentally friendly, speak to the need for exploring the viability of pipe bursting as a replacement method.

II. Pipe Bursting

The International Pipe Bursting Association (2012) defined pipe bursting as a trenchless replacement method in which an existing pipe is broken either by brittle fracture or by splitting, using an internal force that is mechanically applied by a bursting tool. At the same time, a new pipe of the same or larger diameter is pulled/pushed in replacing the existing pipe. The process requires an entry/insertion pit where the replacement pipe attached to the bursting head is launched, and a pulling/exit pit where the winch cable or rod assembly is set up. These pits are generally excavated in conformity to the drawings and specifications. Where available and favorable, manholes and the existing layout condition of the ground can be used as pits. Currently, there are two main classes of pipe-bursting systems in use based on the type of bursting head. These are the pneumatic and static systems.

A. Pneumatic Pipe Bursting

In pneumatic pipe bursting, the bursting tool is a percussive hammer driven by compressed air at the rate of 180 to 580 blows per minute (Atalah, 2008). A pulling device (winch) guides the bursting head via a constant tension cable. The constant tension of the winch cable keeps the bursting head in contact with the unburst section of the pipe and keeps the bursting head inside the existing pipe (IPBA, 2012). The winch cable also helps pull the replacement pipe behind the bursting head. As the head advances forward, the existing pipe is fractured with each stroke.

B. Static Pipe Bursting

This system uses a static head with no moving internal parts and a large tensile force from a pulling rod assembly or a winch cable to fracture the existing pipe (Atalah, 2008).

The tensile force is converted into a radial force by the bursting head to fracture the existing pipe. As the head advances forward, it pushes the fractured pieces of the old pipe into the surrounding soil expanding the cavity and providing space for the replacement pipe. During the process, the hydraulic unit pulls the rods one at a time and the rods are disconnected as they reach the pulling pit. Where a winch cable is used, the process is a continuous one until the head reaches the pulling pit (Atalah, 2008).

C. Breakdown of General Steps Involved in Pipe Bursting

During the pre-design and design phases, the designer collects all the relevant information about the existing pipe as well as the proposed pipe. The designer develops detailed drawings and specifications with complete bid documents. A qualified contractor is then selected who prepares all submittals according to bid documents and completes the job according to the specifications. Generally, the steps involved in pipe bursting vary depending on the pipe-bursting technique used and the type of utility to be replaced. The breakdown of the typical steps involved in a pipe-bursting operation are listed below and the sequence of operation shown in Figure 1. It is essential to note that some of the bursting activities can be done concurrently. For example, machine setup in the pulling pit can be done as insertion pit is being excavated.

- Preconstruction survey
  - Site visits
  - CCTV inspection and cleaning of old pipe, if needed
- Mobilization
  - Transportation of equipment, material, and labor to site
- Pit preparation
  - Clearing of pits
  - Excavation, shaping, and levelling of pits
  - Excavation at services and setting up temporary bypass (where needed)
- Fusion of HDPE pipe
  - Setting up fusion machine
  - Fusing HDPE pipe
- Machine setup
  - Setting up the winch (for pneumatic system) or hydraulic pulling system (for static system)
  - Inserting winch cable (pneumatic system) or rods (static system) through existing pipe

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- Connecting bursting head to the pipe
  - Installation of air supply hoses through HDPE pipe to bursting head (for pneumatic)
  - Connecting and bolting bursting head to HDPE pipe (both pneumatic and static)
  - Connecting bursting head to pulling cable or rod
- Bursting the existing pipe and installing the new pipe
- Disconnecting bursting tools
  - Separating bursting head from pipe
  - Disconnecting air supply hoses (for pneumatic)
  - Removal of winch or hydraulic unit from pit
- Restoration and site cleanup
  - Reconnection of services
  - Backfilling
  - Cleanup, mulching, seeding and other restoration (as applicable)
- Demobilization
  - Transportation of equipment, material, and labor from site to yard.

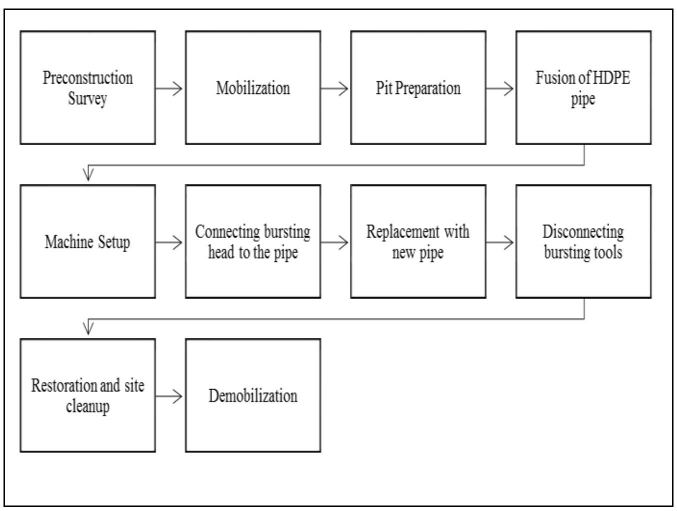

Figure 1. Pipe bursting activities

D. Application Range and Limitations of Pipe Bursting

The suitability of employing pipe bursting depends on numerous factors including depth of cover, burst length, host pipe material, upsize diameter, and geological conditions (Ariaratnam, Lueke, & Michael, 2012).

The typical length of replacement run is between 300 feet and 500 feet, which is the typical distance between manholes; however, longer drives have been completed successfully in favorable conditions. The size of pipes burst typically range from 2” to 30”, although pipes of larger sizes can be burst (Atalah, 2008). The majority of pipe bursting is employed for upsizing from 6” - 8” (150mm - 200 mm), 8” - 10” (200 mm - 250 mm) or 10” – 12” (250mm to 300 mm) (Bennett, Ariaratnam, & Wallin, 2011).

It is important to pay close attention to the project surroundings, depth of installation, and soil conditions when replacing an existing pipe especially in unfavorable conditions such as expansive soils, repairs made with ductile material, collapsed pipe, concrete encasement, sleeves and adjacent utility lines (Atalah et al., 1998). Some further limitations identified by Atalah (2007) include excavation for lateral connections, the need for insertion and pulling pits for larger bursts, point excavation to fix sags, and if the old sewer line is significantly out of line and grade, the new line will also tend to be out of line and grade. Pipe bursting also requires bypassing the flow to allow work on the pipeline that needs to be replaced. Bypass pumping must be part of the design protocol when dealing with live lines.

E. The Case for Pipe Bursting

Pipe bursting has the advantage of increasing the capacity of the pipeline by more than 100%. With the ability to upsize the service lines, one can increase the capacity of the pipeline tremendously using pipe bursting. For pressure applications, a 41% increase in the inside pipe diameter doubles the cross-sectional area of the pipe and consequently doubles the flow capacity of the line. For gravity applications, a 15% and 32% increase in the inside diameter of the pipe combined with the smoother surface of the new pipe can produce an increase in the flow capacity of 100% and 200% respectively (Atalah, 2008).

Pipe bursting is most cost advantageous compared to the lining techniques such as CIPP, fold and form, and sliplining when: (1) there are few lateral connections to be reconnected within a replacement section, (2) the old pipe is structurally deteriorated, and (3) additional capacity is needed. (Simicevic & Sterling, 2001). Pipe bursting also has substantial advantages when compared to open-cut method. In favorable conditions, pipe bursting has been proven to be less expensive than open cut. Pipe bursting requires less time, space, and in some situations less equipment and labor to complete the project (IPBA, 2012).

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This makes pipe bursting a more efficient replacement method. One of the main contributing factors to the cost disparity between pipe bursting and open cut is excavation. While pipe bursting requires minimal amount of excavation, open cut involves complete excavation of the pipeline. The cost advantage of pipe bursting becomes more significant as the depth of installation increases. This is mainly due to the increased depth requiring extra excavation, shoring, and dewatering in open-cut operations. As the depth of installation increases, the cost of pipe bursting remains almost the same while that of open cut increases.

Pipe bursting also provides other benefits over open cut in terms of indirect cost savings. It has less impact on traffic and hence less inconvenience to road users. Other indirect cost benefits of pipe bursting over open cut include less environmental impact in terms of less noise pollution and higher safety for both workers and public due to less excavation (IPBA, 2012).

III. The Challenge Of Bursting Corrugated Metal Pipes

There has been significant research on pipe bursting that has expanded the application of the method. Modifications have been made to the basic pipe bursting technique to enable bursting a variety of pipes. However, CMP still poses some challenges for pipe bursting and hence, requires special modifications and additions to the existing systems (IPBA, 2012; Timberlake, 2011; Matthews, Simicevic, Kestler, & Piehl, 2012).

The main challenge is the folding effect of the CMP when it is subjected to compressive force. Under compressive force, the corrugations fold, thickening the walls of the CMP, and making it almost impossible to burst or cut. This turns the bursting operating into a "pounding" operation that pushes out the remaining section of the CMP unburst. Figure 2 shows a section of compressed CMP that was pushed out of the bore unburst. If the folding occurs early in the drive, there is a good chance that the operation will stall. Any modifications to the bursting system should be able to either burst the thickened corrugations or prevent the CMP from folding before bursting.

Figure 2. Compressed CMP

IV. Case Studies Of Bursting CMP

In 2005, a 15-inch-diameter corrugated metal pipe was burst using a 14-inch Grundocrack Koloss with a 24-inch rear expander in DeKalb County, Georgia. The 15-inch CMP was upsized to a 24-inch HDPE pipe. The original corrugated metal pipe culvert was sheared open and expanded as the new HDPE pipe was pulled in place. Most of the CMP remained in the ground except for the last 8-foot-long section, which was pushed out unburst (Matthews, Simicevic, Kestler, & Piehl, 2012).

In 2013, a research team from Bowling Green State University collaborated with TT Technologies, Hammerhead Trenchless Equipment, and Ohio Department of Transportation to test different designs and modifications for bursting CMPs. They replaced four CMP culverts: one with the pneumatic system and three with the static system.

A "16 (400) AR" pneumatic-bursting tool and a 'HG12' winch from HammerHead Trenchless Equipment were used for the pneumatic burst in ODOT's District 10. The HDPE pipe was bolted to a front-end expander with an external diameter of 27 inches. A pilot, equipped with a blade, was introduced ahead of the bursting head to cut the CMP. 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. The CMP was cut at the weakest part (bottom) and replaced successfully. However, the last 15 feet of the culvert folded around the bursting tool and were pushed out unburst as shown in Figure 3 (Adamtey, Onsarigo, & Atalah, 2016).

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Figure 3. Folded CMP pushed out.

A Grundoburst 1250G and a hydraulic power unit, TTB 110, from TT Technologies were used for the static bursts. 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. Table 1 contains the details of the three tests.

TABLE I
CULVERTS REPLACED USING STATIC PIPE BURSTING

ODOT's District	Test	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

The researchers used different sizes of bursting heads and expanders for the three tests. For Test 1, the research team used an 18-inch bursting head with a tapering cutting blade and an expander with an external diameter of 21 inches. For Test 2, the research team used a 16-inch bursting head with a tapering cutting blade and an expander with external diameter of 19 inches. For Test 3, the team used a 24-inch bursting head and an expander with an external diameter of 27 inches.

While all the bursts were successful, the last section of the existing CMP (about 8 to 15 feet) was always pulled out unburst. This last section of the pipe would ball-up on the bursting head and pulled out unburst creating an overcut around the installed pipe (Adamtey, Onsarigo, & Atalah, 2016).

V. DISCUSSIONS

The main modification to the bursting system that enabled bursting of the CMP culverts was the introduction of a specialized pilot ahead of the bursting head. The pilot, equipped with a cutting blade, was placed in front of the expander to cut the CMP and hold the pipe in place to prevent it from collapsing. The blade on the pilot was oriented towards the weakest part of the pipe (the bottom) to cut the culvert ahead of the bursting head before applying the radial force. For this application, the static system seemed to work better and more efficiently than the pneumatic system. According to the research by Adamtey et al. (2016), the bursting operation with the pneumatic system took up to four times longer than the static system.

For all the installations, part of the existing corrugated pipe folded onto the bursting head forming a 'ball' on the expander and was pulled into the pulling pit uncut. This was the final few feet (estimated to be between 8 to 15 feet) of the existing corrugated pipe. We can attribute the balling effect to these two reasons:

1. The friction between the soil and final few feet of the corrugated pipe did 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 into 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. The force applied on the remaining segment of the pipe pushes/pulls it out uncut.

The balling effect of the CMP creates an overcut around the installed pipe as shown in Figure 4. This overcut is bigger than the size of the expander and may create a void in the ground. It is prudent to fill the void in order to avoid potential settlement and damage to the nearby utilities and/or pavement. Although the overcut occurred only on the final few feet of the installation, it is reasonable to expect it to get bigger for longer runs.

The success of a bursting operation is highly dependent on proper setup. The balling effect is partly a result of poor system setup. Prior to bursting a corrugated pipe, it is important for the construction crew to ensure that the bursting head is concentric with the existing pipe and that the cutting blade is appropriately positioned to cut the CMP at its weakest point (usually the bottom).

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If the bursting head and the existing CMP are not concentric, the force applied is not evenly distributed which reduces the efficiency of the operation.

Figure 4. Overcut created by folded CMP

While pipe bursting is routinely used to replace pipes up to 500 feet in length, the CMP culverts tested were up to 120 feet long. From the field observations, it is reasonable to conclude that pipe-bursting systems can burst similar CMP culverts up to 120 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.

VI. Conclusions And Recommendations

Pipe bursting offers several advantages for the replacement of corrugated metal culverts. In addition to the well-known advantages of being a trenchless technique that causes much less traffic and environmental disruptions, it provides the owner with a quality replacement pipe in the same easement of the old pipe. It usually costs less than open cut in replacing old deteriorated pipes and enables the pipe owner to increase the pipe diameter and increase the flow capacity.

It can be concluded from the highlighted case studies that pipe bursting (both pneumatic and static) is a viable technique for the replacement of CMP culverts up to 24 in. in diameter and 120 feet in length. The static system was however observed to work faster and more efficient than the pneumatic system. In addition to following the good practices of pipe bursting, the bursting head or pilot must be able to hold the CMP in place and prevent it from folding during bursting.

The static bursting system is recommended for replacing corrugated metal culverts up to 120 feet in length because longer lengths have not been investigated. In the same breath, it is also recommended that further study be conducted to establish the viability of bursting corrugated metal pipes longer than 120 feet.

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