POTENTIAL FOR THE APPLICATION OF TRENCHLESS REHABILITATION TECHNOLOGIES IN KENYA: A FOCUS ON PIPE BURSTING.

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Abstract: *Urban populations in Kenya have been expanding over the years. This growth is a result of the high birth rate and migration of people from the countryside in search of better job opportunities and better living standards. With an increase in population comes the need for infrastructure developments. This includes the need for increased capacity of the sewer and water supply networks, and the need for development of new networks capable of meeting the increased demand. However, most of the pipes that need to be replaced are located under congested pavements and can cause a lot of disruption when replaced using the conventional open-cut construction method.Trenchless technologies offer economic alternatives that also reduce disturbance to businesses and residents. This paper gives an overview of the trenchless rehabilitation systems available in the industry today. The paper, especially, focuses on pipe bursting and its potential for application in the rehabilitation of Kenyan sewage disposal and water supply systems.*

Keywords: Trenchless Technology, Open-cut, Pipe Bursting.

Introduction

Urban populations in Kenya have been expanding over the years. This growth is a result of, increased industrialization, high birth rate, and migration of people from the countryside in search of better job opportunities and better living standards. Nairobi's population, for instance, was 8,000 in 1901. It grew to 11,500 in 1906 and then to 108,900 in 1940. By 1969, the city had a population of 509,286. This upward trend continued and by 1989, the population was 1,324,570. By 1999, the population was 2,143,254, and by 2009, the population in the capital had grown to 3,138,369**Invalid source specified.**. With ever-expanding populations, urban communities are bound to grow and to maintain reasonable living standards demands infrastructure developments such as sewage disposal, water supply, gas supply, electricity, and internet connectivity. As the society becomes more environmentally conscious there will be a demand to treat all sewage to a high standard before disposal to water courses and a need to treat all water to a high standard before distribution (Read 2004).

As a result of the high population, there is a tremendous increase in the volume of flow in the existing sewer main lines and water mains that has, to a great extent, exceeded the flow design capacities of the pipelines. Not only are the sewerage pipelines incapable of handling the flows, but the treatment plants are not designed to handle the large volumes of flow either. This strain on the system contributes to the accelerated rate of aging of the pipelines, reducing their life cycle. The water supply system is far from perfect, with most of the water produced being lost in the system before it reaches the consumer. It is estimated that 'unaccounted-for-water is, on average, about 50% of all the water produced. A good proportion of the 'unaccounted-for-water' can be attributed to waterline breaks and leakages mainly because of aging. The rest of this 'unaccounted-for-water' is attributed to administrative losses due to illegal connections and non/under-registration of water meters. The water pipelines are also under strain because of the higher quantity demanded with the need for an increase in capacity of the existing network.

It is clear that most of these pipelines require immediate replacement/expansion or rehabilitation. In order to meet the current high demands without exceeding the limited available funding, construction method alternatives that are both functional and cost effective have to be used.

Trenchless technologies offer an alternative for the replacement and rehabilitation of these pipelines. Pipe bursting, in particular, can be an economic pipe replacement alternative when compared to the open-cut technique. It is especially cost-effective if the existing pipe is out of capacity, deep, and/or below the ground water table (Plastic Pipe Institute, 2008). Beyond the direct cost advantage of pipe bursting over open-cut, trenchless techniques do have several indirect cost advantages over the traditional open-cut and considerably lower impact on the environment. This paper explores some of these trenchless alternatives and introduces pipe bursting as a viable option for Kenya's pipeline replacement needs.

State of the Underground Infrastructure in Kenya

Urban cities in Kenya have been rapidly growing over the years. Industrialization, increased rural-urban migration, and immigration of refugees are all contributing factors to the high population that has put a strain on the utility services. There is a tremendous increase in flow into the existing main sewer lines that has exceeded their design capacities. The problem is compounded with the inability of our treatment plants to handle the large flows which reduces the life of the pipelines by accelerating their rate of aging. The Department of Water Supply and Wastewater Management Services at Nairobi City Council (NCC) is now faced with acute challenges while using conventional open-cut method to replace the under-sized defective pipes located in congested sites and where deep excavations are required. The Nairobi City Council (NCC) in partnership with Nairobi City Water & Sewerage (NCWS) Management Company has embarked on plans to revamp and make major replacements of the existing municipal main sewer lines in Nairobi city streets because of their inability to handle the current flows (Masudi, 2009).

Most of the wastewater pipes in Nairobi have not met or exceeded their design life (most average about 30 years). But their rapid aging can be attributed to persistent overflows, and over utilization of these pipes that are under-sized. During the design of these networks, the population growth projections were grossly inaccurate and as a result, they are unable to meet the current demand. Most of these pipes require immediate replacement or rehabilitation using the most convenient and cost effective methods in order to meet the current high demands while operate within the limited available funding (Irungu, 2007).

Following the report by the City Council of Nairobi (2008), approximately 48% of Nairobi's population is served by the existing water-borne sewerage system which suffers from a number of problems including poor maintenance, illegal connections, use of toilets for the disposal of garbage and deliberate blocking of sewage pipes for irrigation. For instance, at Maili Saba, farmers remove manhole covers and block the city's main sewer, diverting raw sewage to their land to irrigate their crops. Their plots, typically 20 x 40 m, are irrigated by surface irrigation from a hand-dug canal system. Irrigators grow kale, sweet potato, arrowroot and some green maize - crops that are cooked before being eaten (Scott, Faruqui, & Rashid-Sally, 2004).

To meet the growing water demand in Nairobi and other major cities, the water has to be pumped for reasonably long distances. Apart from occasional water shortages, however, especially during the dry seasons, the basic problem has been distribution (City Council of Nairobi, 2008). This report, City Council of Nairobi (2008) further indicates that despite the fact that production exceeds demand, only about 187,000 (or 42 per cent) of households in Nairobi have proper water connections. This highlights the need for increase in capacity of the existing network and construction of new pipelines that can complement the existing pipes and help meet the needs of the city residents.

"Unaccounted-for water" is the difference between the quantity of water supplied to a city's network and the metered quantity of water used by the customers. According to the Citizen Report Card (2007), "unaccounted-for water" was 40% in Nairobi, 66% in the city of Kisumu, and 35% for Mombasa. This loss can be attributed to both: (a) physical losses due to leakage from pipes, and (b) administrative losses due to illegal connections and under-registration of water meters. UFW in a well-run utility is generally in the order of 15 to 20 percent (Citizen Report Card, 2007). City Council of Nairobi (2008) estimates the losses due to leakages and illegal connections in Nairobi to constitute about 50% of the volume of water produced.

Overview of Trenchless Rehabilitation Systems

There are several alternatives available for rehabilitation and replacement of pipelines. Currently, the conventional open-cut is the most common method used for underground utility construction because of its basic approach of excavating soil, laying the pipe and backfilling. Open-cut can get a little more complicated when unstable ground conditions are encountered necessitating shoring. Ground water can also pose problems requiring a dewatering plan that could be costly. But in areas where surface drainage is not an issue and the ground is not muddled with utilities, open-cut construction usually is the least expensive and most cost effective way to install a product. Personnel training requirements are less rigorous and laborious with this traditional method, but when it is neither acceptable nor desirable, trenchless methods offer various alternatives that can be employed in renewing and replacing aging pipelines. The North American Society for Trenchless Technology (NASTT) defines trenchless technology as a family of techniques for utility line installation, replacement, rehabilitation, renovation, repair, inspection, location and leak detection, with minimum excavation from the ground surface (North American Society for Trenchless Technology, 2013). Some of the most common trenchless replacement and rehabilitation systems include: CIPP, Fold and Form, Sliplining, Spiral wound pipe, Spray applied systems, segmental liner and Pipe Bursting.

Cured-In-Place Pipe (CIPP)

CIPP was invented in 1970, being one of the first truly trenchless pipeline renewal processes. The method is used in renewing sever pipelines, water pipelines, pressure pipelines, gas pipelines, industrial pipelines and other pipelines. Cured-in-place pipe comprises a flexible fabric tube manufactured to the required diameter and length (designed to line the inside of the host pipe/existing deteriorated pipe). The fabric tube is saturated with a thermosetting resin, inserted into the pipeline and inflated with air or water pressure. It is then cured by using hot water, hot air, or UV light resulting in a new, tight-fitting pipe within a pipe (Najafi, 2013). The liner can be a structural pipe, designed to take the loads it is subjected to.

The most common thermosetting resin systems used are unsaturated polyester, vinyl ester, and epoxy resin all of which have different chemical, physical, and thermal properties

Fold and Form

In this method, the new plastic pipe is deformed / reduced in size at the factory for easy entry into the old deteriorated / damaged pipe. After it is installed in the old pipe, the new pipe is restored / expanded back to its original size and shape, forming a tight fit with the inside surface of the host pipe. The new pipe can be designed to serve either structural or nonstructural purposes.

Sliplining

This method has been around since the mid twentieth century and is one of the simplest and cost effective trenchless renewal systems. Sliplining is the process of inserting a new pipeline into an existing pipeline and grouting the annular space. Although sliplining decreases the total cross sectional area of a culvert, using a smoother pipe material with a smaller Manning's Roughness coefficient may eliminate this problem (Najafi, Salem, Bhattachar, Salman, & Patil, 2008). The liner can be designed as a structural or nonstructural liner.

Different pipe materials can be installed using sliplining including, but not limited to, high density polyethylene (HDPE), polyvinyl chloride (PVC), coated steel pipe and fiberglass reinforced polyester.

Spiral wound pipe

This is a trenchless method for installing a liner within the old pipe that is not structural. A polyvinyl chloride strip is spirally wound using a special winding machine at the job site hence obtaining a new lining within the old pipe. The annular space between the new spiral wound liner and the existing culvert is grouted, usually using cementitious grout. The continuous spiral lining is watertight and fits very closely to the existing structure (Najafi et al., 2008).

Spray applied systems / Spray-in-Place Pipe (SIPP)

Spray applied systems are widely used to protect new pipelines and renew aging pipelines. The systems are also used to protect and renew other water, sewer, oil, and gas infrastructure. SIPP could be cementitious materials or polymers (Najafi, 2013). Cementitious coatings are used mainly to protect against corrosion and are commonly used because they are considered cost effective. The most common cement materials used are Portland cement and calcium aluminate which coats the underground structure inhibiting corrosion in metal pipes. The cement has the additional benefit of creating a relatively smooth internal surface that improves hydraulic conductivity (Suleiman, Stevens, Jahren, Ceylan, & Conway, 2010).

Polymers possess superior chemical resistance when compared to cementitious products and can be a better alternative in corrosive environments. They can also be structural or nonstructural and could be epoxies, polyurethanes and polyureas, or polyesters (Najafi, 2013)

Pipe Bursting

Pipe bursting is a static and dynamic method of breaking an existing pipe and simultaneously installing, by pulling or pushing, a new pipe of equal or larger diameter along the same alignment as the existing pipe. The International Society for Trenchless Technology (2013) defines pipe bursting as a trenchless replacement method in which an existing pipe is broken by brittle fracture, using mechanically applied force from within. The pipe fragments are forced into the surrounding ground. At the same time a new pipe, of the same or larger diameter, is drawn in as shown in Figure 1.

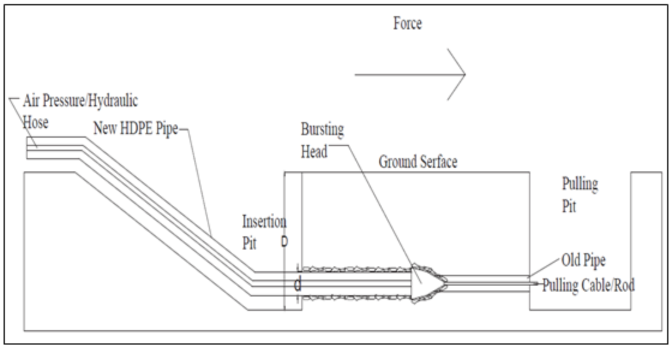

Figure 1. *Pipe bursting layout (Plastic Pipe Institute, 2008)*

Pipe bursting is an economic pipe replacement alternative that reduces disturbance to business and residents when it is compared to the open-cut technique. Pipe bursting is especially cost-effective if the existing pipe is out of capacity, deep, and/or below the ground water table (GWT) (Plastic Pipe Institute, 2008). Pipe bursting was developed in the late 1970's in the UK by D.J. Ryan & Sons and British Gas mainly for the replacement of small diameter gas lines. The process involved a pneumatically driven, cone-shaped bursting head operated by a reciprocating impact process. This method was patented in the UK in 1981 and in the United States in 1986; these patents expired in April, 2005 (Plastic Pipe Institute, 2008). The method was initially used to replace cast iron gas distribution lines but has been continuously developed and is today used to replace water lines, sewer mains and sewer service lines, gas lines, culverts, and communication ducts worldwide (Ariaratnam & Hahn, 2007). Replacement by pipe bursting is commonly done size-for-size or one upsize above the diameter of the existing pipe. Atalah (2006) notes that larger upsizes (up to three pipe sizes) have been successfully done, but the larger the upsizing, the more the energy needed to burst the pipe and the more the ground movement experienced from the displacement.

Almost all types of pipes can be burst which would include cast iron, steel, ductile iron, high density polyethylene (HDPE), polyvinyl chloride (PVC), cast in place concrete, clay, reinforced concrete and asbestos cement (AC). Reinforced concrete cylinder pipes (RCCP) cannot be replaced using this method. Because you can either pull the new pipe or push it in place, almost all types of pipe can be installed using pipe bursting. This would include: high density polyethylene (HDPE), polyvinyl chloride (PVC), clay, steel, fiberglass, polymer, ductile iron, and concrete (Timberlake, 2011) (Plastic Pipe Institute, 2008) (The International Pipe Bursting Association, 2012). Sectional pipes are pushed in place while the continuous pipes that can take tension can be pulled behind the bursting head.

Pipe Bursting Systems

Pipe bursting systems are typically classified into three main classes based on the type of bursting head used as shown in Figure 2.

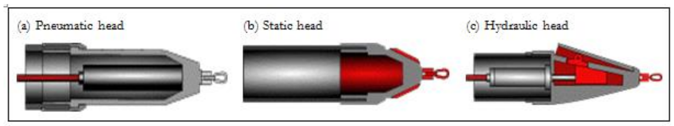

Figure 2. *Bursting heads for the different PB systems*

- **Pneumatic pipe bursting**, which uses pulsating air pressure to drive the head forward and burst the old pipe. A small pulling device guides the head via a constant tension winch and cable. In the pneumatic system, the bursting tool is a soil displacement hammer driven by compressed air and operated at a rate of 180 to 580 blows per minute. With each stroke, the bursting tool cracks and breaks the old pipe, the expander combined with the percussive action of the bursting tool, push the fragments and the surrounding soil providing space to pull in the new pipe. The expander can be front-end (attached to the front end of the hammer) for pipes smaller than 12" or back-end (attached to the backend of the hammer) for pipes larger than 12" (Plastic Pipe Institute, 2008).

- **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, Sterling, Hadala, & Akl, 1998). In this system, tremendous tensile force is applied to the cone-shaped expansion head through a pulling rod assembly or cable inserted through the existing pipe. The cone transfers the horizontal pulling force into a radial force, breaking the old pipe and expanding the cavity providing space for the new pipe (Plastic Pipe Institute, 2008). The new pipe is then pushed or pulled into place behind the bursting head.

- **Hydraulic expansion**, where the hydraulic head expands and closes sequentially as it is pulled through the pipe, bursting the pipe on its way. In this system, the bursting process advances from the insertion pit to the reception (pulling) pit in sequences which are repeated until the full length of the existing pipe is replaced. In each sequence, one segment of the pipe (which matches the length of the bursting head) is burst in two steps: (1). the bursting head is pulled into the old pipe for the length of the segment, and (2). the head is expanded laterally to break the pipe as shown in Figure 3 (Atalah et al., 1998).

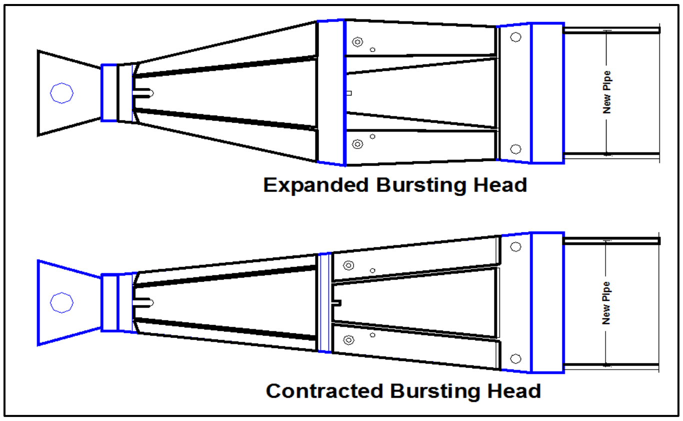

Figure 3. *Hydraulic bursting head (Xpandit) in both expanded and contracted positions (Atalah et al., 1998).*

Additions/modification can be made to these three pipe bursting systems to enable the replacement of flexible pipes, to advance segmental pipes, or to assist in the bursting. These systems include: Pipe Splitting, Pipe Reaming (Inneream), Impactor (Earthtool) Process and Tenbusch Method.

Application Range and Limitations of Pipe Bursting

The application range for the pipe bursting systems follows:

- Typically used to replace water lines, sewer mains and lateral connections, and gas lines.
- Typical length of replacement run is between 300 feet and 500 feet; however, longer drives have been completed successfully in favorable conditions.
- The size of pipes being burst typically range from 2” to 30”, although pipes of larger sizes can be burst.
- Commonly performed replacements are size-for-size and one-size upsize above the diameter of the existing pipe. Larger upsize (up to three pipe sizes) have been successful, but the larger the pipe upsizing, the more energy needed and the more ground movement will be experienced.

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).

For pipelines with shallow cover, typically less than 36 inches, bursting could cause heaving on the surface which can, potentially, damage nearby structures. Open-cut is usually the economical replacement alternative when dealing with these shallow pipelines. For large diameter pipe bursting operations, particularly those requiring upsizing, there is legitimate concern about potential damage to nearby facilities and structures.

Atalah (2007) identified the following as further limitations of pipe bursting:

(1) excavation for the lateral connections is needed,

(2) expansive soils could cause difficulties for bursting,

(3) a collapsed pipe at a certain point along the old pipe may require excavation at that point to allow the insertion of pulling cable or rod and to fix the pipe sag,

(4) point repairs with ductile material can also interfere with the replacement process,

(5) 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 although some corrections of localized sags are possible, and

(6) insertion and pulling shafts are needed especially for larger bursts.

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.

The Case for Pipe Bursting

Pipelines can be rehabilitated by inserting a new lining or replaced by pipe bursting or open-cut. There are several pipe lining technologies available such as cured-in-place pipe, fold and form, and sliplining. The main advantage of the lining methods over pipe bursting is the need for small or no access excavation to the pipeline. However, 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.

Pipe bursting is most cost advantageous compared to the lining techniques 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.

Pipe bursting has substantial advantages over open-cut replacements; it is much faster, more efficient, and often less expensive than open-cut especially in deep installations. With open-cut, increased depth translates to extra excavation, increased shoring/ need for trench support, and dewatering which substantially increases the cost of the pipe replacement. But for pipe bursting, the increased depth has a minimal effect on the cost per foot as shown in Figure 4 (Poole, Rosbrook, & Reynolds, 1985).

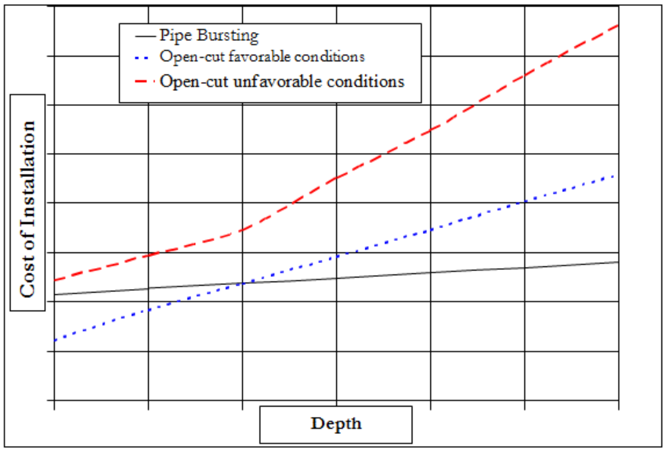

Figure 4. *Cost comparison between pipe bursting and open-cut (Poole et al., 1985).*

In addition to the potential direct cost advantage of pipe bursting over open-cut, as a trenchless technique, it has several indirect cost savings which include:

Table 1. *Indirect Cost Advantages of Trenchless Technology over Open-cut Construction*

less traffic disturbance	lower business interruption
reduced road or lane closure	minimal interference with other utilities
less time for replacement	lower impact on the environment
superior safety (for both working crew & public) due to reduced open excavation	

Conclusions

Urban cities in Kenya have been rapidly growing over the years. Industrialization, increased rural-urban migration, and immigration of refugees are all contributing factors to the high population that has put a strain on the utility services. There is a tremendous increase in flow into the existing main sewer lines that has exceeded their design capacities. The problem is compounded by the inability of our treatment plants to handle the large flows which reduces the life of the pipelines by accelerating their rate of aging. The water supply is also a problem with 'unaccounted-for-water' averaging 50% of all the water produced. A good proportion of the 'unaccounted-for-water' can be attributed to waterline breaks and leakages mainly because of aging.

A majority of these pipelines require immediate replacement or rehabilitation and, in order to meet the current high demands while not exceeding the limited available funding, construction method alternatives that are both functional and cost effective have to be used.

Pipe bursting is an economic pipe replacement alternative that reduces disturbance to businesses and residents when it is compared to the open-cut technique. It is especially cost-effective if the existing pipe is out of capacity, deep, and/or below the ground water table. Beyond the direct cost advantage of pipe bursting over open-cut, pipe bursting has several indirect cost advantages over the traditional open-cut and has a considerably lower impact on the environment. Investors, utility owners, and local governments need to consider pipe bursting alongside other trenchless technologies and the conventional open-cut construction when making decisions on pipeline rehabilitation.

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