MEETING KENYA'S WATER DISTRIBUTION NEEDS: FEASIBILITY OF HORIZONTAL DIRECTIONAL DRILLING FOR WATERLINE INSTALLATIONS IN KENYA

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ABSTRACT:

Water supply systems in Kenya's major cities like Nairobi are under tremendous strain because of the quantity of water demanded that has far surpassed the capacity of the existing infrastructure. There is a need to expand the capacity of the existing network which calls for both rehabilitation and new pipe installation measures. With a struggling economy and an ever increasing need to meet this growing demand, construction method alternatives that are both functional and cost effective have to be employed.This paper takes a look into Kenya's water supply and emphasizes the need for expanding the water distribution networks in the country's major cities. The paper also introduces horizontal directional drilling (HDD) as a viable alternative to the conventional open-cut construction method for installation of waterlines in Kenya's urban areas highlighting both its capabilities and limitations.

Keywords: Horizontal Directional Drilling, Open cut, Trenchless Technology, Water Distribution

Introduction

With the population explosion experienced over the decades in most urban areas, there is a concurrent growth of the underground infrastructure. The congested nature of this underground infrastructure, especially in the urban environments, has made it more difficult and also more costly for municipalities and utility companies to use the conventional open-cut construction method to install, maintain, rehabilitate, and replace their product lines (Onsarigo, Adamtey, & Atalah, 2014). 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 in these cities (Onsarigo, 2014). Following the Kenya population and housing census of 2009 by the Kenya National Bureau of Statistics, the population density in Nairobi and Mombasa counties averaged 4,400 persons per square kilometer (KNBS, 2009). It was also reported, following the two latest national censuses, that Kenya's populaton increased by nearly 10 million between 1999 and 2009. With every expanding population comes the need for expanded infrastructure to meet the population needs. This includes expanded transportation networks, greater capacity of sewer and water systems, expanded power supply networks, and increased data and communication networks.

In major cities in Kenya, water pipelines are under tremendous strain because of the quantity of water demanded that has far surpassed the capacity of the existing infrastructure. There is a need to expand the capacity of the existing network which calls for both rehabilitation and new pipe installation measures. With a struggling economy and an ever increasing need to meet this growing demand, construction method alternatives that are both functional and cost effective have to be employed.

With the advance in technology comes a wide array of options in executing any single kind of job or project. For underground infrastructure, trenchless technologies offer an alternative to the traditional open-cut construction method. Traditional open cut is still the most common method used in underground infrastructure because of its simplistic approach of excavating the soil, laying the pipe, and backfilling (Onsarigo, Atalah, & Roudebush, 2014). However, open-cut construction can get more complicated for deep installations where design of a structural support system is vital. Underground water can also pose significant challenges if encountered and an appropriate dewatering plan must be employed to ensure successful completion of the project.

Horizontal Directional Drilling (HDD) is a steerable trenchless construction method that offers an alternative to the conventional open-cut construction method for installing underground pipes, conduits and cables. The method is used to install pipes, conduits, and cables along a prescribed bore path by using a surface launched drilling rig. In urban settings with dense populations, businesses and local residents usually suffer from inconveniences caused by impacts to traffic flow, delays, and the construction mess. HDD offers an alternative that gets the job done while at the same time minimizing these inconveniencies.

This paper focusses on HDD and its potential for application in Kenya for installation of pressurized water lines. The need for an expanded water infrastructure system in Kenya's urban areas is highlighted and the suitability of the HDD methodology for the Kenyan scenario is explored.

Water Supply In Kenya

The main source of distributed water in Kenya is surface water primarily from rivers and streams. The city of Nairobi, for instance, receives most of its water from the Tana River drainage basin. But while freshwater is also found in the three main rivers that flow through the city (Nairobi, Mathare and Ngong) and their tributaries (Gitathuru, Kasarani, Riara, Kamiti, Mbagathi, Mutuari and Ruiruaka), the quality is not good for consumption. However, these poor-quality rivers are the major sources of water for the majority of people in the poor neighborhoods. (City Council of Nairobi, 2008).

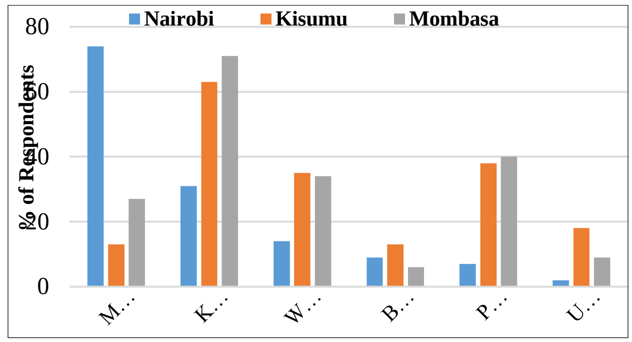

Figure 1. Figure 1. Access to water sources for households in Nairobi, Kisumu and Mombasa (Citizen Report Card, 2007).

Figure 1 shows sources of water for households in Nairobi, Kisumu and Mombasa following a survey by the Citizen Report Card in 2007.

In 2006 only 49% of Kenya's rural population had access to clean water while the urban population with access to clean water stood at 85%. Access to clean water rates were observed to increase from 41% of the total population in 1990 to 57% of the total population in 2006 (Marshall, 2011). But while access to clean water was seen to increase in the rural areas, an opposite effect was observed in the urban areas. This was mainly because of the tremendous increase in population in the urban areas.

In order to meet the growing water demand in Nairobi and other major cities in Kenya, the water has to be pumped for reasonably long distances. For the city of Nairobi, water has to be pumped from distances of around 50 km outside the city. The basic problem with access to water, absent from the occasional shortages during the dry seasons, has been distribution

(City Council of Nairobi, 2008). This report, City Council of Nairobi (2008), further indicates that while 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" (UFW) 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), UFW 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. Most of the water loss through leakages is due to aging pipelines, poor joints, or damaged pipelines. This calls for either rehabilitation or reconstruction. The latter is an option if the lines are excessively deteriorated or if there is a need to increase the flow capacity of the pipelines.

Maoulidi's (2010) proposal for strategies the city can pursue to improve water services emphasizes the need to rehabilitate the water infrastructure and establish a good monitoring system to quickly identify infrastructure needing repair. Rehabilitation calls for consideration of construction alternatives that make sense from an economic standpoint and that have a lower negative impact on the environment and society.

According to Atalah and Kariuki (2009), 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. This is mainly because of the disruption that open-cut construction causes to the normal flow of activities within the city. The indirect costs and social costs of using the conventional open-cut method are usually very high.

OVERVIEW OF HORIZONTAL DIRECTIONAL DRILLING (HDD)

Figure 2. Figure 2. HDD rig during a pilot boring stage (Vermeer, 2015)

Horizontal directional drilling consists of a rig (shown in Figure 2) that makes a pilot bore by pushing a cutting head or drilling head that is steered and guided along a prescribed path from the ground surface. Drilling fluid is pumped through the hollow stem of the drill pipe and ejected through the nozzle(s) on the drill head to assist in cutting and displacing the soil, and maintaining bore stability. When the pilot bore is completed, an expanding reamer is used to enlarge the created bore to the desired size. Increasingly larger reamers are used successively until the hole is large enough to pull the product pipe into place. The pipe is laid out, fused or welded, and then pulled into place by the rig after connecting it to the backend of the backreamer (Onsarigo, Adamtey, & Atalah, 2014).

Construction Process

The HDD procedure consists of three stages as shown in Figure 3: pilot bore and tracking, reaming/hole enlargement, and pullback. Once the rig is set up, a small entry pit is excavated to facilitate entry of the bit at the desired angle and help contain the drilling fluid. The pilot bore is drilled along the prescribed bore path from the entry point to the exit. Drilling fluid is pumped through the nozzle on the drill head to facilitate in cutting and displacing the soil. A transmitter housed in the drill head sends magnetic signals that are received by a locator on the surface which displays information on the drill head in graphical and numerical form. The locator on the surface gives the depth, location and angular direction of the drill head, the temperature of the sonde/transmitter, and the battery level.

After completion of the first stage, the pilot bore and tracking, the drill head is disconnected from the drilling pipe and a reamer is attached in its place. The reamer is then rotated and pulled (or pushed in some cases) to enlarge the bore to the desired size. Increasing reamers are used to enlarge the bore to the desired size-usually 1.5 times the size of the product pipe for small diameter installations. For installations exceeding 600mm (24 inches), the reamed diameter is usually 300mm (12inches) larger than the diameter of the product pipe.

Drilling fluid, which can be air based or water based (more common), is used in both the pilot bore and the reaming stages. The fluid performs various functions which include: transporting the spoils from the cutting face to the ground surface; lubrication to reduce friction between the pipe and the surrounding soil which reduces the pullback force; stabilizing the borehole; cleaning and cooling the down-hole tooling/bottom-hole assembly including the drill bit and reamers; controlling ground water pressure and avoid infiltration of water; reducing migration of drilling fluids from the borehole to the soil formation (exfiltration); and reducing tooling wear and tear.

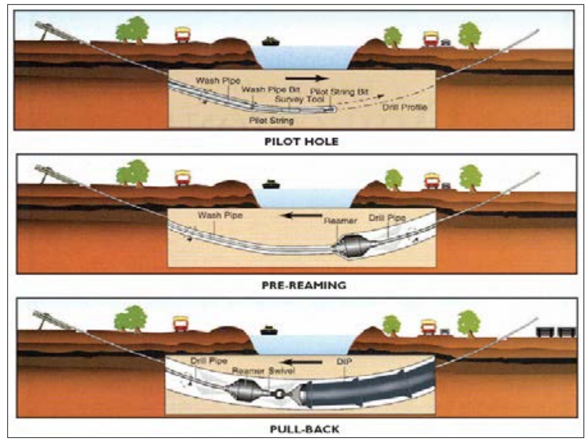

Figure 3. Figure 3. HDD operation (FHWA, 2013)

The second stage is complete once the desired bore is achieved. In the third stage, the product pipe is welded or fused and laid out in preparation for pullback. A pulling head is attached to the product pipe and a swivel is put between the product pipe and the reamer to transfer the pulling force and not the torque which helps prevents rotation of the product. The product pipe is then pulled back in place.

Capabilities of HDD

- HDD is typically used to install utility lines and conduits, pipelines (oil and gas), and force mains across waterways, railroads, runways, and roadways.
- HDD can be used to install different pipes including HDPE, PVC, ductile iron, and steel. These are pipes which can take tension and can, as a result, be pulled in place. Jointless plastic pipes can play a major role in reducing the UFW (unaccounted-for water).
- HDD can be used to install product pipes ranging in sizes between 50mm (2 inches) and 1600mm (63 inches).
- HDD has been successfully used for installations exceeding 2500 m (8200 ft.) in length (Bennett & Ariaratnam, 2008).

Limitations of HDD

- Installations at depths exceeding 9 m (30 ft.) can be challenging to track, making it difficult to install the product at the prescribed path and with the desired accuracy.

- Required accuracy for gravity sewer installations, usually 25mm (1 inch) on line and grade, is challenging to achieve with HDD and can be especially challenging in difficult soil conditions.
- Similar to most trenchless technologies, a skillful operator and crew are critical for successful installations using HDD.
- Lateral connections for pipelines installed using HDD require digging (open cut) from the surface.

It is important to also note that the low environmental and social impact of horizontal directional drilling has made it extremely viable and desirable by municipalities where there is a high investment in surface infrastructure, congestion of existing buried utilities, and where the costs of restricting business or commuter traffic would make open-cut construction method inconvenient (Lueke & Ariaratnam, 2005).

Application of HDD in Kenya

HDD is not a completely foreign construction method to the Kenyan utility construction industry. In April of 2007, H Young & Company (EA) Ltd was awarded a contract by the Kenya Power and Lighting Company (KPLC) to install underground electric cables in the Central Business District of Nairobi City. Following a series of meetings between the contractor and KPLC, a decision was made to use HDD over the conventional open-cut construction method. They purchased a Ditch Witch, Model JT1720, horizontal directional drilling rig with a capacity of 17,000 pounds (thrust and pullback). The company later used the HDD equipment to install 20,000 feet of 2-inch fiber optic cables for KPLC and 3,000 feet of 2-inch fiber optic cables for Kenya's Ministry of Communication (Kariuki, 2009).

Atalah and Kariuki (2009) conducted a study to compare the direct costs incurred when using open-cut construction method and when using HDD to install pressure lines in Kenya. The direct costs considered stemmed from labor, equipment, material resources including markup and overheads. The findings indicated that the cost of HDD was 12.78% higher than the cost of open-cut. The study further indicated that the cost of materials for the HDD estimate constituted a greater proportion of the total project costs than that of the open-cut estimate primarily because the materials were imported. Although this study did not include the social cost and environmental impacts, the results indicated that HDD is a feasible technology for underground pipe installation in Kenya.

Trenchless technologies including HDD have considerably lower social costs than the conventional open-cut construction method. Social costs are the costs to the tax payer that are not included in the bid price or other contractual agreements or tracked by other arrangements and include: road damage, damage to adjacent utilities, damage to adjacent structures, noise and vibration, pollution, vehicular traffic disruption, pedestrian safety, business and trade loss, damage to detour roads, site safety, citizen complaints, and environmental impacts (Gangavarapu, Najafi, & Salem, 2003). Vehicular traffic disruption is perhaps the most critical of these social costs. Social and environmental costs have become a critical component in decision making for installations in urban areas across the globe. It is important to note that trenchless installation methods have lower social and environmental costs because they significantly reduce the amount of excavation, backfill, compaction, and pavement replacement needed (Najafi, 2010). It is in this light that HDD, alongside other trenchless technologies, is gaining popularity in utility construction in urban areas and environmentally sensitive areas.

Conclusions

With every expanding population comes the need for expanded infrastructure to meet the population needs. This includes expanded transportation networks, greater capacity of sewer and water systems, expanded power supply networks, and increased data and communication networks. 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 in these cities.

With the population explosion experienced over the decades in most urban areas, there is a concurrent growth of the underground infrastructure. The congested nature of the underground infrastructure, especially in the urban environments, has also made it more difficult and more costly for municipalities and utility companies to use the conventional open-cut construction method to install, maintain, rehabilitate, and replace their product lines.

Horizontal Directional Drilling (HDD) is a steerable trenchless construction method that offers an alternative to the conventional open-cut construction method for installing underground pipes, conduits and cables along a prescribed bore path. HDD offers an alternative for installing the needed utility lines while minimizing the social costs such as impacts to traffic flow, delays, and the construction mess. It is advisable for utility owners to include HDD as a viable alternative for installation of waterlines in Kenya’s urban areas.

References

Atalah, A., & Kariuki, J. (2009). Cost comparison between horizontal directional drilling and open-cut construction methods in Nairobi, Kenya. *International Conference on Pipelines and Trenchless Technology.* Shanghai, China: American Society of Civil Engineers.

Bennett, D., & Ariaratnam, S. (2008). *Horizontal Directional Drilling Good Practices Guidelines.* HDD Consortium.

Citizen Report Card. (2007). *Citizens' Report Card on Urban Water, Sanitation, and Solid Waste Services in Kenya: Summary of Results from Nairobi, Kisumu, and Mombasa 2007.* Nairobi, Kenya: Citizen Report Card (CRC).

City Council of Nairobi. (2008). *City of Nairobi Environment Outlook.* Nairobi, Kenya: City Council of Nairobi.

FHWA. (2013). *Successful Practices of Broadband Deployment in Highway Rights of Way.* Office of Policy and Governmental Affairs. Washington, DC: United States Department of Transportation.

Gangavarapu, B. S., Najafi, M., & Salem, O. (2003). Quantitative analysis and comparison of traffic disruption using open-cut and trenchless methods of pipe installation. *ASCE International Conference on Pipeline Engineering and Construction: New Pipeline Technologies, Security, and Safety* (pp. 1714-1724). Baltimore, MD, United states: American Society of Civil Engineers Texas Section.

Kariuki, J. G. (2009). *Cost Comparison Between Horizontal Directional Drilling and Open-Cut Construction Method in Nairobi, Kenya.* Bowling Green, Ohio: Bowling Green State University.

KNBS. (2009, August). *County Statistics.* Retrieved from Kenya National Bureau of Statistics: file:///C:/Users/Lameck/Downloads/county_statistics.pdf.

Lueke, J. S., & Ariaratnam, S. T. (2005). Surface Heave Mechanisms in Horizontal Directional Drilling. *Journal of Construction Engineering and Management*, 540-547.

Maoulidi, M. (2010). *A Water and Sanitation Needs Assessment for Kisumu City, Kenya* . New York: MCI Social Sector.

Marshall, S. (2011, June). The Water Crisis in Kenya:Causes, Effects and Solutions. *Global Majority E-Journal, 2*(1), 31-45.

Najafi, M. (2010). *Trenchless Technology Piping: Installation and Inspection.* McGraw Hill Professional.

Onsarigo, L. (2014). Potential for the Application of Trenchless Rehabilitation Technologies in Kenya: A Focus on Pipe Bursting. *7th Annual KESSA Conference.* Florence, Alabama: Kenya Scholars & Studies Association.

Onsarigo, L., Adamtey, S., & Atalah, A. (2014). Analysis of Horizontal Directional Drilling Construction Risks using the Probability-Impact Model: A Contractor's Perspective. *ASCE Pipelines 2014 Conference* (pp. 1772-1783). Portland: American Society for Civil Engineers.

Onsarigo, L., Atalah, A., & Roudebush, W. (2014). An Introduction to Environmental Value Engineering (EVE) and the EVE Assessment of Horizontal Directional Drilling (HDD) versus Open-Cut Construction. *ASCE Pipelines 2014 Conference* (pp. 2096-2107). Portland: American Society for Civil Engineers.

Vermeer. (2015, July 24). *Directional Drills - Utility Installation*. Retrieved from Vermeer: http://www2.vermeer.com/vermeer/NA/en/N/equipment/directional_drills_utility_installation