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Empirical analysis of large diameter water main break consequences

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ABSTRACT

The recent ASCE report card gave a Ďğrade for the state of drinking water infrastructure in the U.S. and reported that there are about 240,000 water main failures annually. Some of these failures result in significant economic, environmental and societal consequences that are difficult to predict for the purpose of accurate risk assessment and subsequent rehabilitation planning. This study analyzed the overall consequences of 20 large diameter water main failures in the U.S., majority of which have occurred in the last seven years, with an objective of identifying factors that aggravate the consequences to be able to reasonably predict them for rehabilitation decision making. It has been found that the overall cost of the failure consequences dependedon several factors that include but not limited to pipeline size, relative elevation and the type of land use, population density, utility response and repair time, and operating pressure.

Direct repair of the failed pipeline, followed by property damage and then travel delays, accounted for 35%, 22% and 21% of the overall failure cost on average, respectively. It has also been found that the direct costs which the water utility pays for accounted for only about 41% while the indirect costs which are usually borne by the society accounted for the remaining 59%. While consideration of the overall failure costs as part of rehabilitation planning may increase the investment needs of water utilities, it remains to be investigated as to how much more investment will be required, who would pay for it and how willing are the water utilities in adopting the overall failure cost approach.

1. Introduction

Water infrastructure, which is constituted by reservoirs, storage tanks, pumping stations, and transmission and distribution mains, plays a crucial role in human survival, public health and economic prosperity. Majority of water infrastructure, especially transmission and distribution mains, is nearing the end of its intended useful life, requiring significant attention and huge investments for keeping up with reliability goals. The American Society for Civil Engineers (ASCE) in their latest infrastructure report card gave a near-failing "D" grade for drinking water infrastructure in the U.S. (ASCE, 2013). Due to the lack of economical and reliable technologies, many of the over million mile pipeline segments were never inspected until a problem aroused or pipeline failed. As a result, water infrastructure has become increasingly vulnerable to failures with about 240,000 reported annually in the U.S. (ASCE, 2013). Consequences include decreased reliability, supply interruptions, and other societal inconveniences. These consequences could be prohibitively expensive depending primarily on size of the failed pipeline, its location, and the influence it has on the overall system functioning.

Preventing water main failures when possible or at least minimizing their consequences are among the primary current challenges of water utilities across the U.S. (Piratla et al., 2015). Pro-active rehabilitation of deteriorated infrastructure may avoid these unwarranted failure consequences. Unfortunately, limited knowledge currently exists on the overall failure consequences of water main breaks for undertaking a more informed rehabilitation decision making (Piratla et al., 2015). There is especially a lack of adequate knowledge on the indirect costs associated with water main breaks for which the society ends up paying, usually. In

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an attempt to address this knowledge gap, this paper empirically analyzes the economical and societal failure consequences of large diameter (≥30 in or 762 mm) water mains based on 20 failure cases of which 18 have occurred in the last seven years. The objective of this paper is to identify the factors that aggravate the overall consequences of large diameter water main failures in order to appropriately account for them in rehabilitation decision making. Empirical understanding of the overall consequential cost of water main failures will help water utilities in pro-active rehabilitation planning through accurate risk assessment.

2. Previous research

The lack of adequate knowledge on the overall consequences of large diameter water main breaks had been recognized by past researchers who have attempted to address this knowledge gap. Cromwell et al. is among the most significant works that focused on the problem studied in this paper (Cromwell et al., 2002). They developed the Grand Central Model (GCM) where different classes of water main failure consequences were delineated and value ranges suggested for model inputs where accurate data is not available. The cost classes proposed by Cromwell et al. include the costs of repair and return to service, service outage and mitigation costs, utility emergency response costs, costs of lost water, police and emergency costs, and administrative and legal costs of damage settlements (Cromwell et al., 2002).

Gaewksi and Blaha synthesized data for 30 cases to study the overall consequential costs of large diameter water main failures (Gaewski and Blaha, 2007). They classified costs into direct and societal categories with societal costs calculated using the GCM model of (Cromwell et al., 2002). They reported that most utilities do not have procedures in place to track failure costs and those who do track the failure costs do not necessarily consider societal cost as an important component in the risk assessment and rehabilitation planning. Their estimated overall cost of failure ranged between $6,000 and $8.5 million with a geometric mean of $500,000 which they thought was a representative measure. The reported societal costs were mainly due to property damages to structures and vehicles followed by traffic disruption. Additionally, strong correlations were reported between utility response time and overall cost, and population density and overall cost (Gaewski and Blaha, 2007).

Grigg synthesized several research reports, which included the studies supported by the Water Research Foundation (WaterRF) and U.S. Environmental Protection Agency (EPA), and provided general explanation of the failure risk problem of water mains while highlighting the challenges with data availability to predict the likelihood or consequences of failures (Grigg, 2013). Coombs reported that the cost of rehabilitation/replacement is rarely less than the cost of repair after a water main breaks, unless the societal costs are taken into consideration (Coombs, 2014). Matthews reported that the traffic costs alone could account for 50% of the total costs of repair work (Matthews, 2010).

Recently, Matthews et al. presented a comprehensive review of information on water main breaks and identified relevant knowledge gaps (Matthews and Stowe, 2015). They found that water main break databases are increasingly being used at the local level, and in some cases at the regional and national levels, to track main breaks, determine their cause and prevent future occurrences. The identified key research needs include the need for a unified data format that all utilities can use for collecting correct and meaningful data in a more structured manner for future use (Matthews and Stowe, 2015).

In an attempt to complement past research on the topic of water main failure consequences, this paper synthesizes data on 20 large diameter water main failure cases and analyzes for trends and other useful information—such as, the true failure impact cost, identifying factors that aggravate the overall consequences, and the proportion of overall consequence costs borne by public in the form of indirect costs—that water utilities may find helpful in their rehabilitation planning exercises.

3. Consequences of water main breaks (COWAMB) model

A simple Microsoft Excel-based model, COWAMB, is developed in this study to estimate the overall consequences of large diameter water main breaks. COWAMB model is inspired by the previously proposed Grand Central Model (GCM) which was reported to be overwhelmingly extensive and complicated for estimating the water main break consequences (Gaewski and Blaha, 2007). COWAMB is a simplified adaptation of the GCM model with some inherent assumptions that are consistent with the GCM model.

Basic data required for the COWAMB model includes pipeline location, material, diameter, operating pressure, outage and repair durations, and prevailing cost of water supply (Piratla et al., 2015). Other information that will make the results more accurate include distribution of different types of buildings and number of consumers affected by possible supply outage and water flooding, average vehicle delay time due to traffic detours, and number of health issues reported in the service area. Given the possibility of lack of accurate data even with a water utility operator in some cases, appropriate values based on the break severity are chosen from the suggested ranges in the GCM model (Piratla et al., 2015).

Mathematical formulations for various impact categories are used to evaluate the failure costs. Six impact categories are considered out of which the cost of the first two are classified as *Direct Costs* and last four as *Indirect Costs*. The six cost categories include: (1) lost product, (2) repair and return to service, (3) travel delay, (4) supply outage and substitution, (5) health risk, and (6) property damage. These impacts along with the procedures followed to calculate the associated costs are described in the following paragraphs.

3.1. Lost product

Volume of lost water is estimated based on the pipeline geometry, operating pressure, and time taken by the utility operator to isolate the failed pipeline section. If surface area of the break is not known, it is taken as the quarter of the pipeline cross sectional area. Upon estimating the surface area of the break, orifice flow equation is employed to calculate the outflow through the break. Cost associated with the lost product is calculated as the sum of operating cost, i.e., pumping and treatment cost invested by the Water Utility, and purchase cost of the water.

3.2. Repair and return to service

Major contributor of cost for this category is repair cost associated with the break and other minor sum of costs such as labor charges (which depend on number of laborers worked and their wages), material and equipment costs (which depend on quantity of material and equipment purchased for repair), transportation charges, fringe benefits for the workers, and cost of miscellaneous tools used in the repair process.

3.3. Travel delay

Cost of traffic delays/detours as a result of the failure and repair work are calculated based on the estimated Average Annual Daily Trips (AADT), estimated proportion of trips per hour during disruption, hourly operational cost of a vehicle, passengers per vehicle,