BUSITEMA UNIVERSITY

Pursuing Excellence

FACULTY OF ENGINEERING

DEPARTMENT OF WATER RESOURCES AND MINING ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN AND SIMULATION OF HYDROINFORMATICS TOOL FOR PREDICTING FAILURES IN WATER DISTRIBUTION NETWORKS CASE STUDY: BUKASA MAINS-KAMPALA

BY

IYEGA HAMIMU

BU/UP/2014/572

Email: hamyrecs45@gmail.com

Tel: +256 753105984/+256781766162

MAIN SUPERVISOR: Mr. KIMERA DAVID

CO-SUPERVISOR: Mr. MASERUKA S BENDICTO

A final year project report submitted in partial fulfillment of the requirements for the award of a Bachelor of Science degree in Water Resources Engineering at Busitema University

Abstract

The need to more intelligently and efficiently manage water distribution systems is increasingly more important to agencies such as NWSC managing such networks and seeking a way to increase the reliability of their systems, the uninterrupted quality service to their customers and the cost-efficient operations and maintenance of the aging distribution networks. Repair and/or replacement of aging water mains, especially in urban environments, impose major expenditures on already financially strained municipalities and state governments, and the need to more actively engage in the monitoring and management of such networks is progressively increasing as existing distribution networks continue to age and therefore deteriorate. Current planning and maintenance strategy is furthermore challenged by insufficient knowledge and data about the prevailing water infrastructure condition and future rehabilitation demand this ignores future dynamics and planning uncertainties. A water distribution system is an important part of the social infrastructure, facilitating water transport, distribution and supply. It is a highly complicated network that combines pipelines, nodes, pumps and valves. Hence, the components in such a system should be continuously improved and updated on the basis of complete and scientific information to maintain the stability, reliability and safety of the network since they keep on deteriorating causing abrupt and recurrent failures (leakages and bursts).

The work presented in this report predicts pipe failures prior to their occurrence and gives the scientific reasons why a pipe is likely to fail and the type of failure it is undergoing. The state of a pipe at any given time is then issued to the network operators and managers through the system being developed and computer pop-ups. The condition of pipes within the network is assessed by mathematical models that were developed to check the different scenarios a pipe along the network can experience during its operation state.

The pipe network was modelled and simulated in Epanet hydraulic tool and using the mathematical models, an algorithm was developed in Matlab R2013 where the inputs are read from the Epanet network.

Declaration

I, IYEGA Hamimu Reg NO. BU-UP-2014-572 declare that all the material portrayed in this final year project report is original and has never been submitted in for award of Bachelor of Science in Water Resources engineering of Busitema University.

Signature **Date**

………………………….. …………………………

Approval

This is to certify that this final year project has been carried out under my supervision and this report is ready for submission to the Board of examiners and senate of Busitema University with my approval.

MAIN SUPERVISOR: Mr. KIMERA DAVID

Signature	Date:
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CO-SUPERVISOR: Mr. MASERUKA.S. BENDICTO

Signature	Date:
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Dedication:

With grate honor I dedicate this report to my great parents Mr. BAKOLE HARUUNA AIGA and Mrs. NEIMA HARUUNA and all my caring brothers who have been supporting me since my entire life of education, thanks to you, my family, without any one of you maybe I wouldn’t make it this far and for that reason I greatly appreciate all the support at your various capacities.

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My greatest thanks and appreciation goes to the almighty Allah for giving me the life, wisdom, courage and health throughout the semester.

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I would love to thank my supervisors who tirelessly guided me during the process of understanding this project and in documenting this final project report.

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List of Acronyms

Etc.   Et cetera

GIS   Geographic information system

GPS   Global Positioning System

GSM/GPRS Global System for Mobile / General Packet Radio Services

NRW   Non-Revenue Water

NWSC National Water and Sewerage Cooperation

PVC Polyvinyl chloride

HDPE High Density Polyethene

WDS   Water Distribution System

GI   Galvanized iron

1.0 CHAPTER ONE: INTRODUCTION

1.1 Background of The Study

A water distribution system is an important part of the social infrastructure, facilitating water transport, distribution and supply (Guen & kang, 2014). It is a highly complicated network that combines pipelines, nodes, pumps and valves. Hence, the components in such a system should be continuously improved and updated on the basis of complete and scientific information to maintain the stability, reliability and safety of the network since they keep on deteriorating causing abrupt and recurrent failures (leakages and bursts).

About 32 billion mf treated water is lost annually as leakage from urban water distribution systems (WDSs) around the world, while 16 billion m3 is used but not paid for (Agathokleous, 2015). These losses cost water utilities as much as US$ 14 billion per year, with a third of it occurring in the developing countries (Sharma, 2011). In light of global pressures (climate change, urbanization, growing populations, increasing water demand and scarcity etc.), water utilities particularly in the developing countries need to operate more efficiently to provide sustainable water services. In Uganda, the determination of these leakages and bursts is done manually by a citizen who notices leakage as a pool of water or water oozing out of the ground and notifies NWSC. Usually by this time, a lot of water is lost in wetting the soil around the pipe and the rest has seeped into the ground (Maseruka, 2015) and all these result in reduction in the water-carrying capacity of the pipes and also lead to substantial repair costs and revenue loss. In addition, water utility operators like NWSC in uganda do not have the technology to detect such failures as fast as they could to avoid extensive losses of nonrevenue water. the current methods used to deal with deteriorating pipelines involve an evaluation of the degree of deterioration based on empirical means, as well as reactive rehabilitation projects undertaken after accidents, leading to economic losses and failure to improve system functions(Guen *et al.*, 2014). The current approach to determining the rehabilitation priority order for pipelines is based only on the year of installation of the pipes, with no clear criteria for evaluating the degree of deterioration (Misiunas, 2013) According to an Engineer at NWSC, there exists a maintenance plan whereby schedule is drawn to carry out maintenance activities along the different parts of the distribution network of Kampala, looking for leakages and bursts along the network etc., however this policy is unreliable and costly. The fragmented structure of the water supply sector leads to inadequate institutional, financial and personnel resources for professional management and planning of water supply systems. Current planning and maintenance strategy is furthermore challenged by insufficient knowledge and data about the prevailing water infrastructure condition and future rehabilitation demand this ignores future dynamics and planning uncertainties.

With the current technological advancements and imperative automation of the global, use of geographical information system (GIS) technology, EPANET hydraulic modelling tool, and MATLAB software, the real time operation conditions and ambient conditions, statistical data etc were used in this project to continuously monitor the network and carry out analysis to predict failures along the network.

1.2 Problem Statement

In Uganda, water supply for domestic and industrial purposes is one of the commercial activities that contribute to the national budget. The water utility operators use different components and devices to ensure that the system operates efficiently and with high reliability so as to deliver water to the final consumers at required national and international standards. However, this efficiency and reliability is difficult to achieve due to the deterioration of pipes and other components in water distribution network systems. This deterioration generally leads to pipe breaks and leaks, which result in increase in nonrevenue water, reduction in the water-carrying capacity of the pipes and also leads to substantial repair costs and revenue loss. Currently, NWSC makes inspection and maintenance decisions about each pipe segment in their network on the basis of incomplete information about pipe status and this becomes critical during evaluation of the current and future conditions of the system for making efficient maintenance decisions.

1.3 Significance of the study

This study is aimed at maximizing preventive maintenance and minimizing corrective maintenance, this enables NWSC to reduce its maintenance revenue loss and non- revenue water since the system that might affirm the maintenance robustness of the distribution network and report any likely scenarios that would lead to pipe bursts and other failure modes.

1.4 Main Objective

To design and simulate a hydro-informatics maintenance tool for predicting failures in water distribution networks

1.5 Specific Objectives

i. To develop a model for the network maintenance tool
ii. To simulate the water maintenance line network tool
iii. To test and validate the hydroinformatics maintenance tool

1.6 Justification

NWSC uses repair after failure approach to maintain its distribution lines and this poor maintenance practice has led to recurrent maintenance problems along the distribution lines which has in turn led to high operation cost, unreliable water supply to the water users and increase in non-revenue water and if better maintenance practices are not employed in the network, these problems will worsen. Hence a hydro-informatics maintenance tool which continuously monitors the network and alerts the operators on the likelihood of failures prior to any further losses and in case of leakages/bursts, the system will detect, locate and give information about pipe details so that faster action is taken and provides the appropriate maintenance and rehabilitation strategies to be undertaken by the decision makers.

1.7 Scope of The Project

This study will be limited to designing and simulating a hydro-informatics maintenance tool for monitoring, the failure scenarios that normally occur along NWSC distribution lines and predict any pipes which are likely to fail and location.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Structure of The Water Supply System

Although the size and complexity of drinking water supply systems may vary dramatically, they all have the same basic purpose to deliver water from the source (or treatment facility) to the customer(Misiunas, 2011). The objectives of an urban water system are to provide safe, potable water for domestic use, adequate quantity of water at sufficient pressure for fire protection and water for industrial use. Sources for municipal supplies are wells, rivers, lakes and reservoirs.

About two thirds of the water for public supplies around the world comes from surface-water sources. Often groundwater is of adequate quality to preclude treatment other than chlorination and fluoridation(Misiunas, 2011). The whole system can be divided into two major parts ie. the transmission system and the distribution system.

2.1.1 Transmission System

A transmission system consists of components that are designed to convey large amounts of water over great distances, typically between major facilities within the system eg. Between a treatment facility and a reservoir. Water transmission pipelines usually have diameters above 300 mm and can be built underground as well as aboveground. The typical elements of transmission pipe lines are inline stop valves, fire plug air valves (FPAV), scour valves and manholes. Pumps may be used to transport the water from one facility to another (treatment plant to reservoir or reservoir to reservoir) (Leonardo, 2006). To minimize the cost of operation, the pumping is performed during the time when the energy costs are lower, i.e. off-peak electricity use hours. The flow rate in the transmission pipeline during the pumping is quite high and the water is often stagnant during the rest of the time. Individual customers are usually not served directly from transmission mains. In some cases, distribution mains can be connected at some points along the length of the transmission pipeline.

2.1.2 Distribution System

The water transported in transmission pipelines to the residential areas is distributed through the water distribution system. Generally, a distribution system has a complex topology and contains a large number of elements. Two types of pipes are found in the distribution system distribution mains and service connections. Typically, distribution mains follow the general topology and alignment of the city streets. Pipes can be interconnected by junctions and form loops (Engineering, 2009). Generally, every single branch in the distribution network has a stop valve at each end. Valves are installed for the purpose of isolation in case of a failure event or during maintenance work. They can also be used to reroute flows in the network: In some cases, valves are closed permanently to establish pressure zones within the network or to form district metering areas

2.2 Threat, Risk, and Vulnerability in distribution network

It is important to distinguish between the terms threat, vulnerability, and risk. A threat is the indication that an attack or event causing a system disruption such as broken pipes, failed nodes, and poor water quality may occur. According to (Hopkins, 2012) examples of threats to a WDS would be natural disasters, chemical contamination, and terrorist attacks.

Risk is a measure of the system's exposure to given threats or the likelihood an event or attack is successful.

Vulnerability, for WDS, refers to system deficiencies that enable the adverse event or attack to be successful. For example, a branched network because if one link is disrupted, the rest of the system downstream will be affected.

The threats, risks, and vulnerabilities are unique for each system. (Galdiero, 2015) identified seven key elements of WDS; the physical components, Management structure, Operating rules and procedures, Institutional structure, Control centers, Laboratories, and Maintenance and storage facilities.

These seven components need to be properly protected against system specific threats, and the need of protection is identified through the evaluation of current vulnerabilities.

2.3 Brief Review Of Some Failure Prediction Models

2.3.1 Statistical models

The first statistical failure prediction models applied to urban water systems were developed from the early 1980s. The first models were deterministic, in which the decision variable (number of failures or time to next failure) is obtained directly from a function of explanatory variables. One of the first models was developed by (Elvet, 1992) that related the number of failures per unit length per year with the exponent of the age of a pipe (Jenkins, 2014). In this model no covariates were used, pipes were divided into homogeneous groups according to some of their attributes, such as diameter and material. Other time exponential models were proposed, in which more covariates were considered, e.g. (Martins, 2011). A different group of deterministic models describes the time to the first failure as a linear combination of several pipe attributes. The main disadvantage of these models is the lack of capability of dealing with censored data.

2.3.2 Deterministic models

These models are either mechanistic, empirical based or both. The long-term mechanical performance of the pipe is related to known parameters describing the pipe's physical characteristics, operational characteristics, and the environment around the pipe. The amount of data and computational effort required for deterministic models limits their application (Jenkins, 2014). Though they can provide a more accurate prediction of the long-term performance of a pipe, they are generally reserved for large-diameter pipes where more properties are known or can be gathered using direct condition assessment techniques.

2.3.3 Spatial models

These models are quicker and cheaper to implement, easy to interpret, and provide value for top level assessment of network risk. In the most recent years researchers have started to focus utilizing the spatial distribution and clustering of failures as decision tools to pipe MR&R prioritization (Dziedzic, 2015).

2.3.4 Artificial Neural Networks

Although there exist other general-purpose data mining techniques, artificial neural networks (ANNs) and genetic algorithms (GAs) are probably the most promising techniques for water industry data mining problems. Based on our present understanding of the brain and its associated nervous systems, ANNs use highly simplified models composed of many processing elements connected by links of variable weights to form "black box" representations of systems (John Willey & sons, 2013). These models have the ability to deal with a great deal of information and to learn complex model functions from examples, i.e., by 'training' using sets of input and output data.

The greatest advantage of ANNs over other modelling techniques is their capability to model complex, non-linear processes without having to assume the form of the relationship between input and output variables. Learning in ANNs involves adjusting the weights of interconnections (Data, 2013). Areas addressed by ANN techniques include pattern matching, combinatorial optimization, data compression and function optimization.

2.3.5 Genetic Algorithms

Genetic algorithms (GAs) belong to the class of stochastic search procedures known as Evolutionary Algorithms (EAs) that use computational models of natural evolutionary processes in developing computer-based problem-solving systems. This form of search evolves throughout generations, improving the features of potential solutions by means of biologically-inspired operations. Steps by which GAs generate their solutions are given in Figure 3. A variety of applications has been presented since the early works of the 1970s and GAs have clearly demonstrated their capability to yield good solutions even in cases of highly complex, multiple-parameter problems.

2.3.6 Machine Learning Models

The machine learning based models developed for water pipes can be categorized as neural network based, fuzzy logic, polynomial regression, and Bayesian.

2.4 Pipe Materials

The materials commonly used for water mains can be split into two main groups. The first group is metallic, whereas the second can be classed as non-metallic. The majority of water distribution systems throughout the world predominantly are made up of metallic mains (Savic, 2010). For example, the percentage of metallic mains is 58% in Sweden, 80% in the UK, 75% in Germany, 71% in Russia and 70% in Australia (Savic, 2010). The deterioration in metallic components and structures due to corrosion is well known. The corrosion of water mains, both internally and externally, has been witnessed to varying degrees in water distribution systems.

2.4.1 Reasons for the Structural Failure of pipes

The factors that cause a main to fail are varied, although usually a main fail due to a combination of factors. The causes of water main failures could be split into four main groups; quality and age of pipe, the type of environment, quality of workmanship in laying of the pipe, and the service conditions under which the main operates.

3 CHAPTER THREE: METHODOLOGY

3.1 Specific objective one: To develop a model for the hydroinformatics tool

3.1.1 The case study: Bukasa NWSC network Grid

Bukasa NWSC network grid located in lower Muyenga as illustrated in Figure 1 is one of the water structures under Kampala NWSC. It consists of about 32.3km of portable water supply mains connecting different centers and residential areas serving up to 28000 people and some small-scale industries.

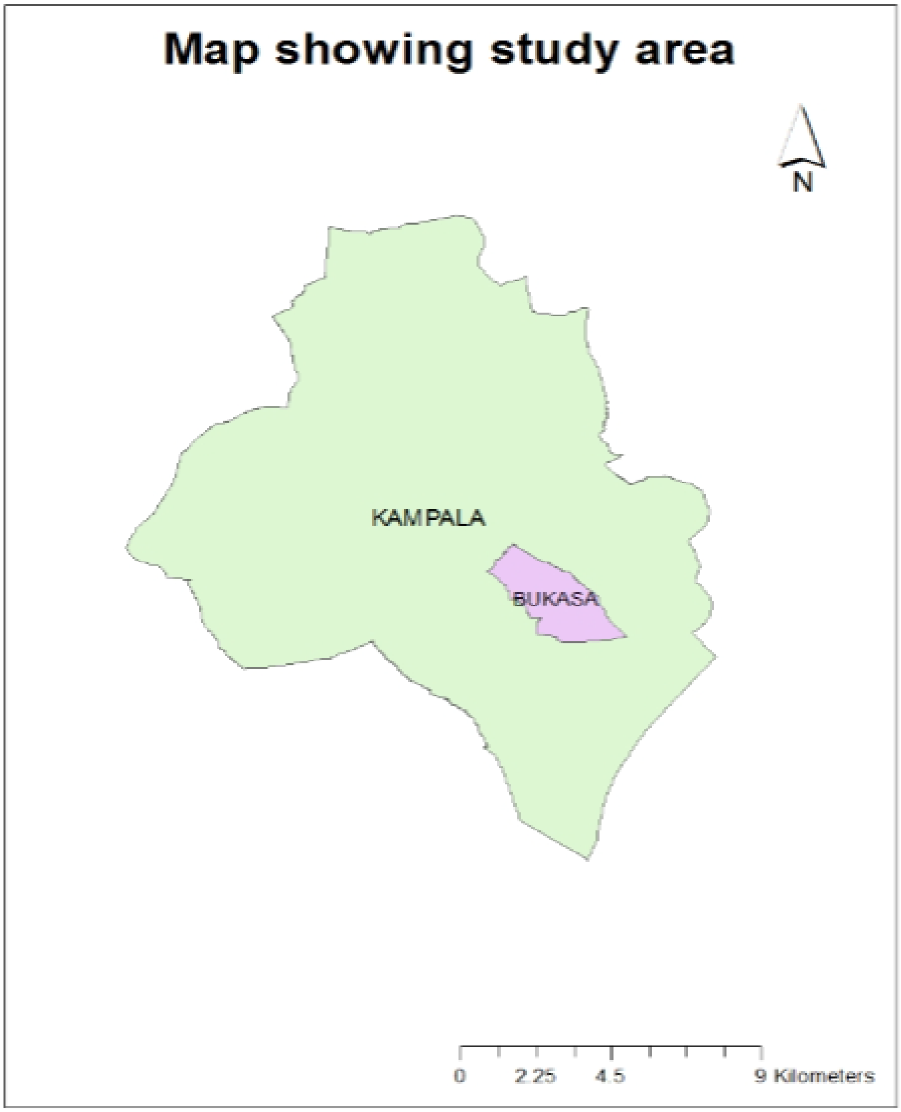

Figure 1:A map of the case study area

3.1.2 Developing the hydroinformatics model

3.1.2.1 Assumptions

This model was developed based on the following assumptions; a pipe material is a linear elastic, steady state flow condition, flow is one dimensional, flow is laminar, the pipes are restrained from movement

3.1.2.2 Applied stress

The applied stress in a pipe is caused by internal pressure and the external load. The internal pressure includes the water pressure applied during usage, and the water-hammer pressure when a water-hammer effect is seen as illustrated in figure 3. External load includes soil pressure, soil expansion etc.

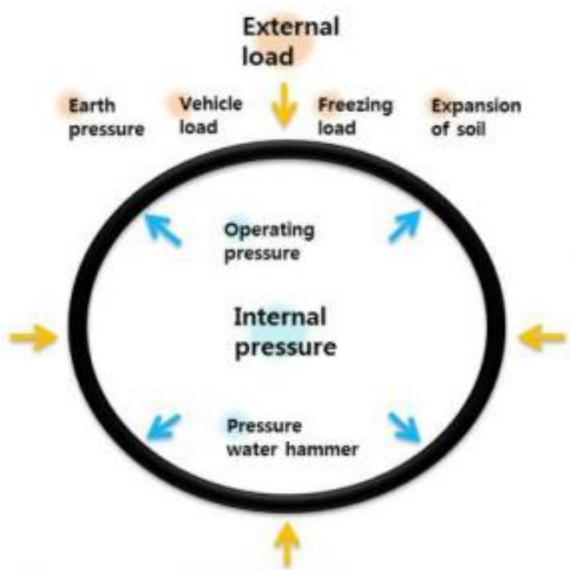

Figure 2:Forces acting on underground pipe

3.1.3 Stress due to internal pressure

In water pipes, stress is generated circumferentially by internal pressure. In this case, the pipe should have a minimum thickness in order to resist the circumferential tensile stress. The circumferential stress is estimated from the operating pressure and water-hammer pressure.

The thickness of a water pipe is sufficiently small compared to the diameter such that the stress across the cylinder is reasonably uniform. When such a pipe is subjected to internal pressure as in figure 4, as a result of the flowing water, tensile stresses σ_c and σ_l are set up in the circumferential and longitudinal directions respectively

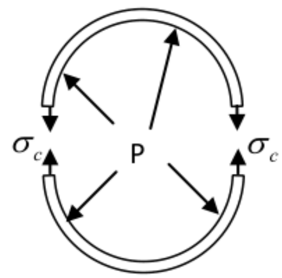

Figure 3: Internal forces acting on a pipe

Let the following be the dimensions of the pipe;

$d - internal\ diameter\ of\ the\ pipe$

$l - Length\ of\ the\ pipe$

$t - Thickness\ of\ the\ pipe$

$P - internal\ pressure\ in\ the\ pipe$

From the above figures, the force tending to separate the top and bottom halves of the pipe is the pressure multiplied by the projected area in the direction perpendicular to the diametral plane.

$F_w = Pdl \rightarrow force\ trying\ to\ seperate\ the\ two\ halves$

Therefore;

$$F_v = Pdl \qquad (1\ )$$

The force F_v is resisted by the tensile stresses σ_c set up in the circumferential direction acting on the area $2tl$

$$F_H = \sigma_c 2tl \qquad (2\ )$$

(Engineering, 2013)

3.1.4 Determining stress due to external factors affecting the pipe

Soil pressure (soil load) is generally the load applied on top of the pipe and is the same as the weight of the soil. The total over burden load on buried pipes is assumed to be equal to a soil prism with width equal to the outer diameter of the pipe and the height equal to the cover depth.

Hence;

$$F_e = \gamma_s Dhl \tag{3}$$

(Wai-fah, 2005)

Where;

$F_e - Total\ overburden\ load\ on\ the\ pipe$

$\gamma_s - Unit\ weight\ of\ soil\ supported\ by\ the\ pipe$

$D - External\ diameter\ of\ the\ pipe$

$h - Depth\ from\ the\ ground\ surface\ to\ the\ top\ of\ the\ pipe$

$$D = d + 2t \tag{4}$$

3.1.5 Determining wear and tear of the pipe material with time

If the thickness of the pipe at the time of installation is "t_0", this thickness keeps wearing (deteriorating) with time. This tear and wear of a given pipe material is governed by the ODE $t' = kT$ and separation and integration of variables,

$$t = t_0 e^{-kT} \tag{5}$$

(Halliday, 2011), (Stroud_K_A, 2003)

Where;

$t - thickness\ of\ the\ pipe\ at\ a\ certain\ time\ T$

$t_0 - intial\ thickness\ of\ the\ pipe\ at\ time\ T = 0$

$k - is\ the\ decay\ constant\ of\ the\ pipe\ material$

$T - time\ in\ years$

3.1.6 The free body Diagrams

The free body diagram as depicted in figure 5 consists of the external forces which include the earth load F_e, due backfill soil and the live loads F_l, acting from the ground surface and the internal forces which include the force acting F_w, on the internal pipe surface due to water pressure and the force F_H, that tends to resist the water force from bursting the pipe. Due to unpredictable nature of live loads, they were not considered during the design of this system.

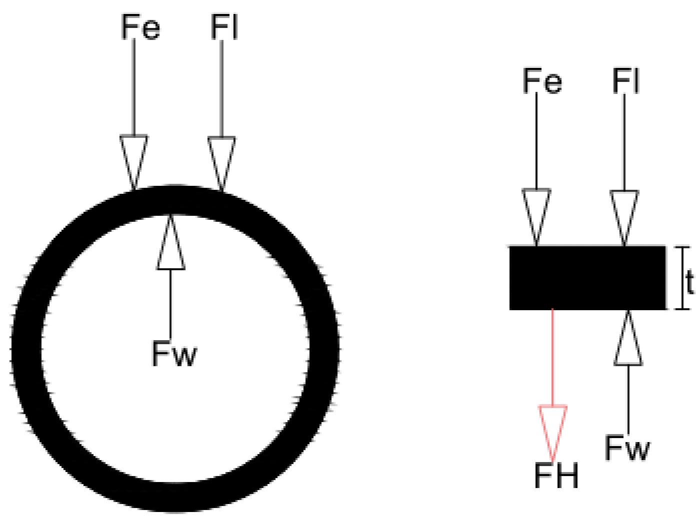

Figure 4: The free body diagram of the forces acting on a pipe

From

$\sum F = 0$

$$F_c + F_e = F_w \tag{6}$$

Hence Substuting

NB; $F_c = F_H$

$\sigma_c 2tl + \gamma_s Dh += Pdl$

$$\sigma_c = \frac{Pdl - \gamma_s Dh}{2tl} \tag{7}$$

Equation (6) is an expression for the stress that will resist bursting as a result of force due to water pressure

If this stress is greater than the yield stress, then the pipe will undergo a deformation that results in a small increase in diameter by a factor Δd and a reduction in the pipe thickness by a factor Δt

3.1.7 Surge pressure analysis

For situations where valves are closed or partially open, high pressure waves develop leading to either and increase or a decrease in the operating pressure P thus affecting the equation (7)

For a pipe of given diameter d, length l, bulky modulus of elasticity K flow rate Q, and cross section area A, From continuity equation

$$V_1 = \frac{Q}{A} \tag{8}$$

(Ia, 2012)

If any valve along the network is closed or partially closed at any time T, the wave speed generated in water at that point is given by

$$c = \sqrt{\frac{K}{\rho}} \tag{9}$$

(D, 2006), (Coleman, 2004)

And the celerity a is given by

$$a = \frac{c}{\sqrt{\left(1 + \frac{K}{E_B} + \frac{d}{t}\right)}}. \tag{10}$$

(D, 2006), (Coleman, 2004)

The change in velocity is be given by $\Delta V = V_2 - V_1$. Hence;

The surge pressure developed is expressed as

$$P_S = \frac{(-a\,\Delta V)}{g} \tag{11}$$

(D, 2006), (Coleman, 2004)

Hence for presence of surge pressure, the resultant pressure in a pipe becomes the sum of the normal operating pressures and the surge pressure as;

$P = P_O + P_S$

3.1.8 Computation of the small increment in diameter Δd and necking of the thickness Δt

When the pipe is subjected to excessive stress due to the internal pressure, it is stretched elastically thus experiencing a small increase in diameter, Δd and a small reduction (necking) of the thickness Δt. This stress is caused when F_H tries to resist F_w, as indicated in figure 6 from causing deformations on the pipe material.

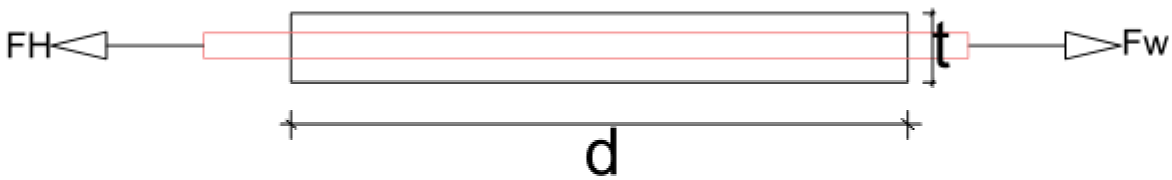

Figure 5:Behavour of a pipe when subjected to stress

Given the young's modulus of elasticity $\boldsymbol{E}$ and the poisons ratio $\boldsymbol{\nu}$ of a given pipe material

The strain $\boldsymbol{\varepsilon} = \frac{\boldsymbol{change\ in\ diameter}}{\boldsymbol{Original\ diameter}} = \frac{\boldsymbol{Hoops\ stress}}{\boldsymbol{Young's\ modulus}}$

$\boldsymbol{\varepsilon} = \frac{\Delta \boldsymbol{d}}{\boldsymbol{d}} = \frac{\sigma_c}{\boldsymbol{E}}$

Hence

$$\Delta \boldsymbol{d} = \frac{\sigma_c}{\boldsymbol{E}} \boldsymbol{d} \qquad (12)$$

Then the new diameter will become

$$\boldsymbol{d\_new} = \boldsymbol{d} + \Delta \boldsymbol{d} \qquad (13)$$

From poison's ratio, $\boldsymbol{\nu} = \frac{\boldsymbol{lateral\ strain}}{\boldsymbol{longtudinal\ strain}}$

Hence $\boldsymbol{\nu} = -\left(\frac{\frac{\Delta t}{t}}{\frac{\Delta d}{d}}\right)$

Rearranging,

$$\Delta \boldsymbol{t} = -\left(\frac{\boldsymbol{\nu}\sigma_c}{\boldsymbol{E}} \boldsymbol{t}\right) \qquad (14)$$

and the new thickness becomes

$$\boldsymbol{t\_new} = \boldsymbol{t} + \Delta \boldsymbol{t} \qquad (15)$$

3.2 Specific objective two: To simulate the water maintenance line network

3.2.1 The Bukasa Mains Network Under NSWC Kampala

The case study network was obtained from NWSC in an AutoCAD format and it was exported to Epanet 2.0 hydraulic simulation tool. The Epanet 2.0 a free hydraulic simulation software was used to simulate the network where the operation pressure, flow rate values and all the other inputs were obtained. The material of pipe used in this network was basically PVC and the network consisted mainly of mains ranging from DN150- DN 450 PVC pipes. The purpose of the Epanet simulation in figure 7 was to obtain real time flow rate and operating pressure values from the case study network since NWSC had no updated data of these parameters by then.

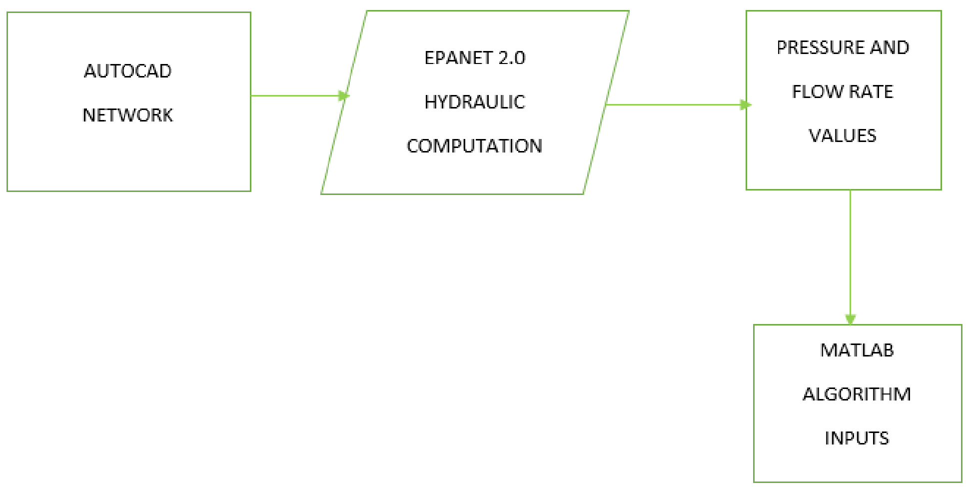

Figure 6:Schematic flow for the simulation process

The pressure and flow rate values from Epanet hydraulic tool were then exported to Matlab software in order to simulate the hydroinformatics tool developed. This data was linked to Ms excel sheet where the inputs into Matlab code were saved

3.2.2 The Algorithm Flow Chat

The algorithm in figure 8 computes the three major failure scenarios and compares the pressure at each scenario with the operating pressure to give the state of a pipe at a given period. It also calculates the small changes in the dimensions of a pipe at that instant and out puts the stress and pressures of a pipe at each scenario

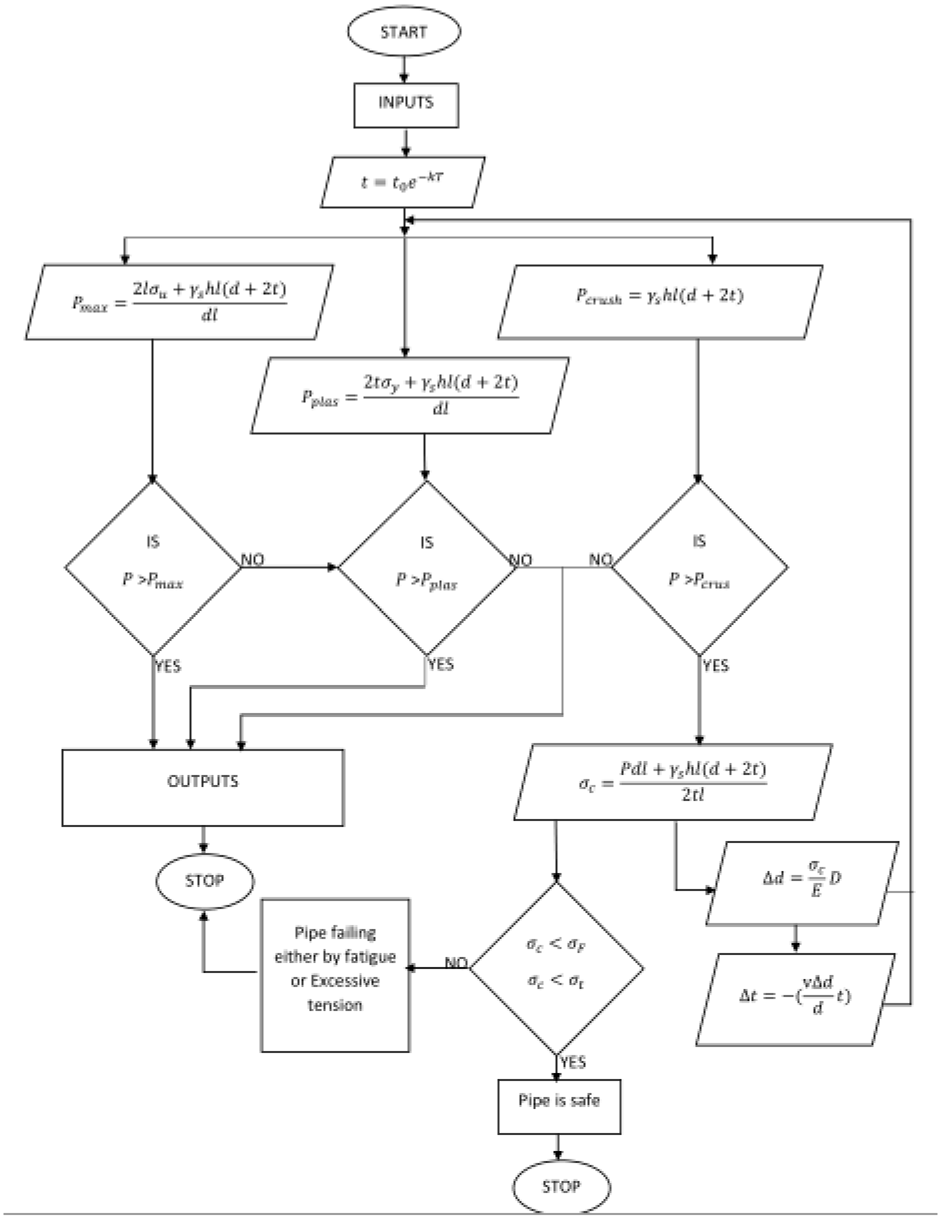

Figure 7:System's algorithm flow chat

The inputs to the algorithm were the simulated pressure(P) from the Epanet 2.0 hydraulic software, length of each pipe in the network, pipe ID numbers, pipe diameter, pipe thickness, depth of installation, pipe age, pipe material decay constant (k), Young's modulus (E) of pipe material being used, yield stress of the material, tensile stress of the material, fatigue stress of the material, ultimate stress and Poisson's ration(v) of the pipe material being used

3.2.3 Simulating different failure scenarios

3.2.3.1 Scenario one: Maximum pressure beyond which a pipe will burst

This scenario occurs when the pipe has reached its ultimate stress or when its load carrying capacity has reduced below its design load but still being operated under normal conditions, the inlet pressure or the operating pressure is greater than the allowable pressure at the then state of the pipe. It is expressed as;

$$P_{max} = \frac{2t\sigma_u + \gamma_s hl(d + 2t)}{dl} \quad (16)$$

Where;

$\sigma_u = the\ ultimate\ stress\ of\ a\ pipe\ material$

$P_{max} = the\ maximum\ allowable\ pressure\ in\ a\ pipe\ at\ particular\ state\ in\ time$

And all the other parameters remain as defined before

3.2.3.2 Scenario two: Pressure that can cause plastic deformation in a pipe

This scenario occurs when the inlet pressure P is beyond the pressure at elastic limit. If the inlet or operating pressure is greater than $P_{plasticity}$, the tensile stress developed within the material can lead to a plastic deformation. It is given by;

$$P_{plasticity} = \frac{2t\sigma_y + \gamma_s hl(d + 2t)}{dl} \quad (17)$$

$\sigma_y = the\ yield\ stress\ of\ the\ pipe$

3.2.3.3 Scenario three: Minimum pressure below which the pipe will start experiencing crushing by the earth overburden load and other live loads

This scenario occurs mostly when the operating pressure P of a pipe is very low or zero and the backfill soil and any other load acting externally on the pipe is suppressing it causing it to gradually crush. It is expressed as;

$$P_{crush} = \gamma_s Dhl \quad (18)$$

3.2.3.4 Comparing the hoops stress with the design stresses of the pipe

Under this section, the hoops stress value calculated in equation (6) is checked with the fatigue stress σ_F and the tensile stress σ_t for safety purposes

Hence for a pipe to be safe, two conditions MUST hold in addition to the pressure checks from equation (8-10).

Thus for safety;

$\sigma_c < \sigma_F$ and $\sigma_c < \sigma_t$

4 CHAPTER FOUR: RESULTS AND DISCUSSIONS

The data from Bukasa water distribution mains were used as the basic input that led to the success of the results. The network was at first simulated in Epanet 2.0 hydraulic tool as in figure 8 to obtained lacking inputs like the operating pressure and the flow rate which of paramount in the hydroinformatics algorithm.

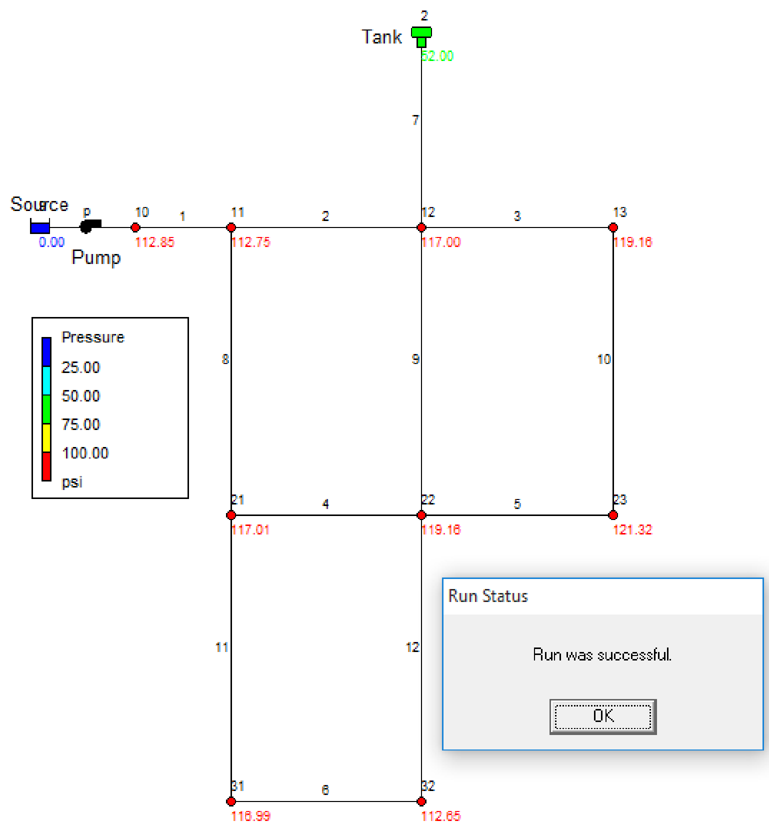

Figure 8:Epanet simulation of the network

It consisted of twelve mains from the case study area, and the results of the successful simulation from Epanet where the pressures at each node have been displayed. The pressure differences were then computed and pressure values at each pipe were then obtain successfully as displayed in the proceeding tables of results.

4.1 Epanet 2.0 simulation results

The simulation in Epanet produced the results in table 1 and table 2 and as state earlier, the main interest of Epanet simulation was to obtain the missing data from Bukasa distribution mains under NWSC Kampala water works. Table 1 contains values of flowrate, velocity, unit head loss friction factor etc. for each pipe in the network

Table 1: Epanet results (flow and unit head loss)

Network Table - Links at 0:00 Hrs

Link ID	Flow GPM	Velocity fps	Unit Headloss ft/Kft	Friction Factor	Reaction Rate mg/L/d	Chlorine mg/L	Status
Pipe 1	2097.14	2.64	2.25	0.031	0.00	0.50	Open
Pipe 2	1414.40	2.95	3.70	0.032	0.00	0.50	Open
Pipe 3	119.26	0.49	0.19	0.044	0.00	0.50	Open
Pipe 4	236.90	0.97	0.69	0.040	0.00	0.50	Open
Pipe 5	130.74	0.37	0.10	0.045	0.00	0.50	Open
Pipe 6	45.85	0.52	0.40	0.048	0.00	0.50	Open
Pipe 7	-997.14	1.26	0.57	0.035	0.00	0.75	Open
Pipe 8	532.75	2.18	3.12	0.035	0.00	0.50	Open
Pipe 9	147.99	0.42	0.12	0.044	0.00	0.50	Open
Pipe 10	19.26	0.12	0.02	0.059	0.00	0.50	Open
Pipe 11	145.85	0.93	0.84	0.042	0.00	0.50	Open
Pipe 12	54.15	0.61	0.54	0.046	0.00	0.50	Open
Pump p	2097.14	0.00	-170.44	0.000	0.00	0.75	Open

In the proceeding table 2 exists values of pressures and demand patterns at the different nodes in the network, head at these nodes. This information led me to the completion of the process of data acquisition hence completed the inputs that were required for the simulation process

Table 2: Epanet results (Nodal pressures and heads)

Network Table - Nodes at 0:00 Hrs

Node ID	Demand GPM	Head ft	Pressure psi	Chlorine mg/L
Junc 10	0.00	970.44	112.85	0.50
Junc 11	150.00	970.21	112.75	0.50
Junc 12	150.00	970.01	117.00	0.50
Junc 13	100.00	970.00	119.16	0.50
Junc 21	150.00	970.04	117.01	0.50
Junc 22	200.00	970.01	119.16	0.50
Junc 23	150.00	970.00	121.32	0.50
Junc 31	100.00	970.00	116.99	0.50
Junc 32	100.00	969.98	112.65	0.50
Resvr 9	-2097.14	800.00	0.00	1.00
Tank 2	997.14	970.00	52.00	1.00

4.2 Pipe Design standards being used in the inputs in the computer code

During the design of the tool, Standard design stresses for different pipe sizes as in figure 3 adopted from (Pvc, 2013) were used to check for the different failure scenarios that are incorporated in the hydroinformatics tool. Table 3 shows the design stress for the various ranges of pipes sizes and their factor of safety of safety

Table 3:Stress design standards for different pipe sizes

Pipe size (mm)	Design stress (MPa)	Factor of safety (50yrs)
16 – 90	10	2.5
110 – 500	18	1.4

4.2.1 Standard pipe diameters, thickness and PN values adopted from (Value, 2011)

In the operation of a water supply system, pipes are operated at pressures that are within their nominal pressure (PN) ratings and during the design process of this project, the pipes in the case study network were grouped using their diameters and PN numbers. Table 4 provides the PN rates for the different pipe diameters that were used in the analysis of operating or inlet pressure of the network.

Table 4: Standard PN values for various pipe thickness

Pipe Nominal Diameter (Mm)	Standard Thickness (Mm)	Maximum Allowable PN Value (Bar)
100	8.1	PN16
150	11.8	PN16
200	14.7	PN16
250	18.4	PN16
300	23.2	PN16
350	26.1	PN16
400	29.4	PN16
450	33.7	PN16

4.2.2 Standard mechanical properties of different pipe materials

The design standards for yield stress, tensile stress, fatigue stress, ultimate stress and the modulus of elasticity of different pipe materials depicted in table 5 were used as inputs in the data base that was created in Microsoft excel 2016.

Table 5:Standard Material properties of pipes

Material	Yield stress (MPa)	Tensile stress (MPa)	Fatigue stress (MPa)	Ultimate stress (MPa)	Modulus of elasticity (MPa)
PVC	52	52	17	57	4000
HDPE	28	32	12	37	193
PE	16	18	12	37	200
STEEL	250			400	192000
GI	95			350	2110000000

If the tensile stress within a pipe is greater than design fatigue stress of the pipe, this pipe particular pipe would be experiencing fatigue implying a gradual failure of that pipe experiencing the stress. If the stress if greater than yield or equal to the tensile stress as of table 5, then the pipe would have been deformed permanently and is tending to rapture. And lastly a situation where the tensile stress within a pipe is greater than the ultimate stress, according to the system, this pipe would have busted thus this system is developed in a way that this last scenario is avoided thus reducing the non-revenue water

4.3 Inputs to the hydroinformatics tool

The inputs that were used are tabulated in table 6, During the simulation process, the state of any given valve in the network is checked and as such, a valve is either closed or open which in the algorithm is coded in the binary language as one (1) for an open valve and a zero (0) for a closed valve. In case a valve is closed, waves propagate and the head in the network rises, this creates changes in the operating pressure and the hydroinformatics tool computes all the failure scenarios checking for the state of each of the pipes. The pipes also are normally installed underground in soils of different types that have got different properties. However, for this particular network used in this tool, the material used was homogeneous (PVC) only thus the physical chemical and mechanical properties were the same and the soils obtained from ARCSWAT/GIS and were found to be basically clay for the case study area.

Tables 6 indicates the variable parameters that were used in the development of the hydroinformatics model. Different pipes along a network are made of different material and each material consists of different physical, chemical and mechanical properties thus showing different behaviors when subjected to a given constant load. However, for this particular network as discussed before, only consists of PVC pipe material with decay constant 0.014, modulus of elasticity 4000000MPa, tensile stress of 57000MPa etc.

Table 6: Inputs to the hydroinformatics tool

Pipe ID	Depth of Installation, h (m)	Pipe Age, T (Years)	Pipe Length, l (Km)	Pipe Diameter, d (mm)	Pipe Thickness, t (mm)	Pressure, P (KPa)	Flowrate, Q (m^3/s)
P1	1.00	10	4.0	450	6.35	822	0.0329
P2	0.90	2	2.8	350	4.78	807	0.0144
P3	0.80	3	3.5	250	3.40	818	0.0122
P4	0.80	20	2.6	250	3.40	811	0.0240
P5	0.85	5	3.0	300	4.20	818	0.0131
P6	0.50	6	5.0	150	2.30	764	0.0053
P7	0.85	3	2.5	300	4.20	358	0.0132
P8	0.80	6	1.8	250	3.40	811	0.0125
P9	0.85	8	1.2	300	4.20	806	0.0130
P10	0.65	9	1.6	200	2.77	832	0.0090
P11	0.65	7	0.8	200	2.77	798	0.0140
P12	0.50	4	3.5	150	2.30	818	0.0112

4.4 The Graphical user interface of the Hydroinformatics tool

For user friendliness and ease in use of the tool, a graphical user interface (GUI) was successfully developed as per figure 9 using Matlab R2013. The GUI displays the state of a pipe at any given time by displaying the failure scenarios which include the bursting pressure, yielding pressure, and crushing pressure and the hoops stress values in each pipe in the network. The GUI then displays the pipe status depending on the scenario a pipe is experiencing at that particular time plotting pressures in each pipe and hoops stresses.

Figure 9: System's Graphical user interface

4.5 Results from the hydroinformatics tool

The simulation gave out results of the failure scenarios which included the maximum pressure at which a pipe can burst, the pressure that can cause plastic deformation in a pipe thus making it to lose its elasticity, the minimum pressure below which the overburden soil and any other live load will start crushing or suppressing a pipe leading to horizontal deflection and lastly the internal hoops stresses were then checked for each pipe in the network

The changes Δd and Δt in diameter and thickness as presented in table 7 are the small expansion of the pipe diameter as a result of water pressure and shrinking or necking of the pipe thickness as a result of the tensile stress that tends to resist the water pressure from bursting the pipe respectively. The greater the operating pressure, the greater will be the tensile stress and the bigger will the values of Δd and Δt respectively. a situation where the tensile stress is greater the yield stress for a given pipe material, this small expansion and necking of the diameter and thickness respectively will not regain their original shapes and at this state, the pipe material is said to have been deformed plastically.

Table 7: Hydroinformatics simulation results

Pipe ID	Operation Pressure (MPa)	Maximum Pressure (MPa)	Deformation Pressure (MPa)	Crushing Pressure (MPa)	Tensile (Hoops) Stress (MPa)	$\Delta d\ (mm)$	$\Delta t (mm)$ ($1X10^{-4}$)
P1	0.822	5.60	6.90	0.040	142.90	0.0155	0.865
P2	0.807	3.34	4.14	0.017	87.31	0.0074	0.410
P3	0.818	4.17	5.16	0.014	112.00	0.0068	0.367
P4	0.811	2.92	3.63	0.010	83.88	0.0052	0.277
P5	0.818	3.64	4.52	0.015	92.93	0.0068	0.378
P6	0.764	6.60	8.19	0.007	133.01	0.0048	0.293
P7	0.358	3.03	3.76	0.013	34.06	0.0025	0.141
P8	0.811	2.08	2.59	0.007	56.24	0.0035	0.187
P9	0.806	1.41	1.76	0.006	36.14	0.0027	0.149
P10	0.832	1.85	2.31	0.004	50.28	0.0025	0.137
P11	0.798	0.92	1.15	0.002	23.90	0.0012	0.069
P12	0.818	4.59	5.71	0.005	95.34	0.0036	0.219

The results in this table (8) include the operating pressure, a check for the maximum pressure beyond which a pipe is likely to burst, a check for pressure beyond which the pipe material may be deformed plastically, table 8 also displays values of pressures below which a pipe may experience crushing or deformation by the overburden soils or any other load subjected to it and lastly, it displays the tensile hoops stresses in each pipe that tends to resist the load carried by the pipe from bursting the pipe.

According to the simulation results, the operating pressure of Bukasa distribution mains is below the maximum pressure beyond which a pipe along the network can burst, however, this pressure is high enough that as a result of the continuous operation of this network to serve the already stated 28000 populations to cause fatigue in the pipes 1,3,6, and 12 hence alerting the operators with a display shown in figure 10.

The pipes 2, 4, 5, 7, 8, 9, 10, and 11 were found to be under normal operating conditions as displayed in figure 12 above.

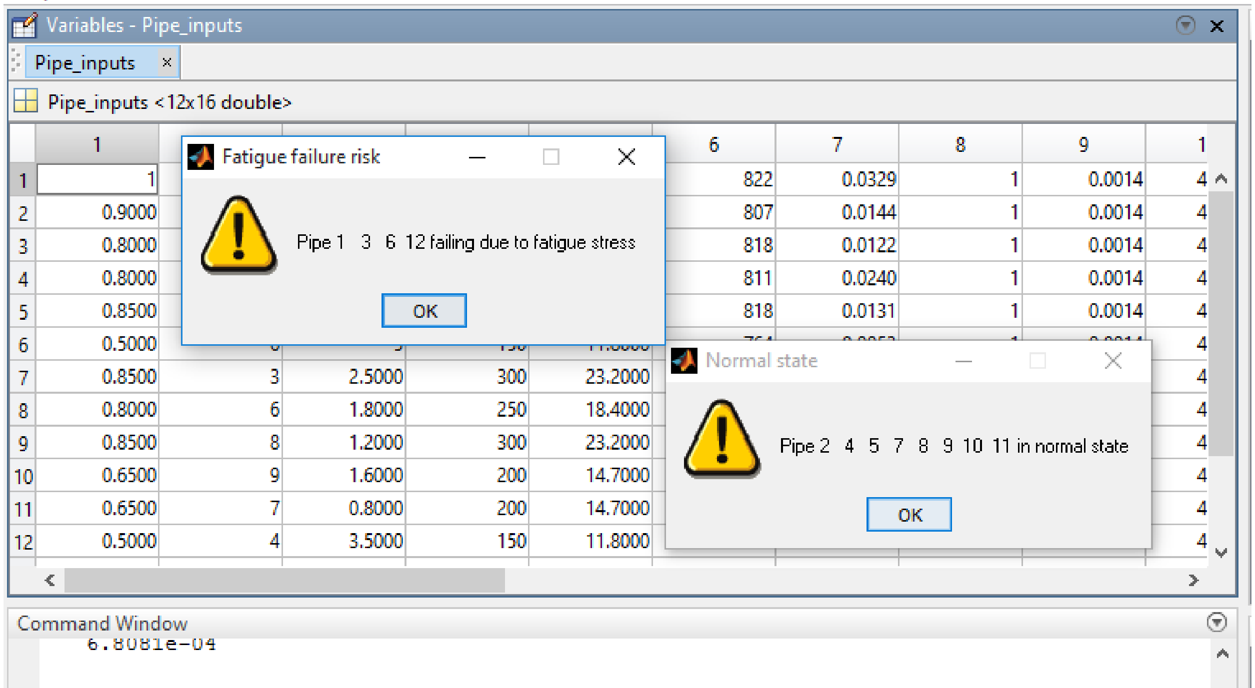

Figure 10:State of the network being simulated

4.5.1 System testing

On varying the input (Operating) pressure from low to high for the different pipes in the network, the results presented in figure 11 were obtained and this shows the flexibility and versatility of the tool in detecting the different scenarios under which pipes are subjected.

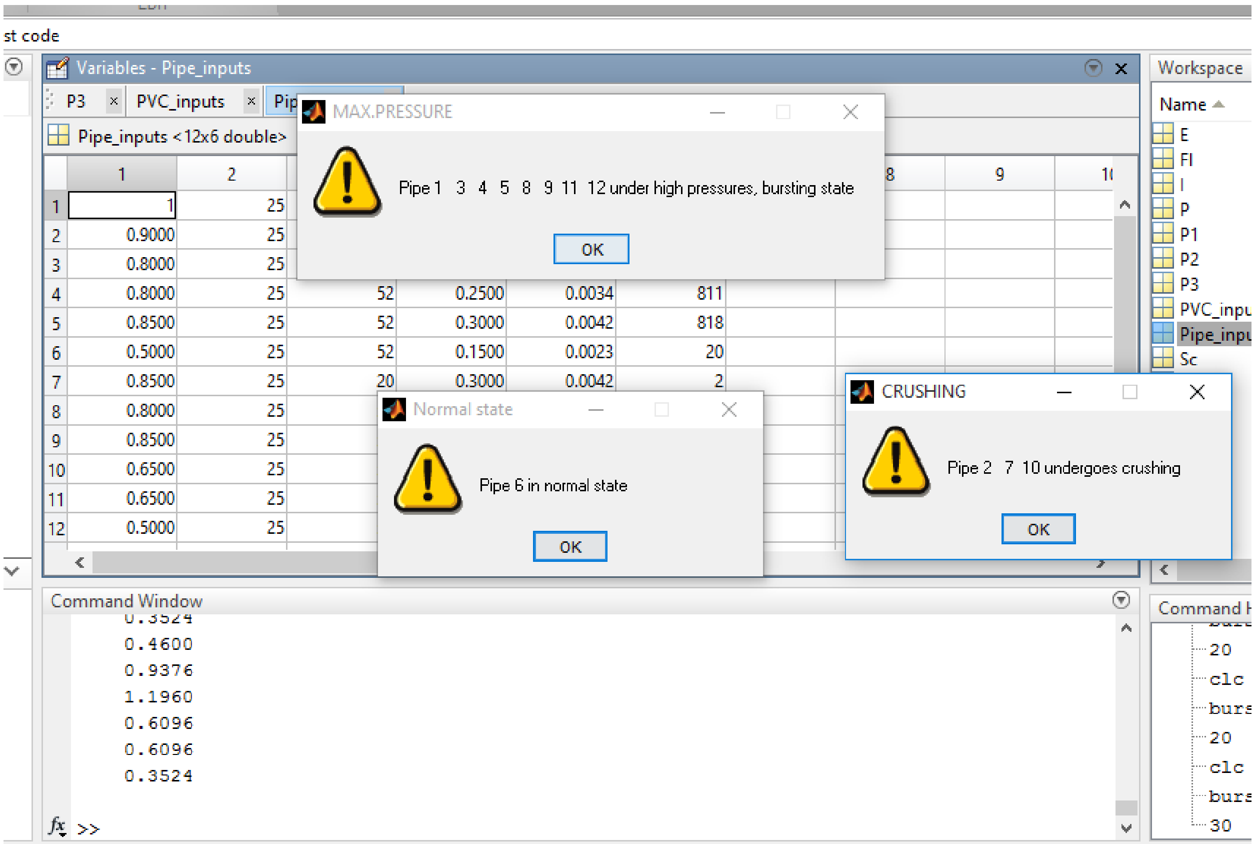

Figure 11:Testing with different input variables

4.6 Analysis of the results from system testing

The tool is built in a way that the maximum pressure at which is likely to occur is set slightly below the yielding pressure. This ensures that the pipe does not undergo plastic deformation during un usual occasions like surge pressure occurrence. The maximum pressure also gives room for network operators to quickly respond to the alert before any damage is done on pipe.

On testing with varying operating pressure, the system indicated that the pipes 1,3,4,5,8,9,11, and 12 were under high pressure thus the system categorised them under bursting state, pipe 6 was only one under normal state of operation and pipes 2,7, and 10 were empty and the overburden load was compressing these three pipes.

When the pipe is yielding, it implies that the stress trying to resist the excess pressure from burst the pipe is greater than the yield stress of that pipe materials thus causing it to deform gradually.

4.7 Validation of the hydroinformatics tool

4.7.1 Testing for validity using external data

During this validation process, hypothetical data was obtained from a journal by (G. Erherd). G. Erhard computed calculated maximum pressures with results presented in table 8 in which a pipe can burst and stresses that cause deformation and fatigue on the material leading gradual failure. Three pipe materials were used in his model which included, PVC, HDPE and Steel pipes.

During the validation of the hydroinformatics tool, the same inputs used by G. Erherd were used used as the inputs for the hydroinformatics tool and outputs of maximum burst pressure and hoops stress in a pipe were compared with his results below.

Table 8: Other Author's results (G. Erherd's)

RESULTS OF TENSILE STRESS AND BURST PRESSURE FROM G-ERHERD'S MODEL					
Pipe ID	Pipe Material	Diameter (d) (mm)	Thickness (s) (mm)	Bursting Pressure (KPa)	Hoops Tensile Stress (MPa)
P1	HDPE	10.0	1.5	157.43	5.433
P2	HDPE	9.0	1.0	91.88	1.61
P3	HDPE	8.5	0.75	51.73	1.873
P4	PVC	10.5	0.75	15.08	2.986
P5	PVC	11.0	0.75	36.79	7.896
P6	STEEL	9.5	0.75	1794.33	30.05
P7	STEEL	10.6	0.75	2599.78	5.503

The input parameters and the results from other authors as illustrated in table 8 who conducted research in similar areas as in this report. This particular research was done by G. Erherd and in it he basically concentrated on computing maximum pressures beyond which a pipe can burst and also, he computed the tensile stresses that can cause deformation in pipes.

The results obtained from simulating the inputs of G. Erherd's model using the hydroinformatics tool were tabulated in table 9. G. Erherd tested his model with a sample of seven pipes of varying diameters and materials. According to these results, the variation between the bursting pressure, the tensile stress values for each pipe in this network for both table 8 and table 9 which consists of the simulated hydroinformatics tool results and G. Erherd's results is not much. Δd and Δt as mentioned earlier this report are the respective increment in diameter and necking of the thickness as a result of pressure at which these pipes were subjected to and the corresponding tensile stress in them.

Table 9:Simulated results for inputs of G. Erherd using the hydro-informatics tool

SIMULATED RESULTS FOR VALIDATION FROM HYDROINFORMATICS TOOL						
Pipe ID	Operating Pressure (KPa)	Burst Pressure (MPa)	Yielding Pressure (KPa)	Hoops Stress σc (MPa)	$\Delta d\ (mm)$ $(1x10^{-4})$	$\Delta t (mm)$ $(1x10^{-5})$
P1	163	159	2.831	5.42	3.310	1.800
P2	358	93.3	1.915	1.622	0.920	3.710
P3	265.6	69.1	1.626	1.923	1.030	3.290
P4	228.6	13.24	3.045	3.354	0.110	0.250
P5	28.2	35.35	7.543	8.486	0.277	0.630
P6	253.5	1871.2	9.354	29.461	0.025	0.004
P7	145	2594.3	7.726	6.404	0.004	0.007

Table 9 shows The pipes were assumed to be installed in sandy soils and they comprise of three different materials (PVC, HDPE and steel)

4.7.2 Computing the error (deviation) between the hydroinformatics model and G. Erherd's model

The computed percentage deviation for tensile stresses in the pipes between the G. Erherd's results and the results simulated from the hydroinformatics tool are presented in table 10. As observed in table 10, the average percentage deviation between the two results are small approximately only 5.4% . this affirms the validity of the tool

From the comparison between the results simulated from the hydroinformatics tool and the results of G. Erherd in table 11, we can clearly see that the average percentage deviation between the two results is so small that is less than 10 %. This percentage clearly indicates that these two results both for burst pressure and the hoops stress are converging and this indicates that this tool is valid and is worth of adopting.

Table 10: Testing for deviation in the tensile stress results

COMPUTING FOR DEVIATION IN STRESS RESULTS					
Pipe Material	Pipe Diameter (mm)	Results from hydroinformatics tool (MPa)	Results from G-Erherd's Model (MPa)	Deviation (MPa)	% Deviation (MPa)
HDPE	10	5.42	5.433	0.013	0.2393
HDPE	9	1.622	1.61	0.012	0.7398
HDPE	8.5	1.923	1.873	0.05	2.6001
PVC	10.5	3.354	2.986	0.368	10.9720
PVC	11.0	8.486	7.896	0.59	6.9526
STEEL	9.5	29.461	30.05	0.589	1.9601
STEEL	10.6	6.404	5.503	0.901	14.0693
Average % Deviation					5.3619

Table 11: Testing for deviation in bursting pressure results

COMPUTING FOR DEVIATION IN BURST PRESSURE RESULTS					
Pipe Material	Pipe Diameter (mm)	Results from hydroinformatics tool (KPa)	Results from G. Erherd's Model (KPa)	Deviation (KPa)	% Deviation (KPa)
HDPE	10	159	157.43	1.57	0.9874
HDPE	9	93.3	91.88	1.42	1.5219
HDPE	8.5	69.1	51.73	17.37	25.1375
PVC	10.5	13.24	15.08	1.84	12.2016
PVC	11.0	35.35	36.79	1.44	3.91411
STEEL	9.5	1871.2	1794.33	76.87	4.2841
STEEL	10.6	2594.3	2599.78	5.48	0.2108
Average % Deviation					6.8939

5 CHAPTER FIVE: CONCLUSION, CHALLENGES AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this study was aimed at predicting failures in pipes along the pipe network. The network used in conducting the simulation was obtained from NWSC Kampala and all the other data used

The hydroinformatics model was successfully developed and later designed using the data obtained from NWSC Bukasa Kampala. However, the data obtained was incomplete and it was first simulated in Epanet hydraulic tool to obtain the missing data like the operating pressure of the network, demand and actual flow rates along the network etc. the elevations of the network were then obtained from google earth software and the elevations at each node were obtained successfully.

During simulation, the tool performed as expected though challenges of code failing to run due to inappropriate parameters and inputs that were used at first but later during debugging, all parameters were adjusted to standards and the inputs were saved in their respective and rightful databases in Microsoft excel where the Matlab code read each individual input from the various databases

A hypothetical data from different authors were downloaded from internet and were fed in the tool for validating the system each failure scenario was test using different data sets and the results were successfully obtained and analyzed. The results obtained from the hydroinformatics tool were then compared with original results of these authors and for each result, the deviation or divergence was computed. This process helped in checking for the validity of the tool for use by NWSC. The reason why this tool was not validated using the local data or data from NWSC is that at the time of collecting the necessary data for designing the tool from NWSC, such information never existed and there were no hopes that such data could be gotten or obtained if given time within the time frame of the project

The different failure scenarios that were successfully tested during the simulation included the maximum pressure beyond which a pipe may be tending to bursting, a pressure in a pipe beyond which a pipe material if deformed beyond the elastic limit of the material, and the minimum pressure below which the pipe will experience crushing or horizontal deflection by the overburden loads like the backfill soils, and any other live or dead loads subjected on the buried pipe

Despite the challenges encountered during the system development, the Hydroinformatics tool has undergone complete and successful development, simulation, testing and validation to meet the earlier stated objectives. The system can state the current operation conditions of a network and predict the future status of a network. The system was also able to analyze the failure scenarios of each pipe along the network and gave out the failure status of each individual pipe.

The system is able to predict failures using the failure scenarios that were modeled, an alarm and popup massage box on the computer screen that displays the state of a pipe at a given time and its mode of failure incase it's a warning massage. All these show that this system can actual reduce non-revenue water, reduce operating costs and increase on the NWSC revenue. Therefore, this system if adopted will emphasize more [preventive maintenance than corrective maintenance and as in engineering and other fields, prevention is always better than care.

Hence Considering the successful processes this tool has gone through, i.e. develop, design, simulation, testing and validation, I am glad to conclude that this tool can be adopted by NSWC not only for Bukasa water supply distribution mains but also to monitor the entire distribution structures country wide.

However, during this project implementation, I was faced by some challenges and among which include the following; during the process of data collection, I faced a challenge of lack of most of the relevant information (data) from case study area. This created a flaw in the methodology and some of the objectives thus it led to un expected adjustments that need to be done in those areas to see the progress of this project. This particular problem delayed the project progress, there was also a challenge of inadequate funds to finance the activities of this project as the entire project was supported by my parents who have got no smooth income inflow, I found it difficult to balance between this project and the class room studies as most of my time was consumed by the project.

Furthermore, in the development and designing of this tool, not all the proposed functional and non-functional requirements were fulfilled due to in adequate resources like funds, data, and time. Therefore the following recommendations are suggested for future and implementation; The system should be modified to create a direct communication (link) with Epanet hydraulic tool, there should be an automatic and instantaneous detection of live loads affecting the buried pipes, the tool should in future be linked with ANN technologies to enable self-learning and prediction of future states of the network.

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5.3 Appendices

5.3.1 The system's code

```
% This programm detects failure senarios in a pressurised water pipe network
clear;clc;
%% HYDRAULIC AND NETWORK INPUTS
Pipe_inputs= xlsread ('PIPE NETWORK DETAILS.xlsx');
%PVC_inputs = xlsread ('PIPE CONSTANTS.xlsx');
leng=size(Pipe_inputs,1);

%Where
% t= thickness of pipe
% y= Specific unit weight of soil
% h= Depth of pipe installation
% l= Pipe length
% d= Pipe diameter
% P= initial pressure from EPANET NETWORK MODEL
%y, specific unit weight of soil
%J= The yield stress of the pipe material
% U= Ultimate stress

% -------- inputted as per the excel columns----------------
h = Pipe_inputs(1:leng,1);
T=Pipe_inputs(1:leng,2);
l = Pipe_inputs(1:leng,3);
t = Pipe_inputs(1:leng,5)./1000;    %mm to m
P = Pipe_inputs(1:leng,6).*1000;    %kpa to pa
Q = Pipe_inputs(1:leng,7);
valve_state = Pipe_inputs(1:leng,8);
k=Pipe_inputs(1:leng,9);
E=Pipe_inputs(1:leng,10).*1000;     %kpa to pa
j = Pipe_inputs(1:leng,11).*1000;   %kpa to pa
U = Pipe_inputs(1:leng,13).*1000;   %kpa to pa
vr=Pipe_inputs(1:leng,14);
```

```
f=Pipe_inputs(1:leng,15).*1000;     %kpa to pa
y=Pipe_inputs(1:leng,16).*1000;     %kpa to pa


%% DECAY RATE OF PIPE

tn=t.*exp(-k.*T);
U=U.*exp(-k.*T);
j=j.*exp(-k.*T);
E=E.*exp(-k.*T);
f=f.*exp(-k.*T);

%% SURGE PRESSURE kPa
%Pipe cross sectional area
A=(pi.*d.^2)./4;
% flow velocity
vel=Q./A;

% Bulk modulus of water
Bk=20684;% pascals
%density of water
dens=1000;

c=sqrt(Bk/dens);
a=c./sqrt(1+(Bk./E).*(d./tn));

for i=1:length(P)
   end


%% CALCULATE MAXIMUM PRESSURE BEYOND WHICH A PIPE WILL BURST, P1

p1 = (2.*tn.*U)+(y.*h.*l).*(d+2.*tn);
P1 =(p1./d.*l)
```

%% CALCULATE ELASTIC PRESSURE, PRESSURE THAT CAN CAUSE PERMANAENT DEFORMATION OF PIPE

```
p2 =(2.*tn.*j)+(y.*h.*l).*(d+2.*tn);
P2 =(p2./d.*l)

%% CALCULATES THE PRESSURE BELOW WHICH CRUSHING OF THE PIPE CAN OCCUR DUE
%OVER BURDEN SOIL LOAD AND LIFE LOAD
%q=1103161600;%pascals
%I=0.04864;
%l1=2.68;
%l2=4.326;
%Fl=q*I/(144*l1*l2);

P3 = (y.*h.*l).*(d+2.*tn)%+Fl
```

%% SCENARIOS AT WHICH PIPE EXPERIENCES FAILURE DUE TO HIGH PRESSURES, YEILDING AND

%DUE TO CRUSHING BY OVERBURDEN SOIL

```
%% CHECKING FOR OPERATING STATUS OF A PIPE
x=1; z=1; mm=1; nn=1; k=1;
burst=[];yield=[];norma=[];fat=[];crush=[];
for i=1:length(P)
    if P(i) > P1(i)



        x=x+1;
    elseif P(i) > P2(i)
        yield(z)=i;


         z=z+1;
    elseif 0<P(i)< P3(i)
         % CALCULATING THE HOOP STRESSES IN THE PIPE
```

```
        Sc(i)= ((P(i)*d(i))*l(i)-(y(i)*h(i)*l(i))*(d(i)+2*tn(i)))/(2*(tn(i)))

        % CALCULATING THE SMALL INCREAMENT IN DIAMETER AND THICKNESS DUE
        % TO ELASTICITY
       dc= Sc(i)*d(i)./E(i) % is the small change in diameter
        ts=-(vr(i).*dc./d(i)).*tn(i) % is the reduction thickness
        tn(i)=tn(i)+ts;
        d(i)=d(i)+dc;

        % CALCULATING THE HOOP STRESSES IN THE PIPE AFTER EXPANSION
        Sc(i)= ((P(i)*d(i))*l(i)-(y(i)*h(i)*l(i))*(d(i)+2*tn(i)))/(2*(tn(i)));

      if Sc(i)>f
          fat(mm)=i;

          mm=mm+1;

      else
          norma(nn)=i;

          nn=nn+1;
      end
    else
       crush(k)=i;

        k=k+1;

    end
end

 %% OUTPUT
    if ~isempty(burst)
       v=['Pipe ',num2str(burst),' under high pressures, bursting state'];
       v = msgbox(v,'MAX.PRESSURE','Warn');
```

```
end
if ~isempty(yield)
   v=['Pipe ',num2str(yield),' yielded, in plastic state'];
   v = msgbox(v,'YEILDING','Warn');
end
if ~isempty(fat)
   v=['Pipe ',num2str(fat),' failing due to fatigue stress'];
   v = msgbox(v,'Fatigue failure risk','Warn');
end
if ~isempty(norma)
   v=['Pipe ',num2str(norma),' in normal state'];
   v = msgbox(v,'Normal state','Warn');
end
if ~isempty(crush)
   v=['Pipe ',num2str(crush),' undergoing crushing'];
   v = msgbox(v,'CRUSHING','Warn');
e
```

5.3.2 Graphical user interface (GUI) code

```
function varargout = pressuremonitor(varargin)
% PRESSUREMONITOR MATLAB code for pressuremonitor.fig
%      PRESSUREMONITOR, by itself, creates a new PRESSUREMONITOR or raises
the existing
%      singleton*.
%
%      H = PRESSUREMONITOR returns the handle to a new PRESSUREMONITOR or the
handle to
%      the existing singleton*.
%
%      PRESSUREMONITOR('CALLBACK',hObject,eventData,handles,...) calls the
local
%      function named CALLBACK in PRESSUREMONITOR.M with the given input
arguments.
%
%      PRESSUREMONITOR('Property','Value',...) creates a new PRESSUREMONITOR
or raises the
%      existing singleton*.  Starting from the left, property value pairs are
%      applied to the GUI before pressuremonitor_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property application
%      stop.  All inputs are passed to pressuremonitor_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
```

```
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help pressuremonitor

% Last Modified by GUIDE v2.5 03-Jun-2018 17:50:52

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @pressuremonitor_OpeningFcn, ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
% --- Executes just before pressuremonitor is made visible.
function pressuremonitor_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to pressuremonitor (see VARARGIN)

% Choose default command line output for pressuremonitor
handles.output = hObject;
[p1, p2, P3, ts, Sc,burst, yield,fat,
handles.maxp=p1;
handles.defp=p2;
handles.ovp=P3;
handles.pnorma=norma;
handles.pcrush=crush;
imshow('stresses.png','parent',handles.axes1);
%imshow('hoopstresses.jpg','parent',handles.axes3);



% Update handles structure
guidata(hObject, handles);

% UIWAIT makes pressuremonitor wait for user response (see UIRESUME)
% uiwait(handles.figure1);



% --- Outputs from this function are returned to the command line.
function varargout = pressuremonitor_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
```

```
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;
% --- Executes on button press in maxpressure.
function maxpressure_Callback(hObject, eventdata, handles)
% hObject    handle to maxpressure (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
set(handles.calmaxpressure,'string',handles.maxp);

% --- Executes on button press in plotmaxp.
function plotmaxp_Callback(hObject, eventdata, handles)
% hObject    handle to plotmaxp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
plot(handles.maxp,'parent',
plot(handles.defp,'parent',handles.axes2);
% --- Executes on button press in evalb.
function evalb_Callback(hObject, eventdata, handles)
% hObject    handle to evalb (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
set(handles.text10, 'string', handles.diachange);
set(handles.text11, 'string',handles.hoopp );
% --- Executes on button press in ovp.
function ovp_Callback(hObject, eventdata, handles)
% hObject    handle to ovp (see GCBO)

% --- Executes on button press in netdefp.
function netdefp_Callback(hObject, eventdata, handles)
% hObject    handle to netdefp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA
set(handles.netdefpt, 'string', handles.defp);

function pipeno_Callback(hObject, eventdata, handles)
% hObject    handle to pipeno (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
pipenumber=str2double(get(hobject, 'string'));
handles.pipenumber=pipenumber;
guidata(hobject,handles);
% Hints: get(hObject,'String') returns contents of pipeno as text
%        str2double(get(hObject,'String')) returns contents of pipeno as a
double
% --- Executes during object creation, after setting all properties.
function pipeno_CreateFcn(hObject, eventdata, handles)
% hObject    handle to pipeno (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
```

```
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
% --- Executes on button press in pushbutton6.
function pushbutton6_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% --- Executes on button press in pushbutton7.
function pushbutton7_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

     if ~isempty(handles.pburst)
        v=['Pipe ',num2str(handles.pburst),' under high pressures, bursting
state'];
         v = msgbox(v,'MAX.PRESSURE','Warn');

     end
     if ~isempty(handles.pnorma)
         v=['Pipe ',num2str(handles.pnorma),' in normal state'];
         v = msgbox(v,'Normal state','Warn');
     end
     if ~isempty(handles.pcrush)
         v=['Pipe ',num2str(crush),' undergoing crushing'];
         v = msgbox(v,'CRUSHING','Warn');
     end
```