SURGE ANALYSIS OF WATER PUMPING PIPELINE SYSTEM (CASE STUDY: AJALLI RAW WATER PUMPING PIPELINE SYSTEM) IN EZEAGU LOCAL GOVERNMENT AREA, ENUGU STATE, SOUTHERN NIGERIA.

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Abstract: Generally, water transmission systems are inherently pressure transients, since the systems must be operated either programmed or unprogrammed. The resulting pressure transients could be destructive to the hydraulic systems, depending on its magnitude. The study concerns surge analysis of pumping water pipeline system using Ajalli raw water pumping pipeline system in Ezeagu Local Government Areaof Enugu State, Nigeria as a case study. The method employed in the analysis is varying the number of pumps in operation from 1-6, that is the flow rate (Q1-Q6) using a mathematical model with the help ofan Excel software to determine the magnitude of surge pressures at selected key points along the pipeline as well as determining the minimum thickness of the pipeline required for safe and efficient operations of the system, since thickness governs the design of pipeline system against surge and the adequacy of the surge allowances provision (ramp up and ramp down times) for an electrically inducedtransient pressures. The analysis of these three parameters, surge pressure, minimum pipe wall thickness required and period of vibrations were carried out with as well as without functional anti- water hammer devices. The results obtained show that the actual pipe wall thickness did not satisfy the minimum thickness required for safe and efficient operation of the system when more than three pumps are simultaneously in operation. However, the surge pressure developed at the key points of the pipelinesystem are well below the test pressure of 41.5 bar when five pumps are in operation but are slightly above the test pressure of 41.5 bar when more than five pumps are in operation from drainage 00m to 210m and from chainage 3+930m to 4+470m. Moreover, the calculated period of vibrations for an electrically induced transient pressures is very well below the actual ramp up and ramp down allowances.For the pipeline to operate safely, efficiently and maximally as designed- six duty and one standby, it wasrecommended to increase the pipeline wall thickness from 7.10mm to 10.8mm from chainage 00m to chainage 5+550m. Moreover, additional anti-water hammer protection devices are also recommendedto improve the operational efficiency and safety of the pipeline against inadmissible surge pressures inan event of electromechanically induced surge pressures in view of poor quality and inadequate poweravailability in Nigeria in general and Ajalli water scheme in particular.
Keywords: Surge, hydraulic systems, Chainage, Water hammer,

INTRODUCTION

In general, water delivery system provides a link between the point source ofwater and the point of usage. There are three types of this delivery system. Pumpingsystem, Gravity system and Combination of pumping and gravity systems. Apumping pipeline is one that is used to convey water from points at lower elevations tothose at higher elevations. The use of pumps is the only way to overcome the difference in elevation, usually of a centrifugal type as regards water and wastewater applications. The design of this type of system is usually performed under steady flow conditions, i.e., variations in hydraulics related conditions such as pump's rotational speed variations or changes in the percent opening of valves installed in the pipeline will not occur throughout the system's operational life (Garg, Santash, (2004). During pipeline design, the movement of fluid is based on steady state calculations of the static head and frictional head losses, using the maximumoperating pressure plus a small safety factor (Lokesh K.., Phanindra V, Adarsh K. 2015). On the other hand, surge pressure or water hammer in pumping pipeline systems, are referring to an unsteady flow phenomenon (hydraulic transients) in which the variations in hydraulics related conditions such as pump's rotational speed variations or changes in the percent opening of valves installed in the pipeline will occur throughout the system's operational life as "disturbances" are generated, leading, eventually, to higher hydraulic head levels than those that would occur under steady flow conditions (Lokesh K. et al. 2015). In this case, pipeline pressuresurges are occurred by a sudden increase in pressure which is produced by a changein velocity of the moving fluid in a pipeline.

A pressure surge or wave that occurs when there is a sudden momentum change of a fluid (the motion of a fluid is abruptly forced to stop or change direction)within a closed conduit is called Water Hammer. Water hammer can lead toinadmissible pressures that could cause pipeline to burst in case of positive or upsurge pressures and vacuum condition leading to intrusion of contaminated waterinto the conduit in case of negative or down surge pressures. Some of the more common causes of primary and secondary pressure surges in a closed conduit are asfollows: Primary surge transients which include, Pump startup or shutdown, pump trip, Load changes (in hydropower plants), Valves operations (opening and closing of valves, full or partial), Check valve slam etc. The Secondary surge transients include, Discharge of air through air vent, valves, Excitation of resonant vibrations,improperly sized pressure reducing valves, Water column separation at high spots etc. (Lokesh K., Phanindra V, Adarsh K. 2015).

The most unfavorable situation (in terms of the maximum possible head pressures in the system) is when sudden or an unexpected stoppage of pumping equipment generates the occurrence of water hammer. This sudden stop is normally associated with failure in

Chainage(m)	**Elevation(m)**	**Chainage(m)**	**Elevation(m)**	**Chainage(m)**	**Elevation(m)**
1710	225.46	2370	247.59	3030	254.48
1740	225.42	2400	248.73	3056	254.41
1770	225.68	2430	250.03	3090	253.87
1800	225.69	2460	251.38	3120	253.05
1830	225.92	2490	252.30	3150	252.83
1860	226.42	2520	253.56	3180	252.16
1890	226.78	2550	254.43	3210	252.11
1920	227.40	2580	255.55	3240	250.53
1950	227.95	2610	256.27	3270	249.78
1980	228.77	2640	256.57	3300	249.95
2010	229.41	2670	257.29	3330	249.69
2040	230.25	2700	257.88	3360	249.60
2070	231.22	2730	257.94	3390	250.22
2100	232.50	2760	258.06	3410	249.09
2130	234.06	2790	258.16	3420	249.25
2160	235.56	2820	258.36	3450	249.01
2190	237.66	2850	258.37	3480	249.00
2220	239.66	2870	257.56	3496	248.42
2250	241.07	2880	257.63	3510	248.65
2280	242.91	2910	256.96	3524	248.27
2290	243.39	2940	256.57	3540	248.55
2310	244.82	2970	256.04	3570	249.04
2340	245.86	3000	255.43	3600	249.71
3630	249.79	4200	254.85	4830	274.52
3637	249.83	4230	255.70	4860	276.28

3650	250.15	4260	256.55	4890	278.06
3660	250.16	4290	257.49	4920	280.76
3681	249.75	4320	257.91	4950	281.98
3690	250.43	4330	258.60	4980	283.87

the electrical energy supply to Pumping Station's drives. This situation is the worst, since it is precisely the one that cannot be controlled by system operators or personnel or by any special device, thus creating major disturbances in the system's hydraulic conditions and causing not only a significant pressure upsurge but also a pressure down surge that might lead to pipe collapsing as a vacuum, i.e. column separation can occur under this condition The aforementioned considerations indicate that the speed at which the equipment stops plays an important role in the analysis of Water Hammer in pumping pipelines. The detention speed of pumping equipment mainly depends on the moment of inertia of the rotating parts of the motor and the pump itself, yieldingto the extent that as the higher this value is, the higher the detention time for the pump will be, which will lead to minor perturbations in the pipeline system. Many times, the surge pressure is as much high that it can damage or fracturethe pipes at one or more places in the pipe line system. Therefore, the proper and considerable attention must be paid to study the physics of water hammer (Hanmer,G., Bachman, S., & Lind, G. 2014). It is a truism that efficient water supply is very crucial to the sustenance of socio-economic activity, alleviating poverty and attaining food security in any country. However, it is also a known fact that in most developing countries, having sufficient water supply even in cities is still a problem.In Nigeria, it has become common for citizens to solely provide basic amenities, especially water, electricity and even security for themselves, all becausethe government falls short of expectation in that regard. The problem is not that thereis no infrastructure to sustain water supply in the country, but that there is no knownplan or, if there is, it has not been implemented, to maintain the structures already inplace to supply water appropriately. There are scores of dams and reservoirsscattered all over the country. What seems to be missing right from when these damswere constructed was a working policy on how they are to be maintained. This lackof maintenance has seen to the dilapidation of those multi- million dollar projects and the strife thereof in the purposes for which they were originally designed to serve, including the most important need which is providing water for residents in the states they are located and beyond (Leadership 2017). Today, most state governments have no functioning water boards. Where the facility still exists, it is operating below capacity because of lack of maintenance. This has, in turn, gone onto affect several other public establishments like hospitals and schools. In this study, the pumping pipeline system will be analyzed to determine the likely parameters that will affect pipeline performance efficiency.

STUDY AREA

The Ajalli Water Scheme is geographically located in Ngwo, Udi Local Government Area of Enugu State Nigeria and lies between Latitude 6°25´N - 6°29´Nand longitudes 7°23´30´´E - 7°25´30´´E (figure 1.1). The Ajalli water scheme was commissioned in 1985. This scheme was developed to supply Enugu urban and environs. Though this supplies Enugu metropolis, it equally supplies other satellite towns of Ngwo, Emene, Iji-Nike, Edem Nike, Nsude and Eke (figure 1.2). The source of water to this scheme is Ajalli River at Owa-Imezi town at Ezeagu Local Government Area, about 38km west of Enugu. The design capacity of this scheme is about 77,000m3 /day and about 80% of water is meant to be distributed to the service areas of Enugu and environs. This scheme basically is comprised of: the intake and weir, Abonuzu headwork, trunk and rising mains, booster station and reservoirs. The water is abstracted through weir and intake structures. It is then liftedto the Abonuzu Headwork where the treatment is done and from there the water is pumped to the Nsude break pressure tanks. After this, the water is then allowed to flow by gravity through a number of reservoirs into the distribution network. The sub-division of the Ajalli water scheme are thus: The weir, intake structure, wet pit, seven vertical pumps with control panels and a 2300KVA generating set as alternative power source. The weir is constructed just downstream of the intake as afree flow concrete structure. However, during the flood period, a gate is used as floodregulator. The radial gate completes the span of the weir across the width of the river.There is a lift pumping station that houses the seven vertical pumps. These pumps have a delivery capacity of 580m^3 /hr. each of raw water to the Abonuzu Headworks,some 5.55km away. The intake can accommodate up to 3,500m^3 /hr. but under design condition, only five of the pumps run simultaneously with total discharge of69, 600m^3 /day, while two are on standby. The water from the pumps moves down from the wet pit to the Abonuzu headwork via a nominal diameter -DN- 1000/900mm ductile/steel pipeline.

Topographical details of the Study Area

The table 1.1 below indicates the drainages, natural ground from the Ajalli river weir and intake (sump) to the flash mixer from where the treatment starts.To capture the data well, the elevations have been taken at a uniform difference of chainage of 30m and at locations of bends and other important fittings and appurtenances -table 1.1. The plan and longitudinal section of the pipeline (pipelineprofile) for surge analysis are drawn as shown in figure 1.1

Table 1.1: Elevation of the Natural Ground Level with Chainage along the existing Raw Water Transmission Pipeline from the Ajalli River to the Flash Mixer at the High lift.

3720	250.28	4350	258.76	5010	285.79
3750	250.67	4380	259.17	5040	287.90
3780	251.05	4410	260.17	5070	289.66
3824	251.41	4440	260.67	5100	291.71
3840	251.93	4470	261.51	5130	293.35
3870	252.00	4500	259.25	5160	295.33
3900	252.58	4530	263.64	5190	295.33
3930	252.66	4560	264.18	5220	299.36
3960	252.96	4590	264.79	5250	301.01
3990	252.70	4620	265.69	5280	303.30
4020	253.08	4650	266.82	5310	305.29
4050	252.87	4680	268.12	5340	306.0
4080	252.73	4710	269.05	5370	306.51
4110	253.46	4740	270.27	5400	306.25
4140	254.02	4770	271.88	5430	309.27
4170	254.17	4800	273.37	5460	310.73
5490	309.70				
5527	312.65				
5550	312.73				

Fig 1. 1: The plan and longitudinal section of the pipeline (pipeline profile) ofthe study area.

Data Source: Drawing office at the office of Executive Director, EngineeringServices Department, Enugu State Water Corporation.

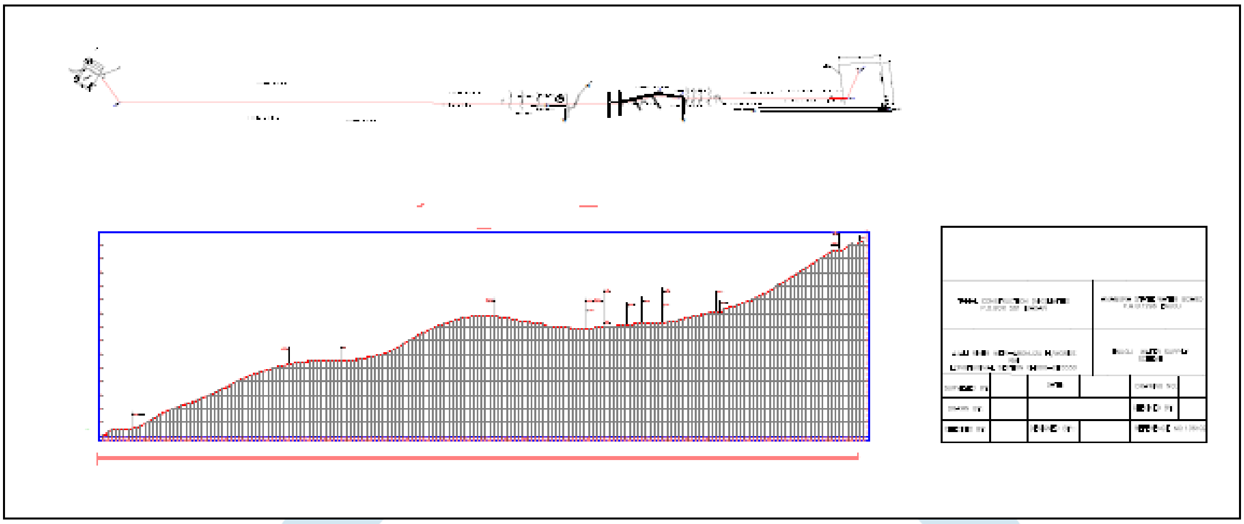


Figure 1.2 and 1.3 show the locations of Udi LGA and the Ajalli water worksin the Udi LGA.
Figure 1.2: location of Udi LGA in Nigeria

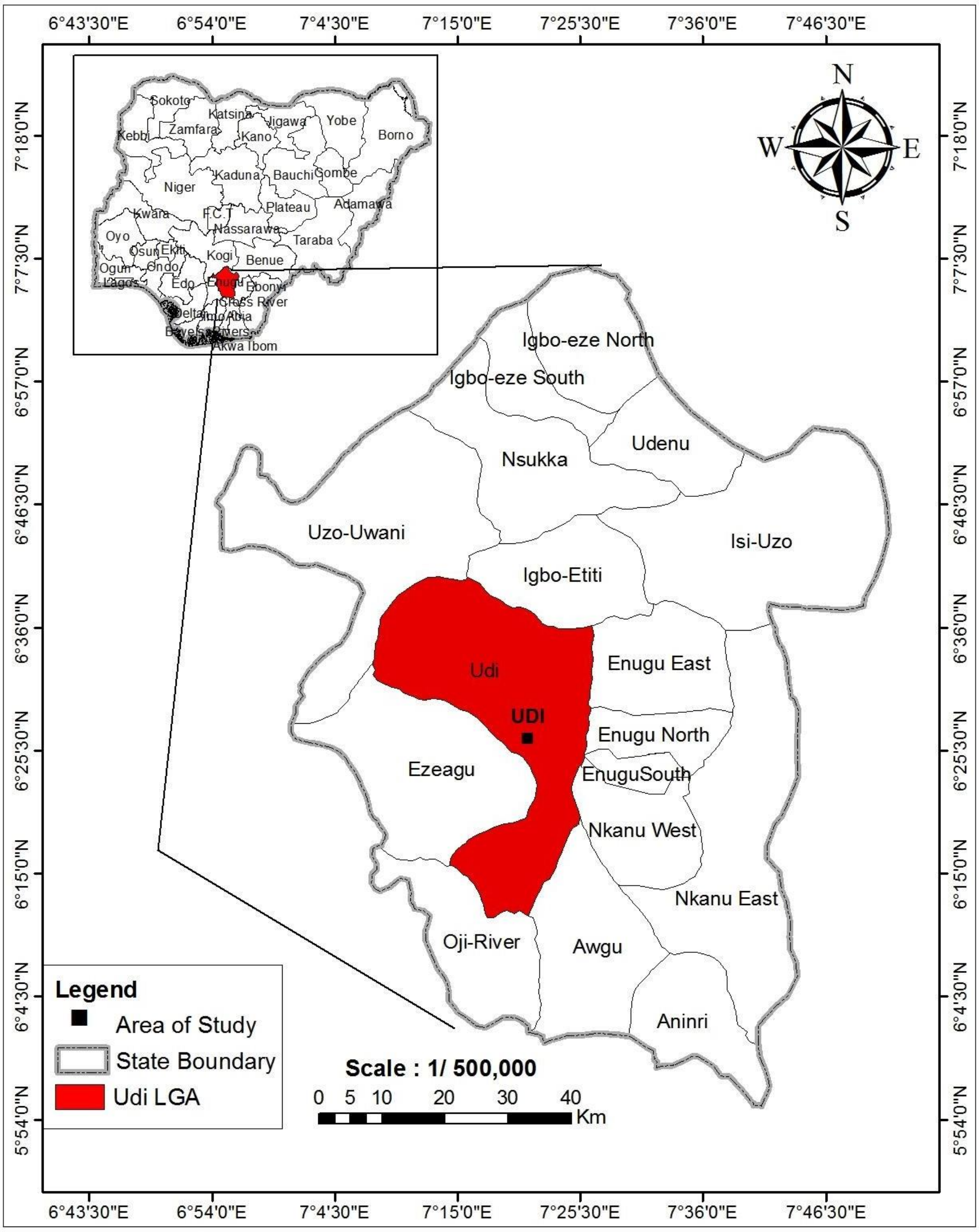
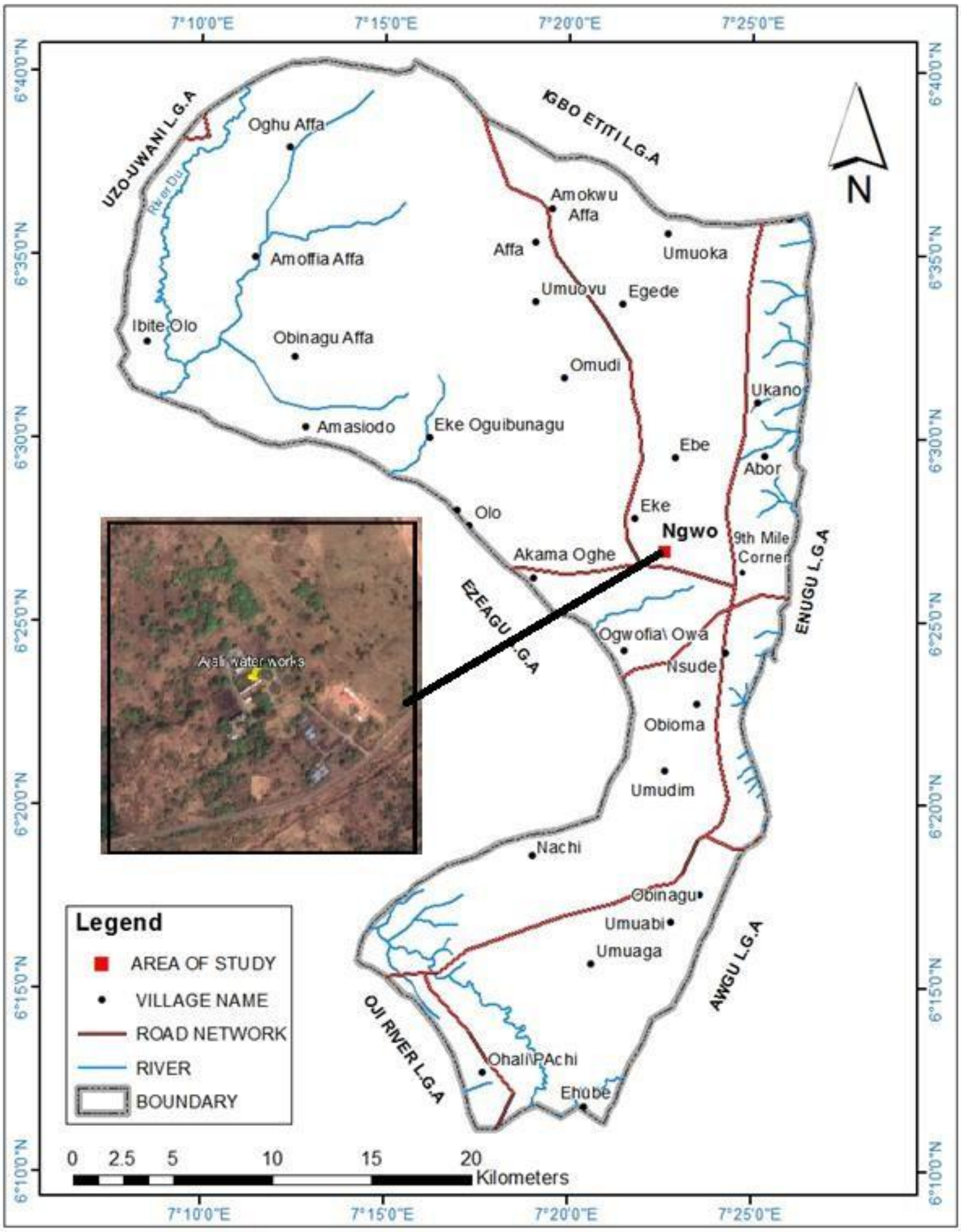


Figure 1.3: Location of Ajalli water work in the Udi LGA.



Materials and Methods

This chapter focused on methods adopted in data collection and analysis. It also dealt with the engineering methods applying in the work. In the same vein, thedescription of the method and instruments that was used for data collection and presentation were highlighted.

The study adopted experimental research design approach. The experimentaldesign was adopted because it involves monitoring of water velocity and pressure inthe pipeline using different number of pumps , maximum seven (7) pumps which translate to using varying flow rates. As the number of pump running increases, thedischarge is increased and the pressure surge is analyzed to determine the magnitudeof the pressure surge and velocity at the key points along the pipeline without as well as with the existing anti-hammer protection devices which will be compared with the allowable or withstood test pressure of the pipe. The thickness of the pipeis also checked under varying flow conditions to compare with the allowable wall thickness of the pipe since thickness governs the design of pipe against surge. The time (t) it takes a wave when perturbation is generated electrically to travel from chainage 00+00 to the flash mixer tank (boundary condition) at chainage 5+550m and back (t=2L/C), where L is the length of pipeline and C is the wave velocity is compared with pump ramp-up or ramp-down time of the electrical equipment (pumpstart and stop time) to provide a decision support system (DSS) for operators of thewater scheme as regards the safety of the electrical equipment and its associated pipeline system.

Sources of Data

Two data sources were used; the secondary data source and the primary datasource.

Secondary data source

This include data that were collected both from published and unpublished sources such as textbooks, journals, magazines, newspaper, internet, online publication etc.

Primary data source

This includes data that were generated from the experimental survey. The experiment survey was adopted on the field to record the velocity and pressure at different starting/stopping of pumps conditions. The Ajalli raw water Transmissionpipeline map of the study area, the construction drawings, water consumption records, pipe rupture records and other water supply network related information, the physical information of the pipe network were also collected from Enugu State Water Corporation.

Grouping of data for convenience of surge analysis

For the purpose of clarity of this surge analysis of Ajalli pumping water pipeline, thedata required for the analysis is grouped into four:

Geometric group

In this group, the geometrical parameters such as the pipeline outside diameter(D), wall thickness (t) and the Hazen-William friction coefficient (C) are listed andare used to calculate the friction losses in the pipe system.

The pipe's diameter and thickness specification is quite important in order to calculate the pressure wave speed required for the water hammer analysis.

Longitudinal profile group

In this group, the values of chainages and elevations for the pipeline's longitudinal profile are tabulated in excel format.

Transient Analysis Parameters group

The required water hammer calculation parameters are defined in this group.

Here, the data required are:

1. The pressure wave speed.
2. Hydraulic transient simulation
3. The number of key points on which the analysis is performed.

Maximum Allowable pressure in pipes group

This is the ability to plot the pipeline's maximum allowable hydraulic grade (piezometric head) envelope accordingly to the rating of pressure of the used pipes.

It is possible to indicate in this group for each section between control points, the rating pressures allowed for the pipe under the different analysis. In this case, we seek the mechanical and geometrical pipeline properties in an easy and very practicalway.

Population of the Study

Ajalli Water Supply Scheme is owned by Enugu State Government, operatedby Enugu State Water Corporation and has a design output of 77,000 m^3/day. The scheme has principal components such as intake, Low Lift Pumping Station, Treatment Process and High Lift Pumping Station. This study analyses pressure surges at the potential locations along the raw water transmission pipeline experiencing frequent pipe bursts from the low lift pumping station to the flash mixerthank at a distance of 5550m. All the Ajalli components and specification information are obtained from Engineering department, Enugu State Water Corporation, Headquarters, Enugu, The Low Lift Pumping Station comprises the following components and specifications:

Pump: 7 identical vertical multi-stage pumps operating 5 duties and 2 stand by.The pumps are currently peerless and Adoli Pumps with specifications as follows: RPM – 1480, head – 178m, flow rate – 580 m^3/hour, Power – 400kW, and efficiency - 80%. These pumps were supplied by Nasting Engineering Limited and Eauxwell Nigeria Ltd. respectively in the year 2010 and have the same specification with the scheme's original Betbow pumps at the inception of the scheme in 1985.

Transmission pipeline: The pipeline has a total length of 5550m comprising3,650m length of ductile iron pipe of 1000mm diameter and 1,900m length of steel pipe of 900mm diameter. The thickness of ductile iron and steel pipes is 7mm each.The transmission pipeline has design/test pressure of 41.5 bars (4150m).

Surge Chambers: The water transmission pipeline has 2.0m^3 and 4.0m^3 surgechambers with double orifice air valve on top of each situated at chainages 1+350mand 2+850m respectively along the pipeline.

Sampling size

Random sampling was employed in the study. The selection of seven (7) stratified random sampling pumps were applied to represent the entire population of the study.Seven (7) pumps were used to monitor the surge along (5550m) Ajalli raw transmission pipeline.

Sample and Sampling Technique

The setup consists of intake sump housing seven vertical pumps, 5550m rawwater ductile/steel pipeline with air valves, non-return, butterfly valves, surgechambers, pump pressure gauges from the intake sump to the flash mixer thank where raw water treatment starts.

The seven raw water pumps have their respective starter panels, some equipped with soft start and thyristors and some with star delta. The function of thesoft starter is to reduce the surge generation effect by gradually allowing the control voltage of the pump to start (more time allowed), while the function of the thyristoris to control electric power and current by acting as a switch. The star delta takes less time to start and increases the surge effect and this should be discouraged if wereally wish to avoid excessive pressure surges.

The experimental method involves putting on one pump and calculating the velocity and Pressure at the key points along the pipeline, the remaining pumps areadded one by one till the six pumps are running.

The project is a 5550m long Ductile iron/ steel raw water transmission pipeline – Ductile iron 3,650 and steel 1,900 designed for an ultimate capacity of 83,520 m3/day.

The profile of the pipeline is shown in figure 1.1. Water is being pumped fromthe intake sump at the low lift pumping station to a semi underground level raw water receiving flash mixer tank with a maximum water level of 4m from the floor.The center line of the discharge and of the main at the tie-in to the flash mixer tank is 1.5m below the tank floor.

Key stations and their elevations along the pipeline are as shown in figure 1.1The objective of the surge analysis is to determine the surge pressure heads
along the key stations with varying flow rates/ number of pumps in operation until all the pumps are in operation.

The key determinant of D1/steel pressure design is the internal pressure. Theexact pipe dimensions are required to determine the flow velocity while the pipelinemechanical properties are required to determine the wave velocity.

The total pressure in the pipeline at any point is the sum of the static head, thefriction and the pressure rise (internal pressure/surge pressure) as a result of suddenvelocity changes.

Instrument for Data Collection

The following tools were used to collect data for surge analysis: Tape for measuring the length of pipeline and size of flash mixer; vernier caliper was used to measure the thickness of the existing pipe to confirm the thickness stated in the as"built drawing" and pressure gauge to measure the output pressure of the pump.

Method of Data Analysis

The problem of surge phenomenon in Ajalli water system is associated with pumps as a results of frequent power failures and hence was analyzed as a result of power failure of pumps or pump trips.

Power failure of pumps, sudden valve actions and operations of automatic control systems among others may cause water hammer problems in a liquid servicepipelines or water delivery systems. These operations (events) normally generate steep pressure increases or decreases otherwise known as pressure variations in thepipeline which propagates over the associated pipeline system by converting kineticenergy of the fluid to potential or pressure energy until the fluid comes to steady state again due to the action of friction.

The maximum or increasing pressure propagation may cause over pressure problem, while the minimum, negative or decreasing pressure propagation may leadto vacuum problem and sometimes include secondary pressure upset due to vapor cavity formation and collapse (vaporization and condensation) at high and low points in the systems, etc.

The problem of surge is solved by formulation of mathematical model whichconsists of a set of partial differential equation of hyperbolic nature which are transformed by the method of characteristics into ordinary differential equations which are solved by the predictor-corrector, finite difference methods among others.The method of characteristics is used to find the pressure increase and decrease alongthe pipeline at various finite times and distances and hence help decision makers todecide the kind of anti-hammer protective devices required in the water main for safety operations and optimal performance of the associated pipeline system.

In most recent times, interactive commercial software is developed thatprovide user to draw the network structure of pipelines with components or appurtenances like valves, pumps, reservoir, etc. and also obtain the results in tabularor graphical format. This allows the operators of the pipeline system or users of thesoftware to not only detect faults but also provides information about which anti-surge devices are to be installed in order to increase the life expectancy of the associated water supply delivery systems.

In Equations 7 and 8, H denotes the piezometric head at the centerline of thepipeline at location x and time t, V is the average velocity of flow, D is the pipe diameter, f is the friction factor in the Darcy-Weisbach formula, x is the distance along the centerline of the pipe, α is the angle between the horizontal and the centerline of the pipe, taken as positive for the pipe sloping downwards in the direction of positive x, g is the gravitational constant; and a is the celerity of the pressure surge, i.e. the velocity with which the surge is propagated relative to the liquid. The positive direction for V coincides with that for x. The Equations 7 and 8 are a simultaneous pair of partial differential Equations which relate the two dependent variables, H and V.

However, this method is beyond the scope of this study since it will not be applied in this study, rather analytical solution is obtained by the help of Willian Hezan equations supported by water hammer calculator.

Surge Analysis Assumption

- The flow is a one directional model
- The pipeline is in full flow condition at all times.
- The elasticity of the pipe wall as well as the compressibility of the fluid are not taken into consideration. The maximum surge pressure will be equal to an instantaneous stoppage of flow at full velocity.

The existing anti-hammer protection devices are assumed to be fully functional during the analysis of the pipeline with anti-hammer protection devices.
All the seven pumps are operating at 580m^3/h at 178m total dynamic head.
Both the 1000mm diameter ductile iron and 900mm diameter steel pipelines are hydraulically connected.
In this project, the analysis was carried out at the identified locations along the pipeline at varying flow rates/number of pumps in operation using the data collected from Enugu State Water Corporation. The analysis has been done manuallyusing Microsoft excel with the help of Hazen Williams formula, taken from American Water Works Association (AWWA) Manual. The table below shows thedata extracted from "as built" drawing of Ajalli raw water pipeline.

Table 2- Data extracted from "as built" drawing of Ajalli raw water pipeline.

	ITEMS	RAW WATER PUMPING MAIN	REMARKS
	Length of Pumping Main	5550m	Profile data
	Material of Pipes	(1.) Ductile iron Pipes with cement mortar in lining and out coating fromchainage 0+00m to 3+650m. (2.) Mild Steel Pipes from 3+650m to 5+550m with the same in lining and out coating	Geometric data
	Internal Diameter of pipeline	1000mm for ductile iron pipe and900mm for Steel Pipe	Geometricdata
	Thickness of both pipes	7.10mm	Geometric data
	Pump Discharge Head	178m	Profile data
	Maximum flow rate of each pump	580m3/hr.	Geometric data
	Pressure wave Velocity	2241m/s from chainage 0+00 to3650m and 2174m/s from chainage 3650m to 5550m	Transient Analysis data
	Laying condition	Under Ground	Profile data
	pump Velocity	1480 RPM	Geometric data
	Pump power	400 KW	Geometric data
	Pump type	Vertical Turbine Type	Geometric data
	Number of key points	14	Transient Analysis data
	Hazen-William friction coefficient (C)	140	Geometric data

Source: Engineering department, Enugu State Water Corporation, Head Quarters,Enugu.

Flow characteristics of Ductile iron and steel pipe

The flow characteristics via cement-mortar-lined ductile iron and steel pipe is usually computed by widely used Hazen-Williams formula (ANSI/AWWA C104/A21.4. Denver, Colo.). in metric units

$$Q = 6.756 * 10^{-3} * C * D^{2.63} * H^{0.54} \text{---} (9)$$

Q = discharge in m
C = Hazen- William flow coefficient.D = actual pipe inside diameter in m.
H = head loss, m/1,000m

A = cross sectional area of pipe in m^2

Determine the maximum flow velocity.

$$V_O = \frac{Q}{A}$$

---(10)

$$A = \frac{\pi d2}{4} ----------------------(11)$$

Where d is pipe inside diameter

Determine pressure wave velocity (a) (Wylie, et al.,1993):

$$a = \left(\frac{k}{\rho}\right)^{0.5}\left(1 + \frac{k}{E}\frac{D}{t} * C_1\right)^{-0.5} ----------------(12)$$

Where:

D= Internal diameter of pipe

K = bulk modulus of liquid in the pipe. = 2.67 x 108 kg/m2ρ= density of the liquid

E = young modulus = 1.7 x 1010 kg/m2

μ = Poison's ratio of the pipe walls material Ct = equivalent thickness of the pipe wall and C1 is a factor which accounts for different condition of restraints of the pipe.

The types of axial restraint commonly encountered in Engineering of thisnature are:

Case a: the pipe is restrained throughout its length against axial movement =C1 = 1-u^2

Case b: The pipe has frequent expansion joints throughout its movement =C1 = 1

Case c: The pipe is restrained at its upstream and only C1 = 5/4 -u

In most engineering applications case a or b or some conditions intermediatebetween them would apply.

For the case of water in a Steel/D1 pipe, (Wylie, et al.,1993):

$$a = 1438\left(1 + 0.01 * \frac{e}{d} * C_1\right)^{-0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(13)$$

Determine the surge pressure (internal Pressure)

In a water transmission pipeline, the amplitude and location of the surge envelope will often be analyzed by computer. In this study, it has been assumed thatthe maximum surge pressure will be equal to an instantaneous stoppage of flow at full velocity.

The pressure rise resulting from instantaneous velocity change in Ductile/steelpressure pipes can be determined using Joukoski equation as shown below (Wylie, et al.,1993):

$$\frac{Vo * a}{g} --(14)$$

where Vo = maximum velocity change m/s

wave velocity m/s

Acc. Due to gravity = m/s^2

Pressure surge m

Determine the friction loss under full flow condition. The Hazen –William equation is convenient to use. Metric (Wylie, et al.,1993):

$$Friction = \frac{10.7*L*Q^{1.852}}{C^{1.852}*D^{4.87}} \quad \text{-----(15)}$$

Where f frictional pressure drop,

Q the volumetric flow rate m3/s

L length of pipe, m

D the pipe internal diameter, m

C factor or Hazen – William constant for the pipe.

C values ranges from 90 to 140 depending on the diameter and velocity. In this study,C is taken as 140

Determine the pressure at key locations in the pipeline underunsteady full flow condition.

Note: The pressure P, at any point in the pipeline is the sum of the static headas a result of difference in elevations, the friction loss and the internal pressure as aresult of change in the fluid flow velocity

$P = Hstatic + Dh\ Hamme + Dh\ Friction$..........(16)

Determine Design Pressure Conditions as per AWWA Guidelines.

1.5times maximum sustained operating head
1.5 times maximum pipeline static head
Sum of maximum sustained operating head and maximum surge headSum of maximum pipeline static head and maximum surge head Design Pressure (Maximum of above).

Determine the minimum thickness of the pipes under varying flowconditions using Design Equation as per ISO 10803 for thickness calculation ofDI pipes, Manual on Water Supply and Treatment (Third Edition), Central Public Health and Environmental Engineering Organization (CPHEEO), Ministry of Urban Development, New Delhi, May 1999.

$$t_1 = \frac{p(D - t_1)SF]}{2Rm} \dots\dots(17)$$

P=Internal Pressure (in Mpa)SF=Safety Factor

Rm=Minimum tensile strength (in Mpa)D=Outside Diameter of pipe (in mm) t_1=Minimum thickness required (in mm)

Compare the pressures at key points under varying flows conditions withpipe nominal or operating or test pressures and the calculated minimum **thicknesses with the wall thickness of pipe as per IS 8329:2000 (Ct) or applicable standards and draw your conclusions on the safety of the pipeline operating under these conditions.**

The time (t) it takes a wave when perturbation is generated electrically totravel from chainage 00+00 to the flash mixer tank (boundary condition) at chainage 5+550m and back (t=2L/C), where L is the length of pipeline and C isthe wave velocity is also compared with pump rampup or rampdown time of the electrical equipment (pump start and stop p time) to provide a decision support system (DSS) for operators of the water scheme as regards the safety of the electrical equipment and its

associated pipeline system.

As earlies said, this analysis has been carried out manually in Excel sheet andwith the help of Hazen William formula taken from AWWA manual. The result is displayed both in tabular and graphical formats with the help of Excel software.

DISCUSSION OF FINDINGS, CONCLUSION ANDRECOMMENDATION

Discussion of Findings

The plan shows the spatial location of surge incidences along Ajalli raw watertransmission pipeline. The following are three potential surge locations. 0+000m chainage: the surge occurred at non return valve location at 170 m of elevation. At 1+350m chainage, the surge occurred where 2.0m^3 surge chamber is located and at 2+850m chainage, the surge occurred where 4.0m^3 surge chamber is located. The experimental method involves putting on one pump and calculating the velocity andPressure (Table 4.1). The remaining pumps are added one by one till the six pumpsare on. The experimental study of the pressure (Table 4.2), revealed that when fourpumps are in real operation, the pipeline is completely safe from the surge pressuregenerated but is not safe at the above mentioned locations when five and above number of pumps are running at the same time. This implies that the pipeline can operate safely and efficiently when five pumps are operating under 100% efficiencyof the pipeline. It is also revealed that if the pipeline is to operate under safety and efficient condition, the surge pressures are not supposed to exceed the withstood testpressure. But in real life, the pipeline cannot operate at 100% efficiency and considering that the test pressure is about 1.5 times the static or operating pressure, the pipeline could be assumed to operate at 80% efficiency. In that case, the admissible pressure should be 80% times the test pressure, equal to 80%*415m=332m. This implies that the pipeline can operate safely and efficiently when all six pumps are running at the same time as regards pressure transients andis not safe when more than three pumps are running at the same time as regards minimum thickness. The figure (4.4) also revealed that since the pipeline is designedfor six pumps to run at the same time, this 7.10mm thickness of the existing pipe isnot meeting the minimum thickness required for safety operations. This could be adduced as one of the factors responsible for the frequent failures of the pipeline andits associated mechanical and electrical machineries as well the cause of persistent water scarcity in Enugu metropolis. The minimum thickness calculations when one,two, three, four, five and six pumps are in operation are 4.727mm, 6.028mm, 7.201mm, 8.375mm, 9.548mm and 11.768mm respectively, while the actual thickness of the pipeline is 7.10mm as per data available. This implies that the pipeline can only operate safely and efficiently when only three out of the six pumpsare running at the same time without optimization. If the pipeline is to be optimizedeconomically, four pumps can run safely and efficiently on the condition that the pipe with about 8.40mm thickness can be laid as from chainages from 00+00 to 00+210. According to field experience, the 1000mm/900mm ductile iron/ steel pipeline has been found to be safe when five pumps are in operation and unsafe as per surge pressure generated when more than five pumps are running at same time.Since six pumps are meant to operate to meet the capacity utilization of the water treatment plant (WTP) as well as the water requirement of Enugu Metropolis, the pipeline thickness can be varied segment by segment to meet up this criterion for thepurpose of best economic choice of pipe dimension ratio (DR). But the study has revealed from the analysis that the operation of the system must satisfy the over pressure system, thickness as well as the electrically induced surge transient allowances specifications. On that framework, a minimum thickness of 10.8mm is recommended to eliminate all aspects and magnitudes of surges in the system in addition to provision of additional anti-hammer protective device at strategic location. This thickness is also considered very economical in relation to the existingthickness used in the main transmission and distribution systems within Enugu Metropolis which ranges up to 12.5mm.

Further analysis carried out with respect to the electrically induced transients(Power loss) revealed and affirmed that the period of vibration upon power loss is calculated to be 5.028 seconds which is less than 10 seconds and 15 seconds respectively for pump ramp-up and ramp-down (pump manufacture's installation and operational manual surge allowance provision). The aforementioned shows apparently that the manufacture's minimum standard surge allowance is sufficient (10seconds > 5.028 secs) and that the critical time for pump ramp-up is 10secs. Aslower ramping would diminish the surge pressure.

Moreover, it appears that the existing anti-water hammer protecting devices are not adequate for efficient hydraulics of the raw water pipeline systems.

Conclusions

The Ajalli raw water pipeline has been analyzed as per the design andhydraulic data available especially in the as "built drawing". The calculatedmaximum pressures including surge at key points along the pipeline when one, two,three, four, five and six pumps are in operation are about 193.944m, 240.827m,287.711m, 334.595m, 381.478m and 428.362m respectively, while the test pressureas per the data available is 415m.This implies that the pipeline can operate safelyand efficiently when five pumps are operating under 80% efficiency of the pipeline.

Similarly, the minimum thickness calculations when one, two, three, four, fiveand six pumps are in operation are 4.727mm, 6.028mm, 7.201mm, 8.375mm, 9.548mm and 10.768mm respectively, while the actual thickness of the pipeline is 7.10 mm.as per data available. This implies that the pipeline can only operate safelyand efficiently when only three out of the six pumps are running at the same time without optimization. If the pipeline is to be optimized economically, four pumps can run safely and efficiently on the condition that the pipe with about 8.40mm thickness can be laid as from chainages from 00+00m to 00+210m. According to field experience, the 1000mm/900mm ductile iron/ steel pipeline has been found tobe safe when five pumps are in operation and unsafe as per surge pressure generatedwhen more than five pumps are running at same time.

Furthermore, the pump manufacture's installation and operational minimum surge allowance provision is sufficient enough to obviate the risk of water hammer in the valves and pipework when an electrically induced transient (power loss) occurs.

Recommendation

Proper training should be conducted to educate the operators on the safety condition of running water pumps in the Ajalli Waterworks Station.

- The 1000mm ductile iron pipeline with at least 10.8mm thickness from chainage 00+00m to 5+550m should be recommended for the raw water transmission system to eliminate all aspects and magnitudes of surge pressures in the system arising from under thickness design if the system is tobe safely, efficiently and maximally operated as designed-six duty and one stand by.
- Moreover, it appears that the existing anti-water hammer protecting devices, $2m^3$ and $4m^3$ are not adequate for efficient hydraulics of the raw water pipeline systems and should be recommended to install one more $6m^3$ surge chamber or air vessel and or zero velocity valve at chainage 00+210m or pump discharge end with an isolation valve which will allow the smooth start up andstopping of the centrifugal pump without any complicated and expensive maintenance. This is discernible from the calculated value of ±0.073m head surge pressure difference when analyzed the pipeline system with and withoutthe existing surge protection devices installed at different locations along the pipeline.
- The damaged trust bocks anchoring the pipeline and its appurtenances duringprevious water hammer events should be properly repaired to provide restraints against pipeline longitudinal or axial movement which was one of the condition for the analysis.
- Finally, I affirm that if all these recommendations are implemented especiallyas Ajalli Water Scheme is slated for rehabilitation under the Agence Franchaise de Development (AFD) support to 3rd National Urban Water Sector Reform Project, the system will be operating safely, efficiently and maximally and the persistent challenges of scarcity of water supply experiences in Enugu Metropolis for the past years will be a thing of the past.

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