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Evaluation of Influence of Hydraulic Transient Phenomenon on the Flow of the Main Pipeline of Moamba Village Water Supply System

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ABSTRACT

The water supply system (SAA) in the Moamba village has suffered frequent leaks and ruptures in the main pipeline, compromising the activities of users as well as losses to the system. The aim of this study was to assess the influence of hydraulic transient (HT) phenomenon on the flow of the main water main in Moamba village water supply system. The following parameters were checked: (i) physical parameters in terms of Nodes (N), by length of each connection; stretches, by defining the pipe wall, internal diameter, celerity and suction cups; and (ii) the profile of the raw water pipeline, through manual excavation, water supply time in working hours, and checking the operation of the pumps, with the aim of analyzing the pressures acting on the system. Simulations were carried out using Allievi *software*. The results of the physical parameters showed celerity with maximum pressures in the permanent regime at the inlet of the pipe of around 97.64mca, *and a* minimum of 5.50mca at the outlet; no HT, the overpressures were close to the pressure line in relation to the permanent regime, however, there was a single case of -21.*08mca* representing a risk to the pipe. As a solution, suction cups, pressure regulating valves and hydropneumatic reservoirs were tested, which proved to be effective in smoothing out the pressure envelopes, but did not solve the problem of underpressures operating below the water vapor pressure.

KEYWORDS: Hydraulic transient, pressure, physical parameters, permanent regime.

I. INTRODUCTION

The hydraulic system can be understood as a set of associated physical elements that pass hydraulic fluid through pipes as a means of transferring energy, allowing the transmission and control of forces and their movement (Furst, 2010).

According to Martins (2014), the water supply system (WSS) and its distribution is made up of a set of infrastructures, given that, according to Silva (2019), water is essential for sustaining life, in addition to its support character in economic activities and development for various purposes such as drinking, consumption, industry, irrigation, among others. Figure 1 illustrates the water supply scheme.

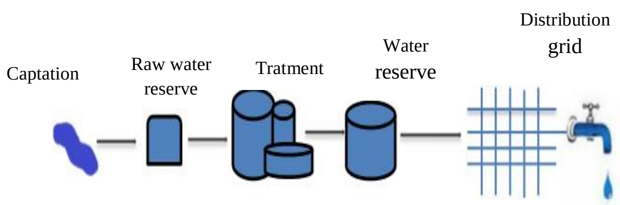

Figure 1. Conceptual diagram of a WSS for human consumption.
Source: Martins (2014).

Hydraulic transient (HT) is the oscillation of pressure, which can be above or below the normal operating value of the forced conduits. HT usually occurs when an intervention is made on a device in the network, such as pumps and valves (BARROS *et al.*, 2019). This phenomenon occurs in the variation from the permanent to the transient regime.

According to Cesteiro (2008), it is important to analyze the effects of HT on hydraulic systems such as: (i) pumping and gravity water supply or wastewater pipelines; (ii) hydraulic circuits; (iii) irrigation systems; (iv) fluid transport pipelines, including fuel and chemical pipelines, among others, because any interruption in flow can cause pressure variations, which can be lower than atmospheric pressure, thus causing the formation of air bubbles and subsequent damage to the pipe. In this sense, the extreme pressure variation is called underpressure, and if it is high the shear stresses cause the pipe to rupture due to the vibrations the walls suffer.

When the system operates in a permanent flow regime and is altered over time, the velocity and pressure values vary until new flow conditions are reached, resulting in new flow variations. Thus, the flow rates reached can cause ruptures in the WSS, influencing the quantity of water to be supplied and also its quality through the entry of impurities into the pipeline, hence the importance and need to study this phenomenon.

II. METHODOLOGY

This study was carried out at Moamba village (figure 2), at the Moamba Water Supply System (SAA). The Moamba village is located in the North of Maputo province, at 24° 27' and 25° 50' South and 31° 59' and 32° 37' East. Its geographical boundaries are the Massintonto River to theN, which separates it from the district of Magude, the districts of Boane and Namaacha to the South, the districts of Manhiça and Marracuene to the East and South Africa to the West (MAE, 2014).

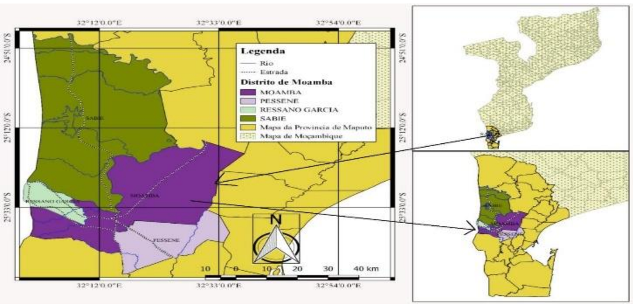

Figure 2. Geographical location of the study area.
Source: Authors.

2.2 *Determining the pipeline profile*

For the *design of* the pipeline profile, surveys were carried out of the components that make up the structures of the WSS in terms of the raw water pipeline, the volume of water passing through and the daily supply time over a total length of 3470m.

2.3 *Raw water pipeline*

In order to determine the type of raw water pipeline, the descriptions on the buried pipe were compared using the Cezan Catalog for 250mm PVC (High Density Polyethylene) pipes, and manual excavation using a shovel and pickaxe to a depth of 1. 50m was used.50m, in accordance with Decree no. 15/2024 of June 15, Regulations for Public Water Distribution and Wastewater Drainage Systems (RSPDADA, 2004), which states that the minimum laying depth for pipes should be between 0.60 and 1.00m, measured between the upper outer generatrix of the pipe and the level of the sidewalk, According to CRP (2013), pedestrian zones are the perimeter within which access to motor vehicles is limited to a certain category of users and access is controlled by signs and/or mechanical or electronic means of access control, which may increase depending on the demands of heavy vehicle traffic, infrastructure, soil type, among other factors. Taking into account operational and personnel safety needs, the width of the trenches for laying the pipes should be 0.85m, and the width used to carry out the survey and length is 6.00m, which corresponds to the length of one 250mm PVC pipe (figure 3).

Figure 3. Raw water pipeline of the Moamba Village SSS
Source: Authors.

2.4 *Daily volume of water from the pipeline*

The raw water flow of the water main was determined using a monthly control table with data from the volume of the previous reading recorded and the volume of the current reading subtracted during the daily reading at the macro-meter installed at the outlet of the system's catchment. Expression 1 was used to determine the water flow.

$$Q = \sum \frac{V_f - V_i}{t} \quad (1)$$

Where: Q - Flow (m^3/day); V_f - Volume of previous reading (m^3); V_i - Volume of current reading (m^3); t - Time (days).

2.5 *Hydraulic machines*

The hydraulic machines installed in the system were identified by looking directly at the catalogs that provided all the information on their operation (Figure 4).

Figure 4: Characteristics of hydraulic machines
Source: Authors.

2.6 *ALLIEVI Computational Method*

The following programs were used: (i) GOOGLE *earth* in order to obtain a drawing of the projection line of the elevations of the pipeline, and the respective devices installed, (ii) ALLIEV I, which was simulated in 2 regimes, first considering the permanent regime, and finally the transient regime. To run the program, it is necessary to configure the model by coupling the Nodes, Stretches, flow control structure, reservoirs and pumps in the SAA.

1) Nodes

The Nodes (N) are elements that serve to join or converge other elements, requiring the introduction of elevations that varied from 76m (N1) to 116m (N22) and hydraulic devices, such as the supply pump (N1), shut-off valve (N1), check valve (N2, N3, N10 and N11), reservoirs of varying levels (N19 and N22) and By Pass (N6 and N21). For this study, a total of N22 obtained from the pipeline profile were recorded using the GOOGLE *earth* program.

2) Excerpts

With a total of 12 sections (T), these are the elements that define the characteristics of the pipes, such as the length between the nodes (every 60m), the thickness of the pipe wall and the type of material where cast iron was installed at the beginning of the pipeline and in the rest of the section PVC pipe with an internal diameter of 239mm, the speed (calculated by the ALLIEVI program) and three suction cups installed one in T5 and two in T8 respectively.

3) Flow control structures

The flow control structures are made up of valves of various types and the system's pressure drop points, such as taps, spillways and others. Butterfly-type control valves were configured for the simulation, with a maneuvering time for closing of 50s, coinciding with the field test time.

4) Reservoirs

For the simulation, 2 large reservoirs were set up at the upstream catchment point and a small reservoir downstream, similar to what was found in the field.

5) Pump

For the configuration of the pumps, the elevation, maneuvering curve, types of valves and moments of stop or start were taken into account. For the operation, two pumps were used, with check valves (with a run-stop interval of 10s for simulation purposes) and without bypass. Figure 5 shows all the elements of the Moamba Village WSS coupled to the hydraulic systems simulated by ALLIEVI.

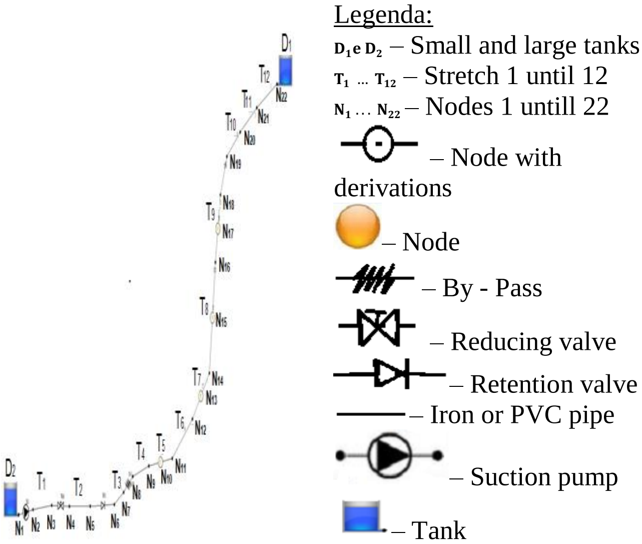

Figure 5 - Profile of the main water main integrated with the hydraulic systems .
Source: Authors.

III. RESULTS AND DISCUSSION

3.1. Permanent operation

The results of the pressures (P) in relation to the height (H) at each Node showed pressure values ranging from 5.50 to 97.64mca, while the manometric height showed ranges from 76m (N1) to 116m (N22) with the highest pressure values (97.64mca) observed at N1, dropping to N2 (88.58mca) and N5 (87.16mca).64mca) was observed at N1, dropping to N2 (88.58mca), N3 (88.38 mca), N4 (87.61 mca) and N5 (87.16mca), with the lowest value at N22 (5.50mca). High pressure values (173.64, 172.58, 172.38mca) were observed in N1, N2 and N3, respectively. Lower values were seen in N18 and 19 (84.00mca), respectively. These observed variations are justified, according to Mattiello (2017), by the fact that they are located at high pressures at the initial node at the outlet of the pumping system. This is because, under permanent conditions, the pressure drop model is adjusted because the downstream boundary condition is fixed.

Results in agreement with this research were reported by Xavier (2014), around 27.99mca of pressure, when he checked the pressures available at the points of building supply after the expansion of the public water supply network in the industrial sector, Nascimento *et al.* (2019) analyzing the overpressures and underpressures in the Poxim

water main, proposed the assembly of alternative maintenance devices to avoid water hammer, and obtained 74.63mca. Teixeira *et al.* (2022), studying the effect of the upper inlet in downstream reservoirs during hydraulic transients in water distribution pipelines, obtained 8.28mca. Diniz *et al.* (2022), in their study entitled Modeling and evaluation of hydraulic transients in an existing pipeline system, obtained a maximum pressure of 34.2mca.
However, as the overpressure and underpressure values are positive, there is no risk to the system.

3.2 Excerpts

The results of the sections showed a head loss of around -3.34 to 19.64m. The greatest (19.64m) loss of distributed load was observed in T7. The lowest distributed head loss (-3.34, 0.14 and 0.12m) was observed in the T10, T1 and T3 sections (table 1), leading to cavitation and separation of the liquid column inside the pipe, thus favoring the occurrence of transient flow. The gross reduction in the amount of flow begins at T10 between N13 and N14, which in turn has an elevation of 112m, preceded by 84m, a difference in elevation of 28m. This difference in elevation, after the force of inertia has been overcome by the force of gravity, enables the rapid formation of the cavitation nucleus, which has an effect on the lowest points in the system, i.e. sections T2, T3, T4 and T5.

Table 1. Flow rate (Q), velocity (V), friction factor of the Darcy-Weisbach equation (f) and distributed loss in the pipe (hf) in the pipes.

Excerpt	Q (l/s)	V (m/s)	F	hf (m)
T1	84.63	1.89	0.02152	0.42
T4	84.63	1.89	0.01623	0.17
T5	84.63	1.89	0.01623	4.29
T6	84.63	1.89	0.01623	3.69
T7	84.63	1.89	0.01623	19.64
T8	84.63	1.89	0.01623	6.16
T9	84.63	1.89	0.01623	2.07
T10	-84.63	-1.89	0.01623	-3.34
T11	84.63	1.89	0.01623	2.07
T12	84.63	1.89	0.01623	2.07
T2	84.63	1.89	0.01623	0.14
T3	84.63	1.89	0.01623	0.12

Source: Authors.

In the evaluation carried out by Schimidit (2016), he reported values ranging from 0.36 to 2.82m of distributed loss in the pipe, when he studied hydraulic transient simulation and the economic combination of the water main for public supply in the municipality of Torrinha - SP, similar results were verified in the sections (T1, T2, T3, T11, T12 and T12) of this work. Sampaio (2016) reported that PVC pipes have advantages in their use, such as light weight, high resistance to corrosion, very low coefficient of friction, ease of handling, low thermal and electrical conductivity and their own permanent color, as well as lower acquisition costs. Cast iron pipes offer the following advantages: high resistance to heat, high resistance to positive and negative pressures, high resistance to external loads and shocks during transportation and laying. Bevilacqua (2006) adds that ductile iron pipes are highly resistant to breakage due to internal pressures.

A. *Transient operation*

The maximum overpressure was found at the system outlet, at the initial node, with a value of 97*.65mca*. It can also be seen that up to 2291 meters into the pipeline, where the second suction valve is located, the overpressures follow the pressure line in the permanent regime, and after this distance they rise without exceeding the service pressures. These findings may be associated with exceptional conditions in the discharge line, such as: failure of any of the TH's protection and control devices; inadequate valve maneuvers, in disagreement with the operating rules specified in the project; rupture of the pipeline in the section of maximum permanent regime pressure; and delayed closure of one of the check valves in the discharge of the pumps until the instant of maximum reverse speed, after pumping has stopped.

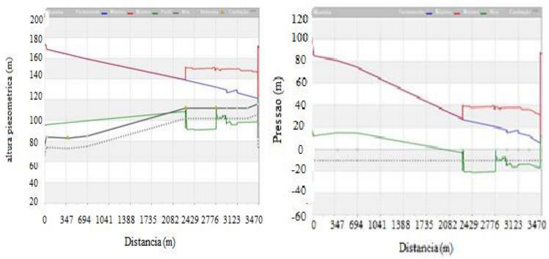

Figure 6. Manometric heights and pressures in transient regime.
Source: Authors.

The underpressures were also found to be negative, with the minimum underpressure being - 21*.08mca*. According to Schmidt (2016), values below the vapor pressure of water (9.8mca) would establish conditions for the formation of a vacuum and breakage of the liquid column, which could damage the equipment (Mattiello, 2017).

3.4 Valve closing and opening time

The records showed that the time taken to close the valves varied from 45 to 59 seconds, with an average time of 50.8 seconds. Based on the calculation of the time taken for the pressure wave to travel back and forth from one end of the system to the other, a time of 30.60s was obtained, which is classified as a fast maneuver.

3.5. Simulations to choose the best HT protection mechanism

3.5.1. Simulation with pressure regulating valve

In order to solve the instability problems caused by the transients, a pressure regulating valve was installed in the area where the instability begins. The simulation results (figure 7) showed a slight increase in the minimum pressure (14.82mca), but did not completely solve the water vapor pressures.

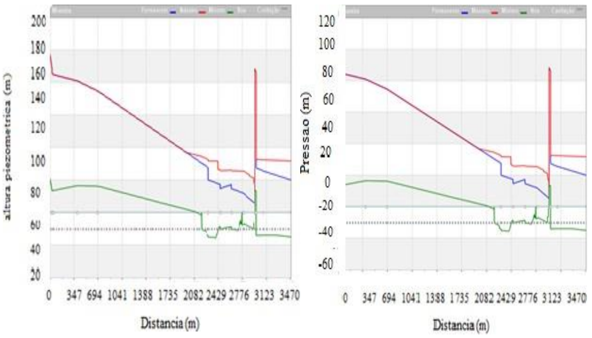

Figure 7. Manometric heights and pressures in transient regime for valve operation.
Source: Authors.

3.5.2. Simulation with hydropneumatic tank

Metal tanks with a diameter of 0.75m and a length of 2.08m were used, in a vertical position with a bladder and an initial pressure of 50mca.

The results showed that during operation transient phenomena were mild, leaving maximum pressures close to the permanent regime, but minimum pressures lower than the vapor pressure, reaching -13.72mca.

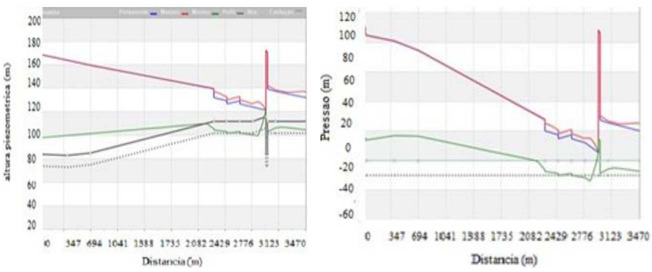

Figure 8. Manometric heights and pressures in transient regime with hydropneumatic reservoir operation.
Source: Authors.

3.5.3. Simulation with suction cup valves

Two suction valves were installed at the high points in the area where the transient phenomenon occurred. The results (figure 9) showed that they were not effective in controlling underpressure, ranging from 0 to -40mca.

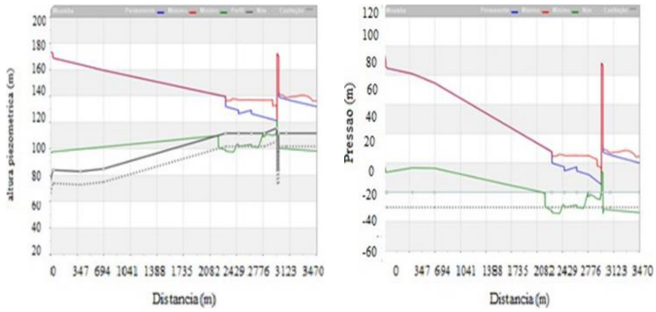

Figure 9. Manometric heights and pressures in transient regime with suction cup valve operations.
Source: Authors.

3.5.4. Simulation with change of pipeline to cast iron

In the process of changing the piping to cast iron, there was a change in the speed of the piping, which did not alter the functioning of the system, with maximum pressures below the operating limit and minimum pressures reaching -15.7mca, also below the operating range (figure 10).

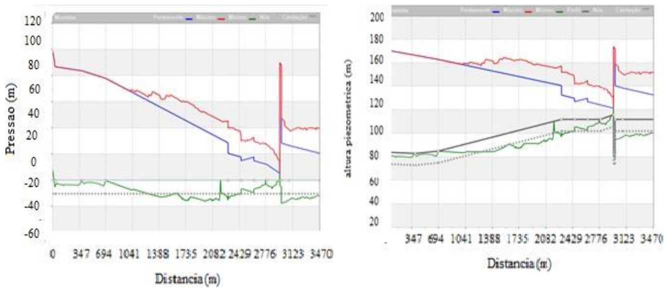

Figure 10. Manometric heights and pressures in transient regime with cast iron operation.
Source: Authors.

3.5.5. Simulation with Unidirectional Feeder Tank

When the simulation was carried out with the Unidirectional Feeder Tank (TAU), it was found that in the critical zone the negative pressures were amortized, being close (-0.96mca) to the atmospheric pressure value. The TAU, whose function is to prevent underpressure, did not have much influence at points far from the installation area; in the case of the recharge line, the TAU increased the underpressure to -17.45mca.

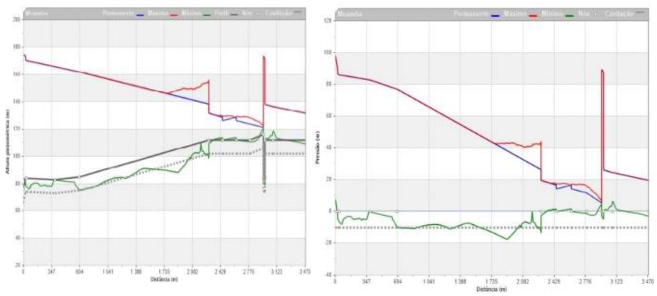

Figure 11. Manometric heights and pressures in transient regime with TAU operation.
Source: Authors.

Diniz *et al.* (2022) in their research entitled Modeling and evaluation of hydraulic transients in an existing water supply system, obtained a continuous flow of water to the recharge line at a time of 30s, from a supply of 2480L and a reduction in its level of 1.4m.

3.5.6. Simulation with equilibrium chimneys

The chimneys have a circular shape with a diameter of 1m and a height of 2m. Two attempts were made (i) the first attempt used 1 chimney, which proved to be inefficient, where the minimum pressure envelopes reached -9.20mca, not solving the underpressure problem, and (ii) in the second attempt, 2 balance chimneys were installed between the check valve, which proved to have better results, raising the minimum pressures and keeping the maximum pressures within the operating limit of the PVC pipe, varying between maximums of 88.34mca and minimums of 5.42mca (figure 12).

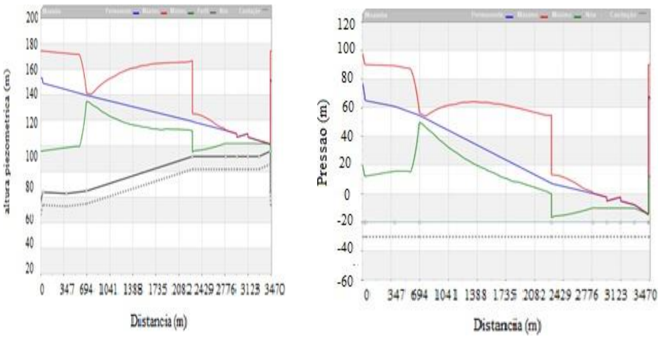

Figure 12. Manometric heights and pressures in transient regime with equilibrium chimney operation.
Source: Authors.

4. CONCLUSION

The study of hydraulic transients comprised 3 phases. The first phase took place under normal operating conditions of the pumping line in permanent regime. In this phase, it was found that the pressures were higher at the outlet of the pipe, reaching 97*.64mca*, but below the maximum service overpressure of the pipe and the variables velocity and flow after the fluid traveled *2429m* showed a sudden reduction that favored the occurrence of hydraulic transients.

In phase 2, given the abnormal operating conditions of the recharge line in a transient regime, the occurrence of TH was notorious, favored by the variation in the Speed and Flow variables, which led to pressure variations reaching minimum underpressures (-21*.08mca*) that posed a risk of the pipe collapsing.

Phase 3 consisted of choosing the best protection mechanism based on simulation in the exchange against the TH of the underpressure wave, with the best alternative for solving the problems being the introduction of balance chimneys installed between the check valve.

However, after carrying out this study, it was clear that the water main leakage events were consistent with the simulation results, and the proposed use of chimneys minimized the damage caused by the overlapping pressures in the system.

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