Considerations on transients in a water supply distribution network

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Abstract. Lipnița is a village situated in a hilly region, in Constanta County. The water supply system has its own groundwater water source, placed in the middle of the village at a low elevation. Water is conveyed, by a long transmission duct to a storage tank from which it flows by gravity to the consumers. The distribution network has two long mains that intersect in a manifold with isolation valves, situated in the middle of the village. This topology of the system shows high static head for the transmission duct and high elevation differences between the end consumers and those in the centre of the village.

The paper presents an analysis, by numerical simulation, on the transients that occur in two different segments of the system. The simulation was performed either for the original old steel made network, aiming at identifying the vulnerable cross sections and extreme pressure values. The results showed that maximal pressure values are not dangerous, but cavitation occurs along the pipeline. The same simulation was carried out for the new PEHD pipelines. The change of material and the increase in diameter of the new pipes showed better results regarding pressure variation during transients. Cavitation is avoided.

1. Introduction

In Constanta County, Romania, apart from the large interconnected water supply system that delivers drinking water to the cities and resorts on the Black Sea coast, there are many independent systems which provide water from their own underground sources, especially in the rural area. One of them is the water system of Lipnița, a village situated in a hilly region, in the South West of the county.

The distribution network is being under modernization process. Therefore an investigation on the safety and reliability of the system is imposed, as a basis for the seizing of the new pipeline and for water quality preservation.

Mechanical failures including pipe breaks, pump’s stoppage due to a power failure or abnormal operation generated by wrong valve manoeuvres may put into jeopardy the hydraulic integrity of the pipeline and subsequently water quality may be impaired. Isolation valves play an important role in the system reliability and security by providing a closure function [1]. Transients are usually present in hydraulic systems as a consequence of the demand variation, planned operation and maintenance activities, emergencies, or simple hydrant flushing. Rapid changes in pressure conditions due to surge events can lead to pipe deformation or even collapse, leakage, deformation of the equipment such as pipeline valves, air valves, and protection devices [2]. Sometimes the damage is hidden, but it may cause pipe collapse at a future moment, as transients continue. A clear analysis of the factors influencing hydraulic and physic integrity of the system, and the way the damaged hydraulic integrity affects the water quality is made by [2]. An emphasis is put on low pressure transients which may lead to leakage.
of contaminants into the pipe, at junctions under sub-atmospheric pressure values. The intruded contaminants can flow with the water downstream from the site of entry as [3] reported, referring to negative pressure values that occur in the distribution system and cause such intrusions. Consequently the admissible concentration values [4] might be overpassed.

These are the main reasons from which we started our study on transients in the water supply system, aiming at preventing possible damages or improper operation.

2. **Description of the drinking water supply system**

The distribution network is a branched one and the mains follow the direction of the streets (figure 1).

![Figure 1. Water supply system in Lipniţa. SR-transmission pipe; RV-network first branch.](image)

The groundwater is pumped from the source S, which is placed in the middle of the village at a low elevation of 63.99m, to a storage tank R, placed at the highest elevation point, of 123.03m, at the end of the main street in the village. As it can be noticed in figure 1, there are two long mains that intersect in a manifold situated at 60.83 m of elevation, close to the water facility that comprises the source. The steel made transmission duct, that connects the source to the storage tank, is 850m in length and 150mm in diameter. From the storage tank water flows by gravity to the consumers. The manifold hosts the isolation valves V (figure 1).
This topology of the system shows high static head for the transmission pipe that conveys water from the source to the storage tank. Moreover, there are high elevation differences between the end consumers and the ones in the centre of the village, so pressure, under normal operation, varies in a wide range. The network is a low pressure one [5], [6].

3. Research methods
The investigations on transients were achieved by numerical simulation. We analysed pressure variation on two different segments of the system, considering the most impairing scenarios:

a. a power failure stops the pump, therefore transients occur on the transmission pipe, (SR line in figure 1).

b. the isolation valve V (figure 1) is quickly closed, due to an accidental wrong manoeuvring, consequently transients occur on the first network branch, between the storage tank R and the valve V (RV line in figure 1);

The software, a non-commercial one, named Hammer, was conceived by the former Institute for Hydraulic Structures in Bucharest, to solve hydraulic shock problems using the characteristics method. The software assumes water flow is one-dimensional, and water is one single phase, [7], [8].

The mathematical model used by this software, composed of the motion equation and the mass conservation equation [7] takes into account either the elasticity of the pipe walls or the water compressibility. The differential equations are linearized. Specific boundary conditions are added, according to the type of the calculus node: constant head reservoir, air chamber, turbine, pump, valve, check valve, node with two or three branches, surge tank etc. [8].

Celerity is considered constant on a pipe section as long as the pipe’s diameter or material do not change.

The input data refer to: the length, diameter and wall thickness of the pipes, and the material they are made of. Regarding the nodes, data about the elevation, base demand and the grade line have to be introduced. The head loss are assumed to be concentrated in the nodes, therefore the moduli of hydraulic resistance are also input data. The software calculates the pressure values in the nodes and the results are given in graph of tabular form.

In the first scenario (a), water flows by gravity from the storage tank along the pipe, and suddenly the downstream valve V is closed. In this case, the border conditions imposed for the valve obturator refer to the reflexion of the pressure waves at the valve obturator, with no change in sign. So, pressure increases in the first phase of the hydraulic shock. At the other end of the pipe, with constant head storage tank, pressure waves reflect with reversed sign, so in the second phase pressure decreases. The longitudinal profile of the pipe is convex, therefore it is more likely to reach negative pressure values [6] in the nodes of high elevation, as the grade line may fall under the duct axis.

The pipe of 1004.5 m in length was divided in 9 sections, that means 10 nodes.

In the second scenario (b), it was assumed that the pump in the well stops as a consequence of a power accidental failure and the check valve undertake a quick closure. In this case, the border conditions are similar, but due to the fact that water, in the regime case, flows to the constant head tank, pressure decreases in the first phase of the hydraulic shock, in the nodes close to the pump and rises in the second phase.

The pipe of 850 m in length was divided in 7 sections, therefore 8 nodes are considered.

For both scenarios, the simulation was firstly conducted in the case of the original steel made network, and secondly, for the new pipes, to make possible a comparison of the pressure variation during transients. In the first scenario, the new pipe of the first distribution branch is PEHD made, and in the second, the new transmission pipe is a composed one: it is steel made only on the first ascendant section (inside the well), and continues with a horizontal PEHD made pipe.

The old network has been proved to be undersized with respect to the fire flow rate [6]. Therefore mobile pumps were needed to operate at a hydrant, to have enough pressure and capacity for fire fight. Thus, the diameter of the new horizontal PEHD made transmission pipe is enlarged at 160 mm, whereas
the ascendant steel made section is 125 mm in diameter. Likewise, the diameter of the new pipe of the first distribution branch is 110 mm, instead of 80 mm. The simulation flow rate is 11.52 l/s.

4. Discussion of the simulation results

The replacement of the old pipes with new larger ones modified the velocity field across the distribution network. In Table 1 there are gathered the velocity values for the old and the new pipe that consists of the first branch of the distribution network. The velocity decreases with about 40%.

| Pipe section [m] | N1-N2 | N2-N3 | N3-N4 | N4-N5 | N5-N6 | N6-N7 | N7-N8 | N8-N9 | N9-N10 |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Dn 80mm         | 2.19  | 2.19  | 2.2   | 2.25  | 2.4   | 2.43  | 2.45  | 2.58  | 2.61  |
| Dn 110mm        | 1.31  | 1.31  | 1.32  | 1.35  | 1.43  | 1.46  | 1.47  | 1.55  | 1.57  |

Although the new PEHD pipes are smoother than the steel ones, the hydraulic losses decrease insignificantly due to the velocity decrease caused by the diameter enlargement. Therefore, the head is slightly different in the nodes of the same pipe as the material changes.

The extreme pressure values in the most representative nodes of the pipes are given in Table 2, in correlation with their elevation.

| Scenario a | Nodes | N1  | N2  | N3  | N4  | N5  | N6  |
|------------|-------|-----|-----|-----|-----|-----|-----|
| Steel      | Elevation [m] | 0   | 63,63 | 67,19 | 98,05 | 113,91 | 121,65 |
|            | p_{max} [mwc]  | 176,1 | 111,7 | 103,4 | 59,3  | 40,2  | 18,7 |
|            | p_{min} [mwc]  | 47,0  | -10,0 | -5,5  | -10,0 | -7,1  | -3,6 |
| Steel and PEHD | p_{max} [mwc] | 133,5 | 69,5  | 65,9  | 32,8  | 23,4  | 10,9 |
|            | p_{min} [mwc]  | 108,4 | 45,3  | 45,0  | 18,1  | 14,1  | 6,6  |
| Scenario b | Nodes | N1  | N2  | N3  | N4  | N5  | N7  | N9  |
| Steel      | Elevation [m] | 60,83 | 69,1 | 74,16 | 85,44 | 93,59 | 110,08 | 117,89 |
|            | p_{max} [mwc] | 98,4 | 99,7  | 79,2  | 66,2  | 56,2  | 33,3  | 16,2 |
|            | p_{min} [mwc] | -8,5 | -8,7  | -2,5  | -8,3  | -10,0 | -10,0 | -1,4 |
| PEHD       | p_{max} [mwc] | 77,6 | 68,8  | 63,0  | 50,9  | 41,6  | 22,0  | 9,0  |
|            | p_{min} [mwc] | 48,1 | 40,6  | 36,4  | 26,2  | 18,9  | 5,0   | 4,1  |

Referring to the amplitude of oscillations, we may notice an important decrease when the steel pipes are replaced. In the first scenario it decreases about five times, whereas in the second scenario it is only three times smaller, when the pipes are PEHD made.

The pressure variation over time, in some representative nodes is given in figure 2, in a comparative manner. In figure 2 a, the graphs show pressure variation for the first scenario, in nodes N1, N2 and N4 of the transmission pipe. The node N1 is close to the pump. The amplitude of the first oscillation is 129mwc, but no harmful values are recorded. In all the nodes along the pipe, except for the first one, N1, minimal pressure is negative. However, in the nodes N2 and N4, cavitation occurs for a few seconds. The oscillations damp rapidly.
a. Transmission line (first scenario).

b. Distribution branch (second scenario).

**Figure 2.** Pressure variation during transients.
The simulation for the new transmission pipe shows that a sudden stoppage of the pump results in only small oscillations around the regime pressure value, in each node (the dashed line in figure 2a).

The oscillation profile is different for the old and for the new pipe. The amplitude of the first oscillation in node N1 is about 129.1 mwc, and the minimal pressure is 47 mwc, in the case of old steel made pipe. In the other nodes along the pipe the minimal pressure is negative. The damping ratio is 0.025. Similar damping ratio may be noticed at the other nodes of the pipe.

The replacement of the old pipe with a new one, larger in diameter and made of a much more elastic material, results in oscillations with a damping ratio of 0.09. The period increases four times in the case of PEHD made pipe.

In figure 2 b, there are represented the pressure variation graphs in some nodes of the network branch considered in the second scenario. There were selected the nodes N1, N2, and N5, where N1 is close to the valve V. The maximal pressure values are once again harmful, as it happened in the first scenario. The threat comes from the minimal pressure values, which are negative along the duct. On some sections, cavitation is reached. For example, cavitation occurs in the nodes N5 and N7, where the slope of the terrain changes. The amplitude of the first oscillation in node N1 is about 108 mwc, and the minimal pressure is -8.5 mwc. The damping ratio is 0.01.

In the case of the new pipe, larger in diameter and made of PEHD instead of steel, the oscillations have a damping ratio 0.008. The period is comparable for the two cases. The minimal pressure values are positive along the pipe. The amplitude of the first oscillation decreases to 29.5 mwc.

5. Conclusions
The numerical simulation of transients in the old water distribution system Lipnița showed a dangerous decrease of pressure along the pipes in both scenarios, and even the occurrence of cavitation on some segments of the pipes. The hydraulic integrity of the pipes may be affected, and consequently the water quality may be impaired by the intrusion of pollutants through the joints where low negative pressure occurs. There were needed, along the pipe, devices for protection from cavitation.

As the considered water distribution network is a branched one, characterized by long pipe sections with convex longitudinal profile and high difference of elevation between the ends, we recommend a thorough study of transients in similar water distribution networks. Even if maximal pressures are not dangerous, cavitation may occur.

The replacement of the steel pipes with more elastic ones, PEHD made, eliminates the danger of cavitation. The increase of the inner diameter of the pipes, and the subsequent decrease of the velocity contributes to the cavitation danger elimination. Consequently, no protection devices are required.

References
[1]  Nekha J and Sumamb K S 2016 Optimal Water Distribution Network Design Accounting for Valve Closure, *Procedia Technology* 24 (2016), pp 332 – 338
[2]  National Research Council 2006 Drinking water distribution systems. Assessing and Reducing Risks (Washington DC: the National Academies Press), https://doi.org/10.17226/11728
[3]  Friedman M, Kirmeyer G, Pierson G, Harrison S, Martel K, Sandvig A and Hanson A 2005 Development of distribution system water quality optimization plans (Denver, CO: AwwaRF)
[4]  STAS 1342-91 1991 *Drink Water. Scope and use field* (Bucharest: The Romanian Institute for Standardization)
[5]  STAS 4163-2 -1996 Water supply. Water distributions. Engineering and operation technical directions (Bucharest: The Romanian Institute for Standardization)
[6]  NP 133-2013 Regulation regarding the design, execution and exploitation of water distribution systems (Bucharest: MDRAP)
[7]  Popescu M 2008 *Hydropower plants and pumping stations. Hydraulic operation during transients* (Bucharest: Editura Universitară)
[8]  Popescu M and Arsenie D 1987 *Methods of hydraulic calculation for hydro-electric plants and pumping stations* (Bucharest, Editura Tehnică)