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Analysis of Transient Phenomena in Water Supply Networks

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Abstract: Alert opening and closing procedures of large water supply taps the significant pressure changes may cause the appearance of transient phenomena. These phenomena can have harmful effects on the elements of the tubing system, often leading to pipe bursts. This study presents a measurement procedure carried out by us with the aim of studying the appearance of transient phenomena, including the details of the applied instruments. Using the results of the measurement procedures, we set up calculations and a computer simulation in order to find the weak points of the analysed water system. By this research, we aim to raise awareness about the dangers of transient phenomena in water supply systems. Furthermore, we wish to improve the operational safety and efficiency of water supply systems.

Keywords: measuring instrument, simulation, transient phenomena, tubing system, water supply system

I. INTRODUCTION

Reliability, continuous operation and pressure consistency are amongst the most important requirements on high-performance water supply systems.[1] Despite proper maintenance, technical failures might prevent water supply systems from functioning normally [2], causing water service outages. There are multiple possible reasons for water supply failures, but for reasons of space, this paper only presents the effects of transient phenomena in water supply systems. Our measurements were carried out on tubing systems owned by Pannon-VízZrt. (water utility service provider), and after data analysis we set up calculations and a computer simulation using Ansys Academic Fluid. The aim of our research is to raise awareness about the importance of measurements regarding transient phenomena in water supply systems. This paper presents our experiences and results (measurements and simulations) regarding the aforementioned topic. The issues regarding underwater sensor usage were also discussed, as mentioned in [3].

II. THE MEASUREMENT PROCESS

Before discussing the measurement process itself, it is necessary to present the location where the measurement was carried out. The field measurement’s location was a main water pipe located in Vámosszabadi municipality, which is part of the water supply system operated by Pannon-VízZrt. On one end of this main water pipe, a water tower is located. The water tower has a volume of $50m^3$ and has a height of 36m. The water tower is intended to even out the differences in peak consumption periods. During low consumption periods, the water tower is refilled. The water tower and the main water pipe are connected by a remote-controlled sluice. Because there are breaks in the operation, and because the sluice might open and close abruptly, our theory is that transient phenomena might occur in the affected tube section. Our theory is sustained by the fact that multiple pipe bursts occurred in the previous period. The inspected pipe section (fig. 1) consists of pipes made of different materials. A stainless steel pipe with 100mm diameter and 4mm wall thickness leads to a rising shaft, where a hydrant is located as well. The rising shaft and the main pipe are connected with two pieces of pipes: a 21m long asbestos-cement pipe which is 100mm in diameter and has a wall thickness of 12mm, and a plastic tube being 110mm in diameter and having a 6,6mm thick wall. The measurement was carried out in December, outside temperature was -1°C, water temperature was 5°C.

Figure 1. Measurement location (source: Pannon-VízZrt, edited by the authors)

III. THE MEASURING INSTRUMENTS

For the measurements regarding transient phenomena we applied two TRAREC® transient measuring instruments developed and patented by Budapest Waterworks (Fig. 2).

Figure 2. TRAREC measuring instrument (Source: [4])

One of the instruments (instrument nr. 12079) was connected to a sampling tube at the water tower, the other one (instrument nr. 12078) was mounted on the hydrant located 20m away from the water tower (Fig.3). Using these two sensors, we were able to analyse transient phenomena on the tube section between the water tower and the first 90-degree curvature.

Figure 3. TRAREC® measuring instruments at the measuring points (Source: authors)

The technical parameters of the measuring instruments are included in Table 1.

Table 1. TRAREC® measuring instrument technical parameters (Source:[4])

Pressure sensor	0 -15 bar; (max. 40 bar)
Accuracy	0,1%
Sampling frequency	50 - 1000 measurement/s
Data storage frequency	1 - 60s
Data resolution	20bit
Measurement length	From unique measurement to 1-2-week period
Data transfer and charging	USB 2

IV. DESCRIPTION OF THE MEASUREMENT

After completing the mounting process of the two measuring instruments, we opened the faucets at the connecting points and checked the seals for possible leaks. After that, we put into operation the two measuring instruments and opened the sluice. The measurement process was repeated, then the transient measuring instruments were demounted. Measurement data was copied to a computer and analysed by using a software developed for this measuring instrument. The diagrams presented in Fig. 4 (first measurement process) and Fig. 5 (second measurement process) include measurement results from sensor nr. 12079 marked with blue colour and from sensor nr. 12078 marked with green colour.

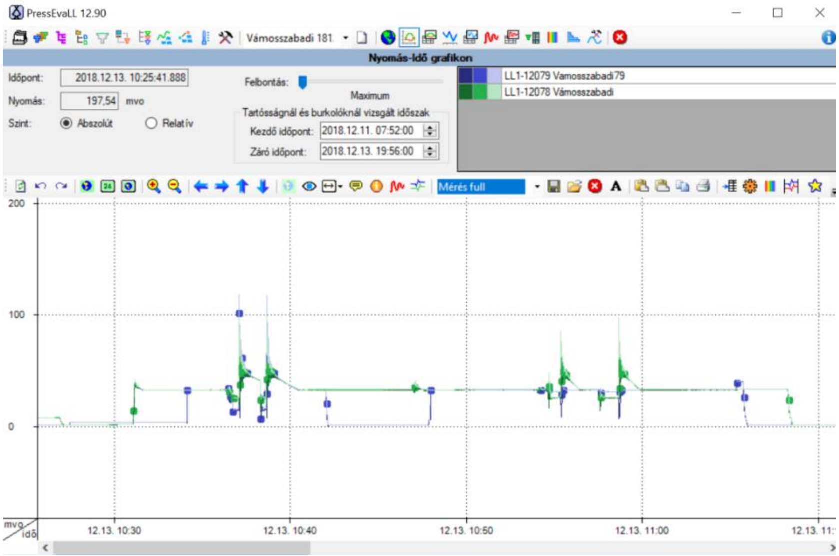
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Figure 4. Measurement data, first measurement process (Source: Authors)

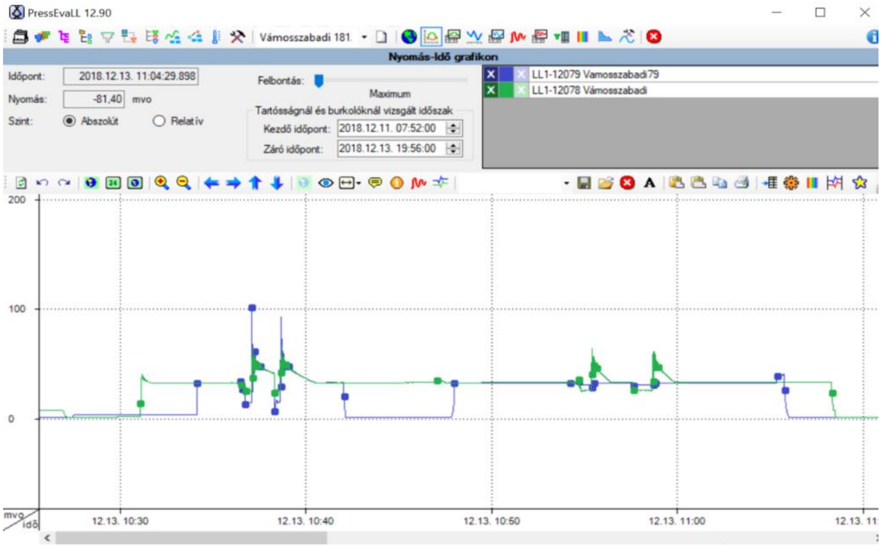
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Figure 5. Measurement data, second measurement process (Source: Authors)

The presence of transient phenomenon in the asbestos-cement pipe is clearly observable on the aforementioned diagrams, which means that further investigation is required.

V. CALCULATIONS, SIMULATION

In Hungary, water supply systems still include pipelines made out of asbestos-cement. This material is highly outdated, and the replacement of these pipe sections has already been started. Since the pipe section analysed by us is also made out of asbestos-cement, our calculations and simulations are based on the properties of this material. The necessary formulae and technical parameters and constants can be found in sources [5][6].

Inside the tube, the water column is shortened because of two main reasons. The abrupt closing of the sluice causes increased pressure, and the increased pressure forces the water column to contract in length, causing the expansion of the tube. We take the assumption that the fluid and the pipe behave according to Hooke's law, and their Young moduli are E_{liquid} and E_{pipe}. Based on these assumptions, we consider a virtual pipe-fluid system. The pipe is considered to be perfectly rigid and the water flowing through the pipe is considered to have E_{red} reduced Young modulus.

$$\frac{1}{E_{red}} = \frac{1}{E_{liquid}} + \frac{1}{\frac{\delta}{D} E_{pipe}} \quad (1)$$

where δ pipe wall thickness,
D pipe interior diameter

Based on the reduced Young modulus, wave speed can be calculated in the reduced system:

$$a = \sqrt{\frac{E_{red}}{\rho_{liquid}}} \quad (2)$$

The calculations were carried out based on data included in Table 2:

Table 2. Calculation data (Source: Authors)

Data	Notation	Value
Pipe Young modulus	E_{pipe}	$24 \cdot 10^9 \frac{N}{m^2}$
Liquid Young modulus	E_{liquid}	$2{,}19 \cdot 10^9 \frac{N}{m^2}$
Pipe wall thickness	δ	12mm
Pipe diameter	D	100mm
Liquid density	ρ_{liquid}	$999 \frac{kg}{m^3}$

Calculations:

$$\begin{aligned} \frac{1}{E_{red}} &= \frac{1}{E_{liquid}} + \frac{1}{\frac{\delta}{D} E_{pipe}} = \frac{1}{2{,}19 \cdot 10^9 \frac{N}{m^2}} + \frac{1}{0{,}12 \cdot 24 \cdot 10^9 \frac{N}{m^2}} = \\ &= 4{,}566 \cdot 10^{-10} \frac{1}{Pa} + 3{,}472 \cdot 10^{-10} \frac{1}{Pa} = \\ &= 8{,}0384 \cdot 10^{-10} \frac{1}{Pa} \end{aligned} \quad (3)$$

Results:

$$E_{red} = 1{,}244 \cdot 10^9 Pa \quad (4)$$

Based on the reduced Young modulus, wave speed was calculated:

$$a = \sqrt{\frac{E_{red}}{\rho_{liquid}}} = \sqrt{\frac{1{,}244 \cdot 10^9 \, Pa}{999 \frac{kg}{m^3}}} = 1{,}1159 \cdot 10^3 \frac{m}{s} \quad (5)$$

Based on Allievi's formula:

$$\Delta p = \rho_{liquid} \cdot a \cdot \Delta v = 999 \frac{kg}{m^3} \cdot 1{,}1159 \cdot 10^3 \frac{m}{s} \cdot 2{,}54 \frac{m}{s} = 28{,}3159 \, bar \quad (6)$$

Based on our calculations, if a water hammer occurs, the pressure can be as high as 28,32bar in the pipe section in question. This pressure might be dangerous, especially if the pipe section is arced.

As a final step, we created the Ansys Fluid computer simulation of the asbestos-cement pipe segment. The boundary conditions of the computer simulation were set based on the calculations presented earlier. We created an importable CAD model, including a curved pipe section and the flowing water volume (Fig. 6).

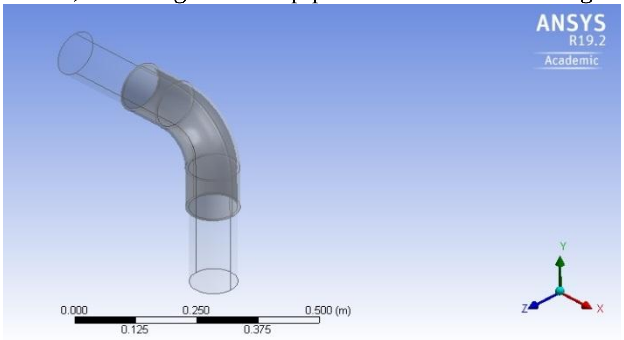

Figure 6. CAD models imported into Ansys (Source: Authors)

After importing the necessary CAD models, we carried out a simulation only focusing on the flowing water volume. The meshing of the water model was done correspondingly to the application. (Fig. 7).

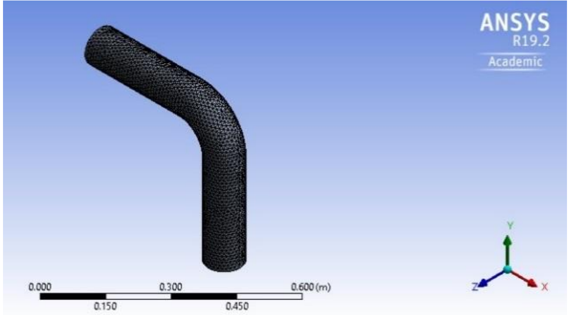

Figure 7. Meshed water volume model (Source: Authors)

After getting the results of the water flow simulation, the curved pipe section was also meshed and prepared for simulation. The pressure values acting on the pipe section were taken as reference from the water flow simulation. Based on this, the Ansys project's structure was formed, consisting of a fluent simulation and a static structural simulation. The curved pipe section was constrained. The constraints were set up based on the real pipe section (Fig. 8).

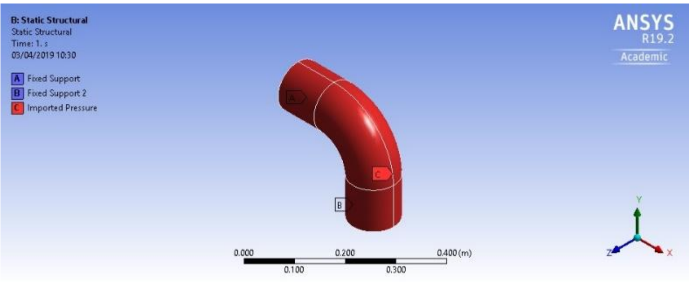

Figure 8. Setting up loads and constraints (Source: Authors)

The combined result of the two simulation modules revealed the stresses acting on the pipe section, and the total deformations were revealed as well (Fig. 9).

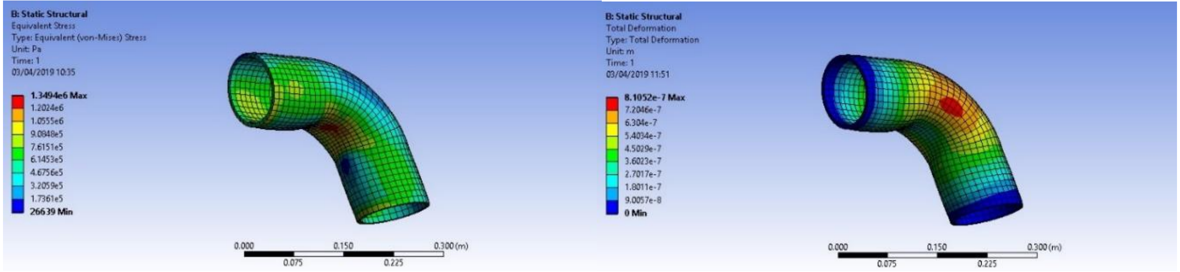

Figure 9. Stress and total deformation results (Source: Authors)

VI. CONCLUSIONS

The importance of the secure operation of domestic water supply systems in unquestionable. Hungary's water supply systems were built using a wide variety of pipe materials, and these materials show different reactions in the event of transient phenomena, often resulting in pipe bursts. The occurrence of transient phenomenonis highly possible in case of supplementary reservoirs or other instruments being responsible for equalising the fluctuations caused by increased consumption. As part of ourresearch, we carried out measurements on pipe sections operated by Pannon-VízZrt., using a sensor specially developed for transient measurements [7]. Then we set up calculations to define the boundary conditions for our computer simulation, by which we were able to find the weak spots of the examined pipe section, by looking at stresses acting upon the pipe and by analysing its deformations. The reason why we decided to analyse a pipe section made out of asbestos-cement is this material's outstanding rigidity, which increases the effect of transient phenomena and water hammer. The results of the simulation revealed that the water hammer structurally affects curved pipe sections. The risk of pipe bursts is the highest at the curved section. It is important to mention that measurements regarding transient phenomena helps the detection of critical pipe sections, marking exactly the location where pressure absorbing elements should be mounted.

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