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Study into the protection of the Galeșu irrigation water supply system from hydraulic shock, by numerical simulation

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***Abstract* – The design of a pumping station must aim, in addition to satisfying the technical requirements of the beneficiary, the energy efficiency and the safety during operation. The study undertaken refers to the modernization of a water supply pumping station, a base station that takes water from the Danube-Black Sea Channel and discharges it into the CA1 supply channel. Investigations into the vulnerability caused by hydraulic shock were made by numerical simulation, aiming to find out the best variant to protect the main discharge duct using air chamber. From either technical or economical viewpoint, the recommended variant is a 15 m^3 air chamber, much smaller than the existing air chamber of 28 m^3.**

Keywords* – *hydraulic pumps's performance, hydraulic shock, numerical simulation, pumping systems.

1. Introduction

Increasing global concerns about water reserves and electricity savings lead to the idea of a meticulous design of large energy consumers around hydraulic systems [1], [2], so that the principles of sustainable development are respected [3]. Regarding energy, primary energy intensity (the ratio of total energy supply to GDP) improved lately by 2.1 % and this progress was partly driven by the reduced energy use, as stipulated by [4]. But the energy efficiency has to be improved by 4.0 % between 2022 and 2030, to meet the sustainability goals of the United Nations [4]. Specialists are developing monitoring systems, affordable for irrigation pumping stations, in order to collect real-time information on water flow rates, volume, turbidity, and energy consumption, for a better management of these consumers [5]. Considering the climate change, only by implementing appropriately measures, the competitiveness of agriculture can be strengthened, so sustainable conditions for water management must be taken [6]. The countries confronted with frequent floods, a special attention is paid to the drainage systems cannels which are lately used more and more, in the context of climate change, as irrigation water supply for the pumping stations in agriculturally exploited regions [7].

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In Dobrogea, Romania, a region with dry climate, agriculture depends on irrigation. The main water source for irrigation is the Danube-Black Sea Channel (DBSC).

The design of a water supply pumping station is a complex process, which must meet both the technical requirements of the beneficiary and the current requirements regarding sustainability.

Sustainability requires increased efficiency in operation, minimal electricity consumption and environmental harmonization of new constructions. The basic water supply pumping station, located in the village of Nazarcea (SPB Galeşu), in Constanța county, is the subject of the study on vulnerability and identification of safety measures in operation as a component of the efficiency in operation. If the initial station, put into operation in the 1970s, had the requested flow rate of 4.62 m^3/s and served an area of 4755ha, following recent analyses a lower flow rate of 3.15 m^3/s was requested, so its modernization is done taking this flow rate into account.

2. ANALYSIS OF THE PUMPING STATION ENERGY EFFICIENCY AND VULNERABILITY

The proposed station is compound of seven horizontal shaft identical pumping units, with constant speed, delivering a flow rate of Qp = 0.45m^3/s, at the pumping head of H = 50 m.The installed motor power is P= 250 kW. The auxiliary installations consist of two priming electric pumps type MIL 50, driven by a 5.5 kW motor with and 1500 rpm speed and 2 exhaust electric pumps type EPET driven by 4 kW motors and 1500 rpm speed.

Suction is siphoned, through 7 metal pipes of 800mm in diameter, and 11 m long. Discharge is made through a metal main duct of 1300 mm in diameter and 530 m long, into a discharge basin, at the end of the CA1 supply channel. The discharge ducts are made of steel, in the station area, and then from polymer reinforced with glass fibres and with insertion of sand (PAFSIN). Each individual discharge pipe is equipped with a butterfly check valve and a butterfly valve, Fig.1. The equipment on the discharge ducts has a nominal pressure Pn=10 bar as recommended [8]. From optimal technical and economic conditions, the diameter of the main discharge duct resulted in 1200 mm. Seven identical, double-flux, horizontal shaft pumps were selected. All the pumps are of right-hand construction.

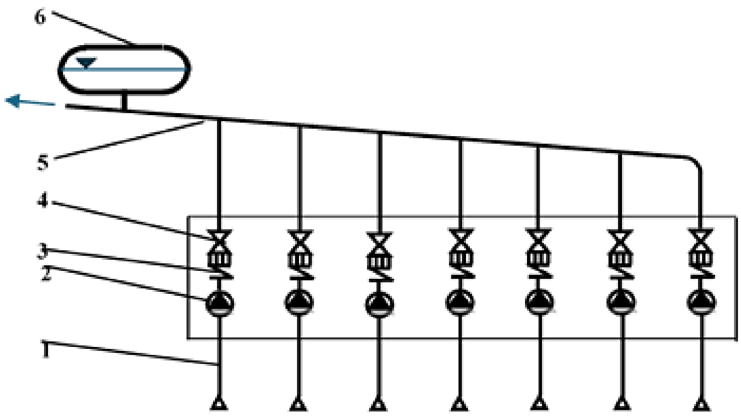

Fig. 1 Layout of the pumping installation. 1.Suction duct. 2.Pump.3.Check valve. 4.Butterfly valve. 5.Main discharge duct. 6.Air chamber

Their arrangement in the horizontal plane can be seen in Fig.1. The arrangement of the pumps in a row, imposed by the topography of the site, leads to a large length of the station building. Furthermore, a hydraulic asymmetry occurs in the operation of the pumps at the ends of the group. Thus, the hydraulic resistance modulus for the extreme right pump is $M_1 = 5.82\ s^2m^{-5}$, and for the extreme left pump P7 it is $M_7 = 4.13\ s^2m^{-5}$. Although this hydraulic asymmetry occurs, the pumped flow rate is very slightly different.

Considering the connection mode, series and parallel, of the discharge pipes, their dimensions and their equipment, the equivalent hydraulic resistance module for the entire station resulted in $M_R = 4.13\ s^2m^{-5}$.

It is found that the maximum required pumping head is of $H_{max} = 50.4m$, at a maximum geodetic height of $Hg_{max} = 45.5\ m$.

Thus, the main duty points, corresponding to the maximum geodetic height, are:

- ✓ One operating pump

$$Q_{min}=1800\,{m^3}/{h};\ H_{min}=45\ m;\ \eta_1=80\% \tag{1}$$

- ✓ All seven pumps in parallel

$$Q_{max}=11340\,{m^3}/{h};\ H_{max}=50.4\ m;\ \eta_7=80\% \tag{2}$$

where Q- flow rate; H-pumping head; η-efficiency.

Taking into account the maximal efficiency of the proposed pump is $\eta_{max}=84\%$, the operation efficiency of the pumps, at each duty point is $0.95\eta_{max}$, that means higher than the minimum recommended value of $0.8 \cdot \eta_{max}$.

The evaluation of the maximum overpressure that occurs in the most disadvantageous case, that of stopping the power supply to the pumps during parallel operation, using Zhukovsky's relationship, led to the value Δp=13.58 bar. As the regime pressure is

$$p=\gamma\cdot H_{max}=9810\cdot 50.4\approx 4,94bar \tag{3}$$

where $\gamma = 9810\ {N}/{m^3}$-water's specific weight, the maximum assessed pressure is up to 18,52 bar. That means there are needed protection devices to be mounted on the discharge duct.

The initial pumping station was equipped with an air chamber of $28\ m^3$ in volume. Due to the new smaller value of the discharge rate, a more economical but effective air chamber must be used.

3. NUMERICAL SIMULATION OF PUMPING STATION PROTECTION FROM WATER HAMMER

Starting from the idea that the initial air chamber of 28 m^3 in volume was designed for a discharge rate of 4.62 m^3/s, it is naturally to look for a smaller but effective one, in accordance with the new value of the discharge rate. Therefore, we considered a series of smaller volume values of 28;20;15 and 10 m^3 , and for each value we performed a numerical simulation of the pressure variation in the case of three different linear shut-off law of the check valve: 5s; 20s and 25s.

Investigations on pressure variations and the sections of the installation where they occur were carried out by the method of characteristics, a finite difference calculation method implemented in an automatic calculation program described in detail in [3]. The calculation was carried out for the most dangerous case, those in which all 7 pumps are in operation and a sudden power outage occurs.

The discharge duct of 528 m in length was divided in 9 steps of 62m in length. Only the second step is shorter, of 32m in length, due to its steepest slope.

The air chamber is mounted in the node 3, where is the most vulnerable section of the duct. The first step is made of steel, so the celerity is of 1154.36 m/s. For the PAFSIN steps, celerity is 398.11 m/s.

The air chamber is horizontally mounted. Its diameter, of 1.5m, remains constant in all considered cases, but the length changes. The water level in the air chamber is 1.05m. The proportion is 70% water and 30% air.

4. RESULTS AND SIGNIFICANCES

The first numerical simulation was performed for the case of the initial pumping station and its air chamber of 28 m^3 in volume. The linear shut-off law of the check valve was recommended to be of 25 s. The station is protected, as it may be seen in Fig.2. Pressure do not rise above 50 mwc and it is positive in each calculation node.

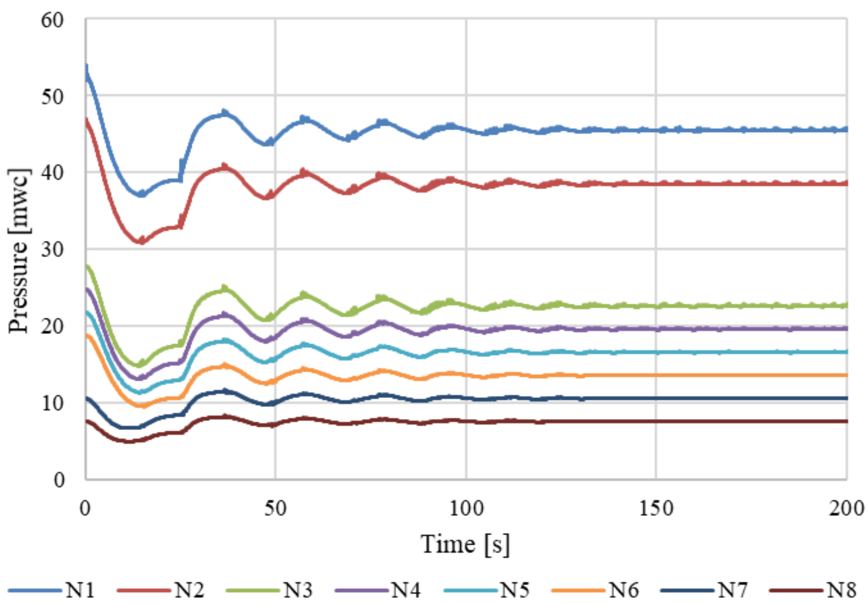

Fig.2 Pressure variation during hydraulic shock for the initial pumping station, for an air chamber of 28 m^3 in volume and a 25 s linear shut-off law of the check valve

The investigations on the discharge duct protection offered by an air chamber, regarding the new proposed pumping station started with the same conditions, namely an air chamber of 28 m^3 in volume and a 25 s linear shut-off law of the check valve. The graphical results may be seen in Fig.3.

Maximal pressure value occurs in the nodes 1 and 2, and is under the regime one, and the minimal pressure value is reached in the node 8 and it is a positive one, of 5.04 mwc.

Trying to decrease the shut-off time for the check valve, we obtained, for the same air chamber of 28 m^3 in volume and a 20s shut-off law, the graph in the Fig.4.

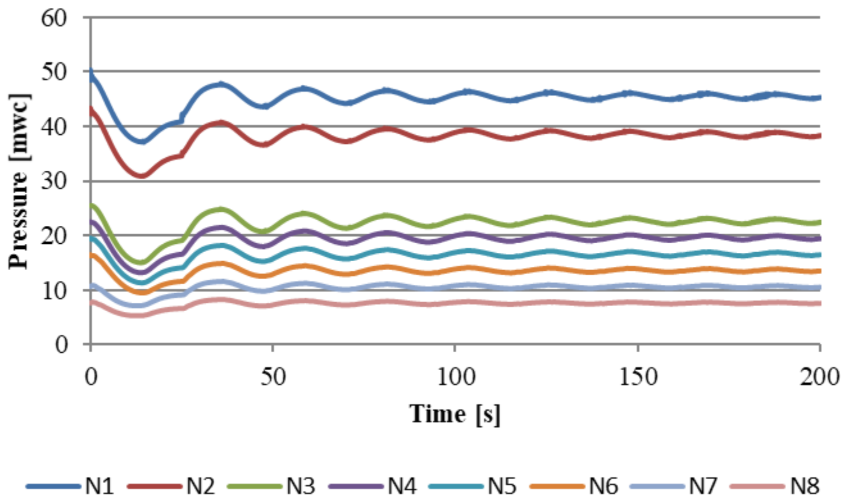

Fig.3 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of 28 m^3 in volume and a 25 s linear shut-off law of the check valve

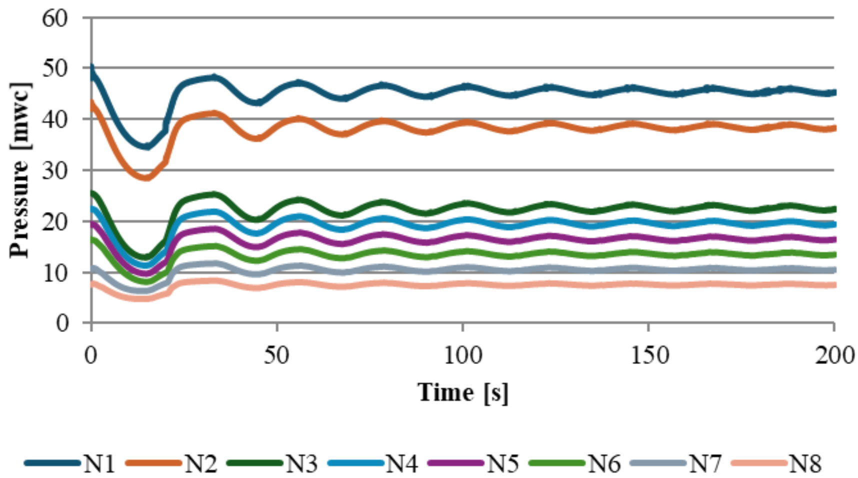

Fig.4 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of 28 m^3 in volume and a 20 s linear shut-off law of the check valve

The protection is also effective in these conditions. Continuing to decrease the closing time of the check valve, a superposed perturbation occurred. For instance, in the case of the same air chamber of 28 m^3 in volume and a 5s shut-off law, resulted the graph in the Fig.5.

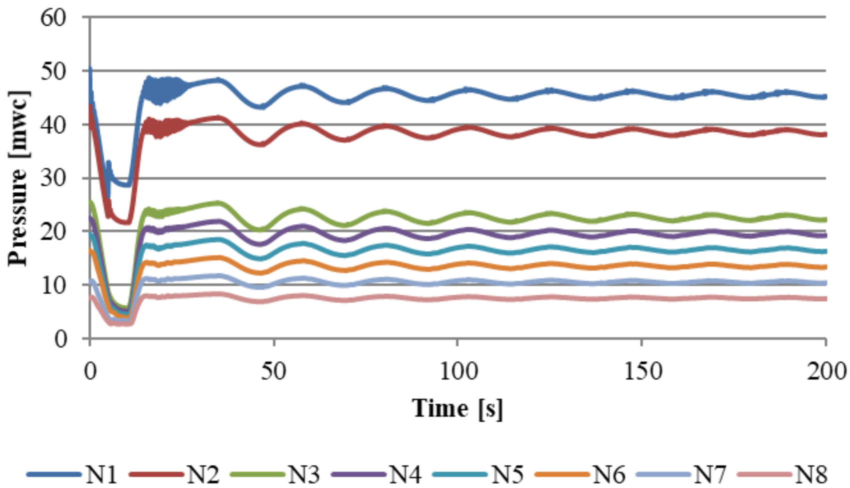

Fig.5 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of 28 m^3 in volume and a 5 s linear shut-off law of the check valve

A superposed oscillation occurs between the 14th and the 25th second of the hydraulic shock, in all the calculation nodes. Its amplitude is higher in the first and the second node, but the presence of the air chamber in the third node attenuate the amplitude of this additional oscillation.

We continue the investigations aiming to find a cheaper air chamber, that means a smaller one, but effective for the discharge duct protection from hydraulic shock. We present, out of the series of the performed simulations, only the results for the two extreme closing time of the check valve (20 s and 5 s) considering the air chamber volume of 20 m^3, Fig.6 and, respectively, Fig.7, then of 15 m^3 Fig.8 and , respectively, Fig.9, and finally of 10 m^3 Fig.10 and , respectively, Fig.11.

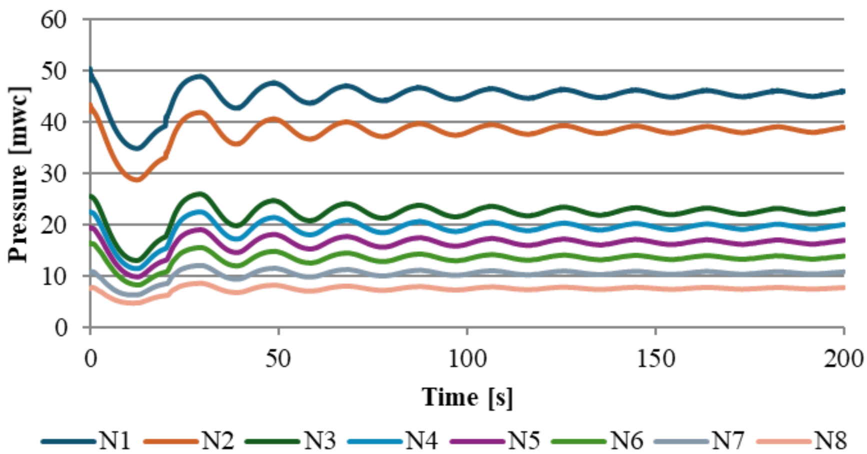

Fig.6 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of 20 m^3 in volume and a 20 s linear shut-off law of the check valve

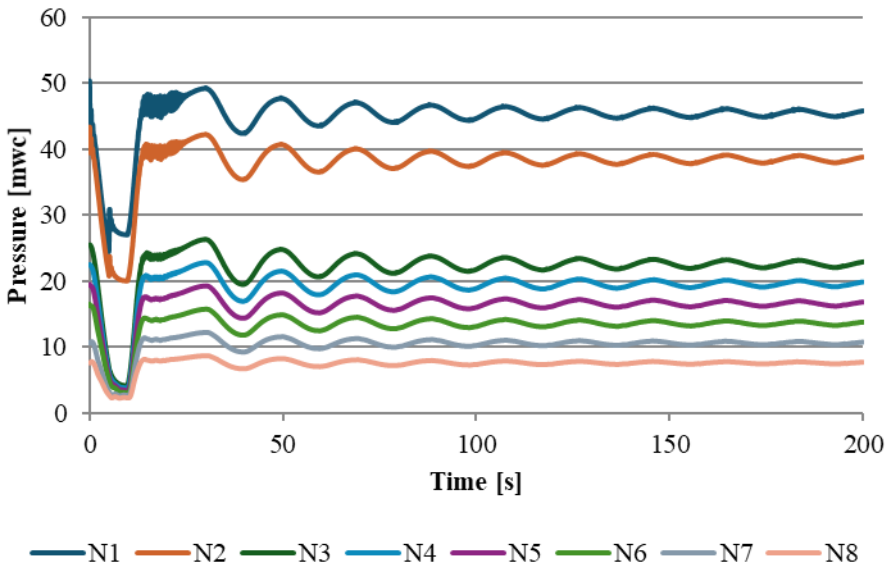

Fig.7 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of $20\ m^3$ in volume and a 5 s linear shut-off law of the check valve

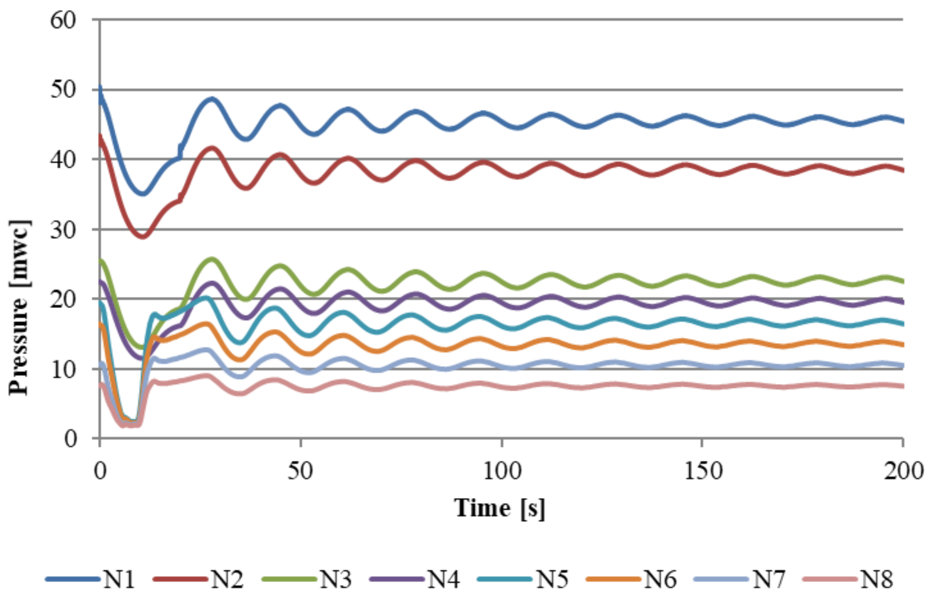

Fig.8 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of $15\ m^3$ in volume and a 20 s linear shut-off law of the check valve

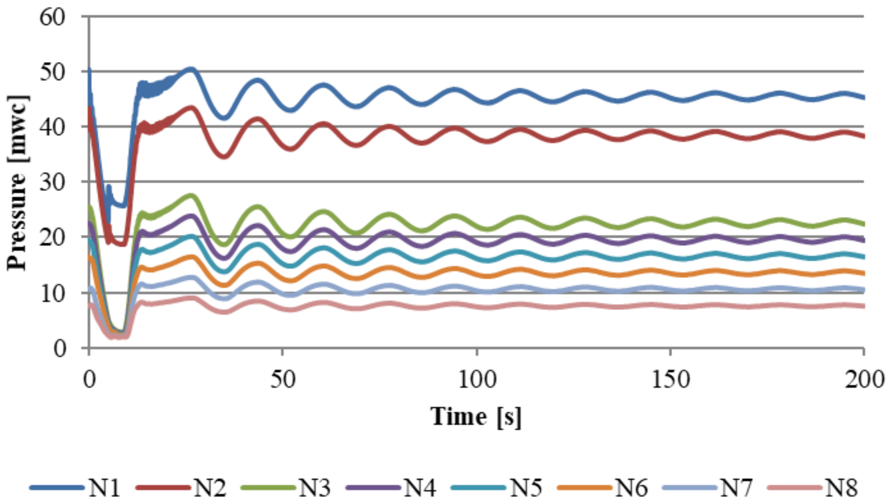

Fig.9 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of $15\ m^3$ in volume and a 5 s linear shut-off law of the check valve

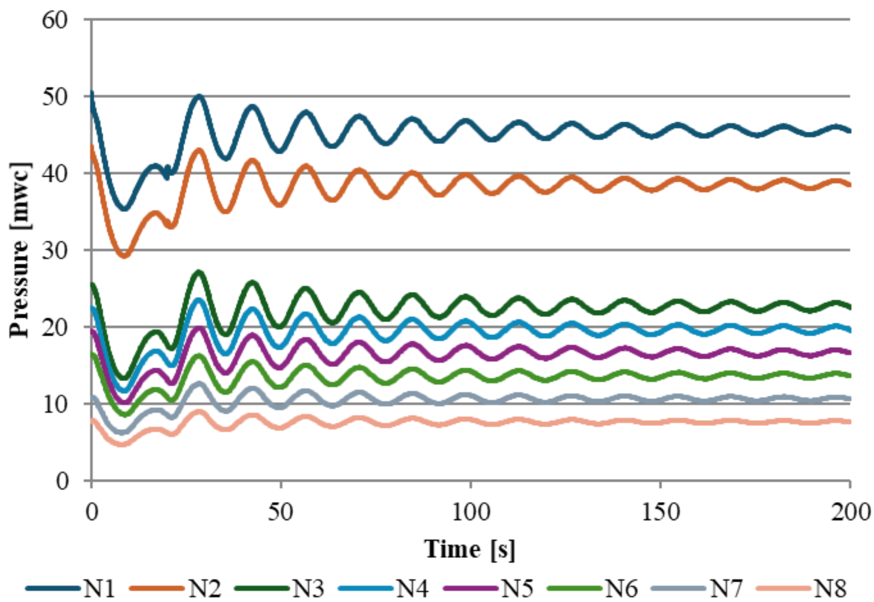

Fig.10 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of $10\ m^3$ in volume and a 20 s linear shut-off law of the check valve

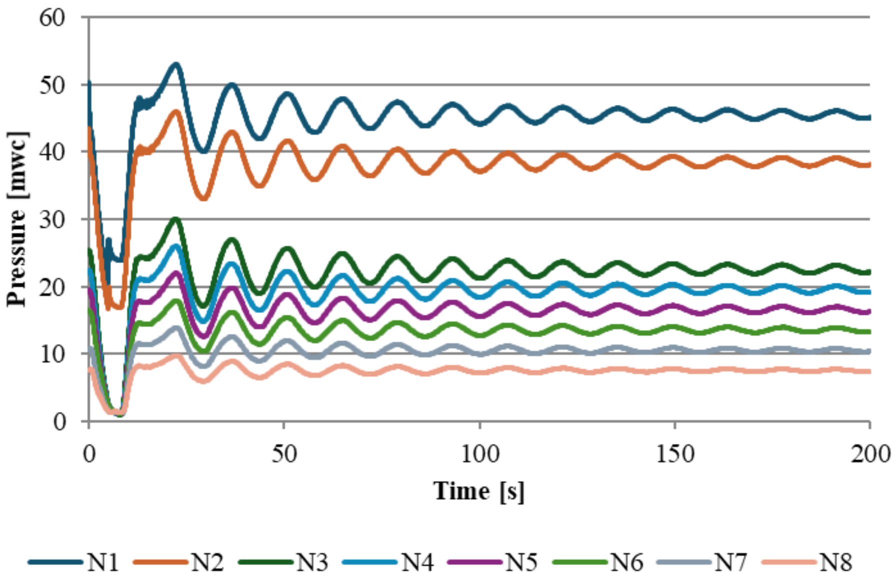

Fig.11 Pressure variation during hydraulic shock for the new proposed pumping station, for an air chamber of $10\ m^3$ in volume and a 5 s linear shut-off law of the check valve

The simulations show that all the considered sizes of the air chamber are suitable for protection.

The pick pressure values are recorded in the simulations with a 5 s linear closing law of the check valve, but they do not put the discharge duct into jeopardy. One can notice the maximum pressure in the first calculation node slightly increases with the decreasing volume of the air chamber, but they are close to the regime pressure. The minimal pressure value, in node 8, decreases with the decreasing air chamber volume, but it is always positive, thus there is no danger of water column breaking.

The 20 s linear shut-off law of the check valve simulations show a narrower field of pressure variation, and the minimal values are higher than in the case of the shorter closing law. Furthermore, the additional oscillation present in the first two calculation nodes for the shorter shut-off law disappears, for the 20s linear shut-off law, all along the discharge duct.

5. CONCLUSIONS

The design of a water supply pumping station is a complex process, which must meet both the technical requirements of the beneficiary and the current requirements regarding sustainability. To this end, the design takes into account the technical and economic optimization, ensuring operational safety and energy efficiency of the designed facility, namely Galesu base pumping station.

The analysis of the operation of the proposed pumping station indicates that it meets the technical and economic conditions imposed by the beneficiary, i.e. the operating points allow the flow rate to be regulated over the entire required range, at the appropriate pumping heads. The operating efficiency is of 94% of the maximum efficiency of the chosen pump, for all parallel possibilities of operation of the seven hydraulic pumps.

The vulnerability of the unprotected installation is highlighted by the danger of reaching a pressure almost twice the nominal value during the hydraulic shock, that may occur in the worst-case scenario - that of the simultaneous shutdown of the electrical power supply to all pumps. Numerical simulation allowed to easy find a more affordable air chamber to replace the existing one of 28 m^3 in volume, therefore, to decrease the investment cost. Furthermore, the operation costs mitigate due to the maintenance of a smaller air volume. The proposed solution for water hammer protection is the use of a 15m^3 air chamber with a single-stage of minimum 20s shut-off law of the check-valves.

6. References

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