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COMPARISON OF MEASURED AND NUMERICAL RESULTS FOR UNSTEADY FLUID FLOW AT WATER DISTRIBUTION SYSTEM

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Abstract The water supply system Studencica was built as a complete steel pipeline that provides water to the settlements of Kicevo, Makedonski Brod and Prilep. It is in operation for more than 40 years. Test measurements are made to determine the stability and the service life of the pipeline. In addition to the NDT inspection, dynamic load tests are performed with a semi-generated hydraulic shock, through rapid changes of the flow in parts of the system. Before the site testing on transient conditions, numerical calculations of the transient conditions are done with intention to predict an allowable increase of pressure into sections of pipeline. The results of the performed numerical calculations and the results of the site measurements are given in this paper. In the part for estimating the stability of the system, a method by measuring the strain-stress deformation at pipe wall was applied. Based on comparison of the hydraulic conditions and deformation of pipe wall in transient flow condition, an assessment is given for the exploitation life of the pipeline. Experiences given in this paper may indicate the idea of testing and estimating pipelines condition and service life for pipelines which are in operation for a long time.

Keywords: Water-hammer; pipeline; unsteady fluid flow; stability; exploitation period.

1. INTRODUCTION

The water supply system Studencica (Figure 1) is constructed as a steel pipeline consisting of an inlet part of the pipeline and branched into two sections: a section to Kicevo and a section to Barbaras. The length of the section towards Kicevo is 12.4 km, and the length of the section towards Barbaras is 45 km. The primary purpose of the pipeline is the distribution of drinking water to the settlements and it has the purpose of a main pipeline.

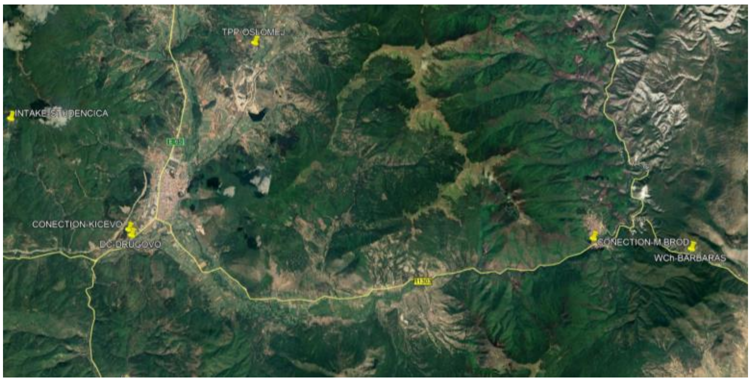


Figure 1. Water supply system Studencica inlet part and branches section Kicevo and section Barbaras.

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

With the intention of energy utilization of the excess water that occurs in the wet period of the year, as well as due to the regulation of water distribution, it is planned to upgrade the main pipeline with additional three SHPP. The longitudinal profile of the main pipeline and the location for upgrade with SHPP is given on Figure 2. If we take into account the long continuous uninterrupted period of operation of the pipeline and that with the upgrade for energy utilization it is converted into an energy pipeline, then it is necessary to perform purposeful tests to see the stability of the pipeline, the possibilities for conversion into energy pipeline, to define the hydraulic characteristics, the damage of the pipeline as well as the service life for future exploitation. The following examinations are planned:

- NDT tests, which include visual inspection of the pipeline, measurement of the wall thickness of the pipe, examination with penetrants on the welded joints,
- dynamic test, which includes causing non-stationary operating conditions of the system (quasi hydraulic shock) by measuring the deformations of the pipeline wall, the change of flow and pressure, the hydraulic losses as well as the response to changes in hydraulic parameters in non-stationary conditions.

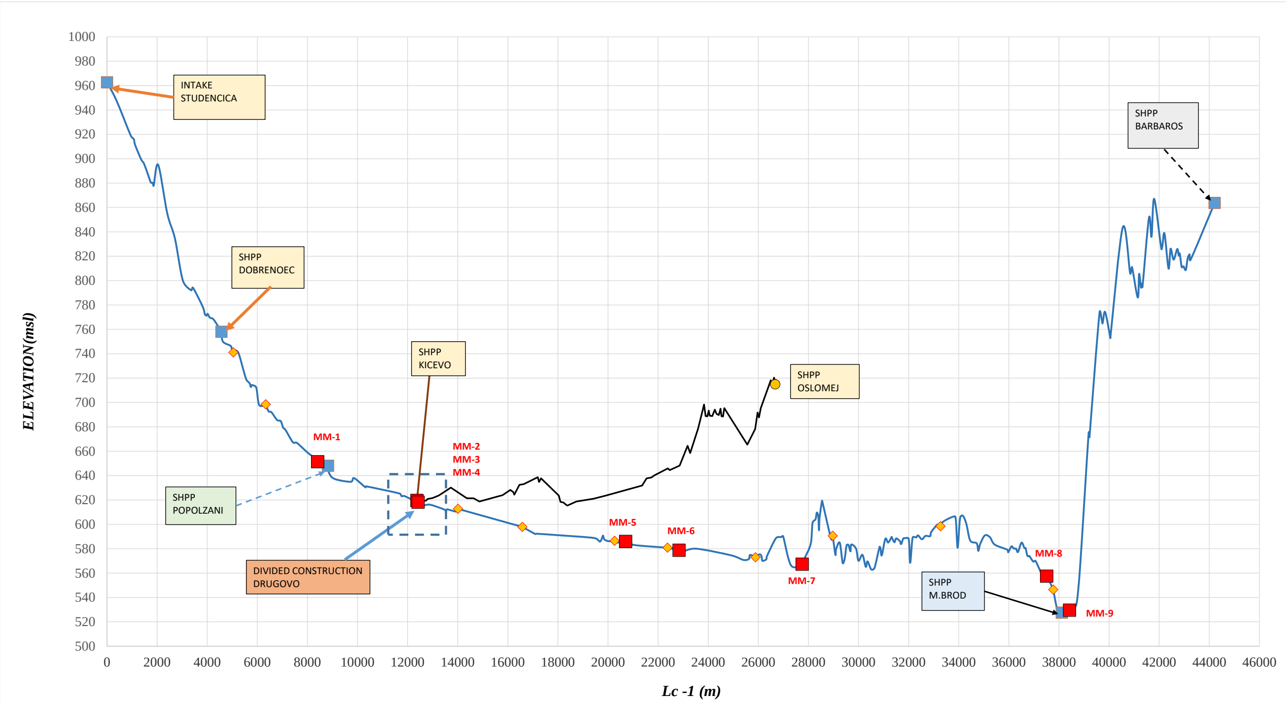


Figure 2. Longitudinal profile of the main pipeline with location for new SHPP.

2. BLOCK DIAGRAM OF ACTIVITY

The activities for realization of the examinations of the main pipeline are given in the block diagram on Figure 3. The activity are divided in two steps, first step includes preparatory work, where the water distribution pipeline system is analyzed numerically and second step, measurement at site (NDT-test and stress-strain test).

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

2.1. Numerical Analyses

The numerical model for the distribution pipeline was performed on the basis of data from documents for geodetic surveys of the route of the pipeline, the projects for construction of the pipeline by sections and the installed hydromechanical equipment of the pipeline. Numerical analysis of the system is performed in conditions of stationary and non-stationary flow mode. The non-stationarity is caused for different scenarios of exploitation of the system, by switching on-off the planned hydropower facilities that upgrade the pipeline system. The results of the calculations analyze the pressure distribution along the pipeline system, in conditions of static pressure, operating conditions in stationary mode of operation as well as in transitional conditions (minimum and maximum pressure). Figure 4 and Figure 5 show diagrams for pressure and stress distribution along the pipeline for two scenarios: flow regulation through imaginary SHPP Drugovo and imaginary SHPP Barbaras in closing conditions.

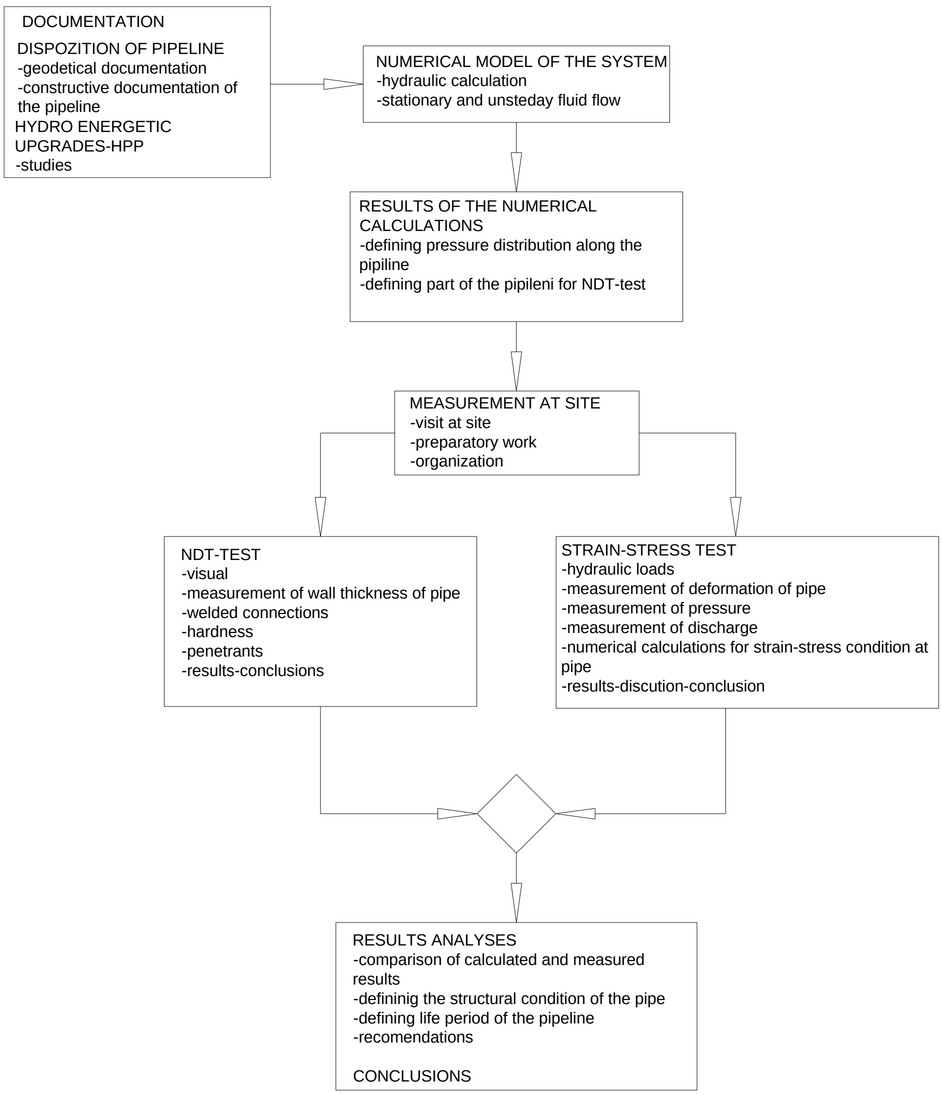
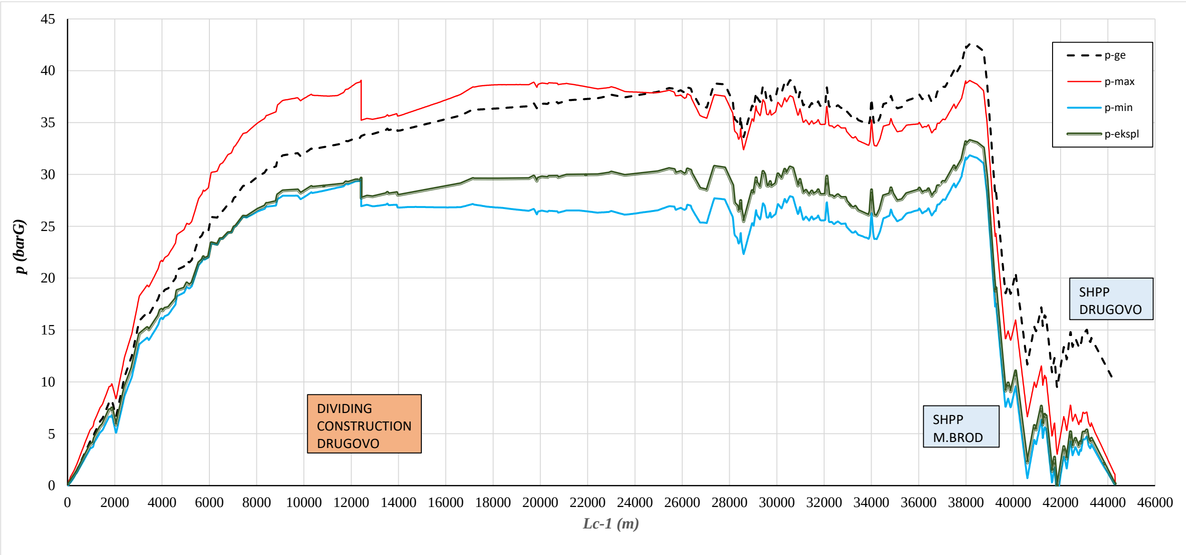


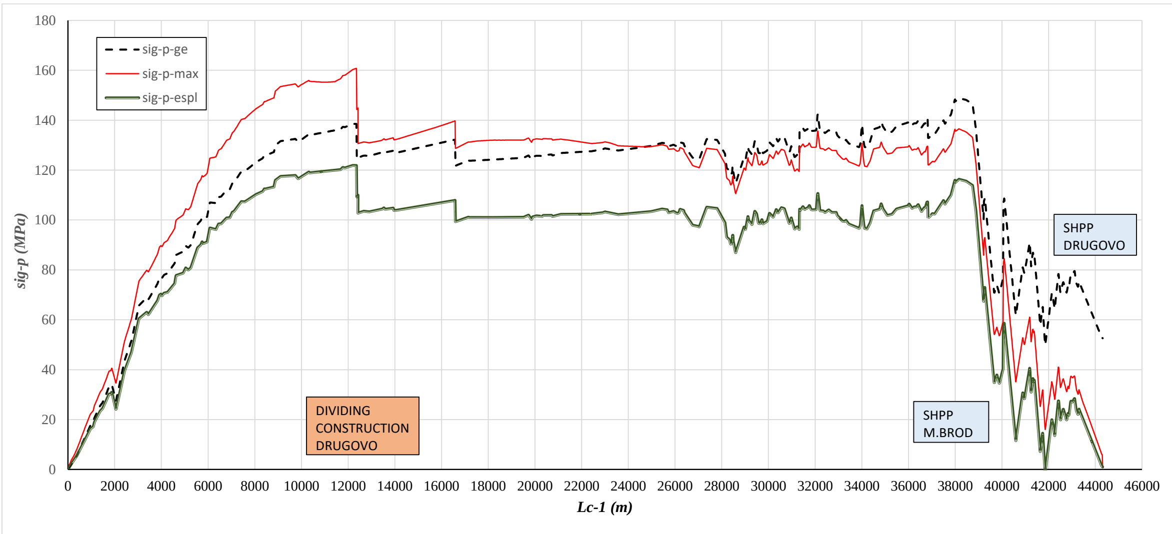
Figure 3. Block diagram for realization of activity.

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

Taking into account that the construction of the pipeline by sections is known (material, diameter of the pipe, wall thickness of the pipe), a stress distribution was calculated along the length of the pipeline in case of stationary fluid flow of use of the pipeline, hydrostatic pressure and pressures achieved during the transition operating modes of the pipeline system. The data obtained for the stresses value of the pipeline by zones for different way of exploitation define the possibilities and limitations of the existing pipeline construction. The obtained calculations also give the location of zones where control tests of the pipeline should be performed and level of degree for safety factor is observed in the pipeline system.



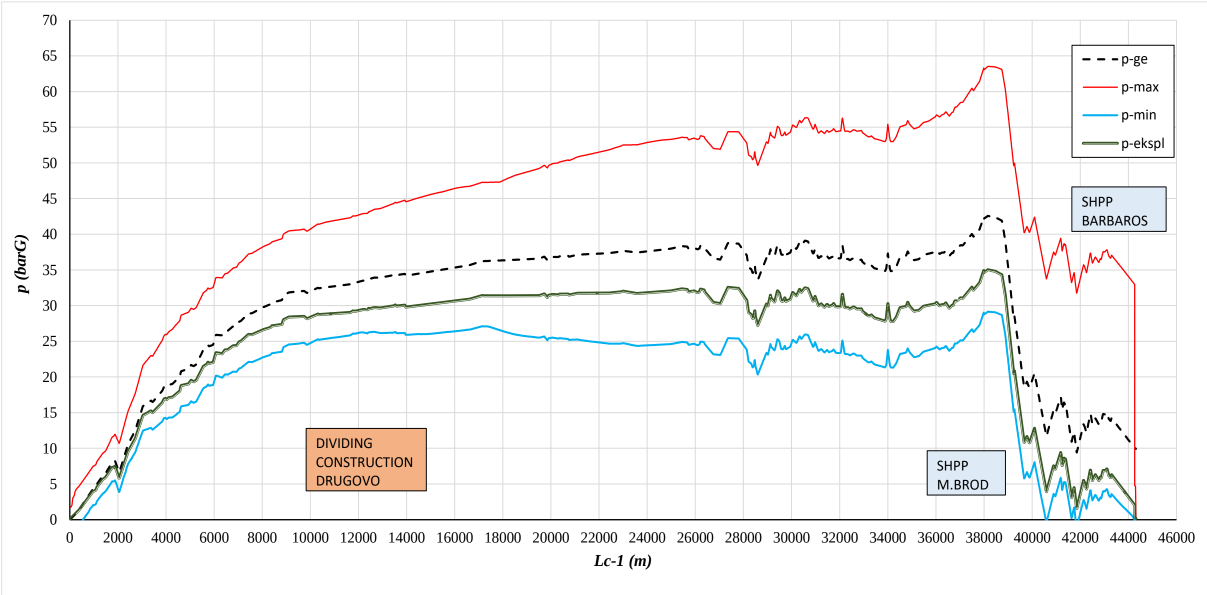
a) pressure distribution



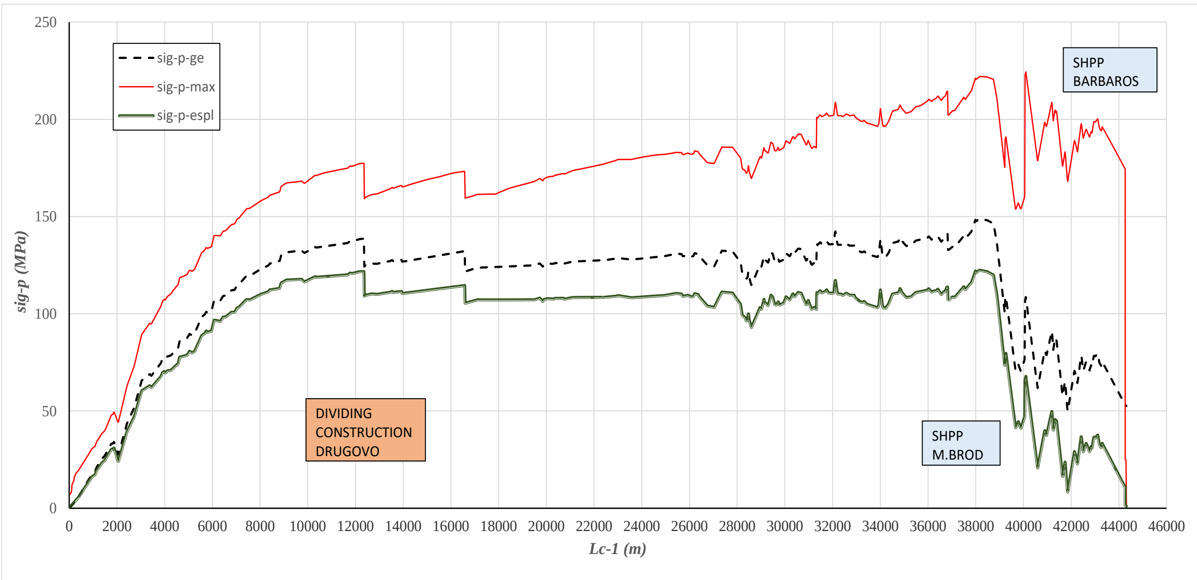
b) effect on stresses

Figure 4. Pressure and stresses distribution along the pipeline with induced unsteady fluid flow SHPP Drugovo.
p-ge, hydrostatic pressure, p-max, maximal pressure in transient condition,
p-min, minimal pressure in transient condition, p-ekspl, pressure in steady state fluid flow (exploitation)

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005



a) pressure distribution



b) effect on stresses

Figure 5. Pressure and stresses distribution along the pipeline with induced unsteady fluid flow SHPP Barbaras.
p-ge, hydrostatic pressure, p-max, maximal pressure in transient condition,
p-min, minimal pressure in transient condition, p-ekspl, pressure in steady state fluid flow (exploitation)

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2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

2.2. NDT Inspection

Based on the results of the calculations, the zones where the control NDT tests should be performed were located, i.e. the zones where the instability of the flow causes an intensive increase of the internal pressure. On Figure 6 is given activity of NDT test on pipeline.

Figure 6. NDT test of pipeline

2.3. Dynamic Testing

Strength-deformation tests (dynamic test) of the pipeline are performed by partial closing-opening of the valve (VP) that distributes water to the section of the pipeline to Barbaras. The hydraulic parameters (pressure and discharge) are measured on the inlet pipeline (shaft 29 and shaft 30) and on the section from the pipeline to Barbaras (shaft BB1 and shaft P1), as shown on Figure 7.

Preparatory works for measuring the hydraulic parameters and strength characteristics of the pipeline are given in Figure 8. An ultrasonic flow meter is used to measure the discharge, the pressure is measured with a pressure probe and the deformation is measured by placing strain gauges. The measuring instruments are connected in a data acquisition system, with a sampling time of 0.2 seconds.

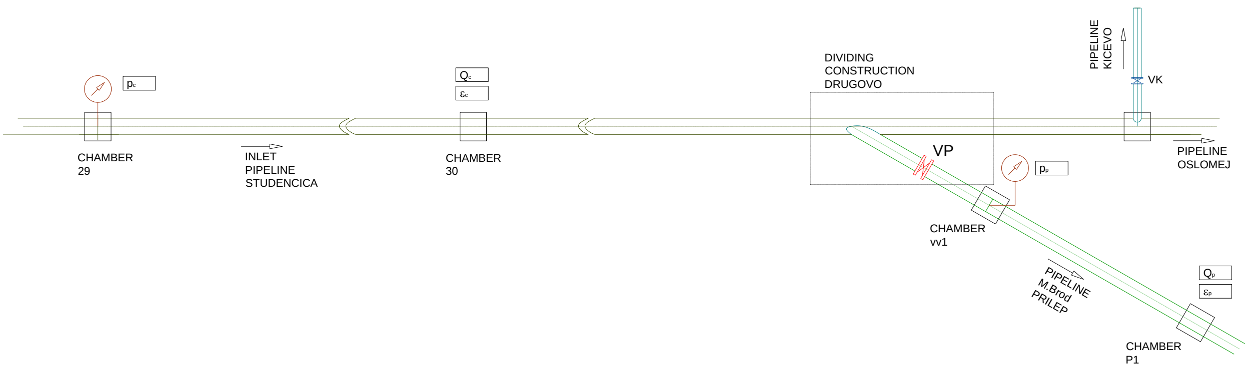


Figure 7. Measuring point for dynamic test of pipeline.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

Installation of instruments in the shaft P1 (ultrasonic flow meter and strain gauge)

Installation of instruments in the shaft VV1 (pressure)

Installation of instruments in the shaft 30 (ultrasonic flow meter and strain gauge)

Installation of instruments in the shaft 29 (pressure)

Figure 8. Measuring instrumentation for dynamic test of pipeline.

3. UNSTEADY FLUID FLOW CONDITIONS

The non-stationary states of water flow in the system, which are achieved by partial opening-closing of the valve BV1 are given through the measurements of the discharge in the supply pipeline and the section of the pipeline to Barbaras. From the diagram in Figure 9 it can be seen that three states of non-stationary flow are caused.

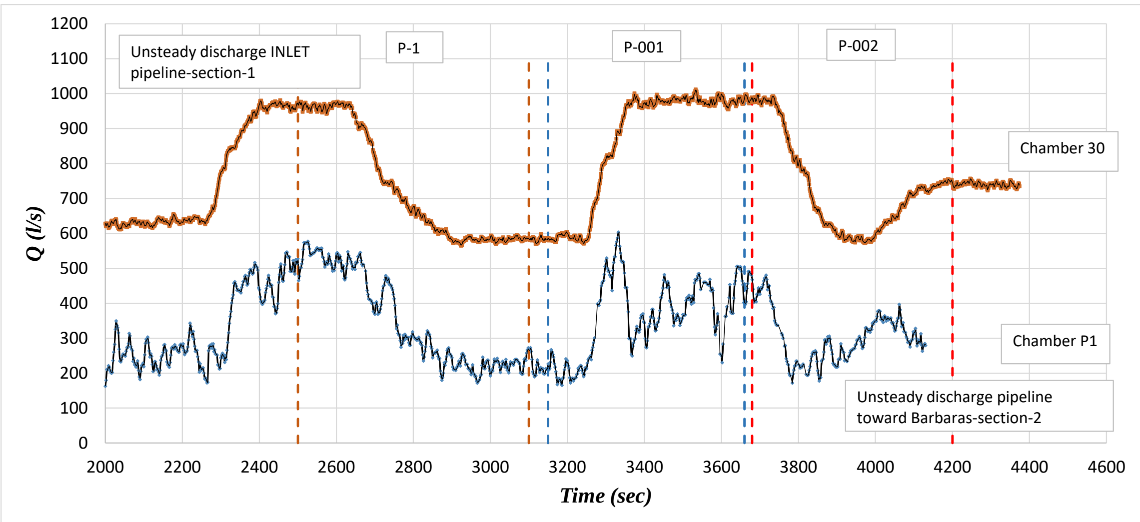
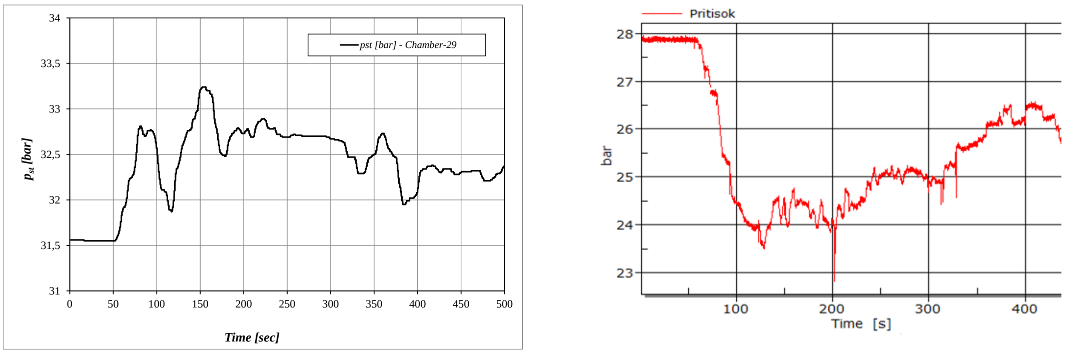


Figure 9. Unsteady fluid flow presented through discharge in the system.

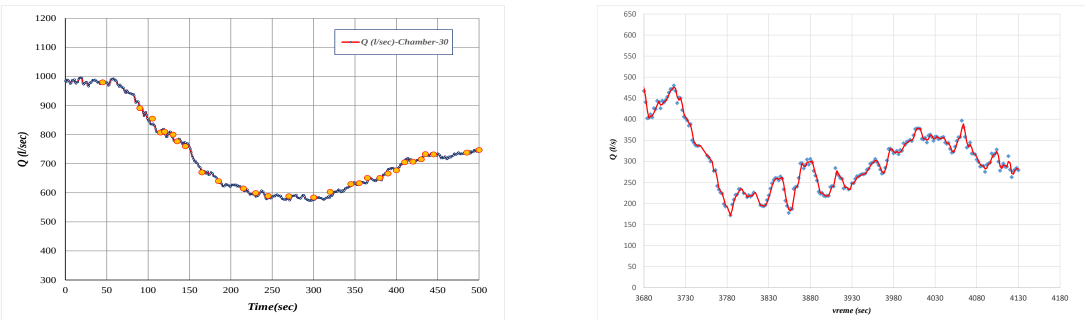
2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

3.1. Measured Parameters

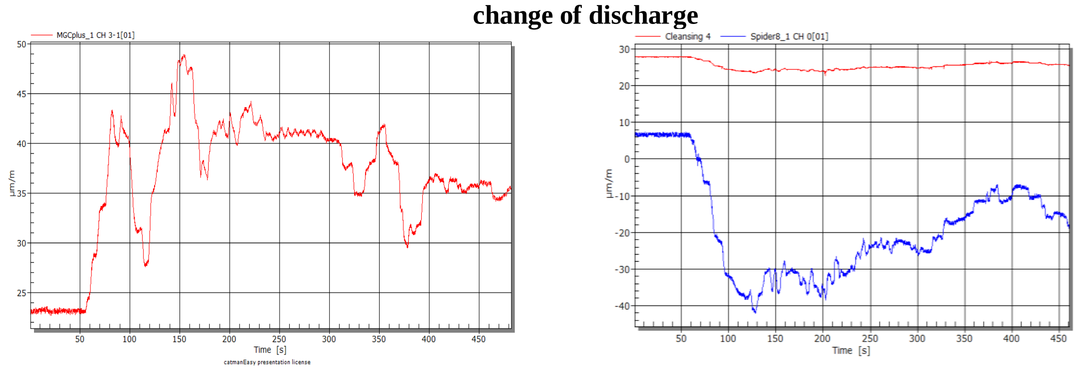
For each of the caused non-stationary conditions of the distribution pipeline system, diagrams of pressure change, discharge and deformation of the pipe wall are made, based on the same time moment of recording the condition. Figure 10 shows the recorded parameters in measured section on inlet pipeline for the pressure, discharge and deformation of the pipe wall for the transition condition P-002, according to the diagram given in Figure 9.



change of pressure



change of discharge



chande of strain

a) meassured section-inlet pipeline **b) measured section of pipe Barbaras**

Figure 10. Recorded parameters for the pressure, discharge and deformation of the pipe wall.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

Based on the recorded results, the following can be concluded:

- non-stationary current covers the phase of decreasing and increasing the flow in the system
- the change in the internal pressure in the pipeline also causes a change in the deformation of the pipeline wall
- as the internal pressure increases, the deformation increases and vice versa.

3.2. Stress-Strain Conditions

Based on the numerical value of the measured parameters, a comparative diagram of the relative stress from the relative pressure change is given in Figure 11.

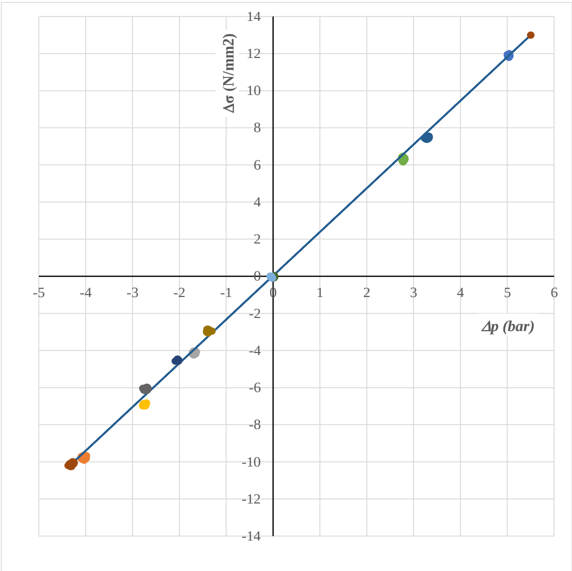


Figure 11. Comparative diagram of the relative change in pressure in the system in relation to the relative change in stress state.

From the obtained measured results, the following can be concluded:

- There is a linear characteristic between the relative change in pressure and the relative change in stresses in the pipeline
- The linearity between the change in pressure and the change in stresses, which are proportionally monitored, indicates that the pipeline is operating in an elastic range
- The reaction of the system in relation to the change in the operation (closing / opening) of valves corresponds to the expected reaction time
- Changes in the measured parameters of the inlet pipeline (ND1000) are muted, without significant pulsating effect
- The changes of the measured parameters of the pipeline towards Barbaras (ND900) are more dynamic, with the presence of a pulsating effect.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

3.3. Comparison of Numerical and Measured Hydraulic parameters

The numerical model is tested by comparing the results obtained from the calculation and the measured values for discharge and pressure in case of transient operating conditions of the system. The numerical model is set in the software package AFT-Impulse - 4.0. It should be kept in mind that the numerical model is built on the basis of theoretical structural parameters for the pipeline, set at elevations for individual sections, but certain local hydraulic losses are not included in the model. The comparison diagrams given in Figure 12 and Figure 13 refer to the measuring section of the inlet pipeline.

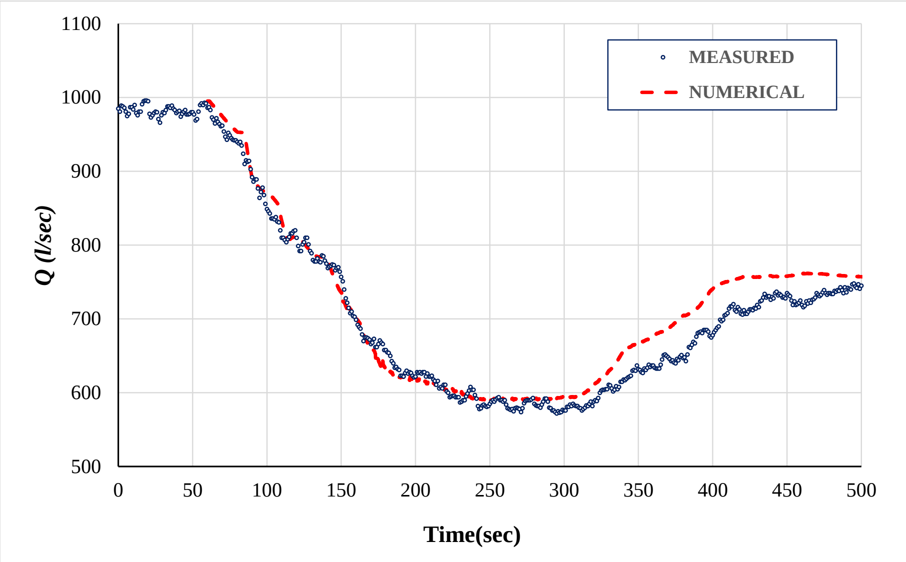


Figure 12. Comparison of calculated and measured values for discharge in unstedy fluid flow conditions.

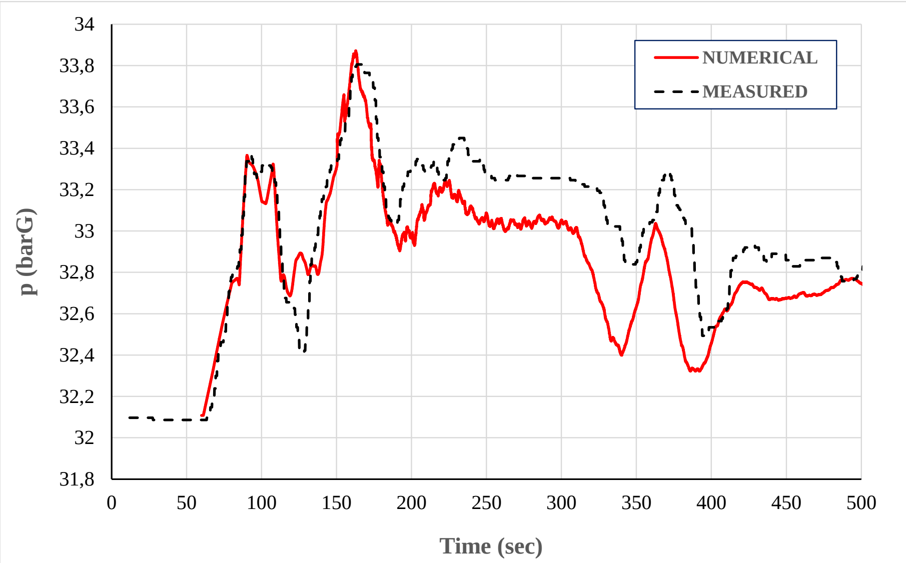


Figure 13. Comparison of calculated and measured values for pressure in unstedy fluid flow conditions.

2021, Volume 5, Issue 1, 34-45, DOI 10.6723/TERP.202102_5(1).0005

Based on the obtained comparative results, it can be concluded:

- The instability in the calculation model is given by the law of closing and opening the valve. The matching of the regularity achieved with the measurements and the given regularity of the valve opening describes the state of change of the discharge in the system.
- As a result of the given discharge change, the change of the pressure in the system is obtained. The comparative diagram for the change of pressure indicates that the same regularity that was obtained during the measurements has been achieved.
- The results of the numerical calculation for the comparison of the pressure change show that the regularities that occur in the system are described, both in terms of intensity and in terms of the time response of the system.

4. CONCLUSION

The required scope of testing and the procedure for conducting tests on a given pipeline that is in operation in order to define the life of the pipeline with conversion from gravity to energy pipeline is given in this paper. The numerical calculation is included in the evaluation procedure, which shows that the obtained numerical results describe the situation in the system well. The estimation of the service life of the pipeline can be estimated on the basis of previously measured-obtained parameters for the pipeline by conducting NDT tests (corrosion, wall thickness of the pipe, stability of welded joints, surface hardness, etc.) and based on the results of dynamic tests (strain-stress behavior of the pipeline at variable load with internal pressure). The proposed program for defining the service life of the pipeline must include both elements – condition of pipeline and prediction of future exploitation by numerical calculations. The necessity for iterative analysis and testing of the pipeline (numerical, NDT and dynamic) fully defines the forecasts for the durability and prediction of the service life of the pipeline system.

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