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GIS AND NONLINEAR DYNAMICS MODEL: SOME COMPUTATIONAL ASPECTS AND PRACTICAL HINTS

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Abstract- A particular challenge in terms of calculations is a hydraulic shock, accompanied by discontinuities of the flow. This phenomenon has not been fully studied, so the works of many scientists are devoted to experimental and theoretical studies of non-stationary processes with column separation of liquid. In this work it was defined the nonlinear heterogeneous model based on Geography Information System "GIS". By the way the process of modeling for unsteady fluid flow at drinking water transmission pipeline was presented.

Keywords: Unsteady Fluid Flow, Nonlinear Heterogeneous Model, Geography Information System.

I. INTRODUCTION

N.E. Zhukovsky introduced the concept of the effective sound speed. He mentioned to reducing the motion of a compressible fluid in an elastic cylindrical pipe to the motion of a compressible fluid in a rigid pipe, but with a lower modulus of elasticity of the liquid. Calculations of hydraulic shock in multiphase systems, including a computer, are devoted to the work of V.M. Alysheva. In that work, integration of differential equations of unsteady pressure flow is also performed by the "method of characteristics" .The works of Streeter, K.P. Vishnevsky, B.F. Lyamaeva, V.M. Alyshev use the method of calculation of water hammer. They are based on replacing the distributed along the length of the flow of gas parameters concentrated in the fictitious air-hydraulic caps installed on the boundaries of the pipeline. A fictitious elastic element is replaced by elastic deformation of the pipe walls, and the elastic deformation of the solid suspension is modeled by fictitious elastic elements of the solid suspension. However, detailed experimental studies are based on the solid component. First detailed study and writing the first design formula, for such cases of hydraulic shocks with discontinuities of continuous flow, was the work of A.F. Masty.

Subsequently, the development of this issue was paid more attention by A. Surin, L. Bergeron, L.F. Moshnin, N.A. Kartvelishvili, M. Andriashev, V.S. Dikarevsky, K.P. Wisniewski, B.F. Laman, V.I. Blokhin, L.S. Gerashchenko, V.N. Kovalenko, and others. The most detailed experimental and theoretical study of water hammer with a discontinuity in the flow conduits performed by D.N. Smirnov and L.B. Zubov. As a result of the research, they describe the basic laws of gap columns, fluid and obtained relatively simple calculation dependences. In the above works, there are methods of determining maximal pressures after the discontinuities of the flow. However, the results of calculations by these methods are often contradictory. In addition, not clarified the conditions under which the maximum pressure generated.

There is little influence of loss of pressure, vacuum, nature and duration of flow control and other factors on the value of maximum pressure. The study of V.S. Dikarevsky for water hammer was included to break the continuity of flow. His work dealt with in detail, the impact magnitude of the vacuum on the course of the entire process of water hammer. Analytically and based on experimental data, scholars have argued that in a horizontal pipe rupture. The continuity of the flow occurs mainly in the regulatory body, and cavitation phenomena on the length of the pipeline are manifested. It investigates only in the form of small bubbles, whose influence on the process of hydraulic impact is negligible. As a result, research scientists have obtained analytic expressions for the hydraulic shock. They mention a gap of continuous flow, taking into account the energy loss, while controlling the flow and the wave nature. However, studies of V.S. Dikarevskogo were conducted mainly for the horizontal pressure pipelines and pumping units with a low inertia of moving masses.

Researches of N.I. Kolotilo and others devoted to the study of water hammer to break the continuity of flow in the intermediate point. N.I. Kolotilo analytically derived the condition for the gap of continuous flow at a turning point of the pipeline when the pressure is reduced at this point (below atmospheric pressure). Studies have shown that the location of the discontinuity of continuous flow at a turning point depends, first of all, the profile of the pipeline. Protection of hydraulic systems against water hammer by releasing part of the transported fluid is the most widespread method of artificial reduction of the hydraulic shock. Devices that perform this function can be divided into valve, bursting disc and the overflow of the column.

Development of algorithms for software simulation of transients by K.P. Vishnevsky was made for the complex pressure systems. It included the possible formation of discontinuities flows, hydraulic resistance, structural features of the pumping of water systems (pumps, piping, valves, etc.). However, a calculation of water hammer is adapted to high-pressure water systems for household and drinking purposes. K.P. Vishnevsky used "characteristics method" for the calculation of water hammer on a computer dedicated to the work of B.F. Lyamaeva was illustrated by Hariri Asli et al., 2009 [1].

II. MATERIALS AND METHODS

The Laboratory has been a leader in the development of sophisticated numerical techniques for analysis of multiphase flows and in the construction of computer codes based on the Geography Information System "GIS" techniques. A model for liquid-vapor flows illustrates the numerical techniques for solving the resulting equations. Hence field test model was chosen for experimental presentation of water hammer phenomenon at the water pipeline. Measuring output for field tests and laboratory experiments were performed at 0:00 hours on 02/10/2007- 02/05/2009. This work although includes the description of air entrance phenomenon at the flow discontinuities and changes for gas content. The wave speed distribution along with a pipeline (with node points *i* = 0, 1, . . . , *N)* was given by Lee and Pejovic, 1991 [2]. In this work, at first it was simulated the transient pressure generation in the system due to an emergency power failure without any protective equipment in service. It was shown that at point P24:J28 of the water pipeline, air was interred to the system. Max. Vol. of penetrated air was equal to 198.483 $\left[\text{m}^3\right]$ and current flow was equal to 2.666 $\left[\frac{\text{m}^3}{\text{s}}\right]$.

Treated or modeled air entrainment problems in real prototype systems and results were shown in Table 1 and Table 2. Consistency for the observed values of maximal pressure (in the first amplitude), the corresponding values were calculated according to Joukowski's formula. Based on validity of results, it was selected protective equipment and the system was simulated. Again by investigation of modeling results, the effectiveness of the devices which selected for controlling the transient pressures was rechecked. At present, work analysis and comparison were included in nonlinear heterogeneous model results by Hariri Asli et al., 2009, Hariri Asli et al., 2010 [3, 4].

A. Formulation of the Problem

Water hammer is the result of sharp changes of fluid pressure by the instantaneous changes in the rate of flow in the pipeline. This phenomena occurs during water hammer are explained on the basis of compressibility of liquid. After closing the valves on the horizontal pipe of constant diameter, which the liquid moves with an average speed V_0, a liquid layer, located directly at the gate valve, immediately stops. Far the away from the gate, there are successively movement of the liquid layers (turbulence, counter flows). As a result by increasing pressure the pipe will be expanded. By the way the tube includes an additional volume of liquid. Since the fluid is compressible, its mass does not immediately be stopped.

B. The Problem Solution Methods and Approbation

It moves from the gate valve along the pipeline with velocity C, called the speed of propagation of the pressure wave which was mentioned by Leon, 2007 [5]. Two cases were considered for modeling using (1) and (2) by Wylie and Streeter, 1982, [6]:

1- The inlet pressure of the pipe along its length is equal to p_0. The slugging pressure has a sharp increasing: $\Delta p_{\text{уд}} : p = p_0 + \Delta p_{\text{уд}}$. The Zhukovsky formula is as the flowing:

$$\Delta p_{\text{уд}} = \left(\frac{C.\Delta V}{g} \right) \tag{1}$$

where g is acceleration of free fall. The speed of the shock wave is calculated by the formula:

$$C = \sqrt{\frac{\dfrac{g.E_{\text{ж}}}{\rho}}{1 + \dfrac{d}{\delta} \cdot \dfrac{E_{\text{ж}}}{E}}} \tag{2}$$

where $E_{\text{ж}}$ is modulus of elasticity of the liquid (water) $E_{\text{ж}} = 2 \cdot 10^9$ [Pa] $\left[\frac{\text{kg}}{\text{m}^2}\right]$, E is modulus of elasticity for pipeline material steel $E = 10^{11}$ [Pa] $\left[\frac{\text{kg}}{\text{m}^2}\right]$, d is outer diameter of the pipe in [mm], ρ is density in $\left[\frac{\text{kg}}{\text{m}^3}\right]$, δ is wall thickness in [mm]. Stopping of a second layer of liquid exerts pressure on the following layers gradually caused high pressure. It acts directly at the valve extends to the rest of the pipeline against fluid flow speed C.

2- The method of characteristics MOC is defined based on a finite difference technique where pressures are computed along pipe for each time step using (3) and (4).

$$H_P = 1/2 \begin{pmatrix} C/g\left(V_{le} - V_{ri}\right) + \left(H_{le} + H_{ri}\right) - \\ C/g\left(f\ \Delta t/2D\right)\left(V_{le}\left|V_{le}\right| - V_{ri}\left|V_{ri}\right|\right) \end{pmatrix} \tag{3}$$

$$V_P = 1/2 \begin{pmatrix} \left(V_{le} + V_{ri}\right) + \left(g/C\right)\left(H_{le} - H_{ri}\right) - \\ \left(f\ \Delta t/2D\right)\left(V_{le}\left|V_{le}\right| + V_{ri}\left|V_{ri}\right|\right) \end{pmatrix} \tag{4}$$

III. RESULTS AND DISCUSSIONS

Significant influence of the discharge rate into the pipeline decreases of duration of the water hammer phenomenon. The duration time decreased with the increase of the air penetration. This was the strong reason for the high deceasing in duration time for water pipeline. In this work column separations due to turned off pump for water pipeline were illustrated in Figures 1 and 2.

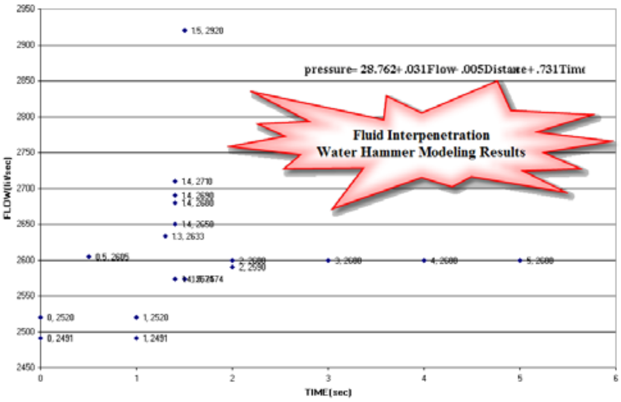

Figure 1. Nonlinear heterogeneous model; water column separation and entered air simulation

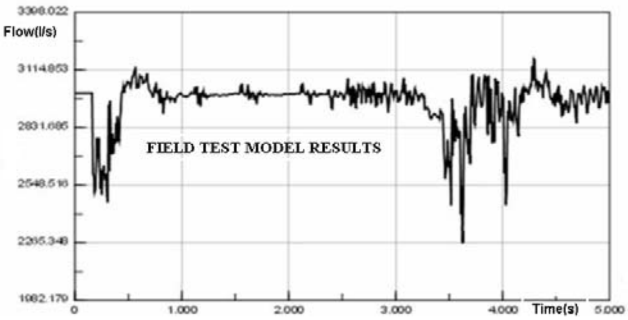

Figure 2. Laboratory experiments and field test results

Table 1. The simulation results of field tests for maximum amount of air infiltration

Node ID	Label	Category	Type	Elevation	X-cord.	Y-cord.	Branch pipes	Vapour Pressure	Max. volume	Type of volume	Code
24	J28	Protection equip.	air valve	95.2	211.71	35.02	2	-10	198.483	Air	76

Table 2. The simulation results of field tests

Node ID	Label	Category	Type	Elevation	X-cord.	Y-cord.	Branch pipes	Vapour Pressure	Max. volume	Type of volume	Code
1	J2	Junction	2 -more	35.5	7.32	0	2	-10	0	Vapour	68
2	J4	Junction	2 -more	37.2	20.52	0.34	2	-10	0	Vapour	68
3	J1	Reservoir	1 -more	40.6	0	0.3	1	-10	0	Vapour	23
4	J3	Pump	shut	35.5	14.33	0.3	2	-10	0	Vapour	74
5	J7	Junction	2 -more	36.3	43.1	3.32	2	-10	0	Vapour	68
6	J8	Junction	2 -more	36.1	49.24	3.14	2	-10	0	Vapour	68
7	J11	Junction	2 -more	38.6	70.34	9.13	2	-10	0	Vapour	68
8	J12	Junction	2 -more	39.7	75.7	12.17	2	-10	0	Vapour	68
9	J14	Junction	2 -more	42.3	91.78	19.48	2	-10	0	Vapour	68
10	J16	Junction	2 -more	43.4	113.54	23.01	2	-10	0	Vapour	68
11	J18	Junction	2 -more	43	133.05	18.76	2	-10	0	Vapour	68
12	J19	Junction	2 -more	42.3	142.26	22.19	2	-10	0	Vapour	68
13	J21	Junction	2 -more	42.5	162.94	33.48	2	-10	0	Vapour	68
14	J22	Junction	2 -more	44.6	174.32	39.89	2	-10	0	Vapour	68
15	J23	Junction	2 -more	69.9	192.14	39.9	2	-10	0	Vapour	68
16	J27	Junction	2 -more	36.5	29.83	0.25	2	-10	0	Vapour	68
17	J26	Prot equip	air valve	37.2	25.22	0.16	2	-10	0	Air	76
18	J9	Prot equip	air valve	38	55.2	7.47	2	-10	0	Air	76
19	J10	Junction	2 -more	38.3	61.71	11.54	2	-10	0	Vapour	68
20	J15	Prot equip	air valve	45.2	104.6	30.77	2	-10	0	Air	76
21	J17	Prot equip	air valve	45	123.39	15.06	2	-10	0	Air	76
22	J20	Prot equip	air valve	44.2	150.66	25.26	2	-10	0	Air	76
23	J24	Junction	2 -more	81.8	204.22	38.36	2	-10	0	Vapour	68
24	J28	Prot equip	air valve	95.2	211.71	35.02	2	-10	198.483	Air	76
25	N1	Reservoir	1 -more	95.9	219.75	28.79	1	-10	0	Vapour	23
26	J6	Junction	2 -more	36.3	35.7	3.5	2	-10	0	Vapour	68
27	J13	Junction	2 -more	41	85.73	17.14	2	-10	0	Vapour	68

A. Air Entrance Approaches

Analysis of the nonlinear heterogeneous model showed that at point P24: J28, air penetrated into water pipeline .The maximum amount of infiltrated air was illustrated in Figure 3 was equal to 198,483 $\left[\mathrm{m}^3\right]$, and the flux was equal to 2,666 $\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$.

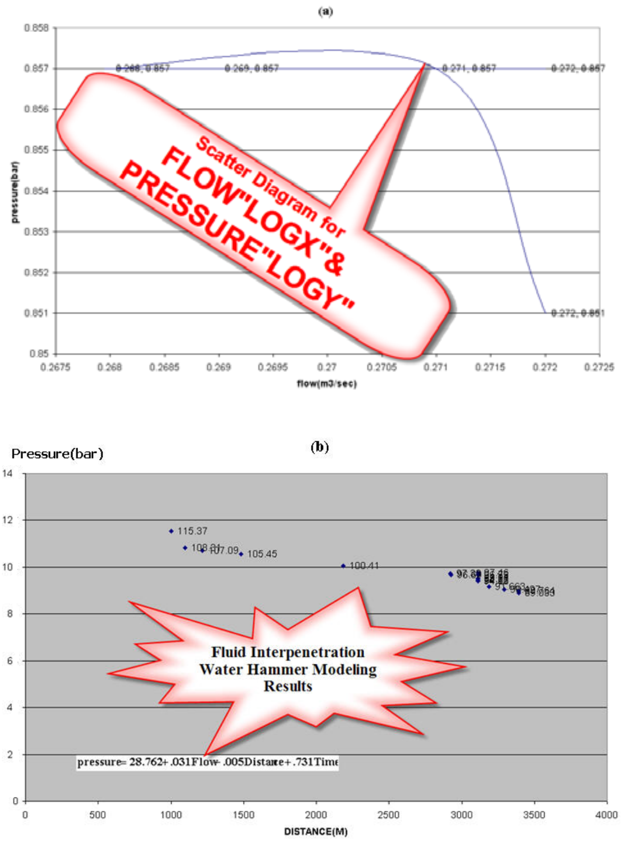

Figure 3. (a) Laboratory experiments, (b) Field test

B. Comparison of Present Work Results with other Expert's Research

Comparison of present work results (nonlinear heterogeneous model-water hammer software modeling), with the results of other expert's works, Apoloniusz Kodura and Katarzyna Weinerowska (2005). In present work water hammer has been run in pressurized pipeline. The observations, experiments and numerical analysis shows air existence in the pipeline have generated the complex condition for water hammer phenomenon. Therefore it has been influenced by some additional factors.

Detailed conclusions were drawn on the basis of experiments and calculations for the pipeline with air entered. Hence the most important effects that have been observed were as the flowing: at first, the influences of the ratio of air have been appointed. Then the total discharge related to the periodic wave oscillations has been investigated. The outflow to the overpressure reservoir from the leak was effected the value of wave celerity. The pipeline was equipped with the valve at the end of the main pipe, which was joined with the closure time register. The water hammer pressure characteristics were measured by extensometers, and recorded in computer's memory. The supply of the water to the system was realized with use of reservoir which enabled inlet pressure stabilization, was ilustrated by Apoloniusz et al., 2005 [7].

C. Application of Achieved Results

Pressure at the beginning of pipeline remains constant. After shock wave generation, flow moves with the same velocity C at the reverse direction of the shock wave. This leads to the generation of high pressure drop due to the wave. At the same time fluid moves in the direction of the initial section of the pipe. As long as the shock wave reaches to the pressure reducing valve, liquid pressure reduces to vapor pressure.

By the way, again and again, the wave of pressure drop moves conversely in the direction of start point on the water pipeline. As long as damping of shock wave, these cycles of increase and decrease of pressure will be continued. It is iterated at time intervals equal to time for dual-path of the shock wave along the length of the pipeline (from the pressure reducing valve prior to the start point of pipeline).

IV. CONCLUSIONS

The hydraulic impact of the liquid in the pipeline will perform oscillatory motion. The hydraulic resistance and viscosity cause the oscillatory motion. It absorbs the initial energy of the liquid as long as overcoming the friction and therefore it will be damped. Water hammer is manifested in hydro-machines various purposes. In most cases this is undesirable; leading to the destruction of pipelines was illustrated by Hariri Asli et al., 2010 [8, 9]. Maximum amount of air infiltration which was calculated based on the simulation results of nonlinear heterogeneous model can be removed by the system (Table 1).

Geography Information System "GIS" can eliminate water hammer during abnormal operations. Abnormal operations include things like initial startup and power out conditions in Earthquake. For these abnormal circumstances it is important to have safety equipment installed. Equipment that will help during a power outage includes surge tanks, gas vessels, surge anticipator valves, and pressure relief valves. Variable speed pumps have computerized electronic controls and are only as dependable as other electronic devices such as computers, cell phones, and monitoring link to GIS.

By application of pipeline geo reference coordination in database under GIS management and data exchange between receiver and transducer from pipeline to Programmable Logic Control "PLC", all of the system can be on-line controlled by transmitting pulse to control valves, sure tank and all of controllable instruments at transmission pipeline and pump station. By the way urban system will be protected from water hammer disaster which was mentioned by Hariri Asli, 2008 [10].

NOMENCLATURES

T - Time $[\mathrm{s}]$

D - Diameter of each pipe $[\mathrm{m}]$

p - Surge pressure $[\mathrm{pa}]$

C - Velocity of surge wave $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$

H_P - Surge wave head at pipeline points- intersection points of characteristic lines $[\mathrm{m}]$

V_P - Surge wave velocity at pipeline points- intersection points of characteristic lines $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$

g - Gravitational acceleration constant $\left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$

V_{ri} - Surge wave velocity at right hand side of intersection points of characteristic lines $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$

H_{ri} - Surge wave head at right hand side of intersection points of characteristic lines $[\mathrm{m}]$

V_{le} - Surge wave velocity at left hand side of intersection points of characteristic lines $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$

H_{le} - Surge wave head at left hand side of intersection points of characteristic lines $[\mathrm{m}]$

C^- - Characteristic lines with negative slope

C^+ - Characteristic lines with positive slope

Min. = Minimum

Max. = Maximum

Lab. = Laboratory

MOC = Method of Characteristic

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BIOGRAPHY

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