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MATHEMATICAL SIMULATION FOR TRANSIENT FLOW IN PIPES UNDER POTENTIAL WATER HAMMER

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ABSTRACT:- To protect the physical integrity of a pipeline system, there may be a need to install surge control devices, such as surge relief valves, surge tanks, or air-vacuum valves, at various points in the system. The main purpose of this study is to simulate the transient flow in pipes with water hammer using a mathematical modeling. By taking Omar Almokhtar Reservoir and Omar Almokhtar Grand Reservoir hydraulic system as a case study, where this system located at 35 Km south of Benghazi city. The analysis of simulation of this study is based on a characteristics method assisted by well known software called WANDA which was developed by Delft Hydraulics / Netherlands. Maximum and minimum pressures generated by the different scenarios implemented in this study confirm that the installed air vessels capacity of 1500 m^3 are sufficient to control all pressure values within the bar rating of the installed pipes. It is also found that the pipe section just upstream of OMG reservoir air valve(s) with adequate capacity is (are) needed at this section of the pipeline. Air vessels with capacity 1000 m^3 are not enough to damps the pressures that occur during transient duration.

***Keywords*:-**Water Hammer, Transient Flow, Air vessels.

INTRODUCTION

In general any disturbance in the water during a change in mean flow conditions initiates a sequence of transient pressures (surge) in the water distribution systems. These can create serious consequences for water utilities if not properly recognized and addressed by proper analysis, appropriate design and operational considerations. [(3)].

Unsteady flow can be subdivided according to the rate at which the velocity or pressure is varying. If changes occur slowly so that compressibility of liquid in unimportant, the phenomenon is referred to as a *surge*. Example would be an oscillating U-tube or the rise and fall of the water level in surge tank. If rapid changes occur in the velocity, pressure waves are generated and transmitted through the pipe at acoustic velocity. Such rapid velocity changes often result in large pressure increases. This type of unsteady flow is called a hydraulic transient or water hammer. [(5)].

WATER HAMMER

Any system containing a fluid, which is in motion through pipes, can experience pressure transients (Water Hammer). Damage will occur when the magnitude of transient pressure variations exceeds the design limit of the pipe system . Both extremes of those pressure variations-maximum values and minimum values may be dangerous. When changes in velocity and pressure, occur rapidly both the compressibility of the fluid and the elasticity of the pipe must be included in the analysis. [(3)]

The pressure waves travel with the velocity of sound (celerity), which depends on the elasticity of the water and the elastic properties of the pipe. As these waves propagate, they create a transient adjustment to the pressure and flow conditions throughout the system. Over time, damping actions and friction reduce the waves until the system stabilizes at a new steady state conditions .[(6)].

The causes of water hammer are varied. There are four common causes that typically make large changes in pressure: sudden power failure at pump station , starting or stopping of pumps ,rapid changes in valve setting and unstable pump characteristic curve [(7)]. Hydraulic systems must be designed to accommodate both normal and abnormal operations and be safeguarded to handle all the above causes.

CHOICE OF SURGE PROTECTION STRATEGY

A number of techniques can be used for controlling transients in water distribution systems. Some strategies involve design and operational considerations alone, and some also use the addition surge protection devices. Devices such as pressure relief valves, surge (air) vessels, surge tank, pump bypass lines, or any combinations are commonly used to control maximum pressures. Minimum pressures can be controlled by increasing pump inertia or by adding surge vessels, surge tanks, air-release/vacuum valves, pump bypass lines, or any combination of that group. The main objective is to reduce the rate at which flow changes occur. Figure (1) illustrates typical locations for various surge protection devices in water distribution systems.

MATHEMATICAL BACKGROUND

The two equations which are used to calculate transients in conveyance systems are the continuity and momentum equations. Even in their simplified form, these two basic equations are complex in solving and represent quasi-linear hyperbolic partial differential equations containing two independent variables and two dependent variables. The most widely used technique for solving these equations is the method of Characteristics [1] . The method of characteristics solves these two equations by first converting them into ordinary differential equations, which are then solved by a finite difference method. This solution technique can be readily programmed into computer software allowing rapid analysis, which overcomes the limitations of graphical methods.[4]

Any change of velocity in a pipe results in a change of pressure. The relationship between these two parameters is given by the following formula, credited to Joukowsky:

$$\Delta h = \frac{c\Delta V}{g} \qquad \text{..........................(1)}$$

Where: Δh = change in head, c = velocity of pressure wave (celerity) , m/s ,ΔV= change in velocity, m/s ,and g = acceleration due to gravity.

To develop an equation for the wave speed, both the basic equations of the mechanics of solid materials for pipe wall and the compressibility of water are considered and the final relation can be represented as [2,3]

$$c = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1+\frac{KDx}{Ee}}} \qquad \text{............................(2)}$$

Where : x = constant depend on the pipe restrained ,ρ = density of water , e = pipe thickness, K =modulus of elasticity of pipe, D =pipe diameter and E = modules of elasticity of fluid.

WATER CONVEYANCE SYSTEM

Four locations have been identified as the most promising areas to be utilized by the Great Man-Made river in region of Benghazi governorate, they are: Al-Khadra area ,Wadi

Al-Gattara, Ghot Al-Sultan, and Benghazi Plain. [8,9] A secondary conveyance system was required to distribute the water among these projects. This secondary conveyance system linking Omar Al-Mokhtar Reservoir and Omar Al-Mokhtar Grand reservoir. Sketch of system setup and the map of Benghazi plain are shown in figure (2) and figure (3) respectively. The system consists mainly of:

1. Conveyance Pump Station (C319)

It consists of 7 pumps (5 main, 1 standby, and 1 for maintenance). Each pump gives a flow rate of 1.78 m^3/sec and the total flow is 8.91 m^3/sec. with vertical position, the available head is 97 meters. It conveys the rest of the water allocation to Omar Al-Mokhtar Grand reservoir through the secondary conveyance pipeline.

2. Secondary Conveyance Pipeline

The type of pipes used for this pipeline is pre-stressed concrete cylinder pipes with a diameter of 2.2 and 2 meters, this pipeline conveys water to Omar Al-Mokhtar Grand reservoir (24 Mm^3 capacity). The available pressure in this pipeline allows the full operation of Al-Khadra large farm project (14,000 hectares) which is the largest project planned to be utilized by that branch. This project will be operated through 4 turnouts built on the pipeline, it consist of 14 air valves with different sizes and 13 manholes along the profile.[8].

3. Omar Al-Mokhtar Grand Reservoir

Its capacity is 24 Mm^3. it has a round shape with a diameter at bottom 1012m and at top 1157m, the wall width at bottom is 150m and at top is 7m. Its height is 30m. This reservoir has been constructed for storage purpose . In emergency cases there is a possibility of water to move back to Omar Al-Mokhtar reservoir. (4.7 Mm^3) and refill it within about 7 days .[8,9] .

HYDRAULIC ANALYSIS

The main objective of this analysis is to illustrate the important of anti surge devices in preventing vaporization and inadmissible excess pressure in the whole system. The following items have been analysed :

- Maximum and minimum pressure heads along the pipeline during transient events resultant from pump tripping during power failure.
- Whether or not the available air vessels capacity is enough to ensure the safety of the system during the transient events.

- And using other air vessels capacity less than the actual to show the effectiveness of the real capacity.

The calculation is based on a characteristics method assisted by well known software called WANDA which was developed by Delft Hydraulics / Netherlands and is a result of many decades of research and experience [10]. Simplified scheme for the system components and nodes is shown in Figure (4) in which CS1 control station , (A,B,C,D,E,…..etc) control nodes , and B1(OMR) and B2(OMGR) represent Omar Almokhtar Reservoir and Omar Almokhtar Grand Reservoir respectively.

SIMULATION SCENARIOS

There are large combination of scenarios could be implemented and analysed, but only some of them could affect the hydraulics of the system more than the others. Based on the importance of the events, table (3) were used to list the scenarios selected for the transient analysis. In all cases the number of pumps in operation are five with total flow of 8.91 m^3/sec, all turnout valves are close, the control station (CS1) is open and all pumps are tripped in 3 seconds.

RESULTS AND DISCUSSIONS

1. Figure (5) shows the pressure distribution along the pipeline for Case#1.The maximum pressure exceeds the normal pressure bar rating for most of the pipeline up to the section just upstream of (CS1). Referring to table (1) , we can conclude that the resulted pressure for this case did not exceed the surge pressure bar rating. Bearing in mind, that the pipe surge pressure bar rating may decrease with time depend on the kind of pipe material and operation conditions. The minimum pressure, for Case#1 dropped to 10 m below the profile level, this fall out of the safe design limits.
2. The fluctuation of pressure with time for Case#1 is shown in figure(6). At 275 sec from the pump trip, the resultant pressure have exceed the pipe surge pressure bar rating and reached about 17.8 bars which is beyond the design specification for the pipes.
3. Figure (7) shows the pumps speed changes after tripping for Case#1. It illustrates how the shaft stay rotating after sudden shut-off. The shaft last in decreasing rotation for about 250 sec after sudden shut-off. This shows the importance of using increase pump inertia system of using a fly wheel system as a protection element. The shaft rotate as long as

possible this will cause the system to accommodate the resultant pressure and act as gradual trip.

4. For Case#2, figure (8) shows the maximum and minimum pressure distribution along the pipeline up to 1400m falls within the design limits of the pipe. But beyond 1400m, needs an air valves with adequate capacity or feed tank to protect it from the admissible pressure.
5. The size of the air vessel used for Case#2 has contributed in controlling the resultant pressures during transient event within the design limits of the pipeline as shown in figure(9) , at time 200 sec, shows that the minimum pressure at node (R) correspond with the minimum fluid level inside the air vessels and the maximum air volume inside the air vessels. This means the air vessels did its job and water has moved from the air vessels into the pipeline due to the reduction of pressure and kept it from going to the extreme and controlled it within the design limits.
6. Figure (10) for Case#3 (protected) showed the effectiveness of the protection system in controlling the pressure values along the pipeline if compared with case#1(unprotected).
7. In case#4 where system is protected with air vessels capacity 0f 1000m^3 the simulation is implemented to study the behaviour of the system if protected by air vessels capacity less than the design capacity of 1500m^3. Figure (11) shows that the pressure value of 12.8 bars was also out of design limits. It is clear that this air vessels capacity (1000m^3) was not enough for the whole system protection.

CONCLUSIONS AND RECOMMENDATIONS

Hydraulic systems must be designed to accommodate both normal and abnormal operations such as pump power failure. Surge modelling provides the most effective and viable ways to identifying weak spots, forecasting potentially negative effects of hydraulic transients under a number of worst-case scenarios, and evaluating how they may possibly be avoided and controlled.

From the simulation results using a number of operation scenarios of the system for the case study we can conclude:

1. The maximum and minimum pressures generated by the different scenarios implemented in this study confirm that the installed air vessels capacities are correct and limit all pressure values within the bar rating of the installed pipes.

2. At the pipe section just upstream of Omar Almokhtar Grand Reservoir (OMGR) air valve(s) with adequate capacity is (are) needed at this section of the pipeline.
3. The suction pipeline upstream of the pump station will require the installation of at least two air valves to protect it from under pressure generated during pumps trip.
4. A feed tank may be providing at the highest level (upstream of OMGR) of the pipe line to make the system work more safely.
5. Air vessels with capacity 1000 m^3 are not enough to damps the pressures that occur during transient duration.

REFERENCES

1. American Society of Mechanical Engineers. [1933]. ASME-ASCE, Symposium on Water Hammer, pp 25 – 28, New York.
2. Street, R. L., Watters, G. Z., and Vennard, J. K. [1996] Elementary Fluid mechanics 7th Ed., John Wiley, New York.
3. Streeter, V. L. and Wylie, E. B. [1993] Hydraulic Transients, McGraw-Hill, New York
4. Tullis, J. P. [1989], Hydraulics of Pipelines Pumps, Valves, Cavitation, Transients. John Wiley, New York.
5. Alan L. PRASUHN. [1992]. Fundamentals of Hydraulic Engineering, Oxford University Press.
6. Gary Z.Watters. [1995]. Modern Analysis and Control of Unsteady Flow in Pipelines. Ann Arbor science.
7. KSB Fluid Systems GmbH. [2004]. Hydraulic Transient Flow Analysis Report for Benghazi End Conveyance Pump Station Contract 319
8. Brown & Root N.A Limited. [1999].Alkhadra Secondary Conveyance Pipeline Final Design Report. Doc.No.30230-s-822-00-RT-EN-0206-01.
9. Brown & Root N.A Limited. [1995]. Hydraulic Analysis of Performance Test Data of Srir/Sirt-Tazerbo/Benghazi Sub-System.
10. WANDA 3, Mathematical simulation software, User Manual, Developed by Delft Hydraulics of the Netherlands.
11. أ.صلاح عبدالله العقورى.1999. ظاهرة الطرق المائى وتائثيرها على انابيب النهر الصناعى.بحث مقدم لاتمام رساله ماجستير فى الهندسه المدنيه. جامعة قاريونس- كليه الهندسه-قسم الهندسه المدنية.

Table(1): Simulation parameters.

Pipe	Diameter (mm)	length (m)	Normal Pressure Rating (bar)	Surge Pressure Rating (bar)
P1	3444	156	13	18.2
P2	2800	71	13	18.2
P3	1800	250	12	16.8
P4	2200	13845	12	16.8
P5	2000	1959	10	14

Table (2): Inlet and outlet conditions for the case study .

Inlet Conditions		
Omar Almokhtar Reservoir B1		
Maximum water level	Minimum water level	Capacity
63.5 m	56.5 m	4.7 Million m3
Outlet Conditions		
Omar Almokhtar Grand Reservoir B2		
Maximum water level	Minimum water level	Capacity
118.5 m amsl	95.0 m amsl	24 Million m3

Table(3): Simulation input data and operation conditions for all cases.

Case No.	Air vessels	Min. operation level at OM reservoir (a.m.s.l)	Max. operation level at OMG reservoir (a.m.s.l)
1	Not including (Unprotected)	55.4 m	118.5 m
2	Air Vessel with 1500 m^3 capacity	63.5 m	95 m
3	Air Vessel with 1500 m^3 capacity	55.4 m	118.5m
4	Air Vessel with 1000 m^3 capacity	55.4 m	118.5 m

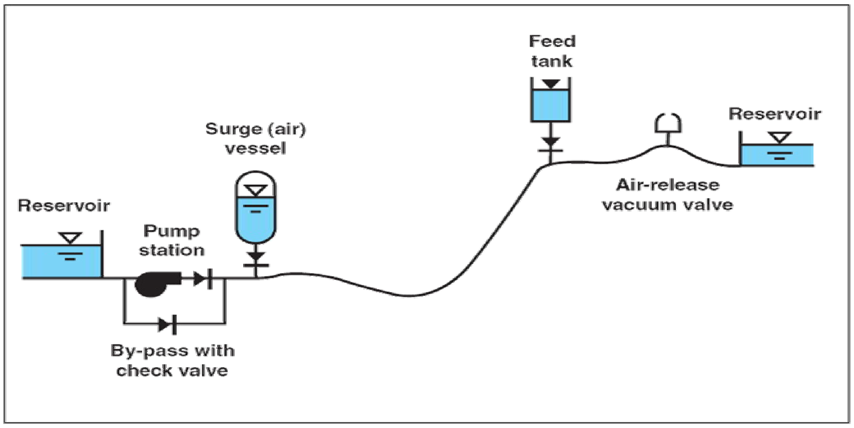

Fig.(1): typical locations for various surge protection devices.

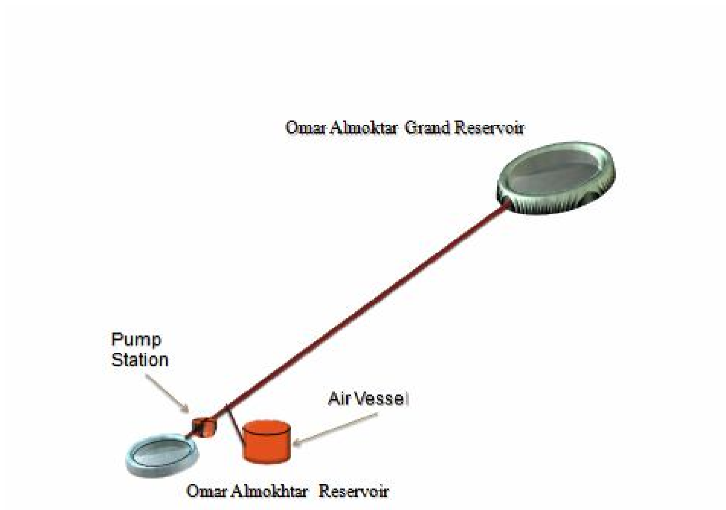

Fig.(2): sketch for the case study setup.

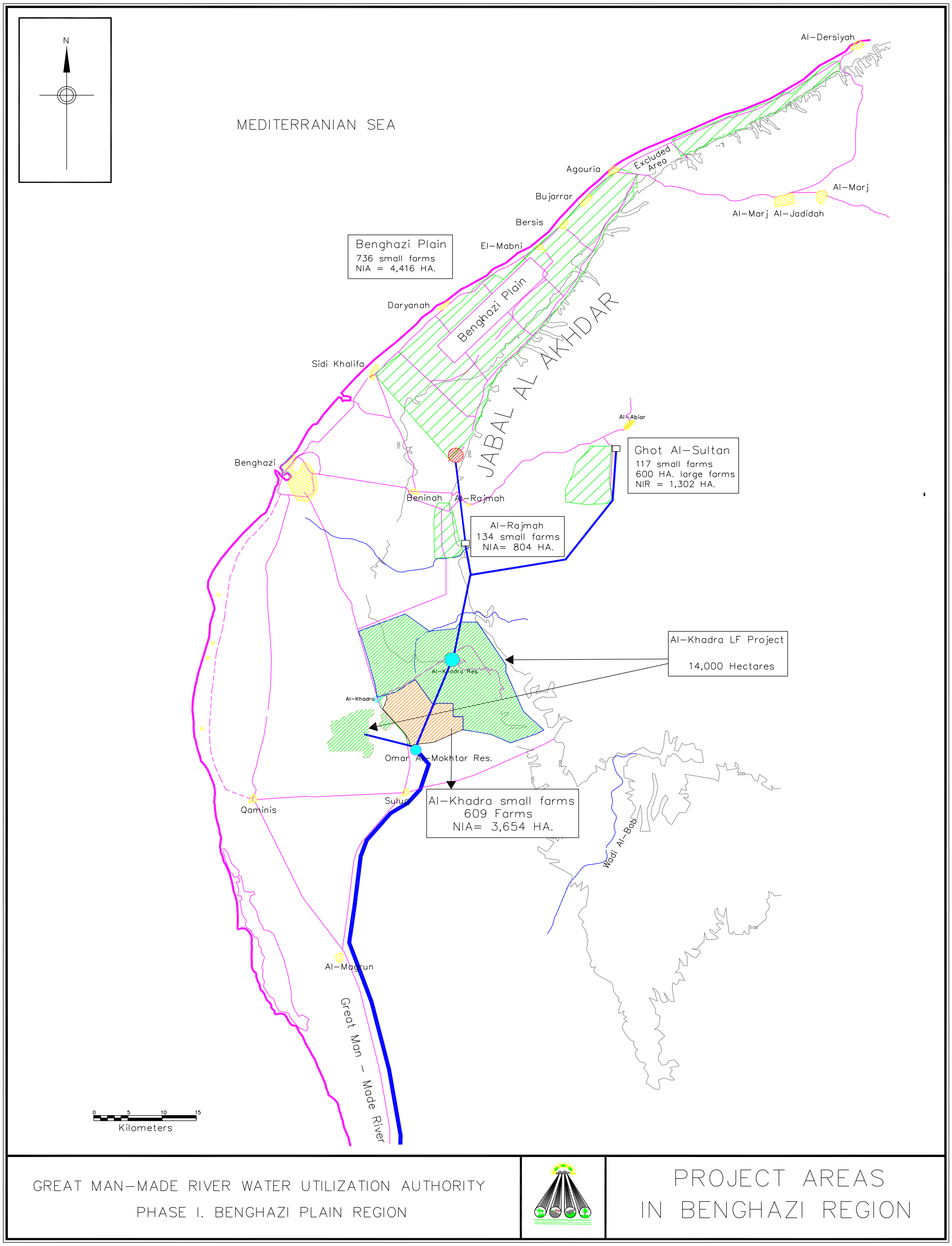

Fig. (3): projects location of Benghazi plain.

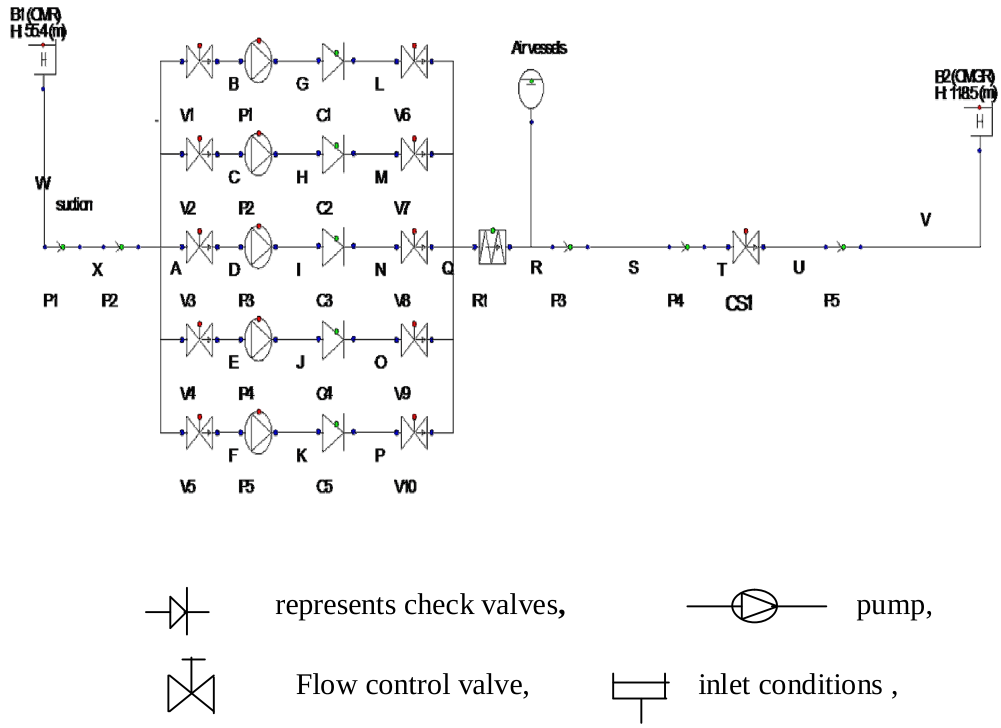

Fig.(4): shows a simplified scheme for the system components and nodes.

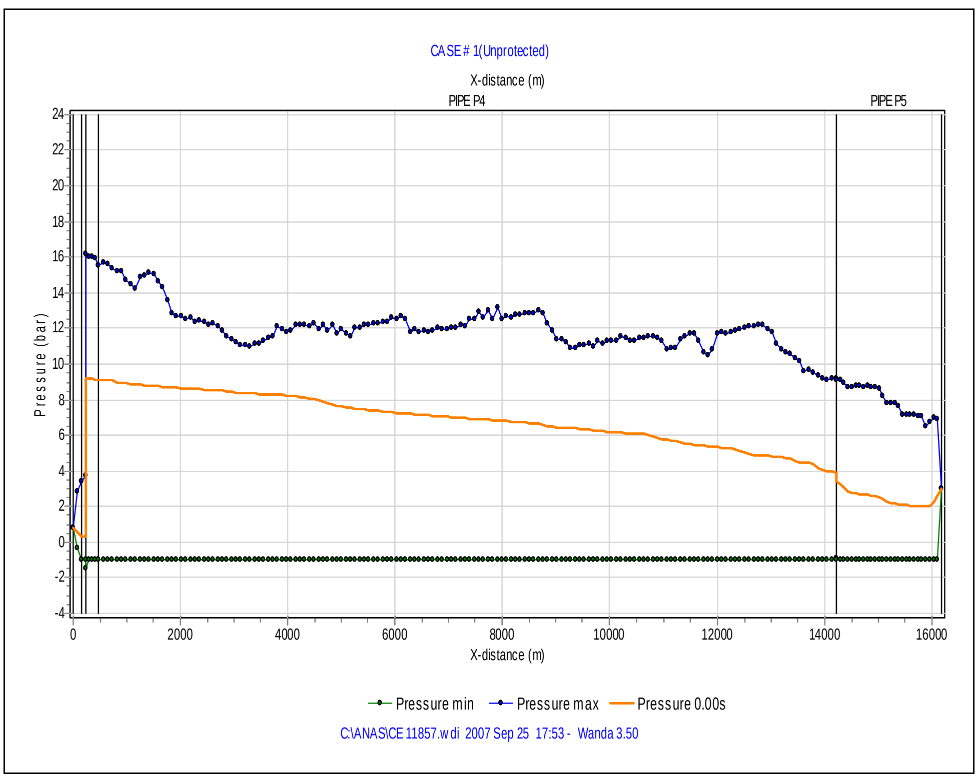

Fig.(5): Pressures along pipeline for Case #1 (unprotected).

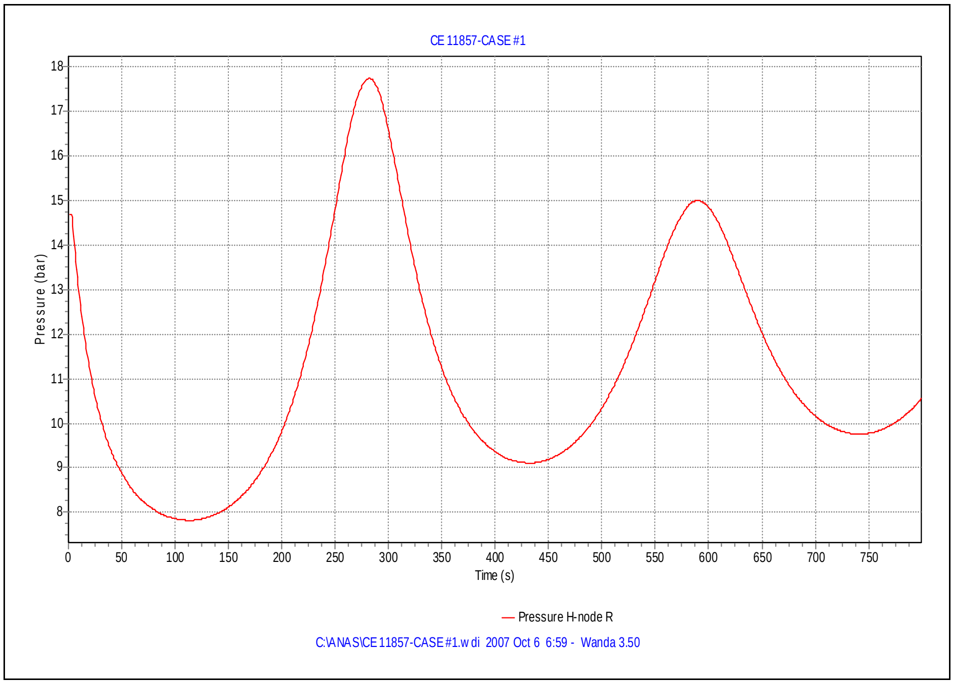

Fig.(6): Pressure at Node (R) for Case #1 (unprotected).

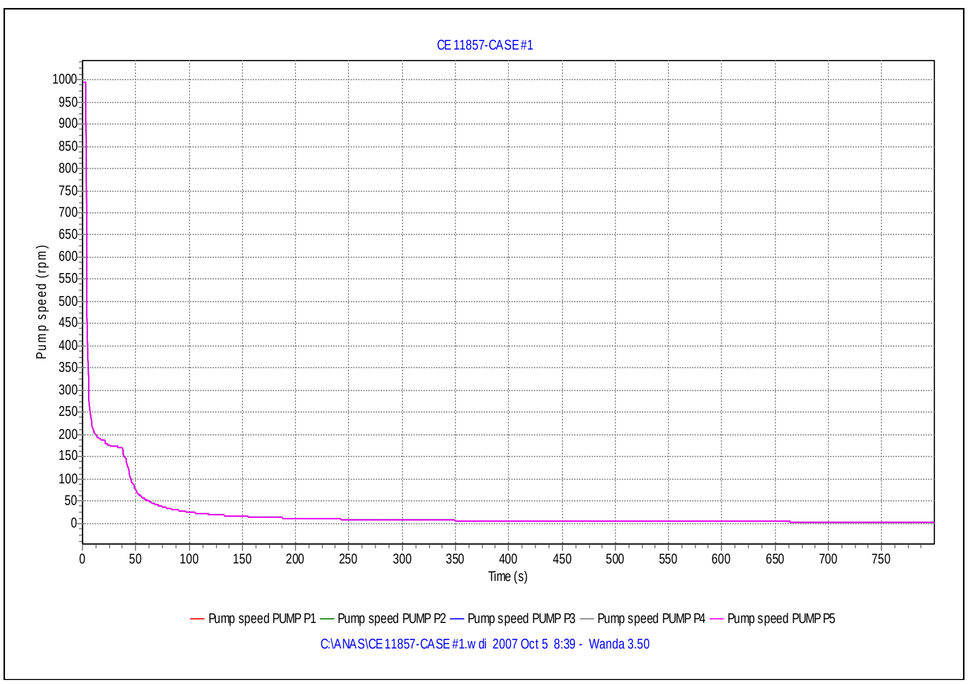

Fig.(7): illustrates the 5 Pumps speed changes after tripping (CASE #1).

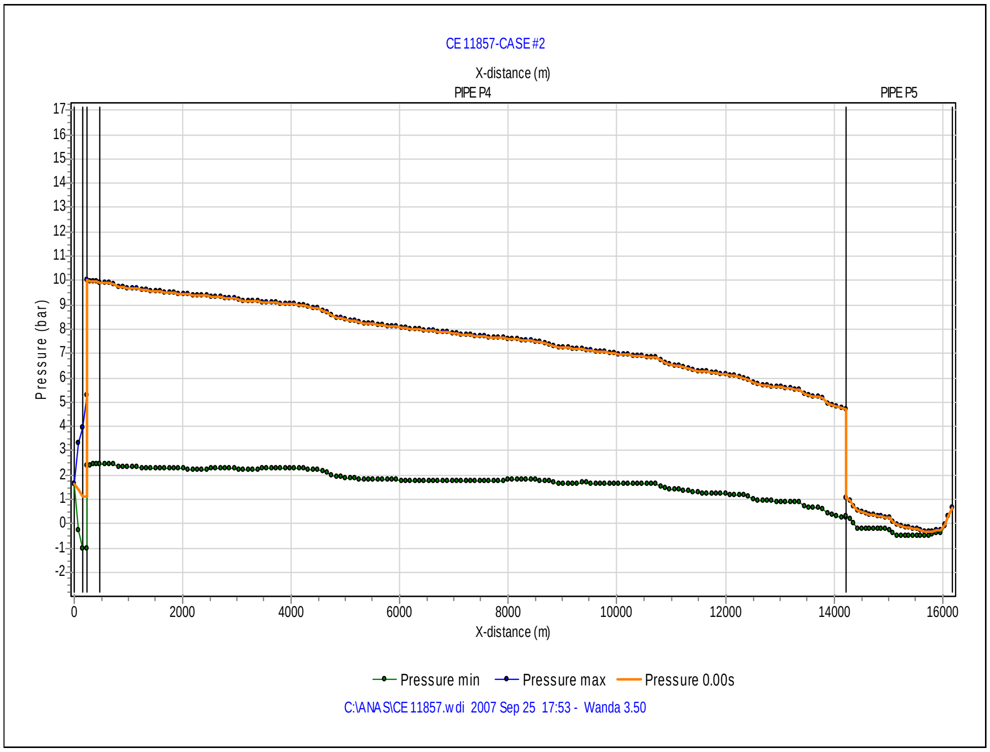

Fig.(8): Pressures along pipeline for Case #2 (protected).

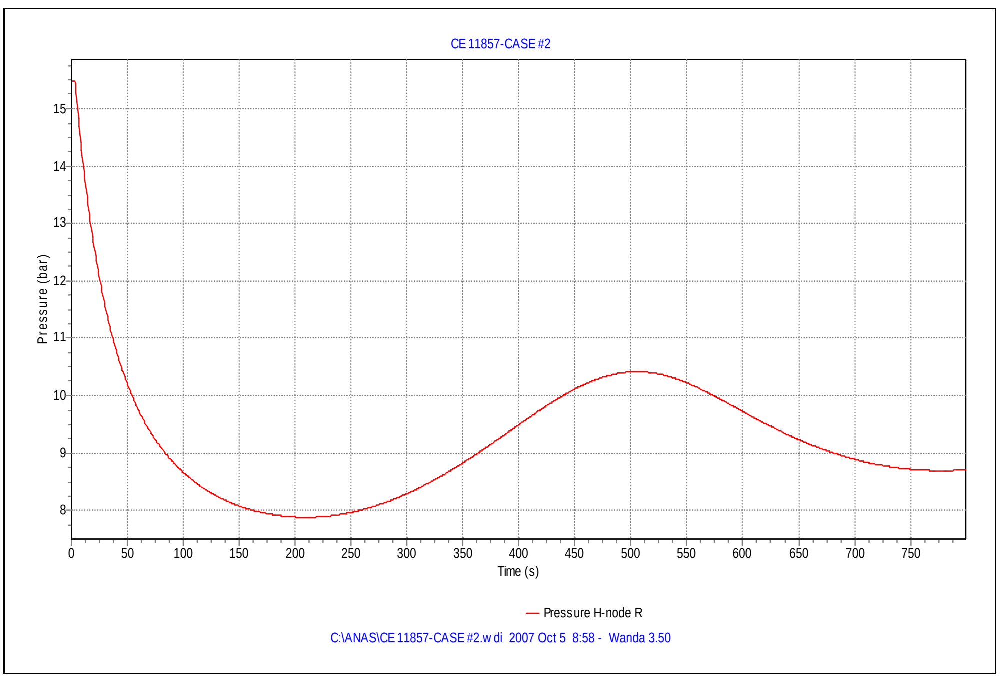

Fig. (9): Pressure at Node (R) for Case #2 (protected).

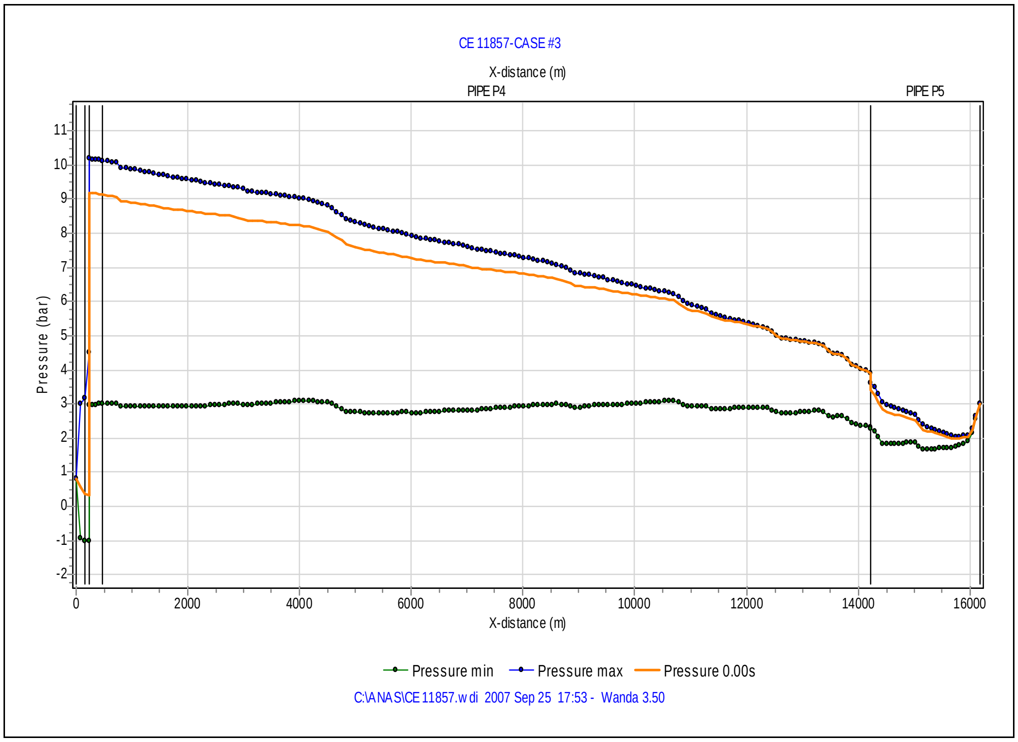

Fig.(10): Pressures along pipeline for Case #3 (protected).

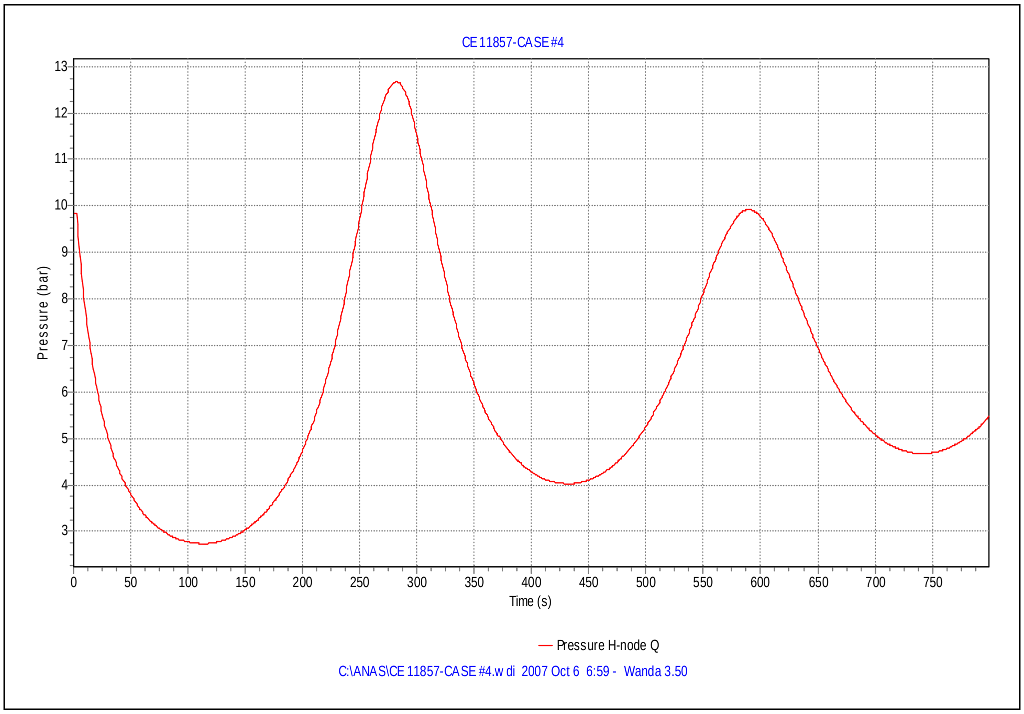

Fig.(11): Pressure at delivery side of pump station for Case #4.

المحاكاة الرياضية للجريان الاضطرابي في الأنابيب المتأثرة بظاهرة الطرق المائي

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الخلاصة

لحماية منظومة الأنابيب المتعرضة للجريان المضطرب تحت تأثير الطرق المائي هناك حاجة لإنشاء وحدات سيطرة في المنظومة مثل صمامات تخفيف الموجة , خزانات امتصاص الموجة , صمامات سحب الهواء وفي أماكن مختلفة فيها. الهدف الرئيسي في هذه الدراسة هو محاكاة الجريان المضطرب في الأنابيب المتأثرة بالطرق المائي باستخدام النموذج الرياضي . الدراسة تم تطبيقها على الأنبوب الواصل بين محطة الضخ في خزان عمر المختار وخزان عمر المختار الكبير. التحليل المستخدم في المحاكاة يعتمد على Characteristic Method وباستخدام برنامج WANDA. الضغوط العالية والواطئة المستخدمة في السيناريوهات المطبقة في الدراسة أثبت أن إنشاء (Air Vessels) بسعة ($1500\ m^3$) كافي للسيطرة على جميع الضغوط المتولدة ضمن مواصفات الأنبوب المستخدم. الدراسة أيضا وجدت أن هنالك حاجة لوضع (Air Valve) في المنظومة مقدم خزان عمر المختار الكبير. كما بينت الدراسة أن استخدام حجم ($1000\ m^3$) لل (Air Vessels) غير كافية لتخفيف تأثير الضغوط المتولدة نتيجة الطرق المائي في المنظومة.