INFLUENCE OF WATER PIPE NETWORK MATERIAL ON WATER HAMMER SURGE WAVE

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ABSTRACT

Water distribution networks represent a major portion of the investment in urban infrastructure and is considered a critical component of the public works. The goal is to design water distribution systems to deliver drinking water for all areas satisfying the designed demand and pressure, Pipe hammer and surge are commonly occurring phenomena in the world. There are different methods which are used to control the undesirable transient effects in pipe network system and reduce their negative effect such as surge tanks, air vessels and check valves. Choosing the control method depends on the design criteria, location, and topography that strongly affect the decision maker.

Pressures may be an acceptable if they oscillate over a range unlikely to induce fatigue failure or exceed maximum or minimum allowable values.

In this research work three pipe network materials have been chosen, namely high density poly ethylene (HDPE), Polyvinyl chloride (PVC), and Asbestos Cement to study the effect of pipe material in sustaining the surge wave pressure. Hypothetical water network similar to Bosat Kareem El- Dien was chosen. Every network has the same number of pipes, nodes, pipe diameters, lengths but having the same pipes material for the whole network

The results are compared and show that the HDPE pipe network gives more resistance to the hammer, followed by PVC pipe network, and no need for protection, but the asbestos cement network needs protection.

1 INTRODUCTION

Pipe surge and water hammer are two related but independent phenomena which arise when fluid flowing in a pipe as accelerated or decelerated. The associated pressure transient can be damaging to pipe network or components and systems must be designed to avoid or withstand them Pipe water hammer and surge are commonly occurring phenomena in the world but are rarely understood, even by engineers. The history of water hammer analysis is marked by various clever and practical schemes for solving the momentum and continuity equations (Watters, 1984).

Water hammer could lead to over pressure which may require either excessive pipe thickness, pipe material to have more resistance for the surge pressure, or any protection device. such as surge tank or air vessel Simplification of the network is necessary to be carried out for eliminating the ineffective elements, such as small networks of villages and cities (internal network) which have no effect on the output data for network main lines. Simplification will facilitate the computation and reduce the computing time. Zidan (2018) showed the water hammerv due to sudden closure followed by immediate sudden opening (the worst case)has cause a surge pressure wave in Bosat Kareem El-Dien pipe network. Air vessel having a volume of 20 m^3 with a liquid air ratio of 67 % has been found found to be a convient device for the protection **(Zidan, 2018).**

2 MATERIALS AND METHODS

2.1 Bosat Kareem–El -Dien Network Description

Details of Bosat Kareem El-Dien pipe network pump station, except for the pipe materials, was used to study the water hammer phenomenon in every hypothetical network**.** Bosat Kareem El-Dien pipe network materials are PVC, steel, ductile iron, asbestos cement, PE, and cast iron., with an approximate percentage of PVC 42%, Steel 20%, Ductile Iron 16%, Asbestos Cement 10%, PE 7% and Cast Iron 5% respectively.

Bosat Kareem El-Dien pump station works with six pumps (2 reserves). Each pumps has maximum operating discharge of 720 lit. /sec and design discharge of 360 lit/sec.to deliver filtered water through the water pipe network, and the shutoff (maximum) head equal to 64 m with design head .of 48 m.(Dakahlia Company for potable water domestic sewage, 2016) Table (1) gives the main six path lines of Bosat Kareem El-Dien pump station, pipe material, diameter, approximate length, and discharge in each path line.

Figure (1) exhibits sketch showing the six path lines, diameter, discharges and velocities (Zidan, 2018)

Table 1. Main path lines of Bosat Kareem–El Dien network (Zidan, 2018)

Path line	Pipeline	Type	Diameter (mm)	Approx. Length (km.)	Q lit./sec	V m /sec
Path. 1	Bosat / El-Mansoura	Ductile Iron	800	8.50	564.64	1.12
Path. 2	Bosat / Menyet El-Nasr	Cast Iron	600	7.10	295.66	1.05
Path. 3	Bosat / Dekerns	Cast Iron	550	6.80	309.53	1.09
Path. 4	Bosat / El-Mansoura	Cast Iron	550	3.53	171.14	0.72
Path. 5	Bosat / Dekerns	P.V.C	600	4.52	209.31	0.88
Path. 6	Bosat / Damietta	Cast Iron	600	8.73	377.64	1.34

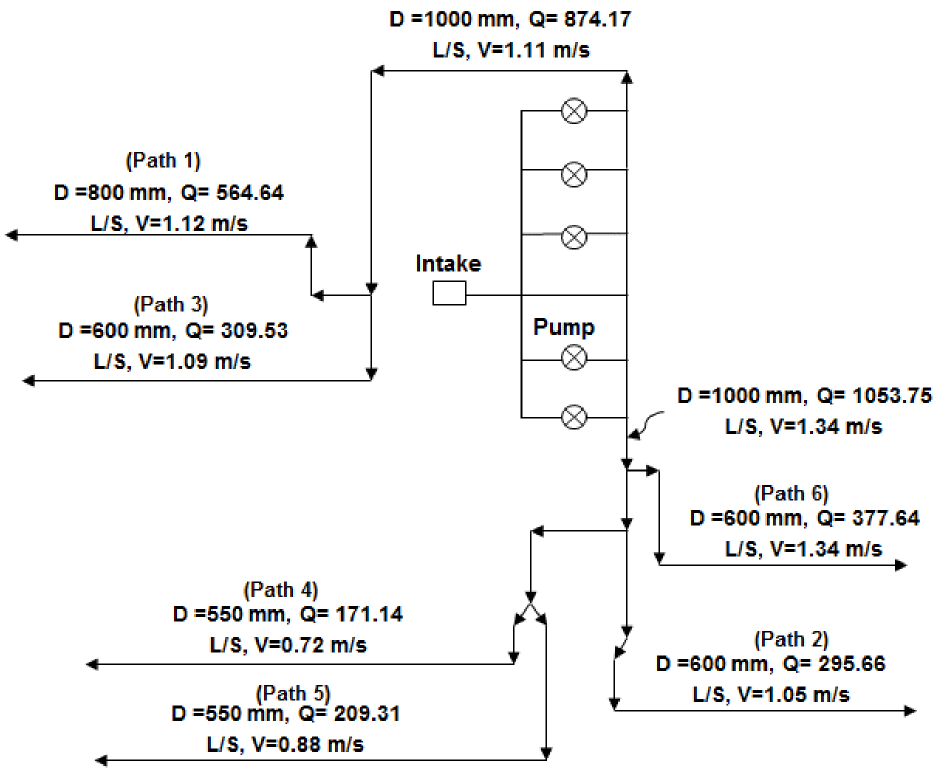

Figure1. Sketch showing the six path lines, diameter, discharges and velocities (Zidan, 2018)

2.2 Network Simplification

The simplified network should also accurately represent the original pressure heads. The operation of the hydraulic network will require heads to be within certain bounds. In order to avoid the danger of outbreak of the network and by the requirement of supply water demand at sufficient pressure for high buildings (Anderson et al.,1995).

relatively small demands along any pipe are added to the node at the end of the pipe. pipes with small diameters are eliminated and the area that is fit by them is represented by single node, and a group of adjacent nodes with similar pressure are reduced to one node(Brandon,(1984) and (Awad, 2005) Simplification of Bosat Kareem El Dien revealed that the number of pipes is 1849 instead of 6099 and the number of nodes is 1632 instead of 5681, Figure (2).

In order to insure the correctness of simplification calibration has been made by measuring pressure head and discharges at some locations before and after simplification (Zidan, 2018) .

Bentley water GEMS was used to t reach a steady condition flow in the network. It is mainly used for simplification. of the network., (Bentley Water GEMS, user's manual, 2006) Bentley water HAMMER was used to study the water hammer and associated waves in the network

3 RESULTS AND DISCUSSION

In this section, it is assumed that the whole pipes network have the same material. Three different hypothetical pipe networks are studied to see the effect of pipe material on the phenomenon of water hammer. Every network has the same characteristics as in Bosat Kareem El Dien network i.e. number of pipes , pipe lengths, pipe diameters, but it differs in pipe material. Figures (9) through

(26) for the six path lines show the influence of water hammer in the three hypothetical networks. It is clear from these figure that in case of HDPE network no need for hammer protection.

From these figures it could be noticed that in case of HDPE necessary .Tables (2) through (7) show a comparison between the actual hydraulic gradient levels of Bosat Kareem El-Dien due water hammer and the corresponding levels of the three hypothetical networks . Also Table (8) presents a comparison between the three networks regarding the maximum and minimum water levels due to the hammer for the six path lines.

It seems from the figures and tables that no need for water protection in cases of HDPE and PVC networks. But Steel network needs protection.

3.1 HDPE Pipe Network

Figures (2) through (7) present the influence of water hammer on the hypothetical HDPE network. It is clear from these figure that in case of HDPE network no need for hammer protection.

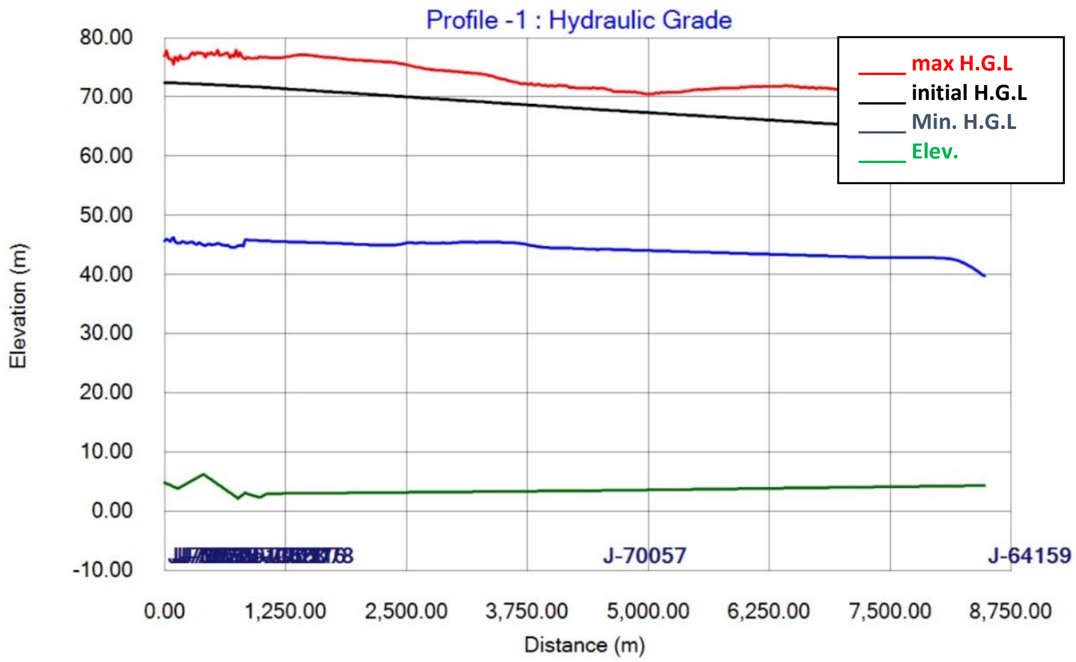

Figure2. Influence of water hammer on Path line (1) HDPE 800 mm diameter

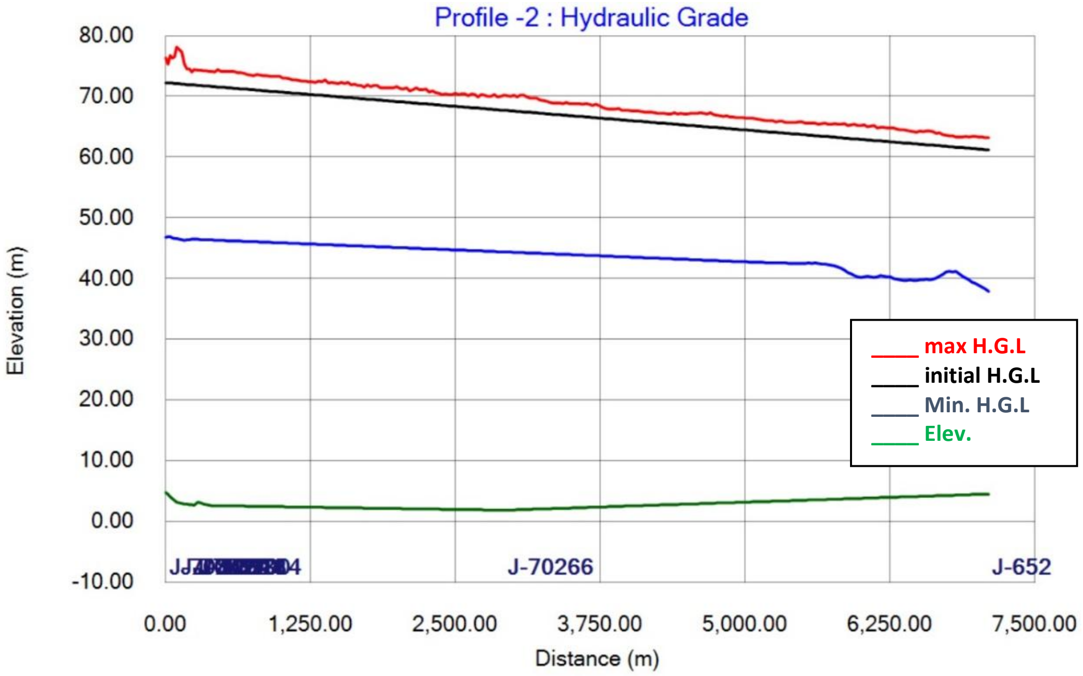

Figure3. Influence of water hammer on Path line (2) HDPE 600 mm diameter

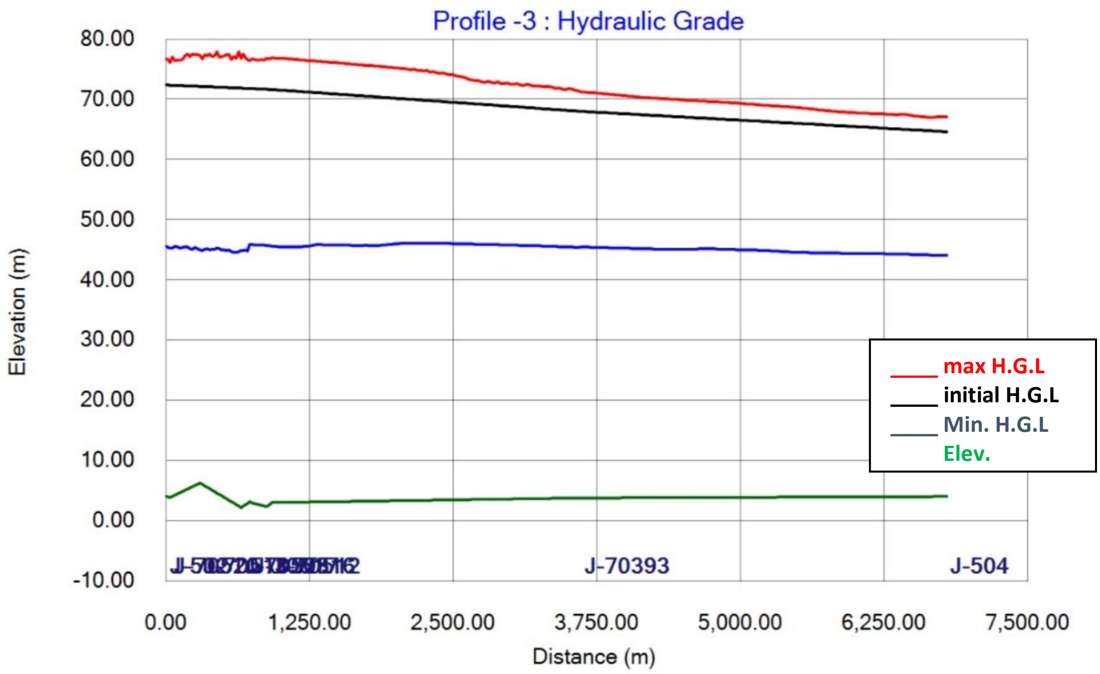

Figure4. Influence of water hammer on Path line (3) HDPE 550 mm diameter.

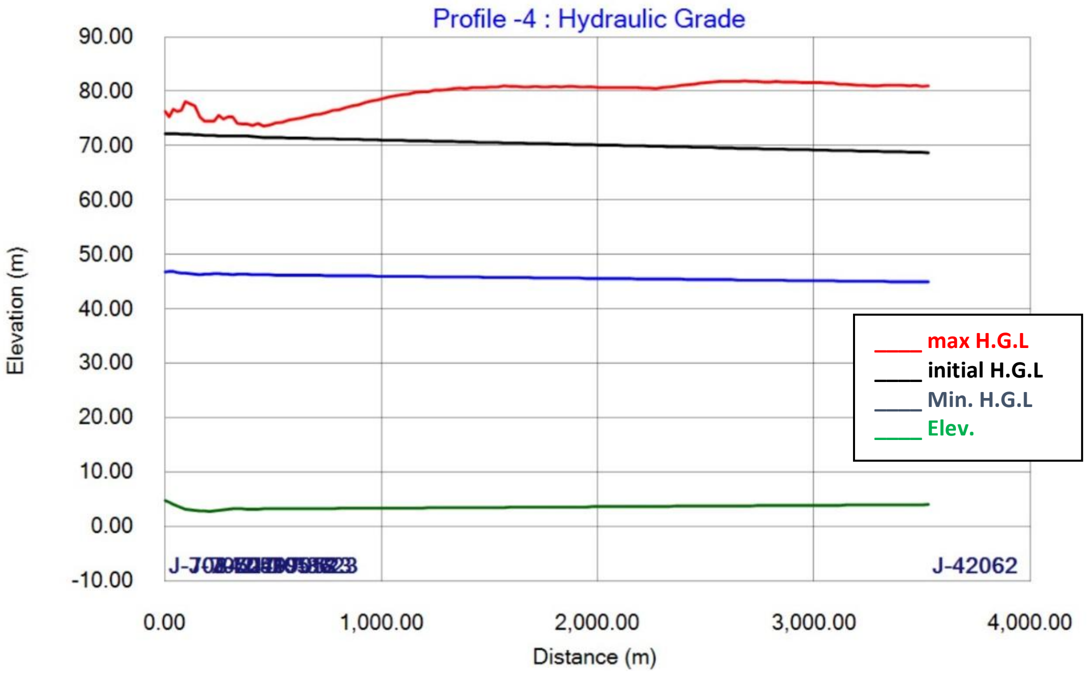

Figure 5. Influence of water hammer on Path line (4) HDPE 800 mm diameter

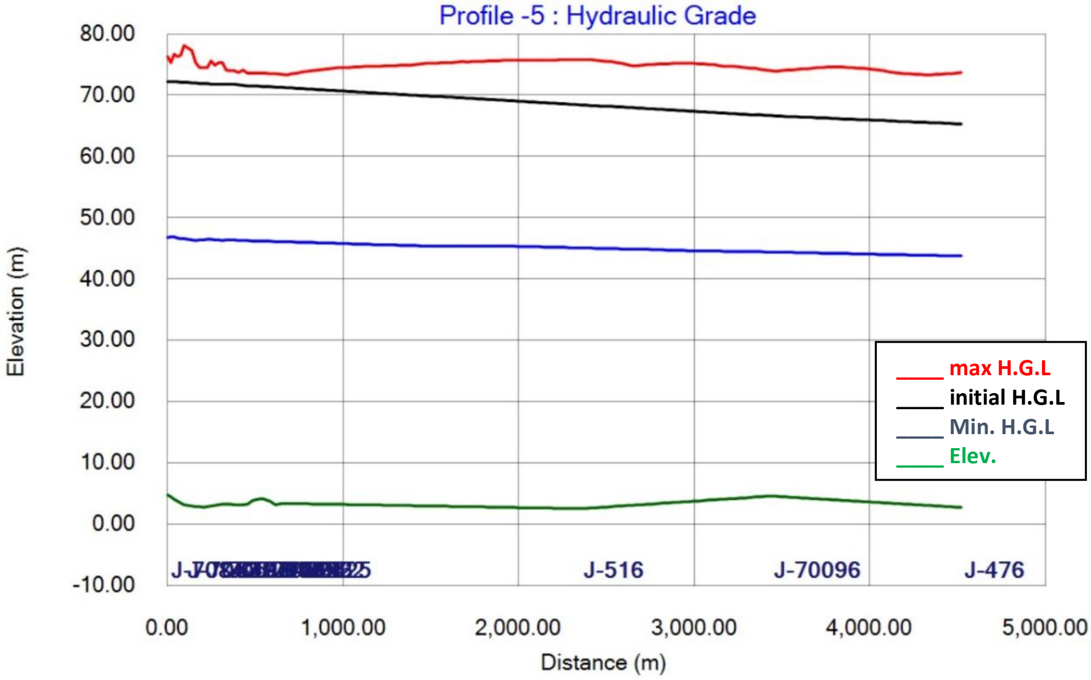

Figure 6. Influence of water hammer on Path (5) HDPE 600 mm diameter

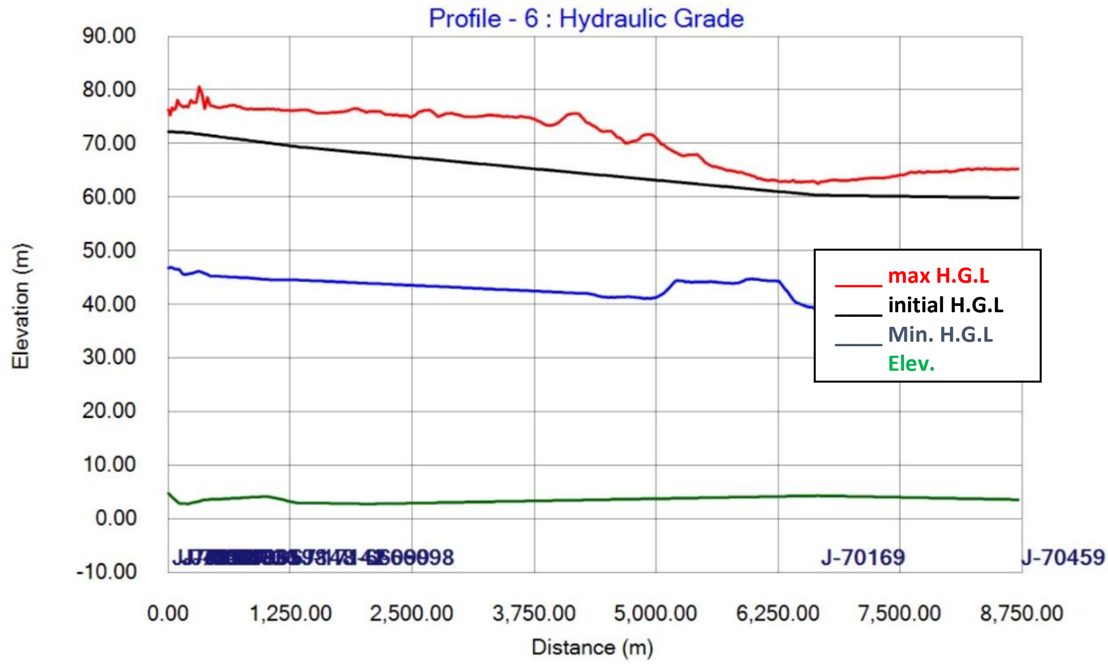

Figure 7. Influence of water hammer on Path line (6) HDPE 600 mm diameter

3.2 PVC Pipe Network

Figures (8) through (13) demonstrate the effect of water hammer on hypothetical PVC pipe **network**

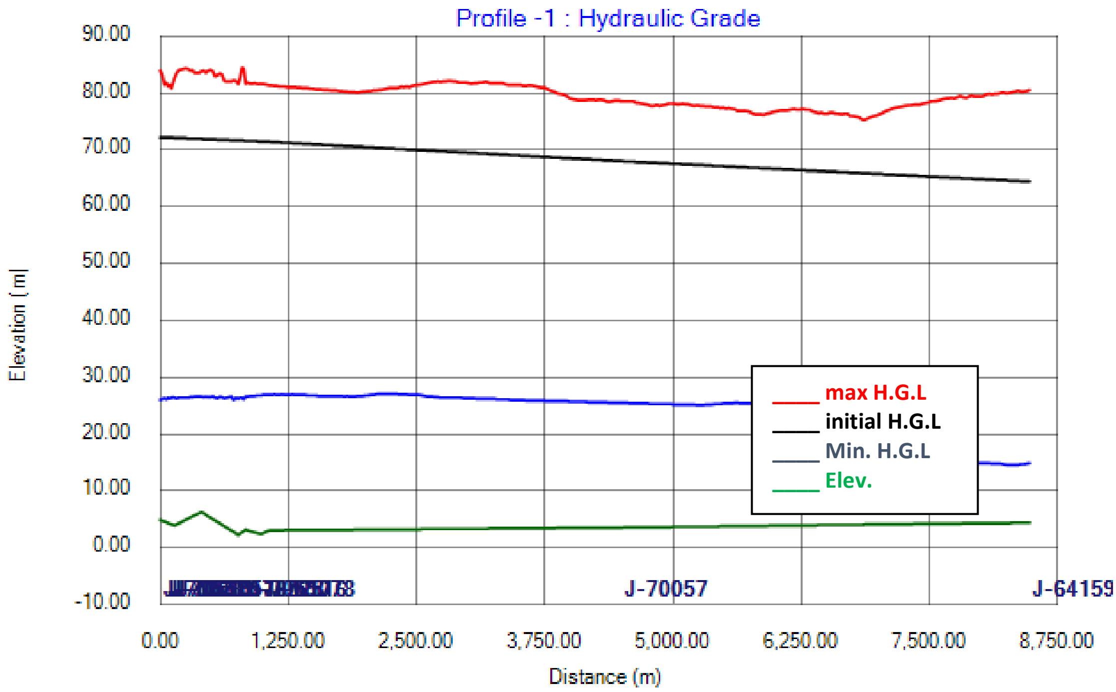

Figure8. Influence of water hammer on Path line (1) PVC 800 mm diameter

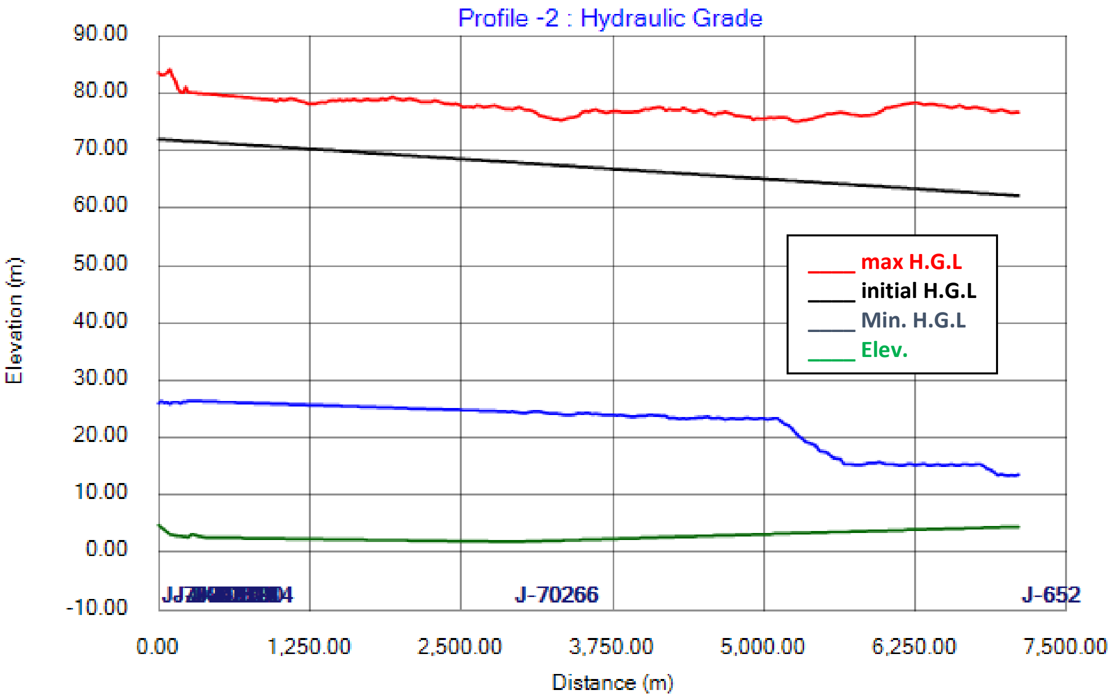

Figure 9. Influence of water hammer on Path line (2) PVC 600 mm diameter

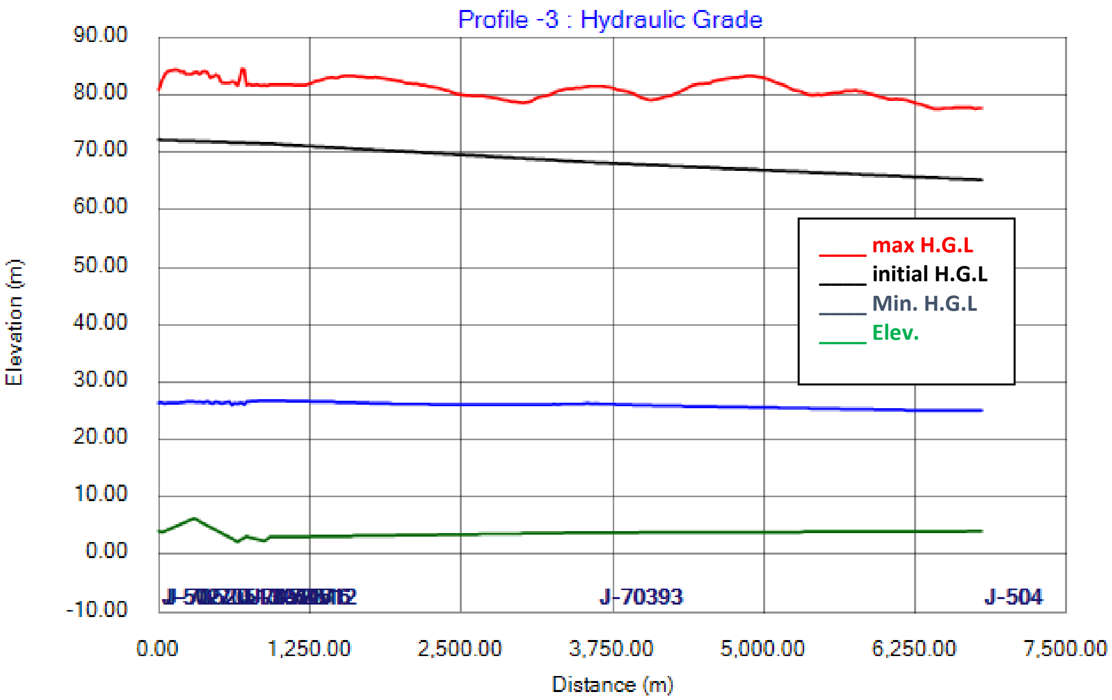

Figure 10. Influence of water hammer on Path line (3) PVC 550 mm diameter

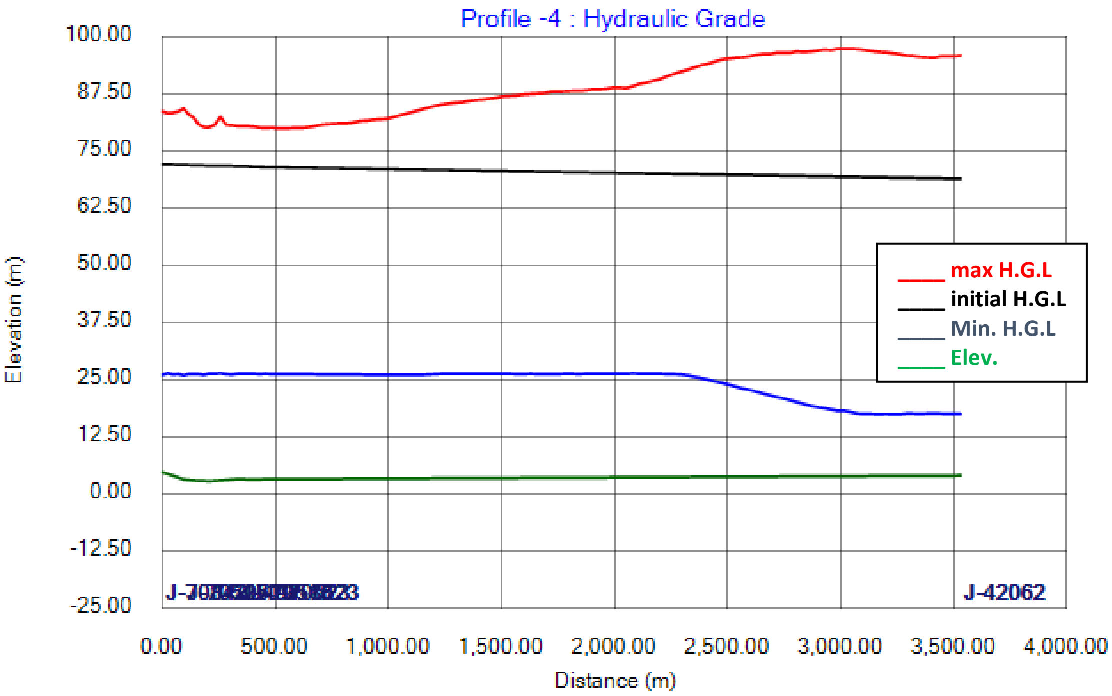

Figure11. Influence of water hammer on Path line (4) PVC 550 mm diameter

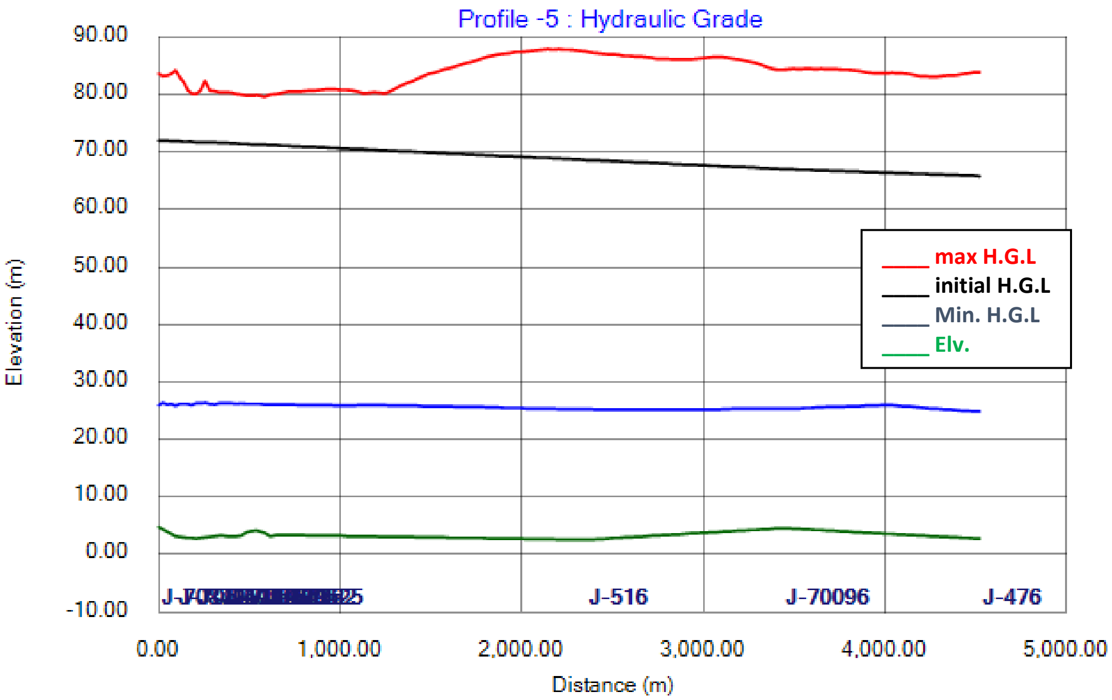

Figure12. Influence of water hammer on Path line (5) PVC 600 mm diameter

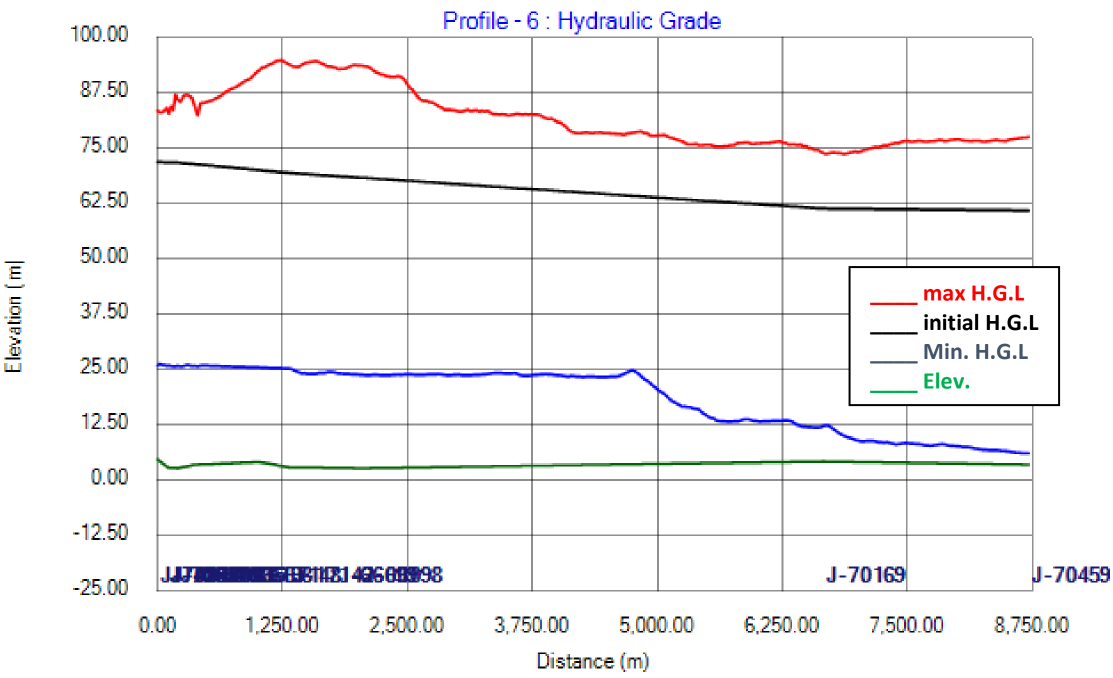

Figure 13. Influence of water hammer on Path line (6) PVC 600 mm diameter

3.3 Asbestos Cement Network

Figures (14) through (26) show the effect of water hammer on Asbestos pipe network

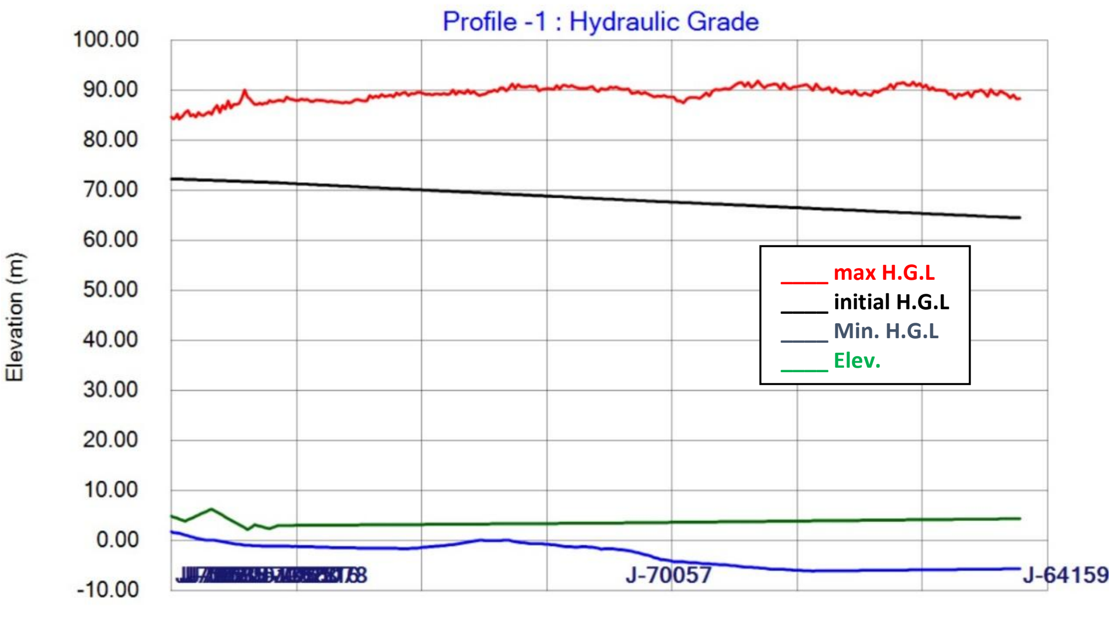

Figure 14. Influence of water hammer on Path line (1) Asbestos Cement 800 mm diameter

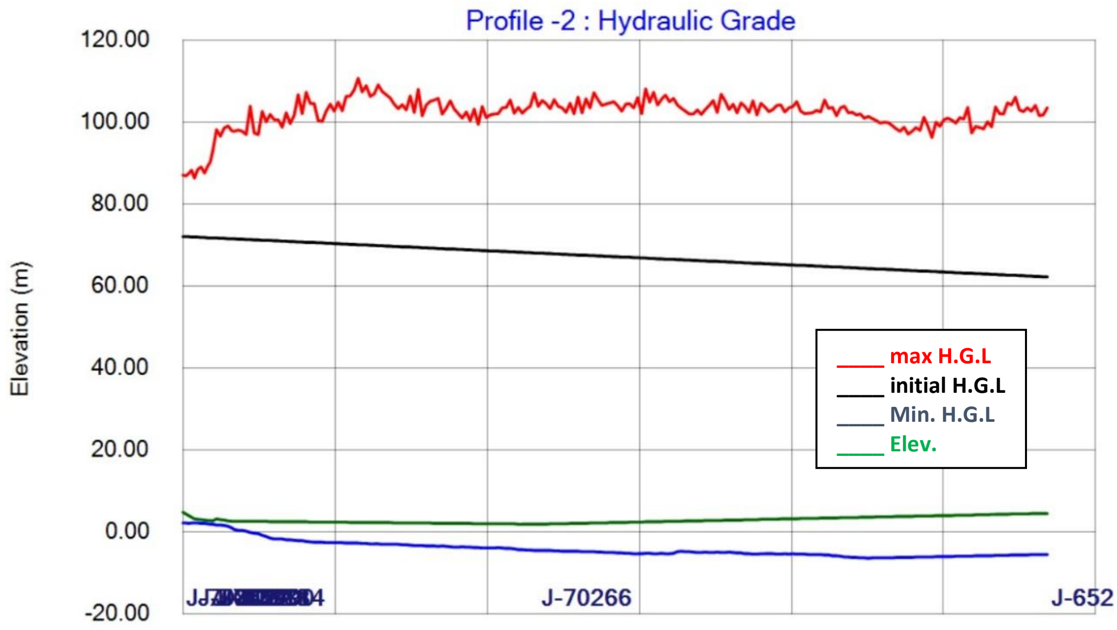

Figure 15. Influence of water hammer on Path line (2) Asbestos Cement 600 mm diameter

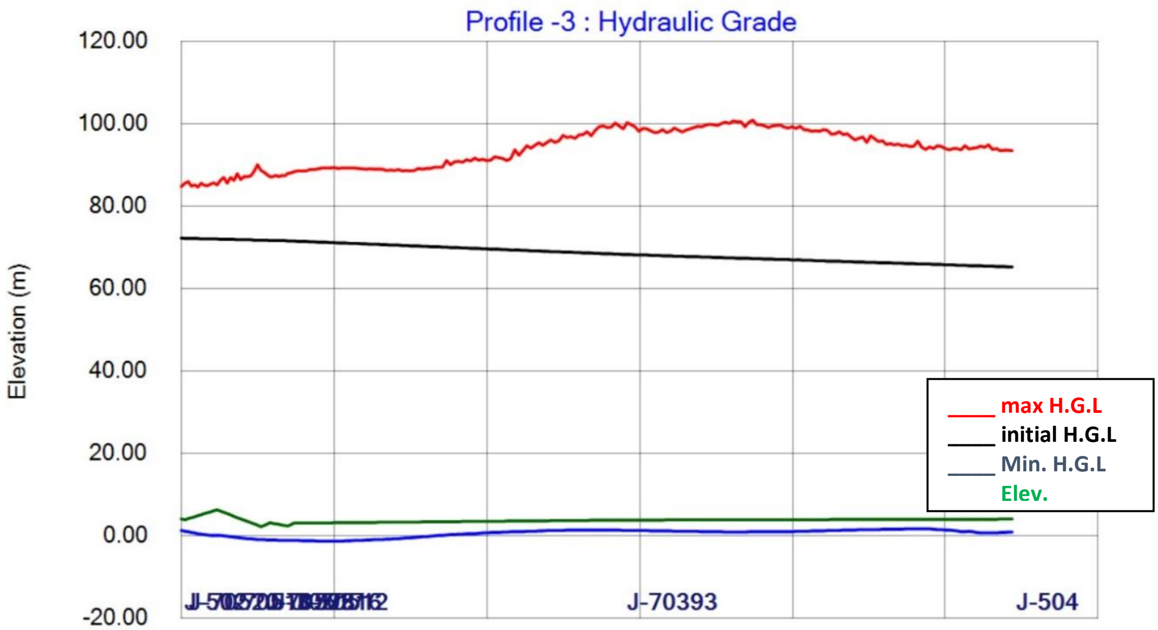

Figure17. Influence of water hammer on Path line (3) Asbestos Cement 550 mm diameter

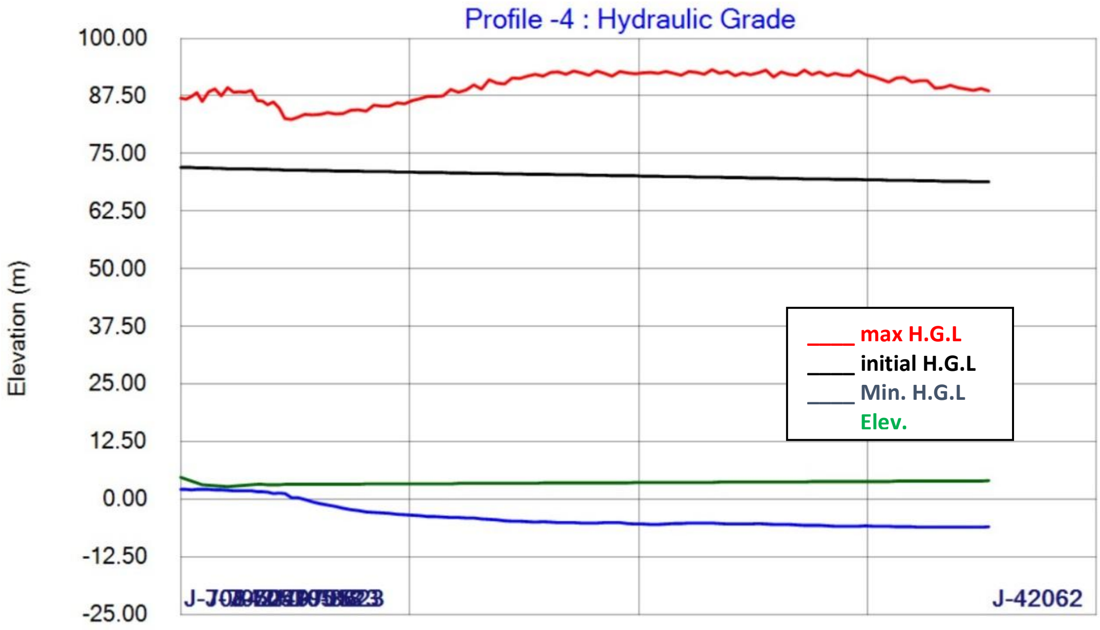

Figure 18. Influence of water hammer on Path line (4) Asbestos Cement 550 mm diameter

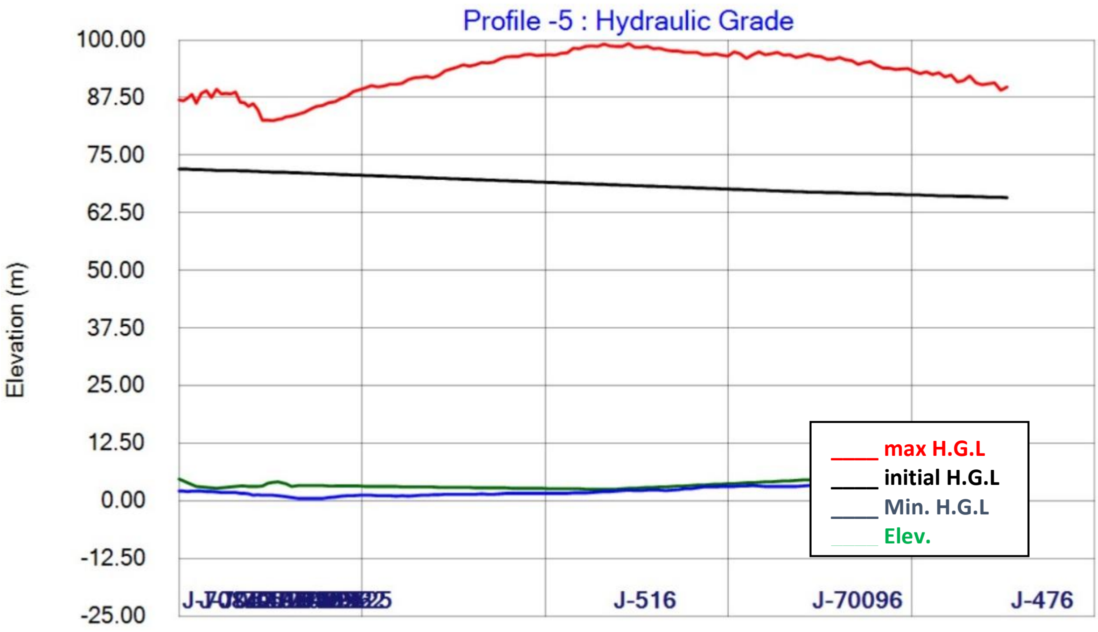

Figure 19. Influence of water hammer on Path line (5) Asbestos Cement 600 mm diameter

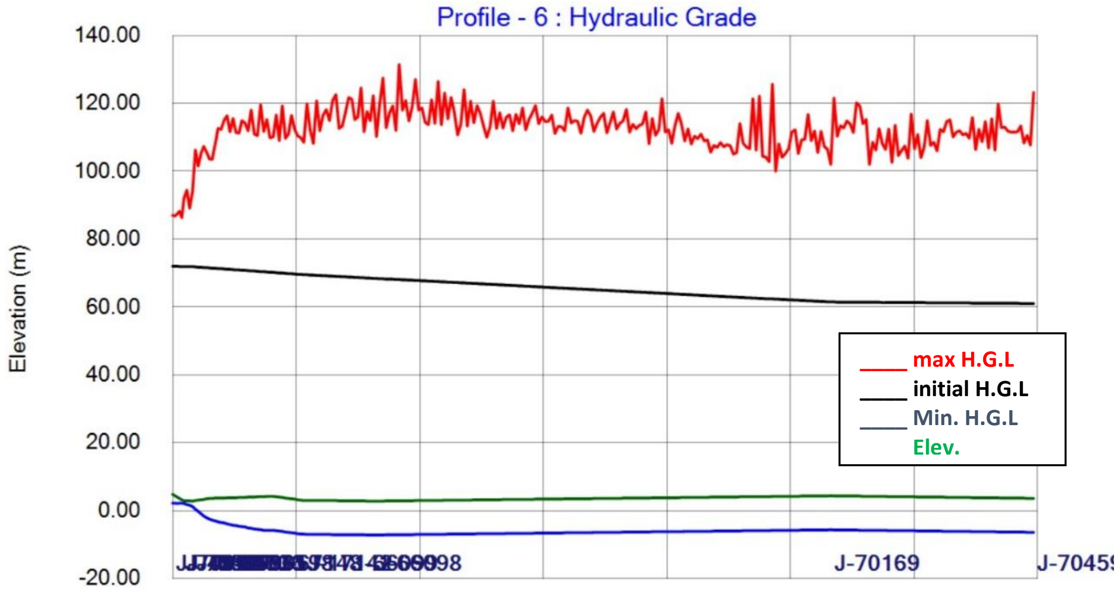

Figure 20. Influence of water hammer on Path line (6) Asbestos Cement 600 mm diameter

Tables (2). through (7) demonstrate the values of maximum and minimum hydraulic gradient at distances 1250 m, 2500 m, 3750 m, and 5000 m from the pump station (P.S) for the actual, HDPE, PVC, and Asbestos Cement hypothetical networks. While table (8) exhibits a comparison between maximum and minimum hydraulic gradients for the three hypothetical networks.

Table 2.Comparison between hypothetical results and actual one Path line (1)
Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	89	87	84	83
HDPE H.G.L	78	76	72	70
PVC H.G.L	81	81	80	78
Asbestos H.G.L	89	90	90	89

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat .H.G.L	-2	-3	-4	-7
HDPE H.G.L	45	45	44	43
PVC H.G.L	28	28	27	25
Asbestos H.G.L	-1	-1	0	-5

Table 3. Comparison between hypothetical results and actual one Path line (2)
Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	122	105	100	102
HDPE H.G.L	72	70	69	67
PVC H.G.L	79	79	77	76
Asbestos H.G.L	105	100	110	102

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	-2	-8	-10	-9
HDPE H.G.L	46	44	43	41.5
PVC H.G.L	25	24	23	22
Asbestos H.G.L	-2	-4	-8	-8

Table 4. Comparison between hypothetical results and actual one Path line (3)

Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	90	93	94	94
HDPE H.G.L.	77	74	71	70
PVC H.G.L	81	80	81	83
Asbestos H.G.L	88	90	100	100

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	-3	-3	-3	-3
HDPE H.G.L	45	46	45	45
PVC H.G.L	28	27	27	26
Asbestos H.G.L	-1	0	0	0

Table 5. Comparison between hypothetical results and actual one Path line (4)
Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	99	100	90	88
HDPE H.G.L	80	81	80	80
PVC H.G.L	85	95	96	96
Asbestos H.G.L	87.5	93	93	87.5

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	-4	-8	-7	-7
HDPE H.G.L	47	46	45	44
PVC H.G.L	26	24	16	16
Asbestos H.G.L	-3	-5	-6	-6

Table 6. Comparison between hypothetical results and actual one Path line (5)

Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	88	87	84	85
HDPE H.G.L.	75	76	75	74
PVC H.G.L	80	87.5	84	85
Asbestos H.G.L	90	100	93	85

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	-1	0	-2	-2
HDPE H.G.L.	45	45	44	43
PVC H.G.L	26	25	25	23
Asbestos H.G.L	1	2.5	3	3

Table 7.Comparison between hypothetical results and actual one Path line (6)
Max H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	106	100	99	96
HDPE H.G.L.	78	75	74	71
PVC H.G.L	94	90	82	78
Asbestos H.G.L	118	128	120	120

Min H.G.L (m)

Distance from P.S. (m)	1250	2500	3750	5000
Bosat H.G.L	-7	-7	-6	-5
HDPE H.G.L.	44	43	42	40.5
PVC H.G.L	25	25	25	20
Asbestos H.G.L	-8	-8	-6	-5

Table 8. Comparison between the results of the different hypothetical Networks

Pipe Material	HDPE		PVC		Asbestos	
H.G.L (m)	Max.	Min.	Max.	Min.	Max.	Min.
Path 1	88	40	85	15	92	--7
Path 2	87	38	85	13	110	-8
Path 3	87	44	85	24	100	-1
Path 4	82	45	98	16	94	-7
Path 5	79	43	88	25	100	0
Path 6	80	31	95	7	132	-8

It seems from the figures and tables that no need for water protection in cases of HDPE and PVC networks. But Asbestos Cement network need protection.

$$a = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{(1+(\frac{d}{e}\times\frac{K}{E\times C1})}} \qquad (1)$$

In which:

a: wave celerity;
K: water compressibility
water density;
d: pipe diameter;
e: pipe thickness;
g: acceleration due to gravity; and
C1 = 1 - ϵ^2 for a pipe without expansion joints and anchored throughout its length.
C1 = 1 - ϵ /2 for a pipe with expansion joints throughout its length (Featherstone and Nalluri, 1982).

Where ϵ is the Poisson's ratio for the pipe wall material.
For rigid theory the wave celerity is given by (Larock et al., 2000):

$$a = \sqrt{\frac{K}{\rho}} \qquad (2)$$

Joukowsky equation (1898) is presented as:

$$\Delta H = (a/g)*\Delta V \qquad (3)$$

Value of surge wave amplitude or change in pressure head(ΔH) depends on the wave celerity (a), bigger value of celerity gives higher amplitude, and the change in water velocity (ΔV). Since the network is subjected to complete closure (ΔV) is equal to the mean velocity of water (V).

Referring to equation (1), the wave celerity in the elastic theory depends Young' modulus (E) of the pipe material and the ratio between pipe diameter and pipe thickness (d/e). The high density polyethylene (HDPE) has Young's modulus of a value equal to $0.8\ x10^9 N/m^2$.), PVC has Young' modulus of a value ranges from 2.4 to $3.3\ x10^9 N/m^2$ and Asbestos Cement has Young' modulus of a value ranges from 21.5 to $30.65\ x10^9 N/m^2$ (larock et al., 2000). Based on that, (HDPE) may exhibit more resistance in dealing with water hammer than other materials and it is preferable to be used in pipe networks.

Asbestos Cement network exhibits negative H.G.L. which may reach to -8.0 m for path lines (2) and (6).

The negative pressure may cause column separation in the pipe network, and consequently cavities and destruction of the network Surge pressures in HDPE pipe network are significantly lower than Asbestos Cement pipe and lower than PVC pipe due to the lower value of dynamic module for HDPE.

4 CONCLUSIONS

Simplification is necessary to study the water transient in pipe network. Without complicated pipe network simplification the analysis of such network will be difficult.

Using three different hypothetical networks HDPE , PVC, and Asbestos Cement as the same as Bosat Kareem El-Dien i.e. the same number of pipes, nodes, diameters, lengths, and fittings shows that the HDPE and PVC networks could sustain water hammer without any protection device, but the Asbestos Cement pipe network needs protection.

Young modulus of the pipe material has a direct effect on water hammer resistance the lower value of this modulus gives more resistance

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