

Waterhammer Analysis Using the Method of Characteristics on Nahand-Tabriz Pumping Station

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Abstract

Waterhammer phenomenon caused by pump failure and the sudden change of discharge and consequently the flow velocity, creates the sudden variation of pressure and initiates the upsurges and downsurges along the pipeline. If this abnormal pressure change does not control and adjust with an appropriate equipment, it may occur the destructive problems along the unprotected system. In this paper, by developing a computer program and using the method of characteristics, the governing equations of waterhammer phenomenon, on Nahand – Tabriz pumping station, as a case study, have been analyzed and the appropriate dimension of air chamber to control the surges has been calculated. It is shown that without using this control device, due to path convexity of discharge pipeline, the cavitation phenomenon may occur intensively along the pipeline.

Key words: Waterhammer, Method of characteristics, Transient flow, Pumping station, Pump failure, Cavitation.

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$$L_1 = \frac{\partial V}{\partial t} + \frac{1}{\rho} \frac{\partial p}{\partial x} + g \sin \phi + \frac{fV|V|}{2D} = 0 \quad () \quad []$$

[]

$$L_2 = \frac{\partial p}{\partial x} + \rho a^2 \frac{\partial V}{\partial x} = 0 \quad () \quad []$$

p V L_2, L_1
 t x []
 ϕ g ρ
 a D
 f
 f

$\lambda = \pm \frac{1}{\rho a}$ ()

$\frac{dx}{dt} = \lambda \rho a^2 = \frac{1}{\lambda \rho}$

$\frac{dx}{dt} = \pm a$ ()

$t \quad x \quad (\pm \frac{1}{a})$

$a = \sqrt{\frac{K}{\rho[1 + \frac{K D}{E e}]}}$ ()

$L = L_1 + \lambda L_2$

$\Delta t \quad (\lambda = \pm \frac{1}{\rho a})$

$L = (\frac{\partial V}{\partial x} \lambda \rho a^2 + \frac{\partial V}{\partial t}) + \lambda (\frac{\partial p}{\partial x} \frac{1}{\rho \lambda} + \frac{\partial p}{\partial t}) +$

$L = \frac{dV}{dt} \pm \frac{1}{\rho a} \frac{dp}{dt} + g \sin \phi + \frac{fV|V|}{2D} = 0$ ()

$g \sin \phi + \frac{fV|V|}{2D} = 0$ ()

$(-)(+)$

$V(x,t) \quad p(x,t)$

$P = \rho g H \quad V = \frac{Q}{A} \quad \sin \phi = \frac{Z_p - Z_A}{\Delta x}$

$\frac{dp}{dt} = \frac{\partial p}{\partial x} \frac{dx}{dt} + \frac{\partial p}{\partial t}$ ()

$\frac{dV}{dt} = \frac{\partial V}{\partial x} \frac{dx}{dt} + \frac{\partial V}{\partial t}$ ()

:(C⁺)

(z_u = 1640 m)

(z_d = 1478 m)
$$Q_p - Q_A + \frac{gA}{a}(H_p - H_A) + \frac{f\Delta t Q_A |Q_A|}{2DA} = 0$$
 ()

:(C⁻)

$\frac{a\Delta t}{\Delta x} \leq 1$

()
$$Q_p - Q_B - \frac{gA}{a}(H_p - H_B) + \frac{f\Delta t Q_B |Q_B|}{2DA} = 0$$
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P

AB

P

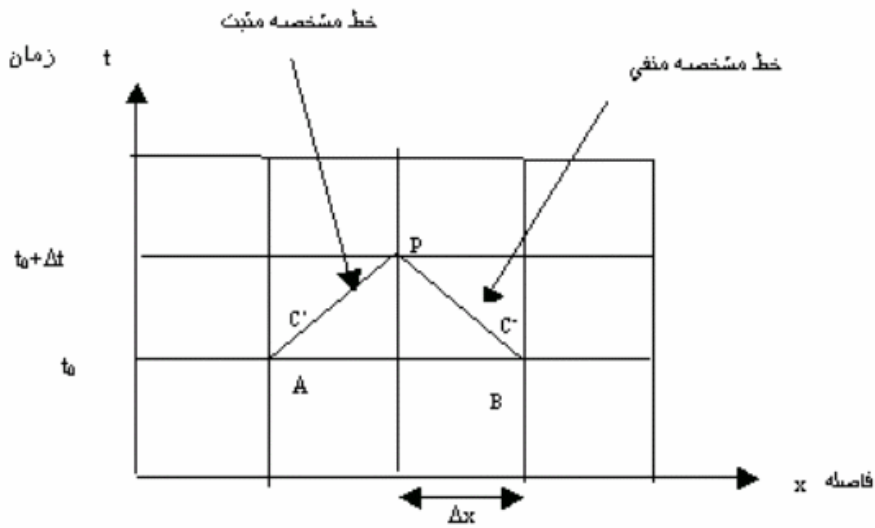
t₀ + Δt

H_p, Q_p

(0 < x < L)

() ()

$\frac{a\Delta t}{\Delta x} = 1$



t x

N

H

Q

T

$$(\quad) \quad R^{(\quad)}$$

:

$$(\quad) \quad \theta \quad \alpha \quad v \quad h = \frac{H}{H_R}; \quad \alpha = \frac{N}{N_R}; \quad v = \frac{Q}{Q_R}; \quad \beta = \frac{T}{T_R}$$

:

$$\frac{\beta}{\alpha^2} = \frac{Q_R}{Q} \cdot \frac{N}{N_R} = cte;$$

$$\frac{\beta}{\alpha^2} = \frac{T}{T_R} \cdot \frac{N^2}{N_R^2} = cte;$$

$$\frac{h}{\alpha^2} = \frac{H}{H_R} \cdot \frac{N^2}{N_R^2} = cte.$$

$$\frac{h}{\alpha^2} = \infty \quad \alpha = 0$$

$$\frac{h}{\alpha^2 + v^2} = \frac{h}{\alpha^2}$$

$$\frac{\alpha}{v} = \infty \quad v = 0$$

$$\theta = \text{Arctg} \frac{\alpha}{v}$$

$$\frac{h}{\alpha^2 + v^2}$$

$$\frac{\beta}{\alpha^2 + v^2}$$

N_s

()

SI

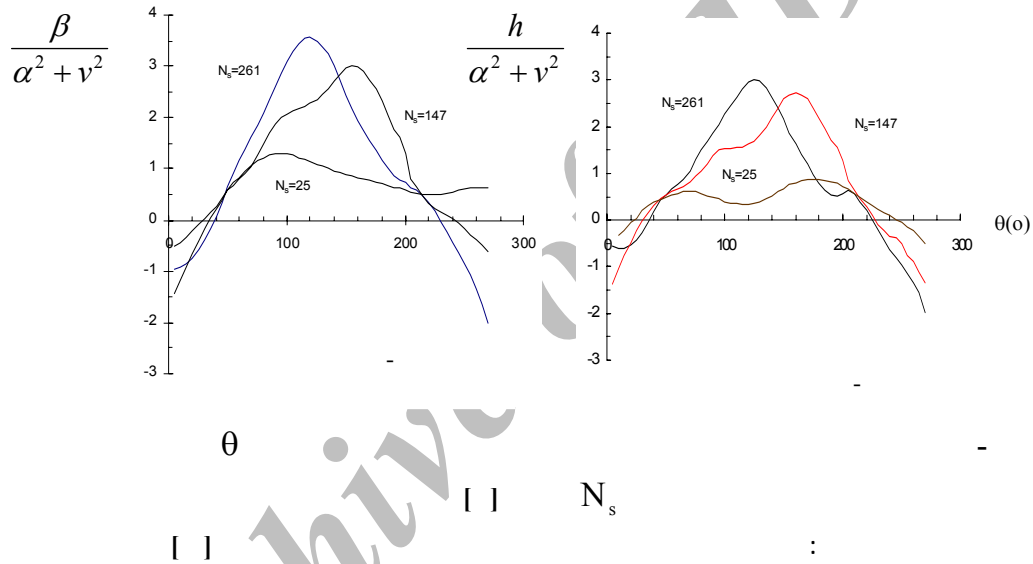
(H= - m)

1- Rated Values

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θ	ν	α	
$0^\circ \leq \theta \leq 90^\circ$	+	+	
$90^\circ \leq \theta \leq 180^\circ$	-	+	
$180^\circ \leq \theta \leq 270^\circ$	-	-	
$270^\circ \leq \theta \leq 360^\circ$	+	-	



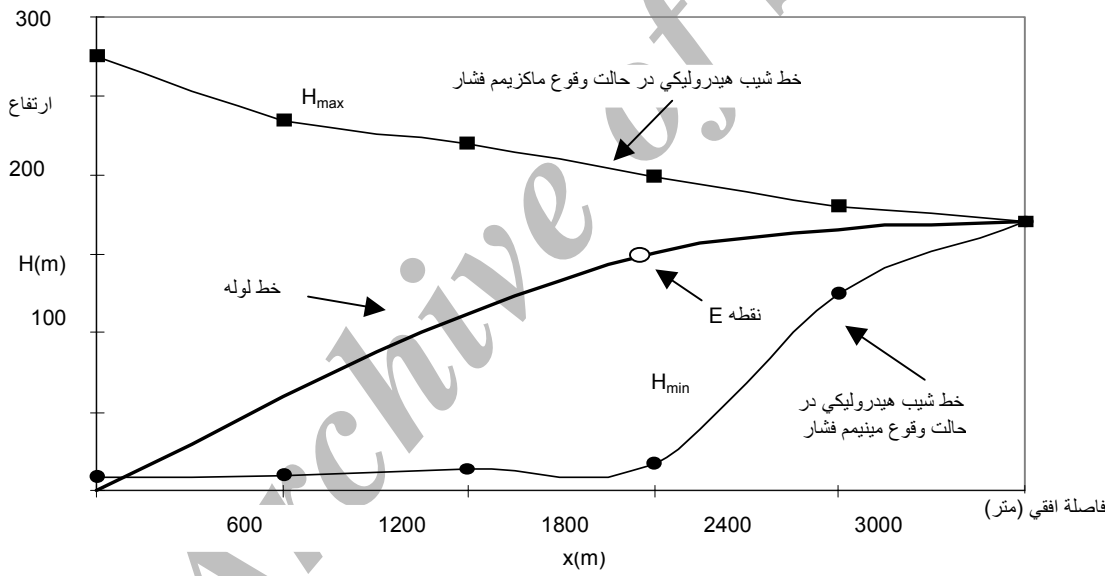
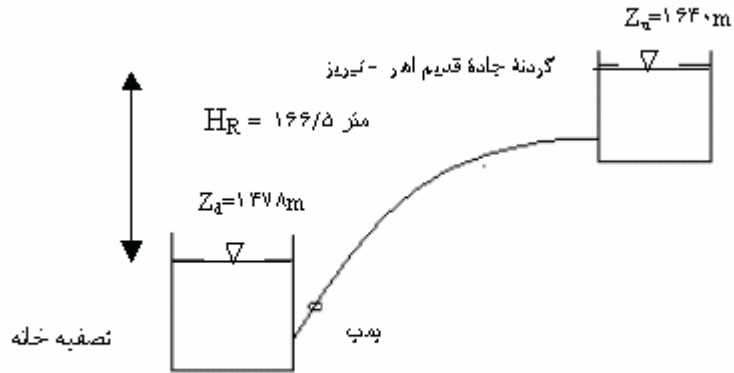
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N_s

:

	(L)	
	(D)	
/	(ΔH)	
	(z_d)	
	(z_u)	
/	(H_R)	
/	(e)	
(+)	(+)	
	(Q_R)	
K.S.B-W.K /		
KW		
/ N.m	(T_R) ()	
r.p.m	(N_R)	



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$$e = \frac{pd}{2\sigma}$$

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[: h_{porf}

()

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$$h_{porf} = C_{orf} \cdot Q_{porf} \cdot |Q_{porf}| \quad ()$$

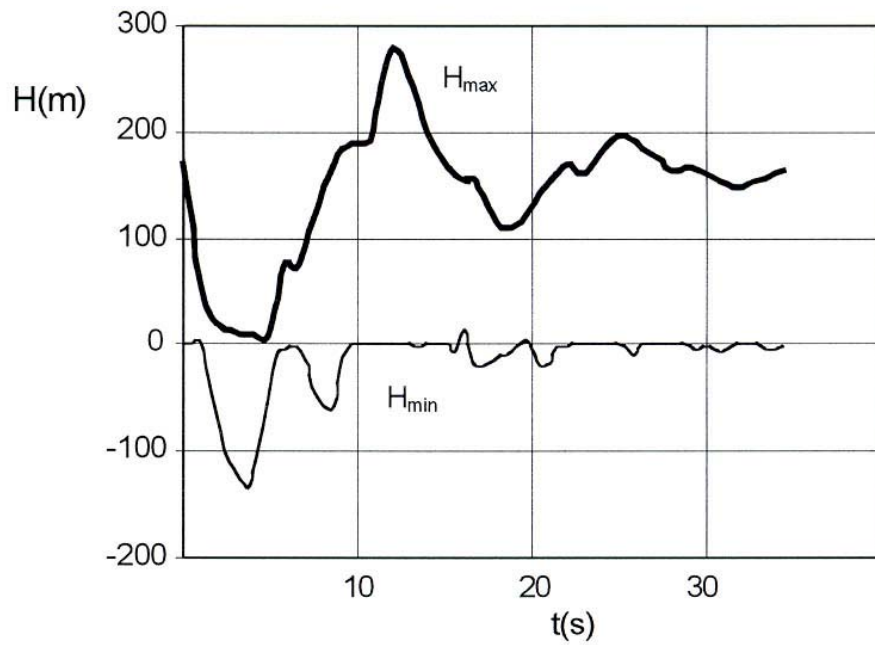
m

m^3

- m -

Q_{porf}

C_{orf}



A

()	()	()	()	

()

()

m^3

()

H_{\min} (m)	H_{\max} (m)	()	
$- 7/02 < H_{\min} < 0$	$121/81 < H_{\max} < 208/02$		
$- 5/56 < H_{\min} < 0$	$127/17 < H_{\max} < 199/46$		
$- 4/81 < H_{\min} \leq 0$	$129/64 < H_{\max} < 195/61$		
$- 4/3 < H_{\min} \leq 0$	$131/7 < H_{\max} < 192/64$		

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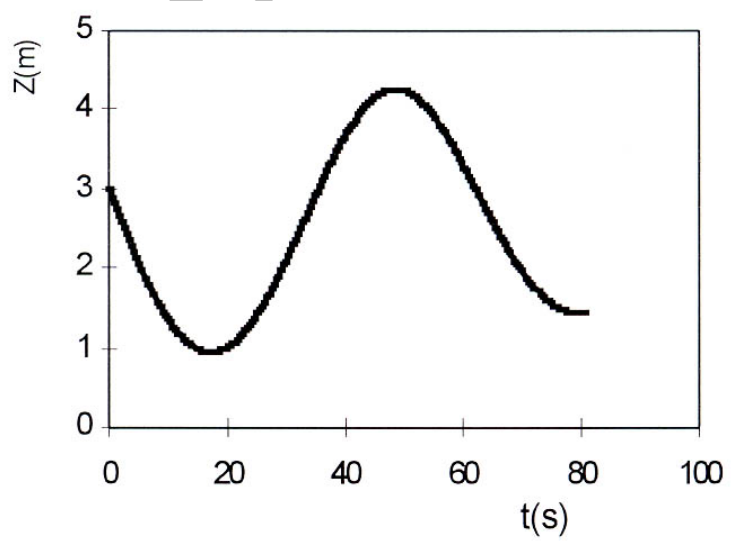
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(E)

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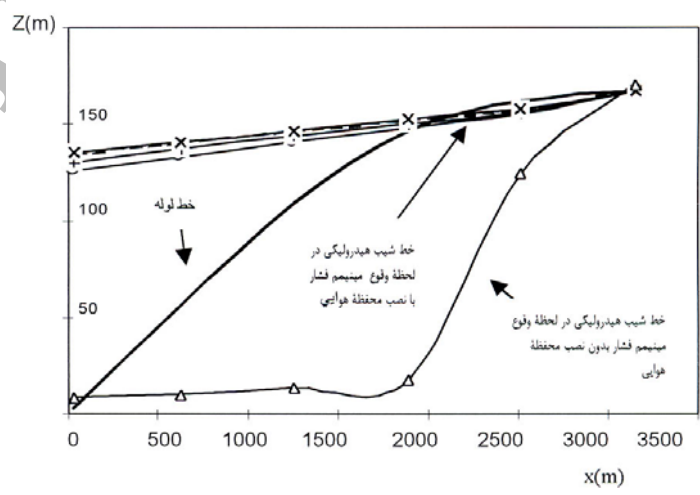
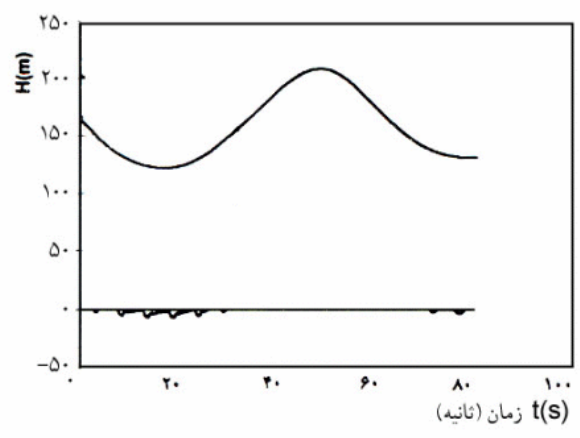
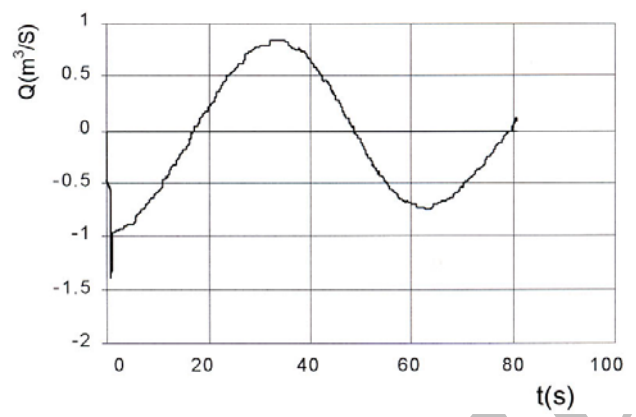


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T(N.m)	-
N(r.p.m)	:
h	-
α	-
v	.
B	-
θ (o)	-
N _s	SI
A(m ²)	-

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V(m/s)
(N/m²)
Q(m³/s)
ρ(Kg/m³)
x(m)
t(s)
g(m/s²)
D(m)
e(m)
a(m/s)
φ(°)
K(N/m²)
E(N/m²)
f
σ(N/m²)
H(m)
C_{orf}
Q_{porf} (m³/s)
h_{porf}(m)

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