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$$R_Q = 0.299 \left(\frac{H_d}{p}\right)^{0.839} \left(\frac{H_d}{y_2}\right)^{2.602} \left(\frac{W}{p}\right)^{-0.226} \left(\frac{d}{p}\right)^{-0.513} (\sin\alpha_1)^{-1.622} \quad ()$$

R_Q
 H_d
 p W y_2
 α_1 d

(2007) Heydari

(Michioku et al., 2005)

(2006) Riahi

...

(2010) Mohammed

amiri@ut.ac.ir :

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(Tractive force)

$$\frac{Q}{\sqrt{gB} y_1^{1.5}} = -0.37 + 0.095 \log Re + 0.063 \frac{H_d}{W} + 0.114 \frac{d}{p} \quad (1)$$

$$\frac{Q}{\sqrt{gB} y_1^{1.5}} = -0.41 + 0.105 \log Re + 0.031 \frac{H_d}{W} + 0.057 \frac{d}{p} + 0.018 s_r \quad (2)$$

$$Re = Q\rho/B\mu \quad Fr = Q/(Bg^{(1/2)}y_1^{(1.5)}) \quad (3) \quad (4)$$

$$s_r = (y_1 - y_2)/H_d$$

Hansen et al.

(2005)

(2002) Lenzi

(step-pool morphology)

$$v_f = \sqrt{\frac{(2(\rho_s - \rho) g \beta) (f \cos s_0 - \sin s_0) D_x}{C_D \rho}} \quad (5)$$

(2005) Hansen et al.

(2002) Maeno et al.

(rubble

mound weirs)

$$V_v = Jm^{0.5} i^{0.54}$$

$(Q/(nA))$

V_v

J

A

n

m

$5.243 (L^{0.5}/T)$

i

$$y_{n_{porous}} = \left[\frac{Q}{Ws_0^{0.54}} \frac{3\sqrt{\lambda}}{4nm^{0.5}} \right]^{2/3} \quad (1)$$

λ

$$\theta_1 y^{sN-2s} + \theta_2 y^{sN+1} - \theta_3 = -x \quad (2)$$

x

$$\theta_{1,2,3} \quad (L) \quad y \quad (L)$$

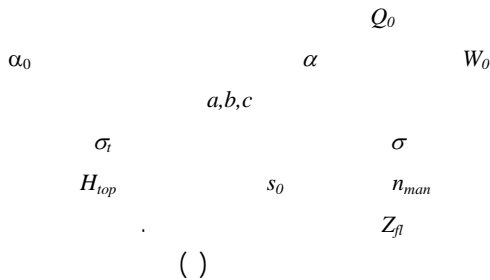
(Hansen et al., 2005)

(rip rap)

(critical stone Froude number)

$$f_j(Q_0, B, p, W_0, W, \alpha, \alpha_0, d, y_1, a, b, c, n, \rho, \rho_s, g, \mu, \sigma, n_{man}, Z_{fl}, S_0, \sigma_t, H_{top}, y_2) = 0 \quad (3)$$

(Rathgeb, 2000)

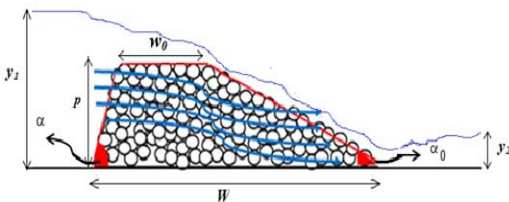


$$Fr_{s,er} = \frac{q_s}{\sqrt{g \cdot \frac{\rho_s - \rho_w}{\rho_w} d_{s,er}^3}} \quad (4)$$

q_s : $Fr_{s,er}$

$d_{s,er}$

(2007) Siebel .



$$d_{s,er} = 1.71 s_0^{0.68} q_s^{\frac{2}{3}} \left(\frac{\rho_w}{\rho_s - \rho_w} \right)^{\frac{1}{3}} \quad (5)$$

(Streeter, 1981)

(2002) Maeno et al

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(Herrera and

Felton, 1991)

$$\tan(\alpha_0) = a \left(\frac{d}{p}\right)^b \left(\frac{d-\sigma}{d}\right)^c \left(\frac{y_1 - y_2}{p}\right)^d \left(\frac{q}{\sqrt{g \cdot \frac{\rho_s - \rho_w}{\rho_w} d^3}}\right)^f$$

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$$d = \frac{\sum d_i \times w_i}{\sum w_i}$$

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$$\sigma = \left[\frac{\sum (d - d_i)^2 \times w_i}{\sum w_i} \right]^{1/2}$$

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d_i

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w_i

lit/s

d_i

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(cm)

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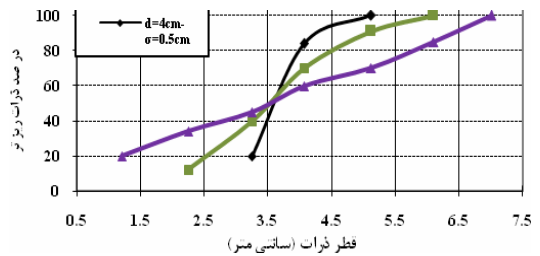
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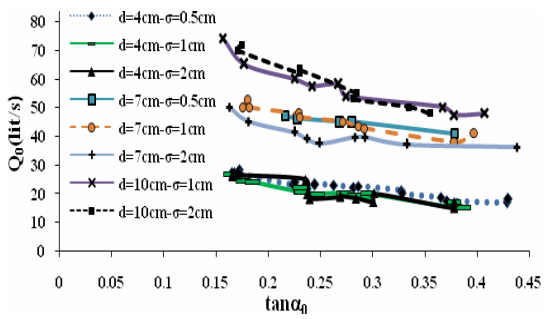
(Profile indicator)

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$N \times \sin \alpha_2$

N

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α_2

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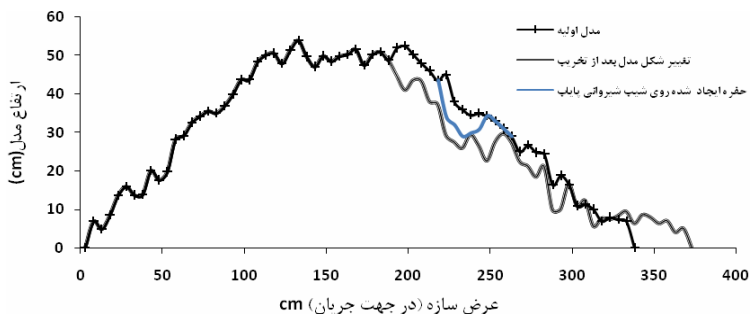
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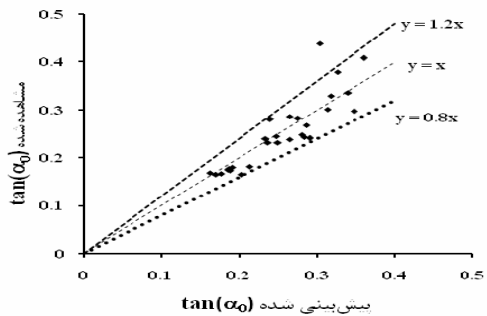
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/ (MRE) ()

SPSS



$$\tan(\alpha_2) = 0.023 \left(\frac{d}{p}\right)^{-0.832} \left(\frac{\sigma}{d}\right)^{-0.117} \left(\frac{y_1 - y_2}{p}\right)^{-1.978} \left(\frac{q}{\sqrt{g \cdot \frac{\rho_s - \rho_w}{\rho_w} d^3}}\right)^{-1.455}$$

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$$MRE = \frac{\sum_{i=1}^N \left| \frac{Q_i - \bar{Q}_i}{Q_i} \right|}{N} \quad ()$$

$$RMSE = \left[\frac{\sum_{i=1}^N (Q_i - \bar{Q}_i)^2}{N} \right]^{\frac{1}{2}} \quad () \quad (MRE)$$

$$\bar{Q}_i = \frac{\sum_{i=1}^N Q_i}{N} \quad () \quad ()$$

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(RMSE)

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) (2006) Riahi

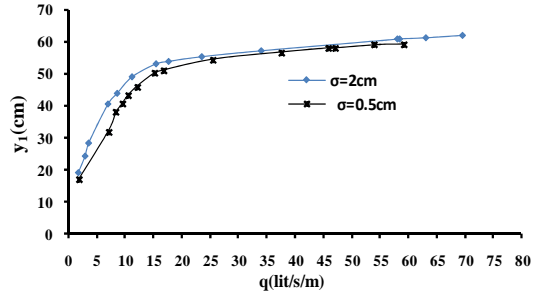
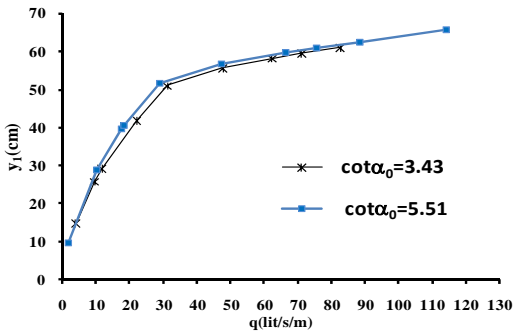
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Riahi

(2006)



d=4cm

$\sigma = 1$ cm d=7cm

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Maeno et al.

Riahi (2006) (2002)

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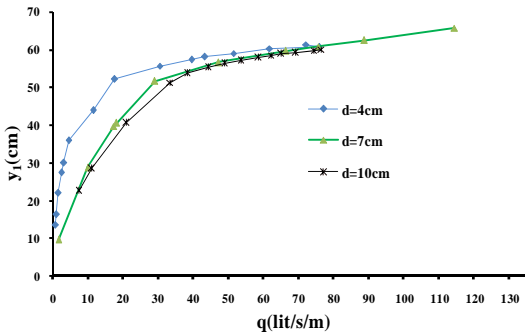
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Q_0

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(Kamann et al, 2007)

(Armor Layer)

Q_0

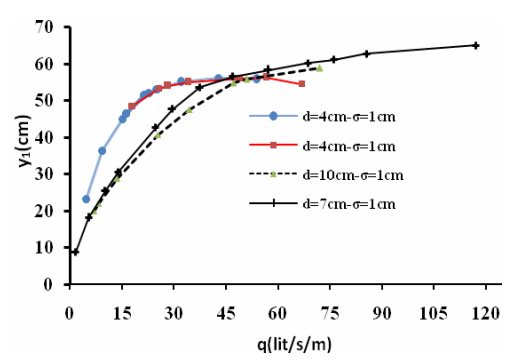
Q_0

(/ : :)
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Q_0

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(Heydari, 2007)



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- J
- a, b, c
- B
- C_D
- d

Z_{fl}	:	$d_{s,er}$
α		D_X
α_0		g :
α_1		H_d
β		H_{top}
μ		n_{man}
ρ		n
σ		P
$\theta_{1,2,3}$:	Q_0
		Q
		q_s
σ_i		R_Q
M		s_0 ()
I		v_f
λ		W
		W_0 :
		y_2

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