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Hydraulic Jump in a Rectangular Open Channel with Abrupt Change in Slope

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Abstract: In his study of jet-assisted hydraulic jump in rectangular channel, France investigated the stability of the hydraulic jump and the effectiveness of the jet over a wide range of operating conditions. He observed that the stabilization of the jump is dependent on a number of parameters like the Froude number, channel bed slope, etc. but concluded however that the angle of inclination of the jets has the most pronounced effect. In the present research researchers develop a mathematical model for dredging a rectangular open channel with hydraulic jump and abrupt change in slope using the conditions of geometrical and dynamical similarities. Applying the model to a numerical example, new parameters of the new (excavated) channel are determined and compared with those of the original channel.

Key words: Hydraulic jump, rectangular channel, dredging, abrupt change, in slope, Nigeria

INTRODUCTION

An open channel is a conduit for flow with a free surface or in other words, when the free surface of the flowing liquid is in contact with the atmosphere the flow is said to be through an open channel, e.g., canals, rivers, a sewer, aquaduct, etc. A channel may be open or closed provided its surface is exposed to constant pressure usually atmospheric. The flow of the liquid in an open channel is not due to the pressure differences as in the case of pipe flow but it is due to the slope of the bed of the channel (Chow, 1959; Khurmi, 2004).

Nasser presented a theoretical and experimental analysis of flow in a channel with a bed slot. Their main objective was to provide an insight into some aspects of spatially varied, open channel flow. In their analysis they showed that the coefficient of discharge for the slot could be expressed by means of a simple equation and they confirmed this experimentally.

Notable contributors in the field of open channel flows include among others (Chanson, 2008; Chiu and Tung, 2002; Firoozabadi *et al*., 2005; Lee *et al*., 2004; Lin, 2006; Moramarco and Singh, 2004; Sarma *et al*., 2000). The objective of the present research is to develop a mathematical model for the excavation of a rectangular open channel with hydraulic jump and abrupt change in slope of the channel bed. A numerical illustration, based on channel flow problem is given and by using the model certain parameters of the new channel are determined and compared with those of the original channel. The results of the analysis are presented in tabular form. It is also observed that some parameters is both channels exhibit interesting characteristics. Here the flow is in a steady state but the flow pattern is non-uniform.

DEVELOPMENT OF MATHEMATICAL MODEL FOR DREDGING A RECTANGULAR CHANNEL

In what follows, the 2 systems in dredging an open channel shall be denoted by the symbols O and N where:

System O = Original open channel (i.e., open channel before dredging)
System N = New open channel (i.e., open channel after dredging)

Also, the subscripts 1 and 2 shall be used to denote the conditions upstream and downstream of the jump, respectively.

MATHEMATICAL MODEL FOR THE ORIGINAL RECTANGULAR CHANNEL

Upstream parameters

Cross sectional area $(A_1)_0$: From geometry area of a rectangle is using modeling notation:

$$(A_1)_0 = b\,(h_1)_0 \tag{1}$$

where, b is the width of the channel and $(h_1)_0$ the depth.

Wetter perimeter $(W_1)_0$: Also, from geometry and by the modeling notation, the wetted parameter is:

$$(W_1)_0 = b\,(h_1)_0 \tag{2}$$

Hydraulic mean depth $(R_1)_0$:

$$(R_1)_0 = \frac{(A_1)_0}{(W_1)_0} = \frac{b(h_1)_0}{b + 2(h_1)_0} \tag{3}$$

Mean velocity $(\mu_1)_0$: From Chow (1959) and using the notation:

$$(u_1)_0 = \frac{1}{n}\left[(R_1)_0\right]^{2/3}\left[(i_1)_0\right]^{1/2} \quad (4)$$

Here, i denotes the slope of the channel.

Discharge Q_0:

$$Q_0 = (A_1)_0(u_1)_0 = b(h_1)_0 \frac{1}{n}\left[(R_1)_0\right]^{2/3}\left[(i_1)_0\right]^{1/2} \quad (5)$$

Froude number $(F_1)_0$: Researchers note that the jump is characterized by the upstream Froude number F_1 where:

$$F_1 = \frac{u_1}{\sqrt{g(h_1)}} \quad (6)$$

[g = acceleration due to gravity]

Thus, using the modeling notation:

$$(F_1)_0 = \frac{(u_1)_0}{\sqrt{g(h_1)_0}} \quad (7)$$

Downstream parameters

Downstream depth $(h_2)_0$: The equation for conjugate depth of the jump is given by (Chow, 1959; Khurmi, 2004):

$$\frac{h_2}{h_1} = \frac{1}{2}\left[\left(1+8F_1^2\right)^{\frac{1}{2}} - 1\right] \quad (8)$$

From Eq. 8, researchers obtain using the notation:

$$(h_2)_0 = \frac{1}{2}(h_1)_0\left[\left(1+8(F_1)_0^2\right)^{\frac{1}{2}} - 1\right] \quad (9)$$

Cross sectional area $(A_2)_0$:

$$(A_2)_0 = b\,(h_2)_0 \quad (10)$$

Wetted perimeter $(W_2)_0$:

$$(W_2)_0 = b+2\,(h_2)_0 \quad (11)$$

Hydraulic mean depth $(R_2)_0$:

$$(R_2)_0 = \frac{b(h_2)_0}{b+2(h_2)_0} \quad (12)$$

Mean velocity $(u_2)_0$: From Chow (1959) and by the notation:

$$(u_2)_0 = \frac{1}{n}\left[(R_2)_0\right]^{2/3}\left[(i_2)_0\right]^{1/2} \quad (13)$$

Discharge Q_0: By continuity:

$$Q_0 = (A_1)_0(u_1)_0 = (A_2)_0(u_2)_0 = b(h_2)_0 \frac{1}{n}\left[(R_2)_0\right]^{2/3}\left[(i_2)_0\right]^{1/2} \quad (14)$$

Froude number $(F_2)_0$:

$$(F_2)_0 = \frac{(u_2)_0}{\sqrt{g(h_2)_0}} \quad (15)$$

Critical depth $(h_c)_0$:

$$(h_c)_0 = \left[\frac{Q_0^2}{gb^2}\right]^{\frac{1}{3}} \quad (16)$$

MATHEMATICAL MODEL FOR THE NEW RECTANGULAR CHANNEL

Similarity conditions: For dynamical similarity conditions the Froude numbers should be identical at all corresponding points in the original and new (excavation) channels. Thus, for the upstream sections of the 2 channels:

$$\frac{(u_1)_0^2}{g(h_1)_0} = \frac{(u_1)_N^2}{g(h_1)_N} \quad (17)$$

And for the downstream sections:

$$\frac{(u_2)_0^2}{g(h_2)_0} = \frac{(u_2)_N^2}{g(h_2)_N} \quad (18)$$

The conditions of geometrical similarity for the 2 channels require:

$$\frac{(h_1)_0}{(h_2)_0} = \frac{(h_1)_N}{(h_2)_N} \quad (19)$$

Upstream parameters for the new channel

Cross sectional area $(A_1)_N$:

$$(A_1)_N = b\,(h_1)_N \quad (20)$$

Wetted perimeter $(W_1)_N$:

$$(W_1)_N = b+2\,(h_1)_N \quad (21)$$

Hydraulic mean depth $(R_1)_N$:

$$(R_1)_N = \frac{(A_1)_N}{(W_1)_N} = \frac{b(h_1)}{b+2(h_1)_N} \quad (22)$$

Mean velocity $(u_1)_N$: From similarity condition Eq. 17:

$$(u_1)_N = \left[\frac{(u_1)_0^2 g(h_1)_N}{g(h_1)_0}\right]^{1/2} \tag{23}$$

Discharge Q_N:

$$Q_N = (A_1)_N (u_1)_N = b(h_1)_N \left[\frac{(u_1)_0^2 g(h_1)_N}{g(h_1)_0}\right]^{1/2} \tag{24}$$

Froude number $(F_1)_N$: From Eq. 6:

$$(F_1)_N = \frac{(u_1)_N}{\sqrt{g(h_1)_N}} \tag{25}$$

Slope $(i_1)_N$: Again, from Chow (1959):

$$(i_1)_N = \left[\frac{n.Q_N}{(A_1)_N((R_1)_N)^{2/3}}\right]^2 \tag{26}$$

Downstream parameters for the new channel

Depth $(h_2)_N$: From geometrical condition Eq. 19:

$$(h_2)_N = \frac{(h_2)_0 (h_1)_N}{(h_1)_0} \tag{27}$$

Cross sectional area $(A_2)_N$:

$$(A_2)_N = b\,(h_2)_N \tag{28}$$

Wetted perimeter $(W_2)_N$:

$$(W_2)_N = b+2\,(h_2)_N \tag{29}$$

Hydraulic mean depth $(R_2)_N$:

$$(R_2)_N = \frac{(A_2)_N}{(W_2)_N} = \frac{b(h_2)_N}{b+2(h_2)_N} \tag{30}$$

Mean velocity $(u_2)_N$: From Eq. 18:

$$(u_2)_N = \left[\frac{(u_2)_0^2 g(h_2)_N}{g(h_2)_0}\right]^{1/2} \tag{31}$$

Discharge Q_N: Again by continuity:

$$Q_N = (A_1)_N (u_1)_N = (A_2)_N (u_2)_N = b(h_2)_N \left[\frac{(u_2)_0^2 g(h_2)_N}{g(h_2)_0}\right]^{1/2} \tag{32}$$

Froude number $(F_2)_N$: Again from Eq. 6:

$$(F_2)_N = \frac{(u_2)_N}{\sqrt{g(h_2)_N}} \tag{33}$$

Critical depth $(h_c)_N$:

$$(h_c)_N = \left[\frac{Q_N^2}{gb^2}\right]^{\frac{1}{3}} \tag{34}$$

Slope $(i_2)_N$: Finally, from Chow (1959):

$$(i_2)_N = \left[\frac{nQ_N}{(A_2)_N((R_2)_N)^{2/3}}\right]^2 \tag{35}$$

MODEL FOR ENERGY (HEAD LOSS), JUMP EFFICIENCY, RELATIVE ENERGY LOSS AND POWER LOSS

The energy loss h_f occurring between the 2 sections of the channel as determined from Bernoulli's equation for any streamline between points 1 and 2 of the hydraulic jump is:

$$h_f = \left[\frac{u_1^2}{2g} + h_1\right] - \left[\frac{u_2^2}{2g} + h_2\right] \tag{36}$$

Or:

$$h_f = E_1 - E_2 \tag{37}$$

Where:

$$E_1 = \frac{u_1^2}{2g} + h_1 \tag{38}$$

And:

$$E_2 = \frac{u_2^2}{2g} + h_2 \tag{39}$$

Here, E_1 and E_2 denote the specific energies before and after the jump, respectively. It is elementary to see Eq. 36 gives after simplification:

$$h_f = \frac{(h_2 - h_1)^3}{4h_1h_2} \tag{40}$$

From Eq. 40 obtain by virtue of the modeling notation Energy loss in the original channel $(h_f)_0$:

$$(h_f)_0 = \frac{[(h_2)_0 - (h_1)_0]^3}{4(h_1)_0(h_2)_0} \tag{41}$$

Energy loss in the new channel $(h_f)_N$:

$$(h_f)_N = \frac{[(h_2)_N - (h_1)_N]^3}{4(h_1)_N (h_2)_N} \quad (42)$$

And from Eq. 38 and 39 researchers get, jump efficiency for the original channel:

$$\frac{(E_2)_0}{(E_1)_0} = \frac{\frac{(u_2)_0^2}{2g} + (h_2)_0}{\frac{(u_1)_0^2}{2g} + (h_1)_0} \quad (43)$$

Jump efficiency for the new channel:

$$\frac{(E_2)_N}{(E_1)_N} = \frac{\frac{(u_2)_N^2}{2g} + (h_2)_N}{\frac{(u_1)_N^2}{2g} + (h_1)_N} \quad (44)$$

Relative energy loss for the original channel:

$$\frac{(E_1)_0 - (E_2)_0}{(E_1)_0} = 1 - \frac{(E_2)_0}{(E_1)_0} \quad (45)$$

Relative energy loss for new channel:

$$\frac{(E_1)_N - (E_2)_N}{(E_1)_N} = 1 - \frac{(E_2)_N}{(E_1)_N} \quad (46)$$

Also, from Eq. 6 and 7 it is obtained, respectively, power loss for the original channel P_0:

$$P_0 = \rho g Q_0 (h_f)_0 \quad (47)$$

Power loss for the new channel P_N:

$$P_N = \rho g Q_N (h_f)_N \quad (48)$$

Finally, height of jump in the original channel H_0:

$$H_0 = (h_2)_0 - (h_1)_0 \quad (49)$$

Height of jump in the new channel H_N:

$$H_N = (h_2)_N - (h_1)_N \quad (50)$$

Here, ρ = fluid density, g = gravitational acceleration, Q_0 and Q_N are as above. Thus, the expressions (Eq. 17-35) constitute the model for the new rectangular open channel with jump. Also while the expressions Eq. 41, 43, 45, 47 and 49 constitute, respectively the model the for energy loss, jump efficiency, relative energy loss, power loss and height of the jump for the original channel, the expressions Eq. 42, 44, 46, 48 and 50 constitute, on the other hand, the model for determining, respectively the energy loss, jump efficiency, relative energy loss, power loss and height of the jump in respect of the new channel.

APPLICATION OF THE MODEL TO NUMERICAL EXAMPLE

Consider for example, a rectangular open channel with hydraulic jump having a width of 8 m, Manning's coefficient n is 0.014. The channel has an abrupt change in the channel slope from 0.009438-0.0008553 and conveys water at the rate of 24.50 m^3 sec^{-1}, the depth of water before the jump occurs being 0.65 m. Using the model is wished to determine, after dredging the channel, parameters like the new discharge, the new cross sectional area, the new downstream depth, the new critical depth, the new energy dissipated in the jump, the new relative energy loss, the new jump efficiency, the new power loss, the new change in bed slope and the new height of the jump if the excavation must be to the depth of 1.8 m upstream.

SOLUTION

Original channel

Upstream data: From the problem:

$$b = 8 \text{ m}, (h_1)_0 = 0.65 \text{ m}, Q_0 = 24.50 \text{ m}^3 \text{ sec}^{-1}$$
$$n = 0.014, (i_1)_0 = 0.009438$$

Using these data appropriately in the model expressions Eq. 1-4 and 7 obtained, respectively:

$$(A_1)_0 = 5.2 \text{ m}^2, (W_1)_0 = 9.3 \text{ m}, (R_1)_0 = 0.5591 \text{ m}$$
$$(u_1)_0 = 4.71 \text{ m sec}^{-1}, (F_1)_0 = 1.8658$$

Downstream data: Also, from the problem:

$$b = 8 \text{ m}, n = 0.014, (i_2)_0 = 0.0008553$$

Moreover, appropriate substitution of the above data in the expressions Eq. 9-16 yields, respectively:

$$(h_2)_0 = 1.42 \text{ m}, (A_2)_0 = 11.36 \text{ m}^2, (W_2)_0 = 10.84 \text{ m}$$
$$(R_2)_0 = 1.0483 \text{ m}, (u_2)_0 = 2.155 \text{ m sec}^{-1},$$
$$Q_0 = 24.50 \text{ m}^3 \text{ sec}^{-1} (F_2)_0 = 0.5774, (h_c)_0 = 0.9851 \text{ m}$$

Furthermore, substituting the above data appropriately in the model expressions Eq. 41, 43, 45, 47 and 49 yields, respectively the energy loss, jump efficiency, relative energy loss, power loss and height of the jump for the original channel. Thus researches find:

$$(h_f)_0 = 0.1239\text{ m}, \frac{(E_2)_0}{(E_1)_0} = 93.04\%$$

$$1 - \frac{(E_2)_0}{(E_1)_0} = 0.0695, P_0 = 29.78\text{ KW}, H_0 = 0.77\text{m}$$

The values of the parameters obtained in respect of the original channel are shown in Table 1.

New channel

Upstream data: From the problem:

$$b = 8\text{ m}, (h_1)_N = 1.8\text{ m}, n = 0.014$$

Substituting the above data appropriately in the model Eq. 20-26 gives, respectively:

$$(A_1)_N = 14.4\text{ m}^2, (W_1)_N = 11.6\text{ m}, (R_1)_N = 1.2413\text{ m}$$
$$(u_1)_N = 7.84\text{ m sec}^{-1}, Q_N = 112.902\text{ m}^3\text{ sec}^{-1}$$
$$(F_1)_N = 1.8658, (i_1)_N = 0.0090334$$

Downstream data: Again, from the problem:

$$b = 8\text{ m}, n = 0.014$$

Similarly, the parameters $(h_2)_N$, $(A_2)_N$, $(W_2)_N$, $(R_2)_N$, $(u_2)_N$, Q_N, $(F_2)_N$, $(h_c)_N$ and $(i_2)_N$ for the new channel are determined, respectively by appropriate substitution of the data in Eq. 27-35. The result is:

$$(h_2)_N = 3.93\text{ m}, (A_2)_N = 31.47\text{ m}^2, (W_2)_N = 15.86\text{ m}$$
$$(R_2)_N = 1.9833\text{ m}, (u_2)_N = 3.58\text{ m sec}^{-1},$$
$$Q_N = 112.902\text{ m}^3\text{ sec}^{-1}\ (F_2)_N = 0.5774,$$
$$(h_c)_N = 2.7253\text{ m}\ (i_2)_N = 0.0010130$$

Finally, the energy loss, jump efficiency, relative energy loss, power loss and height of the jump for the new channel are determined, respectively via appropriate substitution of the above data in the expressions Eq. 42, 44, 46, 48 and 50. Thus, it is obtained:

$$(h_f)_N = 0.34314\text{m}, \frac{(E_2)_N}{(E_1)_N} = 93.04\%$$

$$1 - \frac{(E_2)_N}{(E_1)_N} = 0.06955, P_N = 380.056\text{ KW}, H_N = 2.13\text{m}$$

The values of the new parameters (a-j) for the new channel are shown in Table 2.

Table 1: Result for the original channel

	Original channel with jump	
Characteristics	Upstream parameters	Downstream parameters
Bed slope	0.009438	0.0008553
Manning's n	0.014	0.014
Width	8 m	8 m
Depth	0.65 m	1.42 m
Area of cross section	5.20 m^2	11.36 m^2
Wetted parameter	9.30 m	10.84 m
Hydraulic mean depth	0.5591 m	1.0483 m
Mean velocity	4.71 m sec^{-1}	2.15 m sec^{-1}
Discharge	24.50 m^3 sec^{-1}	24.50 m^3 sec^{-1}
Froude number	1.8658	0.5774
Critical depth	-	0.9851 m
Energy loss	-	0.1239 m
Jump efficiency	-	93.04%
Relative energy loss	-	0.0695
Power loss	-	29.781 KW
Height of jump	-	0.77 m

Table 2: Result for the new channel

	New (excavated) channel with jump	
Characteristics	Upstream parameters	Downstream parameters
Bed slope	0.0090334	0.0010130
Manning's n	0.014	0.014
Width	8 m	8 m
Depth	1.8 m	3.93 m
Area of cross section	14.4 m^2	31.47 m^2
Wetted parameter	11.6 m	15.86 m
Hydraulic mean depth	1.2413 m	1.9833 m
Mean velocity	7.84 m sec^{-1}	3.58 m sec^{-1}
Discharge	112.902 m^3 sec^{-1}	112.902 m^3 sec^{-1}
Froude number	1.8658	0.5774
Critical depth	-	2.7253 m
Energy loss	-	0.34314 m
Jump efficiency	-	93.04%
Relative energy loss	-	0.06955
Power loss	-	380.056 KW
Height of jump	-	2.13 m

RESULTS AND DISCUSSION

Table 1 and 2 show, respectively the result of the analysis of the flow problem for the original and new (excavated) channels. Comparison of the 2 tables indicates that the downstream parameters namely, the downstream depth, area of cross section, wetted perimeter and hydraulic mean depth are generally greater in the original and new channels than the upstream ones. This is in agreement with the model Eq. 9-12 and 27-30 of the original and new channels, respectively. In particular, these same parameters upstream and downstream are greater in the new channel than their counterparts in the original one.

This is also in agreement with the model Eq. 1-3 (upstream), Eq. 9-12 (downstream) of the original channel and Eq. 20-22 (upstream), Eq. 27-30 (downstream) of the new channel. However, this trend is reversed in the case of the Froude number which is lower in the downstream section in both channels than in the upstream section but the striking thing here is that the upstream Froude numbers are equal in both channels just like the downstream Froude numbers. This agrees with the model Eq. 17-18. Researchers also observed that the upstream and downstream mean velocities in the new channel are respectively greater than the upstream and downstream velocities in the original channel (Table 1 and 2). Another feature is that whereas the critical depth, energy loss, power loss and height of the jump are greater in the new channel than the original one, the jump efficiency and relative energy loss, on the other hand, remain unchanged in both channels. Furthermore while the upstream bed slope in the original channel is greater than the one in the new channel, the downstream bed slope in the original channel however, becomes smaller than its counterpart in the new channel. Finally from Table 1 and 2, it becomes very clear that the new channel maintains a higher water lever than the original one.

This high water level in the new channel can be harnessed for water distribution purposes and for mixing of chemicals used for water purification or waste water treatment. Apart from excavation and lining costs, the new channel removes the danger of a ship grounding if it sails too fast.

CONCLUSION

The application of the model in Bernoulli's equation leads to the energy dissipated in the jump for both the original and new channels. Based on this, other parameters like jump efficiency, relative energy loss and power loss are also determined and compared. It is noted, generally that the new parameters in the new channel are greater numerically than their counterparts in the original channel except jump efficiency and relative energy loss which remain constant just like Manning's roughness factor n and width of the channel.

NOMENCLATURE

$(A_1)_0$ = Upstream cross sectional area of the original channel
$(A_2)_0$ = Downstream cross sectional area of the original channel
$(A_1)_N$ = Upstream cross sectional area of the new channel
$(A_2)_N$ = Downstream cross sectional area of the new channel
b = Width of the channel
$(h_1)_0$ = Upstream depth of the original channel
$(h_2)_0$ = Downstream depth of the original
$(h_1)_N$ = Upstream depth of the new channel
$(h_2)_N$ = Downstream depth of the new channel
$(W_1)_0$ = Upstream wetted perimeter of the original channel
$(W_2)_0$ = Downstream wetted perimeter of the original channel
$(W_1)_N$ = Upstream wetted perimeter of the new channel
$(W_2)_N$ = Downstream wetted perimeter of the new channel
$(u_1)_0$ = Upstream mean velocity of the original channel
$(u_2)_0$ = Downstream mean velocity of the original channel
$(u_1)_N$ = Upstream mean velocity of the new channel
$(u_2)_N$ = Downstream mean velocity of the new channel
$(i_1)_0$ = Upstream slope of the bed of the original channel
$(i_2)_0$ = Downstream slope of the bed of the original channel
$(i_1)_N$ = Upstream slope of the bed of the new channel
$(i_2)_N$ = Downstream slope of the bed of the new channel
Q_0 = Discharge of the original channel
Q_N = Discharge of the new channel
n = Manning's coefficient (or Manning's roughness factor)
$(R_1)_0$ = Upstream hydraulic radius of the original channel
$(R_2)_0$ = Downstream hydraulic radius of the original channel
$(R_1)_N$ = Upstream hydraulic radius of the new channel
$(R_2)_N$ = Downstream hydraulic radius of the new channel
$(F_1)_0$ = Upstream Froude number of the original channel
$(F_2)_0$ = Downstream Froude number of the original channel
$(F_1)_N$ = Upstream Froude number of the new channel
$(F_2)_N$ = Downstream Froude number of the new channel
g = Gravitational acceleration
h_c = Critical depth
$(h_c)_0$ = Critical depth of the original channel
$(h_c)_N$ = Critical depth of the new channel
h_f = Energy loss (or Head loss)
$(h_f)_0$ = Energy loss in the original channel
$(h_f)_N$ = Energy loss in the new channel
E_1 = Specific energy before the jump (or upstream specific energy)
E_2 = Specific energy after the jump (or downstream specific energy)
$(E_1)_0$ = Upstream specific energy in the original channel
$(E_2)_0$ = Downstream specific energy in the original channel
$(E_1)_N$ = Upstream specific energy in the new channel
$(E_2)_N$ = Downstream specific energy in the new channel

ρ = Density of the liquid (water)
P_0 = Power loss in the original channel
P_N = Power loss in the new channel
H_0 = Height of jump in the original channel
H_N = Height of jump in the new channel

REFERENCES

Chanson, H., 2008. A simple solution of the laminar dam break wave. J. Applied Fluid Mech., 1: 1-10.

Chiu, C.L. and N.C. Tung, 2002. Maximum velocity and regularities in open-channel flow. J. Hydr. Eng., 128: 390-398.

Chow, V.T., 1959. Open Channel Hydraulics. McGrow-Hill, New York, ISBN-13: 9780070107762.

Firoozabadi, B., A. Tamayol and G. Ahmadi, 2005. Effects of the Inlet Position and Battle Configuration on the Hydraulic Performance of Primary Settling Tanks. ASME/IMECE, Florida, USA.

Khurmi, R.S., 2004. A Textbook of Hydraulics. 19th Edn., Schand and Company Ltd., New DelhiNew Delhi, ISBN: 81-219-0135-9.

Lee, T.S., H.T. Low and W.D. Huang, 2004. Numerical study of fluid transient in pipes with air entrainment. Int. J. Comput. Fluid Dyn., 18: 381-391.

Lin, D.A., 2006. Regression residuals and mean profile in uniform open channel flow. J. Hydr. Eng., 126: 24-32.

Moramarco, T. and V.P. Singh, 2004. Estimation of mean velocity in natural channels based on Chius velocity distribution equation. J. Hydrol. Eng., 9: 42-50.

Sarma, K.V.N., B.V.R. Prasad and A.K. Sarma, 2000. Detailed study of binary law for open channels. J. Hydr. Eng., 126: 210-214.