A multi variable regression model for prediction Water surface profile in a converging compound channels

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Abstract

Natural compound rivers have varying floodplains, so they are called as non-prismatic compound rivers. Due to high discharge, flooded non-prismatic river causes potential damage to life and property. Therefore a reliable water level prediction modelling for predicting surface profile is required for identify flooded areas which will be helpful for flood mitigation and risk management study. Generally non-prismatic compound channels exhibit non-uniform water surface profile in nature. So the analyses of flows in such geometric and hydraulic conditions to model water surface profile are the most challenging task for river engineers. As experimental investigation have been done to compute the water surface profile of non-prismatic compound channel for different converging angles and over bank flow depths. An attempt has been made to formulate linear regression analysis models for predicting water surface profile for different converging compound channels and the method can be successfully apply to predict water surface profile in non-prismatic compound channel.

Keywords: *water surface profile, non-prismatic compound channel, converging angle, flow depth*

1. Introduction

A compound channel consists of a main channel and floodplains. The main river channel carries low flows and the flood plains transport overbank flows during flooding. The storage provided by floodplains in overbank flow reduces river channel that carries low flows flood stages. The interaction between the main channel and floodplain flow is a complex one because of the momentum transfer at the interface. This phenomenon is more complex in non-prismatic compound channels with converging floodplains due to change in geometry. In converging compound channel the flow is forced to leave the flood plains and enter the main channel resulting in increased interactions and momentum exchange (Bousemer and Zech (1999), Bousemer et al. (2004), Proust et al. (2006), Rezaei (2006),Naik & Khatua(2014)). This extra momentum exchange should also be taken into account in the flow modelling. Today more than half of the world's population lives within 65km of a sea cost, and most of the major cities are also located on main river systems. So whenever flood occurs, this has lead to increase in the loss of life and economic cost (Knight and Shamseldin (2005)). All the above-mentioned studies have focused on the effect of changes in floodplain sections. The effect of water and flow conditions on water surface profile in non-prismatic compound channels has not been considered properly. Water surface profile prediction is a vital issue in flood risk management and also in assessing ecological effects of bridge construction or changing the cross section geometry of channels. The effect of contraction on the water depth in a compound channel with converging compound channel is now investigated. In present work based on the experimental data of N.I.T Rourkela data and Rezaei (2006) data an attempt has been made to develop a mathematical model for water surface calculation in converging compound channels. The method can be applied to the converging compound channels of different configurations and flow conditions.

Nomenclature

α Width ratio
δ Aspect ratio
β Relative depth
X_r Relative distance

θ	Converging angle

2. Experimental work

2.1 Experimental Setup

Experiments had been conducted at the Hydraulics and Fluid mechanics Laboratory of Civil Engineering Department of National Institute of Technology, Rourkela, India. Three sets of non-prismatic compound channels with varying cross sections were built inside a concrete flume measuring 15m long × 0.90m width × 0.55m depth and flume with Perspex sheet of same dimensions. The width ratio of the channel was $\alpha = 1.8$ and the aspect ratio was $\delta = 5$. Keeping the geometry constant, the converging angles of the channels were varied as 12.38°, 9º and 5^0 respectively. Converging length of the channels fabricated were found to be 0.84m, 1.26m and 2.28m respectively. Longitudinal bed slope of the channel was 0.0011. Roughness of the floodplain and main channel were identical and the Manning's n was determined as 0.011 from the experimental runs in the channel. A re-circulating system of water supply was established with pumping of water from an underground sump to an overhead tank from where water flows under gravity to the experimental channel. Adjustable vertical gates along with flow strengtheners are provided in upstream section sufficiently ahead of rectangular notch to reduce turbulence and velocity of approach in the flow near the notch section. An adjustable tailgate at the downstream end of the flume helps to maintain uniform flow over the test reach. Water from the channel was collected in a volumetric tank that helps to measure the discharge rate. From the volumetric tank water runs back to the underground sump. Fig.1.shows the plan view of compound channel with non-prismatic floodplains of convergence length L=0.84m, 1.26m, 2.28m.A movable bridge was provided across the flume for both span wise and stream wise movements over the channel area so that each location on the plan of compound channel could be accessed for taking measurements. A micro-Pitot tube of 4.77 mm external diameter in conjunction with suitable inclined manometer is used to measure velocity at these points of the flow-grid. The Pitot tube is physically rotated with respect to the main stream direction till it gives maximum deflection of the manometer reading. A flow direction finder having a least count of 0.1° is used to get the direction of maximum velocity with respect to the longitudinal flow direction. The angle of limb of Pitot tube with longitudinal direction of the channel is noted by the circular scale and pointer arrangement attached to the flow direction meter. The overall discharge obtained from integrating the longitudinal velocity plot and from volumetric tank collection is found to be within ±3% of the observed values.

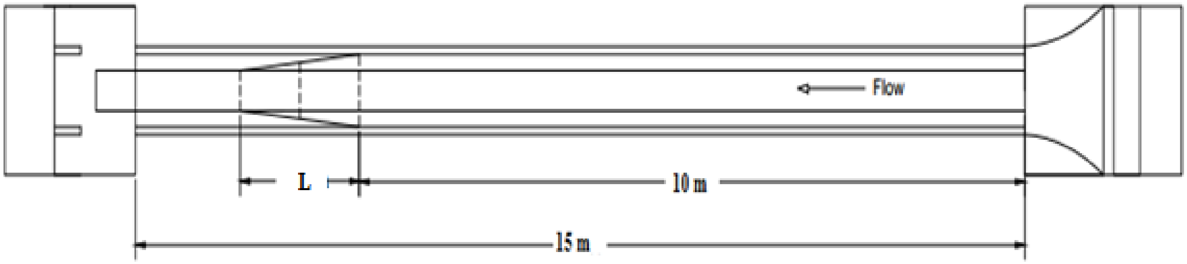


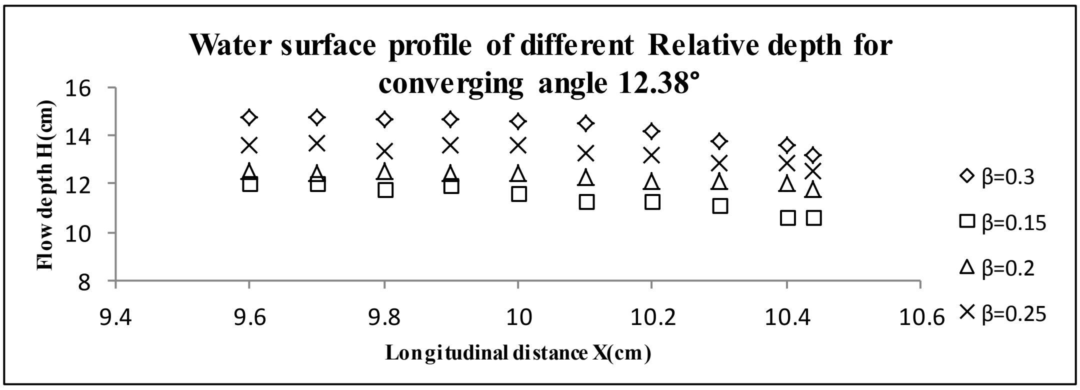
Figure1 Plan view of compound channel with non-prismatic floodplains, convergence length L=0.84m, 1.26m, 2.28m

Table1.Hydraulic parameters for the experimental channel data sets

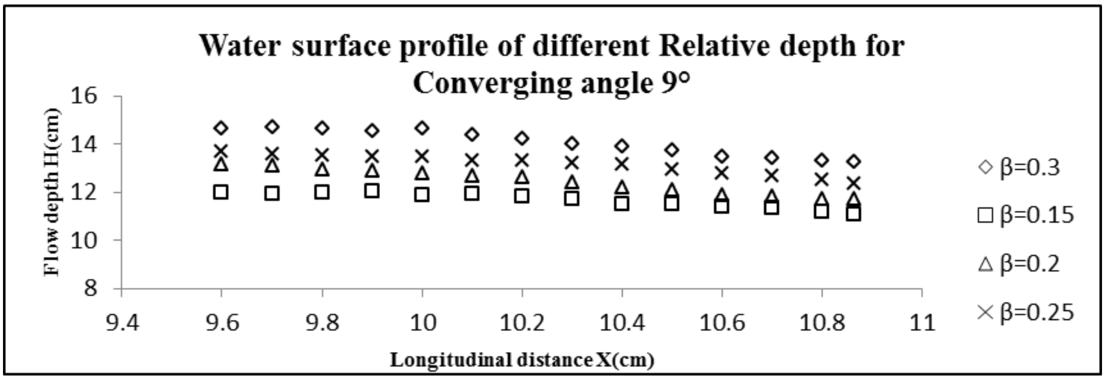
Verified test channel	Type of channels	Converging angle (Ɵ)	Longitudinal slope (S)	Cross sectional geometry	Total channel width (B)	Main channel width (b)	Main channel depth (h)	Width ratio at begining B/b (α)	Converging length ratio (Xr)	Aspect Ratio b/h (δ)
					Meter	Meter	Meter		Meter	
Rezaei (2006)	Convergent (CV2)	11.31°	0.002	Rectangular	1.2	0.398	0.05	3	2	7.96
Rezaei (2006)	Convergent (CV6)	3.81°	0.002	Rectangular	1.2	0.398	0.05	3	6	7.96
Rezaei (2006)	Convergent (CV6)	1.91°	0.002	Rectangular	1.2	0.398	0.05	3	6	7.96
N.I.T. Rkl	Convergent	5°	0.0011	Rectangular	0.9	0.5	0.1	1.8	2.28	5
N.I.T. Rkl	Convergent	9°	0.0011	Rectangular	0.9	0.5	0.1	1.8	1.26	5
N.I.T. Rkl	Convergent	12.38°	0.0011	Rectangular	0.9	0.5	0.1	1.8	0.84	5

3. Experimental results

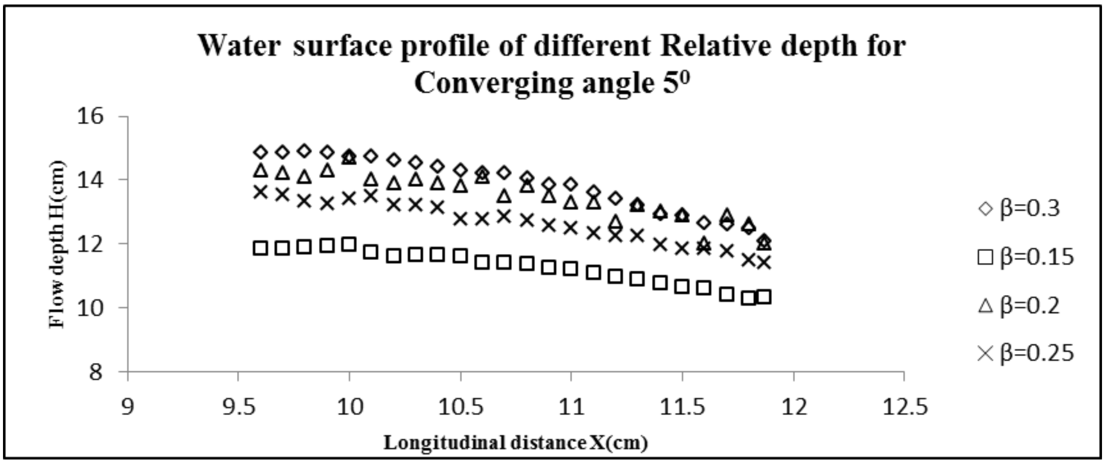
The water surface profile of different sections for the converging compound channel of angle 12.38°, 9^0 and 5^0 are shown in Fig.2 (a) , (b) and (c) respectively.



(a)



(b)



(c)

Figure 2 Water surface profiles for compound channel with converging floodplains, (a) θ=12.38°, (b) $\theta=9^0$, (c) $\theta=5^0$

4. Water surface profile computation

From the literature study, it is seen that water surface profile $(H/h)^* = F(\alpha, \beta, \delta)$ for prismatic compound channel, Where F is the functional symbol. But when all the equations are tested against non-prismatic compound channels of converging sections significant errors are found due variation of geometry. So an attempt has been made here to see the variation of Non prismatic water surface profile with respect to different independent parameters. Non prismatic water surface profile has been derived from the experimental data sets of three different types of converging compound channels of NIT, Rourkela, India along with three series of converging compound channels data of Rezaei (2006) (details of the data sets are given in Table.1) These compound channels have homogeneous roughness both in the main channel and floodplain subsections. Manning's n values for all these smooth surfaces are taken as 0.01. The dependency of Non dimensional water surface profile (H/h - Flow depth over floodplain divided by full main channel depth) and the best functional relationships of it have been found out from different plots described below. The relationships may be in the following form $H/h = F(\alpha, \beta, \delta, \theta, Xr)$ for a compound channel with non-prismatic flood plain .Where θ is converging angle and Xr is relative distance (x/Total non-prismatic length). The independent parameter of β and δ have been chosen from the prismatic part whereas α, θ and Xr have been chosen from non-prismatic part, here our intension is to predict the water surface profile along the non-prismatic part of the channel. The variation of water surface profile for non-prismatic flood plain has been found out for six converging compound channels.

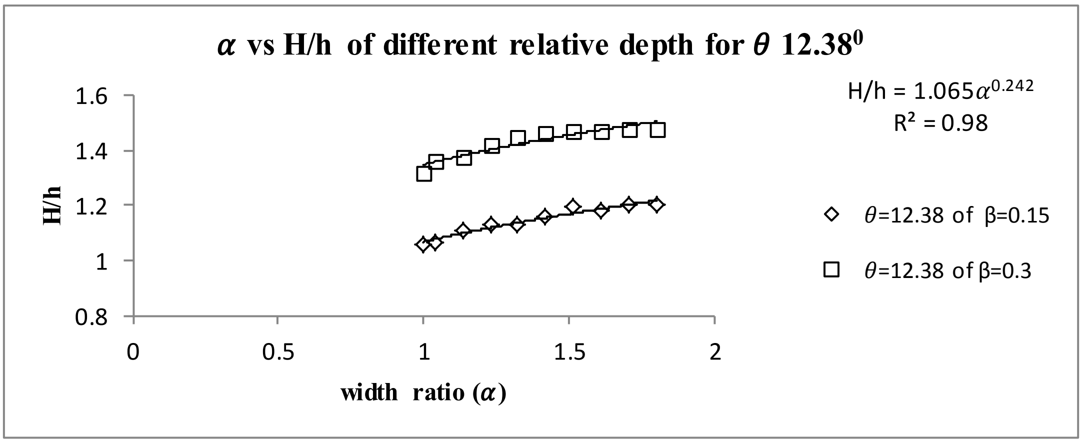


Figure 3 Variation of width ratio vs water depth ratio of different relative depth for converging angle 1212.38°

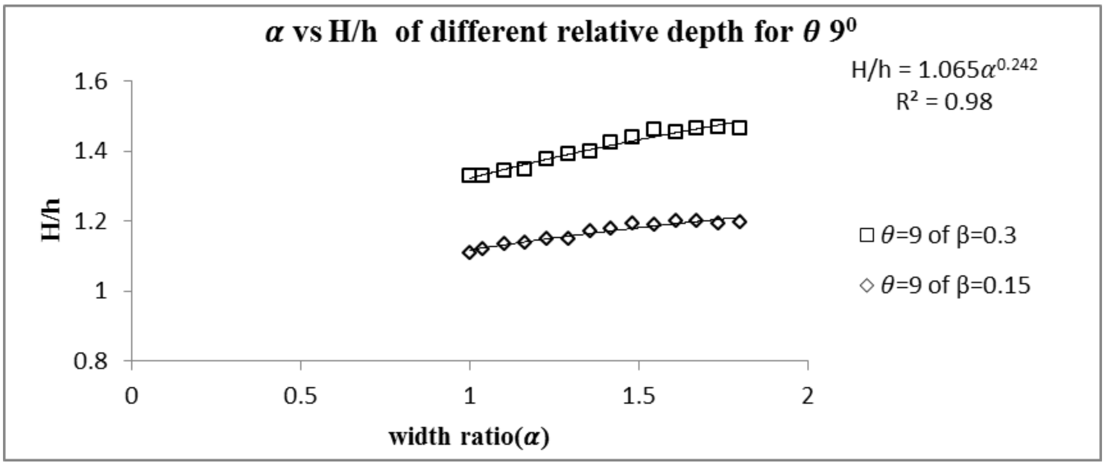


Figure 4 Variation of width ratio vs water depth ratio of different relative depth for converging angle 9˚

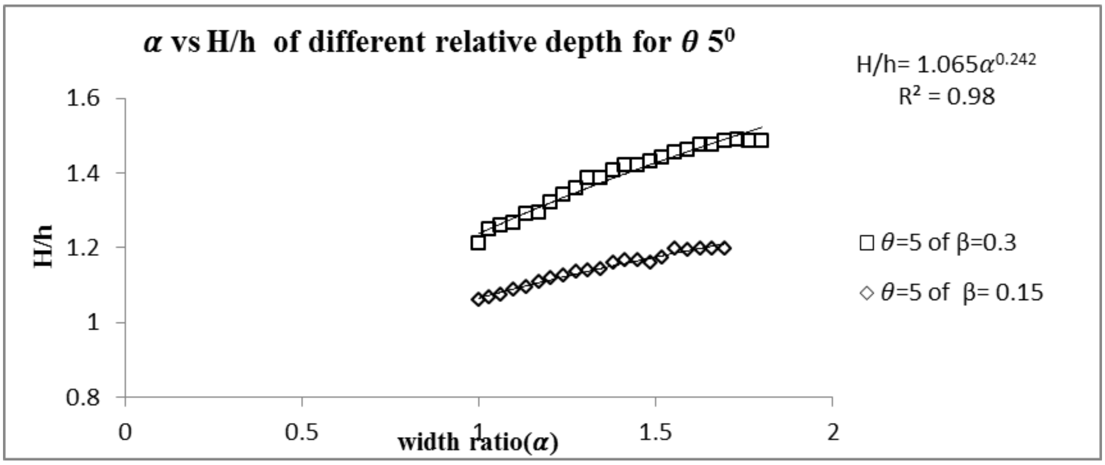


Figure 5 Variation of width ratio vs water depth ratio of different relative depth for converging angle 5˚

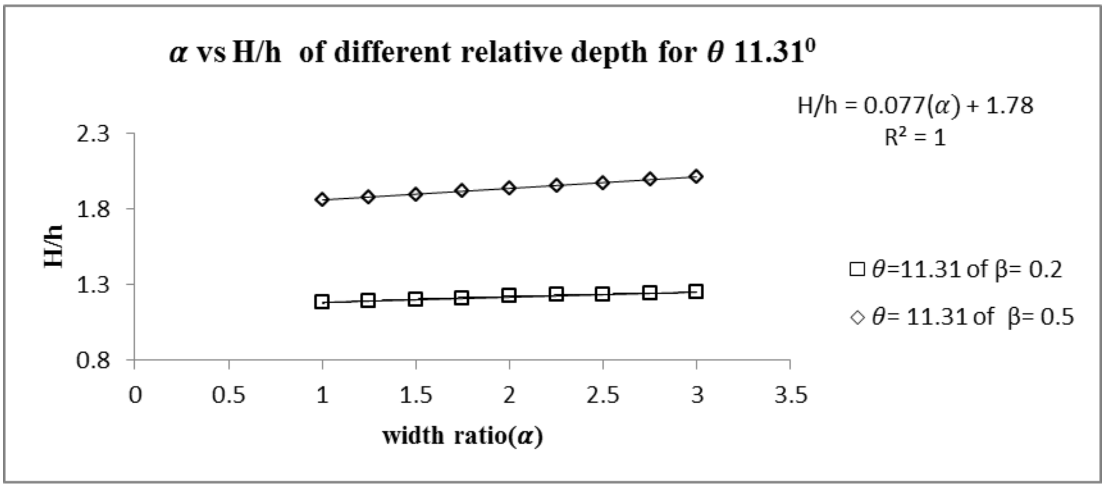


Figure 6 Variation of width ratio vs water depth ratio of different relative depth for converging angle 11.31˚

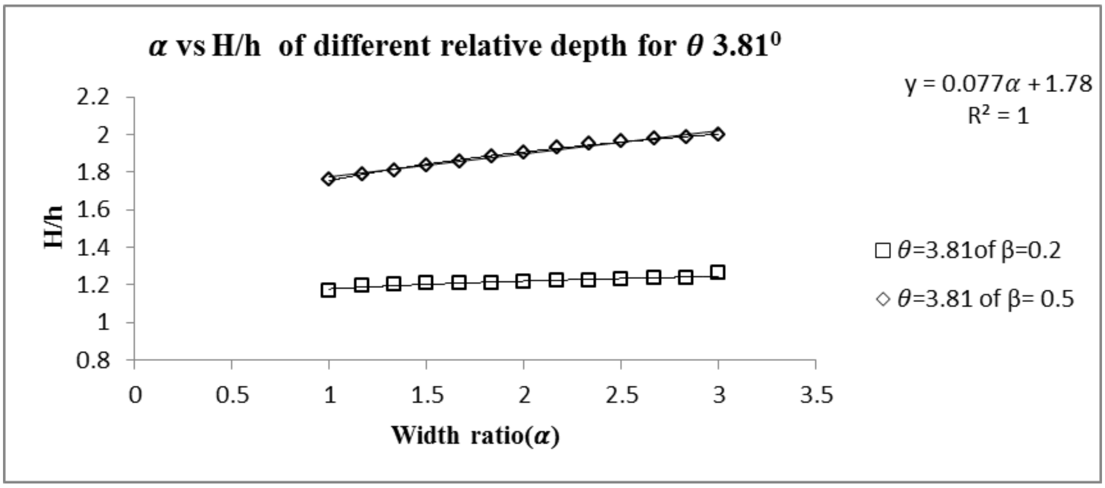


Figure 7 Variation of width ratio vs water depth ratio of different relative depth for converging angle 3.81^0

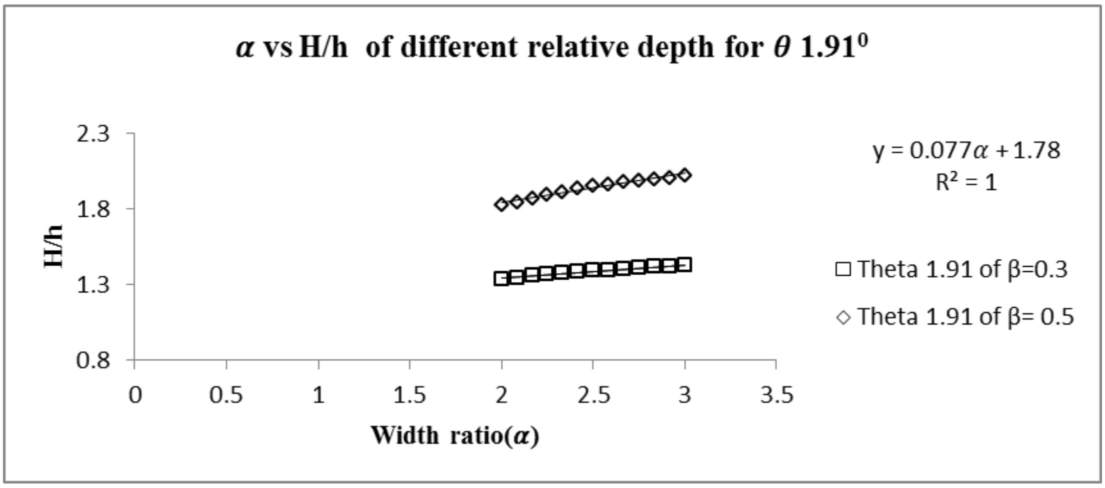


Figure 8 Variation of width ratio vs water depth ratio of different relative depth for converging angle 1.91˚

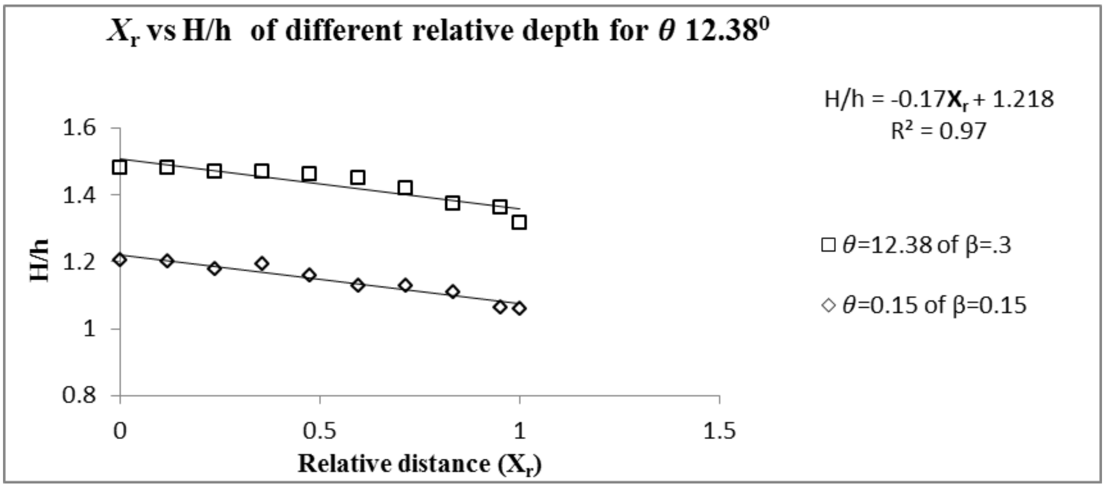


Figure 9 Variation of relative distance vs depth ratio of different relative depth for converging angle 12.38˚

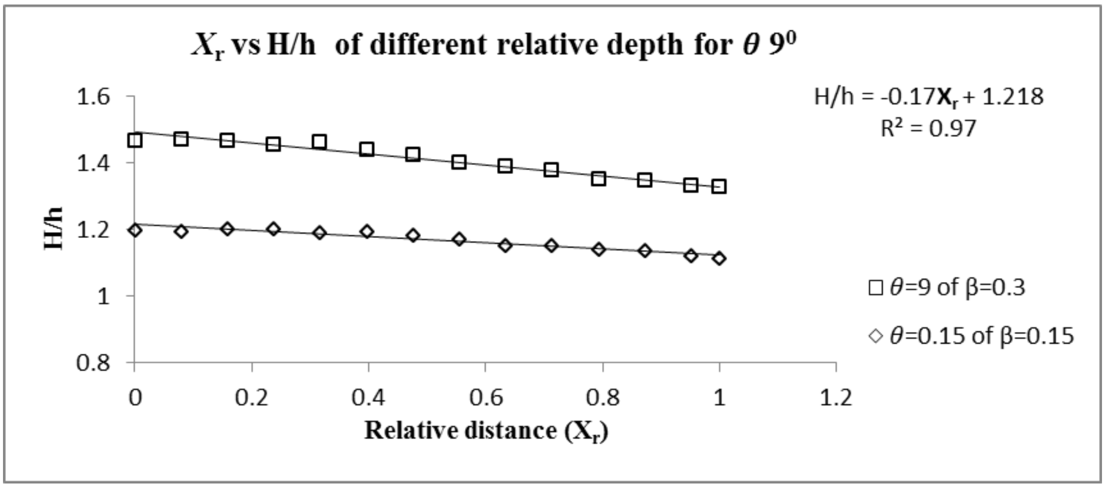


Figure 10 Variation of relative distance vs depth ratio of different relative depth for converging angle 9⁰

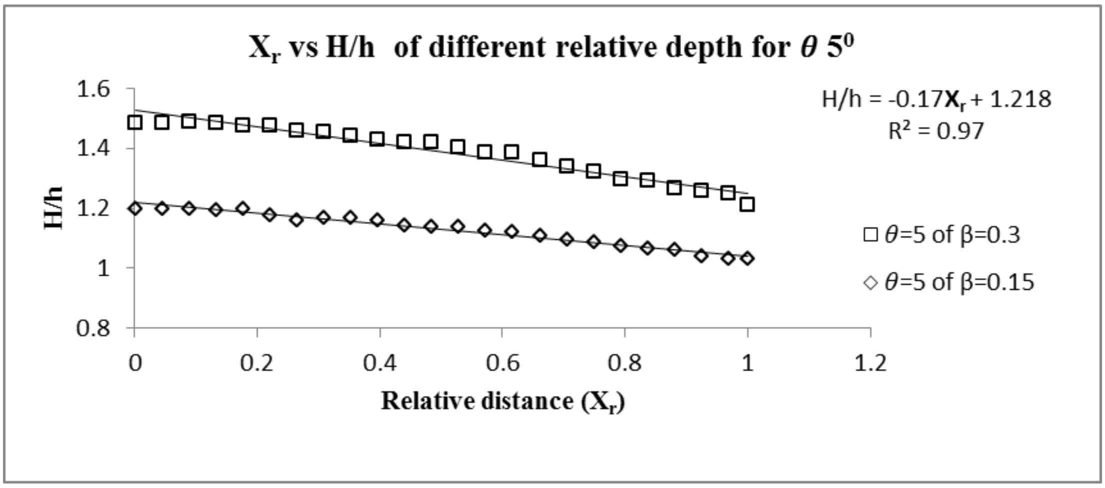


Figure 11 Variation of relative distance vs depth ratio of different relative depth for converging angle 5˚

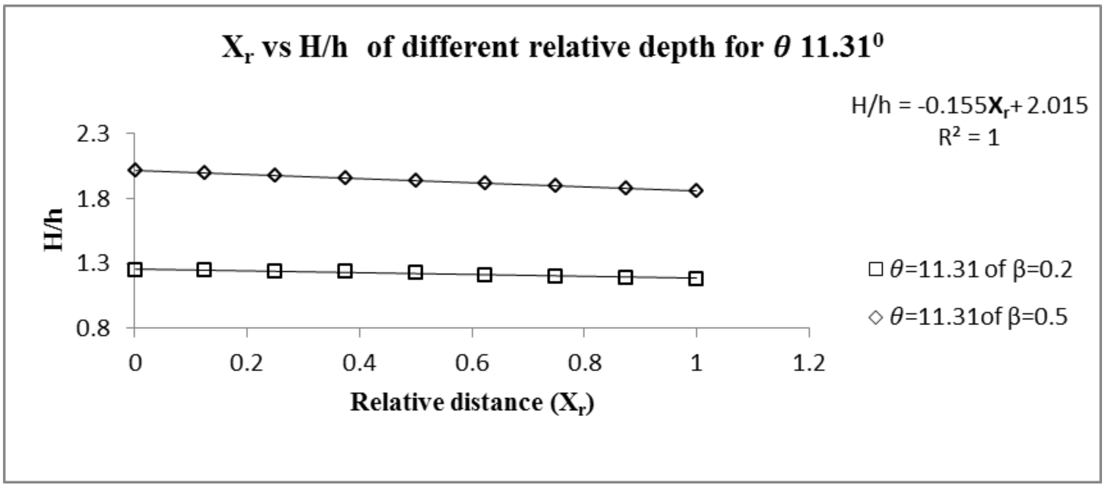


Figure 12 Variation of relative distance vs depth ratio of different relative depth for converging angle 11.31˚

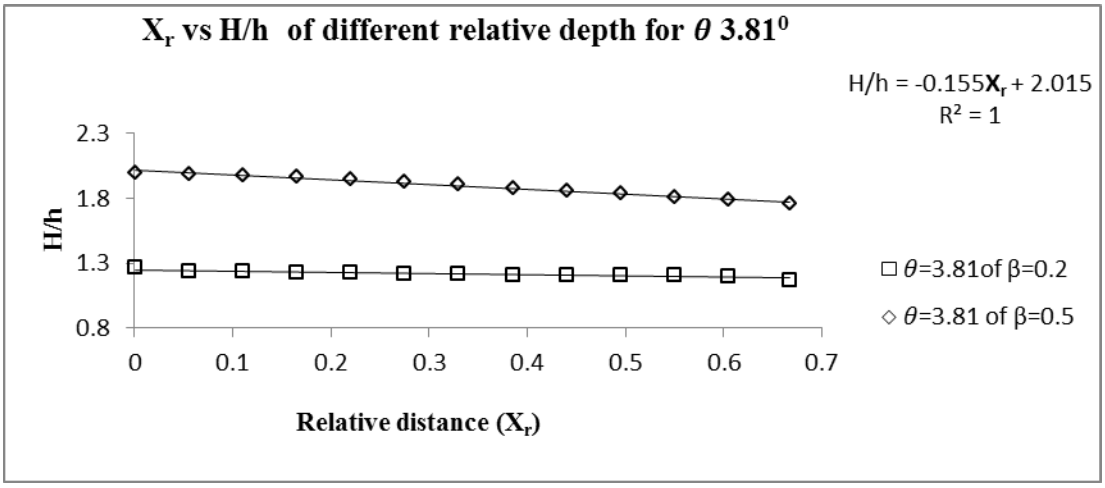


Figure 13 Variation of relative distance vs depth ratio of different relative depth for converging angle 3.81˚

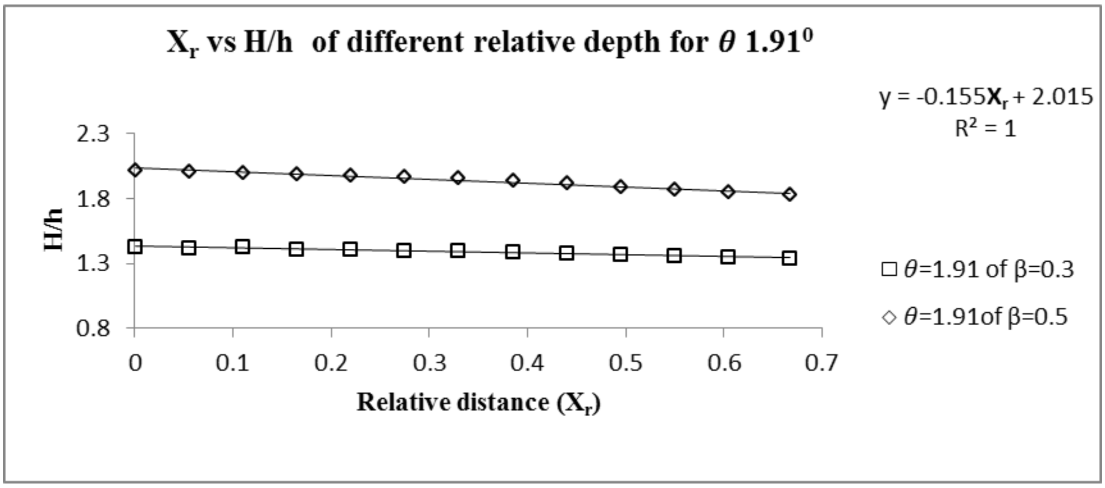


Figure 14 Variation of relative distance vs depth ratio of different relative depth for converging angle 1.91˚

5. Results and discussion

The variation of *(H/h)* in terms of width ratio *α* and relative distance *Xr* are plotted for different converging angles *θ* in Fig 3, 4, 5, 6, 7, 8.From these figures it is seen that *(H/h)* increases with increase in width ratio and relative depth. Similarly from figure 9, 10, 11,12,13,14 we can conclude that that *(H/h)* increases with increase in relative distance and relative depth.The best fit for lower aspect ratio channel(*NITR* channels) are found to exponential in nature whereas the best fit for higher aspect ratio channels (Rezaei 2006) are found to linear in nature as shown in Fig.3,4,5,6,7,8,.Similarly from fig.9,10,11,12,13,14 the dependency of depth ratio*(H/h)* with relative distance *(Xr)* (both lower aspect ratio and higher aspect ratio) are found be linear function. Finally the best functional relationships between depth ratios (*H/h*) with these non-dimensional parameters are listed below.

$$\frac{H}{h} = F_1(\alpha) = A(\alpha)^{0.22} \quad \text{For Lower aspect ratio channel-1} \qquad (1)$$

$$\frac{H}{h} = F_2(\alpha) = B(\alpha)^{0.198} \quad \text{For Lower aspect ratio channel-2} \qquad (2)$$

$\frac{H}{h} = F_3(\alpha) = C(\alpha)^{0.242}$ For Lower aspect ratio channel-3 (3)

$\frac{H}{h} = F_4(\alpha) = D\alpha + E$ For higher aspect ratio channel-1 (4)

$\frac{H}{h} = F_5(\alpha) = F\alpha + G$ For higher aspect ratio channel-2 (5)

$\frac{H}{h} = F_6(\alpha) = H\alpha + I$ For higher aspect ratio channel-3 (6)

Again

$\frac{H}{h} = F_7(X_r) =- jX_r + K$ For Lower aspect ratio channel-1 (7)

$\frac{H}{h} = F_8(X_r) =- LX_r + M$ For Lower aspect ratio channel-2 (8)

$\frac{H}{h} = F_9(X_r) =- NX_r + O$ For Lower aspect ratio channel-3 (9)

$\frac{H}{h} = F_{10}(X_r) =- LP + Q$ For higher aspect ratio channel-1 (10)

$\frac{H}{h} = F_{11}(X_r) =- RX_r + S$ For higher aspect ratio channel-2 (11)

$\frac{H}{h} = F_{12}(X_r) =- TX_r + U$ For higher aspect ratio channel-3 (12)

By analysing the above equations, the best functional relationships of *(H/h)* with different non-dimensional geometric and hydraulic parameters for the ranges of overbank flow depths are given by

$(H/h) = 1.065(\alpha)\, e^{0.242}$ For Lower aspect ratio channel
(13)

$(H/h) = 0.077(\alpha) + 1.78$ For higher aspect ratio channel (14)

$(H/h) = -0.17X_r + 1.218$ For Lower aspect ratio channel (15)

$(H/h) = -0.155X_r + 2.015$ For higher aspect ratio channel (16)

Here the R^2 value of the chosen functional relationship has been found to be very high and varies from 0.97 to 1. The equations 13,14,15,16 can be applied to compute the water surface profile of a converging compound channel flow for different converging angles and at different reaches in terms of width ratio and relative distance from the starting part of non-prismatic reach.

6. Conclusions

The following conclusions can be derived from the above research work on converging compound channels presented in this work.

1. From the experimental results on converging compound channels, the variation of depth ratio *(H/h)* with relative depth β, converging angle θ, relative distance X_r and width ratio α for different converging angles θ have been analysed.

2. The depth ratio *(H/h)* is found to increases with increase in width ratio and relative distance of converging compound channels. Further the depth ratio *(H/h)* found to increase exponentially with width ratio for lower aspect ratio channels and increase linearly for higher aspect ratio channels. Similarly the depth ratio *(H/h)* found to increase linearly with relative distance for both lower aspect ratio channels and higher aspect ratio channels

3. The dependency of depth ratio *(H/h)* with five most influencing non-dimensional geometric and hydraulic parameters of a converging compound channel is analysed. For all the parameters, it is found to bear the non-linear and linear functions.

4. Different error analyses are applied to the present model. It is found to provide least error

7. Acknowledgements

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