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Water Surface Profile Computation In Nonprismatic Compound Channels

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Abstract

A river generally exhibits a two stage geometry i.e. deeper main channel and shallow floodplain called compound section. In most of the compound channels, the floodplain geometry is found to be varying along the length of the flow called non-prismatic compound channel. The modelling of such flows is of primary importance when seeking to identify flooded areas and for flood risk management studies etc. The water surface profile is a series of transition curve from the normal depth line in one sub reach to the normal depth line in the adjacent sub reach. Water surface modeling help for the study of flood waves, water level calculation during flood, stage discharge relation, design of water work structures. All non-prismatic open channel flows are found to be unsteady and non-uniform. So these flows are difficult to analyse. In this paper experiments have been conducted to compute the water surface profile of non-prismatic compound channel for different converging angle and an attempt has been made to formulate mathematical models for predicting water surface profile by using the new experimental data of N.I.T, Rourkela and other standard data sets for different converging compound channels.

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Keywords: water surface profile, 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

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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), Rezai (2006)). This extra momentum exchange should also be taken into account in the flow modelling. Today more than half of the world's population live 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). 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 Rezai (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
Xr	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 α = 1.8 and the aspect ratio was δ = 5. Keeping the geometry constant, the converging angles of the channels were varied as 12.38°, 9° and 50 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. Figure 1(a) shows the plan view of experimental setup. Figure 1(b) shows the plan view of experimental sections.

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. The broad parameters of this channel are aspect ratio of main channel (δ), width-ratio (α).

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.

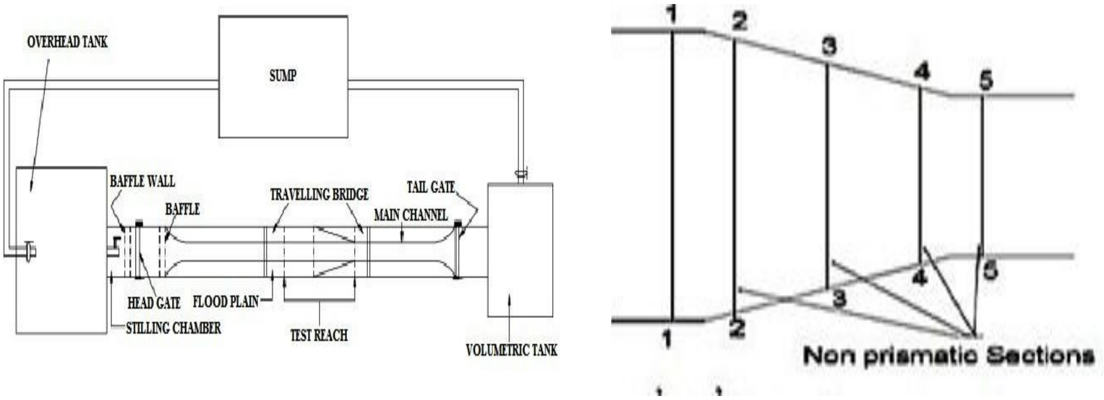


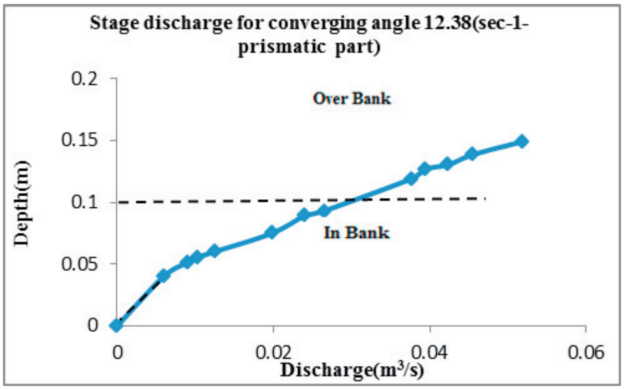
Fig.1 (a). Plan view of experimental Setup (b). Plan view of experimental Section

Table1.Hydraulic parameters for the experimental channel data set collected from literature experiments

Verified test channel	Types of channel	Angle of convergent (Θ)	Longitudinal slope (S)	Cross sectional geometry	Total channel width (B)	Main channel width (b)	Main channel depth (h)	Width ratio (sec-1) B/b (α)	Converging length (Xr)	Aspect Ratio b/h (δ)
					Meter	Meter	Meter		Meter	
Rezai (2006)	Convergent (CV2)	11.31°	0.002	Rectangular	1.2	0.398	0.05	3	2	7.96
Rezai (2006)	Convergent (CV6)	3.81°	0.002	Rectangular	1.2	0.398	0.05	3	6	7.96
Rezai (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 stage discharge relationship of different sections for the converging compound channel of angle 12.38° from in bank to over-bank flow conditions are shown in Fig.2 (a) and Fig.2 (b). A total 13 stage-discharge runs for are observed at the test reach.



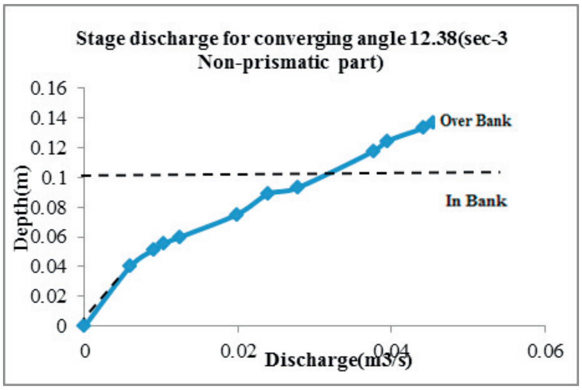


Fig. 2(a). Stage discharge relationship for the converging angle 12.38° (Sec-1 prismatic part) (b). Stage discharge relationship for the converging angle 12.38° (Sec-3- Non-prismatic part)

4. WATER SURFACE PROFILE COMPUTATION AND MODEL DEVELOPMENT

From the literature study, it is seen that water surface profile (*WP)* = *F* (α, β, δ) 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 a wide range of experimental data sets from three different types of converging compound channels of NIT, Rourkela, India along with three series of converging compound channels data of Rezai (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.A multiple-variable regression model is developed by taking five important dimensionless independent parameters. The dependency of Non dimensional water surface profile (*NWP* - 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

$$NWP = F(\alpha, \beta, \delta, \theta, X_r) \quad (1)$$

The variation of *NWP* has been found out for six converging compound channels. The variation of *NWP* in terms of relative depth β and relative distance *Xr* are plotted for different converging angles θ in Fig 4, 5, 6, 7, 8, 9. From these figures it is seen that *NWP* increases with increase in relative depth.

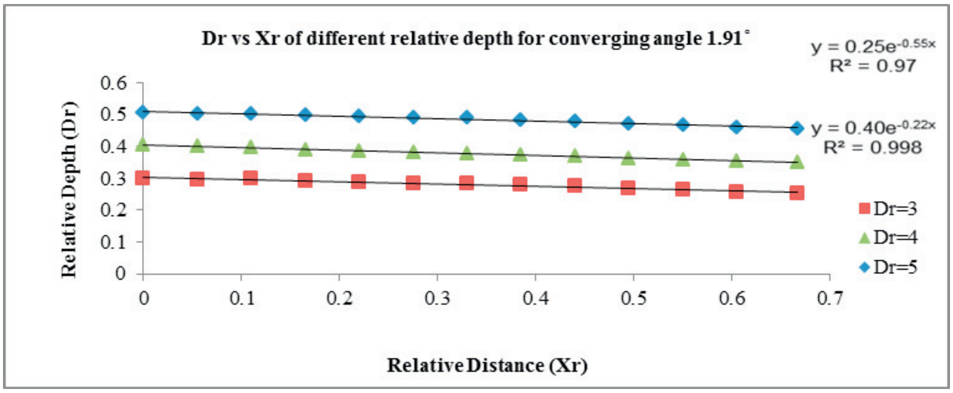


Fig.4. Variation of *NWP* along the Non prismatic length for converging angle 1.91˚

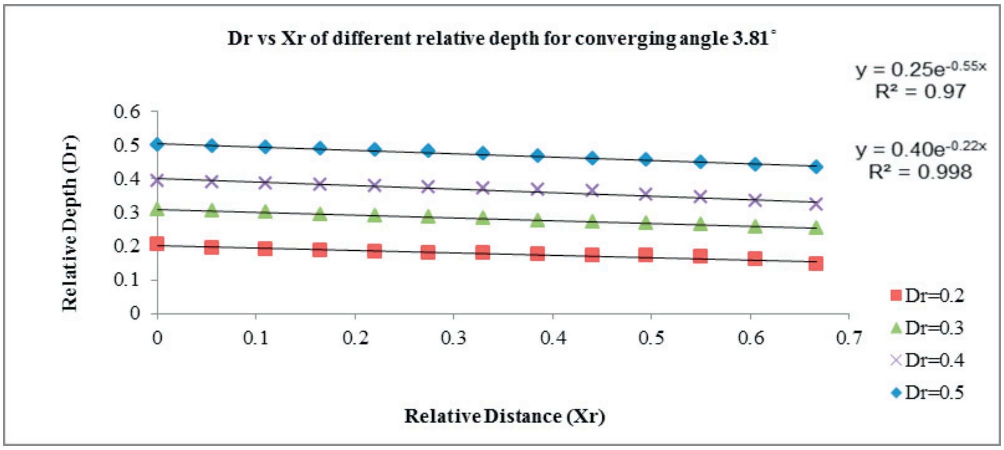


Fig.5. Variation of *NWP* along the Non prismatic length for converging angle 3.81˚

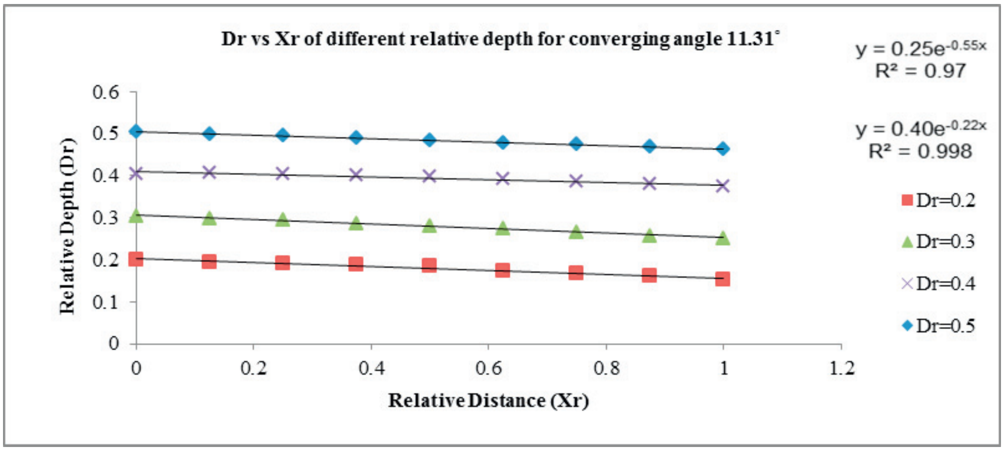


Fig.6. Variation of *NWP* along the Non prismatic length for converging angle 3.81˚

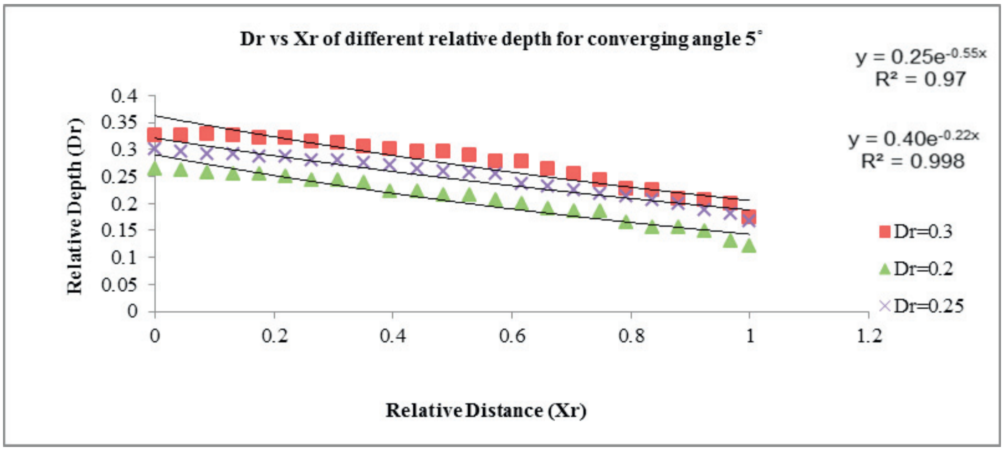


Fig.7. Variation of *NWP* along the Non prismatic length for converging angle 5˚

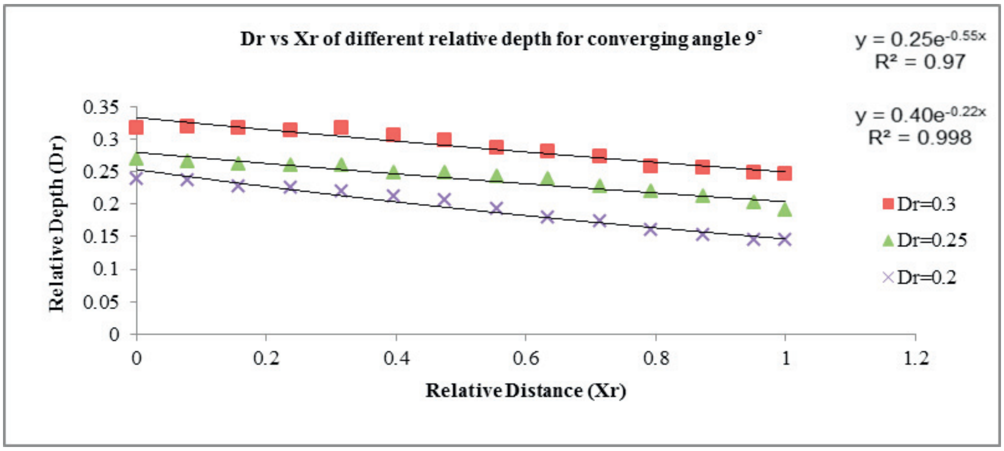


Fig.8. Variation of *NWP* along the Non prismatic length for converging angle 9°

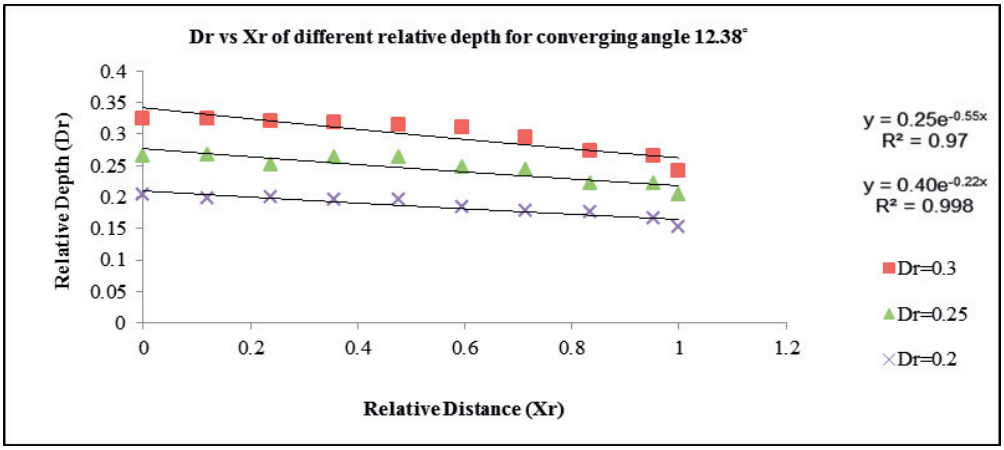


Fig.9. Variation of *NWP* along the Non prismatic length for converging angle 12.38°

By analysing the above plots, the best functional relationships of *NWP* with different non-dimensional geometric and hydraulic parameters for the ranges of overbank flow depths are given by

$NWP = 0.25\, e^{-0.57 X_r}$ for lower Relative flow depth i.e D_r= 0.2, 0.25, 0.3 (2)

$NWP = 0.40\, e^{-0.22 X_r}$ for higher Relative flow depth i.e D_r= 0.4, 0.5 (3)

Here the R^2 value of the chosen functional relationship has been found to be very high and varies from 0.97 to 0.99 (please see the Fig. no. 4, 5, 6, 7, 8, 9). The equations (2) and (3) 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 relative distance from the starting part of non-prismatic reach i.e. X_r.

5. RESULTS AND DISCUSSION

The *NWP* for all the new non-prismatic compound channels and the data of Rezai (2006) has been computed using equation (2) and (3). The variation between the calculated values of *NWP* of equations (2) and (3) and the corresponding observed values for all the six types of channels are shown in Fig.10 for higher Relative depth and Fig.11 for lower Relative depth. The percentage error *NWP* is less for both Present experimental Channel as well as Rezai (2006) Channel proving the effectiveness of the equation (2) and (3).

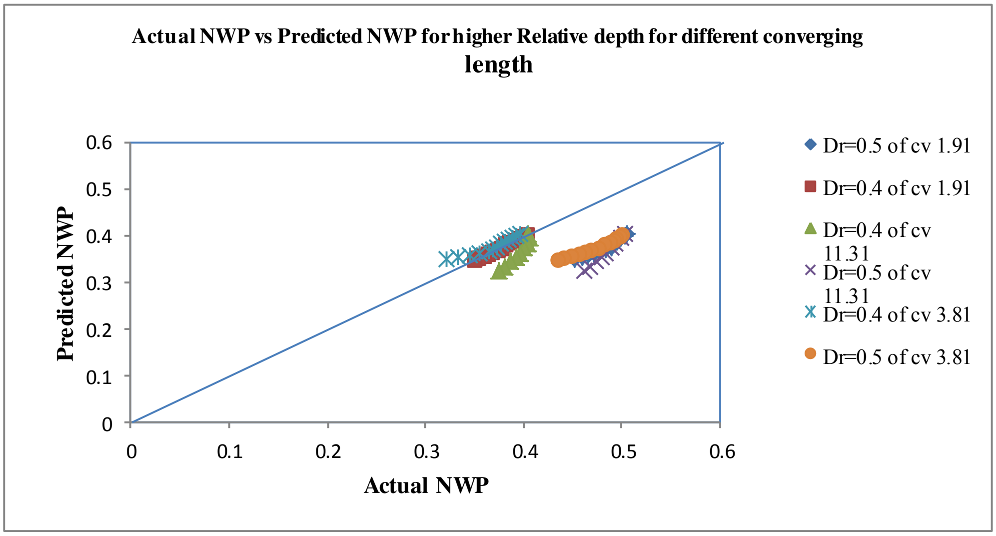


Fig.10. Scatter plot for observed and modelled value of *NWP* for higher D_r

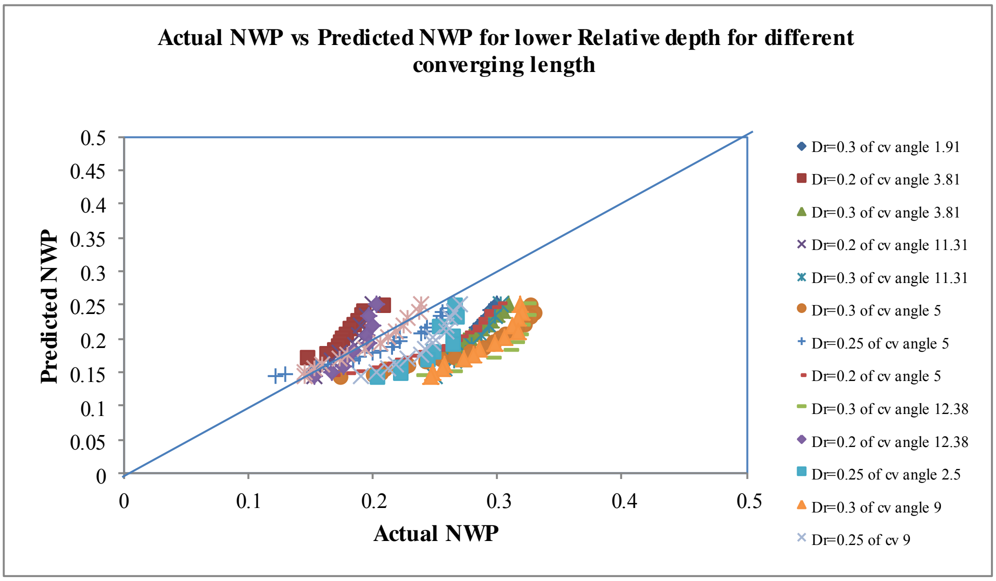


Fig.11. Scatter plot for observed and modelled value of *NWP* for lower D_r

6. CONCLUSIONS

The following conclusions can be derived from the above research presented in this work.

- From the experimental results on converging compound channels, the stage discharge of different sections of the converging compound channels is measured.
- The water surface profile along a non-prismatic compound channel are found to increase with increase of Relative depth for converging compound channels of different converging angles and decreases along the converging lengths of the channel under sub-critical flow conditions.
- The dependency of Non prismatic water surface profile is influenced by non-dimensional geometric and hydraulic parameters. The *NWP* in converging compound channel is found to be a non-linear function of all these non-dimensional parameters.
- The present mathematical model for a converging compound channel showing the dependency of *NWP* with relative distance for different flow depths are presented and modelled. The equations are found to provide good results when compared with the observed *NWP*.

7. ACKNOWLEDGEMENTS

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