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Evaluation of zero shear interface methods in an asymmetric compound channel

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Abstract

In a compound channel, due to strong interaction between the main channel and floodplain flows, the apparent shear stress at different interfaces of the compound sections varies greatly. River channels are often flanked by either side flood plain which is known as asymmetrical compound channel. There are many reports found in literature related to compound channels with symmetrical flood plains and very few are found for asymmetrical cases. In a symmetrical compound channel the transfer of momentum occurs from both sides of the channel to the flood plains uniformly. In case of a compound channel with asymmetrical floodplain, there is a stronger interaction between main channel and flood plains occur as compared to the symmetrical case. Many investigators have studied and modeled in predicting the flow variables of the compound channel which are generally applicable for symmetrical cases. In this paper, some approaches for predicting flow using different area methods in asymmetric channels are described. On the basis of multi linear regression analysis, an improved area method has been proposed. The proposed method is successfully validated to the experimental data and the flood channel facilities of UK data and the merits and demerits of the proposed method with other discussed methods have been done. The comparisons of these methods to different flow conditions are outlined using error analysis.

Keywords: *Compound channel, asymmetric channel, width ratio, relative depth, overbank flow.*

1. Introduction

The utmost area of unpredictability remains in calculating the proper discharge carrying capacity of river along with floodplains, generally appeared at the time of flood is known as compound section. This compound section is consisting of a main channel either flanked by one or two-side floodplains. The first case is considered as an asymmetrical compound channel and second one is symmetrical or unsymmetrical compound channel. During floods, a part of discharge is carried by the main river channel and the rest is carried by the adjacent floodplains. The main channel velocity is usually faster than the velocity of flow in floodplain zones. When these faster and slower moving fluids interact, considerable exchange of mass and momentum between the main channel and floodplain zones takes place. From ancient times, the most frequent tasks of a hydraulic engineer are to estimate discharge through river channels either by recording, estimating or by simulating water level.
Sellin (1964) first investigated the momentum transfer through laboratory investigations. Thereafter, many investigators found that this momentum exchange was responsible for the non-uniformity in the depth averaged velocity distribution at the junction and boundary shear stress distribution across the section perimeter e.g., Ghosh and Jena (1971), Knight and Hamed (1984), Patra, Kar and Bhattacharya(2004). There are many traditional methods developed by past researchers on basis of their direction categorized as 1D, quasi 1D, 2D and 3D models. Owing to their simplicity and effective capability for predicting the discharge particularly in compound channels the so called Divided-Channel Method (DCM) is still being modified and refined for different geometric and hydraulic conditions encountered in the field as the elementary Single Channel method (SCM) is only capable of successfully predicting the discharge in simple channel only. Knight and Hamed (1984) developed a relation by following the works of Knight and Demetriou (1983) to estimate the discharge. Khatua and Patra (2007) carried further study and developed a model for estimation of discharge based on more experimental observations with width ratio α value up to 5.25. However to improve upon the previous models Khatua, Patra& Mohanty (2011) developed a model for percentage shear on flood plain($\%S_{fp}$) relating to percentage area of flood plain ($\%A_{fp}$), by conducting regression

analysis over three sets of data series from Knight & Demetriou (1983),one set from NIT, Rourkela compound channel data and five sets of FCF-A data series. They also derived a new stage-discharge relationship which was valid for compound channels having α value up to 6.67. Then a new modified relationship is developed by Mohanty & Khatua (2014) between %Sfp and %Afp of compound sections by keeping the width ratio nearly equal to 12 i.e., sections having width ratio (α) value more than 6.67. Investigators have proposed different improved divided channel methods based on the apparent shear stress. Some methods are based on the assumption of zero shear stress at the interfaces which may be a straight or curved one Prinos 1984, Cristodoulou 1992, Patra and Kar 2000, Khatua 2008, Martin-Vide 2008 and Khatua (2008). A zero shear interface method is easier as compared to an apparent shear method. This paper presents the prediction of discharge in asymmetric compound channel by an improved area method and compares well with area method of other researchers. Four different sets of asymmetric models with rectangular and trapezoidal compound cross sections (three sets of data series from Khatib et al. (2013) and one set of FCF-A series-6) having different relative depth and width ratio were tested for a wide range of discharges analysis. Comparisons of the methods with the actual discharge have been discussed.

2. Theoretical study

In this study, asymmetric compound channels are divided into a main channel and a floodplain along the imaginary interface at the junction. At that interfaces plane, it cannot be assured that the plane is shear free nor the apparent shear at this surface is equal to average boundary shear of main channel or the floodplain surfaces (Khatua et al 2012). Many researchers have proved the adequacy of proper selection of imaginary interface for accurate estimation of stage discharge relationship.(e.g., Ackers 1992, Wright and Carstens 1970, Wormleaton et al. 1982, Patra and Khatua 2006 and Hutton et al. 2008 Mohanty and Khatua 2014 etc. Stephenson and Kolovopoulos (1990) divided the main channel and flood plain with a curved interface considering the zero shear occurring at that interface and this curved interface is excluded from the wetted perimeter of the main channel. Then the area of correction (ΔA) which will be included with the flood plain area and excluded from the main channel area are calculated as depicted in Figure 1.

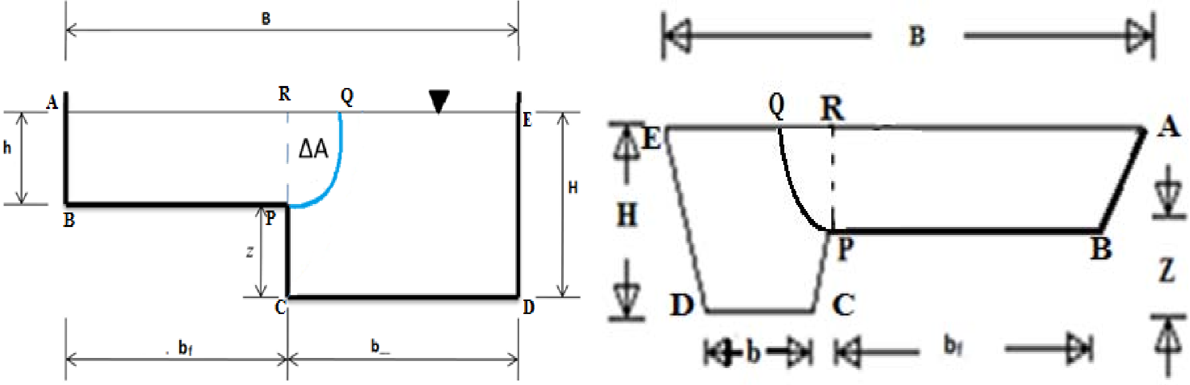

Figure 1 Area for correction PQR at transition between main channel and flood plain

Herein, some numbers of experimental published data of asymmetrical compound channel with rectangular and trapezoidal shape are used. Where, H is the overall depth of flow, Z is the bank full depth, h is the flow depth over the flood plain. B, b, bf are the width of total compound section, bottom main channel and flood plain respectively. Considering the equilibrium of the main channel sub section, the total weight component of force along the longitudinal direction must be balanced by the sum of the boundary shear force acting on the channel wall and its bed and the apparent shear force at the interface. Let an imaginary curved interface PQ is drawn through the interface such that the apparent shear is zero along PQ (Figure.1). Let ΔA is the small area between this curved interface PQ and the vertical interface PR. Now the main channel becomes QPCDE and the flood plain section becomes ABPQ. Let A_{mc} is the area of the main channel when considering the vertical interface PR; so ΔA is the area required for correction to this area A_{mc} ; τ_0 is the average boundary shear stress along the wetted perimeter of the main channel. dP is the element wetted perimeter of the channel; ρ density of water, g acceleration due to gravity and S_0 longitudinal bottom slope of the channel then we can write

$$\rho g(A_{mc} - \Delta A)S_0 = \int \tau_0 dP \tag{1}$$

$$\text{or } \Delta A = \frac{\rho g A_{mc} S_0 - \int \tau_0 dP}{\rho g S_0} \tag{2}$$

By dividing the total area of the compound channel (A) and denoting it as zero shear area ratio $ZSAR = \frac{\Delta A}{A}$ we may write

$$ZSAR = \frac{[\rho g A_{mc} S_0 - \int \tau_0 dP]}{\rho g A S_0} \tag{3}$$

For a given channel geometry and flow depth, $\rho g A_{mc} S_0$ and $\rho g A S_0$ are known and $\tau_0 dP$ need to be find out from the experimental data or numerical models. Shiono and Knight (1989) have proposed a method popularly named as SKM method for accurately predicting boundary shear distribution in a compound channel. The method is widely and trustily used worldwide in the form of software called Conveyance Estimation System (CES, Wallingford, UK).

The present work uses the SKM numerical model to generate the wide ranges of datasets of boundary shear stress distribution $[\int \tau_0 dP]$. The accuracy of the SKM numerical approach to predict the boundary shear distribution has also been tested and presented in Figure (2). It shows the result of boundary shear distribution of compound channel from direct measurements and from CES method. The method has been found to evaluate the boundary shear distribution more accurately with mean average error less than 5%.

An asymmetrical experimental data sets are limited so software CES which is based on the SKM method has been utilized to generate boundary shear distribution for different channels having varying width ratio (3 to 12) and relative flow depths (0.1 to 0.5). SKM method is based on simplification of continuity equation and Navier stokes equation given as

$$\rho\left[\frac{\partial \overline{UV}}{\partial y} + \frac{\partial \overline{UW}}{\partial z}\right] = \rho g S_0 + \frac{\partial \overline{\tau_{yx}}}{\partial y} + \frac{\partial \overline{\tau_{zx}}}{\partial z} \tag{4}$$

(i.e., secondary flows = weight force + lateral Reynolds stresses + vertical Reynolds stresses), where x, y, z = stream wise, lateral, and vertical directions, respectively; $\overline{U}$, $\overline{V}$, $\overline{W}$ = temporal mean velocity components corresponding to x, y z direction. τ_{yx} and τ_{zx}= Reynolds stress on plains perpendicular to the y and z directions respectively. ρ =water density; g= Acceleration due to gravity and S_0= bed slope. Shiono and Knight (1989) obtained the depth-averaged velocity equation by integrating (4) over the water depth H and is simplified to

$$\rho \frac{\partial H(\overline{uv})_d}{\partial y} = \rho H g S_0 + \frac{\partial}{\partial y}\left(\rho \lambda H^2 \left(\frac{f}{8}\right)^{\frac{1}{2}} U \frac{\partial U}{\partial y}\right) - \frac{f}{8}\rho U^2 \sqrt{1 + \frac{1}{s^2}} \tag{5}$$

Where H the depth of flow $\bar{u}$ and $\bar{v}$ are the component of the mean velocity in x and y direction, $(\overline{uv})_d$ the product of the components and averaged over the flow depth, λ the eddy viscosity coefficient, f the local bed friction, s the lateral slope and U the depth averaged velocity which is to be found out.

After the channel is divided into subareas in which the sub-area may be of constant depth domain or variable depth domain, the unknown constants can be solved by applying known boundaries like at junction and at rigid boundary. The boundary conditions applied for the present analysis are

1. $(U_d)_i = (U_d)_{i+1}$, due to continuity of depth averaged velocity.

2. $\left(\frac{\partial U_d}{\partial y}\right)_i = \left(\frac{\partial U_d}{\partial y}\right)_{i+1}$, due to Continuity of the lateral gradient of the depth averaged velocity

3. $U_i = 0$, No slip condition holds for the lateral position at the rigid side wall.

Applying these above boundary conditions for adjacent panels the equation (5) has been solved by a suitable MATLAB programming to find the depth average velocity and boundary shear stress from point to points laterally along the width of the channel.

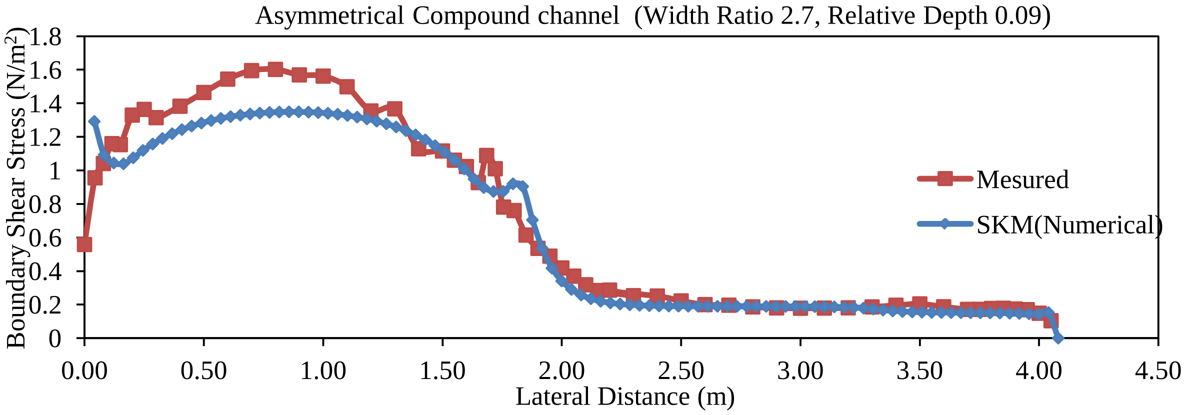

Figure 2 Lateral distribution of the depth averaged boundary shear stress,τb for FCF Series 6.

The NITR asymmetric compound channel bears a single aspect ratio of 3 and width ratio of 5.1, the FCF channel bears a single asymmetrical channel data sets with aspect ratio of 10 and width ratio of 2.7 and one experimental channel of Khatib et al. (2013) bears a aspect ratio of 5 with width ratio of 3.0 are considered for analysis. To get wide range of data sets of boundary shear distribution for varying width ratio corresponding to these dimensions of three experimental channels keeping other parameters same, CES software have been applied. The ranges of data sets produced belong to width ratio between 3 to 12 and depth ratio between 0.1 to 0.5. So the geometrical and flow parameters of the generated experimental channels are given in Table 1.

Table 1 Geometrical and flow parameters of the experimental channels

Series	Main Channel		Depth of flow (H) (m)	Side Slope (s)	Bed Slope (S_0)	Ranges of Relative Depth (β)	Aspect Ratio (δ)	Ranges of Width Ratio (α)
	Bed Width(b) (m)	Bank full Depth(z) (m)						
Series1 (Trapezoidal)	1.5	0.15	0.167 0.1875 0.2142 0.25 0.3	1:1	0.001027	0.1 -0.5	10	3-12
Series2 (Trapezoidal)	0.33	0.11	0.12 0.1375 0.157 0.18 0.22	1:1	0.00238	0.1-0.5	3	3-12

Series3 (Rectangular)	0.1	0.02	0.0222 0.028 0.0286 0.033 0.04	-	0.0025	0.1-0.5	5	3-12

3. Application of the approach

After finding ZSAR, the area correction (ΔA) for zero shear can be found out by multiplying the ZSAR with the total area of compound channel (A). With the present approach an attempt has been made to compare the zero shear models (popularly known as area method) of other investigators. The area method first performed by Holden (1986) which is later analyzed by Stephenson and Kolovopoulos (1990). The area correction (ΔA) has been derived from the equilibrium of the shear forces acting on interface of both the floodplain and main channel assuming the vertical interface divides at the junction. They have considered the equilibrium of the flood plain subsection, the total boundary shear force must be equal to the total weight component of the water through the channel and the apparent shear stress at the vertical interface which they have simplified as

$$F_{bf} - \tau_{av} h = \gamma A_f S_0 \tag{6}$$

Where F_{bf} =total boundary shear force acting on the flood plain region in Kg,
τ_{av}= apparent shear acting on the interface in N/m^2,
h =Depth of water above main channel in m,
γ =specific weight of water in Kg/m^3,
A_f =cross sectional area of flood plain in m^2,
S_0 =bottom slope of the channel
Similarly considering the equilibrium of the flood plain as ABPQ which consider addition of the area correction (ΔA), we can write

$$F_{bf} = \gamma(A_f + \Delta A)S_0 \tag{7}$$

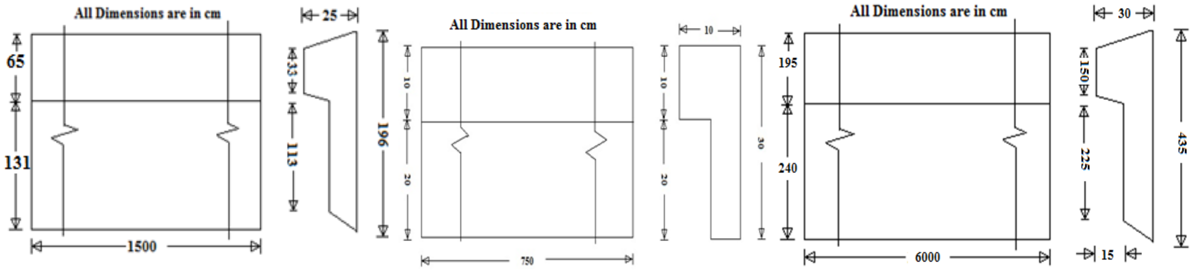

Figure 3 Plan and sectional View of Experimental asymmetrical compound channels of NITR, Khatib et al (2013) and FCF Series 6

By simplifying both equation (6) and (7) the area of correction ΔA have been found out as

$$\Delta A = \frac{\tau_{av} * h}{\gamma S_0} \tag{8}$$

For a compound channel of a given overbank flow depth h and given bottom slope S_0, the area of correction ΔA from the equation (8) can be found out if the apparent shear stress τ_{av}at the vertical interface is known. The aforementioned apparent shear stress can be calculated by different equation given by researchers. For the present work, four equations are considered for finding out the area of correction. They are

1. Prinos (1984)

$$\tau_{av} = 0.874\left(\frac{h}{H}\right)^{1.129}\left(\frac{b_f}{b}\right)^{-.514}(\Delta V_v)^{.92} \tag{9}$$

2. Cristodoulou (1992)

$$\tau_{av} = 0.005\rho\left(\frac{B}{b}\right)(\Delta V_v)^2 \tag{10}$$

3. Martin-Vide (2008)

$$\tau_{av} = 0.002\rho\left(\frac{B}{b}\right)\left(\frac{2Z}{b}\right)^{-\frac{1}{3}}\left(\frac{h}{H}\right)^{-\frac{1}{3}} * (\Delta V_v)^2 \tag{11}$$

4. Khatua (2008)

$$\Delta A = \left[\frac{\%S_f}{100} - \frac{(\alpha-1)\beta}{1+(\alpha-1)\beta}\right]A \tag{12}$$

Where $\%S_f$ is the percentage shear force given by

$$\%S_f = 3.4817\left[\frac{100(\alpha-1)\beta}{1+(\alpha-1)\beta}\right]^{.7317} \tag{13}$$

Where ΔV_v is the difference in velocities between main channel and floodplain with vertical interface as obtained from Manning formula. α is the width ratio $\left[\frac{B}{b}\right]$, β is the relative depth $\left[\frac{h}{H}\right]$. It can be noted that for calculation process the manning's equation is adopted but the area of correction is excluded from the main channel area and while it is included with the area of flood plain .The discharge in main channel and flood plain are calculated from the equation

$$Q_{mc} = \frac{A_{mc}-\Delta A}{n_{mc}} R_{mc}^{\frac{2}{3}} S_0^{\frac{1}{2}} \tag{14}$$

$$Q_f = \frac{A_f+\Delta A}{n_f} R_f^{\frac{2}{3}} S_0^{\frac{1}{2}} \tag{15}$$

Where: A_{mc} =Area of the main channel; R_{mc} = hydraulic radius n_{mc} = Manning's roughness coefficient of the main channel; n_{fp} = Manning's roughness coefficient of the floodplain; $R_f = A_f / P_f$ = hydraulic radius of the section
Consequently, the total discharge (Q) in the asymmetric compound channel is obtained from the equation

$$Q = Q_{mc} + Q_f \tag{16}$$

3.1 Theory of experiments

In this study, three series of experiments are considered. First series, the asymmetrical compound channel is constructed using plain cement concrete inside rectangular steel tilting flume in the hydraulic engineering laboratory of the Civil Engineering Department, National Institute of Technology, Rourkela, India. This channel is having one flood plain at right side of it making the total width of the compound section 198cm (Figure 1). The main channel is trapezoidal in cross section with 1:1 side slope having 33cm bottom width and 11cm at bank full depth. The longitudinal bed slope is taken as 0.001325. The roughness of the flood plain and main channel are kept same and estimated to be 0.01. Second series is the only asymmetrical compound channel data sets of the large channel facility of FCF A series-6 at Wallingford, UK which is used for the validation of the proposed model. This available data for asymmetrical compound channel of width ratio (α=2.7) is taken in to consideration. The geometrical parameters such as total width of main channel are 10 m, main channel width is 1.5m, aspect ratio of main channel is 10, longitudinal slope of the channel is 0.001027 and Manning's roughness coefficient is 0.01. Third series were carried out in a glass-walled horizontal laboratory flume 7.5 m long, 0.30 m wide and 0.3 m deep with a bottom slope of 0.0025 at the fluid mechanics laboratory, Mechanical Engineering Department, Birzeit University, Palestine. The discharge was measured volumetrically at different flow depth using a flow meter with 0.1 litter accuracy. A point gauge was used along the centre line of the flume for head measurements. All depth measurements were done with respect to the bottom of the flume (Khatib et al. 2013). The experiments of consideration were conducted keeping the main channel width as constant i.e. 0.10m with varying step height values i.e. 0.02 m,0.04 m and 0.06 m. In this study, the series of width ratio 3 (α= 3, total width=0.30m and main channel width=0.10m) is considered for analysis and is used for comparison of other models with the developed model. All the experiments in channel were also done under subcritical flow conditions.

4. Results and discussions

Flow in an asymmetric (rectangular and trapezoidal) compound channel can be found out by knowing the zero shear area ratio (ZSAR) and hence the area which is excluded from main channel and included with its adjacent flood plain. Total flow can be predicted by using Equations (14), (15) and (16) respectively. There is always a clear dependence on the relative depth has been observed for the apparent shear values as presented by previous investigators (e.g., Prinos and Townsend 1984, Christodoulou and Myers 1999, Khatua and Patra 2012). From the experimental investigation of Ghosh and Jena 1971, Knight and Demetriou1983, Patra and Kar 2000, Khatua and Patra 2008, it has been seen that flood plain shear increases with increase in both width ratio (α) and relative flow depth (β). This statement is generally valid for symmetrical compound channel where there are both side flood plains contributing more flood plain shear as compared to the asymmetrical compound channel. Further looking to equation 3, it can be stated that for an asymmetrical compound channel the ZSAR decreases with increase in main channel boundary shear or decrease in flood plain shear or we can say ZSAR decreases with increase in both width ratio (α) and relative flow depth (β) (figure 4 to figure 8). The functional dependence of Zero Shear Area Ratio (ZSAR) values with the flow depth and geometry has been tested in a wide range of data sets and the best fit has been considered for present analysis. Figure 4 shows the variation of Zero Shear Area Ratio values (ZSAR) with the relative flow depth (β) for different width ratio (i.e., α = 3 to 12) for Series 1. Also for that series, Figure 5 shows the dependence of ZSAR with width ratio α keeping relative flow depth (β) constant. The area ratio is found to decrease with increase of relative flow depth (β). Similar observations can be noted that the area ratio is found to decrease with width ratio (α). Similarly, Figure 6 and Figure 8 show the linear relationship between ZSAR and relative flow depth(β)for other two channels (Series 2, Series 3) with different width ratio (i.e., α = 3 to 12). Figure 7and Figure 9 confirm the functional linear relationship exists between ZSAR and width ratio (α) for these Series 2 and Series 3 channels.

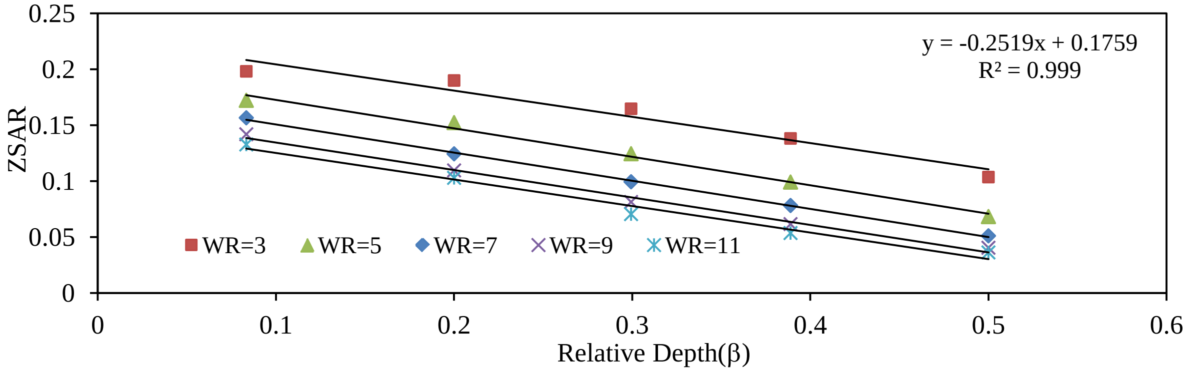

Figure 4 Variation of zero shear area ratio with relative flow depth of Series1

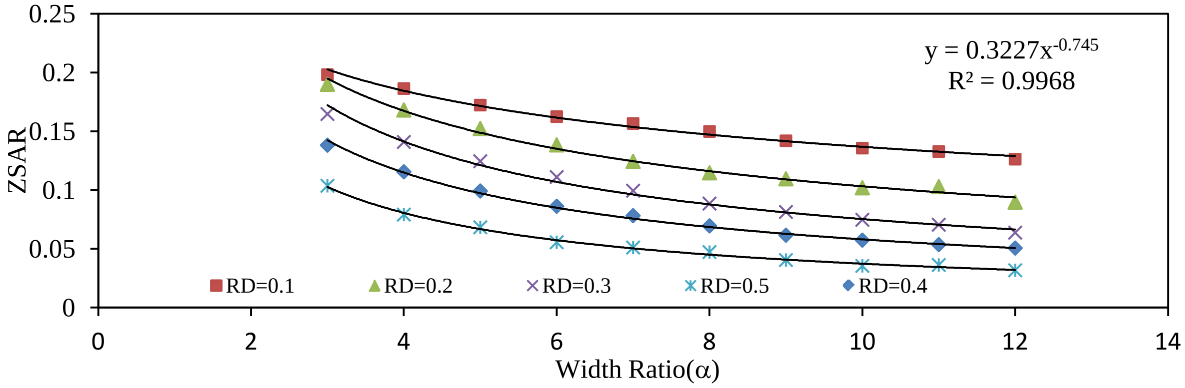

Figure 5 Variation of zero shear area ratio with width ratio for Series 1

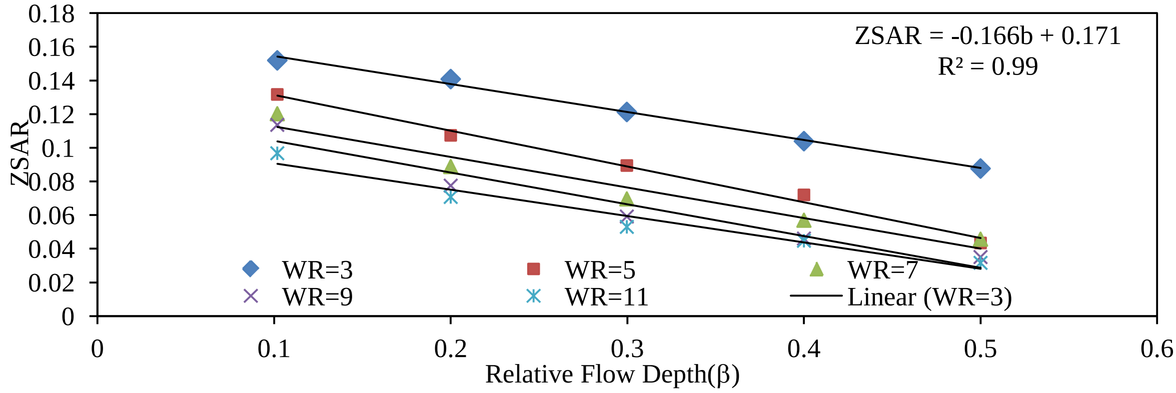

Figure 6 Variation of zero shear area ratio with relative flow depth of Series 2

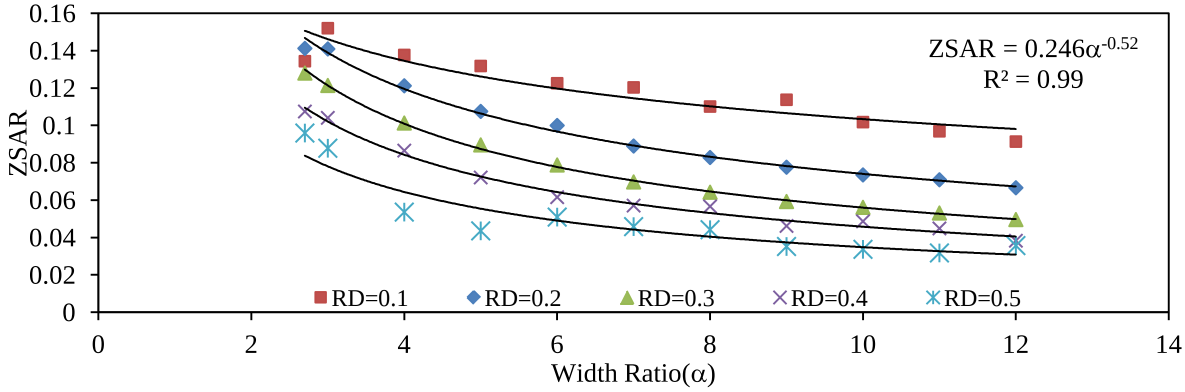

Figure 7 Variation of zero shear area ratio with width ratio for Series 2

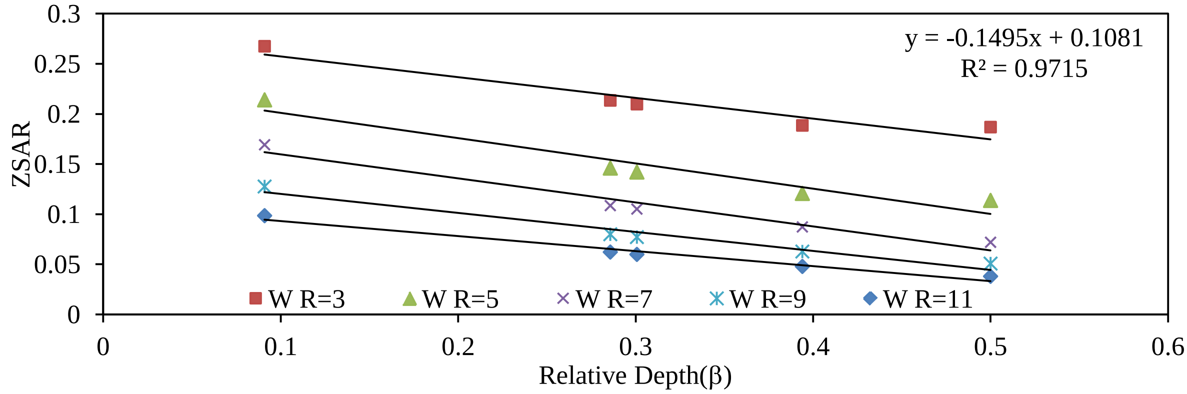

Figure 8 Variation of zero shear area ratio with relative flow depth for Series 3

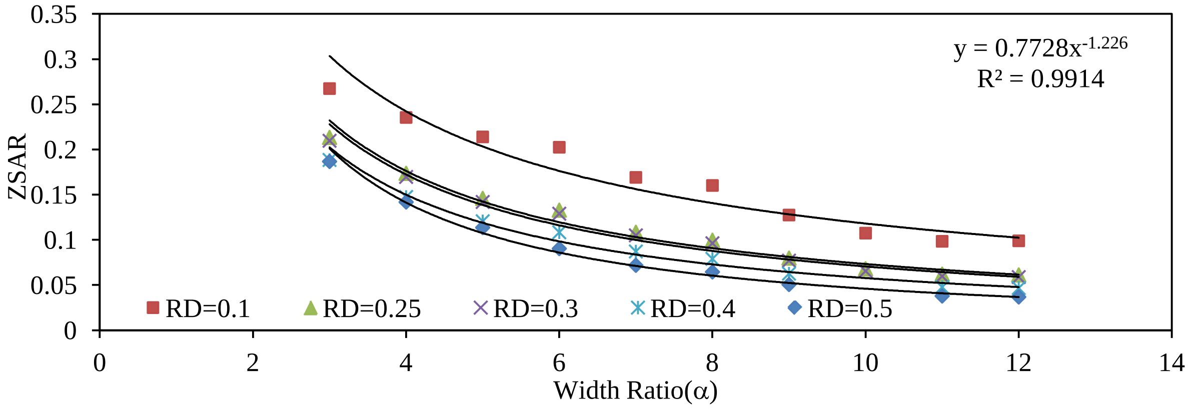

Figure 9 Variation of zero shear area ratio with width ratio for Series 3

The zero shear area ratio (ZSAR) variation has also been tested with aspect ratio (δ) of the main channel and found to increase with inverse of aspect ratio.(Ackers 1993, Moreta and Martin 2010). Moreta and Martin 2010 have demonstrated that for identical width ratio of compound channel, there is a large increase in apparent shear for changing aspect ratio from 2 to 8.

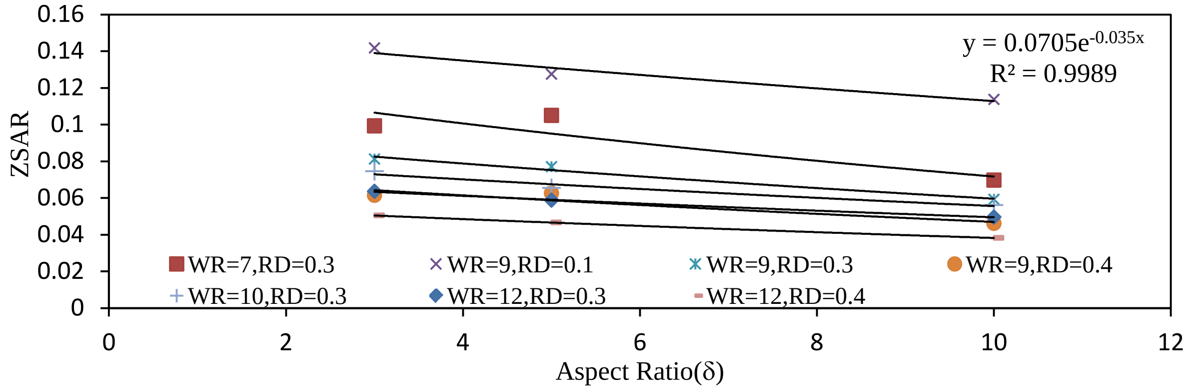

Figure 10 Variation of zero shear area ratio with aspect ratio for different channels

After verifying the dependency of zero shear area ratio (ZSAR) with α , β and δ, now we have attempted to develop a mathematical model to predict ZSAR. From Figure 5, Figure 7 and Figure 9, it is seen that this ZSAR provides a power relationship with high R2 value of 0.99 for all three sets of channels. Figure10 shows the dependence of ZSAR gives exponential relationship i.e., ZSAR = F $\left(De^{m\delta}\right)$with aspect ratio δ. The best fit linear relationship of ZSAR with β is ZSAR = F $(A\alpha + B)$ and best fit power relationship with α is ZSAR = F$(C\alpha^{n})$ have been chosen for the modelling of ZSAR where *A*, *B*, *C*, *D*, *m* and *n* are the functional coefficients. Though we found the dependency of dependent variable ZSAR with individual independent variables like α, β but it is essential to know the resultant dependence of the variables. So a multiple variable regression model has been derived to predict ZSAR as a function of three dimensionless parameters i.e., α , β and δ only. The final expression is tested for reliability using several key statistics with high R^2 value of 0.95 and represented by

$$\mathrm{ZSAR} = A + B\beta + C\alpha^{n} + De^{m\delta} \tag{17}$$

Where *A*, *B*, *C*, *m* and *n* are the functional coefficients with

$$A = -0.11, B = -0.2124, C = 0.35, D = 0.1736\ , n = -0.52 \text{ and } m = -0.03 \tag{18}$$

The expression (17) is developed for a specific range of geometric and hydraulic parameters i.e., α =3-12 and β = 0.1-0.5. Now the discharge in asymmetric compound channel can be estimated by calculating the area of correction equation (17), then the total discharge can be found out by equation 16.

4.1 Validation of different Discharge prediction methods with other experimental channel

The discharge has been calculated at different flow depths for the three tested experimental channel of NITR channels, Flood channel facility (FCF), UK and Khatib et al. (2013). First different regression-based models (equation 9 to equation 12) as listed earlier have been compared with the developed (17) method by applying to the asymmetrical compound channel of NITR, FCF and Khatib et al. (2013) for specific ranges of depths. This equations show the apparent shear stress(τ_{av}), is based on dimensionless parameter like width ratio, relative depth which are used to find out the area correction by equation (8). Then the total discharge is evaluated from equation 16. The overview of these experimental data sets is provided in Table 2.

Table 2 Geometric and hydraulic parameters of data sets

All Series	Bed Width(m)	Bank full Depth(m)	Side Slope	Bed Slope(S)	Relative Depth(β)	Aspect Ratio(δ)	Width Ratio(α)	Manning's *n*
NITR	0.33	0.11	01:01	0.001325	0.043-0.27	3	5.1	0.01
FCF	1.5	0.15	01:01	0.001027	0.05- 0.5	10	2.7	0.01
Khatib et. al.(2013)	0.1	0.02	–	0.0025	0.6-0.82	5	3	0.015
River Trent	15.4	2.1	01:05.2	0.001	0.032-0.12	7.33	5.14	0.032 & 0.015

In order to examine the efficacy of each model for discharge prediction in asymmetric compound channel, three types of errors i.e., Mean percentage error (MPE), Mean absolute percentage error (MAPE) and Root mean square errors (RMSE) for different relative depths for these NITR, FCF and Khatib et al. 2013 channels have been calculated and tabulated in Table 3(a), 3(b) and 3(c) respectively. The average error in discharge estimation for each test case have been demonstrated in Figure11(a), 11(b) and 11(c), which cover a specific range of relative depths and expressed as a percentage.

The present model is found to be well matching with all data sets as compared to other methods and provides minimum 7% error for NITR channels, 2% error for FCF channel and 6% error for Khatib et al. 2013 channels as demonstrated in Figure 11(a), 11(b) and 11(c). From these tables (3.a, 3.b and 3(c), it can be observed that results from Prinos (1984) model has less errors for NITR channels but for other two test cases (FCF, Khatib et. al 2013), the present model shows less error as compared to others. This is because the proposed model is developed for a likely range of relative flow depths (β=0.1-0.5) to be encountered in practice as mentioned before. Below this range the magnitude of errors by the proposed approach increases. Khatua (2008) shows less error for FCF channels but fails to provide better results for Khatib et al. (2013) channel as this model is developed for higher width ratio but the width ratio only.

Table 3 (a) Computed MPE, MAPE and RMSE for five discharge models in NITR Series

Method	MPE	MAPE	RMSE
Model	10.10	6.53	0.03
Prinos	3.00	3.97	0.01
Cristodoulou	19.27	19.27	0.04
Martin-Vide	21.80	21.80	0.05
Khatua	15.29	15.29	0.02

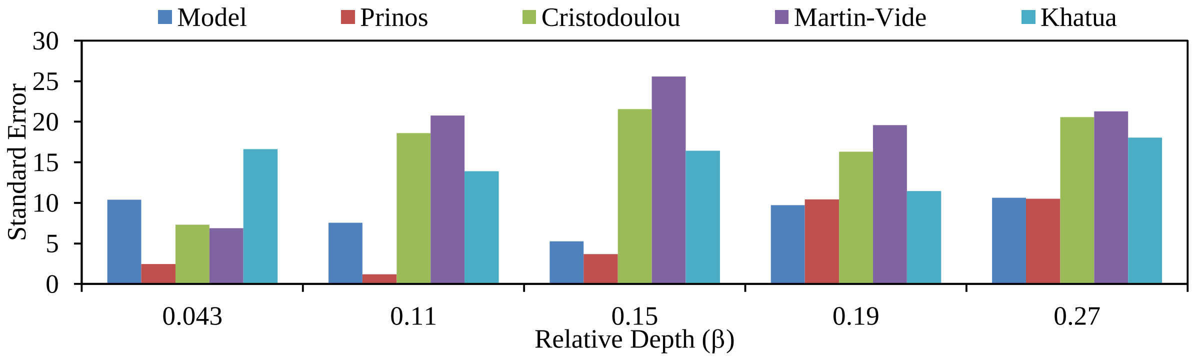

Figure 11 (a) Variation of standard error of discharge for various models in NITR

Table 3 (b) Computed MPE, MAPE and RMSE for five discharge models in FCF Series

Method	MPE	MAPE	RMSE
Model	-3.74	2.64	0.02
Prinos	-3.62	4.48	0.05
Cristodoulou	2.03	4.62	0.05
Martin-Vide	2.55	4.30	0.05
Khatua	2.78	3.64	0.02

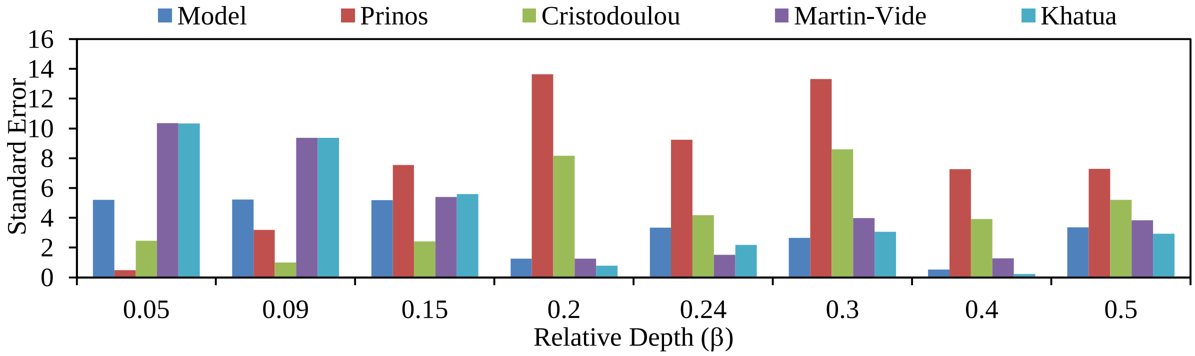

Figure 11 (b) Variation of standard error of discharge for various models in FCF Series 6

Table 3 (c) Computed MPE, MAPE and RMSE for five discharge models in Khatib et al.(2013) Series

Method	MPE	MAPE	RMSE
Model	-5.56	5.83	0.35
Prinos	-7.45	7.77	0.51
Cristodoulou	-7.53	7.81	0.51
Martin-Vide	-7.46	7.76	0.20
Khatua	-11.25	11.38	0.57

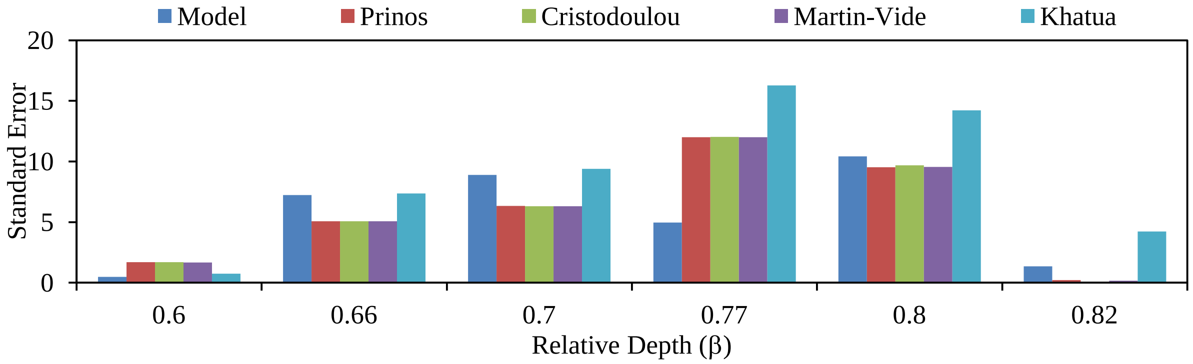

Figure 11 (c) Variation of standard error of discharge for various models in Khatib et al.(2013) Series

4.2 Application of Field Data

The approaches are applied to predict the discharge in a natural river Trent, UK. The river exhibits approximately a trapezoidal shape. The shape has been approximately finalised as a trapezoidal shape in such a way that the total cross sectional area and wetted perimeter of the reach remain unchanged as compared to the original geometry as shown in Figure 12. The cross sectional geometry is shown in Figure 12. The overview of this natural river data are provided in Table 2. The outputs of the discharge values for the river cross section for seven relative flow depths are calculated using all the approaches. The present approach is found to give better result with minimum error up to 4.84% than the results from other researchers because the other methods have been derived solely for symmetrical compound channels where as the present approach has been derived for asymmetrical compound channels. The discharge results in terms of MPE, MAPE and RMSE have been given in Table 4. The present approach provided the best results with minimum errors for all cases thus offers an alternative methodology to predict discharge, which can be applied for practical problems at less computational effort.

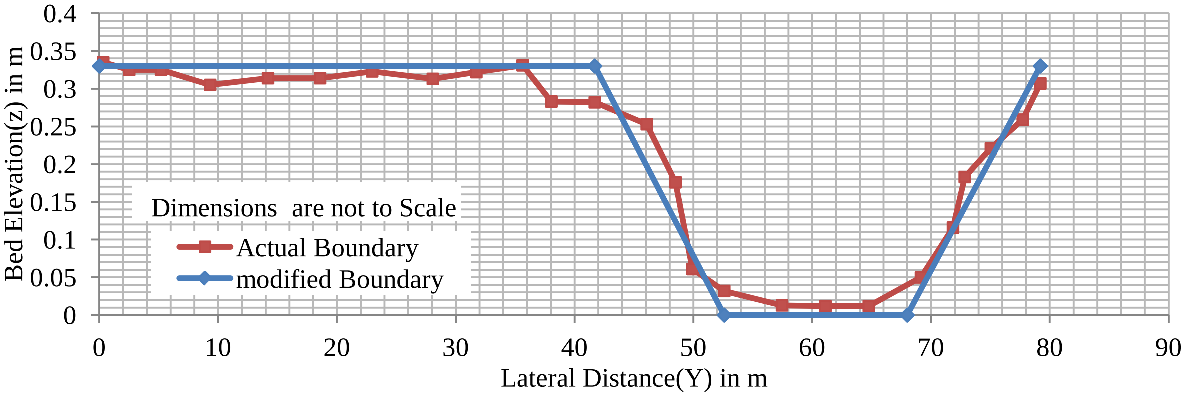

Figure 12 Asymmetrical compound cross sectional geometry of river Trent, UK

Table 4 Computed MPE, MAPE and RMSE for seven discharge models in river Trent

Method	MPE	MAPE	RMSE
Model	4.84	4.84	0.07
Prinos	6.33	6.33	0.08
Cristodoulou	6.03	6.03	0.07
Martin-Vide	5.86	5.86	0.07
Khatua	10.44	10.44	0.11

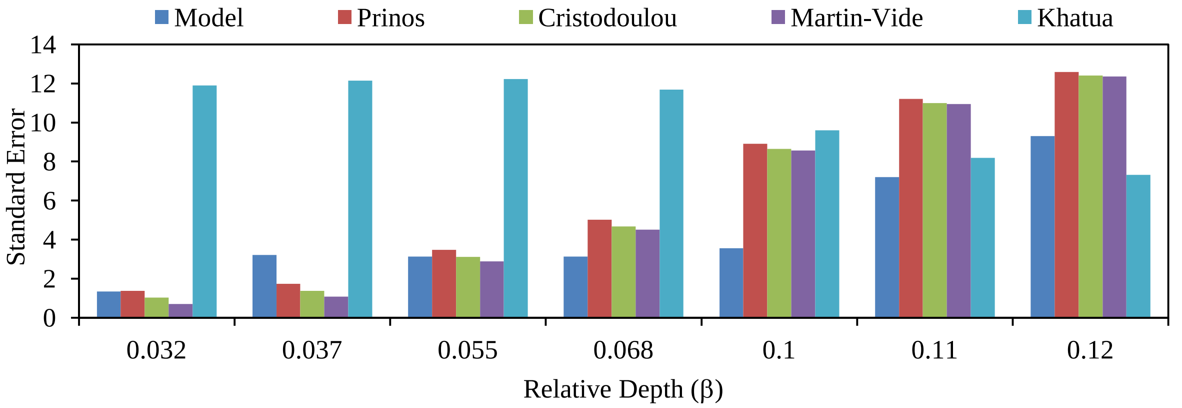

Figure 13 Variation of standard error of discharge for various models in river Trent, UK

5. Conclusions

The following conclusions can be drawn from the above experimental and numerical investigation

The numerical method SKM has been found to provide most accurate boundary distribution results, So in present work CES software, based on the simplification of Navier Stokes equation has been utilised to generate the wide ranges of datasets of boundary shear stress distribution of asymmetric compound channels which in turns helpful for evaluating the area for correction.

The zero shear area ratios of asymmetric compound channels are found to decrease with increase of the non dimensional parameters i.e., width ratio, relative flow depths and aspect ratio of main channel.

The approaches presented by the previous investigators are found to be not suitable for predicting area for correction in an asymmetric compound channel as these methods are suitable either for rectangular or trapezoidal compound channel or also due to improper consideration of interaction mechanism.

A multi linear regression model for predicting area correction has been developed by taking care of the dependency of ZSAR with non dimensional parameters i.e., α , β and δ only. The proposed model on the basis of a new expression of zero shear area ratio for prediction of discharge in a compound channel is found to give very less error as compared to results from previous investigators. This proposed model thus offers an alternative methodology to successfully predict the flow in practical cases at much less computational effort.

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