STUDY OF FLOW RESISTANCE IN COMPOUND CHANNEL WITH CONVERGING FLOODPLAINS

A

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Submitted by

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I, Rahul Kumar, (2K21/HFE/02) student of M.TECH (Hydraulics and Water Resources Engineering), hereby declare that the project dissertation titled as **"Study of Flow Resistance in Compound Channel with Converging Floodplains"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled as **"Study of Flow Resistance in Compound Channel with Converging Floodplains"** which is submitted by **Rahul Kumar**, **2K21/HFE/02** Student of **M.TECH (Hydraulics and Water Resources Engineering)**, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Accurately estimating the flow resistance in open channel flow is crucial for resolving numerous pressing engineering issues. In situations where there is excessive water flow on both banks of a river, the primary channel may become compromised, leading to the outpouring of water into the adjacent floodplain. The flow configuration within compound channels can become intricate due to the exchange of momentum between the main channel and the adjacent floodplains. This phenomenon exerts a noteworthy influence on the flow resistance within distinct segments of the floodplain as well as the primary channel. Furthermore, human activities such as agriculture and construction have been conducted within the floodplain regions of a river system. The floodplain's geometry undergoes modifications along the flow's length, leading to the creation of a compound channel that can be converging, diverging, or skewed. The reliance on empirical methods in conventional formulae has resulted in a lack of success in accurately predicting flow resistance. Consequently, there exists a persistent demand for techniques that are both precise and innovative. The current investigation involves the experimental and computational determination of flow resistance in a compound channel featuring both rough and smooth floodplains. This was accomplished through the utilization of Gene Expression Programming, with consideration given to both geometric factors and flow variables. Statistical measures are employed to validate the proposed models in the experimental investigation, thereby enabling the evaluation of the performance and efficacy of said models. The Manning roughness coefficient exhibits a decline in the prismatic segment, while in the nonprismatic segment, it experiences a reduction until reaching the midpoint. Subsequently, there is a notable surge observed in the roughness metric. Similar patterns of fluctuation have been noted in relation to greater relative depths. The analysis of roughness coefficient in compound channel with both rough and smooth floodplains indicates that the values of roughness coefficient are comparatively greater for the compound channel with rough floodplains. The findings of the computational analysis indicate a robust correlation between the Manning's roughness coefficient derived from Gene Expression Programming (GEP) and both empirical data from experiments and prior research outcomes.

Keywords: Compound channel, Converging floodplains, Flow and geometric parameters Manning's roughness coefficient, Statistical analysis, Gene Expression Programming.

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1.1 General

The two most important means by which water may flow are via pipes or open channels. It falls to the ground as precipitation and then travels via open channels after reaching the ground. The study of the free surface is the most significant component of open channel flow. In spite of the fact that the flow in pipes and flows in open channels are quite comparable to one another, it is a great deal more difficult to figure out and analyze the difficulties connected with the flow in open channels as opposed to the flow in pipes. Open channel flows are notoriously difficult to understand. The forecast of the depth of the flow and the velocity of the free surface flow are both absolutely necessary in order to accurately determine the discharge as well as the bottom slope of the channel. In the study of flow in open channels, roughness is the most important component. The roughness of a pipe may range from poised metal to corroded iron, while the roughness of open channels can be poised metal, vegetation, or even a distinct kind of silt, among other things. It has been discovered that the flow depth in open channels shifts with time, regardless of whether the value is high or low for the given geometry and flow circumstances.

1.2 Flow in compound channels

During times of flooding, rivers often assume the structure of having compound channels. Concerning environmental, ecological, and design challenges, they are of the utmost significance. Due to the large variation in velocity that exists between the main channel and the floodplains, it is very necessary to do research on the flow mechanism of rivers while they are experiencing overbank flow circumstances. Even for prismatic stretches, the complexity of flow behavior significantly increases when the flow is out-of-bank, which generally occurs during a flood. This increase in complexity may be seen in the flow of water. The disparity in velocity between the floodwaters moving through the main channel and those moving across the floodplain may give rise to powerful lateral shear layers, which in turn may cause the formation of large-scale turbulent formations.

In the field of flood control, one of the most important responsibilities of a river engineer is to provide accurate predictions about stage-discharge correlations. It is a well-known truth that the discharge capacity of a compound channel is impacted when the flow is out-of-bank because of the momentum exchange that occurs between the main channel and its related floodplains. This is something that is a well-known fact. The carrying capacity of the main waterway is reduced when momentum is transferred over the junction between the primary channel and the riverbank; as a result, the discharge capacity of the flooded area is increased, especially at small relative levels. As a direct consequence of this, the overall capacity for transporting water through the waterway in its whole is reduced. When dealing with a compound channel that also contains nonprismatic floodplains, the level of difficulty of the task significantly increases. The non-prismatic floodplain might have a converging, diverging, or skewed topography. The geometry of the riverbank creates a restriction that causes water that circulates on the flood zones to flow over water that is flowing in the primary stream. This occurs because the floodplain is constricted. As a consequence, more contact and fluxes of momentum are produced. Compound channels with converging floodplains are an example of this. When modeling the flow, this additional momentum exchange has to be taken into account as well. The hydraulic elements of two-stage channels for prismatic and nonprismatic floodplains are vital for forecasting floods in river channels and building cost-effective flood defense systems and drainage channels. These aspects must be considered when planning prismatic and nonprismatic floodplains. Studies in the field and the lab are absolutely necessary if one want to improve their understanding of the flow resistance of compound channels with converging floodplains. However, in circumstances of unstable flood flow, it is difficult to produce field data that are sufficiently precise and comprehensive. Natural rivers provide this challenge. Therefore, laboratory research is necessary in order to increase our knowledge of the effect of overbank flows on the pattern of flow in a composite stream with narrowing flood zones and to construct models that are more accurate when attempting to anticipate flow. However, all of the earlier approaches were primarily created for simulating uniform flow in prismatic compound channels, and they were unable to provide satisfactory results when applied to converging compound channel situations. In the course of this research, an attempt has been made to investigate the flow resistance that occurs in compound channels that have floodplains that converge.

1.3 Flow resistance in open channels

The term "flow resistance in open channels" refers to the opposition that flowing water experiences as it passes through a channel, such as a river, stream, or canal. Flow resistance may be caused by obstacles such as rocks, vegetation, or other moving bodies of water. It is brought on by a number of different aspects, including as the form, roughness, and slope of the channel itself, as well as the speed and depth of the water that is moving through it. The interaction between the main channel and the floodplains may make the flow resistance in compound channels with convergent flood zones rather complicated. This is because the main channel and the floodplains converge. Frictional forces between the fluid and the channel borders, in addition to turbulence and other variables, are the primary contributors to the resistance to flow that may be found in a channel. These forces may be affected by a number of different elements in compound channels with converging floodplains. These factors include the geometry of the channel, the roughness of the channel edges, as well as the speed and depth of the flow. The influence that the floodplain has on the channel's flow pattern as a whole is an essential aspect that must be taken into consideration. It is possible that the flow will be pushed to converge towards the main channel when the floodplain is broader than the main channel. This will result in an increase in velocity and a drop in depth. This may result in a reduction in flow resistance owing to the lower depth, as well as an increase in flow resistance due to the greater velocity. Flow resistance can rise due to the higher velocity. The roughness of the channel borders is yet another component that has the potential to impact flow resistance in these channels. Because the roughness of the main channel walls may be different from that of the floodplains, this difference has the potential to influence the velocity profile as well as the total flow resistance. It is also possible for the roughness, and therefore the flow resistance, of the channel to be affected by the presence of plants or other impediments. The overall shape of the channel may also have an effect on the flow resistance of the channel. The breadth of the floodplains in relation to the main channel may have an effect on the flow regime as well as the resistance to flow in rivers that have floodplains that converge. For instance, if the floodplains are located in close proximity to the main channel, the flow may be compelled to disperse itself across a vast region, which results in a reduction in the water's velocity as well as an increase in its depth. In addition to these characteristics, there may be other variables that might alter flow resistance in compound channels with converging floodplains. Some examples of these variables include shifts in the gradient of the channel, the existence of bends or other irregularities in the channel, and changes in the direction of the channel's converging floodplains. Taking everything into consideration, the intricate interaction between these components makes it impossible to accurately anticipate the flow resistance in composite waterways with convergent flood zones.

1.4 Objectives of present study

The following is an outline of the goals that this research, which has as its primary emphasis on the conduct of a Study of Flow Resistance in Compound Channel with Converging Floodplains, aims to achieve:

- To determine the flow resistance in compound channel with rough converging floodplains.
- To compare the manning's roughness coefficient of compound channel with rough floodplains to the smooth floodplains.
- To predict the manning's roughness coefficient in compound channel with converging floodplains using Gene Expression Programming.

1.5 Organization of the thesis

This project work is organized in five different chapters whose content are summarized below:

Chapter 1 is introductory chapter which describes the motivation behind the work, objectives and scope of the project.

Chapter 2 is introducing the existing literature for flow resistance in compound channel with converging floodplains.

Chapter 3 deals with the selection of methodology and their properties.

Chapter 4 deals with the results and discussions for the present study.

Chapter 5 is concluding chapter in which conclusions are discussed.

1.6 Scope of the work

The current investigation may serve as a foundation for future research or function as a supplementary resource for comprehensive analysis in the identification of various parameters. Several studies can be conducted to offer a diverse range of applications in the compound channel domain.

- The study can be done using different type of channel shape such as trapezoidal.
- Effect of vegetation can be studied to quantify the effects of roughness on flow in compound channel.

- Effect of different flow parameters on manning's coefficient at different converging angles can be studied.
- Innovative soft computing techniques are the further scope of research for the prediction of roughness coefficient in compound channel with converging floodplains.

2.1 General

This study is centered on a comprehensive examination of existing literature pertaining to flow resistance in compound channels featuring converging floodplains. The review of literature was conducted with consideration to the purpose and goals of the current study. An endeavour was undertaken to ascertain and analyze the literature of previous scholars pertaining to diverse facets in compound channels. The present study systematically examined works utilizing analytical, experimental, and numerical approaches to gain insight into the issues and challenges within the field. This allowed for an appreciation of the research accomplished by scientists and investigators in both past and recent decades.

2.2 Literature review

Einstein and Banks (1950) carried out experiments with the purpose of determining the combined resistance that various forms of roughness provide to the movement of water through an open channel. Each of the several varieties of roughness that were tested had a particular geometrical shape, and each type provided a different amount of resistance to the flow. The combination or composite resistance was sought for by considering the resistances that the various kinds of roughness exerted on their own. It was discovered that the total resistance that is exerted by combined forms of roughness is equal to the sum of the resistance force s that are exerted by each type separately. This was discovered within the range of the variables that were investigated.

Mayers and Brennan (1990) investigate the features of flow resistance in simple and complex streams that have smooth borders. It has been established that the capacity of the compound channel portion and the main channel section is affected by the transfer of momentum from the main channel to the floodplains. They supplied flow resistance relationship information for the composite section, the primary stream, and the flood zones in terms of various resistance coefficients, and compared these links with straightforward stream layouts. The complicated nature of composite channel flow resistance has been brought to light as a result of this, as has the likelihood of making mistakes when attempting to apply techniques of analysis and design developed for simple channels to rivers and channels with complex geometries.

Yen (2002) conducted an analysis of hydraulic resistance in open channels. In addition to the viscosity and wall roughness that are traditionally taken into account, the impacts of cross-sectional shape, boundary non-uniformity, and flow unsteadiness are taken into account. The research investigates the distinctions between momentum resistance and energy resistance, cross-sectional resistance coefficients, reach resistance coefficients, inter-point resistance coefficients, and compound or composite channel resistance. There is also discussion on whether or not a linear-separation technique or a nonlinear approach should be used to alluvial channel resistances.

Stone and Shen (2002) were investigated the hydraulic characteristics of flow with roughness in the form of circular cylindrical in a channel. The laboratory investigation comprises a comprehensive series of flume trials conducted on flows featuring cylindrical stems of varying sizes and concentrations, both emergent and submerged. The findings indicate that the flow resistance exhibits fluctuations in response to alterations in flow depth, stem concentration, stem length, and stem diameter. The optimal way to articulate the resistance of the stem encountered by the flow passing through the vegetation is by means of the maximum depth-averaged velocity amid the stems. The present study has developed physically derived equations for various parameters such as resistance of flow, and flow velocities in the roughness and surface layers. The validity of the formulas has been confirmed through the utilization of flume data obtained from both the current investigation and previous research endeavours.

Yang et al. (2005) presents the Manning and Darcy-Weisbach resistance coefficients because these coefficients play a important role in the estimation of depth average velocity across the wetted perimeter and the local wall shear stresses in composite waterways channels. Additionally, these coefficients contribute to the assessment of the cross-sectional mean velocity and the conveyance capacity. The correlations between the local, zonal, and overall resistance coefficients, as well as a broad variety of geometries, and varied roughness, are developed. These relationships are found between the main channel and the flood plain. The findings of the experiments indicate that the global Darcy-Weisbach resistance coefficient for a compound channel is a function of the Reynolds number; however, the connection between the function and the Reynolds number is not the same as it is for a single channel. When the standard techniques of predicting composite roughness in compound channels are compared and analyzed with the experimental data, it is discovered that these approaches are not appropriate for use with compound channels. This conclusion is reached as a result of the comparison and analysis of both sets of data.

Bjerklie et al. (2005) theoretically generated in-bank river discharge–estimating equations (models) developed which are calibrated and verified with the use of a high quality experimental database. These equations are based on the Manning and Chezy equations. A multiple regression model that was developed from the same data as the models is used to compare and contrast the models. The comparison indicates that in natural rivers, reducing the variation associated with calculating flow resistance may be accomplished by using an exponent on the slope variable with a value of 0.33 rather than the conventional value of 0.5. Assuming a constant value for the conductance coefficient, the mean model uncertainty is less than 5% for a large number of predictions, and 67% of the estimates would be correct within 50% of the value.

Proust et al. (2006) is to assess whether or if 1D models, which were designed for linear and slightly converging geometry, are similarly valid for such a geometry by concentrating on a sudden floodplain contraction with a mean angle of 22 degrees. An asymmetric composite stream flume served as the testing ground for a contraction model's worth of activities. It was found that there was a significant transfer of mass and momentum from the floodplain to the main channel, which resulted in a notable transverse gradient of the water level and distinct differences in the head loss gradients between the two subsections. In this study, experimental data was compared to one 1D model, two 2D simulations, and three 1D models. Each one-dimensional model uses a unique method to describe the transfer of momentum at the interface boundary between the primary waterway and the flood zones. These boundaries separate the main channel from the floodplain. The increase in the mass transfer along laterally causes minor mistakes to be generated on the values of the water level, but considerable errors to be generated on the discharge distribution. Incorrect estimates of momentum exchange owing to lateral mass transfers and boundary conditions that are imposed by the tested 1D models are the root cause of erroneous findings. Erroneous results happen as a consequence of both of these factors.

Cao et al. (2006) proposed new formulations for calculating flow resistance and momentum flux in compound open channels. These formulations, when applied in the St. Venant equations, make it possible to evaluate conveyance, roughness, stage-discharge relationship, and unstable flood routing in compound open channels in a way that is physically more accurate. In addition, it has been shown that the suggested formulations are favourable to eliminating the long-standing computational issue in unstable flood routing caused by tiny flow depths across flat and large floodplains. This difficulty has been a problem for a long time.

Yang et al. (2007) explores the resistance characteristics of inbank and overbank flows, conducted a series of experiments in a large symmetric compound channel that was made up of a rough main channel and rough floodplains. Analyses were performed on the effective Manning, Darcy–Weisbach, and Chezy coefficients, in addition to determining the relative Nikuradse roughness height. In addition to the measured data, a large number of laboratory data and field data for compound channels were gathered and utilized to assess the validity of these techniques for various subsection divisions, such as the vertical, horizontal, diagonal, and bisectional divisions. The measured data were also collected. The calculation revealed that the approaches led to significant mistakes in the assessment of the composite roughness in compound channels, and the causes for this were investigated in further depth. The degree of the mistake has a correlation with the subsection divisions.

Proust et al. (2009) pertains to the examination of one-dimensional modeling of non-uniform flows in compound channels. The present study introduces a novel model termed as the "Independent Subsections Method" (ISM). In contrast to conventional one-dimensional models that address dynamic equations on the overall cross-sectional area, the Integrated Subsection Method (ISM) approximates the water surface profile within individual subsections. Simultaneous calculation of water level and subsection mean velocities is facilitated without any variable being given priority. The Independent Subsection Method (ISM) posits that the discharge in each subsection of the compound channel evolves independently, in contrast to the various methods developed for discharge estimation. This approach does not make any assumptions regarding uniform head loss gradients across all sub-sections, nor does it enforce a specific distribution of downstream discharge. The utilization of the ISM exhibits potential as a valuable theoretical instrument in enhancing our comprehension of the physical mechanisms that govern flows in compound channels.

Moreta and Vide (2010) examined the phenomenon of compound open channel flow, wherein the discharge capacity is significantly influenced by the robust interplay between the primary channel and the shallow floodplains. Since the discovery of this phenomena, a great number of authors have carried out experimental calculations of flow communication in connection to an apparent shear stress that works at the vertical boundary differentiating the primary waterway from flood zones. Empirical equations have been formulated to quantify the observed shear stress; however, their universal applicability remains limited. The present study proposes a mathematically sound expression that is based on the square of the velocity gradient between the primary stream and the areas of flooding, as well as the "apparent friction coefficient".

Rezaei and Knight (2011) presented the experimental findings of overbank flow in composite waterways with nonprismatic flood zones and various convergence angles. Along the converging flume segment, several flow characteristics were measured at a variety of relative depths. The momentum balance is used in the investigation of the driving force behind the flow in the primary channel as well as over the whole cross section. After determining the shear pressures at the junction of composite channels with nonprismatic floodplains, the findings are compared with those of straight floodplains. Utilizing the height of the water's surface is another method that is used to explore the energy balance in non-prismatic compound channels.

Yonesi et al. (2013) examines the impact of roughness in floodplains on hydraulic overbank flow in compound channels that possess nonprismatic floodplains. The floodplain was subjected to experimentation involving three different divergence angles and three distinct roughness sizes. The water surface slope was determined utilizing empirical data pertaining to the shear stress, depth-averaged velocity, roughness coefficient, turbulence parameters, and divided discharge between the main channel and floodplain. Furthermore, a comparative analysis was conducted between the obtained outcomes and those of the prismatic compound channel. Additionally, the Shiono-Knight method was employed to compare the results.

Huai et al. (2013) focused on the investigation of the apparent shear stress exerted on the vertical interface between the main channel and floodplain in prismatic compound open channels, with and without vegetation, through the utilization of artificial neural networks (ANNs). The impact of vegetation is evaluated by taking into account the degree of submersion and the porosity, which refers to the volume ratio that is occupied by water. The mathematical formula for apparent shear stress was determined through the use of dimensional analysis. Seven non-dimensional parameters were identified as the factors that influence this formula. A three-layer, feed-forward neural network was trained and tested using a total of 260 sets of data, which included a new experimental series conducted in a compound channel with vegetated floodplain. The Levenberg-Marquardt (LM) algorithm was chosen as the training algorithm. Furthermore, an analysis was conducted to examine the impact of key influential factors on the observed shear stress.

Mohanta et al. (2014) utilized the momentum balance principle to examine a one-dimensional approach for forecasting water surface elevations in nonprismatic compound channels. Subsequently, the numerical approach is utilized to compute the water surface elevation in nonprismatic compound channel configurations. The outcomes of the computations exhibit a favorable level of concurrence with the empirical data. The present study examines a comprehensive computational fluid dynamics (CFD) model that accounts for both three-dimensional and two-phase flow phenomena in a converging compound channel. A convergence condition was established through the implementation of the finite volume method (FVM) utilizing a dynamic sub grid-scale. The VOF technique was employed to enable unconstrained deformation of the free surface in conjunction with the underlying turbulence. The present study validated the computed results by analyzing the accuracy of the model with observed data from experimental studies of a converging compound channel as the qualitative reference. The anticipated outcomes pertaining to the flow characteristics exhibit a reasonable level of concurrence with the empirical data.

Naik et al. (2014) investigated the phenomenon of overbank flow, wherein the flow characteristics of the compound sections were significantly influenced by the interaction mechanism between the main channel and floodplain. The level of complexity increases when addressing a compound channel that features converging floodplains. In compound channels with converging geometry, alterations to the floodplain's shape can result in significant changes to momentum exchanges, particularly in cases where the transition involves contraction or expansion. Numerous researchers have conducted analyses and expounded upon the intricacy of compound geometry in forecasting fluid dynamics. The present study outlines experimental findings pertaining to compound channels featuring converging floodplains, which are subsequently analyzed and contrasted. This study examines and analyzes the flow properties' variations in both prismatic and nonprismatic floodplains with varying convergence angles.

Das et al. (2015) evaluated the flow characteristics in compound channels, which were identified by the exchange of momentum between the primary channel and the adjacent floodplain(s). The transfer of momentum has a significant impact on the overall conveyance of channels and must be considered in all flood management or engineering endeavors. The momentum transfer in a prismatic compound channel can be classified into two primary processes: turbulent exchange and geometrical transfer. While turbulent exchange is tied to the formation of the shear layer between the main channel and floodplain, geometrical transfer is linked to the interchange of mass and flow across subsections when the floodplain wetted area is no longer constant. Turbulent exchange and geometrical transfer both occur when the floodplain wetted area is no longer constant. Compound channels typically exhibit flow characteristics that fall between those of purely prismatic and fully meandering channels. This is particularly true for skewed channels, symmetrically converging channels, and diverging channels. The current investigation solely focuses on the analysis of skewed and converging channels. The utilization of SCM and DCM interface techniques is determined using the geometry of channel section, level of water, and flow rate for both skewed and narrowing channels. The optimal methods are subsequently deliberated.

Naik and Khatua (2016) formulated a multivariable regression model for the purpose of forecasting the water surface profile in diverse compound channels featuring nonprismatic floodplains. Three distinct channels with different converging angles were studied to demonstrate the phenomenon of out of bank phenomenon in narrowing flood zones. The model was developed by relating the measurement of water surface profiles flow to several dimensionless parameters. The findings obtained from the computations of the surface of water elevations using the current model exhibit a good concurrence with both the recorded data and the data gathered by other studies. Multiple statistical analyses were conducted to confirm the dependability of the multivariable regression model that was created.

Naik and Khatua (2016) carried out an empirical examination on the allocation of shear stress within the primary channel and floodplain of converging compound channels. A novel equation has been formulated to forecast the distribution of boundary shear stress by utilizing non-dimensional geometric and flow variables, based on the outcomes of boundary shear experiments.

Naik et al. (2017) analyzed the pattern of distribution of shear stress in the primary and side zones for straight and narrowing reaches of composite waterways under unsteady flood flow situations. Novel equations have been formulated to forecast the distribution of boundary shear stress in a composite channel featuring a convergent floodplain. The utilization of these expressions has led to the successful estimation of relationships for stage-discharge with lower width ratios in compound channels with converging floodplains. The efficacy of the models is validated through the application of natural river datasets.

Dupuis et al. (2017) examined the flow characteristics of a compound open-channel featuring a longitudinal transition in roughness across the floodplains. The experiment was conducted in a flume measuring 18 meters in length and 3 meters in width. The modeling of transitions between submerged dense vegetation and emergent rigid vegetation, as well as the reverse, is accomplished through the utilization of plastic grass and vertical wooden cylinders. The distribution of upstream discharge between the main channel and floodplain, referred to as subsections, is varied while maintaining a constant total flow rate for a given roughness transition. The present study involves a comparison between flows featuring a roughness transition and those featuring a uniformly distributed roughness along the entire length of the flume. The existence of emergent rigid elements over the floodplains leads to an augmentation in both turbulence production and the magnitude of secondary currents. The autocorrelation functions indicate a direct correlation between the coherent structures' length and the mixing layer width across all flow cases. The proposition posits that coherent structures exhibit a tendency towards a state of equilibrium, wherein the magnitude of velocity fluctuations, pertaining to both horizontal vortices and secondary currents, and the spatial extension of the structures are balanced.

Das and Khatua (2018) conducted experiments on a composite stream with symmetric geometry featuring expanding and narrowing zones of flood, varying the depth of relative flow. The aim was to examine the resistance properties in terms of various roughness coefficients of flow under overbank situations in nonprismatic reaches of the compound channels. The Manning roughness coefficient is dependent on various nondimensional parameters. In order to calculate an estimate of the Manning's roughness coefficient for nonprismatic composite streams, a multivariable regression model has been developed. This model takes into account the geometric and hydraulic factors. The nonlinear regression models that relate to the compound channel with nonprismatic floodplains have been produced using relevant experimental data obtained from laboratory studies as well as data from other researchers. These models were developed using relevant experimental data. The new approach produces positive results in contrast to other techniques across a wide variety of experimental channels and field data, displaying decreased error in the process.

Mendicino and Colosimo (2019) addressed the evaluation of flow resistance in natural gravel-bed rivers. The study conducted an analysis on a novel data set comprising of 136 reaches of 78 gravel-bed rivers (Calabrian fiumare) located in southern Italy. The aim of the study was to evaluate the efficacy of various conventional flow resistance equations in their original form, with respect to predicting the mean flow velocity in gravel-bed rivers. The equations have exhibited significant discrepancies with empirical data, particularly in river segments that exhibit substantial bed load conditions and in the intermediate to large-scale roughness domains. In the majority of cases, a discrepancy arose leading to an undervaluation of the flow resistance. However, this can be rectified by incorporating the Froude number and a specific variant of the Shields sediment mobility parameter into the Manning, Chezy, and Darcy-Weisbach equations. By conducting analyses on both the complete dataset and its subsets, we suggest a semiempirical methodology. This methodology considers the ratio between the sediment mobility parameter and its critical value to account for the tractive forces exerted by the flow on the bed. Additionally, it evaluates water surface distortions using the Froude number.

Zhang and Luo (2021) provide a clarification of hydraulic variables as they pertain to a single cross-section. They also identify the factors that contribute to flow instability and uneven river boundaries. In order to address these issues, the authors propose a redefinition of hydraulic variables, including hydraulic radius, within the context of a river reach. The form drag present in the river reach is resolved by utilizing a flow resistance model that is averaged across the reach. This model is developed by analyzing the force balance of the water body within the specified river reach. The correlation has been observed to exhibit superior concurrence with the field data when forecasting flow velocity, relative to the currently available flow resistance equations. The reach-averaged resistance relation possesses a distinctive characteristic of being applicable to both shallow and deep water zones, thereby serving as a connecting link between the flow hydraulics in plain rivers and mountain streams.

Mahtaj and Rezaei (2022) conducted experimental investigations conducted in nonprismatic compound channels featuring skewed and inclined floodplains. The study examined three different discharges in conjunction with skew angles of 3.81° and 11.31°. This study presents an analysis of the impact of relative depth and relative distance on the percentage discharge distribution within each sub-section of skewed compound channels. The empirical findings indicate that the proportion of discharge within each sub-section is contingent upon various parameters, such as relative depth, relative distance, skew angle, and floodplain side slope. Multivariable regression models were developed utilizing experimental results to estimate the percentage of discharge in both the main channel and on the floodplains. The findings of this study indicate that the coefficient of determination (R^2) for the discharge regression model is 0.96 in the main channel, 0.92 on the diverging floodplain, and 0.91 on the converging floodplain. The study reports the MAPE values for the percentage discharge in the main channel, diverging floodplain, and converging floodplain to be 1.47%, 14.29%, and 21.7%, respectively, based on the comparison between the calculated and measured values.

Kaushik and Kumar (2023) employed machine learning techniques to forecast the surface profiles of water of a two stage channel with narrowing zones of flood. Unlike previous research that primarily concentrated on geometric variables, the authors incorporated both geometric and flow variables in their predictions. A novel equation was proposed utilizing gene expression programming as a means of predicting the water surface profile. Error analysis using various indices are employed to validate the models created for the experimental analysis, with the aim of evaluating their performance and efficacy. The results indicate that the proposed artificial neural network (ANN) model exhibited a high degree of accuracy in forecasting the water surface profile, as compared to gene expression programming (GEP), support vector machine (SVM), and other established techniques.

Kaushik and Kumar (2023) employed Gene Expression Programming, a novel methodology, to formulate a novel equation for compound channels featuring converging floodplains. The equation was developed in terms of nondimensional geometric and flow variables, and was utilized to estimate the boundary shear force carried by the floodplains. The method based on Gene Expression Programming (GEP) that has been proposed exhibits superior performance in comparison to previously established methodologies. The results suggest that the anticipated proportion of shear force supported by floodplains ascertained through GEP exhibits a satisfactory level of concurrence with the empirical evidence.

Kumar et al. (2023) examines various empirical methodologies found in existing literature to ascertain the friction factor in bedload transport conditions. The researchers propose a genetic programming-based formula for this purpose. The flow resistance in bedload transport is influenced by a range of hydraulic and geometric factors. The Multi-Gene Genetic Programming (MGGP) model has been developed and found to provide reasonable predictions of river discharge. This suggests that the model is suitable for application in field studies, provided that the specified range of parameters is adhered to.

3.1 Experimental setup/laboratory limitations

The Hydraulics laboratory, located within the Department of Civil Engineering at Delhi Technological University, served as the site for conducting the experiments. The experimental procedures were carried out within a masonry flume measuring 12 meters in length, 1 meter in width, and 0.8 meters in depth. A compound cross section was erected in the flume utilizing brick masonry. The main channel was 0.5m wide and 0.25m deep, as depicted in figure 3.1.1. Figure 3.1.1 depicts the geometric properties of a two-stage channel. The channel's converging section was constructed utilizing brick masonry and features a converging angle of θ = 4°. The compound channel is comprised of a prismatic section measuring 6 meters in length, a nonprismatic section spanning 3.6 meters, and a downstream portion encompassing the remaining length. The experiment involved the operation of the flume under six distinct flow rates. Measurements were taken for multiple flow characteristics, including the stage-discharge relationship, water surface profile, velocity distribution, and shear stress distribution, for each discharge. These measurements were conducted in both the prismatic section (PS) and various converging sections (NPS), as illustrated in figure 3.1.3. The initial and terminal segments of the converging portion are denoted as NPS1 and NPS5, respectively, while the midpoint of the converging section is referred to as NPS3. The NPS2 segment can be identified as the intermediary component situated between the NPS1 and NPS3 sections. NPS4 can be identified as the intermediary segment situated between NPS3 and NPS5.

The state of subcritical flow was achieved under various circumstances within the two-stage channel, which featured a longitudinal bed slope measuring 0.001. The Manning's n value was estimated using data obtained from both in-bank and over-bank flows in the floodplains and main channel. The water supply in the experimental channel is sourced from an underground sump and transferred to an overhead tank through the system. The aqueous solution originating from the conduit is accumulated within a container of fixed volume equipped with a V-shaped notch. The v-notch has been calibrated for the purpose of measuring the discharge emanating from the experimental channel. Subsequently, it returns to the sump situated below. The experimental configuration and instrumentation utilized in the study are depicted in figure 3.1.2. A tailgate was implemented at the downstream terminus of the flume in order to regulate the water surface profile and enforce a predetermined flow depth within the flume segment. The water surface profile was measured using a point gauge with a precision of 0.1mm, at a distance of 1.0m and 0.3m in the prismatic and nonprismatic portions, respectively. The study utilized an Acoustic Doppler Velocimeter (ADV) to ascertain the mean velocity of the cross-sectional area and the velocity distributions in three dimensions along the wetted perimeter. The measurements were taken at intervals of 2.5 cm and 10 cm in the vertical and horizontal directions, respectively, as illustrated in the grid format presented in figure 3.1.1. The data obtained through the Acoustic Doppler Velocimeter (ADV) underwent filtration utilizing the Horizon ADV software. The measurement of lateral distributions of boundary shear stress was conducted using a Preston tube with an outer diameter of 5mm at the identical sections where the velocity distributions were examined. The pressure differential was measured using a digital manometer. Subsequently, the calibration equations proposed by Patel (1965) were employed to compute the shear stress values.

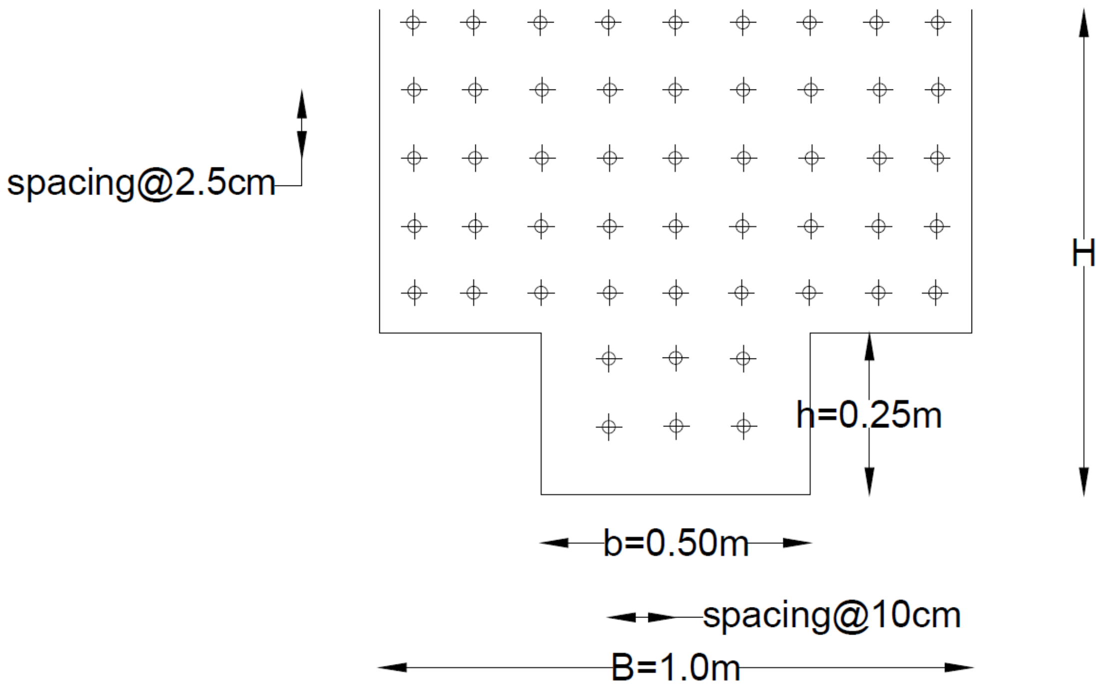

Figure 3.1.1. Cross-section of a compound channel

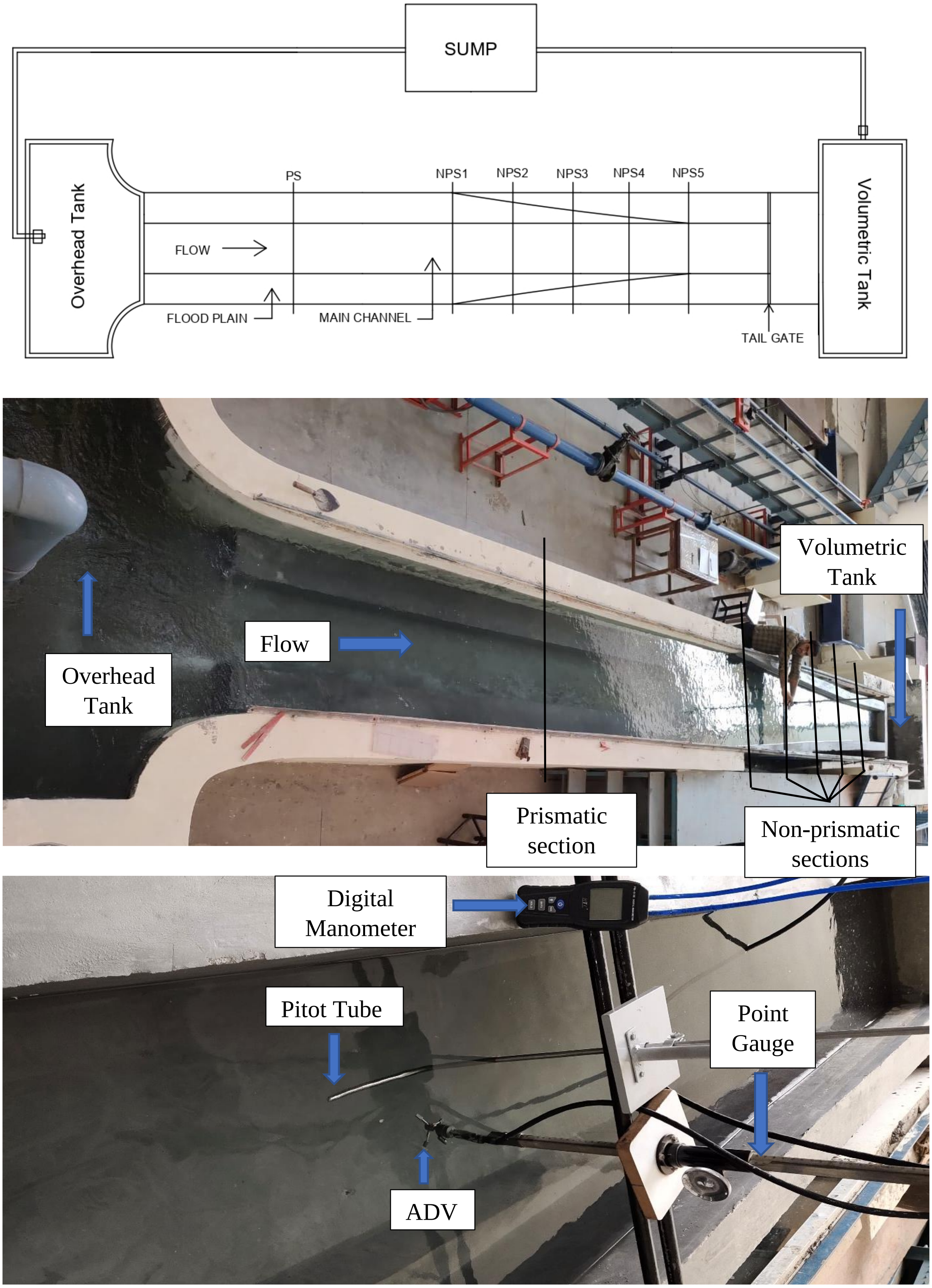

Figure 3.1.2. Experimental setup and equipment's used

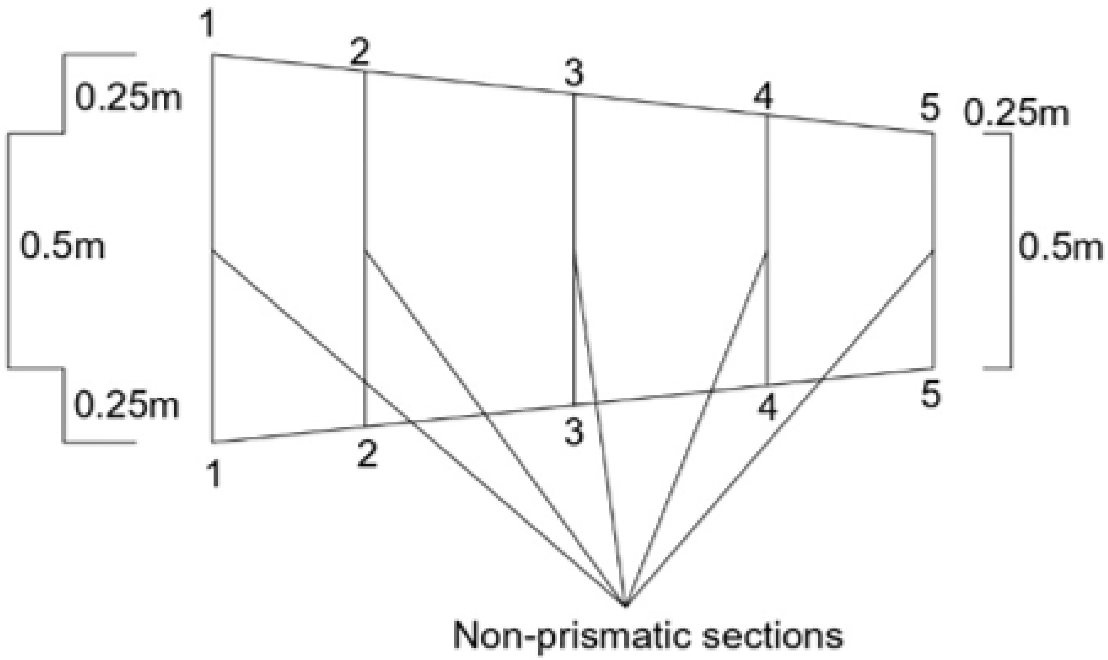

Figure 3.1.3. Converging sections of present channel

3.2 Computation of flow resistance

The lateral variation of channel section roughness is observed along the wetted perimeter in a river that is experiencing flooding. The determination of the conveyance capacity of a compound channel necessitates the consideration of the composite roughness. Despite the varied structures and forms of equations, they can be categorized into distinct groups based on different criteria. These groups include the Cox method (1973) (CM) (as represented by equation 3.2.1), the Einstein and Banks method (1950) (EBM) (as represented by equation 3.2.2), and the Lotter method (1933) (LM) (as represented by equation 3.2.3). The equation (3.2.4) was formulated by Das and Khatua (2018) through the utilization of multivariate analysis, with consideration of geometric and flow parameters, for a compound channel featuring converging floodplains. The composite roughness equations are

$$n = \frac{1}{A}\sum_{i=1}^{i=N} A_i n_i \tag{3.2.1}$$

$$n = \left(\frac{1}{P}\sum_{i=1}^{i=N} P_i\, {n_i}^{3/2}\right)^{2/3} \tag{3.2.2}$$

$$n = PR^{5/3}\left(\sum_{i=1}^{i=N} \frac{P_i\, {R_i}^{5/3}}{n_i}\right)^{-1} \tag{3.2.3}$$

$$n = 0.096\{1 - 0.0131e^{0.211(\alpha)} - 0.068e^{0.3(\beta)} - 0.082(\theta)^{0.046} - 0.235e^{0.101(x)} - 0.791(R)^{-0.214} + ln\, ln\, (\delta^{0.0114} S_0^{0.073} F^{-0.167})\} \quad (3.2.4)$$

Composite roughness for compound channel with converging floodplains is calculated by following expression:

$$n = \frac{AR^{2/3}\sqrt{S_e}}{Q} \quad (3.2.5)$$

Where n = manning's roughness coefficient, A = wetted area, R = hydraulic radius, S_e = energy slope and Q = rate of flow.

The determination of Manning's n values is subject to various factors, among which are the width ratio (α), relative depth ratio (β), aspect ratio (δ), converging angle (θ), relative distance (X_r), longitudinal slope (S_o), energy slope (S_e), discharge ratio (Q_r), Froude's number (F_r), and Reynold's number (R_e). Several parameters are utilized to facilitate the application of the model equation to various compound channels.

The requisite equation in a dimensionless form can be formulated as follows:

$$n = F(\alpha,\ \beta,\ \delta,\ \theta,\ X_r,\ S_o, S_e,\ Q_r,\ F_r,\ R_e) \quad (3.2.6)$$

3.3 Gene expression programming model

The computational technique known as Gene Expression Programming (GEP) is a potent tool utilized to evolve computer programs that possess the ability to solve intricate problems. The initial proposition of this concept was put forth by Dr. Cândida Ferreira in 1992, as part of her doctoral dissertation at the University of Coimbra, located in Portugal. The Genetic Programming (GEP) methodology is grounded in the fundamental principles of genetics and natural selection. Its modus operandi involves the iterative evolution of a population of computer programs via a process of mutation and selection. The Genetic Programming paradigm involves the representation of each program as a sequence of symbols, which can be subjected to a series of genetic operations for the purpose of combination and modification. Through a process of successive generations, programs that exhibit superior performance on a particular problem are chosen to procreate the subsequent generation of programs, resulting in an enhancement of their overall fitness. The capacity of GEP to manage numerous objectives concurrently renders it a valuable tool in the domain of optimization. GEP has been utilized in various domains, encompassing but not limited to data analysis, classification, and modeling. Empirical evidence suggests that Gene Expression Programming (GEP) exhibits superior performance compared to other evolutionary computation techniques, such as Genetic Programming and Evolutionary Strategies, in specific problem domains (Ferreira 2001). In addition, it has been observed that GEP has the capability to effectively manage intricate data structures, including trees and graphs, by employing genetic operators that have been adapted accordingly (Otero et al. 2016).

The present investigation employs a modeling approach wherein the target value is Manning's n, and the input variables consist of ten independent factors as discussed in equation (3.2.6). The model's structure was constructed utilizing the four fundamental arithmetic operators (+, −, ×, /) in conjunction with GeneXproTools 5.0 (2014). Overall, the modeling process utilized high-quality data sets that were randomly distributed across two distinct stages. In the context of the current study, various models were generated with varying proportions of training and testing records, program size, and number of generations, as presented in table 3.3.1. The present study employed the root-mean-squared error (RMSE) as the fitness function (E_i), while determining the fitness (f_i) through equation (3.3.1), which quantified the aggregate sum of errors in relation to the target value. The process of addition was utilized as the linking mechanism to connect the genetic components. The diagram depicts the GEP model 1 for flow resistance in the form of an expression tree (ET). In this particular depiction, the input variables are labelled as d0 through d9, while the constant value assigned to gene one is identified as G1c5. A mathematical equation (eq. 3.3.1) was formulated for model 1 to establish a connection between the input and output variables, which was utilized to decipher the expression tree.

According to the mathematical way, the GEP has been described as follows:

$$n = \left[Q_r - \frac{0.125\delta}{(\delta Q_r + \delta S_e)\times(\theta\delta - \alpha)} + F_r S_o - \alpha S_o + Q_r S_e S_o - \delta Q_r S_o - \alpha F_r S_e S_o + \alpha\delta F_r S_o + S_e - \frac{S_e^2}{(Q_r - 1)S_0} + 3.729\beta^2 + \frac{X_r \beta^2}{\alpha S_e R_e - 9.667 + \delta} - 5.671\right] \quad (3.3.1)$$

Table 3.3.1. Models generated using GEP

Model	Training data (in percent)	Testing data (in percent)	No. of chromo-somes	Head size	No. of genes	Gene size	Program size	Literals	No. of generations
M1	50	50	30	10	4	32	60	23	238614
M2	60	40	30	11	5	35	81	34	589516
M3	70	30	30	12	6	38	98	36	214745
M4	80	20	30	12	6	38	100	41	142698
M5	90	10	30	12	6	38	112	41	324793

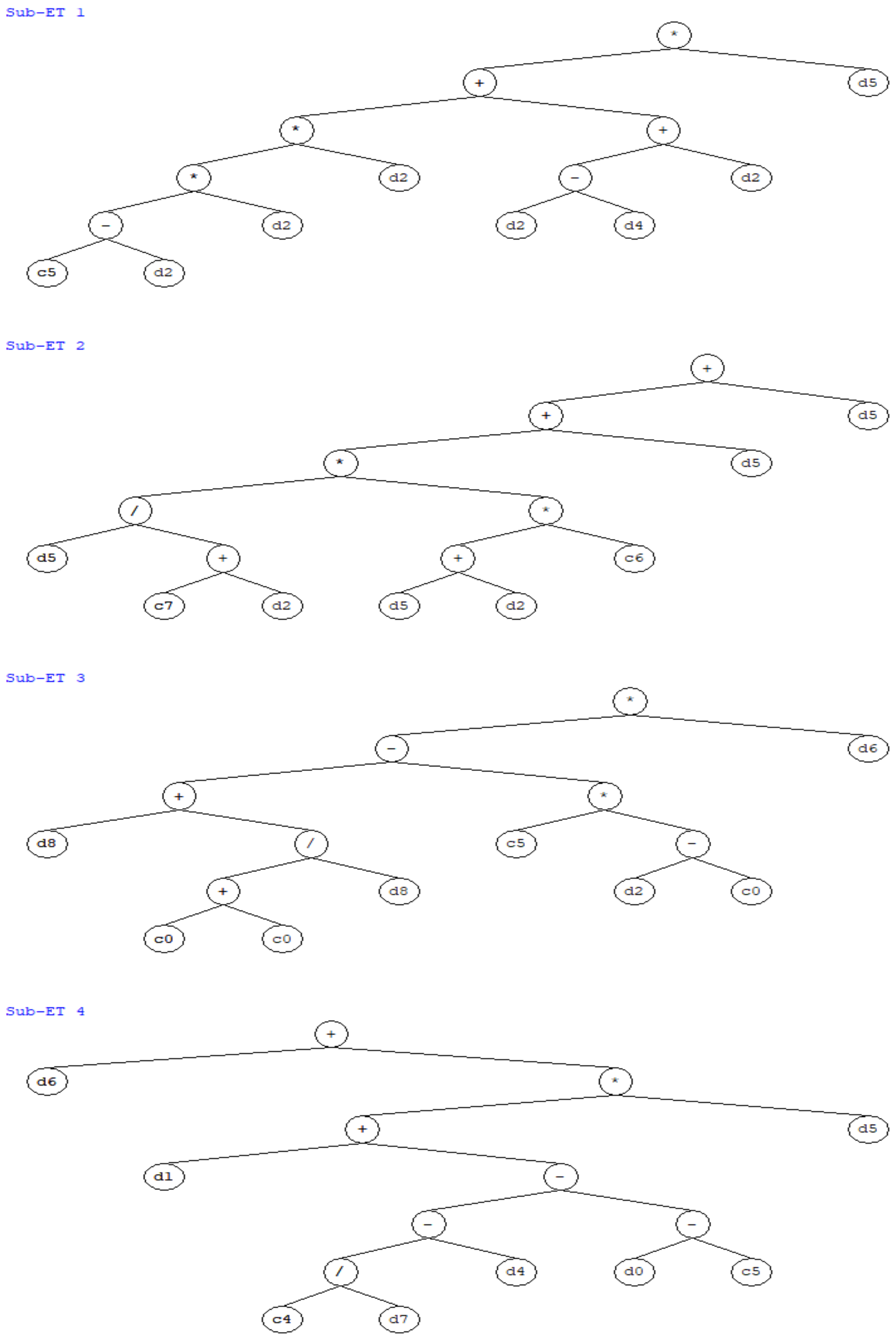

Figure 3.3.1. GEP formulated expression tree

3.4 Statistical measures

In order to conduct a comprehensive evaluation of the precision of the models generated through the GEP approach, diverse forms of error analysis are employed. These include the coefficient of determination (R^2), mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE), which are calculated using the following equations (Kaushik and Kumar 2023).

$$R^2 = \frac{\sum_{i=1}^{N}(a_i - \bar{a})^2 \, (p_i - \bar{p})^2}{\sum_{i=1}^{N}(a_i - \bar{a})^2 \; \sum_{i=1}^{N}(p_i - \bar{p})^2} \quad (3.4.1)$$

$$\text{MAE} = \frac{1}{N} \sum_{i=1}^{N} |p_i - a_i| \quad (3.4.2)$$

$$\text{MAPE}(\%) = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{|p_i - a_i|}{a_i} \times 100 \right) \quad (3.4.3)$$

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (p_i - a_i)^2} \quad (3.4.4)$$

where a and p are the actual and predicted values, respectively, $\bar{a}$ and $\bar{p}$ are the mean of actual and predicted values, respectively, and N is the number of datasets.

4.1 Flow resistance in compound channel with rough converging floodplains

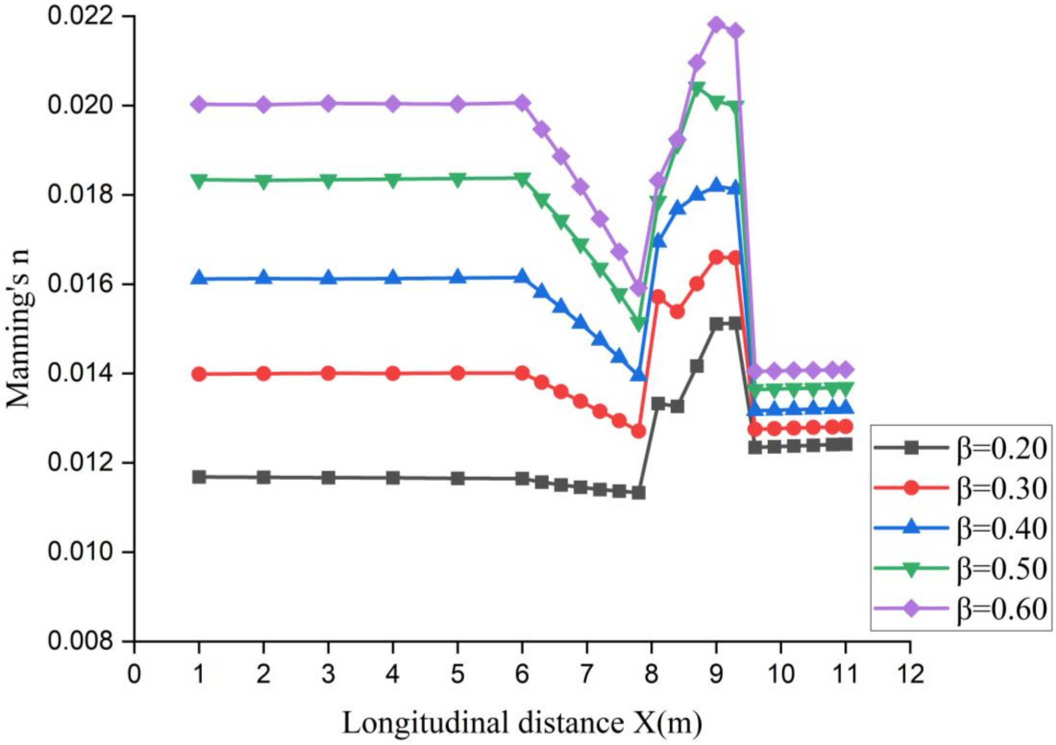

Figure 4.1.1. Variation of Manning's n with longitudinal distance

Figure 4.1.1 depicts the longitudinal distance-dependent variation of Manning's roughness coefficient (n) in a compound channel with rough converging floodplains. The decrease in hydraulic radius along the longitudinal distance results in a corresponding reduction in the n values within the prismatic section, extending up to the midpoint of the converging portion. Following the midpoint of the converging section, there is a notable increase in the numerical values of n due to the convergent nature of the channel's geometry. The observed outcomes are attributed to a significant rise in the energy gradient relative to the hydraulic radius. Subsequently, the downstream section experiences a decrease in n values due to the reduction in hydraulic radius and energy slope as the flow progresses further along its length. Similar fluctuation patterns are observed in higher relative flow depths as well as in lower relative flow depths. The study reveals that a significant increase in roughness occurs primarily in the converging regions as the relative depth escalates from 0.20 to 0.60. This phenomenon can be attributed to the transfer of momentum from the main channel to the floodplains.

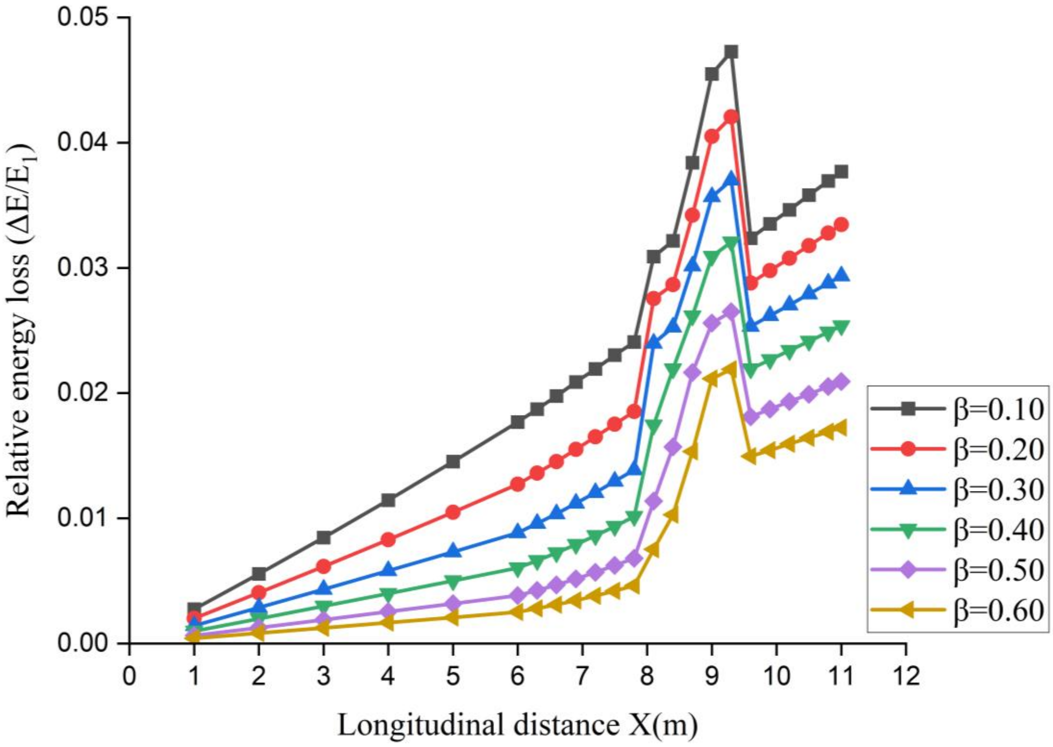

Figure 4.1.2. Variation of relative energy loss with longitudinal distance

Figure 4.1.2 illustrates the fluctuation of relative energy loss concerning longitudinal distance across various relative depths. The dissipation of energy is directly proportional to the longitudinal distance, owing to the loss of head resulting from the frictional resistance of the channel boundaries and bed.

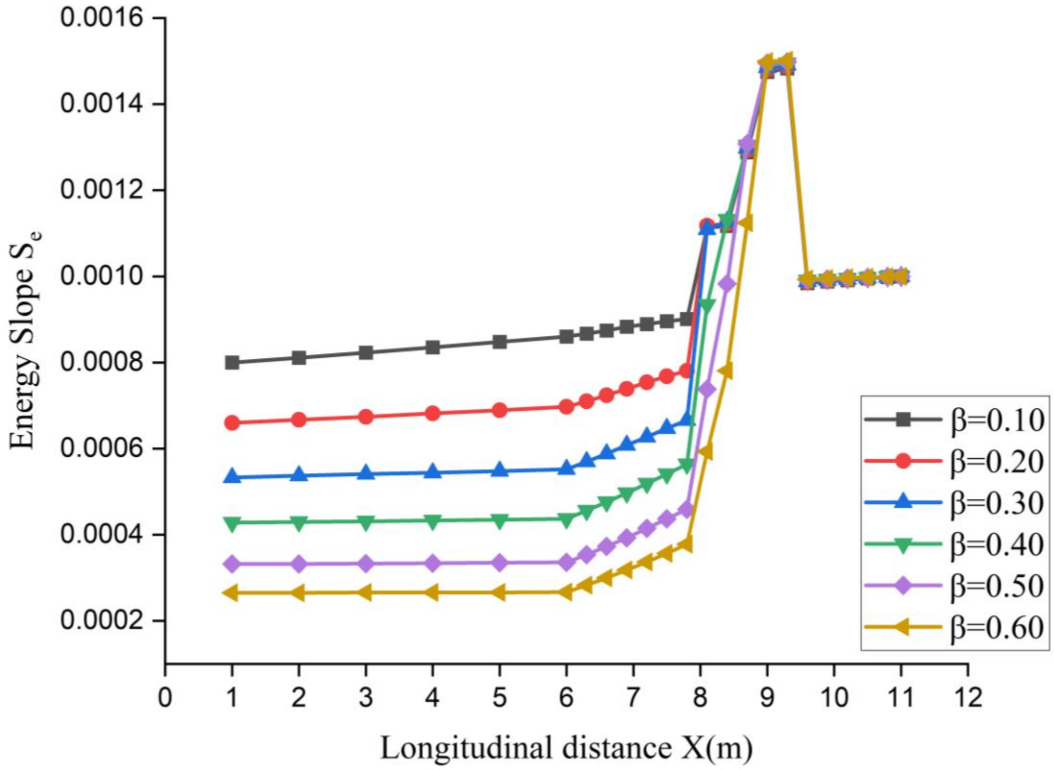

Figure 4.1.3. Variation of energy slope with longitudinal distance

Figure 4.1.3 demonstrates the fluctuation of energy gradient in relation to longitudinal distance across various relative depths. The increase in energy loss results in an increase in the energy slope as the longitudinal distance increases. A gradual increase is observed in the converging section up to its midpoint, followed by a sharp increase in the second half of the section.

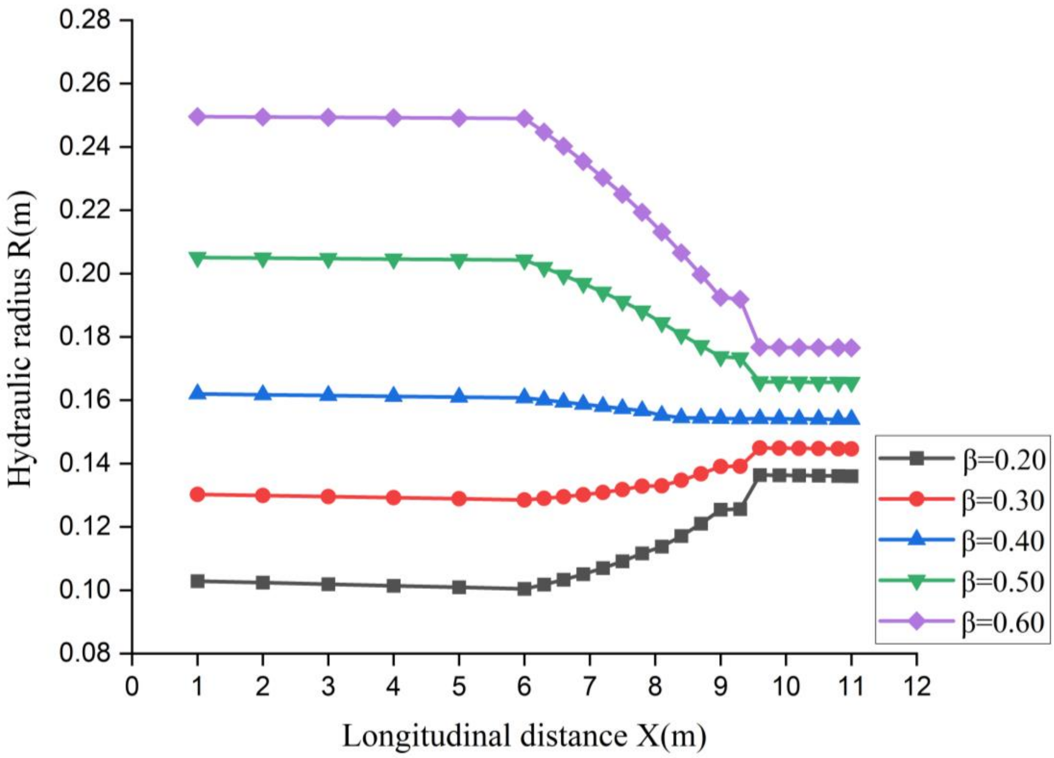

Figure 4.1.4. Variation of hydraulic radius with longitudinal distance

The hydraulic radius variation with longitudinal distance for various relative flow depths is depicted in Figure 4.1.4. It has been observed that the hydraulic radius remains relatively consistent within the prismatic section, while it exhibits an increase in the converging section for depths that are comparatively lower. Nevertheless, in cases of increased flow depths, the hydraulic radius experiences a reduction within the converging section as a result of the decline in flow area of the compound channel.

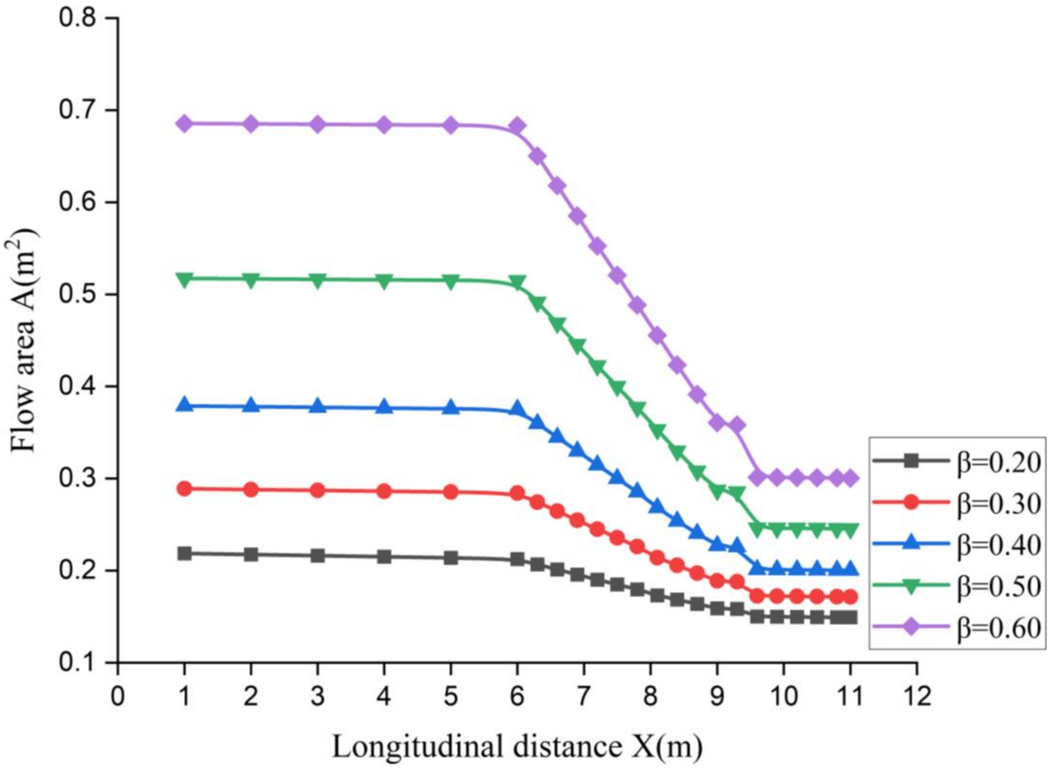

Figure 4.1.5. Variation of flow area with longitudinal distance

Figure 4.1.5 represents the relationship between the longitudinal distance and the flow area for various relative depths. The reduction in flow area over the longitudinal distance is attributed to the convergence of the channel geometry, resulting in flow acceleration primarily in the latter half of the transition. A gradual reduction was noted in the prismatic section, while a sharp decrease was observed in the converging section of the compound channel. Similar patterns of fluctuation have been noted in relation to increased flow depths.

4.2 Comparative study of flow resistance

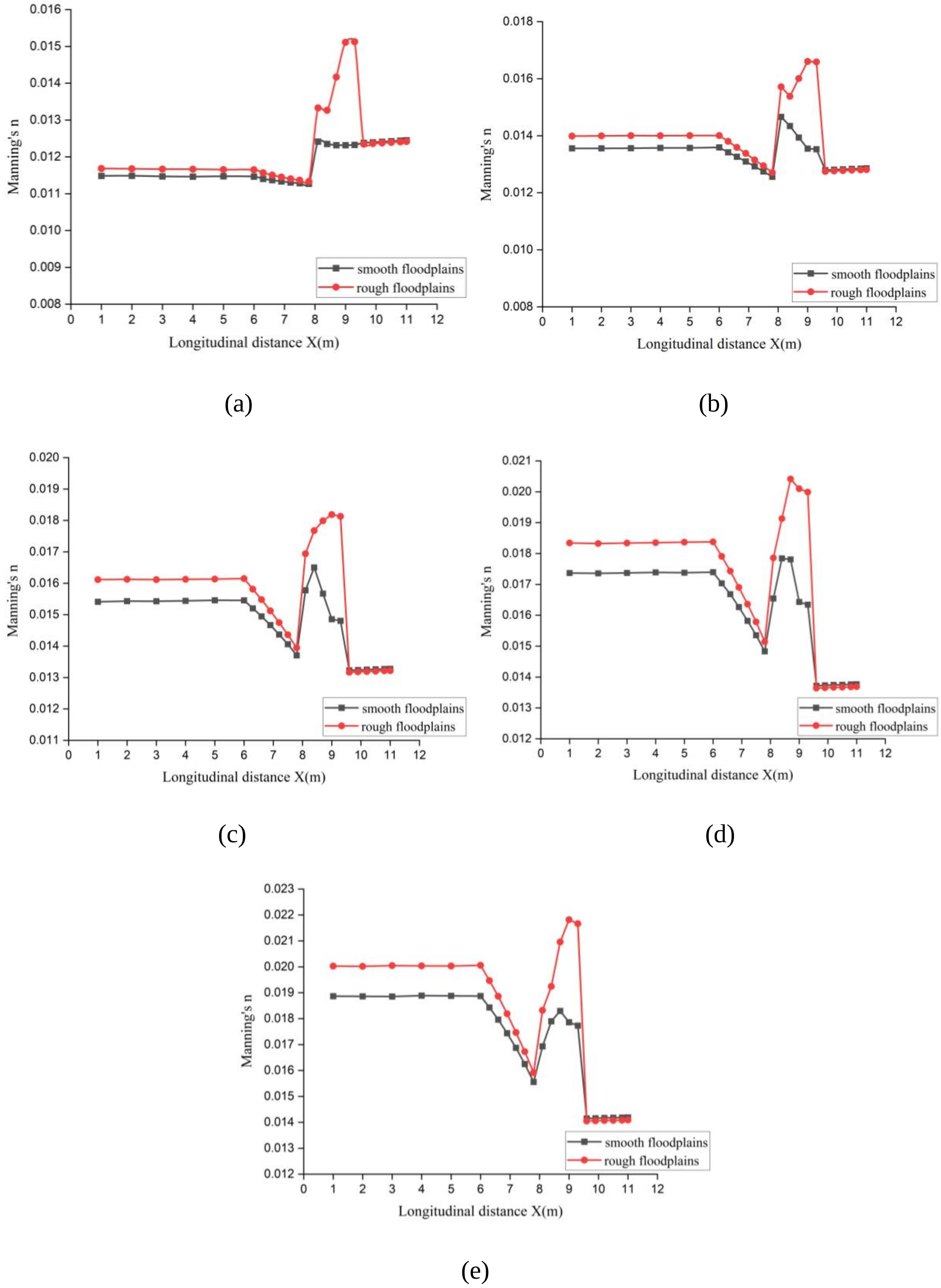

Figure 4.2.1. Comparison of observed manning’s n for different relative flow depths (a) β = 0.20 (b) β = 0.30 (c) β = 0.40 (d) β = 0.50 (e) β = 0.60

Figure 4.2.1 displays a comparative analysis of Manning's n concerning the longitudinal distance for smooth and rough converging floodplains. The analysis was conducted at varying relative flow depths, which ranged from $\beta = 0.20$ to 0.60. The variability pattern of roughness values in converging floodplains with rough surfaces is consistent with that observed in converging floodplains with smooth surfaces. At a relative depth of 0.20, the n values exhibit an increase of 1.8% in the prismatic section spanning up to 6m, and a corresponding increase of 22.73% in the converging section spanning up to 9.6m. At a relative depth of 0.30, the n values exhibit an increase of 3.25% in the prismatic section and 22.64% in the converging section. At a relative depth of 0.40, the n-values exhibit an increase of 4.57% in the prismatic section and 22.47% in the converging section. At a relative depth of 0.50, the n values exhibit an increase of 5.68 percent in the prismatic section and 22.30 percent in the converging section. At a relative depth of 0.60, the n values exhibit an increase of 6.33% in the prismatic section and 22.18% in the converging section. The study has noted that as the relative flow depth increases from 0.20 to 0.60, there is an increase in the rate of increment in the prismatic section and a decline in the converging section.

4.3 Computational analysis

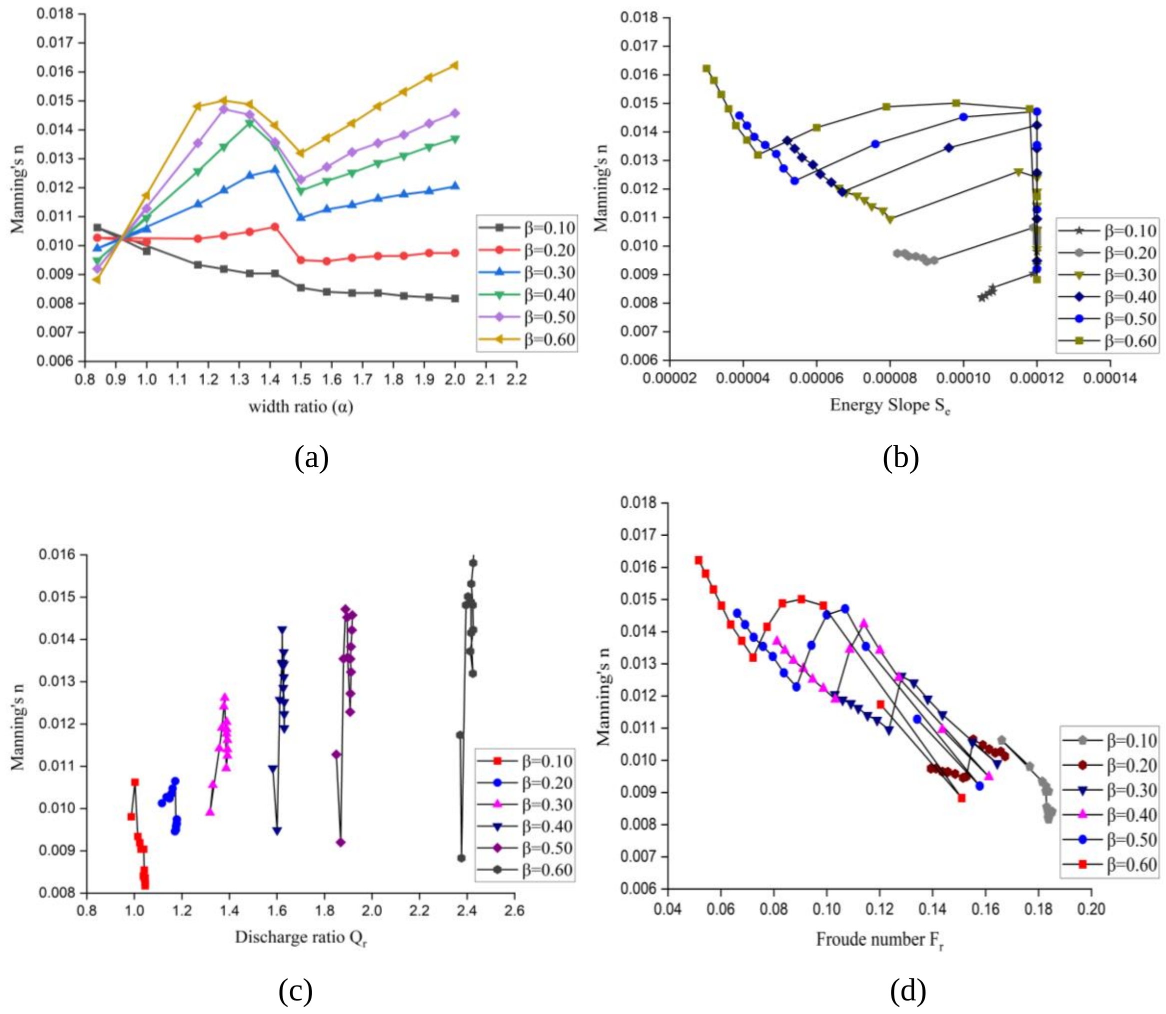

Figure 4.3.1. Variation of Manning's n with (a) width ratio (b) energy slope (c) discharge ratio (d) Froude number

Figure 4.3.1 depicts the variability of Manning's n in relation to nondimensional parameters, including width ratio, energy slope, discharge ratio, and Froude number. The nonlinear relationship between the values of n and the width ratio as well as the discharge ratio is observed, where an increase in both ratios results in a rise in the values of n. Once the n values have reached their minimum, a positive correlation with the energy slope will initiate an upward trend. There exists a correlation between the Froude number and a non-linear decrease in the n values.

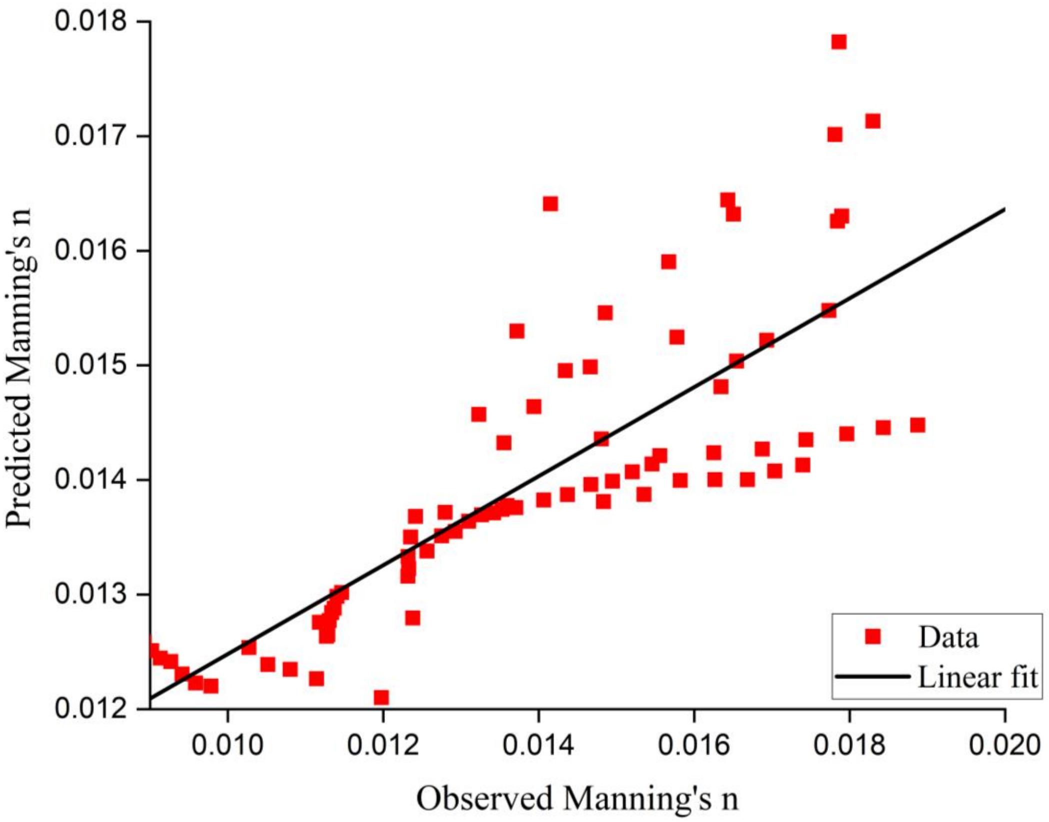

Figure 4.3.2. Scatter plot for predicted n using model 1

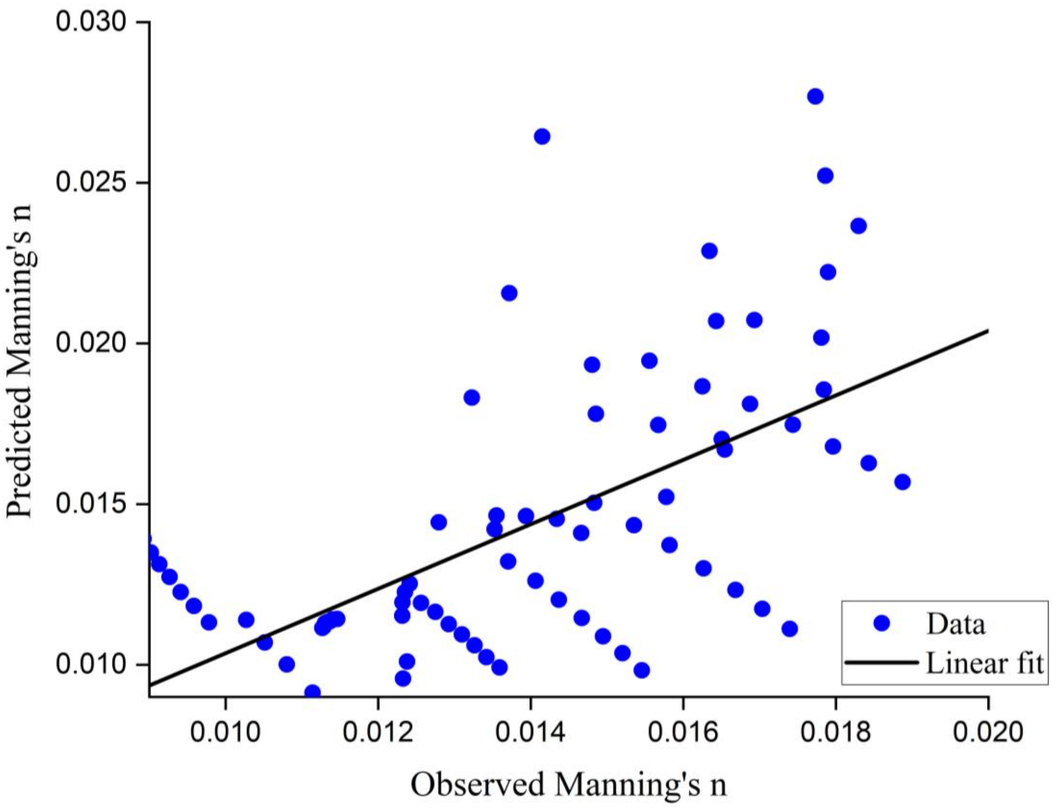

Figure 4.3.3. Scatter plot for predicted n using model 2

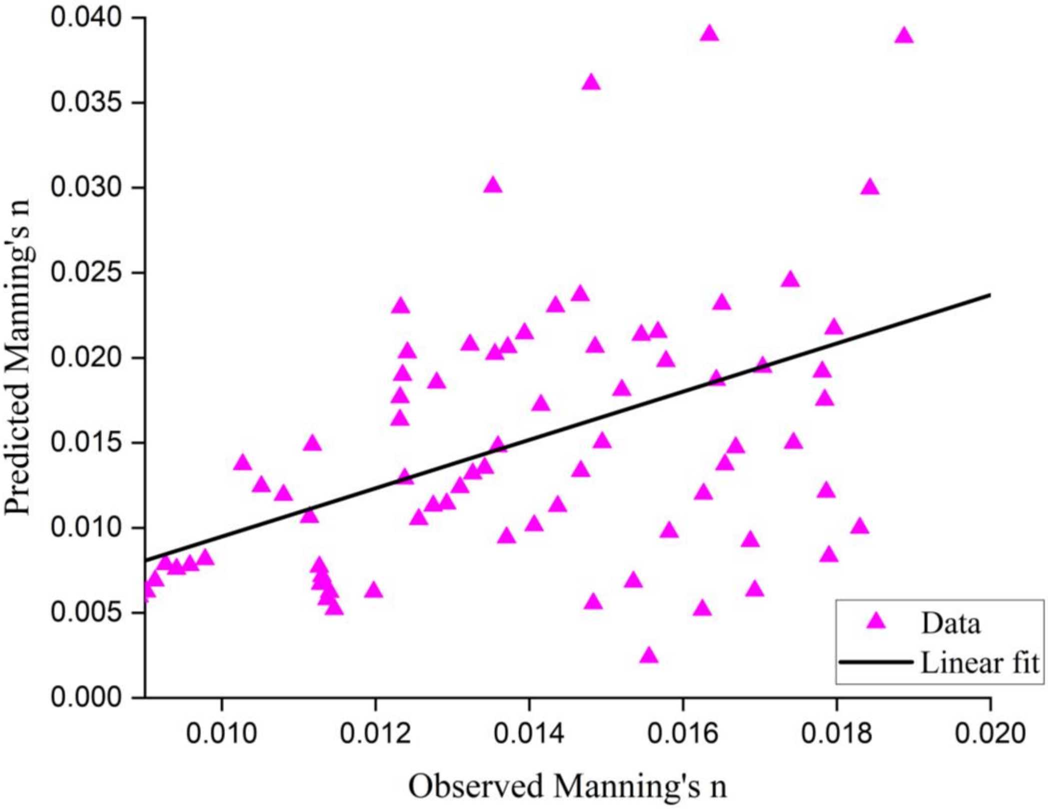

Figure 4.3.4. Scatter plot for predicted n using model 3

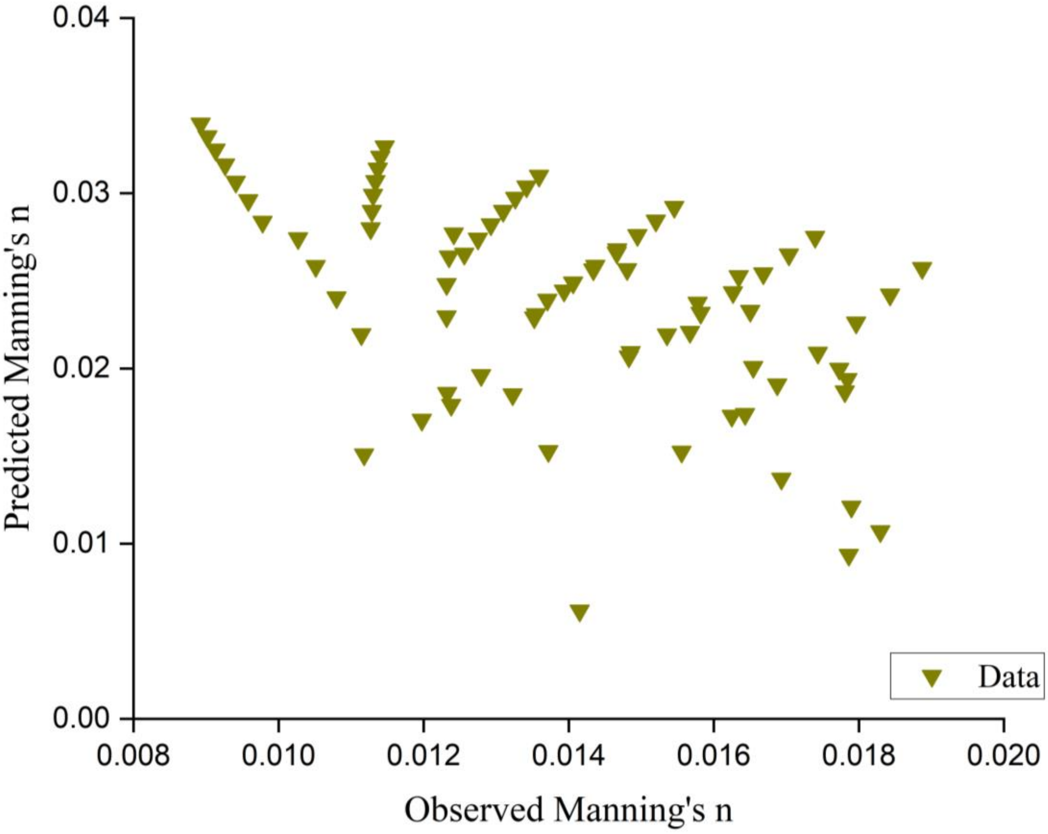

Figure 4.3.5. Scatter plot for predicted n using model 4

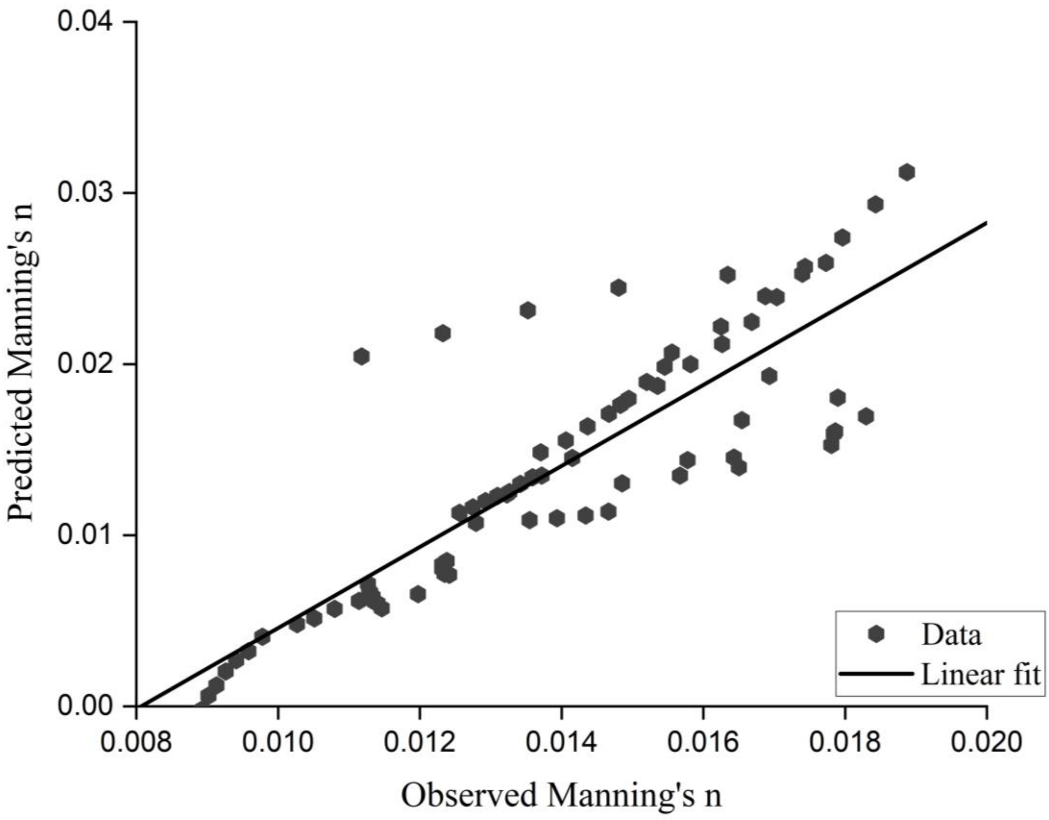

Figure 4.3.6. Scatter plot for predicted n using model 5

The efficacy of the GEP methodology in generating precise forecasts is evidenced by the scatter diagrams that employ diverse models to juxtapose the projected and actual n values, as depicted in Figures 4.3.2 through 4.3.6. The GEP model exhibits significant potential, as evidenced by the notable indication of the values' proximity to the line representing exceptional concurrence. The GEP predicted values that are dispersed over the best-fitting line exhibit a superior level of concurrence with the empirical data, resulting in elevated R^2 values. According to the data presented in Figure 4.3.2, the GEP model one that was created using a 60:40 ratio of data in training and testing yielded predicted values of Manning's n that were more closely aligned with the best fitted line than other developed models. This suggests that the GEP model one is more accurate in its predictions.

Table 4.3.1. Statistical analysis of predicted n by various approaches

Statistical parameters	GEP model 1	GEP model 2	GEP model 3	GEP model 4	GEP model 5	Das and Khatua method	Lotter method	Cox method	Einstein and Banks method
R^2	0.998	0.955	0.988	0.962	0.994	0.70	0.985	0.971	0.964
MSE	2.6×10^{-6}	7.7×10^{-5}	1.86×10^{-5}	7.37×10^{-5}	9.8×10^{-6}	0.0019	0.0025	0.0049	0.0081
RMSE	0.0016	0.0088	0.0043	0.0086	0.0031	0.043	0.05	0.07	0.09
MAE	0.0012	0.0066	0.0029	0.0063	0.0021	0.002	0.043	0.065	0.088

In order to assess the effectiveness of the GEP models, statistical metrics including R^2, MSE, RMSE, and MAE were employed, and their corresponding numerical values are displayed in Table 4.3.1. The GEP model one has demonstrated superior predictive performance (R^2 = 0.998, RMSE = 0.0016 and MAE = 0.0012) in estimating the Manning's roughness coefficient of composite waterways with converging floodplains, when compared to alternative approaches such as Das and Khatua (2018), as well as established theoretical methods including the Lotter method, Cox method, and Einstein and Banks method for composite roughness computation. The GEP model exhibiting the minimum mean absolute error (MAE) is deemed as the most appropriate approach for forecasting flow resistance in compound channels featuring converging floodplains, in comparison to alternative techniques.

The research was carried out on a compound channel featuring converging floodplains that were both rough and smooth, set at an angle of $\theta = 4°$. The objective was to calculate flow resistance using Manning's roughness coefficient (n). The utilization of Gene Expression Programming (GEP) represents a novel method for the prediction of the Manning's roughness coefficient (n) through the consideration of multiple nondimensional flow and geometric variables. The GEP model has been constructed utilizing superior experimental datasets from past and current studies that encompass a range of geometrical and flow variables. The study findings permit the formulation of the subsequent conclusions and inferences:

- The Manning roughness coefficient experiences a decrease in the prismatic segment, while in the nonprismatic segment, it decreases until reaching the midpoint. Subsequently, there is a notable surge observed in the roughness metric. Similar fluctuations have been noted for greater relative depths.
- The observed variation of Manning's roughness coefficient is significantly influenced by the energy slope. The energy slope experiences a significant increase in the converging section owing to the convergence of the channel geometry. As a result, the roughness coefficient also undergoes a sharp increase in the converging section, regardless of the flow area and hydraulic radius.
- The analysis of roughness coefficient in compound channel with rough and smooth floodplains indicates that the values of roughness coefficient are elevated for compound channel with rough floodplains.
- The observed n values exhibit an increase in the converging section in comparison to the prismatic section, and this increase is positively correlated with the relative flow depth values. The study reveals that the increase in the prismatic section ranges from 0 to 7 percent, while in the compound channel with converging floodplains, the increment varies from 5 to 23 percent with the rise in flow depth.
- The research findings suggest that the various characteristics, including but not limited to the width ratio, relative depth of flow, aspect ratio, angle of convergence, relative longitudinal distance, longitudinal bed slope, energy slope, discharge ratio, Froude number, and Reynolds number, have an impact on the proposed models of manning's roughness coefficient.

- In a compound channel featuring converging floodplains, the Manning's roughness coefficient exhibits a non-linear increase with respect to the width ratio, energy slope, and discharge ratio, while it experiences a decrease in relation to the Froude number. The observation has been made that the variation of Manning's n in nonprismatic compound channels remains consistent irrespective of the angle of convergence.
- The objective of this study is to investigate the relationship between the nondimensional Manning's n coefficient and the nondimensional geometric and flow variables of a composite waterway that features narrowing floodplains. A non-linear relationship has been identified among the parameters.
- The recently developed models utilizing Gene Expression Programming (GEP) exhibit enhanced performance in various statistical parameters for diverse datasets when compared to previous methods for estimating composite roughness in compound channels.
- Consistent with the prescribed evaluation criteria, the GEP methodology has demonstrated the ability to accurately predict the manning's roughness coefficient in compound channels featuring converging floodplains. The GEP model one exhibited superior performance in comparison to other GEP models and prior methodologies, as evidenced by its highest R^2 and lowest MSE, RMSE, and MAE values.
- A new equation for Manning's roughness coefficient in a compound channel with narrowing floodplains has been introduced. This equation is formulated based on several geometric and flow variables, utilizing an expression tree technique that employs the Gene Expression Programming (GEP) method. Furthermore, the equation has been decoded into an analytical form.

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LIST OF PUBLICATIONS

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