CAPABILITY OF INTELLIGENT TECHNIQUES FOR FRICTION FACTOR SIMULATION IN WATER CHANNELS

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Abstract- This study proposes Meta model approaches as a new intelligent technique for the explicit formulation of friction factors of water conveyance structures. For this purpose, experimental Data of movable bed Flume with dune bed form was used. Analyzing the result clears the high capability of Meta model approaches (MNE= 0.05, R= 0.92) as a powerful tool for optimizing and explicit simulation of Manning roughness coefficients of water conveyance structures compared other nonlinear approaches.

Keywords- Intelligent Techniques, Explicit Simulation, Roughness Coefficient, Experiments

I. INTRODUCTION

Estimation of flow resistance in a water conveyance structure with reasonable accuracy is of great interest to hydraulic engineers. However, the problem remains unsolved despite numerous investigations over the past decades. The difficulty arises because the bedform affect the flow resistance. In addition, the bed in an alluvial channel is not fixed but continually undergoes changes in is characteristic geometry and dimensions as a result of the interaction between the flow and bed. This interaction is responsible for the occurrence of a variety of bed forms- starting with ripples at low shear stress with progressive developments of dunes, washed out dunes (transition), flat bed, anti dunes, and standing waves with increasing shear stresses or velocities. The form resistance due to these bed forms, caused by local flow separation and recirculation, can be significant and is dependent on their dimensions as well as on flow and sediment characteristics. Early important works on dune geometry were done by Yalin, Fredsoe [reported in Raudkivi A.J., Ranja Raju and Allen who developed relations for dune height as a function of bed shear stress and other variables according to experimental and field data. Van Rijn expressed form resistance as equivalent sand diameter and derived an exponential relation for it based on dune height and flow depth. This study employs genetic programming (GP) which has been applied to a wide range of problems in different processes.

II. NONLINEAR APPROACHES TO WATER CONVEYANCE STRUCTURES RESISTANCE

In the nonlinear approach the resistance coefficient is not divided into grain roughness and bed form roughness as in the linear superposition approaches. Instead, it is kept as a single factor. Most of the existing nonlinear approaches were derived from dimensional analysis and statistical fitting of data to the parameters considered in the functional relationships. Some representative investigations are listed in Table 1. They can be identified into four groups: (a) those considering the resistance coefficient as a dependent variable in their analysis; (b) methods based on shear stresses; (c) those giving an equation of the mean velocity whose coefficients are related to resistance; and (d) the energy approach derive from Bagnold's stream power concept for expressions of velocity that could be used to calculate the resistance.

Most of them implicitly assume the flow to be steady, reach wise uniform with equilibrium sediment transport. Unlike the linear separation methods, the use of many of the nonlinear approaches does not require knowledge of the bed configuration. Only group (a) considers the resistance coefficients explicitly. The other three groups consider the resistance indirectly and implicitly. A brief description of the methods listed in Table 1 is given in the following.

The hydraulic resistance in a straight channel with flowing sediment is a function of the flow characteristics, the geometry of the channel cross-section and the properties of the fluid and sediment. For steady flow the Darcy- Weisbach coefficient λ can be expressed as:

$$\lambda = f(\rho, \mu, \rho_s, d_{50}, g, S, u, R_h, \varsigma) \quad (1)$$

Where ρ and μ are density and dynamic viscosity of the fluid; ρs and d50 are density and mean size of the sediment particles respectively; g is the gravitational acceleration; S is the slope; u and R_h are mean velocity and hydraulic depth of the flow and ζ represents a non- dimensional cross- sectional shape factor. In the present analysis, it is assumed that channel cross- sectional non- uniformities such as contraction and expansion do not exist. Otherwise factors describing the non- uniformities should be included in the analysis. Through dimensional analysis of Eq. (1) can be written non- dimensionally as:

$$\lambda = f_1(Fr, \mathrm{Re}, \frac{d_{50}}{R_h}, \frac{\rho_s}{\rho}, g, S, \varsigma) \quad (2)$$

Where the Froude number, Fr, represents the effect of the gravity on the flow; Re, the Reynolds number represent the effect of viscosity of the fluid. The dimensionless parameter d_{50}/R_h indicates the interference of the sediment particles to the flow in the channel.

III. GENETIC PROGRAMING (GP)

GP, a branch of the genetic algorithm (GA), is a method for learning the most "fit" computer programs by means of artificial evolution and GEP is an extension to GP that evolves computer programs of different sizes and shapes encoded in linear chromosomes of fixed length. The chromosomes are composed of multiple genes, each gene encoding a smaller sub-program. The structural and functional organization of the linear chromosomes allows the unconstrained operation of important genetic operators such as mutation, transposition, and recombination. One strength of the GEP approach is that the creation of genetic diversity is extremely simplified as genetic operators work at the chromosome level. Another strength of GEP consists of its unique, multigenic nature, which allows the evolution of more complex programs composed of several subprograms. As a result, GEP surpasses the old GP system in 100-10000 times.

The two main parameters of GEP are the chromosomes and ETs. The process of Information decoding (from the chromosomes to the ETs) is called translation, which is based on a set of rules. The genetic code is very simple where there are one-by-one relationships between the symbols of the chromosome and the functions or terminals they represent. The rules also very simply determine the spatial organization of the functions and terminals in the ETs and the type of interaction between sub-ETs.GEP technique starts the solution of a specific Problem with the Random generation of the chromosomes of the initial population.

Then the chromosomes are expressed and the fitness of each individual is evaluated. The individuals are then selected according to fitness to reproduce with modification, leaving progeny with new traits. The individuals of this new generation are, in their turn, subjected to the same developmental process: expression of the genomes, confrontation of the selection environment and reproduction with modification. The process is repeated for a certain number of generations or until a solution has been found.

This study adopted a multi- criterion approach (RMSE, MNE, and R) in evaluating the overall performances of the adopted models, as each of the performance indicators provide different information about the predictive ability of the model. The performance indicators RMSE, MNE and R are calculated using equations (3), (4), and (5), respectively:

$$RMSE = \sqrt{\frac{1}{N}.\sum (n_i - n_i')^2} \quad (3)$$

$$MNE = \frac{1}{N}.\sum \left| \frac{n_i - n_i'}{n_i} \right| \quad (4)$$

$$R = \frac{\sum_{i=1}^{n} (n_i - \bar{n}_i)(n_i' - \bar{n}_i')}{\sqrt{\sum_{i=1}^{n} (n_i - \bar{n}_i)^2 . \sum_{i=1}^{n} (n_i - \bar{n}_i')^2}} \quad (5)$$

Where, n_i and n_i represents the measured and computed Manning coefficients values, $\bar{n}_i$ and $\bar{n}_i$ represents the mean of the measured and computed Manning coefficients values, respectively, and N represents the number of data instances.

IV. APPLICATION AND RESULTS

In this research, four function set (F_1, F_2, F_3, F_4) contains different combinations of mathematical operators are defined. The objective functions are divided to dimensional Manning Roughness coefficient (n) or GP and dimensionless Manning Roughness coefficient $n = \frac{n\sqrt{g}}{(R)^{\frac{1}{6}}}$ or $G'P$.

Different Input sets (terminals) are shown in Table 1 in which SW is water surface slope. Fr is Froude number of flow, Re is Reynolds number, R is hydraulic radius, D_{50} is mean diameter of bed material □ is water density, $□_s$ is sediment density and $\Delta□_s$ = □ - $□_s$. In the proposed model 75% of experimental Data were used for training and %25 of them used for test of the model. Run of each model (consist of two objective function, fifteen terminal set and four function set or totally 120 models) is done more than one hundred times for both of training and testing of Data.

Among 120 models, the best result is obtained from GP_8- F_4 model performance. In the proposed model, there is no need to know the bed form height in using of this equation.

According to the best proposed model, GP can select more effective and optimized input parameters $\left(S_w, \mathrm{Re}, \frac{R}{D_{50}}\right)$ and eliminate unnecessary parameters in the simulation of friction factor. To evaluate the accuracy and capability of the applied models in prediction of alluvial channel flow resistance, a

comparison between the proposed new GP model and famous kisi method was undertaken according to Figure 1.

The GP model is explicit and simple that can be used by any one not necessarily being familiar with GP. In this study, the results and final formulas are complex. The main reason of this complexity is related to non linear relation between hydraulic parameters and Manning coefficient that some of these relations are simplified in literature formulas and introduced permanent error for these simple formulas.

TABLE 1: DIFFERENT GP INPUT SETS (OR TERMINALS) AND RESULTS OF GP- F4 PERFORMANCE

	Ranking of Model Performance- F4 Function set	Criteria		
Objective function (Dimensional Manning coefficient)	Terminals or independent variables	MNE	R	RMSE
GP_1	S_w	10	8	10
GP_2	Fr	14	12	14
GP_3	Re	13	14	13
GP_4	S_w, Fr	7	4	7
GP_5	S_w, Re	5	6	7
GP_6	S_w, Fr, Re	6	5	8
GP_7	S_w, Fr, Re, $\frac{R}{D_{50}}$, $\frac{\Delta\int_{s}}{\int}$	2	3	3
GP_8	S_w, Re, $\frac{R}{D_{50}}$, $\frac{\Delta\int_{s}}{\int}$	1	1	1
GP_9	S_w, Fr, $\frac{R}{D_{50}}$, $\frac{\Delta\int_{s}}{\int}$	3	2	2
GP_{10}	Fr, Re, $\frac{\Delta\int_{s}}{\int}$	9	9	8
GP_{11}	Fr, Re, $\frac{\Delta\int_{s}}{\int}$, $\frac{R}{D_{50}}$	8	7	9
GP_{12}	Fr, $\frac{VR}{\sqrt{gD_{50}^3}}$, $\frac{\Delta\int_{s}}{\int}$	12	11	11
GP_{13}	Re, $\frac{VR}{\sqrt{gD_{50}^3}}$, $\frac{\Delta\int_{s}}{\int}$	11	13	12
GP_{14}	S_w, $\frac{VR}{\sqrt{gD_{50}^3}}$, $\frac{\Delta\int_{s}}{\int}$	4	6	4
GP_{15}	S_w, Fr, $\frac{VR}{\sqrt{gD_{50}^3}}$, $\frac{\Delta\int_{s}}{\int}$	5	5	5

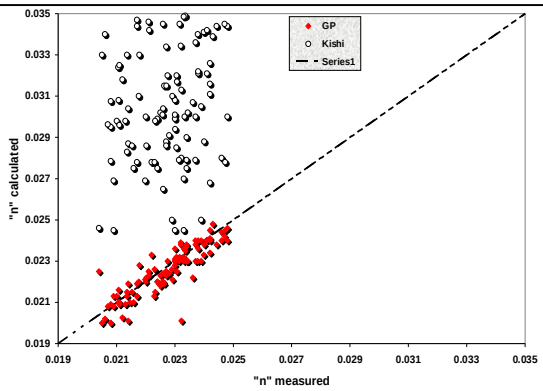
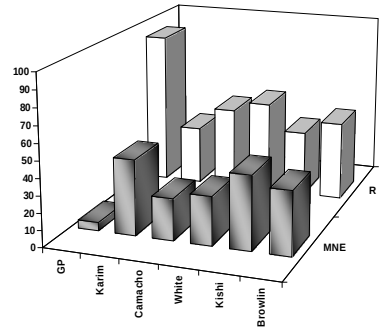


Fig. 1. Comparison between the proposed new GP model and kisi method



	GP	Karim	Camacho	White	Kishi	Browlin
MNE	5	45	25	29	44	38
R	92	35	49	55	39	47

Fig. 2. Comparison between R and MNE of GP and selected nonlinear methods of flow resistance

CONCLUSION

This study reports a new and efficient approach for the formulation of friction factor of alluvial channels using GP for the first time in the literature. The original experiment data (156 tests) is used for training and testing of GP and best formula (for this study) is reported using 3 input parameters of S_w, Re, $\frac{R}{D_{50}}$. Also a comparison between produced GP results and existing equations in the literature confirms the capability and workability of GP as an artificial intelligent model in predicting of movable bed friction factor .The results confirm that the selection of input variables has a large impact on the model accuracy and the complexity of GP formula is necessary for the problem of flow resistance.

The outcomes of this study are very promising and encourage the use of GP in open channel flow resistance, bed form resistance, and complex water engineering problems.

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