IJE TRANSACTIONS B: Applications Vol. 26, No. 2, (February 2013) 187-196

International Journal of Engineering

Journal Homepage: www.ije.ir

Estimation of Friction Coefficient in Sediment Contained Flow through Rockfill

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PAPER INFO

Paper history:
Received 13 August 2012
Received in revised form 19 October 2012
Accepted 15 November 2012

Keywords:
Non-Darcy Flow
Sediment Contained Flowthrough
Friction Coefficient

ABSTRACT

An increase in the flow velocity in flow through large porous media and deflection of flow regime from Darcy law causes a nonlinear relationship between hydraulic gradient and pore velocity of media. One of the most important subjects in flow through large porous media is relationship between friction coefficient and flow characteristics which was previously focused by some investigators but it is needed to extract general and more accurate relationships for all of their data series. Also, in most of previous studies the friction coefficient was presented in Darcy-Weisbach form which is not so common in the open channel flow between hydraulic engineers like Manning coefficient. In this study, the required data were collected from four different sources. Three series of them were operated in the sediment contained flowthrough mode and another one was operated in sediment free flowthrough mode. Using some basic equations about pore velocity and frictional coefficient, the new relationships were developed and calibrated for estimation of manning coefficient in open channel fow through porous media. It was found that modified Wilkins equation had a better estimation for manning coefficient in both sediment free and sediment contained flow rather than Ergun and Sedghi's one. Also, it was found that general trend of Moody diagram for pipe flow is established in flow through large porous media such that by increase in the media Reynolds number, the Manning coefficient limits to a constant value and become dependent to the media characteristics.

doi: *10.5829/idosi.ije.2013.26.02b.09*

1. INTRODUCTION

In the cases such as flow filtration through sand column, the flow is one dimensional and can be estimated from Darcy equation. This equation has some limitations such as linear relation between hydraulic gradient and flow velocity. If the flow condition deflects from mentioned status, the flow regime changes to the new condition which is called non-Darcy flow regime which contains higher turbulence and momentum exchange. With an old agreement between hydraulic engineers, the flow in large porous media is simulated with pipe flow relationships. Therefore, the concepts and non-dimensional parameters like friction coefficient and Reynolds number which is used in pipe flow analysis are also used in flow through large prose media [1]. Since the presented length characteristic which is used in the calculations of Reynolds number is different in different researches, the criterion for recognizing of Darcy and non-Darcy flow is different [2].

According to the basis of fluid mechanics, Moody diagram is used for recognizing of turbulent, transition and laminar flow [3]. Against flow in the pipes, the transient flow regime in the large porous media has an extensive range and is not limited to the Reynolds number between 2000-4000. For aforementioned reason in these media, Darcy and non-Darcy expressions are used for classifications of flow. In fact Darcy flow is limited to the laminar flow regime and non-Darcy is used for transient and turbulent flow regimes. But, no clear definition for beginning of turbulent flow in large prose media was presented by previous investigators [4].

Turbulent flow is a stochastic system in which various variables have random variations but mean magnitudes are known and can be defined. Rotational flow in different directions with various velocities is the main characteristic of turbulent flow through porous media. During the time when the water particle velocity

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is not constant the mean velocity is taken into account [3]. Actually, when inertia forces exceed viscous forces, turbulent flow occurs and big rotational flows with capability of transforming to small rotational flows are formed [5].

In turbulent open channel flow, the intensive momentum exchange between flow layers is observed. But any especial instrument for measurement of velocity fluctuations through large porous media still does not exist.

Usually, for experimental investigation on 1D flow through porous media permeameters, and for 2D flow, opens channels is used. To avoid the wall effect in laboratory experiment, the ratio between media (channel or permeameter) diameter to average material diameter should be about 10 [6].

Analytical turbulent flow equations are derived from the fundamentals of hydrodynamics, but due to the stochastic nature of turbulent flow, these equations are complicated and are in the form of partial differential equations [5].

Rockfill structures such as detention permeable dams and rockfill drainage filters are most applicable structures which have such porous media. Recently, more rockfill dams have been used to control and mitigate floods in Iran. This kind of dam is constructed of rock particles without any core inside and shell on the upstream face. This kind of detention dams acts in such a way that peak point of the outflow hydrograph will be smaller than that of the inflow hydrograph. The amount of reduction of peak point depends on the rock particle size, and geometry of dam, storage and shape of reservoir [5].

During floods, the flow through rockfill dams are mostly sediment contained. If sediments pass through it, the dam will be safe, function well and downstream scour will be low. But gradually, sediment particles may settle in pore spaces of dam and partial clogging occurs. In this case, the flood may overflow the dam, erode the downstream bed and bank and may cause some damage [7].

Sedimentation at upstream of the detention dam and scouring of the river bed and bank at downstream are two of the most important parameters which could affect the dam function and stability. High sediment concentration in the river, especially during floods, results in sedimentation at the upstream of the dam which will reduce dam storage capacity and could be one of the restricting parameters in the detention dam function [5].

Therefore, it is necessary to investigate the various aspects of the sediment laden flow through the rockfill structures to achieve a safe hydraulic design. Some semi empirical approaches have been developed previously to provide answers of these problems but results have indicated some limitations to their applications. Therefore, a generalization is not done for any field condition.

Therefore, the generalization and formulation of basic equations of the friction coefficient in the form of Manning friction coefficient for sediment contained flow is considered in this research.

To achieve this subject, the data were collected from four different sources. Three series of them were operated in sediment contained flowthrough mode but another one was in clear water condition.

2. THEORETICAL BACKGROUND

In this section, the most important relations in flow friction criteria which have been investigated in previous studies are presented. Manning coefficient is an empirical relation. In this equation, the exponent of energy slope and hydraulic radius are constants; therefore, there are some uncertainty about these constants. The flow hydraulic is upon energy grade line and geometrical characteristics of the open channel. The basic criteria of flow through rockfill media are similar to open channels and there should be a significant relationship between Manning coefficient and friction of the flow through porous media. Since, the coefficient is well known for most of hydraulic engineers in their practical projects. The necessity for presentation of favorable equations for this subject is being felt. Also, if Manning equation is used and calibrated for these type of media, the analysis would be easy and comprehensive [8]. Manning equation generally is written as follows (Equation (1)) [4]:

$$V = \frac{1}{n_m} m^{2/3} s^{1/2} \tag{1}$$

where, m =hydraulic radius of porous media $s =$ energy grade slope and $n_m =$ Manning friction coefficient.

The Darcy-Weisbach equation for pipe flow is defined as below (Equation (2)):

$$h_f = f \frac{l}{D} \frac{V^2}{2g} \tag{2}$$

where, $f =$ friction coefficient, $l =$ pipe length, $D =$ pipe diameter and $V =$ average pipe velocity.

The above equation could be rewritten as below (Equation (3)):

$$\frac{h_f}{l} = \frac{fV^2}{2gD} \tag{3}$$

By assuming $i = \frac{h_f}{l} = s$, some other assumption [4] and equating (1) and (3) with some algebra and also substituting of m with $\frac{ed}{6}$ [9], the relationship between f and n_m could be obtained as below (Equations (4, 5)):

$$\xrightarrow{s=i=\frac{h_f}{l}} \frac{fV^2}{2gd} = \frac{V^2 n_m}{m^{4/3}} \tag{4}$$

$$f = 2gd\left(\frac{n_m}{m^{2/3}}\right)^2 \xrightarrow{m=\frac{ed}{6}} n_m = \frac{\sqrt{f}\, e^{2/3}}{14.6} d^{1/6} \tag{5}$$

Most of previously presented frictional relationships are between R_e (Reynolds Number) and f (coefficient of friction in Darcy-Weisbach equation) which is considered by assuming flow in pores of porous media, similar to flow in pipe network. Generally, two types of relationships between above mentioned variables such as exponential and quadratic have been presented for turbulent flow in porous media which is presented as follow [10] (Equations (6, 7)):

$$f = a' R_e^{\,b'} \tag{6}$$

$$f = \frac{a_1}{R_e} + b_1 \tag{7}$$

where a', b', a_1 and b_1 are the constantans and depend on the flow and media characteristics.

Since flow through porous media include extensive regimes of flow, the quadratic form has better estimation rather than exponential form. Exponential equations are named single-regime equations and are mostly used in turbulent flow [11].

Ergun [11] by investigation on one dimensional flow introduced the following equation (Equation (8)):

$$f\left[\frac{n^3}{1-n}\right] = 150\left[\frac{1-n}{R_e}\right] + 1.75 \tag{8}$$

where, $f =$ Darcy-Weisbach coefficient, $n =$ media porosity and $R_e =$ is media Reynolds number which were introduced as below (Equations (9, 10)):

$$f = \frac{id}{V^2/2g} \tag{9}$$

$$R_e = \frac{Vd}{\vartheta n} \tag{10}$$

where, $V =$ bulk velocity, $i =$ hydraulic gradient, $d =$ medium diameter and $\vartheta =$ kinematic viscosity.

Stephenson [12] defined Reynolds number and Darcy–Weisbach equation as follows (Equations (11, 12)):

$$R_e = \frac{d}{\vartheta}\left(\frac{V}{n}\right) \tag{11}$$

$$i = \frac{f}{gd}\left(\frac{V}{n}\right)^2 \tag{12}$$

The parameters are similar to abovementioned parameters. He used his own laboratory test results to develop the following relationship (Equation (13)):

$$f = \frac{800}{R_e} + K_t \tag{13}$$

Where $K_t =$ 1, 2 and 4 for smooth, semi spherical and angular stones respectively.

The Equation (13) shows that when flow is fully turbulent, f is not dependent of R_e.

Herrera and Felton [13] used standard deviation (δ) of rock particle sizes and substituted the term of $(d-\delta)$ instead of d in Darcy- Weisbach and Reynolds number equations (Equations (14- 17)).

$$R_e = \frac{(d-\delta)}{\vartheta}\left(\frac{V}{n}\right) \tag{14}$$

$$\frac{\Delta h}{L} = \frac{f}{g(d-\delta)}\left(\frac{V}{n}\right)^2 \tag{15}$$

$$\delta = \left[\frac{\sum (d-d_i)^2 P_i}{\sum P_i}\right]^{0.5} \tag{16}$$

$$d = \frac{\sum d_i P_i}{\sum P_i} \tag{17}$$

Based on Herrera and Felton's research, with larger standard deviations, finer particles fill the pores between coarser particles and the contact surface of particles with water increases. This condition increases flow resistance and decreases flow velocity and Reynolds number.

They also used linear regression to check correlation between f and R_e and derived following relationship (Equation (18)) with coefficient of correlation of 0.86.

$$f = \frac{3858}{R_e} + 17.6 \tag{18}$$

Ghazimoradi and Masumi [14] carried out a series of tests on the laboratory rockfill dam with particle size in the range of 4.1cm< d < 12.5cm. Their tests were done under several different hydraulic gradients and several different standard deviations of rock particle sizes. They used their own test results and the test results of Herrera and Felton to do a regression analysis. Accordingly they proposed a different relationship between f and R_e as below (Equation (19)):

$$f = \frac{4670}{R_e} + 14.4 \tag{19}$$

Li et al. [10]used the Darcy-Weisbach equation and presented following relationships (Equations (20- 22)):

$$f = \frac{fLV_p^2}{2gD} \tag{20}$$

$$D = 4R_h \xrightarrow{\text{yields}} h_f = \frac{fLV_p^2}{8R_h g} \tag{21}$$

$$f = \frac{8gR_h h_f}{LV_p^2} \tag{22}$$

The hydraulic gradient is defined as Equation (23):

$$i = \frac{h_f}{L} \tag{23}$$

In seepage flow V_p is the void velocity in the porous media which can be defined as Equation (24):

$$V_p = \frac{V}{n} \tag{24}$$

$$A_{vs} = \frac{6r_E}{d} \tag{25}$$

where, $r_E =$ shape factor, $A_{vs} =$ volume-specific surface area of media particles and V= bulk velocity in porous media.

Substituting Equations (25), (24) and (23) in Equation (22) they derived Equation (26) as bellow:

$$f = \frac{8giR_h n^2}{V^2} = \frac{4eidgn^2}{3r_E V^2} \tag{26}$$

Also the Reynolds number could be defined as Equation (27) and the n parameter could be defined as Equation (28):

$$R_e = \frac{R_h V_p}{\vartheta} = \frac{VR_h}{n\vartheta} \tag{27}$$

$$e = \frac{n}{1-n} \tag{28}$$

Substituting $R_e = \frac{ed}{6r_E}$ and Equation (28) in Equation (27), Equation (29) could be obtained as below:

$$R_e = \frac{Ved}{6\vartheta n r_E} = \frac{Vd}{6\vartheta(1-n)r_E} \tag{29}$$

With more algebra the final equation could be obtained (Equation (30)):

$$f = \frac{4idgn^3}{3r_E V^2(1-n)} \tag{30}$$

Based on Hansen's data prepared in Otawa and Nanching universities [6], an equation for rock particle size in the range of 1.6 cm to 4 cm was proposed as below (Equation (31)):

$$f = \frac{98}{R_e} + 3 \tag{31}$$

and in exponential form (Equation (32)):

$$f = 8.75R_e^{-0.017} \tag{32}$$

They also proposed another relationship for the rock particle size in the range of 0.04 to 2 m (Equation (33)):

$$f = \frac{1298}{R_e} + 3.84 \tag{33}$$

Emadi et al. [15] used a nonlinear optimization technique to derive the following relationships for one and two dimensional flows (Equations (34, 35)):

$$f = 54R_e^{-0.077} \text{ for 1D} \tag{34}$$

$$f = 80R_e^{-0.034} \text{ for 2D} \tag{35}$$

Calibration and validation of Equations (34) and (35) was done using Hansen's data. Results showed that in non-Darcy flow, velocity is proportional to hydraulic gradient with the power of 0.52 (close to the pipe flow with the power of 0.5), while in Darcy flow the power is 1.

3. LABORATORY AND EXPERIMENTAL CONDITIONS OF DATA SERIES

The data which were used in this research were collected from four different sources. Three of them were sediment contained flowthrough and another one was in the clear water condition. The brief characteristics of experimental testes which were used in this research are illustrated in Table. 1. Total numbers of experiments were 197. All experiments were accomplished in the non-Darcy flow condition but as mentioned by previous investigators, fully developed turbulent flow occurs in the Reynolds Number more than 200, therefore except a few experiments (number of 7); all of experiments were operated in the fully developed turbulent flow. It is also noteworthy to mention that all of these experiments were operated in the free water surface conditions and none of them were operated in the pressurized condition. In all of data sets, during the operation, water profiles were measured by taking photo from piezometers and digitizing of them using image processing software (Grapher).

4. RESULTS AND DISCUSSION

4. 1. Observation Magnitudes of Manning and Darcy Coefficients

After data collections, the magnitudes of observed Manning coefficient and Darcy-Weisbach coefficient were estimated using developed Equations of (36) and (37), respectively and depicted (Figures 1, 2). A Hansen's relation with assuming of spherical particles is also used in the estimating of hydraulic radius [4]:

$$V = \frac{1}{n_m} m^{\frac{2}{3}} s^{\frac{1}{2}} \xrightarrow{s=i, m=\frac{ed}{6}} n_m = \frac{\left(\frac{ed}{6}\right)^{\frac{2}{3}} i^{\frac{1}{2}}}{V} \tag{36}$$

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \xrightarrow{i=\frac{h_f}{L}} f = \frac{id}{V^2/2g} \tag{37}$$

All of the parameters were identified in the previous section.

As illustrated in Figures 1 and 2, significant differences were observed in the magnitudes of friction coefficients in the conditions of clear water flowthrough and sediment contained flow in both Manning and Darcy form.

As illustrated, by increase of Reynolds number, the friction coefficient decreases to the constant magnitude. In fact, by increasing in velocity, the turbulence of flow increases and kinetic forces overcome the viscous forces. Therefore, friction coefficient decreases in similar trend of Moody diagram. The major difference between this diagram and Moody's one is the larger magnitudes of friction coefficient in the flow through porous medium rather than flow through pipe lines.

Otherwise, the ratio between friction coefficient in sediment contained flow and clear water condition are several folds.

The tendency of friction coefficient to the constant magnitude illustrates that like Moody diagram, by increase in the Reynolds number the dependency of friction coefficient to the Reynolds number in turbulent flow through porous media decreases and friction coefficient become dependent to the geometrical configurations of porous media. It is also noteworthy to mention that for different sizes of media at the same Reynolds number, the magnitudes of friction coefficient for larger media sizes is higher than smaller sizes. Generally, magnitude of Manning coefficient for clear water condition limited to 0.01 which is a large value in the open channel flow.

On the other hand, Manning coefficient in the sediment contained flow limits to 0.06 which belongs to the grassed channels with irregular cross sections.

TABLE 1. Experimental characteristics of data series

No.	Data index	Description of data series	Name of investigator	Number of medium diameter	d50 of medium diameter (mm)	Range of Reynolds number	Medium length, width and height (m)
1	WS	Without sediment flowthrough	Salehi [16]	6	2.83, 5.5, 8.7, 15.6, 31.1 and 56.8	10-12000	1, 35, 40
2	SC-1	Sediment contained flowthrough	Emadi [15]	2	14.5 and 21	1100-4000	0.6, 0.3, 0.3
3	SC-2	Sediment contained flowthrough	Mousavi [7]	2	30 and 45	7000-13000	0.3, 0.6, 0.7
4	SC-3	Sediment contained flowthrough	Nazemi [17]	2	50 and 120	2000-20000	0.78, 0.6, 0.58

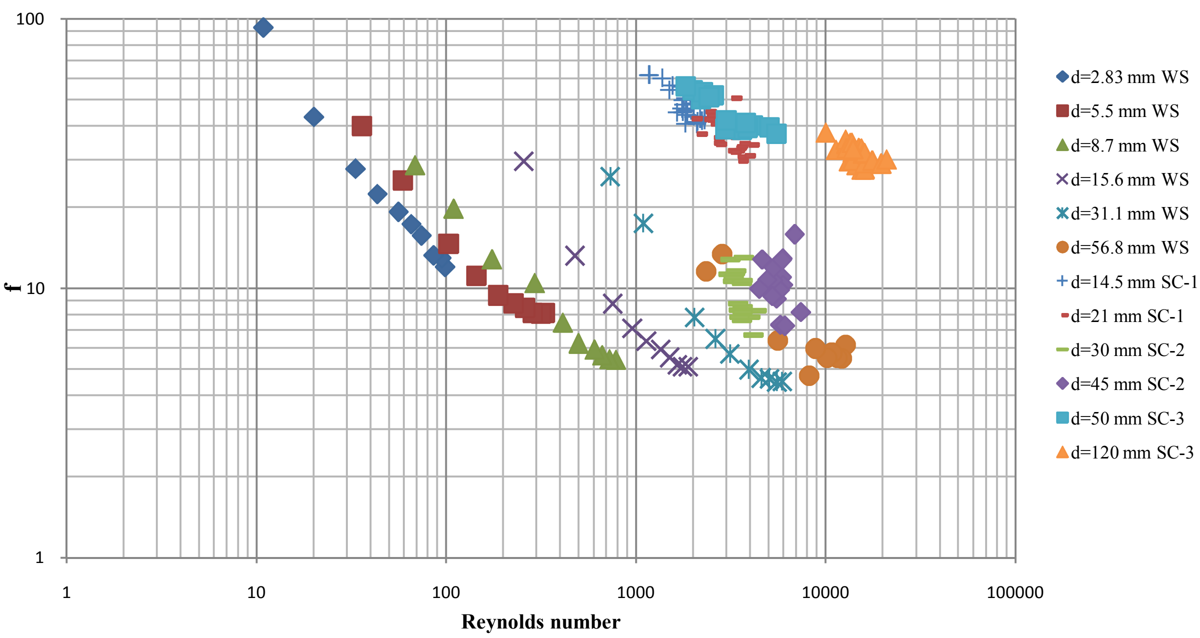

Figure 1. Darcy-Weisbach friction coefficient versus Reynolds number in different data sources and media sizes

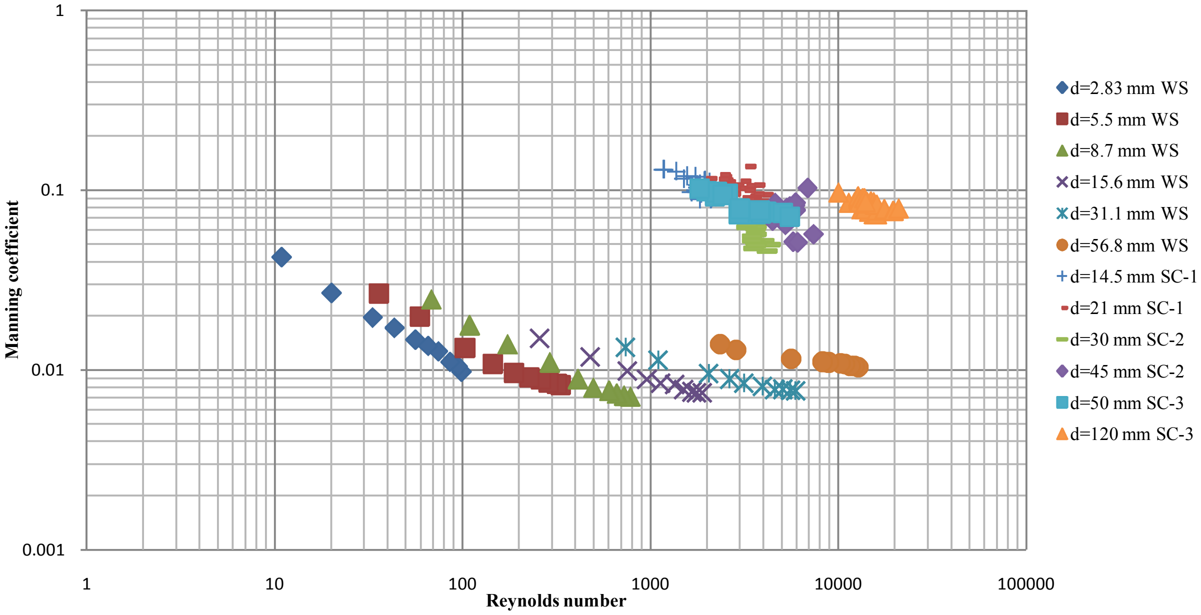

Figure 2. Manning coefficient versus Reynolds number in different data sources and media sizes

Significant differences observed between sediment free flow and another one is because of clogging action in the pores of porous media which changes the geometrical tubes of flow. Clogging phenomenon imposes more resistance against flow direction. Additionally, as is mentioned in the sediment transport literature, the nature of existence of sediment particles, took more energy from flow which outcome of it is reflected in the friction coefficient. In fact, there is additional friction in the alluvial flow because of the existence of sediment particles.

In the hydraulic engineering, usually the magnitude of Manning coefficient is taken constant. But the trend of depicted diagram (Figure 2) shows that this assumption is only true in the hydraulically rough flow through porous media [4]. In the open channel hydraulic, the magnitude of Manning coefficient is the sum of skin friction, bed form friction and sediment particles friction. But, in the case of large porous media like rockfill media, this magnitude is sum of friction due to the shape of porous tubes, skin frictions of rock material, irregularity of flow path, existence of suspended sediment particles and the clogging process of pores. It is noteworthy to mention that the rock shape and compaction of them in the media which generates the pore tubes also affects the friction coefficients of media. Such as if a same material down fall twice, the shape of pores would be different therefore the magnitude of flow friction would be different. So, there is more uncertainty in the flow through large porous media. Additionally, in the pore system of porous media, the magnitude of friction is also spatially different but since the velocity in the media is taken in the bulk velocity system therefore the effects of heterogeneity and spatially changes disappears and the velocity is shown with average magnitude. But whatever flow regime moves to fully rough turbulent in the pore systems, the effects of boundary condition and skin friction decreases to the constant magnitude.

Since the manning formula is applied to the fully developed rough turbulent flow with a constant magnitude of friction coefficient, the assumption of a constant magnitude of manning coefficient in flow through porous media is only valid in the rough turbulent flow.

4. 2. Development of an Equation Based on Wilkins Equation and its Accuracy In this section development of relationships were done using mathematical approaches on the basic relation of hydraulic engineering and calibrated with non-liner multiple regression analysis.

For void velocity Wilkins (1952) presented a favorable equation as below (Equation (38)):

$$V = Wm^a i^b \tag{38}$$

where:

$V = velocity\ in\ the\ voids = V_{bulk}/prosity$(m/s);
$m = hydraulic\ mean\ radius$ (m);
$W = empirical\ coefficient$ (=5.24 for crushed stones);
$i = hydraulic\ gradient$ (dimensionless);
$a\ and\ b = regression\ coefficients$ (in the basic relationship which is presented by Wilkins a=0.5 and b=0.54)

In general, scale effects/defects are associated with the nature of the assumption about the level of turbulence and can be counted for selecting the correct value of the exponent of hydraulic gradient .If the assumed value of exponent is incorrect, the shape of a computed water surface profile will not be correct. If, on the other hand, the value of the coefficient ($V = Wm^{0.5}$ in the case of Wilkins equation) is incorrect, the quantity of flow will be incorrect. It is "fortunate" that the scale effect is as simple as this to account for; this is so because friction completely dominates the process in question [9].

As the value of exponent of hydraulic gradient changes from 1 to 0.5, the flow regime in the voids actually goes through a series of transitions. The subcategories represented by these transitions, together with their underlying causes, have been discussed by Wright (1968). As this to account for; this is so because friction completely dominates the process in question [9].

The steps of developing friction coefficient from Wilkins's pore velocity equation are outlined as below (Equations (39, 40 and 41):

$$V_v = Wm^a i^b \tag{39}$$

Application of Sedghi-Asl and Rahimi's assumption will be outlined as:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \xrightarrow{S=i, R=m, V_v=\frac{V}{n}} n_m = \frac{n\, m^{\left(\frac{2}{3}-a\right)} i^{\left(\frac{1}{2}-b\right)}}{W} \tag{40}$$

$$n_m = \frac{1}{W}\, n\, m^A i^B \xrightarrow{m=\frac{ed}{6}, e=\frac{n}{1-n}} n_m = kn\left(\frac{n}{1-n}\right)^A d^A i^B \tag{41}$$

This new equation is a general form of Sedghi-Asl and Rahimi's equations [4].

After regression analysis of gained data in two categories of sediment free and sediment contained, the coefficients and exponents of developed equations obtained. For 30 percent of data which were not participated in the calibration of equations, the predicted magnitudes were depicted versus observed magnitudes (Figures 3 and 4). It was found that average standard relative error for predicting of Manning coefficient in clear flow through is about 13% (Equation (42)) and for sediment contained flow is about 16% (Equation (43)).

$$n_m = 0.0057\, n\left(\frac{n}{1-n}\right)^{-0.181} d^{-0.181} i^{-0.259} \tag{42}$$

$$n_m = 0.1926\, n\left(\frac{n}{1-n}\right)^{-0.1064} d^{-0.1064} i^{\,0.187} \tag{43}$$

Precision to the obtained equations reflects that the factors of $\left(\frac{n}{1-n}\right)$ and d in both Equations (42 and 43) have negative exponent sign which shows inverse effect on the manning coefficient. This fact has a good corresponding with pore network of media such that by increase in media size, the pore size is also increased then the Manning coefficient should be decreased. Also, by increase in the porosity of media the $\left(\frac{n}{1-n}\right)$ increases therefore, the manning coefficient should be decreased.

A significant difference between Equations (42) and (43) is the difference between the magnitude and sign of the exponent of hydraulic gradient. But, it seems that the effect of media diameter and porosity are similar in both of them.

In fact, when sediment contained flow was employed to the porous media, hydraulic gradient had a more important and effective impact on estimation of Manning coefficient.

Sediment free experiments were operated in the wide range of Reynolds number (10-10000) because sediment transport in the large porous media begins in the condition which is called critical hydraulic gradient for sediment transport. Therefore, different investigators for operation of their experiments increased hydraulic gradient of system to achieve beginning level of sediment motion through porous media.

4. 3. Development of an Equation Based on Ergun's Friction Equation and its Accuracy Ergun [11] presented a frictional equation based on R_e, n, f and two constant coefficients (a and b). Based on previously derived equation [4] (Equation (5)) and Ergun equation, following derivation for Manning coefficient was outlined (Equation (46)):

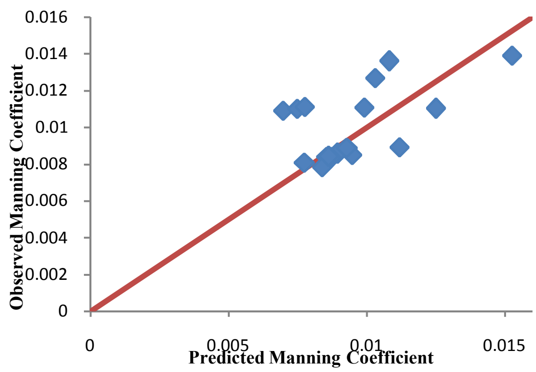

Figure 3. Observed and predicted sediment free Manning coefficient using modified Wilkins equation

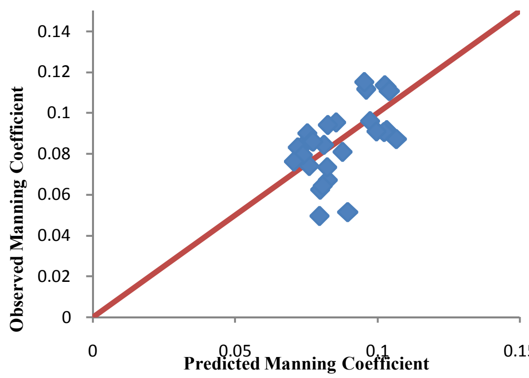

Figure 4. Observed and predicted sediment contained Manning coefficient using modified Wilkins equation

$$f\left(\frac{n^3}{1-n}\right) = a\left(\frac{1-n}{R_e}\right) + b \tag{44}$$

$$f = \frac{a\left(\frac{1-n}{R_e}\right)+b}{\left(\frac{n^3}{1-n}\right)} \tag{45}$$

$$n_m = \frac{\sqrt{f}\, e^{2/3}}{14.6} d^{1/6} \xrightarrow{yields} n_m = \sqrt{\frac{a\left(\frac{1-n}{R_e}\right)+b}{\left(\frac{n^3}{1-n}\right)}} \frac{d^{1/6}}{14.6} \left(\frac{n}{1-n}\right)^{2/3} \tag{46}$$

The parameters are the same as the previously mentioned parameters

After regression analysis, the constants of equation were obtained as Equation (47). As is found, in the case of sediment free data series, this equation had unfavorable magnitudes with large standard error but in the case of sediment contained flow the constants of derived equation were obtained by regression analysis as below (Equation (47)) with standard error of about 19%.

$$n_m = \sqrt{\frac{3860\left(\frac{1-n}{R_e}\right)+0.3427}{\left(\frac{n^3}{1-n}\right)}} \frac{d^{1/6}}{14.6} \left(\frac{n}{1-n}\right)^{2/3} \tag{47}$$

As is presented in this equation, n_m is a function of porosity, media size and Reynolds number where Reynolds number is also a function of pore velocity, media size and fluid viscosity. The value of standard error in this equation is larger than modified Wilkins equation (Equation (43)).

4. 4. Combination of an Equation Based on General form of Friction Coefficient and Reynolds Number and its Accuracy In the previously published literature, investigators tried to establish an exponential relationship between Darcy friction coefficient and Reynolds number (Equation (48)). In this approach the same connection was tried to be established between mentioned variables (Equation (49)).

$$f = aR_e{}^b \tag{48}$$

$$n_m = aR_e{}^b \tag{49}$$

After establishing of a regression between mentioned variables, the constant variable and exponent of equation for both sediment free and contained flow were obtained such as Equations of (50) and (51), respectively.

$$n_m = 0.0483R_e{}^{-0.2371} \tag{50}$$

$$n_m = 0.2879R_e{}^{-0.1433} \tag{51}$$

The average relative error for above relationships is about 28% and 19%, respectively. As is found in the clear water flow condition, because of wider range of Reynolds number and friction coefficient rather than sediment contained flow the mean standard error is higher. In such cases, it is possible to fit another graph between constants and exponents of Equations of (50, 51) and another variable such as media mean diameter. One of favorable published relationships is Sedghi's one which is illustrated in Equations (52) and (53).

$$a = 0.805 \tag{52}$$

$$b = 0.096\ln(d_{50}) - 0.483 \tag{53}$$

where, $d_{50} = median\ size\ of\ porous\ media$

All new relationships in two general categories are depicted in Figures 5 and 6. The comparison shows that in all presented equations, both of computed and observed magnitudes are around the line of agreement with different relative errors and the modified Wilkins equations have better and more accurate estimations.

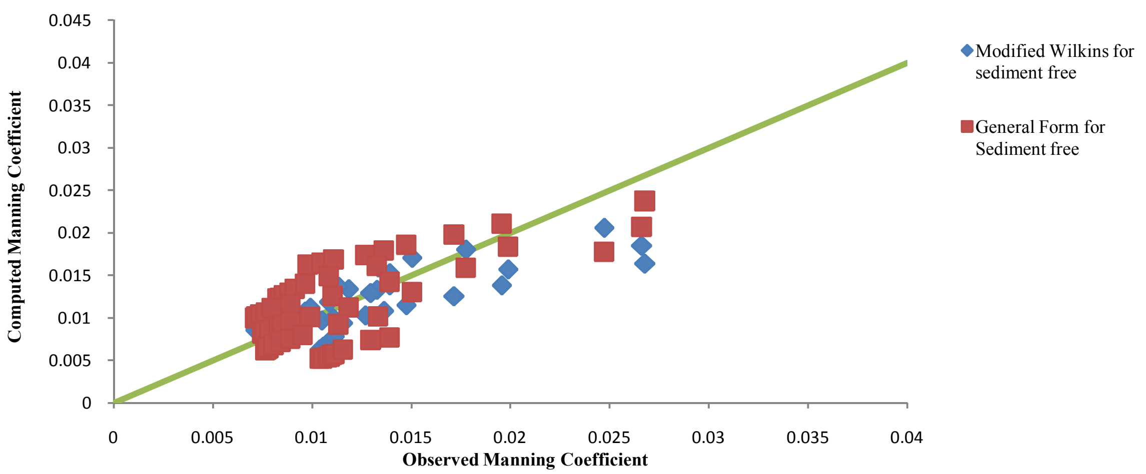

Figure 5. Observed and computed sediment free Manning coefficients with modified Wilkins and general form equations

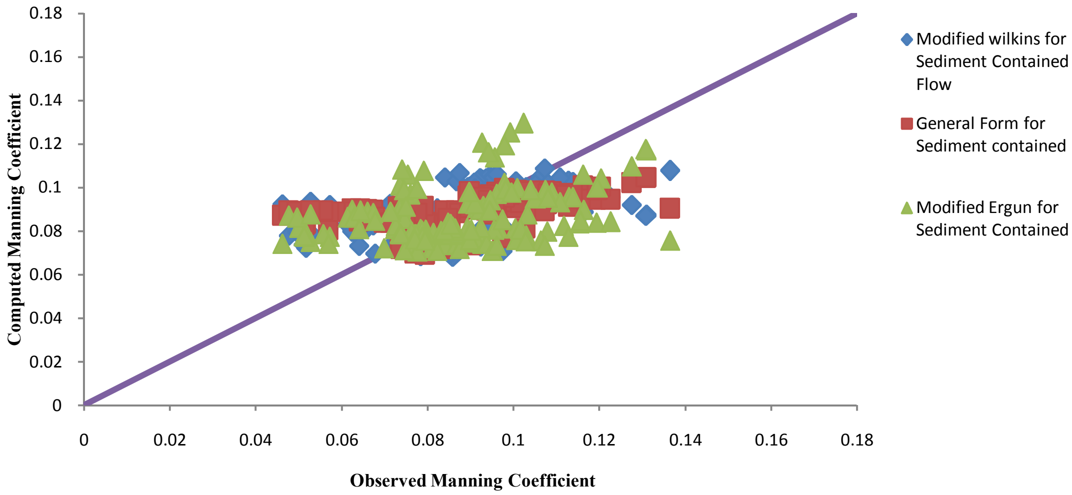

Figure 6. Observed and computed sediment contained Manning coefficients with modified Wilkins, general form and modified Ergun equations

5. CONCLUSION

In this study, it was tried to investigate the basic characteristics of flow through large porous media. In most of previous studies, the friction coefficient in flow was presented in Darcy-Weisbach form which is not so common between hydraulic engineers like Manning coefficient. Because of conveying of sediment contained flow in the structures which are generated from rockfill porous media, and the lack of knowledge about frictional characteristics of media, a detailed investigation was needed.

- As was found, significant differences were observed in the magnitudes of friction coefficients in the conditions of clear water flow and sediment contained flow in both Manning and Darcy form.
- By comparison between depicted diagram in porous media and Moody diagram, it is also found that the magnitude of larger friction coefficient in the flow through porous medium is several times larger than flow through pipe lines. One of the most important reasons for this outcome was clogging phenomenon which imposes more resistance against flow direction.
- By using some basic equations about pore velocity and frictional coefficient new relationships were developed by mathematical approaches and calibrated with regression analysis for estimation of Manning coefficient in open channel flow through porous media. It was found that modified Wilkins equation had a better estimation for Manning coefficient in sediment free and contained flow rather than Ergun and general form equation.

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Estimation of Friction Coefficient in Sediment Contained Flow through Rockfill

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PAPER INFO

Paper history:
Received 13 August 2012
Received in revised form 19 October 2012
Accepted 15 November 2012

Keywords:
Non-Darcy Flow
Sediment Contained Flowthrough
Friction Coefficient

چکیده

افزایش سرعت جریان درون محیط های متخلخل درشت دانه و انحراف از قانون دارسی باعث ایجاد رابطه غیرخطی مابین گرادیان هیدرولیکی و سرعت درون منافذ محیط می گردد. یکی از موضاعات مهم در زمینه جریان داخل این نوع محیط ها نحوه ارتباط ضریب اصطکاک با مشخصات جریان می باشد که در گذشته توسط محققان مختلفی مورد بررسی قرار گرفته است. با این وجود همچنان نیاز به استخراج یک رابطه کلی و دقیق که همه داده های آزمایشگاهی موجود را پوشش دهد احساس می گردد. همچنین محققان گذشته دراستخراج روابط خود از ضریب اصطکاک دارسی–ویسباخ استفاده کرده اند که این ضریب همانند ضریب مانینگ برای مسائل جریان کانال های روباز مابین مهندسین هیدرولیک متداول نیست. در این مطالعه داده های آزمایشگاهی مورد نیاز از چهار منبع مختلف گرد آوری گردید که داده های مربوط به سه منبع در حالت جریان حاوی رسوب و داده های منبع چهارم در حالت جریان صاف اجرا گردیده بود. با استفاده از روابط پایه ای موجود مابین سرعت جریان درون محیط متخلخل و ضریب اصطکاک، روابط جدیدی برای تخمین ضریب مانینگ درون محیط های متخلخل با جریان آزاد استخراج و واسنجی گردید. در انتها مشاهده گردید که رابطه اصلاح شده ویلکینز تخمین بهتری نسبت به روابط ارگان و صدقی برای هر دوحالت جریان صاف و جریان حاوی رسوب ارائه می نماید. همچنین مشاهده گردید که روند عمومی دیاگرام مودی برای جریان درون محیط های متخلخل درشت دانه نیز حکمفرما می باشد بدین صورت که با افزایش عدد رینولدز جریان مقدار ضریب اصطکاک به یک میزان محدود گردیده و به مشخصات محیط متخلخل وابسته می گردد.

doi: *10.5829/idosi.ije.2013.26.02b.09*