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Investigation of Particle-Size Distribution and Friction Factor for a Gravel-Bed river: Marbar

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ABSTRACT

The study of flow and sediment size distribution in gravel – bed Rivers has been the pivotal attention of many researchers for more than three decades. The surface grain size of gravel and cobble-bed rivers reflects the caliber and volume of sediment that is supplied to the channel and magnitude of discharge events that are capable of moving sediment. Also, defining friction factor, the relationship between the mean shear velocity and the mean flow velocity in rivers, has been a central problem in river studies for a very long time, but it continues to defy a complete analytical solution. Most of rivers in Zagros Mountains located in the central Iran consist of gravel and cobble-bed Rivers showing very difficult flow measurements and various grain size distributions. In this paper, two reaches were selected to investigate the particle-size distribution and friction factor estimation of Marbar River. The results showed that particles stability in pools is due to their larger median diameter in comparison to riffles. The contribution of form friction factor is more important than skin friction in Marbar river.

KEYWORDS

Morphology, Gravel Rivers, Pool-Riffle Sequence, Friction Factor, Bed Form

INTRODUCTION

Nowadays, gravel rivers are attracting considerable attention for studying their hydraulic flow properties. River morphology is the first step in determining the hydraulic flow parameters and their modeling in laboratory channels. Most rivers of Zagros Mountains have gravel and rocks beds such as rivers in Esfahan Province. That is, the particle size of these river beds is often more than 2 cm. As the region's slope decreases, the river bed particle size decreases as well, and the river bed shape transforms from bed-rock to gravel having the diameter size variation range of 2 mm to 64 mm.

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Marbar River located in Semirom, Esfahan Province, is one of Iran's gravel rivers. Marbar River is considered as the river with pool-riffle channels.In the early 1950s, many researchers attempted to determine the river bed's particle size distribution, since it made it possible for them to estimate the roughness of the river bed. While researchers were trying to determine design criteria for channels, they presented a method for determining Manning's roughness coefficient. In this method, some bed particles were randomly measured in a hypothetic area of one square meter [13].

Wolman [13] developed a method in 1954. Accordingly, the river is divided into perforated squares and 100 particles are withdrawn from each hypothetical square and their median diameter is measured. Many of researchers recognized the median diameter as a good representative of an oval particle shape. Unlike common methods where the particle's weight frequency (td-idf) is used for determining the particle-size distribution, Wolmanused the particle frequency instead. Walkotten [11] presented a method entitled "Freeze-Core" sampling in which carbon dioxide or nitrogen were injected on the bed base by means of a tube and therefore, the particles were solidified, fixed and ready to be extracted for further analysis. Rood and Church [7] explained some of the disadvantages of this method, and developed a new method by combining the two previous methods. Wohl [12] showed that the underwater channel sampling technique can yield different values of d_{16} and d_{84} by different sample takers.

During the last 30 years, researchers have obtained different results regarding the particle size distribution in pool-riffle sequences. According to some particle stability hypotheses in high flow rates, the largest bed particles should be found in the center of pools, whereas finer particles lie on the outlet slope and riffle crests [5, 9, 10]. However, based on field observations, a number of scientists, namely Keller (1971), Clifford (1993) and Sear (1996), found that the particles on riffles are often coarser and possess higher roughness coefficients than that of pools. Later, Clifford (1993) and Sear (1996) presented results that rejected the previous researches and reported the presence of coarser particles in pools [2, 5, 8].

The research conducted by Latulippe et al. [6] showed that particles on riffles have a geometric mean of 32 to 64 mm, thus classifying them into the very coarse category, whereas this parameter is 8 to 16 mm in pools which belongs to the average particle size category. The geometric mean of particles is defined as below (Eq. 1):

$$d_g = \sqrt{d_{84} \times d_{16}} \quad (1)$$

Where d_g is the geometric mean, d_{84} is the diameter for which 84% of the particles are finer than this diameter and $d_{16}$is the diameter for which 16% of the particles are finer than that of $d_{16.}$ For homogenous river beds, d_g has a value less than ¼.

Furthermore, the S_g coefficient is defined as follows (Eq. 2):

$$S_g = \sqrt{d_{84}/d_{16}} \quad (2)$$

Where S_g is the dispersion index and its value varies between *1-2* and *2-4* on riffles and pools, respectively [6].

Latulippe calculated the Manning coefficient in his research using (Eq.3):

$$n=0.0151d_{50} \quad (3)$$

where$n$ is Manning's roughness coefficient and d_{50} is the median particle diameter. This coefficient is 0.028 - 0.031 on riffles, while it varies from 0.024 to 0.026 in pools [6].

Robert (1993, 1990) and Clifford (1992) stated that total average shear stress (or flow resistance) in gravel bed rivers is categorized into 3 groups: 1- Skin friction which is induced by the bed roughness, 2- method friction, 3- form friction which is different for sand, rock or gravel rivers. The total and participation value of each of these resistances in the total resistance value depends on flow conditions, flow type and river morphology [3, 4]. The Darcy–Weisbach equation was selected to calculate the bed resistance. The Darcy–Weisbach friction factor is defined as (Eq. 4):

$$\sqrt{\frac{8}{F}} = \frac{Um}{U*} \quad (4)$$

where U_m is the mean flow velocity, U^* is the shear velocity defined as (Eq.5) in which g is the gravitational acceleration, h is the stream flow depth, and S_f is the energy grade line slope in the channel. Eq. (5) and Eq. (6) are used to calculate shear velocity (*m/s*) and shear stress (*Pa*), respectively,

$$U *= 0.4 \times \frac{(U2-U1)}{Ln\left(\frac{z2}{z1}\right)} \quad (5)$$

$$\tau = \rho \times U *^2 \quad (6)$$

In order to develop appropriate habitats for aquatic creatures, determination of bed particle sizes and their dispersion pattern in Gravel Rivers is of great importance. Due to field difficulties, the study of morphological parameters of gravel and rock-bed Rivers has been often neglected. Therefore, in this paper, the effect of particle size distribution on different parts of the bed forms (pools & riffles) on determining the river's roughness coefficient will be studied.

MATERIALS AND METHODS

In order to study the Marbar River bed form, data acquisition was carried out during several stages and from two separate sites in Semirom, a city located at the southwest of Esfahan Province. Marbar River which rises in the Dena Mountains and flows through the Padena region of the Semiron County is a minor sub-branch of Karoon River. The geographical situation of Marbar River is illustrated in Fig. 1.

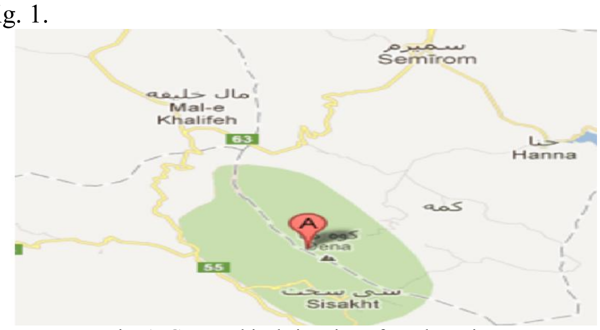

Fig. 1. Geographical situation of Marbar River

In Fig. 2 and Fig. 3 the two river sites investigated in this research is shown. The data collected from the first site are encoded as R_1 to R_{12}, whereas the data from the second site are named from *N* to *T*. By conducting surveying operations, the riffles and pools of the site river bed were determined in three spans and particle samples were collected from pools and riffles, distinctively.

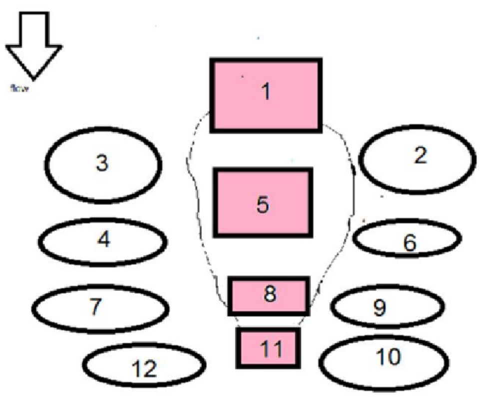

Fig. 2. First river site location

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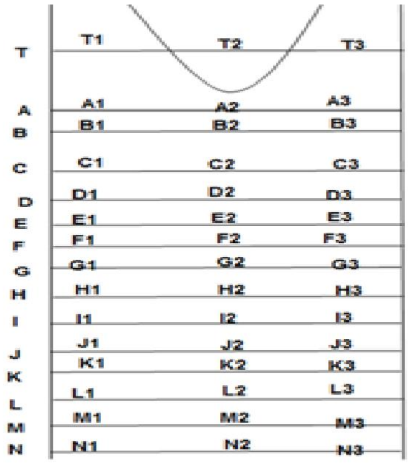

Fig. 3.Second river site location

Wolman's pebble count procedure (1954) was applied to determine the distribution of different diameters [13]. The research procedure can be summarized into five stages as follows:

1) Proper site selection for data acquisition from river bed pools and riffles. For this purpose, first the bed form and its variation throughout the selected span were identified by carrying out surveying operations using the Total Device.
2) In each 100-meter span, on average 3-4 sections were chosen to be graded from which 100 particles were withdrawn.
3) By means of a caliper, the three axes of the particles were measured and the median axis was chosen as the particle representative.
4) These operations were entirely repeated in the width direction of the river (from one river side to its opposite river coast). In order to correctly determine the particle distribution, two cross sections must be chosen.
5) The semi-logarithmic graph of the particle size distribution for Zayanderud and Lordegan Rivers as well as the particle distribution in pools and riffles of Zayanderud River are plotted separately in Fig. 4 and Fig. 5 for points R_5 and T_2, respectively. The data for other graphs is presented in Tab. 1 and Tab. 2.

At the first site, points R_5, R_8 and R_{11} are, respectively, representatives of a riffle particle distribution, while points R_2, R_3, R_4, R_6, R_7, R_9, $R_{10}$and R_{12}indicate consecutive pools.

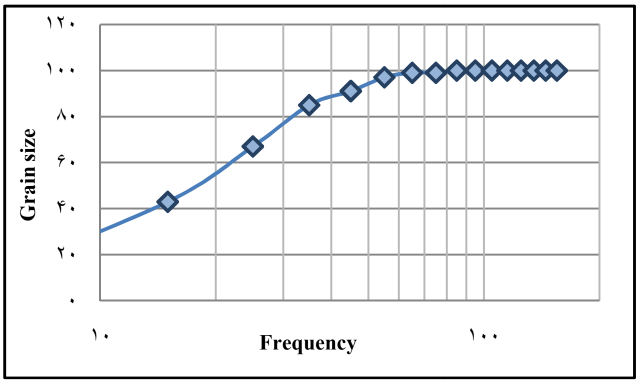

Fig 4. The Semi-logarithmic Particle distribution for point R_5

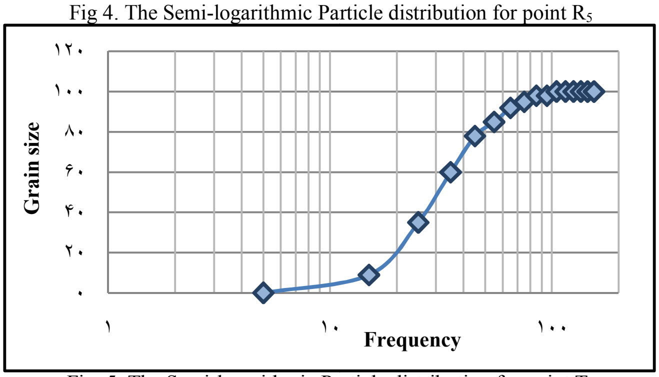

Fig. 5. The Semi-logarithmic Particle distribution for point T_2

Tab. 1.Particle size distribution at the first site

Points	D_{50} (mm)	D_{16}	D_{84}	D_{90}	S_g	d_g	n
R_1	40	35	55	65	1.25	43.87	0.604
R_2	35	15	55	65	1.91	28.72	0.529
R_3	35	15	55	65	1.91	28.72	0.529
R_4	35	20	75	95	1.94	38.72	0.529
R_5	18	25	35	45	1.18	29.58	0.272
R_6	35	20	55	65	1.66	33.17	0.529
R_7	65	45	105	115	1.27	82.26	0.982
R_8	21	25	40	45	1.26	31.62	0.317
R_9	55	35	75	78	1.46	51.23	0.831
R_{10}	50	30	65	75	1.47	44.16	0.755
R_{11}	16	25	30	35	1.09	27.39	0.242
R_{12}	55	35	75	85	1.46	51.23	0.831

Tab. 2.Particle size distribution at the second site

T	1	2	3
D_{16}	45	25	15
D_{50}	65	30	35
D_{84}	75	55	55
D_{90}	85	65	60
Sg	1.29	1.48	1.91
dg	58.1	37.08	28.72
B	35	35	30
D	30	35	17
F	50	30	25
H	55	45	30
I	60	60	30
J	45	39	25
K	50	50	25
L	45	40	20
M	-	30	-
N	-	35	-

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In order to determine flow resistance in this research, the method of Afzalimehr et al. (2010) was applied. According to this method, flow resistance is divided into two sections [1]:

1) Skin friction which is induced by the river bed's roughness.
2) Form friction which is different, depending on the river bed type (sand, rock or gravel).

Size Friction, f', is calculated by Eq. 7, where S_f is the energy grade line slope in the channel:

$$f'=[0.9742-1.5225 \log(S_f)] \quad (7)$$

The form friction (f'') is calculated by Eq. 8:

$$f''=f-f' \quad (8)$$

In this research, friction factor was estimated as well. For this purpose, sections A, B and Cat the first site and sections A to N at the second site were named and identified using surveying operations. In each section, the velocity profile for calculating the fiction coefficient was withdrawn. The procedure stages are as follows:

1) First, using the Total Device and surveying operations, the bed form and its variations along the selected span were identified.
2) Velocity meter was used in order to measure the velocity for each section of the two sites for the studied river.
3) The operations were repeated in the width direction of the river (from one river side to its opposite river coast) in order to determine the velocity and to extract the velocity profile in the river cross section.
4) The velocity profiles were plotted for each section, separately. The graph for points A_3 and A_{11} is shown in Fig. 6 and Fig. 7.

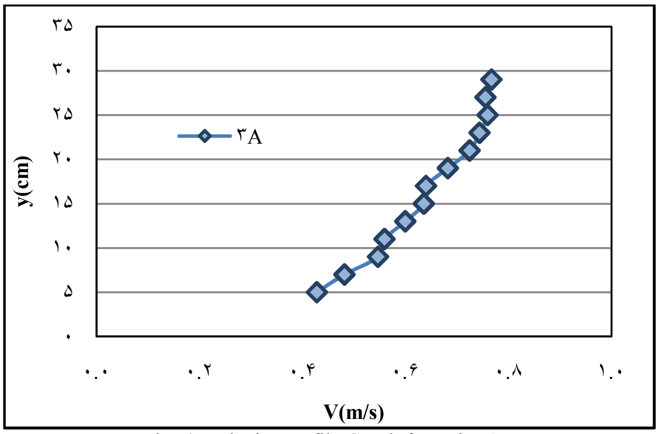

Fig. 6. Velocity Profile Graph for Point A_3

RESULTS AND DISCUSSIONS

Fig. 8 and Fig 9 show two photos of the particle size distribution of Marbar Gravel River at two site location 1 and 2.

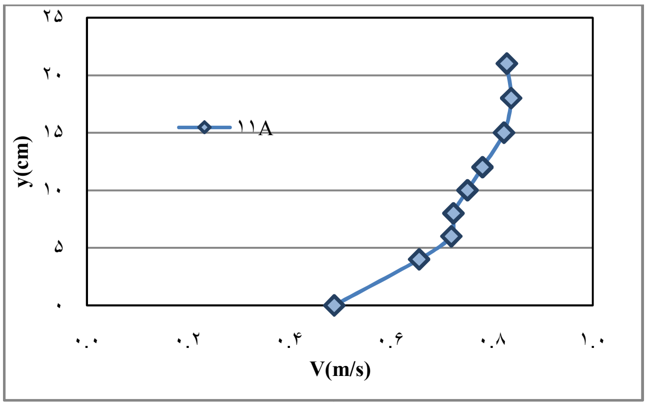

Fig. 7. Velocity Profile Graph for Point A_{11}


Fig. 8. Particle distribution of Marbar gravel river at the first site


Fig. 9. Particle distribution of Marbar gravel river at the second site

At the first site, the smaller d_{90}value of riffles indicates that the particles are finer on riffles. Therefore, the current observations are in accordance with the findings of Clifford (1993) and Sear (1996) who reported coarser particles in the pools [2, 8]. Perhaps this difference is due to the high river flow rate at this studied section.

The geometric mean of particles at pools was reported between 28.72-82.26 mm defining them as the very coarse category, whereas this value was 8 to 16 mm for riffles categorizing them as average size particles. This result disagrees with that of Latulippe et al.'s research [6].

The S_g coefficient was calculated as 1.27-1.94 for pools and 1-1.26 for riffles. As stated before, the results for pools do not agree with that of Latulippe et al. (2000) [6].

At the second site at section T, the median diameters of sediments in the studied span are very close to one another and their particle-size distribution follows the normal distribution. The smaller d_{90} value of riffles indicates that the particles are finer on riffles.

Tab. 3. Flow Resistance estimation at the first site

Point	$U^*(m/s)$	$(pa)\tau$	$\bar{U}(m/s)$	f	SF	f'	f''
A3	0.103477	10.70755	0.64	0.209	0.0227	0.082709	0.126305
A11	0.062743	3.93665	0.735	0.05852	0.00012	0.020741	0.037512
D4	0.027723	0.768561	0.542	0.020925	0.00026	0.208	0.000125

Tab. 4. Flow Resistance estimation at the first site

Points	$U^*(m/s)$	τ (pa)	$\bar{U}(m/s)$	f	S_f	f'	f''
A'3	0.185229	34.33572	1.206242	0.188785	0.00638	0.0536	0.135111
A'5	0.117507	13.80852	1.009442	0.108402	0.00856	0.0585	0.04955
A'14	0.045195	2.0422577	0.928	0.01897	0.00507	0.05	0.10447
A'17	0.083264	6.93288	1.20305	0.03832	0.001606	0.0365	0.00174
A40	0.182508	33.3091	1.33372	0.149804	0.009421	0.0496	0.10016
B'1	0.114121	13.02354	0.65782	0.240771	0.003793	0.046046	0.16255
B6	0.138927	19.3006	0.849892	0.213763	0.005465	0.05122	0.16255
B29	0.086331	7.45296	1.01239	0.058173	0.043	0.04773	0.01044
B'2	0.332342	110.4513	0.701889	1.793595	0.00021	0.02314	1.7705

Hence, the current observations are in accordance with the results of Clifford (1993) and Sear (1996) who reported coarser particles in the pools [2, 8]. As before, perhaps this difference is due to the high river flow rate at this studied section. The obtained results disagree with that of Litiulip et al.'s research (2000) [6].

By examining the particle sizes in sections B to L, it is observed that there is no considerable difference in the d_{50} value of particles at the three points (1, 2, 3) of each section. The particle sizes become coarser downstream and just after the riffle crest (section T), the pool region is developed till section L.

According to Fig. 6 and Fig. 7, it can be stated that the particle-size distribution of the bed form (pool-riffles) at Marbar River confirms that particles are finer on riffles, whereas the coarser and angled particles can be found at the pools of the river bed.

The friction factor estimates are summarized in Tab.3 and Tab. 4. Tables3 and 4 shows that the application of the friction factor equations of Afzalimehr et al. (2010) reveals the form friction values (f″) are more than that of the skin friction (f′) which is representative of the pool-riffle sequences form of Marbar's river

CONCLUSIONS

This research showed that particle stability in pools is due to their larger median diameter in comparison to riffles. The current observations are in accordance with the findings of Clifford (1993) and Sear (1996) who reported coarser particles in the pools. Perhaps observed difference is due to the high river flow rate at studied sections. In according to friction factor equations of Afzalimehr et al. (2010) concludes the friction values (f″) are more than that of the skin friction (f′) which is representative of the pool-riffle sequences form of Marbar's river. As a result, the contribution of form friction factor is more important than skin friction in Marbar River.

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