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Determination of Equivalent Roughness for Estimating Flow Resistance in Stabled Gravel-Bed River:

Ⅱ. Review of Model Applicability

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Abstract

In this study, we estimated the equivalent roughness using an estimation model, which considered grain distribution on the bed and the protrusion height of the grains. We also reviewed the appropriateness of the estimated equivalent roughness at the Goksung and Gurey station in the Seomjin River. To review the appropriateness of this model, we presented the water level-discharge relation curve applying the equivalent roughness to the flow model and compared and reviewed it to observed data. Also, we compared and reviewed the observed data by estimating the Manning coefficient n, the Chezy coefficient C, and the Darcy-Weisbach friction coefficient f by the equivalent roughness. The calculation results of the RMSE showed within 5% error range in comparison with observed value. Therefore the estimated equivalent roughness values by the model could be proved appropriate.

Key Words : Equivalent roughness, Grain distribution, Protrusion height, Numerical integration method

1. Introduction

To analyze the flow of the natural stream, we used one-dimensional, two-dimensional or three-dimensional flow models, as the estimation of the flow resistance parameter is necessary. The flow resistance parameter representatively used for the flow model includes Manning coefficient n, the Chezy coefficient C, and the Darcy-Weisbach frictional coefficient f and the equivalent roughness k_s. Of these, n, C, f not only include the meaning as physical scale by the roughness but also has variability by the change of the water depth or discharge as they are connected to the hydraulic radius R and the frictional slope S_f. That is, these flow resistance parameters cannot be estimated only by the scale of physical factors but the flow condition also has to be considered. For this reason, data such as the actually measured water depth, discharge, mean velocity and water surface slope is required. However, the equivalent roughness k_s only includes the physical scale, and if the roughness scale is known it can be easily estimated. Also, as k_s is related to n, C, f, it is possible to estimate their values for each water depth or discharge using k_s.

The relationship between flow resistance and roughness or height on a gravel bed stream whose grains are of various sizes has not been clearly determined and it is assumed that the roughness of the stabilized gravel bed stream is the same as a certain grain diameter distributed on the bed(D_{50}, D_{84} etc.: the grain diameter D when the cumulative pass weight of the bed materials are 50% and 80%)[1,2]. However, in a gravel bed stream, whose grain diameter distribution is quite di-

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verse, there is much uncertainty in expressing the roughness of the bed by a certain grain diameter. Moreover, flow resistance equation and term of equivalent roughness proposed using the data actually measured from the limited experiments and the field bring about many errors when applied to streams with varying bed characteristics. To complement this, we need to consider the flow resistance for each grain on the bed. Therefore, in this study, we estimated the equivalent roughness by applying the equivalent roughness estimation model, which considers the grain protrusion height from the bed to the actual gravel bed stream. Also, to review the model's applicability, we applied k_s, the equivalent roughness estimated through the model, made the water level-discharge relationship curve and estimated the flow resistance parameters n, C, f and compared and reviewed them with the observed values.

2. Equivalent roughness estimation model

The equivalent roughness estimation model was developed under the assumption that 'the average bed shear stress in the steady uniform flow is the same as the grain shear stress per unit area distributed on the bed'. Equation (1) is the basic equation of the equivalent roughness estimation model, and it is the equation proposed under the primary premise that flow resistance is caused only by grains distributed on the bed.

$$f(k_s) = \sum \left\{ C_{Di}* \frac{1}{2} \left[5.75 \log\left(\frac{30 y_{mi}}{k_s}\right) \right]^2 \right\} F_i - 1 = 0 \qquad (1)$$

Here, C_D* is the drag coefficient for the relative protrusion proposed by Martin[3], y_m is the mean velocity height used to estimate the mean velocity hit on the grains. F is the weight composition ratio of each grain diameter through the cumulative grain diameter analysis, and the subscript i is the diameter of each grain.

Equation (1) is the equation for grains composing in unit area. It cannot be used to estimate k_s directly satisfying Equation (1), and the estimation should be performed through trial and error or through a simple numerical analysis. In this study, we used the incremental search method for this purpose.

The incremental search method is to find the solution by directly substituting k_{sn} from the initial value of k_{s1} that $f(k_s)$ value becomes zero or within the allowable error e and apply the increment decrease ratio S. In Fig. 1, Δk_{s1} is initial increment and second increment $\Delta k_{s2} = (\Delta k_{s1}/S)$ applying the increment decrease ratio S.

3. Application of the model

3.1. Subject stream

In this study, to estimate equivalent roughness, we applied the developed equivalent roughness estimation model to the actual streams, the Gokseong station and the Gurey station located in the middle stream of the Seomjin River. The bed slope is 0.00195 in the Gokseong station and 0.00070 in the Gurey station, and the river width is 400 m and 300 m, respectively. The gravel distributed on the bed gives an absolute impact on the flow resistance and its impact on the vegetation of the bank is very small. As shown in Fig. 2, a survey of the bed showed that it was stable as the sectional change is not large as gleaned from the result of the comparison with cross-sectional data of the two stations gathered in the past. Also, a change of the maximum depth bed elevation is not big as 0.11 m and 0.06 m.

3.2. Grain diameter analysis

To estimate equivalent roughness by applying the

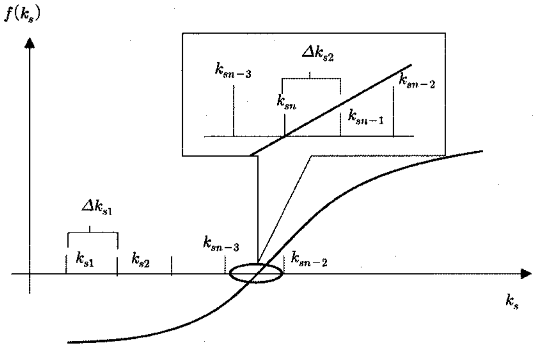
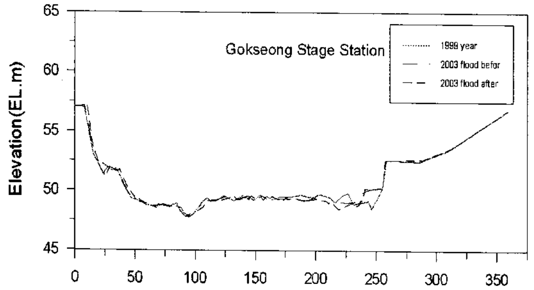
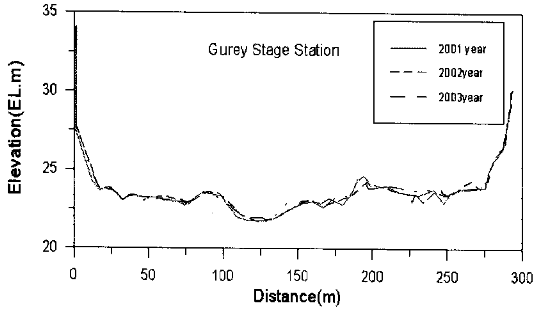


Fig. 1. Section incremental by incremental search method.



(a) Gokseong station



(b) Gurey station

Fig. 2. Review of the change of the cross-section of the subject station.

model to the two stations in the Seomjin River, the grain diameter data of the bed is necessary. Therefore, we used the result of the grain analysis performed by collecting bed materials in two stations in June 2003. Table 1 shows the characteristic values for bed materials of two stations, including effective diameter, median diameter and uniformity coefficient.

In this study, we used each grain diameter D_i and the geometric mean between two grain diameters D_{gi} as the data for model application. Fig. 3 and Table 2 shows the cumulative grain diameter distribution of bed materials in the two stations and the analysis of basic statistics value, showing that over 80% of them are organized by grains over gravel.

The geometric mean of bed materials D_G, standard deviation σ_G, skewness D_S and geometric mean between two grain diameters D_{gi} for bed materials in Table 2 were calculated using Equations (2)~(5).

$$D_G = \sqrt{D_{84} \times D_{16}} \tag{2}$$

$$\sigma_G = \sqrt{D_{84}/D_{16}} \tag{3}$$

$$D_S = \log(D_G/D_{50})/\log(\sigma_G) \tag{4}$$

$$D_{gi} = \sqrt{D_i \times D_{i+1}} \tag{5}$$

3.3. Equivalent roughness Estimation

In this study, the equivalent roughness was calculated using Equation (1). Here, regarding the mean velocity height y_m, we applied Equation (6), the protrusion function of the proposed grain through the numerical integration, and Equations (7) and (8) considering $k_s/30$, the height the flow velocity theoretically becomes 0 for $0.35H$ experimentally proposed by Einstein and El-Samni[4] and $0.50H$ proposed by Coleman[5], respectively.

Model 1 :

$$y_m = [0.490 - 0.538\frac{H}{D} + 0.704(\frac{H}{D})^2 - 0.213(\frac{H}{D})^3] \times H + \frac{k_s}{30} \tag{6}$$

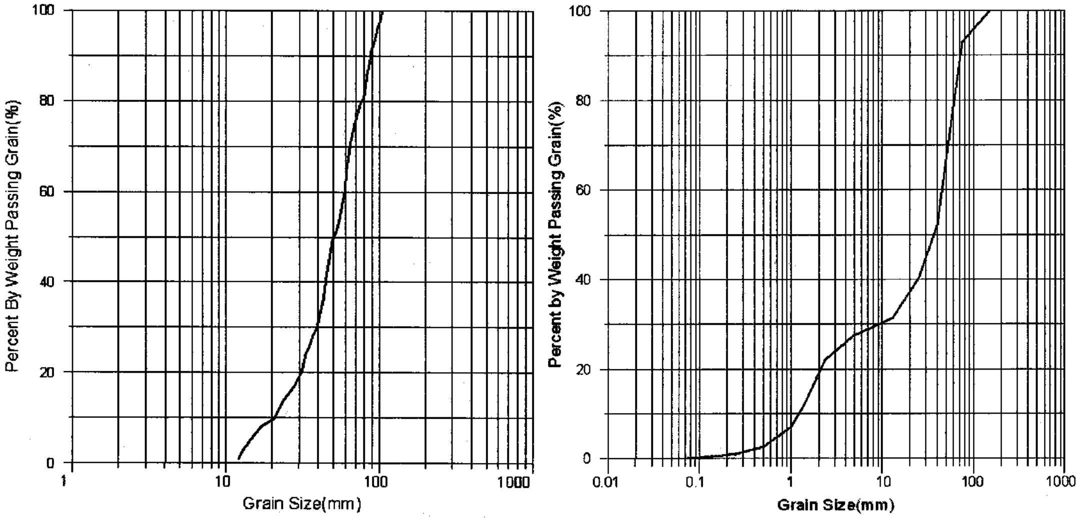
Model 2: $y_m = 0.35H + k_s/30$ (7)

Model 3: $y_m = 0.50H + k_s/30$ (8)

To calculate the drag coefficient C_D^* for Equations (6)~(8) and the relative protrusion H/D, the protrusion height of each grain is required to be measured. However, it is very difficult to measure the protrusion height for all grains on the actual bed. According to Chepil[6], as a result of the experiment using grains with three different grain diameters, he suggested that the

Table 1. The Characteristic value for sediment in the two stations

Station	Effect diameter (D_{10})	D_{15}	Median diameter (D_{50})	D_{60}	Uniformity coefficient (D_{60}/D_{10})	D_{84}
Gokseong	42 mm	45 mm	50 mm	60 mm	1.33	75 mm
Gurey	1.3 mm	17 mm	38 mm	45 mm	34.6	65 mm



(a) Gokseong station (b) Gurey station

Fig. 3. Cumulative grain diameter distribution curve of bed materials.

Table 2. Cumulative grain diameter distribution of bed materials

D_i (mm)	D_{gi} (mm)	Cumulative grain diameter distribution(%)	
		Gokseong	Gurey
200	-	-	-
150	173.21	100.00	100.00
75	106.07	100.00	93.01
40	54.77	60.67	52.13
25	31.62	13.27	40.12
13	18.03	4.34	31.48
10	11.40	0.20	30.22
4.75	6.89	0.00	27.41
2.36	3.35	0.00	22.16
1.4	1.82	0.00	12.13
1	1.18	0.00	7.01
0.5	0.71	0.00	2.50
0.25	0.35	0.00	1.01
0.18	0.21	0.00	0.64
D_G (geometric mean)		58.09	33.24
σ_G (standard deviation)		1.29	1.96
D_S (skewness)		0.002	-0.023

effective bed is in $0.55D$ of each grain. As there are various grains with different grain diameters distributed on an actual bed, it could be helpful to the fact that the protrusion height of each grain has an average value of $0.5D$. Therefore, we assumed the protrusion height of each grain H_0, as $0.5D$ and calculated the relative protrusion(H/D) as shown in Equation (9) by subtracting $k_s/30$ the height that the flow velocity becomes zero and dividing it again into diameter D.

$$\frac{H}{D}=\frac{0.5D-\frac{k_s}{30}}{D} \tag{9}$$

To estimate the equivalent roughness k_s through this model, we used the median diameter D_{50} of each station in Table 1 for initial value k_s, applied 1 mm for the initial increment Δk_{s1}, applied $\Delta k_{s2}=\Delta k_{s1}/10$ using the generally applied factor S of 10 for the increment decrease ratio, and set the allowable error e is 0.02 kg/m^2 to perform the calculation. As a result, the equivalent roughness was estimated as shown in Table 3.

Kamphuis and Gessler[7,8] suggested that the equivalent roughness generally exceeds the maximum diameter of bed materials. As a result of the equivalent roughness estimation, as all the three equivalent roughness models were estimated to be larger than the max-

Table 3. The result of equivalent roughness estimation

Section	Equivalent Roughness k_s(mm)	
	Gokseong	Gurey
Model 1 (numerical integral method)	205.9	212.9
Model 2 ($y_m = 0.35H + k_s/30$)	193.4	199.3
Model 3 ($y_m = 0.5H + k_s/30$)	251.9	263.9

imum diameter of bed materials, we obtained the same result. Comparing the equivalent roughness estimated by the three models, the smallest value was estimated by Model 2, the largest value was estimated by Model 3, and the value of k_s between the values of those two models was estimated by Model 1. This is because the mean velocity height y_m and k_s have a proportional relationship in Equation (1) that the mean velocity height is highest in Model 3, followed by Model 1(average $y_m = 0.4H + k_s/30$) and Model 2. Also, regarding the equivalent roughness estimated by those three methods in this study and in previous studies, Table 4 shows the comparison between $6.80D_{50}$[9] and $3.50D_{84}$[10]which was used in the calculation of the flow resistance. Further, by applying the coefficient C_e for D_{50} and D_{84} of the two stations to express k_s, we expressed those three methods estimated in this study.

The estimated equivalent roughness by the three methods in this study and $6.80D_{50}$ and $3.50D_{84}$ show a large difference, a maximum of 176%, in the Gokseong station. However, for the Gurey station, we showed $3.50D_{84}$ and 7% of error for Model 1, and 6.80 D_{50} and 2% of error for Model 3, thereby showing a comparatively closer value. Expressing the equivalent roughness estimated in this study as D_{50} and D_{84}, they could be displayed as $3.87D_{50} \sim 6.94D_{50}$ and $2.58D_{84} \sim 4.06D_{84}$ that two stations all expressed in different coefficients about D_{50} and D_{84}.

Table 4. Comparison of equivalent roughness by method

Section		Equivalent Roughness k_s(mm)	
		Gokseong	Gurey
Model 1		205.9	212.9
Model 2		193.4	199.3
Model 3		251.9	263.9
$6.80D_{50}$		340.0	258.4
$3.50D_{84}$		262.5	227.5
Model 1	C_eD_{50}	$4.12D_{50}$	$5.60D_{50}$
	C_eD_{84}	$2.75D_{84}$	$3.28D_{84}$
Model 2	C_eD_{50}	$3.87D_{50}$	$5.24D_{50}$
	C_eD_{84}	$2.58D_{84}$	$3.07D_{84}$
Model 3	C_eD_{50}	$5.04D_{50}$	$6.94D_{50}$
	C_eD_{84}	$3.36D_{84}$	$4.06D_{84}$

4. Review of applicability of equivalent roughness

To review the applicability of the equivalent roughness estimated through the model proposed in this study, we applied the equivalent roughness to the flow model, calculated the discharge for the water level, compared the actually measured water level-discharge data, also calculate the flow resistance parameters.

4.1. The water level-discharge relation curve

To compare the observed water level-discharge data for the two stations and the flow models with the water level-discharge calculated by applying k_s estimated in this study, we used a simple flow model of Equation (10) proposed by Wark et al.[11]. The flow model is combining the continuity equation and momentum equation of the flow for q(m²/s), the discharge per unit width in the floodplain or the stream with complex sections under the assumption that it is a steady uniform flow and the water surface of the lateral direction is horizontal.

$$gys_0 - \frac{B_s f q^2}{8y^2} + \frac{\partial}{\partial x}\left(\epsilon\frac{\partial q}{\partial x}\right) = 0 \qquad (10)$$

Here, f is the local Darcy-Weisbach friction coefficient, g is the gravitational acceleration, y is the local water depth, s_0 is the bed slope, x is the horizontal direction coordinate, and ϵ is the local eddy viscosity coefficient. Factor B_s relates the stress on an inclined surface to the stress in the horizontal plane, which is as shown in the following Equation (11).

$$B_s = \sqrt{1+s_z^2+s_x^2} \tag{11}$$

Here, s_z is the longitudinal bed slope and s_x is the local bed slope.

Equation (10) works on the assumption that the weight by unit volume of the water (term 1: Gravity) is parallel only with the frictional bed shear (term 2: bed shear) and the lateral shear (term 3: lateral shear). The third term is important in analyzing the flow of floodplain or significant during overbank flow[11,12]. However, as this study only analyzes about flow of a single section in reach, the diffusion of lateral is judged to be not large, with term 3 excluded and composed of a simple one-dimensional flow model like in Equation (12).

$$gyS_0 - \frac{B_s f q^2}{8y^2} = 0 \tag{12}$$

Hey[10] proposed the semi-experimental equation like Equation (13) for the flow resistance in fixed boundary channel and uniform flow in straight gravel bed stream.

$$\frac{1}{\sqrt{f}} = 2.03\log\left(\frac{aR}{3.50D_{84}}\right) \tag{13}$$

Here, R is the hydraulic radius, and Hey expressed coefficient a in equation (13) are dependent on the shape of the channel.

$$a = 11.1\left(\frac{R}{y_{\max}}\right)^{-0.314} \tag{14}$$

Here, $y_{\max}$ is the maximum flow depth.

In Equation (13), $3.50D_{84}$ was used for the term of equivalent roughness. In this study, if k_s is applied instead, it becomes the same as in Equation (15), which was used to estimate the frictional coefficient f.

$$\frac{1}{\sqrt{f}} = 2.03\log\left(\frac{aR}{k_s}\right) \tag{15}$$

For the water level-discharge data and the section data to analyze and review the water level-discharge relationship, the actually measured data and section data through the discharge measurement taken in the same year the grain diameter data of the bed materials of each station were analyzed, as shown in Table 5.

Table 5. Data for apply to the model

Station	Measurement Duration	
	Water Level-Discharge Data	Section Data
Gokseong	2003. 7. 9 - 7. 10	2003. 6
Gurey	2003. 7. 9 - 7. 10	2003. 6

As Equation (12) is the equation for the discharge per unit width, it was differentiated in 1m intervals for the cross-section of two stations. And to estimate coefficient B_s in calculating the shear stress in consideration of longitudinal and lateral bed slope, we used the average bed slope s_0 for the longitudinal slope s_z, and estimated the lateral bed slope s_x by subsections. Also, the frictional coefficient f was estimated by subsections through Equation (15), and for the equivalent roughness k_s, the values estimated by each method in Table 4 were used. By applying the coefficient estimated like this to Equation (12), we estimated the discharge per unit width for each water level by subsection and estimated the total discharge in the section by integrating it into the entire water surface width. The results are shown in Table 6~7 and the Fig. 4.

The most appropriate method to the water level-discharge data observed in the Gokseong station and the Gurey station is the application of the equivalent roughness by Model 1, which estimated and applied the mean velocity height by the numerical integration method to the flow model that it showed the smallest absolute average error of 2.21% and 2.51%, and the largest error of 6.57% and 7.01%. As a result of the application of the equivalent roughness estimation using Models 2 and 3, the Gokseong station showed 2.55% and 4.28% and the Gurey station showed 2.80% and 4.81 of the absolute average error, which comparatively agreed well with the observed discharge. However, with the estimation method for obtaining the equivalent roughness using $6.80D_{50}$ and $3.50D_{84}$, it showed 9.68% and 4.98% in the Gokseong station and 4.55% and 2.94% in the Gurey station of the absolute average error, thereby showing an even larger error than the equivalent roughness estimation model of this study. The reason for this is as $6.80D_{50}$ and $3.50D_{84}$ is estimated to be larger than the equivalent roughness

Table 6. Comparison of discharge calculated by each method at the Gokseong

Observed		Calculated									
h (m)	Q_{obs} (m³/s)	Model 1		Model 2		Model 3		$6.80D_{50}$		$3.50D_{84}$	
		Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)
3.205	1,340	1,428	6.57	1,446	7.93	1,369	2.19	1,282	-4.32	1,357	3.205
3.355	1,579	1,578	-0.02	1,598	1.24	1,514	-4.09	1,419	-10.13	1,501	3.355
3.520	1,720	1,752	1.88	1,774	3.15	1,681	-2.22	1,577	-8.31	1,667	3.520
3.670	1,910	1,917	0.37	1,941	1.62	1,841	-3.62	1,727	-9.57	1,825	3.670
3.915	2,217	2,203	-0.62	2,230	0.59	2,116	-4.53	1,988	-10.33	2,099	3.915
4.070	2,349	2,393	1.86	2,422	3.09	2,299	-2.11	2,161	-8.01	2,280	4.070
4.250	2,649	2,622	-1.04	2,653	0.15	2,521	-4.86	2,370	-10.54	2,500	4.250
4.270	2,764	2,648	-4.21	2,680	-3.06	2,546	-7.90	2,394	-13.40	2,525	4.270
4.310	2,792	2,709	-3.28	2,733	-2.12	2,597	-7.00	2,442	-12.53	2,575	4.310
RMSE		-	2.21	-	2.55	-	4.28	-	9.68	-	4.89

Table 7. Comparison of discharge calculated by each method at the Gurey

Observed		Calculated									
h (m)	Q_{obs} (m³/s)	Model 1		Model 2		Model 3		$6.80D_{50}$		$3.50D_{84}$	
		Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)	Q_{cal} (m³/s)	Q_{error} (%)
3.460	1,591	1,703	7.01	1,724	8.36	1,633	2.62	1,640	3.05	1,681	5.65
3.725	1,821	1,945	6.81	1,969	8.13	1,866	2.49	1,874	2.91	1,921	5.47
3.865	2,070	2,078	0.39	2,104	1.63	1,995	-3.64	2,003	-3.25	2,053	-0.86
3.910	2,119	2,122	0.15	2,148	1.38	2,037	-3.86	2,045	-3.47	2,096	-1.09
4.025	2,252	2,236	-0.72	2,263	0.50	2,146	-4.67	2,155	-4.28	2,208	-1.94
4.100	2,292	2,311	0.83	2,339	2.06	2,219	-3.17	2,228	-2.78	2,282	-0.40
4.250	2,441	2,465	0.97	2,494	2.19	2,367	-3.02	2,377	-2.63	2,435	-0.26
4.290	2,576	2,506	-2.69	2,537	-1.51	2,408	-6.52	2,417	-6.15	2,476	-3.88
4.340	2,589	2,559	-1.18	2,590	0.01	2,458	-5.06	2,468	-4.68	2,528	-2.38
4.435	2,657	2,660	0.12	2,692	1.33	2,556	-3.80	2,566	-3.41	2,628	-1.09
4.500	2,720	2,730	0.36	2,763	1.57	2,623	-3.55	2,634	-3.17	2,697	-0.85
4.645	2,976	2,889	-2.91	2,923	-1.76	2,777	-6.68	2,788	-6.31	2,854	-4.08
4.780	3,209	3,041	-5.24	3,077	-4.11	2,923	-8.90	2,935	-8.54	3,004	-6.37
RMSE		-	2.51	-	2.80	-	4.81	-	4.55	-	2.94

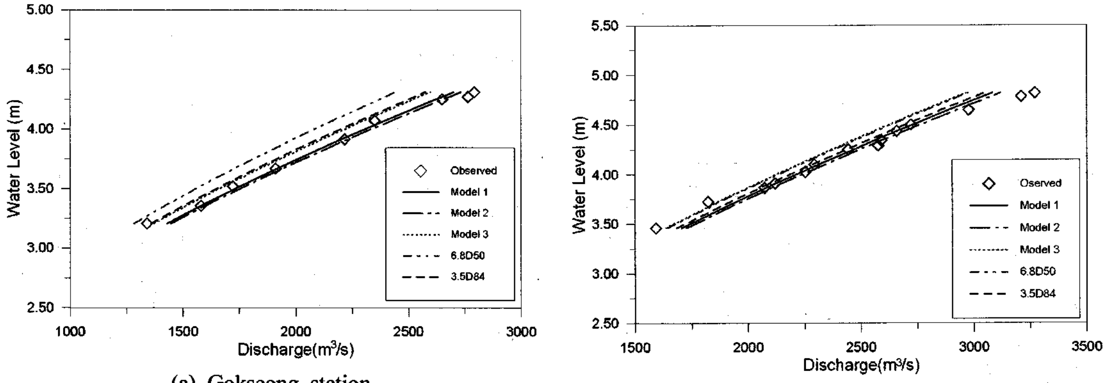
by this study, it made the flow resistance for the same water level larger while underestimating the discharge.

4.2. Calculation of flow resistance parameter

The one-dimensional flow resistance equation is the equation used for finding the flow velocity or discharge with the geometry characteristic of the channel and the resistance characteristic of the boundary. Generally, the representative equations used for the one-dimensional flow resistance equation include the Manning equation, Chezy equation and Darcy-Weisbash equation, and their relationship could be expressed as in equation (16).

$$\frac{1}{\sqrt{f}}=\frac{C}{\sqrt{8g}}=\frac{R^{1/6}}{8.86n}=2.03\log\left(\frac{12.2R}{k_s}\right) \qquad (16)$$

As flow resistance parameters n, C, f in Equation (16) can be expressed as a function of the equivalent roughness k_s, these three parameters could be calculated through k_s. Therefore, in this study, we calcu-



(a) Gokseong station

(b) Gurey station

Fig. 4. Comparison water level-discharge relationship by each method.

lated the flow resistance parameter through the observed data and compared and reviewed it with the flow resistance parameters estimated using each equivalent roughness estimated from the three models. Here, we include the assumption that the flow resistance is caused only by grains distributed on the bed, and the slope here was assumed as the uniform flow using the bed slope. Tables 8 ~ 9 show the results of estimating the flow resistance parameters by the equivalent roughness calculated by the numerical integration method for the two stations and the experimental methods. Also, for the flow resistance parameter using the observed data, we calculated the RMSE(Root Mean Square Error) and performed a comparison as in Equation (17).

$$SE = \sqrt{\frac{\sum_{i=1}^{n}(y_{oi} - y_{ci})^2}{(N-1)}} \tag{17}$$

Here, y_{oi} is the observed value, y_{ci} is the calculated value, and N is the number of data.

As a result of the comparison of the flow resistance parameter calculated using the equivalent roughness of each station estimated by the three models with the calculated value through the observed data, we determined that both are comparatively well agreed in two stations. Also, as a result of the comparison by the calculated RMSE, the result using the equivalent roughness estimated by Model 1 applying the numerical integration method for the mean velocity height

Table 8. Comparison of parameter calculated by each method at the Gokseong

Observed						Calculated								
						Model 1			Model 2			Model 3		
Q (m^3/s)	U (m/s)	R (m)	f	C	n	f	C	n	f	C	n	f	C	n
1,340	2.57	2.32	0.0538	38.2	0.0302	0.0531	38.4	0.0299	0.0518	38.9	0.0296	0.0577	36.9	0.0312
1,579	2.83	2.37	0.0451	41.7	0.0277	0.0526	38.6	0.0299	0.0513	39.1	0.0295	0.0572	37.0	0.0312
1,720	2.88	2.50	0.0460	41.3	0.0282	0.0515	39.0	0.0299	0.0502	39.5	0.0295	0.0559	37.4	0.0311
1,910	2.89	2.64	0.0483	40.3	0.0292	0.0504	39.4	0.0298	0.0492	39.9	0.0294	0.0547	37.9	0.0310
2,217	2.98	2.88	0.0495	39.8	0.0300	0.0487	40.1	0.0297	0.0475	40.6	0.0294	0.0528	38.5	0.0309
2,349	2.95	3.01	0.0528	38.5	0.0312	0.0479	40.5	0.0297	0.0467	41.0	0.0293	0.0518	38.9	0.0309
2,649	3.09	3.18	0.0508	39.3	0.0309	0.0469	40.9	0.0297	0.0458	41.4	0.0293	0.0507	39.3	0.0308
2,764	3.20	3.19	0.0475	40.6	0.0299	0.0468	40.9	0.0297	0.0457	41.4	0.0293	0.0506	39.3	0.0308
2,792	3.19	3.20	0.0482	40.3	0.0301	0.0468	40.9	0.0296	0.0457	41.4	0.0293	0.0506	39.4	0.0308
RMSE						0.0041	1.68	0.0012	0.0041	1.71	0.0017	0.0064	2.46	0.0019

Table 9. Comparison of parameter calculated by each method at the Gurey

Observed						Calculated								
						Model 1			Model 2			Model 3		
Q (m^3/s)	U (m/s)	R (m)	f	C	n	f	C	n	f	C	n	f	C	n
1,591.9	1.85	3.08	0.0508	39.3	0.0307	0.0481	40.4	0.0299	0.0469	40.9	0.0295	0.0523	38.7	0.0312
1,821.5	1.95	3.33	0.0495	39.8	0.0307	0.0467	41.0	0.0298	0.0455	41.5	0.0294	0.0507	39.3	0.0311
1,996.5	2.04	3.47	0.0470	40.8	0.0301	0.0459	41.3	0.0298	0.0448	41.8	0.0294	0.0499	39.6	0.0310
2,224.3	2.14	3.69	0.0455	41.5	0.0299	0.0449	41.8	0.0297	0.0438	42.3	0.0294	0.0487	40.1	0.0310
2,441.5	2.26	3.84	0.0425	42.9	0.0291	0.0442	42.1	0.0297	0.0432	42.6	0.0294	0.0480	40.4	0.0310
2,657.1	2.34	3.99	0.0410	43.8	0.0288	0.0436	42.4	0.0297	0.0426	42.9	0.0293	0.0473	40.7	0.0309
2,720.5	2.36	4.05	0.0409	43.8	0.0289	0.0434	42.5	0.0297	0.0423	43.0	0.0293	0.0470	40.8	0.0309
2,976.3	2.50	4.20	0.0380	45.4	0.0280	0.0428	42.8	0.0297	0.0418	43.3	0.0293	0.0463	41.1	0.0309
3,269.5	2.64	4.37	0.0355	47.0	0.0272	0.0422	43.1	0.0297	0.0412	43.6	0.0293	0.0457	41.4	0.0309
RMSE						0.0033	1.68	0.0011	0.0035	1.88	0.0012	0.0063	3.14	0.0022

was calculated to be smaller than the values produced by Models 2 and 3, showing that it is in better agreement with the flow resistance parameter estimated through the observed data.

5. Conclusions

In this study, we reviewed the applicability of the equivalent roughness estimation model we have developed, which considers the flow resistance acting on each grain, characteristics of the grain diameter distribution, and the protrusion height of the grain to an actual stream in order to estimate the equivalent roughness. Also, we compared the model with the existing experimental methods. The results are summarized in the following.

1) As a result of the application of the three models for the estimation of equivalent roughness, the equivalent roughness was estimated in the order of Model 2, Model 1 and Model 3, from the highest to the lowest mean velocity. And, the comparison with $6.80D_{50}$ and $3.50D_{84}$ that has been used as the equivalent roughness showed relatively large differences.

2) To review the applicability of the equivalent roughness estimation model, we compared the results of the estimation for the two stations in the Seomjin River and made the water level-discharge relationship curve applying this to the flow model, and the value estimated the flow resistance parameter using the equivalent roughness. As a result, Model 1 was mostly in good agreement with observed data that it is considered that it is better to estimate the mean velocity height in consideration of grain protrusion height to ensure validity.

3) As a result of the analysis of the equivalent roughness estimated by this model, a relationship with a certain grain size like in previous studies, it all showed different relationships in the two stations, which raises concerns that its estimation of the relationship with a certain grain for a uniform constant would produce errors in the result of the flow analysis.

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