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A study of the influential factors affecting the slopes of deposited sediments behind the porous check dams and model development for prediction

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Abstract

Spacing between check dams depends on the stream bed slope, effective height of check dams and slope of deposited sediments behind the check dams. The slope of deposited sediments is more important than the other two factors because of complications in the way of its occurrence and its measurement after several years of dam construction. This research presents the effective factors affecting the slope of deposited sediments behind 60 selected check dams among 2000 evaluated ones in the watershed of Doroudzan Dam. Such factors as stream bed slope, slope of deposited sediments behind dams, height of check dams, width of stream on the dam site, sand, silt, clay, granule, pebble, cobble and D_{50} of sediments were assessed. Based upon the collected data three models: linear-logarithmic, modified linear –logarithmic and simplified linear-logarithmic, for determining the slope of the deposited sediments as well as the space between check dams were developed and compared. The results showed the factors significantly affecting the slope of deposited sediments are: stream bed slope, height of check dams, stream width, sand, granule and D_{50} of sediments.

Keywords: Check dams; Optimum spacing; Loose rock dams; Doroudzan watershed; Slope of deposited sediments

1. Introduction

Water erosion is the most conspicuous type of land degradation worldwide (Oldman et al. 1991). Gully erosion aggravates off-site damages such as flooding, silting of reservoirs and pollution of streams by increasing the connectivity of the landscape. One of the conservation practices to control sediments is constructing check dams along the streams and gullies. Check dams decrease the velocity of water and, therefore, deposited sediments and change the long profile of the channels (Oldman et al., 1991). Decreasing the stream bed slope reduces the flow velocity and therefore flow shear stress (Ayres and Scoates, 1993). For optimum control of stream long profiles, several check dams should be designed and constructed along each waterway. To do this, the economic spacing between check dams is when the deposited sediments behind the first downstream check dam covers the foot slope of the next dam toward the upstream (Paul et al., 1971). This space depends on the slope of stream bed, effective height of downstream check dam, and slope of the deposited sediment behind the check dam. An estimation of the slope of the deposited sediments is inevitably desired because its accurate measurement is time consuming. Underestimation of this slope brings about overcost in the project (Fig. 1) while its overestimation increases the chance of bed erosion at the foot slope of the upstream dam.

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Woolhiser and Lenz (1965) cited slope ratio from Kaetz and Rich (1939) as a ratio between the sediment slope to channel bed slope which varied between 0.22 and 0.65 behind 22 studied check dams in Arizona, New Mexico, and Utah. Slope ratio was 0.37 for clay sediments while 0.49 for sandy sediments. Heede (1960) based upon field surveying of the loose rock dams, earth dams as well as slab check dams found that slope ratio varies between 0.53 and 0.63 behind structures established on a gully of 9.5 percent bed slope. Whoolhiser and Lenz (1965) using a field study conducted by Amidon (1974) stated that slope ratio would be decrease with increasing channel bed slope. In this field study, the average slope ratio for 100 sites was 0.52 while for 67 sites with bed slopes less than 14% it was 0.66.

To determine the effective factors on the channel bed slope behind check dams in west and southwest of Wisconsin, Woolhiser and Lenz (1965) measured and analyzed some variables such as channel bed slope, sediments slope, stream width behind structure, height of check dam, drainage area of the stream, vegetation inside the channel, as well as clay, silt and sand particles. The results revealed that variables such as channel bed slope, width of stream behind structure and height of check dam had significant impacts.

Ayres and Scoates (1939) reported a balance slope equal to 2% for small gravel, about 1% for fine sand and silt loam, and 0.5% for fine silt and clay. Heede and Muffich (1973) found that only channel bed slope had a remarkable role in the spacing between check dams. Tulu (1999) with field surveying the success and failure of 135 check dams with different spacing and soil textures on 50 gullies with bed slopes between 3 and 6 percent found that the balance slope was affected by channel bed slope as well as by soil type.

The main aim of this paper was to develop the models for estimating the slope of deposited sediments behind the porous check dams that are required for calculation of the spacing between the these check dams.

Fig. 1. Buried check dam in the Duroudzan river basin

2. Materials and Methods

The research area of the study is located in the Southwest of Iran, Northwest of Fars province, between longitudes 51° 40' and 55° 52' East and latitudes 30° 7' and 30° 55' North. This area is a part of Duroudzan river basin and the basin of Kour as well as a part of Maharloo-Backtegan big watershed. The area of the basin of Kour river up to the dam reservoir is about 4522.5 Km^2 (Naseri, 1992). This watershed is one of the most outstanding watersheds in Fars province. The climate of the research area as based on the data collected in the Chamriz station is cold semi-arid. The mean annual precipitation is about 485.7 mm with variation coefficient of 24.8 percent (Haseb, 1995). The studied porous check dams were located in four sub-basins including Abmahi sub-basin (between Tang-e-borugh and Chamriz in the east of Kour river), Ghomeyshloo sub-basin (in the West Kour river), Tang-e-tir sub-basin and Choobkaleh sub-basin. The first two sub-basins comprising 89 percent of the studied check dams are of high erodibility. These two first sub-basins are similar ones regarding soil, geology and vegetation. In these the oldest (more than 27 years old) check dams have been constructed. The research area is covered by Pabdeh-gourpi geologic formation containing marl and shale. The dominant land type is hilly with gradient between 8 and 25 percent and located at the foot slope of the mountains. After field observations of over 2000 check dams, 60 porous check dams were selected. All 60 selected check dams were loose rock dams with the exception of 30 year old gabion check dams in the Abmahi sub-basin.

In order to collect the required information, a survey of the streams and selected check dams was done. Long profiles of streams were prepared using Autocad software based on the surveyed data. Using the provided long profiles, slope of stream bed, balance slope of sediments (by dividing the height difference by the sediment length behind check dams), width of stream behind check dams as well as check dam heights were calculated. Samples of the deposited sediments behind the check dams, with depth increments of 15 cm, were collected in spaces at one fourth of the length of deposition behind check dams, in relation to crest spillway, (as an average sample of deposits) for particle size analysis.

Sediment samples with a weight of about 1 kg were collected. Soil texture was determined by hydrometery and particle size analysis using dry sieve. Variables of sand, silt and clay were determined using hydrometry test.

The percentage of granule, pebble and cobble, as well as the percentage of sand, silt and clay were determined using dry sieve and particle size curve. In order to assess the effects of measured variables on the balance slope of deposited sediments the following regression models were estimated. These models were initially estimated and then their coefficients determined using the collected data from the research.

a) Log-linear model:

$$LnS=C+\alpha_1LnG+\alpha_2LnH+\alpha_3LnB+\alpha_4LnPs_1+\alpha_5LnD_{50}+\alpha_6LnPgr+\alpha_7LnPc+\alpha_8LnPp+\alpha_9LnPs_2 \quad (1)$$

b) Linear model:

$$S=C+\alpha_1G+\alpha_2H+\alpha_3B+\alpha_4Ps_1+\alpha_5D_{50}+\alpha_6Pgr+\alpha_7Pc+\alpha_8Pp+\alpha_9Ps_2 \quad (2)$$

Where S is the balance slope (percent), G the stream bed slope (percent), B is the stream width behind the check dams (meter), while H is the height of check dams (meter), P_{s1} is the sand (percent), P_{s2} the silt (percent), and Pc the clay (percent). P_{gr} is the granule (percent), P_p the pebble and cobble with D_{50} stands for a particle size than which the sizes of 50 percent of the particles are smaller. The obtained data and the data used in model estimation are presented in Table 1.

Mackinnon, White and Davidson (MWD) test was employed to determine the suitable estimation models for determining the balance slope. For this, the variable S (Balance slope for sediments) was fitted with such variables as G, H, Ps_1, Ps_2, Pgr, Pp, Pc and D_{50}.

A sample of this fitting fegarding Log-linear model is presented in Table 2. In this analysis, the variables lacking statistical value were omitted to find a more suitable model, while variable S being subsequently fitted with the remaining variables. The results of the new fitting about log-linear model are shown in Table 3. Also, for presenting a simpler model especially for sites lacking constructed check dams and being limited in data a model with three variables of G, H and B whose measurements is easier was estimated (Table 4). The model estimation was carried out using ordinary least square (OLS) along with Eviews 3 software. The balance slope of the sediments is needed for check dams spacing using equation 3 (Tulu, 1999).

$$L = \frac{100H}{G-S} \quad (3)$$

where L represents the spaces between check dams (m).

3. Results and discussions

The results of MWD test indicated that log-linear model was preferred to the linear model. There was no problem in the surveying of linearity using correlation matrix among variables. Ramsey reset test (for evaluating of existence or non-existence of error in model) was carried out and the results revealed that there was no problem in the estimation model. In this way, the balance slope of sediments (S) as a dependent variable in the log-linear model was fitted with nine independent variables (Table 2).

Table 1. Measured variables of check dams used for model estimation

Check dam no.	Bed slope (%) (G)	Sediment slope (%) (S)	Check dam height (m) (H)	Stream width (m) (B)	D_{50} (mm)	Clay (%) (Pc)	Silt (%) (ps2)	Sand (%) (Ps1)	Granule (%) (Pgr)	Pebble cobble (%) (Pb)
67	2.34	0.41	2.74	37.32	0.42	9	16	53	8	13
26	2.42	1.23	0.62	8.98	2	4	5	42	25	24
65	2.46	0.46	2.07	27.32	0.65	7	14	50	17	12
66	2.54	0.71	2.70	29.87	2	4	7	40	21	29
48	3.40	1.68	0.46	6.14	0.7	27	28	34	10	1
2	3.41	0.83	0.79	5.95	0.53	21	31	36	11	1
21	3.79	1.84	1.13	15.03	0.88	24	26	31	13	6
57	3.98	0.92	1.61	11.16	0.78	31	23	23	13	9
50	4.01	0.83	1.00	10.36	0.9	25	20	32	15	8
49	4.04	0.89	1.04	10.29	0.86	22	22	37	14	4
22	4.28	1.02	1.98	18.03	1.1	11	16	42	20	11
47	4.56	1.96	0.93	7.97	1	10	14	46	17	13
38	4.85	2.30	1.66	9.48	0.52	21	28	38	10	3
7	5.12	1.18	0.74	7.32	0.67	23	28	31	12	5
1	5.25	0.91	1.04	16.98	0.76	15	21	50	13	1
4	5.33	1.04	0.73	6.50	0.53	23	34	34	8	2
24	5.72	1.59	1.04	12.48	1.3	10	16	36	15	23
20	5.80	2.79	1.32	9.44	1.7	17	16	22	19	25
9	5.91	3.11	0.56	7.86	1.7	13	16	24	18	28
51	6.08	2.30	1.02	6.04	0.8	32	25	27	12	4
63	6.40	1.18	1.44	7.85	0.5	28	30	29	11	2
69	6.60	3.62	0.92	5.43	20	6	6	14	8	66
5	6.70	1.50	0.78	4.44	0.54	23	32	40	5	0.5
64	6.86	2.02	1.25	8.77	0.75	24	30	32	12	1
25	6.94	3.41	0.71	21.84	1.35	16	24	24	20	16
37	7.02	1.77	2.15	24.63	0.7	39	25	25	9	2
6	7.08	1.51	0.90	3.81	0.73	21	25	42	10	1.5
52	7.22	4.07	0.53	7.56	0.82	32	25	21	15	7
60	7.36	1.60	0.92	5.80	0.77	8	18	64	9	1
46		2.09	1.56	6.40	1.1	17	19	32	18	14
29	7.36	1.27	1.30	21.65	0.8	17	15	47	17	4
11	4.69	3.47	1.08	9.95	1.3	1	7	60	19	13
70	7.78	2.62	0.74	8.72	0.34	31	25	28	8	9
10	8.02	3.04	1.07	5.59	1.2	17	23	26	17	17
58	8.24	2.15	1.06	6.24	0.55	43	30	18	8	1
8	8.37	3.76	0.92	5.71	0.94	17	25	35	18	4
61	8.46	2.88	1.82	5.51	0.85	22	27	27	18	6
12	8.70	3.80	1.78	16.58	0.86	15	21	32	19	13
30	8.81	3.20	1.04	9.28	1.1	4	5	64	19	8
19	8.92	4.53	1.16	7.17	1.65	20	18	20	22	20
27	9.46	5.48	1.25	5.61	1.55	14	21	23	16	26
72	9.72	4.11	0.61	4.16	15	6	5	15	10	64
53	9.86	6.66	0.69	7.94	0.94	29	27	17	18	8
18	10.34	2.42	0.99	3.21	0.86	20	23	35	17	5
36	10.34	2.84	1.11	6.41	30	3	3	3	8	82
41	11.08	2.75	1.41	5.65	1.25	17	20	29	18	16
16	11.13	3.54	1.20	5.33	0.98	15	10	45	22	8
17	11.35	1.74	0.67	4.08	1.2	24	19	22	18	17
43	11.40	3.03	1.48	6.74	1.2	18	21	31	25	6
73	11.60	7.06	0.96	3.51	0.97	18	13	30	13	26
44	11.88	1.51	1.39	6.70	0.7	25	26	28	10	10
34	12.48	8.34	1.74	11.94	0.83	27	20	32	14	7
32	12.59	6.44	0.84	13.49	1.9	6	11	34	16	33
59	12.61	4.99	0.99	3.57	0.74	20	26	41	11	3
42	13.67	5.88	1.21	8.43	0.94	21	40	14	18	7
14	14.81	6.05	0.88	7.36	0.42	26	20	30	15	10
54	15.46	10.33	0.76	5.33	0.82	37	27	18	12	6
40	17.81	8.19	0.91	3.43	1.2	16	21	31	20	12
31	22.06	15.58	1.05	6.13	1.6	3	4	48	17	28
55	25.27	11.48	1.10	5.01	0.78	37	29	20	8	7

Table 2. Results of estimation by primary log-linear model (model No. 1)

Variables	t statistic	Coefficient	Significance level
Ln G	13.34	1.36	0.01
Ln H	-4.95	-0.53	0.01
Ln B	1.79	0.17	0.10
Ln Ps_1	2.28	0.21	0.05
Ln Ps_2	-0.48	0.08	ns
Ln Pc	0.87	0.09	ns
Ln D_{50}	4.47	0.31	0.01
Ln Pp	0.29	0.01	ns
Ln Pgr	-1.57	-0.2	0.10
constant	-2.34	-2.34	0.01
F= 58.84	R_2=0.91	D_w=1.92	R_2=0.93

ns: not significant

As shown in Table 2, variables of G, H, B, Ps_1, D_{50}, and Pgr significantly affect the balance slope of sediments. Variables of G, B, Ps_1, and D_{50} had a positive effect whi variables H and Pgr negatively affected on the balance slope. The coefficient of variables of G, H and D_{50} in the 99% confidence level and of H and Pgr in the 90% significance level were significant. The coefficient of the variable Ps_1 was significant in the 95% confidence level. The coefficient of variables of Ps_2, Pc and P_p lacked any statistical value. F value indicated the significance of the model in the 99% confidence level. In total, the variable used in the model determined 91 percent of variations in the slope of deposited sediments behind check dams. By replacing the values of coefficients estimated of fitting of S variable, Log-linear model was obtained as follows:

Primary log-linear model (model 1)

$$LnS=-2.34+1.36LnG-0.53LnH+0.17LnB+0.21LnPs_1+0.31LnD_{50}-0.2LnPgr+0.09LnPc+0.01LnPp-0.08LnPs_2 \quad (4)$$

In this analysis, in order to obtain a more suitable model, variables Ps_2, Pc and P_p with no statistical value were omitted and again variable S was fitted with independent variables, G, H, B, Ps_1, D_{50}, and Pgr. The results of the new fitness are shown in Table 3.

As shown in Table 3, the variables G, H, B, Ps and Pgr have significant effect on S statistically. The variables G, B, D_{50} and Ps_1 have a direct relationship while the variables H and Pgr show an inverse relationship with S. The coefficient of variables G, H, D_{50} and Ps_1 at 99% level and the coefficient of variables B and Pgr at 95% level are significant.

F value also indicates the significance of the fitted model in the 99% significance level. Statistic R2 in the modified equation was improved in relation to the equation prior to modification. It indicates the preference of the modified model. Based on this fitness, the modified log-linear model is as follows (model 2):

$$LnS=-2.22+1.38LnG-0.53LnH+0.17LnB+0.17LnPs_1+0.3LnD_{50}-0.18LnPgr \quad (5)$$

Some variables such as G, H and B have a more pronounced effect on S. Their measurement is easier in the field with no need of a lab. Also, their measurement in the sites lacking a check dams is feasible. So the simplest equation based on these three variables was estimated. The results obtained are presented in Table 4 and the final simplified log-linear modified model is shown as Equation (6) bellow.

$$LnS=-2.27+1.38LnG-0.56LnH+0.25LnB \quad (6)$$

Table 3. Results of estimation of modified log-linear model (model 2)

Variable	t statistic	Coefficient	Significant level
Ln G	18.56	1.38	0.01
Ln H	5.25	-0.53	0.01
Ln B	2.05	0.17	0.05
Ln Ps_1	2.43	0.17	0.01
Ln Pgr	-1.93	-0.18	0.05
Ln D_{50}	5.01	0.3	0.01
Constant	-5.35	-2.22	0.01
F= 92.31	R_2=0.92	Dw=1.91	R^2=0.93

Table 4. Results of estimation of simplified log-linear modified model (model 3)

Sig. level	t statistic	coefficient	variable
0.01	14.57	1.38	LnG
0.01	-4.36	-0.56	LnH
0.05	2.34	0.25	LnB
0.01	-6.3	-2.27	Constant
R^2=0.86	$\bar{R}^2$=0.85	D_w=2.3	F= 103.2

As observed in Table 4, all the three variables G, H and B have a significant effect on S. Variables G and H are significant at the 99% confidence level while variable B is significant at a 95% level. The sign of variables G and B is positive which reveals the positive effect of these variables on S. But variable H has a negative effect on the slope of deposited sediments. Statistic F indicates the significance of the model. The value of statistic $\bar{R}^2$ is equal to 0.85. Therefore, it is concluded that 85 percent of the variation in the slope of deposited sediments could be interpreted by variations in three variables of G, H and B. It is obvious that statistic $\bar{R}^2$ of simplified log-linear model is less than that for the other two models. It means simplicity and requirement of fewer variables when there is need for a lower accuracy.
The results of the three cited models are in line with those obtained by Woolhiser and Lenz (1965). In their research in the west and southwest of Wisconcine (USA), they found that three variables, G, H and B had a significant effect on the slope of deposited sediments (S). In their research, the sign of variables B and G was positive while the sign of H negative. In our research based on statistical analysis, three models, log-linear (model1), modified log-linear (model2) and simplified log0linear (model 3) played important roles in the estimation of balance slope of deposited sediments behind check dams. Their estimations were in satisfactory agreement with the data measured in the field.

4. Conclusions

For calculating the space between check dams, the slope of depositing sediments is needed. Balance slope is obtainable several years following dam construction. So determining the balance slope of deposited sediments as well as factors influencing it are needed in different ecological conditions. In the ongoing research, important and effective factors on the sediment slope behind constructed check dams in the Duroudzan dam were surveyed. Three models of log-linear, modified log-linear and simplified log-linear were developed for this river basin. The last model has three variables, measurements of which are simple and feasible without the need for check dam's construction. The results of this research revealed that such factors as stream bed slope, height of dam, stream bed width, sand, granule and D_{50} significantly affected the balance slope of the deposited sediments. Among these factors, bed slope and width of the stream behind check dam had a positive effect while the height of dam a negative effect.

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