International Journal of Water Resources and Environmental Engineering Vol. 1 (2), pp. 027-034, December, 2009
Available online at http://www.academicjournals.org/ijwree
ISSN 1991-637X

Full Length Research Paper

Scouring control of the eroded stilling basin: Case study, Namrood Dam

H. Taebi and M. Fathi-Moghadam*

[1]Graduate Student, School of Water Sciences Engineering, Shahid Chamran University, Ahwaz, Iran.
[2]School of Water Sciences Engineering, Shahid Chamran University, Ahwaz, Iran.

Accepted 15 October, 2009

Local scouring immediately downstream of stilling basin is unavoidable local velocity exceeds incipient motion velocity. This phenomenon causes a difference level between concrete floor of basin and river bed. In such circumstances a riprap is normally used to prevent the development of scouring hole. In this study, hydraulic model of Namrood dam is used to estimate stone size that is able to resist scouring as result of basin turbulent outlet flow. Tail water (y_t), the difference in level between basin floor and river bed (Z) and critical depth of flow in stilling basin (y_c) are required to be measured in order to develop a mathematical model for estimation of scouring. Results confirm considerable reduction of the stone size with increase of (Z) and (y_t) for same flow discharges, while stone size increases with flow discharge.

Key words: Riprap protection, stilling basin, hydraulic jump, stability number.

INTRODUCTION

Scouring in downstream of a stilling basin will gradually degrade the river bed resulting to a difference in level with concrete of the basin floor. Hence, downstream of basin and the whole structure is always vulnerable to scouring and the potential threats caused by scouring. Figures 1 and 2 show pictures of Jafarabad diverging-regulating dam in south west of Iran before and after dam operation, respectively. As it is shown in Figure 2, the scouring has caused 2.5 m difference in level of the basin and river bed.

Many studies have been conducted in the past for estimation of scouring in channels and downstream of the hydraulic structure when the structure bed and the down-stream channel bed are level. Peterka (Chanson, 2008) presented a method to estimate the stone size for riprap to protect downstream of stilling basin against scouring. The flow velocity near the bed was key parameter for estimation of stone size. Since the nature of flow near bed and stones is not clear, the method contains many uncertainties in practice. Rice and Kadavy (1991, 1992) conducted experiments to formulate scouring down-stream of straight drop spillways and riprap design for SAF stilling basins as a function critical flow depth and drop height. Shafai-bajestan and Albertson (1993) carried out several studies on designing riprap for outlet flow from pipes and developed an equation for estimating minimum stone diameter for a stable riprap. Lauchlan and Melville (2001) studied riprap protection at bridge piers. Farhoudi and valizadegan (2004) conducted an experimental work on a physical model of stilling basin leveled with channel bed in order to develop criteria for protection of downstream against scouring. Having Froude Number, riprap diameter that could resist against the outflow can be determined. More studies on grade control of scouring downstream of structures can be found in Maynord (1991) and D'Agos-tino and Ferro (2004).

The purpose of this study is to investigate effects of tail water and difference in level between floor of stilling basin and downstream channel bed on incipient motion of ripraps downstream of basins. The Namrud dam stilling basin model with eroded downstream was used to develop a mathematical model for estimation of stable stone size of riprap.

Dimensional analysis

Size of stable riprap downstream of stilling basin is a

*Corresponding author. E-mail: fathi49@gmail.com. Tel: +98-611-3738359. Fax: +98-611-3365678.

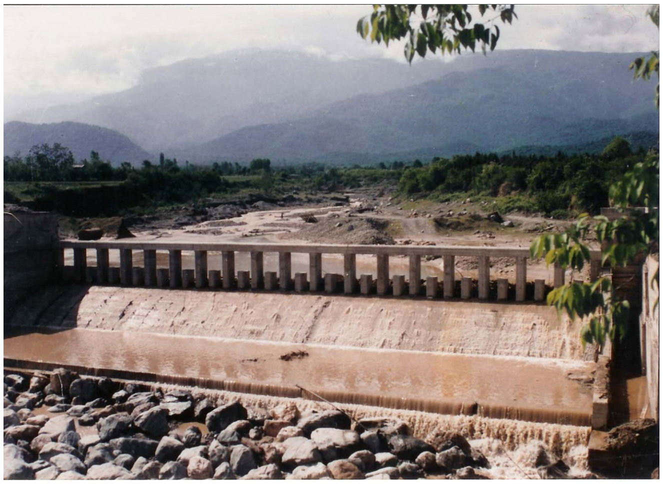

Figure 1. Jafarabad dam - Before scouring

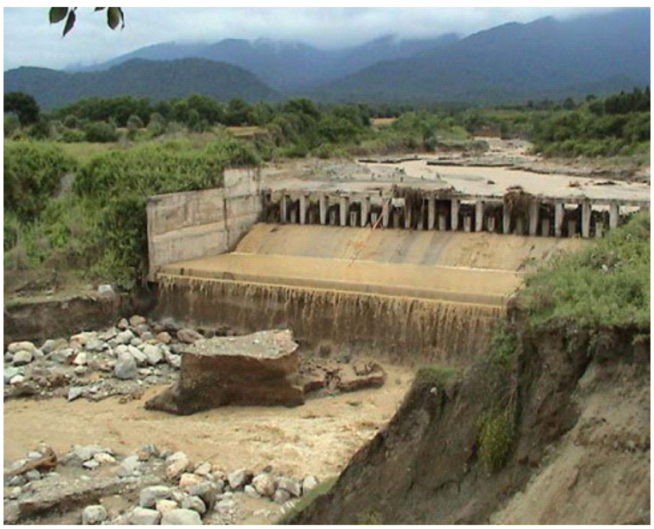

Figure 2. Jafarabad dam - After scouring.

function of flow characteristics, stone material characteristic and river characteristic as follows:

A. Flow characteristics: critical flow depth (y_c), flow velocity (v), water specific density (ρ_w), dynamic viscosity (μ), and gravity (g).

B. Riprap characteristics: stone size (D_s), stone specific density (ρ_s), geometric variance of distributing riprap (σ_g), static angle of riprap particles (ϕ), shape factor (F_s).

C. River characteristics: bed slop(s), bed roughness (n), level difference between basin and downstream bed (Z), river width (B), water depth downstream of stilling basin (y_t), spillway height (H_p), stilling basin length (L_B).

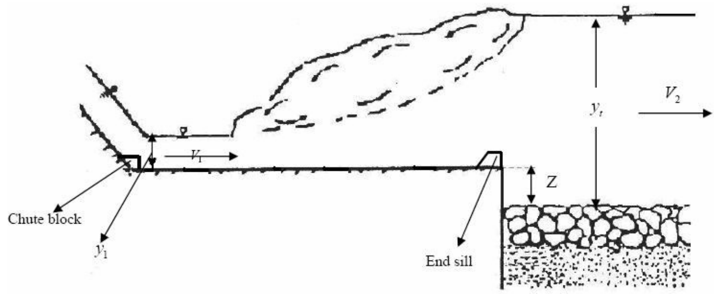

Figure 3. Profile of stilling basin flow and downstream riprap.

The influential parameters on riprap stable downstream of degraded stilling basin are show in Figure 3 and summarized as follow;

$$f(y_c ,V,\upsilon,\rho_w ,g,D_s ,\rho_s ,\sigma_g ,\phi,F_s ,n,Z,y_t ,S,B,H_p ,L_B)=0 \quad (1)$$

Since n (manning roughness coefficient) is a function of stone size, it is ignored; with respect to trivial change in riprap size and to the unifying hypothesis, the same happens to static angle (ϕ) and shape factor of sediment particles (F_s). In present study, bed width downstream of basin is kept constant in all the experiments and bed slop is supposed to be zero; there for, (B) and (S) are ignored in experiments.

For all tested ripraps, geometric variance (σ_g) of particles were calculated to be less than 1.066, thus ripraps used in the study are unified and (σ_g) is cancelled out from analysis.

In the experimental model basin length and spillway level are constant, so the effect of (H_P) and (L_B) can also be ignored.

Since stilling basin floor and downstream bed are not at the same level and flow characteristic are not same within basin and downstream, y_c (calculated based on flow discharge at sub-critical flow inside of basin) is applied as flow depth in basin and y_t as flow in downstream of basin.

$$f\left(y_c ,V,\rho_w ,\upsilon,D_s ,\rho_s ,g,Z,y_t\right)=0 \quad (2)$$

Following dimensionless parameters can be produced from Equation 2,

$$f\left(\frac{D_s}{y_c},\frac{D_s}{y_t},\frac{D_s}{Z},\frac{Z}{y_t},\frac{Z}{y_c},\frac{y_c}{y_t},Fr,S.N,Re\right)=0 \quad (3)$$

Where;

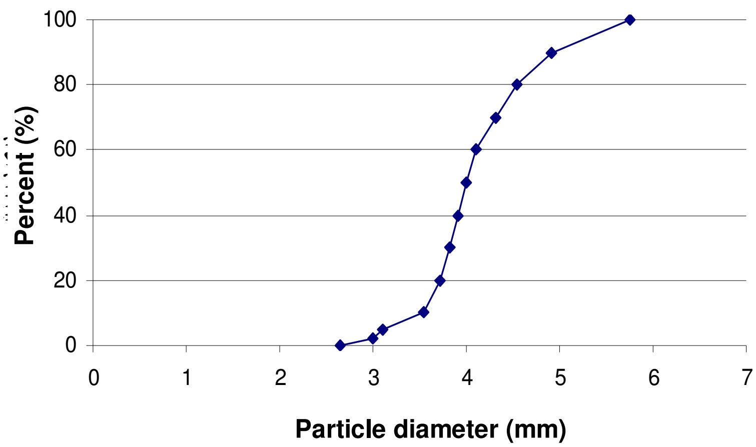

Figure 4. Particle size distribution of riprap material.

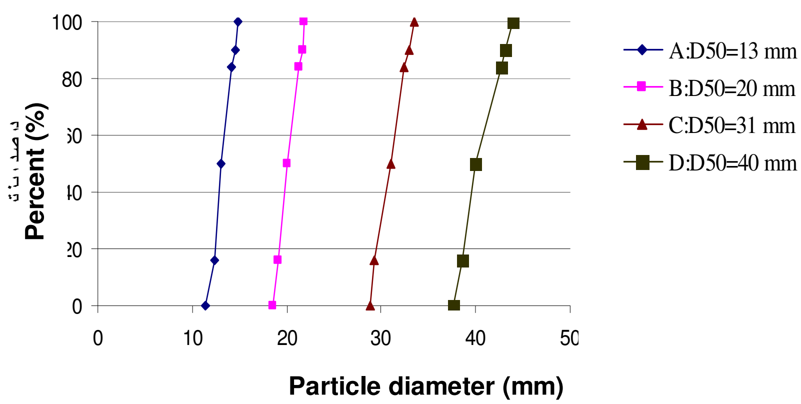

Figure 5. Particle size distribution of bed material.

$$S.N = \frac{V}{\sqrt{(G_s - 1) g D_s}}$$

is Density Froude Number (which is called Stability number in literature) and Gs = g. □s. The seventh and eighth dimensionless parameters stand for Froude Number (Fr) and Reynolds Number (Re), respectively. Since S.N takes car of gravity effect as well, (Fr) is ignored in farther analysis. All flows passing on riprap are turbulent, (Re) is deleted and final form of the equation is:

$$S.N = f\left(\frac{D_s}{y_c}, \frac{D_s}{y_t}, \frac{D_s}{Z}, \frac{Z}{y_t}, \frac{Z}{y_c}, \frac{y_c}{y_t}\right) \tag{4}$$

MATERIAL AND METHODS

To estimate the diameter appropriate for riprap in eroded downstream of stilling basin, the experiments were carried out on a hydraulic model of Namrood dam constructed with scale of 1/40 in Water Research Institute of Ministry of Power of Iran. The characteristic and parts of model are as follows;

- Approach channel
- Ogee
- Chute cannel
- Stilling basin (USBR type II)
- Downstream area
- Check gate
- Bed and riprap material

The bed material were chosen from gravels with a diameter of D_{50} = 4.2 mm in model (0.17 m in prototype). The average diameters of the ripraps were 13, 20, 31, 40 mm in the model, fixed on the top layer of bed material. The particles size distribution of riprap materials and bed materials are shown in Figures 4 and 5.

A Nixon probe micro-propeller was used to measure average flow velocity of downstream of stilling basin the flow velocity was measured in middle direction of the flow, in two depths of 0.2 and 0.8 from water level; then these measures were used to calculate the average flow velocity. 0.8 from water level; then these measures were used to calculate the average flow velocity The experiments were conducted for level differences (Z) of 2.5, 5, 7.5 and

Table 1. S.N correlation and mean square error with individual parameters.

Mean square error *(MSE)*	Correlation coefficient (%)	Independent variable	Dependent variable
0.14	7.8	Z/y_c	$S.N$
0.345	19.1	D_s/Z	$S.N$
0.567	31.4	Z/y_t	$S.N$
1.613	89.5	D_s/y_c	$S.N$
0.563	31.3	y_c/y_t	$S.N$
1.532	85.0	D_s/y_t	$S.N$

Table 2. S.N correlation and mean square error with two parameters.

Mean square error *(MSE)*	Correlation coefficient (%)	Independent variable	Dependent variable
0.795	88.2	$Z/y_t, D_s/y_t$	$S.N$
0.776	86.1	$Z/y_t, y_c/y_t$	$S.N$
0.815	90.5	$Z/y_t, D_s/y_c$	$S.N$
0.831	92.2	$y_c/y_t, D_s/y_c$	$S.N$
0.813	90.2	$D_s/y_t, D_s/y_c$	$S.N$
0.771	85.6	$D_s/y_t, y_c/y_t$	$S.N$

10 cm. So the ratio of z/yt were measured as 2/3, 0.5, 0.4, 1/3, 0.25 and 0.2 respectively. For each (Z), the downstream water depth was increased (decreasing z/yt ratio) to get the best classic jump; for Z=2.5 cm, the experiments were repeated for z/yt = 0.15, and also for Z = 5 cm, there was an experiment for z/yt = 0.15. The experiments were conducted for classic hydraulic jump while hydraulic jump was adjusted so that end of jump exactly corresponds the beginning of riprap downstream of stilling basin then downstream water depth was recorded and z/yt ratio was calculated.

RESULTS AND DISCUSSION

A linear regression process was conducted to evaluate the resulted dimensionless parameters in Equation 4. Table 1 shows result of correlation of individual parameters with S.N. According to the results, z/yt and Ds/yt did not show a significant relation with S.N, that they were deleted from multiple regression analysis.

A multiple regression for two parameters in Table 2 reveals some improvement in MSE and R^2 coefficients. Moreover, result of correlation with three parameters shows a slightly improvement in Table 3, while no improvement was recognized for involvement of more parameters. However, results of most significant correlation of S.N with one, two, and three parameters are summarized in Table 4 for ease in practice. Among all equations in Table 4, Equation 8 is the most useful one due to (a) having variable of Z, and (b) appearance of the stone size (Ds) just in left hand side of the equation. Moreover, based on available parameters in practice, other equations can be used with a trial and error procedure to estimate the required stone size for riprap. The single parameter equations can be just used to get rough idea of scouring when Z is not known.

However, results of most significant correlation of S.N with one, two, and three parameters are summarized in Table 4 for ease in practice. Among all equations in Table 4, Equation 8 is the most useful one due to (a) having variable of Z, and (b) appearance of the stone size (Ds) just in left hand side of the equation. Moreover, based on

Table 3. S.N correlation and mean square error with three parameters.

Mean square error *(MSE)*	Correlation coefficient (%)	Independent variable	Dependent variable
0.541	90.0	$D_s/y_t, y_c/y_t, Z/y_t$	$S.N$
0.557	92.7	$D_s/y_c, y_c/y_t, Z/y_t$	$S.N$
0.554	90.5	$D_s/y_c, D_s/y_t, Z/y_t$	$S.N$
0.564	93.9	$D_s/y_c, D_s/y_t, y_c/y_t$	$S.N$
0.423	93.9	$D_s/y_c, D_s/y_t, y_c/y_t, Z/y_t$	$S.N$

Table 4. Linear regression equations for estimation of S.N.

(*MSE*)	R^2 *(%)*	Formula	Equation number	Number of independent variable
1.613	89.5	$S.N = 1.252 - 0.723\,(\frac{D_s}{y_c})$	(5)	1
1.532	85.0	$S.N = 1.203 - 1.291(\frac{D_s}{y_t})$	(6)	1
0.795	88.2	$S.N = 1.234 - 0.153\,(\frac{Z}{y_t}) - 1.171\,(\frac{D_s}{y_t})$	(7)	2
0.776	86.1	$S.N = 1.673 - 0.597\,(\frac{Z}{y_t}) - 1.105\,(\frac{y_c}{y_t})$	(8)	2
0.815	90.5	$S.N = 1.241 - 0.792\,(\frac{D_s}{y_c}) + 0.105\,(\frac{Z}{y_t})$	(9)	2
0.831	92.2	$S.N = 1.343 - 0.662\,(\frac{D_s}{y_c}) - 0.263\,(\frac{y_c}{y_t})$	(10)	2
0.813	90.2	$S.N = 1.243 - 0.536\,(\frac{D_s}{y_c}) - 0.361\,(\frac{D_s}{y_t})$	(11)	2
0.771	85.6	$S.N = 1.154 - 1.386\,(\frac{D_s}{y_t}) + 0.146\,(\frac{y_c}{y_t})$	(12)	2
0.564	93.9	$S.N = 1.503 - 1.178(\frac{D_s}{y_c}) - 0.642(\frac{y_c}{y_t}) + 1.169(\frac{D_s}{y_t})$	(13)	3

available parameters in practice, other equations can be used with a trial and error procedure to estimate the required stone size for riprap. The single parameter equations can be just used to get rough idea of scouring when Z is not known.

Figure 6 illustrates graphical relation of S.N with z/yc for number of dimensionless degradation parameters, and Figure 7 shows variation the stone size with critical water depth for same number of degradations. Both figures confirm a minor nonlinearity or relationship between parameters. Figure 6 confirms reduction of stone size with increase of (Z) and tail water (y_t) for same flow discharges, while Figure 7 demonstrates increase of stone size with discharge. Alternatively, Figures 6 and 7 can be used to estimate the required stone sizes based on the available parameters. Since estimation of velocity over riprap for calculation of S.N contains many uncertainties, application of Figure 7 has advantage over Figure 7.

Comparison of the results with previous studies: Previous studies by large have investigated incipient motion and scouring for the stilling basins leveled with the downstream channel bed, and have suggested different coefficients of (a) and (m) for following equation.

$$\frac{V}{[\,g(G_s - 1)D_s\,]^{0.5}} = a(\frac{y_t}{D_s})^m \qquad (14)$$

In order to show effect of degrading level (Z) on scouring and S.N, experimental results of this study are correlated

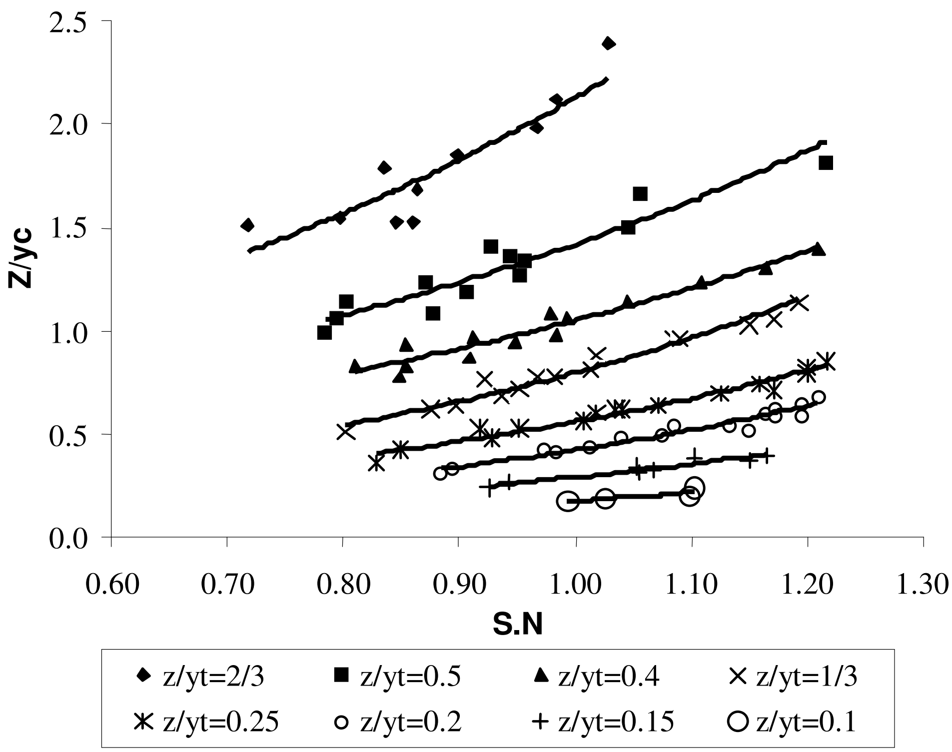

Figure 6. Relation of S.N with z/yc for variable ratio of_z/yt.

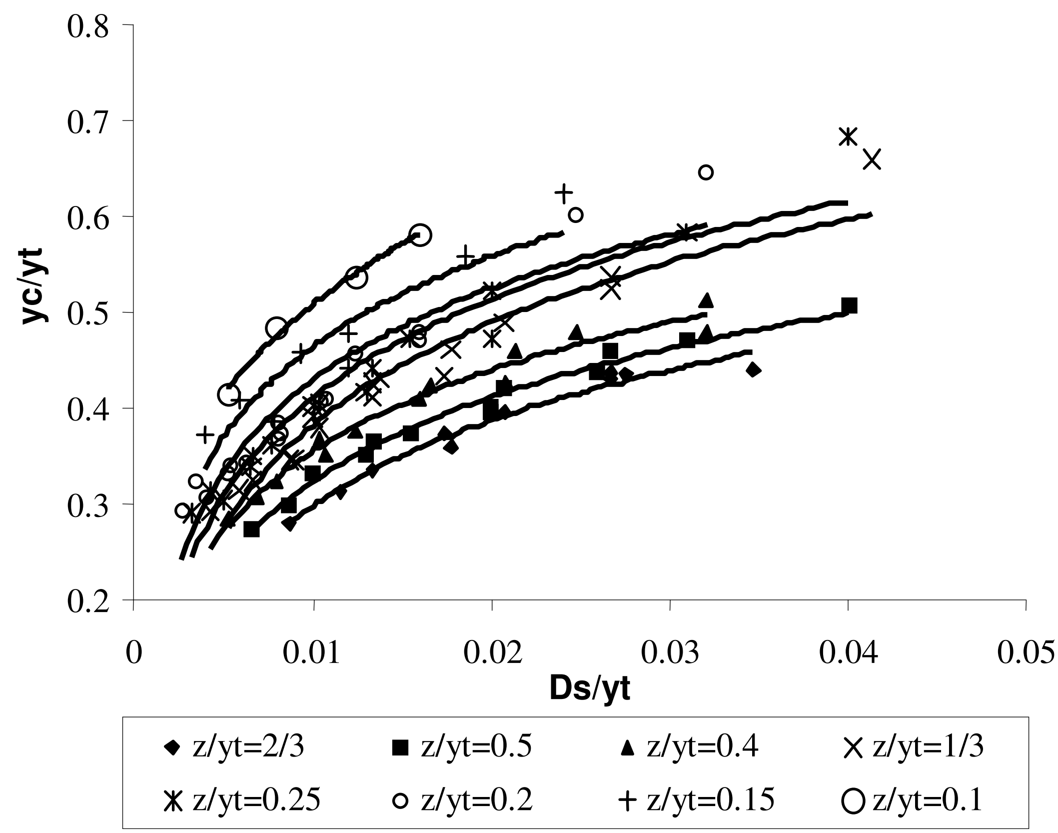

Figure 7. Relation of Ds/yt with z/yc for variable ratio of z/yt rations.

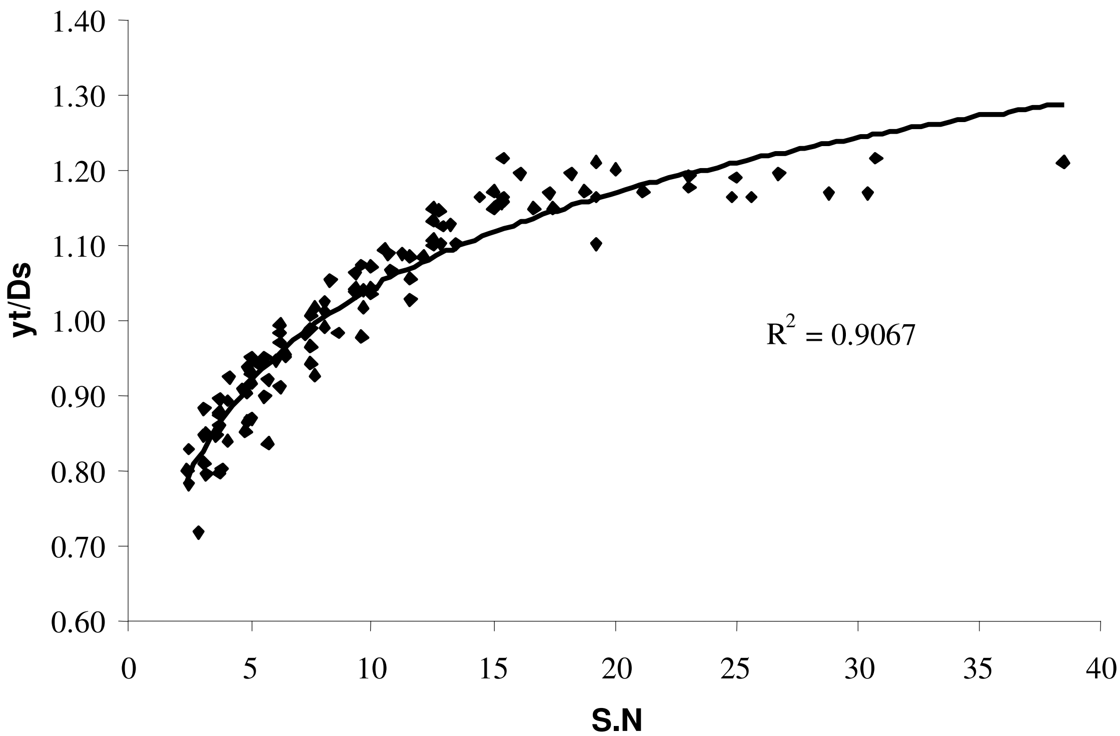

Figure 8. y_t/Ds verses S.N for all degrading levels (Z).

based on same parameters in Equation 14 (that is, Z affects the correlation indirectly) and following coefficients for (a) and (m) were calculated.

$$S.N = 0.68(y_t/D_s)^{0.18} \qquad (15)$$

The graphical illustration of Equation (15) is shown in Figure 8. For a particular riprap, decrease of S.N (that is, decrease of flow velocity) with tail water is observed in Figure 8. The suggested coefficients of (a) and (m) for the leveled stilling basins from previous studies in Brown and Clyde (1989) are compared with calculated coefficients of this study in Table 5. A considerable variation of coefficients with previous study confirms significant effect of degrading on increase of S.N. in this study. This means that scouring is reduced with increase of (Z) for particular tail water.

Conclusion

Results of this study reveal considerable effect of degradation on scouring of channel bed downstream of the stilling basins. This finding disqualifies application of previous methods and equations which by large have been developed for condition of leveled basin floor with the downstream channel bed. A linear relationship proposed for scouring and estimation of size for stable riprap. Alternatively, nonlinear relations of the involved dimensionless parameters are presented graphically which can be used to estimate size of riprap based on available filed information. Since estimation of velocity near bed in S.N is difficult in practice, Figure 7 can be used to estimate the stable stone size based on critical flow depth. However, to some extends results reveal a decrease of scouring as degradation level (Z) increases. In general, previous findings such as increase of scouring with decrease of tail water and increase of discharged are confirmed in this study.

Table 5. (a) and (m) coefficients for Equation

Researchers	m	a
Isbash	0	1.7
Straub	0.17	1.49
Neill	0.1	1.58
Bogardi	0.095	1.7
Maynord	0.1	3.33
Current Study	0.18	0.68

ACKNOWLEDGEMENT

The authors would like to acknowledge Shahid Chamran University of Ahwaz, Iran for financial support of the research (Grant No. 696) and the Research Institute of the Ministry of Power of Iran for facilitation of the experiments.

REFERENCE

Agostino D, Ferro V (2004). Scour on Alluvial Bed Downstream of Grade-Control Structures J. Hydraulic Eng. 130 (1): 24-37.
Brown SA, Clyde ES (1989). Design of RipRap Revetment. Hydraulic Engineering Circular No, 11, Federal Highway Administration. McLean, Va., USA p156.
Chanson H (2008). Hydraulics of Open Channel Flow: An Introduction – Basic Principles, Sediment Motion, Hydraulic Modeling, Design of Hydraulic Structures, 2nd ed., Butterworth Heinemann pub., Oxford, UK, p 650.
Farhoudi J, Valizadeghan E, (2004). "Bed protection criterion down-stream of stilling basins", Proc. 9th ISRS conference, China.
Lauchlan CS, Melville BW (2001). Riprap Protection at Bridge Piers J. Hydraulic Eng. 127 (5): 412-418.
Maynord ST, (1991). "Flow resistance of riprap", J. Hydraulic Eng., ASCE, 117 (6).
Rice CE, Kadavy KC (1991). "Riprap design downstream of straight drop spillways", Trans. ASCE 34(4): 7-12.
Rice CE, Kadavy KC (1992). "Riprap design for SAF stilling basins", Trans. ASCE, 35 (6): 1817-1825.
Shafai-Bajestan M, Albertson ML (1993). "Riprap criteria below pipe outlet", J. Hydraulic Eng., ASCE 119 (2): 181-200.