



Design of riprap for stilling basins

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Abstract

Downstream of stilling basin is projected to the sever scouring as results of high kinetic energy leaving the basin. This scouring, normally causes degradation of the channel bed immediately downstream of the basin. The progress of degradation will affect design criteria and size of riprap for control of scouring. Experiments were conducted to evaluate the effect of the degradation level on the bed shear force and size of the riprap required to protect scouring. Results revealed increase in incipient motion of riprap as degradation level and tail water was increased.

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

Introduction

Local scouring immediately downstream of stilling basin is unavoidable when local velocity exceeds incipient motion velocity. Hydraulic jump and energy dissipation within the basin is always accompanied with high flow turbulence. The resulting turbulence causes a drastic increase in shear stress rather than instant local shear stress of incipient motion of the particles and consequently, downstream of stilling basin bed is scoured. This phenomenon causes a difference level between concrete floor of basin and river bed. Hence river protection is a necessary process to prevent scouring. One of the common and economic methods to do so is using riprap. Though the safety dimension makes it a better choice to use larger stones, from economical dimension, it is required to use the safe stones with the smallest diameter able to resist turbulent flows. The purpose of this study was to estimate the minimum stone size able to resist scouring in downstream of stilling basin previously eroded.

Peterka ¹ 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 the 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 ^{2,3} conducted experiments to formulate scouring downstream of straight drop spillways and to design riprap for SAF stilling basins as a function critical flow depth and drop height. Shafai-Bajestan and Albertson ⁴ 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 ⁵ studied riprap protection at bridge piers. Farhoudi and Valizadegan ⁶ conducted experiments on a scaled 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 could be determined. More studies on grade control of scouring downstream of structures can be found in Maynard ⁷, and D'Agostino and Ferro ⁸.

The purpose of this study was to develop a mathematical model for estimation of stable riprap downstream of stilling basin where the channel downstream of the basin is degraded below the basin bed. The results will be compared with the field studies of Peterka ¹, and the laboratory experiments conducted by Pilarczyk ⁹ and Escarameia ¹⁰ on leveled stilling basins. This will allow to detect degrading effect on stability of the riprap.

Dimensional Analysis

Function (1) formulates the parameters affecting riprap resistance in downstream of stilling basin:

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

in which critical flow depth (y_c), flow velocity (v), water specific density (ρ_w), dynamic viscosity (μ), gravity (g), 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), 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). The parameters being unchanged or dependent, they have been removed from analyses and following equation is achieved

$$f(y_c, V, \rho_w, \nu, D_s, G_s, g, Z, y_t) = 0 \quad (2)$$

in which G_s is specific weight of submerged stone. The normalization of the parameters produces following equation:

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

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

is Density Froude number (which is called stability) and the seventh and eighth dimensionless parameters stand for Froude number (Fr) and Reynolds number (Re), respectively. Since $S.N$ takes care of gravity effect as well, (Fr) is ignored in further analysis. Flow being turbulent over riprap, Re will not be considered and final form of the equation is:

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

Materials and Methods

To estimate the appropriate diameter 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 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 and 40 mm in the model, fixed on the top layer of bed material. 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 m 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 10 cm. So the ratio of z/y_t was measured as 0.67, 0.50, 0.40, 0.33, 0.25, 0.20, 0.15 and 0.10, respectively. For each (z), the tail water depth was adjusted to prevent jumps swept out of the basin. This has limited number of data for $z = 2.5$ and 5.0.

The experiments were conducted for classic hydraulic jump while hydraulic jump was adjusted so that the end of jump exactly corresponds to the beginning of riprap downstream of stilling basin; then downstream water depth was recorded and z/y_t ratio was calculated.

Fig. 1 depicts stilling basin and the way riprap was placed in levels lower than basin floor, which is disposed to scouring caused by hydraulic jump.

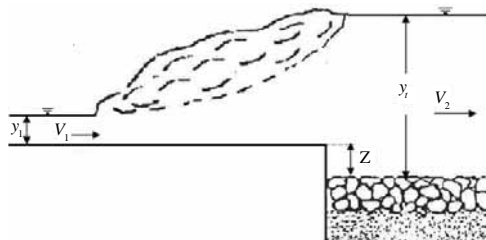


Figure 1. Profile of stilling basin flow and downstream riprap.

Results and Discussion

A linear regression process was performed to evaluate the effect of individual dimensionless parameters on stability number in Eq. 4. The effects z/y_t and D_s/z did not show to be significant and they were removed from multiple regression analysis.

A multiple regression for two parameters in Eq. 4 on stability number revealed minor improvement, while the correlation with three parameters showed a slightly improvement in MSE and R^2 coefficients. No improvement was recognized for involvement of more parameters. However, results of correlation of $S.N.$ with one, two and three parameters showed the following equation to be the most useful one due to involvement of most significant parameters and ease in practice.

$$S.N = 1.67 - 0.59 \left(\frac{Z}{y_t}\right) - 1.10 \left(\frac{y_c}{y_t}\right) \quad (5)$$

The previous studies have concentrated on the leveled basin bed with the downstream channel. To evaluate effect of degradation on scouring, the proposed equations by Peterka¹, Pilarczyk⁹ and Escarameia¹⁰ were used to calculate the incipient motion velocities for riprap used in the present study. Fig. 2 demonstrates comparison of the present studies for calculation of incipient motion with previous researchers. A considerable increase of incipient motion is demonstrated in the figure as result of degradation of channel downstream of the basin. The figure also reveals increase of the incipient motion with increase in level of degradation. A considerable difference of the Peterka¹ results with others in the figure is most likely due to the large scale of the field measurements when it is being compared with other studies in a small laboratory scale.

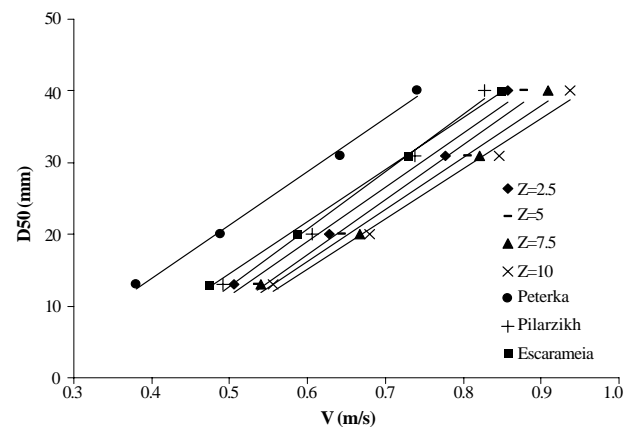


Figure 2. Incipient motion velocity versus riprap size.

Conclusions

The following findings were acquired from the analysis of the results in this study:

- In general, increase in tail water depth increases the incipient motion of stones, thus increases the stability of riprap materials.
- For a given tail water depth (y_t), incipient motion of the riprap materials increases as degrading level (z) is increased. This is due to the decrease in bed shear stress with increase in (z).
- Comparison of the results with previous studies on the leveled

- stilling basins reveals a considerable effect of (z) on incipient motion of the materials
- The proposed equation is able to estimate the riprap materials with minimum possible of field measurements of y_1 , z and Q .
 - Observations confirmed decrease of incipient motion to some extent as hydraulic jump was swept out of the basin.

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Notations:

- B = river width
 D_s = stone size
 Fr = Froude Number
 F_s = shape factor
 g = gravity
 G_s = specific weight of submerged stone
 H_p = spillway height
 L_B = stilling basin length
 n = bed roughness
 Re = Reynolds Number
 s = bed slope
 $S.N$ = Density Froude Number, or Stability number
 V_1 = flow velocity before jump
 V_2 = flow velocity after jump
 y_1 = flow depth before jump
 y_2 = flow depth after jump
 y_c = Critical flow depth
 y_t = water depth downstream of stilling basin
 Z = level difference between basin and downstream bed
 ρ_w = water specific density
 ρ_s = stone specific density
 μ = dynamic viscosity
 σ_g = geometric variance of distributing riprap
 ϕ = static angle of riprap particles