A NEW CONCEPT IN THE DESIGN OF STONE SIZE FOR RIPRAP BANK PROTECTION

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Abstract

This paper presents a new empirical formula for the design of Riprap bank protection. The theory of critical velocity (Yang, 1973) was applied instead of the well known theory of the critical shear stress (Shields parameter). The relative roughness in term of roughness height to water depth and turbulent effects are taken into consideration in form of the universal logarithmic velocity distribution. For the verification of the developed formula, the data of Mae Kong river bank protection at Chiang-Rai, Nong-Kai, and Nakorn-Phanom provinces in the northeast of Thailand were used. It was found that the present formula gives reasonable results compared to the existing formula.

1 Introduction

Riprap is the term given to loose rock armor, usually obtained by quarrying. It continues to be the most widely used for protection of erodible channel boundaries. Riprap is normally placed by machine. The major advantage of riprap is that it is very flexible, so that damage tends to occur gradually and, as stones can move relative to one another, is to some extent self-healing. This allows maintenance work to be carried out on a routine basis. However, for the protection using concrete blocks. This requires to prevent widespread progressive failure once localised failure occurs.

The theory of critical shear stress is frequently used in the riprap design(Office, Chief of Engineers, 1970) because it deals with the force on the channel boundaries. However, several investigators(Meyer-Peter and Muller, 1948; Bogardy, 1978; Bettess, 1984) have demonstrated that the Shields parameter or the dimensionless shear stress is not constant as used in many riprap design procedure but varies directly with the relative roughness. Therefore, many existing design procedures may apply over a limited range of the relative roughness.

Instead of the use of the critical shear stress, the present study uses the theory of the critical velocity developed by Yang(1973). To include the effect of turbulence, the universal logarithmic velocity distribution is adopted resulting in a non-linear implicit equation. The solution is, then obtained easily by Newton's method. Verification of the developed formula is made by using the data from Mae Kong river bank protection. Comparisons are also made among the previous formulae.

2 Method of study

2.1 Dimensional analysis

The pertinent variables applicable to the stability of coarse particles are

$$f(D, h, \rho, V, \gamma_s', z_o) = 0 \qquad (1)$$

where D = mean stone size, h = water depth, ρ = water density, V = characteristic velocity, γ_s' =(γ_s - γ_w), γ_s, γ_w = specific weights of stone and water respectively, z_o = roughness height of stone.

General equation of the relative stone size can be expressed by(on using V, h, and γ_s' as repeating variables).

$$\frac{D}{h} = f'(\frac{V^2}{gh}, \frac{\gamma_s - \gamma_w}{\gamma_w}, \frac{z_o}{h}) \qquad (2)$$

Equation (2) indicates the important of the relative roughness(z_o/h) in determination of the stone size.

2.2 The critical velocity concept

The boundary shear stress(τ_b) for a uniform flow can be written as

$$\tau_b = \rho g h S_f \qquad (3)$$

where S_f = friction slope

For a rough turbulent flow, the velocity distribution follows the universal logarithmic law, i.e.

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{z}{z_o} \qquad (4)$$

where u = flow velocity at height a above the bottom, u_* = bottom shear velocity, κ = von Karman constant, and z_o = roughness height.

Yang(1973) demonstrated that for a completely rough turbulent regime, the critical velocity(U_c) can be expressed by

$$\frac{U_c}{\omega} = C_u \qquad (5)$$

where ω = fall velocity of the particle, C_u = empirical constant(2.05)

By integration Eq. (4) and inserting Eq. (5), the critical bottom shear stress(τ_c) can be written from the definition $\tau = \rho u_*^2$ as

$$\tau_c = \rho \left(\frac{C_u \omega \kappa}{\ln \frac{h}{z_o} + \frac{z_o}{h} - 1} \right)^2 \qquad (6)$$

The fall velocity(ω) for the turbulent flow (Gruat et al., 1970) can be expressed by

$$\omega = C_\omega \left\{ gD(\frac{\rho_s - \rho}{\rho}) \right\}^{1/2} \qquad (7)$$

where C_ω = empirical constant, ρ_s and ρ = density of stone and water

Combination of Eqs. (3), (6), and (7), the relative stone size(D/h) can be obtained as

$$\frac{D}{h} = C \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{gh}} \left\{ \ln\left(\frac{h}{z_o} \right) + \frac{z_o}{h} - 1 \right\} \right]^3 \qquad (8)$$

$$C = \left\{ \frac{1}{\Omega^{0.5}} \frac{g^{0.5}}{k_n} \frac{1}{\kappa C_u} \frac{1}{C_w} \right\}^3 \qquad (9)$$

$$\Omega = \{1 - (\sin^2 \alpha / \sin^2 \theta)\}^{1/2} \qquad (10)$$

where V = averaged near bank velocity, α = bank slope angle, θ = angle of repose of bank material, k_n = empirical in the Manning-Strickler equation, i.e.

$$n = \frac{1}{k_n} D^{1/6} \qquad (11)$$

Equation (8) is similar to the general equation(Eq. (2)) and will be used to find the mean stone size in the present study. Because the roughness height is normally a function of the stone size($z_o = k_s/30 = D/30$, Chow(1957)). The solution, therefore, can not be explicitly computed. However, with the application of

Newton's method, the solution can be obtained easily.

3 Results and discussions

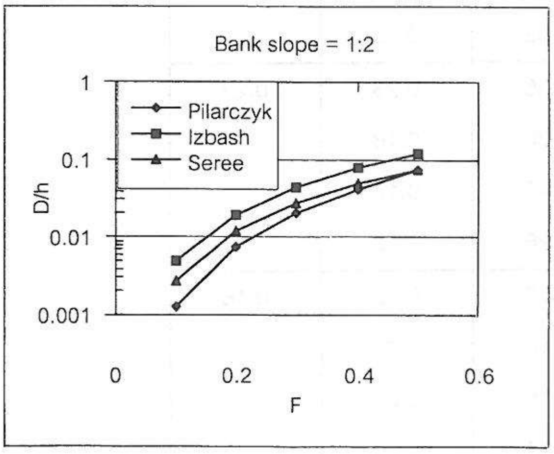
Figure 1 shows examples of the relationship between the relative mean stone size to the water depth(D/h) and the Froude number(F). For practical ranges, the Froude number is varied from 0.1 to 0.5. The well known equation of Pilarczyk(1984)(Eq. 12, PIANC, 1987a) and also Izbash's formula(Eq. 13, Izbash, 1970) are also verified in the same figure. The angle of repose of the bank material is set equal to 35 degrees. The bank slope is varied from 1 : 2 to 1 : 3.5.

$$D = \frac{\phi_c K_T}{\Delta K_s} \frac{0.035}{\theta_c} \frac{V^2}{2g} \qquad (12)$$

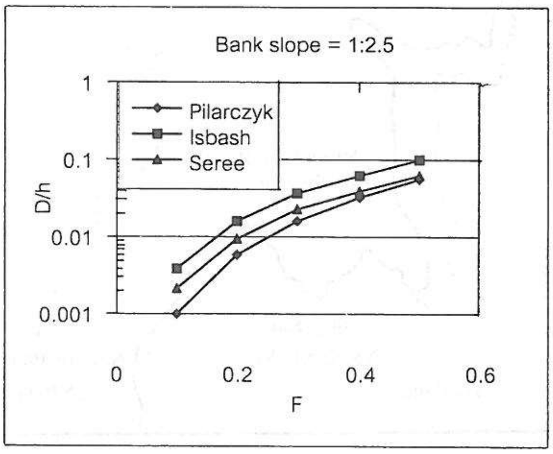
$$D = \frac{b}{K_s} \frac{V^2}{2g\Delta} \qquad (13)$$

where ϕ_c = stability factor, K_T = turbulence factor, K_s = slope factor, $\Delta = (\gamma_s - \gamma)/\gamma$, θ_c = Shields parameter, b = degree of turbulence

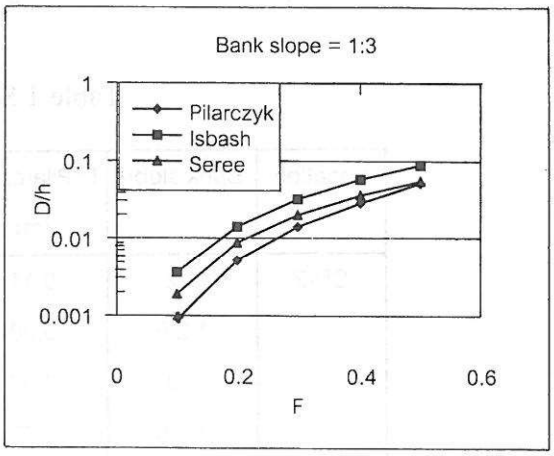
It is found that the present study results give compromise results between Pilarczyk's and Izbash's. It is also noticed that the more Froude number, the closer of the results between the present study and Pilarczyk's.



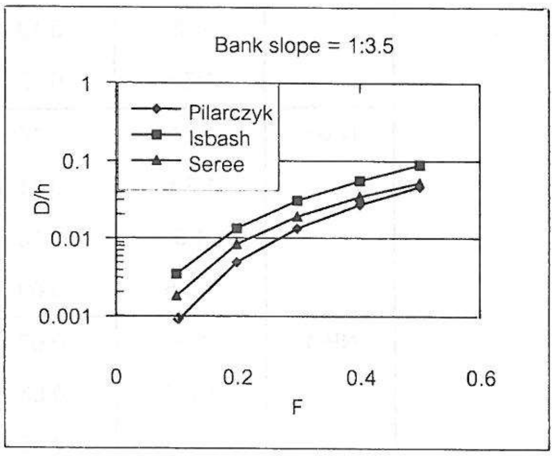
a) Bank slope 1:2



b) Bank slope 1:2.5



c) Bank slope 1:3



d) Bank slope 1:3.5

Fig. 1 Relationship between D/h and F

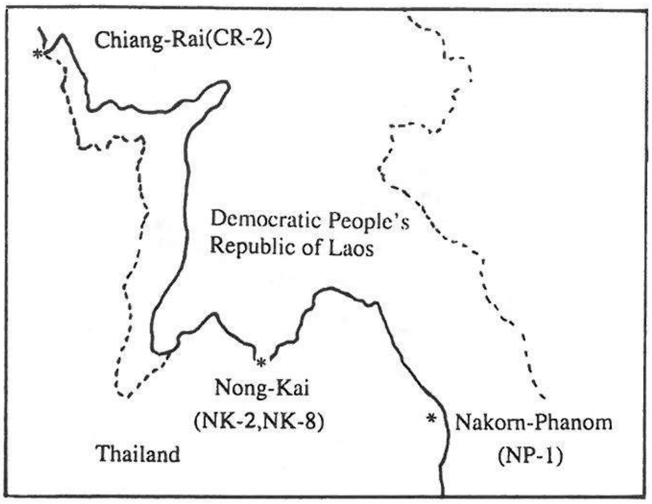


Fig. 2 Study location

For field investigation, data from Mae Kong river bank protection at Chiang-Rai, Nong-Kai, and Nakorn-Phanom provinces(see Fig. 2) were used to verify Eq. (8).

Table 1 shows comparisons of the mean stone size among the three formulae. It is again found that the mean stone size computed by the present formula are smaller than Izbash's but a little greater than Pilarczyk's which was used in the design for these four locations . In general, the use of Pilarczyk's and Izbash's need experienced engineer. This is because some parameters in those two formulae, i.e. the Shields parameter and degree of turbulence have to be defined before hand. This, in practical, creates difficulties. On the contrary, the present study does not use the Shields parameter. The turbulence effects are also taken into consideration in form of the universal logarithmic velocity distribution.

Table 1 Stone size comparisons

Location	Bank slope	D(Pilarczyk) (m)	D(Izbash) (m)	D(Present) (m)	Froude no. F
CR-2	1:2	0.11	0.28	0.18	0.19
	1:2.5	0.08	0.23	0.14	
	1:3	0.07	0.21	0.13	
	1:3.5	0.07	0.20	0.12	
NK-2	1:2	0.18	0.44	0.28	0.24
	1:2.5	0.14	0.36	0.23	
	1:3	0.13	0.33	0.21	
	1:3.5	0.12	0.32	0.19	
NK-8	1:2	0.14	0.36	0.23	0.22
	1:2.5	0.11	0.30	0.18	
	1:3	0.10	0.27	0.17	
	1:3.5	0.09	0.26	0.16	
NP-1	1:2	0.07	0.20	0.12	0.16
	1:2.5	0.05	0.16	0.1	
	1:3	0.05	0.15	0.09	
	1:3.5	0.04	0.14	0.08	

4 Conclusions

A new formula for the calculation of stone size in the design of Riprap bank protection was developed. The theory of critical velocity(Yang, 1973) was applied instead of the well known theory of the critical shear stress (Shields parameter). The turbulent effects have also been taken into consideration in term of the universal logarithmic velocity distribution. It was found that the present study results gave compromise results between Pilarczyk(1984) and Izbash(1970). For the verification of the developed formula, the data of Mae Kong river bank protection at Chiang-Rai, Nong-Kai, and Nakorn-Phanom provinces were used. Comparisons among the three formulae indicate more advantage of the present developed formula than the previous two formulae.

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