Size And Weight Of Loose And Wire Crated Stone Matress For River Bank Protection

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ABSTRACT

Stone pitching are popularly used for river bank protection preventing erosion of bed and bank during passage of flood. Now-a days, stone mattress in wire crated mesh are also being extensively used in place of loose pitching because of several advantages.. Size and weight of stone and thickness of mattress on sloping and launching apron are to be found so that it can resist the erosive forces for stability. IRC and IS codes recommend formulae for computing size and weight of stones in terms of mean flow velocity. However, Pylarczyk and other research scientists have proposed equations not only in terms of velocity but several other parameters governing stability. Starting from fundamentals, author has derived the basic equations, compared with IRC , IS and Pylarczyk's equations. He has also introduced drag concept in computing size and weight of stones and thickness of stone mattresses for both rough and smooth surfaces. An example has been worked out with some assumed data and the size and weights found by different methods have been compared in a table which also includes required thickness of mattress having rough and smooth surfaces.

Key Words: Stone pitching, size and weight of stones, sloping and launching apron, mattress thickness

1.0 INTRODUCTION

One of the major causes of flooding and flood damages is scouring and breaches in embankments in rivers. Use of loose stone pitching/mattress is a common practice to prevent erosion for protection of river banks and embankments. Now-a-days, stone gabions made up of packed stones in GI double twisted wire mesh have also been popular, since size and weight of loose stones are too high resulting in handling and placement difficulties. In case of gabions, smaller stone size (depending upon the mesh size) can be used. Wire crates are machine made with galvanized wire of about 3 to 4mm size with sufficient tensile strength, flexibility and resistance against puncturing.

Indian codes e.g.:IRC-89(1997) and IS: 14262(1995), IS8408(1994), IS10751(1994), IS 12094 (2000), specify size and weight of stones in terms of mean flow velocity of in the river in order to prevent dislodgement of stones used in banks, guide bunds, flood and approach embankments etc. Stone pitching, also known as rip-rap, is also used in earthen dams, bridge piers and abutments and approach embankments in bridges on wide flood plains. Some of the important criteria which govern the performance of pitching/ mattresses are size and weight, gradation, shape and angularity and proper placement over a layer of either graded filter or geo-synthetic textile (woven or non-woven, depending upon size of river bed/bank materials).to prevent winnowing of the bed/bank materials through the pores and joints of pitching/mattress.

Chitale (2006), Maynord (1989),Mittal and Kothyari(2003), US Army Core of Engineers (1989,1991a), Austoroads (1994) etc. have developed several equations for finding size and weight of stones. Pylarczyk (1997) made most exhaustive study and proposed a unified general equation in terms of several parameters e.g. stability factor, bank slope factor, turbulence factor, critical tractive stress factor, velocity profile factor, and roughness factor.

In this paper, author has made an attempt to derive from fundamentals the size and weight of stones in pitching/mattress and compare them by different methods. At the end, a specific case has been taken up by assuming some river flow data.

2.0 SIZE AND WEIGHT OF STONES ON SLOPING PLAIN

Size and weight of stones lying on side slope should be sufficient so that it does not get dislodged from its position due to erosive forces owing to forward flow drag as well as the component of its own weight trying to pull down the stone along the slope. Referring to Fig.1, a stone 'P' lying on the side slope are subjected to the following forces:

(i) Self weight – Ws

(ii) Component of self weight along the sloping plain – Ws Sin θ

(iii) Flow drag in the forward direction - $F_d = \tau_0 a_s$

Where, θ = angle of inclination of the side slope with horizontal, τ_0 = tractive or shear stress along flow

a_s = area of stone normal to flow = $(\pi / 4) D^2$, where D is the diameter of a stone assumed to be spherical.

Resultant force (R) acting on the inclined plane is given by

$$R = (Ws^2 \sin^2 \theta + \tau_0^2 a_s^2)^{0.5} \tag{1}$$

Resisting force (F_R) on the particle due to its angle of internal friction (ϕ) is given by

$$F_R = Ws \cos \theta \tan\phi \tag{2}$$

Under equilibrium condition, $R = F_R$

Therefore, from equations (1) and (2)

$$(Ws^2 \sin^2 \theta + \tau_0^2 a_s^2 = Ws^2 \cos^2 \theta \tan^2 \phi$$

or, $$Ws = \tau_0 a_s / (\cos^2 \theta \tan^2 \phi - \sin^2 \theta)^{0.5} \tag{3}$$

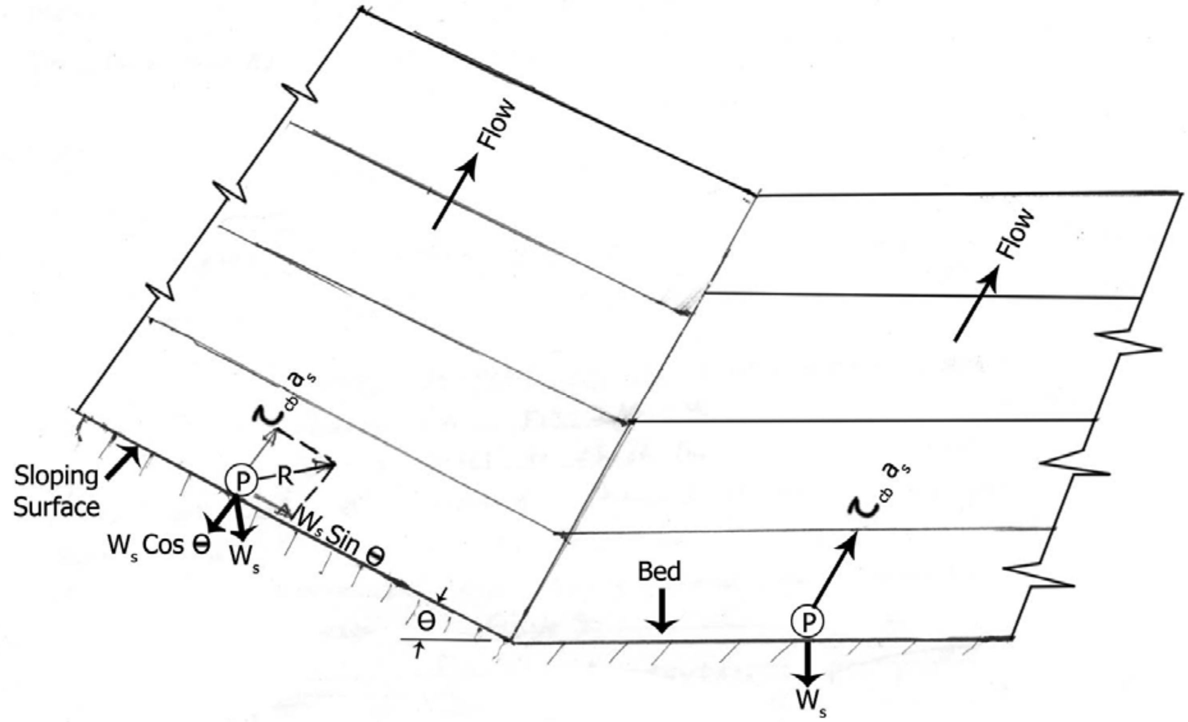

Fig. 1, Showing the various forces on a particle 'P' line on bed and sloping surface in a straight channel.

In turbulent flow,

$\tau_0 = kV^2$ and putting $(\cos^2\theta \tan^2\phi - \sin^2\theta)^{0.5} = k_0$

$$Ws = C\,V^2 \qquad (4)$$

where,

$C = (k/k_0)\, a_s = (k/k_0)\,(\pi/4)\, D^2$

For the stability of the particle, θ must be less than ϕ. It may be noted that as θ- value increases, k_0 decreases and hence weight Ws of stone will increase.

For spherical stones, $a_s = (\pi/4)\, D^2$ and $Ws = (\gamma_s - \gamma)\,(\pi/6)\, D^3$ (5)

Therefore,

$$(\gamma_s - \gamma)\,(\pi/6)\, D^3 = CV^2\,(\pi/4)\, D^2$$

Or, $D = 3/2((\gamma_s - \gamma)\, CV^2$

i.e $D\ \alpha\ V^2$ (6)

and $Ws\ \alpha\ V^6$ (7)

where, γ_s and γ are unit weights of stones and water respectively.

2.1 Weight of Individual Stone on Sloping Apron

Stone weights , computed by different methods, are given under the clauses 2.1.1, 2.1.2 and 2.1.3 below..

2,1.1 As per IS codes

In all the IS codes IS:14262 (1995),IS:8408 (1995),IS:10751 (1994), IS:12094 (2000), all related to river training, the formula (Eq 8) is recommended for finding stone weight

$$Ws = 0.02323\ V^6 / k_1\ (Ss - 1)^2 \qquad (8)$$

Where $k_1 = (1 - \sin^2\theta / \sin^2\phi)^{0.5}$ and Ss is the specific gravity of stone

With 2 (H) : I (V) side slope, $\theta = 26.5^0$; ϕ for stones is 43^0 and Ss = 2.65 for stones, $k_1 = 0.76$

Putting the above values in Eq. (8)

$$Ws = 0.018\ V^6 \qquad (9)$$

And $$D = 0.0236\ V^2 \qquad (10)$$

where

Ws is in Kg, D is in m and V is in m/sec units

2.1.2As per IRC Code

IRC-89 (1997) on river training recommends Eq. (11) and (12) for size and weight of stones on sloping apron with 2(H):1(V) slope ($\theta = 26.5^0$), $\phi = 43^0$ and Ss =2.65

$$D = 0.036\ V^2 \qquad (11)$$

and $$Ws = 0.031\ V^6 \qquad (12)$$

2.1.3 As per Pylarczyk (1997)

Pylarczyk proposed a unified general formula (Eq 13) for stone size

$$(S_s - 1)\ D_n = [(0.035\phi_c k_h k_t) / (\theta_c k_l)]\ V^2 / 2g \qquad (13)$$

Where, D_n =0.84 D_{50}, k_t = turbulence factor, S_s = Specific gravity of stones, θ_c= shear stress factor, K_i= slope stability factor = $[1 - (\sin^2\theta/\sin 2\phi)]^{0.5}$, V= Mean velocity of flow, ϕ_c =Gradation factor and k_h = velocity profile correction factor.

With θ =26.5 ^{0}, ϕ =43^0, k_1=0.76, k_t =1.0, θc = 0.035 and other factors taken as 1.0 (from Pylarczyk's table), it may be proved that the general unified equation reduces to

$$D_{50}/Y = 0.187\ Fr^{2.5}/\ k_1^{1.25} \qquad (14)$$

Where, Fr is Froude's number of flow, D_{50} is the mean size of stones, Y is depth of flow and k_1 is slope stability factor . It may be noted that equations (14) is non-dimensional derived from equation (13) under the specified values of parameters as stated above. With the above values of Pylarczyk's parameters, the IS and IRC equations (10 and 11)for stone size (D) can also be expressed in non-dimensional forms as follows:

$$D/Y=0.175\ Fr^2/k_1 \quad \text{from eq. (10)} \qquad (15)$$

$$D/Y = 0.210\ Fr^2/k_1 \quad \text{from eq. (11)} \qquad (16)$$

Thus, IS and IRC equations are almost similar to Pylaczyk's equation (14) applicable for the stated values of parameters (Factors). It is desirable that both IS and IRC equations should be replaced by Pylarczyk's general unified equation (13) and stone size/weight should be found for the different values of the parameters as proposed by him under different flow and boundary conditions.

3.0. WEIGHT OF INDIVIDUAL STONES IN LAUNCHING APRON

Launhing apron, as originally proposed by Inglis (1949), Sprigs (1903) and Gales (1938), are very popular in India. Its main function is to protect the toe of embankment and guide bund. Against scouring during passage of flood. As illustrated in Fig.2, launching apron is laid on the low water bed during lean flow period in summer. During flood season, when scouring of bed takes place, the apron is launched in the scoured areas as indicated in Fig.2 thereby protecting the toe and preventing undermining of bank/embankment.

Design criteria for launching apron are given in CBIP (1989) and most of the text books on hydraulic structures. Scour depth (R) below HFL is estimated by Lacey's regime formula, Then the maximum possible scour is found by multiplying R with factor varying from 1.25 to 2.5 (depending on location of scour) and deducted from HFL to find maximum scoured bed level and hence the maximum scoured depth (Ds) below low water bed. Usually, length of apron is equal to 1.5 Ds. All the stones in the sloping and launching apron must be laid over graded filter / geo-synthetic textiles in order to prevent winnowing(loss of base materials due to suction) of bed and bank materials through pores and joints in stones.

3.1 Weight and Size of Stones as per IS Codes

It is assumed that the stones in the apron is launched (Fig.2) uniformly at a slope same as the bank slope. For a bank slope of 2(H):1 (V), weight and size of stone will be then the same as that given by Equations (9) an (10) respectively.

3.2 Weight and Size of Stones as per IRC Code

IRC code recommends use of much heavier stones as per equations (17) and (18) below.

$$D = 0.04176\ V^2 \quad (17)$$

$$Ws = 0.101\ V^6 \quad (18)$$

Where,

D is in m, V is in m/sec and Ws is in Kg units. Stones in launching apron are much heavier

-5.8 times heavier than that found from IS code (eq.9) and 3.4 times heavier than stone weights in sloping (2:1) apron by IRC method (Eq.12). IRC formulae for stone weight and size are applicable for individual isolated stone only. Referring to an earlier IS code (IS: 2408, 1976), it is seen (Fig.3) that the weight

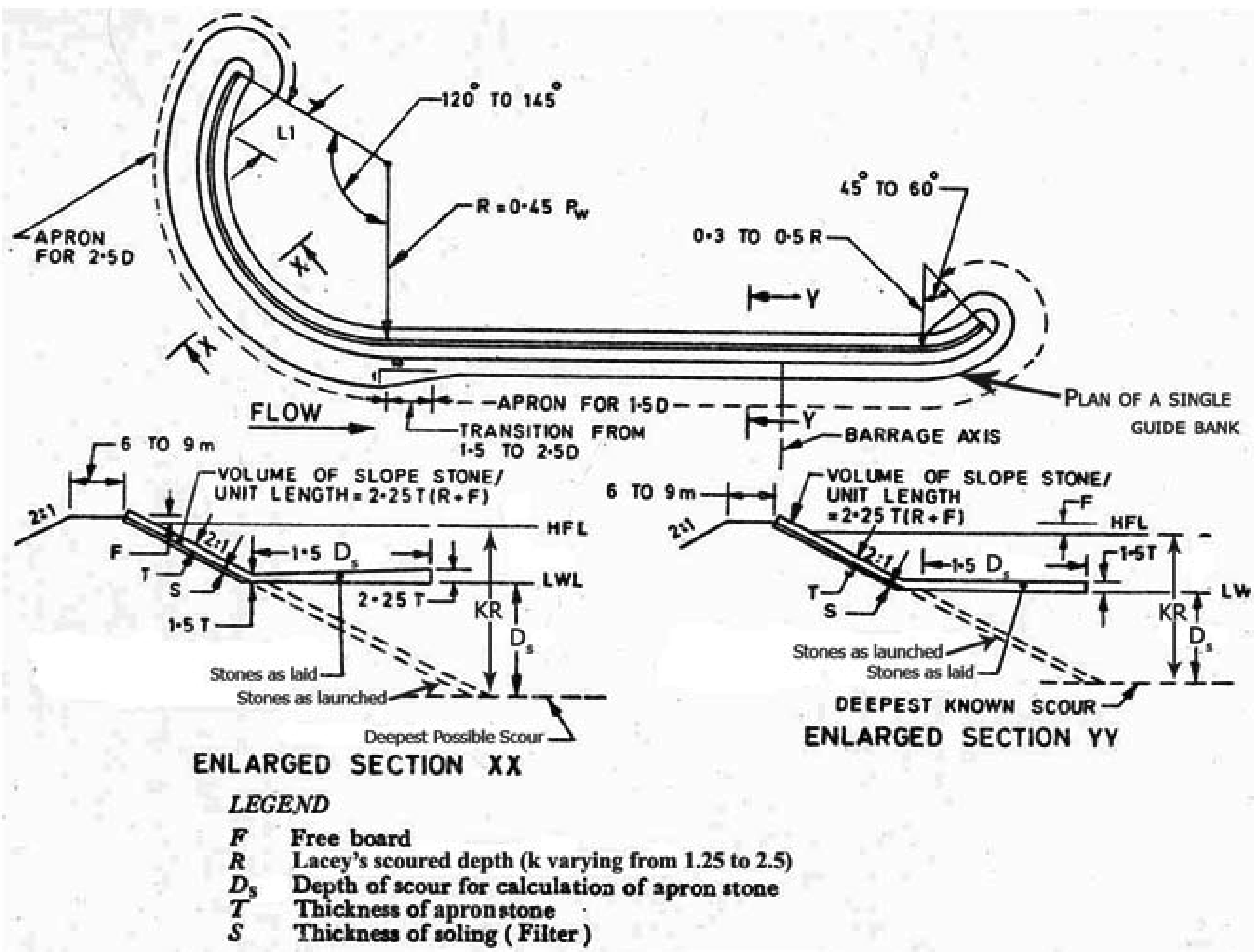

Fig. 2 Details of Guide bank showing horizontal apron as laid (Solid line) and when launched (doted line)

required for stability is about 5.8 times heavier than that for stone in groups as in sloping and launching aprons. This is mainly due to drag difference. A spherical isolated stone will experience much more drag compared to that in a group of stones in a mattress. Thus, it appears that IRC equation (17) and (18) need revision. On the other hand, weights of stones found from equation (9) and (10) for stone in a sloping apron should not be blindly used for determining weights for stones in launching apron also. There is hardly any data regarding status of stones/stone surface when they are actually launched (may be over years).Actual surface of launched stones may be rough and wavy and far from a smooth surface as that in bank as assumed in the BIS codes. Drag force substantially differ on a smooth surface and a rough and wavy surface, being more in later compared to that in the former.

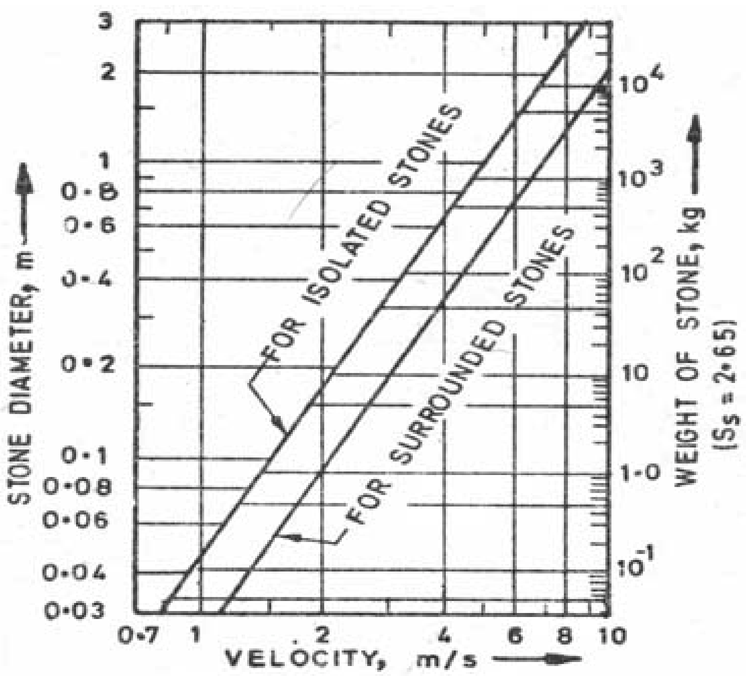

FIG. 3 SIZE & WEIGHT OF APRON STONE VS VELOCITY

33 US and Indian Practice for Toe Protection

In USA, launching apron is hardly used and as such Pylarczyk has not proposed any equation for launching apron. Usually, cut-offs and toe trenches are provided for toe protection. Also, the mattresses are usually laid during high flood by use of ships and cranes so that the deepest scoured areas are protected. Several types of mattresses such as willow mattress, articulated concrete blocks, asphalt blocks etc have been used for bank protection in Missisipi and Missouri rivers in USA.

There is a lot of doubt regarding performance of so called launching aprons popularly used in our country. Author had the opportunity of visiting some site upstream of Farakka barrage where long stone apron (1m thick) with bed bars (2m height) were constructed along with impervious groins. Almost all of them have been washed out and the river has scoured the bed severely and shifted its course about 7 km inside Malda district in West Bengal.

4.0 DRAG APPROACH FOR FINDING INDIVIDUAL STONE WEIGHT

Refering to Fig.1, the forward drag on the stone ‘P’ is given by

$$F_d = \tau_0 \, a_s$$

$$\tau_0 = 0.5\ \rho\ C_d\ Vs^2\ (\pi/4)\ D^2 \qquad (19)$$

Where,

ρ is density of water, C_d is coefficient of drag, Vs is the velocity over stone surface

Putting Vs =kV (actually the vertical distribution of velocity above stone bed is logarithmic).

$$F_d = 0.5(\ \gamma/g)\ C_d\ k^2 V^2\ (\pi/4)\ D^2 \qquad (20)$$

Resultant force (R) on the stone on the sloping plain

$$R = (F_d^2 + Ws^2\ sin^2\theta)^{\ 0.5} \qquad (21)$$

Resisting force (F_R) is given by Ws cos θ tanϕ which must be equal to R for equilibrium

Therefore,

$$F_d2 + Ws^2\ sin^2\theta = Ws^2\ cos^2\ \theta\ tan^2\phi$$

Or, $$F_d = Ws(cos^2\ \theta\ tan^2\phi - sin^2\ \theta)^{0.5} = k_0 Ws \qquad (22)$$

Where,

$$k_0 = (cos^2\ \theta\ tan^2\phi - sin^2\ \theta)^{0.5}$$

Equating (20) and (22), putting Ws =(γs - γ)(π/6)D^3 and simplifying, it can be shown that

$$D = [\ (3/2)C_d\ /(Ss\text{-}1)\ (k^2/k_0)]\ [V^2/2g]$$

For spherical stone with Reynold's number more than 5.5 x 10^5, C_d = 0.5 (Garde and Mirajgaonkar,1977), Ss =2.65, k_0=0.7 (for θ =26.5^0 and ϕ =43^0, k=0.9 (due to turbulent flow) and g =9.8m^2/sec

$$D = 0.026\ V^2 \qquad (23)$$

This is almost the same as equation (10) proposed by BIS for determining size of stone lying on sloping or launching apron and not substantially different from eq. (11) recommended by IRC for stones on sloping (2:1) apron..

5.0 DRAG APPROACH FOR FINDING THICKNESS OF WIRE CRATED GABIONS

Weight of mattress will depend on its thickness for a given size, say, a_s =a.b. Where 'a' is the length and 'b' is the breath of the apron. 't' is the thickness required and e as the void ratio, then

$$Ws = a\ b\ t\ e\ (\gamma_s - \gamma)$$

From (22)

$$F_d = \tau_0\ a_s\ = 0.5\ (\gamma/g)\ c_d\ k^2 V^2\ ab = k_0 Ws = k_0\ abte\ (\gamma_s - \gamma) \quad (24)$$

or, $$t = (k^2/k_0 e)\ /(Ss - 1) c_d\ V^2 / 2g \quad (25)$$

with $c_d = 0.5$, Ss =2.65, k_0=0.7 (for θ =26.5^0 and ϕ =43^0), k=0.9 (for turbulent flow), e= 0.7 (IS:8408,1995) and g =9.8m^2/s

$$t = 0.025\ V^2 \quad (26)$$

Where t is in meter and V is the mean velocity of flow in m/sec. It may, however, be noted that wire crated gabions will offer a much smoother surface compared to an individual isolated stone and hence c_d will be much less. Assuming c_d for crated stones to be only 50% of an individual one i.e. c_d =0.25, thickness of wire crated gabion will be

$$t = 0.0125\ V^2 \quad (27)$$

6. ILLUSTRATIVE EXAMPLE

Diameter (D) and Weight (W) of spherical stones and thickness of Gabions used for protection of side slopes/aprons have been computed by using IS and IRC formulae given in the respective codes and compared with the values obtained from Pilarczyk's equation used in USA as well as those obtained from the formulae derived from drag approach. The following data are assumed for computations.

(i) Mean Velocity of flow: V= 3m/sec
(ii) Flow Depth: Y= 4m
(iii) Side Slope: 2(H):1 (V)
(iv) Angle of internal friction for stones: Φ=43^0
(v) Specific gravity of stone: S_S = 2.65
(vi) Unit weight of water :γ = 1000 kg/ cu. m.
(vii) Unit weight of stone $\gamma_s = S_{s.}\ \gamma$ = 2650 Kg /m^3
(viii) Coefficient of kinematic viscosity of water at normal temperature, υ =10^{-6} m^2/sec
(ix) Froude's no. of Flow, Fr = V / √ (gY) = 0.48
(x) Reynold's no. of flow, Re =VY/υ = 12x 10^6

<u>For Stones used in Side- Slope Protection</u>

(a) By IS equation:

$Ws = 0.02323\ S_S\ V^6 / [K\ (S_S - 1)^3]$ Eq. (8)

With side slope as 2 (H):1 (V), corresponding angle of inclination with horizontal $\theta = 26.5^0$ and

$K_1 = [1 - Sin^2\ \theta / Sin^2\ \Phi]^{½} = 0.76$

Substituting values of S_S and K in Eq. (8)

$W = 0.018\ V^6$

With V= 3m/sec, **<u>Ws= 13 kg</u>**

Since $W = \pi/6\ D^3\ S_S\ \gamma$,

$D = 0.0236\ V^2$

Corresponding to the weight (W), Diameter of stone **<u>D=21 cm</u>**.

(b)By IRC Equation

$D = 0.0282\ V^2$ for 2 (H) :1 (V) side slope Eq.(11)

For V = 3 m/Sec, **<u>D = 0.254m =25.4 cm</u>** and corresponding value of **<u>Ws =22.6 kg.</u>**

(c)By Pilarczyk Equation

$D_{50} / Y = 0.187\ Fr^{2.5} / K^{1.25}$ Eq.(14).

Where Fr is the Froude's number of Flow. Here Fr = 0.48, for V= 3m/sec and Y = 4m, Therefore, D_{50} / Y = 0.042 and **<u>D_{50} = 0.168 m = 16.8 cm</u>**. and corresponding **<u>Ws = 6.57 kg</u>**

Pilarcczyk's Eq.3, which is in a non- dimensional form, unlike IS and IRC equations, is, however, applicable only for a given stability factor (k_l= 0.76), turbulence factor (K_t = 1.0), shear stress factor(θc =0.035) and slope factor ($K_1 = [1 - Sin^2\ \theta / Sin^2\ \Phi]^{½} = 0.76$).

(d) From Drag Concept

$D = 0.026\ V^2 = (0.026)\ (9) = 0.236\ m$

<u>D =23.6 cm</u>

$Ws = (\pi/6)\ D^3\ \gamma_s$

<u>Ws = 18.2 Kg</u>

<u>For Stones used in Launching Apron</u>

(a) By IS equation

In none of the revised IS codes, no separate equation is proposed for stone size and weight for stones in launching apron. They recommend use of same equation and monogram recommended for stones in side slope pitching.

(b)By IRC equation

IRC:89(1997), however, proposes a separate equation for stone size in launching apron, namely,

$$V = 4.893\ D^{1/2}$$

which may be expressed as

$$D = 0.04176\ V^2$$

or $$Ws = 0.101\ V^6$$

For a velocity of 3 m/sec, the above equations give the following values of stone size and weight, namely,

D = 0.375 m =37.5cm and

Ws =76 kg.

which is 5.84 times heavier than the stone weight by IS equation and 3.39 times heavier than that on the sloping sides found by IRC equation.

(c) By Pilarczyk formula

There is no mention of lauching apron by Pilarczyk. Usually toe protection is provided by cut-off trench at toe filled with stones.

THICKNESS OF WIRE CRATED GABION

(a) Assuming Cd =0.5(for rough surface)

$t = 0.025\ V^2$ =0.225 m = 22.5cm

(b) Assuming Cd =0.25 (for smooth surface)

$t = 0.0125\ V^2$ =.0.1125 m = 11.25 cm

Summary of sizes and weights of stones and thickness of wire crated gabions for the assumed values of different parameters in the illustrative example are given in table-1 for the purpose of comparison.

CONCLUSIONS

Size and weight of stones computed by IRC and IS equations differ considerably when compared with Pylarczyk's equation popularly used in USA. One of the primary reasons for such variation is that in both IRC and IS methods; weight and size are expressed in terms of mean flow velocity in the channel. Whereas, in Pylarczyk's unified type general equation, several other parameters e.g.safety factor, stability factor, turbulence factor, velocity and shear stress factor, critical tractive stress factor, roughness factor etc have been introduced. Author has introduced a new concept of drag for finding stone size and weight and computing thickness of wire crated stone mattress. It has been shown that neither IRC method nor IS method for finding stone weight and size is correct. It needs field data collection for proving the model.

Table – 1

Size and weight of stones in sloping and launching aprons

	Sloping Apron		Launching Apron		Thickness in cm	
Method	**D in cm**	**W_S in kg**	**D in cm**	**W_S in kg**	**t in cm (rough)**	**t in cm (smooth)**
IS method	21.0	13.0	21.0	13.0	--	--
IRC Method	23.4	22.6	37.5	76.0	--	--
Pylarczyk	16.8	6.57	--	--	--	--
Drag Approach	23.6	18.2	23.6+	18.2+	--	--
Gabion thickness required, wide ratio e = 0.7					22.5	11.25

+ Assuming that the roughness and drag on sloping and launching apron are the same.

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