ENGINEER - Vol. LIII, No. 04, pp. [45-52], 2020

DOI: http://doi.org/10.4038/engineer.v53i4.7427

Model Study to Determine the Manning's Coefficient for Gabion Lining against Canal Erosion

D.P.M.B. Thibbotuwawa, V. Thawishnee, H.M.E.J.B. Herath, H.M.P.S. Karunarathne and G.N. Paranavithana

Abstract: Canal erosion often happens in unlined canals due to high velocity water flows. Because of this natural phenomenon, numerous problems occur in canal systems and finally change the topography of the canals in the long-term. Canal lining is the method adopted worldwide, to prevent canal erosion using different lining materials available such as concrete, rock masonry, brick or clay, with the modern practice being gabion nets filled with rubble. Considering several factors such as, economy, stability, material availability and manpower requirement, gabion lining is a suitable canal lining method compared to other prevention methods used at present.

To make the gabion lining method very effective, economical and feasible in canal lining applications, the surface roughness or the Manning's coefficient (*n*) value of gabion linings needs to be experimentally determined first, as this value is unknown at present and will be useful for the scientists and engineers in design stages later on.

A 300 mm x 300 mm rectangular field channel was selected as the prototype to model it dimensionally in a laboratory hydraulic flume. The Manning's formula, which applies to uniform flow conditions in open channel flow, was used to determine "*n*" experimentally.

Present experimental observations indicate a value range of 0.05044 $m^{-1/3}s$ to 0.0552 $m^{-1/3}s$ as Manning's coefficient for the test model study and that of 0.0597 $m^{-1/3}s$ to 0.0654 $m^{-1/3}s$ for the prototype.

Keywords: Open canal, Canal erosion, Roughness coefficient, Gabion lining

1. Introduction

Sri Lanka has a large irrigation canal network to convey water for day to day needs and for irrigation purpose of the people living in remote and drought zones of the country. Most of these canals are natural or man-made unlined earthen canals. Due to this nature, the bed and banks of these canals are susceptible to wash away by the flowing water constantly and finally change their topography in the long term. This natural process is known as canal erosion and leads to several other problems such as, scouring of bed and banks making canal inner banks more unstable, deposition of local eroded materials along the canal leading to growth of weeds, increase in seepage and leakages, water logging, and finally reducing the capacity of the canal system. As such, unlined canals getting washed away by high flowing water become a worldwide problem. Therefore, canals are needed to be protected against the erosive forces developed by flowing water and as a solution, canal lining may be used [11].

There are many types of canal lining, some of which are concrete lining, shotcrete lining, rock masonry lining, lining with brick or clay, and at present, the trend of using gabion mattresses as lining is popular in the world [4],[14].

Eng. D.P.M.B. Thibbotuwawa, AMIE(SL), BSc (Colombo), BTech.Eng (Hons), AMSSE(SL), MGS(SL) Lecturer, Department of Civil Engineering, The Open University of Sri Lanka.
Email:dpthi@ou.ac.lk
ORCID ID: http://orcid.org/0000-0003-0881-4933
Eng. (Miss.) V. Thawishnee, Undergraduate in BTech.Eng, Department of Civil Engineering, The Open University of Sri Lanka.
ORCID ID: http://orcid.org/0000-0001-6359-4422
Mr. H.M.E.J.B. Herath, Undergraduate in BTech.Eng, Department of Civil Engineering, The Open University of Sri Lanka.
ORCID ID: http://orcid.org/0000-0002-0865-7854
Mr. H.M.P.S. Karunarathne, Undergraduate in BTech.Eng, Department of Civil Engineering, The Open University of Sri Lanka.
ORCID ID: http://orcid.org/0000-0002-1162-8157
Eng. (Dr.) G.N. Paranavithana, AMIE(SL), BScEng(Peradeniya), MScEng(Peradeniya), PhD(Eng)(Saitama),
ORCID ID: http://orcid.org/0000-0001-6223-613X

Selection of a suitable lining depends on several effective parameters such as imperviousness, hydraulic efficiency, durability, structural stability, economy, resistance to high velocity, weed growth ability, availability and constructional cost, life span, operational and maintenance cost, resistance to abrasion etc. [6], [7], [8]. Thus, gabion lining favours over other solutions when considering above parameters, hence gabion lining is becoming the most frequently used method to mitigate canal erosion worldwide [1], [9].

Even though gabion lining is a commonly used method in canal lining there is a persisting gap of knowledge to design gabion structures effectively. Over the years there have been almost no attempts made to find the Manning's coefficient (n) of gabion linings which is essential to identify the character of hydraulics of the gabion lined canals. Therefore, this paper aims to elaborate the laboratory experimental setup to determine the Manning's coefficient (n) of gabion lining used in canal linings.

2. Literature Review

2.1 History of using Gabions in Canal Lining

Gabions are cellular structures of rectangular cages made of zinc-coated or polymer coated steel wire mesh and filled with stones of appropriate size and necessary mechanical characteristics. Individual units are stacked, paired, and tied to each other with zinc-coated wire or fasteners to form a continuum [21], [23].

Gabions, which are utilized in many civil construction applications including canal banks lining, are one among many others such as retaining walls for earth excavations and embankments, sea, river and, small dams, spillways, weirs etc. Gabion applications were first used by Italians over 75 years back [20], mainly in riverbank protection projects. The Food and Agricultural Organization of the United Nations has long experience in gabion mattresses in water related development and irrigation projects in the various developing world countries like Botswana, China, Egypt, Eritrea, Ethiopia, Guinea Bissau, Haiti, Niger, Nigeria, Malawi, Vietnam, etc. Apart from these developing countries, many of the developed countries such as America, Australia, France, Germany and many others are also using gabions for riverbank restoration against erosion, where all have made use of either imported or locally-made gabion baskets [1].

2.2 Why Gabions are Preferred Over Other Lining Materials

The wire mesh of gabions is less expensive than most other lining materials and in gabion structures there is no need of any mechanical equipment and are virtually maintenance free [24]. They provide an economical construction with structural stability while allowing to deform rather than crack and break the structure. In gabion lining, interstitial spaces in between the stone fill within the baskets, provide a great degree of permeability. Thus, it is preventing build-up of hydrostatic pressure which causes displacement and cracks. This prevents the loss of structural efficiency. Another benefit of gabion lining is its ability to tolerate tensile forces by the extremely strong wire mesh. The wire mesh shell is not simply a container for the stone filling, but also a reinforcement for the entire structure. Further, it does not prohibit the growth of vegetation due to the flexibility of gabion structure [20], [22].

On the other hand, most of other continuous canal lining materials are susceptible to damage by hydrostatic and pore pressure forces developed under the lining than reinforced concrete linings. At some places, unexpected hydrostatic pressures are encountered under these linings leading to ruptures more readily than in reinforced concrete. However, as a continuous lining membrane, the shotcrete linings are more economical than concrete linings and only permits in thin layers of 1/4″ to 1/2″ on soil, but it often gives trouble in implementing. Brick or clay tile linings are very porous and are not much effective in preventing crack development. In asphalt concrete linings, seepage losses can be reduced to as low as in the case of Portland cement concrete linings. However, the seepage will be increased considerably after weed growth over time with crack development [6].

Another function of gabion lining is the erosion control and water management; gabions can be used to fortify eroding banks. They can serve as a water diffuser in the spillway or at the base of the dam to keep churning water from eroding the base of the beam or dam wall [22].

2.3 What Causes Canal Scoring

Generally, in places that are susceptible to erosion, canals can be seriously damaged by scouring forces exerted by water flow. Flow friction, high velocity flow, hydrostatic pressure developed on embankment materials, sudden changes in surface roughness or Manning's coefficient along and across the canal sections, are the main factors affecting canal erosion in irrigation canals [21]. For instance, canal sections immediately downstream of structures suffer from the effect of water jets and the lower sections of canal bank can be easily overtopped due to under cutting effect. Further, there are canal sections which suffer from erosion by water that spills over and also, the presence of local high velocities at curved localities where, sudden changes of directions cause turbulence as well intensify scoring effect [17].

2.4 Importance of Manning's Coefficient in Canal Lining

In natural canals, the roughness coefficient (Manning's coefficient) 'n' is influenced by many factors, among them the meandering character of the canal, bed and bank material with the average grain size, channel obstructions, geometry variations between sections and the degree of vegetation in the channel are significant [19]. Moreover, due to these parameters, the roughness of the channel is not equally distributed over the channel, the bed, banks, and the floodplains. Therefore, the use of literature data does not always lead to a satisfactory result to determine the roughness coefficient of a natural canal, due to prevailing situations in the field [10]. For that reason, measurements are necessary to determine the variation of the Manning's coefficient.

Many references have been made to determine manning's coefficient 'n' for natural streams and channels for both lined and unlined, assigned with the conditions that prevails at that time of a specific flow event with average conditions over a range in stage, or for anticipated conditions at the time of a future event. Manning's constant values for different type of canal lining material have been discovered by Ven Te Chow in 1959 [2].

There is a matter arising when using gabions mattresses for canal lining against erosion, since the surface roughness coefficient or the Manning's coefficient of such lining material is not available in the literature. This coefficient is important for the design engineers to design and guide the canal lining more scientifically than just laying the mattresses packed with rubbles along the stretches of canal banks, where the erosion happens or just after a water regulating structure.

Thus, knowing the roughness coefficient for gabion lining is very much important on this aspect. Else due to this gap of knowledge, the designing of canal lining against canal erosion is solely based on engineer's estimation.

2.5 Determination of Manning's Coefficient of a Canal

Researchers have adopted different methods and empirical equations to determine the roughness coefficient of natural canals (unlined or lined) by considering the major factors and criteria that contribute to the loss of energy in flowing water.

The French engineer Antoine Chezy in 1770, developed the first uniform flow formula to the engineering world to determine the flow resistance factor, for an open channel flow under two assumptions with respect to flow resistance and based on the basic principle of uniform flow propounded by Brahms in 1754. Based on his findings with the formula, he introduced the flow resistance factor (Chezy's constant "C") which is believed to be dependent on the canal slope, the hydraulic radius, and the coefficient of roughness "n". With Chezy's findings, an Irish Engineer Robert Manning, presented in 1889, a formula for open channel uniform flow incorporating the roughness coefficient "n", which was later simplified and subsequently modified to the present form, expressed in metric units and known as Manning's formula [3].

$$V = (1/n)\, R^{2/3}\, S^{1/2} \qquad \text{... (1)}$$

Where, V = mean velocity of the flow, m/s
R = (A/P) the hydraulic radius, m
S = bed slope of the canal, m/m
n = roughness coefficient, m $^{(-1/3)}$ s
A= cross sectional area of the flow, m^2
P = wetted perimeter of the flow, m

Engineer Ven Te Chow [2], proved with his research work, that the Manning's roughness coefficient for open channels with uniform flow can be determined by using the Manning's equation which is the most widely used uniform flow formula for open channel flow computations at present [2],[3] and, as previously stated, Chow has discovered a range of roughness coefficients for different canal linings with the canal conditions that exist at specific flow events, average conditions over a range of flows, or for anticipated conditions at the time of a future event [2].

Chow's work has been evidenced by the studies of Barnes [16] and William [15], who state that reliable results can be obtained using the Manning's equation on the assumption of uniform flow in which the cross sectional area, hydraulics radius and depth remain constant, and the slope of the water surface, energy gradient and canal bed are parallel. However, in natural channels, these conditions are seldomly met; therefore, the equation is assumed valid for reaches of non-uniform flow if the energy gradient is modified to reflect only the energy losses due to boundary friction [15], [16].

Literature indicates that laboratory experiments can be performed using model testing studies with a linear scale adopted to form a model (to replicate the prototype) in a laboratory flume [13], [14].

3. Methodology

The following sequential steps have been carried out under the methodology.

3.1 Preparation of Physical Test Model in the Laboratory

To determine the Manning's coefficient, a dimensionally similar physical test model was developed in the laboratory rectangular flume with dimensions of (10 m x 0.25 m x 0.45 m) long, wide, and deep respectively, considering the prototype as 0.3 m x 0.3 m square field irrigation canal which is fully lined with gabion mattresses.

To indicate the presence of gabion lining in the physical test model as of field canal, a geometrically similar wire mesh was selected to make dimensionally similar gabion like baskets. Subsequently, the baskets were modelled giving due consideration to, mesh material made of, mesh wire diameter, mesh opening, pattern of fabrication, and surface treatment of mesh material etc,. The intended physical test model been developed in the laboratory flume to represent the actual field canal conditions by adopting the dimensional analysis method, while considering necessary similarities (geometric, kinetic and dynamic similarities) to be fulfilled between the test model built in the laboratory flume and the field irrigation canal.

The details of modelled gabion materials are produced in Table 2, and Figure 1 indicate the gabion lining like physical test model arranged within the laboratory open channel flume.

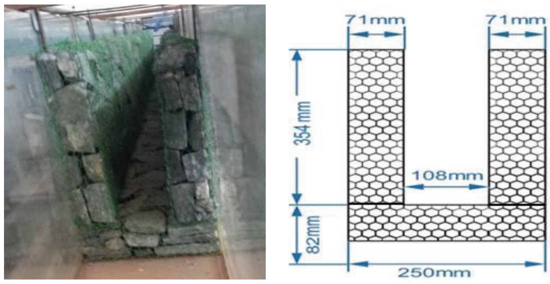

Figure 1 – Dimensionally Modelled Gabion Boxes Laid within the Flume

3.2 Model Study using Dimensional Analysis

The main rationale behind the preparation of the test model is to predict field irrigation canal behaviour out of the test model. Thus, similar studies of predicting prototype behaviour based on test model observations was adopted incorporating geometric, kinematic, and overall dynamic similarity between the field canal and the test model. Chang et.al. [12] expressed that, the geometric similitude means that the model be an exact geometric replica of the prototype. Thus, this similitude is satisfied in the model study by having an exact geometrical shape between physical test model and prototype field canal and thus, a linear scale ratio can be expressed between the model and the prototype [12]. The width of model (l_m) and the prototype (l_p) are geometrically similar, the linear scale being,

$$\lambda = l_m/l_p = 108/300 = 0.36 \qquad \text{... (2)}$$

The kinematic similarity requires that the flow conditions to be similar between the model and the prototype, implying that velocities at corresponding points to be similar, and streamline patterns for the flow over the model and the prototype also to be similar. Thus, indicating that kinematic similarity includes geometrical similarity under same flow conditions. Dynamic similarity exists between the model and the prototype when forces at corresponding points are similar [3], [23].
The cross sectional area, hydraulics radius, and depth remain constant and the slope of the water surface, energy gradient and canal bed are parallel, thus confirming the assumption that the flow condition was uniform [15],[16] in the test model as well as in the field canal, respectively. These satisfy the conditions required by the kinematic similarity between the model and the prototype.

Seven variables have been identified as governing the roughness coefficient of gabion mattress lining and they are, density of water (ρ), velocity (V), dynamic coefficient of viscosity (μ), Manning's coefficient (n), acceleration due to gravity (g), cannel slope (S_0) and hydraulic radius (R). Subsequently, Buckingham π-Theorem was adopted to arrange these variables into suitable non-dimensional parameters. Thereby, it was possible to generalise the problem by dropping out less important parameters while involving only with the most important parameters which have greater influence upon the phenomenon. Thus, the dynamic similarity between prototype and model requires that these parameters to be the same [3].

To formulate non-dimensional groups among the identified parameters, three repeating variables were selected (V, R and ρ) out of the seven and the resulting four non- dimensional groups were,

$$\Pi_1 = V^2/gR = Fr^2$$
$$\Pi_2 = \rho VR/\mu = Re \quad \text{... (3)}$$
$$\Pi_3 = R^{2/3}/nV$$
$$\Pi_4 = 1/S_0$$

Thus, the functional relationship between the non-dimensional number involving roughness coefficient and other non-dimensional groups can be expressed as,

$$(R^{2/3}/nV) = f\,(Fr^2, Re, 1/S_0) \quad \text{... (4)}$$

According to the above nondimensional relationship, both the Froude number (Fr) as well as Reynolds number (Re) were in the non-dimensional groups, implying both have greater influence upon the roughness coefficient "n" in open channel flow. However, always the free surface flow in test model and the prototype, was under the influence of gravity due to the gravitational acceleration. Thus, gravitational forces are predominant than the viscous forces that are acting on free surface flows. Thus, the Froude number criterion is considered as predominant for dynamic similitude between model and prototype [3], [12].

Therefore, following are the velocity and Manning's roughness ratios of physical test model and the field canal prototype to satisfy the kinematic similarity and finally the dynamic similarity.

$$\lambda_V = V_m/V_p = (l_m/l_p)^{1/2} = 0.36^{1/2} \quad \text{... (5)}$$

$$\lambda_n = n_m/n_p = (l_m/l_p)^{1/6} = 0.36^{1/6} \quad \text{... (6)}$$

3.3 Determination of Manning Coefficient "*n*" for Modelled Gabion Lining

After completion of assembling the test model physically in the laboratory flume, the next step was to introduce a control flow condition (uniform flow conditions) to the test model to determine the roughness coefficient with a constant slope (0.00035 m/m) [5] similar to the field canal and following observations and steps were made to determine "n".

- the width of the free surface of the flow (B), and the average depth of flow (D), i.e. the flow depths were determined at regular intervals within the lining length using a depth gauge and averaged to consider as the flow depth (D).

- the mean velocity of the flow was measured using the current meter (model no LS1201). Since, the bed roughness is affecting the vertical velocity profile across a cross section of a point considered, usually 0.2D and 0.8D velocities are considered as characteristic velocity values for the vertical velocity distribution. However, for low-flow measurements, 0.6D velocity is considered as the mean velocity of the flow of that section [18].

- Repeated the above two steps while changing the flow velocity in terms of discharge (Q) in the flume but keeping the slope of the flume bed (S) as constant for several further attempts.

- Tabulated the observations for V, B, D, and S, which are given in Table 3, and performed following calculations using the Manning's equation (1) to determine "n" based on laboratory observations.

4. Calculations

4.1 Calculation of Manning's "*n*" for Laboratory Test Model

To determine the Manning's coefficient for laboratory test model, a graph was plotted between V and $R^{2/3}$. Where, according to Manning's equation, these two variables follow a linear relationship which passes through the origin of the graph, having one to one mapping between observations. In other words, a variation similar to $y = mx$.

$$V = \{(1/n).\, S^{1/2}\}\, R^{2/3} \quad \text{... (7)}$$

$Y = \mathrm{m}\,X$

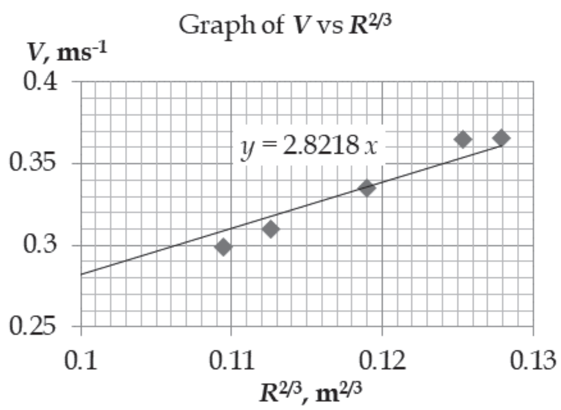

Figure 2 – Graph of Linear Variation between Velocity (*V*, at 0.6*D* of Lined Section) against R$^{2/3}$

Thus, $\{(1/n).\ S^{1/2}\} = 2.8218$

$n_m = 0.00663\ \mathrm{m}^{-1/3}.\ S$

4.2 Error Margin involved in the Derivation of Manning's Coefficient for the Laboratory Test Model,

The following equation is obtained by re-arranging the Manning's equation (1),

$$n = R^{2/3}.\ S^{1/2} / V \qquad \text{... (8)}$$

Therefore, the error involved in determining "*n*" is given by the equation,

$$\delta n/n = \pm 2/3*(\delta R/R)\ \pm 1/2*(\delta S/S) \pm (\delta V/V) \qquad \text{... (9)}$$

Where,

δn =Error in Manning's coefficient

δR =Error in calculating hydraulic radius

δS =Error in slope calculation

δV =Error in velocity measurement

Similarly, For wetted area,

$$\delta A/A = \pm(\delta B/B)\ \pm(\delta D/D) \qquad \text{... (10)}$$

For hydraulic radius,

$$\delta R/R = \pm(\delta A/A) \pm (\delta P/P) \qquad \text{... (11)}$$

For channel Slope,

$$\delta S/S = \pm(\delta h_1/h_1) \pm (\delta h_2/h_2) \pm (\delta L/L) \qquad \text{... (12)}$$

Where,

δA = Error in wetted area

δB = Error in width of wetted area

δD = Error in depth of wetted area

δh_1, δh_2 =Error in canal slope heights

δL = Error in open channel length

Substituting respective values in above equations give the values of the variables as,

$\delta A/A = \pm\ 0.0092$

$\delta R/R = \pm\ 0.0138$

$\delta S/S = \pm\ 0.0051$

and, from direct measurement of velocity meter,

$\delta V/V = \pm\ 0.0334$

Therefore, substituting all these values,

$\delta n/n = \pm\ 0.04515$

Thus,

$\delta n = \pm\ 0.04515 \times 0.00663$

$\delta n = \pm\ 0.0003\ \mathrm{m}^{-1/3}\mathrm{s}$

Therefore, the Manning's coefficient including the error involved varies in between,

$n - \delta n <$ Manning's Coefficient $< n + \delta n$

i.e. $0.00633\ \mathrm{m}^{-1/3}\mathrm{s} < n < 0.00693\mathrm{m}^{-1/3}\mathrm{s}$

4.3 Predicting of Manning's "*n*" for Prototype Based on Model Study

The Manning's coefficient variation in the prototype can be estimated according to equation (6) considering model study as,

$$n_p = n_m\,(1/0.36^{1/6}) = 1.1856\ n_m$$

$1.1856 \times 0.00633 < n_p < 1.1856 \times 0.00693$

$0.0075\ \mathrm{m}^{-1/3}\mathrm{s} < n_p < 0.0082\mathrm{m}^{-1/3}\mathrm{s}$

5. Results and Discussion

Based on the experimental observations from the model testing, the Manning's coefficient for test model gabion lining varies in the range between 0.00633 $\mathrm{m}^{-1/3}\mathrm{s}$ - 0.00693 $\mathrm{m}^{-1/3}\mathrm{s}$ for the flow velocity ranging between 0.30 ms^{-1} to 0.37 ms^{-1} with the fair level slope as 0.00035 m/m and the predicted roughness coefficient "*n*" value ranging for the prototype indicates 0.0075 $\mathrm{m}^{-1/3}\mathrm{s} < n < 0.0082\ \mathrm{m}^{-1/3}\mathrm{s}$; a lower value range than that for other linings specified in Chow's studies even under uneven surfaces like stones and rubble linings including riprap. Hence, the experimentally obtained roughness value for fully gabion lined canal section (sides and canal bottom), indicates a quite a smooth intra-surface where the resistance develop by the canal bed and bank surfaces against the flow is reasonably low.

From the functional relationship between the non-dimensional numbers involving roughness coefficient indicates, the Froude number (*Fr*) as well as Reynolds number (*Re*), both have large influence upon the roughness coefficient "*n*".

However, the experimental observations indicate, that the influence of "*Re*" in the test model flow, is less significant as resulting with corresponding higher "*Re*" numbers involved with the test model flow velocities. The variation of "*Re*" number for the model indicates a range beyond 13500 while the flow is subcritical as Froude number indicates lower than one for all test model experimental flow velocities.

6. Conclusion and Recommendations

By using a dimensionally similar physical test gabion lining model, the experimentally determined Manning's coefficient indicates a lower range of roughness value compared with the roughness coefficient values established by the Chinese engineer Ven Te Chow in 1959.

By changing the denseness of the packing, it allows to vary the amount of voids and surface irregularities of the boundary surface which will directly affect the variation of the roughness coefficient of the boundary surface. Therefore, by varying the packing density of the of rock material in the modelled mesh while maintaining the shape of mesh as rectangular and the integrity of all the meshes in the lining to act as a whole, will reflect more precise roughness coefficient range for the gabion materials in canal lining.

However, it is necessary to perform further experiments on the test model study on a wide range of flow velocities to understand the exact variation of Manning's coefficient for a fully gabion lined section.

References

1. Charman, J., Kostov, L., Minetti L., Stoutesdijk, J., and Tricoli, D., *Small Dams and Weirs in Earth and Gabion Materials*, FAO Land and Water Development Division, Rome, Italy, 2001, pp. 3 - 9.

2. Chow, V. T., *Open Channel Hydraulics*, International Student Edition, McGraw-Hill Book Company Inc., New York,1959, 136 p.

3. Jain, A. K., *Fluid Mechanics Including Hydraulic Mechanics,* 9th Edition, Khanna Publishers, Delhi, 2006, pp. 265-308.

4. Kraatz, D.B., *Irrigation Canal Lining, Chapter 6*, FAO Land and Water Development Series, No 1., FAO, Rome, 1977, pp. 44-50.

5. Ponraj, A. J. P., *Technical Guideline for Irrigation Work*, Irrigation Department, Sri Lanka, 1989, pp. 105-108.

6. Dahigaonkar, J. G., *Textbook of Irrigation Engineering*, 2nd ed., A. H. Wheeler & Co. (P) Limited, Allahabad, 1985, pp. 208-209.

7. Varshney, R. S., Gupta, S. C., and Gupta, R. L., *Theory and Design of Irrigation Structures, Vol I. Channels and Tube Wells*, 7th ed., New Chand & Bros Roorkee (U.P.), 2005, 228-229p.

8. Raghunath, H. M., *Irrigation Engineering*, Wiley, India, 2012, 150 p.

9. Shah, S. Y., Islam, Z. U., and Rather, S. A., "Engineering Feasibility of Gabion Structures Over Reinforced Concrete Structures", *International Research Journal of Engineering and Technology*, Vol: 05, Issue: 10, October, 2018, pp. 990-994.

10. Werner, M., Hunter, N. and Bates, P., "Identifiability of Distributed Floodplain Roughness Values in Flood Extent Estimation", *Journal of Hydrology*, Vol. 314, Issue 1-4, November, 2005 pp. 139–157.

11. Snell, M., "Lining Old Irrigation Canals: Thoughts and Trials 1. Irrigation and Drainage", *The Journal of the International Commission on Irrigation and Drainage*, 50(2), June, 2001, pp.139-157.

12. Chang, T.H., Huang, S.T., Chen, S. & Lai, J.C. "Estimation of Manning Roughness Coefficient on Precast Ecological Concrete Blocks", *Journal of Marine Science and Technology*, Vol. 18, No. 2, August, 2010, pp. 308 - 316.

13. Merry, M. A., "Experimental Study for determine Manning's Coefficient with Different Slopes and Channel Bed Materials", *Kufa Journal of Engineering*, Vol.8, No. 3, October, 2017, pp. 76-88.

14. Toprak, B., Sevim, O., & Kalkan, I., "Gabion Walls, and Their Use", *International Journal of Advances in Mechanical and Civil Engineering,* Vol.3, Issue 4, August, 2016, pp. 56-58.

15. William, F. C., *Estimation of Roughness Coefficients for Natural Channels with Vegetated Banks*, US Geological Survey Water Supply paper 2441, Prepared in corporation with the New York State Department of Transportation, 1998, pp. ##.

16. Barnes, H.H., Jr., *Roughness Characteristics of Natural Channels*, U.S. Geological Survey Water-Supply Paper 1849, United States Government Printing Office, Washington, 1967, 213 p.

17. Vende Boasch, B. E., Snellen, W. B., Brouwer, C. and Hatcho, N., *Structures for Water Control and Distribution,* Irrigation Water Management

Training Manual No. 8, FAO, Rome, 1993, pp. 38-46.

18. Limerinos, J. T., *Determination of the Manning's Coefficient from Measured Bed Roughness in Natural Channels – Studies of Flow in Alluvial Channels*, Geological Survey Water-Supply paper 1898 -B, US Department of the Interior, Washington, 1970, pp B1 – B13.

19. Jarrett, R. D., *Determination of Roughness Coefficients for Streams in Colorado*, US Geological Survey, Water Resources Investigation Report 85-4004, Lakewood, Colorado, 1985.

20. Thomas, J. L., and Pope, J. U*se of the Gabion in the Coastal Environment*, Report of CERC Coastal Engineering Research Center, U.S. Army Engineering Waterways Experiment Station, Mississippi, 1986.

21. Hill. R. 2000. *How Well does your Irrigation Canal Hold Water? Does it Need Lining?"* Electronic publishing, Utah State University Extension in corporation with the U. S. Department of Agriculture, Cooperative Extension Service, Utah State University, Logan, Utah (EP/03/2000/DF).

22. Andrew S, Earls, 2004. *Gabions for Erosion Canals. Modular Gabion Systems* Inc.www.gabions.net, visited, 2019/07/08.

23. http://www.aerodynamics4students.com/fluid-mechanics/fluidmechanics_w.php?page=7& visited, 2019/07/08.

24. Shepherd Company.C.E.2005. *Modular Gabion Systems,* http://www.gabions.net/news.html, visited, 2019/07/08.

Table 2 - Details of Standard and Model Gabion Materials

Description	Standard gabion material	Physical test model material
Appearance		
Dimension of box	6m X 2 m X 0.23 m (Hexagonal Triple Twist)	2.142 m X 0.714 m X 0.082 m
Mesh coating type	P.V.C Coated gabion box	P.V.C Coated wire meshed box
Mesh opening	80 mm X 100 mm	20 mm X 25 mm
Wire mesh gauge	2.7 mm - 3.7 mm	1.3 mm - 1.4 mm
Production process	Weaving, welded	Weaving, welded
Filling material	Rubble of size 0.150 m - 0.225 m	Rubble of size 0.053 m – 0.08 m

Table 3 - Observations of Flow Measurements on Test Model

Test Sq. No	Flow depth in test model (cm)						Velocity at different flow depths using current meter (ms^{-1})				
	Unlined	Modelled gabion lined					lined	unlined			
	L_0	L_1	L_2	L_3	L_4	L_5	0.6D	0.2*D*	0.4*D*	0.6*D*	0.8*D*
01	18.9	18.9	19.1	19.1	19.4	19.5	0.299	0.076	0.076	0.076	0.076
02	20.72	20.72	20.74	20.8	20.83	20.91	0.310	0.082	0.082	0.082	0.082
03	25.51	25.3	25.3	25.3	25.2	25.41	0.335	0.097	0.099	0.099	0.096
04	30.47	33.04	33.1	33.11	33.13	33.15	0.365	0.130	0.128	0.128	0.129
05	38.83	38.2	38.08	38.04	38.28	38.16	0.366	0.122	0.123	0.123	0.122