DETERMINATION OF CONSTANTS IN UNIFORM FLOW FORMULA FOR SMALL DISCHARGES IN OPEN CHANNELS

By

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THESIS

Submitted in partial fulfilment of
the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
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Tavanur, Malappuram

1990

DECLARATION

I hereby declare that this thesis entitled "Determination of Constants in Uniform Flow Formula for Small Discharges in Open Channels" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society

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Tavanur,

-1990

CERTIFICATE

Certified that this thesis entitled "Determination of Constants in Uniform Flow Formula for Small Discharges in Open Channels' is a record of research work done independently by **Miss. Parvathy, S.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We, the undersigned members of the Advisory Committee of **Miss. Parvathy, S.,** a candidate for the degree of Master of Science in Agricultural Engineering, agree that the thesis entitled "Determination of Constants in Uniform Flow Formula for Small Discharges in Open Channels" may be submitted by Miss Parvathy, S in partial fulfilment of the requirement for the degree.

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To my grandfather

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PARVATHY S.

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SYMBOLS AND ABBREVIATIONS

ASAE - American Society of Agricultural Engineers

ASCE - American Society of Civil Engineers

cm - centimere(s)

cfs - cubic feet(s) per second

gm - gram

kg - kilogram

l - litre(s)

l/s - litre(s) per second

log - logaritham

m - metre(s)

m/s - metre(s) per second

m^2 - square metre(s)

m^3/s - cubic metre(s) per second

min - minute(s)

° - degree

% - percentage

Introduction

INTRODUCTION

Water is a precious commodity which plays a greater part than anything else in promoting animal and plant life on earth. The human civilization owes its existence to the benefits derived from the exploitation of water for power, irrigation, industries and domestic purposes. The steady increasing population, expanding industries and rehabilitation problem common to many parts of the world are placing increased demand on water. As a result of this, in certain countries scarcity of water is already being felt keenly. India as a whole, is fortunate in having abundant water resources. Eventhough these resources are being utilised for various purposes, by far the largest use is being made for irrigating millions of acres of land through a network of canals.

Productivity is the index for the development of any nation. Scientific water management is an inter-disciplinary area of research involving agronomist, economists, engineers, plant scientists and soil scientists. Land and water being limited, their efficient use is basic to the survival of an ever increasing population. Scientific management of irrigation water is the only way in which we can make our agriculture competitive and profitable. Hence by scientific agronomic operations, efficient water management and modernisation of irrigation system, additional area can be brought into the command. Integrated development of water resources, efficient methods of conveyance and distribution of water on the farm, judicious methods of water application, proper soil management practices and cropping patterns for high water use efficiency are the important aspects of a comprehensive irrigation development programmes. The major problem encountered in ensuring rationalised irrigation supply is the wastage of water at outlet point owing to the lack of borrowpit crossing or absence of appropriate regulation of water to the remote areas through field channels wherever needed.

At present in almost all the river valley projects, water is conveyed from the canal outlets to individual field through makeshift arrangements. Large quantities of water are lost by seepage under such a system. In case where the fields are far from the outlet point, water do reach them. In this context, the Government of India introduced the command area development programme which consisted of development of irrigation through construction of field channels.

In many irrigation projects, a network of canals demand a sizeable share of financial outlay. Proper design of canals thus gains importance in governing economics and efficiency of the project. Channels are designed to get maximum permissible velocity. Natural slope of the land is the primary deciding factor in determining the channel bed slope. The various states in India adopt Kennedy's, Lacey's, Manning's and Chezy's equation for the design of channel sections and practices vary from state to state. Among these equations Manning and Chezy's equations are the most widely used formulae for the design of channels. All these equations were developed for large canals and streams and the validity of these equations were never tested for small channels. In the area of open channel hydraulics, the design of small channels capable of transporting water between two points in a safe, cost effective manner is a critical topic. So an attempt was made to develop an empirical equation for the design of small channels capable of carrying discharges less than 10 l/s This is very relevant in designing small field channels in command area development projects.

The objectives of the study are (1) to develop an empirical equation for uniform flow in open channels for discharges less than 10 l/s in cement lined and earthen channels (2) compare these equations with the well known uniform flow formulae, and check their validity in small channels (3) to find out the textural classification of the soil in which experiments were conducted in this study.

Review of Literature

REVIEW OF LITERATURE

The importance of irrigation in the world as well stated by Gulhati (1958) as an old art - as old as civilization but for the whole world it was a modern science - the science of survival. The scope of irrigation science extended from the watershed to the farm and on to the drainage channel. Irrigated agriculture is by far the biggest consumer of water, one of the most inefficient. Dakshinamurthi (1973), Chaturvedi (1978) and Senapathy (1981) suggested that as our water resources were limited, efforts have to be continuously made to optimise the use of available water resources by bringing improvements in design, planning and operation. While analysing the factors that contributed to under utilization of irrigation water Satpathy (1984) observed the deficiencies such as inadequate maintenance and poor distribution system were the main reasons.

1. Necessity of field channels

Poor distribution system characterised by the absence of field channels constituted a major cause of under-utilization. According to Indapurkar (1968) proper layout of field channels was one of the most important feature in developing successful irrigation. Madan et al (1968) pointed out that the field channels helped to promote general efficiency of irrigation, prevention of waterlogging and to ensure uniformity of water application. The failure of farmers to construct field channels within the irrigation commands was found to be the major reason for under-utilization of water from irrigation projects (Easter, 1975, Kumar, 1977). Senapathy, Ahmed (1981) and Sharma (1983) pointed out that in the absence of any conveyance channel from the outlet point to the interior, there was field to field inundation leading to undue waste and relatively prolonged period for the water to reach the remote areas.

According to Singh et al (1968) adequate capacity, minimum land area lost in channels, reducing seepage losses and erosion hazards in field channels were the main criteria in the design of channels. Considering the site conditions, land topography, supply level and easy operation of farmers, transmission of water by open channel was preferred (Senapathy et al., 1981). According to Thatte (1983) the efficiency of the canal system in India has been assumed at about 30 per cent but it could be raised by choosing the most economical section of canal Sankara Iyer (1983) after a case study on Panam project concluded that it was necessary to ensure that the irrigation potential already created and to be created in future was full utilised by improved canal network design and layout so that each farmer in the command area of the project got assured deliveries of water according to pre-determined schedule.

2. Design of channels

The design of small channels capable of transporting water between two points in a safe, cost effective manner was a critical topic in the area of open channel hydraulics (Mohammed, 1978) But according to Streeter (1945) and Houk (1956), the designer simply computed the dimensions on the basis of hydraulic efficiency, practicability and economy. The other factors to be considered in the design were kind of material forming the body and the maximum permissible velocity. Richard (1989) suggested that the channel cross sections were very important part of hydrologic analysis and design.

A. Shape of the channel

Earthen channels were generally trapezoidal with side slope determined by the stability of the bank material (Linsley, 1964). In artificial canals, the trapezoidal section being often preferred in the interest of economy and bank stability according to ASCE reports. According to Houk (1956), Chow (1959) and Ned (1979) trapezoidal sections were most commonly used for larger canals. Kurse et al (1980) observed that the size of the canal depended upon the water available, soil topography, method of irrigation and farm management practices.

B. Side slope

Side slope depends primarily upon the stability of the soil. For lined canal, slopes should be such that no earth pressure was exerted over the back of the lining. Side slope in unlined canals through earth formation should be flatter than angle of repose of saturated bank materials, so that portions would not slough into the canal sections Kurse et al. (1956) recommended $1\frac{1}{2}$ 1 to 2 1 side slope for earthen sections. Chow (1959) recommended the side slope for earth with concrete lining as $\frac{1}{2}$ 1 to 1 1, for stone lining as 1 1 and for small earthen ditches as 1$\frac{1}{2}$ 1. According to IS 10430 (1982) for sandy soil recommended value of side slope was 1 1 to 2 1 in cutting.

C. Free board

According to Chow (1959) and Ned (1979) the height of free board might vary from 5 to 30 per cent of the designed water depth depending on the channel design and purposes. For small ditches Kurse _et al_. (1980) recommended a minimum value fo 10 cm for earthen ditches and 7.5 cm for lined ditches. IS 10430 (1982) recommended a free board of 0.1 to 0.15 m for water courses having discharges less than 0.6 cummecs

D. Bed slope

The bed slope was fixed primarily according to country slope consistent with economy. Velocity of flow is influenced by the canal slope. In general the slope required to obtain maximum permissible velocity would make construction to be economical. The slope to adopted should be within the maximum and minimum permissible velocities. For uniform flow the energy gradient was taken as the slope of the canal. In Kerala, Framji (1972) and Purushottam (1980) recommended a slope of 1/2000 to 1/5000 for canals depending upon the soil condition. Kurse _et al_. (1980) recommended a minimum slope of 0.0004 for an unlined farm ditch.

C. Permissible velocity

The maximum permissible velocity or the non-erodible velocity is the greatest mean velocity that will not cause erosion of the channel body Maximum permissible velocity varies with soil texture For most farm ditches, the value of permissible velocity was 0 5-1 m/s. According to Chow (1959) the minimum permissible velocity or nonsilting velocity was the lowest velocity that would not start sedimentation and induce the growth of aquatic plant and moss Hence a mean velocity of 0.6-0 9 m/s may be used safely when the percentage of silt present was small According to IS 3873 (1978) limiting velocity for cement concrete lining was 2 7 m/s. Maximum permissible velocity for different types of soils in bare channels are as follows

Silt and sand	0.45 m/s
Loam, sandy loam, silt loam	0.6 m/s
Clay loam	0.65 m/s
Clay	0 7 m/s

3. Measurement of discharge in open channels

Godbole et al. (1983) from their case study in chambal canal system showed the necessity of field measurements for assessing the performance of a canal system and for estimating the losses Many flow measurement devices and methods are in use throughout the world (Thomas, 1960) Weir is probably the most common device used for water measurement in small canals According to Parshall (1950), US Bur. Reclam (1953) and US Dept. Agric. (1962), with proper installation and maintenance, weirs gave accurate results. While using a weir, the blade should be fairly sharp on the upstream edge. Permissible errors in discharge measurement were 10-15 per cent. The errors in discharge measurement were due to inaccurate measurement of the head over the weir, deposition in the upstream pool etc (Thomas, 1959) According to Bos (1976) the possible source of errors were instrumental errors, errors in zero setting and in reading and other construction faults.

Creages (1950), Robinson et al. (1967); Bos (1976) and Ned et al (1976) recommended triangular (V-notch) weirs for accurate measurement for a wide range of water elevation. For V-notch, the head for extremely small discharges was proportionally greater due to the reduction of crest length near the apex. According to King (1948) the cross sectional area of the nappe was usually much smaller than that of the channel approach. The velocity of approach was therefore small and the error introduced by neglecting it was usually inappreciable. Sharpness of crest edge was very important since a slight dullness or rounding of the upstream edge results in increase in flow. According to Thomas (1959) heads were measured in a stilling well by means of a hook gauge. In order to avoid errors due to drawdown at the nappe, King et al. (1963) and Bos (1976) recommend that the head should be measured at least 3 to 4 times the head upstream from V-notch weirs. The basic head discharge equation

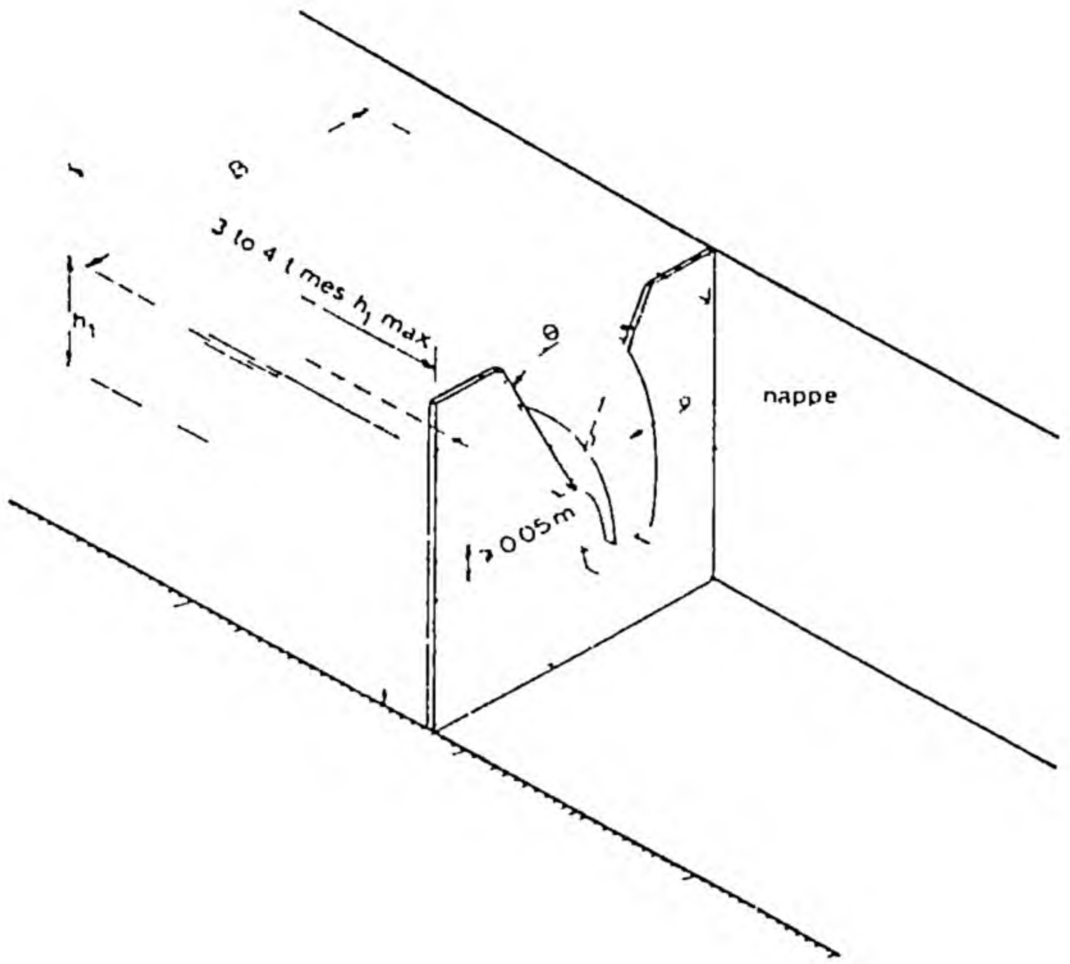


Fig 1(1) V-notch sharp-crested weir

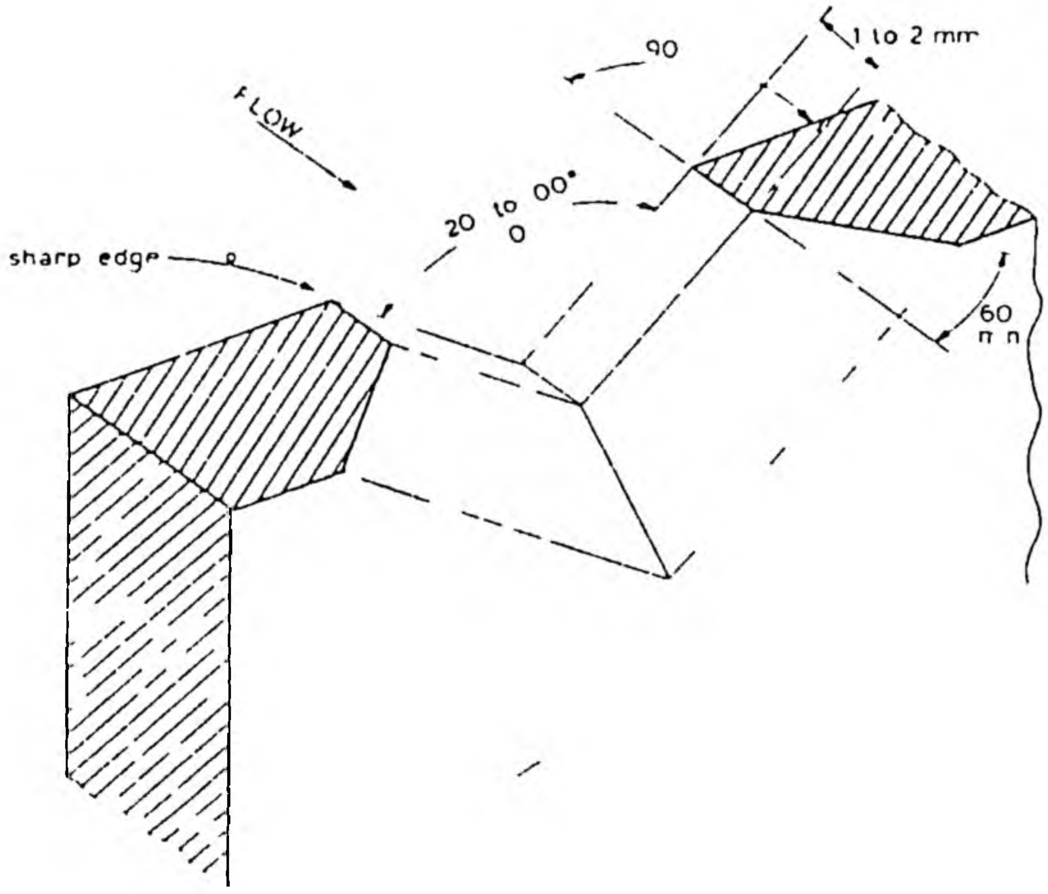


Fig 1(2) Enlarged view of V-notch

for a V-notch sharp crested weir (Kindsvater et al. (1957) in fully and partially contracted condition was

$$Q = \frac{8}{15} \; Cd \sqrt{2g} \; \tan \; \Theta/2 \; H^{5/2}$$

where,

Q = discharge, m^3/s

H = the effective head, m

Θ = angle included between the sides of V-notch, degree

Cd - coefficient of discharge

According to Bos (1976) commonly used size of V-notch for fully contacted thin plate weir was 90° in which the dimensions across the top was twice the vertical depth. Discharges for V-notch sharp crested weirs for different heads are given in Appendix I BY U.S.B.R. the discharge equation of standard 90° V-notch weir was given as $Q = 2.49 \; H^{2.48}$. Thomson (1861) from his experiments indicated that the value of coefficient of discharge increased very slightly as the head diminishes. With a right angled notch this variation was less than one per cent. He estimated the mean value of coefficient of discharge for a right angled notch as 0.593, thus giving a discharge $Q = 2.536 \; H^{5/2}$ cfs. According to Israelson et al. (1962) the coefficient of discharge must be varied slightly to take care of changing contrations and losses when boundaries were changed.

A. Uniform flow in open channels

In open channels, flow is said to be uniform if the depth of flow is the same at every section of the channel (Chow, 1959, Ned et al., 1976). A turbulent uniform flow was most commonly encountered in engineering problems. Under usual field conditions flow is non-uniform and unsteady (Chow, 1959). But for easier mathematical handling, simple conditions of steady uniform is substituted. In general uniform flow can occur only in very long straight prismatic channels. In turbulent flow, the water particles move in irregular paths which are neither smooth nor fixed but which in the aggregate still represent the forward motion of the entire stream.

5. Uniform flow formulae

Most practical uniform flow formula can be expressed in the general form

$$V = CR^{x} S^{y}$$

where,

V = mean velocity, m/s
R = hydraulic radius, m
S = longitudinal slope
C = roughness factor

A good uniform flow formula with turbulent flow should take into account the variables such as velocity, perimeter, hydraulic radius, maximum depth of water area, slope of water surface, temperature of water etc Antoine Chezy (1769) developed the first uniform flow formula which is of the form

$$V = C\sqrt{RS}$$

where,

V = mean velocity, m/s

R = hydraulic radius, m

S = slope of the energy line

C = Chezy's constant

This formula was derived mathematically from two assumptions First assumption stated that the force resisting the flow per unit area of the streambed was proportional to the square of the velocity. The surface of contact of the flow with the streambed was equal to the product of wetted perimeter and the length of the channel reach. Second assumption explained that the effective component of gravity force causing the flow must be equal to the total force of resistance (Chow, 1959).

Many attempts were made to determine the value of C Gangenillet and Kutter (1869) published a formula expressing the value of 'C' from flow measurement data in various types of channels (Chow, 1959).

$$C = \frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}$$

where,

n = coefficient of roughness (Kutter's n)

Bazin (1897) proposed a formula according to which Chezy's C was considered as a function of R (Chow, 1959).

$$C = \frac{157.6}{1.81 + m/\sqrt{R}}$$

Where 'm' is a coefficient of roughness whose values proposed by Bazin are given in Appendix II Bazin formula was developed primarily from the data collected from small experimental channels. The Miami Conservance District (1918) compared the variations in Chezy's C. Bazin's 'm' and Kutter's 'n' for Bazin's experimental data obtained from several natural streams and their results are given in Appendix III. The values of average variation indicated that Bazin's formula was not as good as Kutter's even for his own measurements Powel (1950) suggested a logarthmic formula for roughness of artificial channels and is given as

$$C = 42 \log \left(\frac{C}{4R} + \frac{\epsilon}{R} \right)$$

where,

ϵ = a measure of the channel roughness

The practical application of this was limited Garbrecht (1961) listed several empirical and salient formulae from turbulence theory for Chezy's coefficient. Karman-Prandtl equation was one among them which give

$$C = \sqrt{8g}\ [2 \log(2R/Ks)+1.74]$$

where,

Ks - equivalent roughness magnitude

Irish engineer Robert Manning (1889) presented a formula which was later modified to it's present form

$$V \quad \frac{1}{n} R^{2/3} S^{1/2}$$

Where 'n' is the coefficient of roughness known as Manning's n This formula developed from seven different formulae based on Bazin's experimental data, and further verified by 170 observations. This is the most widely used uniform flow formula in open channels Manning's n was developed empirically as a coefficient which remained a constraint for a given boundary condition, regardless of slope of the channel and size of channel. As a matter of fact however, each of these factors causes n to vary to some extent For practical purposes Manning's n and Kutter's n were considered identical and are given in Appendix IV. The exponent of hydraulic radius in Manning's formula was actually not a constant but varied in a range depending mainly on the channel shape and roughness.

For this reason some hydraulicians preferred to use the formula with a variable exponent. For example Pavlovski (1925) proposed the uniform flow formula widely used in USSR is given as

$$C = \frac{1}{n} R^{y}$$

where,

$y = 2.5\sqrt{n} - 0.13 - 0.75\sqrt{R}\,(\sqrt{n} - 0.10)$

C - Chezy's resistence factor

The exponent 'y' depended on the roughness coefficient and hydraulic radius. Manning's n was highly variable and depended on a number of factors. At the University of Illinois (1931) an investigation was made to determine the effect of vegetation on the coefficient of roughness and found that it increased the coefficient of roughness and reduced the capacity of the channel and retarded the flow. Channel irregularity definitely introduced roughness in addition to that caused by other factors. The value of n decreased due to silting and increased due to scouring. Recognizing several primary factors affecting roughness coefficient, Cowan (1956) developed a procedure for estimating the value of n as

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\ m^5$$

where,

n_0 - the basic n value for a straight uniform, smooth channel in natural materials involved

n_1 - a value added to n_0 to correct for the effect of surface irregularities

n_2 - a value for variation in shape and size of the channel cross section

n_3 - a value for obstruction

n_4 - a value for vegetation and flow conditions

m_5 - a correlation factor for meanduring of channel

The value of n_0 to n_4 and m_5 for different conditions are given in Appendix V.

Johnston and Goodrich (1911) proposed an exponential formula of the form $V = CR^p S^q$ and gave values of C and p making q uniformly equal to 0.5 for simplicity (Ellis, 1916). Other open channel equations that often used are given below (Garbrecht _et al._, 1961 and Bhowmik, 1965).

1. Weisbach (1845) and Darcy (1854)

$$f = \frac{8g\ RS}{V^2}$$

where,

f = friction factor

This equation was applicable to uniform and nearly uniform flows in open channels. Stanton Diagnam (1914) gave a relation between Reynold's number and friction factor of the Darcy-Weisbach equation

2 Hazen William formula (1933)

$$V = 1.318\ C_1\ R^{0.63}\ S^{0.54}$$

Where C_1 would depend upon roughness only. It has been used exclusively for design of water supply system in U.S.

3. G H. Keulegan (1938)

$$C - \frac{8}{f^{1/2}}$$

where,

C = Chezy's coefficient

f = Darcy-Weisbach coefficient

4 A.E. Bretting (1948)

$$\frac{1}{f^{1/2}} = 2 \log (Ks/14.83R)$$

where,

f = Darcy-Weisbach coefficient

Ks = equivalent sand grain diameter

5 J.H. Thijsee (1949)

$$\frac{1}{f^{1/2}} = 2.03 \left[\log \frac{12.2R}{0.282\delta + Ks} \right]$$

where,

δ = thickness of laminar sublayer

Ks = a measure of roughness

6. A.D Alfshul (1952)

$$\frac{1}{f^{1/2}} = 1.8 \log \frac{Re}{Re(\Delta/D)+7}$$

where,

Re - Reynold's number

Δ - a linear measure of roughness height

D - depth of flow

7 P. Ackers (1958)

$$C = (32\ g)^{1/2} \log \left(\frac{14.8\ R}{Ks} \right)$$

where,

Ks = a measure of amplitude of roughness

8. W.W. Sayre and M.L. Albertson (1961)

$$\frac{C}{g^{1/2}} = 6.06 \log \left(\frac{Dn}{x} + 2.6 \right)$$

where,

Dn = normal depth

x = a general roughness parameter

9. H.J. Koloseus and Davidian (1961)

$$\frac{1}{f^{1/2}} = 2 \log \left(\frac{0.56\ \lambda^{0.9}\ R}{Ks} \right)$$

where,

λ - a measure of concentration of roughness elements

Ks - a measure of the amplitude of the roughness elements

Keulegan (1938) and Rouse (1950) stated that velocity distribution in the cross section has appreciable influence only if the froude number of the flow is considerably greater than one. For a channel of given cross sectional area, R varied with the form of its section, while the resistance to flow increased as R diminished (Gibson, 1951). Measurements carried out by Martcinec (1958) confirmed the unsuitability of mean velocity equations with a constant exponent of hydraulic radius for more accurate computations This shortcoming was eliminated by equation of Pavlovski or Agnoskin *which* was a modification of Prandtl-Karman equation. Martcinec give the equation as

$$V = (18 \log R/d + 13) \sqrt{RS}$$

where,

S = slope from 0.0004 - 0.0039

d = diameter of particle from 0.004-0.25 m

R = hydraulic radius from 0.15-2.5 m

Shih <u>et al.</u> (1967) conducted a study which was concerned with the validity of applying the hydraulic radius as a sole geometric quantity for various channel shapes in the computation of turbulent uniform flow. The concept of hydraulic radius was based on the assumption that the distribution of shearing stress around the wetted perimeter of a channel cross section was uniform In open channel flows in a channel of any shape, the distribution of shearing stress was known to be uniform. The effect of channel shape and hydraulic radius relationship was in the reciprocal order. When the shape effect was more influencial, the hydraulic radius become less valid as a sole geometric quantity.

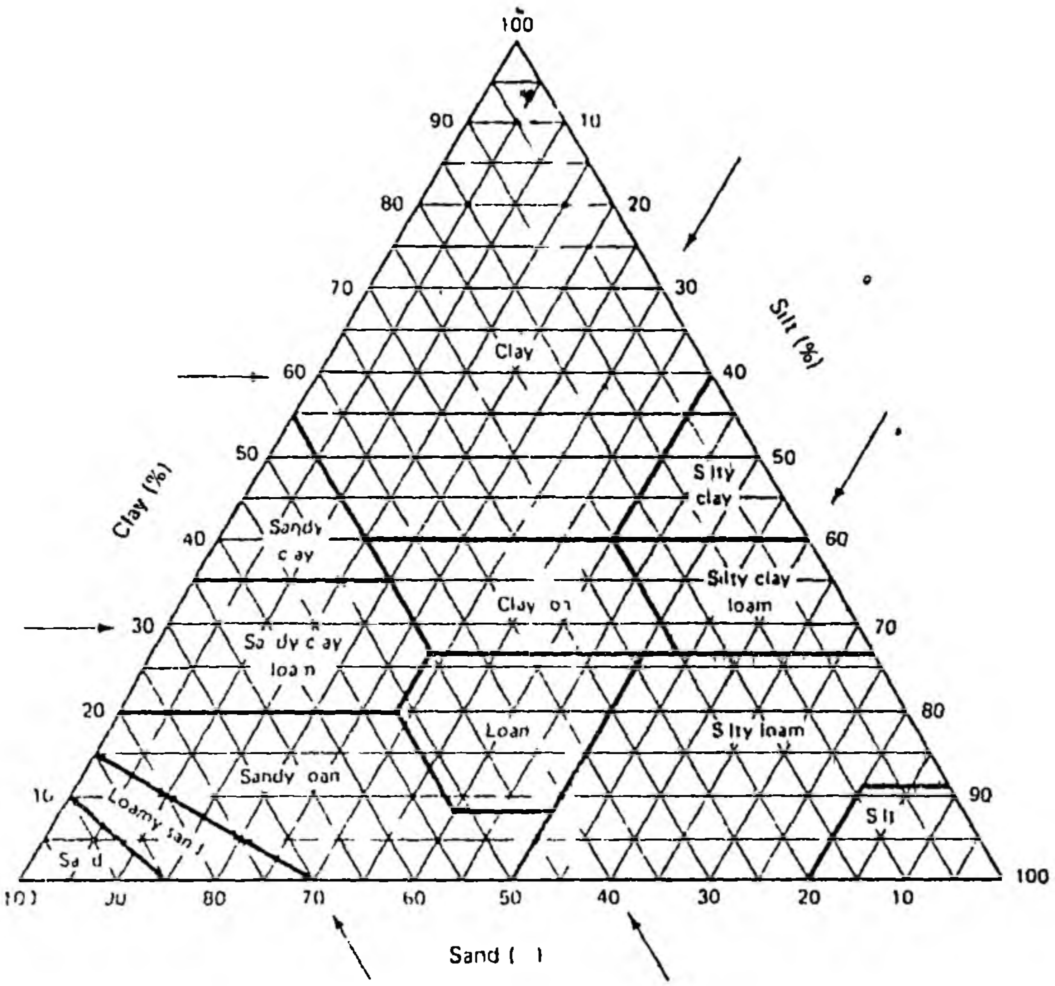
Liu *et al.* (1959) suggested that stable condition for a channel in an alluvial material were achieved through the adjustment of channel width, depth and channel slope. Resistance to the flow was a function of grain roughness and the form roughness caused by bed configeration and bank irregularities. Suryavanshi (1971) pointed out that for designing canal section by Manning's equation for a given velocity, discharge and side slope, there was a limiting minimum slope below which the section could not be designed.

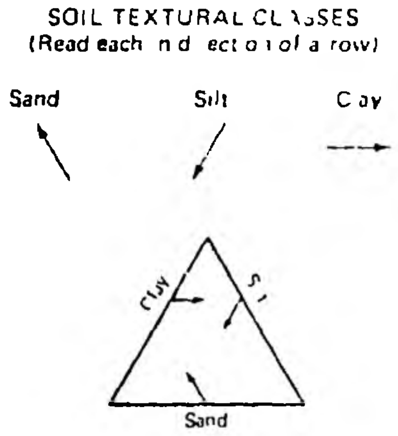
6. Textural classification of soil

Solid fraction of the soil was mainly composed of mineral particles which differ in sizes. The particle size distribution differed considerably in different soil types. Soil texture, quantitatively referred to the relative proportion of various sizes of soil particles in a given soil. The different particle sizes are usually divided into three textural fractions or separates such as sand, silt and clay The classification of soil separates was done on the basis of particle diameter ranges. The U.S.D.A., International Soil Science Society (ISSS) and Indian Standard (IS) classification which are the most commonly used are as follows.

Soil separates	U.S.D.A.	I.S.S.S.	I.S.
Gravel	>2 mm	>2 mm	>4.75 mm
Very coarse sand	1-2 mm	--	--
Coarse sand	0.5-1 mm	0.2-2 mm	0.625-4.75 mm
Medium sand	0.25-0.5 mm	--	0.425-0.625 mm
Fine sand	0.1-0.25 mm	0.02-0.2 mm	0.075-0.425 mm
Very fine sand	0.05-0.1 mm	--	--
Silt	0.002-0.05 mm	0.002-0.02 mm	0.002-0.075 mm
Clay	<0.002 m	<0.002 mm	<0.002 mm

Soil texture was designated on the basis of the proportion of the above mentioned soil separates. The field soil sample was analysed to find out the relative proportions of these particles and its texture was designated using the texture triangle shown in Fig.2 (Sinha, 1977 and Mc Cuen, 1989). According to them soil texture was an important factor in determining the water holding characteristics of the soil. Linsley *et al.* (1964) pointed out that the rate of seepage from unlined canals was influenced chiefly by the character of the soil and the location of the ground water level. Seepage rate for different type of materials in cu ft/sq ft/day were given as follows Clay loam 0.25-0.75, sandy loam 1-1.5, loose sandy soils 1.5-2.0 and gravelly soil 3.0-6.0. According to Landon (1984) mechanical analysis was used to determine the promotion of different sized particles in a soil. The mechanical analysis was performed in two stages, viz., Sieve analysis and Sedimentation analysis. First stage was meant for coarse grained soils only and for silt and clay size fractions sedimentation techniques were used (Punmia, 1988).





SIZE LIMITS OF SOIL SEPARATES	
Name of separate	Diameter range
	Millimeters
Very coarse sand	2.00-1.000
Coarse sand	1.00-0.500
Medium sand	0.50-0.250
Fine sand	0.25-0.100
Very fine sand	0.10-0.050
Silt	0.05-0.002
Clay	Below 0.002

Fig 2 Guide for textural classification by the U S System for texture designations

7. Necessity of lining in channels

Capacity of the canal system was fixed on the basis of culturable command area, water allowance and transmission losses (Purushottam, 1980). In the case of earthen channels the conveyance losses may range from 25-40 per cent which were mainly due to seepage Senapathy et al. (1981) from their seepage loss study in earthen channels in different types of soils revealed that loss was the highest in sandy loam soil. Further losses per unit time were much more in small field channels than in continuously flowing channels Haque (1978) found that a plane erodible bed was inherently unstable under the action of a flowing fluid. It deformed into various types of bed undulation which offered increased resistance to flow. Bed features such as ripples and dunes played a significant role in the make up of hydraulic resistance to flow in alluvial channels According to Vora (1977) and Ned (1979) from conjuctive use aspect, legal aspect and hydrological cycle aspect canal lining was beneficial and recommended it for economic use of scarce water resources.

A. Advantages and requirements of lining

According to Sain (1957) for water conservation and control of water logging and seepage in earthen canals, irrigation engineers were constructing lined canals wherever feasible. Sain, 1957 and Ned, 1976 enumerated the advantages of canal lining as (1) the coefficient of rugosity in a lined canal was much less than in an earthen channel which gave a higher velocity for the same slope,

(2) for higher velocity, area can be reduced for a given discharge resulting a reduction in construction cost, (3) seepage loss were reduced to 1/4th to 1/5th and prevented water logging, (4) maintenance and operation charges were reduced, (5) a lined canal can withstand erosion better than earthen canals. According to Purushottam (1980) lined canals were expensive and cost 3 to 4 times more than the unlined ones of equal capacity. Therefore lining of canals and optimum length for lining was based one economic analysis of benefits and capital cost (Khepar, 1979, Sharma, 1981) The essential requirements of a satisfactory lining were low cost, impermiability, hydraulic efficiency, durability and structural stability. The selection has to be made after considering climatic conditions, position of water table, availability of material, size of the canal etc.

B. Materials used for lining

Different types of materials commonly used for lining are as follows. (1) concrete cast in situ (2) precast concrete (3) brick masonry (4) stone masonry (5) bituminous material (6) earth material (7) films of plastic and synthetic material. Senapathy et al. (1981) observed that the brick lined channel with concrete base gave longer service with minimum repair and maintenance cost and appeared to be the most effective.

Materials and Methods

MATERIALS AND METHODS

The mean velocity of a turbulent uniform flow in open channels is usually expressed in the general form

$$V = CR^{x} S^{y}$$

where,

V = mean velocity of flow, m/s

R = energyslope or longitudinal slope

x&y = exponents

C = a factor of flow resistance which varies with mean velocity hydraulic radius, channel roughness, viscosity and many other factors

In the present study, experiments were conducted to find out the following constants in the uniform flow formula for discharages less than 10 l/s in cement lined and earthen channels.

1. Exponent 'x' of hydraulic radius, R
2. Exponent 'y' of energy slope, S
3. Factor of flow resistance, C

Experiments were conducted for different discharges varying from 1 l/s to 9 l/s and for slopes of 1/2000, 1/3000, 1/4000 and 1/5000. Observations were taken for the above slopes and discharges in lined and earthen channels. The values obtained were compared with Manning's and Chezy's equation for checking the extent of their validity for discharges less than 10 l/s in small canals.

1. Location

The experimental site selected was in the Instructional Farm of Kelappaji College of Agricultural Engineering and Technology at Tavanur. The size of the plot was 45 x 6 m.

2. Clearing the site

The site selected was cleared and levelled approximately.

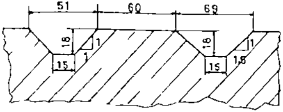
3. Canals

a. Lined canal

A trapezoidal canal was designed for a discharge of maximum 10 l/s. The cross section of the canal was as follows.

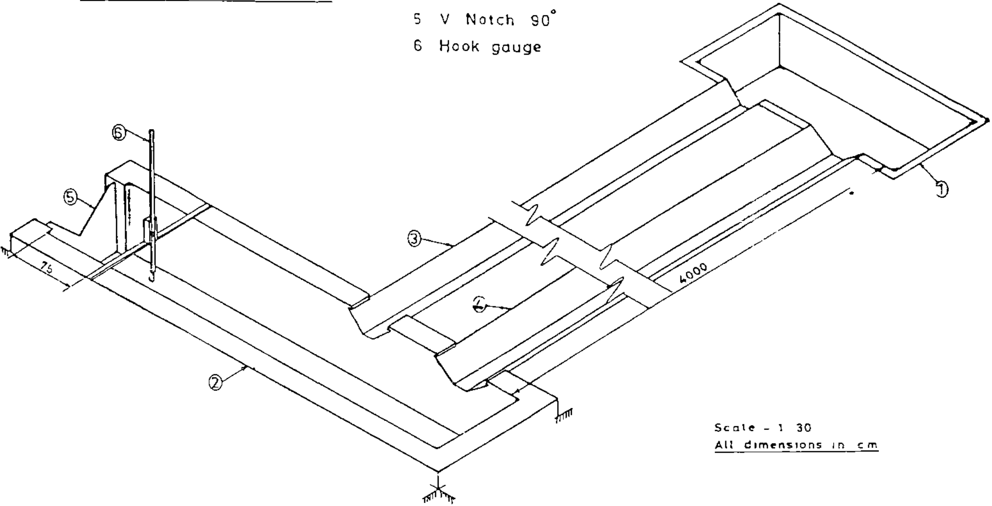
Bottom width = 15 cm
Side slope = 1 1
Depth of canal = 18 cm
Length of canal = 40 m

Longitudinal slopes of 1/2000, 1/3000, 1/4000 and 1/5000 were used for conducting the experiments in the lined channel. Cement was used as the lining material.



Cross section of Channel

1 Upstream tank (260×110×60)
2 Downstream tank (510×110×80)
3 Cement lined channel
4 Earthen channel
5 V Notch 90°
6 Hook gauge



Scale - 1 30
All dimensions in cm

Fig 3 EXPERIMENTAL SITE (an isometric view)

b. Earthen channel

A trapezoidal canal was designed for a discharge of maximum 10 l/s. The dimensions of the section were

Bottom width = 15 cm
Side slope = 1.5 1
Depth of canal = 18 cm
Length of canal = 40 m

Longitudinal slopes of 1/2000, 1/3000, 1/4000 and 1/5000 were used for conducting the experiment in the earthen channel.

c Upstream tank

A tank of size 2.6 x 1.1 x 0.6 m was made at the upstream, common to both the channels. Water entered the channel directly from the tank when the water level was above the bottom level of the channel.

d. Downstream tank

A tank of size 5.1 x 1.1 x 0.8 m was made at the downstream, common to both the channels. Water flowing through the channel fell into the downstream tank. On the breadthwise side of the tank, a V-notch was installed to measure the discharge in the channel. The V-notch was installed avertically such that the apex of the notch above the floor level of the tank was atleast two times the maximum expected head over the notch to form the nappe.

4. Materials used for construction

1.	Bricks	Country burned bricks of 22 x 11 x 7 cm were used for canal lining and tank construction
2.	Cement	Portland cement was used for the whole construction work
3.	Sand	River sand was used for the whole construction work
4.	Aggregates	Gravel of 6 mm and 12 size were used for concreting the bottom of channel and tanks respectively

5. Method of construction

a. Canals

For a length of 40 m, two channels were excavated side by side, trapezoidally to get the required size. The size of excavation used for lined channel was such that the required size was obtained after lining. A mixture of 1 4 8 with a water cement ratio of 1 6 was used for concreting the bottom of the channel to a thickness of 20 mm Bricks were used for lining the sides of the channel. Inside and top cover were plastered with 1 5 mix and trowel finished to a thickness such that the dimensions of the channel were precise The dimensions and side slope were checked by using a template of correct dimensions, at different sections of the channel.

b Upstream tank

The tank was constructed common to both the channels with a wall thickness of 11 mm. The bottom of tank was concreted with 1 4 8 mix, 50 mm thick and plastered completely with cement mortar 1 5.

c Downstream tank

The tank was constructed common to both the channels with a wall thickness of 25 cm A mixture of 1 4 8, 50 cm thick was used for concreting the bottom and cement mortar 1 5 was used for plastering the tank and finished with a neat flushing coat.

d. V-notch

A V-notch was used for measuring the discharge in the channel, It is one of the most precise discharge measuring device suitable for a wide range of flow.

6. Hook gauge

A large hook gauge with vernier arrangement was used to measure the head of water over the notch and hence the discharge The hook gauge was fixed on a 6 mm thick MS flat and the whole arrangement was placed at a distance of 5 times the maximum expected head, i.e 75 cm from the notch to get a still water surface where velocity was essentially zero while measuring the head over the notch This was made necessary by the downward curvature of the water surface near the crest

7. Stop watch

A stop watch was used to note the time taken for filling the drum for the calibration of the notch.

8. Scale

A 15 cm, thin bevel edged, transparent and non-flexible scale was used to measure the depth of water in the channel at different sections

9. Source of water

The main well in the Instructional Farm and two filter point tube wells near the site were used as the source of water for the experiment

10 Aluminium pipes

Since the source of water was at some distance away from the site, aluminium pipes were used for conveyance of water from the source to the site.

11. Pipe bends

90° aluminium pipe bends were connected to the end of the last conveyance pipes at the upstream tank in such a way that the mouth of the bends were below the water surface to avoid turbulance on the water surface during the experiment.

12. Pump

Pumps were used to draw water from the wells

13. Sieves

2 mm, 1 mm, 600, 425, 300, 212, 150 and 75 microns with lid and receiver, weighing balance, sieve bursh, evaporating dish, metal trays, drying oven and mechanical sieve shaker were used in dry sieve analysis for determining the particle size distribution.

14. Hydrometer

A density hydrometer, hydrometer jars, thermometre, stirrer, dispersing agent and a stop watch were used for sedimentation analysis to find out the texture of the soil.

15. Basic hydraulics

An open channel is a conduit in which water flows with a free surface When flow occurs in an open channel, the resistance is encountered by water as it flows downstream. This resistance is generally counteracted by the components of gravity forces acting on the body of the water in the direction of motion A uniform flow will be developed if the resistance is balanced by the gravity forces The magnitude of the resistance, when other physical factors of the channel are kept unchanged, depends on the velocity of flow. In uniform flow, depth, water area, velocity and discharge at every section of the channel reach are constant and the energy line, water surface and channel bottom are parallel.

1 Channel geometry

A channel built with unvarying cross-section and constant bottom slope is known as prismatic channel. A channel section refers to the cross section of a channel taken normal to the direction of flow Geometric elements of a channel section are the properties of a channel section that can be defined entirely by the geometry of the section and the depth of flow. The definitions of several geometric elements of basic importance are given below

a. Bottom width (B) is the width of the bottom of the channel section

b. Depth of flow (Y) is the vertical distance of the lowest point of a channel section from the free water surface

c Top width (T) is the width of the channel section at the free water surface

d Water area (A) is the cross sectional area of the flow normal to the direction of flow e Wetted perimeter (P) is the length of the line of intersection of the channel wetted surface with a cross sectional plane normal to the direction of flow

f Free board in a channel is the vertical distance from the water surface to the top of the banks while water is being conveyed at full capacity

g Hydraulic radius (R) is the ratio of the water area to its wetted perimeter.

$$A = (B \times my)\ Y$$

$$P = B + 2y\sqrt{1+m^2}$$

$$R - A/P$$

where,

A - water area, m^2

P - wetted perimeter, m

R = hydraulic radius, m

B = bottom width, m

Y = depth of flow, m

m 1 = side slope of the channel

The basic equation for any flow past a across section is given by

$$Q = A \times V$$

where,

Q = discharge at a channel section, m^3/s

A – flow cross sectional area normal to the direction of flow, m^2

V – mean velocity of flow, m/s

2 Velocity distribution in a channel section

Owing to the presence of a free water surface and to the friction along the channel wall, the velocities in a channel are not uniformly distributed in the channel section The measured maximum velocity in ordinary channels usually appears to occur below the free water surface at a distance of 0 05 to 0.25 of the depth. The pattern of velocity distribution in trapezoidal channel section is shown in Fig 4 The velocity distribution in a channel section depends also on other factors, such as the unusual shape of the section, the roughness o the channel, and the presence of bends. The maximum velocity may often be found at the free surface. The roughness of the channel will cause the curvature of the vertical velocity distribution curve to increase (Fig 5). On a bend, the velocity increases greatly at the convex side, owing to the centrifugal action of the flow. Surface wind has very little effect on velocity distribution

3 Pressure distribution in channel section

The pressure at any point on the cross section of the flow in a channel of small slope is measured by the height of the water column in a piezometer installed at the point (Fig 6). The distribution of pressure over the cross section of the channel is the distribution of hydrostatic pressure

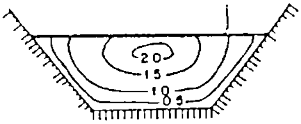


Fig.4 Velocity distribution in trapezoidal channel

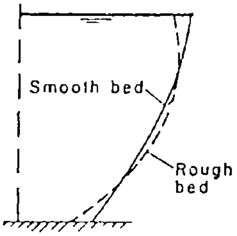
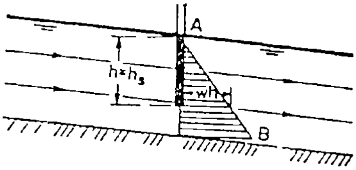


Fig.5 Effect of roughness on velocity distribution in open channel



h = piezometric head

hs hydrostatic head

Fig 6 Pressure distribution in straight channel of small slope

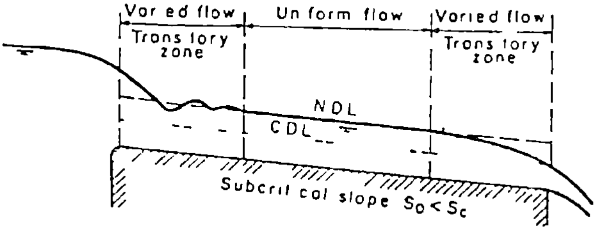


Fig.7 Establishment of uniform flow in long channel

4 State of flow

The state or behaviour of open channel flow is governed basically by the effects of viscosity and gravity relative to the inertial forces of the flow The surface tension of water may affect the behaviour of flow under certain circumstances Depending on the effect of viscosity relative to inertia, the flow may be laminar, turbulent or transitional The flow is laminar if the viscous forces are so strong relative to the inertial forces that viscosity plays a significant part in determining flow behaviour In turbulent flow, the viscous forces are weak relative to the inertial forces. Transitional state is in between laminar and turbulent states The effect of viscosity relative to inertia can be represented by Reynold's number and is given by

$$Re = \frac{VL}{\nu}$$

where,

Re = Reynold's number

V = Velocity of flow, m/s

L = Characteristic length i e hydraulic radius for channel, m

ν = Kinematic viscosity of water, m^2/s

Open channel flow changes from laminar to turbulent in the range of Re' between the critical value 500 and a value that may be as high as 12500

5. Establishment of uniform flow

A uniform flow will be developed if the resistance is balanced by the gravity forces. The magnitude of the resistance, when other physical factors of the channel are kept unchanged, depend on the velocity of flow. If the water enters the channel slowly, the velocity and hence the resistance are small, and the resistance is out balanced by the gravity forces, resulting in an accelarating flow in the upstream reach. The velocity and the resistance will gradually increase until a balance between resistance and gravity forces is reached. At that moment and afterward the flow become uniform. The upstream reach that is required for the establishment of uniform flow is known as the transitory zone. In this zone the flow is accelarating and varied. Toward the downstream end of the channel the resistance may again be exceeced by gravity forces, and the flow may become varied again. Establishment of uniform flow in a long channel is shown in Fig.7. The water surface in the transitory zone appears undulatory. The flow is uniform in the middle reach of the channel but varied at the two ends. The length of this zone depend on the discharge and on the physical conditions of the channel, such as entrance condition, shape, slope and roughness From a hydrodynamic standpoint, the length of the transitory zone should not be less than the length required for the full development of the boundary layer under the given conditions.

Most practical uniform flow formula can be expressed in the general form

$$V = CR^{x} S^{y}$$

where,

V = mean velocity of flow, m/s

C = a factor of flow resistance

R = hydraulic radius, m

S = longitudinal slope on energy slope

x & y = exponents

The best known and most widely used uniform flow formulae are the Chezy's and Manning's. Chezy's formula is given by

$$V = C\sqrt{RS}$$

where,

V = mean velocity of flow, m/s

R = hydraulic mean radius, m

S = slope of the energy line

C = °Chezy's constant

Chezy's resistance factor is determined by Ganguillet and Kutter's formula and Bazin's formula. Ganguillet and Kutter published a formula expressing the value of C as

$$C = \frac{23 + \frac{1}{n} + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}$$

where,

C = Chezy's constant

S = slope

R = hydraulic mean radius, m

n = (Kutter's constant) coefficient of roughness

Using Bazin's formula, Chezy's constant 'C' is given by

$$C = \frac{157.6}{1.81 + \frac{m}{\sqrt{R}}}$$

where,

C = Chezy's constant

R = hydraulic mean radius, m

m = coefficient of roughness

Manning's formula is in the well-known form

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where,

V = mean velocity of flow, m/s

R = hydraulic radius, m

S = slope of the energy line

n = coefficient of roughness known as Manning's constant

16. Lining materials

Lining channels is an effective way to prevent erosion, control rodent damage and reduce seepage at reasonable cost. Lining also reduces maintenance, controls weed growth and ensures more dependable water delevaries. The seepage reduction helps to protect neighbouring land from water logging and salt accumulation. Selection of the lining material should be governed by availability of the material, installation equipment, ditch size, climate etc. Concrete is probably the most popular lining material, but asphaltic materials, bricks, membaranes, and impermeable earth materials are also used. In the experiment, concrete and bricks with cement mortar plastering was used as the lining material.

17. Earthen channel

Unlined ditches can generally be used in any soil that is suited to crop production. Special precautions may be needed in erodible soils to prevent structure and ditch washouts. Seepage losses may be excessive in sandy and gravelly soils. Losses can be very high in non-cohesive, coarse textured soils and low in fine textured clay soils. Light and medium textured soils with a low clay content usually erode easily. Small channels should be designed using maximum permissible velocity criteria according to soil texture.

18. Measurement of discharge in canals

The discharge through a channel is usually measured using notches especially V-notch. Discharge through a V-notch is given by

$$Q = 8/15\ Cd \sqrt{2g}\ \tan \theta/2\ H^{5/2}$$

where,

Q = discharge, m^3/s

Cd = coefficient of discharge

H - head of water over the apex of the notch, m

θ = angle included between the sides of the notch, degree

g = accelaration due to gravity, m/s^2

19. Experimental set-up

As per the above mentioned construction procedure, lined and earthen channels were constructed for a length of 40 m with a slope of 1/5000. Upstream and downstream tanks were constructed common to both the channels. Aluminium pipes were used from the source to the upstream tank for the conveyance of water. A 90° bend was connected to the last pipe in the upstream tank to avoid the formation of ripples on the water surface during experiment. A hook gauge fixed on MS flat was placed on the downstream tank at a distance of 75 cm from the V-notch.

For experiment on lined channel, first the entrance from the tank to the earthen channel was closed. Motor was started and water then collected in the tank upto the bottom level of the channel and then entered the channel. The water flowing through the channel was collected in the downstream tank upto the crest level or apex of the notch and when the water reached above this level, flow through the notch started.

Plate 1 Experimental site
(View from upstream side)

When the water surface was just at the level of the apex of the notch, the zero reading of the hook gauge was taken. While taking the hook gauge readings, the top of the hook was just at the still water surface. A cylindrical drum of 58.5 litres capacity was used for the calibration of the notch. For different heads, the time taken to fill the drum was taken using a stop watch. The average time taken to fill the drum for different heads were found out and the actual rate of flow for different heads were then computed. Coefficient of discharge for different heads were then calculated. A curve was drawn with head over the notch as abscissa and coefficient of discharge as ordinate. From the calibration curve, the values of coefficient of discharge for maximum and minimum expected heads in the experiment were taken and their average value was used throughout the experiment for computation.

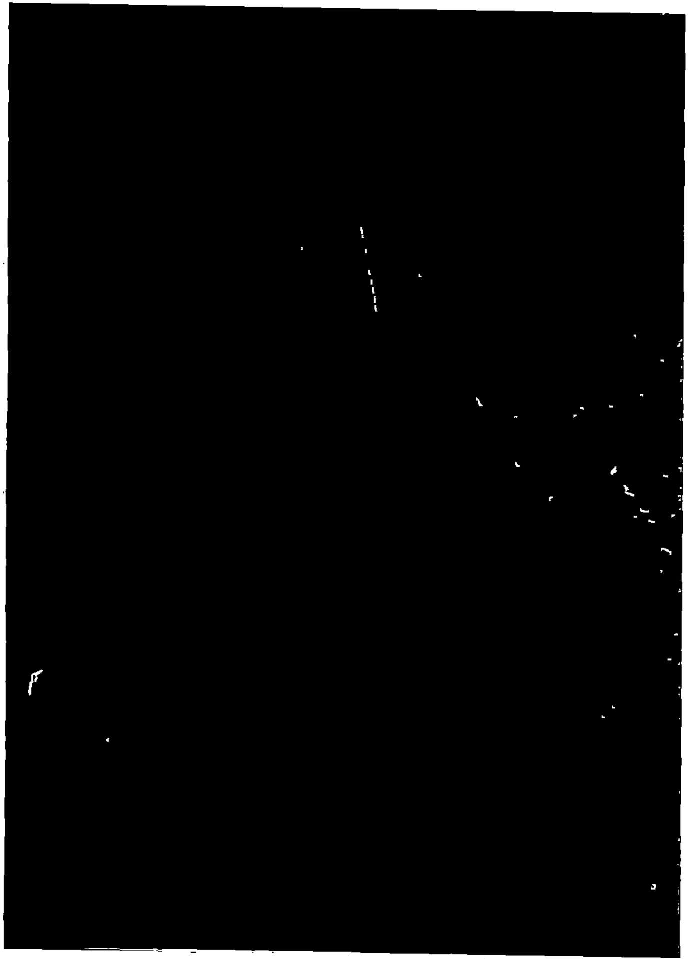
For discharge measurement, depth of water in the channel was measured first. Depth of water was measured at the middle 15 m to get a uniform flow. For depth measurement the first 10 m and the last 15 m were neglected for avoiding turbulence and approach velocity respectively in the channel. The hook gauge reading was taken at the same time at which depth of water was measured. Rate of flow to the upstream tank was varied by pumping water from different sources and in each case, depth in the channel and head over the notch were measured. Then slope was changed to 1/4000 by applying a cement mortar paste to the previous slope from the upstream end to get the required level difference at different reaches of the canal. The same procedure was repeated for slopes 1/3000 and 1/2000.

Plate II Water entering the channel from upstream tank
(Turbulence effect can be seen at the upstream reach)

Plate III Water flowing into the downstream tank
(Effect of approach velocity can be seen at the downstream reach)

Plate IV Steady uniform flow in the middle reach of the channel

Plate V V-notch and hook gauge



For experiments in earthen channel, the entrance from the upstream tank to the lined channel was closed and entrance to the earthen channel was opened. For the first slope of 1/5000, readings were taken for different discharges. The procedure was repeated for different slopes, viz., 1/4000, 1/3000 and 1/2000 by providing proper level differences between the ends of the channel.

20. Textural classification of soil

Soil samples collected from the earthen channel site was dried in an over at 105°C and powdered it with fingers. To designate the texture, percentage of each particle size in the soil was found out by conducting sieve analysis and hydrometer analysis.

Sieve were cleaned with brush. A 1500 gm of oven dried soil was weighed accurately and sieved through a nest of sieves, viz., 2 mm, 1 mm, 600, 300, 212, 150 and 75 microns with lid and receiver using a mechanical shaker for 10 minutes. The weight of soil retained on each sieve and on the pan were taken and the percentage weight retained on each sieve was calculated on the basis of the total weight of soil sample taken. From the above results, percentage passing through each sieve was calculated.

Hydrometer analysis was done to determine the grain size distribution of fine grained soil finer than 75 microns. It was a mechanical analysis based on stoke's law. Procedure of the experiment was as follows. Hydrometer was calibrated and the curves A & B were drawn and the calibration curve gave the depth from the surface of suspension to the centre of volume of the hydrometer for any hydrometer reading. For the observations in the first two minutes curve A was used and then onwards curve B was used. A representative sample of 50 gm of soil passing through 75 microns was taken, placed it in an evaporating dish, covered it up with 100 cc of distilled water, and 100 cc of deflocculating agent (sodium hexa meta phosphate) was added and allowed the material to soak for 5 minutes. The mixture was washed into the dispersion cup of the mixer using distilled water until the cup was about two thirds full. The suspension was mixed in the mixer until the soil was broken down into its individual particles. Meanwhile a graduated jar was filled with distilled water to store the hydrometer in between the readings. After mixing, the specimen was washed into a graduated cylinder and enough distilled water was added to bring the level to 1000 cc mark. When the suspension was well mixed, a hydrometer was inserted in the suspension carefully and at the same time a timer was started. Hydrometer readings were taken at total elapsed time of 1/4, 1/2, 1 and 2 minutes without removing the hydrometer. The hydrometer reading was also taken at total elapsed time intervals of 2, 5, 15, 30, 60 and 120 minutes etc. The hydrometer was removed from the suspension and stored in the graduated jar of distilled water after each reading. The temperature of the soil suspension was noted after each hydrometer reading. Percentage finer, N was given by

$$N = \frac{Rs - Rw}{w} \times \frac{G}{G-1} \times \frac{2.65-1}{2.65} \times 100\%$$

where,

G = sp. gravity of soil solids

W = weight of dry soil used, gm

R_s = hydrometer reading in suspension

R_w = hydrometer reading in water

Effective diameter 'D' was computed from

$$D = \sqrt{\frac{18\mu}{\gamma_s - \gamma_w} \times \frac{z}{t}}$$

where,

μ = viscosity of water, poise

γ_s = unit weight of soil grains, g/cm^3

γ_w = unit weight of water, g/cm^3

z = distance from the suspension to the centre of volume of hydrometer (from calibration curve), cm

t = total elapsed time, minutes

The grain size distribution curve was plotted with effective particle diameter (D) in logarithmic scale against percentage finer (N) in natural scale for both the analysis. From the graphs, percentages of sand, silt and clay were found out which gave the textural class of the soil according to USDA textural classification (texure triangle).

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Results & Discussion

RESULTS AND DISCUSSION

The results of the following experiments conducted are presented and discussed in this chapter.

1. Determination of constants in uniform flow formula for small discharges less than 10 l/s
2. Comparison of the above constants with the constants in uniform flow formulae and check their validity in small channels
3. Textural classification of soil

1. Channel geometry

For each set of experiments, the depth of water in the middle 15 m of the channel were measured accurately. Area, perimeter and hydraulic radius were found out from the equations

$$A = (B + my)y \qquad 4.1$$

$$P = B + 2y\sqrt{1+m^2} \qquad 4.2$$

$$R = A/P \qquad 4.3$$

where,

A = water area, m^2

P = wetted perimeter, m

R = hydraulic radius, m

B = bed width of the channel, m

y = depth of water in the channel, m

$m{:}1$ = side slope of the channel

2. Discharge

Head of the notch for each set of experiments was measured using a hook guage. The discharge in the channel was calculated using the equation

$$Q = 8/15\ Cd \sqrt{2g}\ \tan\ \theta/2\ H^{5/2} \qquad 4.4$$

where,

Q = discharge, m^3/s

H = head over the notch, m

θ =angle of notch, degree

g = accelaration due to gravity, m/s^2

Cd = coefficient of discharge

While calibrating the V-notch, it was observed that the value of coefficient of discharge decreased with increase in head (Table 1). From the calibration curve of the V-notch, (Fig.3), the maximum and minimum values of coefficient of discharge (Cd) were obtained as 0.71 and 0.612 respectively. For calculation purposes the average of these two values 0.661 was used throughout the experiment. This value of Cd was greater than the standard value of 0.593 for 90° V-notch. Hence the calculated discharges against each head over the notch were greater than the values given in Appendix I.

Table 1 Calibration of V notch

Capacity of the drum = 58.5 l

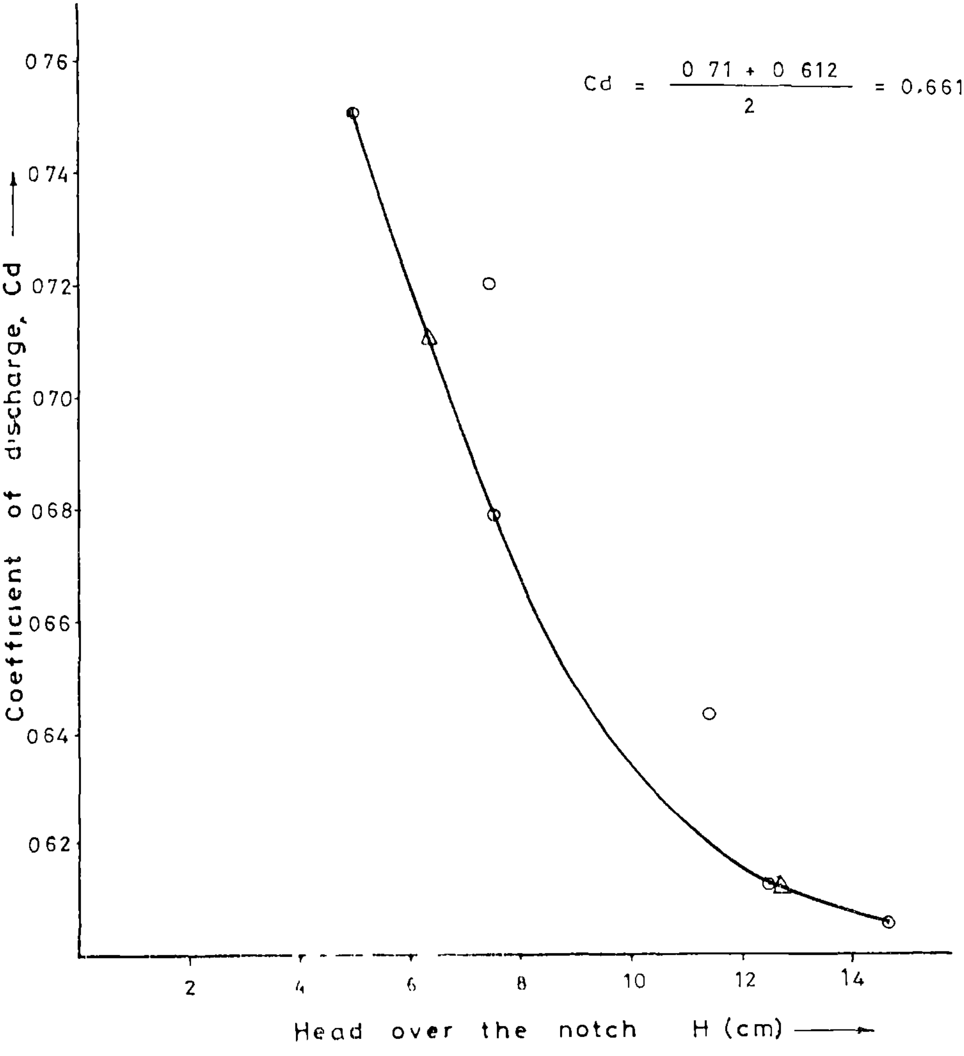
Reading of the apex of the notch = 288.5 mm

Sl No	Time taken to fill the drum(s) t	Reading over the notch (mm)	Head over the notch (cm) H	Discharge (l/s) Q	Co-efficient of discharge Cd
1	2	3	4	5	6
1	59.4	238.6	4.99	0.9848	0.750
2	23.1	214.5	7.40	2.5325	0.720
3	24.0	213.9	7.46	2.4380	0.679
4	8.7	174.1	11.44	6,7239	0.643
5	7.4	164.0	12,45	7,9054	0.612
6	5.1	143.4	14.51	11,4706	0.605

SCALE

Abscissa - 1 cm = 1 cm

Ordinate - 1 cm = 0.02 units



$$Cd = \frac{0.71 + 0.612}{2} = 0.661$$

Fig - 8 CALIBRATION CURVE OF V - NOTCH

3. Velocity

From the known discharge and area, the velocity of water flowing through the channel was found out from the equation

$$Q = A \times V \qquad 4.5$$

$$V = Q/A$$

where,

Q = discharge, m^3/s

A = water area, m^2

V = velocity of flow, m/s

4. Uniform flow formula

Most practical uniform flow formulae can be expressed in the general form

$$V = CR^x S^y \qquad 4.6$$

where,

V = velocity of flow, m/s

R = hydraulic radius, m

S = energy slope

C = a factor of flow resistance

There was no expirical equation available for uniform flow in open channels for small discharges less than 10 l/s. Since the general uniform flow formulae viz., Chezy's equation and Manning's equation were derived on certain assumptions which were mostly valid for large canals, a verification was needed to assess their validity for channels of small discharges.

Experiments were conducted to determine the constants in the general uniform flow formula in open channels for small discharges less than 10 l/s. Depth of water in the channel and head over the notch for different rate of flow under different slopes were taken. The observations and calculated values in lined and earthen channels are given in Table 2 and 3 respectively.

5. Empirical equation for uniform flow

The relationship between the parameters viz., velocity, hydraulic radius and longitudinal slope in a uniform flow were estimated for different conditions for different slopes in lined and earthen channels by fitting a log linear multiple regression equation. With the help of a computer, the above analysis was made for different flow conditions for different slopes in two types of channels. The best fit equation obtained in the two cases are as follows.

In lined channel

$$V = 9.199\, R^{0.7591}\, S^{0.1103} \qquad 4.7$$

In earthen channel

$$V = 47.2286\, R^{0.844}\, S^{0.307} \qquad 4.8$$

Table 2 Observations in lined channel

Reading at the apex of the notch = 288.5 mm, Discharge $Q = 1.5615\ H^{5/2}$ where H in m

Sl. No.	Reading over the notch (mm)	Head over the notch (cm) H	Discharge (m^3/s) Q	Depth of water in canal (cm) Y	Water area (m^2) A	Wetted perimeter (m) P	Hydraulic radius (m) (6/7) R	Velocity (m/s) V	Slope S
1	2	3	4	5	6	7	8	9	10
1	220.7	6.78	1.8690×10^{-3}	3.9	7.3710×10^{-3}	0.2603	0.0283	0.2536	0.0002
2	201.3	8.72	3.5062×10^{-3}	5.7	0.0118	0.3112	0.0379	0.2971	
3	177.5	11.10	6.4099×10^{-3}	7.9	0.0181	0.3734	0.0485	0.3541	
4	163.1	12.54	8.6953×10^{-3}	8.9	0.0213	0.4017	0.0530	0.4082	
1	217.2	7.13	2.1197×10^{-3}	4.2	8.0640×10^{-3}	0.2688	0.0300	0.2629	0.00025
2	200.4	8.81	3.5973×10^{-3}	5.8	0.0121	0.3140	0.0385	0.2973	
3	187.6	10.09	5.0498×10^{-3}	7.0	0.0154	0.3480	0.0442	0.3279	
4	175.2	11.33	6.7471×10^{-3}	8.1	0.0187	0.3791	0.0493	0.3608	
1	220.2	6.83	1.9037×10^{-3}	4.0	7.6000×10^{-3}	0.2631	0.0289	0.2505	0.00033
2	200.0	8.85	3.6383×10^{-3}	5.6	0.0115	0.3084	0.0373	0.3164	
3	187.6	10.09	5.0498×10^{-3}	6.6	0.0143	0.3367	0.0425	0.3531	
4	177.5	11.10	6.4099×10^{-3}	7.6	0.0172	0.3650	0.0471	0.3727	
1	213.0	7.55	2.4457×10^{-3}	4.5	8.7750×10^{-3}	0.2773	0.0316	0.2787	0.0005
2	192.2	9.63	4.4937×10^{-3}	6.2	0.0131	0.3254	0.0403	0.3430	
3	182.5	10.60	5.7122×10^{-3}	6.8	0.0148	0.3423	0.0432	0.3860	
4	174.5	11.40	6.8518×10^{-3}	7.6	0.0172	0.3650	0.0471	0.3984	

Table 3 Observations in earthen channel

Reading at the apex of the notch = 288.5 mm, Discharge $Q = 1.5615\ H^{5/2}$ where H in m.

S. No.	Reading over the notch (mm)	Head over the notch (cm) H	Discharge (m^3/s) Q	Depth of water in canal (cm) Y	Water area (m^2) A	Wetted perimeter (m) P	Hydraulic radius (m) (6/7) R	Velocity (m/s) V	Slope S
1	2	3	4	5	6	7	8	9	10
1	220.3	6.82	1.8967×10^{-3}	4.5	9.7875×10^{-3}	0.3122	0.0314	0.1938	0.0002
2	205.1	8.34	3.1366×10^{-3}	5.6	0.0131	0.3519	0.0372	0.2394	
3	179.9	10.86	6.0690×10^{-3}	8.2	0.0224	0.4457	0.0503	0.2709	
4	173.2	11.53	7.0488×10^{-3}	8.3	0.0228	0.4493	0.0507	0.3092	
1	233.1	5.54	1.1280×10^{-3}	3.5	7.0875×10^{-3}	0.2762	0.0257	0.1592	0.00025
2	218.6	6.99	2.0171×10^{-3}	5.1	0.0116	0.3339	0.0347	0.1739	
3	190.2	9.83	4.7307×10^{-3}	7.2	0.0186	0.4096	0.0454	0.2543	
4	179.7	10.88	6.0970×10^{-3}	8.2	0.0224	0.4457	0.0503	0.2722	
1	207.8	8.07	2.8889×10^{-3}	5.1	0.0116	0.3339	0.0347	0.2490	0.00033
2	204.3	8.42	3.2123×10^{-3}	5.3	0.0122	0.3411	0.0358	0.2633	
3	200.0	8.85	3.6383×10^{-3}	5.8	0.0137	0.3591	0.0382	0.2656	
4	164.5	12.40	8.4547×10^{-3}	8.7	0.0244	0.4637	0.0526	0.3465	
1	219.5	6.90	1.9528×10^{-3}	4.0	8.4000×10^{-3}	0.2942	0.0286	0.2325	0.0005
2	205.6	8.29	3.0898×10^{-3}	5.0	0.0113	0.3303	0.0342	0.2734	
3	185.4	10.31	5.3295×10^{-3}	6.8	0.0171	0.3952	0.0433	0.3117	
4	164.6	12.39	8.4376×10^{-3}	8.4	0.0232	0.4529	0.0512	0.3637	

where,

V = mean velocity of flow, m/s

R = hydraulic radius, m

S = longitudinal slope

For the above equations, the coefficients of determination (R^2) were 0.9505 and 0.8658 respectively. In lined channel, since the coefficient of determination was near unity, the errors in the estimation of velocity under different conditions were practically negligible. In earthen channels since the coefficient of determination was only 0.8658, the reliability of the equation was not as high as in the case of the equation obtained for lined channel but it was still good. Soil erosion started marginally as the rate of flow increased which to some extent affected the geometry of the channel and his could be the reason for less reliability of the equation for earthen channels.

The equations obtained were compared with the well known Manning's and Chezy's equations and checked their validity in small channels. The Manning's equation is, given by

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad 4.9$$

where,

V = mean velocity of flow, m/s

R = hydraulic radius, m

S = longitudinal slope

n = roughness coefficient

The Chezy's equation is given by

$$V = CR^{1/2} S^{1/2} \qquad 4.10$$

where,

V = mean velocity of flow, m/s

R = hydraulic radius, m

S = longitudinal slope

C = Chezy's constant

Chezy's constant C was determined using Bazin's formula or Ganguillet and Kutter's formula.

5. A. Lined channel

1. Comparison with Manning's equation

For cement mortar lining, Manning recommended an average value of n as 0.013.

$$V = \frac{1}{0.013} R^{2/3} S^{1/2} \qquad 4.11$$

IS 10430 (1982) recommended the value of n as 0.015-0.017 for concrete bed, trowel or float finish and slopes masonry plastered. Taking the mean value, Manning's equation for lined channels is

$$V = \frac{1}{0.016} R^{2/3} S^{1/2} \qquad 4.12$$

In the best fit equation obtained in the study for lined channels, the value of n was 0.1087.

$$V = \frac{1}{0.1087} R^{0.7591} S^{0.1103} \qquad 4.7$$

$$\text{i.e. } V = 9.199 R^{0.7591} S^{0.1103}$$

Manning's equation was developed for large canals and streams. The value of the coefficient of resistance n under different conditions were arrived at with the exponent of S and 0.5 and the exponent of R as 0.67. But the validity of the equation developed was never tested for small channels. The value of n obtained in the study was approximately eight times greater than the recommended value of n for the same boundary conditions. The high value of n obtained in the best fit equation would reduce the value of C which is its inverse by the same proportion.

Manning for the derivation of the exponent of R used Bazin's experimental data on artificial channels. Bazin's data were collected from experiments conducted in small channels for different shapes and roughness, the average value of the exponent was found to vary from 0.6499 to 0.8395. Hence he adopted an approximate value of 2/3 as exponent. The exponent of hydraulic radius R obtained in this study, 0.7591 was within these limits.

Chezy derived the exponent theoretically on certain assumptions and fixed it as 0.5 which Manning also accepted when he derived his equation. The value of exponent of S obtained in the best fit equation in the study was 0.1103. The lower value of this exponent of S in the best fit equation would correspondingly increase the value of the factor S_a in the equation which would give a higher value for computed velocity. However this increase to a large extent was compensated by the higher value of n obtained in the best fit equation.

An attempt was made to compare the actual velocity with the velocity obtained using Manning's equation. The actual velocity was roughly 2.13 times greater than the Manning's velocity. From the Table 4, it can be seen that this ratio varied from 1.64 to 2.68. So Manning's recommended values derived for large canals and streams was found not applicable to small channels having discharges less than 10 l/s. The ratio of actual and computed velocity using the best fit equation varied from 1.055 to 0.950 and the average value was 0.9998 which was near unity. The computed velocities were coming very close to the actual velocity. The sum of squares of deviations of computed velocity from the actual velocity was only 0.00251 and hence the reliability of the equation was good. So the equation obtained was the best one for these conditions.

Manning fixed the value of exponent of S as 0.5 on certain assumptions based on theory. So it was decided to fix the value of the exponent of S as 0.5 and to find the value of n and the exponent of R. The equation obtained is of the form

$$V \doteq \frac{1}{0.00428} R^{0.7827} S^{0.5} \qquad 4.13$$

Table 4 Comparison of velocities in lined channel

$$V = \frac{1}{0.1087} R^{0.7591} S^{0.1103} \qquad 4.7 \text{ (Best fit equation)}$$

$$V = \frac{1}{0.013} R^{0.67} S^{0.5} \qquad 4.11 \text{ (Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using 4.7 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed velocity from the actual	Velocity using 4.11 (m/s)	Ratio of actual and Manning's velocity 2/6
1	2	3	4	5	6	7
0.0002	0.2536	0.2402	1.055	1.7956×10^{-4}	0.0998	2.54
	0.2971	0.2998	0.991	7.2900×10^{-6}	0.1214	2.45
	0.3541	0.3615	0.979	5.4760×10^{-5}	0.1432	2.47
	0.4082	0.3867	1.055	4.6225×10^{-4}	0.1520	2.68
0.00025	0.2629	0.2573	1.022	3.1360×10^{-5}	0.1161	2.26
	0.2973	0.3109	0.956	1.8496×10^{-4}	0.1372	2.17
	0.3279	0.3453	0.950	6.9696×10^{-4}	0.1505	2.19
	0.3608	0.3751	0.962	2.0449×10^{-4}	0.1619	2.23
0.00033	0.2505	0.2579	0.971	5.4760×10^{-5}	0.1300	1.93
	0.3164	0.3130	1.011	1.1560×10^{-5}	0.1543	2.05
	0.3531	0.3456	1.022	5.6250×10^{-5}	0.1684	2.10
	0.3727	0.3736	0.997	8.1000×10^{-7}	0.1804	2.07
0.0005	0.2787	0.2889	0.965	1.0404×10^{-4}	0.1699	1.64
	0.3430	0.3475	0.987	2.0250×10^{-5}	0.2000	1.72
	0.3860	0.3663	1.054	3.8809×10^{-4}	0.2096	1.84
	0.3984	0.3911	1.019	5.3290×10^{-5}	0.2220	1.69
			0.9998	0.00251		2.133

Table 5 Comparison of velocities in lined channel

$$V = \frac{1}{0.00428} R^{0.7827} S^{0.5} \qquad 4.13 \text{ (with exponent of S restricted to 0.5)}$$

$$V = \frac{1}{0.013} R^{0.67} S^{0.5} \qquad 4.11 \text{ (Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using 4.13 (m/s)	Ratio of actual and computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using 4.11 m/s	Ratio of actual and Manning's velocity 2/6
1	2	3	4	5	6	7
0.0002	0.2536	0.2029	1.250	2.5705×10^{-3}	0.0998	2.541
	0.2971	0.2550	1.165	1.7724×10^{-3}	0.1214	2.447
	0.3541	0.3093	1.145	2.0070×10^{-3}	0.1432	2.473
	0.4082	0.3315	1.231	5.8829×10^{-3}	0.1520	2.686
0.00025	0.2629	0.2374	1.107	6.5025×10^{-4}	0.1161	2.264
	0.2973	0.2886	1.030	7.5690×10^{-5}	0.1372	2.167
	0.3279	0.3216	1.020	3.9690×10^{-5}	0.1505	2.179
	0.3608	0.3502	1.030	1.1236×10^{-4}	0.1619	2.229
0.00033	0.2505	0.2649	0.946	2.0736×10^{-4}	0.1300	1.927
	0.3164	0.3235	0.978	5.0410×10^{-5}	0.1543	2.051
	0.3531	0.3583	0.985	2.7040×10^{-5}	0.1684	2.097
	0.3727	0.3883	0.960	2.4336×10^{-4}	0.1804	2.066
0.0005	0.2787	0.3497	0.797	5.0410×10^{-3}	0.1699	1.640
	0.3430	0.4230	0.811	6.4000×10^{-3}	0.2000	1.715
	0.3860	0.4467	0.864	3.6845×10^{-3}	0.2096	1.842
	0.3984	0.4779	0.834	6.3203×10^{-3}	0.2220	1.795
			1.009	0.0351		2.13

Table 6 Comparison of velocities in lined channel

$$V = \frac{1}{0.00609} R^{0.67} S^{0.5} \qquad 4.14 \text{ (with Manning's exponents)}$$

$$V = \frac{1}{0.013} R^{0.67} S^{0.5} \qquad 4.11 \text{ (Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using 4.14 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using 4.11 (m/s)	Ratio of actual and Manning's velocity 2/6
1	2	3	4	5	6	7
0.0002	0.2536	0.2129	1.191	1.6565×10^{-3}	0.0998	2.54
	0.2971	0.2589	1.147	1.4592×10^{-3}	0.1214	2.45
	0.3541	0.3055	1.159	2.3620×10^{-3}	0.1432	2.47
	0.4082	0.3242	1.259	7.0560×10^{-3}	0.1520	2.68
0.00025	0.2629	0.2475	1.062	2.3716×10^{-4}	0.1161	2.26
	0.2973	0.2926	1.016	2.2090×10^{-5}	0.1372	2.17
	0.3279	0.3209	1.022	4.9000×10^{-5}	0.1505	2.18
	0.3608	0.3453	1.045	2.4025×10^{-4}	0.1619	2.23
0.00033	0.2505	0.2774	0.903	7.2361×10^{-4}	0.1300	1.93
	0.3164	0.3291	0.961	1.6129×10^{-4}	0.1543	2.05
	0.3531	0.3592	0.983	3.7210×10^{-5}	0.1684	2.10
	0.3727	0.3848	0.968	1.4641×10^{-4}	0.1804	2.07
0.0005	0.2787	0.3625	0.769	7.0224×10^{-3}	0.1699	04
	0.3430	0.4266	0.804	6.9890×10^{-3}	0.2000	1.72
	0.3860	0.4469	0.864	3.7088×10^{-3}	0.2096	1.84
	0.3984	0.4736	0.841	5.6550×10^{-3}	0.2220	1.79
			0.999	0.0375		2.13

Here the exponent of R was within the limits. The value of n in this equation was three times less than the recommended value of n. The decrease in n value resulting in an increase in C value was compensated to some extent by the decrease in the value of hydraulic radius factor due to the increase in the value of its exponent. The ratio of actual and computed velocities varied from 1.250 to 0.811 but the average ratio of 1.009 was near unity. The variation of computed velocities from the actual was increasing with increase in slope. The sum of squares of deviation of computed velocities from the actual was obtained as 0.0351. Though this was greater than the previous case but was still reasonably reliable (Table 5).

Since Manning's equation is an universally accepted form it was decided to compare the value of n obtained in the study with the recommended value of n by fixing the exponent of R and S as 0.67 and 0.5 respectively. The equation obtained in this case is given as

$$V = \frac{1}{0.00609} R^{0.67} S^{0.5} \qquad 4.14$$

The value of n in this case was half the recommended value of n. The variation in the ratio of actual and computed velocities was ranging from 1.259 to 0.804 and was decreasing with an increase in slope (Table 6). But the average value obtained was 0.999 which was approximately unity. Since the sum of squares of deviation of computed velocity from the actual was only 0.0375, the equation obtained was reliable and good within these ranges. But the reliability of this equation was comparitively less than the earlier two cases. The computed velocities were approximately 2.13 times greater than the Manning's velocity.

From the above three cases it was observed that the actual and computed velocities were approximately two times greater than the Manning's velocities. Since the sum of squares of deviation of computed velocity from the actual has the least value in the best fit equation, this equation gave the more reliable results Hence this best fit equation obtained in the study is recommended for velocity computation in small channels having discharges less than 10 l/s. Since Manning's equation is an universally accepted form, the equation 4.14 obtained in the study which was in the Manning's orm by fixing the value of exponent of R and S, is also recommended because this also gives reasonably reliable results provided the new rugosity coefficient obtained in the study is used. This rugosity coefficient for cement mortar lining in small channels carrying discharges less than 10 l/s is 0.00609.

2. Comparison with Chezy's equation

In Chezy's equation, the Chezy's constant C is determined from Ganguillet and Kutter's formula which is of the form

$$C = \frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}} \qquad 4.15$$

where,

n = Kutter's constant

S = longitudinal slope

R = hydraulic radius, m

Chezy's constant is also calculated from Manning's equation

$$C = \frac{1}{n} R^{1/6} \tag{4.16}$$

where,

n = Manning's constant

R = hydraulic radius, m

The value of C using the recommended n value of 0.013 is determined as 36.98 from Kutter's equation and 44.96 from Manning's equation (Appendix VI). The equations are of the form

$$V = 36.98 \sqrt{RS} \tag{4.17}$$

and

$$V = 44.96 \sqrt{RS} \tag{4.18}$$

The variation in these two recommended C values was due to the consideration of slope in Kutter's equation.

A comparison was made between these C values and the value of C obtained in the best fit equation by fixing the exponent of S and R as 0.5. The equation obtained is

$$V = 94.91 \sqrt{RS} \tag{4.19}$$

Table 7 Comparison of velocities in lined channel

$V = 94\ 91\ \sqrt{RS}$ 4 19 (Best fit equation)

$V - 36\ 98\ \sqrt{RS}$ 4 17 (Chezy s equation with C from Kutters equation)

$V\ \ 44\ 96\ \sqrt{RS}$ 4 18 (Chezy s equation with C from Manning s equation)

Slope	Actual velocity (m/s)	Computed velocity using 4 19 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using C from Kutter's equation 4 17 (m/s)	Velocity using C from Manning's equation 4.18 (m/s)	Ratio of actual velocity and velocity using Chezy's equation 2/6	2/7
1	2	3	4	5	6	7	8	9
0 0002	0 2536	0 2258	1 123	$7\ 7284\times10^{-4}$	0.0880	0 1069	2.88	2 37
	0 2971	0 2613	1 137	1.2816×10^{-3}	0 1018	0 1238	2 92	2 40
	0 3541	0.2956	1 198	$3\ 4222\times10^{-3}$	0 1152	0 1400	3 07	2 53
	0 4082	0 3090	1 321	$9\ 8406\times10^{-3}$	0 1204	0 1464	3 39	2 79
0 00025	0 2629	0.2529	1 011	$9\ 0000\times10^{-6}$	0 1013	0 1231	3 60	2 14
	0 2973	0 2944	1 001	$8\ 4100\times10^{-6}$	0 1147	0.1395	2 59	2 13
	0 3279	0 3155	1 039	$1\ 5376\times10^{-4}$	0 1229	0 1494	2 67	2 19
	0 3608	0 3332	1 083	$7\ 6176\times10^{-4}$	0 1298	0 1578	2 78	2 29
0 00033	0 2505	0 2931	0 855	$1\ 8148\times10^{-3}$	0 1142	0 1388	2.19	1 80
	0 3164	0 3330	0 950	$2\ 7556\times10^{-4}$	0 1297	0 1577	2 44	2 01
	0 3531	0 3554	0 993	$5\ 2900\times10^{-6}$	0 1385	0 1684	2 55	2 10
	0 3727	0 3742	0 996	$2\ 2500\times10^{-6}$	0 1458	0 1772	2 56	2 10
0 0005	0 2787	0 3773	0 734	$9\ 7220\times10^{-3}$	0 1470	0 1787	1 90	1 60
	0 3430	0 4260	0 805	$6\ 8890\times10^{-3}$	0 1660	0 2018	2 07	1 63
	0 3860	0 4411	0 875	$3\ 0360\times10^{-3}$	0 1 18	0 2089	2 25	1 85
	0 3984	0 4606	0 865	$3\ 8688\times10^{-3}$	0 1794	0 2182	2 22	1 83
			0 999	0 0419			2 57	2 11

The ratios of actual and computed velocities using equation 4.19 varied from 1.321 to 0.734 but the average value 0.999 was near unity (Table 7). Since the sum of squares of deviation of computed velocities from the actual was only 0.0419 the reliability of the equation was not bad and the errors were within the permissible limits. From the table it was observed that the actual velocity was roughly 2.57 times greater than the velocity obtained using the C value from Kutter's equation and 2.11 times greater than the values obtained using C from Manning's equation. Since the experiment was conducted in small channels, the roughness factor C in the study was approximately two times greater than the recommended values derived for large canals and streams. Hence these recommended values were not applicable to small channels carrying discharges less than 10 l/s. So it is recommended to use C value of 95 for cement lined channels for the above conditions in Chezy's equation.

Chezy's constant C was also determined from Bazin's formula which is given as

$$C = \frac{157.6}{1.81+m/\sqrt{R}} \qquad 4.20$$

where,

R = hydraulic radius, m

m = coefficient roughness

An attempt was made to calculate the value of m in the Bazin's formula from the data obtained in th study. In many cases, negative values were obtained for Bazin's roughness coefficient especially in the cases where slopes were flatter However in cases, this value could be calculated and the computed values are given in Appendix VII The mean value of m obtained in this study was 0.0386. But Bazin recommended the value of m as 0 11 for the same boundary conditions which was approximately 2.8 times greater than the value obtained in this study.

B. Earthen channel

1 Comparison with Manning's equation

For excavated earthen channels straight and uniform with clean and recently completed condition, Manning recommended an average value of n as 0.018.

$$V = \frac{1}{0.018} R^{0.67} S^{0.5} \qquad 4.21$$

In the best fit equation obtained in the study for earthen channel the value of n was 0.0212.

$$V = \frac{1}{0.0212} R^{0.844} S^{0.307} \qquad 4.8$$

$$\text{i.e.} \quad V = 47.2286 \quad R^{0.844} S^{0.307}$$

The value of n obtained was approximately 1.2 times greater than the recommended value. The value of n increased with the decrease in stage and discharge. Here the exponent of R was within the limits

Table 8 Comparison of velocities in earthen channel

$$V = \frac{1}{0.0212} R^{0.844} S^{0.307} \qquad 4.8 \quad \text{(Best fit equation)}$$

$$V = \frac{1}{0.018} R^{0.67} S^{0.5} \qquad 4.21 \quad \text{(Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using 4.8 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed velocity from actual	Velocity using Manning's equation 4.21 (m/s)	Ratio of actual and Manning's velocity 2/6
1	2	3	4	5	6	7
0.0002	0.1938	0.1862	1.041	5.7760×10^{-5}	0.0773	2.409
	0.2394	0.2149	1.114	6.0025×10^{-4}	0.0866	2.481
	0.2709	0.2772	0.977	3.9690×10^{-5}	0.1060	2.615
	0.3092	0.2790	1.108	9.1204×10^{-5}	0.1066	2.617
0.00025	0.1592	0.1684	0.945	8.4640×10^{-5}	0.0756	2.227
	0.1739	0.2170	0.801	1.8576×10^{-3}	0.0924	2.348
	0.2543	0.2722	0.934	3.2041×10^{-4}	0.1106	2.461
	0.2772	0.2968	0.934	3.8416×10^{-4}	0.1185	2.505
0.00033	0.2490	0.2363	1.054	1.6129×10^{-4}	0.1062	2.225
	0.2633	0.2426	1.085	4.2849×10^{-4}	0.1084	2.238
	0.2656	0.2562	1.037	8.8360×10^{-5}	0.1132	2.263
	0.3465	0.3357	1.032	1.1664×10^{-4}	0.1403	2.393
0.0005	0.2325	0.2280	1.020	2.0250×10^{-5}	0.1148	1.986
	0.2734	0.2652	1.030	6.7240×10^{-5}	0.1294	2.049
	0.3117	0.3236	0.963	1.4161×10^{-4}	0.1516	2.134
	0.3637	0.3727	0.976	8.1000×10^{-5}	0.1696	2.197
			1.003	0.00454		2.322

The value of exponent of S was obtained as 0.307. The lower value of the exponent of S in the best fit equation would correspondingly increase the value of the factor S in the equation which would give a higher value for computed velocity. However this increase to a large extent was compensated by the higher value of n obtained in the equation.

A comparison was made between the actual velocity and the recommended velocity using Manning's equation. The actual velocity was approximately 2.3 times greater than the velocity using Manning's equation and their ratio varied from 1.882 to 2.764. So Manning's equation was not applicable to small earthen channels. While comparing the actual and computed velocities using the best fit equation it was observed that their ratio varied from 1.114 to 0.801 (Table 8). This large range of variation compared to lined channel could be due to soil erosion in the channel which marginally affected the geometry of the channel during the experiment. But the average ratio, 1.003 came near to unity. The sum of squares of deviation of computed velocity from the actual was only 0.00454. So the equation obtained was reliable and was the best one for these conditions.

Based on theoretical assumptions, it was decided to fix the value of exponent of S as 0.5 and to find the value of n and the exponent of R. The equation obtained is of the form

$$V = \frac{1}{0.00408} R^{0.8696} S^{0.5} \qquad 4.22$$

Table 9 Comparison of velocities in earthen channel

$$V = \frac{1}{0.00408} R^{0.8696} S^{0.5} \qquad 4.22 \quad \text{(with exponent of S restricted to 0.5)}$$

$$V = \frac{1}{0.018} R^{0.67} S^{0.5} \qquad 4.21 \quad \text{(Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using of 4.22 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using Manning's equation 4.21 (m/s)	Ratio of actual and Manning's velocity 2/6
1	2	3	4	5	6	7
0.0002	0.1938	0.1709	1.134	5.2441×10^{-4}	0.0773	2.211
	0.2394	0.1981	1.208	1.7059×10^{-3}	0.0866	2.287
	0.2709	0.2575	1.052	1.7956×10^{-4}	0.1060	2.429
	0.3092	0.2593	1.192	2.4900×10^{-3}	0.1066	2.432
0.00025	0.1592	0.1605	0.992	1.6900×10^{-6}	0.0756	2.123
	0.1739	0.2084	0.834	1.1903×10^{-3}	0.0924	2.255
	0.2543	0.2633	0.966	8.1000×10^{-5}	0.1106	2.381
	0.2772	0.2879	0.963	2.4649×10^{-4}	0.1185	2.429
0.00033	0.2490	0.2395	1.040	9.0250×10^{-5}	0.1062	2.255
	0.2633	0.2461	1.070	2.9584×10^{-4}	0.1084	2.270
	0.2656	0.2604	1.020	2.7040×10^{-5}	0.1132	2.300
	0.3465	0.3438	1.008	7.2900×10^{-6}	0.1403	2.450
0.0005	0.2325	0.2492	0.933	2.7889×10^{-4}	0.1148	2.171
	0.2734	0.2911	0.939	3.1329×10^{-4}	0.1294	2.250
	0.3117	0.3574	0.872	2.0885×10^{-3}	0.1516	2.357
	0.3637	0.4134	0.880	2.4701×10^{-3}	0.1696	2.437
			1.006	0.01199		2.32

Table 10 Comparison of velocities in earthen channel

$$V = \frac{1}{0.00778} R^{0.67} S^{0.5} \qquad 4.23 \quad \text{(with Manning's exponents)}$$

$$V = \frac{1}{0.018} R^{0.67} S^{0.5} \qquad 4.21 \quad \text{(Manning's equation)}$$

Slope	Actual velocity (m/s)	Computed velocity using 4.23 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using Manning's equation 4.21 (m/s)	Ratio of actual & Manning's velocity 2/6
1	2	3	4	5	6	
0 0002	0.1938	0.1788	1.084	$2\ 2500\times10^{-4}$	0.0773	2 3 [illegible]
	0.2394	0.2003	1.195	1.5288×10^{-3}	0.0866	2 313
	0.2709	0.2452	1.105	6.6049×10^{-4}	0.1060	2 313
	0.3092	0.2465	1.254	3.9313×10^{-3}	0 1066	2.312
0.00025	0.1592	0.1748	0.911	2.4336×10^{-4}	0 0756	2 312
	0.1739	0.2137	0.814	1.5840×10^{-3}	0 0924	2 313
	0.2543	0.2559	0 994	2.5600×10^{-6}	0.1106	2 314
	0.2772	0.2741	1.011	9.6000×10^{-6}	0.1185	2 313
0.00033	0.2490	0.2456	1.014	1.1560×10^{-5}	0 1062	2 313
	0.2633	0.2508	1.050	1.5625×10^{-4}	0 1084	2.314
	0.2656	0.2619	1.014	1.3690×10^{-5}	0 1132	2 314
	0.3465	0.3245	0.068	$4\ 8400\times10^{-4}$	0 1403	2 313
0.0005	0.2325	0.2655	0.876	$1\ 0890\times10^{-3}$	0 1148	2.313
	0.2734	0.2993	0.913	$6\ 7081\times10^{-4}$	0 1294	2 313
	0.3117	0.3506	0.889	1.5132×10^{-3}	0 1516	2 3 3
	0 3637	0.3923	0.927	$8\ 1786\times10^{-4}$	0 1696	2 313
			1.007	0 0129		2 313

Here the exponent of R was within the limits. The value of n was four times less than the recommended value. The decrease in n value was compensated to some extent by the discrease in the value of hydraulic radius factor due to the increase in the value of its exponent. The ratio of actual and computed velocities varied from 1 208 to 0.834 and this variation could be due to soil erosion and other minor experimental errors. But the average ratio obtained was 1.006 which was near unity. The sum of squares of deviation of computed velocity from the actual was 0.01199 which was higher than the previous case, but still reliable (Table 9).

Since Manning's equation is an universally accepted form the values of exponent of R and S were fixed as 0.67 and 0.5 respectively and compared the value of n obtained with Manning's n. The equation obtained is given as

$$V = \frac{1}{0.00778} R^{0.67} S^{0.5} \qquad 4.23$$

Here the value of n obtained was 2.3 times less than the recommended value of n by Manning. The ratio of actual and computed velocities varied from 1.254 to 0.814 but the average, 1.007 was near unity (Table 10). The sum of squares of deviation of computed velocity from the actual (0.0129) has the highest value in this case, and the reliability of the equation was less than the other two cases

Since the actual velocities were approximately two times greater than the recommended values, it was concluded that Manning's equation derived for large canals and streams was not applicable to small channels. The best fit equation obtained in the study was more reliable than the other two cases because the sum of squares of deviation of computed velocity from the actual has the least value in that case. Hence this best fit equation is recommended for small earthen channels carrying discharges less than 10 l/s. But for the application of this equation in the universally accepted Manning's form, this study recommends an average value of n as 0.00778 for earthen channels carrying discharges less than 10 l/s

2 Comparison with Chezy's equation

The value of Chezy's constant C calculated from Kutter's equation was 23.91 and from Manning's equation was 32.42 using n value of 0.018 which was the recommended value for earthen channels (Appendix VIII). Then the velocities were computed using these equations

$$V = 23.91 \sqrt{RS} \qquad 4.24$$

$$V = 32.42 \sqrt{RS} \qquad 4.25$$

The difference in these two recommended C values was due to the consideration of slope for determination of C in Kutter's equation. Using the values obtained in this experiment, the best fit equation was found out by fixing the value of exponent of R and S as 0 5. The equation obtained is given below.

$$V = 74.771 \sqrt{RS} \qquad 4.26$$

le 11 Comparison of velocities in earthen channel

V 74 771 $\sqrt{RS}$ 4 26 (Best fit equation)

V - 23 91 $\sqrt{RS}$ 4 24 (Chezy's equation with C from Kutter's equation)

V 32.42 $\sqrt{RS}$ 4 25 (Chezy's equation with C from Manning's equation)

e	Actual velocity (m/s)	Computed velocity using 4 26 (m/s)	Ratio of actual & computed velocity 2/3	Square of deviation of computed from actual velocity	Velocity using C from Kutter's equation 4 24 (m/s)	Velocity using C from Manning's equation 2 25 (m/s)	Ratio of actual velocity and velocity using Chezy's equation 2/6	2/7
	2	3	4	5	6	7	8	9
02	0 1938	0.1874	1.034	4 0960×10^{-5}	0 0599	0 0812	3 235	2 387
	0 2394	0.2039	1.174	1 2600×10^{-3}	0 0652	0.0884	3 671	2.708
	0.2709	0.2372	1 142	1 1350×10^{-3}	0.0758	0.1028	3 574	2.635
	0 3092	0.2381	1 299	5 0550×10^{-3}	0 0761	0.1032	4 063	2 996
0025	0 1592	0.1895	0.840	9.1809×10^{-4}	0 0606	0 0822	2 627	1 937
	0 1739	0 2202	0 790	2 1430×10^{-3}	0 0704	0 0955	2 470	1 821
	0 2543	0 2519	1 009	5 7600×10^{-6}	0 0805	0 1092	3 159	2 329
	0 2772	0 2651	1 046	1 4640×10^{-4}	0 0848	0.1149	3 269	2 413
0033	0 2490	0.2530	0 984	1 6000×10^{-5}	0 0809	0 1097	3 078	2 270
	0 2633	0 2570	1 024	3 9690×10^{-5}	0 0822	0 1114	3 203	2 364
	0 2656	0 2655	1 000	1 0000×10^{-8}	0 0849	0 1151	3 128	2 308
	0 3465	0 3115	1 112	1 2250×10^{-3}	0 0996	0 1351	3 479	2 565
005	0 2325	0 2827	0 822	2 5200×10^{-3}	0 0904	0 1226	2 572	1 896
	0 2734	0 3092	0 884	1 2810×10^{-3}	0 0989	0 1341	2 764	2 039
	0 3117	0 3479	0 896	1 3100×10^{-3}	0 1112	0 1508	2 803	2 067
	0 3637	0 [illegible]783	0 [illegible]6	2 [illegible]10×10^{-4}	0 1210	0 1640	3 006	2 218
			1 001	0 01731			3 131	2 31

The computed velocity using this equation were compared with the actual velocities. The variation in the range of ratio of actual and computed velocities was 1.299 to 0.822 and this was higher than in the other cases, but the average was 1.001. The sum of squares of their deviations 0.0173 was comparitively higher. The actual velocities were 3.13 times greater than the velocity obtained using C from Kutter's equation and 2.31 times greater than the values obtained using C from Manning's equation (Table 11). Hence it was concluded that these values were not applicable to small earthen channels carrying discharges less than 10 l/s. So this study recommends a C value of 75 for earthen channels in sandy loam soils for the above condition in Chezy's equation.

The value of Bazin's roughness coefficient m computed from the data obtained in the study was 0.075 (Appendix IX). In this case also some negative values were obtained. This value was 31 times smaller than Bazin's recommended value of 2.36 for earthen channels under the same conditions. Bazin's formula may not give good result and hence its application for determination of Chezy's constant C is not advised for small channels with discharges less than 10 l/s.

6. Effect of textural classification of soil

Soil used in earthen channel was classified based on texture by conducting sieve and hydrometer analysis Their results were presented in the form of grain size distribution curve by plotting the

Table 12 Results of particle size distribution Sieve Analysis

Total weight of soil = 1500 gm

I S Sieve (mm) 1	Weight retained (gm) 2	% weight retained 3	Cululative % weight retained 4
4.750	14.0	0.93	0.93
2.000	55.0	3.67	4.60
1.180	87.9	5.86	10.46
1.000	36.7	2.51	12.97
0.600	135.9	9.06	22.03
0.425	232.5	15.50	37.53
0.212	525.5	35.03	72.56
0.150	210.0	14.00	86.56
0.075	131.1	8.74	95.30
0.063	42.7	2.85	98.15
0.045	20.2	1.35	99.50
Pan	7.5	0.50	100.00

Table 13 Results of particle size distribution - Sedimentation Analysis

Weight of dry soil = 50 gm

Specific gravity, Gs = 2.65

Viscosity of water, μ = 10 millipoise

Elapsed time, t (min)	R_s	R_w	R_s-R_w	N in %	Z (cm)	$\frac{\text{Z in cm}}{\text{t in min}}$	D in mm
1	2	3	4	5	6	7	8
2 50 P M							
1/4	42	2	44	88	11 10	6 663	0 091
1/2	40	-2	42	84	11 40	4 775	0 065
1	36	-2	38	76	12 00	3 464	0 047
2	32	-2	34	68	12 60	2 510	0 034
4	28	-2	30	60	12 10	1 739	0 024
8	26	-2	28	56	12 35	1 242	0 017
15	22	-2	24	48	12 95	0 929	0 013
30	20	-2	22	44	13 20	0 663	0 009
45	19	-2	21	42	13 35	0 545	0 007
60	18	-2	20	40	13 50	0 474	0 006
1260 11 50 A M	11	-2	13	26	14 55	0 107	0 0014

$$N = \frac{R_s - R_w}{W} \times \frac{G}{G-1} \times \frac{2\ 65-1}{2\ 65} \times 100\% \qquad 2 \times (R_s - R_w)$$

$$D = \frac{18\mu}{\gamma_s - \gamma_w} \times \frac{z}{t} = \frac{18 \times 10 \times 10^{-3} \times Z}{(2\ 65-1)981 \times 60 \times t} = 1\ 3614 \times 10^{-3}\ \frac{Z\ (\text{in cm})}{(t\ \text{in min})}$$

SCALE

Ordinate - 1cm = 10%

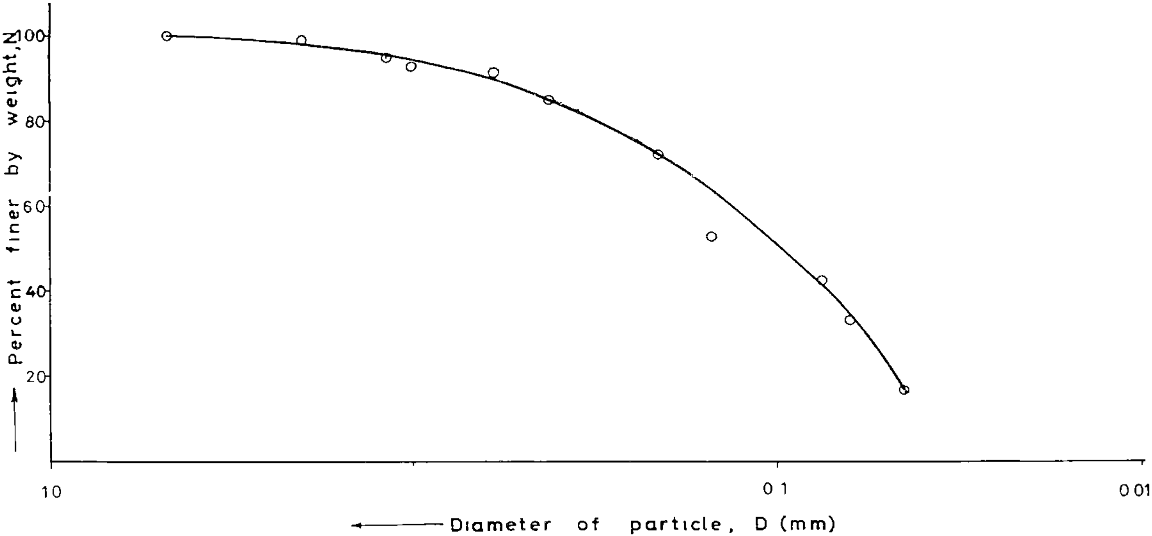
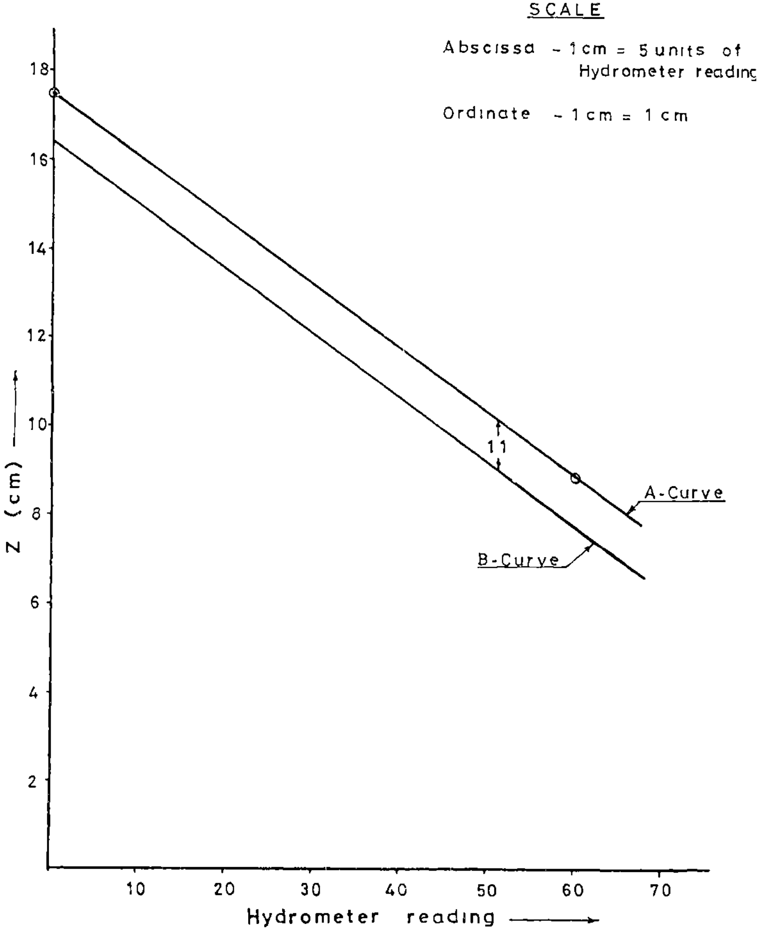


Fig.9 GRAIN SIZE DISTRIBUTION CURVE (Sieve Analysis)



SCALE

Abscissa - 1 cm = 5 units of Hydrometer reading

Ordinate - 1 cm = 1 cm

Fig-10 CALIBRATION CURVE OF HYDROMETER

SCALE

Ordinate - 1cm = 10%

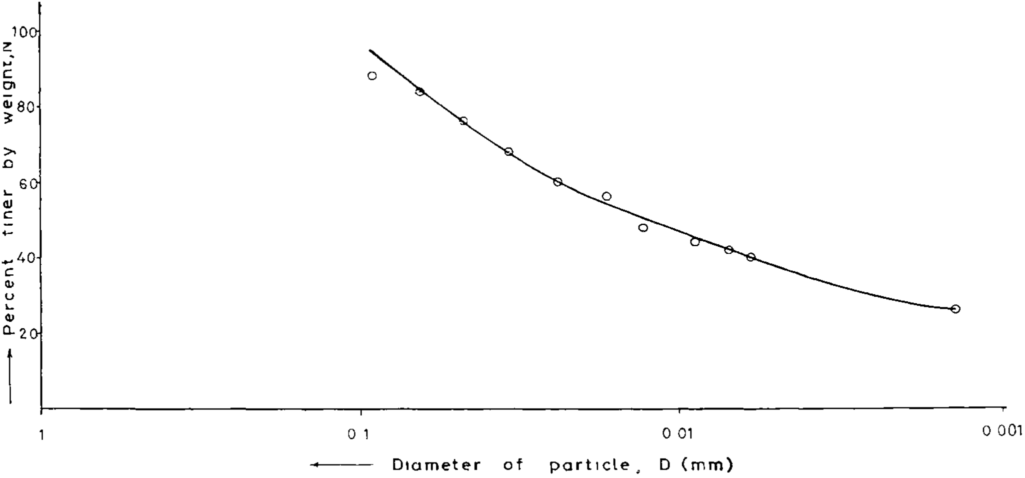


Fig-11 GRAIN SIZE DISTRIBUTION CURVE (Hydrometer Analysis) particle diameter D as abscissa to a logarithmic scale and the corresponding percentage finer N as ordinate to a natural scale (Fig.9 and 11). From the above two analysis the percentages of sand, silt and clay were determined as 62.6, 25.5 and 11.9 respectively. According to USDA textural classification by using triangular chart, the type of soil was sandy loam. Light and medium textured soils with a low clay content eroded easily and was unstable in newly constructed structures. Special precautions were needed in this type of soil to prevent ditch washouts. So canals should be designed using maximum permissible velocity criteria according to soil texture to minimise soil erosion in earthen channels. Since this experiment was conducted only for one type of soil, the best fit equation obtained can be recommended only for sandy loam soil.

7. Manning's equation was developed for large canals and streams. The value of the coefficient of resistance n under different conditions were arrived at with the exponent of S as 0.5 and the exponent of R as 0.67. But the validity of the equations developed was never tested for small channels. The Manning's n was developed empirically as a coefficient which remained a constant for given boundary condition regardless of slope of channel, size of channel or depth of flow. However each of these values have influence on the value of n to some extent. According to Manning, major factors affecting roughness coefficient were surface roughness, vegetation, channel irregularity, channel alignment, silting and scouring, obstructions, size and shape of the channel, stage and discharge.

The value of n increased with the decrease in stage and discharge. When water was shallow, the irregularities of the channel bottom were exposed and their effects became more pronounced. The boundary effects and surface tension would have more influence on the value of n under such conditions. Hence for small channels and for small discharges the value of n would be higher. The large values of n obtained in the best fit equations obtained in this study could be attributed to the boundary effects and surface tension.

8. This study recommends the following equations for computing velocities in cement lined channels and earthen channels in sandy loam soil for discharges less than 10 l/s.

In cement lined channel

$$V = \frac{1}{0.1087} R^{0.7591} S^{0.1103}$$

In earthen channel

$$V = \frac{1}{0.0212} R^{0.844} S^{0.307}$$

These equations would give better results under the conditions mentioned above.

However Manning's equation being an universally accepted equation, it is suggested that for better results the following n values may be used in small channels when Manning's equation is used.

$$V = \frac{1}{0.00609} R^{0.67} S^{0.5}$$ for cement lined channels

$$V = \frac{1}{0.00778} R^{0.67} S^{0.5}$$ for earthen channels

Chezy's equation also does not give reliable results in small charnels when C values computed from Kutter's equation and Manning's equation are used. Better results can be obtained by using C value obtained in this study. These values are 95 for cement lined channels and 75 for earthen channels in sandy loam soil.

9. The following are some of the suggestions for further investigations.

1. Conduct the experiments in different types of linings for different rate of flows and develop equations for these conditions

2. Conduct experiments in different types of soils for obtaining values of exponents and constants valid for different types of soils.

3. Compare all the equations and develop an equation in the form of Manning's equation with different values of roughness factor for different types of linings.

Summary

SUMMARY

Conveyance and control of irrigation water is an important phase of agricultural water management. Scientific management of irrigation water is the only way in which we can make our agriculture competitive and profitable. The major problem in irrigation schemes are the wastage of water at outlet point owing to the absence of appropriate regulation of water to the remote areas through field channels. So proper design of canals thus gains importance in improving the economics and efficiency of the project.

The well known and widely used uniform flow formulas were derived from experiments conducted in large canals and streams with certain theoretical assumptions. The validity of these equations were never tested in small channels. There was no empirical equation available for the design of small channels having discharges less than 10 l/s. So an attempt was made to find out the constants in the general uniform flow formula for discharges less than 10 l/s in cement lined and earthen channels.

The site selected for the experiments was the Instructional Farm of Kelappaji College of Agricultural Engineering and Technology at Tavanur. A cement lined and earthen channel of 40 m length were constructed side by side. The bottom width, depth and side slope of the lined channel were 15 cm, 18 cm, and 1 1 and for earthen channels were 15 cm, 18 cm and 1.5 1 respectively. An upstream tank of size 2.6 × 1.1 × 0.6 m and a downstream tank of 5.1 × 1.1 × 0.8 m were constructed common to both the channels. A V-notch installed at one side of the downstream tank and a hook gauge with vernier arrangement were used for discharge measurements in channels.

The mean velocity of a turbulent uniform flow in open channels is usually expressed in the general form

$$V = CR^{x} S^{y}$$

The study was conducted to find out the constants C, x and y in the uniform flow formula for discharges less than 10 l/s in cement lined and earthen channels. Experiments were conducted for different discharges varying from 1 to 9 l/s and for different slopes of 1/2000, 1/3000, 1/4000 and 1/5000 in cement lined and earthen channels. The relationship between velocity V, hydraulic radius R and slope S were estimated by a computer analysis by fitting a log linear multiple regression equation. The best fit equations obtained for these two channels are

In cement lined channel

$$V = 9.199\ R^{0.7591}\ S^{0.1103}$$

$$\text{i.e.}\quad V = \frac{1}{0.1087}\ R^{0.7591}\ S^{0.1103}$$

In earthen channel

$$V = 47.2286\ R^{0.844}\ S^{0.307}$$

$$\text{i.e.}\quad V = \frac{1}{0.0212}\ R^{0.844}\ S^{0.307}$$

These equations were compared with the well known Chezy's and Mannning's equations and checked their validity for small channels.

Manning's recommended value of roughness coefficient n for cement lined channels was 0.013 and for earthen channels was 0.018. The value of n obtained in the study was approximately eight times greater than the recommended value for cement lined channels and 1.2 times greater than the recommended value for earthen channels. The higher value of n obtained would reduce the value of C which is its inverse by the same proportion. The exponent of R was within the limits. The lower value of the exponent of S to a large extent was compensated by the differences in the value of n.

An attempt was made to compare the actual velocity with the velocity obtained using Manning's equation. In both the channels, actual velocity was roughly 2 times greater than the Manning's velocity. So Manning's recommended values derived for large canals and streams were found not applicable to small channels having discharges less than 10 l/s. Since the average ratio actual and computed velocity using the best fit equations and the coefficient of determinations in the two cases were near unity, these best fit equations were good and gave more accurate results.

Manning fixed the value of exponent of S as 0.5 on certain assumptions based on theory. So it was decided to fix the value of exponent of S as 0.5 and find the value of n and the exponent of R. The equations obtained in the two channels are

In cement lined channel

$$V = \frac{1}{0.00428} R^{0.7827} S^{0.5}$$

In earthen channel

$$V = \frac{1}{0.00408} R^{0.8696} S^{0.5}$$

The exponent of R was within the limits in both cases. The value of n obtained was three times less than the recommended value in cement lined channels and four times less than the recommended value in earthen channels. This decrease in n value was to some extent compensated by the decrease in the value of hydraulic radius factor due to the increase in the value of its exponent. These equations were good within these conditions, but the reliability of the equations were less than the previous case.

Since Manning's equation is an universally accepted form, a comparison was made between the recommended values of n and the values of n obtained in the study by fixing the value of exponent of R and S as 0.67 and 0.5 respectively. The equations obtained are

In cement lined channel

$$V = \frac{1}{0.00609} R^{0.67} S^{0.5}$$

In earthen channel

$$V = \frac{1}{0.00778} R^{0.67} S^{0.5}$$

Here the values of n in the two cases were approximately half the recommended values. These equations gave reasonably good results, though their reliability were comparitively less than the earlier two cases.

Since Manning's equation was not applicable for the design of small channels, the best fit equations obtained in the study are recommended for velocity computation in small channels having discharges less than 10 l/s. Since Manning's equation is an universally accepted form, this study developed equations in the form of Manning's with different values of n for two conditions. These recommended values for rugosity coefficient are 0 00609 for cement lined channels and 0.00778 for earthen channels in sandy loam soils.

In Chezy's equation, Chezy's constant C is determined by using Ganguillet and Kutter's formula and Manning's formula. In cement lined channels using a recommended n value of 0.013, Chezy's constant C was calculated as 36.98 from Kutter's equation and 44.96 from Manning's equation. In earthen channels, using the recommended n value of 0.018, the value of C obtained was 23.91 from Kutter's equation and 32.42 from Manning's equation. The C values obtained in the study by fixing the value of exponent of R and S as 0.5 in the best fit equation were 94.91 in cement lined and 74.771 in earthen channels. Velocities were compared using the following equation.

In cement lined channel

$$V = 94.91 \sqrt{RS} \qquad \text{(from best fit equation)}$$

$$V = 36.98 \sqrt{RS} \qquad \text{(from Kutter's equation)}$$

$$V = 44.96 \sqrt{RS} \qquad \text{(from Manning's equation)}$$

In earthen channel

$$V = 74.771 \sqrt{RS} \qquad \text{(from best fit equation)}$$

$$V = 23.91 \sqrt{RS} \qquad \text{(from Kutter's equation)}$$

$$V = 32.42 \sqrt{RS} \qquad \text{(from Manning's equation)}$$

The actual velocities in both the channels were more than double the velocities obtained using Kutter's and Manning's equation. Hence these C values computed from Kutter's and Manning's equation were not applicable to small channels. The velocities computed using the equations developed in the study were very close to the actual velocities. So this study recommends a C value of 95 for cement lined channels and 75 for earthen channels carrying discharges less than 10 l/s in Chezy's equation.

Sieve and hydrometer analysis were done to designate the textural class of the soil where earthen channel was constructed. The type of soil was sandy loam.

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* Originals not seen

Appendices

Appendix I

DISCHARGES FOR V NOTCH SHARP CRESTED WEIRS FOR HEADS IN METRES (ADAPTED FROM ISO/TC 113/GT 2 (FRANCE 10) 152)

HEAD	DISCHARGE l/sec			HEAD	DISCHARGE l/sec			HEAD	DISCHARGE l/sec			HEAD	DISCHARGE l/sec		
metre	90°	½ 90°	¼ 90°	metre	90°	½ 90°	¼ 90°	metre	90°	½ 90°	¼ 90°	metre	90°	½ 90°	¼ 90°
0 050	0 803	0 406	0 215	0 100	4 420	2 249	1 161	0 150	12 066	6 130	3 140	0 200	24 719	12 506	6 379
0 051	0 843	0 427	0 225	0 101	4 530	2 305	1 190	0 151	12 267	6 231	3 192	0 201	25 028	[illegible]	6 458
0 052	0 884	0 448	0 236	0 102	4 641	2 362	1 219	0 152	12 471	6 334	3 245	0 202	25 339	12 819	6 537
0 053	0 926	0 469	0 247	0 103	4 754	2 420	1 249	0 153	12 676	6 437	3 297	0 203	25 652	12 977	6 617
0 054	0 970	0 491	0 259	0 104	4 869	2 478	1 278	0 154	12 883	6 542	3 350	0 204	25 969	13 136	6 698
0 055	[illegible]	0 514	0 271	0 105	4 985	2 537	1 309	0 155	13 093	6 648	3 404	0 205	26 288	13 296	6 780
0 056	[illegible]	0 537	[illegible]	0 106	5 103	2 598	1 339	0 156	13 304	6 755	3 458	0 206	26 610	13 457	6 862
0 057	[illegible]	0 561	[illegible]	0 107	[illegible]	2 659	1 371	0 157	13 517	6 863	3 513	0 207	[illegible]	13 620	6 944
0 058	[illegible]	[illegible]	0 308	0 108	5 344	[illegible]	1 402	0 158	13 732	6 971	3 568	0 208	27 261	13 786	[illegible]
0 059	1 206	0 611	0 321	0 109	5 467	2 783	1 434	0 159	13 950	7 081	3 624	0 209	27 590	13 949	7 111
0 060	1 257	0 637	0 334	0 110	5 592	2 847	1 466	0 160	14 169	7 192	3 680	0 210	27 921	[illegible]	[illegible]
0 061	1 309	0 663	0 348	0 111	5 719	2 911	1 499	0 161	14 391	7 304	3 737	0 211	28 254	14 282	[illegible]
0 062	1 362	0 691	0 362	0 112	5 847	2 976	1 533	0 162	14 614	7 417	3 794	0 212	28 588	[illegible]	[illegible]
0 063	1 417	0 718	0 376	0 113	5 977	3 042	1 566	0 163	14 840	7 531	3 852	0 213	28 924	14 620	7 453
0 064	[illegible]	0 747	0 391	0 114	6 108	3 109	1 601	0 164	15 067	[illegible]	3 911	0 214	29 264	[illegible]	7 539
0 065	1 530	0 776	0 406	0 115	6 242	3 177	1 635	0 165	[illegible]	7 762	3 969	0 215	29 607	14 964	7 627
0 066	[illegible]	0 806	0 421	0 116	6 377	3 246	1 670	0 166	15 529	[illegible]	4 029	0 216	29 953	15 138	7 715
0 067	[illegible]	0 836	0 437	0 117	[illegible]	[illegible]	1 706	0 167	[illegible]	[illegible]	[illegible]	0 217	[illegible]	[illegible]	7 803
0 068	[illegible]	0 867	[illegible]	0 118	[illegible]	[illegible]	[illegible]	0 168	[illegible]	8 112	[illegible]	0 218	30 651	15 489	7 893
0 069	1 772	0 899	0 470	0 119	6 793	[illegible]	1 778	0 169	[illegible]	[illegible]	4 210	0 219	[illegible]	15 661	7 982
0 070	1 836	0 932	[illegible]	0 120	6 935	3 529	1 815	0 170	[illegible]	8 358	4 272	0 220	31 359	15 844	8 073
0 071	1 901	0 965	0 503	0 121	7 079	3 602	1 853	0 171	16 719	8 481	[illegible]	0 221	31 717	16 026	8 164
0 072	1 967	0 999	0 521	0 122	7 224	3 677	1 891	0 172	16 964	8 606	4 397	0 222	32 077	16 204	8 255
0 073	2 035	1 033	0 539	0 123	7 372	3 751	1 929	0 173	17 210	8 728	4 460	0 223	32 439	16 386	8 347
0 074	[illegible]	1 069	0 557	0 124	7 522	3 827	1 968	0 174	17 459	[illegible]	[illegible]	0 224	32 803	16 576	[illegible]
[illegible]	2 176	[illegible]	[illegible]	0 125	7 673	3 904	2 007	0 175	[illegible]	8 980	[illegible]	0 225	33 168	[illegible]	[illegible]
0 076	2 248	1 141	0 596	0 126	7 827	3 982	2 046	0 176	17 963	9 108	4 651	0 226	[illegible]	16 940	[illegible]
0 077	2 322	1 179	[illegible]	0 127	7 982	4 060	2 086	0 177	18 219	9 237	4 718	0 227	33 907	17 127	8 724
0 078	2 397	1 217	0 633	0 128	8 139	4 140	2 127	0 178	18 478	9 367	[illegible]	0 228	34 282	17 315	8 819
0 079	2 473	1 256	0 653	0 129	8 298	4 220	2 168	0 179	18 738	9 497	4 851	0 229	34 659	17 506	8 915
0 080	2 551	1 296	0 673	0 130	8 458	4 302	2 209	0 180	19 001	9 629	4 918	0 230	35 039	17 695	9 011
0 081	2 630	1 336	0 694	0 131	8 621	4 384	2 251	0 181	19 265	9 762	4 986	[illegible]	35 421	17 886	9 108
0 082	2 710	1 377	0 715	0 132	8 785	4 467	2 294	0 182	19 531	9 896	5 054	[illegible]	[illegible]	18 079	9 207
0 083	2 792	[illegible]	[illegible]	0 133	8 951	4 551	2 337	0 183	[illegible]	10 032	5 122	0 233	36 139	18 274	[illegible]
0 084	2 876	1 462	[illegible]	0 134	9 119	4 636	2 380	0 184	20 071	[illegible]	5 192	0 234	36 582	18 469	9 405
0 085	2 961	1 503	0 781	0 135	9 289	4 722	2 424	0 185	20 343	10 305	[illegible]	0 235	36 974	18 666	9 506
0 086	3 048	[illegible]	0 803	0 136	9 461	4 809	2 468	0 186	20 621	10 444	5 332	0 236	37 369	18 864	[illegible]
0 087	[illegible]	1 594	0 826	0 137	9 634	4 897	2 513	0 187	20 899	[illegible]	5 403	0 237	37 766	19 063	[illegible]
0 088	[illegible]	[illegible]	[illegible]	0 138	[illegible]	4 986	2 559	0 188	[illegible]	[illegible]	5 475	0 238	38 166	19 263	[illegible]
0 089	3 316	1 686	0 874	0 139	9 983	5 075	2 604	0 189	21 461	[illegible]	5 547	0 239	[illegible]	[illegible]	[illegible]
[illegible]	3 403	1 734	[illegible]	0 140	10 167	5 165	2 651	0 190	21 748	11 010	5 620	0 240	38 973	19 668	10 013
0 091	3 503	1 782	0 922	0 141	[illegible]	5 258	2 697	0 191	22 036	11 155	5 693	0 241	39 380	19 872	10 116
0 092	3 598	1 830	0 947	0 142	10 532	5 351	2 744	0 192	22 322	11 300	5 766	0 242	39 790	20 079	10 220
0 093	3 696	1 880	0 973	0 143	10 717	5 444	2 792	0 193	22 612	11 447	[illegible]	0 243	40 203	20 287	[illegible]
0 094	3 795	1 930	0 998	0 144	10 904	5 539	2 840	0 194	22 906	11 595	5 916	0 244	40 617	20 496	10 430
0 095	3 895	1 981	1 025	0 145	11 093	5 635	2 889	0 195	23 203	11 743	5 992	0 245	41 034	20 705	10 536
0 096	3 997	[illegible]	1 051	0 146	11 284	5 732	2 938	0 196	23 501	11 893	6 068	0 246	41 454	20 916	10 642
0 097	[illegible]	2 086	1 078	0 147	11 476	5 830	2 988	0 197	23 802	12 044	6 145	0 247	41 877	21 127	10 750
0 098	4 206	[illegible]	1 106	0 148	11 671	5 929	3 038	0 198	24 106	12 197	6 222	0 248	[illegible]	21 340	10 858
0 099	4 312	2 194	1 133	0 149	11 867	6 029	3 089	0 199	24 411	12 351	6 300	0 249	42 730	21 555	10 967

Appendix II

Proposed values of Bazin's m

Description of channel	Basin's m
Very smooth cement of planed wood	0.11
Unplaned wood, concrete, or brick	0.21
Ashlar, rubble masonry, or poor brickwork	0.83
Earth channels in perfect condition	1.54
Earth channels in ordinary condition	2.36
Earth channels in rough condition	3.17

Appendix III

Comparison of Variations in Chézy's *C*, Bazin's *m* and Kutter's *n*

Measurements	Average values			Average variations %		
	C	*m*	*n*	*C*	*m*	*n*
Bazin's Series 6		0.185	0.0127		5.2	1.1
7		0.156	0.0120		3.4	1.0
8		0.142	0.0116		3.8	2.5
9		0.109	0.0130		10.6	1.2
10		0.144	0.0117		3.4	1.4
11		0.129	0.0113		3.7	3.8
12		0.324	0.0151		1.6	1.0
13		0.311	0.0148		2.7	1.2
14		0.821	0.0150		4.4	1.8
15		0.715	0.0209		4.2	1.2
16		0.711	0.0212		5.7	1.6
17		0.721	0.0216		6.7	2.2
32		0.424	0.0168		1.8	0.4
33		0.444	0.0171		3.1	1.2
44		0.658	0.0195		18.6	8.8
46		0.704	0.0205		11.1	5.7
Miami River at Tadmor, Ohio, 1915–1916	67.4*	1.98	0.0316	4.08	10.9	4.9
Bogue Phalia River, Miss., 1914	63.3*	4.09	0.0704	24.20	35.7	22.2
Arkansas Drainage Canals, Ark., 1915	65.9*	2.12	0.0324	3.18	4.8	1.6
Mississippi River, Carrolton, La., 1912		1.33	0.0320	1.30	5.4	3.0
Mississippi River, Carrolton, La., 1913		1.40	0.0334	2.80	12.8	2.8
Irrawaddy River, Burma		1.35	0.0332	4.10	23.0	6.2
Volga River at Samara, Russia		1.59	0.0311	1.87	13.0	4.1
Volga River at Zhiguly, Russia		1.76	0.0363	18.80	36.5	5.0
Average variation				7.54	9.67	3.68

* Values averaged by the author

Appendix IV

VALUES OF THE ROUGHNESS COEFFICIENT n

(Boldface figures are values generally recommended in design)

Type of channel and description	Minimum	Normal	Maximum
A. CLOSED CONDUITS FLOWING PARTLY FULL			
A-1. Metal			
a. Brass, smooth	0.009	0.010	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
A-2. Nonmetal			
Lucite	0.008	0.009	0.010
b. Glass	0.009	0.010	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
g. Brickwork			
1. Glazed	0.011	0.013	0.015
2. Lined with cement mortar	0.012	0.015	0.017
h. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
i. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
j. Rubble masonry, cemented	0.018	0.025	0.030

Contd.

Appendix IV (Contd.)

VALUES OF THE ROUGHNESS COEFFICIENT n (continued)

Type of channel and description	Minimum	Normal	Maximum
B LINED OR BUILT-UP CHANNELS			
B-1 Metal			
a Smooth steel surface			
1 Unpainted	0.011	0.012	0.014
2 Painted	0.012	0.013	0.017
b Corrugated	0.021	0.025	0.030
B-2 Nonmetal			
a Cement			
1 Neat surface	0.010	0.011	0.013
2 Mortar	0.011	0.013	0.015
b Wood			
1 Planed, untreated	0.010	0.012	0.014
2 Planed, creosoted	0.011	0.012	0.015
3 Unplaned	0.011	0.013	0.015
4 Plank with battens	0.012	0.015	0.018
5 Lined with roofing paper	0.010	0.014	0.017
c Concrete			
1 Trowel finish	0.011	0.013	0.015
2 Float finish	0.013	0.015	0.016
3 Finished, with gravel on bottom	0.015	0.017	0.020
4 Unfinished	0.014	0.017	0.020
5 Gunite, good section	0.016	0.019	0.023
6 Gunite, wavy section	0.018	0.022	0.025
7 On good excavated rock	0.017	0.020	
8 On irregular excavated rock	0.022	0.027	
d Concrete bottom float finished with sides of			
1 Dressed stone in mortar	0.015	0.017	0.020
2 Random stone in mortar	0.017	0.020	0.024
3 Cement rubble masonry, plastered	0.016	0.020	0.024
4 Cement rubble masonry	0.020	0.025	0.030
5 Dry rubble or riprap	0.020	0.030	0.035
e Gravel bottom with sides of			
1 Formed concrete	0.017	0.020	0.025
2 Random stone in mortar	0.020	0.023	0.026
3 Dry rubble or riprap	0.023	0.033	0.036
f Brick			
1 Glazed	0.011	0.013	0.015
2 In cement mortar	0.012	0.015	0.018
g Masonry			
1 Cemented rubble	0.017	0.025	0.030
2 Dry rubble	0.023	0.032	0.035
h Dressed ashlar	0.013	0.015	0.01[illegible]
i Asphalt			
1 Smooth	0.013	0.013	
2 Rough	0.016	0.016	
j Vegetal lining	0.030		0.500

Contd

Appendix IV (contd.)

VALUES OF THE ROUGHNESS COEFFICIENT *n* (*continued*)

Type of channel and description	Minimum	Normal	Maximum
C EXCAVATED OR DREDGED			
a Earth straight and uniform			
1 Clean recently completed	0.016	0.018	0.020
2 Clean after weathering	0.018	0.022	0.025
3 Gravel uniform section clean	0.022	0.025	0.030
4 With short grass few weeds	0.022	0.027	0.033
b Earth winding and sluggish			
1 No vegetation	0.023	0.025	0.030
2 Grass some weeds	0.025	0.030	0.033
3 Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4 Earth bottom and rubble sides	0.028	0.030	0.035
5 Stony bottom and weedy banks	0.025	0.035	0.040
6 Cobble bottom and clean sides	0.030	0.040	0.050
c Dragline-excavated or dredged			
1 No vegetation	0.025	0.028	0.033
2 Light brush on banks	0.035	0.050	0.060
d Rock cuts			
1 Smooth and uniform	0.025	0.035	0.040
2 Jagged and irregular	0.035	0.040	0.050
e Channels not maintained weeds and brush uncut			
1 Dense weeds high as flow depth	0.050	0.080	0.120
2 Clean bottom brush on sides	0.040	0.050	0.080
3 Same highest stage of flow	0.045	0.070	0.110
4 Dense brush high stage	0.080	0.100	0.140
D NATURAL STREAMS			
D-1 Minor streams (top width at flood stage <100 ft)			
a Streams on plain			
1 Clean straight full stage no rifts or deep pools	0.025	0.030	0.033
2 Same as above but more stones and weeds	0.030	0.035	0.040
3 Clean winding some pools and shoals	0.033	0.040	0.045
4 Same as above but some weeds and stones	0.035	0.045	0.050
5 Same as above lower stages more ineffective slopes and sections	0.040	0.048	0.055
6 Same as 4 but more stones	0.045	0.050	0.060
7 Sluggish reaches weedy deep pools	0.050	0.070	0.080
8 Very weedy reaches deep pools or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Contd.

Appendix IV (contd.)

VALUES OF THE ROUGHNESS COEFFICIENT n (*continued*)

Type of channel and description	Minimum	Normal	Maximum
b Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1 Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2 Bottom: cobbles with large boulders	0.040	0.050	0.070
D-2 Flood plains			
a Pasture, no brush			
1 Short grass	0.025	0.030	0.035
2 High grass	0.030	0.035	0.050
b Cultivated areas			
1 No crop	0.020	0.030	0.040
2 Mature row crops	0.025	0.035	0.045
3 Mature field crops	0.030	0.040	0.050
c Brush			
1 Scattered brush, heavy weeds	0.035	0.050	0.070
2 Light brush and trees, in winter	0.035	0.050	0.060
3 Light brush and trees, in summer	0.040	0.060	0.080
4 Medium to dense brush, in winter	0.045	0.070	0.110
5 Medium to dense brush, in summer	0.070	0.100	0.160
d Trees			
1 Dense willows, summer, straight	0.110	0.150	0.200
2 Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3 Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4 Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5 Same as above, but with flood stage reaching branches	0.100	0.120	0.160
D-3 Major streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance			
a Regular section with no boulders or brush	0.025		0.060
b Irregular and rough section	0.035		0.100

Appendix V

Values for the Computation of the Roughness Coefficient

Channel conditions		Values	
Material involved	Earth	n_0	0.020
	Rock cut		0.025
	Fine gravel		0.024
	Coarse gravel		0.028
Degree of irregularity	Smooth	n_1	0.000
	Minor		0.005
	Moderate		0.010
	Severe		0.020
Variations of channel cross section	Gradual	n_2	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010–0.015
Relative effect of obstructions	Negligible	n_3	0.000
	Minor		0.010–0.015
	Appreciable		0.020–0.030
	Severe		0.040–0.060
Vegetation	Low	n_4	0.005–0.010
	Medium		0.010–0.025
	High		0.025–0.050
	Very high		0.050–0.100
Degree of meandering	Minor	m_5	1.000
	Appreciable		1.150
	Severe		1.300

Appendix VI

Determination of Chezy's constants from Kutter's and Manning's equation in lined channel

$$C = \frac{23 + \frac{0.00155}{s} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{s}\right)\frac{n}{\sqrt{R}}} \qquad 4.15 \qquad\qquad C = \frac{1}{n} R^{1/6} \qquad 4.16$$

where $n = 0.013$ where $n = 0.013$

Velocity (m/s) V	Hydraulic radius (m) R	Slope S	$\sqrt{R}$	$n/\sqrt{R}$	Value of C from Kutter's equation 4.15	Value of C from Manning's equation 4.16
1	2	3	4	5	6	7
0.2536	0.0283	0.0002	0.1682	0.0773	31.88	42.46
0.2971	0.0379	0.0002	0.1947	0.0668	35.25	44.58
0.3541	0.0485	0.0002	0.2202	0.0590	38.26	46.45
0.4082	0.0530	0.0002	0.2302	0.0565	39.33	47.15
0.2629	0.0300	0.00025	0.1732	0.0751	33.24	42.88
0.2973	0.0385	0.00025	0.1962	0.0663	36.15	44.70
0.3279	0.0442	0.00025	0.2102	0.0618	37.84	45.74
0.3608	0.0493	0.00025	0.2220	0.0586	39.14	46.58
0.2505	0.0289	0.00033	0.1700	0.0765	33.54	4 62
0.3164	0.0373	0.00033	0.1931	0.0673	36.53	44.46
0.3531	0.0425	0.00033	0.2062	0.0630	38.11	45.44
0.3727	0.0471	0.00033	0.2170	0.0599	39.34	46.23
0.2787	0.0316	0.0005	0.1778	0.0731	35.43	43.25
0.3430	0.0403	0.0005	0.2007	0.0648	38.28	45.04
0.3860	0.0432	0.0005	0.2078	0.0626	39.11	45.57
0.3984	0.0471	0.0005	0.2170	0.0599	40.19	46.23
					36.98	44.96

Appendix VII

Determination of Chezy's constant C and Bazin's roughness coefficient in lined channel

$$C = \frac{V}{\sqrt{RS}} \qquad 4.10$$

$$m = \left(\frac{157.6}{C} - 1.81\right)\sqrt{R} \qquad 4.20$$

Velocity (m/s) V	Hydraulic radius (m) R	Slope S	$\sqrt{R}$	Value of C using 4.10	Bazin's roughness coefficient using 4.20 m
1	2	3	4	5	6
0.2536	0.0283	0.0002	0.1682	106.596	--
0.2971	0.0379		0.1947	107 912	-
0.3541	0.0485		0.2202	113.695	--
0.4082	0.0530		0.2302	125.378	--
0.2629	0.0300	0.00025	0.1732	95.998	
0.2973	0.0385		0.1962	95 828	--
0.3279	0.0442		0.2102	98.642	-
0.3608	0.0493		0.2220	102 772	-
0.2505	0.0289	0.00033	0.1700	81.115	0,0236
0.3164	0.0373		0.1931	90.183	--
0.3531	0.0425		0.2062	94 286	--
0.3727	0.0471		0.2170	94.535	--
0.2787	0.0316	0.0005	0.1778	70.115	0 0778
0.3430	0.0403		0.2007	76.411	0 0507
0.3860	0.0432		0.2078	83 054	0 0182
0.3984	0.0471		0.2170	82.096	0 0238
				94 91	0.0386

Appendix VIII

Determination of Chezy's constants from Kutter's and Manning's equation in earthen channel

$$C = \frac{23 + \frac{0.00155}{s} + \frac{1}{n}}{1 + \left(23+\frac{0.00155}{s}\right) + \frac{1}{\sqrt{R}}} \qquad 4.15 \qquad\qquad C = \frac{1}{n} R^{1/6} \qquad 4.16$$

where $n = 0.018$ where n 0.018

Velocity (m/s) V	Hydraulic radius (m) R	Slope S	$\sqrt{R}$	$n/\sqrt{R}$	Value of C from Kutter's equation 4.15	Value of C from
0.1938	0.0314	0.0002	0.1772	0.1016	20.93	31.20
0.2394	0.0372		0.1929	0.0933	22.31	32.09
0.2709	0.0503		0.2243	0.0802	14.90	33.75
0.3092	0.0507		0.2252	0.0799	24.97	33.80
0.1592	0.0257	0.00025	0.1603	0.1123	25.85	30.18
0.1739	0.0347		0.1863	0.0966	22.18	31.73
0.2543	0.0454		0.2131	0.0845	24.44	33.18
0.2722	0.0503		0.2243	0.0802	25.36	33.75
0.2490	0.0347	0.00033	0.1863	0.0966	22.65	3 73
0.2633	0.0358		0.1892	0.0951	22.91	31.89
0.2656	0.0382		0.1954	0.0921	23.45	32.24
0.3465	0.0526		0.2293	0.0785	26.23	34.00
0.2325	0.0286	0.0005	0.1691	0.1064	21.62	30.72
0.2734	0.0342		0.1849	0.0973	23.07	31.65
0.3117	0.0433		0.2081	0.0865	25.07	32.92
0.3637	0.0512		0.2263	0.0795	26.55	33.85
					23.91	32.42

Appendix IX

Computation of Chezy's constant C and the Bazin's roughness coefficient in earthen channel

$$C \qquad \frac{V}{\sqrt{RS}} \qquad\qquad 4.10$$

$$M = \frac{(157.6-1.81)}{C}\sqrt{R} \qquad\qquad 4.20$$

Velocity (m/s) V	Hydraulic radius (m) R	Slope S	$\sqrt{R}$	Value of C from the data obtained using 4 10	Bazin's roughness coefficient using 4 20 m
1	2	3	4	5	6
0.1938	0.0314	0.0002	0.1772	77 33	0 0404
0.2394	0.0372	0.0002	0.1929	87 76	
0.2709	0.0503	0.0002	0.2243	85 41	0.0079
0.3092	0.0507	0.0002	0.2252	97.10	
0.1592	0.0257	0.00025	0.1603	62.807	0.1121
0.1739	0.0347	0.00025	0.1863	59.04	0.1601
0 2543	0.0454	0.00025	0.2131	75.483	0.0592
0.2722	0.0503	0.00025	0.2243	76.76	0.0545
0.2490	0.0347	0.00033	0 1863	73 583	0.0618
0 2633	0.0358	0.00033	0.1892	76.60	0 0468
0.2656	0.0382	0.00033	0.1954	74.806	0 058
0 3465	0.0526	0.00033	0.2293	83.167	0.0195
0.2325	0.0286	0.0005	0.1691	61.483	0.1274
0.2734	0.0342	0.0005	0.1849	66 115	0 1061
0 3117	0.0433	0.0005	0.2081	66.99	0 1129
0 3637	0.0512	0.0005	0.2263	71 88	0 0866
				74.771	0.075

DETERMINATION OF CONSTANTS IN UNIFORM FLOW FORMULA FOR SMALL DISCHARGES IN OPEN CHANNELS

By

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ABSTRACT OF A THESIS

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ABSTRACT

Irrigated agriculture is by far the biggest consumer of water and is one of the most inefficient. As our water resources are limited, effort have to be continuously made to optimise the use of available water resources by bringing improvements in design, planning and operation. Poor distribution system characterised by the absence of field channels constituted a major cause of under utilization. So proper design and layout of field channels is one of the most important feature in developing successful irrigation.

An attempt was made to find out the constants in the general uniform flow formula for small discharges less than 10 l/s in cement lined and earthen channels. These constants were compared with the constants in the well known and widely used uniform flow formulae such as Manning's and Chezy's equation and checked their validity for small channels. Experiments were conducted for different discharges varying from 1 to 9 l/s and for different slopes of 1/2000, 1/3000, 1/4000 and 1/5000 in cement lined and earthen channels. With the help of a computer, analysis was made to establish a relationship between velocity V, hydraulic radius R and slope S. The expirical equation obtained are

In cement lined channel

$$V = 9.199\ R^{0.7591}\ S^{0.1103}$$

$$\text{i.e. } V = \frac{1}{0.1087}\ R^{0.7591}\ S^{0.1103}$$

In earthen channel

$$V = 47.2286\ R^{0.844}\ S^{0.307}$$

$$\text{i.e. } V = \frac{1}{0.0212}\ R^{0.844}\ S^{0.307}$$

From the comparison of actual velocity with velocity obtained by using Manning's equation, it was found that Manning's equation was not applicable to small channels having discharges less than 10 l/s. In both the channels, actual velocity was roughly two times greater than the Manning's velocity. The average ratio of actual and computed velocity using the best fit equations and the coefficient of determinations in the two cases were near unity. Hence the best fit equations obtained in the study are recommended for the design of small channels.

Manning fixed the value of exponent of S as 0.5 based on some theoretical assumptions. So it was decided to find the value of n and the exponent of R in both the channels by fixing the value of exponent of S as 0.5. The equations obtained are

In cement lined channel

$$V = \frac{1}{0.00428}\ R^{0.7827}\ S^{0.5}$$

In earthen channel

$$V = \frac{1}{0.00408}\ R^{0.8696}\ S^{0.5}$$

These equations were good but their reliability were less than that of the previous equations.

Since Manning's equation is an universally accepted form, comparison was made between the recommended n values and the n values obtained in the study by fixing the value of exponent of R and S as 0.67 and 0.5 respectively. The equations obtained are

In cement lined channel

$$V = \frac{1}{0.00609} R^{0.67} S^{0.5}$$

In earthen channel

$$V = \frac{1}{0.00778} R^{0.67} S^{0.5}$$

Though the reliability of these equations were comparitively less than the earlier cases, it gave reasonably good results. So these equations are also recommended for the design of small channels with different n values for cement lined and earthen channels.

Chezy's constant C was determined from the best fit equations by fixing the value of exponent of R and S as 0.5. The equations obtained in two channels are

In cement lined channel

$$V = 94.91 \sqrt{RS}$$

In earthen channel

$$V = 74.771 \sqrt{RS}$$

These C values obtained are recommended for the design of small channels in Chezy's equation than the C values obtained from Manning's and Kutter's equations using Manning's recommended n values.

Soil in which earthen channel was constructed was classified based on texture. Since the soil was sandy loam, the best fit equation obtained in earthen channel is applicable only for sandy loam soil.

By adopting the best fit equations obtained in the study or the equations obtained in the Manning's form with different n values for the design of small channels in the field, better and more reasonable results can be obtained. These equations will be very useful in command area development programmes for the design of field channels.