GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION

MANUAL ON
IRRIGATION AND POWER CHANNELS

NEW DELHI
MARCH 1984

MANUAL ON
IRRIGATION AND POWER CHANNELS

Prepared by

CENTRAL WATER COMMISSION

Published by

Central Board of Irrigation and Power

Malcha Marg, Chanakyapuri, New Delhi-110021

PUBLICATION No. 171

New Delhi March 1984

PREFACE

The economy and the well-being of the rural masses depends on agriculture of which irrigation is the most important single input. The canal system is a vital element for the success of an Irrigation Project. Canals are also vital components of many run-of-the-river hydro-electric power projects. Although India has a long and enviable record of successful design and construction of irrigation and hydro-power projects, it was felt desirable to compile useful information in the form of a manual for the benefit of those engaged in the planning, designs, construction, operation and maintenance of canals. This manual on Irrigation and Power Channels deals, in brief, with the planning and design of both lined and unlined canals.

Chapter I introduces the importance and advantages of irrigation and the additional uses of canal waters.

Chapter II gives in brief the planning and investigations necessary before detailing an irrigation scheme. The field data to be collected, preliminary and detailed surveys to be done, different types of canal alignments generally adopted, and other features regarding the L-Section and X-Sections are brought out.

Chapter III on design of unlined canals gives in brief some of the important farmulae used in the design of stable channels. Recommendations of I.S.I. in their various Codes have also been mentioned with respect to provision of side slopes, inspection paths, free-board, bed width to depth ratio, allowable velocities, berms, dowels, etc.

Chapter IV on design of lined canals describes different types of lining in use and their suitability in different situations. I.S.I. recommendations pertaining to various aspects of the design of lined canals have also been included. Necessity and details of under-drainage arrangements are also described in details.

Chapter V on power channels describes the special considerations to be taken into account while designing power channels.

Chapter VI gives in brief the various types of problems faced during construction, operation and maintenance of the canals.

Appendix I gives some examples on design of unlined canals, while Appendix II gives examples on design of lined canals. A number of plates have been included to simplify the calculations and save time.

The Manual gives the broad guidelines for planning and design of a system. A satisfactory and successful design depends upon the individual skill and practical experience of a Designer and should cater to the site requirement. I hope this Manual will be of assistance to the engineers in the field of Irrigation and Power in planning and design of canal systems.

I would like to bring on record the useful work done by Shri P.C. Lau, Deputy Director, Shri P. Sen, former Director, and Shri R.P. Malhotra, Director (B.C.D.-II) in preparation of this Manual. Contributions of Shri R. Rangachari, Member (JRC), Shri K. Madhavan, Chief Engineer (Designs) and Shri N.K. Agrawal, former Member (D&R) in the preparation of this Manual are acknowledged.

Comments and suggestions for improvement of the Manual are welcome.

March 1984

PRITAM SINGH
Chairman
Central Water Commission

CONTENTS

NOTATIONS

A	=	Area of Cross-section of Channel in Square Metre
B	=	Bed Width in Metres
Cd	=	Coefficient of Discharge
Cumecs	=	Cubic Metres per Second
C.B.L.	=	Canal Bed Level
C.V.R.	=	Critical Velocity Ratio
D	=	Depth of Water in Metres
f	=	Lacey's Silt Factor
F	=	Free Board in Metres
F.S.L.	=	Full Supply Level
F.S.D.	—	Full Supply Depth
G.L.	=	Ground Level
I.P.	=	Inspection Path
N	=	Coefficient of Rugosity
P	=	Wetted Perimeter in Metres
Q	=	Discharge in cumecs
q	=	Discharge in Cumecs/Meter Width
R	=	Hydraulic Mean Depth in Metre
r	—	Side Slope Ratio
S	=	Longitudinal Surface Slope of Water
S.R.	=	Service Road
V	=	Mean Velocity in Metre/sec.
Vo	=	Kennedy's Critical Velocity in Metre/sec.
W	=	Water Surface Width in Metres

CHAPTER I

Introduction

1.1 India is potentially one of the richest agricultural countries in the world. The total arable land in India is estimated to be 147 million hectares which is the third largest in the world, ranking behind only the U.S.S.R. with 225 million hectares and the U.S.A. with 194 million hectares. This is owing to the fact that the proportion of arable land to total geographical area is the highest in India being 45 percent against 10 percent for U.S.S.R. and 25 percent for U.S.A.

Irrigation has been practised in India from very early times from wells, tanks, inundation canals and small channels. Major projects were built by the British starting in the middle of the 19th Century, and the rate of development though, moderate, was steady.

1.2 Irrigation is defined as the natural or artificial application of water to soil for the purpose of supplying the moisture essential or beneficial to plant growth.

Water is normally supplied to the plants by nature through the agency of rain. A second agency is through the flood waters of rivers which spread and inundate large areas during the flood season and recede back leaving the land well irrigated for cultivation of a crop during the dry season. These natural processes are usefully supplemented by canals to maximise the benefits to cultivators.

1.3 This manual is an attempt to cover broad guidelines, keeping in view the practices recommended by ISI in their various published Codes and the practices adopted by reputed Agencies and Organisations like U.S.B.R., U.S. Army Corps of Engineers, etc., which may be of some help to the designers. The Irrigation distribution system consists of various components like regulation structures, cross drainage structures, bridges, lined or unlined channel sections, etc. In this manual, only the channel part has been dealt in detail.

1.4 The source of all water used for irrigation is 'precipitation', i.e., the water received on the earth from the atmosphere in the form of rain, snow and hail etc. The process of utilisation of this water involves the construction of engineering works of appreciable magnitude, and is termed 'artificial Irrigation.' Artificial Irrigation may be divided into 'lift' irrigation and 'flow' irrigation according to whether the water is lifted to the fields by some mechanical/manual means or flows by gravity from the source to the field.

In order to provide artificial irrigation, irrigation schemes are planned and executed utilising the available natural source of water. The schemes mainly consist of storage or diversion structures and distribution systems. In this publication an attempt has been made to cover the latter, comprising open channels.

1.5 In addition to the surface water, ground water reservoirs provide very useful sources which are being more and more utilised for irrigation purposes these days. Augmentation Tube Wells have been installed to promote conjunctive use of surface and sub-surface waters to meet the increased demand of irrigation and to maintain suitable ground water conditions. Due to introduction of high yielding crop varieties and multiple cropping such conjunctive use of water has several advantages. Some of these are:

(1) Water loss due to seepage from canals and water courses, irrigated areas, etc., is utilised again there by mitigating to some extent the waterlogging problem.

(2) Compared to surface water, ground water is relatively free from surface pollutants, and has the advantage of being less susceptible to changes in quality, chemical composition and temperature variation.

(3) During the period when canal water supply is inadequate or not available, the farmers could draw supply from tube wells to irrigate their fields in time.

In North India, Tube Wells have been found to be so useful and advantageous that their number has been increasing rapidly.

1.6 It is hardly necessary to emphasise the importance and advantages of irrigation development when the pressing necessity of stepping up food production for the growing population of the country has automatically brought it to the forefront. Even so, some of the salient advantages of development of irrigation are recapitulated below :

(i) Protection from Famine

This is the most important function of irrigation in this country. Though most parts of India receive considerable rainfall, it is mostly seasonal and often erratic. The subsistence level of the farmers being very low, and their surplus wealth even in normal years practically nil, failures of rains even in a single year would lead to large scale distress and more than one successive failures to acute famine causing impoverishment and starvation in the affected area, but for the protection offered by artificial irrigation.

(ii) Improvement in Yield and Value of the Crops

The yield of practically all crops increases by a rational and scientific and assured application of water. The optimum quantity of water, i.e., delta to give best results for a certain crop in a certain area can be determined experimentally. Any quantity lesser than or in excess of optimum reduces yield. When permanent, regular and timely supply of water is assured, hybrid crops naturally replace inferior crops to increase yield.

(iii) Addition to the Wealth of the Country

Almost all the large irrigation systems in India are very well planned, financially sound and pay revenue to the State. More important, perhaps, is the increase in the wealth and prosperity of the cultivators. With the introduction of irrigation land value appreciates and it is beneficial to both the land holder and the State, as the latter can legitimately enhance the irrigation cess on such land.

(iv) Generation of H.E. Power

On projects primarily designed for irrigation, power generation can often be obtained at comparatively low cost by utilising the available head.

(v) Inland Navigation

Irrigation canals can be used for inland navigation to mitigate the load of transport on Road System and consumption of petroleum products.

(vi) Effect of Health

In case suitable drainage system is not provided for irrigated areas, the direct influence of a canal irrigation project is to increase the sub-soil water level and water logging in lower areas and the incidence of malaria could occur in the area. The indirect effect of reducing the risk of crop failures and increasing food production improves the nutrition of the people considerably. This leads to increased resistance to disease.

(vii) Domestic Water Supply

In large dry areas the canals are the only source of water for domestic purposes. The rise in sub-soil water level in dry area could assist in meeting demands of domestic water supply by pumping the ground water.

(viii) Improvement of Communications

On all important channels and upto distributaries, an unsurfaced driving road/service road is provided primarily for purpose of inspection and control. These roads are sometimes the only motorable roads available into the interior for essential purpose in command area. This net work of canals with roads improve the communications in remote areas of command.

(ix) Canal Plantations

Trees are planted along banks of channels, near masonry works and in any open land available with the canals. They add to the timber wealth of the country and play their part in checking soil erosions and keeping ecological balance in the area.

(x) Industrial Water Supply

Often the requirements of the neighbouring industry or the Thermal Power Stations for cooling etc. could also be met with from these channels.

CHAPTER II

Planning and Investigations

2.1 Preliminary Surveys

When the proposal for extending canal irrigation into a new area is taken up for consideration, the first steps is to make a thorough reconnaissance survey of the area. During this survey all the factors which effect irrigation development must be carefully observed and notes made from judgement and from quick measurements which can be taken on the spot. The following are the main factors to be considered :

(*i*) *Spring Levels in the Area*

The spring levels in the area should be ascertained and noted as they have an important bearing on the desirability of canal irrigation. If the spring levels are already high, it would be a factor against though not necessarily decisive to the introduction of canal irrigation for the following reasons :

(*a*) The seepage from the canal system, if constructed, may raise the water-table still further by making the area prone to waterlogging.

(*b*) *Uncertainty of Demand* : In areas where the water-table is high, irrigation demand may be slack. At the same time, such areas may be well adopted to development of cash crops which cannot be grown without irrigation.

(*c*) Rise of water-table may increase the incidence of malaria in the area and the opinion of public health authorities on this point should be obtained.

(*ii*) *Rainfall Figures in the Area*

The available rainfall data of the area should be obtained and studied with respect to the percentage of years in which the rainfall departs from the normal during monsoon and in winter. This will give a good idea of the likelihood of irrigation demand in the area.

(*iii*) *Type of Soil*

The type of soil should be judged by visual inspection and by enquiry. Subsequently, soil surveys should be carried out before finalising the scheme.

(*iv*) *Topography of the Area*

A canal system operates essentially by gravity flow system. It has to be so laid out in an area that all the channels run on ridges so that they may irrigate on either side by flow. The topography of the area may be judged keeping in view the above mentioned requirements. If the project is considered worth further investigations contoured maps are prepared.

(*v*) *Crops Already Sown in the Area*

The crops grown in the area should be noted and Agriculture Department should be consulted for existing and proposed cropping pattern and cropping calendar. Water requirement of each crop should be finalised considering the local practice, useful rainfall, and type of soil in the area. The water demand initially will depend on the crops grown/proposed and fortnightly water requirements. The intensity of irrigation in the area should be assessed from records to arrive at reasonable intensity of irrigation in the area.

(*vi*) *Extent of Existing Well and Pond Irrigation in the Area*

(*a*) The limited resources available in the country should be considered and deployed suitably where there is maximum need and provides the greatest benefit. If an area has an extensive system of irrigation from open wells and ponds which is sufficient for its protection against failure of rains, it should naturally receive a low priority for the introduction of canal irrigation.

(*b*) Since it may not be possible to meet the demand of irrigation during low supplies/closures from the sources, i.e., river/reservoir, the possibility of conjunctive use of ground water to meet the demand of sowing, transplant ation/maturing of crops during low supplies/closure should be examined. This will, on occasion reduce the capacity of channels and save in construction cost and encourage the optimum utilisation of available water resources. This will incidently keep the rise of sub-soil water level within permissible limit and give more time for maintenance of distribution system.

(*vii*) *Quality of Cultivators and their Views of Irrigation*

Intelligent, hardworking cultivators would adapt themselves to irrigated cultivation, avail of its advantages and make economical, efficient use of water. The reverse would be the case if they are otherwise. This can make all the difference to the success or failure of an irrigation project.

After reconnaissance, all the information gathered should be carefully analysed. If the result indicates feasibility of the project, more detailed surveys and collection of data would then be carried out.

2.2 Detailed Survey

2.2.1 In settled areas the work of detailed investigations is very much facilitated with the help of revenue records and mouza maps which are available for each village. The following statistics of area for each village should be obtained from revenue records—total area of land, cultivated area, culturable waste, area of each crop grown in the last few years, and the area irrigated under existing arrangements from ponds and wells. This information, will be required in computing gross and culturable commanded areas and in determining the intensity of irrigation and the area to be irrigated.

2.2.2 *Crops and Crop Calendar*

After examining the records of existing cultivated areas and the crops, the proposed cropping pattern and crop calendar should be evolved considering the existing soil and climatic conditions in the area in consultation with the Agricultural Department.

Water requirement of each crop should be worked out by suitable methods like Penman's formula or by carrying out experiments considering the type of soil, temperature, rain fall in the area, etc. Net fortnightly water requirements are then worked out considering effective useful rain fall for each crop and the capacity of canal assessed on the peak demand.

2.2.3 The village settlement maps called "Shajra" maps are prepared at the time of settlement to the scale of 1:4000. These maps show the boundary and number of each field, location of inhabited areas, culturable and barren land, groves, tanks and a few other distinguishing features.

These sheets are then to be completed for topographical detail not available on them but essential for planning of an irrigation scheme. The first necessity is to mark out the contours after carrying out levelling in the area. The contours should preferably be at 0.5 m intervals. In other areas similar contoured plans to a scale of 1:15000 and a contour interval of 0.50 m will be prepared abinitio by usual methods of engineering survey—chain and compass or plane table as convenient,

2.2.4 The trial pits/augerholes at intervals of 500 m or at suitable intervals depending on the variation of soil strata along the canal alignment should be taken upto the designed bed level. The strata met with should be brought out alongwith the L-Section of the canal. Transmission losses should be estimated as per the strata met with in various reaches to arrive at realistic figure.

2.3 Channel Alignment

The distribution system should be economical from considerations of capital investment and cost of annual maintenance. It should provide adequate irrigation facilities to the areas under the command of channel. The following broad principles may be considered for the layout of distribution system.

(*i*) Water should be taken directly as far as possible to the area of the command, subject to pratical considerations of maximum permissible height of the bank filling and cutting. The alignment of the canals will have to be that which would result in the greatest saving of both captial and maintenance costs and also in the loss of head and transmission losses.

In an undulating country a straight alignment of canal for any length may not be possible as it would involve heavy filling and cutting resulting in both heavy capital and maintenance investments. The economically shortest route is to be kept in view which can be attained by an alignment (which could be arrived at by trial and error) between :

(*a*) A line strictly following the falling contour line where balanced filling and excavation is feasible.

(*b*) A straight line from head to tail in a rolling country involves heavy filling and deep cutting. In a flat country saving in loss of head through the straight alignment is an important factor. The transmission losses assume more significance in case of unlined canals than in case of lined canals.

(*ii*) An irrigation channel must run on a water shed or ridge and where that is not possible it should run as near a ridge as possible. In ridge position the canal will be able to command on both sides and will avoid interfering with natural drainage. Where the main canals are not aligned along the ridge, branch/distributaries could be aligned along subsidiary ridges which the canal would cross during its course.

(*iii*) The alignment of an irrigation channel/canal should be central in its command as far as possible and the length of the off-take canals should be minimum.

(*iv*) Water should be carried in bulk as far as possible and whenever the canal bifurcates the total wetted perimeter increases and results in greater losses. Generally, the cost of one canal is not proportionate to the capacity as the two channels are costlier than one for their combined capacities. Canals with a bigger capacity can be designed with a flatter slope and will be ultimately beneficial in a flat country.

(*v*) The drainage line should not be blocked as the canal itself may get damaged and result in flooding and water logging of the surrounding areas. When irrigation channel is on the ridge/water shed interference with drainage is avoided but if it is not located on ridge and it has to cross various drainage lines adequate provision to pass the drainage water safely across the channel is necessary.

(*vi*) In addition to the above, the following practical points should also be considered while fixing the alignment of canals.

(*a*) Proper location of cross drainage works is most important as the cost of C.D. Works in a canal system is a expensive item. The crossing should be located at places where the waterway is sufficient, the catchment is minimum, the foundations are good and the material of construction is available nearby.

(*b*) The alignment of canal should avoid difficult country, i.e., one having ridges, rocky, sandy and alkaline strata and also religious centres such as mosques, temples and burial grounds.

(*c*) When a canal passes near a village or an important town, it should pass on the lower side even at additional cost. In case it passes on the higher side of the town it should be at a considerable distance and may be lined as the seepage from canal may create difficulties.

Irrigation channels are generally aligned with reference to the contours of the country in one of the following different ways :

(*i*) as contour channels,

(*ii*) as Ridge channels, and

(*iii*) as side-slope channels.

2.3.1 *Contour Channels*

A contour channel is carried on an alignment which conforms generally to that of the contours of the country traversed by giving, such slope along its length as is necessary to produce the required velocity of flow. As the line of flow of surface drainage is at right angles to the ground contours such a channel cuts across the natural drainage lines of the country traversed. Such an alignment does not imply an exact conformation with the contours of the natural ground, as it is usual, when traversing undulating country which displays any marked natural features to shorten the line by crossing ridges in deeper cutting and valleys in higher bank than the general average. Thus, in such country a contour channel would be of shorter length than the corresponding falling contour laid out along the ground surface without taking any short cuts.

2.3.2 *Ridge Channels*

A ridge channel is one alignment along any natural watershed. There will clearly be no drainage crossing such a line. The watershed being the highest ridge in the doabs, water from a channel on the watershed can flow by gravity to fields on either side, directly or through some other irrigation channels.

The main canal has to take-off from the river, the lowest point in the cross-section, and it must mount the ridge or the highest point in the area in as short a distance as possible. This is possible because the canal requires much less bed slope than is usually available in the country near its head reaches. It is within this reach that all the important cross drainage works on the canal have to be constructed. In its head reaches a canal is also generally in heavy cutting and this combined with the C.D. works makes this portion of the canal very expensive. The alignment in this reach is to be determined by studying the various alternatives, and comparing the advantages and disadvantages and the costs of each.

2.3.3 *Side Slope Channels*

A side slope channel is one alignment at right angles to the contours of the country traversed and not on a watershed or valley line. Such a line would be parallel to natural run-off of drainage and thus such an alignment avoids intercepting cross-drainage.

2.4 The main aim of these arrangements of the layout of a distribution system is to secure in the most economical way effective water distribution combined with adequate command of the area to be irrigated with as little interference as possible with natural drainage. The above statement of aims at once suggest an alignment along any watershed within the irrigable area as securing command of all the ground upto the next valleys on either side of the alignment without any interference with drainage and it may be taken as axiomatic that the watersheds laying in any irrigated tract should be occupied by distribution channels unless there are strong reasons against such an arrangement. Side slope channels have the advantage of not intercepting cross-drainage but their course must follow the shortest route to the nearest valley and such channel will be along a line of steepest possible slope except in very flat areas. Only the smaller of the distributary channels should be so located. Contour channels are carried on slopes, the main watersheds of which are not commanded. Such channels with minor exceptions only irrigate on one side of them from the upper boundaries of the irrigated area.

One of the 3 ways of aligning the canal may be adopted but there may be situations in which it may be necessary to deviate the canal off the adopted course for short reaches. For example, the watershed or the contour might take a sharp loop between some points, the alignment may cut across "abadi", or a large number of drainages may cross the alignment. In the case of watershed or contour taking a sharp loop, by aligning the canals straight considerable length can be saved. It will, however, intercept the drainage of the pocket of land between the watershed and the canal, in such reaches. This drainage will either have to be passed across the canal by suitable C.D. work or the feasibility of diversion to adjacent catchment could be done to avoid the C.D. work. The alignment of canal may have to be diverted so as to bye-pass towns or villages located on them. Number of cross-drainage works may be reduced by shifting alignment as far as economically and technically feasible.

2.5 Curves

Curves in unlined canals shall be as gentle as possible as they lead to disturbance of flow and a tendency to silt on the inside and to scour on the outside of the curve. The curves are usually, simple circular curves. At the velocities, permissible in unlined channels, the super-elevation of water surface is very small. The situation will be different in lined channels where higher velocities are permissible. In any reach of a lined channel, with hyper-critical velocity, curves are best avoided; in case they have got to be provided, the water surface profile must be very carefully worked out.

As per I.S.I. recommendations, radii of curves should be usually 10 to 15 times the bed width subject to minimum given in Table I.

TABLE I

Radii of Curves for Canals

Unlined Canals		*Lined Canals*	
Discharge m^3/sec	*Radii Min.* *m*	*Discharge* m^3/sec	*Radii Min.* *m*
80 & above	1500	280 & above	900
Below 80 to 30	1000	Below 280 to 200	760
Below 30 to 15	600	Below 200 to 140	600
Below 15 to 3	300	Below 140 to 70	450
Below 3 to 0.3	150	Below 70 to 40	300
Less than 0.3	90		

Note : 1. The above radii are not applicable to unlined canals located in hilly reaches and in highly permeable soil.

2. On lined canals where the above radii cannot be provided, proper super-elevation shall be provided.

3. For navigation channels further modification may have to be made.

2.6 Transmission Losses

From the headworks where water enters the main canal to the outlet where it enters the watercourse there are continuous losses which have to be accounted for in the designs. These losses are quite considerable roughly forming 25 to 50 percent of the water diverted. There are losses in the water course and on the field also, but they are taken to be covered in the outlet discharge factor.

The losses in the canals take place on account of two causes: (1) evaporation and (2) seepage. The evaporation losses are usually a small proportion of the total losses in earthern channels and are generally neglected. The seepage loss is influenced by the nature and porosity of the soil; the depth, turbidity and temperature of water; the age and shape of the canal section; and the position of the ground water level. The seepage losses in unlined channels as suggested by Etcheverry and Harding are given in Table II.

TABLE II

Seepage Losses in Unlined Channel

Character of Material	*Seepage Loss Cumecs/million m^2 of wetted Perimeter*
Impervious clay loam	0.90 to 1.20
Medium clay loam under laid with hard pan at depth of not over 0.60 to 0.90m below level	1.20 to 1.80
Ordinary clay loam silt soil or lavash loam	1.80 to 2.70
Gravelly or sandy clay loam, cemented gravel, sand and clay	2.70 to 3.60
Sandy loam	3.60 to 5.20
Loose sandy soils	5.20 to 6.10
Gravelly sandy soils	7.00 to 8.80
Porous gravelly soil	8.80 to 10.70
Very gravelly soil	10.70 to 21.30

In the case of lined canals seepage losses may be assumed as 0.60 cumec/million m^2 of wetted perimeter.

2.7 Capacity and Design Statement

A capacity and design statement along with command statement should be drawn up for each channel to enable its L-Section to be prepared. Specimen forms for the above statements are given in Plates 1 and 2. For this purpose the locations of outlets and the boundaries of areas to be irrigated by each outlet should be marked on the contoured survey plan of the area showing the alignment of the channel and its irrigation boundary. The irrigation boundaries usually follow the drainage lines between two ridges. In marking the boundaries of irrigated areas, the following points should be kept in view:

(*i*) The area allotted to each outlet should not require more than 0.09 cumecs or less than 0.03 cumecs.

(*ii*) The length of main water course should not exceed 3 km.

(*iii*) Water course should not be required to cross natural drainages.

(*iv*) The crossing of national highways and roads should be avoided as far as possible.

The disadvantages of large sized outlets are:

(*i*) Cultivators find it difficult to manage or maintain the field channel.

(*ii*) Disputes arise due to greater number of shareholders on one outlet.

(*iii*) 'Warabandi' troubles arise particularly for shareholders of small holdings.

The disadvantages of small sized outlets are:

(*i*) There is greater loss of water by absorption. An outlet with 0.015 cumecs discharge may irrigate only 1/3rd the area irrigated by an outlet of 0.03 cumecs.

(*ii*) The cost is comparatively more owing to the greater number of outlets, V.R. Culverts and W.C. Culverts required.

(*iii*) Low velocity in water course causes silting up requiring frequent clearance.

(*iv*) Greater number of outlets cause trouble in distribution of water and regime of the channel.

Having marked the boundaries of the areas that could be irrigated by each outlet, the next step is to fix the intensity of irrigation. The intensity of irrigation is governed by the existing protection by well and pond irrigation, types of crops sown or likely to develop after introduction of canal irrigation, performance of existing channels in similar areas and quantities of water available,

"Duty" of canal water can be defined as the area irrigated by unit discharge which in metric units will mean the number of hectares irrigated by 1 cumec for the specific number of days called the base period for the duty. Duty for a channel is usually calculated on the head discharge. Duty based on discharge passed through the outlet and thus excluding all losses in the canal system, is called the outlet discharge factor.

2.8 Full Supply Level

The commanded and uncommanded area and the water levels required at the head of water courses or field channels and supply channels should be marked out. This is more a process of trial and error.

A good deal of judgement which can-be acquired by practice is required in fixing the water level at the head of water course and marking commanded areas which will neither pitch the F.S.L. in an irrigation channel unnecessarily high in an attempt to command isolated high patches, nor lower it too much at the cost of irrigation on which the whole success of the project depends. It has to be remembered that such high patches are levelled up in course of time by the cultivators themselves.

For determining the F.S.L. in a distributary channel, the water levels required at the head of water courses all along the length of channel should be plotted on the L-Section on which G.L. spring levels and other field information have already been plotted. The F.S. Line should thus be so marked at the predetermined slope, as to give a good average working head into the water courses. This procedure readily determines the location of falls on the distributary channel as well. The F.S.Ls. determined at distributary heads should similarly be plotted on the L-Sections of branch and main canals and their F.S. lines fixed in the same manner as for distributaries. If however, the consideration of balancing depth enables higher full supply to be fixed, it may have to be done. Usually, it is found sufficient to work at the command of offtaking channels upto the first fall, for the purpose of fixing F.S.Ls. in the main and branch canals. But, when there is a reverse slope in the country, the F.S.L. at the head should be determined after considering the command from head to tail.

In working out the F.S.Ls. in channels, the following working heads are usually allowed:

Head over field	0.075m
Slope in water course	1 in 5000
Min. working head from major distributary to a minor	0.30m
Min. working head at outlet	0.15m
Min. working head from branch to branch or to major distributary	0.50m
Min. working head from main canal	0.60m

A control point on a regulating bridge should be provided below the off take. A minimum working head of 0.075m should be allowed at these points.

2.9 Plotting of L-Section

(*a*) It is essential that an L-Section of channel showing all salient information observed in the field such as natural surface levels and sub-soil water levels, full supply levels, canal bed levels, water surface slopes, bed widths, free board, broad details of hydraulic data of outlets, regulators, bridges, drainage crossings, offtaking channels etc. and nature of soil where the canal is passing through by giving test pit or auger hole data at about 500 m intervals be prepared. For the L-Section a longitudinal scale of about 1:10,000 to 1:20,000 and vertical scale of about 1:100 are recommended. A specimen L-Section of canal is shown in Plate No. 3.

(*b*) While plotting L-Section designed discharge bed gradient, bed width, full supply depth should be indicated. Designed discharge should account for off take channel discharges and losses in canal. Water levels should be assessed after considering head losses in various structures, i.e., regulators, falls, bridges, C.D. works etc.

2.10 Structures in Canals

The following main types of structures will be required on a canal :

(*i*) Cross drainage works

(*ii*) Regulating structures

(*iii*) Communication structures/bridges.

The first two types of structures are more essential for the safety and maintenance of the canals and are usually provided on all canals irrespective of its capacity. The regulating structures could be useful in equitable distribution of water in the command area. Communication works are necessary to provide intercommunication in the command area lying on either side.

(*i*) *Cross Drainage Works* : Generally the alignment of the canals crosses the natural drainage valleys and provision has to be made to take the drains safely across the canal without damaging it. The usual kind of cross drainage works are :

(1) Super passage

(2) Drainage syphon

(3) Canal Syphon

(4) Level crossing

(5) Aqueduct.

In effect there are three ways of crossing of the drainage water and the canal.

(*a*) To pass the drainage over the irrigation channel, the bed level and the water level of the drain is higher than the canal. This type is named as a super passage.

(*b*) To pass the drainage into the irrigation channel so that the drainage and irrigation water mix up. This type is called a level crossing.

(*c*) To pass the drainage under the canal. This type is called a drainage syphon or a syphon aqueduct. The full supply level, the bed level of canal and the HFL and bed level of the drainage reach for the most suitable alignment of canal will determine the type of structures. The particular type to be adopted could further be determined by the magnitude of the flood discharge of the nallah and the design discharge of the canal.

(*ii*) *Regulating Structures* : These structures are required to maintain the level and the discharges at the designed figure. Some of the works may be automatic and some require regulation, establishment and manipulation. The Control could be from upstream or by downstream, i.e., "Demand Management".

The usual types of structures include :

(*a*) Falls

(*b*) Cross regulator

(*c*) Head regulator of distributaries/minors

(*d*) Escapes

(*e*) Outlets for water courses

(*f*) Silt ejectors.

Falls are provided in a canal when the fall of the terrain is more than that of the canal and the water level becomes in excess of the level required in the canal to reduce maximum permissible velocity and earth work. This structure dissipates the excess energy and the filling reach is minimised.

Cross regulators are required to maintain the full supply level in the canal. These are provided at intervals across the canal and below major off-take points so that when the canal is running at less than full supply discharge water can be raised to feed the off-take canal/channel to take its authorised discharge at design full or part supply levels.

Head regulators are provided for regulating the discharges to feed the distributaries.

Escapes are provided for discharging the excess water out of the canal during periods of low demand in the command. They are generally provided upstream of cross regulators near a natural valley so as to release the water from the canal and avoid flooding in the command area during flood/rainy season.

Outlets for water courses are provided from minors and distributaries according to the demand in the command. Canals taking off from the head works generally carry silt along with water. The silt load and size of silt requires critical examination. In case silt is of coarse or medium coarse, this gets deposited in the canal and reduces its capacity. Medium coarse and coarse silt is also harmful for fields in case this finds its way to the fields through the water courses. Power channels also need to consider the safe silt size permitted for the turbines. Silt ejectors are provided in the head reach so as to remove the silt to permissible limits to save the canal from silting and fields/irrigated areas from losing the fertility. Silt ejectors are provided in power channels to eject the silt from water to save turbines from getting damaged.

(*iii*) *Communication Works* : These are mostly road bridges and are provided for all existing and future anticipated roads to provide communications facility in the command area. In addition to this some more road bridges are also provided so as to provide communication facilities to towns and villages. These are generally provided at interval of about 6 km. But in case of distributaries, road bridges are generally provided at intervals of 2 to 3 km depending on local conditions to facilitate the movement of material and people.

COMMAND STATEMENT
OF

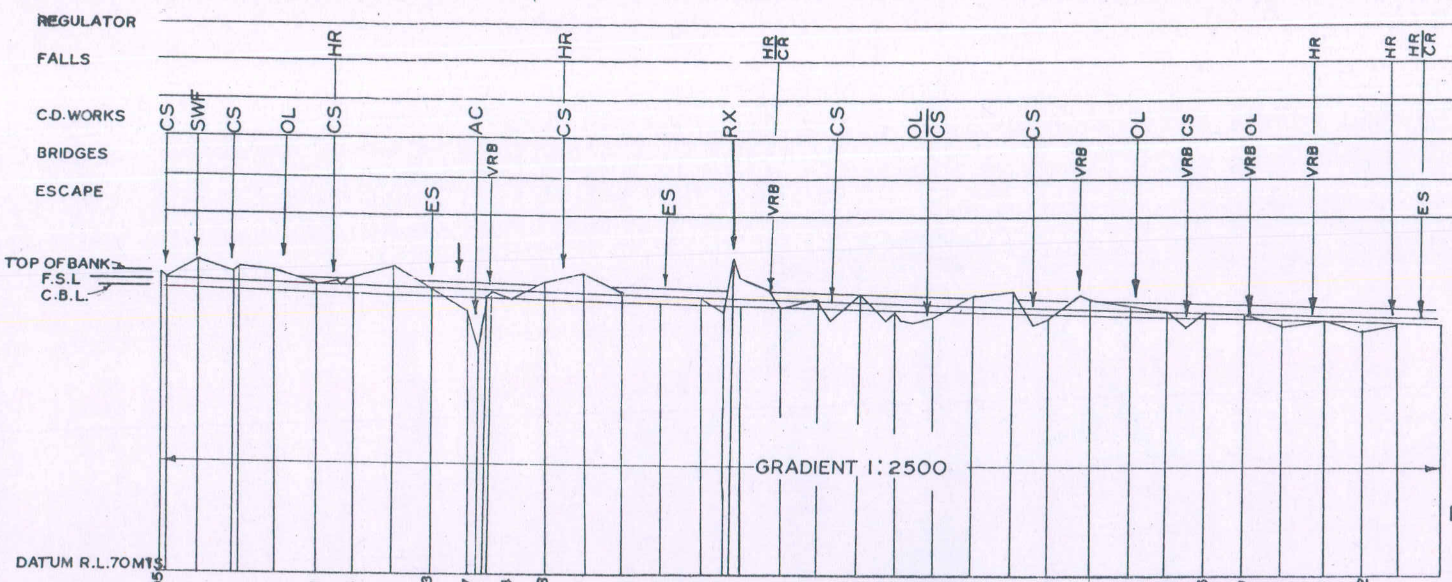
SL. NO.	R.D. OF AN OFF TAKE OR OUTLET	CRITICAL POINT IN N.S.	DISTANCE FROM CRITICAL POINT TO HEAD OF OUTLET	LOSS OF HEAD	DEPTH OVER FIELD	WATER LEVEL AT HEAD OF OUTLET (COLUMN 3+5+6)	F.S.L. IN THE CHANNEL	WORKING HEAD (COLUMN 8-7)	REMARKS
1	2	3	4	5	6	7	8	9	10

PLATE NO. 1: COMMAND STATEMENT FORM

CAPACITY & DESIGN STATEMENT
OF

SL. NO.	BELOW KM.	R.D. OF AN OFF TAKE OR OUTLET	GROSS AREA (G.A.) (HECT.)	GROSS COMMANDED AREA (G.C.A.) (HECT.)	CULTURAL COMMANDED AREA (C.C.A.) (HECT.)	AREA TO BE IRRIGATED			OUTLET DISCHARGE FACTOR	OULET DISCHARGE IN CUMECS	LOSSES IN REACH	TOTAL LOSSES	TOTAL DISCHARGE	CHANNEL DIMENSIONS								VELOCITY IN M/SEC.	REMARKS
						RABI (HECT.)	SUGAR	RICE						BED SLOPE	BED WIDTH	FULL SUPPLY DEPTH	FULL SUPPLY LEVEL	BED LEVEL	DESIGN DISCHARGE	LACEY'S 'f' OR n	HT. OF BANK		
	1	2	3	4	5	6			7	8	9	10	11	12	13	14	15	16	17	18	19	20	

PLATE NO. 2: CAPACITY & DESIGN STATEMENT



CHAINAGE IN MTS.	GROUND LEVEL	C.B.L.	F.S.L.	CUTTING	EMBANKMENT	TOP OF BANK
0	93.26	92.15	92.65	1.135		93.05
150	93.53	92.09	92.59	1.435		
300	93.24	91.98	92.48	1.255		
450	92.86	91.92	92.42	0.955		
600	91.93	91.86	92.36	0.065	0.885	92.81
750	92.57	91.80	92.30	0.765	0.189	91.75
900	93.31	91.74	92.24	1.559		
1050	91.00	91.68	92.16	0.115	0.835	92.63
1200	99.95	91.62	92.12		2.625	92.57
1350	90.97	91.39	91.59		1.375	92.34
1500	92.13	91.33	91.83	0.795	0.153	92.28
1650	92.77	91.22	91.72	1.547		92.19
1800	91.46	91.16	91.66	0.297	0.608	91.11
1950	91.41	91.10	91.50	0.307	0.596	91.05
2100	91.15	91.04	91.54	0.197	0.843	91.99
2250	92.85	90.88	91.38	3.607		
2400	90.34	90.77	91.22		1.36	91.67
2550	91.06	90.71	91.16	0.347	0.503	91.61
2700	91.33	90.55	91.00	0.777	0.123	91.45
2850	90.47	90.49	90.94		0.923	91.39
3000	89.89	90.33	90.78		1.413	91.23
3150	91.50	90.27	90.72	1.227		91.17
3300	91.57	90.21	90.66	1.351		91.11
3450	89.68	90.05	90.50		1.273	99.95
3600	91.17	89.94	90.39	1.027		
3750	90.74	89.88	90.33	0.857	0.043	90.78
3900	90.41	89.82	90.27	0.587	0.317	90.72
4050	90.19	89.66	90.11	0.827	0.755	90.56
4200	90.14	89.60	89.05	0.587	0.313	90.50
4350	89.21	89.49	89.24		1.193	90.39
4500	89.65	89.38	89.83	0.217	0.683	90.28
4650	88.94	89.30	89.77		1.283	90.22
4800	89.22	89.26	89.71		0.943	90.16
4950	88.76	89.20	89.65		1.343	90.10

REFERENCES:-

H.R. .... HEAD REGULATOR
C.R. .... CROSS REGULATOR
C.F. .... CANAL FALL
C.S. .... CANAL SYPHON
S.W.F. .... STANDING WAVE FLUME
E.S. .... ESCAPE
A.C. .... AQUEDUCT
V.R.B. .... VILLAGE ROAD BRIDGE
R.X. .... RAILWAY XING
O.L. .... OUT LET

PLATE NO. 3: L-SECTION OF MAIN CANAL

SCALE:- HOR = 1:15000
VER. = 1:300

CHAPTER III

Design of Unlined Canals

3.1 General

The flow of water specially in earthern channels presents a complicated problem, which cannot be solved with mathematical precision. The unlined channel is an open channel excavated and shaped to the required cross-section in natural earth or fill, without special treatment to the sub-grade. Where a channel is constructed partly or entirely in fill or in natural earth of unstable characteristics it may become necessary to prevent seepage and percolation by compacting the sub-grade.

The motive force of flowing water in open channels is entirely due to the slopes of the channel. The water flows from higher to a lower point by virtue of gravity. The flowing water has to overcome the resistance in the channel caused by numerous factors such as surface tension, atmospheric pressure at surface and friction at side and bottom of the channel. The friction on the channel section depends on the material forming the wetted perimeter, the irregularity of the wetted perimeter, variation in the size and shape of the cross-sections, curves, weeds and various kinds of growth, scouring, silting, suspended material and the bed load. In practice the resultant of all these forces is expressed by a coefficient of roughness determined by experiments.

3.2 Flow Characteristics of Open Channels

The discharge passing in an open channel is expressed by the continuity formula :

$$Q = A \times V$$

where,

Q = Discharge in cumecs

A = Cross-sectional area in sq m

V = Mean velocity of flow in m/sec

The mean velocity is given by the Chezy's formula;

$$V = C\sqrt{R.S}$$

where,

C = a co-efficient

R = Hydraulic mean radius in m

S = Sine of slope of water surface

This is a practical and fundamental formula for the uniform flow of water in open channels and it is the basis of all modern velocity formulae. Since coefficient 'C' represents the retarding influences various investigators have determined its value on the basis of experiments and observed data. The most widely used values of 'C' are given by :

(*a*) *Kutter's Formula*

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

where,

N = Rugosity coefficient.

The values of 'N' as recommended by I.S.I. are given in Table III.

For some conditions value of 'C' from Kutter's formula are given in Plates 4 and 5.

(*b*) *Manning's Formula*

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

The Chezy's 'C' and Manning's 'n' are related by the Equation :

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

In normal ranges of slopes and hydraulic mean radius the values of Manning's 'n' and Kutter's "N" generally seem to be numerically very close for practical purposes.

(*c*) *Bazin's Formula*

$$C = \frac{87}{1 + \frac{M}{\sqrt{R}}}$$

TABLE III

Values of Rugosity Coefficient (n) for Unlined Canals

Sl. No.	Type of Canal	Value of '*N*' Min.	Normal	Max.
1.	*Earth, straight and uniform*			
	(*a*) Clean, recently completed	0.016	0.018	0.020
	(*b*) Clear, after weathering	0.018	0.022	0.025
	(*c*) Gravel, uniform section, clean	0.022	0.025	0.030
	(*d*) With short grass, few weeds	0.022	0.027	0.033
2.	*Earth, winding and sluggish*			
	(*a*) No vegetation	0.023	0.025	0.030
	(*b*) Grass, some weeds	0.025	0.030	0.033
	(*c*) Dense weeds or aquatic plants in deep channels	0.030	0.035	0.035
	(*d*) Earth bottom and rubble sides	0.030	0.035	0.040
	(*e*) Stony bottom and weedy banks	0.025	0.035	0 040
	(*f*) Cobble bottom and clear sides	0.030	0.040	0.050
3.	*Dragline excavated or dredged*			
	(*a*) No Vegetation	0.025	0.028	0.033
	(*b*) Light brush on banks	0.035	0.050	0.060
4.	*Channels not maintained (Weeds and brush uncut)*			
	(*a*) Dense weeds, high as flow depth	0.050	0.080	0.120
	(*b*) Clean bottom, brush on sides	0.040	0.050	0.080
	(*c*) Same, highest stage of flow	0.045	0.070	0.110
	(*d*) Dense brush, high stage	0.080	0.100	0.140

Where '*M*' is the roughness coefficient. The value of "*M*" for various surfaces are as below :

Type of Channel	*Bazin's M*
Smooth plaster, planed timber	0.06
Timber, ashlar, neat brickwork	0.16
Rubble masonry	0·46
Plaster, very smooth earth	0.85
Earth channels in usual conditions	1.30
Earth channels in bad conditions	1.75

The values of "*C*" as per Bazin's formula are given in Plate 6.

3.3 Stable Channel

A stable channel may be defined as one in which neither scouring nor silting takes place. A satisfactory design of stable channel depends largely upon the experience and judgement of the designer. An attempt has, therefore, been made by investigators to obtain a critical velocity of flow at which there will be neither scouring nor silting. Formulae that have been proposed for stable conditions of the channel express either a relationship between the C.V. and depth of flow or the relationships between the width of channel and depth of flow. The various formulae available for design of stable channels are given below :

(*a*) *Kennedy Formula*

The general form of equation based on the observation on stable channels is :

$$V_0 = C^m . D^n$$

where

V_0 = Critical velocity in m/sec (Non-silting and Non-scouring)

D = Depth of flow in metres

m = Critical velocity ratio

C and n = Constants

Mr. R.G. Kennedy made his observations on the Upper Bari Doab Canal system, one of the oldest in the Punjab. On this system he selected a number of sites on various channels which had not required any silt clearance for the last thirty years and were thus considered stable. By plotting his observations of velocity and depth on stable reaches, Kennedy obtained his well known equation.

$$V_o = 0.55\ D^{0.64}$$

This equation is applicable to channels flowing in sandy silt of the same grade as that which exists on the Upper Bari Doab canal system on which the observations were made. Kennedy later recognised that the grade of silt played a part in this relationship and introduced another factor in the equation, called by him as "the critical velocity ratio" and given the symbol 'm'. The equation was then written as

$$V = 0.84\ m\ D^{0.64}$$

Sands coarser than the standard were assigned values of m from 1.1 to 1.2 and those finer from 0.9 to 0.8. Kennedy made no correlation between water surface slope of regime channels and the mean velocity or the vertical depth. He relied on Kutter's equation to give slopes to the channels.

The values of V_o for different depths are shown in Plate No.7

The following equations were obtained by observations at other places :

$V = 0.391\ D^{0.55}$	Godavari Delta
$V = 0.53\ D^{0.52}$	Krishna Western Delta
$V = 0.567\ D^{0.57}$	Lower Chenab Canal
$V = 0.283\ D^{0.73}$	Egyptian Canals

A general feature of these formulae was that the value of 'C' was proportional to the size of the bed material.

In actual practice, the design can be carried out with the help of Garret's diagrams which provide a graphical solution of Kennedy's and Kutter's equations. Garrets diagrams are given in Plate Nos. 8 and 9. The procedure for their use is as follows :

(*i*) Follow the given discharge curve till it meets the given horizontal slope line and mark off their point of inter-sections.

(*ii*) Draw a vertical line through the point of intersection. This will intersect several bed width curves.

(*iii*) Choose the point of intersection of the vertical line on any bed width and read the corresponding value of water depth (D), and critical velocity V_o, on the right hand ordinate.

(*iv*) Calculate the actual velocity of flow (V) for the chosen bed width and the corresponding value of the water depth.

(*v*) Determine the critical velocity ratio 'm' $\left(\frac{V}{V_o}\right)$ taking V as calculated and V_o as read.

(*vi*) If the value of V/V_0 is not the same as given, repeat the procedure with other values of the bed width till the C.V.R. approximates to the given value.

These diagrams are drawn for side slopes of ½:1 on the assumption that irrigation channels after some time acquire this slope due to silt deposition on the berms, irrespective of the initial side slope provided. These curves are drawn for $N = 0.0225$. They can also be utilized for any value of N with the help of a monogram provided at the top of the curves. When using for any other value of N, the vertical line drawn at the intersection of the discharge and slope line has to be shifted, either to the left or to the right side to the extent given in the monogram. Further procedure for determining bed width and depth remains unaltered.

(*b*) *Lacey's Formula*

Lacey used Kennedy's data and substituted 'F' "Lacey's silt factor" for 'm' and found that 'f' worked out to be square root of the critical velocity ratio $\left(\frac{V}{V_0}\right)$ for velocities not exceeding more than 1m/sec and if the hydraulic mean radius 'R' is substituted for 'D' the variation in exponent as found on the different canal system disappears. The concept of 'R' in place of 'D' by Lacey, according to him, is because eddies which keep the silt in suspension are generated from bed and sides both normal to the surfaces of generation and not from bed only as stated by Kennedy. He,therefore, assumed that hydraulic mean radius (R) as variable. However, it has been observed that there is hardly any difference in values of R & D in wide channels. On the basis of the above arguments Lacey derived a set of equations by plotting mean values of observed data.

$$V = 0.639\sqrt{fR} \qquad \ldots(i)$$

$$Af^2 = 141.24\ V^5 \qquad \ldots(ii)$$

where,

A = Area of the channel section in m^2

V = Velocity of flow in m/sec.

f = Lacey's silt factor.

Lacey's regime flow equation is

$$V = 10.8\, R^{2/3} S^{1/3} \quad ...(iii)$$

From the above equations (*i*) and (*ii*) he derived perimeter—discharge relation :

$$P = 4.825\sqrt{Q}$$

where,

P is wetted perimeter in m

Q is discharge in cumecs

From this equation it was thus established that wetted perimeter of a channel in regime was dependent on the discharge only and was independent of the grade of silt denoted by 'f'.

From these equations a number of other important relationships have been obtained which are given below :

$$S = \frac{f^{5/3}}{3316\,Q^{1/6}} \quad ...(iv)$$

$$V = 0.4382(Q f^2)^{1/6} \quad ...(v)$$

$$R = 0.47\left(\frac{Q}{f}\right)^{1/2}$$

or

$$1.35\left(\frac{q^2}{f}\right)^{1/3} \quad ...(vi)$$

$$A = 2.28\,\frac{q^{5/6}}{f^{1/2}} \quad ...(vii)$$

Silt Factor 'f'

According to Lacey, the silt factor 'f' will be dependent on the average size of boundary material in the channel and its density. Its value varies as the square root of the mean diameter of the particles.

$$f = 1.76\sqrt{m_r}$$

where,

m_r = average size of particles in mm.

Designs based on the Lacey's equations can be solved with the help of graphs in plates 10, 11, 12 and 13 representing graphically the equations.

3.4 Selection of Method of Design

From the designer's view point, the whole of India can broadly be divided into two regions, the northern states of India comprising of the Punjab, Haryana, U.P., Bihar, West Bengal, Rajasthan and some parts of M.P. where canals draw their supplies from rivers carrying heavily sediment laden water. These canals carry sediment similar to that forming their bed and banks. On the other hand, the canals in South India though not devoid of sediment, carry much lesser sediment and the boundary material of canal section is dissimilar to the sediment in transport. On the basis of above dissimilarity the following practices of design are recommended :

(*i*) For channels taking off from reservoirs carrying silt free water and flowing through hard soils or disintegrated or fresh rock, it appears quite desirable from the point of view of economy to design the channel for as high a velocity as the soil can withstand without erosion, consistent with the slope available from the command point of view and economies of the channel section. Too steep a slope should normally be avoided. Lacey's design is generally not applicable to design of such channels. The permissible velocity should first be fixed and the channel section should be determined from Chezy's formula with Kutter's value of C & N. The Kennedy or Garrets' diagrams may be used to facilitate designs and avoid calculations by trial and error method.

Different sections are possible depending upon the choice of depth. The channel section should be deep and narrow particularly for small channels like distributaries and minors. Practical bed width-depth ratios as given in para 3.5 may be used for general guidance. Departure may however, be made where found necessary to provide shallow and wide section to avoid cutting in hard soil below the ground. The criteria of balancing depth may not be desirable to be adhered to in such cases.

(*ii*) For the canals carrying heavily sediment laden water the design practice are mostly based on the Lacey's and Kennedy's formula. Lacey's method of design should be used for design of new channels flowing through alluvial soils. Greatest care should be excercised in selecting the value of 'f'. The section may then be determined either by calculations as illustrated in the example in Appendix-II or read from Lacey's diagram. It should be examined to see that the mean velocity is neither too high nor too low for the type of the soil along the alignment of the channels. If necessary, the value of 'f' may be correlated to the Kennedy's *C V.R.* Lacey's design cannot, however, be used for silt bearing channels carrying low discharges, the limit of which is given by the straight line on the left side of Plate-9 beyond which the discharge curves are discontinued. In such cases water surface slope may be worked from Lacey's equations and dimensions determined from Kutter's formula. This method is also usually adopted for design of channels with low silt factor in cohesive soils.

(*iii*) In case of existing channels requiring remodelling which have not been originally designed with Lacey's equation, it will not generally be found convenient and economical to adopt Lacey's design. Lacey-cum-Kutter or Kennedy-cum-Kutter formula may be used.

3.5 Bed Width-Depth Ratio

Problem of selecting a section often arises in case of channels or reaches of channels in which more than one water surface slope can be adopted without affecting the command. This results in more than one section with different bed-width-depth ratios for the same discharge, value of n and critical velocity ratio as may be seen from the Table IV.

TABLE IV

Q (Cumecs)	n	CVR	Slope per 1000	Bed width m	F.S. Depth m
28 317	0.0225	1.0	0.22	9.75	2.53
28.317	0.0225	1.0	0.20	12.04	2.30
28.317	0.0225	1.0	0.18	16.15	1.98
28.317	0.0225	1.0	0.16	28.96	1.42

The same difficulty has been experienced in channels taking off from reservoirs and carrying relatively silt free water. The CVR is not the dominant factor in such cases and the channel may be designed for permissible velocity which the soil can stand without scouring.

According to Ellis the best channel section for the same cross-section area and slope, posses water at maximum velocity with greatest hydraulic mean radius. For any trapezoidal channel of fixed sectional area (A), if 'r' is the ratio of horizontal to vertical of the side slopes and 'S' is the length of the two side slopes per unit depth which equals $2\sqrt{r^2+1}$ and 'M' is the ratio of bed width to depth.

$$\text{Hydraulic Mean Radius } (R) = \sqrt{\frac{M+r}{M+s}}\sqrt{A}$$

and it is maximum when $M = S - 2r$

Accordingly for a channel of side slope $\frac{1}{2}$: 1, for the best discharging section, the value of M works out to be 1.23^6 or say $M = 1\frac{1}{4}$.

For least absorption, M works out to be 4. Ellis also stated that in case of all sizes of channels in which the relationship of velocity to depth is given by Kennedy's equations, the absorption is minimum for values of M between 1.5 and 3.2. For values of M varying from 1.2 to 5 the loss due to absorption is never more than 5 per cent in excess of minimum.

The experience of the working of irrigation channels in alluvial soil has however, shown the existence of certain bed-width-depth ratio depending upon the discharge or in other words size of channel. The Kennedy depth formula gives maximum depth that can be allowed in an earthen open channel. As for example, a channel situated in a soil which can stand mean scouring velocity of 1 m/sec. cannot have full supply depths of more than 2.56 metres as may be seen from Plate No. 7 This however, has no relationship with the shape of channel i.e. bed-width-depth ratio. Whenever therefore, there is a free choice for selecting dimensions of bed width and depth the ratios which may be obtained from Plate No. 14 may generally be used for guidance.

3.6 Most Efficient Cross-Section

Considering purely from the stand point of hydraulics of a channel, the most efficient cross sections is the one which with a given slope and area has the maximum carrying capacity. Chezy's formula indicates that for a given water surface slope, the velocity and consequently, the discharging capacity of the section is maximum when the hydraulic mean radius (R) is maximum. The maximum R is given by the circular section. Since channel in earth have usually trapezoidal section, maximum R is given by half hexagonal described about the semi circle with its centre at the water surface. Such a section however, requires great depths for larger discharges. The velocity induced in such section may also become so great as to cause erosion of the sides and scour in the bed of the channel. The non-scouring mean velocities as recommended by various authorities including CWPRS, Pune are given below :

(1)	Very light, loose sand to average sandy soil.	0.3 to 0.6 m/sec.
(2)	Sandy loam, black cotton soil & similar soil.	0.6 to 0.9 m/sec.
(3)	Ordinary soils.	0.6 to 0.9 m/sec.
(4)	Firm loam, clay loam, alluvial soil, soft clay and murum.	0.9 to 1.1 m/sec.
(5)	Hard clay or grit.	1.0 to 1.5 m/sec.
(6)	Gravel and shingle.	1.5 to 1.8 m/sec.
(7)	Cemented gravel conglomite, hard pan.	1.8 to 2.4 m/sec.
(8)	Soft rock.	1.4 to 2.4 m/sec.
(9)	Hard rock.	2.4 to 3.7 m/sec.
(10)	Very hard rock or cement concrete.	4.5 to 7.6 m/sec.

3.7 Side Slopes

The side slopes to be adopted depend upon the nature of the soil in which the channel is to be excavated, depth of cutting and height of embankment and shall be designed with the following conditions, in alluvial soils.

(*a*) Sudden draw down conditions for inner slopes.

(*b*) The canal running full with plenty of rainfall for outer slopes.

The minimum slopes usually allowed are given in Table V

TABLE V

Minimum Side Slopes of Channels

Sl. No.	Type of Soil	Side slopes	
1.	Very light loose sand to average sandy soil.	1.5:1 to 2:1 2:1 to 3:1	(cutting) (embankment)
2.	Sandy loam, loamy soil and similar soils	1:1 to 1.5:1 2:1	(cutting) (embankment)
3.	Sandy soil or gravel.	1:1 to 2:1	
4.	Murum, hard soil etc.	0.75:1 to 1.5:1	
5.	Rock	0.25:1 to 0.5:1	

The slopes given above are suitable for average height upto 3 metres. For greater heights, it is preferable to provide ledges 1.5 to 3 m wide at intervals of 3 m instead of flattening the slopes. The latter method is, however, slightly economical.

In alluvial and sandy soils the side slopes in cutting genrally assume side slopes of ½ : 1 on silting up, in course of time. This slope is therefore, assumed in designing the section for computation of hydraulic mean radius, area and perimeter even though in execution actually flatter slopes are adopted.

In hard clays and rocky soils, however, it is not necessary to follow the above practice. The side slope actually provided in excavation may be taken into account for working out the sectional area of channel.

3.8 Free Board

Free board in general will be governed by consideration of the following aspects:

(*i*) Soil Characteristics.

(*ii*) Size of canal and its locations.

(*iii*) Hydraulic gradient.

(*iv*) Water surface fluctuations.

(*v*) Percolation.

(*vi*) Service road requirements.

According to U.S. Bureau of Reclamation practices free board may be determined by the formula:

$$F = \frac{1}{1.812} \times \sqrt{C.D}$$

where, F= Free board in metres.
C= Coefficient.
D= Depth of water in canal in metres.

The coefficient 'C' varies linearly from 1.5 where the canal capacity is 0.7 cumecs to 2.5 for canal of 85 cumecs or more. However, greater free boards and bank heights than those within these ranges may be used in exceptional circumstances.

As per I.S.I. recommendations a minimum free board of 0.50 m for discharges less than 10 cumecs and 0.75 m for discharges greater than 10 cumecs is to be provided. The free board shall be measured from the F.S.L. to the level of the top of bank. The height of dowel portion should not be used for free board purposes. It is observed that the free-board given by the formula of U.S.B R. is very much higher than those recommended by I.S.I.

3.9 Bank Top Width

The minimum values adopted for top width of the banks are as follows :

Discharge (cumec)	Minimum Bank top width Inspection Bank (m)	Non-inspection (m)
0.15 to 7.5	5 0	1.5
7.5 to 10.0	5.0	2.5
10.0 to 15.0	6.0	2.5
15.0 to 30.0	7.0	3.5
30 and above.	8 0	5.0

Width different than those recommended above may be used when justified by specific conditions. For distributary canals carrying less than 1.5 cumecs and minor canals, it is generally not economical to construct a service road on top of bank as this usually requires more materials than the excavation provides. In such cases, service road may be provided on natural ground surface adjacent to the bank. However, the importance of providing adequate service roads where they are needed should always be kept in view.

The banks should invariably cover the hydraulic gradient. The width of the non-inspection bank should be checked to see that cover for hydraulic gradient is provided.

3.10 Berms

Berm is a horizontal space initially left at ground level between the toe of bank and excavation. The principal objectives for providing berms are:

(*a*) To provide wider waterway above F.S.L. to limit the height of rise of water at the time of positive fluctuations.

(*b*) To afford less pervious silt lining on the sides of the silt carrying channels to decrease absorption losses.

(*c*) To recede the banks away from the direct action of water to prevent breaches.

(*d*) To provide a scope for future widening of canal.

(*e*) To provide space for borrowing earth during construction at times of necessity and later on for maintenance when the berms are formed.

(*f*) To break the flow of rain water down the bank slope. Berms are to be provided in all cuttings, when the depth of cutting is more than 3 m. Where a canal is constructed in a deep through cut requiring waste banks, berms should be provided between the canal section cut and the waste bank.

The following practice is recommended:

(*i*) When the F.S.L. is above G.L. but the bed is below G.L., that is, the canal is partly in cutting and partly in filling, berm may be kept at N.S.L. equal to 2D in width where, D is F.S.D.

(*ii*) When the F.S.L. and the C.B.L. are both above the G.L. that is, the canal is in filling, the berm may be kept at the F.S.L. equal to 3D in width.

(*iii*) When the F.S.L. is below G.L., that is the canal is completely in cutting, the berm may be kept at the F.S.L. equal to 2D in width. In embankments, adequate berm may be provided so as to retain the minimum cover over the hydraulic grade line.

3.11 Cover

For a channel running in embankment. the percolation line through the bank though actually curved, is assumed straight and sloping at 1:4 to 1:6 gradient depending upon the bank material. It is taken for ordinary loamy soil as 1:6, average clayey soil 1:5 and good clayey soil 1:4. A soil having hydraulic gradient flatter than 1:6 is not suitable for canal banks. When the height of bank is such that percolation line intersects the outer slope above G.L., an extra layer of earth is put to provide a minimum cover of 0.30 m. The surface of this cover is either kept parallel to the hydraulic gradient or is in horizontal steps.

For embankments more than 5 m height, the true position of saturation line shall be worked out and stability of slope should be checked as in earth dams.

3.12 Dowels

Dowel is generally constructed on the inner side of the bank, while in those places, where rains are heavy, dowels are provided on both sides of the bank to prevent their cutting. Water is then led out at intervals through artificial gutters. The height of the dowel is generally kept 0.5 m with side slopes 1.5:1 and top width as 0.5 m.

Typical cross-sections of unlined canal are shown in Plate 15.

Some typical examples of design of unlined canal are given in Appendix-I

APPENDIX-I

Example I

Design of Channel section by Kennedy, Chezy & Kutter formulae.

DATA

$Q = 30$ cumecs
$N = 0.02$
$S = 1/8000$
Side Slope $\frac{1}{2} : 1$

DESIGN

Against $Q = 30$ cumecs the value of b/d ratio from curve from plate No. 12 works out $= 7.5$

Let the depth of channel $= 2.15$ m

$b = 2.15 \times 7.5 = 16.125\ m =$ say 16.0 m

Area $= (16+1.08)\times 2.15 = 36.72\ m^2$

$Pw = 16+4.81 = 20.81$ m

$$R = \frac{A}{Pw} = \frac{36.72}{20.81} = 1.76 \text{ m}$$

$$C = \frac{23+\frac{1}{N}+\left(\frac{0.00155}{S}\right)}{1+\left(\frac{23+00155}{S}\right)\times\frac{N}{\sqrt{R}}}$$

$$= \frac{23+\frac{1}{0.020}+0.00155\times 8000}{1+(23+.00155\times 8000)\times\frac{0.02}{\sqrt{126}}}$$

$$= \frac{23+50+12.40}{1+(23+12.40)\times\frac{0.02}{1.33}}$$

$$\frac{85.40}{1.532} = 55.8$$

$V = C\sqrt{RS}$

$= 55.8 \times \sqrt{1.76\times 1/8000}$

$= \frac{55\ 8\times 1.33}{89.4} = 0.84$ m/sec.

$Q = A\times V = 36.72\ 0.840 = 30.84$ cumecs

Critical velocity $= 0.55\ D\ 0.64$

$= 0.58\times 2.15^{0.64}$

$= 0.90$ m/sec

$C.V.R. = \frac{0.84}{0.90} = 0.93$ *O.K.*

Example II

Design of channel section for 30 cumecs discharge using Lacey's formulae.

DATA

$Q = 30$ cumecs
$f = 1.0$
Side slopes $= \frac{1}{2} : 1$

DESIGN

$$R = 0.47 \times \left(\frac{Q}{f}\right)^{1/3}$$

$$= 0.47 \times \left(\frac{30}{1}\right)^{1/3}$$

$= 1.46$ m

Pw or $P = 4.825\sqrt{Q}$

$= 4.825\sqrt{30} = 26.43$ m

$$D = \frac{Pw - \sqrt{Pw^2 - 6.944\ RPw}}{3.472}$$

$$= \frac{26.43 - \sqrt{698.54 - 6.944\times 1.46\times 26.43}}{3.472} = 1.64 \text{ m}$$

$B = Pw - 2.236\ D$

$= 26.43 - 2.236 \times 1.64 = 22.76$ say 22.8

$$S = \frac{f\ 5/3}{3316\ \ Q1/6} = \frac{1}{3316\times(30)1/6}$$

$$= \frac{1}{3316\times 1.76}$$

$= \frac{1}{5836}$ i.e. 17 cm/km

$$V = \left(\frac{Qf2}{140}\right)^{1/6} = 0.77 \text{m/sec.}$$

Example III

Design of channel sections for 30 cumecs discharge using Garrett's diagram

DATA

$Q = 30$ cumecs
Side slope $= \frac{1}{2} : 1$
Longitudinal slope $= 1/8000$ or 12.5 cm/km
$N = 0.02$

From Garrett's diagram

$B = 16$ m
$D = 2.15$ m
$Vo = 0.9$ m/sec.

SLOPE = ·0002 PER UNIT OF LENGTH, = 1 IN 5000.

MEAN RAD-R METRES	.009	.010	.011	.012	.013	.015	.017	.020	.025	.030	.035	.040	MEAN RAD-R METRES
.025	52	45	40	35	31	25	21	17	12	9	8	6	.025
.050	63	55	48	43	39	32	27	21	16	12	10	8	.050
.1	75	66	59	53	48	40	34	27	21	16	13	11	.1
.2	87	77	69	62	57	48	41	34	26	21	17	15	.2
.4	99	88	80	72	68	57	49	41	32	26	22	19	.4
.6	104	93	84	77	71	61	53	45	36	29	25	22	.6
1	111	100	90	83	77	67	59	50	40	33	28	25	1
2	118	107	98	90	84	74	65	56	46	39	34	30	2
4	124	113	104	97	90	79	71	62	51	44	39	35	4
10	130	119	110	102	96	85	77	67	57	50	45	40	10
30	135	124	114	107	100	90	82	73	62	55	50	46	30

SLOPE = .0004 PER UNIT OF LENGTH, = 1 IN 2500.

.025	55	47	41	37	33	27	22	17	13	10	8	7	.025
.050	66	58	51	45	40	33	28	23	17	13	11	9	.050
.1	78	68	61	55	50	42	35	28	21	17	14	12	.1
.2	90	80	70	64	59	49	42	35	27	22	18	15	.2
.3	95	85	76	70	63	54	47	39	30	24	21	17	.3
.4	99	89	80	73	67	57	50	42	32	27	22	20	.4
.6	105	94	85	78	72	62	54	45	36	30	25	22	.6
1	111	100	90	83	77	67	59	50	40	33	28	25	1
2	117	106	97	89	83	73	65	56	45	38	34	30	2
4	123	111	102	95	88	78	70	61	50	43	38	34	4
6	125	114	105	97	91	81	72	63	53	46	40	36	6
10	128	117	108	100	93	83	75	66	55	48	43	39	10
30	132	121	112	104	98	87	79	70	60	52	48	43	30

SLOPE = .0010 PER UNIT OF LENGTH, = 1 IN 1000.

MEAN RAD-R METRES	.009	.010	.011	.012	.013	.015	.017	.020	.025	.030	.035	.040	MEAN RAD-R METRES
.025	57	50	43	38	34	28	23	18	13	11	9	7	.025
.050	69	59	52	47	42	34	29	23	17	13	11	9	.050
.1	80	70	63	56	50	42	36	30	22	17	14	12	.1
.2	90	80	72	65	60	50	43	35	27	22	18	16	.2
.3	96	86	77	70	64	54	47	39	30	25	21	18	.3
.4	100	89	81	74	67	58	50	42	33	27	23	19	.4
.6	104	94	85	78	72	62	54	46	36	30	25	22	.6
1	111	100	90	83	77	67	59	50	40	33	28	25	1
2	116	106	97	90	83	72	64	55	45	38	33	29	2
4	121	111	102	94	87	77	69	60	50	42	37	33	4
6	124	113	104	97	90	80	71	62	52	45	40	36	6
10	127	115	106	99	92	82	73	64	54	47	42	38	10
30	130	119	110	102	96	86	77	68	58	51	46	42	30

COEFFICIENTS n OF ROUGHNESS

PLATE NO. 4: VALUES OF 'C' FROM KUTTER'S FORMULA

SLOPE = ·000025 PER UNIT OF LENGTH = 1 IN 40000

MEAN RAD-R METRES	COEFFICIENTS n OF ROUGHNESS .009	.010	.011	.012	.013	.015	.017	.020	.025	.030	.035	.040	MEAN RAD-R METRES
	C	C	C	C	C	C	C	C	C	C	C	C	
.025	34	29	25	22	20	17	14	11	9	7	6	5	.025
.05	44	38	33	30	27	22	19	16	12	9	8	7	.05
.1	58	50	44	40	36	30	26	21	16	13	11	9	.1
.2	72	63	56	51	46	39	34	28	21	18	15	13	.2
.3	82	72	64	58	53	45	39	33	25	21	17	15	.3
.4	89	79	71	64	59	50	44	37	29	23	20	17	·4
.6	99	88	80	72	67	57	50	42	33	28	23	20	·6
1	111	100	90	83	77	67	59	50	40	33	28	25	1
1·50	121	109	100	92	85	74	66	57	46	38	33	29	1·50
2	127	115	106	98	91	80	71	61	50	42	37	32	2
3	136	124	114	106	99	87	78	68	56	48	42	37	3
4	142	130	120	111	104	93	83	73	61	52	46	41	4
6	149	137	127	119	111	100	90	80	67	58	51	46	6
10	158	145	135	127	120	108	98	88	75	66	59	53	10
15	164	151	141	133	126	114	104	94	81	72	64	59	15
20	167	155	145	137	130	118	108	98	85	75	68	62	20
30	172	160	150	142	135	123	113	103	90	81	74	68	30

SLOPE = ·00005 PER UNIT OF LENGTH = 1 IN 20000

.025	40	35	30	26	24	20	17	13	10	8	7	5	.025
.05	52	44	39	34	31	26	22	18	13	11	9	7	.05
·1	65	57	50	44	40	34	29	24	18	14	12	10	·1
·2	79	69	62	55	51	43	37	30	23	19	16	13	·2
·3	87	77	69	62	57	48	42	35	27	22	18	16	·3
·4	93	83	74	67	62	53	46	38	30	25	21	18	·4
.6	102	90	82	74	69	59	52	43	34	28	24	21	·6
1.	111	100	90	83	77	67	59	50	40	33	28	25	1.
1·5	118	107	97	90	83	73	65	55	45	38	33	28	1·5
2	123	111	102	94	87	77	68	59	48	41	35	31	2
3	129	117	108	100	93	83	74	64	53	45	40	35	3
4	133	121	112	104	97	86	77	68	56	49	43	38	4
6	138	126	117	109	102	91	82	72	61	53	47	42	6
10	143	131	122	114	107	96	87	78	66	58	52	47	10
15	147	135	126	118	111	100	91	82	70	62	56	51	15
20	150	137	128	120	113	103	94	84	72	64	58	53	20
30	152	140	131	123	116	105	97	87	76	68	62	57	30

SLOPE = ·0001 PER UNIT OF LENGTH = 1 IN 10000.

MEAN RAD-R METRES	COEFFICIENTS n OF ROUGHNESS .009	.010	.011	.012	.013	.015	.017	.020	.025	.030	.035	.040	MEAN RAD-R METRES
.025	47	40	35	31	28	22	19	15	11	9	7	6	.025
.05	59	50	44	40	35	29	25	20	15	12	10	8	.05
.1	72	62	55	50	45	37	32	26	19	16	13	11	·1
·2	84	74	66	60	54	46	39	32	25	20	17	14	·2
·3	91	81	73	66	60	51	44	37	28	23	19	17	·3
·4	97	86	77	70	64	55	48	40	31	25	21	18	·4
.6	104	92	83	76	70	60	53	45	35	29	25	21	·6
1·	111	100	90	83	77	67	59	50	40	33	28	25	1
1·5	117	105	96	88	82	72	64	54	44	34	32	28	1·5
2	120	109	100	92	85	75	67	57	47	40	34	30	2
4	128	116	107	99	92	82	73	64	53	46	40	36	4
6	131	119	110	102	96	85	77	67	56	49	43	39	6
10	135	123	114	106	100	89	81	71	60	53	47	43	10
15	137	126	116	109	102	92	83	74	63	55	50	46	15
30	141	129	120	112	106	95	87	78	67	59	54	50	30

PLATE NO. 5: VALUES OF 'C' FROM KUTTER'S FORMULA

HYDRAULIC MEAN DEPTH(R) (IN METERS.)	VALUES OF C FROM BAZIN'S FORMULA					
	VERY SMOOTH CEMENT & PLANED BOARDS.	SMOOTH BOARDS BRICK CONC. GLAZED EARTHEN WARE PIPES.	ASHLAR MASONRY.	EARTH CANALS IN GOO CONDITION AND CANALS PITCHED WITH STONE.	EARTH CANALS IN ORDINARY CONDITION.	EARTH CANALS EXCEPTIONALLY ROUGH.
	M=0.1085	M=0.29	M=0.83	M=1.54	M=2.35	M=3.17
0.05	69	51	29	18	13	10
0.10	73	60	36	23	17	13
0.15	75	62	40	27	20	16
0.20	77	64	43	30	22	18
0.25	78	66	45	32	24	19
0.30	79	67	47	34	26	21
0.35	79	68	49	36	27	22
0.40	80	70	51	37	29	23
0.50	80	71	53	39	31	25
0.60	81	72	55	41	33	27
0.70	81	73	56	43	34	28
0.80	82	74	58	45	36	30
1.00	82	75	60	47	38	32
1.50	83	77	63	51	42	36
2.00	84	78	66	55	46	39
2.50	84	79	68	57	48	42
3.00	85	79	69	59	50	44
3.50	85	80	70	60	52	45

CHEZY'S FORMULA :- $V = C\sqrt{RS}$

BAZIN'S FORMULA :- $C = \dfrac{157.6}{1.81 + \dfrac{M}{\sqrt{R}}}$

PLATE NO. 6:
VALUES OF C FROM BAZIN'S FORMULA

TABLE GIVING VALUES OF $V_0 = 0.55 D^{0.64}$ (KENNEDY'S V_0) FOR ALL VALUES OF D

DEPTH FROM 0 TO 3.95 METRES

D	0.00	·05	0·10	0·15	0·20	0.25	0·30	0·35	0·40	0·45	0·50	0·55	0·60	0·65	0·70	0·75	0·80	0·85	0·90	0·95
0·00	0·00	.081	.122	.163	0.196	.225	.254	.280	0.306	0.330	·353	.375	·397	.417	.437	.457	.476	.495	0·514	0·531
1·0	0.552	.568	·585	·602	.618	·634	·651	.667	.682	·698	·713	.730	·748	.761	·773	.787	.801	·816	0·830	0·844
2·0	0·857	.870	·882	·896	.911	·923	·935	·949	·963	·976	·989	1.002	1·014	1·027	1.039	1·051	1·063	1·075	1·087	1·099
3·0	1·110	1·122	1.134	1·146	1.158	1.170	1·181	1·192	1·203	1·215	1·226	1·237	1·248	1·260	1·271	1.282	1·292	1·303	1·314	1·325

PLATE NO. 7: VALUES OF KENNEDY'S V_o

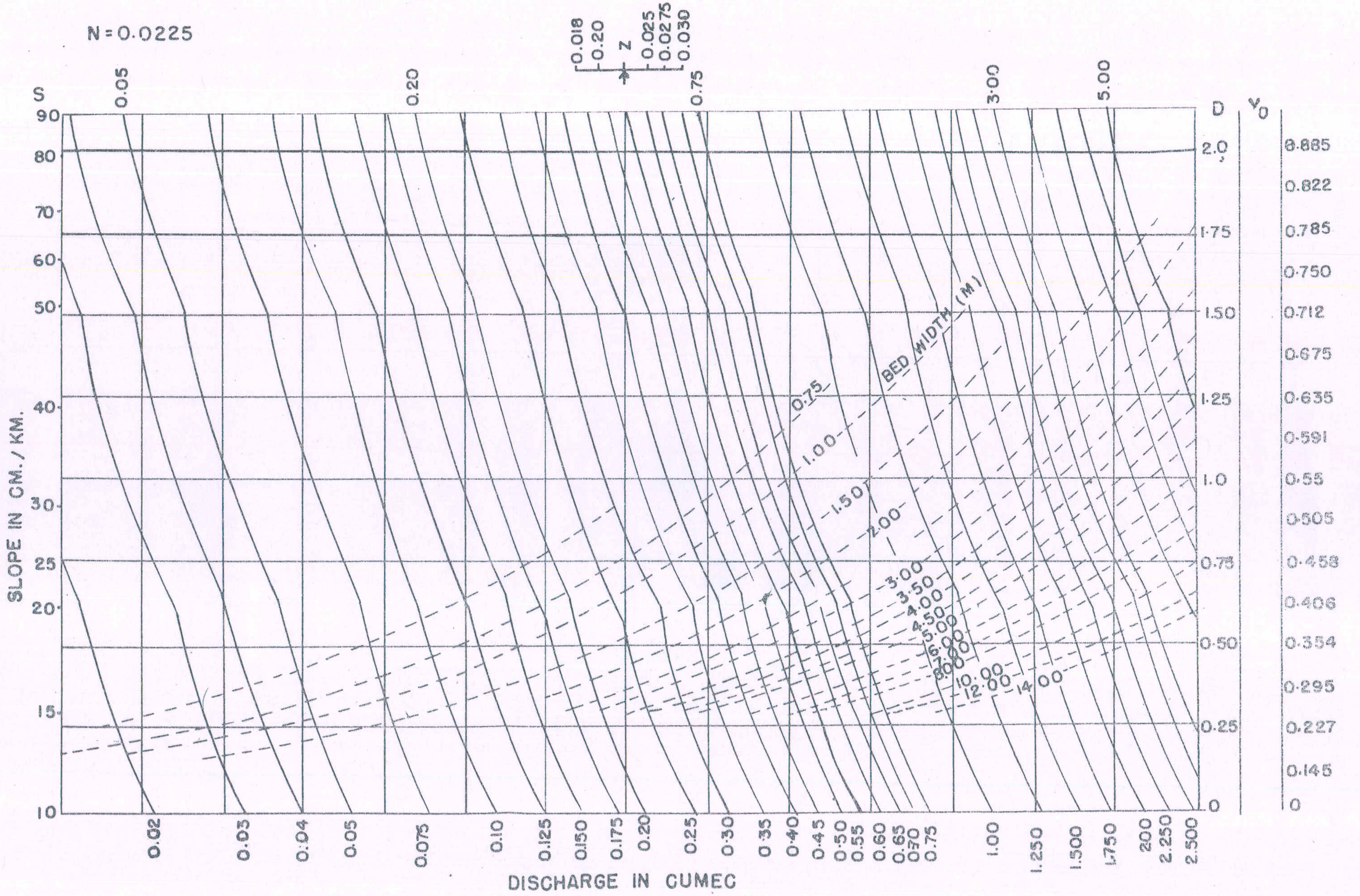


PLATE NO. 8: GARRET'S DIAGRAM

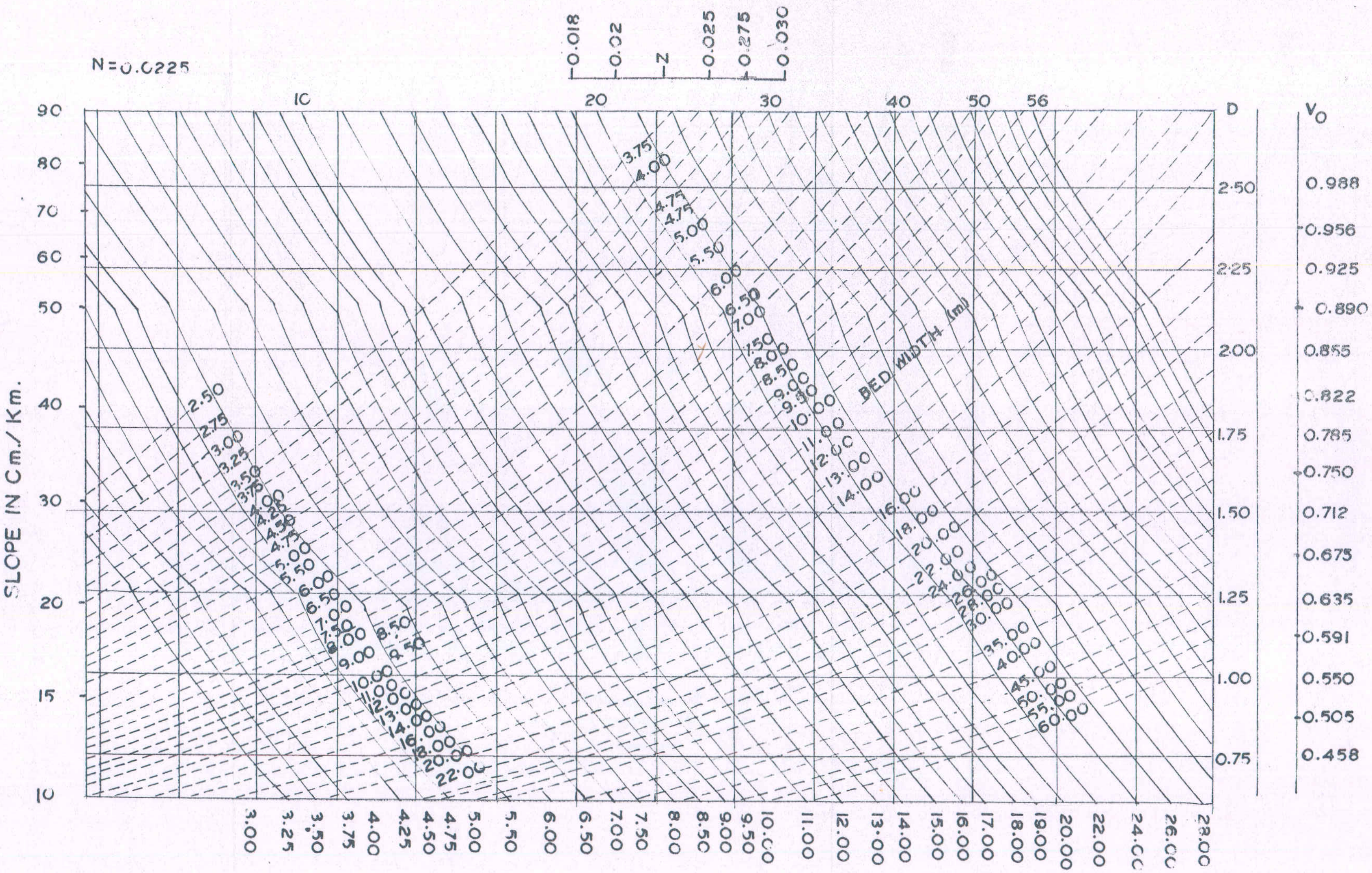


PLATE NO. 9: GARRET'S DIAGRAM

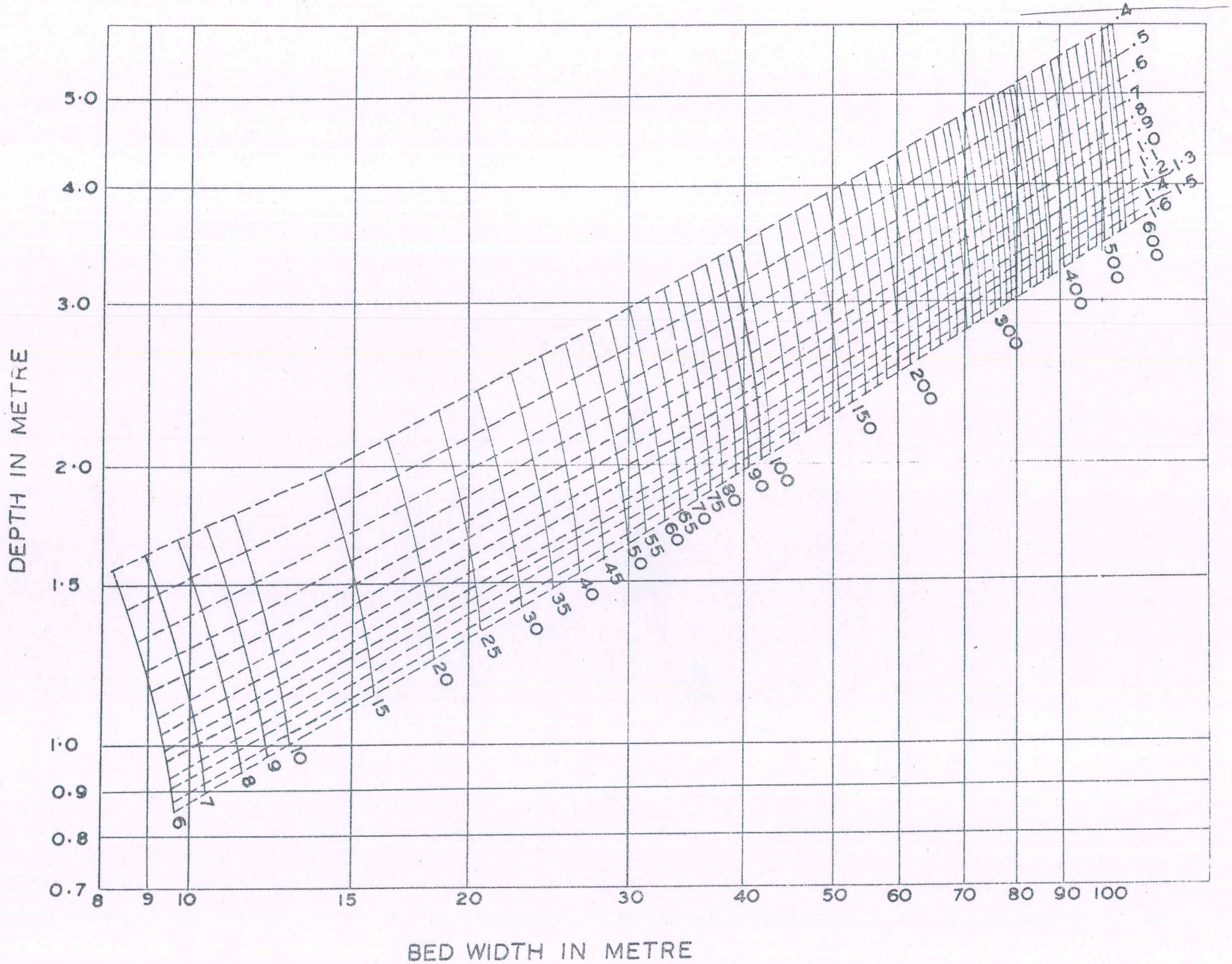


PLATE NO. 10: LACEY'S REGIME DIMENSIONS DIAGRAM
DISCHARGES FROM 6 TO 600 CUMEC
SILT FACTOR 'f' 0·4 TO 1·6

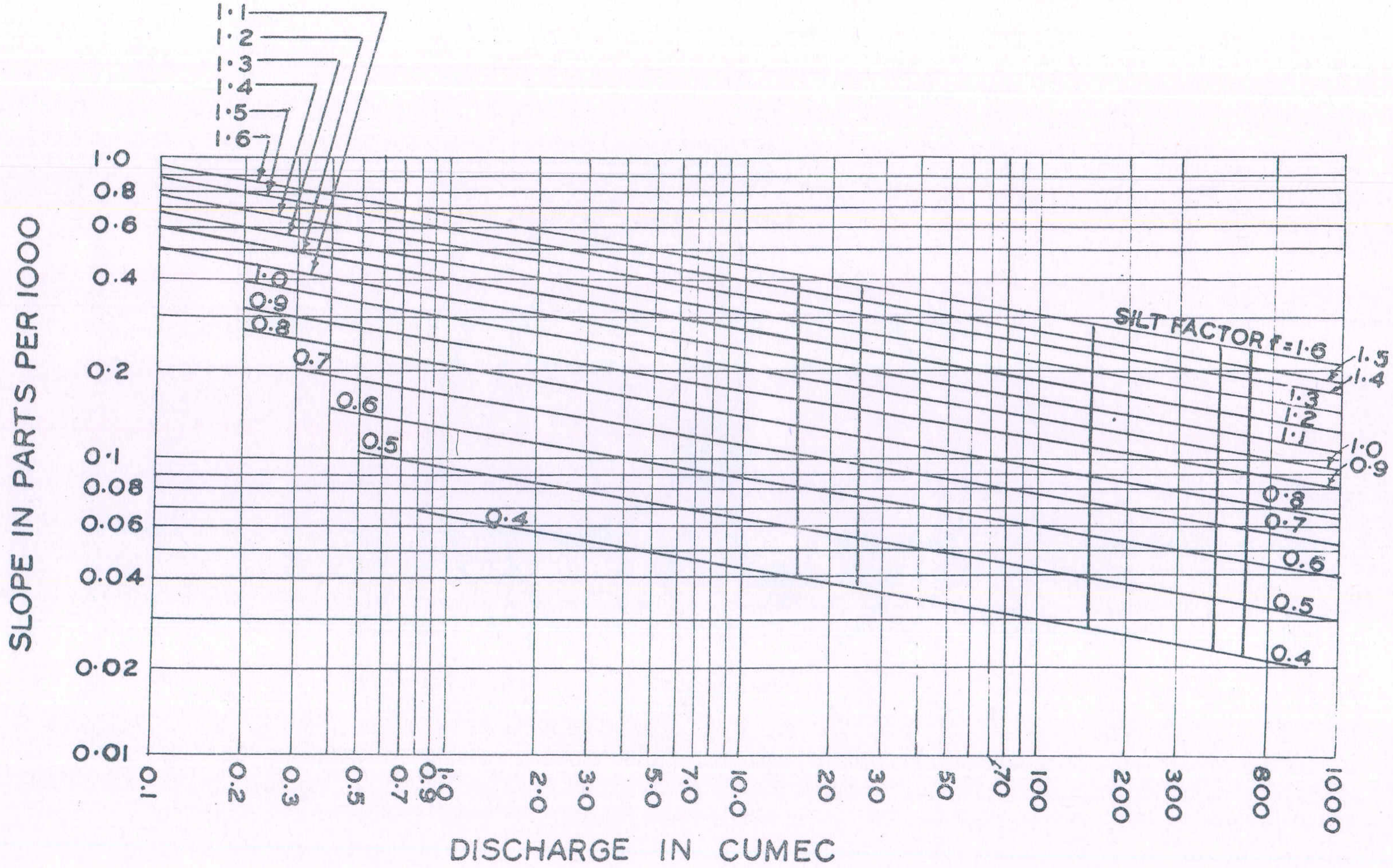


PLATE NO. 11: LACEY'S REGIME SLOPE DIAGRAM
DISCHARGES 0·1 TO 600 CUMEC
SILT FACTOR (f) 0·4 TO 1·6

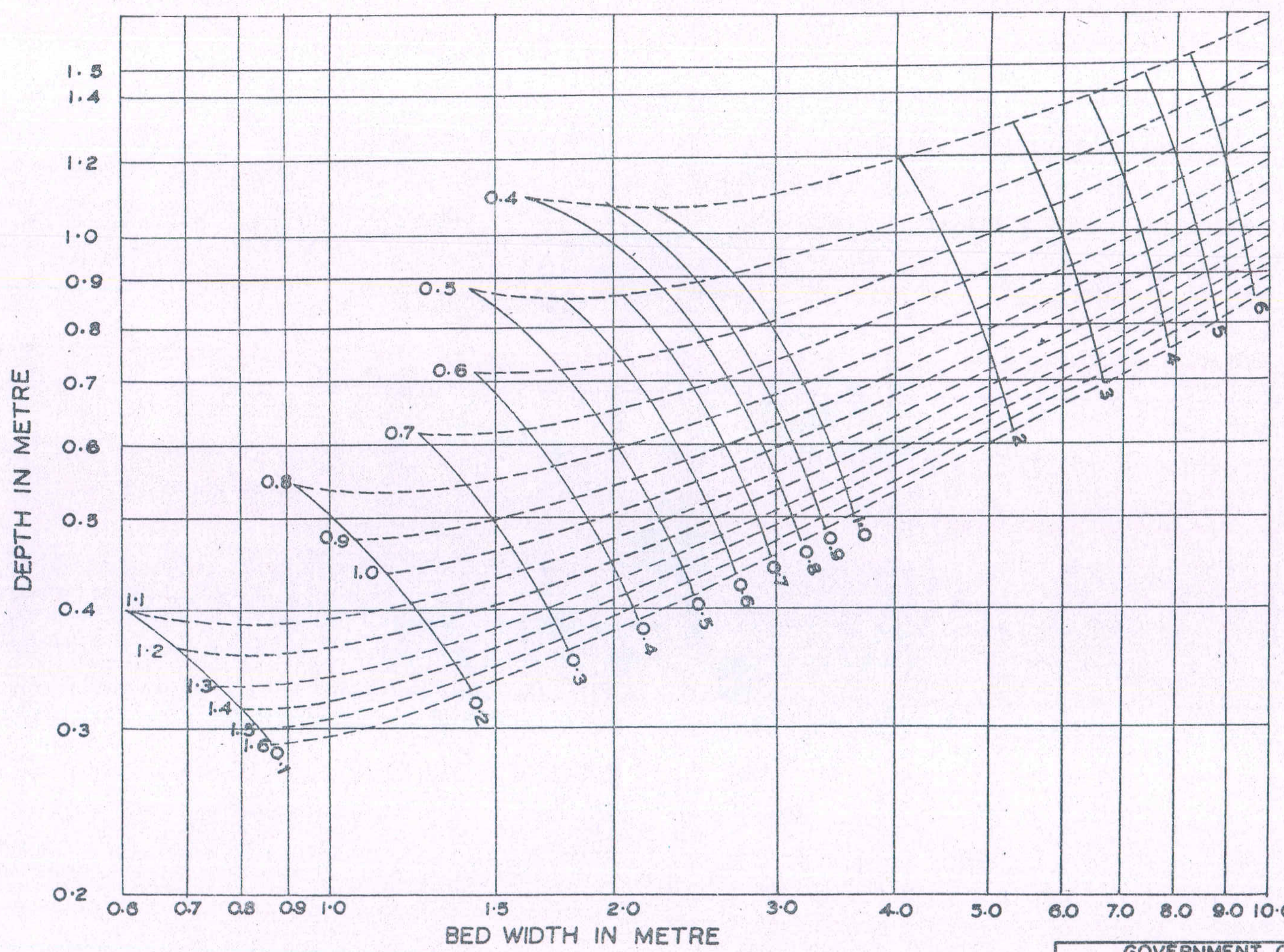


PLATE NO. 12: LACEY'S REGIME DIMENSIONS DIAGRAM
DISCHARGE FROM 0·1 TO 0·6 CUMEC
SILT FACTOR 'f' 0·4 TO 1·6

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CENTRAL WATER COMMISSION

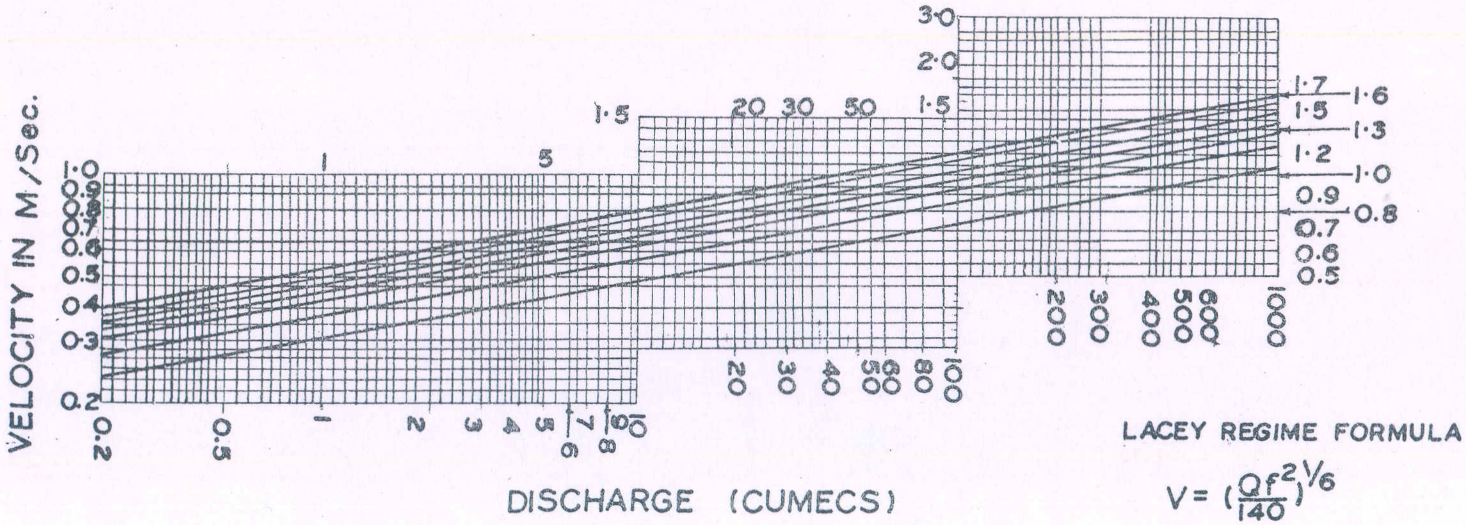


PLATE NO. 13: LACEY'S REGIME DISCHARGE AND VELOCITY DIAGRAM

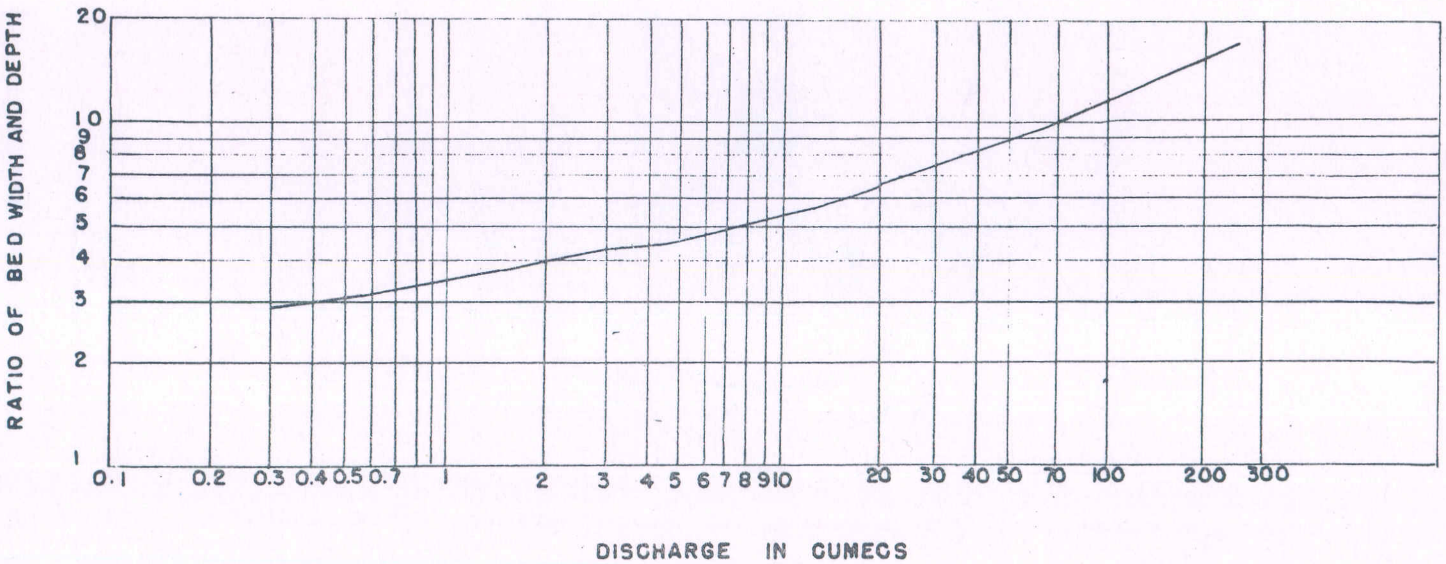


PLATE NO. 14: GRAPH FOR BED WIDTH AND DEPTH RATIO FOR UNLINED CHANNELS

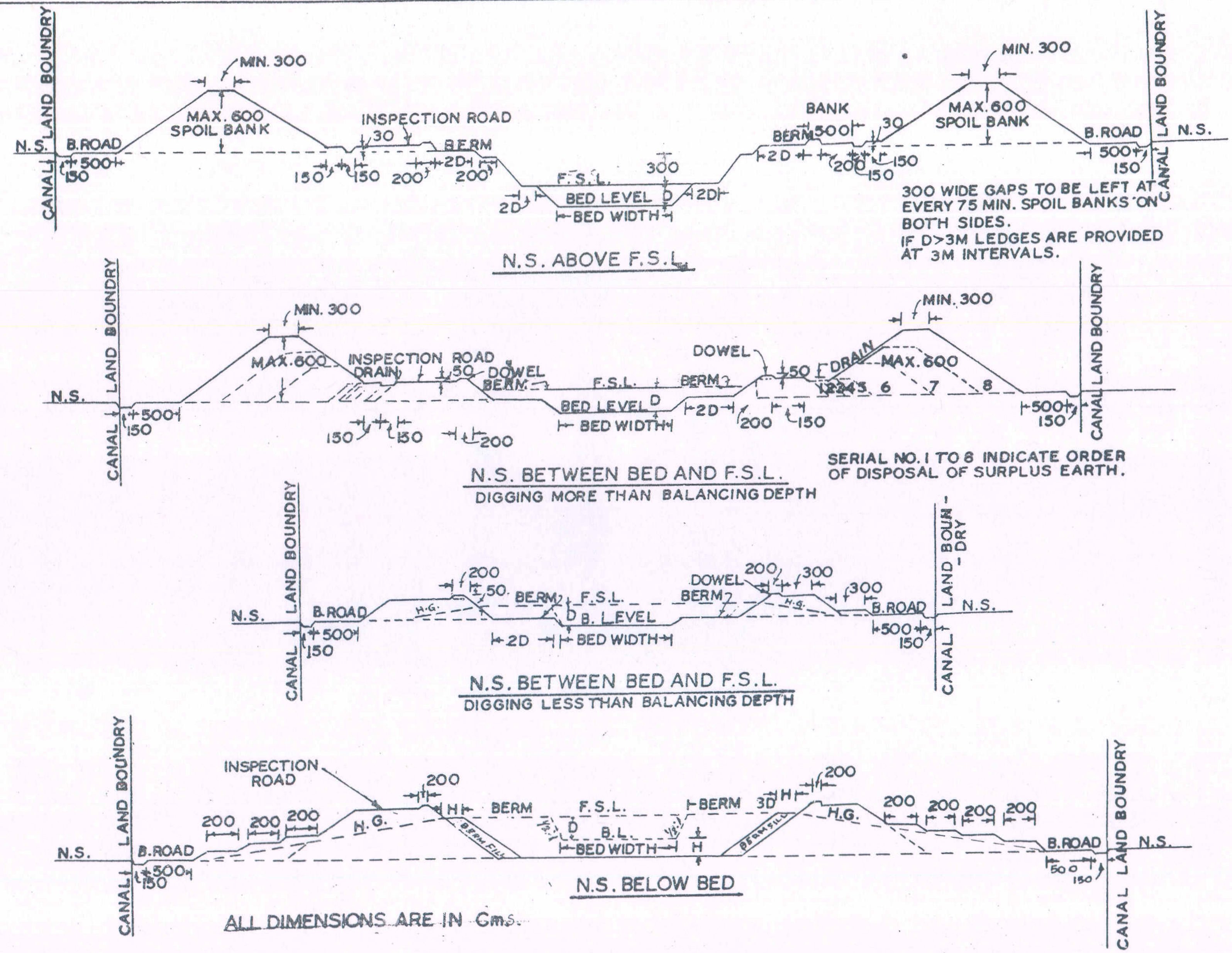


PLATE NO. 15: TYPICAL CROSS SECTIONS FOR UNLINED CANALS

CHAPTER IV

Design of Lined Canals

4.1 Necessity of Lining

It has been estimated that seepage losses in irrigation channels constitute 35 to 50 per cent of the available water at the canal head. The necessity of lining irrigation canals with a view to save these losses cannot be over-emphasised. As more and more water resources are utilised and water demand increases the canal lining will have to play an important role in conserving losses and thereby extend and improve irrigation facilities.

Lining of an irrigation channel is resorted to achieve all or some of the following objectives keeping in view the overall economy of the project.

(*a*) Reduction of seepage losses resulting in a saving of water which can be utilised for additional irrigation.

(*b*) Prevention of water-logging by reducing seepage to water table.

(*c*) Reduction in area of cross-sections (and thereby, saving in land) due to increase in permissible velocity by reduction in the value of rugosity and availing of steeper slope, where available.

(*d*) Improvement of discharging capacity of existing channels.

(*e*) Improvement of operational efficiency.

(*f*) Prevention of weed growth.

(*g*) Reduction of maintenance cost.

(*h*) Reduction in evaporation and transportation losses due to reduced exposed area.

(*i*) Elimination of silting problems, inherent in unlined canals, due to higher velocities.

(*j*) Increase in available head for power generation as a flatter gradient can be provided in power channels due to reduced value of '*N*'.

(*k*) Reduction in erosion which occurs in unlined channels constructed in steep lands.

In order to establish necessity of lining in a certain area, it is necessary to quantify the contribution of each of the factors mentioned above for assessing the overall economy achieved by lining.

4.2 Types of Lining

The various types of lining can be grouped into two categories: (*i*) Exposed and hard surface linings and (*ii*) Buried membrane linings. The advantages and disadvantages of various types of linings which need be kept in view while selecting the type of lining to be adopted are indicated below:

4.2.1 *Exposed and Hard Surface Linings*

Exposed linings include all linings exposed to abrasion erosion and deterioration effect of the flowing water, operation and maintenance equipment and other hazards. Such linings are constructed of cement concrete, asphaltic materials bricks, and boulders/stones. Although, the initial cost of these linings is generally high, the reinforced cement concrete linings being the costliest, they are usually recommended for use only where structural safety is the prime consideration.

(*a*) *Cement Concrete*

Cement concrete in-situ lining is one of the most conventional type of lining which has successfully been used in India and other parts of the world. A suitably designed and properly constructed cement concrete lined channel can withstand high velocities which are considered appropriate for a canal. Cement concrete lining is more preferable than any other lining where channel is to carry high velocity water because of its greater resistance to erosion. Velocities upto 2.5 m/sec. are generally considered permissible with adequate water depth although higher velocities up to 5 m/sec in case of Kosi Feeder canal in U.P. have been provided. Cement concrete lining eliminates weed growth and thereby, improves flow characteristics. Burrowing animals cannot penetrate concrete and provision of concrete lining reduces maintenance charges to a minimum.

A distinct disadvantage of concrete lining is its lack of extensibility, which results in frequent cracks due to contraction taking place on account of temperature changes drying, shrinkage and settlement of subgrade. It is also likely to be damaged by alkaline water. Cement concrete lining without reinforcement may be damaged due to excessive external water pressure. However, reinforced concrete lining can withstand the external water pressure but at a very high cost. Where unexpected water pressures are encountered, unreinforced lining will crack more easily than the reinforced lining and will relieve the pressure thereby reducing the area of damage.

(*b*) *Shotcrete*

In this type of lining cement mortar is applied by pneumatic pressure. Shotcrete lining can be easily placed over rough subgrade and is therefore, better suited for use on existing cuts where finishing to exact shape and slope would be expensive. The lining may be constructed with or without reinforcement (in the form of mesh or expanded metal), although reinforcement increase its useful life, especially, when laid over earth subgrade.

Since the thickness of lining is limited, 5.0 cm mostly, such linings are applied on smaller channels or where operational requirements are not severe. The lining is also likely to be damaged by external water pressure easily due to small thickness. It is very difficult to control the thickness of lining, which may leave areas where thickness is less than the minimum required. Such patches constitute the areas of weakness where lining may give way.

(*c*) *Soil Cement*

This type of lining is made of a mixture of cement and natural sandy soil. This type of lining may sometimes result in considerable saving as compared to cement concrete lining. It may be adopted on economic considerations both for small and large channels. The use of soil cement lining is, sometimes, handicapped by the non-availability of suitable soil. It is not weather resistant.

(*d*) *Asphaltic Concrete*

Asphaltic concrete lining may be substituted for cement concrete lining where it works out to be cheaper and aggregate is not of sufficiently good quality for cement concrete but is suitable for asphaltic concrete. Asphaltic concrete has greater ability to withstand changes in the subgrade. Asphaltic concrete lining can be used for repairing cement concrete lining by placing a resurfacing layer of asphaltic concrete. Disadvantages of the asphaltic concrete lining are: velocities in the lining are limited to 1.5 m/sec, danger of weed growth resulting in puncturing of linings, insufficient resistance to external hydrostatic pressure, and danger of sliding during hot season.

(*e*) *Brick Lining*

This type of lining has been extensively used in India and elsewhere. The brick linings, are not only equally impermeable as C. C. linings, but have the additional advantage of low initial and maintenance cost, quicker construction and natural safeguard against cracking due to closely spaced joints. This type of lining is economical where aggregates for concrete lining are not available. It does not require skilled labour as needed for concrete lining.

(*f*) *Exposed Membrane Lining*

The various types of exposed membrane linings are : sprayed in place asphalt cements, prefabricated sheets of asphaltic materials, fibre glass and films of plastic and synthetic rubber. Experiments have shown that where as the exposed membranes have low resistance to puncturing and disintegrate rapidly, thicker sheets with greater resistance are expensive.

(*g*) *Earth Linings*

Thick compacted earth lining may prove to be economical where suitable material for construction is available at site. The lining is durable and can withstand considerable external hydrostatic pressure and can be provided over expansive clays also. Bentonite has shown considerable promise for use as a good lining material. Bentonite containing large percentage of montmorillonite, is characterised by high water absorption accompanied by swelling and imperviousness. It can be used as 5.0 cm thick membrane covered by protective blanket or as a mixed in place layer of soil bentonite well compacted.

(*h*) *Boulder Lining*

Boulder lining may prove to be cheaper than cement concrete where boulders obtained during excavation are readily available. Boulder lining has very little flexural resistance or flexibility and the slightest settlement of the sub-grade may cause distress. Such lining is not satisfactory for canal in filling.

(*i*) *Pre-cast Concrete Lining*

Concrete tiles are more compact and impervious. The usual size of concrete tiles is $500 \times 250 \times 50$ mm or $250 \times 250 \times 50$ mm. They are laid in 1:3 cement mortar in single or double layer directly on the compact subgrade. A spacing of 3.5 to 5 m is usually provided for siting of expansion joints on sleepers. The joints are sealed with bituminous mastic.

The pre-cast tiles are manufactured by hand casting on vibrating table or/are machine made depending upon requirement and availability of equipment.

4.2.2 *Buried Membrane Linings*

Hot applied asphaltic, prefabricated asphalt materials, plastic film and a layer of bentonite or other types of clays protected by earth or gravel cover are cheap linings. These linings can be provided immediately after completion of excavation or even later. Membrane linings are susceptible to damage by weed root and permissible water velocity is limited to avoid erosion. The life of the lining is uncertain.

(*a*) *Sprayed-in place asphaltic membrane lining* : It is composed of a special high softening point asphalt and sprayed in-situ at a high temperature and is laid on the prepared sub-grade to form approximately 6 mm thick water proof barrier. It is protected from damage and weathering usually by a protective layer of earth and gravel. It provides an effective and cheap means of seepage control and can be satisfactorily laid in a cold and wet weather.

(*b*) *Pre-fabricated asphaltic membrane linings* : These ready made membranes are used in smaller channels or in relatively short reaches of large canals, where the use of sprayed-in-place linings is costlier on account of the requirement of special equipment and skilled personnel. Such linings are fabricated from low cost material of adequate water tightness and durability. They are relatively thin and light and can be transported to long distances, stored in hot weather and placed at low temperatures.

(*c*) *Plastic film and synthetic rubber membrane lining* : These linings using polyvinyl and polythelene plastic and butyl coated fabrics have been tried experimentally on a limited scale. Out of the various types tested so far, polyvinyl and polythelene appear to be the best. A protective cover of earth or earth and gravel is provided. Plastic film can be manufactured in any convenient size. More over being light it can be transported and handled easily. Synthetic rubber also has found use in canal lining although it is highly durable, it undergoes mechanical damage when exposed.

(*d*) *Bentonite and clay membrane linings* : Bentonite has got the peculiar characteristics of becoming impervious on wetting due to swelling and imbibing of water. As such, it is a very useful material, for controlling seepage from canals, if available locally at low cost. It has been used by spreading as a membrane 25 to 50 mm or more in thickness over the canal sub-grade and covering with a 15 to 30 cm protective blanket of suitable earth or gravel.

For further details of linings, standard manuals and reports such as the CBIP Technical Report No. 14 may be referred.

4.3 Considerations for Selection

Keeping in view the advantages and disadvantages of various types of linings discussed above, it is seen that no single type of lining can be recommended for all the conditions encountered. Type of subgrade, positions of water-table, climatic conditions, availability of materials, size of canal, service requirements and experience are the major factors affecting the economy and selection of suitable lining material. Adoption of a particular type of lining material will require consideration of all these factors and hence it is not possible to recommend any one type of lining suitable for all conditions. However, a broad indication can be given for the type of lining that may be considered for various sizes of canals. Following classifications of channels may be made for deciding the type of lining for a particular channel.

(*a*) *Channels with Bed Width upto 3.0 m*

(*i*) Single burnt clay tile or brick lining should be preferred where seepage considerations are of over-weighing importance.

(*ii*) Soil cement lining may be adopted at reasonable cost when burnt clay tiles are not available and the initial cost is the foremost consideration.

(*iii*) Polythelene plastic or alkathene lining with adequate earth/tile cover may be adop.ed for stable channels.

(*iv*) 50 to 80 mm thick asphaltic concrete lining may be adopted for continuous running channels where there is no likelihood of weed growth.

(*v*) 25 to 50 mm thick bentonite membrane lining with earth cover may be considered, wherever economical.

(*b*) *Channels with Bed Widths between 3.0 and 8.0 m*

(*i*) Lining of single burnt clay tile should be preferred.

(*ii*) Precast concrete lining may be adopted if coarse aggregates for concrete are available within economical leads and burnt clay tile lining proves to be uneconomical. However, the concrete lining is more impervious than burnt clay tile lining.

(*iii*) Composite lining (membrane in bed and brick tile or concrete lining on sides) may be adopted for existing channels which have become stable and no danger of scour is expected.

(*iv*) Bentonite membrane lining protected by earth cover.

(*c*) *Channel with Bed Width Greater than 8 0 m*

(*i*) In-situ concrete lining or precast concrete lining may be preferred for reducing the seepage losses.

(*ii*) Burnt clay tile lining (double on sides and single on bed) may be adopted where aggregates for manufacture of concrete are not available within economical leads.

(*iii*) Thick compacted earth lining may be provided where suitable and sufficient materials are available and the job is large enough to warrant use of heavy earth moving equipment.

4.4 Flow Formula and Velocities

The same formulae as for unlined channels will apply in general to lined canals. However, Manning's formula, i.e., $V = \frac{1}{n} R^{2/3} S^{1/2}$ is widely used for lined canals. Experiments in various research institutes have been conducted by taking actual observations for finding the value of rugosity coefficient on lined canals. Some values of '*n*' for various surfaces as recommended by ISI are given in Table VI.

TABLE VI

Value of Coefficient of Rugosity Coefficient 'n' for Lined Channels

Sl. No.	Surface Characteristics	Value of 'n'
I	*Concrete with surface as indicated below*	
(*a*)	Formed, no finish/PCC tiles or slabs	0.018—0.020
(*b*)	Trovel/Float finish	0.015—0.017
(*c*)	Gunited finish	0.018—0.022
II	*Concrete bottom float finished and sides as indicated below*	
(*a*)	Hammer dressed stone masonry	0.019—0.021
(*b*)	Coursed rubble masonry	0.018—0.020
(*c*)	Random rubble masonry	0.020—0.025
(*d*)	Masonry plastered	0.015—0.017
(*e*)	Dry boulder lining	0.020—0.030
III	*Brick tile lining*	0.018—0.020

Note : With channels of an alignment other than straight, loss of head due to resistance forces will be increased. A small increase in the value of n may be made to allow for additional loss of energy. There are no rigid velocity limits for lined canals. If the water is clear from silt and sand, considerable velocities can be allowed in lined section. This is, however, not possible in actual practice. In canals taking of from rivers, the slope is further limited from considerations of command. In view of this velocity is usually limited to 2 m/sec and the critical velocity ratio should be aimed at higher than unity though critical velocity ratios are not applicable to lined canals but the possibility of silting cannot be neglected.

4.5 Design of Lined Sections

It has been seen that the most economical section, i.e., having maximum area with minimum perimeter, is the one with a curved bed with its centre at the F.S.L. and the sides tangential to the curve. This type of section, however, does not give any horizontal portion in the bed and is suitable for small channels only carrying discharges upto 60 cumecs. For discharges exceeding 60 cumecs, it becomes necessary to provide horizontal bed to keep depth within reasonable limits. The bed is however, joined to the side slopes in a curve of radius equal to F.S.D.

The water surface slope, side slopes and the value of '*n*' having been decided upon, the section may be worked out from Manning's formula as given below :

1. *For Small Channels*

(i)	Side Slopes	1:1	1.25:1
(*ii*)	Angle ψ	45°	38° 40'
(*iii*)	Sectional Area (A)	$1.785\ d^2$	$1.925\ d^2$
(*iv*)	Wetted Perimeter (P)	$3.57\ d$	$3.85\ d$
(*v*)	Hydraulic Mean Depth (R)	$0.5\ d$	$0.5\ d$

(*vi*) Velocity $V = \frac{1}{n} R^{2/3} S^{1/2}$

(*vii*) Discharge $Q = A \times V$

2. *For Large Channels*

(*i*)	Side Slopes	1:1	1.25:1
(*ii*)	Angle θ	45°	38° 40'
(*iii*)	Length of Tangent (t)	$0.4142\ d$	0.35d
(*iv*)	Sectional Area (A)	$bd + 1.785d^2$	$bd + 1.925d^2$
(*v*)	Wetted Perimeter (P)	$b + 3.57\ d$	$b + 3.85\ d$

(*vi*) Hydraulic mean depth $R = \frac{A}{P}$

(*vii*) Velocity $V = 1/n\ R^{2/3} S^{1/2}$

(*viii*) Discharge $Q = A \times V$

Typical examples have been given in Appendix II.

4.6 Side Slopes

In order to keep down the thickness of lining on sides it is usually made to rest on slopes corresponding to the angle of repose of the natural soil so that the slopes shall be such that no earth pressure is exerted on the back of lining. The slopes steeper than these have to be designed as gravity sections and require greater thickness and are consequently uneconomical. The side slopes 1:1 to 1.25:1 the flatter being for deeper canals have been found convenient to work. Generally, a slope 1:1 for depth less than 3.66 m and 1.25:1 slope for more than 3.66 m is adopted. In filling compaction at optimum moisture content is done and stable slopes for such compacted banks are adopted.

4.7 Full Supply Depth

Full supply depth is more a matter of assumption. It is however, guided by the following considerations:

(*i*) Having fixed the alignments and F.S.L. from the command point of view, the depth may be such as to give balancing depth as far as possible.

(*ii*) Velocity may not exceed 2 m/sec.

(*iii*) The bed of the channel may be higher than the sub-soil water level as far as possible, so as to avoid pumping during constructions and uplift pressures after closure of channel.

(*iv*) In case of main and branch canals the depth should be such that it gives bed width enough to provide convenient working space within it, consistent with maximum economy in the cost of excavations, land and masonry works.

4.8 Bank Width and Free Board

The following bank widths shall be provided :

(*i*) 8 m for cutting and filling reaches for main canals.

(*ii*) 6.5 m for cutting reaches of branch canals.

(*iii*) 6.5 m on left side and 5.0 m on right side for filling reaches of branch canals.

A free board of 0.75 m shall be provided for canals carrying a discharge of more than 10 cumecs. For canals carrying a discharge less than 10 cumecs a free board of not less than 0.60 m shall be adopted. Free board shall be measured from the full supply level to the top of lining.

4.9 Berms and Dowels

A typical cross-section is shown in plate No. 16. No berms are provided for lined canals to reduce chances of water finding its way behind lining. A dowel is also provided for this purpose, i.e., to prevent rain water on bank flowing into the channel. Both the banks and dowels should be sloped outwards to drain off the water quickly into the catch water drain provided at the outer edge of bank. Other details provided are in the same manner as for unlined channels.

4.10 Drainage and Pressure Release Arrangements

Failures of canal lining in most cases occur due to excess hydrostatic pressure behind the lining resulting from either high water-table condition or pressure build up due to time lag in drainage of the sub-grade following drawdown of the canal. In order, therefore, to improve stability of canal under such conditions, it is essential to eliminate the excess pressure by provision of adequate drainage arrangement.

4.10.1 *Various Conditions of Water Table*

The drainage arrangement to be provided would depend upon the site conditions, viz. Subsoil water level and permeability of subgrade. The hydrostatic pressure at the soil-lining interface is the determining factor for the stability of the lining. Even when the pressure build-up behind the lining is controlled through provision of adequate drainage, pressure lag in a poorly draining subgrade may be important from the point of view of the stability of the bank itself. Any inadequacy of drainage at the time of initial design or due to subsequent malfunctioning will lead to gradual accumulation of water within the contact space and cause failure of lining. Drainage arrangements have, therefore, to be designed such that excess hydrostatic pressures are eliminated. The necessity for provision of filter behind the lining is also stressed from the considerations of inhibiting the movement of fine material from the subgrade following drawdown which, if not guarded against, may lead to progressive formation of cavities resulting in subsidence of the lining. The various considerations governing the design of drainage arrangements and pressure release valves for different water-table conditions are given below :

(*a*) *Water-Table below Canal Bed* : If the water-table is below canal bed and the bank-fill is free-draining, there will be no time lag in the dissipation of drawdown pore pressures in the backfill as such no drainage arrangement is necessary in such a condition.

When the water-table is below canal bed and the bank-fill is of low permeability, the back-fill will get saturated in course of time due to seepage of water through joints and cracks, and in case of drawdown the water will not be drained out as quickly as the drawdown occurs. Hence, pressure will be built up behind the lining necessitating a well designed drainage arrangement.

(*b*) *Water-Table between Canal Bed and F.S.L.*: Whether the bankfill is composed of free-draining or clayey material, the soil behind the lining will remain submerged to the elevation of the water-table. In case of lowering or emptying of the canal, lining will be subjected to hydrostatic pressure due to water-table and also drawdown pressures arising from drainage of the backfill above the elevation of water-table. Drainage must, therefore, be provided to help in reducing such pressures to safe limits.

(*c*) *Water-Table or H.F.L. above Canal F.S.L.*: If the water-table outside the canal is above the F.S.L. of the canal, the canal lining would continuously be subject to uplift pressures during normal running of the canal. In order to release these pressures, extensive drainage arrangements consisting of longitudinal drains in the bed, drains or continuous inverted filter behind the side slope and pressure release valves to discharge seepage water into the canal will have to be provided.

4.10.2 *Selection of Drainage Arrangements*

The drainage arrangements provided to reduce or eliminate hydrostatic pressure behind lining usually comprise longitudinal drains and cross-drains in the bed and pressure release valves or continuous filter below the lining on the sides. The adequacy of various drainage arrangements can be determined on the model.

In case of high water-table, the lining will be subjected to uplift pressure corresponding to head difference irrespective of the type of subgrade. In case of the lining being subjected to drawdown, however, the excess pressure will depend upon the rate of drawdown and the drainage characteristics of the subgrade. In most cases it should be possible to adjust the drawdown by suitably restricting the rate of drawdown to an extent that there is little pressure lag. In such cases, drainage may be provided as a precautionary measure. A broad categorisation based on Cassagrande's classification indicating the range of free draining and poorly draining subgrade is given as below :

(*i*)	Free draining	Clear gravel on clear sand	Permeability greater than 10^{-4}cm/sec
(*ii*)	Poorly draining	Very fine sand, mixtures of sand, silt and clay, clays.	Permeability less than 10^{-4} cm/sec and greater than 10^{-6} cm/sec
(*iii*)	Practically impervious	Homogeneous clays below zone of weathering	Permeability less than 10^{-6} cm/sec

The criteria may be used to broadly decide the necessity or otherwise and type of drainage measures to be provided below the side lining. In case permeability is less than 10^{-6} cm/sec. no drainage may be required. In case of permeability higher than 10^{-4} cm/sec, the drainage of the backfill material is likely to closely follow the drawdown in the canal, and no continuous filter may be required and only pressure release valves may be provided to drain out the seepage water as a precautionary measure. In case of poorly draining soils ($K<10^{-4}$cm/sec), continuous filter should usually be necessary in case of fast drawdown due to lag in drainage unless the rate of drawdown can be controlled by cross drains or pressure release valves. In case of high water-table conditions, continuous filter with non-return valves to discharge seepage waters into the canal would be required to eliminate the excess hydrostatic pressure behind the lining. Details of filter material around pressure release valve is given in Plates No. 19 and 20.

4.10.3 *Pressure Release Valves*

Pressure release valves which open into the canal are provided to relieve excessive hydrostatic pressure behind lining. The valves should be provided in pockets filled with graded filter underneath the lining. The pockets may be cylindrical with depth and diameter as 85 cm or cubical with sides as 85 cm. Horizontal and vertical pressure release valves are installed. 50 mm diameter valves are normally used on the side slopes and 150 mm diameter valves are used in the bed. The number of rows of pressure release valves in the slopes of canal should be such that for each 4 m width along the slope a row is provided. The first row should be provided at the junction of the curve and the sides. The number of rows on the bed of canals shall be such that for every 10 m bed width a row is provided. The spacing of the pressure release valves in a row should be decided on the basis of experiments carried out on models simulating site conditions. Valves in adjacent rows should be staggered. The longitudinal drains consisting of open jointed pipes encased in graded filter, should have outlets in a trench of width 45 cm and depth 50 cm. The trench should be filled with graded filter and have outlet into the canal through pressure release valves. The outlet may be provided through precast concrete boxes collecting water from drains with pressure release valves on the top of boxes.

The performance of metallic pressure release valves recommended by ISI has not been satisfactory. The flaps are easily damaged and leakage of water is substantial. There is a need for evolving a better design and should be made of plastics or fibre glass which are strong but have no resale value. This would discourage pilferage which is common with metallic valves. Suitable non-metallic pressure release valves for use in bed and sides of lined canals were developed for Sharda Sahayak Project. These valves were tested by I.R.I., Roorkee and their hydraulic performance was found to be very satisfactory.

Details of one type of pressure release valves are given in Plate No. 17 and details of filter material around pressure release valve is given in Plates No. 19 and 20.

4.10.4 *Provision of Dwarf Regulator*

Dwarf regulators are regulators of part height constructed across lined canals at suitable intervals for ponding up water to counteract excess uplift pressure below the lining. These are provided in areas where the water-table remains continuously high and the conventional pressure release arrangements are not likely to prove adequate. The height and spacing of the dwarf regulators will depend upon the minimum depth of water required to be maintained inside the canal for counter balancing residual pressures for safety of the canal. The regulators also help in maintaining minimum water depth inside the canal even when the canal is operated at part capacity with lower normal depths. Their disadvantage is that the canal made stable with dwarf regulator cannot be emptied for repairs (till the water-table goes down to bed level) and these may cause additional head loss in the canal.

The under drainage arrangements should be as per the recommendations of I.S. 4558—1968.

4.11 Lining of Expansive Soils

Canals excavated in expansive soils pose several problems of stability. To have economical sections and prevent erosion due to given velocities, it is necessary to line the canal bed and slopes. Pre-cast cement concrete slabs for side slopes and in-situ concrete for bed are common types of lining adopted for canals. However, it is often experienced that the lining material directly placed against the soil undergoes deformations, disturbing the lining and throwing the canal out of commission. This deformation is traceable to the unduly high swelling pressures developed by expansive soils when they absorb water. The heaving of soil mass is often attempted to be contained by protecting the soil with a thin layer of murum or gravel. From experiments in the laboratory and field it is concluded that the deformations can be correlated to the thickness of the murum layer and swelling pressure in the soil.

To counter the swelling pressures and prevent deformation of the rigid lining material a Cohesive Non-Swelling layer (CNS) of suitable thickness depending on the swelling pressure of the expansive soil is sand-witched between the soil and rigid lining material.

The CNS material may contain gravel or murum or a combination of sand and murum or gravel. Typical gradation based on the concept of stress transfer from micro-particles to the soil may be indicated as :

(*a*) Clay : 15-20%

(*b*) Silt : 15-20% or more

(*c*) Gravel and sand 60-70%

The minimum gradation shall be ensured to avoid swelling of clay particles in the voids and to restrict the pore size.

The shear parameters may range from 10 to 30 KN/m^2 for cohesion and angle of internal friction 12° to 25°.

APPENDIX-II

Example I

DESIGN OF LINED SECTION

DATA

$Q = 300$ cumecs

$N = 0.018$

$S = \frac{1}{10\,000}$

Side Slope = 1:1

Assume section 26.0 m × 5.7 m (d = 5.7m)

Section Area = $bd + 1.785\ d^2$

$= 26.0 \times 5.7 + 1.78 \times 5\ 5.7^2$

$= 148.2 + 57.99 = 206.19\ m^2$

Pw $= b + 3.57\ d$

$= 26\ 0 + 3.57 \times 5.7 = 46.35\ m$

$R = \frac{A}{Pw} = \frac{206.19}{46.35} = 4.45\ m$

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

$= \frac{1}{0.018} \times 4.45^{2/3} \times \left(\frac{1}{10\,000}\right)^{1/2}$

$= \frac{1}{0.018} \times 2.71 \times \frac{1}{100}$

$= \frac{0.0271}{.0180} = 1.51$ m/sec

$Q = 206.19 \times 1.51 \times 311$ cumecs

Hence O.K.

Example II

Design of Distributary with the following data:-

$Q = 20$ cumecs

$S = \frac{1}{10\,000}$

$n = 0.014$

Side slope = 1.25 : 1

DESIGN

Let Depth of Channel = d

Area $= 1.925\ d^2$

$R = d/2$

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

$= \frac{1}{0.014} R^{2/3} \frac{1}{(10{,}000)}^{1/2}$

$= 0.715\ R^{2/3}$ ...(1)

Also $V = \frac{Q}{R} = \frac{20}{1.925 \times d^2}$ ... (2)

Equating (1) and (2)

$0.715\ R^{2/3} = \frac{20}{1.925 \times d^2}$ As $R = d/2$

$0.715 \left(\frac{d}{2}\right)^{2/3} \times 1.925\ d^2 = 20$

From above

$d = 3.25$ m

Example III

Design a lined canal with the following data with the help of the curves in plote No 18

DATA

$Q = 300$ cumecs

$N = 0.018$

Side slope = 1.25 : 1

Longitudinal slope = 1: 10000

From the curves

Assuming a bed with of 30 m

Depth required is 5.20 m

Velocity of flow would be around 1.44 m/sec.

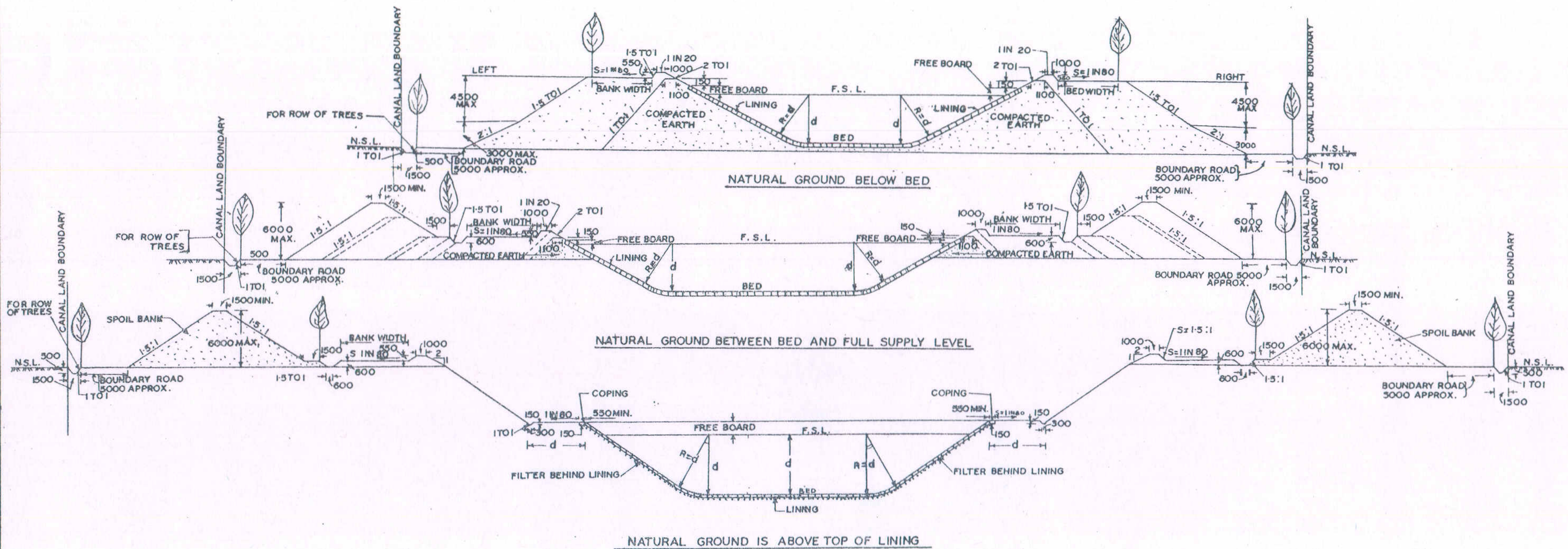
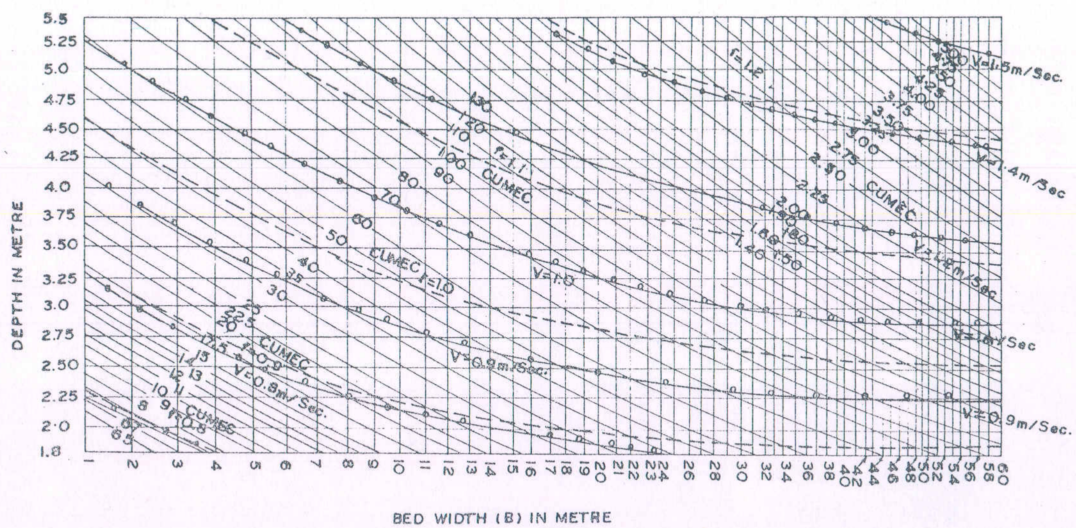


PLATE NO. 16: TYPICAL CROSS SECTIONS FOR LINED CANALS



DESIGN CHART FOR CHANNEL

(A) FOR OTHER VALUES OF N

1. TO DETER MINE R

READ BED WIDTH AND DEPTH AGAINST DISCHARGE MULTIPLIED BY N_1/N (N=0·016)

N_1= 0.015	0.016	0.020	0.022
$\frac{N_1}{N}$=0.833	0.889	1.111	1.222

2. TO DETER MINE "f"

READ FOR THE DISCHARGE CALCULATED ABOVE & MULTIPLY IT. $(N/N_1)^2$

N_1= 0.015	0.016	0.020	0.022
$(N/N_1)^2$=1.44	1.266	0.810	0.669

3. TO DETERMINE V.

READ FOR DISCHARGE CALCULATE ABOVE & MULTIPLY IT. N/N_1 (N=0.018)

N_1=0.015	0.016	0.020	0.022
(N/N_1)=1.200	1.125	0.900	0.818

(B) FOR OTHER VALUE OF SLOPES.

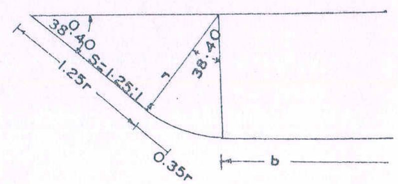
1. READ BED WIDTH & DEPTH AGAINST DISCHARGE DIVIDED BY $(S_1/S)^{1/2}$ WHERE S_1 IS THE NEW SLOPE.

2. TO DETERMINE f

READ FOR DISCHARGE CALCULATED ABOVE & MULTIPLY BY $(S_1/S)^{1/2}$

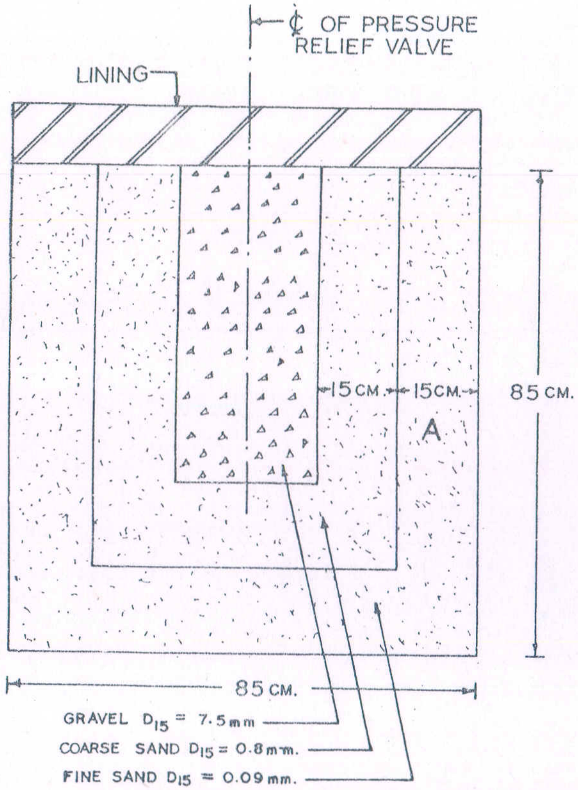
3. TO DETERMINE V

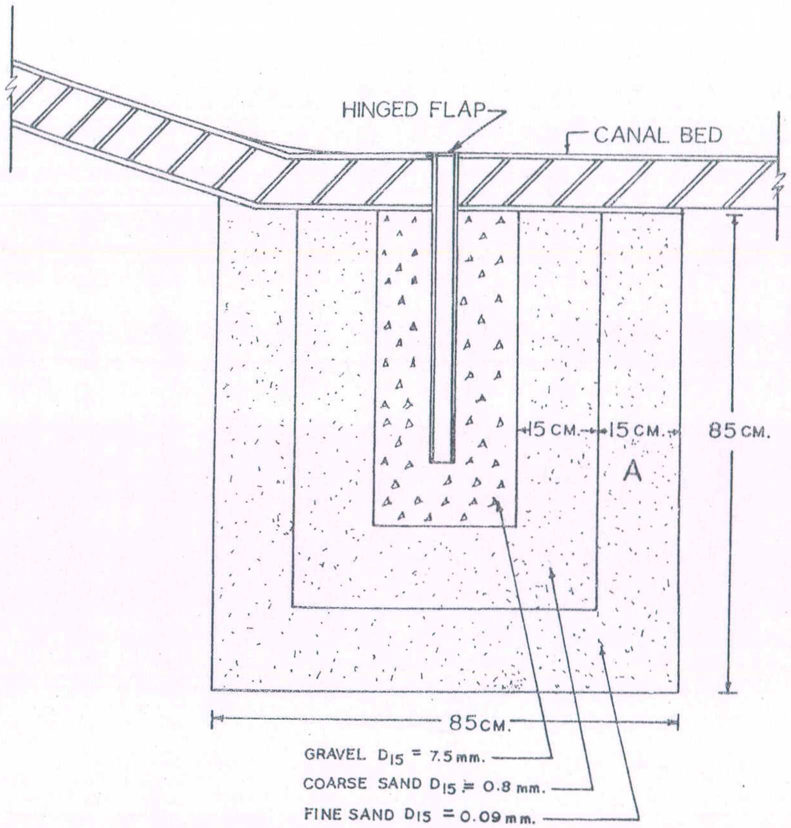
READ FOR THE Q CALCULATED ABOVE & MULTIPLY BY $(S_1/S)^{1/2}$



$$V= \frac{1.0}{N} \times R^{2/3} \times S^{1/2}$$

PLATE NO. 18: CURVES FOR DESIGN OF LINED CHANNEL SIDE SLOPE 1·25:1
N=0·018 S=0·1/1000



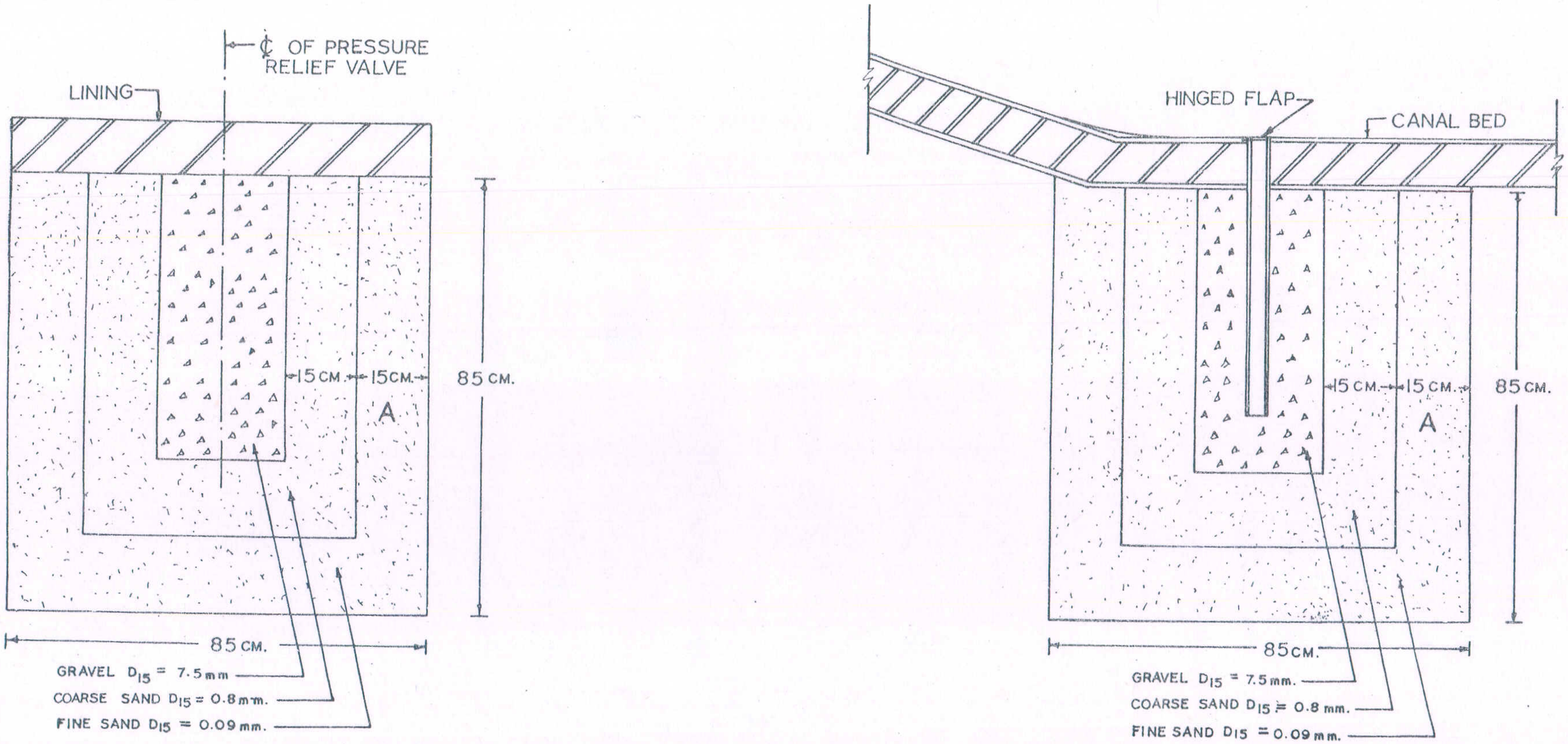


NOTE :-

THE GRADED FILTER SHALL BE DESIGNED IN SUCH A WAY THAT THERE IS NO LOSS OF SOIL PARTICLES. THE GRADATION CURVE OF BED MATERIAL SHOULD BE OBTAINED FROM THE SIEVE ANALYSIS. THE 15% SIZE (D_{15}) OF THE LAYER (A) SHOULD BE AT LEAST FOUR TIMES AS LARGE AS 15% SIZE OF THE SOIL AND LESS THAN FOUR TIMES 85 PERCENT SIZE D_{85} OF THE SOIL. DESGIN OF THE OTHER LAYER SHOULD BE DESGINED IN A SIMILAR WAY TILL THE REQUIREMENT OF THE FILTER OPENING IS MET.

THE 15% SIZE OF VARIOUS LAYERS SHOWN ARE ONLY TYPICAL.

PLATE NO. 19: DETAILS OF FILTER AROUND PRESSURE RELEASE VALVE

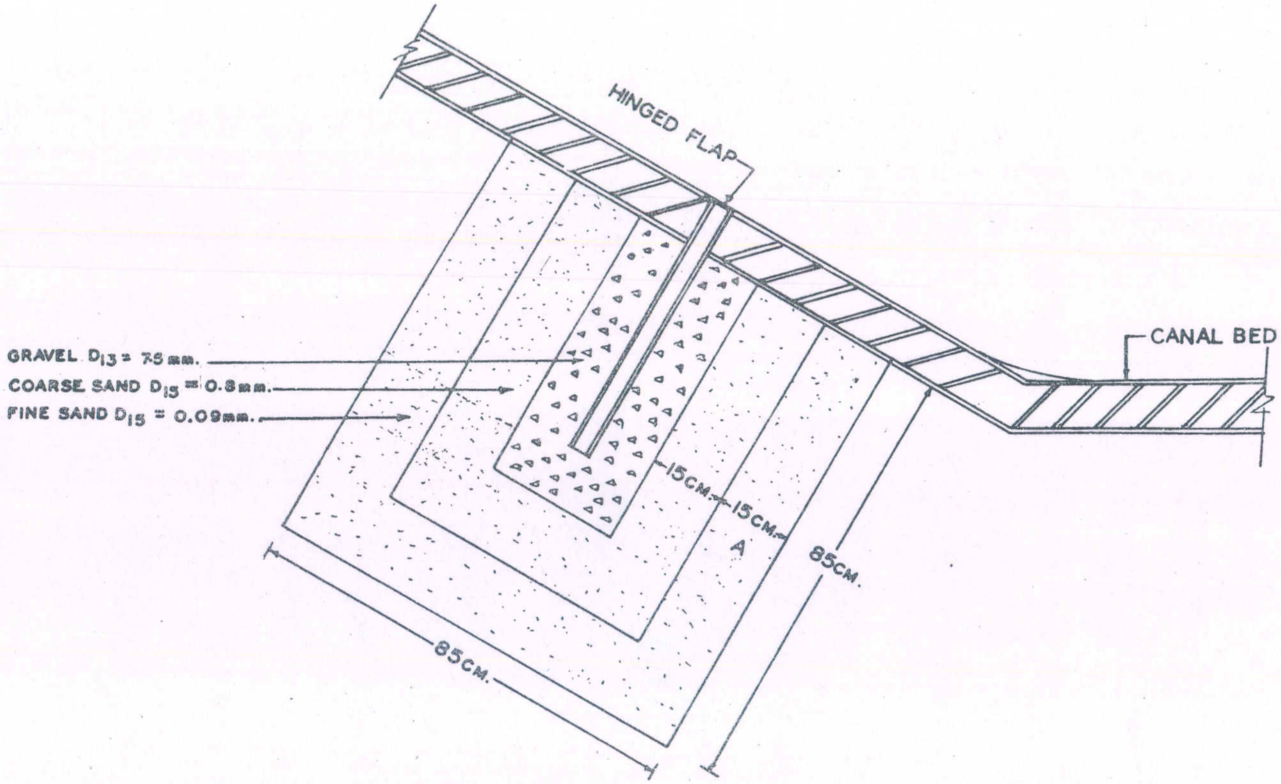


NOTE :-

THE GRADED FILTER SHALL BE DESIGNED IN SUCH A WAY THAT THERE IS NO LOSS OF SOIL PARTICLES. THE GRADATION CURVE OF BED MATERIAL SHOULD BE OBTAINED FROM THE SIEVE ANALYSIS. THE 15% SIZE (D_{15}) OF THE LAYER (A) SHOULD BE AT LEAST FOUR TIMES AS LARGE AS 15% SIZE OF THE SOIL AND LESS THAN FOUR TIMES 85 PERCENT SIZE D_{85} OF THE SOIL. DESGIN OF THE OTHER LAYER SHOULD BE DESGINED IN A SIMILAR WAY TILL THE REQUIREMENT OF THE FILTER OPENING IS MET.

THE 15% SIZE OF VARIOUS LAYERS SHOWN ARE ONLY TYPICAL.

PLATE NO. 19: DETAILS OF FILTER AROUND PRESSURE RELEASE VALVE



NOTE:-

THE GRADED FILTER SHALL BE DESIGNED IN SUCH A WAY THAT THERE IS NO LOSS OF SOIL PARTICLES. THE GRADATION CURVE OF BED MATERIAL SHOULD BE OBTAINED FROM THE SIEVE ANALYSIS. THE 15% SIZE (D_{15}) OF THE LAYER (A) SHOULD BE AT LEAST FOUR TIMES AS LARGE AS 15% SIZE OF THE SOIL AND LESS THAN FOUR TIMES 85 PERCENT SIZE D_{85} OF THE SOIL. DESIGN OF THE OTHER LAYER SHOULD BE DESIGNED IN A SIMILAR WAY TILL THE REQUIREMENT OF THE FILTER OPENING IS MET.

THE 15% SIZE OF VARIOUS LAYER SHOWN ARE ONLY TYPICAL.

PLATE NO. 20: DETAILS OF FILTER AROUND PRESSURE RELEASE VALVE

CHAPTER V

Power Channels

5.1 General

A power channel constitutes an important component of a hydro electric project. Its proper planning and design and maintenance assumes great significance in the efficient functioning of the power project. In addition to the requirements for planning and layout of irrigation canals, power channels need considerations of their own, like water-power studies, surges etc.

5.2 Planning

A prerequisite in the planning of a power channel is to fix the discharge capacity which is based on the water-power studies to be made for arriving at the installed capacity of the power plant. These studies include the flow duration curves and mass curves for available discharge or storage capacity of reservoir and extent of balancing storage/pondage requirements to be provided at suitable points of water conductor system to suit the load demand and type of operation of power stations. In case of stage development of the project the capacity of the channel may have to be fixed for the ultimate stage of power development as indicated by economic studies.

5.3 Design

Power channel design is determined by the type of system adopted. The following three types of operation are normally adopted:

(*a*) Constant discharge in channel with constant water levels upstream to downstream with bypass arrangement from upstream to downstream;

(*b*) Channels with balancing reservoir to take care of fluctuations. This will in many cases, result in reduced capacity requirements of the channel upstream of the reservoir; and

(*c*) Lock operation of channel, in which the channel is used similar to a lock and the discharges in channel fluctuate with the load.

5.4 Cross-Section

The cross-section of the power channel, bed slope etc., are designed on the basis of economic studies considering the optimum cost of construction and cost of energy lost due to head loss in friction. Also, the side slope of the channel section is designed to suit the drawdown conditions in the power channel.

5.5 For power channels carrying water to the power house the phenomenon of surges due to variation of discharge on account of load demand or rejection should be analysed fully. Sufficient free board shall be provided to avoid overtopping of water on channel sides which may endanger the channel section. Depending on the topography, provision of suitable spillover or balancing reservoir of sufficient capacity to act as an open surge basin at forebay may be considered. Factors involved in the analysis of surge phenomenon are as follows :

(*a*) Hydraulic section, slope of the channel and velocity of flow in the channel;

(*b*) Amount of load rejection or load acceptance;

(*c*) Rate of closure of units or acceptance of load; and

(*d*) Size of forebay or surge basin on the channel.

Criteria for analysis of the maximum and minimum surges in power channel shall be the same as for the surges in head race tunnels. Maximum surge height in a power channel due to load rejection may be calculated from the empirical formulae given below :

(*a*) For abrupt closure $h_{max} = \sqrt{K^2+2Kh}$

(*b*) For gradual closure within the period required for the first wave to travel twice the length of the channel.

$$h_{max} = \frac{K}{2} + V\sqrt{\frac{h}{g}}$$

where,

h_{max} = maximum surge wave height

$K = \frac{V^2}{2g}$ = velocity head

V = mean velocity of flow, and

h = effective depth = $\frac{\text{area of cross-section}}{\text{top width}}$

5.6 Lining of Power Channel

Power channels should preferably be lined since:

(*a*) It is hydraulically more efficient thus ensuring smaller cross-section, relatively flatter slope for the same discharge capacity resulting in economy.

(*b*) Loss of water due to seepage or leakage is minimised.

(*c*) Closure of power channel for repairs, if any, are remote and also they would be of short duration only thus interrupting power generation for brief periods only.

(*d*) Cost of operation and maintenance is lower, and

(*e*) Weed growth is minimised.

5.7 Drawdown

Depending upon the pattern of load demand and extent of storage provided, fluctuations occur in water level of the power channel due to utilisation of balancing storage. This effect of drawdown and the rate at which it occurs govern the stability of the side slopes and lining of the channel. In cases of excessive and rapid drawdown suitable automatic control structures may have to be provided to regulate the rate of drawdown. For instant a crest may be required at the outlet of the channel into a balancing reservoir to control the drawdown.

5.8 Sediment Control

Necessary desilting arrangements i.e., silt ejectors shall be provided to remove sediment content to a degree safe for operation of generating units as given in Table VII. The quantity and size of sediment that can be permitted depends on the type of turbine, its head, the size and mineralogical content of the sediment.

The exact requirement is fixed in consultation with manufacturers. Upstream of desilting arrangements, the channel is provided with extra capacity to allow for discharge required to flush out the sediment.

Generally a provision of 15 to 20 percent extra discharge for flushing purposes is considered to be quite adequate. Prototype studies have shown that there is no appreciable increase in the efficiency of the ejectors with further increases in the escapage discharge.

In channels carrying considerable sediment, it may be desirable to design the channel throughout for full capacity even though balancing reservoir is provided, due to necessity for by-passing the balancing reservoir and reducing or avoiding sediment deposition in it. Balancing reservoir and canal system are so designed and operated as to minimise sediment deposition in the reservoir and reduce the necessity of dredging which add to difficulties in operation and maintenance.

TABLE VII

Safe Particle Size for generating units.

Head (*m*)	*Largest Particle Size* (*mm*)
Below 100	0.5
100 to 300	0.2
Above 300	0.1

5.9 Trash Rack

Suitable trash racks are provided at the exit end of power channel that is at the forebay portion wherefrom the penstocks offtake to avoid trash entering the penstocks which would otherwise damage parts of the generating unit.

Suitable provisions are also made for surplusing arrangements in the balancing reservoir in the event of sudden load rejection. Also in case of very long power channels provisions may be made for escape, regulations in power channels for emptying it in case of emergency/periodical closure, if any.

CHAPTER VI

Construction, Operation and Maintenance

6.1 Construction of Channels

Earth channels for irrigation or power projects should be constructed after thorough examination of the materials met with along the alignment. The samples of the soil should be examined in the laboratory and the results of the test should be utilised for making of the canal banks, ensuring that losses of water by seepage and other undesirable factors are avoided. The earthwork should be done as per I.S. 4701 (Latest).

6.1.1 *Service Roads*

In addition to an inspection road provided on the top of the bank in the case of main and branch canals and at the toe of the banks in the case of distributaries a service road is usually provided on the other side of the toe of bank. This road is used for transporting materials during construction and as a public road after construction. In the case of main and branch canals, service roads are sometimes provided, on both the banks particularly in the reaches of the Government waste land and in proprietory areas if the cost of land is not prohibitive. A width of usually 6 m including 2 m for the boundary trench, is provided for this purpose. The boundary trench which is usually 0.30 m deep is excavated as the name implies to mark the boundary of canal land.

6.1.2 *Borrow Pits*

If the earthwork from digging is less than that required for making the banks, borrow pits have to be dug out. Borrow pits, should first be dug from inside the channel section from beds or berms which if properly taken, silt up after running and do not spoil the section. In the bed, the borrow pits may be taken in the Central half width of the section. Along the direction of flow a portion not less than half the length of borrow pits should be left between successive borrow pits. This will ensure quick silting up of the pits. Where berms are wide, similar discontinuous pockets may be taken from the berms. If the internal borrow pits are inadequate to meet the demand, the remaining earth has to be borrowed from outside. The borrow pits should not start at a distance less than 5 m from toe of embankment in small channels and 10 m in the case of large channels. They should not be deeper than 1 m and should be connected by a drain so that they do not hold stagnant water.

6.1.3 *Spoil Banks*

Earth from excavation of a channel surplus to the requirements of banks is deposited as spoil banks. The height of the spoil banks is limited to 6 m. A 3 m space is left between the outer edge of banks and the toe of the spoil for the drain. 3 m wide gaps should be left in the spoil banks after every 100 m length, to dispose off the rain water coming in the drains.

6.1.4 *Boundary Stones*

Boundary stones are fixed at the land boundary every 250 m apart and at every change of land width. These are considered very necessary to avoid any encroachment in Government land. On main canals and branches, distance marks are often provided on both banks, fixed in dowels with top of concrete block flush with its top. On small channels these are fixed on one side only along the service or inspection road.

6.2 Maintenance of Channels

The importance of proper maintenance of canal system is well understood by the field engineers and needs hardly any emphasis. For proper maintenance it is necessary that regular hydraulic surveys comprising longitudinal sections and cross-sections, measurement of discharge and corresponding water levels attained in different reaches etc., be carried out. Stress should also be laid on the importance of eradication of weeds, jungle clearance, berm, cutting etc. It should be obligatory for the field engineers that the longitudinal sections and cross-sections at suitable intervals of each channel may be examined once in five years and revised, if necessary. Inspection roads along the canals should be kept in fit condition and canal banks to be maintained properly for the removal of rain water away from the canals.

6.2.1 *Maintenance of Unlined Channels*

The unlined channels suffer from the problem of silt entry. The position is further aggravated when their full supply discharge is increased. The main problem confronting the engineers charged with the maintenance and operation of such channels, involves complex relationships governing the flow of water and the sediment which it transports.

The following aspects, therefore, should be considered to keep these channels in regime :

(*i*) Hydraulic functioning of channel.

(*ii*) Equitable distribution of irrigation supplies.

(*iii*) Judicious silt clearance, weed clearance berm trimming and jungle clearance.

(*iv*) Proper maintenance of the inspection road for any emergency.

All these aspects are briefly discussed below :

6.2.1.1 *Hydraulic Functioning of a Channel :* The perfectly developed "regime theory" for the design and proper maintenance of unlined canals has won worldwide recognition. Canals which have run for long periods may have already attained final regime and there may be no difficulty in their operation. But this regime is disturbed when a channel is remodelled. This position is further aggravated when their full supply discharge is increased.

In the case of channels where regime is yet to be attained, regular watch need be kept by conducting hydraulic surveys at regular intervals. The hydraulic survey of each channel should be carried out every alternate year and should include observations of bed levels, berm levels, full supply levels, natural surface levels, crest levels, and working heads of flumes, falls regulators and sizes of outlets. If a channel shows repeated tendency to silt up or scour then suitable remedial measures be undertaken to bring the channel back to the regime conditions.

The rules adopted for the regulation of river supplies at head works if not judicious, also affect the hydraulic functioning of barrage ponds and the canals off taking therefrom. The keen demand of irrigation water compeils field engineers to overlook the maintenance aspect and the flushing of sediment deposits in the undersluice pockets/ponds which is vital for efficient operation of canals, is seldom resorted to as the water required for flushing is considered a waste. Thus, review of regulation rules is very essential for proper maintenance of canals.

Another aspect in this regard is inadequate dissipation of energy downstream of falls in unlined canals which causes bed scour and bank erosion.

6.2.1.2 *Equitable Distribution of Irrigation Supplies :* The irrigation system is required to be properly operated and maintained with a view to secure optimum crop yield at minimum cost. The primary aim is to see that water is conveyed to the cultivated land and utilised there in an efficient manner to achieve optimum use of the capital invested in the irrigation system. For this purpose the distribution network should be maintained in good shape and the flow of water closely controlled. Another significant factor is the distribution of supplies from the channel into the field, which contributes a great deal to their economic utilisation. With proper distribution, more area is brought under irrigation with the same supply and there is less wastage. Besides, the water also reaches the tail-end of the system instead of benefiting a few in the head reaches.

6.2.1.3 *Judicious Silt and Weed Clearance :* (*a*) *Silt Clearance :* As regards silt clearance, the prevalent instructions provide that silt clearance upto theoretical bed level and sides as indicated by bed bars is an important aspect of maintenance of the canal system. It, however, provides only temporary relief towards restoring regime of an irrigation channel. Since irrigation channels are required to be non-scouring and non-silting, the cause of silting has to be investigated and remedial measures undertaken.

(*b*) *Weed Growth and its Removal :* Weed growth reduces the carrying capacity of irrigation channel and deteriorates its regime and hydraulic function. The decrease in the carrying capacity is mainly due to two accounts, decrease in the cross-sectional area, and increase in the frictional resistance to flow.

Some of the important factors which encourage the growth of weeds in a canal system are : temperature of water and its chemical compositions, velocities of flow, deposition of silt on the bed, depth of water and reduction of sunlight.

The types of control may be divided into :

(*i*) Regulation measures, alternate wetting and drying.

(*ii*) Chemical measures.

(*iii*) Mechanical

(*iv*) Increase in the velocity of flow by regrading the slope of the channel. This remedy was adopted on the Bhakra Canal. The channels were regraded so that the minimum velocity was not lower than 0.61 m/sec.

6.2.1.4 *Maintenance of Banks and Inspection Roads :* A dry road surface disintegrates rapidly and it is, therefore, necessary that road should be watered regularly. On the main canals and branches, after watering the surface should be worked with rings to give a good even surface. When, however, the soil is poor for this treatment, the road surface should be properly levelled after watering and subsequently scraped to make it smooth. On the distributaries, the watering of road surface should be resorted as frequently as possible. Ruts should be repaired as early as possible. Regarding boundary road, it is usual to construct a small dowel, along the outer edge of the road. The boundry road is flooded of watered and after such watering the boundary road should be properly scraped by means of a scraper. Inspections roads which are not metalled, should be closed to traffic following rain. This is to be done because not only the surface gets badly damaged by the traffic, immediately after rainfall but it may not be safe for the moving traffic also on account of the road being soft and slippery. As soon as the road is firm enough after rain, but before it is dry, it should be scraped and then rolled over with a fairly heavy roller.

It should be realised that both banks of a channel need be given equal attention, because, otherwise, the safety of the channel will be jeopardized and leakage, breaches and over-flow etc. may occur at the non-inspection bank.

6.2.1.5 Generally it is observed that tail reaches are deprived of their due share of water. The reasons for this could be due to low discharges or more transmission losses in canals. In view of this, discharge observations should be carried out in various reaches of canals to assess the transmission losses. In case seepage loss/transmission loss are observed to be more than those planned, this should be studied and remedial measures adopted in those reaches to conserve the water.

6.2.1.6 As per regulation rules minors and distributaries should be fed at full supply level, in case of low discharges in main/branch canals to feed the outlets. Observations should be made whether minors/distributaries are fed at FSL or not. This may be possible with and without cross regulator depending upon FSL of paraet and off-take channels and other design assumptions. In case the system is not able to meet this requirement, feasibility of providing cross regulator at suitable locations may have to be examined to assure full supply to minor/distributary. As pointed out earlier gauge discharge observations should be carried out. Gauges on the upstream and downstream of the structures should be installed to assist in taking the gauge readings and discharges.

6.2 2 *Maintenance of Lined Channels*

Lining of irrigation channels and their subsequent maintenance is of great importance. Lining affects directly the design as well as the operation of irrigation system, the lining not only facilitates more proper operation but also reduces maintenance cost. The reduction in maintenance cost would be substantial only if the lining is sufficiently strong to resist the hydrostatic pressure behind it and the backfill has been properly compacted so as to avoid any settlement. Lining also ensures the stability of section which in the case of distributaries, reduces remodelling and alteration of outlets. The following measures should be taken for maintaining the channel in perfect condition.

6.2.2.1 *Proper Drainage of Banks* : The catch water drains alongwith their outfalls should be thoroughly cleaned before the rainy season and again from time to time as required. Proper cross slopes of the banks should be maintained so that rain water is drained off quickly through the catch water drain, thereby reducing the chances of pressure being exerted on lining due to percolation. To facilitate drainage of the bank and to avoid flow on the bank along the canal, passage for water at suitable intervals should be provided. The slope at the top of dowel be maintained properly so that rain water should drain towards the bank and not towards the lining.

6.2.2.2 *Removal of Weeds :* The growth of weeds on the lining is removed with a sharp edge and cracks/open joints are raked and filled with mortar and bitumen.

6 2.2.3 *Maintenance of inner slopes in high cutting reaches :* For preventing erosion of soil on inner slopes in cutting reaches, the grass grown there should not be allowed to be cut from roots.

6.2.2.4 *Repairs to cracks in lining and joints* : Whenever any opportunity is available for lowering or stopping the supplies for any reason, efforts should be made to repair the cracks and joints in lining at the earliest. These should be properly raked and then filled with cement mortar and bitumen as per site conditions.

6.2.2.5 *Sand Grouting behind lining* : From perusal of causes of damages to lining it is clear that lining slabs generally fail due to formation of cavity behind the slabs. The cavity is filled by filling sand behind lining. A hole of about 150 mm dia is cut in the lining slab and water is poured in the hole with drums. If sufficient quantity of water is taken by the hole, then it is established that a cavity behind the lining exists. In that case coarse sand is poured in the hole alongwith water so that sand flows in the cavity with the flow of water. The process is continued till the inflow of sand ceases and whole cavity is filled. In some cases intake of the sand is abnormal which is attributed to existence of wider cracks in lining at greater depths, which does not allow the sand to be retained in the cavity. In that case, in order to provide a check to the flow of sand through the crack into the channel, sand mixed with shingle is poured along with water till the cavity is filled. Sand grouting behind lining is very important for the life of lining and safety of the canal. It is a sort of continuous process which should be considered as an essential part of general maintenance of a lined canal system.

6.2.2.6 *Membrane lining :* In cases of membrane lining buried under earth there is every chance of rupture due to animal hooves or weed growth. Location of rupture point should be ascertained and earth burden should be removed and cleaned. Patch of membrane should be added so as to make the joint water tight. Overlaping of 150 mm on all sides is suggested to provide proper water seal joint. Animal/cart crossings could also be provided.

6.2.2.7 In case of canals where the sub-soil water level is high above the bed level, closure of the canal should not be sudden as otherwise the lining is likely to be damaged due to excessive hydrostatic pressures behind the lining. Experiments have been conducted in the Irrigation and Power Research Institute, Amritsar, regarding the safe limits of hydrostatic pressure which single brick tile and double brick tile linings can withstand without getting damaged. It has been found that single tile lining can withstand differential pressure up to 15 cm whereas double tile lining can tolerate pressures up to 24 cm.

In the particular case tested in the Research Institute, it has been found that drawdown rate of 30 cm per hour is safe in case of single tile lining whereas double tile lining remains safe up to drawdown rate of 45 cm/hour. However, each case of a lined canal should be studied separately to assess the safe drawdown rate and the same should be kept in view by the operation and maintenance staff.

6.2.2.8 As indicated in Para 2.10 the silt charge in the water entering into canal at diversion works is considerable inspite of providing silt excluders in the head works. It is observed that the canals are run in the initial stages of the project at very low discharge resulting in low velocities and high silting which reduces the capacity of canal. Taking into consideration these factors it is desirable that the main canals taking off from the diversion structures should as far as possible not be run at less than 0.5 to 0.7 of designed discharge particularly during high flow periods. Portions of discharge in excess of irrigation demand can be escaped through the escapes provided in the system.

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