21.1 Design of Canals

Many procedures have been developed over the years for the hydraulic design of open channel sections. The complexity of these procedures vary according to flow conditions as well as the level of assumption implied while developing the given equation. The Chezy equation is one of the procedures that was developed by a French engineer in 1768 (Henderson, 1966). The development of this equation was based on the dimensional analysis of the friction equation under the assumption that the condition of flow is uniform. A more practical procedure was presented in 1889 by the Irish engineer Robert Manning (Chow, 1959). The Manning equation has proved to be very reliable in practice.

The Manning equation invokes the determination of flow velocity based on the slope of channel bed, surface roughness of the channel, cross-sectional area of flow, and wetted perimeter of flow. Using this equation, the solution procedures are direct for determination of flow velocity, slope of channel bed, and surface roughness. However, the solution for any unknown related to the cross-sectional area of flow and wetted perimeter involves the implementation of an implicit recursive solution procedure which cannot be achieved analytically. Many implicit solution procedures such as the Newton-Raphson, Regula-Falsi (false position), secant, and the Van Wijngaarden-Dekker-Brent Methods (Press et al., 1992).

One of the important topics in the area of Free surface flows is the design of channels capable of transporting water between two locations in a safe, cost - effective manner. Even though economics, safety, and aesthetics must always be considered, in this unit thrust is given only to the hydraulic aspects of channel design. For that discussion is confined to the design of channels for uniform flow. The two types of channels considered are

(1) lined or nonerodible;

(2) unlined, earthen, or erodible.

There are some basic issues common to both the types and are presented in the following paragraphs.

1. Shape of the cross section of the canal.

2. Side slope of the canal.

3. Longitudinal bed slope.

4. Permissible velocities - Maximum and Minimum.

5. Roughness coefficient.

6. Free board.

1. Shape of cross section

From the Manning and Chezy equation, it is obvious that the conveyance of a channel increases as the hydraulic radius increases or as the wetted perimeter decreases. Thus, there is among all channel cross sections of a specified geometric shape and ares an optimum set of dimensions for that shape from the viewpoint of hydraulics. Among all possible channel cross sections, the hydraulically efficient section is a semicircle since, for a given area, it has the minimum wetted perimeter. The proportions of the hydraulically efficient section of a specified geometric shape can be easily derived. The geometric elements of these sections are summarized in Table. It should be noted that , the hydraulically efficient section is not necessarily the most economic section.

In practice the following factors are to be kept in mind:

a. The hydraulically efficient section minimizes the area required to convey a specified discharge. however, the area which required to be excavated to achieve the flow area required by the hydraulically efficient section may be much larger if one considers the removal of the over burden.

b. It may not be possible to construct a hydraulically efficient stable section in the available natural condition. If the channel is to be lined, the cost of the lining may be comparable with the cost of excavation.

c. The cost of excavation depends on the amount of material that is to removed, in addition to. Further Topography of the land access to the site also influence the cost of disposal of the material removed.

d. The slope of the channel bed must be considered also as a variable since it is not necessarily completely defined by topographic consideration. For example, a reduced channel slope may require a larger flow area to convey the flow, on the other hand the cost of excavation of the overburden may be reduced.

2. Side slopes

The side slopes of a channel depend primarily on the engineering properties of the material through which the channel is excavated. From a practical viewpoint, the side slopes should be suitable for prelimianary purposes. However, in deep cuts, side slopes are often steeper above the water surface than they would be in an irrigation canal excavated in the same material.In many cases, side slopes are determined by the economics of construction. In this regard following observations are made:

a. In many unlined earthen canals, side slopes are usually 1.5 : 1; However, side slopes as steep as 1:1 have been used when the channel runs through cohesive materials.

b. In lined canals, the side slopes are generally steeper than in an unlined canal. If concrete is the lining material, side slopes greater than 1 : 1 usually require the use of forms, and with side slopes greater than 0 .75 : 1 the linings must be designed to withstand earth pressures. Some types of lining require side slopes as flat as those used for unlined channels.

c. Side slopes through cuts in rock can be vertical if this is desirable.

Table: Suitable side slopes for channels built in various types of materials (chow, 1959)

Material	Side slope
Rock	Nearly vertical
Muck and peat soils	1 / 4 : 1
Stiff clay or earth with concrete lining	1 / 2 : 1 to 1 : 1
Earth with stone lining or each for large channels	1 : 1
Firm clay or earth for small ditches	1 1/2 : 1
Loose,sandy earth	2 : 1
Sandy loam or porous clay	3 : 1

Indian standards for canal in cutting and embankment

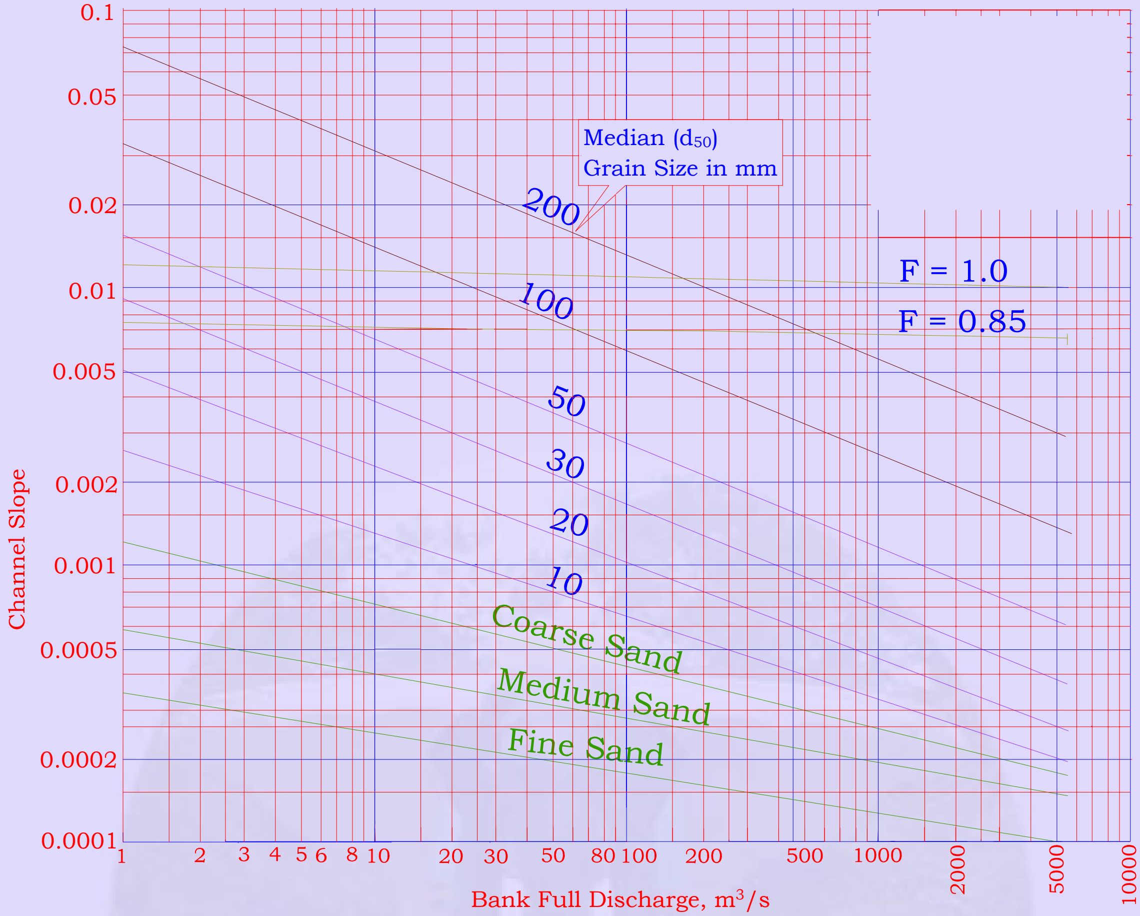
	Side slope (Horizontal to Vertical m:1)	
Material (soil)	Cutting	Embankment
Hard clay or gravel	0.75 : 1	1.5 to 1.0
Soft Clay and alluvial soils	1.0 to 1.0	2.0 to 1.0
Sandy loam	1.5 to 1.0	2.0 to 1.0
Light sand	2.0 to 1.0	2.0 to 1.0 to 3.0 to 1.0
Soft rock	0.25 to 1.0 to 0.5 to 1.0	-
Hard rock	0.125 to 1 to 0.25 to 1.0	-

3. Longitudinal slope

The longitudinal slope of the channel is influenced by topography, the head required to carry the design flow, and the purpose of the channel. For example, in a hydroelectric power canal, a high head at the point of delivery is desirable, and a minimum longitudinal channel slope should be used. The slopes adopted in the irrigation channel should be as minimum as possible inorder to achieve the highest command. Generally, the slopes vary from 1 : 4000 to 1 : 20000 in canal. However, the longitudinal slopes in the natural river may be very steep (1/10).

Slope of the channels in Western Ghats

Gentle slope	10 m / km	$S_0 = 0.01$
Moderate slope	10 to 20 m / km	$S_0 = 0.01$ to 0.02
Steep slope	$\geq$20 m / km	$S_0 \geq 0.02$



4. Permissible Velocities: Minimum and Maximum

It may be noted that canals carrying water with higher velocities may scour the bed and the sides of the channel leading to the collapse of the canal. On the other hand the weeds and plants grow in the channel when the nutrients are available in the water. Therefore, the minimum permissible velocity should not allow the growth of vegetation such as weed, hycinth as well you should not be permitting the settlement of suspended material (non silting velocity). The designer should look into these aspects before finalizing the minimum permissible velocity.

"Minimum permissible velocity" refers to the smallest velocity which will prevent both sedimentation and vegetative growth in general. an average velocity of

(0.60 to 0.90 m/s) will prevent sedimentation when the silt load of the flow is low.

A velocity of 0.75 m /s is usually sufficient to prevent the growth of vegetation which significantly affects the conveyance of the channel. It should be noted that these values are only general guidelines. Maximum permissible velocities entirely depend on the material that is used and the bed slope of the channel. For example: in case of chutes, spillways the velocity may reach as high as 25 m/s. As the dam heights are increasing the expected velocities of the flows are also increasing and it can reach as high as 70 m/s in exceptional cases. Thus, when one refers to maximum permissible velocity, it is for the normal canals built for irrigation purposes and Power canals in which the energy loss must be minimised. Hence, following table gives the maximum permissible velocity for some selected materials.

Maximum permissible velocities and n values for different materials		
material	V (m / s)	n
Fine sand	0.5	0.020
vertical Sandy loam	0.58	0.020
Silt loam	0.67	0.020
Firm loam	0.83	0.020
Stiff clay	1.25	0.025
Fine gravel	0.83	0.020
Coarse gravel	1.33	0.025
Gravel	1.2	
Disintegrated Rock	1.5	
Hard Rock	4.0	
Brick masonry with cement pointing	2.5	
Brick masonry with cement plaster	4.0	
Concrete	6.0	
Steel lining	10.0	

5. Resistance to the flow

In a given channel the rate of flow is inversely proportional to the surface roughness. The recommended values for a different types of lining are given below:

Manning roughness for the design of several types of linings is as follows

Surface Characteristics	Value of n
Concrete with surface as indicated below	
(a) Trowel finish	0.012 - 0.014
(b) Flat finish	0.013 - 0.015
(c) Float finish some gravel on bottom	0.015 - 0.017
(d) Gunite, good section	0.016 - 0.017
Concrete bottom float finished sides as indicated below	
(a) Dressed stone in mortar	0.015 - 0.017
(b) Random stone in mortar	0.017 - 0.020
(c) Cement rubble masonry plastered	0.016 - 0.020
Brick lining	0.014 - 0.017

Asphalt lining	
(a) Smooth	0.013
(b) Rough	0.016
Concrete lined excavated rock with	
(a) Good section	0.017 - 0.020
(b) Irregular section	0.022 - 0.027

These values should, however, be adopted only where the channel has flushing velocity. In case the channel has non-flushing velocity the value of n may increase due to deposition of silt in coarse of time and should in such cases be taken as that for earthen channel. The actual value of n in Manning formula evaluated on the basis of observations taken on Yamuna Power Channel in November 1971 ranged between 0.0175 and 0.0229 at km 0.60 and between 0.0164 and 0.0175 at km 2.05. The higher value of n evaluated at km 0.60 could be attributed to the deposition of silt in head reaches of the channel.

Table: Manning Roughness Coefficients

Lining Category	Lining Type	n-value different depth ranges		
		Depth ranges		
		0 – 15 cm	15 – 60 cm	> 60 cm
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temporary	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.021	0.019
	Straw with Net	0.065	0.033	0.025
	Cured Wood Mat	0.066	0.035	0.028
	Synthetic Mat	0.036	0.025	0.021
Gravel Riprap	2.5-cm (d_{50})	0.044	0.033	0.030
	5 -cm (d_{50})	0.066	0.041	0.034
Rock Riprap	15-cm (d_{50})	0.104	0.069	0.035
	30-cm (d_{50})	-	0.078	0.040

6. Freeboard

The term freeboard refers to the vertical distance between either the top of the channel or the top of the channel is carrying the design flow at normal depth. The purpose of freeboard is to prevent the overtopping of either the lining or the top of the channel fluctuations in the water surface caused by

(1) wind - driven waves,

(2) tidal action,

(3) hydraulic jumps,

(4) superelevation of the water surface as the flow goes round curves at high velocities,

(5) the interception of storm runoff by the channel,

(6) the occurrence of greater than design depths of flow caused by canal sedimentation or an increased coefficient of friction, or

(7) temporary mis-operation of the canal system.

There is no universally accepted role for the determination of free board since, waves, unsteady flow condition, curves etc., influence the free board. Free boards varying from less than 5% to 30% of the depth are commonly used in design. In semi-circular channels, when the velocities are less than 0.8 times the critical velocity then 6% of the diameter as free board have been proved to be adequate.

The freeboard associated with channel linings and the absolute top of the canal above the water surface can be estimated from the empirical curves. In general, those curves apply to a channel lined with either a hard surface, a membrane, or compacted earth with a low coefficient of permeability. For unlined channels, freeboard generally ranges from 0.3m for small laterals with shallow depths of flow to 1.2m for channels carrying 85 m^3 /s at relatively large depths of flow. A prelimimary estimate of freeboard for an unlined channel can be obtained from USBR formula.

$$F_B = \sqrt{Cy}$$

in which F_B *is the freeboard in feet, y is the design depth of flow in feet,*

C is a coefficient. However, it may be noted that C has dimensions of $L^{1/2}$.

C varies from 1.5 at $Q = 0.57\ m^3/s$ to 2.5 for canal capacity equal to and more than 85 m^3/s.

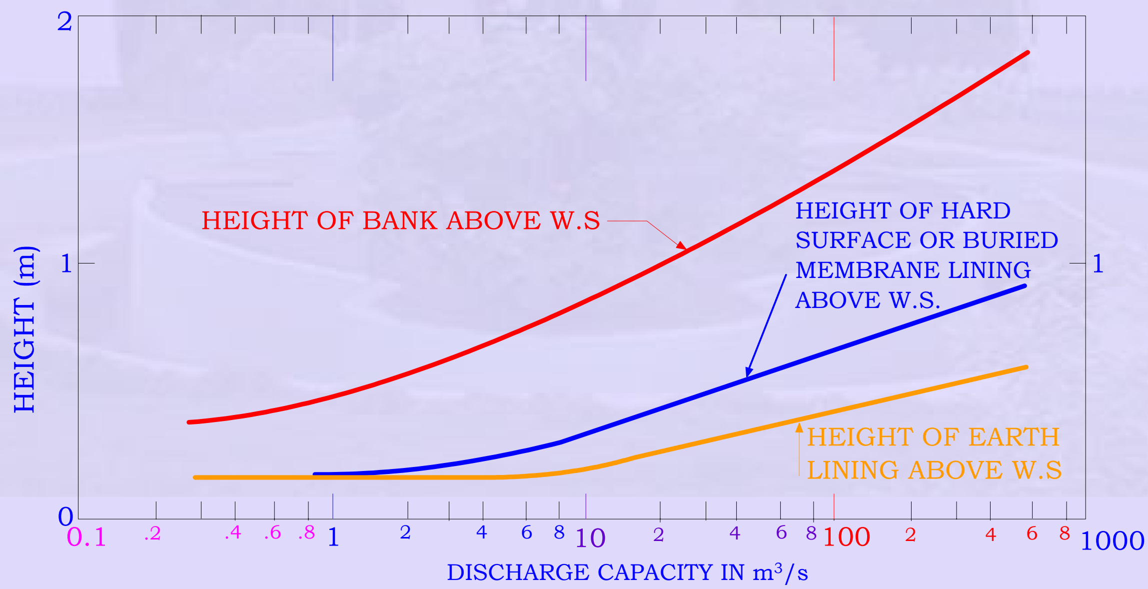
The free board recommended by USBR for channels are given below

Q m^3/s	Free board F_B in m
< 0.75	0.45
0.75 - 1.5	0.60
1.5 - 85.0	0.75
> 85	0.90

The free board (measured from full supply level to the top of lining) depends upon the size of canal, velocity of water, curvature of alignment, wind and wave action and method of operation. The normal free board is 15 cm for small canals and may range up to 1.0 m for large canals. The U.S.B.R. practice for the minimum permissible free board for various sizes of canal is given in Figure. Indian Standard IS : 4745 recommends a free board of 0.75 m for canal carrying a discharge of more than 10 m^3/sec.

Free board as per Indian Standards (IS 4745 - 1968), (IS 7112 - 1973)

Discharge Q (m^3/s)	Free board (m)	
	Unlined	Lined
< 10.0	0.50	0.60
> 10.0	0.75	0.75



Bank height for canals and free board for hard surface or buried membrane and, earth lining

Free boards provided in some of the major lined canals in India are given below

Sl.No.	Name of Canal	Free Board F_B in m
1	Yamuna Power Channel	0.75
2	Nangal Hydel Channel	0.76
3	Gandak Canal	0.45
4	Lower Ganga Canal (Link Canal)	0.30
5	Rajasthan Feeder Channel	0.76
6	Tungabhadra Canal	0.30
7	Mannaru Canal	0.30
8	Sunder Nagar Hydel Channel	0.91
9	Sarda Sahayak Feeder Channel	1.25

Actually adopted Free board for different ranges of discharge in India are below

Q (m^3/s)	< 0.15	0.15 - 0.75	0.75 - 1.50	1.50 - 9.00	> 9.00
Free board (m)	0.30	0.45	0.60	0.75	0.90

References

1. IS: 4745 - 1968, Code of practice for Design of Cross Section for Lined Canals, Indian Standards Institution, New Delhi, 1968.

2. IS: 7112 - 1973, Criteria for Design of Cross Section for Unlined Canals in Alluvial Soil, Indian Standards Institution, New Delhi, 1974.

When flow moves around a curve, a rise in the water surface occurs at the outer bank with a corresponding lowering of the water surface at the inner bank. In the design of a channel, it is important that this difference in water levels be estimated. If all the flow is assumed to move around the curve at the subcritical average velocity , then super elevation is given by

$$\Delta y_{max} = \frac{V_{mb}^2}{2g}\left(\frac{2T}{r_c}\right)$$

In India, the minimum radii of curvature are often longer than those used in the United States. For example, Some Indian engineers recommend a minimum radius of 91m for canals carrying more than 85 m^3/s (Houk, 1956). Suggested radii for different discharges are given in table below.

Radius of curves for lined canals

Discharge (m^3/s)	Radius (minimum) in m
280 and above	900
Less than 280 to 200	760
Less than 200 to 140	600
Less than 140 to 70	450
Less than 70 to 40	300

Note: Where the above radii cannot be provided, proper super elevation in bed shall be provided.

The width of the banks along a canal are usually governed by a number of considerations which include the size of the need for maintenance roads. Where roads are needed, the top widths for both lined and unlined canals are designed so that precipitation will not fall in to the canal water and, to keep percolating water below the ground level beyond the banks.

21.1.1 Hydraulically Efficient Channel

It is well known that the conveyance of a channel section increases with increases in the hydraulic radius or with decrease in the wetted perimeter. Therefore, from the point of hydraulic aspects, the channel section having the least wetted perimeter for a given area has the maximum conveyance; such a section is known as the Hydraulically efficient channel. But this is popularily referred as Best Hydraulic section. The semicircle has the least perimeter among all sections with the same area; hence it is the most hydraulically efficient of all sections.

The geometric elements of six best hydraulic section are given in Table. It may be noted that it may not be possible to implement in the field due to difficulties in construction and use of different materials. In general, a channel section should be designed for the best hydraulic efficiency but should be modified for practicability. From a practical point of view, it should be noted that a best hydraulic section is the section that gives the minimum area of flow for a given discharge but it need not be the minimum excavation. The section of minimum excavation is possible only if the water surface is at the level of the top of the bank. When the water surface is below the bank top of the bank (which is very common in practice), channels smaller than those of the best hydraulic section will give minimum excavation. If the water surface overtops the banks and these are even with the ground level, wider channels will provide minimum excavation. Generally, hydraulically efficient channel is adopted for lined canals. It may also be noted that hydraulically efficient channel need not be economical channel (least cost).

Geometric elements of best hydraulically efficient section (figures)

Cross Section	A	P	R	T	D	$Z = A\sqrt{D}$
Rectangular	$2y^2$	4y	0.5 y	2y	y	$2y^{2.5}$
Trapezoidal	$\sqrt{3}y^2$ $(1.732y^2)$	$2\sqrt{3}y$ (3.464y)	0.5 y	$\frac{4\sqrt{3}}{3}y$ (2.3094y)	$\frac{3}{4}y$ (0.75y)	$\frac{3}{2}y^{2.5}$ $(1.5y^{2.5})$
Triangular	y^2	$2\sqrt{2}y$ 2.828y	$\frac{\sqrt{2}}{4}y$ 0.3535y	2y	$\frac{y}{2}$ 0.5y	$\frac{\sqrt{2}}{2}y^{2.5}$ $0.707y^{2.5}$
Semi Circular	$\frac{\pi}{2}y^2$	πy	$0.5y$	2y	$\frac{\pi}{4}y$	$\frac{\pi}{4}y^{2.5}$ $0.25\pi y^{2.5}$
Parabola $\frac{4}{3}\sqrt{2}\ y^2$	$\frac{4}{3}\sqrt{2}\ y^2$ $1.89y^2$	$\frac{8}{3}\sqrt{2}y$ 3.77y	y/2 0.5y	$2\sqrt{2}y$ 2.83y	$\frac{2}{3}y$ 0.667y	$\frac{8}{9}\sqrt{3}y^{2.5}$ $1.5396y^{2.5}$
Hydrostatic Catenary	1.40 y^2	2.98 y	0.468 y	1.917 y	0.728y	1.91 $y^{2.5}$

** Hydrostatic Caternary (Linteria)

Flexible sheet: Filled with water upto rim, and held firmly at the top ends without any effect of fixation on shape. Shape assumed under self height of water is called Hydrostatic Catenary.

21.1.2 Selection of Lining

Introduction

The need for lining channels in alluvium has long been identified to conserve every bit of water for more and more utilisation. Lining of an irrigation channel is restored to achieve all or some of the following objectives keeping in view the overall economy of the project.

The major advantages of rigid impermeable linings are as follows:

(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-section (and there by saving in land) due to increase in permissible velocity by reduction in the value of rugosity and availing of steeper slope, where available. Minimize excavation costs

(d) Improvement of discharging capacity of existing channels.

(e) Improvement of operational efficiency.

(f) Prevention of weed growth.

(g) Reduction of maintenance cost.

(h) Long economic life

(i) Insure Cross section stability from scour, low flow conditions etc.

Canal Lining

The lining commonly adopted for irrigation channels can be classified into three groups

1. Rigid-impermeable Lining,

2. Flexible and Permeable Permanent Linings and

3. Flexible Temporary Linings.

Example for the same are indicated in the box.

Canal Lining

Rigid Impermeable Linings	Flexible and Permeable Permanent Linings	Flexible Temporary
Rubble Masonry	Rip-rap or Stone Blocks	Bare Soil
Cast-in-place Concrete	Gabions	Straw with Netting
Grouted Rip-rap or Grouted	Interlocking Pre-cast Concrete	Hemp or Jute Mats
Pre-cast Concrete	Interlocking Synthetic Units	Synthetic Matting
Soil Cement	Vegetation and Grasses	

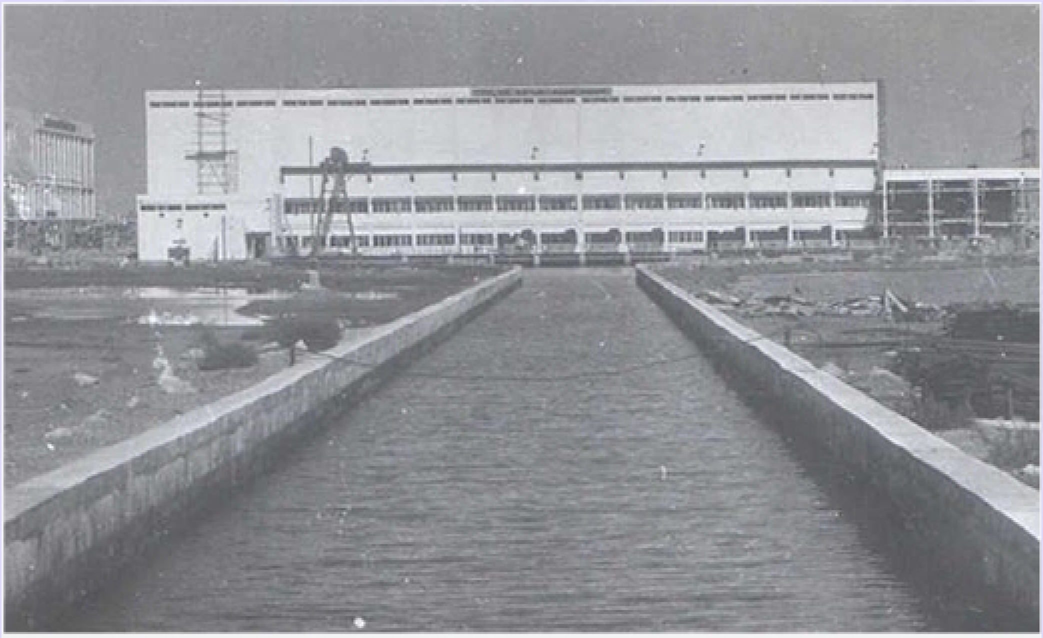
There are different types of lining like Cement Concrete, Shotcrete, Soil cement, Asphaltic Concrete, etc.

Advantages of Flexible and Permeable Linings:Lining easily fits to cross section shape.

Allows infiltration into channel bed, hence loss of water. Partial failure can occur and still can resist erosion.

Canal piercing through a hill range by a tunnel, Tungabhadra Project

A lined canal, Tungabhadra Project



Cooling water intake channel, Tuticorin
View towards the Power Station

Intake Canal - View towards the Sea, Tuticorin

Lined Canal, Tungabhadra

Concrete Flume - Super Critical Flow
(2 m^3/s, 1 m width)

21.1.3 Design of Lined Channels

Lined channels are built for five primary reasons:

1. To permit the transmission of water at high velocities through areas of deep or difficult excavation in a cost - effective fashion.

2. To permit the transmission of water at high velocity at a reduced construction cost.

3. To decrease canal seepage, thus conserving water and reducing the waterlogging of lands adjacent to the canal.

4. To reduce the annual cost of operation and maintenance.

5. To ensure the stability of the channel section.

The design of lined channels from the view point of hydraulic engineering is a rather elementary process which generally consists of proportioning an assumed channel cross section. Details of some typical cross section of lined channels used on irrigation projects in the India are given elsewhere. A recommended procedure for proportioning a lined section is summarized in table given below. In this table, it is assumed that the design flow Q_D, the longitudinal slope of the channel S_0, the type of channel cross section e.g., trapezoidal, and the lining material have all been selected prior to the initiation of the channel design process.

Step	Process
1	Estimate n or C for specified lining material and S_0
2	Compute the value of section factor $AR^{2/3} = nQ/\sqrt{S_o}$ or $AR^{1/2} = Q/\left(C\sqrt{S_o}\right)$
3	Solve section factor equation for yn given appropriate expressions for A and R (Table) Note: This step may be required with assumptions regarding side slopes, bottom widths, etc. (As a thumb rule for quick computation y can be taken as $0.5\sqrt{A}$ and for trapezoidal section it can be shown as $\frac{b}{y} = 4 - m$. In India, y for the trapezoidal channel can be taken as $0.577\sqrt{A}$ which corresponds to $\frac{b}{y} = 3 - m$ for earth canals).
4	If hydraulically efficient section is required, then the standard geometric characteristics (click) are used and yn is to be computed.
5	Check for 1. Minimum permissible velocity if water carries silt and for vegetation (Check whether the velocity is adequate to prevent sedimentation (V= 0.6 to 0.9 m / s). Check whether velocity is adequate to prevent vegetation growth (V = 0.75 m/s)). 2. Froude number (Check Froude number and other velocity constraints such as (for non-reinforced concrete linings $V \leq 2.1$ m/s and Froude number ≤ 0.8. For reinforced linings $V \leq 5.5$ m/s)). Generally, Froude number should be as small as possible for Irrigation canals and should be less than 0.35. Higher Froude numbers is permitted as in the case of super critical flows such as in chutes, flumes. Decide the dimensions based on practicability.

6	Estimate 1. Required height of lining above water surface, 2. Required freeboard, Figure. Balance excavations costs, costs of channel lining and assess the needs to modify "Hydraulically efficient section".
7	Summarize the results with dimensioned sketch.

Example of Rigid Lined Channel Design: Design a concrete lined channel (rough finish n = 0.015) to carry 20 m^3/s on a slope of 0.0015. Consider the hydraulically efficient trapezoidal shape.

Solution

For hydraulically efficient trapezoidal channel

$$A = 1.73y^2,\ P = 3.46y,\ R = \frac{y}{2}$$

$$\boxed{n = 0.015,}$$

$$Q = \frac{1}{n} AR^{2/3}\ S_0^{1/2}$$

$$20 = \frac{1}{0.015}\left(1.73y^2\left(\frac{y}{2}\right)^{\frac{2}{3}}(0.0015)^{\frac{1}{2}}\right)$$

$$y^{\frac{8}{3}} = 7.107$$

$$y = 2.086\ m$$

For Trapezoidal channel width is given by

$$b = \frac{2}{\sqrt{3}}y,$$

$$b = 1.15y = 2.409\ m$$

$$m = \frac{\sqrt{3}}{3} = 0.5773\ \left(\text{i.e.,} = 60^o\right)$$

$$\text{Velocity} = \frac{Q}{A} = \frac{20}{1.73y^2} = 2.656 \text{ m/s}$$

$$\text{Hydraulic mean depth } D = \frac{A}{T} = \frac{1.73y^2}{\frac{4}{\sqrt{3}}y} = 0.749y = 1.563 \text{ m}$$

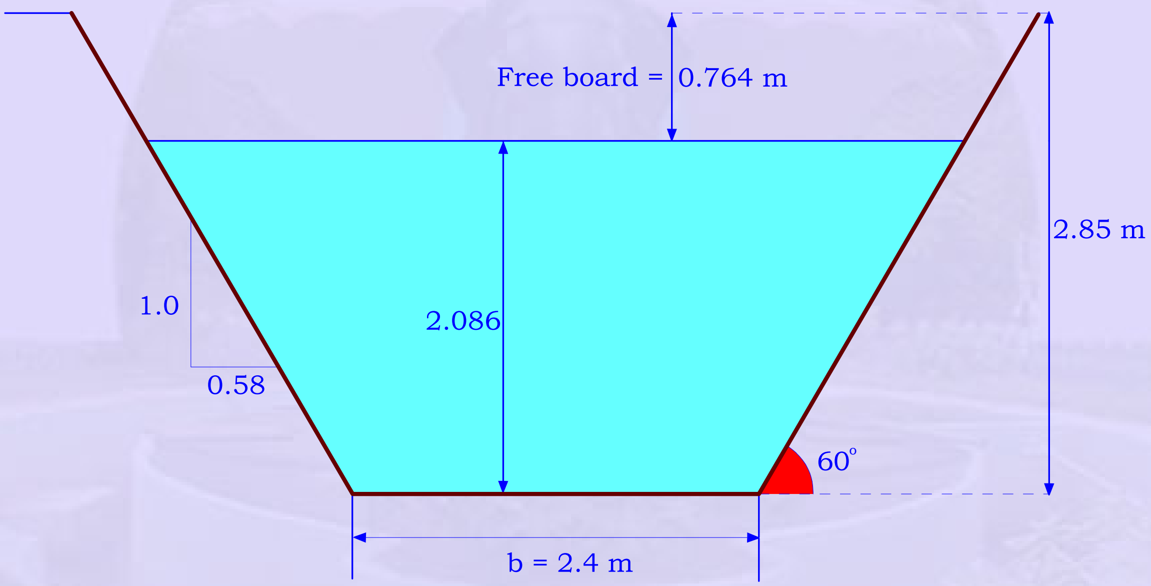
$$\text{Froude Number} = \frac{V}{\sqrt{gD}} = 0.678$$

Freeboard for discharge Q = 20m^3/s is 0.75 m to nearest convenient elevation.

Freeboard may be modified to 0.764 m.

Hence, the total depth of the channel 2.086 + 0.764 = 2.850 m

Hence the total depth of the channel is 2.850 m. The designed cross section is shown in the figure.



Design a trapezoidal channel to carry Q = 20.25 m^3/s, V = 1.5 m^3/s, n = 0.025, S_0 = 0.0016, side slope m = 2. Assume a bed width of 6 m.

Solution

Step 1: Q, n, S_0 and m have been given

$$A = (b + my)$$

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

$$R = \frac{(b+my)}{b+2y\sqrt{1+m^2}}$$

$$AR^{2/3} = \frac{nQ}{\sqrt{S_0}} = 0.025 * \frac{20.25}{\sqrt{0.0016}} = 12.656$$

$$\text{Area} = \frac{\text{Discharge}}{\text{Velocity}} = \frac{20.25}{1.5} = 13.5\, m^2$$

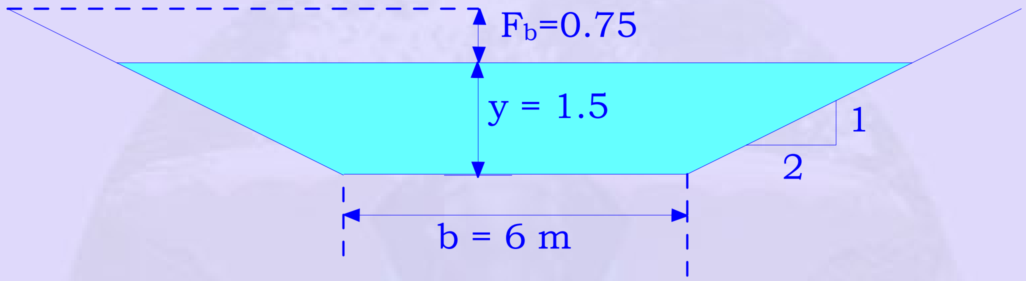
$$13.5 = (6 + 2y)\,y$$

$$\text{Solving for } y, \text{ we get } y = 1.5 \text{ m}$$

$$\frac{b}{y} = 4$$

Add a free board of *0.75 m.*

Designed channel is shown in figure.



21.1.4 Design of Stable Unlined Channels

Erodible Channels which Scour but do not silt. The behaviour of flow in erodible channels is influenced by several parameters and precise knowledge is not available on various aspects. Unlined channels with channel bed and banks composed of earth, sand or gravel must be designed so that they maintain a stable configuration. There are three procedures.

1. Velocity based Method of maximum permissible velocity.

2. Regime Theory - Emprical equations for channels with equilibrium sediment throughput ("Live - Bed" equations).

3. Shear Based - Tractive force methods, Shield analysis.

Method of maximum permissible velocity also known as non erodible velocity:

It is the highest mean velocity that will cause no erosion in the channel body.

When compared with the design process typically used for lined channels, the design of stable, unlined or erodible, earthen channels is a complex process involving numerous parameters, most of which cannot be accurately quantified. The complexity of the erodible channel design process results from the fact that in such channels stability is dependent not only on hydraulic parameters but also on the properties of the material which composes the bed and sides of the channel.

A stable channel section is one in which neither objectionable scour nor deposition occurs. There are three types of unstable sections: (USBR).

The pioneering work of Fortier and Scobey (1926) was the basis of channel design.

1. The banks and bed of the channel are scoured but no deposition occurs.

Example: When the channel conveys sediment free water (or water with only a very small amount of sediment) but with adequate energy to erode the channel.

2. Unstable channel with deposition but no scour.

Example: When the water being conveyed carries a large sediment load at a velocity that permits sedimentation.

3. Unstable channel with both scour and deposition occur.

Example: When the material through which the channel is excavated is susceptible to erosion and the water being conveyed carries a significant sediment load.

These types of channels can be designed using the method of maximum permissible velocity.

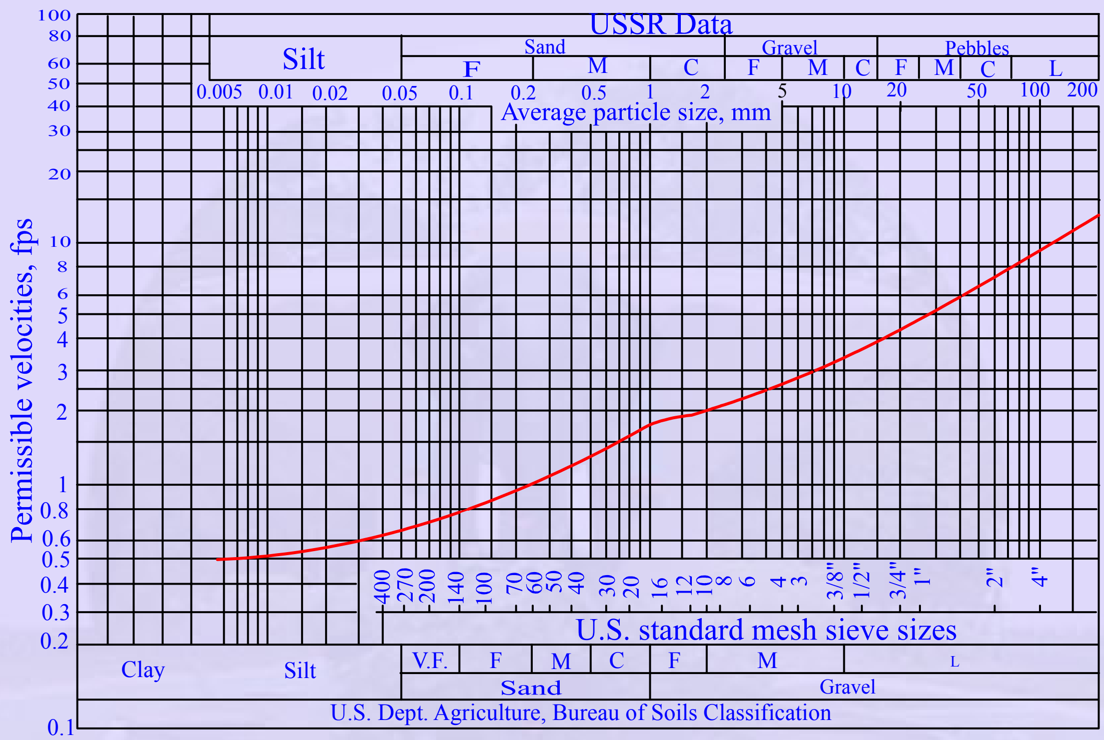
The following important points are to be noted.

1. First, the maximum permissible velocity is recommended for canals with a sinuous alignment.

2. Second, these data are for depths of flow less than 0.91 m . For greater depths of flow, the maximum permissible velocity should be increased by 0.15 m/s.

3. Third, the velocity of the in canals carrying abrasives, such as basalt raveling, should be reduced by 0.15 m /s.

4. Fourth, channels diverting water from silt - laden river such as Ganga River should be designed for mean design velocities 0.3 to 0.61 m/s greater than would be allowed for the same perimeter material if the water were transporting no sediment.



Legend: V.F. - very fine; F- fine; M-medium; C-coarse; L-large

U.S. and U.S.S.R. data on permissible velocities for noncohesive soils.

Following Steps are used for Designing

Given a particular soil type, the channel is designed so that the design velocity does not exceed V_{max} for that soil and the channel side walls are with appropriate side slopes.

General guidelines: Froude number should be less than 0.35

Step 1: For the given kind of material estimate the roughness coefficient n, side slope m, and the maximum permissible velocity.

Step 2: Hydraulic mean radius is computed by using Manning formula.

Step 3: Area of flow is obtained using continuity equation.

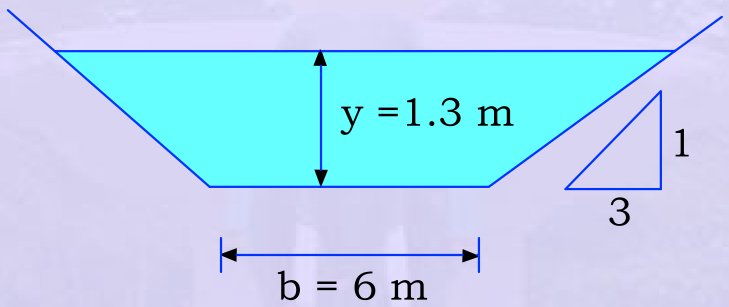
Step 4: The wetted perimeter is computed using the information obtained in steps 2 and 3.

Step 5: Solve simultaneously for b and y.

Step 6: Add a proper free board. Modify the section for practicality.

Example

A trapezoidal channel with bottom width of 6m, side slopes of 3H:1V carries a flow of 50 m^3s^{-1} on a channel slope, So of 0.0015. The uniform flow of depth for the channel is 1.3 m with n = 0.025. This channel is to be excavated in stiff clay. Check whether the channel will be susceptible to erosion or not.



$$A = (b+my)\,y = (6+3*1.3)*1.3 = 12.87 \text{ Sq.m}$$

$$\overline{V} = \frac{Q}{A} = \frac{20}{12.87} = 1.554 \text{ m s}^{-1}$$

which is higher than the permissible velocity (of V = 1.25 ms^{-1})

From graph

$$S_o = 0.0015 < 0.0065 \ (0.65\%)$$
$$\therefore \text{Side slope adopted 3:1 which is} < (1:1)$$

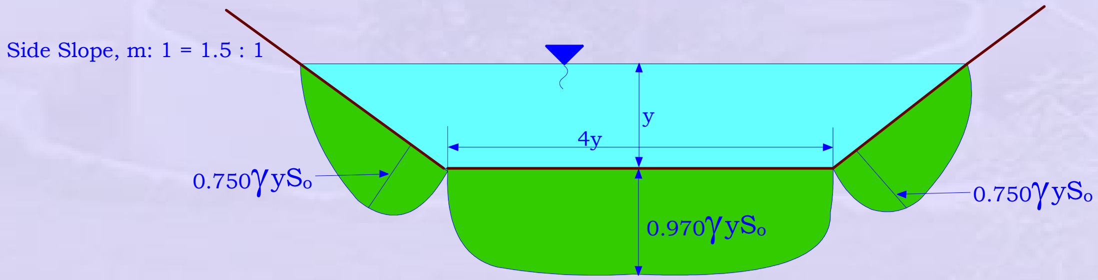
Suggestion : Increase width, b, to reduce velocity:

$$\text{For b} = 8.4 \text{ m}, y_n = 1.3 \text{ m Corresponding area of flow A} = (8.4+3)*1.3 = 15.99 \text{ m}^2$$
$$V = \frac{Q}{A} = \frac{20}{15.99} = 1.251 \text{ m/s which is equal to the permissible velocity}$$

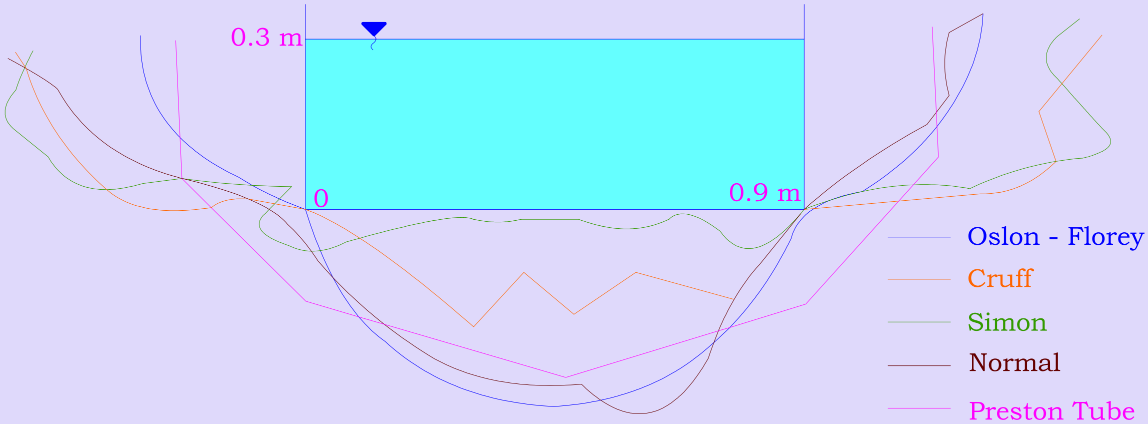
21.1.5 Method of Tractive Force

However, a design methodology based primarily on experience and observation rather than physical principles. The first step in developing a rational design process for unlined, stable, earthen channels is to examine the forces which cause scour. Scour on the perimeter of a channel occurs when the particles on the perimeter are subjected to forces of sufficient magnitude to cause particle movement. when a partical rests on the level bottom of a channel, the force acting to cause movement is the result on the flow of water past the particle. A particle rests on the slope side of a channel is acted on not only by the flow - generated forces, but also by a gravitational component which tends to make the particle roll or slide down the slope. If the resultant of those two forces is larger than the forces resisting movement, gravity, and cohesion, then erosion of the channel perimeter occurs. By definition, the tractive force is the force acting on the partical composing the perimeter of the channel and is the result of the flow of water past these particles. In parctice, the tractive force is not the force acting on a single particle, but the force exerted over a certain area of the channel perimeter. This concept was first stated by duBoys(1879) and restated by Lane (1955).

In most channels, the tractive force is not uniformly distributed over the perimeter.



Tractive force distribution obtained using membrane analogy
This distribution varies depending on the cross section and material



Boundary shear distribution,
Central Water Power Research Station
(August, 1968)

Discharge: 0.06 and 0.11 m^3/s
Cross section of the flume: 0.9 m wide , 0.3 m deep

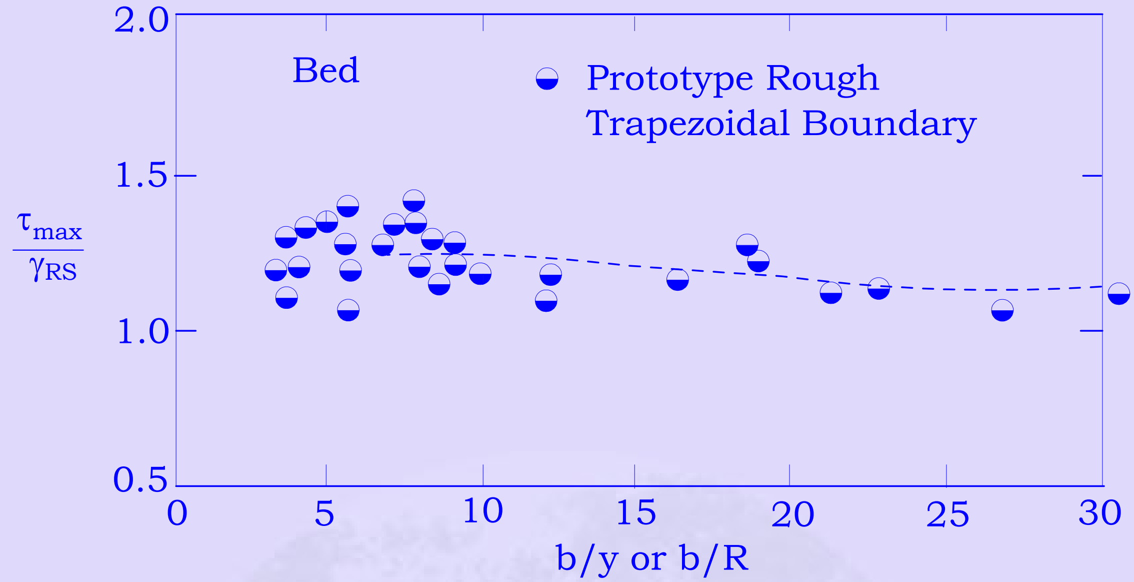
Normal's Method: Based on the concept of zero momentum

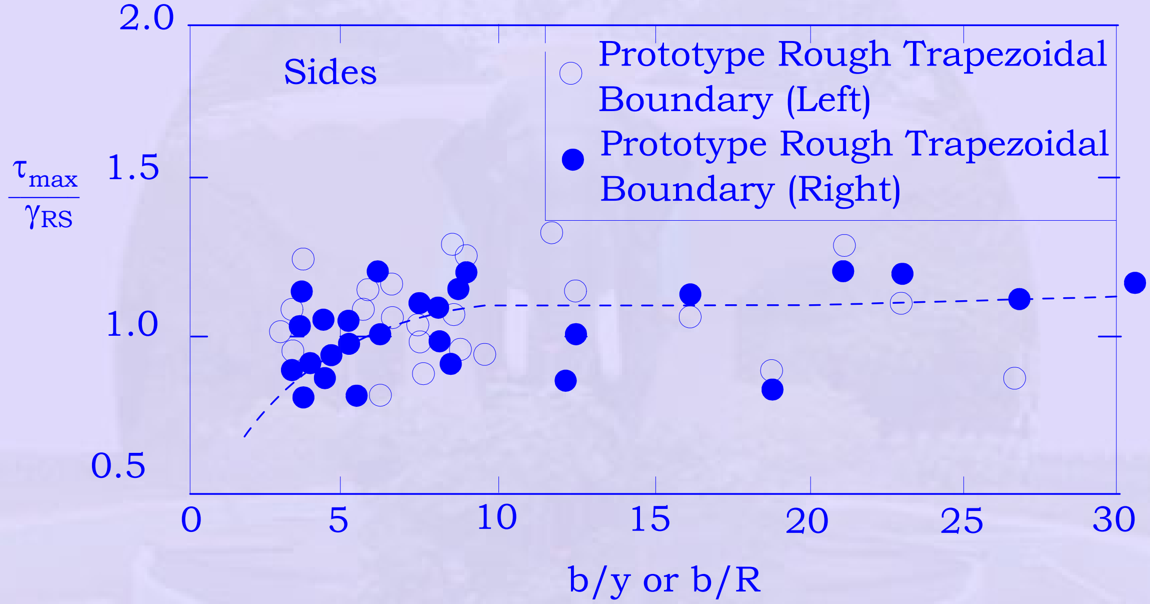
Simon's Method: Based on the following equation assuming Karmann constant to be 0.4

$$\tau_0 = \rho\left[\frac{u_2 - u_1}{\frac{2.3}{k}\log\frac{y_2}{y_1}}\right]^2$$

Cruff's Method: Uses the above equation but k value is obtained from velocity profiles.

Oslon and Florey Method: Membrane analogy.





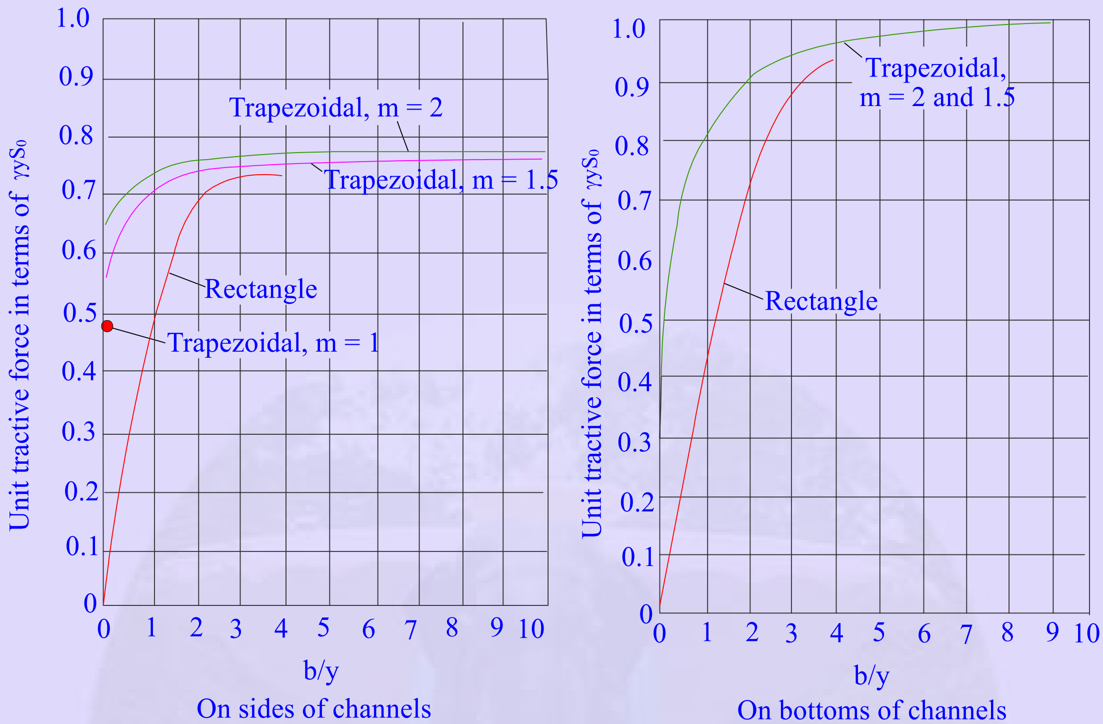
Maximum shear on bed and sides for alluvial channel based on Normal's Method.
(U.P. Irrigation Research Institute Roorkee, Annual Review, 1971)

$\frac{\tau_{max}}{\gamma RS}$ = 1.2 for bed and 0.6 for the sides when $\frac{b}{y}$ exceeds 10

when compared to Lanes values of 0.98, 0.78 respectively

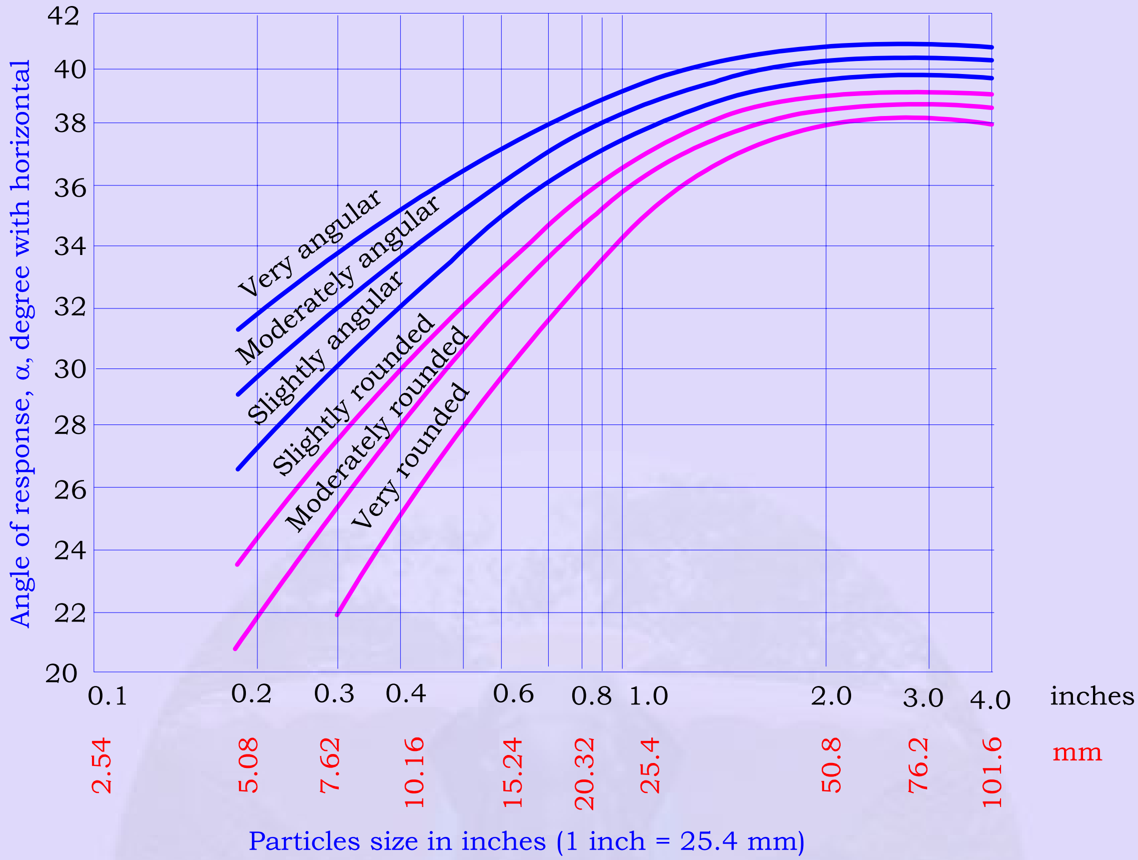
The maximum net tractive force on the sides and bottoms of various channels as determined by mathematical studies are shown as a function of the ratio of the bottom width to the depth of flow. It may be noted that for the trapezoidal section, the maximum tractive force on the bottom is approximately $\gamma y s_0$ *and on the sides 0.76* $\gamma y s_0$.

The figures show the maximum unit tractive forces in terms of $\gamma y s_0$ for different $\frac{b}{y}$ ratios.



Maximum unit tractive forces in terms of $\gamma y S_0$

When a particle on the perimeter of a channel is in a state of impending motion, the forces acting to cause motion are in equilibrium with the forces resisting motion. A particle on the level bottom of a channel is subject to the unit tractive force on a level surface and effective area.



Angles repose for non cohesive material

In the above figure the particle size is the diameter of the particle of which 25 percent of all the particals, measured by weight, are larger.

Lane (1955) also recognized that sinuous canals scour more easily than canals with straight alignments. To account for this observation in the tractive force design method, Lane developed the following definitions.

Straight canals have straight or slightly curved alinments and are typical of canals built in flat plains.Slightly undulating topography.

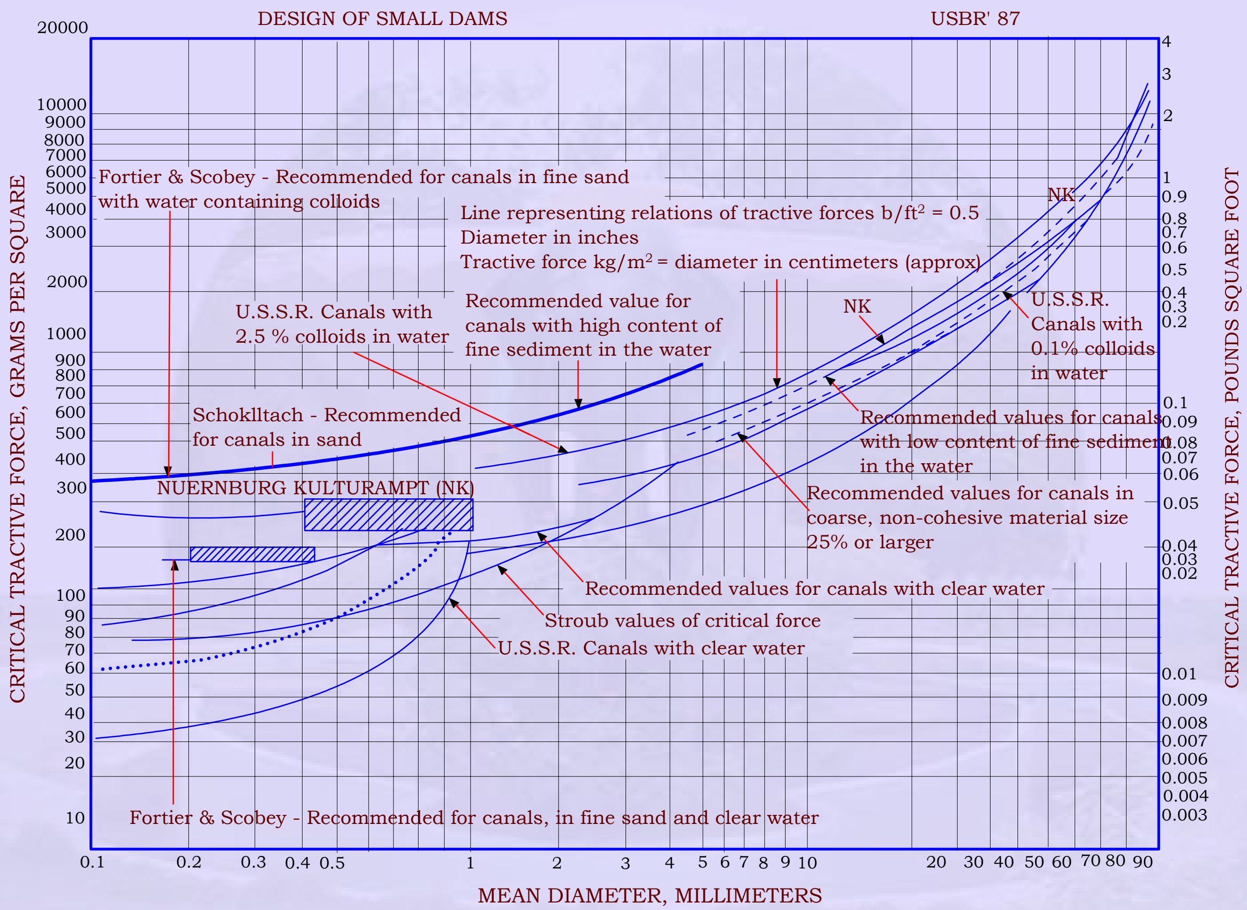
Moderately sinuous canals have a degree of curvature which is typical of moderately rolling topography.

Very sinuous canals have a degree of curvature which is typical of canals in foothills or mountainous topography. Then, with these definitions, correction factors can be defined as in Table.

Degree of sinuousness (stream length/ valley length)	Correction Factor
Straight Channels	1.00
Slightly Sinuous Channels	0.90
Moderately Sinuous Channels	0.75
Very Sinuous Channels	0.60

Reference

Craig Fischenich "Stability Thresholds for Stream Restoration Materials", May 2001.



Conversion Factor $1\ \mathrm{lb/ft^2} = 47.87\ \mathrm{N/m^2}$

Plasticity index (PI) is the difference in percentage of moisture between plastic limit and liquid limit in Atterberg soil tests. For canal design PI can be taken as 7 as the critical value. In this figure, for the fine non cohesive , i.e.,average diameters less than 5mm , the size specified is the median size of the diameter of a partical of which 50 percent were larger by weight. Lacey developed the following equations based on the analysis of large amount of data collected on several irrigation canals in the India.

$$P = 4.75\sqrt{Q}$$
$$f_s = 1.76\ d^{1/2}$$
$$R = 0.47\left(\frac{Q}{f_s}\right)^{1/3}$$
$$S_0 = 3*10^{-4}\ f_s^{5/3}\ Q^{1/6}$$

In which P is the wetted perimeter (m), R is the hydraulic mean radius (m), Q is the flow in m^3/s, d is the diameter of the sediment in mm, f_s is the silt factor, S_0 is the bed slope.

Table: particle size and silt factors for various materials

Material	Size (mm)	Silt factor
Small boulders, cobbles, shingles	64 - 256	6.12 to 9.75
Coarse gravel	8-64	4.68
Fine gravel	4-8	2.0
Coarse sand	0.5-2.0	1.44 - 1.56
Medium sand	0.25-0.5	1.31
Fine sand	0.06-0.25	1.1 - 1.3
Silt (colloidal)		1.0
Fine silt (colloidal)		0.4 - 0.9
Taken from Gupta (1989)		

Combining the above equations the following resistance equations similar to the Manning equation based on the regime theory is obtained.

$V = 10.8\ R^{2/3}\ S_0^{1/3}$ in which V is the velocity in m/s.

21.1.6 The Tractive Force Method

When water flows in a channel, a force that acts in the direction of flow on the channel bed is developed. This force, which is nothing but the drag of water on the wetted area and is known as the tractive force. A particle on the sloping side of a channel is subject to both a tractive force and a downslope gravitational component. It is noted that the tractive force ratio is a function of both the side slope angle and the angle of repose of the material composing the channel perimeter.In the case of cohesive materials and fine noncohesive materials, the angle of repose is small and can be assumed to be zero;

i.e.. for these materials the forces of cohesion are significantly larger than the gravitational component tending to make the particles roll downslope.

Consider the shear stress at incipient motion (which just begins to move particles) for uniform flow.

The tractive force is equal to the gravity force component acting on the body of water, parallel to the channel bed.

Gravity component of weight of water in the direction of flow is equal to γALS_0 in which, γ is the unit weight of water, A is the wetted area, L is the length of the channel reach, and S_0 is the slope. Thus, the average value of the tractive force per unit wetted area, is equal to $\tau_0 = \frac{\gamma ALS_0}{PL} = \gamma RS_0$, in which P is the wetted perimeter and R is the hydraulic mean radius; For wide rectangular channel, it can be written as $\tau_0 = \gamma yS_0$

The tractive force is also called Drag Force.

Consider a sediment particle submerged in water and resting on the side of a trapezoidal channel. For this case the tractive force $A_p\tau_s$ must be equal to gravity force component $w_s \sin\alpha$

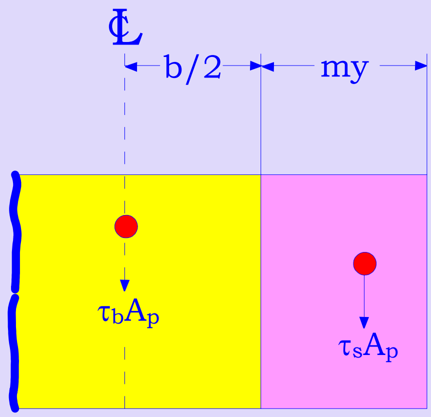
Let

τ_b be the critical shear stress on bed, τ_s be the critical shear stress on side-walls

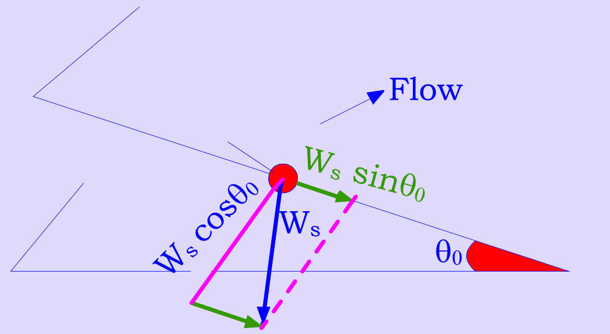
A_p be the effective surface area of typical particle on bed or side wall

θ_0 be the angle of the Side slope and

α be the angle of repose (angle of internal friction) of bank material.

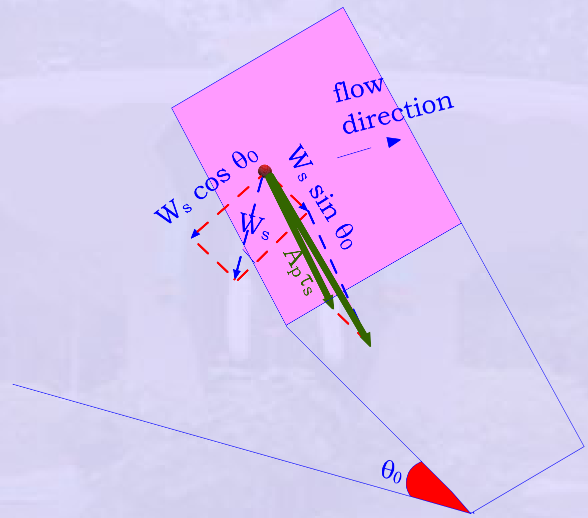


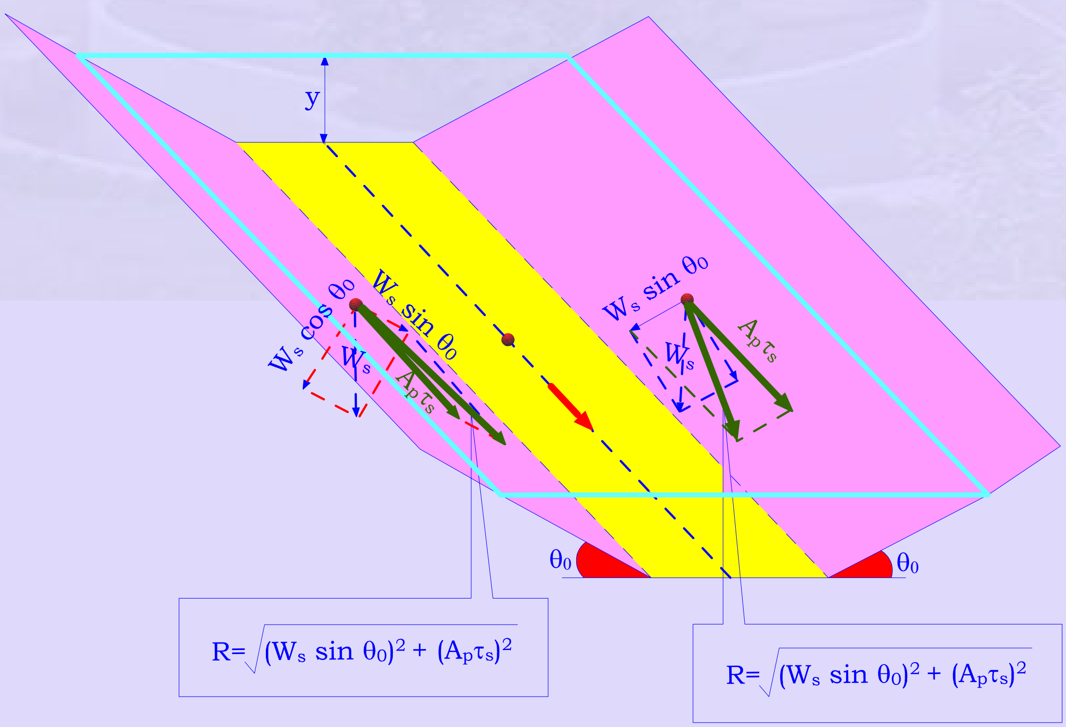
Plan View



W_s = submerged weight of the particle

On the surface of the side slope





From Force diagram, resultant Force, R:

$$R = \sqrt{\left(W_s \sin\theta_0\right)^2 + \left(A_p \tau_s\right)^2}$$

Resisting Force, F_s:

$W_s \cos\theta_0$ is the weight component normal to side slope

$\tan\alpha$ is the coefficient of friction (due to angle of internal friction)

$F_s = W_s \cos\theta_0 \tan\alpha$

Therefore

$R = F_s$ at incipient motion.

$W_s \cos\theta_0 \tan\alpha = \sqrt{W_s \sin^2\theta_0 + A_p^2 \tau_s^2}$

Solving for the unit tractive force τ_s that causes impending motion on a sloping surface

$$\therefore \tau_s = \frac{W_s}{A_p} \tan\alpha \cos\theta_0 \sqrt{1 - \frac{\tan^2\theta_0}{\tan^2\alpha}}$$

On the channel bed, with θ_0 being zero it reduces to

$$A_p \tau_b = W_s \tan\alpha \quad \rightarrow \tau_b = \frac{W_s \tan\alpha}{A_p}$$

Tractive Force Ratio

$$K = \frac{\tau_s}{\tau_b} = \cos\alpha \sqrt{1 - \frac{\tan^2\alpha}{\tan^2\theta_0}} = \sqrt{1 - \frac{\sin^2\alpha}{\sin^2\theta_0}}$$

K is the reduction factor of critical stress on the channel side.

Thus the ratio is a function of only side slope angle θ_0 and angle of repose of the material α.

Example:

Canal cross section: World's largest canal

Full supply level at Head Regulator	91.44 m
Length upto Rajasthan border	458.00 km
Length in Rajasthan	74.00 km
Total	532 km

Bed width at head reach	73.1 m
Fully supply depth at head reach	7.60 m
Design discharge(head reach)	1133 m^3s^{-1}
Gujarath - Rajasthan border	71m^3s^{-1}
No. of branches	42
Length of distribution Network	66000 km

concrete lining of 100 mm to 125 mm concrete

Total Lining

Phase I 150.58 + 93.93 + 39.26 = 283.77

Phase II 126.14 + 1.08 +22.60 = 149.82

Total = 435.59 x 10^5 Sq.m

2) Sardar Sarovar Project

design disharge 86937.2 m^3s^{-1} will be the 3rd largest in the world.

Gazenba, china 1.13 x 10^5 m^3s^{-1}

Tucurri Brazil 1.0 x 10^5 m^3s^{-1}

Radial gates of chute spillway 7 nos 18.3m x 18.3m

For sertvice spillway 23 radial gates of 18.3m x 16.75.

Dam is 12.0 m concrete gravity dam

Height of dam from foundary 163.00 m

Gross storage 9497.07 m^3

The design procedure for flexible lining channel consists of following steps:

1. Channels are usually trapezoidal or triangular (with rounded corners) or parabolic.

2. If lined with rip-rap, m > 3, no need to check for blank stability.

3. Channel slopes can be steep depending on application.

4. Most flexible linings give adequate protection upto $S_0 \approx 0.01$.

The Limiting shear stress or limiting velocity procedure is also commonly used. In this approach, the uniform depth is calculated for the maximum discharge Q and this value is to be compared either τ_{max} vs. $\tau_{permissible}$ or V_{max} vs. $V_{permissible}$, and if they satisfy their add the freeboard and the design is complete. Table below lists the values for various lining types.

Table : Permissible shear stresses for lining materials

Lining Category	Lining Type	Permissible Unit Shear Stress (kg/m^2)
Temporary	Woven Paper Net	0.73
	Jute Net	2.20
	Fiberglass Roving	
	Single	2.93
	Double	4.15
	Stream with Net	7.08
	Cured wood Mat	7.57
	Synthetic Mat	9.76
Vegetative	Class A	18.06
	Class B	10.25
	Class C	4.88
	Class D	2.93
	Class E	1.71
Gravel Riprap	2.5 cm	1.61
	5 cm	3.22
Rock Riprap	15 cm	9.76
	30 cm	19.52

Channel Design using Tractive Force

Procedure:

1. Estimate the roughness in the channel

2. Estimate angle of repose of candidate material.

3. Estimate channel sinuosity and tractive force correction factor.

4. Specify side slope angles.

5. Estimate "tractive force ratio", K, between the sides and the bottom of the channel.

6. Determine the maximum permissible tractive force for the canditate material.

7. Assume that side channel shear stress limits design and determine the uniform flow depth in channel.

8. Calculate the required bottom width.

9. Check that the permissible tractive force is not exceeded on channel bed.

10. Check that the design velocity exceeds the minimum permitted velocity (usually 0.6 to 0.9 m/s) and check the Froude number of the flow (F= subcritical).

11. Estimate the required freeboard.

Example:

1. Design a trapezoidal channel to carry 20 m^3/s through a slightly sinuous channel on a slope of 0.0015. The channel is to be excavated in coarse alluvium with a 75 percentile diameter of 2 cm of moderately rounded particles.

1. Manning n:

$$\begin{aligned}&\text{n for gravel ranges: } 0.020 - 0.030\\&\text{Assume } n = 0.025\\&n = 0.038\left(d_{75}\right)^{1/6} = 0.020\end{aligned}$$

2. Angle of repose:

$$d_{75} = 2\text{cm} = 0.8 \text{ in} \rightarrow \alpha = 32^{o}$$

3. Slightly sinuous channel: Cs = 0.90

4. Side Channel slope: Try 2H:1V

$$\theta = \tan^{-1}\left(\frac{1}{2}\right) = 26.6^{\circ}$$

5. Tractive force ratio:

$$K = \frac{\tau_s}{\tau_b} = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\alpha}} = \sqrt{1 - \frac{\sin^2 26.6^{\circ}}{\sin^2 32^{\circ}}} = 0.53$$

6. Permissible Tractive Force:

$$\begin{aligned}&\text{Bed: } \tau_b = C_s\left(16 \text{ N/m}^2\right) = 14.4 \text{ N/m}^2\\&\text{Side: } \tau_s = K\tau_b = 0.53\left(14.4\right) = 7.6 \text{ N/m}^2\end{aligned}$$

7. Assume incipient motion on side wall:

$$\tau_s = 0.76\gamma\, y_o S_o = 7.6 \text{ N/m}^2$$

$$y_n = \frac{\tau_s}{0.76\gamma\, S_o} = \frac{7.6}{0.76(9790)(0.0015)} = 0.68 \text{ m}$$

8. Solve for bottom width b:

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2} = \frac{1}{n}\frac{A^{5/3}}{P^{2/3}} S_0^{1/2}$$

$$\text{where } A = by + my^2,\; P = b + 2y\sqrt{1+m^2}$$

$$b = 2.42\text{m (smallest positive real solution)}$$

9. Tractive force on bed:

$$\tau_b = 0.97\,\gamma\, y_0 S_0 = 0.97(\gamma)(0.68)(0.0015) = 9.7 \text{ N/m}^2$$

$$1.7 \text{ N/m}^2 < 14.4 \text{ N/m}^2$$

10. Check velocities:

$$\text{Area} = by + my^2 = (24.2)(0.68) + 2(0.68)^2 = 17.4 \text{ m}^2$$

$$V = \frac{Q}{A} = \frac{20}{17.4} = 1.1 \text{ m/s}$$

$$F = \frac{V}{\sqrt{gD}} = \frac{V}{\sqrt{g\left(\frac{A}{B}\right)}}$$

$$T = \text{Top width} = T + 2\text{ my} = 26.92 \text{ m}$$

$$D = A/T = 0.65 \text{ m}$$

$$\text{Froude number} = 0.44$$

11. Free board:

$$\text{For } Q = 20 \text{ m}^3\text{/s the freeboard will be } 0.75 \text{ m}$$

$$\text{Total depth} = 0.68 + 0.75 = 1.43 \text{ m}$$

2. Design a straight trapezoidal channel for a design discharge of 20 m3/s. The bed slope 0.00025 and channel is excavated through the fine grave having particle size of 8 mm. Assume the material to be rounded moderately and water has low concentration of sediment. Q = 10 m3/s, S0 = 0.00025, moderately rounded. Diameter = 8 mm = $\frac{8}{25.4} = 0.3149''$.

For fine gravel n = 0.025 is assumed

Side slope (assume) = 2.5 : 1 = 21.80° = 21°48'

$$\theta = \tan^{-1}\frac{1}{2.5}$$

From fig for 8 mm diameter moderately rounded angle of repose

$$K=\sqrt{1-\frac{\sin^2\theta_0}{\sin^2\alpha}}=\sqrt{1-\frac{\sin^2(21.80)}{\sin^2 24}}=\sqrt{1-\frac{0.1379}{0.1654}}$$

$$\sqrt{0.1663}=0.4077$$

$\therefore$ Critical Shear Stress = 0.13 * 47.87 = 6.2231 N/m^2

No correction for alignment.

Maximum unit Tractive force = 0.785 y S0 = 0.75 * 9806 * y * 0.00025 = 1.8386 y.

$\therefore$ 1.8386 y = 6.2231

$$\therefore\ y=\frac{6.2231}{1.8386}=3.385\text{ m}$$

width required to carry the flow of 20 m^3/s^{-1}

$$\frac{1}{n}(b+my)\,y\left\{\frac{(B+my)\,y}{\left(B+2\sqrt{1+m^2}\right)y}\right\}^{\frac{2}{3}}\sqrt{S_0}=Q$$

$$\frac{1}{0.025}\frac{\left\{\left(b_0+2.5(3.385)\right)3.385\right\}^{\frac{5}{3}}}{\left\{\left(b_0+2\sqrt{5}\right)3.385\right\}^{\frac{2}{3}}}\sqrt{0.00025}=20$$

$$\frac{\left\{\left(b_0+8.4625\right)3.385\right\}^{\frac{5}{3}}}{\left\{\left(b_0+15.138\right)\right\}^{\frac{2}{3}}}=31.6227$$

Solve by trial and error for b.

21.1.7 Economic Aspects of Canal Design

$$\text{(i) } AR^{2/3} = \frac{\left(by + my^2\right)^{5/3}}{\left[b + 2y\sqrt{1+m^2}\right]^{2/3}} - \frac{Q_n}{\sqrt{S_0}}$$

solve *the above equation for y*

$$\textit{(ii)}\ \ y = \frac{\left[b/y + 2\sqrt{1+m^2}\right]^{1/4}}{\left(b/y + m\right)^{5/8}}\left(Q_n/\sqrt{S_0}\right)^{3/8}$$

if b/y, z are specified the equation can be solved explicitly for y and b.

The cost of materials used in lining a channel can be specified interms of the value of material used. This may be expressed as

$$\text{(iii) } \textit{Cost of bed material } C_b = \mu_B t_b\left(b + 2b'\right) = Bb + k \textit{ per unit length}$$

$$\textit{(iv) Cost of side material } C_s = \mu_s t_s\left(2E + E'\right) = 2\Gamma\left[\left(y + F_B\right)\sqrt{1+m^2}\right]$$

$$\text{Therefore } C = C_b + C_s = bB + k + 2\Gamma\left[\left(y + F_B\right)\sqrt{1+m^2}\right]$$

Notation :

C = *total material cost per unit length,*

C_b = *material cost per channel base per unit length,*

C_s = *material cost of sides per unit channel length,*

b' = *bottom corner width,*

t_b = *thickness of the base material,*

t = *channel side lining thickness,*

μ_B = *cost of base lining material per unit volume,*

μ_s = *cost of side lining material per unit volume,*

B = *cost of base material for specified thickness per unit area,*

Γ = *cost of side lining material for specified thickness per unit area,*

F_B = *vertical free board requirement,*

E = *wetted length of the side,*

E' = *side length of the free board.*

Minimum Cost Trapezoidal Section by Optimisation Technique

Lagrange Multiplier technique can be used. Ratio of marginal changes in section factor are equal to the marginal changes in the costs i.e.

$$\frac{\dfrac{\partial\left(AR^{2/3}\right)}{\partial b}}{\dfrac{\partial\left(AR^{2/3}\right)}{\partial y}}=\frac{\dfrac{\partial C}{\partial b}}{\dfrac{\partial C}{\partial y}}$$

The above equation represents the minimum cost of the optimal cost subject to the equation. Substituting, then the optimal solution of the above is given by,

$$K_1\left(\frac{y}{b}\right)^2+K_2\left(\frac{y}{b}\right)+K_3=0$$

$$K_1=20\left(z^2+1\right)-\left[1+4\left(\frac{B}{\Gamma}\right)\right]4z\sqrt{z^2+1}$$

$$K_2=\left[1-\left(\frac{B}{\Gamma}\right)\right]6z\sqrt{z^2+1}-10z\left(\frac{B}{\Gamma}\right)$$

$K_3=-5\dfrac{B}{\Gamma}$ then,

$$\frac{b}{y}=\frac{2K_1}{-K_2+\left[K_2^2+20\dfrac{B}{\Gamma}K_1\right]^{1/2}}$$

which is a function of z and the ratio of the unit costs of the base to side slope material viz;

$$\frac{B}{\Gamma}=\frac{\text{Unit Cost of Base Material}}{\text{Unit Cost of Side Material}}$$

Solution Steps

1. S_0, B, Γ, n, z and Q are given. Determine K1, K2, and K3.

2. Estimate b/y for minimum cost using equation.

3. Estimate the minimum cost depth of flow using equation.

4. Obtain the minimum cost bottom width by multiplying y times the ratio of b/y.

5. Generate the graphs for y Vs b for different values of B/Γ and $\dfrac{n/Q}{S_0}$ for a given value of z.

6. Also study the sensitivity of lining cost to variations of side slope (or side slope ratios).

Sample Run

Data

Q in cumecs, B, Γ and k in R_s, F_B in m

0.08, 0.001, 0.014, 0.50, 105.0, 65.0, 15.0, 0.15

Result

Minimum Lining cost per unit Length = Rs. 109.51

Minimum cost bottom width = 0.186 m

Minimum cost depth of flow = 0.366 m

$$K_1 = 20(0.25+1) - \left(1 + 4\frac{105}{65}\right)4(0.50)\sqrt{1+0.25} = 8.3189$$

$$K_2 = \left[1 - \left(\frac{105}{65}\right)\right]6(1+0.25) - 10(0.50)(1.615) = -12.2005$$

$$K_3 = -5(1.615) = -8.075$$

$$\frac{b}{y} = \frac{2(8.315)}{12.20 + \left[12.25^2 + 20(1.615)8.315\right]}$$

References

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21.1.8 Seepage in Canal

Introduction

Seepage is one of the most serious forms of water loss in an irrigation canal network. Water lost by seepage cannot be recovered without the use of costly pumping plant. In addition excessive seepage losses can cause low lying areas of land to become unworkable. As the water table rises, water logging and soil salinisation can occur, necessitating the installation of elaborate and costly drainage systems. Furthermore the cultivable area is reduced, resulting in a loss of potential crop production.

The accurate measurement of seepage in existing irrigation canals enables very previous reaches to be identified and lined to conserve water; losses amounting to as much as 40% of the total inflow to a scheme have been recorded. Moreover valuable information about the long term performance of different types of canal linings in general use can be obtained, enabling conveying efficiencies to be improved in the future.

Three methods of seepage measurement are in common use at the present, namely: ponding; inflow/outflow; seepage meter. Other methods of seepage detection are also used, such as for example, chemical tracers, radioactive tracers, piezometric surveys, electrical borehole logging, surface resistivity measurements, and remote sensing. These methods suffer from the disadvantage that they are either more difficult to use or interpret.

Ponding Method

Ponding is considered to be the most accurate method of seepage measurement. It is frequently used as standard with which to compare other methods. The procedure, in principle is simple, a stretch of canal under investigation is isolated and filled with water. The rate of seepage is determined by one of two methods. In the first, which is the one usually employed, the rate of fall of the water level is recorded (falling level method). Alternatively, the rate at which the water must be added to keep the water level constant is recorded, (constant level method).

In practice the ponding method has certain advantages:

1. The accuracy of measurement is not dependent on the length of the test reach provided it is sufficient to compensate for normal errors.

2. The requirement for trained manpower is small.

3. Sophisticated equipment is not required for the test.

The disadvantages of the method are

1. Costly bulkheads must be built at each end of the reach if existing structures are not available.

2. The normal flow through the canal must be stopped for the duration of the test. Hence the methods is usually restricted to smaller canals.

3. The rate of seepage loss from the test section can vary with time because of the sealing effect of fine material settling out in the water, or in the case of a canal which is initially dry, because of the time taken to re saturate, or a combination of both.

4. The rate of seepage loss can be very different from that measured in the canal in flowing water because of 3.

5. Large quantities of water are required if the canal under test is initially dry.

Inflow / Outflow Method

Next to ponding, inflow/ outflow, is the most commonly used method for the measurement of seepage. The discharges into, and out of a selection reach of a river or canal are measured. the rate of seepage is derived from the difference. In comparison with the ponding method, the inflow/ outflow method has certain advantages:

1. Any impedance to the normal operation of the canal os minimised.

2. No costly bulkheads are required.

3. Seepage is measured with the canal in its normal discharge state, thus eliminating the effects of silting, algae and fungoidal growth, and distortion of the local seepage flow.

4. Measurements can be made even when numerous off takes are spread without too great an increase in overall cost.

The disadvantage of the method on the other hand are

1. The errors in the flow measurement tend to overshadow the seepage losses, especially in large canals greatly reducing its accuracy.

2. Measurement becomes very labour intensive if a large number of off takes are present.

3. Only the bulk measurement of seepage, over the test reach is obtained, which can attain a considerable length because of 4. In large canals very large reaches are required to improve the accuracy of an individual measurement because of 1. Various methods are available for the measurement of a canal or river discharge. These can be divided into two classes: Continuous methods; Occasional methods. Only gauging structures, ultra-sonic, and electro-magnetic, among the Continuous methods, and velocity area, and dilution gauging among the Occasional methods are considered to be potentially accurate enough for the estimation of seepage. Each of these techniques is outlined briefly below in the context of the inflow/ outflow method.

Velocity Area Method

This method is the mostly used of all discharge measurement techniques. The area of flow is determined by sounding, and the mean velocity by current metering. The product of the two giving the discharge. Some care must be taken when selecting a site on a canal or river however. Ideally the test reach should be straight and free from obstructions, weeds, or off takes, and have a stable bed. Before beginning a discharge measurement, a preliminary survey should be carried out to determine the bed profile, and to ensure that a well-developed velocity distribution exists along the channel. All soundings should be related to an established datum.

The method of current metering depends on the depth of flow and velocity, ranging from the use of wading rods to a cable car suspended across the channel. For most gauging work on irrigation canals however the current metering is usually carried out either with wading rods of from boat. The accuracy of the measurement depends firstly on a number of verticals at which velocity readings are taken and to a lesser extent on the number of levels velocities are measured at on each vertical.

The achievable accuracy can be optimised with the available equipment, time, and manpower. The length of time given to each current meter reading depends very much on flow conditions, but during the preliminary tests it is advisable to record for the recommended 3 minutes while taking readings after each minute for comparison. If very accurate results are required it is essential that the survey is carried out by an experienced, well-trained team.

The inflow/ outflow method is very sensitive to canal size.