MOST EFFIECEIENT CHANNEL SECTION

UNIFORM FLOW AND DESIGN OF CHANNELS

UNIFORM FLOW IN OPEN CHANNELS

- **Definitions**
- **a) Open Channel:** Duct through which Liquid Flows with a Free Surface - River, Canal
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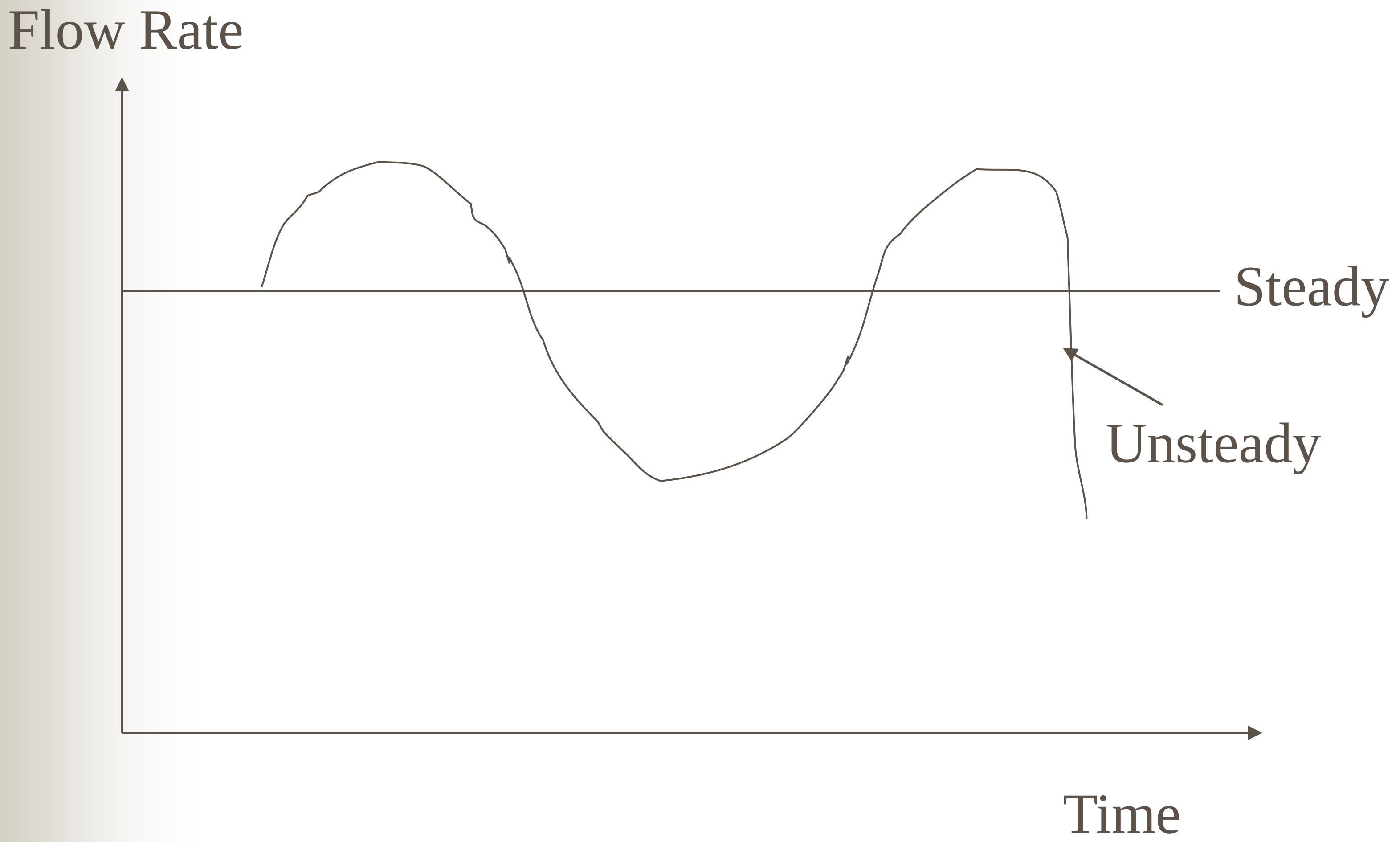
- **b) Steady and Non- Steady Flow:** In Steady Flows, all the characteristics of flow are constant with time. In unsteady flows, there are variations with time.

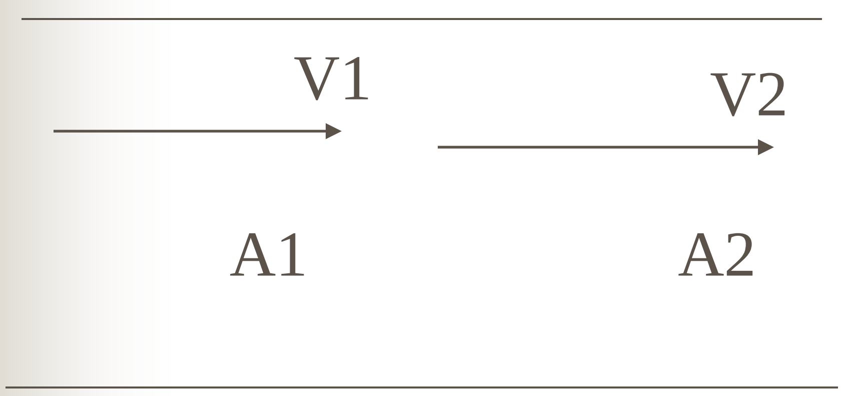
Steady and Non-Steady Flow



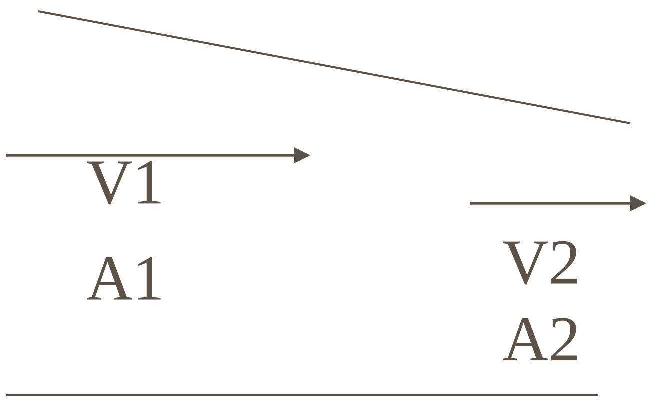
Uniform and Non-Uniform Flow

- In Uniform Flow, All Characteristics of Flow Are Same Along the Whole Length of Flow.
- Ie. Velocity, $V_1 = V_2$; Flow Areas, $A_1 = A_2$
- In Uniform Channel Flow, Water Surface is Parallel to Channel Bed. In Non-uniform Flow, Characteristics of Flow Vary along the Whole Length.

Uniform and Non-Uniform Flow



Uniform Flow



Non-Uniform Flow

More Open Channel Terms

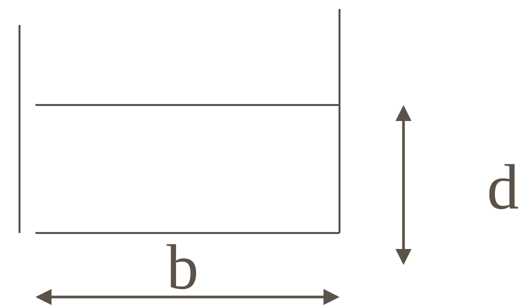
- **d) Normal Flow:** Occurs when the Total Energy line is parallel to the bed of the Channel.

- **f)Uniform Steady Flow:** All characteristics of flow remain constant and do not vary with time.

Parameters of Open Channels

- **a) Wetted Perimeter, P :** The Length of contact between Liquid and sides and base of Channel
- **P = b + 2 d ; d = normal depth**

Wetted Perimeter



Hydraulic Mean Depth or Hydraulic Radius (R): If cross sectional area is A, then R = A/P, e.g. for rectangular channel, A = b d, P = b + 2 d

Empirical Flow Equations for Estimating Normal Flow Velocities

- **a) Chezy Formula (1775):** Can be derived from basic principles. It states that: ;
- $$V = C\sqrt{RS}$$
- Where: V is velocity; R is hydraulic radius and S is slope of the channel. C is Chezy coefficient and is a function of hydraulic radius and channel roughness.

Manning Formula (1889)

- Empirical Formula based on analysis of various discharge data. The formula is the most widely used.
- $V = \frac{1}{n} R^{2/3} S^{1/2}$
-
- 'n' is called the Manning's Roughness Coefficient found in textbooks. It is a function of vegetation growth, channel irregularities, obstructions and shape and size of channel.

Best Hydraulic Section or Economic Channel Section

- For a given Q, there are many channel shapes. There is the need to find the best proportions of B and D which will make discharge a maximum for a given area, A.
- Using Chezy's formula: $V = C\sqrt{RS}$
- Flow rate, Q = A$C\sqrt{RS} = AC\sqrt{\frac{A}{P}S}$ .....(1)

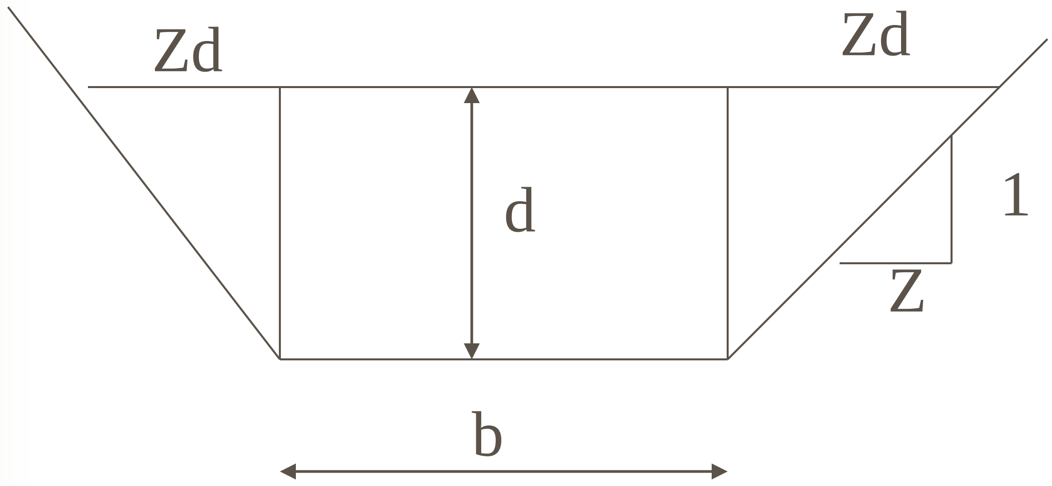
- For a rectangular Channel: P = b +2d
- A = b d and therefore: b = A/d

i.e. P = A/d + 2 d

Best Hydraulic Section Contd.

- For a given Area, A, Q will be maximum when P is minimum (from equation 1)
- Differentiate P with respect to d
- $dp/dd = -A/d^2 + 2$
- For minimum P i.e. P_{min} , $-A/d^2 + 2 = 0$
- $A = 2d^2$, $d = \sqrt{A/2}$
- Since A = b d ie. $bd = 2d^2$ ie. b = 2 d
- i.e. for maximum discharge, b = 2 d **OR** $d = \sqrt{A/2}$

For a Trapezoidal Section



Area of cross section(A) = $b\,d + Z\,d^2$

Width , b = $A/d - Z\,d$ ....(1)

Perimeter = $b + 2\,d\,(1 + Z^2)^{1/2}$

From (1), Perimeter = $A/d - Z\,d + 2\,d(1 + Z^2)^{1/2}$

For maximum flow, P has to be a minimum

i.e $dp/dd = -A/d^2 - Z + 2(1 + Z^2)^{1/2}$

For P_{min}, $-A/d^2 - Z + 2(1 + Z^2)^{1/2} = 0$

$A/d^2 = 2(1 + Z^2) - Z$

$A = 2d^2 (1 + Z^2)^{1/2} - Z d^2$

But Area = $b d + Z d^2$ ie. $bd + Z d^2 = 2d^2 (1 + Z^2) - Z d^2$

For maximum discharge, $b = 2d(1 + Z^2)^{1/2} - 2Zd$

or:

$$d = \sqrt{\frac{A}{2(1+Z^2)^{1/2} - Z}}$$

Try: Show that for the best hydraulic section:

$$\frac{b}{d} = 2\left(\frac{1}{\cos\theta} - \tan\theta\right)$$

DESIGN OF CHANNELS FOR STEADY UNIFORM FLOW

- Channels are very important in Engineering projects especially in Irrigation and, Drainage.
- Channels used for irrigation are normally called canals
- Channels used for drainage are normally called drains.

ESTIMATION OF CANAL DESIGN FLOWS (Q)

- For Irrigation Canals, Design Flows are estimated Using the Peak Gross Irrigation Requirement
- For Example, in a Location with the Peak Gross Irrigation Requirement of 7.69 mm/day.
-
- Peak flow (Q) = 7.69/1000 m x 10000 x 1/3600 x 1/24 x 1000
- = 0.89 l/s/ha
- For a canal serving an area of 1000 ha, canal design flow is then 890 l/s or 0.89 m /s.
- Typically, for humid areas, magnitude of discharges are in the range of 0.5 to 1.0 l/s/ha.

Dimensions of Channels and Definitions

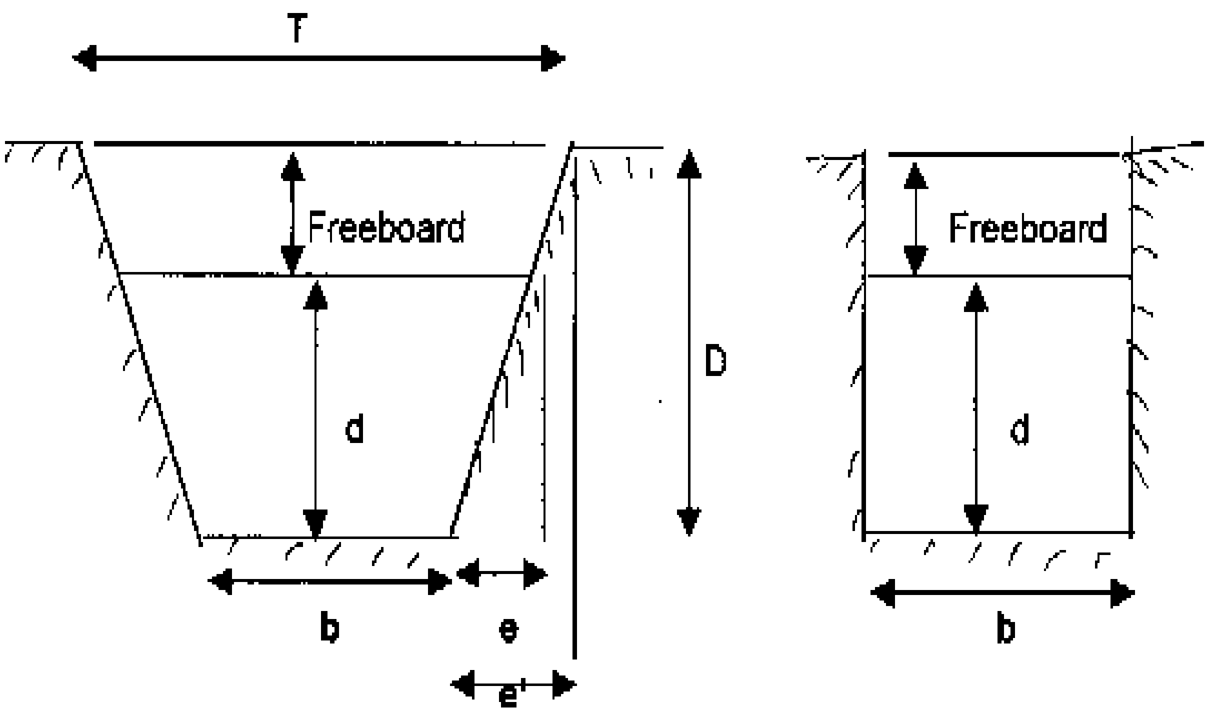


Figure 6.1: Main Parts of Trapezoidal and Rectangular Channels

Definitions

- **a) Freeboard:** Vertical distance between the highest water level anticipated in the design and the top of the retaining banks. It is a safety factor to prevent the overtopping of structures.
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- **b) Side Slope (Z):** The ratio of the horizontal to vertical distance of the sides of the channel. $Z = e/d = e'/D$

Table 6.1: Maximum Canal Side Slopes (Z)

Sand, Soft Clay	3: 1 (Horizontal: Vertical)
Sandy Clay, Silt Loam, Sandy Loam	2:1
Fine Clay, Clay Loam	1.5:1
Heavy Clay	1:1
Stiff Clay with Concrete Lining	0.5 to 1:1
Lined Canals	1.5:1

- **Estimation of Velocity in Channels**
- The most prominent Equation used in the design is the Manning formula described in 6.1.3. Values of Manning's n can be found in standard texts (See Hudson's Field Engineering).

Design of Channels

- Design of open channels can be sub-divided into 2:
- a) For Non-Erodible Channels (lined)
- b) Erodible Channels carrying clean water

Table 2.3

Maximum safe velocities in channels

Material	*Bare*	*Medium grass cover*	*Very good grass cover*
	Maximum velocity on cover expected after two seasons		
	m/sec	m/sec	m/sec
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Firm clay loam	1.0	1.7	2.3
Stiff clay or stiff gravelly soil	1.5	1.8	2.5
Coarse gravels	1.5	1.8	unlikely to form
Shale, hardpan, soft rock, etc.	1.8	2.1	very good grass cover
Hard cemented conglomerates	2.5	—	—

Intermediate values may be selected

Table 2.4

Manning's roughness coefficient

	n
A *Channels free from vegetation*	
Uniform cross-section, regular alignment free from pebbles and vegetation, in fine sedimentary soils	0.016
Uniform cross section, regular alignment, free from pebbles and vegetation, in stiff clay soils or hardpan	0.018
Uniform cross section, regular alignment, few pebbles, little vegetation, in clay loam	0.020
Small variations in cross section, fairly regular alignment, few stones, thin grass at edges, in sandy and clay soils, also newly cleaned, ploughed and harrowed channels	0.0225
Irregular aligoment, ripples on bottom, in gravelly soil or shale, with jagged banks or vegetation	0.025
Irregular section and alignment, scattered rocks and loose gravel on bottom, or considerable weeds on sloping banks, or in gravelly material up to 150 mm diameter	0.030
Eroded irregular channels, channels blasted in rock	0.040
B *Vegetated channels*	
Short grass (50–150 mm)	0.030–0.060
Medium grass (150–250 mm)	0.030–0.085
Long grass (250–600 mm)	0.040–0.150
C *Natural stream channels*	
Clean and straight	0.025–0.030
Winding, with pools and shoals	0.033–0.040
Very weedy, winding and overgrown	0.075–0.150

Design of Non-Erodible Channels

When a channel conveying clear water is to be lined, or the earth used for its construction is non-erodible in the normal range of canal velocities, Manning's equation is used. We are not interested about maximum velocity in design. Manning's equation is:

`

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \quad ....(1)$$

Q and S are basic requirements of canal determined from crop water needs. The slope of the channels follows the natural channel. Manning's n can also be got from Tables or estimated using the Strickler equation: $n = 0.038 \ d^{1/6}$, d is the particle size diameter (m)

Design of Non-Erodible Channels Contd.

- LHS of equation (1) can be calculated in terms of $A R^{2/3}$ termed section factor. For a trapezoidal section:
- $A = b\,d + Z\,d^2$; $P = b + 2\,d\,(1 + Z)^{1/2}$
- The value of Z is decided (see Table 6.1) and the value of b is chosen based on the material for the construction of the channel.
- The only unknown d is obtained by trial and error to contain the design flow. Check flow velocity and add freeboard.

Example 6.1

Design a Non-Erodible Channel to convey 10 m^3/s flow, the slope is 0.00015 and the mean particle diameter of the soil is 5 mm. The side slope is 2 : 1.

- Solution: $Q = 1/n \ AR^{2/3} \ S^{1/2}$ ….. (1)
- With particle diameter, d being 5 mm, Using Strickler Equation, $n = 0.038 \ d^{1/6}$
- $= 0.038 \times 0.005^{1/6} = 0.016$

Solution of Example Contd.

$$Q = \frac{1}{0.016} \; A\,R^{2/3} \; 0.00015^{1/2} = 0.77\,A\,R^{2/3}$$

Z = 2. Choose a value of 1.5 m for 'b'

For a trapezoidal channel, A = b d + Z d^2 = 1.5 d + 2 d^2

P = b + 2 d $(Z^2 + 1)^{1/2}$ = 1.5 + 2 d $5^{1/2}$ = 1.5 + 4.5 d

Try different values of d to contain the design flow of 10 m^3/s

Soln of Example 6.1 Contd.

d(m)	$A(m^2)$	P(m)	R(m)	$R^{2/3}$	$Q(m^3/s)$	Comment
2.0	11.0	10.5	1.05	1.03	8.74	Small flow
2.5	16.25	12.75	1.27	1.18	14.71	Too big
2.2	12.98	11.40	1.14	1.09	10.90	slightly big
2.1	11.97	10.95	1.09	1.06	9.78	slightly small
2.13	12.27	11.09	1.11	1.07	10.11	O.K.

The design parameters are then d = 2.13 m and b = 1.5 m

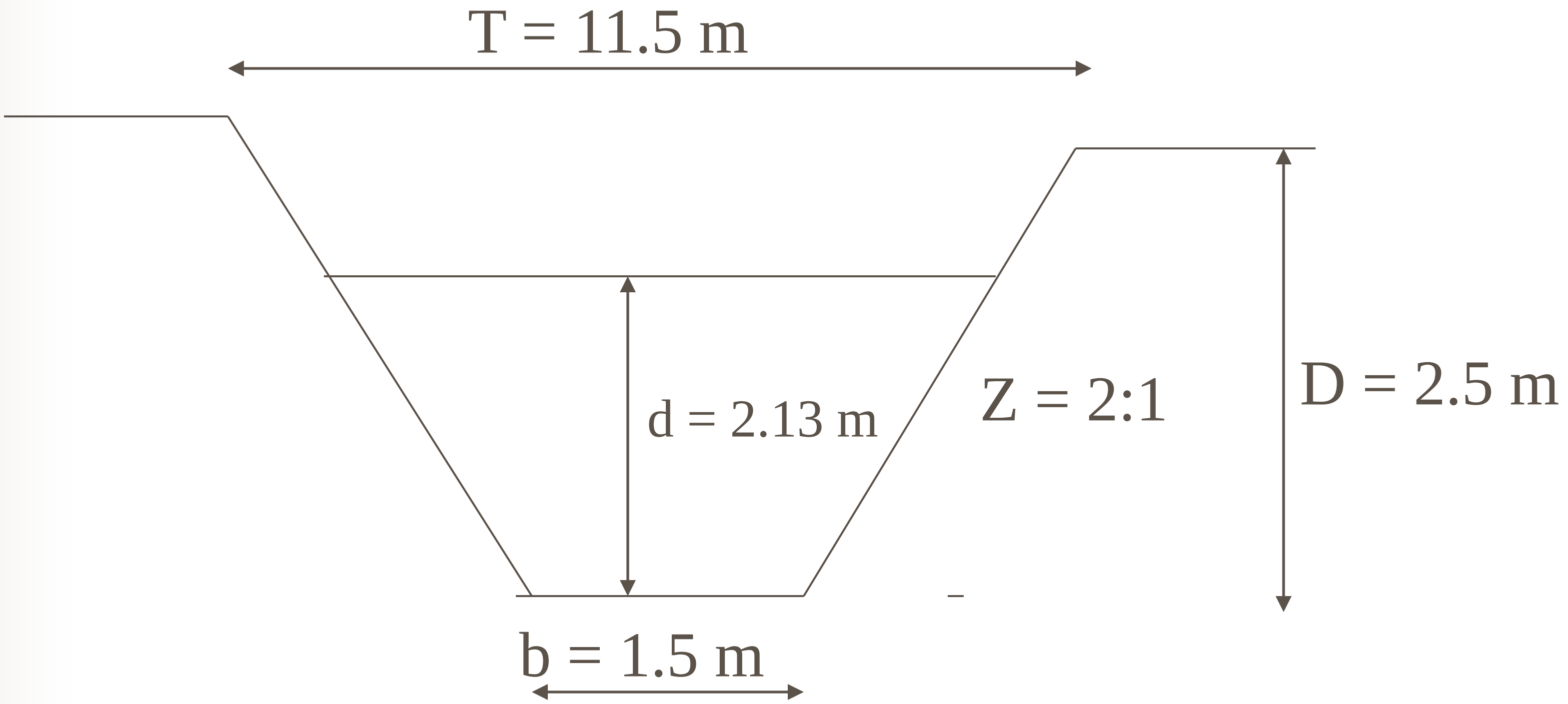
Check Velocity : Velocity = Q/A = 10/12.27 = 0.81 m/s

Note: For earth channels, it is advisable that Velocity should be above 0.8 m/s to inhibit weed growth but this may be impracticable for small channels.

Assuming freeboard of 0.2 d ie. 0.43 m, Final design parameters are:

D = 2.5 m and b = 1.51 m

Final Design Diagram



T = b + 2 Z d = 1.5 + 2 x2 x 2.5 = **11.5 m**

Design of Erodible Channels Carrying Clean Water

- The problem here is to find the velocity at which scour is initiated and to keep safely below it. Different procedures and thresholds are involved including maximum permissible velocity and tractive force criteria.
- **Maximum Permissible Velocities:** The maximum permissible velocities for different earth materials can be found in text books e.g. Hudson's Field Engineering, Table 8.2.

Procedure For Design

- i) Determine the maximum permissible velocity from tables.
- ii) With the permissible velocity equal to Q/A, determine A.
- iii) With permissible velocity = $1/n\ S^{1/2}\ R^{2/3}$
- Slope, s and n are normally given.
- iv) R = A/P , so determine P as A/R
- v) Then A = b d + Z d and
- $P = b + 2\ d\ (Z^2 + 1)^{1/2}$,
- Solve and obtain values of b and d

Example 6.2

- From previous example, design the channel using the maximum permissible velocity method.

Example 6.2:

From previous example, design the channel using the maximum permissible velocity method.

Solution: Given: Q = 10 m^3 /s , Slope = 0.00015 , n = 0.016 , Z = 2 : 1

i) From permissible velocity table, velocity = 0.75 m/s

ii) A = Q/V = 10/0.75 = 13.33 m

iii) ` $R = \left[\frac{Vn}{S^{1/2}} \right]^{3/2}$ $R = \left[\frac{0.75x0.016}{0.00015^{1/2}} \right]^{3/2}$ = 0.97

iv) P = A/R = 13.33/0.97 = 13.74 m

v) A = b d + Z d^2 = b d + 2 d^2

P = b + 2 d $(Z^2 + 1)^{1/2}$ = b + 2 d $5^{1/2}$ = b + 4.5 d

ie. b d + 2 d^2 = 13.33 m^2 ....(1)

b + 4.5 d = 13.74 m .... (2)

Solution of Equation 6.2 Contd.

From (2), b = 13.74 - 4.5 d ....(3)

Substitute (3) into (1), (13.74 - 4.5 d)d + 2 d^2 = 13.33

13.74 d - 4.5 d^2 + 2 d = 13.33

13.74 d - 2.5 d^2 = 13.33

ie. 2.5 d^2 - 13.74 d + 13.33 = 0

Recall the quadratic equation formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4\,a\,c}}{2\,a}$$

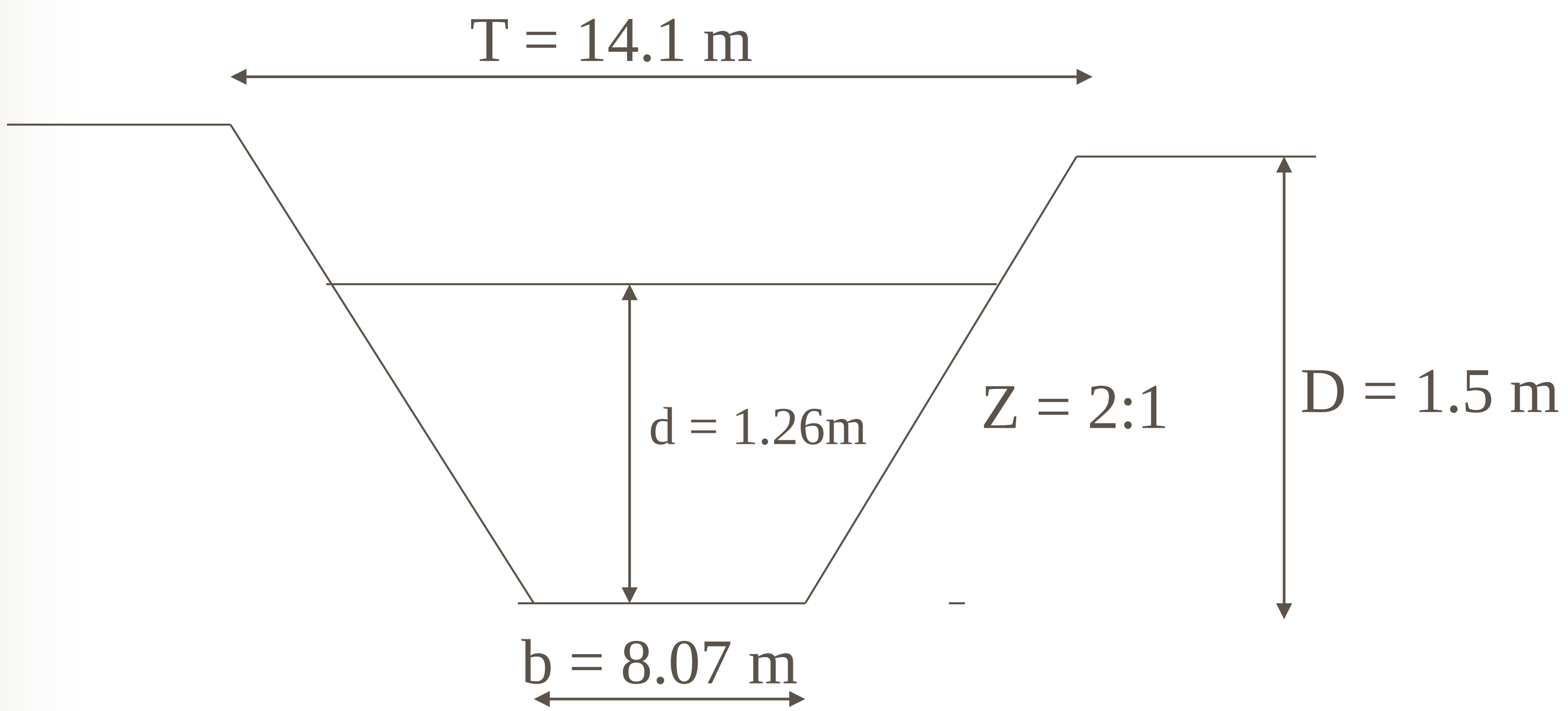
$$d = \frac{13.74 \pm 7.44}{5} = 10.16\,m \quad and \quad 1.26\,m$$

d = 1.26 m is more practicable

From (3), b = 13.74 - (4.5 x 1.26) = 8.07 m

Adding 20% freeboard, Final Dimensions are depth = 1.5 m and width = 8.07 m

Final Design Diagram



T = b + 2 Z d = 8.05 + 2 x2 x 1.5 = **14.1 m**