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IRRIGATION ENGINEERING

[BTAI 2201]

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Economic Channel Section Design

The most economical channel section is one that gives maximum rate of discharge with a minimum cross sectional area.

For an economical channel section, the earth obtained from cutting can be fully utilized in forming the banks which is possible for a channel formed by partial cutting and partial banking.

For a given channel section, the discharge will be maximum when the mean velocity of flow is maximum.

For a given land slope, velocity will be maximum when the hydraulic mean radius is maximum i.e. wetted perimeter is minimum.

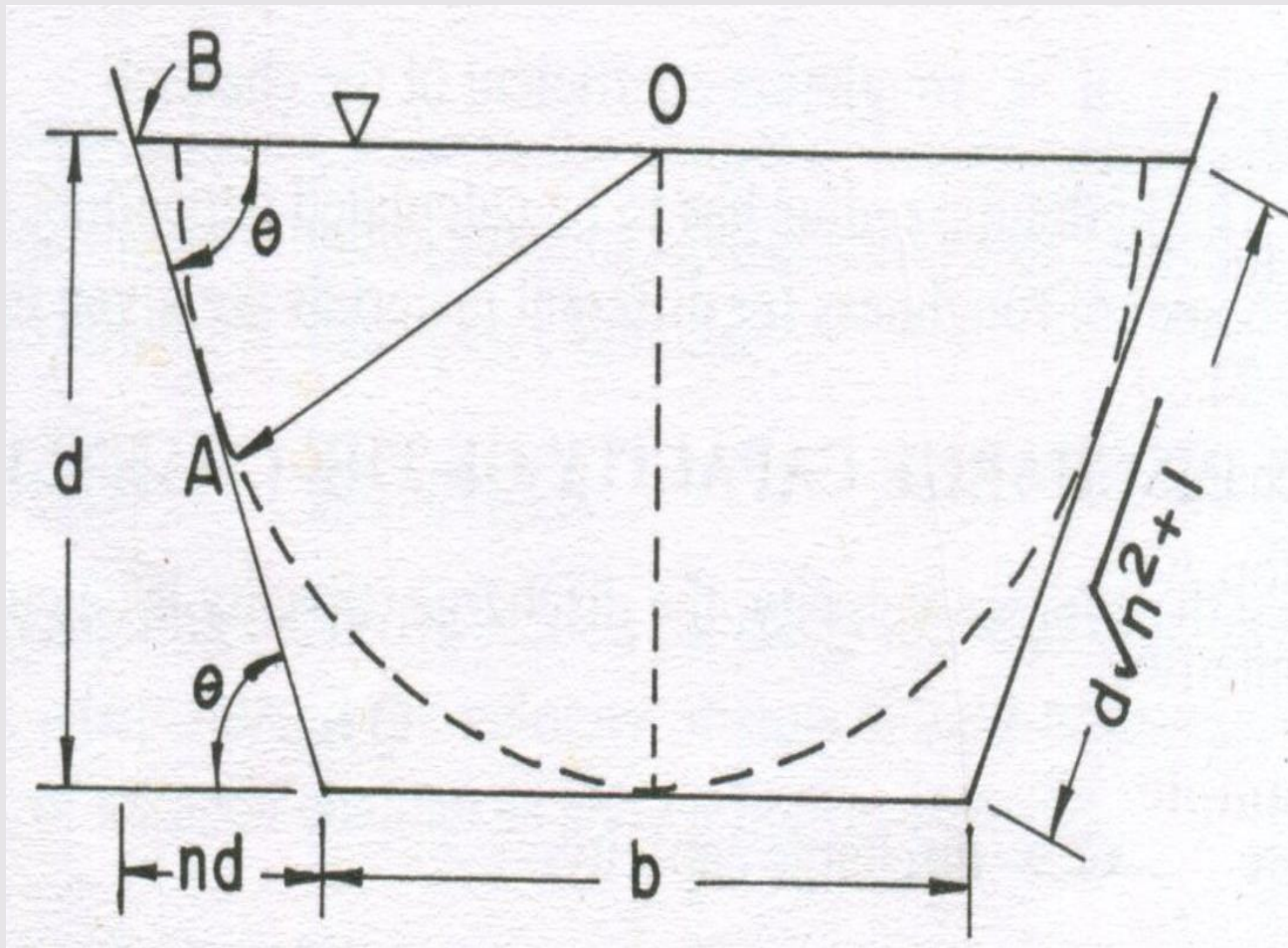
Theoretically, the most efficient cross section for an open channel is semi-circle.



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Economic Channel Section Design





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Economic Channel Section Design

Let the side slope of the section be $n : 1$ (n horizontal to 1 vertical).

Now, $\tan \theta = 1/n$

Top width of the section = $(b + 2 n d)$ and sloping side = $d \sqrt{(n^2 + 1)}$

The wetted perimeter, $P = b + 2$

Cross sectional area, $A = (b + n d) d$

Hydraulic mean radius, $R = A/P =$

$$\frac{(b + n d) d}{[b + 2 d \sqrt{(n^2 + 1)}]}$$



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Economic Channel Section Design

$$b = \frac{A}{d} - n d$$

$$P = \frac{A}{d} - n d + 2 d \sqrt{n^2 + 1}$$

For an economical channel section, P should be minimum and $dP/dd = 0$

Differentiating Above Eq. for P with respect to depth, d & equating it to zero gives

$$A = d^2 \left[2 \sqrt{n^2 + 1} - n \right]$$



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Economic Channel Section Design

Putting the value of A from above Eq. in to compute b and simplifying we get

$$b = d \left[2 \left(\sqrt{n^2 + 1} \right) - n \right] - n d$$

$n = \cot \theta$ Put $n = \cot \theta$ in above Eqn. and simplify

$$b = 2 d \tan \theta / 2$$



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Economic Channel Section Design

For economical rectangular section, putting $\theta = 90$, we get

$$b = 2d \text{ and } R = d/2$$

Hence, for the most economical rectangular channel section, depth of flow should be half of the base width or hydraulic mean radius is half of depth



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Unlined Canal design in Non-Alluvial Soil

Canals in non-alluvial soil have stable base. The coefficient of rugosity plays a major role in the design. But the silt factor has little role. Velocity of flow is close to critical velocity. So, the mean velocity given by Chezy's or Manning's equation can be applied for the design.



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Sample Calculation:

Design an irrigation canal to carry a discharge of 24 cumecs with permissible mean velocity of 2.88 km/hr. Bed slope of the canal section is 0.02 percent and side slope is 1:1. Assume Chezy's constant (C) as 44. Assume any other data not given in the problem.

Solution:

Given discharge, $Q = 24 \text{ m}^3/\text{sec}$

Mean velocity of flow, $V = 2.88 \text{ km/hr} = 0.80 \text{ m/sec}$

Cross sectional area, $A = Q/V = 24/0.80 = 30 \text{ m}^2$

Let base width of the canal be B and depth be D . Since side slope is 1:1, top width is $(B + 2D)$

Cross sectional area = $(B + D) D$

Hence, $(B + D) D = 30$

Mean velocity by Chezy's formula is



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

Given, $V = 0.80$ m/sec, $C = 44$ and $S = 0.02$ percent =
0.0002

Hence, $0.80 = 44 \sqrt{R \times 0.0002}$ $R = 1.65$

Wetted perimeter, $P = B + 2 \sqrt{2} D$

Hydraulic mean radius, $R =$ Cross sectional
area/wetted perimeter =

$$\frac{(B + D) D}{B + 2 \sqrt{2} D}$$



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$$\frac{(B + D) D}{B + 2 \sqrt{2} D} = 1.65$$

$$\frac{30}{B + 2 \sqrt{2} D} = 1.65$$

Simplifying $B = 18.18 - 2.83 D$

Now Put value of B in Eq. $(B + D) D = 30$ and solve

$1.83 D^2 - 18.18 D + 30 = 0$ which gives $D = 7.84$ or 2.09

If $D = 7.84$, $B = -4.0$ (impossible)

If $D = 2.09$, $B = 12.27$ (OK)



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Sample Calculation 2:

Design the most economical trapezoidal canal section to carry a discharge of $20 \text{ m}^3/\text{sec}$ with mean velocity of flow of 3.06 km/hr . Side slope of the canal is $1.5:1$. Assume Bazin's constant, $K = 1.30$. Also calculate the allowable bed slope of the canal.



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Sample Calculation 3:

Design a canal section to carry a discharge of 40 m³/sec with mean velocity of flow of 3.42 km/hr. Side slope of the canal is 1:1. The ratio of base width to depth of flow in the section is given as $B/D = 6.5$. Assume value of coefficient of rugosity, $N = 0.0225$.



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Design the most economical trapezoidal canal section to carry a discharge of 20 cumecs with mean velocity of flow of 3.06 km/hr. Side slope of the canal is 1.5:1. Assume Bazin's constant, $K = 1.30$. Also calculate the allowable bed slope of the canal.

$$Q = 20 \text{ cumecs}$$

$$V = 3.06 \text{ km/hr} = 0.85 \text{ m/sec}$$

$$\text{Cross sectional area, } A = Q/V = 20/0.85 = 23.53 \text{ m}^2$$

Let base width of the canal be B and depth be D

Since side slope is 1.5:1, top width is $(B + 3 D)$

$$\text{Cross sectional area } A = (B + 1.5 D) D$$



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$$\text{Hence, } (B + 1.5 D) D = 23.53 \quad (\text{Eq.9.21})$$

**Wetted
perimeter,
P =**

$$B + 2 \left\{ \sqrt{D^2 + (1.5 D)^2} \right\} = B + 3.60 D$$

**Hydraulic mean
radius, R =**

$$\frac{(B + 1.5 D) D}{B + 3.60 D} \quad (\text{Eq.9.22})$$

$$\text{For economical canal section, } R = D/2 \quad (\text{Eq.9.23})$$

From Eq. (9.22) and (9.23),

$$\frac{D}{2} = \frac{(B + 1.5 D) D}{B + 3.60 D} \quad \text{Eq.(9.24)}$$



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Simplifying Eq. (9.24), we get $B = 0.60 D$ (Eq.9.25)

Putting the value of B from Eq. (9.25) in Eq. (9.21)
& simplifying $D = 3.35$ m, $B = 2.01$ m & $R = D/2 = 1.675$ m.

Bazin's Formula

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

Bazin's constant, $K = 1.30$ and $R = 1.675$

Chezy's constant, $C = 43.5$



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Chezy's formula is :

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

$$\text{Hence, } 0.85 = 43.5 \times \sqrt{1.675 S}$$

$$S = 0.00022 = 0.022 \text{ percent} = 1:4374$$

Hence, base width & depth of canal are 2.01 and 3.35 m, respectively & bed slope is 0.022 percent.



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Design a canal section to carry discharge of 40 cumecs with mean velocity of flow of 3.42 km/hr. Side slope is 1:1. Ratio of base width to depth of flow in the section is given as $B/D = 6.5$. Assume value of coefficient of rugosity, $N = 0.0225$.

$$Q = 40 \text{ cumecs}$$

$$V = 3.42 \text{ km/hr} = 0.95 \text{ m/sec}$$

$$A = Q/V = 40/0.95 = 42.11 \text{ m}^2$$

Let base width of the canal be B and depth be D .

Since side slope is 1:1, top width is $(B + 2D)$



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$$A = (B + D) D$$

$$\text{Hence, } (B + D) D = 42.11 \quad (\text{Eq. 9.26})$$

Given $B/D = 6.5$ which gives $B = 6.5 D$

Putting $B = 6.5 D$ in Eq. (9.26)

$D = 2.37$ m and hence, $B = 15.40$ m

Wetted perimeter, $P = B + 2\sqrt{2} D$

Putting $B = 15.40$ and $D = 2.37$, $P = 22.10$ m



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Hence, hydraulic mean radius, $R = 42.11 / 22.10$
 $= 1.90 \text{ m}$

Manning's Formula:

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

$R = 1.90$, $N = 0.0225$ (given), $V = 0.95$ (given)

and using Manning's formula we get
 $S = 0.000194 = 0.019$ percent = 1:
5155

So $B = 15.4 \text{ m}$, $D = 2.37 \text{ m}$ and $S = 0.019\%$.



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Unlined Canal Design in Alluvial Soil:

Regime Channel: A channel is said to be in state of 'regime', if flow is such that 'sitting & scouring' need no special attention. Such a state is not easily possible in rivers, but in artificial channels, such a state can be obtained by properly designing the channel. Design of regime channels is based on mainly two approaches: (i) **Kennedy's theory** and (ii) **Lacey's theory**.



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Kennedy's Theory:

R.G. Kennedy Carried out a number of study in Upper Bari Doab Canal System in Punjab

He selected some straight reaches of canal section, which had not posed any silting & scouring problems during the previous 30 years or so.



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He concluded that silt supporting power in a channel cross-section is mainly dependent on generation of eddies, rising to the surface.

These eddies are generated due to friction of flowing water with channel surface.

Vertical component of these eddies try to move sediment up, while weight of sediment tries to bring it down, thus keeping in suspension.

So if velocity is sufficient to generate these eddies, so as to keep sediment just in suspension, silting will be avoided.



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Based upon this concept, he defined the critical velocity (V_0) in a channel as the mean velocity which will just keep the channel free from silting or scouring and related it to the depth of flow by the equation.

$$V_0 = c D^n \quad (\text{Eq. 9.28})$$

where c and n are constants depending upon silt charge.

Values of c and n were found to be 0.55 and 0.64, respectively.

Therefore, Eq. (9.28) can be written as

$$V_0 = 0.55 D^{0.64} \quad (\text{Eq.9.29})$$



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Above Eq. (Eq.9.29) is true for Upper Doab Section. For general sections carrying silt laden water, he introduced critical velocity ratio (C.V.R.) (denoted by symbol m) which depends upon the silt grade.

The modified Kennedy's formula is given as:

$$V_0 = 0.55 m D^{0.64} \quad (\text{Eq. 9.30})$$

where, V_0 = Critical velocity in the channel in m/sec and D = Depth of flow in the channel, m.



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Recommended values of critical velocity ratio, m for different silt carried channel

Sl. No.	Type of silt	Value of m
Sl. No.1	Silt of river Indus (Pakistan)	0.70
Sl. No.2	Light sandy silt in North Indian River	1.0
Sl. No.3	Light sandy silt, a little coarser	1.1
Sl. No.4	Sandy, loamy silt	1.2
Sl. No.5	Debris of hard soil	1.3



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The values of constant c in Eq. (9.28) for various grades of materials are:

Types of materials	Values of c
Light sandy silt	0.53
Coarser light silt	0.59
Sandy loam	0.65
Coarse silt	0.70



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Design Procedure: Kennedy's design procedure is based on following steps.

Assume a trial depth, D & then compute critical velocity V_0 by Eq (9.29).

Determine area by dividing discharge by velocity (velocity calculated as in step above.)

Then determine channel dimensions.

Finally, compute actual mean velocity (V) by Chezy's equation with Chezy's constant C calculated either by Bazins formula or by Kutter's formula.

- i. If two velocities V_0 and V are same, then assumed depth is **ok**, otherwise change it and repeat the procedure. Thus several iterations are required to get dimensions of channel.



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Kutter's formula to Calculate Chezy's Constant, C

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



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An irrigation channel has side slope 1:1 & base width 3 m. It has flow depth of 1 m. Bed slope is 0.04%. Assume Manning's rugosity coefficient $N = 0.028$. Determine if channel will be regime channel. Assume critical velocity ratio as 1.0.

Given $N = 0.028$ and $S = 0.04$ percent = $1/2500$

Base width = 3 m & slope is 1:1. Depth of flow = 1m.

Hence top width of the channel = 5 m.

Area of the trapezoidal section = $(5 + 3)/2 = 4$ sq. m.

Wetted perimeter = $3 + 2\sqrt{2} = 5.83$ m.

Mean hydraulic radius, $R = A/P = 0.69$ m.



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Using above values of n , R and S , velocity by Manning's formula,
 $V = 0.56 \text{ m/s}$.

Using Kennedy's formula,
velocity $V_0 = 0.55 m D^{0.64}$
 $= 0.55 \times 1.0 \times (1.0)^{0.64} = 0.55 \text{ m/s}$.

Since the two velocities are
nearly same,
the channel is stable i.e. **regime**.



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Drawbacks in Kennedy's Theory

- (i) The theory is limited to average regime channel only.
- (ii) The design of channel is based on trial & error method.
- (iii) The value of critical velocity ratio was fixed arbitrarily.
- (iv) Silt charge & silt grade were ignored.
- (v) Kennedy did not notice importance of B/D ratio.
- (vi) No account was taken of silt concentration and bed load.
- (vii) No slope equation was given except depending on Kutter's equation



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Lacey's Theory

According to Lacey's theory, there is a relationship between velocity, V & hydraulic mean radius/scour depth, R in the form

$$V = R^{1/2}.$$

As a measure of silt grade, Lacey introduced a silt factor, f & he proposed an equation

$$V = K \quad (\text{Eq.9.31})$$

where K is a constant. The value of K proposed is $K =$

$$\sqrt{f R}$$

Hence Eq. (9.31) in SI unit can be written as:

$$\sqrt{\frac{2}{5}}$$



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$$V = \sqrt{\left(\frac{2}{5} f R\right)}$$

$$\text{Hence, } f = \frac{5 V^2}{2 R} \quad (\text{Eq.9.33})$$

$$f = 1.76 m_r^{1/2} \quad (\text{Eq.9.34})$$

where m_r is average particle size, mm



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He also proposed the following relationship between area, A vs. velocity, V :

$$A f^2 = 140 V^5 \quad (\text{Eq.9.35})$$

Lacey's regime flow equation is:

$$V = 10.8 R^{\frac{2}{3}} S^{\frac{1}{3}} \quad (\text{Eq. 9.36})$$

Eqns. (9.32, 9.35 and 9.36) are called as Lacey's fundamental equations from which other flow equations are derived



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$$V = \left(\frac{Q f^2}{140} \right)^{\frac{1}{6}}$$

(Eq. 9.37)

$$P = 4.75 \sqrt{Q}$$

(Eq. 9.38)

$$S = \frac{f^{3/2}}{4980 R^{1/3}}$$

(Eq. 9.39)

$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$

(Eq. 9.40)



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Eqns. (9.39 and 9.40) are called as Lacey's regime slope equation.

$$Q = \left(\frac{f^{5/3}}{3340 x S} \right)^6 \quad \text{(Eq. 9.40)}$$

Eqns. (9.39 and 9.40) are called as Lacey's regime slope equation.



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Lacey's design procedure

Step I. Calculate the silt factor.

Step II. Find out velocity,

Step III. Find out the cross sectional area, $A = \frac{Q}{V}$

Step IV. Find out the wetted perimeter,

$$P = 4.75 \sqrt{Q}$$

Step V. Find out base width, B and depth, D of the channel section since area & wetted perimeter are known.



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Step VI. Calculate R as

$$R = \frac{5 V^2}{2 f}$$

Step VII. Also calculate R as ratio of A and P . Both the values of R should be same which serves as a check from step I to V.

Step VIII. Find out the slope,

$$S = \frac{f^{3/2}}{4980 R^{1/3}}$$



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or as

$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$



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Design a channel section to carry a full supply discharge of 30 cumecs having side slope 0.5 :1 & mean diameter of silt particle is 0.33 mm.

Silt factor, $f = 1.76 \sqrt{0.33} = 1.0$

Mean velocity,

$$V = \left(\frac{Q f^2}{140} \right)^{\frac{1}{6}}$$
$$\left(\frac{30 \times 1^2}{140} \right)^{\frac{1}{6}} = 0.773 \text{ m/sec}$$



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$$A = Q/V = 30/0.773 = 38.8 \text{ m}^2$$

$$\text{Wetted perimeter, } P = 4.75 \sqrt{Q}$$

$$= 4.75 \sqrt{30} = 26 \text{ m.}$$

Since side slope is 0.5:1, base width

& depth are B and D respectively

$$\text{Area, } A = B D + \frac{D^2}{2}$$

$$\text{wetted perimeter, } P = B + D \sqrt{5}$$



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Hence,

$$D = \frac{P - \sqrt{P^2 - 6.944 A}}{3.472}$$

$$= \frac{26 - \sqrt{26^2 - 6.944 \times 38.8}}{3.472} = 1.67 \text{ m}$$



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$$B = P - D \times \sqrt{5} = 26 - 1.67 \times \sqrt{5} = 22.6 \text{ m.}$$

$$\mathbf{R = Area/wetted perimeter = 38.8/26 = 1.49 \text{ m}}$$

$$\mathbf{Again, R = \frac{5V^2}{2f} = \frac{5 \times 0.773^2}{2 \times 1} = 1.49 \text{ m}}$$

Since values of R by both methods are same, calculation is checked.



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$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$

$$\frac{1^{5/3}}{3340 \times 30^{1/6}} = 1/5900 = 0.017 \text{ percent}$$

So, B = 22.6 m, D = 1.67 m, & S = 0.017%



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Drawbacks in Lacey's Theory:

Concept of true regime is theoretical & cannot be achieved practically.

Various equations are derived considering silt factor f which is not at all constant.

Concentration of silt is not taken into account.

Silt charge & silt grade are not clearly defined.

Equations are empirical & based on available data from a particular type of channel which may not be true for other channels.

Characteristics of regime channel may not be same for all cases.

Lacey did not take into account silt left in channel by water that is lost in absorption which is as much as 12 to 15 percent of the total discharge of the channel.

Lacey introduced semi ellipse as ideal shape of a regime channel which is not correct.



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