Design of Irrigation Canals
Lacey's Theory

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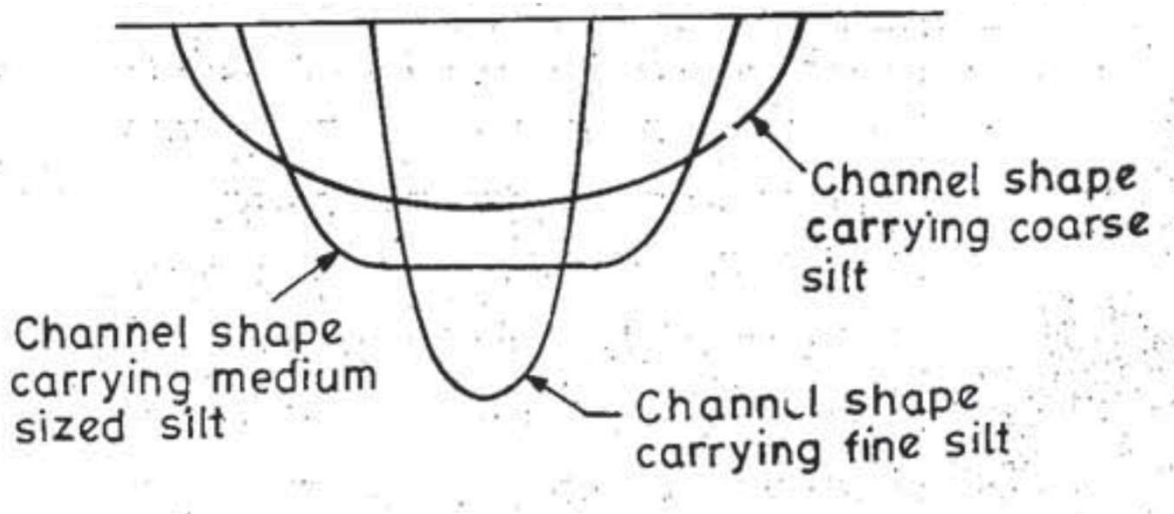
Regime Channels



- True Regime
  - Discharge is constant
  - Flow is uniform
  - Silt charge is constant
  - Silt grade is constant
  - Channel is flowing through a material which can be scoured as easily as it can be deposited.(incoherent alluvium)

- Initial Regime
- Final Regime

Design Procedure

(1) Calculate the velocity from equation

$$V = \left[\frac{Qf^2}{140}\right]^{1/6} \text{ m/sec.} \qquad \ldots(4.23)$$

where Q is in cumec :
V is in m/s ; and
f is the **silt factor**, given by

$$f = 1.76 \cdot \sqrt{d_{mm}} \qquad \ldots(4.24)$$

where d_{mm} = Average particle size in mm, as given in Table 4.6.

Table 4.6. Values of Particle size (d_{mm}) for Various types of Alluvial materials for use in eq. (4.24)

S. No. (1)	*Type of material (soil)* (2)	*Av. grain size in mm* (d_{mm}) (3)
1	*Silt,*	
	Very fine	0.05 to 0.08
	Fine	0.12
	Medium	0.16
	Standard	0.32 ($f = 1.0$)
2	*Sand,*	
	Medium	0.51
	Coarse	0.73
3	*Bajri and Sand,*	
	Fine	0.89
	Medium	1.29
	Coarse	2.42
4	*Gravel,*	
	medium	7.28
	heavy	26.10
5	*Boulders,*	
	small	50.10
	medium	72.50
	large	188.80

Design procedure

(2) Work out the hydraulic mean depth (R) from the equation

$$R = \frac{5}{2}\left(\frac{V^2}{f}\right) \qquad \ldots(4.25)$$

where V is in m/sec ;
R is in m.

(3) Compute area of channel section $A = \frac{Q}{V}$ ...(4.26)

(4) Compute wetted perimeter, $P = 4.75\sqrt{Q}$ ...(4.27)

where P is in m ; Q is in m^3/sec.

(5) Knowing these values, the channel section is known ; and finally the bed slope S is determined by the equation

$$S = \left[\frac{f^{5/3}}{3340\, Q^{1/6}}\right] \qquad \ldots(4.28)$$

where f is the silt factor, given by Eq. (4.24)
Q is the discharge in cumec.

Design Procedure

Lacey's Regime Width and Scour Depth for Alluvial Rivers :

For wide streams or rivers, as we know, wetted perimeter P, approximately equals the river width. Therefore, according to Lacey, for alluvial rivers :

The regime width $= W = 4.75\sqrt{Q}$ ...(4.29)

For such streams, Lacey has also defined the regime scour depth, as

Lacey's Normal Regime Scour Depth* $= \mathbf{R'}_r = 0.473\left(\frac{Q}{f}\right)^{1/3}$ ...(4.30)

Design a regime channel for a discharge of 50 cumecs and silt factor 1.1 using Lacey's theory

$$V = \left[\frac{Qf^2}{140}\right]^{1/6}$$

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

$$A = \frac{Q}{V}$$

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

$$S = \left[\frac{f^{5/3}}{3340\,Q^{1/6}}\right]$$

Solution. $Q = 50$ cumecs, $f = 1.1$

$$V = \left[\frac{Qf^2}{140}\right]^{1/6} = \left[\frac{50 \times (1.1)^2}{140}\right]^{1/6}$$

$$A = \frac{Q}{V} = \frac{50}{0.869} = 56.3\ \text{m}^2$$

$$R = \frac{5}{2} \cdot \frac{V^2}{f} = \frac{5}{2} \cdot \frac{(0.869)^2}{1.1} = 1.675 \text{ m.}$$

$$P = 4.75\sqrt{Q} = 4.75 \cdot \sqrt{50} = 33.56 \text{ m}$$

For a trapezoidal channel with $\frac{1}{2}H : 1V$ slopes

$$P = b + \sqrt{5} \cdot y$$

and $$A = \left(b + \frac{y}{2}\right) y$$

$$\therefore \quad 33.56 = b + \sqrt{5} \cdot y$$

and $$56.3 = by + \frac{y^2}{2}$$

From Eq. (*i*), we get, $b = 33.56 - 2.24y$

Putting this value of b in Eq. (*ii*)

$$56.3 = [33.56 - 2.24y]\, y + \frac{y^2}{2}$$

$$= 33.56y - 2.24y^2 + 0.5y^2 = 33.56y - 1.74y^2$$

or $$1.74y^2 - 33.56y + 56.3 = 0$$

or $$y^2 - 19.3y + 32.4 = 0$$

$$\therefore \quad y = \frac{19.3 \pm \sqrt{372 - 129.6}}{2}$$

$$= \frac{19.3 \pm \sqrt{242.4}}{2} = \frac{19.3 \pm 15.6}{2}$$

$$V = \left[\frac{Qf^2}{140}\right]^{1/6}$$

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

$$A = \frac{Q}{V}$$

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

$$S = \left[\frac{f^{5/3}}{3340\, Q^{1/6}}\right]$$

$$V = \left[\frac{Qf^2}{140}\right]^{1/6}$$

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

$$A = \frac{Q}{V}$$

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

$$S = \left[\frac{f^{5/3}}{3340\,Q^{1/6}}\right]$$

Neglecting unfeasible + ve sign, we get

$$y = \frac{19.3 - 15.6}{2} = 1.65\text{ m}$$

$\therefore$ $y = 1.65$ m. **Ans.**

$$b = 33.56 - 2.24 \times 1.65 = \mathbf{29.77\text{ m}}$$

or $b = 29.77$ m. **Ans.**

$$S = \frac{f^{5/3}}{3340\,Q^{1/6}} = \frac{(1.1)^{5/3}}{3340 \cdot (50)^{1/6}} = \frac{1}{5420}$$

Use a bed slope of 1 in 5420. **Ans.**

Limitations of Lacey's theory

- The Lacey's work is based on field observations and empirically derived equations and therefore it cannot be said to be theory in strict sense.

- Regime equations in their derived from cannot be applied universally as they hold good mostly for the regions whose data was taken for study.

- Like Kennedy's theory even though perfect definition of silt grade and silt charge is not given most of the equations are based on the silt factor 'f'.

Limitations of Lacey's theory

- In practice regime condition stated by Lacey is very rarely achieved and that too after a long period.

- The field observations have shown limited acceptance of the concept of semi-elliptical section of a regime channel.

- Complex phenomenon of sediment concentration and transport has not been scientifically considered.

Comparison of Kennedy and Lacey's theory

- The concept of silt transportation is same in both the cases, both agree that the silt is carried by the vertical eddies generated due to friction of the flowing water against rough surface of canal. Kennedy considered a trapezoidal channel section and, therefore, he neglected eddies generated from the sides. For this reason, Kennedy's critical velocity formula was derived only in terms of depth of flow(y). Lacey considered that an irrigation channel achieves a cup-shaped section(semi-ellipse) and that entire wetted perimeter of the channel contributes to the generation of silt supporting eddies. He, thus, used hydraulic mean radius(R) as a variable in his regime velocity formulas instead of depth(y).

- Kennedy stated all the channels to be in state of regime provided they did not silt or scour. But Lacey differentiated between two regime conditions, i.e. initial regime and final regime.

Comparison of Kennedy and Lacey's theory

- According to Lacey, grain size of material forming the channel is an important factor, and should need much more attention than what was given to it by Kennedy. He connected grain size(d) with his silt factor(f) as $f= 1.76(d_{mm})^{0.5}$.

- Kennedy used Kutter's formula for determining actual generated channel velocity. The value of Kutter's rugosity coefficient(n) is again a guess work. Lacey, on the other hand, has produced a general regime flow, after analyzing huge data on regime channels.

Comparison of Kennedy and Lacey's theory

- Kennedy has not given any importance to bed width and depth ratio. Lacey has connected wetted perimeter(P) as well as area(A) of the channel with discharge, thus, establishing a fixed relationship between bed width and depth.

- Kennedy did not fix regime slopes for his channels, although, his diagrams indicate that steeper slopes are required for smaller channels and flatter slopes are required for larger channels. Lacey, on the other hand, has fixed the regime slope, connecting it with discharge.

4.10. Cross-section of an Irrigation Canal

A typical and most desired section of a canal is shown in Fig. 4.19. This section is 'partly in cutting and partly in filling', and aims at balancing the quantity of earth work in 'excavation' with that in 'filling'.

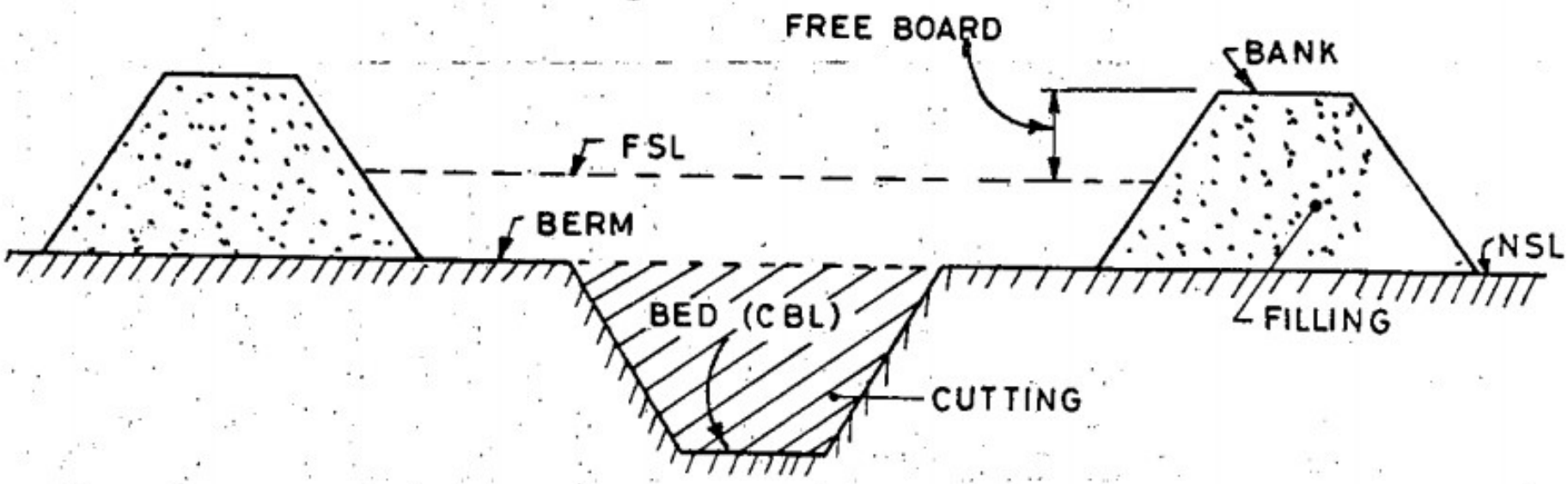


Fig. 4.19.

Side Slopes. The side slopes should be such that they are stable, depending upon the type of the soil. A comparatively steeper slope can be provided in cutting rather than in filling, as the soil in the former case shall be more stable.

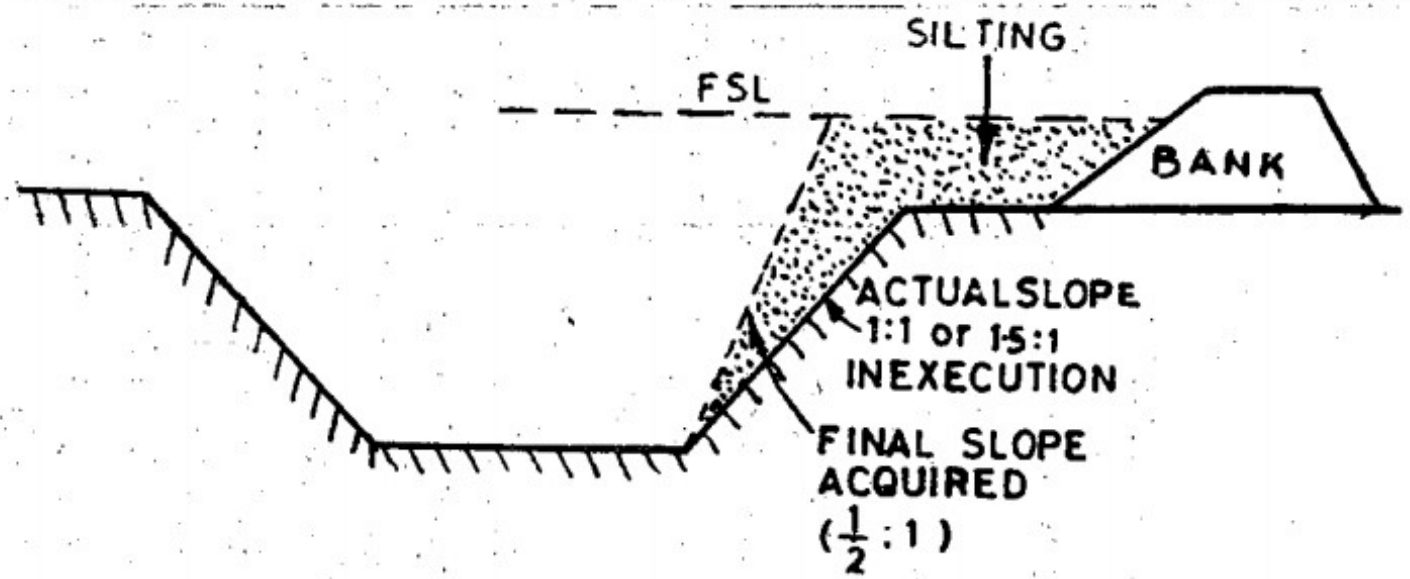
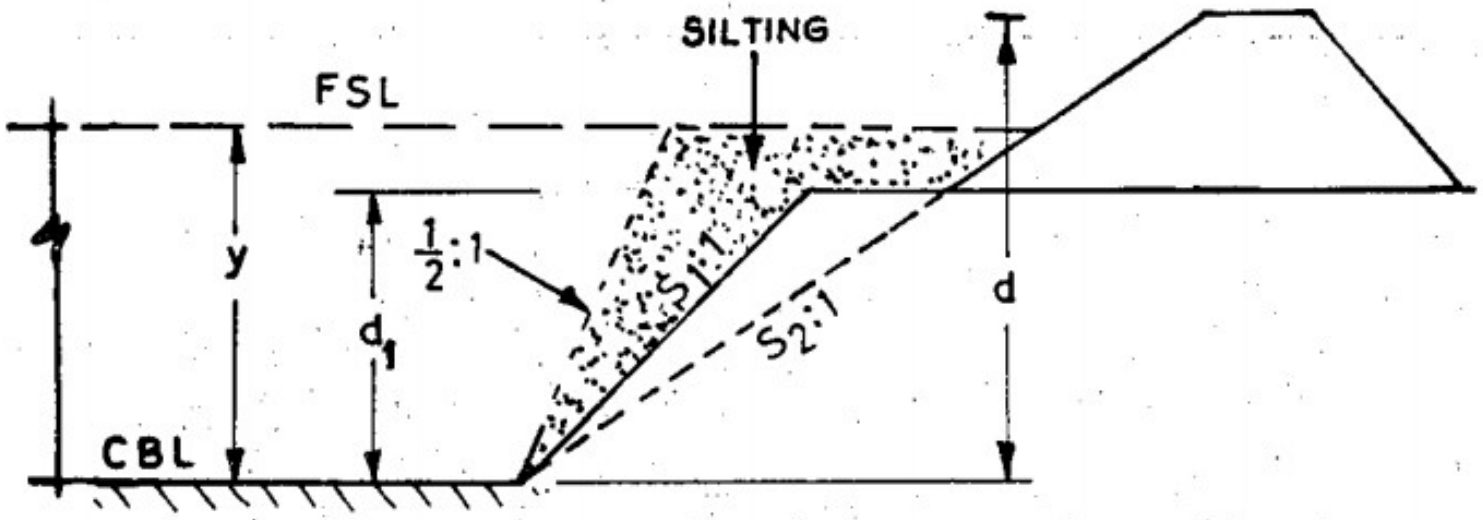


Fig. 4.20.

$1H:1V$ (1 : 1) to $1\frac{1}{2}H:1V$ ($1\frac{1}{2}$: 1) slope in cutting, and $1\frac{1}{2}H:1V$ to $2H:1V$ in filling, are generally adopted.

Berms. Berm is the horizontal distance left at ground level between the toe of the bank and the top edge of cutting.

The berm is provided in such a way that the bed line and the bank line remains parallel. If $s_1 : 1$ is the slope in cutting and $s_2 : 1$ in filling, then the initial berm width $= (s_2 - s_1)\, d_1$. Since ground level (NSL) fluctuates considerably, while canal bed level (CBL) varies very slightly, d_1 shall vary ; and, therefore, the berm width shall vary.



Freeboard. The margin between FSL and bank level is known as freeboard. The amount of freeboard depends upon the size of the channel. The generally provided values of freeboard are given in Table 4.7.

Table 4.7. Values of Free-boards in Canals

Discharge in cumecs	*Extent of freeboard in metres*
1 to 5	0.50
5 to 10	0.60
10 to 30	0.75
30 to 150	0.90

Banks. The primary purpose of banks is to retain water. They can be used as means of communication and as inspection paths. They should be wide enough, so that a minimum cover of 0.5 metre is available above the saturation line, as shown in Fig. 4.22. High banks will have to be designed as earth dams.

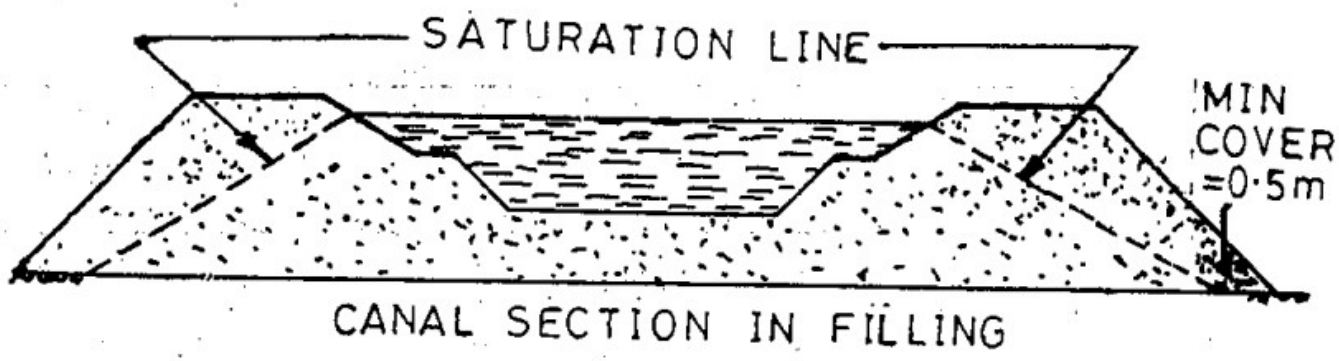


Fig. 4.22.

Service Roads. Service roads are provided on canals for inspection purposes, and may simultaneously serve as the means of communication in remote areas. They are provided 0.4 m to 1.0 m above FSL, depending upon the size of the channel.

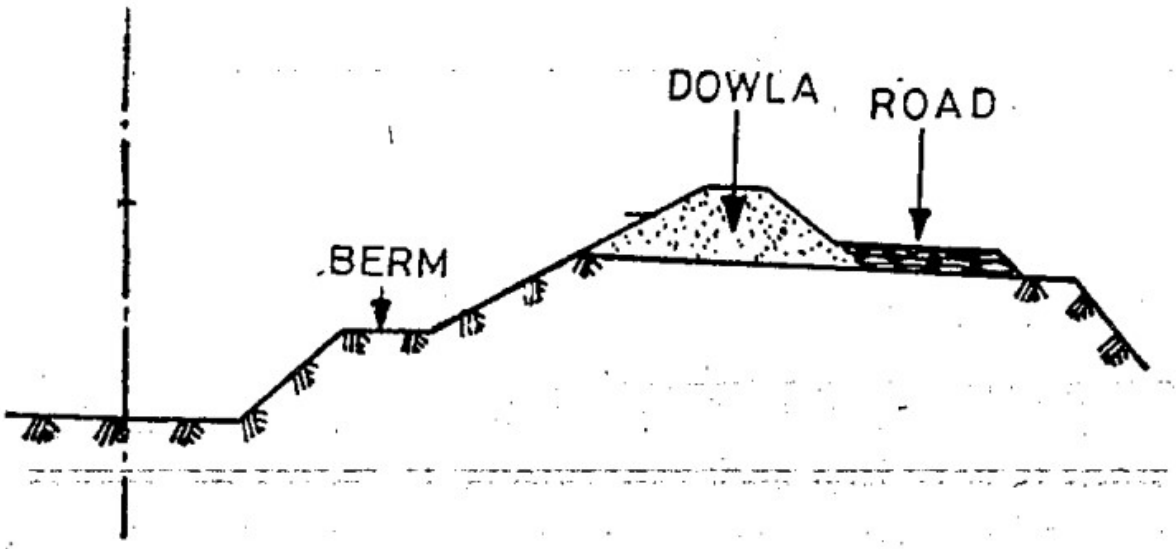
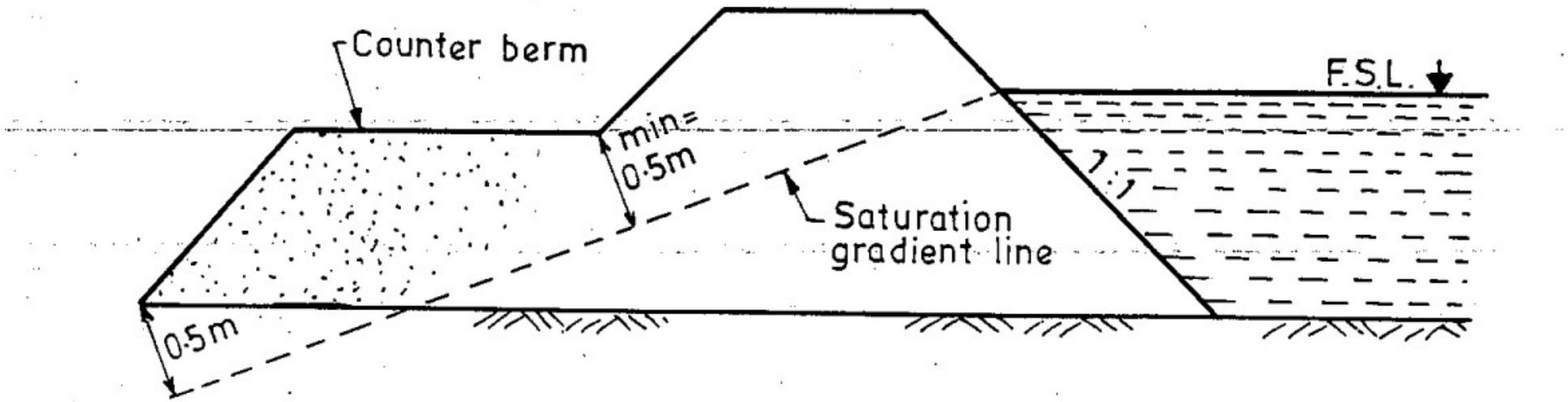


Fig. 4.23.

Dowlas. As a measure of safety in driving, dowlas 0.3 m high and 0.3 to 0.6 m wide at top, with side slopes of $1\frac{1}{2}:1$ to $2:1$, are provided along the banks, as shown in Fig. 4.23. They also help in preventing slope erosion due to rains, etc.

Back Berm or Counter Berms. Even after providing sufficient section for bank embankment, the saturation gradient line may cut the downstream end of the bank. In such a case, the saturation line can be kept covered at least by 0.5 metre with the help of counter berms, as shown in Fig. 4.24.



Spoil Banks

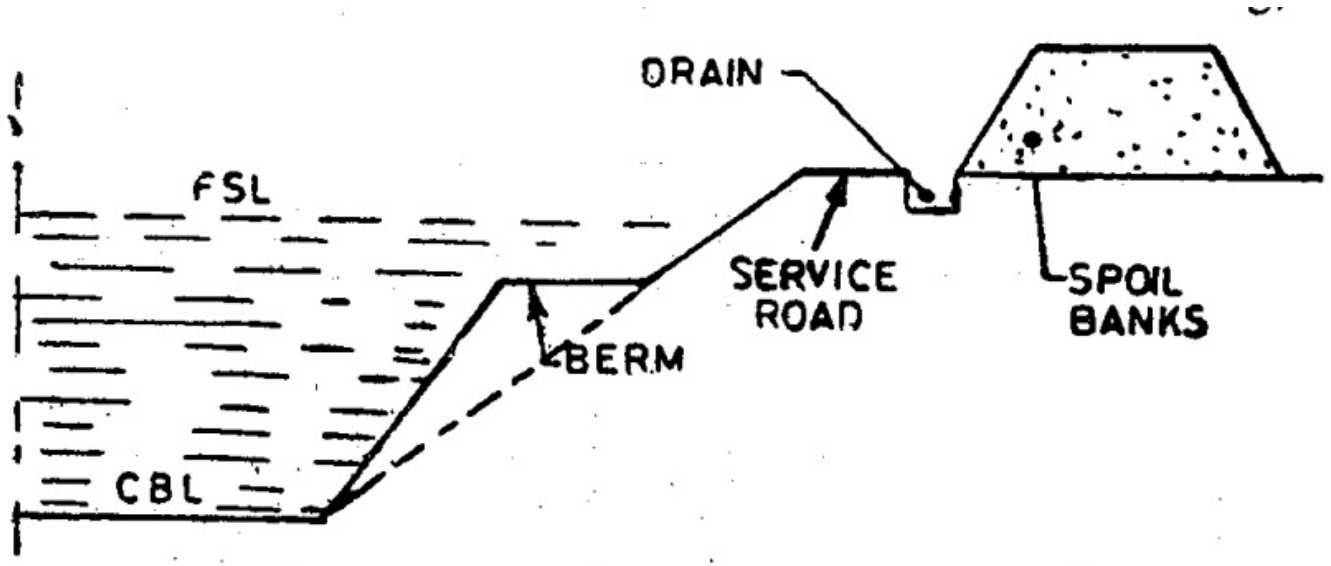
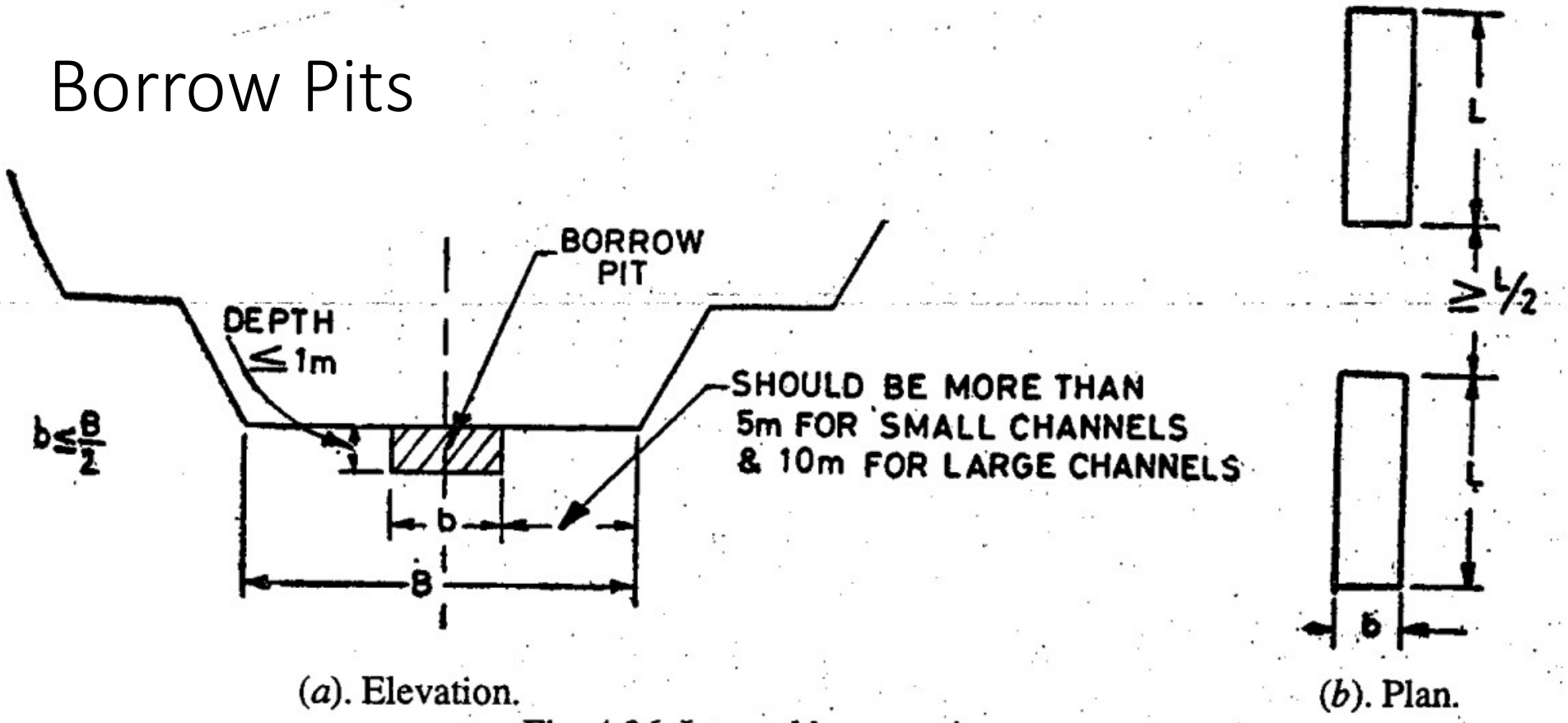


Fig. 4.25. Spoil bank.

Borrow Pits



(*a*). Elevation. (*b*). Plan.

Fig. 4.26. Internal borrow pits.

Longitudinally, these pits should not run continuous, but a minimum space of $\frac{L}{2}$ should be left between two consecutive pits, (where L is the length of one pit) as shown in Fig. 4.26 (*b*).

Balancing depth for excavating canals

- Earthwork in excavation= Earthwork in filling ➔ Maxmum economy

- For a given cross section of a channel, there can be only one depth, for which such a balance between cutting and filling will occur.

- If this balance between cutting and filling can occur, then the need for spoil banks or borrow pits is entirely eliminated, and moreover, earthwork has to be paid only once in a single item.

Calculate the balancing depth for a channel section having a bed width equal to 18m and side slopes of 1:1 in cutting and 2:1 in filling. The bank embankments are kept 3.0m higher than the ground level (berm level) and crest width of the bank is kept as 2m.

Solution. The channel section is shown in Fig. 4.27. Let d_1 be the balancing depth, *i.e.* the depth for which excavation and filling becomes equal.

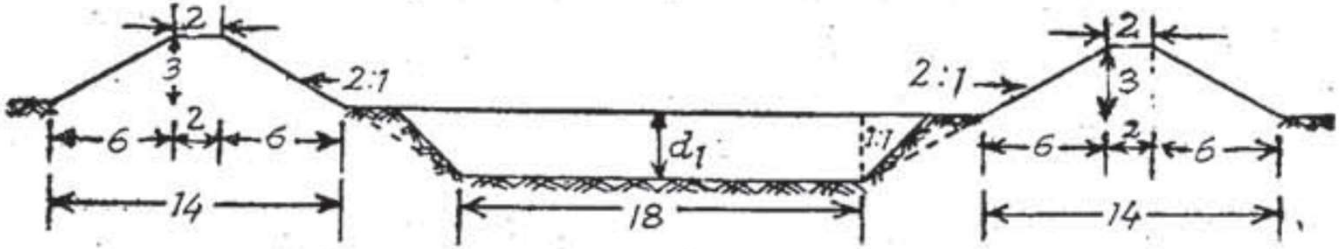


Fig. 4.27.

Area of cutting $= (18 + d_1)\, d_1$ sq. m.

Area of filling $= 2\left[\dfrac{2+14}{2} \times 3\right] = 48$ sq. m.

Equating cutting and filling, we get

$$(18 + d_1)\, d_1 = 48 \qquad \text{or} \qquad 18d_1 + d_1^2 = 48$$

or $$d_1^2 + 18d_1 - 48 = 0$$

or
$$d_1 = \frac{-18 \pm \sqrt{324 + 192}}{2}$$
$$= \frac{-18 \pm 22.7}{2}$$

Ignoring unfeasible – ve sign, we get

$$d_1 = \frac{-18 + 22.7}{2} = \frac{4.7}{2} = 2.35 \text{ m}$$

$\therefore$ Balancing Depth = **2.35 m. Ans.**