# INTEGRATED DESIGN OF CANAL AND CANAL FALL

**A DISSERTATION**

*Submitted in partial fulfilment of the requirements for the award of the degree*

*of*

**MASTER OF ENGINEERING**

*in*

**CIVIL ENGINEERING**
**WITH SPECIALIZATION IN**
**COMPUTER AIDED DESIGN**

**By**

**VINOD KUMAR**



**DEPARTMENT OF CIVIL ENGINEERING**
**UNIVERSITY OF ROORKEE**
**ROORKEE-247 667 (INDIA)**

**JANUARY, 1995**

# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled "**INTEGRATED DESIGN OF CANAL AND CANAL FALL**" in partial fulfillment of the requirement for the award of degree of **MASTER OF ENGINEERING** with specialization in **COMPUTER AIDED DESIGN**, submitted in the Department of Civil Engineering, University of Roorkee, Roorkee, India, is an authentic record of my own work carried out for a period of about five months from September 1994 to January 1995, under the guidance of **Dr. P.K. PANDE** , Professor, and **Dr. C.S.P. OJHA**, Lecturer, Department of Civil Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree of diploma.

Dated : 29 Jan, 1995

**(VINOD KUMAR)**

---

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief.

**Dr. P.K. PANDE**
Professor
Department of Civil Engg.
University of Roorkee
Roorkee, INDIA

**Dr. C.S.P. OJHA**
Lecturer
Department of Civil Engg.
University of Roorkee
Roorkee, INDIA

Dated : Jan. 1995

# ACKNOWLEDGMENT

It is with fervid sincerity that I owe my grate debt and gratefulness to **Dr. P.K. PANDE**, Professor, and Dr. C.S.P. **OJHA**, Lecturer, Department of Civil Engineering, University of Roorkee, Roorkee, for their expert guidance, invaluable suggestions and incessant encouragement throughout the course of dissertation work. Their readiness to help at any hour coupled with their personal interest made it possible to complete this work with stipulated time.

I owe a grate deal of appreciation to **Prof. (Dr.) P.K. SWAMEE**, Department of Civil Engineering, University of Roorkee, Roorkee for his valuable encouragement and kind Behavior.

I am indebted to my friends Gautam Hazarika, Sanjay Agarwal, Anurag Tankha, Prabhat Gupta and Elanchezhian P.V. for their moral support.

Thanks are also due to NCF and library staffs.

Finally I have no words to express my gratitude to my parents who have been my inspiration throughout this study.

Dated : 29 Jan, 1995

(VINOD KUMAR)

# INTEGRATED DESIGN OF CANAL

# AND

# CANAL FALL

## ABSTRACT

The two main components in the design of an irrigation canal are design of canal cross section and the design of canal fall. It is important to design the canal and canal falls integrally. In the present work a computer code is developed which includes twelve different methods of canal design. These design methods are basically divided into two categories, namely, design methods for lined canal and unlined canal. The design methods for unlined canals are further subdivided in two categories depending upon whether the canal sediment transport capacity is specified or unspecified. The developed computer program is based on the integrated approach to design a canal. The canal cross section design of canal fall and the determination of the best canal alignment is done in a single program. Flexibility is provided for the user to design the canal, taking one reach at a time or to design a number of reaches with or without providing canal falls in between. The user may give a number of canal routes and can select the best route out of these feasible routes by comparing the cost of different routes.

## CONTENTS

| | |
|---|---|
| $A$ | Area of flow |
| $B$ | Bed width of canal |
| $B_1$ | Width of U/S curtain wall |
| $B_2$ | Width of D/S curtain wall |
| $B_B$ | Bottom width of wing wall |
| $B_T$ | Top width of wing wall |
| $B_W$ | Width of wing wall |
| $b_b$ | Berm width |
| $b_r$ | Roadway width |
| $C$ | Bed sediment concentration |
| $C_b$ | Unit cost of brick work |
| $C_c$ | Unit cost of concrete |
| $C_e$ | Unit cost of earth work |
| $C_v$ | Critical velocity ratio |
| $D$ | Depth of flow |
| $D_1$ | Depth of U/S curtain wall |
| $D_2$ | Depth of D/S curtain wall |
| $D_c$ | Constrained flow depth |
| $D_r$ | Difference between ground level and canal bed level |
| $d_f$ | Free-board |
| $d$ | Median diameter of sediment particle |
| $d_{75}$ | Diameter of particle 75% finer |
| $f$ | Darcy - Weisbach friction factor |
| $f_b$ | Silt factor for bed material |
| $f_o$ | Lacey's silt factor |

| | |
|---|---|
| $f_s$ | Silt factor for side material |
| $G_E$ | Safe exit gradient |
| g | Acceleration due to gravity |
| $H_c$ | Head over the crest |
| $H_F$ | Height of fall |
| $H_s$ | Maximum static head |
| $K_1$ | Unit cost of cutting |
| $K_2$ | Unit cost of filling |
| $K_3$ | Unit cost of lining |
| $L_o$ | Upstream approach length of wing wall |
| $L_1$ | Horizontal length of upstream glacis plus width of crest |
| $L_2$ | Horizontal length of downstream glacis |
| $L_3$ | Cistern length |
| m | Side slope of canal |
| $m_2$ | Outer side slope of road way |
| $m_3$ | Inner side slope of road way |
| n | Manning's coefficient |
| p | Wetted perimeter |
| $P_{tg}$ | Pressure at the toe of glacis |
| Q | Discharge |
| $q_s$ | Volumetric bed load discharge per unit channel width |
| R | Hydraulic radius |
| S | Canal bed slope |
| s | Specific gravity of concrete |
| $T_1$ | Thickness of foundation concrete in curtain wall |
| $T_2$ | Thickness of foundation concrete in wing wall. |
| $T_c$ | Constrained top width of canal |

| | |
|---|---|
| $T_F$ | Thickness of floor |
| $U$ | Velocity of flow |
| $U_d$ | Upstream full supply depth |
| $W$ | Mean width of canal |
| $W_s$ | Water surface width of canal |
| $\gamma_f$ | Unit weight of fluid |
| $\gamma_s$ | Unit weight of solids |
| $\rho_f$ | Mass density of fluid |
| $\rho_s$ | Mass density of solids |
| $\tau_{LH}$ | Tractive stress for bed |
| $\tau_{LS}$ | Tractive stress for sides |
| $\theta$ | Angle of canal sides with horizontal |
| $\phi$ | Angle of repose |
| $\varphi$ | Flow intensity |
| $\phi_T$ | Bed load intensity |

# LIST OF FIGURES AND TABLES

# INTRODUCTION

A canal is an artificial channel, generally trapezoidal in shape, constructed on ground to carry water to fields either from the river or from a tank or a reservoir. If velocity of flow in the unlined channel is more, then scouring may take place on the bed and sides. In case the velocity is less, silting may take place. Hence a canal is usually designed for no silting -no scouring velocity, which is known as the critical velocity.

A lined canal costs about 2 to 2.5 times more as compared to the lined canal; but where seepage is heavy, the saving of costly irrigation water may itself be sufficient to fully justify the capital expenditure on lining. Prevention of seepage by lining would reduce their impounding capacity and construction costs. Besides this lining of canals checks water logging and salinity and thus ensures better sanitary condition in the area. Consequently, more land can be brought under irrigation and drainage cost, land reclamation charges, and expenses on site clearances, etc., can be reduced.

Besides irrigation canals are also constructed for the purpose of navigation, generation of Hydro-electric power and flood control. These canals are generally designed as lined canals.

From the above discussions, it is clear that a canal may be designed and constructed as a lined or unlined canal depending on the available funds and the purpose for which it is to be constructed. The first method for the design of canals was developed in India by Kennedy in 1895 (Singh, 1988). Since then a number of methods have been developed for the design of unlined and lined canals. Some of the important methods are discussed in the next chapter.

As the maximum slope that can be provided in a canal without generating excessive velocities is usually less than the country slope in its head reaches, vertical falls have to be constructed in the canal to accommodate this extra drop in level. Power houses can be provided to generate power on these falls. If generation of power is taken up simultaneously with the construction of the irrigation project, these falls can be adjusted to be of maximum use in power generation without impairing irrigation potential of the project. Smaller number of high falls have to be provided for economical power generation. For irrigation projects, the relative economy of providing a large number of smaller falls or a smaller number of high falls has to be determined always subjected to over-riding considerations of obtaining a suitable waterline for command. In this respect, the integrated design of canal and canal falls becomes very important. Thus, the objective of the present study is to develop a software which offers flexibility in terms of various methods of canal design and the variability in location of canal falls. The available methods of canal design are shown in Fig. 1.1.

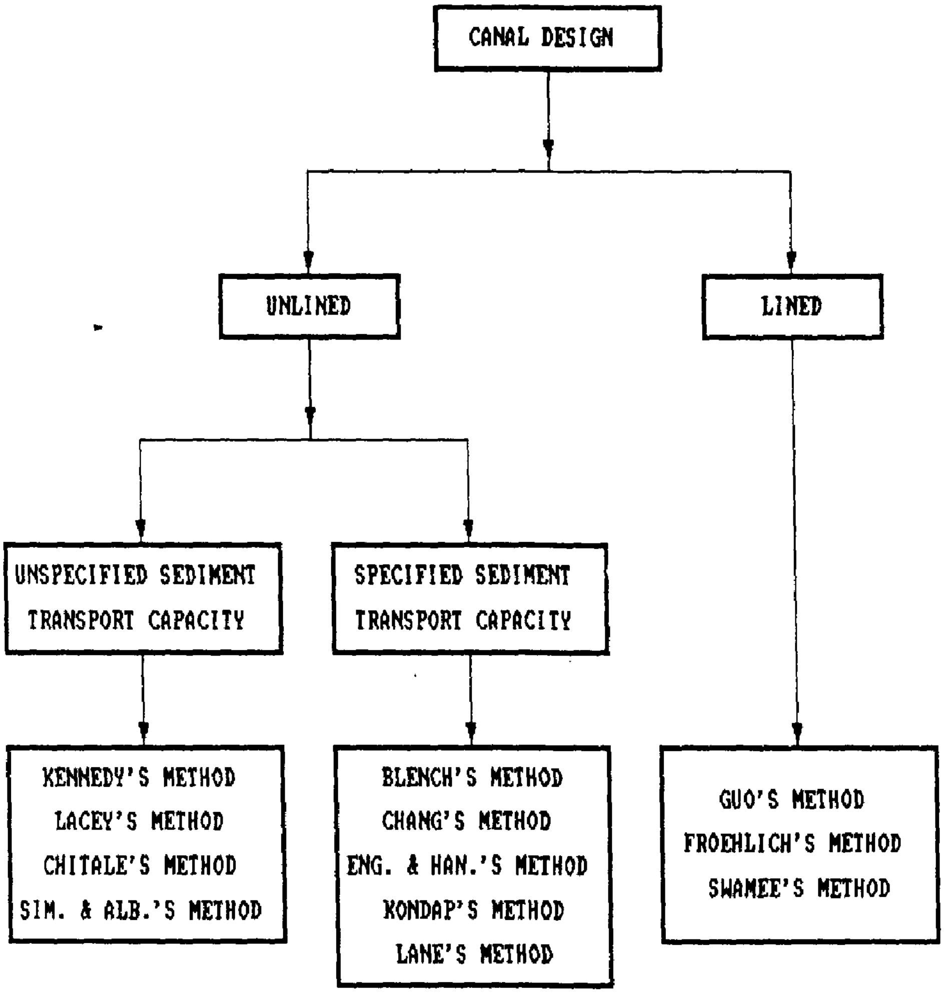



FIG. 1.1 DIAAGRAM SHOWING AVAILABLE DESIGN METHODS

# CANAL DESIGN PROCEDURE

## 2.1 INTRODUCTION

Irrigation channels in India are often constructed in alluvial soil without lining in bed and banks. Power channels are constructed for conveyance of water for hydro-power generation. These channels are mostly lined. Depending upon the use and funds available for construction, a canal can be constructed as lined or unlined. Thus the available canal design methods can also be classified into two categories i.e. design methods for lined canal and unlined canals.

## 2.2 DESIGN OF LINED CANALS

Design of lined channels for uniform flow generally involves the optimization of cost by reducing the flow area and perimeter to a minimum. This is an essential requirement for lined canals as the minimum flow area (i.e. maximum velocity) will ensure not only economy but non-silting velocity also and the minimum perimeter results in minimizing the lining cost. Some of the methods for the design of lined canals are described next.

### 2.2.1 Swamee and Bhatia (1972) Method

This method expresses all channel dimensions in a single parameter of form $K\left[\frac{Qn}{\sqrt{S}}\right]^{3/8}$, where K is a function of side-slope m. The parameter K gives complete information about the design of an optimal channel section. The pertinent design equations are:

$$B = K_b \left[ \frac{Qn}{\sqrt{S}} \right]^{3/8} \qquad (2.1)$$

$$D = K_d \left[ \frac{Qn}{\sqrt{S}} \right]^{3/8} \qquad (2.2)$$

$$A = K_a \left[ \frac{Qn}{\sqrt{S}} \right]^{3/4} \qquad (2.3)$$

$$U = K_v \left[ \frac{Qn}{\sqrt{S}} \right]^{1/4} \qquad (2.4)$$

where

$$K_b = 4^{5/8} \left[ \frac{\sqrt{1+m^2} - m}{(2\sqrt{1+m^2} - m)^{3/8}} \right] \qquad (2.5)$$

$$K_d = 2^{1/4} \left[ \frac{1}{(2\sqrt{1+m^2} - m)^{3/8}} \right] \qquad (2.6)$$

$$K_a = \left[ 4\left( 2\sqrt{1+m^2} - m \right) \right]^{1/4} \qquad (2.7)$$

$$K_v = 1/K_a \qquad (2.8)$$

and for the most economical trapezoidal section $m = 1/\sqrt{3}$ .

### 2.2.2 Guo and Hughes (1984) Method

This method suggests an approach for computing the optimal lined cross-section with a specified free-board. The design steps are (Geo and Hughes - 1984):

1. $$Q' = \left( \frac{Qn}{\sqrt{S}} \right)^3 \qquad (2.9)$$

2. Assume $z = \frac{d_f}{D}$ (2.10)

3. $$\eta = \frac{1}{(5m+2)}\left[-(3kz + 2mz - 2k + 3m) + \sqrt{9k^2z^2 - 16m^2z^2 + 4k^2 + m^2 + 32z^2km - 12k^2z + 38zkm - 16m^2z - 4km}\right]$$ (2.11)

where $k = \sqrt{1+m^2}$

4. $$D = \left[Q'(\eta+m)^{-5}(\eta+2k)^2\right]^{1/8}$$ (2.12)

5. Find new free-board $d_f = Dz$ and compare it with specified free-board. Adjust z in step 2 and repeat steps (3) & (4) until the desired accuracy is achieved.

6. $B = \eta D$ (2.13)

### 2.2.3 Froehlich (1994) Method

This method considers the possibility of constraints on the top width or depth of the channel cross-section that site conditions will occasionally impose. The constrained minimization problem of finding the best hydraulic section is solved using the Lagrange multiplier method with dimensionless forms of the objective and constraint functions (Froehlich-1994). The design steps for both the cases are given below:

(a) Top Width-Constrained Case

1. $$T_* = T_c \left[\frac{Qn}{\sqrt{S}}\right]^{-3/8} \qquad (2.14)$$

2. Find m using

$$m = 0 \qquad \text{for } T_* \le 1.316$$

$$m = -0.612 + 0.367\ T_* + 0.074\ T_*^2$$

$$\text{for } 1.316 < T_* \le 2.235 \qquad (2.15)$$

3. $$D_* = T_* \left[\frac{\sqrt{1+m^2} - m}{1+m\left(\sqrt{1+m^2} - m\right)}\right] \qquad (2.16)$$

$$B_* = T_* - 2m\ D_* \qquad (2.17)$$

4. $$D = D_* \left[\frac{Qn}{\sqrt{S}}\right]^{3/8} \qquad (2.18)$$

$$B = B_* \left[\frac{Qn}{\sqrt{S}}\right]^{3/8} \qquad (2.19)$$

(b) Depth-Constrained Case

1. $$D_* = D_c \left[\frac{Qn}{\sqrt{S}}\right]^{-3/8} \qquad (2.20)$$

$$B_* = 1.1\ D_*^{-1.61} \qquad (2.21)$$

2. $$D = D_c \qquad (2.22)$$

$$B = B_* \left[\frac{Qn}{\sqrt{S}}\right]^{3/8} \qquad (2.23)$$

## 2.3 DESIGN OF UNLINED CANALS

Channels take their water supply from rivers which always carry a certain amount of sediment. The sediment is usually loose, non-cohesive and also termed as alluvium. The aim of designer in respect of such channels is to obtain physical stability, i.e., a balance between silting and scouring, and a dynamic equilibrium in the forces generating the scouring and maintaining the channel cross-section and gradient (Singh 1988).

The design methods for unlined channels may be broadly classified as design methods for unspecified transport capacity and specified transport capacity.

### 2.3.1 Design Methods for Unspecified Transport Capacity

These methods were developed by different investigators after studying a large number of channels which had been in operation for a long time without any major problem of silting or scouring. These methods are also called regime methods of channel design. These methods are empirical and relate all the parameters directly related to practical design and do not consider the influence of sediment load.

The first method under this category was developed by Kennedy in 1895. He recommended the use of critical velocity concept for the design of stable channels. Lacey in 1936, developed equations based on available data of stable channels in Punjab, for wetted perimeter, hydraulic radius, and bed slope, relating them with discharge and sediment size. Simons and Albertson (Varshney, 1983) in 1960, analysed the stable channel data from U.S.A., Punjab and Sindh. They classified the data based on nature of bed and bank materials. Chitale (1966) also proposed equations for design of stable channel based on data from Punjab, U.P., Bengal and Sindh canal systems. Generally the design based on these methods have a transport capacity of about 500 ppm. If the sediment load in a particular channel differs from this value then the sediment load should be taken into account in the design equations for stable channel.

#### 2.3.1.1 Kennedy (1895) method

$$U = 0.55\ C_v\ D^{0.64} \qquad (2.24)$$

$C_v$ = 1 for Punjab region or regions having similar sediment.

$C_v < 1$ for regions having finer sediment than that of Punjab.

$C_v > 1$ for regions having coarse sediment than that of Punjab

This equation being based on limited data, the coefficient and exponent in Kennedy's equation have been found to vary significantly for other canal systems (Singh, 1988).

#### 2.3.1.2 Lacey's (1936) method

Lacey proposed the following equations for design of stable channel:-

$$P = 4.75\ Q^{1/2} \qquad (2.25)$$

$$R = 0.47\ (Q/f_o)^{1/3} \qquad (2.26)$$

$$U = 0.439\ Q^{1/6}\ f_o^{\ 1/3} \qquad (2.27)$$

$$S = 0.00033\ f_o^{\ 5/3} /\ Q^{1/6} \qquad (2.28)$$

$$f_o = 1.76\ \sqrt{d}\ , \text{ here d is in mm.} \qquad (2.29)$$

**2.3.1.4 Chitale (1966) Method**

Chitale proposed the following relationships in place of Lacey:

$$P = 4.3\ Q^{0.523} \qquad (2.30)$$

$$R = 0.499\ Q^{0.341} \qquad (2.31)$$

$$S = 0.00028\ Q^{-0.165} \qquad (2.32)$$

$$U = 7.34\ R^{1/2}\ (R^{1/2}S)^{0.293} \qquad (2.33)$$

**2.3.1.3 Simons and Albertson (1960) Method**

Simons and Albertson classified the regime channels into four categories depending on the nature of bed and banks as those with,

(i) Sand bed and banks

(ii) Sand bed and cohesive banks

(iii) Cohesive bed and banks

(iv) Coarse non-cohesive materials

They used tractive force method along with Lacey's method of analysis. They gave the following equations in general form,

$$P, A, R = aQ^b \tag{2.34}$$

$$U = c(R^2 S)^d \tag{2.35}$$

$$\frac{U^2}{gDS} = e\left[\frac{U\,W}{\nu}\right]^f \tag{2.36}$$

where $W = 0.92\, W_s - 0.6$

The values of multipliers (a,c and e) and exponents (b,d and f) are given in Table-2.1.

### 2.3.2 Design methods for Specified Transport Capacity

Following are the design methods for a specified transport capacity.

#### 2.3.2.1 Lane (1955) Method

In this method the bed material is considered to be non-cohesive. For stability or non-scouring of a channel, the shear stress exerted by water on the particles, either resting cn bed or sides must be less than the limiting tractive stress of the particles. As per Lane even though the average shear stress on the periphery is given by $\gamma_f R\, S$, the shear stress is not uniformly distributed over the sides and bed, due to different B/D ratios and side slopes. The tractive stresses for bed and sides are given as,

$$\tau_{LH} = 0.754\, d_{75} \tag{2.37}$$

$$K = \frac{\tau_{LS}}{\tau_{LH}} = \cos\theta \sqrt{1 - \frac{\tan^2\theta}{\tan^2\phi}} \tag{2.38}$$

Lane suggested the use of Manning's resistance equation using the coefficient of roughness as

$$n = \frac{(d_{75})^{1/6}}{66.724} \quad ; \quad d_{75} \text{ is in mm.} \tag{2.39}$$

The steps involved in the design are:

1. Calculate $\tau_{LH}$.

2. Assuming suitable side slope $\theta$, calculate K and hence $\tau_{LS}$.

3. Find the ratio of maximum shear stress to $\gamma_f$ DS for bed and sides, for an assumed value of B/D.

4. Find minimum value of DS computed form,

   $\tau_{LH} \geq (\text{maximum shear stress})_{bed}$

   $\tau_{LS} \geq (\text{maximum shear stress})_{sides}$

5. Start with an assumed value of D, and find S, B and other geometric parameters.

6. Calculate discharge from Manning's equation and adjust the value of D in step (5) until the calculated discharge match with the design discharge.

#### 2.3.2.2 Blench (1951) Method

Blench (Prasad-1993) presented the equations for stable channel design considering that the influence of sides and bed are different in attaining the stability of channel for low sediment concentration. For appreciable sediment load he modified his earlier equations by introducing sediment concentration as a variable. He suggested the following equations for design,

$$W = \sqrt{\frac{f_b Q}{f_s}} \tag{2.40}$$

$$D = \left[\frac{Q f_s}{f_b^2}\right]^{1/3} \tag{2.41}$$

$$S = \frac{f_b^{5/6} \, f_s^{1/12} \, \gamma_f^{1/4}}{1.11g \; Q^{1/6}\left[1 + \frac{C}{2333}\right]} \qquad (2.42)$$

where

$f_b = 1.9\sqrt{d}$

$f_s$ = 0.1 for slightly cohesive banks

$f_s$ = 0.2 for cohesive banks

$f_s$ = 0.3 for highly cohesive banks

### 2.3.2.3 Engelund and Hensen (1967) Method

Englund and Hansen, in 1967, developed a method for design of stable channel using the resistance law as,

$$U = 10.97 \; d^{-3/4} \; D^{5/4} \; S^{9/8} \qquad (2.43)$$

and the sediment transport law as,

$$f\phi_T = 0.4 \; \tau_*^{5/2} \qquad (2.44)$$

where

$$f = 8 \left(\frac{U_*}{U}\right)^2 \qquad (2.45)$$

$$U_* = \sqrt{gDS} \qquad (2.46)$$

$$\phi_T = \frac{Q_T}{B\gamma_s} \sqrt{\frac{\rho_f}{(\rho_s - \rho_f) g d^3}} \qquad (2.47)$$

$$\tau_* = \frac{\tau_o}{\Delta\gamma_s d} \qquad (2.48)$$

$$\tau_o = \gamma_f DS \qquad (2.49)$$

$$\Delta\gamma_s = \gamma_s - \gamma_f \tag{2.50}$$

They gave the equation for water surface width of canal as,

$$W_s = 0.78 d^{-0.316} Q^{0.525} \tag{2.51}$$

In all these equations d is in metre.

#### 2.3.2.4 Kondap (1977) Method

Kondap (1977) analysed the data of various alluvial channels and using the principle of dimensional analysis established the following equations,

$$\frac{W_s}{d} = 0.212 \left[\frac{g^{1/2} d^{3/2}}{\gamma_f}\right]^{0.231} \left[\frac{Q}{d^2\sqrt{(\Delta\gamma_s/\rho_f)d}}\right]^{0.548} \tag{2.52}$$

$$\frac{A}{d^2} = 2.21\left[\frac{Q}{d^2\sqrt{(\Delta\gamma_s/\rho_f)d}}\right]^{0.855} \tag{2.53}$$

$$\left[\frac{S}{(\Delta\gamma_s/\gamma_f)}\right] = 0.0422\left[\frac{U}{\sqrt{(\Delta\gamma_s/\rho_f)d}}\right]^{1.5}\left[\frac{d}{y_1}\right]^{1.095} \tag{2.54}$$

where $y_1 = \frac{A}{W_s}$

d is in metre for all these equations.

#### 2.3.2.5 Chang (1980) Method

Chang (1980) presented the theory of minimum stream power per this, an alluvial channel with given water discharge and sediment inflow tends to establish its width, depth and slope such that the stream power or slope is a minimum. Chang has given separate methods for design of canals in sand streams and gravel streams. He assumed that gravel streams are streams which have bed material with a median diameter exceeding 16mm.

**(a) Design Method for Sand Stream**

This method uses Manning's resistance equation and Engelund-Hansen sediment discharge formula for the design of canals in sand streams.

The Engelund-Hansen formula is,

$$q_s = 0.05\, \gamma_s\, U^2 \sqrt{\frac{d}{g(\Delta\gamma_s/\gamma_f)}} \left[\frac{\tau_o}{(\gamma_s - \gamma_f)d}\right]^{3/2} \qquad (2.55)$$

(b) Design Method for Gravel Streams

Unlike sand streams, resistance to flow in gravel streams is primarily due to grain roughness since dunes tend to be poorly developed.

The use of Bray's (Chang 1980) resistance equation is suggested. This equation is given as,

$$\frac{1}{\sqrt{f}} = 1.36 \left(\frac{D}{d}\right)^{0.281} \qquad (2.56)$$

Chang developed sediment load equation as,

$$\phi_T = 6.62\left(\frac{1}{\psi} - 0.03\right)^5 \psi^{3.9} \qquad (2.57)$$

The three independent conditions of flow resistance, sediment load, and minimum stream power or bed slope are to be solved using a computer program, a flow diagram of which is given in Fig.2.1.

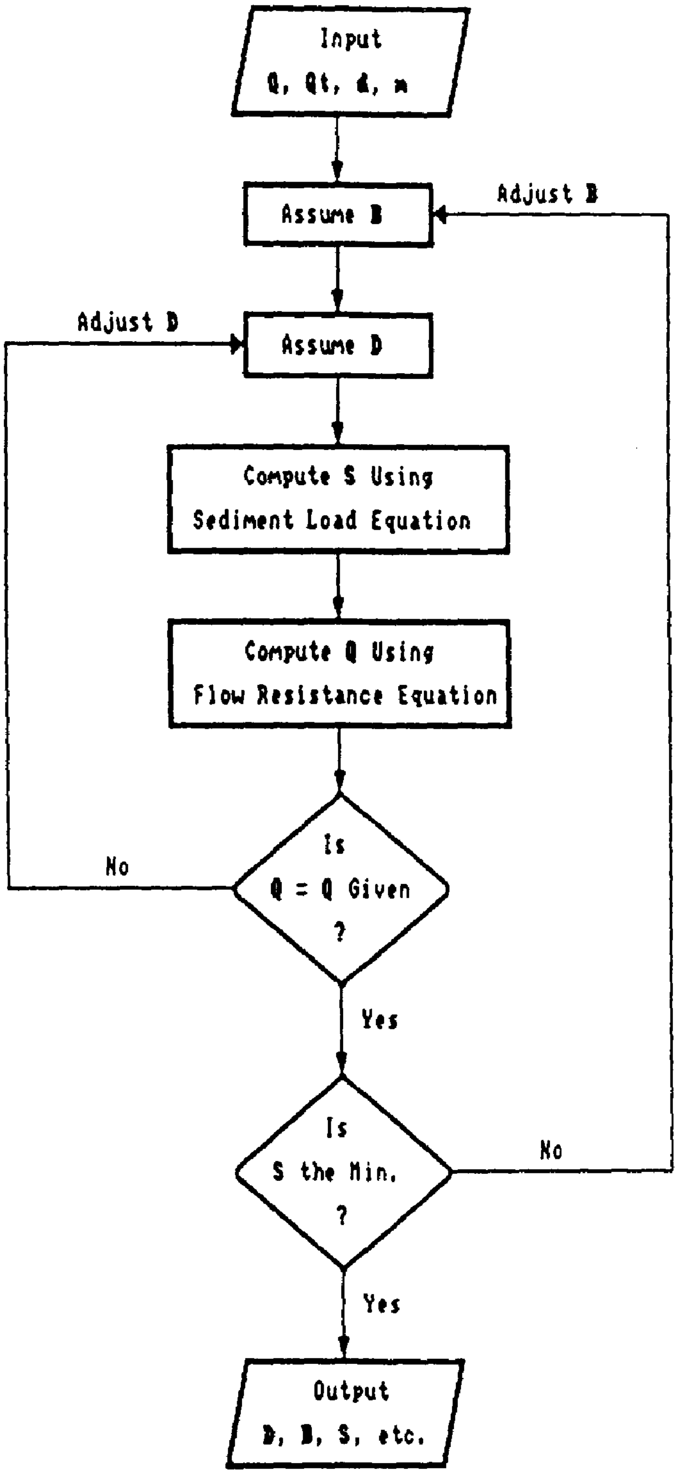



Fig. 2.1 Flow Diagram Showing Major Steps of Computation

**Table 2.1**

**Values of Multipliers and Exponents (Simons- Albertson Method)**

| Category | | Sand bed and banks | Sand bed and cohesive banks | Cohesive bed and banks | Coarse non-cohesive materials |
|---|---|---|---|---|---|
| P | a | 6.33 | 4.74 | 4.63 | 3.44 |
| | b | 0.512 | 0.512 | 0.512 | 0.512 |
| A | a | 2.57 | 2.25 | 2.25 | 0.939 |
| | b | 0.873 | 0.873 | 0.873 | 0.873 |
| R | a | 0.403 | 0.475 | 0.557 | 0.273 |
| | b | 0.361 | 0.361 | 0.361 | 0.361 |
| U | c | 9.33 | 10.80 | - | 4.75 |
| | d | 0.333 | 0.333 | - | 0.333 |
| $\frac{U^2}{gDS}$ | e | 0.324 | 0.525 | 0.885 | - |
| | f | 0.370 | 0.370 | 0.370 | - |

# DESCRIPTION OF CANAL CROSS-SECTION

## 3.1 INTRODUCTION

An irrigation canal may be in full cutting, full filling or partial cutting and filling depending upon the ground level, bed level and the bank top level of the canal. When the ground level is above the top of the bank, the canal is said to be in cutting. Similarly, when the ground level is below the bed level of canal, the canal is said to be in filling. A canal is in partial cutting and filling when the ground level is in between bed level and the top of bank. A canal is generally taken in such a way that its section is partly in cutting and partly in filling in order to approach close to balancing depth. Fig 3.1 shows different types of canal cross-sections.

## 3.2 COMPONENTS OF CANAL CROSS-SECTION

There are various components of canal cross-section. The standards for these components have been adopted according to Table-3.1 (Prasun, 1994).

### 3.2.1 Free-Board

Free-board is the margin provided between the full supply level(F.S.L.) and the top of the bank. Free-board in a channel is governed by the consideration of size of canal, its location, water surface fluctuations, etc. As given in Table 3.1, equation for calculating free-board is :

$$d_f = 0.43\ Q^{0.2} \tag{3.1}$$

### 3.2.2 Berm-Width

Berm is the horizontal distance left at ground level between the toe of the bank and the top edge of cutting. Berm is, generally, not provided in case of lined canals. From Table 3.1, equation for berm-width is:

$$b_b = 1.1\ D^{0.7} \tag{3.2}$$

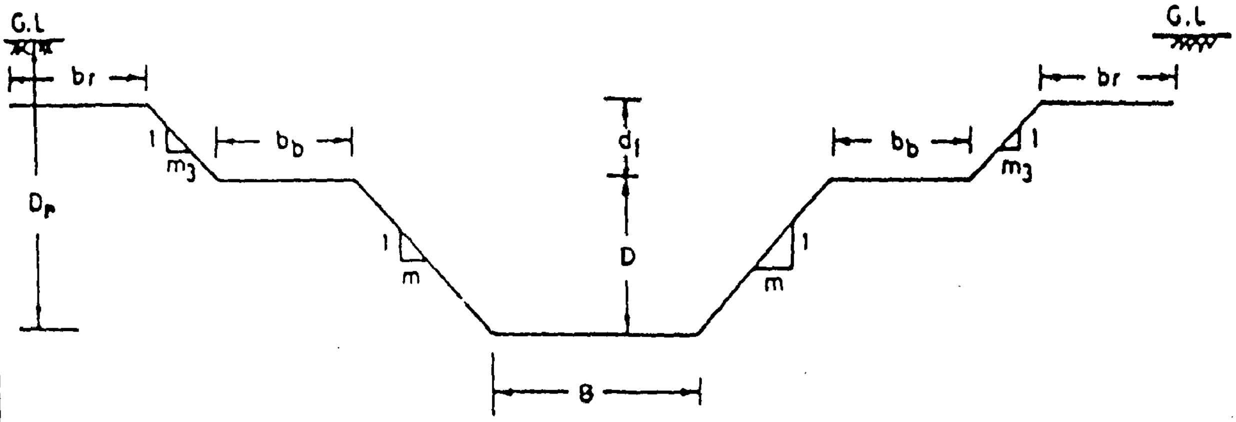
### 3.2.3 Roadway-Width

It is very necessary to have access to all parts of canal system so that proper inspection may be done. Main and branch canals have roadways on both sides. The road on the left is used as inspection road and the right side road is used for transportation purpose. On smaller branches and distributories the roadway is provided on the left side only and it is meant for inspection. Generally, roadway is not provided along minor distributories. From Table-3.1, equation for roadway-width is:

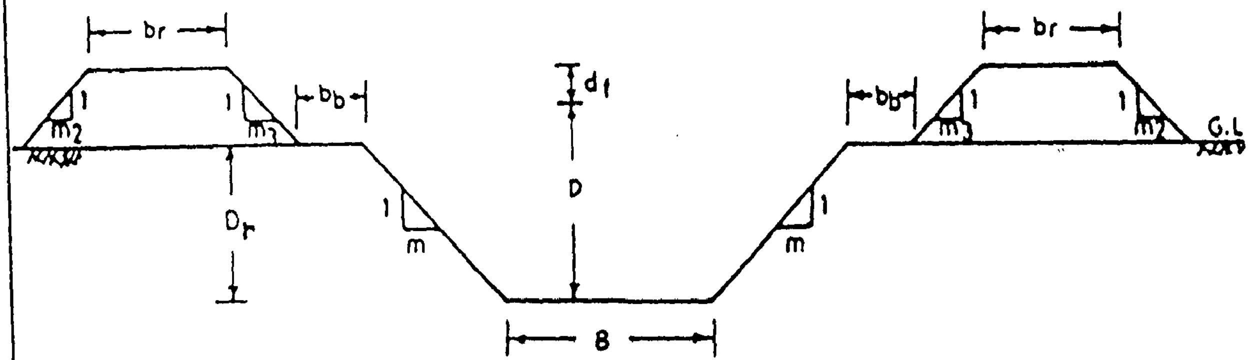
$$b_r = 3.3\ Q^{0.146} \tag{3.3}$$

### 3.2.4 Side-Slopes

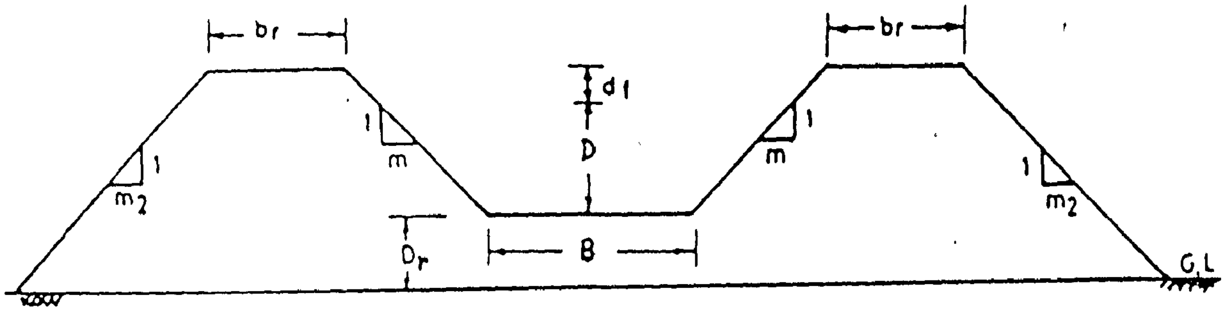
The canal side-slopes should be such that they are stable depending upon the type of soil. A comparatively steeper slope can be provided in cutting rather than in filling as the soil in former case is more stable. 1H : 1V to 1.5H : 1V slope in cutting and 1H : 1V to 2H : 1V in filling are generally adopted.




(i) Cross-Section of canal in cutting reach




(ii) Cross-Section of canal in cutting-filling reach




(iii) Cross-Section of canal in filling reach

FIG. 3·1–VARIOUS CROSS SECTION OF IRRIGATION CHANNEL

TABLE 3.1 STANDARDS FOR FREE BOARD, ROADWAY AND BERM WIDTH OF A CANAL SECTION

| ITEMS | MAIN AND BRANCH CANAL $Q(m^3/s)$ | | MAJOR DISTRIBUTARIES | | MINOR DISTRIBUTARIES | |
|---|---|---|---|---|---|---|
| | 150 to 30 | 30 to 10 | 10 to 5 | 5 to 1 | 1 to 0.3 | below 0.3 cumecs |
| FREE BOARD | 0.9m | 0.75m | 0.6m | 0.5m | 0.4m | 0.3 |
| ROADWAY WIDTH | 6m | 5m | 5m | 3.5m | 3.5m | NO ROAD-WAY PRO-VIDED |
| BERM WIDTH | Upto 4.25 cumecs | | | $b_b = 0.6 + 0.5D$ | | |
| | From 4.25 to 28 cumecs | | | $b_b = 1.25 + 0.5D$ | | |
| | Above 28 cumecs | | | $b_b = 1.25 + 0.53D$ | | |
| | NOTE - $b_b$ and D are in metres | | | | | |

# CANAL FALL

## 4.1 NECESSITY OF CANAL FALLS

Canal fall is a structure intended to secure lowering of water surface in a canal and to dissipate safely the surplus energy so liberated. There is a certain limiting velocity which can be allowed in a canal depending on the nature of soil through which canal is passing, and whether the canal is lined or unlined. This limiting velocity in turn depends upon the slope of the canal. Therefore, there is a limiting slope of canal which cannot be exceeded without detrimence to the canal.

The slope of the country through which canal passes is, generally, steeper than the maximum permissible canal slope. The introduction of falls at intervals becomes, therefore, a necessity to absorb the differential head and to keep the canal against any detrimence.

## 4.2 CLASSIFICATION OF CANAL FALLS

The following two types of falls are commonly used:

1. Vertical Drop type fall,
2. Glacis type fall.

### 4.2.1 Vertical Drop Type Fall

In this type of fall, the nappe impinges clearly into the water cushion below. There is no standing wave and dissipation of energy is due to the turbulent diffusion as the high velocity jet enters the deep pool of water downstream.

### 4.2.2 Glacis Type Fall

In this type of fall, full advantage is taken of the fact that a standing wave is an effective natural means of energy dissipation. This type of fall can further be classified as :

**(a) Straight glacis with baffle platform and baffle wall**

In this type of fall a straight glacis with baffle platform and baffle wall is provided at a certain height and distance from the toe of glacis. This type of fall is commonly known as Poona type or Baffle type canal fall.

**(b) Straight glacis without baffle platform and baffle wall**

In this type of fall a straight glacis is provided without baffle plateform and baffle wall. For higher discharges, the straight glacis may be replaced by half gravity parabolic glacis, commonly known as Montague Profile.

**(c) Modified Glacis Type**

The modifications are in respect of glacis, pavement length and spacing, location and design of friction and toe blocks. This works satisfactorily under drowned conditions in unflumed small falls.

The above types of falls may further be subdivided into following categories :

(i) Flumed or Unflumed falls, depending upon the crest being equal to or smaller than the bed width of canal.

(ii) Metering or Non-metering falls, depending upon whether they can be used for the purpose of discharge measurement or not.

## 4.3 LOCATION OF FALL

If the ground slope exceeds the slope given to the channel the extra fall in ground level has to be consumed by providing canal falls. A fall may be provided at a location where the F.S.L. outstrips the ground level but before the bed of the channel comes into filling ( Singh, 1988). The drop should be such that below the fall, F.S.L. remains below the ground level for two to three hundred meters but not much more, as to this extent the area can be easily irrigated by a water coarse from an outlet at high level upstream of the fall. The location of fall may also be influenced by the possibility of combining it with a regulator or a bridge and the resulting economy. The alignment of a smaller off taking channel and suitable location of its head may also govern the location of the fall, as it may be necessary to takeoff the channel upstream of the fall to provide it with the required full supply level for irrigation of its commanded area by flow. The relative economy of providing a large number of smaller falls or a smaller number of high falls has to be determined, subject always to over-riding considerations of obtaining a suitable waterline for command.

## 4.4 SELECTION OF TYPE OF FALL

In selecting a type of fall most suitable for a particular site, the main consideration is the height of drop and the discharge passing over the fall, or in other words, the amount of energy to be dissipated downstream of fall.

Based on extensive testing of various types of falls, the criteria (Table-4.1) recommended by the Central Water Commission (Manglik, 1994) may be adopted for selecting the type of fall.

TABLE 4.1 SELECTION OF THE TYPE OF FALL

| SN. | Q ($m^3/s$) | $H_L$ (m) | Type: Unflumed — Clear overfall | Type: Unflumed — Drowned | Type: Flumed — Clear over fall | Type: Flumed — Drowned |
|---|---|---|---|---|---|---|
| 1. | High Dischage High Falls Q > 15 | $H_L > 1$ | Baffle type (suitable up to retrogression of 25% also) | Baffle Type | Baffle Type | Straight Glacis or Baffle type |
| 2. | High discharge Low Fall Q>15 | $H_L < 1$ | Baffle type | Modified Glacis type | Baffle type | Straight Glacis type |
| 3. | Low discharge High fall Q<15 | $H_L > 1$ | Baffle or Glacis type depending upon merit of each | Baffle or glacis | Baffle type | Straight Glacis type |
| 4. | Low discharge Low Fall Q<15 | $H_L < 1$ | Baffle or glacis or vertical type depending on economy and suitablits at site | Modified glacis type | Baffle or glacis type | Glacis type type |
| 5. | Q < 8 | All drops | Vertical type is suitable, selection of other types depends on consideration of cost. | | | |

# COST FUNCTIONS AND CONSTRAINTS

## 5.1 COST OF CANAL

The cost of canal for a given alignment depends upon various design variables such as depth of flow, bed width, side slops, bed slope, etc. For different cross-sections of the canal (Fig.3.1), the cost of canal per metre length is given by the following equations (Prasun, 1994)

**For cutting reach :**

$$C_c = K_1\left[(D_r-D)\left[(B+2\,b_b + 2mD) + m_3(D_r-D)\right] + (B+mD)\right]$$

$$+ 2K_3\left[d_f\sqrt{1 + m_3^2} + b_b + D\sqrt{1 + m^2} + B/2\right] \qquad (5.1)$$

**For filling reach :**

$$C_F = K_2\left[\left[B + 2b_r + 2m\,(D + d_f)\right](D + d_f + D_r)\right.$$

$$\left. + m_2(D+d_f+D_r)^2 - B(D+d_f) - m(D+d_f)^2\right]$$

$$+ 2K_3\left[(D+d_f)\sqrt{1 + m_4^2} + B/2\right] \qquad (5.2)$$

For cutting and filling reach :

$$C_{CF} = K_1 \left[BD_r + mD_r^2\right] + K_2\left[2b_r(D+d_f-D_r) + (m_2 + m_3)(D+d_f-D_r)^2\right]$$

$$+ 2K_3\left[(D+d_f-D_r)\sqrt{1 + m_3^2} + b_b + D\sqrt{1 + m_3^2} + B/2\right] \quad (5.3)$$

## 5.2 COST FUNCTION FOR CANAL FALL

The cost of canal fall can be divided into three categories, namely, the Earthwork, Cement concrete and Brick work. For developing the cost function for a canal fall, an unflumed glacis type of canal fall is considered. (Manglik, 1994). Fig. 5.1 shows the position of ground level, bed level of canal and various dimensions of canal fall in terms of geometric parameters.

### 5.2.1 Cost Function for Earth Work

The cost function for earth work in canal fall can be written as (Manglik, 1994) :

$$CE = C_e\Big[B\left[B_1 * D_1 + B_2 * D_2 + L_1 * H_1 + 0.5 * L_2 * (H_1 + L2/2)\right.$$

$$\left.(H_1 \quad L_2/2) \quad L_3\right] \quad 2 * B_w\Big[\sqrt{2} - L_o * - D_1 \quad L_1$$

$$+ (H_1 + L_2/2) * L_3 + 0.5 * L_2 * (H_1 + L_2/2)\Big]\Big] \quad (5.4)$$

### 5.2.2 Cost Function for Cement Concrete

The cost function for cement concrete in canal fall, in terms of geometric parameters can be written as :

$$CCC = C_c\left[B\left[2 * B_1 * T_1 + \left[2 * L_1 - \frac{1}{2}\left\{U_d + \frac{Q^2}{(B + U_d)^2 U_d^2} - H_c\right\}\right]\right.\right.$$

$$* \left[U_d + \frac{Q^2}{(B + U_d)^2 U_d^2} - H_c + H_1\right] + \left[U_d + \frac{Q^2}{(B + U_d)^2 U_d^2} - H_c + H_1 + T_F\right]$$

$$\left. * 0.5 * L_2 + T_F * L_3 \right] + 2 * B_w\left[\sqrt{2} * L_o * T_2 + L_1 * T_2\right.$$

$$\left.\left. + \left[U_d + \frac{Q^2}{(B + U_d)^2 U_d^2} - H_c + H_1 + T_F\right] * 0.5 * L_2 + T_F * L_3\right]\right] \quad (5.5)$$

### 5.2.3 Cost for Brick Work

The cost function for brick work can be written as :

$$BWC = C_b\left[B_T * B\left(D_1 + D_2 - 2T_1\right) + \left(\sqrt{2}\, L_o + L_1 + L_2 + L_3\right)\right.$$

$$\left. * \left(B_T + B_B\right)\left(U_d + d_f\right)\right] \quad (5.6)$$

In formulating the above cost functions, following assumptions have been made (Manglik, 1994) :

(i) Design of wing wall has not been considered, it is taken as such by thumb rule.

(ii) No consideration for upstream or down stream protection work is considered. However, in case of unflumed glacis canal fall no protection work is necessary.

The cost function for the unflumed glacis canal fall can be written as sum of equations (5.4), (5.5) and (5.6).

Total cost can be given as :

Total Cost = CE + CCC + BWC

## 5.3 CONSTRAINTS IN THE DESIGN OF CANAL FALL

The constraints which must be satisfied while designing the canal fall are as follows (Manglik, 1994).

### (a) Exit Gradient Constraint

The depth of downstream curtain wall and total length of floor should be such as to satisfy the exit gradient conditions

$$G_E \leq \frac{H_s}{D_2 \pi} \frac{1}{\sqrt{\lambda}} \qquad (5.7)$$

where

$$\lambda = \frac{1 + \sqrt{1+\alpha^2}}{2} \qquad (5.7a)$$

$$\text{and } \alpha = \frac{L}{D_2} \qquad (5.7b)$$

$$L = L_1 + L_2 + L_3$$

The recommended values for safe exit gradient for different type of soil are given in Table - 5.1.

### (b) Constraint for Thickness of Floor

Constraint for thickness of floor is given as

$$T_F \geq \frac{P_{tg}}{(s - 1)} \qquad (5.8)$$

where pressure at toe of glacis is given as

$$P_{tg} = \frac{P_E(L_1 + L_2) + P_C L_3}{(L_1 + L_2 + L_3)} \tag{5.8a}$$

$$P_E = \frac{H_s}{\pi}\left[\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) - \frac{T_F}{D_2}\left[\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) - \cos^{-1}\left(\frac{\lambda-1}{\lambda}\right)\right]\right] \tag{5.8b}$$

$$P_C = H_s - \frac{H_s}{\pi}\left[\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) + \frac{T_F}{D_1}\left[\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) - \cos^{-1}\left(\frac{\lambda-1}{\lambda}\right)\right]\right] \tag{5.8c}$$

**(c) Constraint for Basin Length of Basin**

Constraint for basin length is given as:

$$\frac{4.5\ Q^{2/3}\ g^{0.05}}{L_3\ B^{2/3}}\left[1-\left[\left[\frac{Q^2}{gB^2H_F^3}\right]^{1.257} + \left[\frac{Q^2}{gB^2H_F^3}\right]^{1.09}\right]^{-0.1}\right]$$

$$* \left[1 - \frac{2}{3}\left[\left[\frac{Q^2}{gB^2H_F^3}\right]^{0.463} + \left[\frac{Q^2}{gB^2H_F^3}\right]^{0.13}\right]^{0.216}\right] \le 1 \tag{5.9}$$

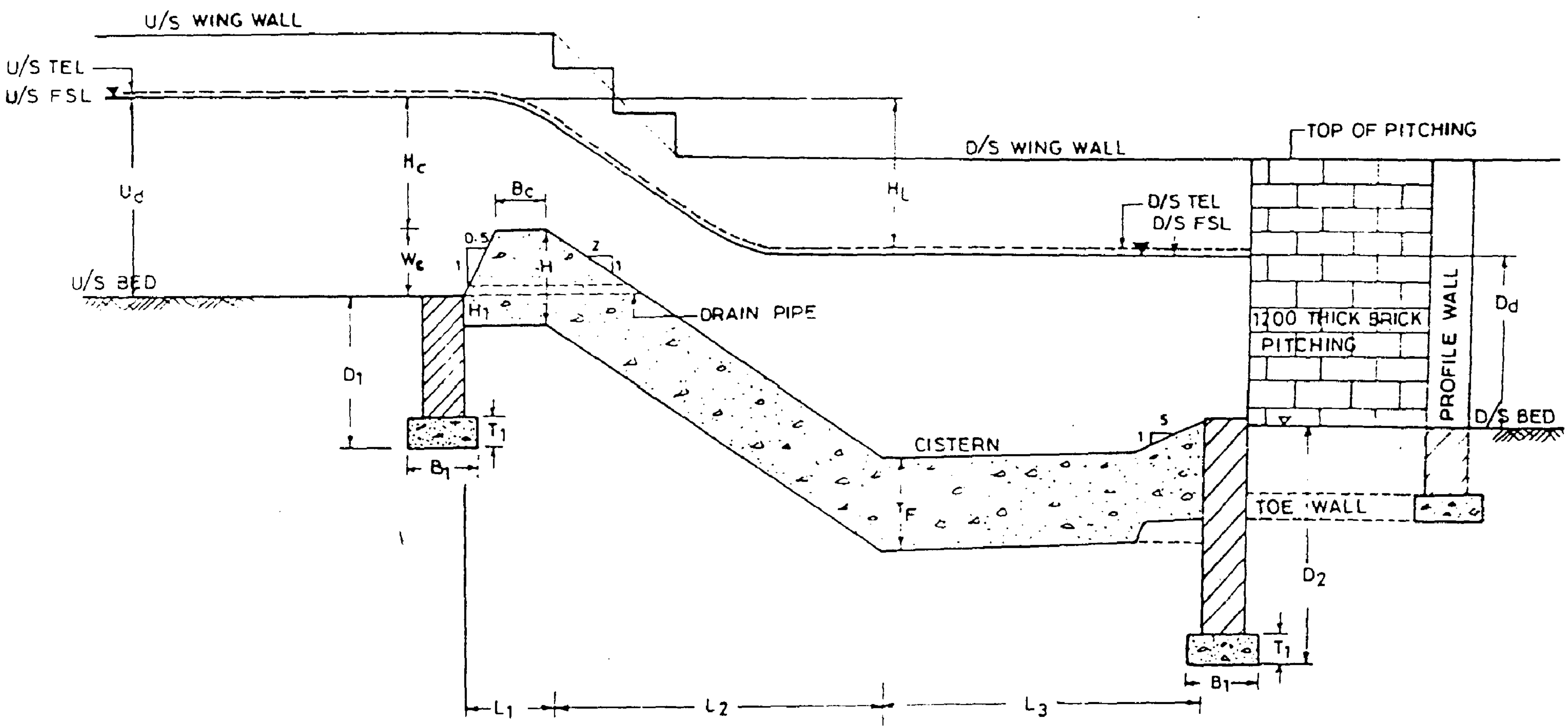



FIG. 5.1 SECTION OF NON METER UNFLUMED CANAL FALL

**Table 5.1 Safe Exit Gradient For Different Types Of Soil**

| Type of Soil | Range of Size | Safe Exit Gradient |
|---|---|---|
| Shingle | > 1.00 mm | 0.25 to 0.20 |
| Coarse sand | 0.50 to 2 mm | 0.20 to 0.17 |
| Fine sand | 0.05 to 5 mm | 0.17 to 0.14 |

# INTEGRATED DESIGN APPROACH

## 6.1 STEPS OF COMPUTATION

A computer code is developed in C programming language for the design of canal and canal fall. The computer code is flexible to deal with various methods of canal design. However, it considers only unflumed glacis type of fall. For a given alignment of the canal, the total cost including canal and canal fall can also be obtained using the present software. This may offer considerable advantage in selecting the most economical canal route. Fig.6.1 is a flow diagram of the developed computer program. The procedure of the integrated design methodology is explained in the following steps:

1. Read the total number of feasible routes to be checked for finding out the best route.
2. Take first canal route.
3. Read total number of control points on this canal route. The points at which ground slope is changing or a fall is provided, are taken as control points. The canal off take point is the first control point.
4. Read the ground levels and distances between control points.
5. Check if canal falls are provided on this route; if canal falls are provided:

   a) Read the total number of canal falls.

   b) Read control point numbers and respective drop of fall.

6. Take the first canal reach i.e canal reach between first two control points.

7. Design the cross section of canal choosing one of the available methods of design.

8. Compute the cost of earth work.

9. Compute the cost of lining (if canal is lined).

10. Check if it is a control point at which fall is provided. If **Yes**:

    a) Design the canal fall by the method of optimal fall design.

    b) Compute cost of canal fall.

11. Compute cost of this canal reach

    = cost of earth work + cost of lining + cost of fall.

12. Take next canal reach and repeat step (8) onwards, till the costs of all the canal reaches are computed.

13. Compute total cost of this canal route by adding the costs of all the canal reaches.

14. Take the next canal route.

15. Display the details and total costs of all the canal routes for choosing the best canal route.

## 6.2 DESIGN OF CANAL CROSS SECTION

Twelve methods of canal design are included in the computer program; three methods for the design of lined canals, four methods for the design of unlined canals for which sediment transport capacity is unspecified, and five methods for the design of unlined canals for which sediment transport capacity is specified. There is a flexibility in the computer program for the designer to select any of the available methods for the design of canal cross-section.

## 6.3 OPTIMAL DESIGN OF CANAL FALL

The cost of canal fall mainly depends upon the length of floor, thickness of floor and height of crest, as discussed earlier. The functional relationship between the cost and the design variables is the objective function given in equations (5.4) to (5.5) and this has to be minimized with the constraints given by equations (5.7), (5.8) and 5.9).

Since the objective function and constraints are non-linear function with seven variables $L_1$, $L_2$, $L_3$, $D_1$, $D_2$, $H_s$ and $T_F$; non-linear optimization techniques have to be applied.

To minimise the objective function an algorithm based on grid search method is utilised. This algorithm gives the cost for various choices of feasible design variables from which the minimum cost can be obtained.

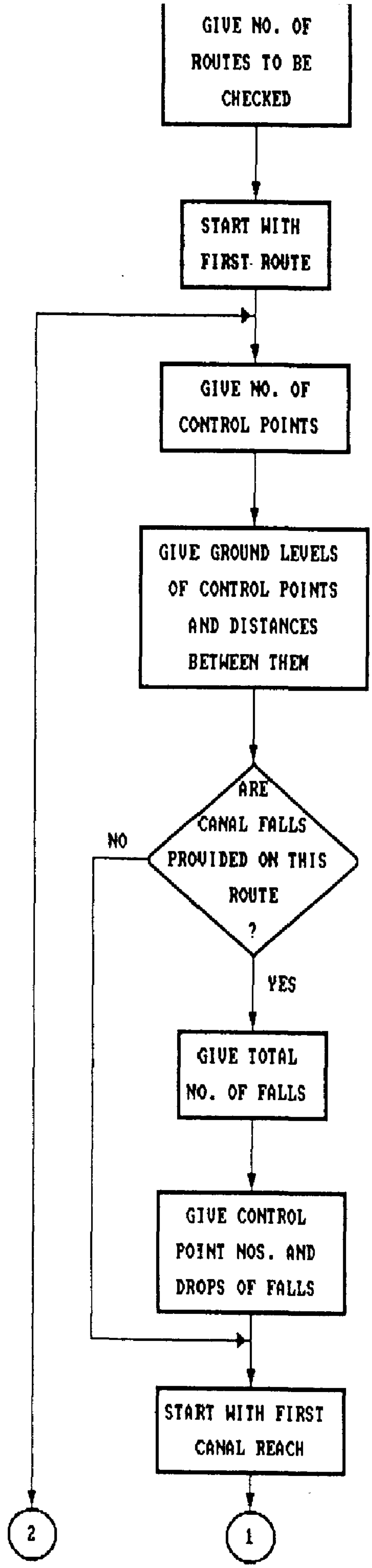



FIG. 6.1 FLOW CHART OF COMPUTER PROGRAM

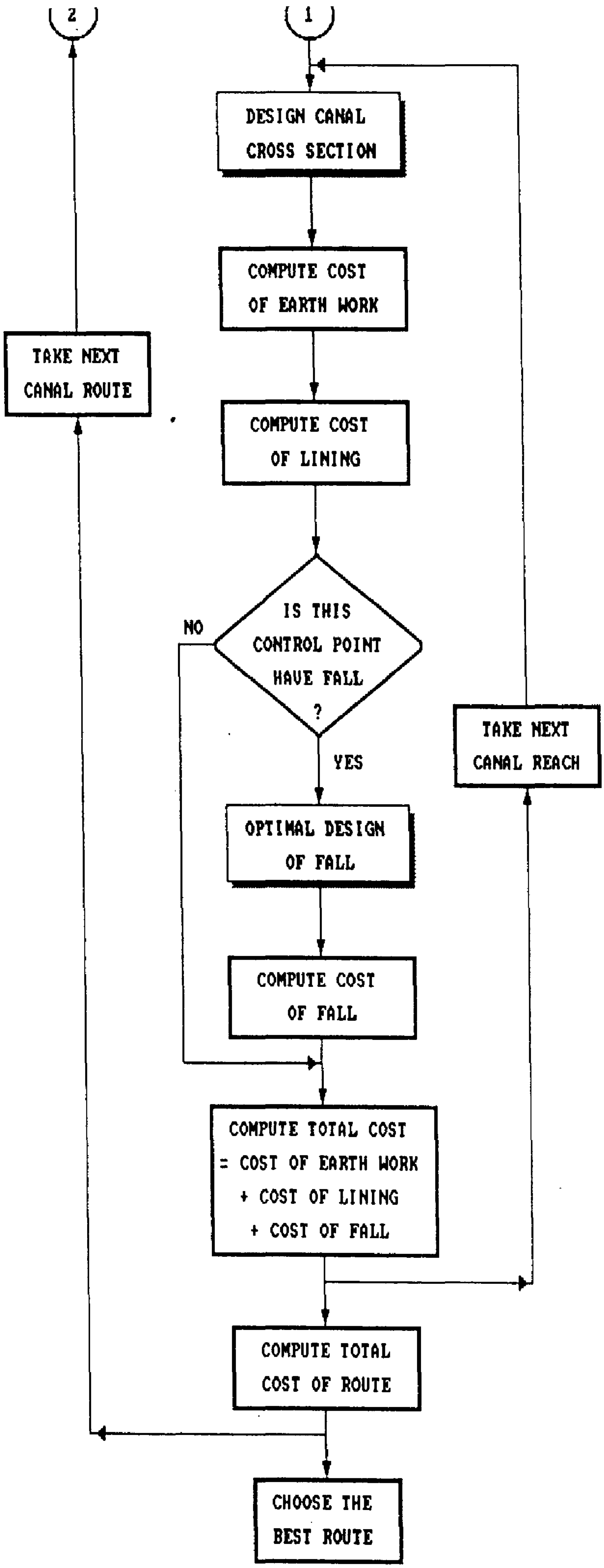



FIG. 6.1 FLOW CHART OF COMPUTER PROGRAM

# ILLUSTRATIVE EXAMPLE AND DISCUSSION

To highlight the potential of the present software, an hypothetical example is considered. For designing a lined canal, the results are presented based on Swamee and Bhatia method while for unlined canal design, the results have been obtained using Chitale's method.

Normally the canal cross section will change after every 1 to 2 Km.. The present program has the flexibility to design canal cross section after every such distance. For the present example canal discharge is assumed to vary between different reaches (See Table 7.1). The cross sectional details of the canal in different reaches are shown in Table 7.1.

The canal falls with a drop height of 0.55 and 0.45 m have been provided at chainage of 1.2 Km. and 3Km..

In the program, it is possible to vary the location of fall and to study its influence on the overall cost of the canal. Thus, the user can specify different options of canal design, canal fall location and the route of a canal. A solution criteria based on the cost of canal can be helpfull in finalising the design project.

Table 7.1 (a)

Design of Lined Canal Using Swamee and Bhatia's Method

$m = 0.577$, $n = 0.015$

| Distance (from A) (km.) | Discharge Q (cumec) | Bed Width B (m) | Depth D (m) | Velocity U (m/s) | Bed Slope S (cm/km) | Free Board $d_f$(m) |
|---|---|---|---|---|---|---|
| 0.0-1.0 | 3.44 | 1.78 | 1.54 | 0.84 | 22.5 | 0.55 |
| 1.0-2.0 | 3.26 | 1.74 | 1.51 | 0.83 | 22.5 | 0.54 |
| 2.0-3.0 | 3.04 | 1.70 | 1.47 | 0.81 | 22.5 | 0.54 |
| 3.0-3.6 | 2.49 | 1.54 | 1.34 | 0.81 | 25.0 | 0.52 |

$G_E = 0{\cdot}178$

| Fall No. | Distance (from A) | Drop (m) | $L_1$ (m) | $L_2$ (m) | $L_3$ (m) | $D_1$ (m) | $D_2$ (m) | $T_F$ (m) | Cost (Rs.) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 1.2 km. | 0.55 | 0.51 | 1.0 | 1.02 | 0.5 | 1.0 | 0.3 | 37927 |
| 2. | 3.0 km. | 0.45 | 0.5 | 1.0 | 1.0 | 0.5 | 1.0 | 0.28 | 34918 |

Total Cost of Canal and Canal Fall = Rs. 4209962*

* Depends upon Cost Coefficients

$C_e = 50$ ; $C_b = 1000$ ; $C_c = 3000$ ; $K_1 = 60$ ; $K_2 = 50$ ; $K_3 = 300$

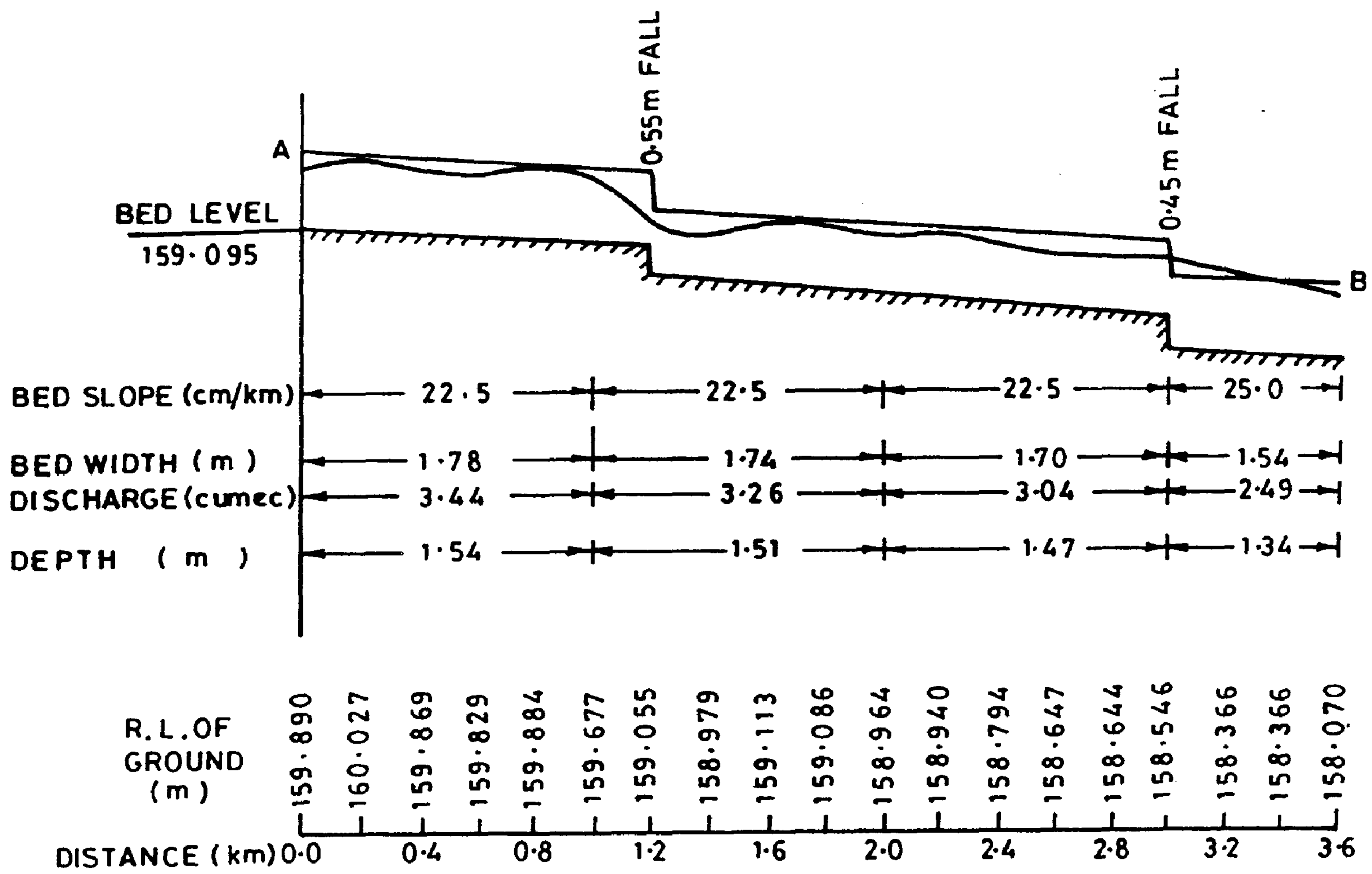



FIG. 7·1 (a) LONGITUDINAL SECTION (SWAMEE-BHATIA METHOD)

## Table 7·1 (b)

Design of Unlined Canal Using Chitale's Method

m = 2.0

| Distance (from A) (km.) | Discharge Q (cumec) | Bed Width B (m) | Depth D (m) | Velocity U (m/s) | Bed Slope S (cm/km) | Free Board $d_f$(m) |
|---|---|---|---|---|---|---|
| 0.0-1.0 | 3.44 | 2.93 | 1.18 | 0.53 | 22.84 | 0.55 |
| 1.0-2.0 | 3.22 | 2.69 | 1.17 | 0.52 | 23.09 | 0.54 |
| 2.0-3.0 | 2.96 | 2.38 | 1.16 | 0.51 | 23.41 | 0.53 |
| 3.0-3.6 | 2.37 | 1.49 | 1.18 | 0.49 | 24.28 | 0.51 |

$G_E = 0{\cdot}178$

| Fall No. | Distance (from A) | Drop (m) | $L_1$ (m) | $L_2$ (m) | $L_3$ (m) | $D_1$ (m) | $D_2$ (m) | $T_F$ (m) | Cost (Rs.) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 1.2 km. | 0.55 | 0.51 | 1.0 | 1.02 | 0.5 | 1.0 | 0.3 | 36157 |
| 2. | 3.0 km. | 0.45 | 0.5 | 1.0 | 1.0 | 0.5 | 1.0 | 0.28 | 33718 |

Total Cost of Canal and Canal Fall = Rs. 1070170*

* Depends upon Cost Coefficients

$C_e = 50$ ; $C_b = 1000$ ; $C_c = 3000$ ; $K_1 = 60$ ; $K_2 = 50$

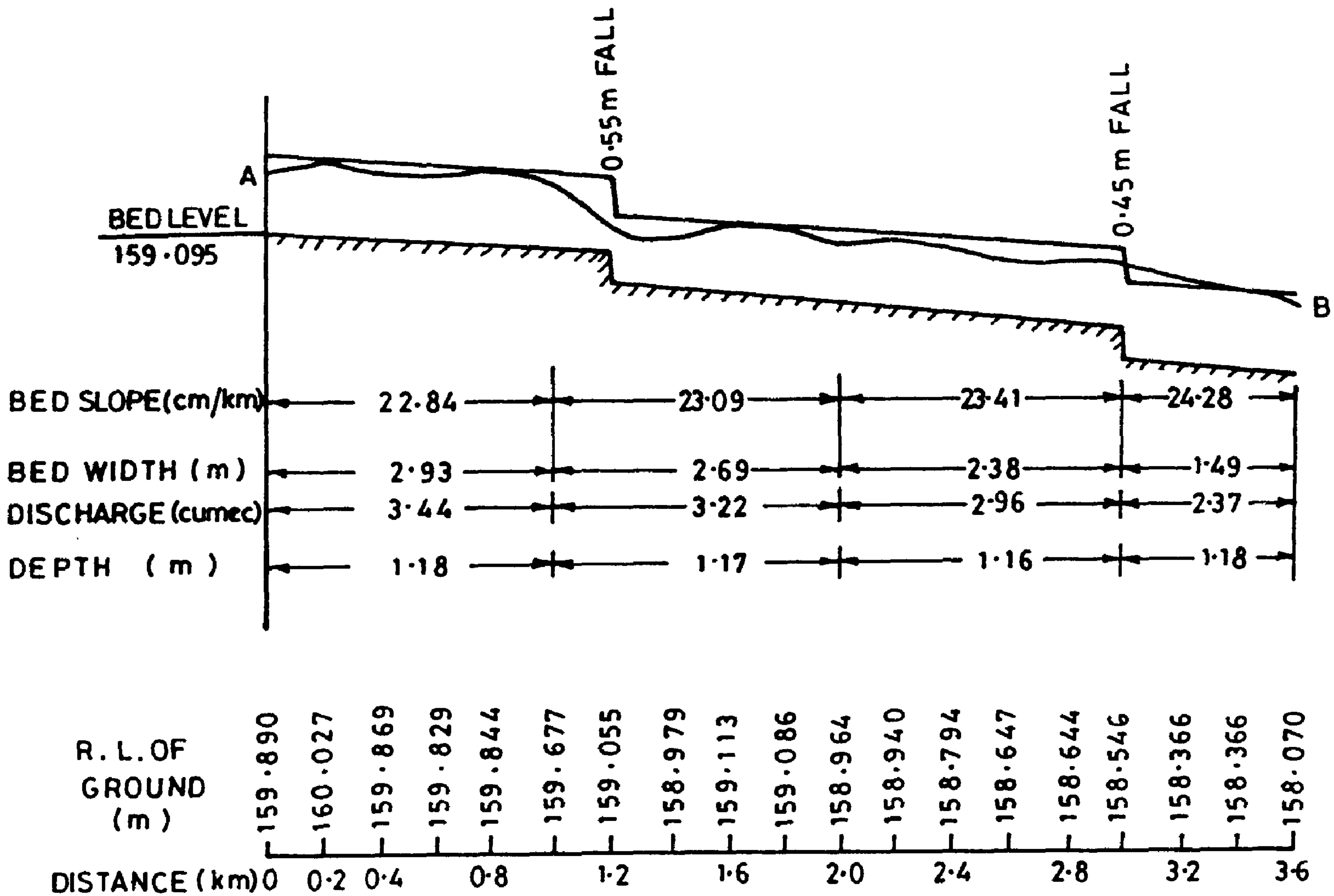



FIG. 7·1 (b)–LONGITUDINAL SECTION (CHITALE'S METHOD)

CHAPTER - 8

# CONCLUSION

A software is developed for the integrated design of canal and canal falls. Using this software, the design of canal cross-section, design of canal falls, and the determination of the best alignment can be done in a single program. Flexibility is provided for the user to design the canal, taking one reach at a time or to design a number of reaches with or without providing canal falls in between. The cost of different components can be worked out after designing and the total cost of canal with canal falls can be calculated. The user can give a number of canal routes and can select the best route out of these feasible routes by comparing the cost of different routes.

In developing the computer program only unflumed non-metric fall is used. The program can further be improved by including other types of falls. The design of cross drainage works has not been incorporated in the present program which can also be included in the program.

# REFERENCES


1. Chang, H.H., "Stable Alluvial Canal Design," J. Hyd. Engg., ASCE, May 1980, pp.873-891.
2. Chang, H.H., "Geometry of Gravel Streams, " J. Hyd. Engg., ASCE, Sept. 1980, pp. 1443-1456.
3. Chitale, S.V., " Adjustment in Alluvial Canal," J.Irrig. and Power, Jan.1973, pp.13-31.
4. Froehlich, D.C., "Width and Depth Constrained Best Trapezoidal Section," J.Irrig. and Drain., ASCE, July 1994, pp. 828-835.
5. Guo, C.Y., and Hughes, W.C., "Optimal Channel Cross Section With Freeboard," J.Irrig. and Drain., ASCE, Sept. 1984, pp.304-314.
6. Kondap, D.M., and Grade, R.J., "Design of stable Alluvial Channels," J. Irrig. and Power, Oct. 1979, pp. 409-423.
7. Lane, E.W., "Stable Channels in Alluvium," Transactions, ASCE, Vol. 120, 1955.
8. Manglik, N.K., " Design of Unflumed Glacis Canal Fall, " M.E. Thesis, U.O.R., Roorkee, 1994.
9. Prasad, T.D., "Design of Canals for Non-Uniform Sediment," M.E. Thesis, U.O.R., Roorkee, 1993.
10. Prasun, Ashok, "Optimal Route Alignment of an Irrigation Canal," M.E. Thesis, U.O.R., Roorkee, 1994.
11. Singh, Bharat, Fundamentals of Irrigation Engineering, Nem Chand & Bros, Roorkee, 1988.
12. Swamee, P.K., and Bhatia, K.G., "Economical Open Channel Sections, "J.Irrigation and Power, April 1972, pp. 169-176.
13. Varshney, R.S., Gupta, S.G., and Gupta, R.L., Theory & Design of Irrigation Structures, Vol.1, Nem Chand & Bros, Roorkee, 1983.