Full Length Research Paper

A computer model for designing of permanent gully control structures

D. Khalkho[1]*, N. S. Raghuwanshi[2], S. Khalkho[1] and R. Singh[2]

[1]Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) – 492012, India.
[2]Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur (W.B.) – 721302, India.

Engineering measures of soil and water conservation are an integral part of watershed management or development, and thus they must be designed accurately and economically. Designing of various gully control structures plays a vital role in the success of any watershed development programme. Analytical designing of these structures in terms of hydrologic, hydraulic and structural stability is very important. The study aims at developing comprehensive module for software namely SCS_Designer model for designing of different permanent gully control structures (drop spillway, drop inlet spillway and chute spillway) and other structures along with testing and validation of the developed module of the model. SCS_Designer model also has the provision to check the step-wise procedure followed by the model for the designing of various structures. These help the users especially students to analyze the differences in design parameters by changing the input data. Also these saved step-wise procedure files make SCS_Designer an effective teaching tool. SCS_Designer was tested with the help of standard examples for different permanent gully control structures. The design results obtained using the SCS_Designer were compared with the corresponding design results from different sources and error analysis was performed. In most cases, the design results obtained using the model matched exactly with the respective design results given in the source. Small deviation in design parameters was due to truncation and round off errors. Thus, it was concluded that SCS_Designer is validated and can be used as a standard designing tool for different permanent gully control structures *viz* drop spillway, drop inlet spillway and chute spillway. Furthermore, it can be used as an effective teaching tool.

Key words: Gully control, structures, validation, computer model.

INTRODUCTION

Erosion encompasses a series of interrelated natural processes that have the effect of loosening and moving away soil and rock material under the action of water, wind and other geologic agents. The happening of soil removal creates a very serious problem to perform agricultural activities and thereby causes reduction in crop yield, too. The implications of soil erosion extend further when sheet erosion converts to rill erosion. Once rills are large enough to restrict vehicular access they are referred to as gullies or gully erosion. Major concentrations of high-velocity run-off water in these larger rills remove vast amounts of soil. Removal of topsoil and subsoil by fast-flowing surface water creates abrupt deep and wide gullies, of two different kinds: Scour gullies and headward erosion. In scour gullies, run-off water concentrated in rills or depressions removes soil particles through sluicing - the washing effect of running water on loose grains. Singh et al. (1981), shows that the

problems of soil erosion in India, their extent, severity and nature vary greatly in different parts of the country depending upon climate, topography, soil, land use and also with the pattern of agricultural economy. According to Dhruva and Ram (1983), it was estimated that about 5334 m ton (16.35 ton/ha) of soil is detached annually due to agricultural and associated activities alone. The country's rivers carry about 2052 m tons (6.26 ton/ha). Of this, nearly 1572 m ton (29% of the total eroded soil) is carried away by the rivers to sea every year and 480 m ton is being deposited in various reservoirs, resulting in the loss of 1 to 2% of storage capacity. Das (1985) estimated that out of a total reported geographical area of 329 Mha, about 167 Mha (51% of the total) is affected by serious water and wind erosion. Out of which, about 127 Mha is subjected to serious soil erosion and 40 Mha degraded through gully, ravines, shift cultivation, water logging, salinity, alkalinity, shifting of river courses and desert area etc. The objectives of every watershed development programmes is to increase infiltration into the soil, to control damaging excess runoff, to manage and utilize runoff and to reduce soil erosion to protect land. Altogether, soil and water conservation programmes are called as watershed development programmes. Economic and safe design of structures requires sound knowledge of the subject and engineering skills along with a good field experience. It is also important to keep in mind the local design consideration, depending upon the soil texture, rainfall pattern and farming culture of the local people. Many people involved in watershed management do not posses sufficient design skills and also the available textbooks on soil and water conservation lack information on comprehensive designs specifically for particular regions. Therefore, there is a need to develop comprehensive software for soil and water conservation structures design for professional uses as well as to be used as an educational tool. Therefore, keeping these points in consideration, study was undertaken to develop software with easy and friendly GUI for the designing of various soil and water conservation structure. The model was developed using Visual Basic 6.0. The model was conceptualized to work as soil and water conservation structures designer for field worker as well as an educational tool for students to analyses the changes in the design output with changes made in the input parameters.

Overview of the permanent gully control structures module of SCS_Designer

The module for permanent gully control structures designing is an important module of the model. For permanent gully control structures designing, the user has to enter the information about the drop and the storage requirement of the structure. The software will then decide the optimal structure namely drop spillway, drop inlet spillway and chute spillway, as per the

information provided by the user data. Anyhow the user can change the selection and can select the desired structure manually. The design and result displays separately by clicking on different tabs of the model. Finally, the model has provision for displaying the detailed design in text format. The user has to save the input data after the design in order to save the procedure file. This procedure file can be viewed separately from the main menu. Permanent structures, built of masonry, reinforced concrete or earth, are efficient supplemental control measures in soil and water conservation. Permanent structures are generally used in medium to large gullies with medium to large drainage area. Three basic permanent structures employed in stabilizing gullies are: (1) Drop spillway, (2) Drop inlet spillway and (3) Chute spillway. Each of these is adaptable to specific site conditions. The basic components of permanent gully control structures are inlet, conduit and outlet. These are of various types and the structures are classified and named in accordance with the form these components parts take. The working is explained by flow chart as shown in Figure 1.

Drop spillway

The drop structure is a weir structure, is limited to a maximum drop of 3 m and it is not a favorable structure where temporary spillway storage is desired to obtain a large reduction in the discharge at or d/s from the structure. The three designs in consideration were:
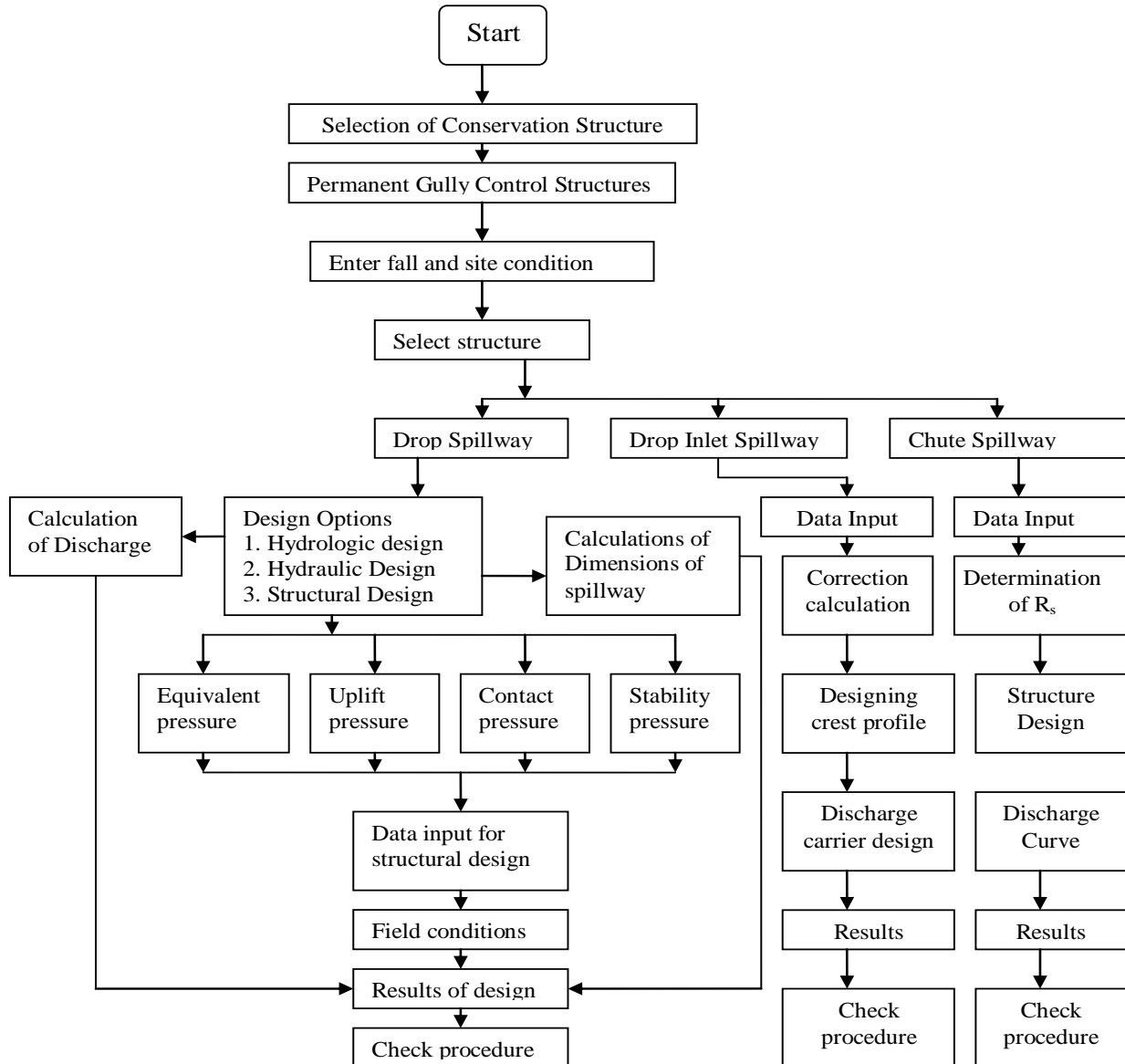
(1) Hydrologic design, involving the estimation of design runoff rate and flood volume, which the structures have to handle safely. This is done by computing the runoff rate for 25 to 30 years return period, which indicates that the heaviest rain occurred once in 25 to 30 years period. Runoff rate is calculated by rational method.
(2) Hydraulic design, assuming that the total drop, F should be known to the user. The design consists of determining the length of crest, L, and depth, h, of the weir to provide required capacity and to maintain an adequate freeboard under free flow condition. (3) Structural design, involving the determination of strength and stability of different parts of the structure. The various forces which act on the structure are mainly, water pressure, force due to overflow and effect of water flow below the structure (that is, seepage and sub-surface flow). The structural design comprises of estimation of horizontal pressure (equivalent fluid pressure), uplift pressure, contact pressure and factor of safety.
The discharge capacity of an aerated, rectangular weir under free flow condition is

$$Q = C\left(H + \frac{V_a^2}{2g}\right)^{3/2}$$

(1)

where, Q = discharge, cumec; H = head on weir, m; V_a =

```
                          ┌─────────┐
                          │  Start  │
                          └────┬────┘
                               ↓
              ┌────────────────────────────────────┐
              │ Selection of Conservation Structure │
              └────────────────┬───────────────────┘
                               ↓
              ┌────────────────────────────────────┐
              │ Permanent Gully Control Structures  │
              └────────────────┬───────────────────┘
                               ↓
                  ┌─────────────────────────────┐
                  │ Enter fall and site condition │
                  └──────────────┬──────────────┘
                                 ↓
                     ┌─────────────────────┐
                     │  Select structure   │
                     └──────────┬──────────┘
```

| Drop Spillway | Drop Inlet Spillway | Chute Spillway |

| Calculation of Discharge | Design Options 1. Hydrologic design 2. Hydraulic Design 3. Structural Design | Calculations of Dimensions of spillway | Data Input | Data Input |

| Equivalent pressure | Uplift pressure | Contact pressure | Stability pressure |

| Correction calculation | Determination of R_s |

| Data input for structural design | Designing crest profile | Structure Design |

| Field conditions | Discharge carrier design | Discharge Curve |

| Results of design | Results | Results |

| Check procedure | Check procedure | Check procedure |

mean velocity of approach, m/sec; and C = discharge coefficient (1.77). From functional studies, it is found that

$$Q = \frac{CLh^{3/2}}{(1.10 + 0.03F)} \qquad (2)$$

$$h = \left[\frac{Q(1.10 + 0.03F)}{CL}\right]^{3/2} \qquad (3)$$

$$L = \frac{Q(1.10 + 0.03F)}{Ch^{3/2}} \qquad (4)$$

In order to determine the dimensions of the weir for a given discharge and fall condition, different combinations of L and h can be obtained for a range of assumed h values using Equations (3) and (4). Out of these

combinations a suitable combination can be selected based on local site conditions. The design equations for component parts are given as follows:

Height of transverse sill (S),   S = h/3 $\qquad$ (5)

Height of headwall (H_B), H_B = F + S $\qquad$ (6)

Height of headwall extension (H_E), H_E = F + S + h $\qquad$ (7)

Minimum length of headwall ext., E = 3h + 0.6 or 1.5 F, whichever is greater $\qquad$ (8)

Minimum length of apron,

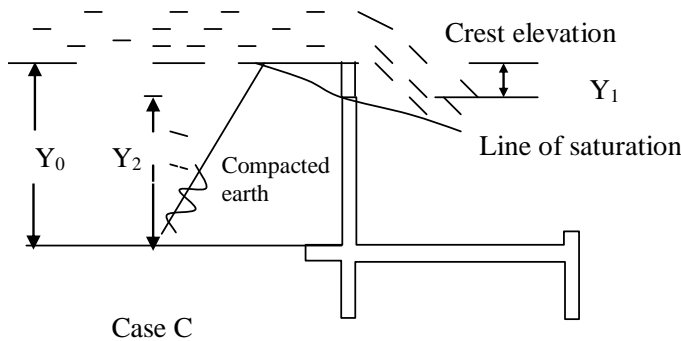L_B $\quad L_B = F\left[2.3\dfrac{h}{f} + 0.05\right]$ or 2[F + S + 0.3 - J], whichever is greater $\qquad$ (9)
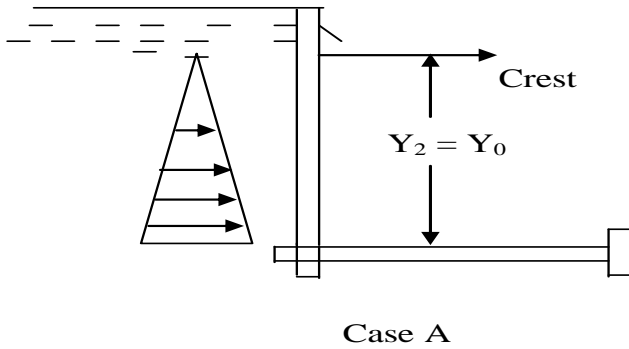
Figure 2. No fill against head wall. Y0 = elevation of crest, Y2 = elevation of saturation line above the top of apron.
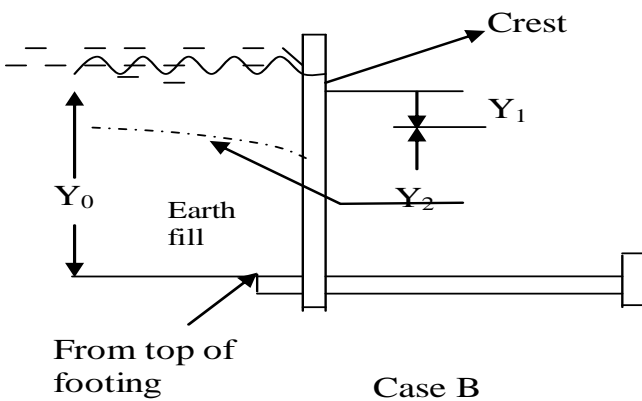
Figure 3. Sectional view of drop spillway. Y0 = elevation of crest, Y2 = elevation of saturation line above the top of apron.

Figure 4. A compacted earth fill berm constructed to crest elevation.

Height of sidewall and wing wall at the junction, J:

$$J = 2h \text{ or } \{F + h + S - \frac{L_B + 0.13}{2}\},$$ (10)

whichever is greater

Depth of cutoff wall (C) and toe wall (T):

$$C = T = \frac{1.65(S + 0.4F + 0.75)}{4}$$ (11)

Horizontal pressures (equivalent fluid pressure): It is calculated on the basis of relative permeability of foundation and backfill material, different conditions of backfill, water table conditions, flow conditions and drainage conditions. Case A (no back fill against head wall), Case B (gully graded full to crest elevation) and Case C (compacted earth fill berm constructed to crest elevation) are the three conditions of back fill that must be considered as shown in Figures 2 to 4.

Piping: The design against failure by piping is done by the line of creep theory because the majority due to piping occurred along the line of creep. Lane (USDA, 1957) defined the weighted line of creep as the sum of all steep contacts and one third of all those contacts which are flatter than 46°, between the head and tail water along the contact surface of the structure. The line of creep is the contact surface between the structure and the soil at the base of the foundation. To prevent failure of structure due to piping the weighted creep ratio (C_w) as estimated using Equation (12) must be greater than the recommended C_w values. The formula for weighted creep ratio is:

$$C_w = \frac{\sum L_v + \frac{1}{3}\sum L_H}{H}$$ (12)

where, L_H = horizontal or flat contact distance, L_V = vertical or step contact distances, and H = head between head water and tail-water (difference in head).

Uplift: Due to the pressure transmitted through the water in the saturated foundation material, upward hydrostatic pressures may exist on the base of the spillway.

Contact pressure: Contact pressure should be computed for three loading conditions, namely before any backfill has been placed around the spillway, after all the backfill has been placed but without flow over spillway and with the spillway operating at design discharge capacity. Contact pressure can be estimated for rectangular base as follows:

$$P_1 = \frac{V}{A}\left(1 \pm \frac{6e}{d}\right)$$ (13)

where, P1 = contact pressure at u/s or d/s edge of base, V = algebraic sum of all the vertical loads and weights that act on the structure, A = base area, e = eccentricity and d = base length.

Overturning and sliding: The structure is safe against overturning if positive contact pressures exist over the entire base area. The force resisting sliding is,

$$\mu \sum V + CA \tag{14}$$

where $\mu = \tan\phi$, ϕ = angle of internal friction of foundation material, $\sum V$ = total vertical load, C = cohesion resistance of foundation material, and A = area of plane of sliding. The structure is safe against overturning and sliding for the ratio greater than 1.5.

Anchor design: If $\mu \sum V + CA$ is not greater than or equal to 1.5 H then it will be necessary to provide an anchor whose pull or resistance to sliding, T, will satisfy the equation:

$$T = 1.5\,H - (\mu \sum V + CA) \tag{15}$$

Drop inlet spillway design

The drop inlet spillway is suitable in the location with fall greater than 3 m that provides an appreciable amount of temporary storage above the inlet. If the inlet is funnel shaped, this type of structures is often called as "Morning glory" or "Glory Hole" spillway. Discharge characteristics of the drop inlet spillway may vary with the range of head. As the head increase on a glory hole spillway, the control will shift from weir flow over the crest to tube flow in the transition and then to full pipe flow in the downstream portion. Equations (16) and (17) represent discharge through box inlet and pipe respectively.

$$Q = \frac{2}{3} C_d \quad \sqrt{2g} \quad L \quad H^{3/2} \tag{16}$$

where, Q = discharge (cumec), L = crest length of a straight weir or sum of the lengths of 3 sides of box inlet (m), H = energy head of water over crest and C_d = coefficient of discharge (fraction).

$$Q = \frac{A\sqrt{2gh}}{\sqrt{1 + ke + k_c l}} \tag{17}$$

where, l = length of the pipe, K_e = coefficient due to head loss at entrance, K_c = coefficient due to friction head loss in the pipe and depends upon pipe diameter and resistance coefficient. The K_c values can be obtained from standard graphs. The neutral slope (S_n) governs the condition for riser or pipe flow. The neutral slope for a conduit is given by, $S_n = \tan\theta =$

$$\frac{K\dfrac{V^2}{2g}}{\sqrt{1 - \left(K\dfrac{V^2}{2g}\right)^2}} \tag{18}$$

Crest discharge: For small heads, flow over the drop inlet spillway is governed by the characteristics of crest discharge, which can be expressed as:

$$Q = C L H^{3/2} \tag{19}$$

where, H = head measured either to the apex of the under nappe of the overflow, and length 'L' is related to some specific point of measurement such as the length of the circle at the apex, along some other reference line. The value of C will change with different definitions of L and H. If L is taken at the outside periphery of the overflow crest and if the head is measured to the apex of the overflow shape, the above equation can be written as,

$$Q = C_o(2\pi R_s)\,H_o^{3/2} \tag{20}$$

It will be apparent that the coefficient of discharge for a circular crest differs from that for a straight crest because of the effects of submergence and back pressure incident to the joining of the converging flows. Thus, C_o must be related to both H_o and R_s and can be expressed in terms of H_o/R_s. These coefficients are valid only if the crest profile and transition shape conform to that of the jet flowing over a sharp crested circular weir at H_o head and if aeration is provided so that sub-atmospheric pressures do not exist along the lower nappe surface contact. The weir formula (Equation 19) is used as the measure of flow through the drop inlet entrance regardless of entrance, by using a coefficient which reflects the flow condition through the various H_o / R_s ranges.

Crest profiles: Values of co-ordinate to define the shape of the lower surface of the nappe flowing over an aerated sharp-crested circular weir for various conditions of p/R_s and H_s/R_s are available in tables developed by U.S.B.R.
Typical upper and lower nappe profiles for various values of H_s/R_s are plotted in terms of $\dfrac{x}{H_s}$ and $\dfrac{y}{H_s}$ for $\dfrac{p}{R_s}$.

Transition design: If friction and other losses are neglected. For a circular jet, the area is equal to πR^2. Therefore

$$Q = A.V = \pi R^2 \sqrt{2gh_v} \text{ and } R = \frac{Q}{\pi\sqrt{2gh_v}} = \frac{Q^{1/2}}{KHa^{1/4}} \tag{21}$$

where H_a = different between the water surface and the elevation under consideration, and K = unit conversion factor (5 for FPS and 3.73 for MKS). Thus, the diameter of jet decreases with the distance of the free vertical fall for normal design applications. If an assumed total loss (to allow for jet contraction losses, friction losses, velocity losses due to direction change etc.) is taken as 0.1 H_a,
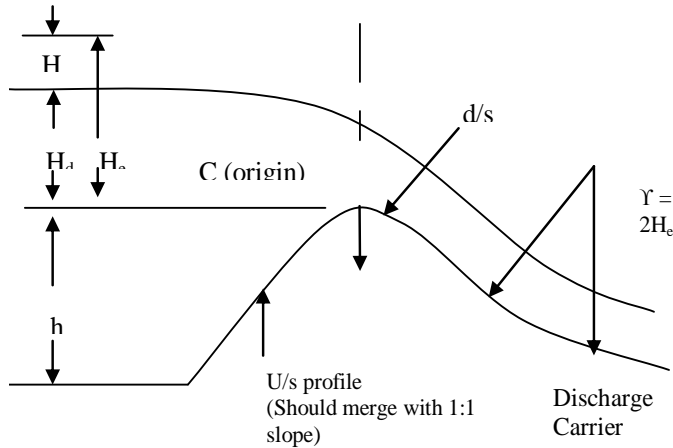
Figure 5. Control structure of the chute spillway.

the equation for determining the approximate required shaft radius can be written as:

$$R = k \frac{Q^{1/2}}{H_a^{1/4}} \tag{22}$$

where, k = unit conversion factor (k=0.204 FPS, k=0.275 MKS).

Design of chute spillway

Chute spillway consist of four components, namely, entrance channel or approach channel, control structure, chute channel or discharge carrier, and energy dissipation arrangement in the form of a stilling basin. Flow is generally super – critical at energy dissipater. It is generally used when the drop exceeds 3.0 m. It is superior to drop–inlet spillway when large discharges are required.

Approach channel and control structure: Approach channel is constructed to lead the reservoir water upto the control structure. The friction head $h_f = S_f . l$, lost in the channel upto the spillway crest, may be calculated by Manning's equation, as follows:

$$h_f = \frac{n^2 \ V^2}{R^{4/3}} . \ell \tag{23}$$

where, S_f = energy gradient between two points, n = Manning's roughness coefficient, V = velocity in the channel, R = hydraulic radius and L = length of the channel. Ogee shape spillway is generally provided as control structure (Figure 5). The important feature of the

ogee shape spillway is that the profile of this spillway is made in accordance with the shape of the lower nappe of the free falling jet.

Design of crest profile: The crest profiles (U/S and D/S) are drawn considering the known heads, namely, head due to velocity of approach (H_a), design head (H_d), total head ($H_e = H_d + H_a$) and height of weir crest from bed level(h). Standard table is used to determine the u/s profile coordinates of the ogee weir. The u/s profile is joined at an angle of 45° to the bottom.
Discharge equation for ogee spillway:

$$Q = C \ L \ H_e^{3/2} \tag{24}$$

where, L = length of the spillway crest, H_e = total head over the crest including velocity head and C = coefficient of discharge, depends on many factors such as depth of approach, downstream side submergence and u/s slope. The effect of individual component is described following.

Depth of approach: Coefficient of discharge (C), depends on the depth of approach or in other words on ratio $\dfrac{h}{H_d}$; e.g., If $\dfrac{h}{H_d}$ > 1.33, velocity of approach has negligible effect on Q. In such a case H_a = 0 (that is, $H_e = H_d$) and C = 2.2. However C is evaluated considering $\dfrac{H_e}{H_h}$ and $\dfrac{h}{H_d}$ ratios in standard graph for $\dfrac{h}{H_d}$ <1.33.

Submergence: There is no effect on C, if $\dfrac{h_d + d}{H_e} \geq 1.7$.

Thus we get the final value of C.

Chute channel or discharge carrier: A concave vertical curve is provided whenever the slope of the chute changes from steeper to milder. The curvature is expressed by,

$$y = -x . \tan\phi - \frac{x^2}{K \left[4(d + h_v) \cos^2 \phi \right]} \tag{25}$$

where, ϕ = slope angle of the floor u/s , (d + h_v) is the specific energy of flow at junction point; K = constant $\geq$ 1.5 and x, y are the coordinates of the point under consideration.

Stilling basin design: Hydraulic jump phenomenon is generally used for designing these basins:

$$\frac{y_2}{y_1} = \frac{1}{2} \left(\sqrt{1 + 8 \ F_1^2 - 1} \right) \tag{26}$$
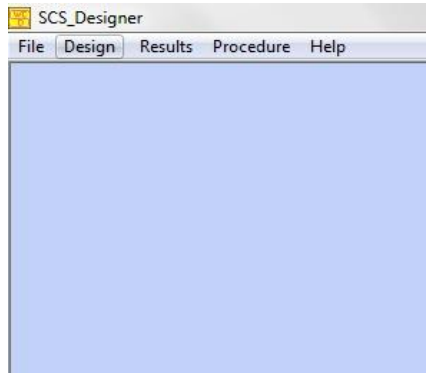
Figure 6. Model main window.
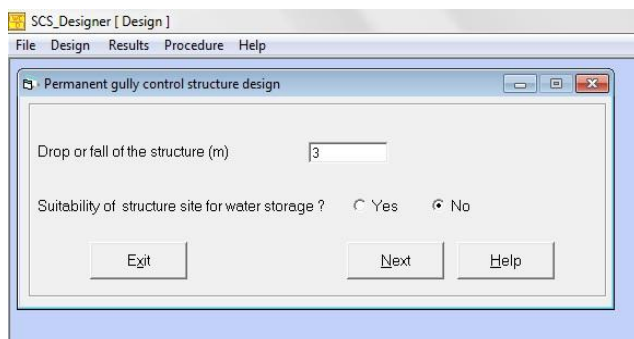
Figure 7. Input window for drop.
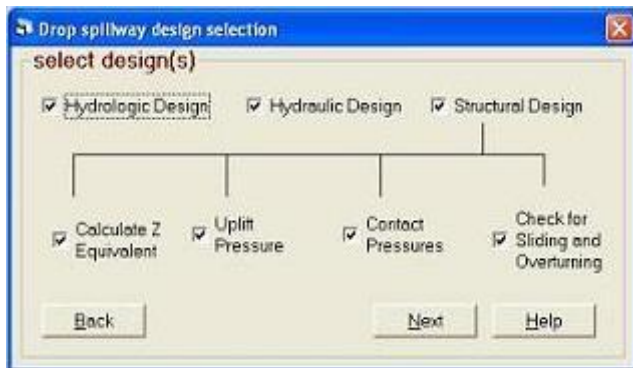
Figure 8. Structure selection window.

Figure 9. Drop spillway design(s) selection.

$$F_1 = \text{Froude No.} = \frac{V_1}{\sqrt{gy_1}} \tag{27}$$

where, y_1 = pre jump depth, y_2 = post jump depth and F1 = Froude number corresponding to the jump velocity (V_1).

DSS FOR PERMANENT GULLY CONTROL STRUCTURES DESIGN

To design a permanent gully control structure, the user has to click on Design menu and Permanent gully control structures submenu (Figure 6). A window is displayed in which the user has to enter information on drop and has to select either YES or NO option for site suitability for storage (Figure 7). After providing all necessary data, clicking on Next button leads to a structure selection window (Figure 8). Depending upon the information provided in the previous form, one of the three options (drop spillway, drop inlet spillway and chute spillway) is selected. The drop spillway is selected if the fall is less than or equal to 3 m. The drop inlet spillway is selected for fall greater than 3 m, and site suitable for storage (YES option). The chute spillway is selected for higher discharge, fall greater than 3 m and site unsuitable for storage (NO option). However, the user has been provided with a flexibility to change the selection to design a specific structure. Once selection is finalized, the design process can be initiated by clicking on the New file button.

DSS for drop spillway

If drop spillway is to be designed, a selection window (Figure 9) is displayed with the three designs of drop spillway, that is, hydrologic, hydraulic and structural design. The user has to select whether he wants to design only one or two or all of them at the same time. If structural design is selected then the user also has to select one of the four check boxes of Z equivalent, uplift pressure, contact pressure and check for sliding and overturning. Thereafter clicking on the Next button will display the window as per the selection. If only hydrologic design is selected in window of Figure 8, the design discharge can be calculated using the rational method by clicking on the Calculate Discharge button (Figure 10). Thereafter clicking on OK button will finalize the design.

In case if only hydraulic design is selected (Figure 9) then also the hydrologic design window will be displayed at first. Entering the fall and discharge and then clicking on Next will display the window for hydraulic design (Figure 11), showing several combinations of practical length and depth of the drop spillway. The user can select any one of the combinations according to the site constraints for length of spillway. Clicking on Design button will finalize the dimensions. When the design is completed a completion message appears on the screen. The input data and procedure can be saved by Save button and can be retrieved in future by clicking on Open an existing button.

In case if only structural design is selected, then the data entry window for structural design will appear (Figure 12) after clicking on the Next button on the design selection window (Figure 8). The user has to enter all the information on material properties and the dimensions of the structure as well. When the user clicks on the Next button, next window is displayed (Figure 13), which shows different conditions about the site. The site conditions include three conditions of backfill namely, no backfill against headwall (Case A), gully graded full to crest elevation (Case B), and compacted earth fill berm constructed to crest elevation (Case C), three conditions of relative permeability, namely the permeability of foundation material greater than, equal to or less than the permeability of backfill, two conditions of drainage (Type a and type b) and flow conditions. The description on these conditions is provided in the previous section.
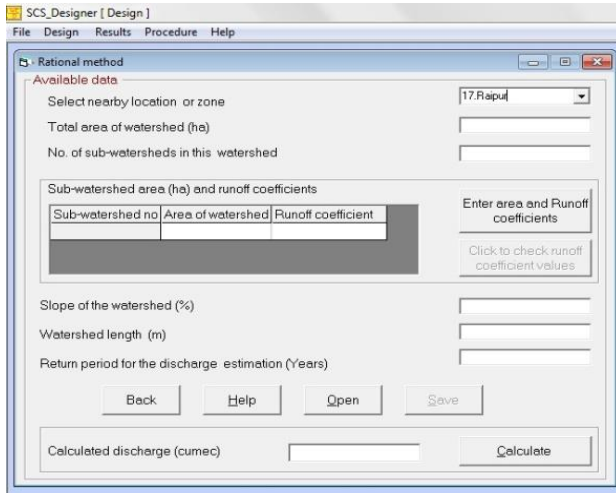
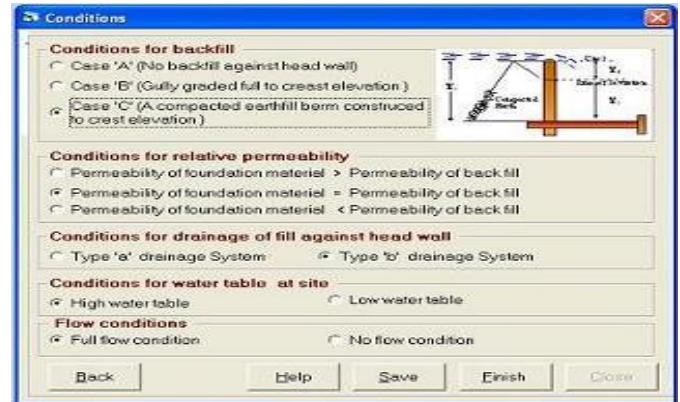**Figure 10.** Discharge by rational method.
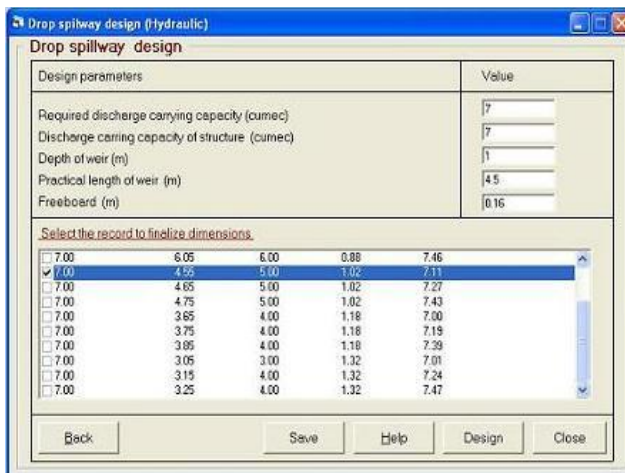

Figure 11. Drop spillway design window.
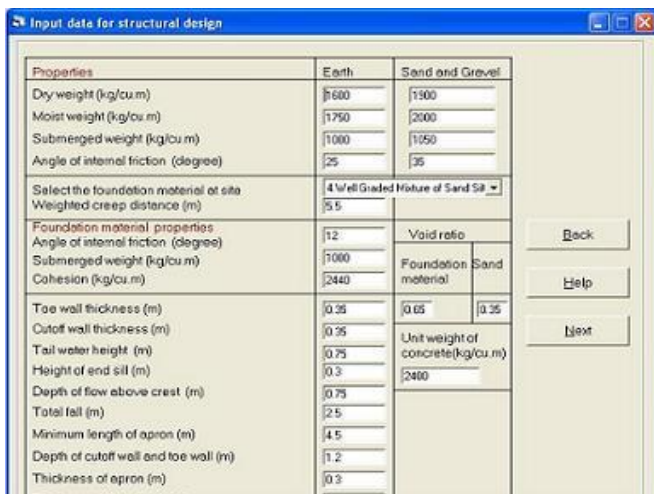
Figure 12. Data input for structural design.

Figure 13. Site selection condition window.

The user has to select appropriate conditions according to the site and click on the Finish button for completing the design. When the design is completed, a completion message appears on the screen. The input data and procedure can be saved by clicking on the Save button and can be retrieved in future by clicking on Open an existing file button.

If all the three viz. hydrologic, hydraulic and structural design is selected then the procedure will be the same with the only difference that on hydrologic design window the user has to click on Next button (Figure 8) after entering the fall and discharge values. Thereafter, in hydraulic design window, again the user has to click on Next button after selecting one combination according to the site constraints for the length of spillway. Then the structural design window will appear with all the dimensions of the structure entered into their respective boxes. After entering all the information on material properties, click on the Next button. The user has to select appropriate conditions, as explained above, according to the site and click on the Finish Button for completing the design. When the design is completed a completion message appears on the screen. The input data and procedure can be saved by clicking on the Save button and can be retrieved in future by clicking on Open an existing button.

The results can be viewed from the Results menu by clicking on Drop spillway under Permanent Gully Control Structures sub menu. The results window (Figure 14) includes tabs for hydraulic design, uplift pressure calculations, contact pressure calculations and stability analysis with the tabs of their figures. The input data and procedure can be saved with Save button.

DSS for drop inlet spillway

The Drop Inlet Spillway design consists of two options, namely, Full Drop Inlet Design and Hydrographs of Drop Inlet, and any one-design option can be selected (Figure 15). Clicking on the Next Button leads to the data input window for the chosen design. Figure 16 shows the data input window for the Hydrographs of Drop Inlet option. After entering all the required data, clicking on OK button completes the design and the results can be seen from Results | Permanent Gully Control Structures | Drop Inlet Spillway.

On the other hand when the user selects the Full Drop Inlet Design, a window as shown in Figure 17 is displayed. The user has to select the design option and
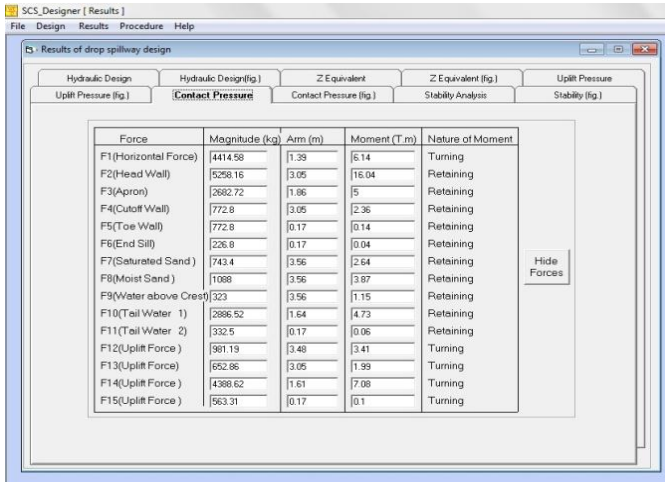
Figure 14. Results window of drop spillway.

Figure 15. Drop inlet spillway design.
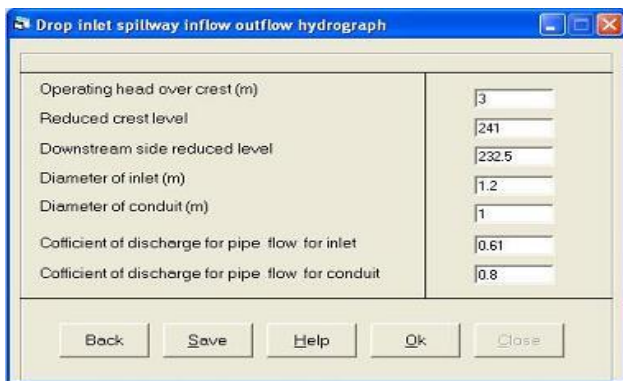
Figure 16. Data input for discharge hydrographs

P/R_s ratio, enter all input data with an approximate value of R_s. Then the user has to click on the Determination of R_s Button to get exact value of the radius of conduit. Thereafter, clicking on the Design button will open a new window with the calculated ratios displayed in it. The user is provided with an option to verify the calculated ratios using the Show Graphs for Reference. Thereafter, the

Figure 17. Drop inlet spillway design.

user has to enter different discharge coefficients to get hydrographs for the design and has to click on Discharge Curve Button. Once the design is completed successfully, the user can close the active window by clicking on the Close Button after saving the data by clicking on the Save button. The saved data can be opened by clicking on Open an existing file button.

The results can be viewed by clicking Results | Permanent Gully Control Structures | Drop Inlet Spillway. Again the result window contains four tabs, namely, design parameter (Figure 18), discharge curve, transition curve and drop inlet figure.

DSS for Chute spillway

Figure 19 shows the data input window for the design of chute spillway. The user has to enter input data and has to click on the Calculate Corrections Button. Two input box will appear for entering the length of clear width of spillway length and the thickness of each spillway pier. After entering the values in the input boxes a new window will appear with the calculated ratios displayed in it, based on which the user has to enter the correction factors. The correction factors graphs can be seen for ready reference by clicking Show Graph's for Reference Button. After entering correction factors, clicking on the Close Button brings back to data input window (Figure 19). The crest profile can be obtained by clicking the Design Crest Profile Button. Thereafter, user has to select an appropriate equation for the design of downstream side profile of low ogee weir depending upon the ratios and has to click on Apply Button (Figure 20). Now, the data input window for discharge carrier activates (Figure 21), in which the user has to enter all the data according to the instructions given on the window and click on the Design Discharge Carrier Button. This is the last stage in the chute spillway design. The
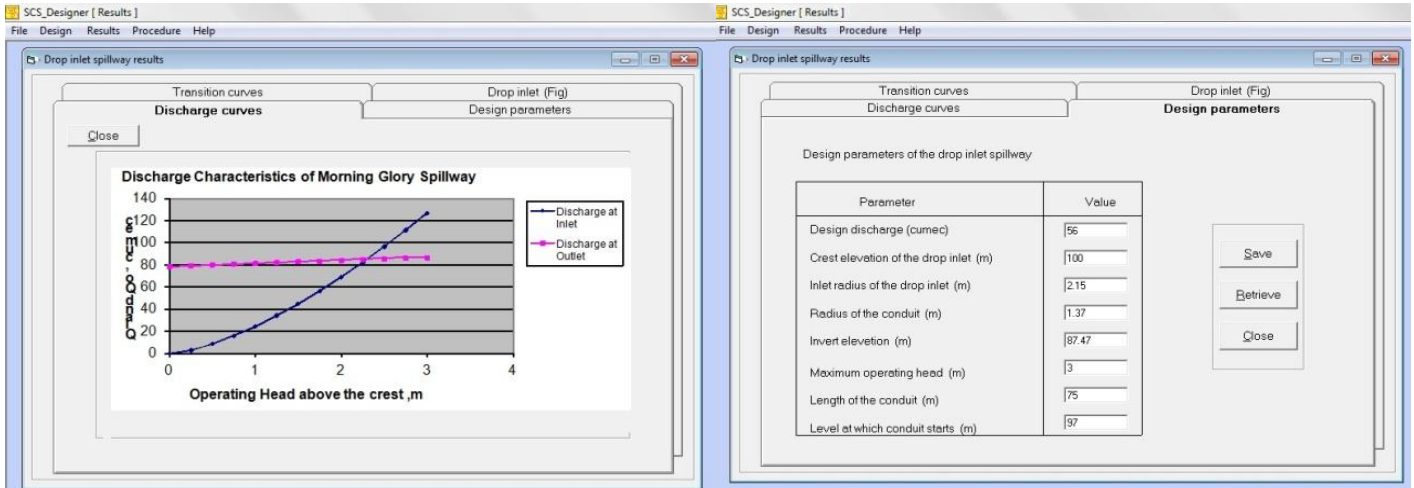
Figure 18. Results window for design of drop inlet spillway.
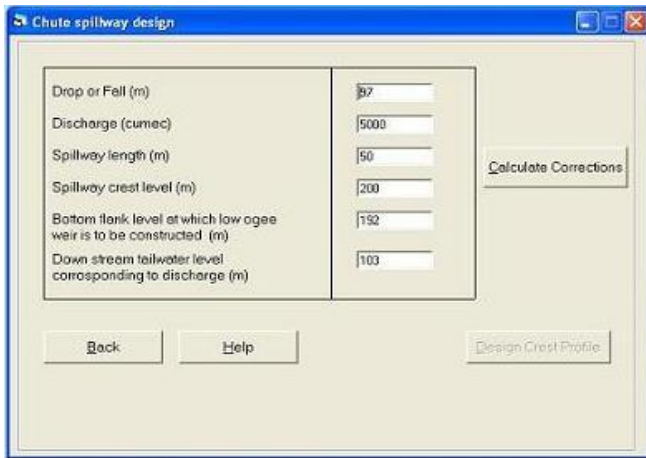
Figure 19. Data input for chute spillway.
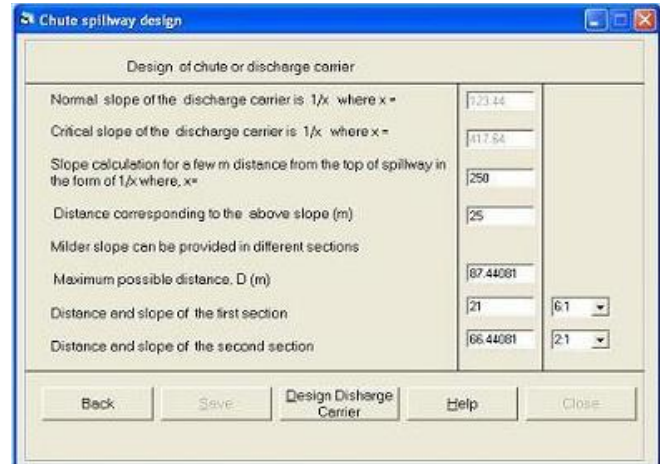
Figure 21. Design of discharge carrier.
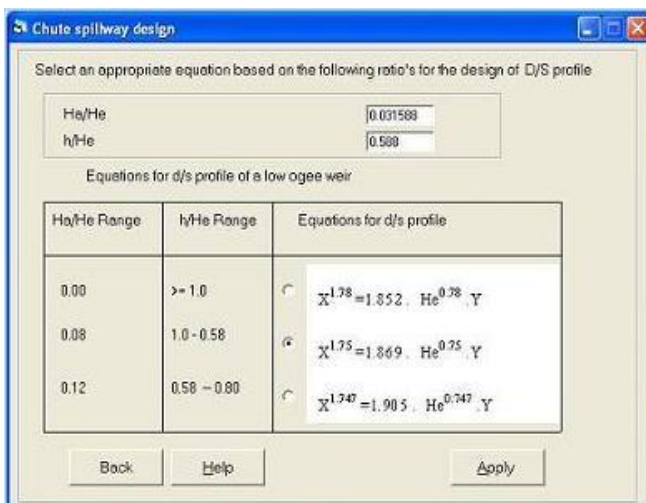
Figure 20. Equation for profile of low ogee weir.

input data can be saved by clicking on the Save button. The data can be retrieved in future by clicking on the Open an existing file button. The results can be viewed by clicking Results | Permanent Gully Control Structures | Chute Spillway. Again the result window contains six tabs, namely, design of discharge carrier (Figure 22), co-ordinates of u/s and d/s profiles, design of curve No. 1 and 2, curve No. 1 (graph), curve No. 2 (graph) and stilling basin design. The user has to click on Click here to draw graph button to view graphs of curve no. 1 and 2.

RESULTS AND DISCUSSION

The model was tested against the solved numerical from different sources. Wherever, solved numerical were not available, the model was tested against the hand calculations. For validation and testing of drop spillway

Figure 22. Results of chute spillway discharge carrier design.

Table 1. Validation of the SCS_designer for drop spillway design (hydraulic).

Design parameter	Source	SCS_designer	% Error	Remarks
Height of head wall (m)	2.82	2.81	-0.355	Truncation error
Height of headwall extension	3.82	3.82	0	---do--
Height of transverse sill (m)	0.315	0.32	1.587	--do--
Height of sidewall at end sill (m)	2.00	2.00	0	--
Length of apron (m)	3.55	3.58	0.845	Truncation error

Table 2. Validation of the SCS_designer for equivalent fluid pressure and uplift pressure for structural design of drop spillway.

Design parameter		Source	SCS_Designer	% Error	Remarks
Equivalent fluid pressure (T/m^3)		0.805	0.805	0	
	A, B	1.2	1.2	0	-
	B, C	0.117	0.117	0	-
	C, D	1.2	1.2	0	-
Weighted creep distance	D, E	1.1	1.1	0	-
between points (m)	E, F	1.2	1.2	0	-
	F, G	0.117	0.117	0	-
	G, H	1.2	1.2	0	-
	H, I	0.167	0.167	0	-
	B,C	498.71	498.71	0	-
Uplift pressure between	D, E	5057.22	5057.38	0.003	Truncation
points (kg)	F, G	574.03	574.06	0.005	Truncation
	H, I	860	860.02	0.002	Truncation
Total uplift (kg)		6989.96	6990.17	0.003	Truncation

(Rao, 1986), data were entered in the data input window (Figure 11) and corresponding design results are shown in Figure 14. Comparison between the design parameters obtained through the SCS_Designer and source is presented in Table 1 for hydraulic design and in Table 2 for structural design.
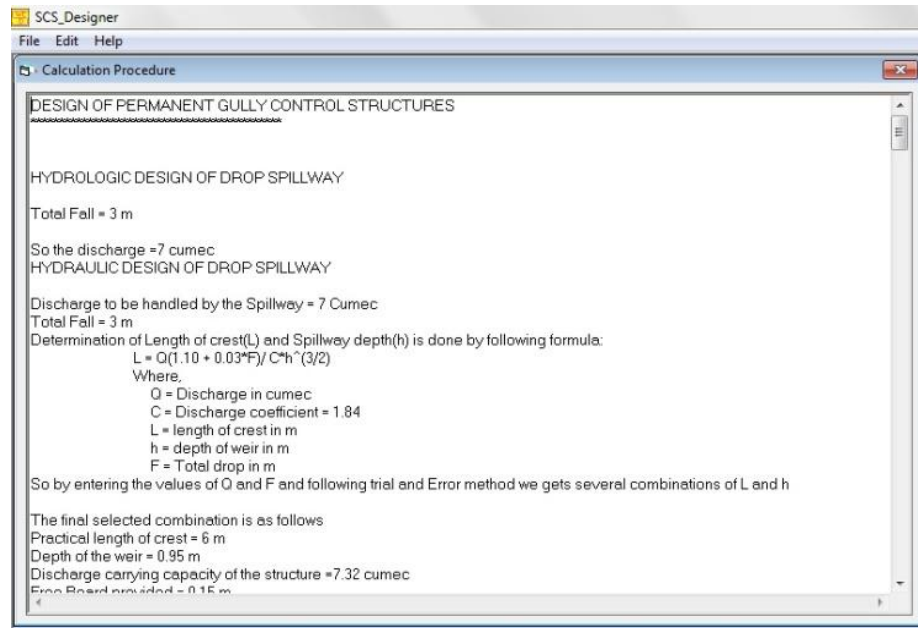
Figure 23. Procedure file window for SCS_designer.

The design results for permanent gully control structures obtained using the SCS_Designer matched well with the respective designs taken from various sources. Slight variation in values is due to truncation and round off errors. This suggests that the model provides accurate design of the selected permanent gully control structures and can be used for their designs.

Conclusions

The comprehensive package for the designing of permanent gully control structure module of SCS_Designer was developed, tested and validated as user-friendly software with advanced graphical user interface (GUI) using Visual Basic as the programming language. The important property of GUI is that, it allows user to select and edit data, determine the design parameters and coefficients, implement the simulation and display the results in tabular form. It also informs the user of any wrong activity and even the way to rectify it by its message boxes. In drop spillway design, user has the flexibility to choose hydrologic, hydraulic and structural designs separately. The design of drop inlet spillway and chute spillway are made easier and simpler for the users.

SCS_Designer has the provision for step wise design procedure to be displayed. These procedure files (Figure 23) are generated when the input data are saved, after the successful designing of a structure by the model. The procedure file has the same file name as that of the saved input data file but with *.txt, as its filename

extension. The SCS_Designer is equipped with help file for user's reference. The help file contains the detailed information about the theoretical consideration of the structures as well as the step-by-step procedure of the working of the model. These help files are window based easy to use reference files which will appear automatically on the screen by pressing the 'F1' key on the keyboard or by clicking on the 'Help' buttons of the respective windows of SCS_Designer.

The other objective of this study was to validate the SCS_Designer for the portion which has been modified and included so far. The SCS_Designer was validated against the available design examples for each of the structures it supports (Raghuwanshi, 2003; Suresh, 2002; Singh et al., 1981). Mostly these design examples were taken from standard books and in case if a proper example was not available, then problem was formulated and solved by hand calculations. Sometimes solved problems from the class notes were also used to validate SCS_Designer. In some cases, the model was validated in stepwise manner due to changes in design parameters. Thus, it can be concluded that the SCS_Designer is validated successfully and can be used as a standard tool to design permanent gully control structures namely drop spillway, drop inlet spillway and chute spillway.

REFERENCES

Das DC (1985). Problems of soil and land degradation in India. National Seminar on Soil Conservation and Watershed Management, September 17-18, New Delhi.

Dhruva NVV, Ram B (1983). Estimation of soil erosion in India. J. Irrigat. Drain. Eng. 109(4):419-434.

Raghuwanshi NS (2003). Lecture notes on Soil and Water Conservation Structures. IIT Kharagpur. Dept. of Agric. Food Eng. IIT, Kharagpur.

Rao D (1986). Development of optimal stilling basin for drop structures. Ph.D thesis. Dept. of Agril. and Food Engg., IIT Kharagpur. pp. 50-55.

Singh G, Venkataraman C, Sastry G (1981). Manual of Soil and Water conservation practices in India. Central Soil and Water Conservation Research and Training Institute (I.C.A.R.) Dehradun, India.

Suresh R (2002). Soil and Water Conservation Engineering. Standard Publishers Distributors, New Delhi.

USDA (1957). Drop spillway, Section II, Engineering Hand Book, Soil Conservation Service Washington D.C.