Recent Trends in Civil Engineering & Technology
Volume 1, Issue 1-3 Compilation 2011

STM JOURNALS

Slope Stability Analysis by Swedish Slip Circle Method Using C-Programming

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ABSTRACT

The side slopes of an earthen dam should be safe against shear failure. Out of the various methods of stability analysis of slopes, "Swedish Slip Circle Method" is commonly used in practice. Here in the Swedish circle method, potential failure surface is assumed to be cylindrical in shape (i.e., circular in cross section). After determining the actuating and resisting forces for assumed failure surface, the factor of safety is calculated. The slope is considered safe if the minimum factor of safety is greater than the specified value. This paper aims at presenting the procedure for determination of factor of safety using C-program. The program helps to calculate normal component (N) and tangential component (T) at a faster rate as compared to graphical method. With the use of co-ordinate system for determination of normal and tangential components, the program results in a very accurate value which will otherwise be approximate, if calculated by graphical method. The program also displays N-plot, T-plot and U-plot which are important features of rectangular plot method. Another important feature of the program is the graphical representation of cross section of the dam along with assumed slip surface and number of slices with different forces acting on them. This paper aims at comparing the value of factor of safety obtained by graphical method with that obtained by C-program. With this computational approach, the obtained factor of safety is more accurate than that obtained by conventional graphical method.

Keywords: *N-plot and T-plot, factor of safety, rectangular plot method, normal and tangential components, slope stability, graphical method*

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INTRODUCTION

The movement of a soil mass in downward and outward direction of a slope is called as slide or slope failure. Slides occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation. They are usually caused by excavation, by undercutting the foot of an existing slope, by a gradual disintegration of the structure of the soil, by an increase of the pore water pressure in a few exceptionally permeable layers, or by a shock that liquefies the soil.

Two types of slope stability problems occur in clays – short-term stability (end-of-construction case) and long-term stability (steady seepage case).

The short-term case applies after a cut is made in a slope. In excavating for a cut, shear stresses are induced that may cause failure in the undrained state. Theoretically, it is possible to analyze the stability of a newly cut slope on the basis of either total or effective stresses; however, since it is difficult to ascertain the distribution of pore pressures under these conditions, the $\Phi = 0$ method of analysis (total stress method) has proved more successful.

The long-term case is encountered in natural slopes and should also be considered in analyzing the stability of embankments. In this case, pore pressures may be assumed to be in equilibrium and are determined from considerations of steady seepage; thus, no excess pore pressures are included. This case is analogous to that of the drained shear test, and effective stress parameters should be used.

Necessity

Stability analysis determines whether the existing or proposed slope meets the safety requirements; soil mass under given loads should have an adequate safety factor with respect to shear failure and the deformation of the soil mass under the given loads should not exceed certain tolerable limits. The analysis must be made for the worst conditions, which seldom occur at the time of investigation. Not only is knowledge of analytical methods required, but experience and judgment are necessary to predict probable changes in conditions.

The stability of earth slopes, embankments and hill sides is a factor which needs to be considered in the construction of new roads, dams and canals , both for economic reasons and the safety of human lives which may be affected due to badly designed dams and embankments.

There are numerous methods currently available for performing analysis of slope stability. The majority of these may be categorised as limit equilibrium methods .The basic assumption of the limit equilibrium approach is that the Coulomb's failure criterion is satisfied along the assumed failure surface, which may be a straight line, circular arc, logarithmic spiral, or other irregular surface.

Methods that consider only the whole free body include the Culmann's method and the friction circle method.

Another approach is to divide the free body into many vertical slices and to consider the equilibrium of each slice. The best known are the Swedish circle method and the Bishop method.

Traditional methods like Swedish slip circle method have resulted in approximate methods for dealing with stability of slopes. These approximations are generally accepted in engineering practice but the question can be rightfully raised as to how these approximations can be converted into accuracy.

Software technology has significantly changed in recent years and is now at the point where it is much easier to perform accurate slippage analysis. There are certain questions that can be asked. Is it possible to compare results obtained by graphical method with that obtained by C-programming? If so, under what conditions? This paper aims at comparing the value of factor of safety obtained by graphical method with that obtained by C-program.

The computation technique used in any of above methods can be classified as:
(1). Conventional or Traditional Computation
(2). Computation Technique Using C-Programming

At every location where the ground is not at the same level, different forces act which tend to cause movements of soil from high points to low points. One of the most important forces is the component of gravity that acts in the direction of probable motion.

The side slopes of an earthen dam should be safe against shear failure. The soil mass in an earthen dam, because of its slope, is subjected to the driving forces which tend to cause movement or sliding of the soil mass. This movement is resisted by the resisting forces which develop at the potential sliding surface because of the shear strength of the soil. The side slopes of the earthen dam will remain stable if the sum of the resisting forces on every possible surface of failure or surface of slippage is greater than the sum of the driving forces. Even if there is a single surface on which this condition is not satisfied, slippage of the soil mass will occur on that surface and the dam may fail.

There are various methods of the stability analysis of slopes. The slope-stability analysis is usually carried out by Fellenius method also called Swedish circle method. It ignores inter slice forces and considers only moment equilibrium and not force equilibrium conditions. Thus, it provides only moment factor of safety and not force factor of safety [1–4].

SWEDISH SLIP CIRCLE METHOD

Conventional or Traditional Computation

Let us consider the stability of slopes of an earthen dam as shown in Figure 2.1:

To check the stability of the slope, a trial slip surface is considered. For the trial slip surface, a circular arc is drawn through the toe of the slope with its centre at any point 'o'. If the assumed slip surface is a possible surface of failure, then the soil mass lying above this surface will slide along this surface and cause failure. In that case, the moment of the actuating forces about the centre 'o' will exceed the moment of the resisting forces about the same point.
For determination of forces and moments, the soil mass in the trial wedge above the assumed slip surface is divided into a convenient number of slices by drawing vertical lines. Greater accuracy can be obtained by considering greater number of slices. But it increases computational efforts and gives more accurate results.

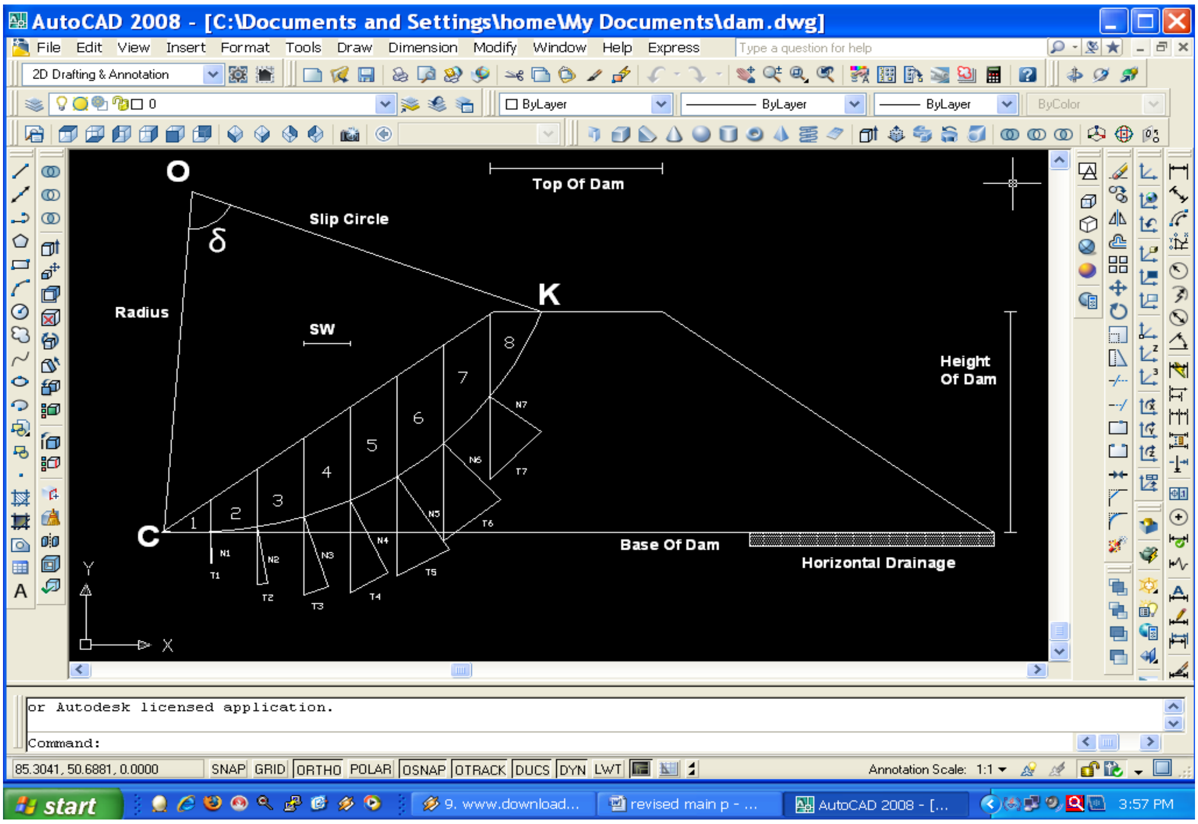

Fig. 2.1 Swedish Slip Circle Method.

Various forces acting on the slices are:

(1). Weight (W) of the slice acting vertically downward through its centre of gravity

(2) Normal component (N) and tangential component (T) of weight W

(3) Reaction (R) at the base of the slice which is acting at an angle phi (Φ) to the normal

(4). Soil reactions P_R and P_L acting on the vertical sides of slice which are exerted by adjacent slices on the right and left sides respectively. But in Swedish slip circle method, it is assumed that reactions P_R and P_L are equal and opposite and they cancel each other thereby not affecting the force or moment equilibrium

(5) The forces due to pore water pressure U_R and U_L acting on the vertical sides of slice which are also equal and opposite and they cancel each other thereby not affecting the equilibrium. But the effect of force U_B acting on the base of the slice needs to be considered

(6). Cohesive force (C) acting along the curved surface in the direction opposite to the direction of probable movement of the soil wedge

(7). The force U_B due to pore water pressure is zero if the soil is dry

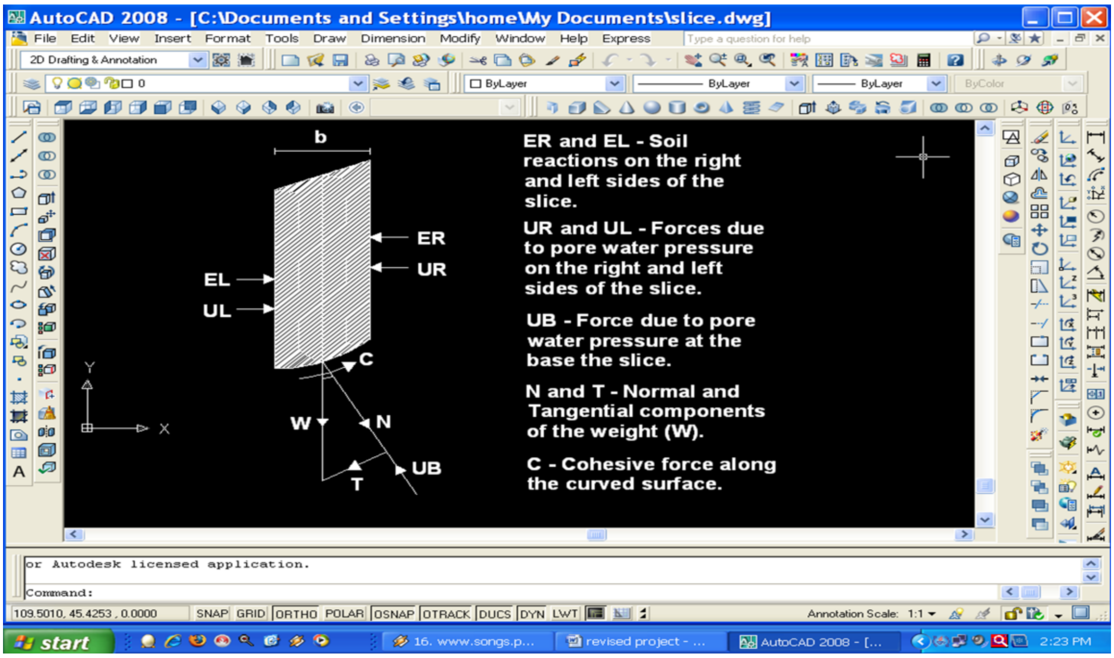

Fig. **2.2** Different Forces Acting on the Slice.

Forces are computed for all the slices above the assumed slip surface and the corresponding actuating and resisting moments can be computed. On any trial surface, the factor of safety is the ratio of the maximum possible resisting moment to the actuating moment.

The factor of safety is given by,

$$F_s = \frac{\text{Sum of resisting forces}}{\text{Sum of actuating forces}}$$

The effect of force due to pore water pressure is not considered, if the soil is fully dry.

The procedure for determination of factor of safety of the trial slip surface is as follows:

- Take a trial slip surface and divide the wedge above the slip surface into 8 to15 vertical slices.
- The weight W can be taken corresponding to the end ordinates of each slice. The end ordinate is extended below the slip surface equal to its own length. Thus the vertical line below the slip surface represents the weight of the slice to some scale.
- The weight of each slice is resolved graphically into the normal and tangential components. It is the general practice to determine the normal and tangential components graphically.
- The following two methods are commonly used in practice:

(1). Curved plot method

(B). Rectangular plot method

(1). Curved plot method: In this method N-diagram and T-diagram are plotted and the areas of N-diagram and T-diagram are measured with a planimeter or a square overlay.

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(2) Rectangular plot method: Alam Singh devised a simple method for determination of ∑N, ∑T and ∑U as shown in Figure 2.3.

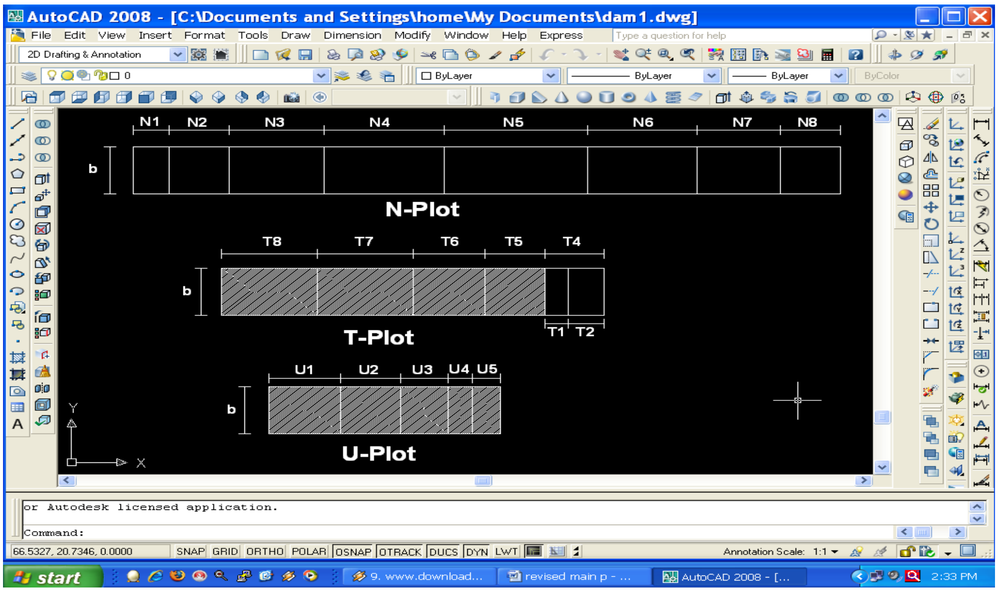


Fig. 2.3 Rectangular Plot Method.

(1). N-Plot: For the N-Plot, the width of rectangle is taken equal to the width of the slice. The normal components N1, N2, etc., are marked on the rectangle in the horizontal direction.

(2). T-Plot: Likewise, the T-Plot is drawn by marking the components T1, T2, etc, and taking the width of rectangle equal to the width of the slice. The T-components which are negative are plotted in the reverse direction. The net area of the T-Plot is then shown hatched in Figure 2.

(3). U-Plot: Likewise, the U-Plot is drawn after construction of flow net.

- The values of ∑N , ∑T and ∑U are computed as:

$\sum N = A_N * \gamma$

$\sum T = A_T * \gamma$

$\sum U = A_U * w$

where A_N and A_T are the areas the N-Plot and the T-Plot, respectively and γ is the unit weight of the soil.

If the scale is 1 cm = x m, then

$A_N = a_n * x^2$

$A_T = a_t * x^2$

$A_U = a_u * x^2$

where a_n and a_t are the actual measured areas of the plots.

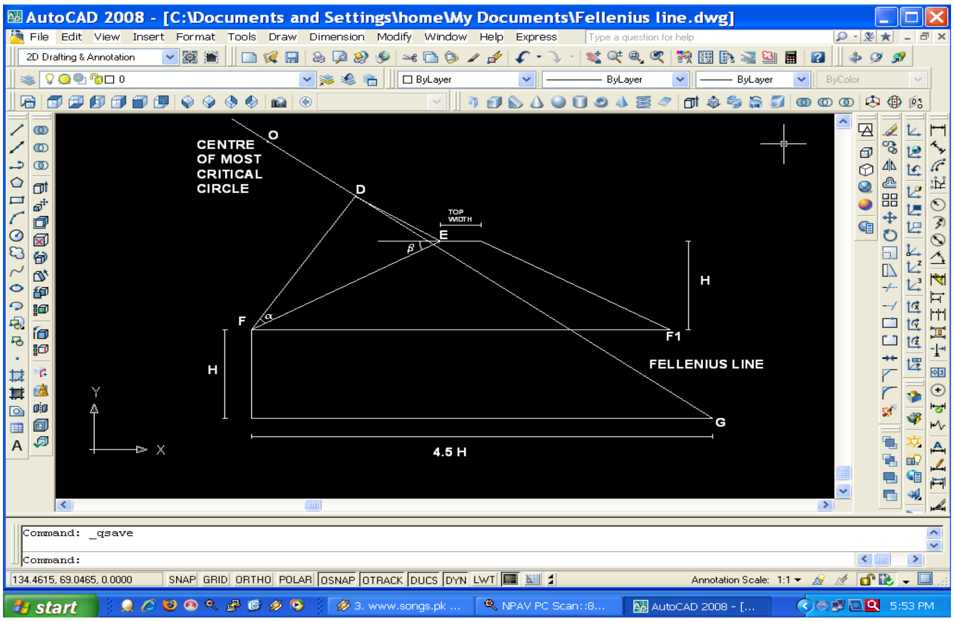
Thus,

$\sum N = a_n * x^2 * \gamma$

$\sum T = a_t * x^2 * \gamma$

$\sum U = a_u * x^2 * w$

The rectangular plot method simplifies the determination of the areas, as areas of the rectangles can be easily measured without a planimeter.



- Determine the pore water pressure (u) at the base of the slice from the flow net.
- Determine the cohesive force c.
- Determine the factor of safety for the trial slip surface by

$$Fs = \frac{\tan \Phi * \sum(N - U) + c * La}{\sum T}$$

- An approximate value of the factor of safety of the upstream slope under the sudden drawdown conditions can be obtained as follows:

$$Fs = \frac{\tan \Phi * \sum N' + c * La}{\sum T}$$

- Repeat the above procedure for a number of trial surfaces. The trial surface which gives the minimum factor of safety is the most critical circle. The minimum factor of safety should be greater than the specified safe value. Specified safe values are given in the Table 2.1.
- For determination of the factor of safety, the values of the angle θ which the normal make with the vertical are required. The accuracy of the method depends upon the accuracy with which the angles are measured. As the angles are usually small, it is difficult to measure them accurately. It is the general practice to determine the normal and tangential components graphically.
- For location of the most critical circle, a number of trial slip surfaces are assumed and the factors of safety are found. The circle which gives the minimum factor of safety is the most critical circle. To reduce the number of trials, the Fellenius line is usually drawn. Fellenius has shown that for a homogeneous slope, the centre of the most critical circle lies on a line DG, called the Fellenius line as shown in Figure 2.4.

For drawing the Fellenius line DG, point G is located at a depth of H below the toe of the slope and at a distance of 4.5 H from it, where H is the total height of the dam. The point D is located by drawing two lines FD and ED. The line FD makes an angle α with the slope line FE and the line ED makes an angle β with the horizontal line drawn through point E.

Table 2.1 : The Values of A and B Depend Upon Slope of the Dam.

Slope	α	β
1 : 1	28^o	37^o
1.5 : 1	26^o	35^o
2 : 1	25^o	35^o
3 : 1	25^o	35^o
5 : 1	25^o	35^o

The line DG is drawn through D and G and it may be extended. The centre of the most critical circle 'o' may lie anywhere on the line DG or on its extension. Its exact position can be obtained after conducting the stability analysis for different slip surfaces.

The above construction is for a c-Φ soil. For a purely cohesive soil (Φ = 0), the point D itself represents the centre of the most critical circle.

The factors of safety to be designed for are:

(1).The most critical stage for the upstream slope, i.e., at the end of construction and during rapid drawdown of the level in the reservoir

Table 2.2 Guidelines for Limit Equilibrium of a Slope.

Sr. No.	Factor of Safety	Details of Slopes
1.	< 1.0	Unsafe
2.	1.0 – 1.25	Questionable Safety
3.	1.25 – 1.4	Satisfactory for Routine cuts and Fills, Questionable for Dams, or Where Failure Would be Catastrophic
4.	> 1.4	Satisfactory for Dams

(2).The most critical stage for the downstream slope, i.e., at the end of construction and during steady seepage when the reservoir is full

The Swedish circle method is used for checking the stability of the earth dam for the following critical conditions:

(1).Stability of D/S slope during steady seepage condition

(2) Stability of U/S slope during sudden drawdown condition

(3). Stability of D/S and U/S slopes during construction

Computation Technique Using C-Programming

C-Program includes following parameters in the form of input. The important feature of the program is the graphical representation of cross-section of the dam along with assumed slip surface and the number of slices with different forces acting on them.

Table 2.3 Parameters for Example.

Sr. No.	Soil Parameters	Circle Parameters
1.	Saturated Unit Weight = 21kN/cum	Radius of Circle = ----
2.	Average Unit Weight under Steady Seepage = 20 kN/cum	Centre of Circle = ----
3.	Angle of Internal Friction = 25	No. of Slices = ----
4.	Cohesion = 20 kN/sqm	
5.	U/S Slope = tan(1/3) = 18.43	
6.	D/S Slope = tan(1/2.5) = 21.80	

The C-program begins with fixing of geometry of cross-section of dam depending upon the value of height of dam (H), crest width (cw),U/S and D/S slopes of the dam as shown in the following output file.

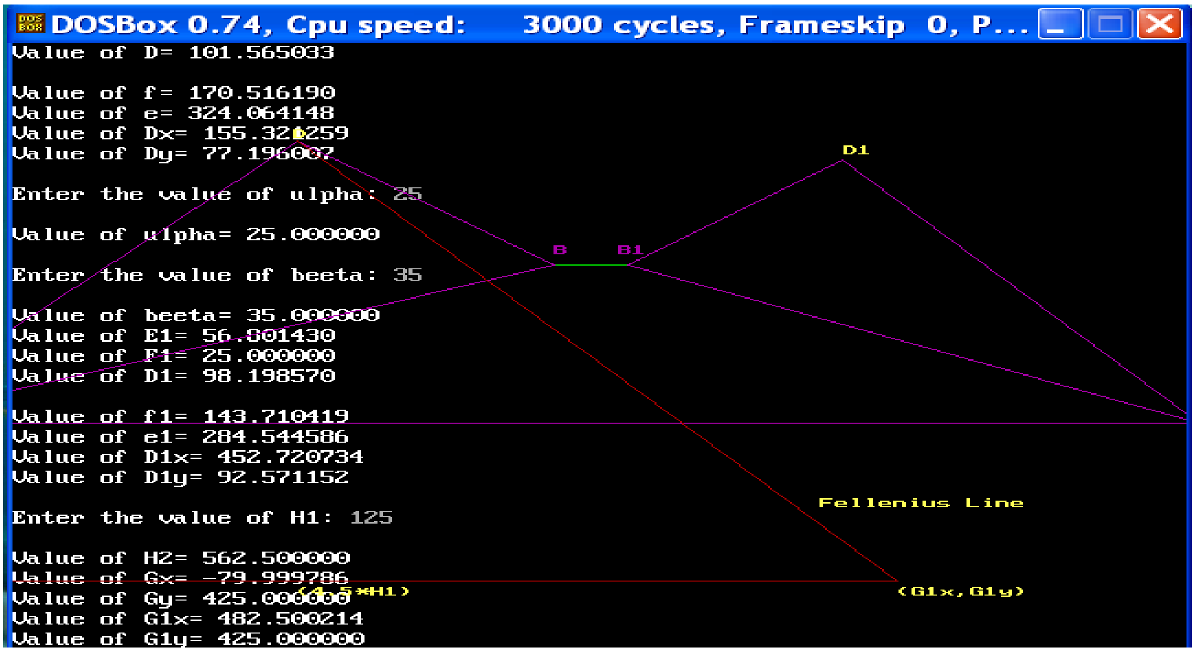


Fig. 2.5 Obtained Geometry of Cross-Section of the Dam.

Certain empirical formulae are commonly used for determination of the crest width as follows:

(1). For low dams (i.e., $H < 10m$)
$cw = (0.2 * H) + 3$

(2). For medium dams (i.e., $10 < H < 30$ m)
$cw = (0.55 * H^{1/2}) + (0.2 * H)$

(3). For high dams (i.e., H > 30 m) cw = 1.65 * $(H + 1.5)^{1/2}$
In general, the crest width varies from 6 to 12 m; the larger values are for higher and more important dams. The crest width should be adequate to withstand shock due to earthquake and wave action. Moreover, the crest should be wide enough to keep the phreatic line well within the dam. The U/S and D/S slopes of the dam depend upon the type of material, foundation conditions and the height of the dam. The general practice is to select the side slopes on the basis of the experience gained with similar dams elsewhere and to check the stability of selected slopes. If the adopted slopes are not safe or economical, they are suitably modified. Table 2.4 gives the side slopes recommended by Terzaghi for the preliminary section.

Table 2.4 Side Slopes Recommended by Terzaghi.

Sr. No.	Type of Section	Type of Material	U/S Slope	D/S Slope
1.	Homogeneous Section	Well-Graded Material	2.5 : 1	2 : 1
2.	Homogeneous Section	Coarse Silt	3 : 1	2.5 : 1
3.	Homogeneous Section	Silty Clay or Clay (i) Height < 15 m (ii) Height > 15 m	 2.5 : 1 3 : 1	 2 : 1 2.5 : 1
4.	Zoned Section	Sand or Gravel Shells with Clay Core.	3 : 1	2.5 : 1
5.	Zoned Section	Sand or Gravel Shells, with R.C.C. Core.	2.5 : 1	2 : 1

The Fellenius line is drawn to get the centre of slip circle (o). After obtaining the centre of slip circle, trial slip circle is drawn. The starting co-ordinates (x1, y1) and end co-ordinates (x2, y2) of the slip circle are given as input to the program .With this input, program calculates the slice width depending upon the number of slices. It then generates the co-ordinates of all the slices along with the values of N-components and T-components as shown in Figure. It then calculates the value of factor of safety stating whether the slope is safe or unsafe.

The program helps to calculate normal component (N) and tangential component (T) at a faster rate as compared to graphical method. With the use of co-ordinate system for determination of normal and tangential components, the program results in a very accurate value which will otherwise be approximate, if calculated by graphical method. The program also displays N-plot, T-plot and U-plot which are the important features of rectangular plot method. With this, the obtained factor of safety is more accurate than that obtained by graphical method.

This program has been tested for checking the stability of U/S slope under sudden drawdown. It has also been tested for checking the stability of D/S slope under steady seepage, which included construction of flow net. Because of steady seepage condition, it is necessary to determine the pore pressure which can be obtained after drawing flow net. For value of pore pressure, it is required to draw pore pressure diagram.

Output of this program indicates safety of U/S and D/S slopes depending upon the value of factor of safety.

The drawback of this program is that as pore pressure can be obtained after
drawing a flow net, it is required to draw flow net manually and then the value of pore pressure is given as input in the program and then we get the value of factor of safety.

EXAMPLE

Check the stability of U/S and D/S slopes of the earth dam as shown in Figure 3.1. Also determine the seepage through the dam.

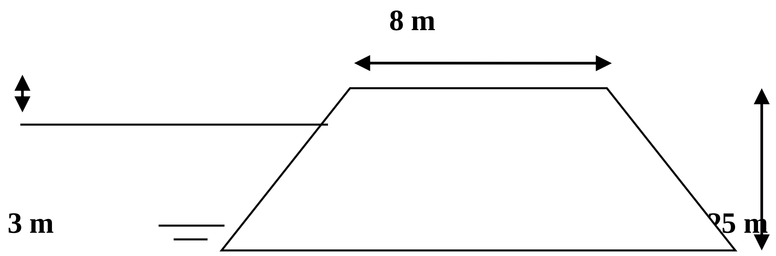


Fig. 3.1 Cross Section of Dam along with Slip Surface. Assume the following properties of the soil:

Saturated unit weight = 21 kN/m^3
Average unit weight under steady seepage = 20 kN /m^3
Coefficient of permeability = 5 1 $^{-6}$ m/s
Φ = 25 and c = 20 kN/m^2
U/S Slope is 1 : 3
D/S Slope is 1 : 2.5
Assume the foundation to be impervious.

Stability of D/S Slope under Steady Seepage

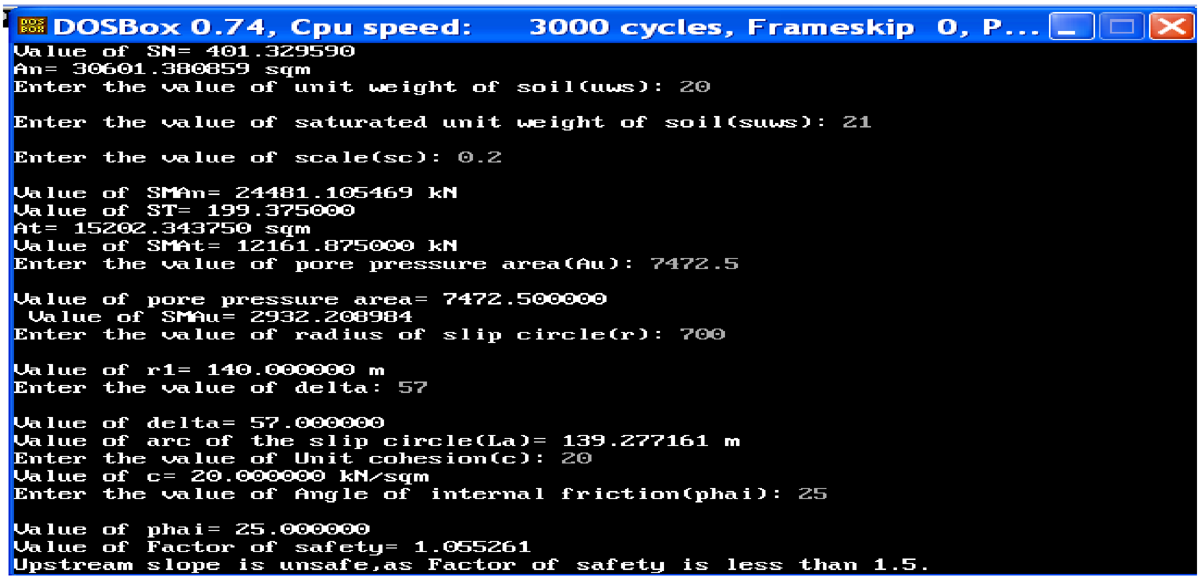
Graph 3.1 (ATTACHED) Location of Centre of Slip Circle along with Fellenius Line.

Graph 3.2 (ATTACHED) Slip Circle Analysis for D/S Slope of the Dam.

For this case, it is required to construct a flow net for obtaining the value of pore pressure. After construction of flow net, U-Plot is drawn and A_U, i.e., area of U-Plot is measured which gives the value of ∑U.

With this value of ∑U, factor of safety can be determined for steady seepage condition.

This program has been used to determine the factor of safety for three different values of ∑U as follows:



Graph 3.3: (ATTACHED) Flow Net for x = 50.

Determination of Factor of Safety by Graphical Method for Graph 3.3

SN = N1 + N2 + N3 + N5 + N6 +N7

SN = 400.00

a_n = SN * SW

a_n = 30500

$\sum N = a_n * x^2 * \gamma'$

∑N = 30500 * 0.2 * 0.2) * 20 = 24400

ST = T1 + T2 + T3 + T4 + T5 + T6 + T7

ST = 166.64

a_t = ST * SW

a_t = 12706.3

$\sum T = a_t * x^2 * \gamma'$

∑T = 12706.3 * (0.2 * 0.2) * 20 = 10165.04

a_u = VI * b

a_u = 7472.5

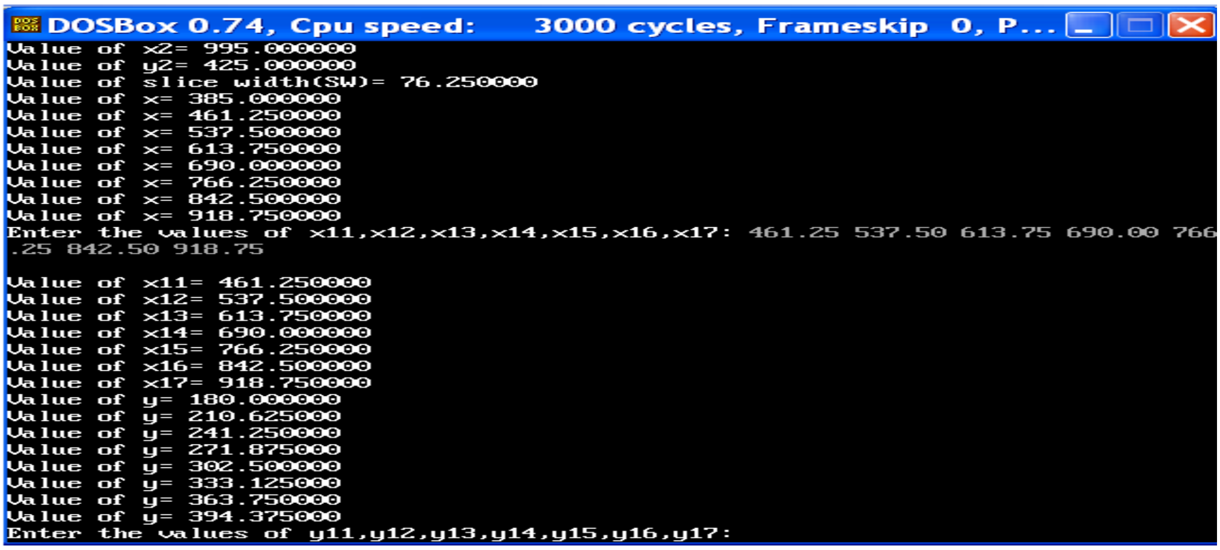
$\sum U = a_u * x^2 * 9.81 = 2932.21$

La = (2 * Π * r * δ)/360

La = 139.27

$$Fs = \frac{\tan \Phi * \sum(N - U) + (c * La)}{\sum T}$$

Fs = 1.26 < 1.5   Hence unsafe.



```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
Value of x2= 995.000000
Value of y2= 425.000000
Value of slice width(SW)= 76.250000
Value of x= 385.000000
Value of x= 461.250000
Value of x= 537.500000
Value of x= 613.750000
Value of x= 690.000000
Value of x= 766.250000
Value of x= 842.500000
Value of x= 918.750000
Enter the values of x11,x12,x13,x14,x15,x16,x17: 461.25 537.50 613.75 690.00 766
.25 842.50 918.75

Value of x11= 461.250000
Value of x12= 537.500000
Value of x13= 613.750000
Value of x14= 690.000000
Value of x15= 766.250000
Value of x16= 842.500000
Value of x17= 918.750000
Value of y= 180.000000
Value of y= 210.625000
Value of y= 241.250000
Value of y= 271.875000
Value of y= 302.500000
Value of y= 333.125000
Value of y= 363.750000
Value of y= 394.375000
Enter the values of y11,y12,y13,y14,y15,y16,y17:
```

Output File for Graph 3.3

Graph 3.4: (ATTACHED) Flow Net for x = 100.

Determination of Factor of Safety by Graphical Method for Graph 3.4.

SN = N1 + N2 + N3 + N5 + N6 + N7

SN = 400.00

a_n = SN * SW

a_n = 30500

$\sum N = a_n * x^2 * \gamma'$

$\sum N = 30500 * (0.2 * 0.2) * 20 = 24400$

ST = T1 + T2 + T3 + T4 + T5 + T6 + T7

ST = 166.64

a_t = ST * SW

a_t = 12706.3

$\sum T = a_t * x^2 * \gamma'$

$\sum T = 12706.3 * (0.2 * 0.2) * 20 = 10165.04$

a_u = VI * b

a_u = 11323.13

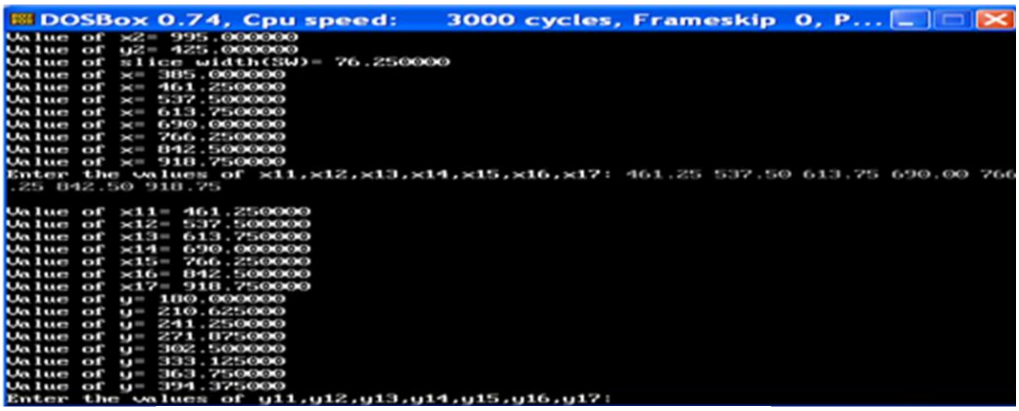
$\sum U = a_u * x^2 * 9.81 = 4443.19$

$La = (2 * \Pi * r * \delta)/360$

La = 139.27

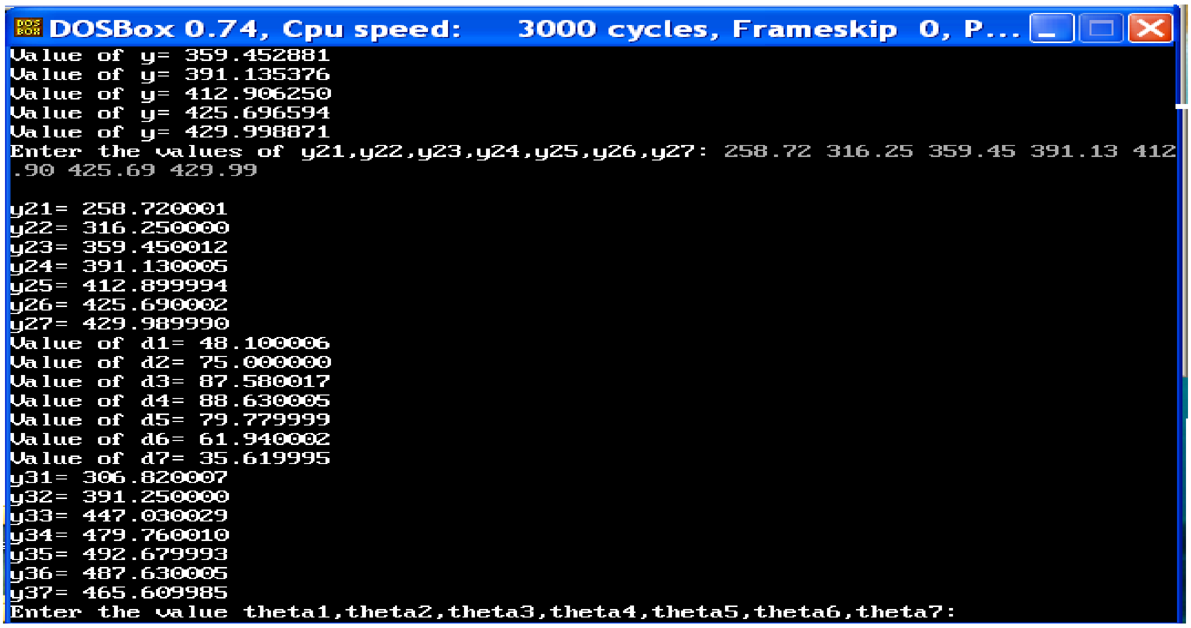
$$Fs = \frac{\tan \Phi * \sum(N-U) + (c * La)}{\sum T}$$

Fs = 1.19 < 1.5   Hence unsafe.



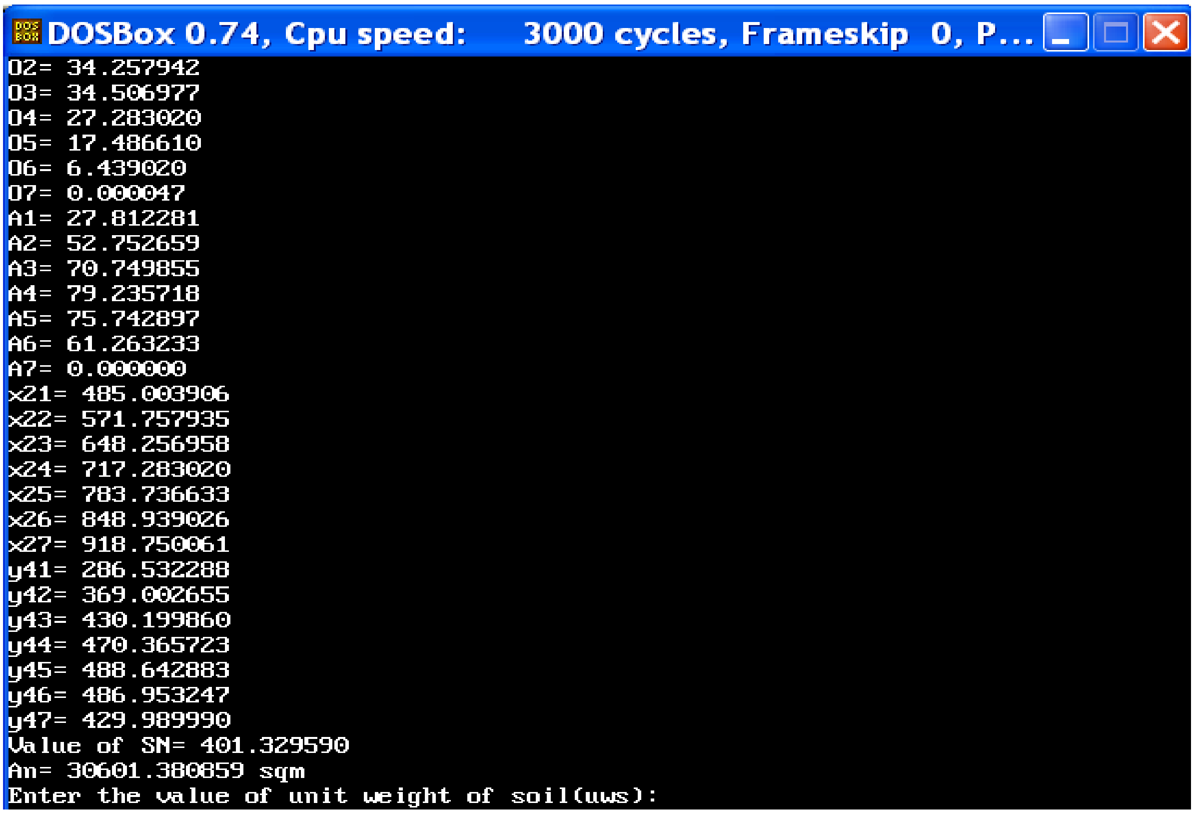

```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
Value of x2= 995.000000
Value of y2= 425.000000
Value of slice width(SW)= 76.250000
Value of x= 385.000000
Value of x= 461.250000
Value of x= 537.500000
Value of x= 613.750000
Value of x= 690.000000
Value of x= 766.250000
Value of x= 842.500000
Value of x= 918.750000
Enter the values of x11,x12,x13,x14,x15,x16,x17: 461.25 537.50 613.75 690.00 766
.25 842.50 918.75

Value of x11= 461.250000
Value of x12= 537.500000
Value of x13= 613.750000
Value of x14= 690.000000
Value of x15= 766.250000
Value of x16= 842.500000
Value of x17= 918.750000
Value of y= 180.000000
Value of y= 210.625000
Value of y= 241.250000
Value of y= 271.875000
Value of y= 302.500000
Value of y= 333.125000
Value of y= 363.750000
Value of y= 394.375000
Enter the values of y11,y12,y13,y14,y15,y16,y17:
```


Output File 2 for Graph 3.4



```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
Value of y= 359.452881
Value of y= 391.135376
Value of y= 412.906250
Value of y= 425.696594
Value of y= 429.998871
Enter the values of y21,y22,y23,y24,y25,y26,y27: 258.72 316.25 359.45 391.13 412
.90 425.69 429.99

y21= 258.720001
y22= 316.250000
y23= 359.450012
y24= 391.130005
y25= 412.899994
y26= 425.690002
y27= 429.989990
Value of d1= 48.100006
Value of d2= 75.000000
Value of d3= 87.580017
Value of d4= 88.630005
Value of d5= 79.779999
Value of d6= 61.940002
Value of d7= 35.619995
y31= 306.820007
y32= 391.250000
y33= 447.030029
y34= 479.760010
y35= 492.679993
y36= 487.630005
y37= 465.609985
Enter the value theta1,theta2,theta3,theta4,theta5,theta6,theta7:
```

Output File 5 for Graph 3.4



```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
O2= 34.257942
O3= 34.506977
O4= 27.283020
O5= 17.486610
O6= 6.439020
O7= 0.000047
A1= 27.812281
A2= 52.752659
A3= 70.749855
A4= 79.235718
A5= 75.742897
A6= 61.263233
A7= 0.000000
x21= 485.003906
x22= 571.757935
x23= 648.256958
x24= 717.283020
x25= 783.736633
x26= 848.939026
x27= 918.750061
y41= 286.532288
y42= 369.002655
y43= 430.199860
y44= 470.365723
y45= 488.642883
y46= 486.953247
y47= 429.989990
Value of SN= 401.329590
An= 30601.380859 sqm
Enter the value of unit weight of soil(uws):
```

Output File 5 for Graph 3.4

Graph 3.5 (ATTACHED) Flow Net for x = 150.

Determination of Factor of Safety by Graphical Method for Graph 3.5.

SN = N1 + N2 + N3 + N5 + N6 + N7

SN = 400.00

a_n = SN * SW

a_n = 30500

$\sum N = a_n * x^2 * \gamma'$

$\sum N$ = 30500 * (0.2 * 0.2) * 20 = 24400

ST = T1 + T2 + T3 + T4 + T5 + T6 + T7

ST = 166.64

a_t = ST * SW

a_t = 12706.3

$\sum T = a_t * x^2 * \gamma'$

$\sum T$ = 12706.3 * (0.2 * 0.2) * 20 = 10165.04

a_u = VI * b

a_u = 12047.5

$\sum U = a_u * x^2 * 9.81 = 4727.43$

La = (2 * Π * r * δ)/360

La = 139.27

$$Fs = \frac{\tan \Phi * \sum(N-U) + (c * La)}{\sum T}$$

Fs = 1.18 < 1.5 Hence unsafe.

Stability of U/S Slope under Sudden Drawdown

Graph 3.6 (ATTACHED) Slip Circle Analysis for U/S Slope of the Dam (Case 1).

Determination of Factor of Safety by Graphical Method for Case 1

SN = N1 + N2 + N3 + N5 + N6 + N7

N = 325.06

a_n = SN * SW

a_n = 15846.67

$\sum N = a_n * x^2 * \gamma_{Sat}$

$\sum N$ = 15846.67 * (0.2 * 0.2) * (21−9.81) = 70 92.97

ST = − T1 − T2 + T3 + T4 + T5 + T6 + T7

ST = 97.78

a_t = ST * SW

a_t = 4766.77

$\sum T = a_t * x^2 * \gamma_{Sat}$

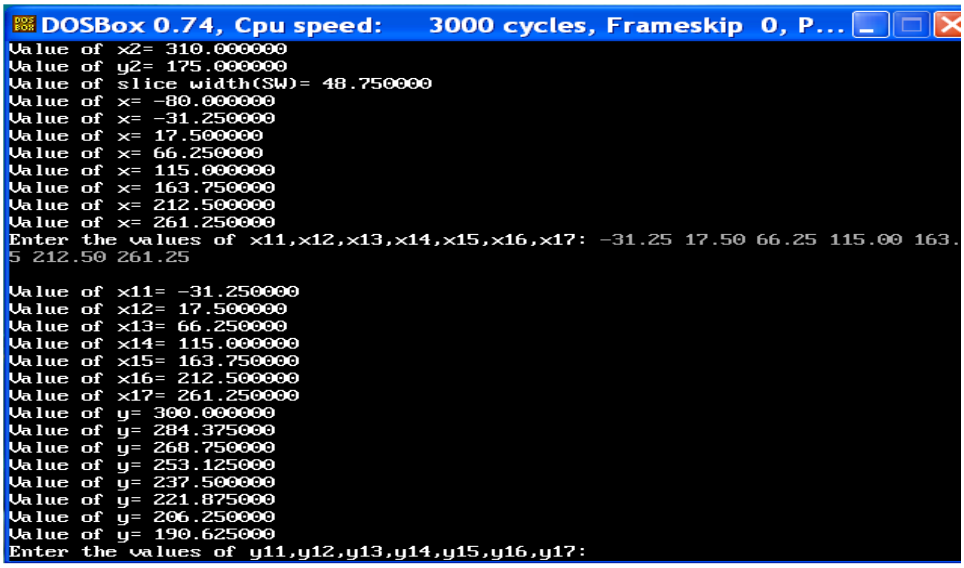
$\sum T$ = 4766.77 * (0.2 * 0.2) * 21 = 4004.09

La = (2 * Π * r * δ)/360

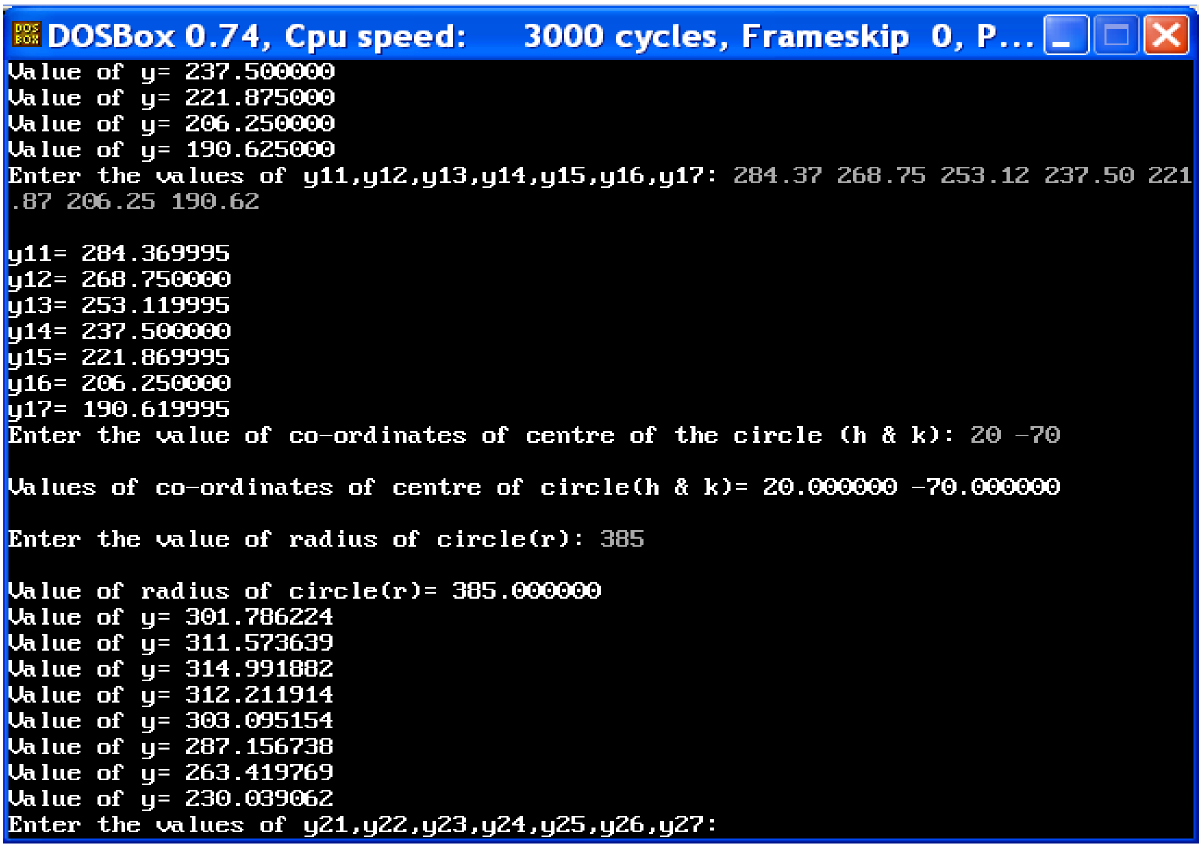
La = 87.35

$$Fs = \frac{\tan \Phi * \sum N + (c * La)}{\sum T}$$

Fs = 1.26 < 1.5 Hence unsafe.

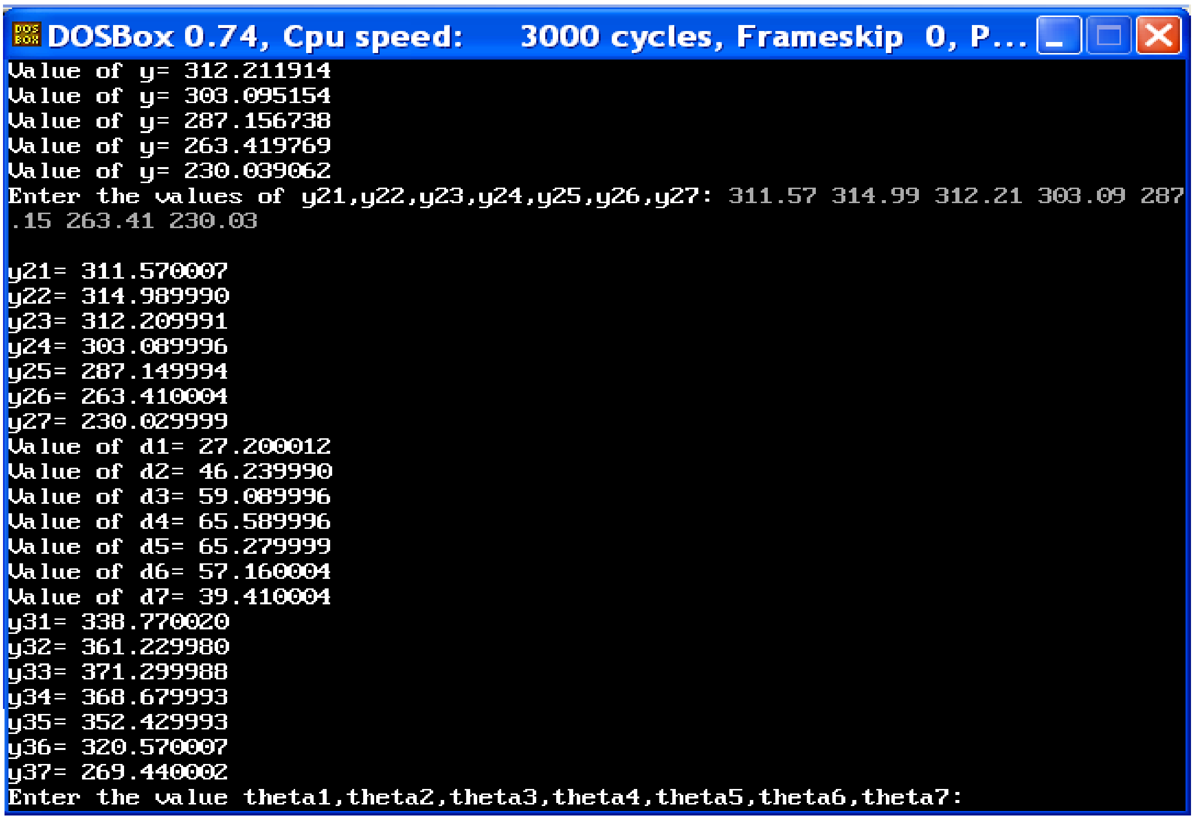


Output File 1 for Case1



```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
Value of y= 237.500000
Value of y= 221.875000
Value of y= 206.250000
Value of y= 190.625000
Enter the values of y11,y12,y13,y14,y15,y16,y17: 284.37 268.75 253.12 237.50 221
.87 206.25 190.62

y11= 284.369995
y12= 268.750000
y13= 253.119995
y14= 237.500000
y15= 221.869995
y16= 206.250000
y17= 190.619995
Enter the value of co-ordinates of centre of the circle (h & k): 20 -70

Values of co-ordinates of centre of circle(h & k)= 20.000000 -70.000000

Enter the value of radius of circle(r): 385

Value of radius of circle(r)= 385.000000
Value of y= 301.786224
Value of y= 311.573639
Value of y= 314.991882
Value of y= 312.211914
Value of y= 303.095154
Value of y= 287.156738
Value of y= 263.419769
Value of y= 230.039062
Enter the values of y21,y22,y23,y24,y25,y26,y27:
```

Output File 2 for Case1



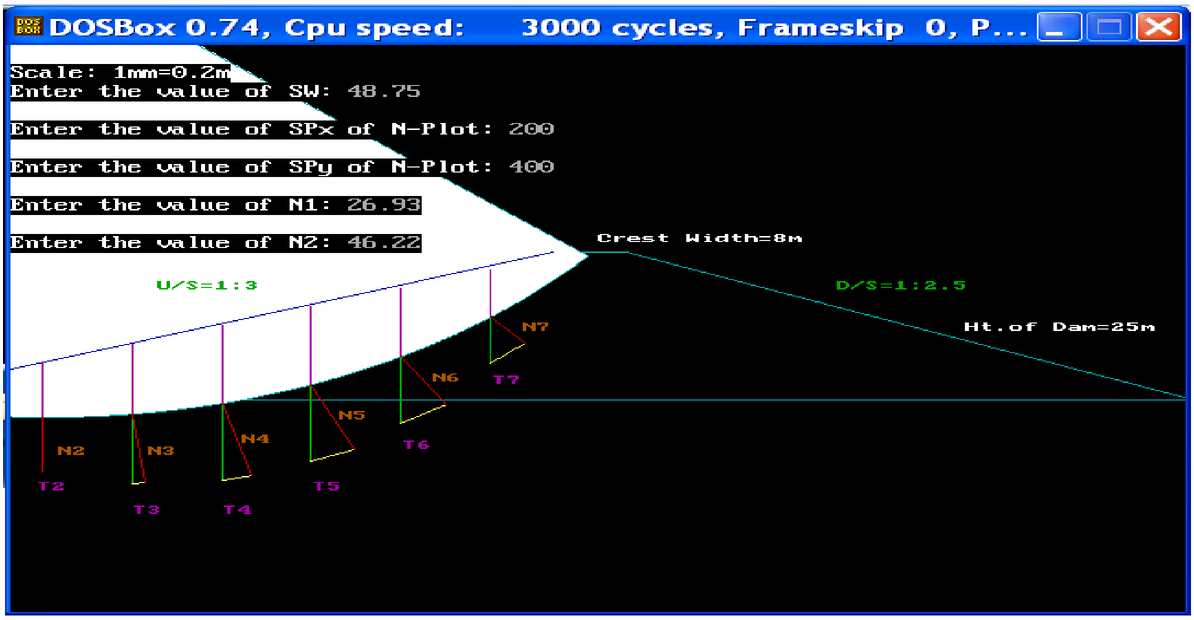
```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
Value of y= 312.211914
Value of y= 303.095154
Value of y= 287.156738
Value of y= 263.419769
Value of y= 230.039062
Enter the values of y21,y22,y23,y24,y25,y26,y27: 311.57 314.99 312.21 303.09 287
.15 263.41 230.03

y21= 311.570007
y22= 314.989990
y23= 312.209991
y24= 303.089996
y25= 287.149994
y26= 263.410004
y27= 230.029999
Value of d1= 27.200012
Value of d2= 46.239990
Value of d3= 59.089996
Value of d4= 65.589996
Value of d5= 65.279999
Value of d6= 57.160004
Value of d7= 39.410004
y31= 338.770020
y32= 361.229980
y33= 371.299988
y34= 368.679993
y35= 352.429993
y36= 320.570007
y37= 269.440002
Enter the value theta1,theta2,theta3,theta4,theta5,theta6,theta7:
```

Output File 3 for Case1

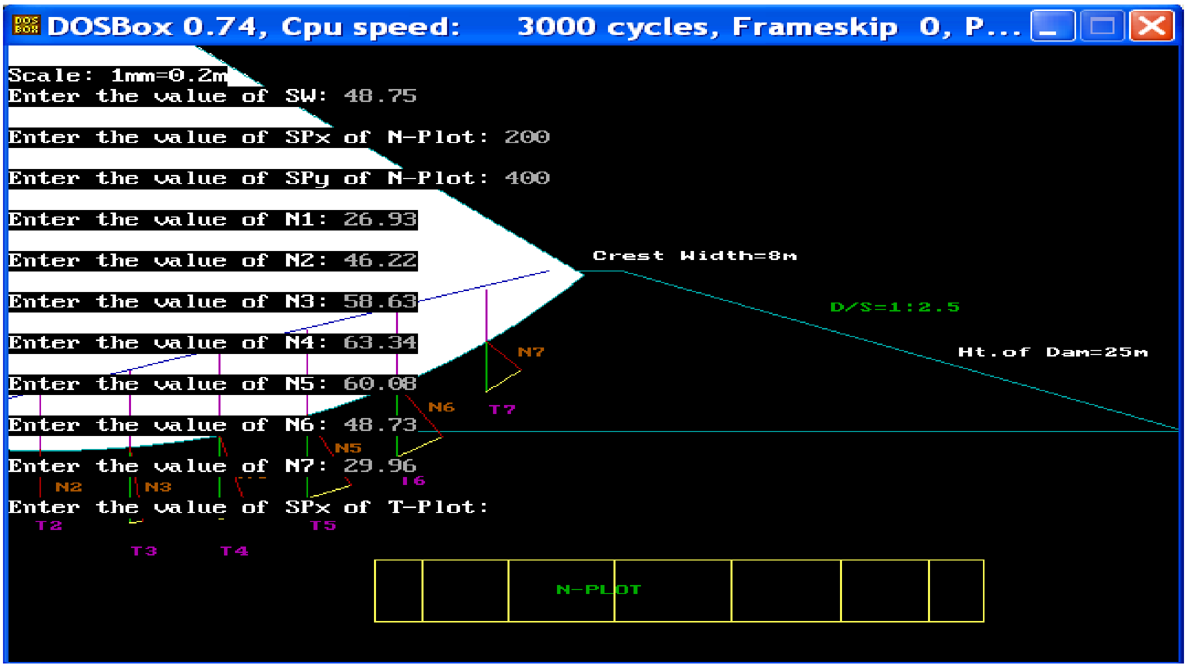
```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
O2= 0.403499
O3= 7.147576
O4= 16.397488
O5= 23.479235
O6= 25.464954
O7= 19.462397
A1= 26.673172
A2= 46.236465
A3= 58.212383
A4= 61.196308
A5= 55.313663
A6= 41.555073
A7= 22.787567
x21= -34.998665
x22= 17.096500
x23= 73.397575
x24= 131.397491
x25= 187.229233
x26= 237.964951
x27= 280.712402
y41= 338.243164
y42= 361.226440
y43= 370.422363
y44= 364.286316
y45= 342.463654
y46= 304.965088
y47= 252.817566
Value of SN= 333.973267
An= 16281.196289 sqm
Enter the value of unit weight of soil(uws): 20
```

Output File 4 for Case1

```
DOSBox 0.74, Cpu speed:    3000 cycles, Frameskip  0, P...
y44= 364.286316
y45= 342.463654
y46= 304.965088
y47= 252.817566
Value of SN= 333.973267
An= 16281.196289 sqm
Enter the value of unit weight of soil(uws): 20

Enter the value of saturated unit weight of soil(suws): 21

Enter the value of scale(sc): 0.2

Value of SMAn= 7287.463867 kN
Value of ST= 100.955795
At= 4921.595215 sqm
Value of SMAt= 4134.140137 kN
Enter the value of radius of slip circle(r): 385

Value of r1= 77.000000 m
Enter the value of delta: 65

Value of delta= 65.000000
Value of arc of the slip circle(La)= 87.353653 m
Enter the value of Unit cohesion(c): 20
Value of c= 20.000000 kN/sqm
Enter the value of Angle of internal friction(phai): 25

Value of phai= 25.000000
Value of Factor of safety= 1.244581
Upstream slope is unsafe,as Factor of safety is less than 1.5.
```



Output File 6 for Case1



Output File 7 for Case1

Graph 3.7 (ATTACHED) Slip Circle Analysis for U/S Slope of the Dam (Case 2).

Graph 3.8 (ATTACHED) Slip Circle Analysis for U/S Slope of the Dam (Case 3)

COMMENTS ON SWEDISH CIRCLE METHOD

The Swedish circle method is the most common method for checking the stability of a slope. The method is general and can be used for homogeneous as well as non-homogeneous soil masses, stratified deposits, for partially or fully sub-merged conditions or dry conditions. The method can also be used when pore water pressure exists in the soil mass. However, the method is necessarily an approximate one because it neglects the effect of forces acting on the sides of the vertical strips. For considering the effect of the side forces, more accurate methods such as the Bishop method can be used. Fortunately, the Swedish slip circle method errs on the safe side, because the factor of safety obtained by this method is less than that obtained from the more accurate methods. The method, therefore, can be safely used in practice.

In the Swedish slip circle method, the least factor of safety of about 1.3 to 1.5 is usually specified in the stability analysis of the earth dams.

Theoretically, it is necessary to try a very large number of possible slip surfaces for locating the most critical circle.

However, in actual practice, only 10 to 15 slip surfaces are usually considered. The slip surfaces are selected on the basis of the past experience with similar dams.

The Fellenius method of locating the most critical slip surface may also be used as a guide.

If the minimum factor of safety of all the trial surfaces is greater than the lowest permissible value, the dam slope is assumed to be safe.

However, if the value of the minimum factor of safety is less than the permissible value, the slope is flattened and again the minimum factor of safety is determined. On the other hand, if the minimum factor of safety is much greater than the permissible value, the slope is uneconomical. It may be steepened and the widths of the berms, if any, may be reduced [5, 6].

PERFORMANCE ANALYSIS

Comparison of Results Obtained by Graphical Method and by C-Program

CONCLUSIONS

The C-programming language is one of the most powerful programming languages even today. It is widely used all over the world for scientific and research purposes to create simulation models in advance. C-graphics has been used here to achieve this. The code so designed with C-graphics will be useful for slope stability analysis especially using the Swedish slip circle method. It shows cross-section of the dam along with assumed slip surface and number of slices with different forces acting on them. It outputs the safety of U/S and D/S slopes depending upon the value of factor of safety.

Case 1 Stability of D/S Slope under Steady Seepage.

SN	ST	SW	a_n	X^2	γ'	γ_{Sat}	a_t	∑N	∑T	Fs
Determination of Factor of Safety by C-Program										
N1 = 27.81	T1 = 79.43	76.25	401.32	0.04	20	21	30601	24481	12162	0.99
N2 = 52.75	T2 = 34.25									
N3 = 70.74	T3 = 34.50									
N4 = 79.23	T4 = 27.28									
N5 = 75.74	T5 = 17.48									
N6 = 61.26	T6 = 6.43									
N7 = 0.0	T7 = 0.0									
Determination of Factor of Safety by Graphical Method										
N1 = 56.68	T1 = 5.95	76.25	30500	0.04	20	21	12706.3	24400	10165.04	1.19
N2 = 77.94	T2 = 17.99									
N3 = 82.26	T3 = 28.32									
N4 = 79.09	T4 = 38.57									
N5 = 63.73	T5 = 41.39									
N6 = 40.30	T6 = 34.42									
N7 = 0.0	T7 = 0.0									

Case 1 Stability of U/S Slope under Sudden Drawdown:

Table 4.1 Trial 1.

SN	ST	SW	a_n	X^2	γ'	γ_{Sat}	a_t	∑N	∑T	Fs
Determination of Factor of Safety by C-Program										
N 1= 26.93	T1 = −3.78	48.75	16277.13	0.04	20	21	4920.82	7285.64	4133.49	1.24
N2 = 46.22	T2 = −0.4									
N3 = 58.63	T3 = 7.20									
N4 = 63.34	T4 = 16.97									
N5 = 60.08	T5 = 25.50									
N6 = 48.73	T6 = 29.86									
N7 = 29.96	T7 = 25.59									
Determination of Factor of Safety by Graphical Method										
N1 = 24.75	T1 = −3.47	48.75	15846.67	0.04	20	21	4766.77	7092.97	4004.09	1.26
N2 = 44.99	T2 = −0.39									
N3 = 59.55	T3 = 7.31									
N4 = 62.78	T4 = 16.82									
N5 = 55.23	T5 = 23.44									
N6 = 51.15	T6 = 31.34									
N7 = 26.61	T7 = 22.73									

Table 4.2 Trial 2.

SN	ST	SW	a_n	X^2	γ'	γ_{Sat}	a_t	∑N	∑T	Fs
Determination of Factor of Safety by C-Program										
N1 = 19.68	T1 = −0.85	44	10448.68	0.04	20	21	3426.28	4676.82	2878.07	1.29
N2 = 33.89	T2 = 2.37									
N3 = 42.69	T3 = 7.91									
N4 = 45.70	T4 = 13.97									
N5 = 42.65	T5 = 18.99									
N6 = 33.71	T6 = 20.25									
N7 = 19.15	T7 = 15.23									
Determination of Factor of Safety by Graphical Method										
N1 = 19.98	T1 = −0.87	44	10511.16	0.04	20	21	3459.72	4704.79	2906.16	1.29
N2 = 31.92	T2 = 2.23									
N3 = 44.24	T3 = 8.20									
N4 = 47.81	T4 = 14.61									
N5 = 41.10	T5 = 18.30									
N6 = 34.28	T6 = 20.60									
N7 = 19.56	T7 = 15.56									

Table 4.3 Trial 3.

SN	ST	SW	a_n	X^2	γ'	γ_{Sat}	a_t	∑N	∑T	Fs
Determination of Factor of Safety by C-Program										
N1 = 13.01	T1 = 0.22	39	6500.13	0.04	20	21	2096.25	2909.45	1760.85	1.55
N2 = 23.41	T2 = 2.46									
N3 = 29.83	T3 = 6.07									
N4 = 32.14	T4 = 9.82									
N5 = 30.25	T5 = 12.53									
N6 = 24.08	T6 = 13.07									
N7 = 13.95	T7 = 9.58									
Determination of Factor of Safety by Graphical Method										
N1 = 9.99	T1 = 0.17	39	6317.22	0.04	20	21	2086.89	2827.58	1752.98	1.54
N2 = 22.87	T2 = 2.40									
N3 = 29.39	T3 = 5.98									
N4 = 28.68	T4 = 8.77									
N5 = 32.33	T5 = 13.39									
N6 = 26.36	T6 = 14.31									
N7 = 12.36	T7 = 8.49									

Feasibility and Relevance of Present Work

(1). Rectification of human errors in complex calculations.
(2). Degree of precision can be enhanced several times than that of the conventional computation techniques.
(3). A remarkable degree of saving in time, effort and money.
(4). User friendly interfacing will lead to exact solution of more complex real life problems, which are approximated till date.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to all staff members of the Department of Civil Engineering, Government

Engineering College, Aurangabad and Mr. C.R. Ghushinge, Professor, MIT, Aurangabad, for showing his enthusiasm in the construction of flow net. Particular mention must be made of Mr. K.S. Pande, Software Engineer, Mr. P. D. Chandge, System Analyst, Mahadiscom, and Mr. S.G. Quadri, Assistant Professor, DSQIET, Aurangabad, for their excellent support.

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NOTATIONS

The following symbols are used in this paper:

a_n = area of N-Plot
a_t = area of T-Plot
a_u = area of U-Plot
c = unit cohesion
Fs = factor of safety
La = length of the entire arc of the slip circle
r = radius of slip circle
SN = summation of all normal components
ST = summation of all tangential components
SW = slice width
W = unit weight of water
x^2 = scale
δ = angle in degrees subtended by the slip surface at the centre
Φ = inclination of the reaction to the normal
γ_{Sat} = saturated unit weight
γ' = unit weight under steady seepage
θ = critical angle of failure.

