PARAMETRIC ANALYSIS OF SLOPE STABILITY FOR RIVER EMBANKMENT

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Abstract. *This paper has aimed to investigate the slope stability for various conditions like embankment geometry, water level and soil property. The analysis has been performed by using the XSTABL program for different slope heights, slope angles and flood conditions with a fixed soil cohesion value. Since the rapid drawdown is the worst case for a particular embankment therefore, the analysis has been further performed with different cohesion values. From this investigation it has been noticed that the increase of cohesion of soil can increase the stability to a great extent. All the analysises have been performed for twenty bore logs. It has been found that the underlying soil affects the stability of slope as the failure surface intersects the soil of this region. It has been also observed that the loose, liquefiable sandy soil decreases the stability while the stiff soil with sufficient cohesion value stabilizes the slope of embankment.*

Keywords

Factor of safety, embankment geometry, rapid drawdown, XSTABL.

1. Introduction

Slope stability becomes a major concern for civil engineers more precisely geotechnical engineers. In geotechnical engineering different sections of river embankment are used to investigate slope stability, settlement and regulation measures [1]. Over the years, engineers put their effort to find out the best, easy, reliable and simple solution for measuring slope stability based on different parameters. Nowadays, rivers are the beauty of the city. Most of the cities of the world are built around the river. Hence, Slope stability of river embankments becomes the issue of research for the engineers. Slope stability design of river embankment are generally controlled by different factors. The construction of river embankment is related to cost and safety [5]. For this reason, engineers conducted their studies to make slope stability analysis as simple and reliable as possible.

Many studies have been conducted by a number of researchers around the world considering different types of embankment. In the beginning of the 20th century the concept of discretizing a potential mass into slices was introduced. Petterson (1955) investigated the slope stability of the Stigberg Quay in Gothenberg, Sweden in 1916 considering the slip surface to be circular where the sliding mass was divided into slices [2]. Janbu (1954) and Bishop (1955) made some advancement in this method [2]. Later Bishop

(1955) proposed an analysis process that took into account inter-slice normal forces neglecting the inter-slice shear forces. Bishop's simplified method satisfies moment equilibrium while Janbu's Simplified method satisfies only horizontal force equilibrium [3]. In the design and analysis of river embankment rapid drawdown condition is considered to be a significant phenomenon. In the book on earth and earth rock dams Sherard et al. (1963) discussed about several slope failures due to rapid drawdown conditions. Being concerned about the stability of river banks under rapid drawdown conditions Desai (1971, 1972, 1977) performed experimental investigation at the Waterways Experiment Station to analyze the stability conditions of the Mississippi earth and presented his studies in a series of papers [4]. In the modern era a number of software have been developed to handle the complexity within slope stability analysis. With the help of the software it has become possible to deal with complex or critical stratigraphy, irregular pore water pressure condition, linear and non-linear shear strength models, different kinds of slip surface shape. Computer-aided graphical viewing of data used in the slope stability calculations makes it possible to get not only the factor of safety but also many other things such as observing the distribution of a variety of parameters along the slip surface or graphically observing the forces on each slice in the potential sliding mass helps to understand the details of the technique [11]-[13]. Some of the available software related to slope stability are SLOPE/W, GALENA, SVslope, Slope Stability (GE 05), Plaxis 2D Program, STB 2010, XSTABL [9]. XSTABL is a slope stability analysis program which permits the engineer to develop the slope geometry in interactional manner and perform the slope stability analysis within a single program. The software was originally developed at Purdue University and it has some similarities with the popular STABL program [6]. In geotechnical engineering analyzing the stability of earth structures is a very common type of numerical analysis. In Bangladesh, no such extensive investigation was carried out to find the slope stability of river embankment till now and the motivation of us to research on the issue came from this.

The study is aimed to determine the stability of embankment on selected conditions. Basically, this research investigate the slope stability of embankment for different geometry (height and slope angle), investigates the slope stability for different water level condition (low flood level, high flood level and rapid drawdown), and analyze the stability of slope for different cohesion value (C) of soil at rapid drawdown condition. The research presents the general methodology adopted to perform the analysis, deal with the brief description of the program XSTABL and stability analysis for different condition. This paper also put forward the findings of the study and some recommendations.

2. Methodology for analysis

In this study, slope stability has been analyzed for 20 bore logs data of embankment foundation soil, different embankment geometry (height, slope angle), different water level condition and different cohesion values of soil for rapid drawdown condition. So, it means that a huge number of the factor of safety would be determined for different embankment with different conditions. That is why a comparatively simple, time saving program is needed to make the analysis. As the XSTABL program is very easy to use and saves time as well as provides reliable Factor of Safety, the analysis has been done through this program. There are two methods available in XSTABL program for the determination of critical surface and minimum Factor of Safety which are Simplified Bishop's method and Janbu method. As the Simplified Bishop's method is most widely used and provides reliable analysis considering inter-slice forces that's why it is chosen here as the method of analysis [6].

The analysis has been done for four values of cohesion with different combination of slopes and heights for Rapid Drawdown condition. The values of 'C' for rapid drawdown condition are 40 kPa, 60 kPa, 80 kPa and 100 kPa.

Bore log data provide only the SPT-N value. The foundation soil has been taken as subsurface soil in XSTABL. The subsurface soil needs

Tab. 1: Conditions for analysis.

Embankment slope angle	26.5 degree
	35 degree
	45 degree
Embankment height	6.1 m
	7.6 m
	9.1 m
Water level condition	Low flood level
	High flood level
	Rapid drawdown

shear strength parameters cohesion, C and internal friction angle, Φ. So, SPT value needs to be converted into 'C' and 'Φ' value. Before that, the SPT value needs overburden correction especially for sandy soil.

For slope stability analysis, effective cohesion (C) and effective angle of internal friction (Φ) of soil for different layers are necessary. For cohesionless soil the relationship between Φ and SPT value according to Kishida (1967) is given in equation (1) [7, 8].

$$\Phi = 15^o + \sqrt{20N}. \tag{1}$$

According to Terzaghi and Peck relation between SPT and cohesion of clays is given in equation (2) [9].

$$C = 6.54N(\text{kPa}) \tag{2}$$

For silty clay with sandy soil the relationship of C and Φ with SPT value are given in equations (3) and (4) [10].

$$\Phi = 0.209N^{''} + 19.68 \tag{3}$$

$$C = (0.014N^{''} - 0.18) * 98.066 \tag{4}$$

Where N is denoted as corrected SPT number and $N > 13$; Φ is measured in degree and C is in kPa.

2.1. XSTABL program

The slope stability analysis by the XSTABL program has to be followed by certain steps. The geometry of the slope (slope profile), soil data for both surface and subsurface have been provided. To analyze the slope using these characteristic data of number, origin and end of circular failure surface have been provided. At last the critical failure surface and the minimum Factor of Safety has been found. The critical failure surface can be Circular, irregular or block shaped. Circular surfaces are readily generated and their factor of safety analyzed by simplified Bishop or Janbu methods. Analysis using circular surfaces is comparatively easy and time saving as well as provides reliable results.

According to Dr. Sunil Sharma (University of Idaho) in XSTABL reference manual, noncircular or irregular shaped surfaces may be analyzed using the simplified Janbu method. The algorithms for generating non-circular surfaces are very sensitive to the specified segment length. If the segment length is too small kinematically inadmissible surfaces may generated and analyzed. This erroneous surfaces will contaminate the search for the critical surfaces and may give the user a false impression about the minimum factor of safety. Block shaped surfaces provide a means to concentrate the surface generation within a confined zone that may potentially represent a weak layer. This option utilizes search boxes for generating the central portion of a failure surface and then offers two methods which are Rankine and Block for generating passive and active portions to complete the block surface.

In this study slope stability of river embankment would be determined for different soil investigation report with variable geometry and flood level conditions. As circular surfaces provide reliable analysis as well as comparatively easy and time saving, in our analysis "Circular Surface Search" is selected.

Slope stability analysis of a particular embankment has been completed after all the necessary data input of slope profile, soil parameter and, water surface. Total 2500 surfaces are generated. Number of most critical surfaces and the minimum factor of safety have been found 10.

3. Analysis of slope stability

The slope stability has been analyzed for twenty boring log of embankment foundation. Here procedure has been discussed with only one boring log data (Tab. 2).

3.1. Embankment profile

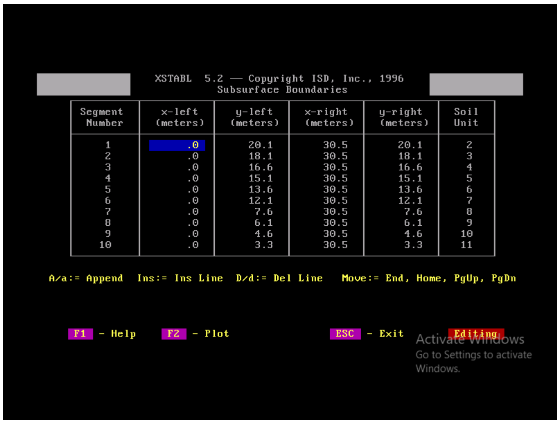
The soil surface parameters C & Φ for the embankment analysis were assumed 40 KPa and 35 degree respectively. The analysis was done for various combinations of different angles or slopes, different heights and different water surfaces or phreatic surfaces prescribed in Tab. 1. The soil parameters for the sub-surfaces have been determined from the prescribed equations (Tab. 3).

According to Tab. 2 it can be considered that the soil of the boring log is cohesionless. Hence the value for C taken as 0 and effective angle of internal friction is calculated from equation (1).

3.2. Data input in XSTABL

Slope stability analysis for an embankment slope of 6.10 meter height and 26.5 degree angle with different water level conditions have been described in this study. The analysis for other geometric conditions have been done similarly.

The profile geometry has been entered for the assumed surface and subsurface data. For example, the data for a slope of 6.10 meter height and 26.5 degree has been assigned as shown in Fig. 1. A soil unit is assigned to each surface or subsurface segments according to the parameters of the soil directly beneath each segment. A value of 9.81 $\mathrm{KN/m^3}$ has been taken as the unit weight of water. Unit weight of soil, C, Φ values are provided for surface soil according to the assumed value and for subsurface soil as shown in Fig. 2.



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              XSTABL  5.2 —— Copyright ISD, Inc., 1996
                        Subsurface Boundaries
     Segment    x-left     y-left    x-right    y-right    Soil
      Number   (meters)   (meters)   (meters)   (meters)   Unit

        1          .0       20.1       30.5       20.1       2
        2          .0       18.1       30.5       18.1       3
        3          .0       16.6       30.5       16.6       4
        4          .0       15.1       30.5       15.1       5
        5          .0       13.6       30.5       13.6       6
        6          .0       12.1       30.5       12.1       7
        7          .0        7.6       30.5        7.6       8
        8          .0        6.1       30.5        6.1       9
        9          .0        4.6       30.5        4.6      10
       10          .0        3.3       30.5        3.3      11

 A/a:= Append  Ins:= Ins Line  D/d:= Del Line   Move:= End, Home, PgUp, PgDn

   F1 - Help    F2 - Plot                ESC - Exit     Editing
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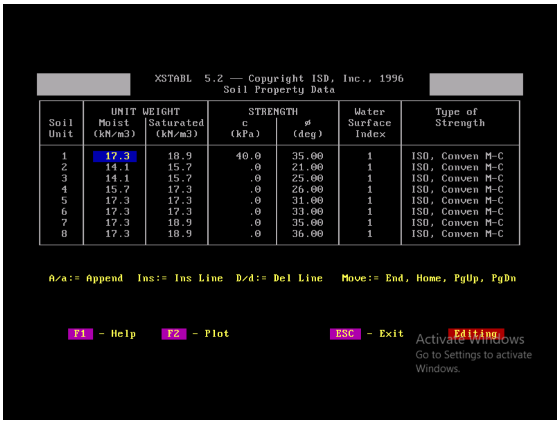
Fig. 1: Data input or assigning sub-surface.



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              XSTABL  5.2 —— Copyright ISD, Inc., 1996
                          Soil Property Data
        UNIT WEIGHT         STRENGTH          Water         Type of
 Soil   Moist  |Saturated     c        ø      Surface       Strength
 Unit  (kN/m3)  (kN/m3)     (kPa)    (deg)     Index

  1     17.3     18.9       40.0     35.00       1      ISO, Conven M-C
  2     14.1     15.7         .0     21.00       1      ISO, Conven M-C
  3     14.1     15.7         .0     25.00       1      ISO, Conven M-C
  4     15.7     17.3         .0     26.00       1      ISO, Conven M-C
  5     17.3     17.3         .0     31.00       1      ISO, Conven M-C
  6     17.3     17.3         .0     33.00       1      ISO, Conven M-C
  7     17.3     18.9         .0     35.00       1      ISO, Conven M-C
  8     17.3     18.9         .0     36.00       1      ISO, Conven M-C

 A/a:= Append  Ins:= Ins Line  D/d:= Del Line   Move:= End, Home, PgUp, PgDn

   F1 - Help    F2 - Plot                ESC - Exit     Editing
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Fig. 2: Typical soil properties input.

Tab. 2: Data from the Boring Log (Ground water level 0.3 m from EGL).

Number of sample	Depth (m)	Thickness (m)	Description of material	SPT Value-N	INDEX (m)
D-1	2	2	Grey very loose silty Fine Sand trace mica	1	1.5
D-2	3.5	1.5	Reddish brown soft silty clay trace fine sand high plastic	3	3.0
D-3	5	1.5	Brown loose sandy silt trace mica	5	4.5
D-4	20.0	15.0	Reddish brown to brown medium dense to dense silty fine sand trace mica	10	6.0
D-5				14	7.5
D-6				17	9.0
D-7				19	10.5
D-8				20	12.0
D-9				22	13.5
D-10				26	15.0
D-11				32	16.5
D-12				36	18.0
D-13				39	19.5

Tab. 3: Conversion of SPT value to C & Φ value.

N_{field}	N_{cor}	C=0	$\Phi = 15^o + \sqrt{20N}$
1	2	0	21
3	5	0	25
5	7	0	26
10	13	0	31
14	17	0	33
17	20	0	35
19	21	0	35
20	21	0	35
22	22	0	36
26	25	0	37
32	30	0	39
36	33	0	40
39	34	0	41

3.3. Analysis

Number of initiation points of circular surfaces is chosen 50. Number of surfaces to be generated is chosen 50 from each initiation point. Hence total number of surfaces generated is $50 \times 50 = 2500$. The completed plots of embankment slope for different water surfaces low flood level, high flood level and rapid drawdown have been shown in Figs. 3-5, respectively.

1) Critical surfaces and minimum factor of safety determination

After all the necessary data input of slope profile, soil parameter, water surface and analysis, the slope stability analysis of a particular embankment is done. Total 2500 surfaces have been generated. The generations of 2500 surfaces have shown in Fig. 6. Total 10 most critical surfaces and the minimum Factor of Safety have been found and shown in Figs. 7-9.

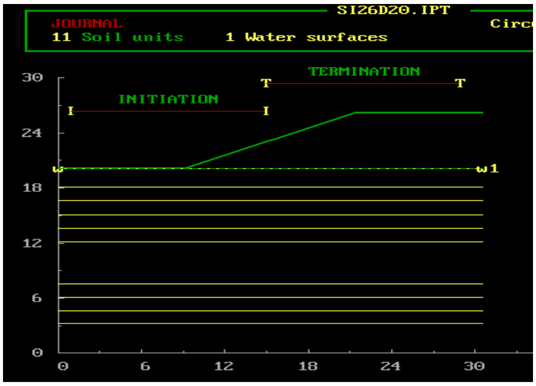

Fig. 3: Plot for low flood level.

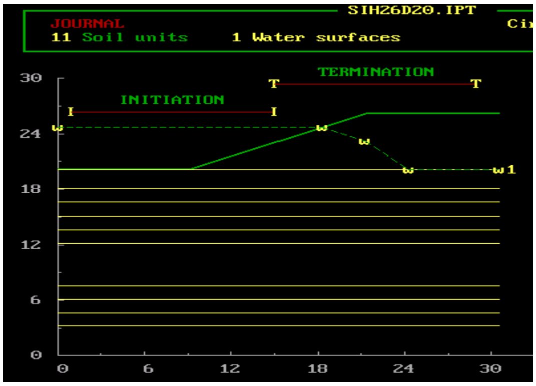

Fig. 4: Plot for high flood level.

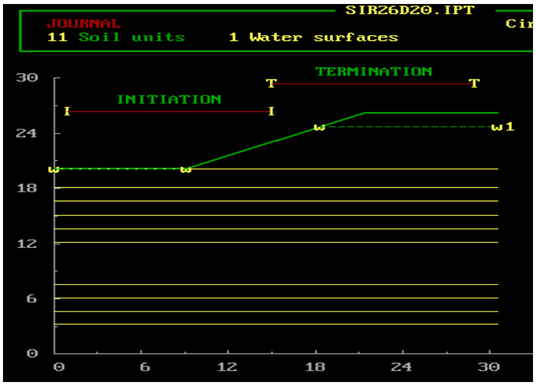

Fig. 5: Plot for rapid drawdown.

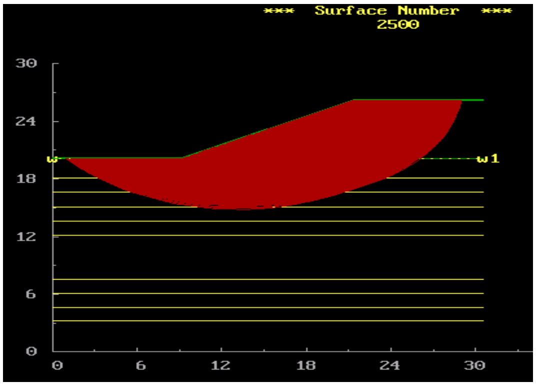

Fig. 6: Generated 2500 surfaces for low flood level.

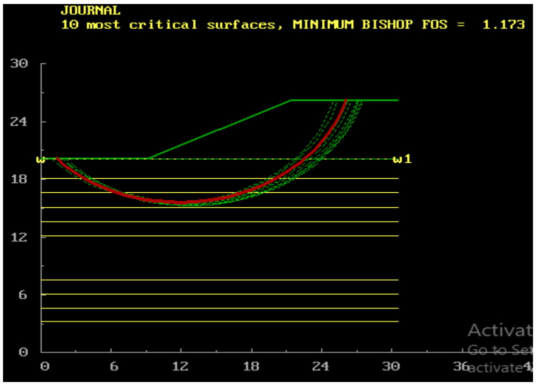

Fig. 7: Ten most critical surfaces and minimum factor of safety for low flood level.

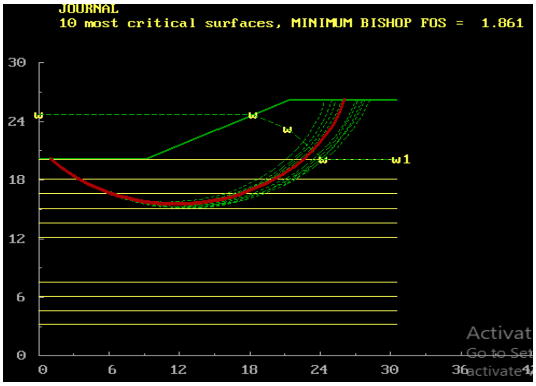

Fig. 8: Ten most critical surfaces and minimum factor of safety for high flood level.

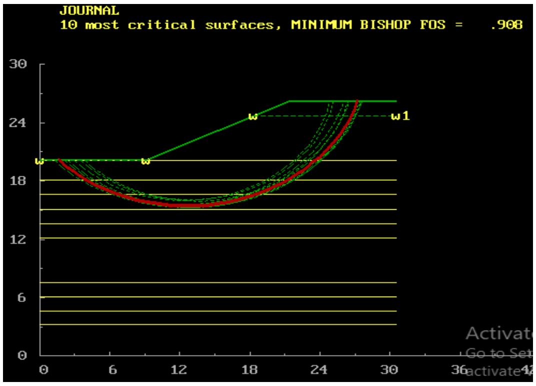

Fig. 9: Ten most critical surfaces and minimum factor of safety for rapid drawdown.

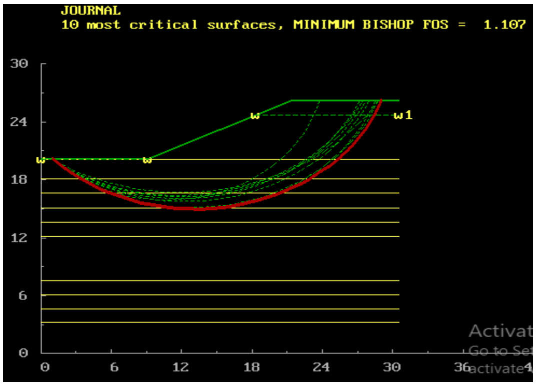

Fig. 10: FS for rapid drawdown for cohesion value 60 kPa.

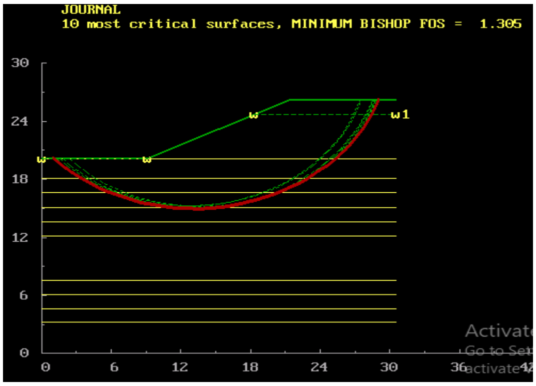

Fig. 11: FS for rapid drawdown for cohesion value 80 kPa.

2) Analysis for rapid drawdown condition with variable cohesion values

Analysis for different geometry and water surface conditions previously described have been done for embankment soil cohesion value of 40 kPa. Further analyses have been done with cohesion values of 60 kPa, 80 kPa and 100 kPa for rapid drawdown condition for different geometry. The 10 most critical surface and minimum factor of safety under rapid drawdown condition have been prescribed in Figs. 10-12.

4. Findings

The slope stability has been analyzed for 20 bore logs of embankment foundation. Factor of safety has been obtained for only one bore log with different conditions have been provided (Tab. 4).

4.1. Variation of slope stability with embankment geometry

From the analysis it has been observed that slope stability decreases with the increase of height for a fixed angle. For a homogenous soil, the embankment slope angle and soil parameter being constant the shear strength decreases with the increase of height. Figure 13 shows the factor of safety for 26.5 degree slope. For other angle the curves are similar. In case of 26.5 degree slope angle it has been found that the stability decreases with the increase of angle for a fixed height. For a homogenous soil, the embankment height and soil parameter being constant the shear strength decreases with the increase of angle. Figure 14 shows the factor of safety for 6.1 m height. For other heights the curves are similar.

Tab. 4: Factor of safety for different conditions.

Angle (Degree)	Height (m)	Low Flood Level	High Flood Level	Rapid Drawdown (40 kPa)	Rapid Drawdown (60 kPa)	Rapid Drawdown (80 kPa)	Rapid Drawdown (100 kPa)
26.5	6.1	1.17	1.86	0.91	1.11	1.31	1.51
	7.6	1.09	1.74	0.82	1.00	1.16	1.33
	9.1	1.04	1.27	0.76	0.91	1.06	1.21
35	6.1	1.12	1.73	0.87	1.08	1.29	1.49
	7.6	1.04	1.58	0.80	0.96	1.14	1.32
	9.1	0.95	1.18	0.70	0.87	1.02	1.19
45	6.1	1.10	1.70	0.82	1.02	1.24	1.45
	7.6	0.96	1.58	0.75	0.93	1.12	1.30
	9.1	0.88	1.10	0.67	0.82	0.99	1.15

4.2. Slope stability for different water level condition

Figure 15 shows the change of Factor of safety for different water level condition (26.5 degree and 6.10 m height). It is observed that slope stability is highest when the river water gets higher during flood. However, the slope stability is lowest during rapid drawdown condition. This is because of the loss of stabilizing effect of water on the upstream and high pore water pressure within the embankment during rapid drawdown.

4.3. Slope stability for rapid drawdown condition at different cohesion value

It has been observed that stability of embankment slope is lowest at rapid drawdown condition with cohesion value 40 kPa. So, slope stability has been analyzed for previous heights and slopes with increased cohesion values 60 kPa, 80 kPa and 100 kPa. Figure 16 shows the factor of safety under rapid drawdown with variable cohesion value for a particular angle with different heights. Similarly Fig. 17 shows the factor of safety with variable cohesion value for a particular height with different heights. Observing the figures for both the cases it is proved that slope stability increase with the increase of cohesion value.

Tab. 5: Sub-surface soil property for bore hole-01.

Depth (m)	Soil Type	N	C =6.54 N (kPa)	Φ
1.5	Clay	4	26	0
3.0	Clay	6	39.24	0
4.5	Clay	7	45.78	0
6.0	Clay	10	65.4	0
7.5	Clay	11	71.94	0
9.0	Clay	13	85.02	0
10.5	Clay	15	98.1	0
12.0	Clay	14	91.56	0
13.5	Clay	16	104.64	0
15.0	Clay	18	117.72	0
16.5	Clay	19	124.26	0
18.0	Clay	17	111.18	0

4.4. Effect of underlying soil

From the analysis it is clear that the subsurface soil has a major role on the stability. The subsurface soil up to the depth where the failure surface intersects the soil has similar importance as the embankment soil itself. For the Bore Hole No. 1, 2, 4, 6, 7 and 12 which have clay soil within the circular failure surface show higher factor of safety. For Bore Hole No. 8, 9, 10, 11, 13, 14, 16, 17, 18, 19 and 20 the situations are alarming because for these particular bore holes, the underlying soil portion of the embankment within the circular failure surface is sandy. Tabs. 5 and 6 describe the subsurface soil property and factor of safety for bore hole 1.

Tab. 6: Factor of safety at different conditions for bore hole-01.

Angle (degree)	Height (m)	Low Flood Level	High Flood Level	Rapid Drawdown (40 kPa)	Rapid Drawdown (60 kPa)	Rapid Drawdown (80 kPa)	Rapid Drawdown (100 kPa)
26.5	6.1	2.58	3.58	2.19	2.55	2.93	3.12
	7.6	2.36	3.25	1.88	2.23	2.53	2.77
	9.1	2.14	2.95	1.67	1.98	2.26	2.48
35	6.1	2.43	3.28	2.11	2.45	2.80	3.15
	7.6	2.15	2.88	1.71	2.01	2.30	2.54
	9.1	1.88	2.57	1.48	1.75	2.00	2.22
45	6.1	2.29	3.1	1.89	2.20	2.51	2.83
	7.6	1.96	2.71	1.58	1.88	2.16	2.39
	9.1	1.74	2.45	1.38	1.62	1.87	2.00

Compared to Tab. 4 which is for bore hole-08 Tab. 6 represents higher factor of safety. The reason lies in the cohesion of subsurface soil. Tab. 3 and Tab. 5 depict that bore hole-08 contains cohesionless while bore hole-01 comprises cohesive soil. Hence it can be said that slope stability of river embankment increases with the increase of cohesion of underlying soil.

5. Conclusions

The analysis have been done for various combination of embankment slope geometry (height, slope angle), water level condition and for rapid drawdown condition with different cohesion value. From the detailed investigation, it was found that slope stability has inverse relationship with slope angle and height. For every case the factor of safety has been found lowest for rapid drawdown condition. It happens due to the stabilizing effect of the water on the upstream is lost but the pore water pressure within the embankment remains high during rapid drawdown. This helps to reduce the stability of the embankment. From analysis for rapid drawdown with different cohesion values, it is clear that the stability increases with the increase of cohesion value. For ensuring stability, the embankment should be designed with proper geometry, soil property and considering rapid drawdown which is the worst case.

6. Recommendations

The following recommendation can be made for future study from the present research.

a. In this research, the analysis has been carried out for generalized criteria. Similar investigation can be carried out with geometry of a specific embankment of a river and soil samples collected from that particular embankment.

b. In this study one software XSTABL and one method Bishop's simplified method have been used as the investigation is generalized. For any particular embankment analysis other software and other methods can also be used to get the most reliable factor of safety.

c. Further analysis can be made with different types of stabilizing and soil improvement techniques and comparison can be made among them.

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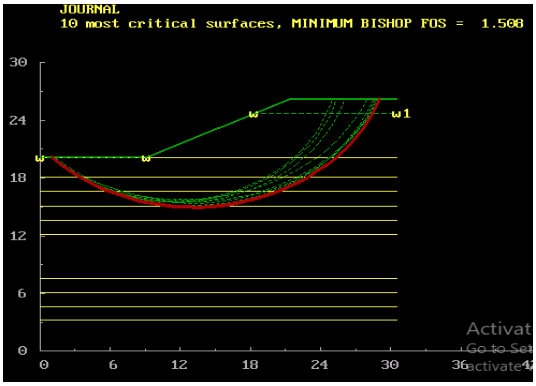

Fig. 12: FS for rapid drawdown for cohesion value 100 kPa.

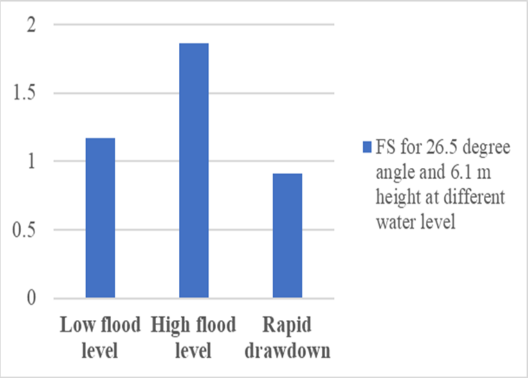

Fig. 15: Comparison of slope stability with different water level (26.5 degree & 6.10 m height).

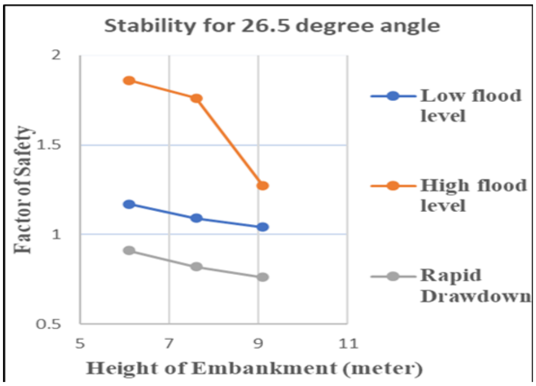

Fig. 13: Comparison of slope stability with height (26.5 degree slope).

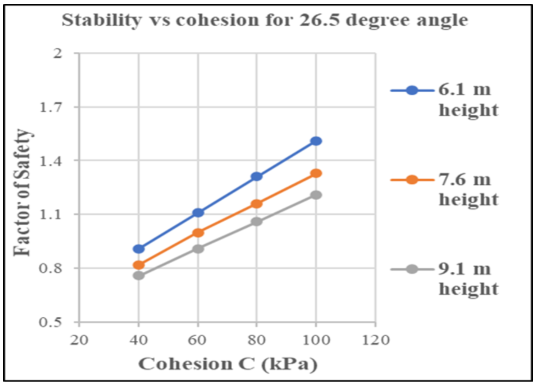

Fig. 16: Comparison of slope stability with cohesion values (26.5 degree).

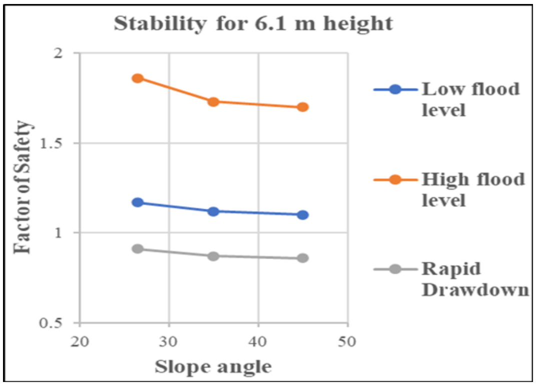

Fig. 14: Comparison of slope stability with slope angle (6.10 m height).

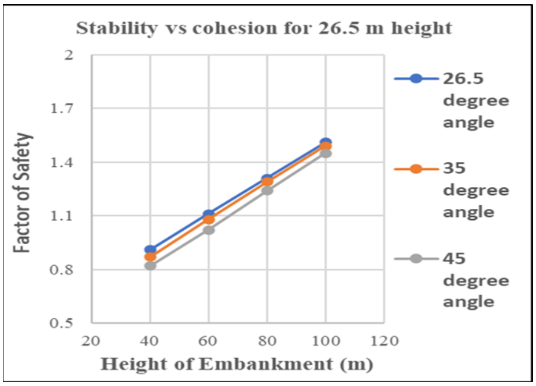

Fig. 17: Comparison of slope stability with cohesion values (6.10 m height).

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