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A Study on Efficacy of Design Charts in Slope Stability of an Earthen Dam

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Abstract. Slope stability is a matter of tremendous concern in construction of earthen dams where the failure of slopes may incur severe loss of life and damage to property and should be designed in such a way that it satisfies both safety and economic consideration. The basic design requirement of earth dam is overtopping, stability analysis and seepage control. Slope stability chart are useful for preliminary analysis before using a computer programme to determine the approximate values of the Factor of Safety (FoS) as it allows some quality control and a check for the subsequent computer-generated solutions [1]. Another use of slope stability charts is to back calculate strength values for failed slopes to aid in planning remedial measure. The various design charts available in literature are Taylor stability chart, Spencer Chart, Bishop and Morgenstern Chart, Michalowski Chart etc. The primary objective of the study is to identify the stability of a proposed homogeneous earthen dam composed of low compressibility clay (CL) to be constructed in Eastern Part of India. The study focusses stability of adopted section for End of Construction, Steady State Seepage and Rapid draw down condition using SLIDE 2D (Rocscience) software (Bishop Method) as well as with design charts. In the present study, Taylor Chart for End of construction condition, Bishop and Morgenstern Chart for Steady state seepage condition and Morgenstern Chart for Rapid draw down condition have been used.

Keywords: End of construction, Steady state seepage and Rapid draw down, Factor of Safety, Design Charts

1 Introduction

1.1 Background

The design and assessment of the slope stability of small embankment dams is usually not carried out using slope stability calculations but rather by the comparison of proposed or existing dam slopes with those recommended by technical standards or guidelines [1]. Practical experience shows that in many cases the slopes of small dams are steeper than those recommended. However, most of such steeper slopes at existing dams do not exhibit any visible signs of instability, defects or sliding. For the dam owner and also for dam stability engineers, the safety of the slope, expressed as factor of safety, is crucial [2]. The aim of this study is to evaluate the safety margin provided by original proposed section of one of the Reservoir Scheme of Eastern Part of India by using SLIDE 2D (Rocscience) software as well as with Taylor Chart, Bishop and

Morgenstern Chart and Morgenstern Chart for End of construction, Steady state seepage condition and Rapid draw down condition [5] respectively. The factor of safety values evaluated using design charts are compared with factor of safety values calculated using SLIDE 2D software (Bishop Method).

1.2 Objective

The primary objective of the investigation is to identify the stability of earthen dam under End of Construction, Steady State Seepage and Rapid draw down condition. The objective has been sub divided in following ways:

I. To determine Factor of Safety of U/s of adopted section under End of construction and Rapid draw down conditions using SLIDE 2D software (Bishop Method)

II. To determine Factor of Safety of D/s of adopted section under End of construction and Steady state seepage conditions using SLIDE 2D software (Bishop Method)

III. To determine Factor of Safety of U/s adopted section under End of construction and Rapid draw down conditions using Taylor Chart and Bishop and Morgenstern Chart respectively.

IV. To determine Factor of Safety of D/s of adopted section under End of construction and Steady state seepage conditions using Taylor Chart and Morgenstern Chart respectively.

1.3 Methodology & Scope

The outline of scope of work and methodology are following:

I. A proposed small earth dam section of 12.5 m height to be founded on strong base at one of the reservoir schemes of Eastern part of India has been modified and used as a adopted section.

II. Selection of shear strength parameters are based on testing of borrow area samples in the laboratory of CSMRS, New Delhi.

III. U/s and D/s of adopted sections of the dam to be analysed for slope stability using design charts and SLIDE 2D software under different conditions (i.e., End of construction, Steady state seepage and Rapid draw down) to arrive at factor of safety of dam.

1.4 Physical Significance of Failure Conditions:

I. End of Construction: This represents a situation when structure is just constructed. In this condition pore pressure developed as a result of dam material compression due to overlying fill are not dissipated or are partly dissipated. Construction pore pressure may exceed the pore pressure likely to be developed due to seepage from the reservoir and may consequently control the design of dam [5].

II. Steady State Seepage: This condition is developed when water level is maintained at a constant level for sufficiently long time and seepage line are developed in dam sections. The stability analysis of earth dam shall be done assuming that the dam is fully saturated below pheratic line for calculating driving forces and buoyant for resisting force [5].

III. Rapid Draw Down: Earth Dam may get saturated due to prolong higher reservoir level. Rapid Draw Down condition corresponds to subsequent lowering of reservoir level rate faster than pore water can dissipate. This induces unbalances seepage forces and excess pore water pressures. This condition become critical if the material of up-stream portion of the dam are not freely draining.

2 Reservoir Scheme

2.1 **Data Collection about reservoir scheme**

The reservoir scheme is located in eastern part of India. The Figure 1 & 2 below shows location map of reservoir scheme and layout plan of reservoir scheme

Fig. 1 Location Map

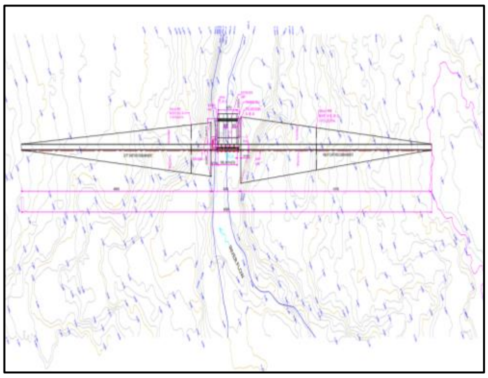

Fig. 2 Layout plan of reservoir scheme

The reservoir scheme envisages construction of composite dam with ogee spillway in central portion of the river at FRL 396 m and MDDL at 392 m. The Gross storage, dead storage and live storage capacity of reservoir Scheme is 2.40 MCM, 0.42 MCM and 1.98 MCM respectively.

The proposed reservoir scheme is homogeneous dam having U/s and D/s 2.75H: 1V as well as 2.25H: 1V respectively. The height of the dam is 12.5m and top width is 6.0m. It is also provided with various drainage component.

2.1 Properties of Borrow area Material

Selection of shear strength parameters are based on testing of borrow area samples in the laboratory of CSMRS, New Delhi. The properties of borrow area material tabulated in table No. 1 below:

Table No.1 Properties of borrow area material

SL	Properties	Value
1	Type of Soil	CL
2	Maximum Dry Density (MDD), g/cc	1.75
3	Optimum Moisture Content (OMC), %	14.0
4	Specific Gravity	2.72
5	Co-efficient of Permeability, k(cm/s)	2.3×10^{-7}
6	Total Cohesion (c), kg/cm^2	0.22
7	Total Angle of Shearing Resistance (ϕ), degree	26.4
8	Effective Cohesion (c′), kg/cm^2	0.11
9	Effective Angle of Shearing Resistance (ϕ'), degree	31.0

2.2 Adopted *Section*

A simplified cross section with flat base has been adopted for the present study as shown in Figure 3. As the foundation of the proposed dam section was competent, the same has not been modelled in the present study. The particulars of dam shown in table No.2.

Table No.2 Properties of dam

SL	Particulars	Value
1	Height of Dam (H)	12.5 m
2	Upstream Slope of Dam	2.75H: 1V
3	Downstream Slope of Dam	2.25 H : 1V
4	Top Width of Dam	6.0 m
5	Maximum Water Level	10.0 m
6	Base Width of Dam	68.5 m

The Figure 3 below shows adopted cross section of the proposed dam

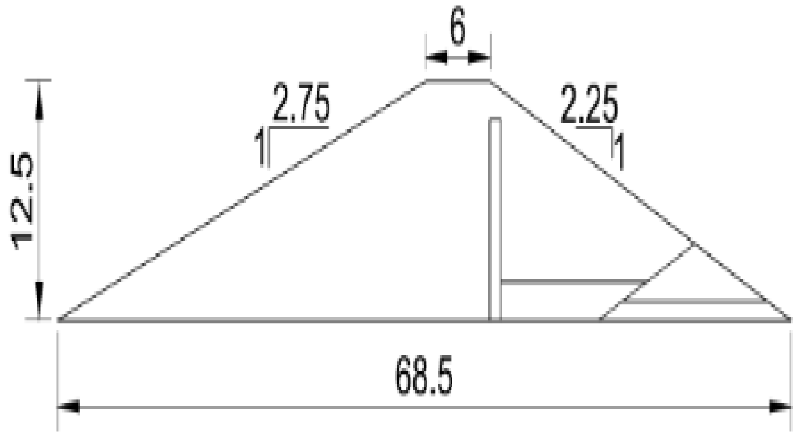

Fig.3 Adopted cross section of Dam (All dimensions are in meter)

3 Stability Analysis of Adopted Section

3.1 Design Charts:

Slope stability charts are useful for preliminary analysis, to compare alternates that later be examined by more details analyses. Chart solutions also provide a rapid means of checking the results of detailed analyses [2]. Engineers are encouraged to use these charts before using a computer program to determine the approximate value of the FoS as it allows some quality control and a check for the subsequent computer-generated solutions.
The major shortcomings in using design charts is that most of them are ideal, homogeneous soil conditions, which are not encountered in practice. The charts have been devised using two-dimensional limit equilibrium analysis, simple homogeneous slopes and Slip surfaces of circular shape [5].

The various charts available in literature for different failure conditions are as follows:

End of construction:

a. **Taylor Stability Chart [3]:** Taylor (1948) developed slope stability chart for soil with $\phi = 0$ and $\phi > 0$. If the slope angle β, height of embankment H, the effective unit weight of material γ, angle of internal friction ϕ', and unit cohesion c' are known, the factor of safety may be determined. In order to make unnecessary the more or less tedious stability determinations, Taylor (1937) conceived the idea of analyzing the stability of a large number of slopes through a wide range of slope angles and angles of internal friction, and then representing the results by an abstract number which he called the "stability number". The Fig. 4 depicts Taylor chart for End of construction:

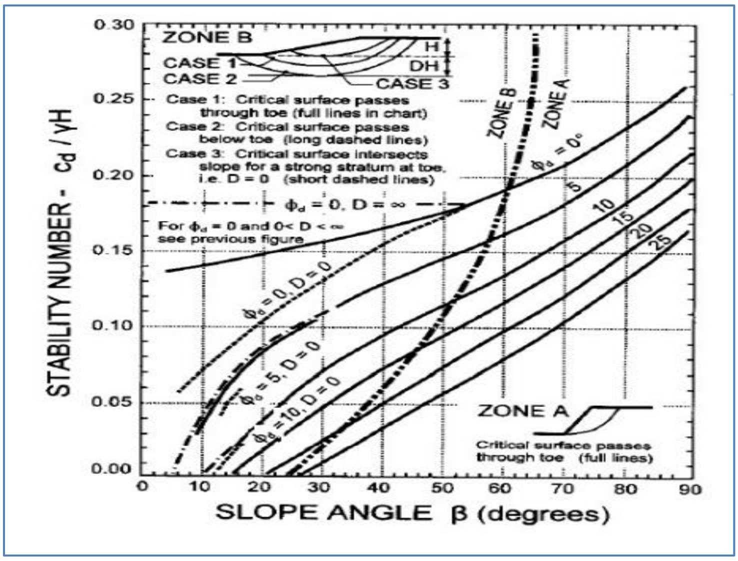

Fig. 4 Taylor Chart [3]

Steady state seepage:

a. **Bishop and Morgenstern Solution [3]:** A method involving the use of stability co-efficient similar to that devised by Taylor, but in terms of effective stress. The factor of safety dependent on five variable: slope angle β, depth factor D, angle of shearing resistance ϕ', a non-dimensional parameter c'/ γH, pore pressure co-efficient r_u. The factor of safety varies linearly with r_u and is given by $F = m - nr_u$, where m and n are co efficient related to variables. The Fig.5 shows one of the Bishop & Morgenstern Chart/table.

c'γ/H = 0.050													
Slope cot β		0.5:1		1:1		2:1		3:1		4:1		5:1	
D	ϕ	m	n	m	n	m	n	m	n	m	n	m	n
1.00	20	0.69	0.78	0.90	0.83	1.37	1.06	1.83	1.38	2.32	1.77	2.77	2.08
	25	0.80	0.98	1.05	1.03	1.61	1.33	2.18	1.75	2.77	2.20	3.33	2.64
	30	0.91	1.21	1.21	1.24	1.88	1.62	2.56	2.15	3.24	2.68	3.91	3.24
	35	1.02	1.40	1.37	1.46	2.17	1.95	2.99	3.78	2.58	3.25	4.57	3.96
	40	1.14	1.61	1.55	1.71	2.50	2.32	3.44	3.06	4.40	3.91	5.30	4.64
1.25	20	1.16	0.98	1.24	1.07	1.50	1.26	1.82	1.48	2.22	1.79	2.63	2.10
	25	1.40	1.23	1.50	1.35	1.81	1.59	2.21	1.89	2.70	2.28	3.19	2.67
	30	1.65	1.51	1.77	1.66	2.14	1.94	2.63	2.33	3.20	2.81	3.81	3.30
	35	1.93	1.82	2.08	2.00	2.53	2.33	3.10	2.84	3.78	3.39	4.48	4.01
	40	2.24	2.16	2.42	2.38	2.94	2.78	3.63	3.38	4.41	4.07	5.22	4.78
1.50	20	1.48	1.28	1.55	1.33	1.74	1.49	2.00	1.69	2.33	1.98	2.68	2.27
	25	1.82	1.63	1.90	1.70	2.13	1.89	2.46	2.17	2.85	2.52	3.28	2.88
	30	2.18	2.01	2.28	2.09	2.56	2.33	2.95	2.69	3.42	3.10	3.95	3.56
	35	2.57	2.42	2.68	2.52	3.02	2.82	3.50	3.25	4.05	3.75	4.69	4.31
	40	3.02	2.91	3.16	3.02	3.55	3.37	4.11	3.90	4.77	4.48	5.50	5.12

Fig. 5 Part of Bishop & Morgenstern Chart/table.

Rapid draw down:

a. **Morgenstern [4]**: Morgenstern (1963) used Bishop's method of slice to determine the factor of safety, Fs, during rapid draw-down. Morgenstern also assumed that

i. The embankment is made of homogeneous material and rests on an impervious base.

ii. Initially, the water level coincides with the top of the embankment

iii. During draw-down, pore water pressure does not dissipate.

iv. The unit weight of saturated soil (γ_{sat}) =2γ_w (γ_w=Unit weight of water)

Relevant portion of Morgestern chart used in the present study.The Fig. 6 shows Part of Morgenstern Chart:

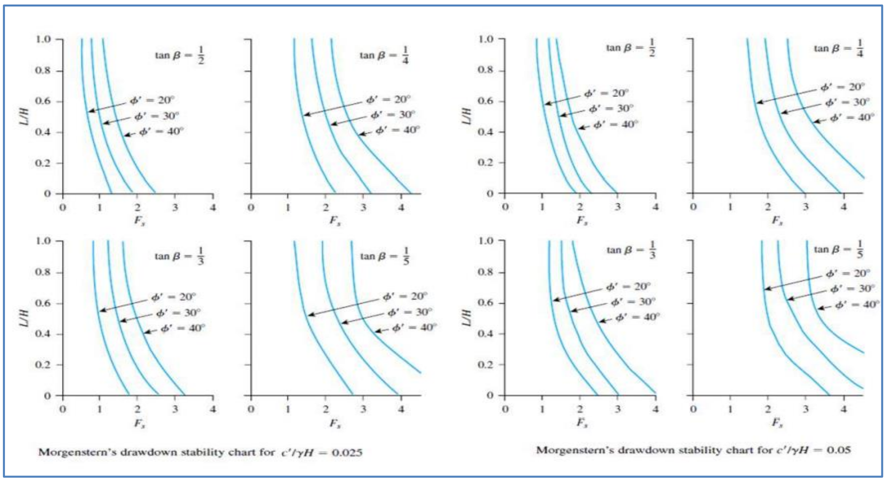

Fig. 6 Part of Morgenstern Chart

3.2 Stability analysis software

SLIDE- 9.0 (Rocscience) is used in the present study. It is a 2D slope stability programs for evaluating the safety factor of circular or non-circular failure surfaces in soil or rock slopes using vertical limit equilibrium methods [6]. Within the Slide2 program, Slide2 has the capability to carry out a finite element groundwater seepage analysis for steady state or transient conditions.

3.3 Determination of Factor of Safety of Adopted Section by using SLIDE 2D software

The U/s slope of adopted proposed section of reservoir scheme is analysed for End of construction as well as Rapid draw down (Minimum draw down level) analysis and D/s slope is analysed for End of construction as well as Steady state seepage condition using effective shear strength parameter as c'= 11 kPa, ϕ'=31

a. U/s Stability:

The table No. 3 depicts factor of safety evaluated for U/s during End of construction condition with $r_u = 0.5$ and Rapid draw down condition (minimum draw down level, MDDL):

Table No. 3 FoS of U/s for end- of- construction condition, $r_u = 0.5$ and rapid draw down condition:

Original Section	Condition	Factor of Safety	Acceptable FoS (IS 7894)
U/s: 2.75 H: 1V	End of construction	1.458	1.0
	Rapid draw down	1.903	1.3

From the above table No. 3, it is clear that U/s is stable under end of construction as well rapid draw down condition, as FoS calculated on both the cases are above acceptable FoS as per IS 7894.The critical failure surface developed using SLIDE 2D software for both the conditions are depicted in Figure 7 and Figure 8 respectively.

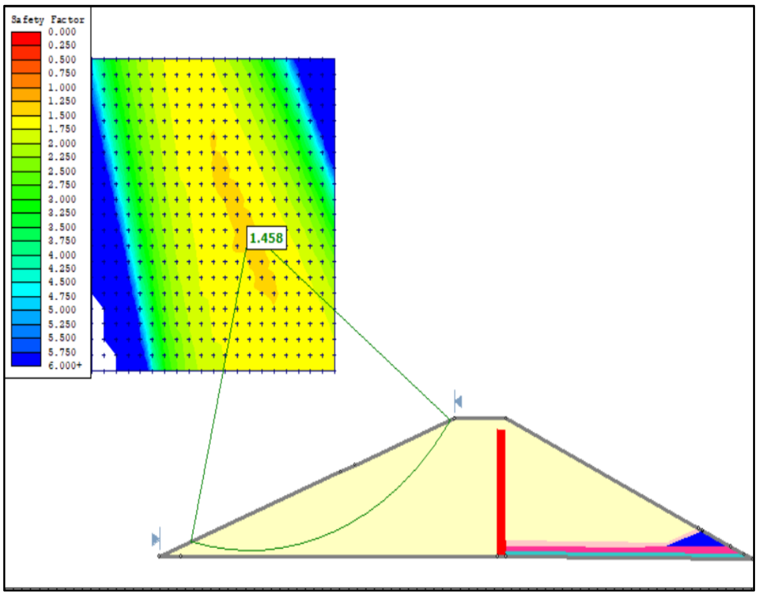

Fig. 7 Critical failure surface U/s, End of construction

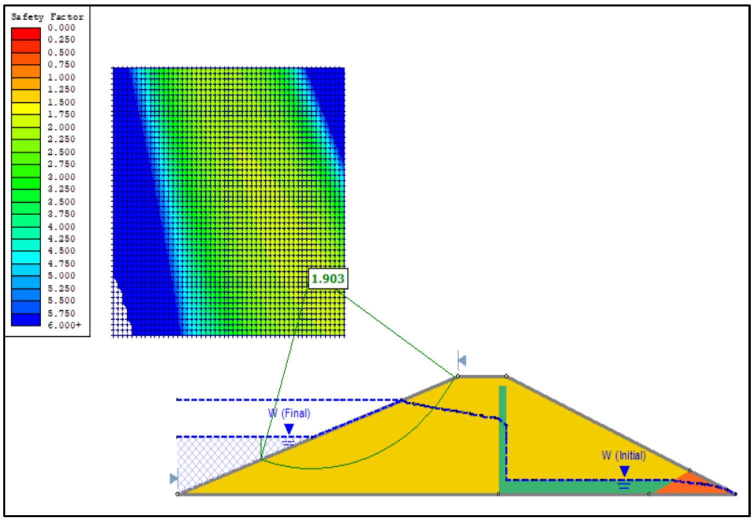

Fig.8 Critical failure surface U/s, Rapid draw down

b. D/s Stability:

The table No. 4 presents factor of safety evaluated for D/s during End of construction condition and Steady state seepage condition:

Table No. 4 FoS of D/s for end- of- construction condition, $r_{u=}$ 0.5 and steady state seepage condition

Original Section	Condition	Factor of Safety	Acceptable FoS (IS 7894)
D/s: 2.25 H: 1V	End of construction	1.234	1.0
	Steady state seepage	1.890	1.50

From above table it is clear that, D/s is stable under End of construction as well as Steady state seepage condition, as FoS calculated on both the cases are above acceptable FoS as per IS 7894. The critical failure surface developed using SLIDE2D software for End of construction as well as Steady state seepage conditions are represented in Figure 9 and Figure 10 respectively.

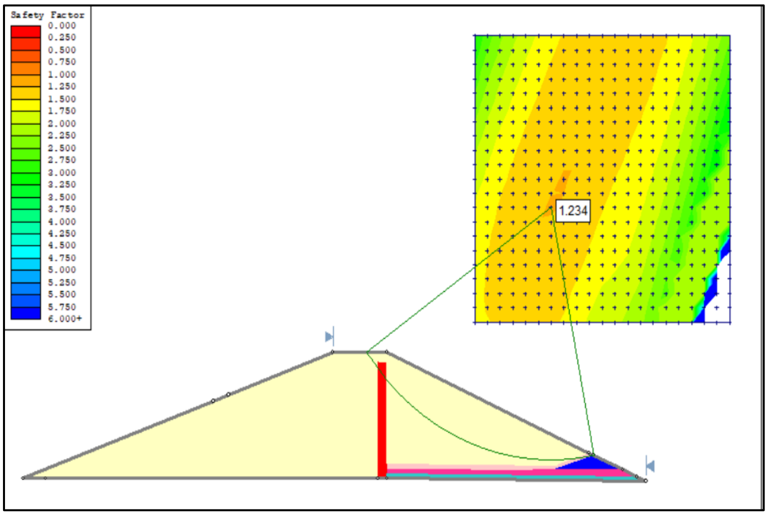

Fig. 9 Critical failure surface D/s, End of construction

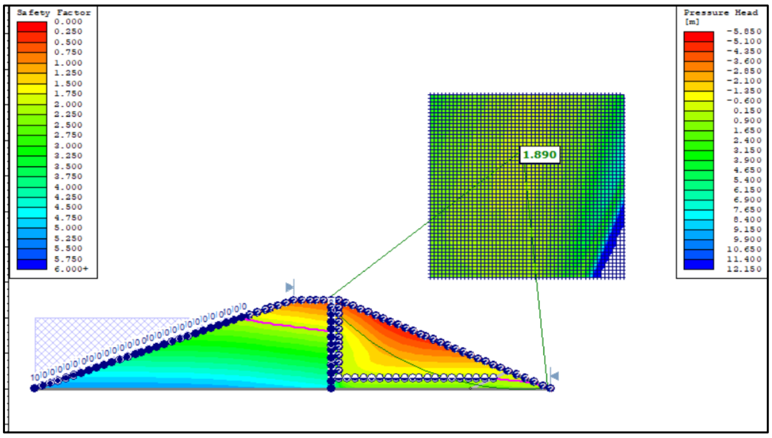

Fig. 10 Critical failure surface D/s, Steady state seepage

3.4 Determination of Factor of Safety of Adopted Section by using Design Charts

a. U/s Stability:

The table No. 5 depicts factor of safety evaluated for U/s during End of construction and rapid draw down condition

Table No. 5 FoS of U/s for end- of- construction and Rapid draw down condition,

Original Section	Condition	Factor of Safety	Acceptable FoS (IS 7894)	Remarks
U/s: 2.75 H: 1V	End of construction	2.30	1.0	Taylor Method
	Rapid draw down	2.80	1.30	Morgenstern's Method

From the above table No. 5, it is clear that U/s is stable under End of construction as well Rapid draw down condition, as FoS calculated on both the cases are above acceptable FoS as per IS 7894.

The table No. 6 presents factor of safety evaluated for D/s during End of construction and Steady state seepage condition

Table No. 6 FoS of D/s for end- of- construction condition

Original Section	Condition	Factor of Safety	Acceptable FoS (IS 7894)	Remarks
D/s: 2.25 H: 1V	End of construction	2.0	1.0	Taylor Method
	Steady state seepage	1.395	1.5	Bishop and Margestern

From the above table No. 6, it is clear that D/s is stable under End of construction. However, in Steady state seepage condition, FoS calculated using design chart for adopted section is below acceptable FoS as per IS 7894. It is pertinent to mention that, influence of drainage components has not been considered in design charts for calculation of factor of safety.

4 Conclusion

The present study reveals the following:

i. The U/s and D/s of original proposed section of Reservoir scheme is safe under End of construction, Rapid draw down and Steady state seepage condition when analysed by SLIDE 2D software (Bishop Method). The critical safety factor evaluated for all the conditions are well above acceptable limits as per IS 7894.

ii. The U/s and D/s of adopted section of Reservoir scheme is safe under End of construction, Rapid draw down when analysed by using Design Charts. However, D/s is not safe for Steady state seepage condition when analysed using Design Chart. Design charts do not consider influence of drainage components in evaluating factor of safety values for Steady state seepage condition. Therefore, we can say that use of design charts for Steady state seepage condition do not give correct factor of safety values.

iii. Factor of safety evaluated using Taylor Chart in End of construction condition for U/s & D/s of adopted section gives higher FoS Value.

iv. Factor of safety evaluated using Morgenstern's Chart in Rapid draw down condition for U/s of adopted section gives higher FoS Value.

v. So finally, we can conclude that the practice of making small dam by technical standards/design charts or guidelines is not safe as charts gives higher factor of safety values, in case of End of construction as well as Rapid draw down condition. However, in case of Steady state seepage condition, charts give lower factor of safety values as it do not take into consideration the influence of drainage component while evaluating factor of safety values. Therefore, it will be beneficial if stability calculations are checked during construction of small dam by actual stability calculation method.

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