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STABILITY ANALYSIS OF DOWNSTREAM SLOPE WITH BERM OF EARTHEN DAM (CASE STUDY-BEMBLA DAM)

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Abstract—Slope stability is an extremely important consideration in the design and construction of earth dams. The results of a slope failure can often be catastrophic, involving the loss of considerable property and many lives. The important cause of failure is sliding. It may occur slowly or suddenly and with or without forewarning.

The design of earthen dams involves many considerations that must be examined before initiating detailed stability analysis. Such as geological and subsurface explorations, the earth and/or rock-fill materials available for construction should be carefully studied.

This paper deals with study of testing the materials and stability analysis of "Bembla earthen dam" situated near Yavatmal Dist. Yavatmal (Maharashtra State) as per IS 7894-1975(Reaffirmed 2002) by Graphical method using Auto-cad

Keywords- Earth Dam, Factor of safety, Slope stability, stability number

I. INTRODUCTION

The methods of stability analysis currently in use have been developed largely as a result of studies of actual slides on old dams. The stability computations serve as a basic either for the redesign of slope of an existing structure or for deciding the slope of a new structure in accordance with the specified safety requirement. Because of wide variations in the properties of sub soil formation and the heterogeneity of soils available for construction of earth dam, the de earth dam constitutes a problem that calls for individual treatment.

The important factors that cause instability in a slope and lead to failure are:-

1. Gravitational force
2. Force due to seepage water
3. Erosion of the surface of slopes due to flowing water
4. The sudden lowering of water adjacent to a slope
5. Forces due to earthquakes

The quantitative determination of the stability of slopes is necessary in number of engineering activities, such as:

a) The design of earth dams and embankments
b) The analysis of stability of natural slopes
c) Analysis of the stability of excavated slopes
d) Analysis of deep-seated failure of foundations and retaining walls.

II. FACTORS OF SAFETY

The factor of safety is commonly thought of as the ratio of the maximum load or stress that a soil can sustain to the actual load or stress that is applied. Referring to **Fig.1** the factor of safety F. with respect to strength may be expressed as follows:

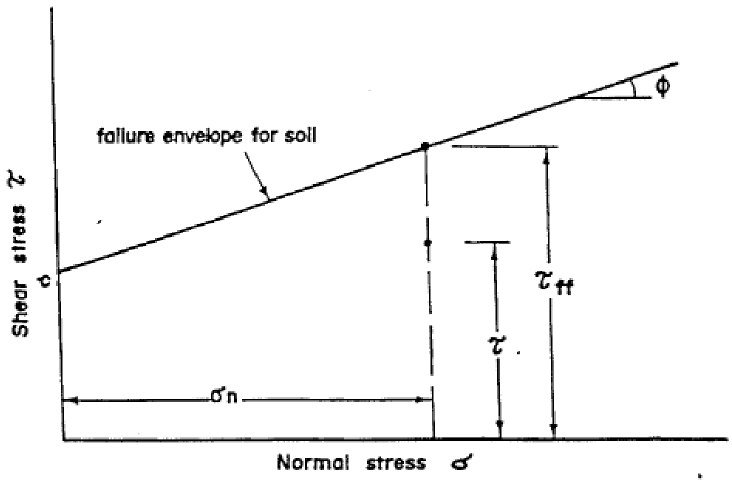

Fig. 1. Definition Diagram for Factor of Safety

In the graphical method the FOS is calculated using this equation: FOS= [ćL+tanΦ' ∑N]/ ∑T
Where,

∑N = total of normal components
∑T =total of tangential components
Ć = effective cohesion
Φ' = effective angle of friction
L = length of arc

III. MATERIAL TESTING

Samples collected from the quarry near by the Bembla Project are tested in the laboratory and following properties are found which are tabulated below:

Table 1 Properties of soil.

Sr.no.	***Name***	***Ć***	***Φ'***	***G***	***γ***	***PI***	***OMC***	***MDD***
01	***Murum***	***30KN/m²***	***20°***	***2.01***	***18KN/m³***	***7.0***	***19.00%***	***21KN/m³***

IV. PROCEDURE OF ANALYSIS OF FORCES BY METHOD OF SLICES.

4.1 General

After deciding upon the tentative cross section of the proposed earth dam, a possible circular failure surface through the dam and foundation (in case foundation is not firm and through which failure is anticipated) shall be assumed. The trial sliding mass shall be divided into a number of vertical slices. The number of slices depends on the width and profile of the sliding mass, number of various zones included in the sliding mass and the accuracy desired. Usually 10 to 15 slices are desirable. For zoned embankment and stratified foundations with different properties, where an arc of the potential failure surface passes through more than one type of material, the vertical ordinates of the slices for each zone or part of the foundation shall be obtained by locating the slice at each such dividing point.

The slices, for convenience, may be of equal width though it is not rigidly necessary to do so. For this, trial surface computations are made of the shear force needed for equilibrium and the strength forces available.

4.2 Graphical Method

Any vertical line within sliding mass from the outer slope of the dam to the bottom of failure surface represents weight of strip or slice infinitely small in width. This is resolved into two components, one normal to the failure surface .N and other tangential to it T. These components for other various vertical slices selected within the failure are plotted separately on two horizontal base lines after projecting the verticals of the failure surface on the base lines. The extremities of these normal and tangential components are then joined by smooth and continuous curves. The areas under these curves represent the summation of the normal and tangential forces acting on the failure surface. The areas for various zones are planimetered and multiplied by the respective unit weights of the material. In order to account for the effect of the pore pressure, the normal forces shall be worked out on the basis of effective unit weights. The summation of normal forces when multiplied by the respective tangent of angle of internal friction along with addition of cohesion gives the total resisting force. The summation of tangential forces gives total driving force. The factor of safety shall then be calculated.

Refer Appendix A (slip circle) and Appendix B (table) for procedure adopted.

Theoretically if the materials of the dam and foundation are entirely homogeneous, any practicable earth dam slope may have its critical failure surface below the toe of the slope. Fellenius found that the angle intersected at O is about 133.5°. The directions of the angle α and β for locating the center of the slip circle is given in Table 10.1 on page 398 in reference book, Geotechnical Engineering by V. N. S. Murthy, CRC Publication.

- The weight, W, of a slice per unit length of dam may be computed from

$$W=\gamma h_a b$$

Where, γ=total unit weight of soil, h_a=average height of slice, b=width of slice.

If the widths of all slices are equal, and if the whole mass is homogeneous, the weight W can be plotted as a vector passing through the center of slice. The vector may be made equal to the height of the slice.

- Draw the vector along the center of slice having magnitude $W=h_a$
- Join the point on the slip circle to the center of slip circle.
- Extend the line having magnitude h_n
- Draw tangential magnitude h_t
- Tabulate the results in the table
- Calculate the factor of safety by using: FOS= [ćL+tanΦ’ ∑N]/ ∑T

V. RESULTS AND CONCLUSION

- Seven slip circles having ’α’ constant and β varying solved graphically.

As per Bishop’s recommendation β=35° and α=25°

Critical slip circle found β=30° and α=25°

Factor Of Safety (minimum) is found to be 2.31 at critical slip circle. Refer **Fig 2.**

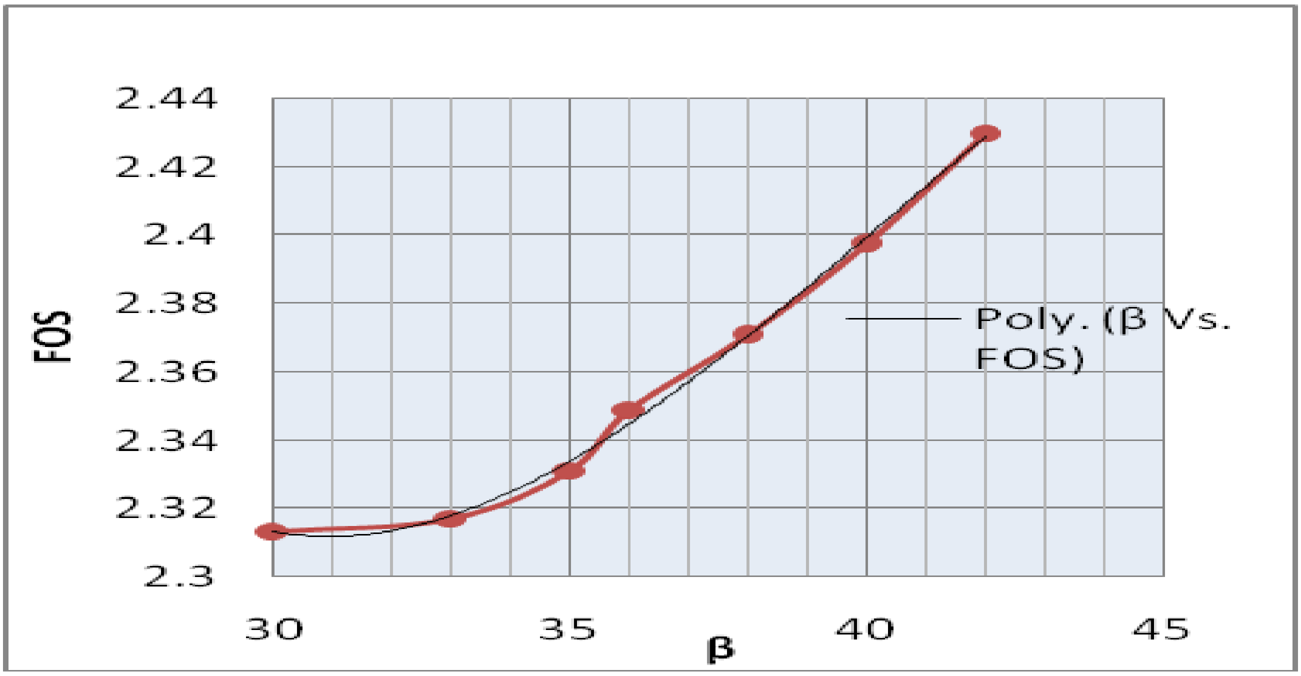

Fig. 2. β vs. Factor of Safety

- Minimum desired value of Factor Of Safety for steady seepage with reservoir full for downstream slope is 1.5 as per IS 7894-1975 (Reaffirmed 2002).

  The minimum FOS =2.31 which is greater than 1.5 Hence, downstream slope of the dam is safe.
- Normal components of all the slices cause stability to the slope as shown in the **Fig. 3**

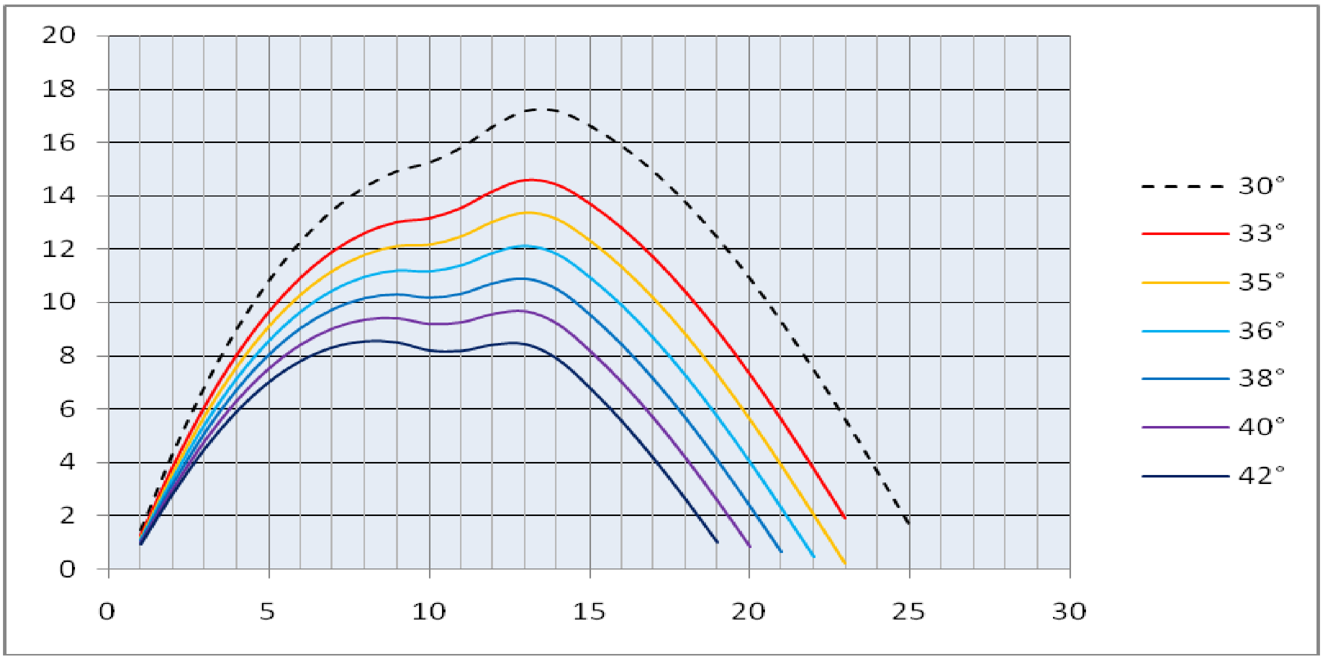

Fig. 3. h_n vs. Slice Number

- Slice no. 11,12,13,14 are included in the berm. The normal component for these slices increases slightly and hence, factor of safety increases.
- Tangential components of some slice cause stability to the slope and some of the slices cause instability to the slope as shown in the **Fig. 4.**

For critical slip circle slice no.14 (where the berm ends) has approximately 'zero' magnitude of tangential component. Slice no.15-23 cause stability to the slope.

Slice no.4 carries maximum tangential component which cause the instability to the slope and hence reduce the factor of safety.

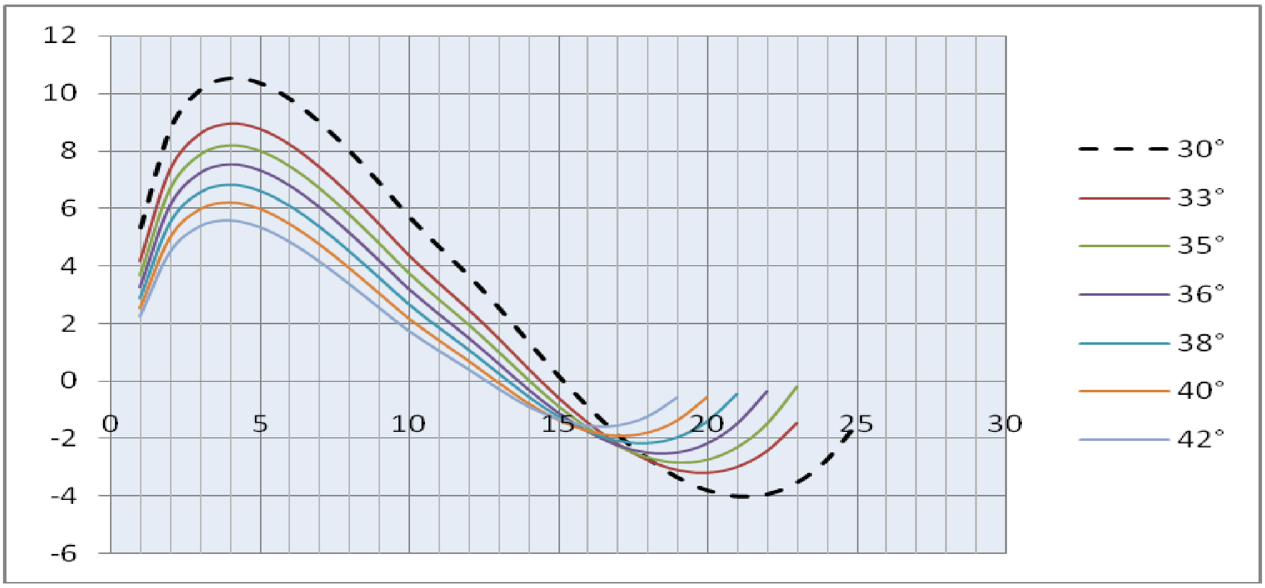

Fig. 4. h_t vs. Slice Number

- Taylor's stability number for φ=20° and β=30° and for zone B is found to be 0.0375 Factor Of Safety for height 19m is found 2.34.
- FOS=2.31 which is approximately equal to FOS=2.34 as per Taylor's stability number for circle passing through the toe. Hence, downstream slope of the dam is found more stable.

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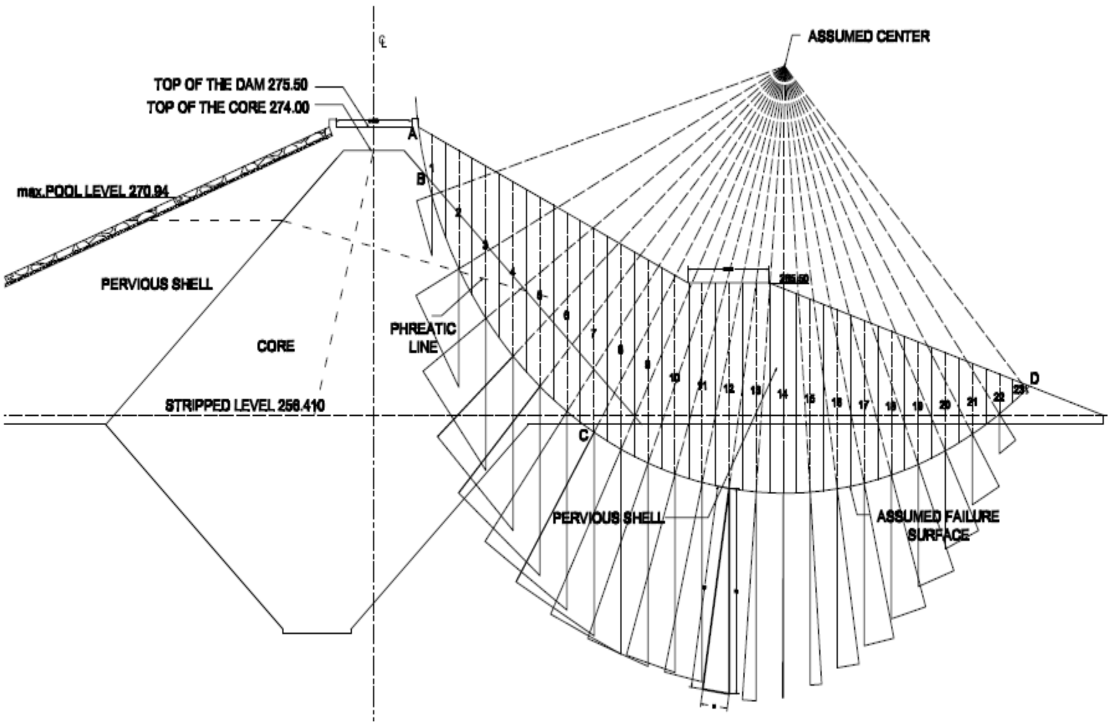
APPENDIX –A

FOR CRITICAL SLIP CIRCLE



APPENDIX –B

Calculation Sheet (For FOS)														
	TRIAL NO.1		TRIAL NO.2		TRIAL NO.3		TRIAL NO.4		TRIAL NO.5		TRIAL NO.6		TRIAL NO.7	
	forβ=30°L=61.8942		for β=33° L=61.8942		for β=35° L=58.9229		for β=36°L=55.9984		for β=38°L=53.1224		for β=40°L=50.2964		for β=42°L=47.5215	
slice no.	hn(m)	hT(m)	hn(m)	ht(m)	hn(m)	ht(m)	hn(m)	ht(m)	hn(m)	ht(m)	hn(m)	ht(m)	hn(m)	ht(m)
1	1.4709	5.3528	1.2514	4.1659	1.1694	3.6912	1.0976	3.2652	1.0453	2.8837	0.9762	2.5427	0.9232	2.2377
2	4.3466	8.7846	3.8248	7.3211	3.6023	6.6832	3.3926	6.0781	3.1942	5.5058	3.0055	4.9663	2.825	4.4591
3	6.8548	10.1343	6.0974	8.5741	5.7604	7.8783	5.4345	7.2082	5.1185	6.5647	4.8114	5.9486	4.5119	5.3606
4	9.0016	10.5373	8.0346	8.9343	7.5947	8.2129	7.1632	7.5139	6.7394	6.8386	6.3225	6.1883	5.9115	5.5643
5	10.8054	10.3684	9.642	8.7533	9.1052	8.0241	8.5742	7.3163	8.0485	6.6314	7.5273	5.971	7.0102	5.3367
6	12.2832	9.8188	10.9309	8.2146	10.3009	7.4907	9.6742	6.7886	9.0504	6.11	8.429	5.4567	7.8097	4.8307
7	13.4505	9.0073	11.9136	7.4339	11.1929	6.7264	10.4731	6.0421	9.7541	5.383	9.0355	4.7512	8.3174	4.149
8	14.3211	8.0165	12.6026	6.4928	11.793	5.8119	10.9822	5.1566	10.1704	4.5292	9.3574	3.932	8.5435	3.3675
9	14.9078	6.9089	13.0101	5.4537	12.1131	4.8095	11.2133	4.1941	10.311	3.6101	9.4063	3.0601	8.4998	2.5468
10	15.223	5.7343	13.1482	4.367	12.1655	3.7698	11.1787	3.2054	10.1882	2.6766	9.1947	2.1865	8.1991	1.7379
11	15.7831	4.6844	13.5396	3.4039	12.4756	2.8533	11.4066	2.3397	10.3332	1.8663	9.2565	1.4362	8.1778	1.0528
12	16.5785	3.6776	14.1713	2.4806	13.0286	1.9756	11.8801	1.5119	10.7269	1.0931	9.5703	0.7227	8.412	0.4043
13	17.1605	2.5785	14.588	1.4815	13.3663	1.0307	12.1384	0.6266	10.9058	0.2729	9.6702	-0.0263	8.4339	-0.2672
14	17.1674	1.3885	14.4149	0.4273	13.1259	0.0505	11.8193	-0.2736	10.5084	-0.5402	9.196	-0.745	7.8848	-0.8834
15	16.6288	0.2103	13.7227	-0.5734	12.3445	-0.8561	10.9616	-1.0776	9.5766	-1.2331	8.1926	-1.3175	6.8134	-1.3259
16	15.8763	-0.8797	12.8097	-1.4586	11.358	-1.6319	9.9038	-1.7347	8.4506	-1.7615	7.0023	-1.7066	5.5638	-1.5644
17	14.9197	-1.8537	11.7001	-2.1967	10.1799	-2.2439	8.6607	-2.2098	7.147	-2.0879	5.6438	-1.8719	4.1574	-1.5552
18	13.77	-2.6833	10.4074	-2.7552	8.8255	-2.6571	7.2497	-2.465	5.6856	-2.1714	4.1401	-1.7686	2.6213	-1.2486
19	12.4392	-3.3389	8.9473	-3.0993	7.3128	-2.8338	5.6914	-2.459	4.0908	-1.9659	2.5201	-1.3451	0.9901	-0.5866
20	10.9415	-3.7888	7.3388	-3.1906	5.6636	-2.7312	4.0118	-2.1439	2.3937	-1.4173	0.8215	-0.5394		
21	9.2934	-3.9981	5.6047	-2.9851	3.9056	-2.2977	2.2443	-1.4627	0.6353	-0.4593				
22	7.5147	-3.9271	3.7759	-2.4322	2.0744	-1.4786	0.4339	-0.3435						
23	5.6303	-3.5294	1.8862	-1.4629	0.2196	-0.1896								
24	3.6724	-2.7479												
25	1.6848	-1.5086												
Total	281.7255	68.947	223.3622	57.35	198.6777	52.0882	175.5852	47.0769	154.0739	42.3288	134.0792	37.8419	115.6058	33.6161
Length of arc		68.3598		61.8942		58.9229		55.9984		53.1224		50.2964		47.5215
∑N	10142.12		8041.039		7152.397		6321.067		5546.66		4826.851		4161.809	
∑T		2482.09		2064.6		1875.175		1694.768		1523.84		1362.308		1210.18
FOS	2.313583		2.317042		2.331067		2.348888		2.370763		2.397303		2.42984	