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Stability Analysis of Finite Slope using Limit Equilibrium Method

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Abstract – *Stability analysis for the finite slopes is done by calculating Factor of Safety (FOS). Soil sample was collected and experimentation was done to find various Index properties and engineering property of soil. Stability analysis was done using Bishop Method on assumed 2D single material model of earthen (embankment) dam with GeoStudio using Limit Equilibrium Method. Comparative study was done on the same model to check how FOS varies with respect to height and material properties. Also a real world example (Aruna medium irrigation project, Vaibhavwadi, Dist. Sindhudurg) modelled on GeoStudio for stability analysis.*

Key Words: Finite slope, FOS, Bishop Method, GeoStudio, Limit Equilibrium method.

1. INTRODUCTION

On any conceivable surface across the slope, the soil mass must be stable against failure. For the stability analysis of slope methods using the theory of elasticity and plasticity being increasingly used, the most used methods are based on limiting equilibrium where it is assumed that the soil is at the verge of failure. In the analysis, the resultant of all forces causing the soil mass to slide is calculated. Also the shear strength of soil is estimated. FOS (Factor of Safety) is the ratio of Shear strength and forces causing the Failure.

Slopes with FOS values more than 1.5 are considered to be stable where those with value between 1 and 1.5 are considered to be critical. FOS value less than 1 indicates that forces causing failure are more than shear strength of soil thus the slope is not safe.

1.1 Assumed Model

The model assumed was essentially consisting of 35° slope. For comparison of FOS with respect to height 35° slope was modelled with 5m top width for varying height of 5m – 50m with intervals of 5m. For comparison of FOS with respect to materials modelled 35° slope having 5m top width and 40m height.

It was observed that for 35° slope shear strength and forces causing failure maintain equilibrium, due to this 35° slope chosen for analysis.

1.2 Bishop Method

Bishop (1955) developed a simplified method of analysis in which forces between the slices are considered. Slices analysed as per conditions of equilibrium. The factor of safety is defined as the ratio of the maximum shear strength possessed by soil on the trial surface to the shearing resistance mobilized.

1.3 Aruna medium irrigation project

Aruna dam is a medium irrigation project by Konkan Irrigation Development Corporation. This project is located in vaibhavwadi sub-district in Sindhudurg District of Maharashtra. This project consists of the construction of dam across the Aruna River having water storage capacity of 93.4 Mm^3. The project aims to irrigate 5310 ha of land in Sindhudurg district.

2. EXPERIMENTATION

Results obtained from experimentation of soil are as below

Table -1: Experimentation Results

Sr. No.	Parameter	Result
1.	Water content (%)	27.48
2.	Specific gravity	2.62
3.	Bulk Density (kN/M^3)	17.95
4.	Dry Density (kN/M^3)	15.56
5.	Liquid Limit (%)	39.58
6.	Plastic Limit (%)	14.81
7.	Plasticity Index (%)	24.77
8.	Flow Index (%)	22.86
9.	Toughness Index (%)	1.08
10.	UCS classification	SW
11.	Cohesion (kN/M^2)	28
12.	Angle of internal friction - Ø (°)	36

3. Variation in Factor of Safety with height.

For 35° slope, earthen dam was modelled with top width 5m and height varying from 5m – 50m with regular intervals of 5m on GeoStudio. Material properties were kept constant. This comparison showed that FOS decreases as height goes on increasing but the relation is not linear.

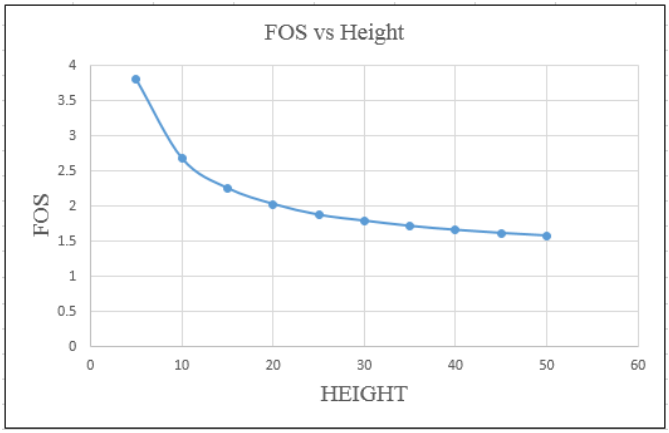

Chart -1: Graph between Height and FOS

4. SOIL PROPERTIES AND FACTOR OF SAFETY.

Table 2: Soil properties and FOS

Properties of Soils (UCS) & FOS calculated from GeoStudio					
Sr. No.	Soil(UCS)	C (kN/M^2)	Ø (°)	Weight (kN/M^3)	FOS
1	GW	0	38	18.7	1.117
2	GP	0	37	17.3	1.077
3	GM	0	34	17.9	0.965
4	GC	0	31	18.1	0.859
5	SW	39	38	18.7	1.875
6	SP	23	37	17.3	1.636
7	SM	51	34	17.9	1.866
8	SM-SC	61	33	18.7	1.912
9	SC	75	31	18.1	2.013
10	ML	67	32	16.2	2.058
11	ML-CL	71	32	17.1	2.061
12	CL	87	28	17	2.134
13	MH	72	25	12.9	2.095
14	CH	103	19	14.8	2.121

FOS for the same dam model with different material properties shown in the table above. Properties of soil are used when soil is at compacted state. It can be seen that clays show high values of FOS compared to sands when compacted.

5. STABILITY ANALYSIS OF ARUNA DAM

5.1 Material Properties

Material properties for three sections of Aruna dam was obtained from official drawing. These properties being used as design parameters which are shown in following table.

Table 3: Material properties at Aruna dam

Design parameters				
Sr. No.	Designation	Ø (°)	Cohesion (kN/M^2)	Dry density (kN/M^2)
1	Matrix Casing	23.75	9.81	13.538
2	Hearting	21.8	14.715	12.56
3	Foundation	21.8	17.658	12.56

5.2 Results of analysis

Factor of Safety calculated from GeoStudio for various conditions is shown below.

Table 4: Stability analysis

Factor Of Safety	
Condition	FOS
U/S slope without water	2.326
U/S slope with water	2.597
D/S slope without water	1.842
D/S slope with water	1.663

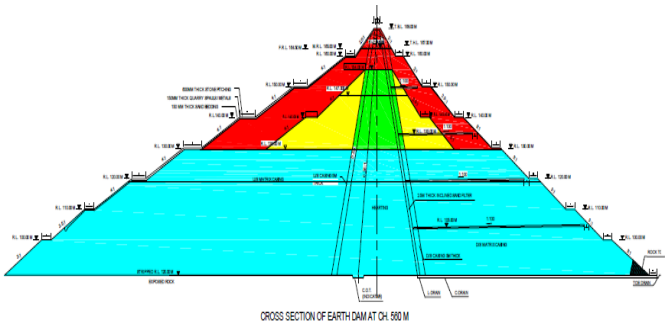

Fig. 1: Cross section of Aruna Dam

5.3 Software model of Aruna Dam showing slip surfaces

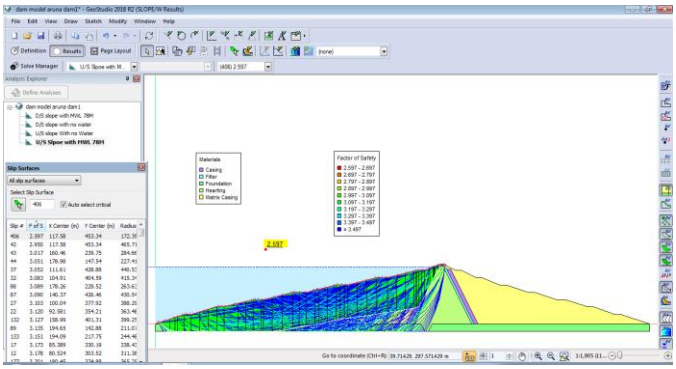

Fig. 2: Upstream side slope with maximum water level

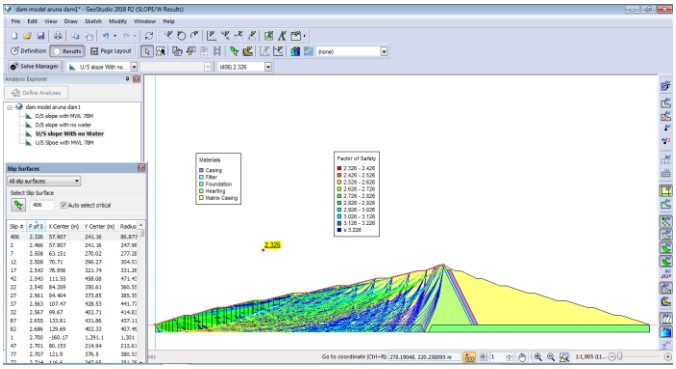

Fig. 3: Upstream side slope with no water

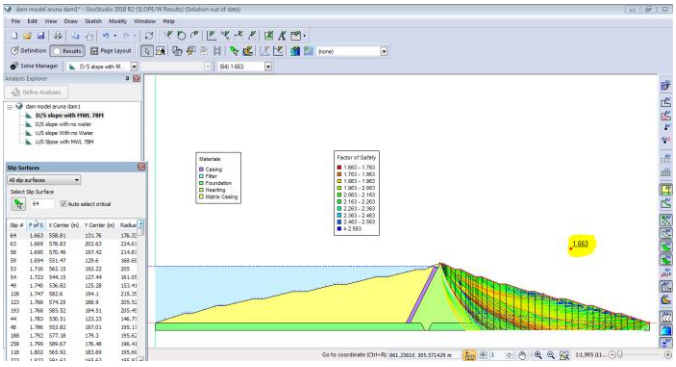

Fig. 4: downstream side slope with maximum water level.

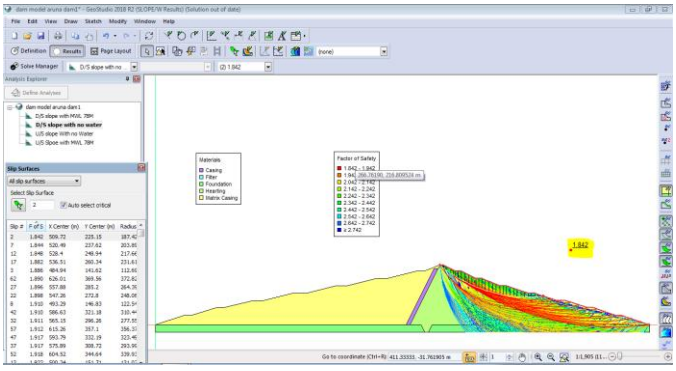

Fig. 5: downstream side slope with no water

CONCLUSIONS-

1. For same material properties and same angle of slope FOS varies with respect to height. FOS gets decreased with increase in height.
2. Compacted High plasticity clay (CH) shows highest value of FOS thus seems best material but due to high plasticity, swelling and shrinkage will be more. Thus while designing the slopes along with shear strength, other properties like seepage, swelling, shrinkage should be taken into account.
3. U/S side slope is safer with water than without water i.e. water contributes to total resisting moment.
4. D/S side slope is safer when water is absent than when water is at maximum level i.e. water contributes to overturning moment.

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