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INTRODUCTION OF VARIOUS REMEDIAL MEASURES FOR IMPROVEMENT IN STABILITY OF EARTHEN DAM

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Abstract: Dam is a hydraulic structure built to create reservoir on its upstream side to serve numerous purposes such as irrigation, water supply, flood control, hydroelectric power generation and recreation. Dams which are constructed of earthen materials such as gravel, sand, silt and clay are called as Earthen dam. Dams are an important part of our infrastructure which represents large economic values. Dams require high initial investment for design, construction and surveillance. For these reasons dams should certainly be designed, built and monitored with high assurance for a long duration of time. The Stability of earth dam is very crucial as huge volume of water is stored in reservoir which is very hazardous to downstream location for worst –case scenario at the time of breach in dam. It is therefore very important to design the dam in such a way that it satisfies both safety and economic consideration. Analysis of stability of dam is very important before, during and after construction of dam. Stability of dam depends upon existing stresses in different loading condition, suitability and strength of construction material, destabilising parameters and type of foundation. The present study is directed towards introduction of various remedial measures for improvement in stability of earthen dam carried out using limit equilibrium method. Slope stability analysis of downstream dam slope for steady seepage and upstream slope for sudden drawdown condition is considered for analysis. Slope stability analysis is carried out on typical dam section of 25 m height. It is found that design dam section is unsafe for both steady seepage and sudden draw down condition. To make dam safe various remedial measures are provided and optimum solution is recommended to make dam safe for stability

Keywords: *Slope stability analysis, phreatic line, Finite element method, Factor of Safety*

1. INTRODUCTION :

Dam is a hydraulic structure built to create reservoir on its upstream side to serve numerous purposes such as irrigation, water supply, flood control, hydroelectric power generation and recreation. Dams which are constructed of earthen materials such as gravel, sand, silt and clay are called as Earthen dam. Dams are an important part of our infrastructure which represents large economic values. Dams require high initial investment for design, construction and surveillance. For these reasons dams should certainly be designed, built and monitored with high assurance for a long duration of time.

Typical dam section having 25 m height is considered for slope stability analysis. It is assumed that dam is working in ideal condition and PL is passing through horizontal filter. Slope stability analysis is conducted byMStab software by using Limit equilibrium method. This analysis describes studies conducted, results, modifications and conclusion. Based on the result of slope stability analysis on design dam section, modifications and remedial measures required in existing design dam are suggested.

2. DAM CHARACTERISTICS :

Geometry :

The design section of dam comprises of zoned dam with casing, core, cut off and filter. The upstream slope consist of two berms of width 5 m each at height 15m and 6 m from ground level with slope 1(V):3(H) throughout height of dam. The downstream slope is having two berms of width 5 m each with 1(V):2(H) slope throughout height of dam. Horizontal filter is of 1m thickness is provided on downstream side. A central COT of base-width 5 m and depth 8.0 m below hearting zone is provided to restrict seepage through foundation. Dam having foundation layer of soft rock and hard rock of thickness 4 m and 5 m each as shown in fig. 1

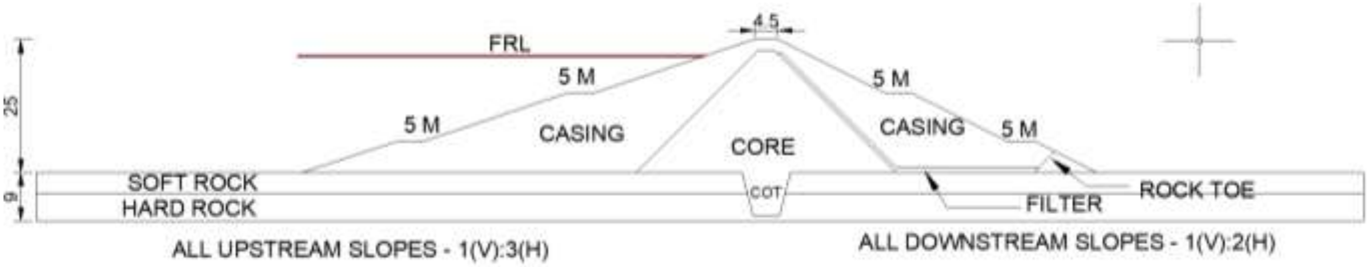

Fig. 1 Design dam cross section

Material Properties :

Soil properties for different zones of the dam and foundation used for slope stability analysis are listed in Table 1.

Table.1 Soil properties adopted for dam body and foundation

Sr. No.	Parameter	Casing	Hearting and COT	Filter	Rocktoe	Foundation		
						Soft rock	Hard rock	Shear Key
1	Bulk density (kN/m^3)	20.00	18.00	17.00	21.00	21.00	22.50	23.00
	Saturated density (kN/m^3)	21.00	19.00	17.00	21.00	22.00	23.00	23.00
2	Cohesion(kN/m^2)	7.00	30.00	0	0	0	0	0
3	Friction Angle (deg.)	24	8	31	41	35	40	38

3. SLOPE STABILITY ANALYSIS :

For stability analysis it is considered that dam is working in ideal condition and PL is drawn for steady state condition. For slope stability analysis a model of dam section is modelled in Mstab software with FRLat22.50 m on upstream side.

Slope stability analysis of dam is conducted for steady seepage and sudden drawdown condition and factor of safety is evaluated. Factor of safety is defined as the ratio of resisting moment to disturbing moment of slip circle. Factor of safety is determined from critical circle. The critical slip circle is the one which has minimum factor of safety.As per IS 7894-1975 minimum factor of safety required for steady seepage and sudden drawdown condition is 1.5 and 1.3 respectively.

3.1 Results of slope stability analysis for Design section of dam:

Values obtained from slope stability analysis of design cross section for steady seepage and sudden drawdown condition are 1.28 and 1.12 respectively (Figs.2a and 2b) which is less than required values of 1.5 and 1.3. It indicates the section is unsafe for both steady seepage and drawdown condition and require remedial measures to make safe for operation.

Steady Seepage

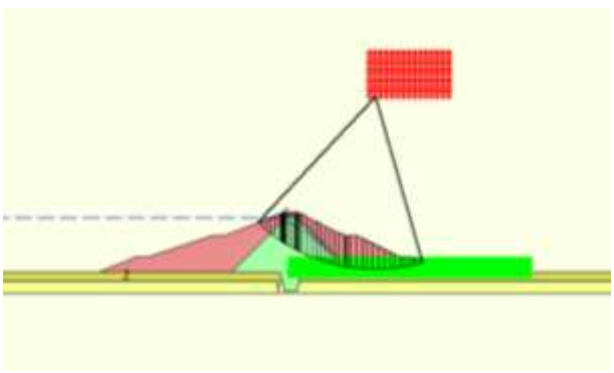

Fig.2a Critical Slip circle FOS= 1.28

Sudden Drawdown

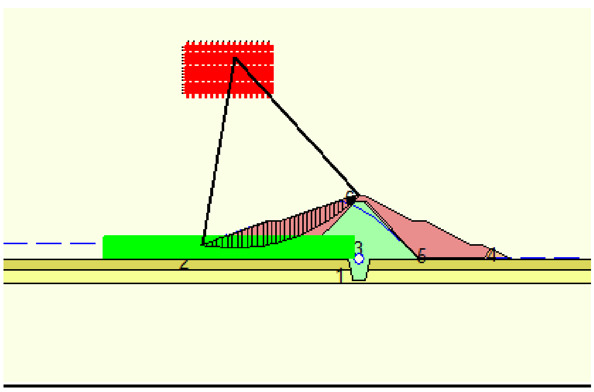

Fig.2b Critical Slip circle FOS= 1.12

To increase factor of safety value and make dam more stable, the section required modifications. Following modificationsare made to make dam section safe in operation.

3.2 Increasing of berm width (Modified Section I):

For upstream and downstream side berm width is increased to 12 m at elevation 6 m and 15 m from GL. Result obtained for modified section I is 1.53 and 1.30 for steady seepage and sudden drawdown condition respectively (Figs.4a and 4b). By increasing of berm width base width of dam is increased 14 m on upstream side and 14 m on downstream side. The modified section is shown in fig. 3

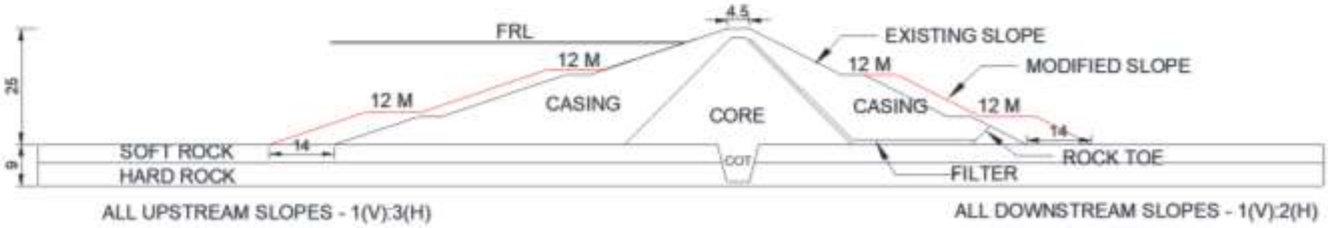

Fig.3 Modified dam cross section – I

Steady Seepage

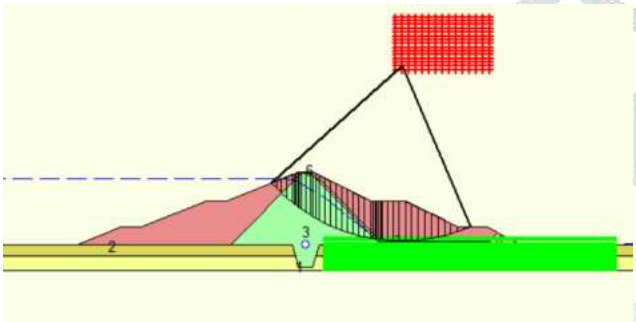

Fig.4a Critical Slip circle (Modified section I) FOS=1.53

Sudden Drawdown

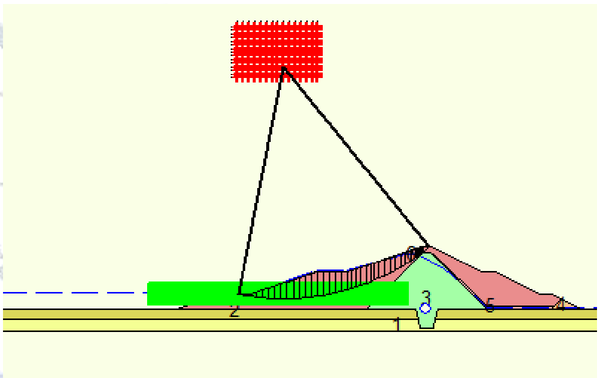

Fig.4b Critical Slip circle (Modified Section I) FOS= 1.30

3.3 Flattening of slopes (Modified Section II):

All upstream slopes are flattened to 1(V):3.5(H) and downstream slopes are flattened to 1(V):2.5(H) at different elevations.Result obtained for modified section is 1.52 and 1.33 for steady seepage and sudden drawdown condition respectively (Figs. 6a and 6b). By flattening of slopes base width of dam is increased by 12.5 m on upstream side and 12.5 m on downstream side. The modified section is shown in fig. 5.

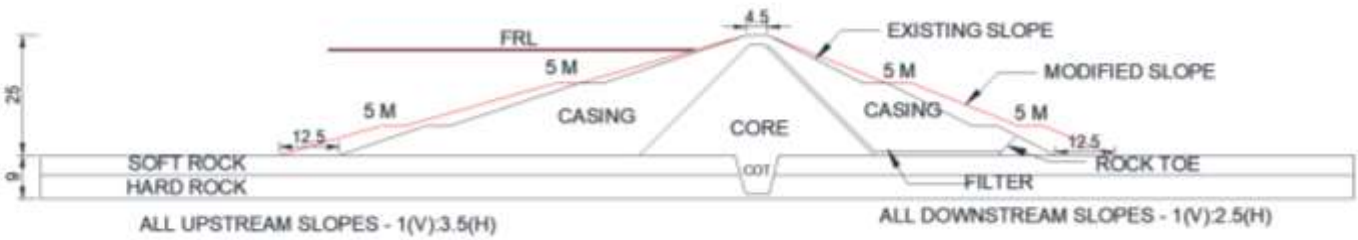

Fig.5 Modified dam cross section – II

Steady Seepage

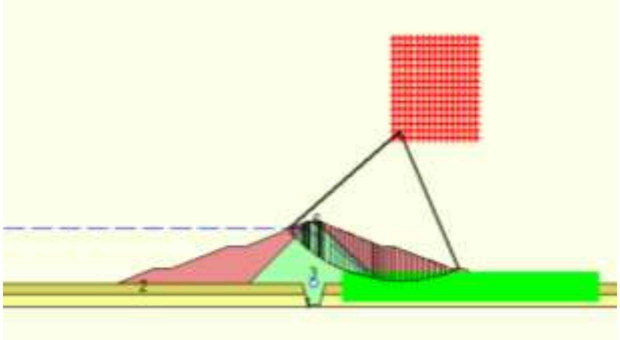

Fig.6a Critical Slip circle (Modified section II)

FOS=1.52

Sudden Drawdown

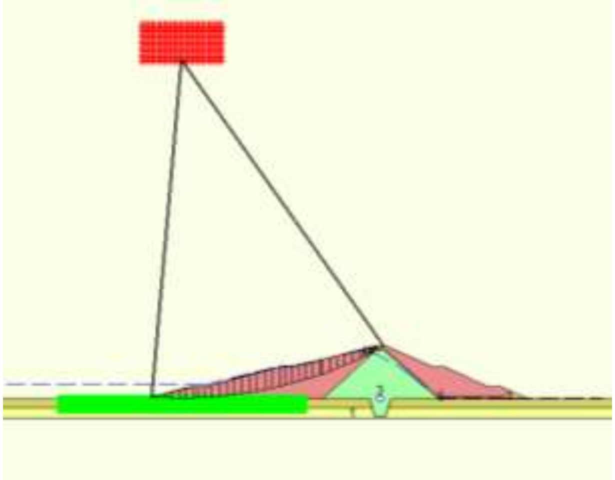

Fig.6b Critical Slip circle (Modified Section II)

FOS= 1.33

3.4 Increasing berm width and flattening of slopes (Modified Section III):

For upstream slope berm width is increased to 12 m and 10 m at elevation 15 m and 6m respectively from GL and slope below top berm level is flattened to 1(V):3.5(H) upto elevation 15 m. For downstream slope both berm width is increased to 7 m at elevation 15 m and 6m respectively and slopes are flattened to 1(V):2.5(H) throughout dam height at different elevations. Result obtained for modified section is 1.60 and 1.36 for steady seepage and sudden drawdown condition respectively (Figs. 8a and 8b). By flattening of slopes and increasing berm width base width of dam is increased by 17 m on upstream side and 16.5 m on downstream side.The modified section is shown in fig. 7.

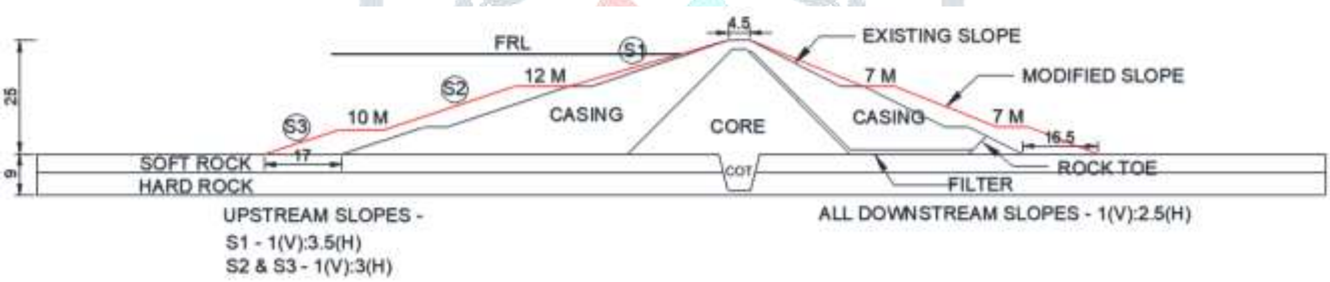

Fig.7 Modified dam cross section – III

Steady Seepage

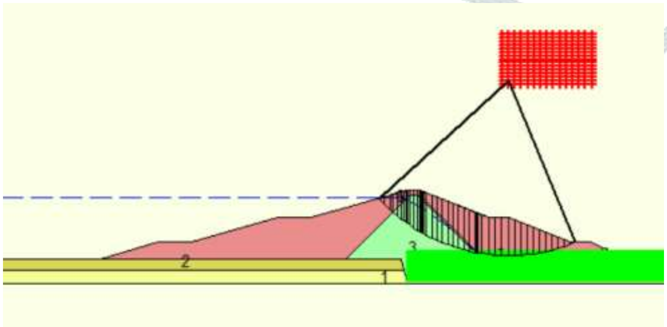

Fig.8a Critical Slip circle (Modified section III) FOS=1.60

Sudden Drawdown

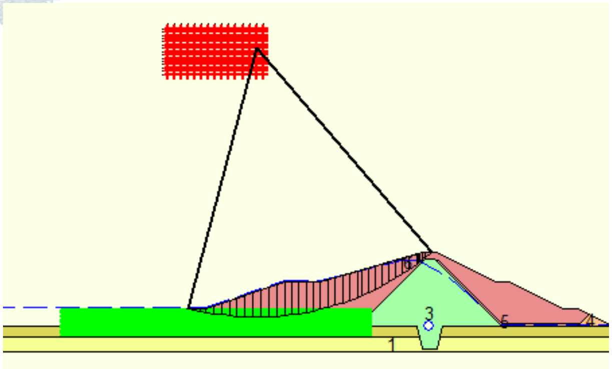

Fig.8b Critical Slip circle (Modified Section III) FOS= 1.36

3.5 Increasing berm width, flattening of slopes and shear key with gabion fill (Modified Section IV) :

Dam section is modified by widening of berm, slope flattening and providing shear key of gabion fill material at upstream and downstream slope. Various trials with increasing berm width, flattening of slopes and different dimensions of shear key are taken till the required values of factor of safety are obtained. On upstream side both berm width is increased to 8 m at elevation 15 m and 6m respectively from ground level and shear key of size 6.00 m (width) X 2.00 m (depth) is provided near upstream toe. On downstream side berm width is increased to 7 m at elevation 15 m from GL and slope is flattened to

1(V):2.5(H) from top berm levelupto 6 m and shear key of size 11.50 m (width) X 2.00 m (depth) is provided near downstream toe. The values obtained for modified section is 1.62 and 1.31 which are more than required value of 1.5 and 1.3 for steady seepage and sudden draw down condition respectively. Hence the section is found safe for both the conditions and the critical slip circles are shown in Figs.10a and 10b. By addition of shear key base width of dam is increased by 6 m on upstream side and 11.5 m on downstream side. The modified section is shown in fig. 9.

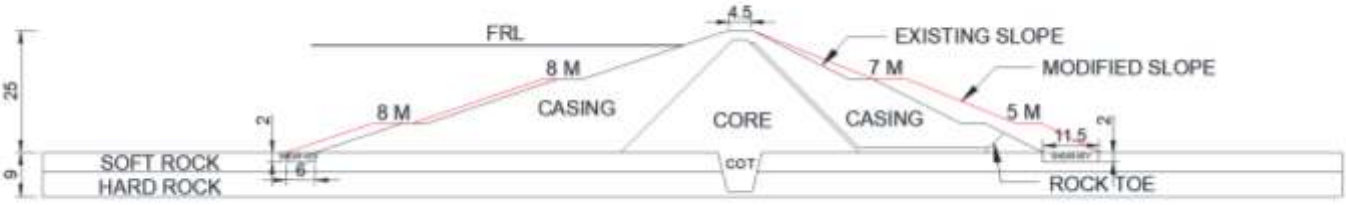

Fig.9 Modified cross-section IV

Steady Seepage **Sudden Drawdown**

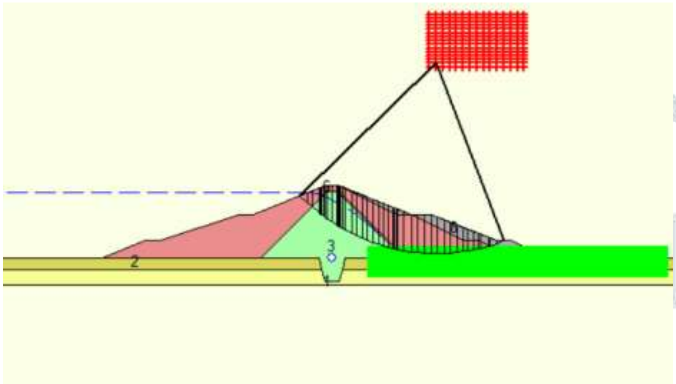

Fig. 10a Critical Slip circle (Modified section IV) FOS=1.62

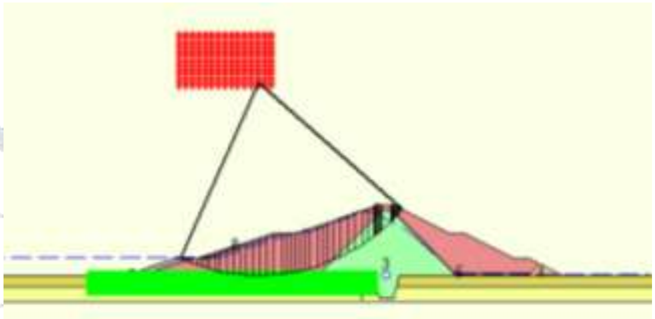

Fig. 10b Critical Slip circle (Modified section IV) FOS=1.31

4. CONCLUSION :

i) It is concluded from analysis that existing design section of dam is unsafe from slope stability point of view for steady seepage and sudden drawdown conditions and the sections require modifications to make the slopes stable.

ii) For Modified section I, factor of safety is increased from 1.28 to 1.53 for steady seepage35 and 1.12 to 1.30 for sudden drawdown condition after increasing of berm width. Base width increased by 14 m on upstream side and 14 m on downstream side.

iii) For modified section II, factor of safety is increased from 1.28 to 1.52 for steady seepage and 1.12 to 1.33 for sudden drawdown condition after slope flattening. Base width increased by 12.5 m on upstream side and 12.5m on downstream side.

iv) For modified section III, factor of safety is increased from 1.28 to 1.60 for steady seepage and 1.12 to 1.36 for sudden drawdown condition after increasing berm width and slope flattening. Base width increased by 17 m on upstream side and 16.5 m on downstream side.

v) For modified section IV, factor of safety is increased from 1.28 to 1.62 for steady seepage and 1.12 to 1.31 for sudden drawdown condition after slope flattening and increasing berm width and addition of shear key of gabion material. Base width increased by 6 m on upstream side and 11.5 m on downstream side.

vi) From analysis it is found that shear key with gabion fill is appropriate solution as locally available rock material is used for gabion fill. It is more practical and cost effective.

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