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Study on Slope Stability of Earthen Dams by using GEOSTUDIO Software

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Abstract**: This paper research explained about slope stability of earthen dams using GEOSTUDIO software. Generally, in earthen dams, the factors included in this analysis are the specific site, foundation conditions, construction material characteristics and hazard potential associated with the particular site. To control the slope failures it is important to analyse the factor of safety of the slopes. To derive factor of safety, the tests are carried out by using numerical modelling of SLOPE/W and SEEP/W tools of GEOSTUDIO software for steady state seepage and sudden drawdown conditions. In this paper factor of safeties are analysed for four cases, such as (i) without berm without a drained blanket (ii) with berm without a drained blanket (iii) without berm with a drained blanket and (iv) With berm with a drained blanket. Out of four cases, the best case to improve the factor of safety of the slope is (IV) with berm with a drained blanket of the earthen dam.

Keywords: Slope Stability, Steady State Seepage, Sudden Drawdown, Berm, Drain, Earthen Dam, GEOSTUDIO Software.

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1. INTRODUCTION

In olden days, designing of slopes are based on the experience of Geotechnical Engineers and design approach was based on prevailing site conditions. This approach of designing slopes has resulted in extensive property damage and occasionally resulted in the loss of life.

Now a day's there is an increased demand for engineering cut and fill slopes on construction projects. The construction of finite height sloped embankments is a common practice in dams, highways and railway projects. The finite element analysis of stability failures and seepage analysis demands increased to handle complex problems in the construction field.

Stability and seepage analysis for earthen dams are very important to maintain the stability of the structure. Embankments of earthen dams must be designed to construct stable against any type of force conditions which develops in the life of the structure. Mostly loading conditions are critical like sudden drawdown and steady seepage which can cause piping through the foundation or within the embankment.

To derive factor of safety, slope stability analysis of the embankment may be carried out for the 10m height of the homogeneous dam. The analysis has been performed using Mohr-Coulomb constitutive model. There are many analysis methods such as Method of Slices, Bishop's method, Janbu's method and Morgenstern Method etc. using any of the methods we can determine the stability analysis.

GEOSLOPE is developed by *GEO-SLOPE* International, Canada, based on the principle of limit equilibrium which incorporates a finite element method which is developed specially for the deformation and stability of embankment structures. It includes modelling of stability with (*SLOPE/W*), modelling of seepage with (*SEEP/W*), modelling of stress

and deformation with (*SIGMA/W*), modelling of dynamic with (*QUAKE/W*), modelling of thermal with (*TEMP/W*), modelling of containment with (*CTRAN/W*) and modelling of vadose zone with (*VADOSE/W*).
SLOPE/W and SEEP/W has been used with "Morgenstern method" to do the stability analysis. It is designed and developed to be a general software tool for the stability analysis of earth structures for the proposed project of the raw water reservoir.

2. MATERIALS USED

In this study embankment and drain, properties satisfy the Morh-Coulomb criterion like CΦ soils and Φ soils to find out the shear strength of soils. Therefore, CΦ soil analysis meant for shear strength equal to cohesion plus normal stress multiplied in to tan Φ (Φ means the angle of internal friction) and Φ soils meant for shear strength equal to normal stress multiplied in to tan Φ.

2.1 Moorum

Moorum contains the properties like the unit weight of soil, cohesion, and angle of internal friction. The properties of Moorum are given in table 1

Table 1: Embankment Properties

Type of Soil	Symbol	Units	Property	Assumed values
MOORUM	Γ	kN/m³	Unit Weight of soil	19
	C	kN/m²	Cohesion of soil	5
	Φ	°	Angle of internal friction	32

2.2 Sand

Sand contains the Drain properties like the unit weight of soil, cohesion, and angle of internal friction. The properties of sand are given in table 2

Table 2: Drain Properties

Type of Soil	Symbol	Units	Property	Assumed values
SAND	Γ	kN/m³	Soil's Total Unit Weight	20
	C	kN/m²	Cohesion of soil	0
	Φ	°	Angle of internal friction	45

3. PURPOSE OF SLOPE STABILITY ANALYSIS

Dams must be designed and maintained safely to prevent the slope failure. Steady seepage analysis and sudden drawdown conditions are carried out for the following reasons:

- To evaluate the phreatic surface within an earthen dam
- To evaluate pore pressures within dam or foundation
- To estimate exit gradients or uplift pressures at the toe of an embankment
- To evaluate the permeability may pass through an embankment
- To estimate the permeability through drainage blanket as per IS: 9429-1999
- To estimate the factor of safety for stability slopes on both upstream and downstream side of earthen dam

4. SOFTWARE USED IN STABILITY MODELING AND SEEPAGE ANALYSIS OF EARTHEN DAMS

Many numerical software's are developed from last six decades to evaluate engineering complex problems. Based on modelling approach, various numerical models are determined using softwares.

In our study, SLOPE/W and SEEP/W are components of a complete suite of geotechnical products called GEOSTUDIO. SLOPE/W can effectively analyse both simple and complex problems like Geometry, soil strength, pore water pressure, analysis methods and loading conditions like Steady state seepage and rapid or sudden drawdown condition applied on both upstream and downstream sides of the dam.

SLOPE/W is framed in terms of force and moment equilibrium to get a factor of safety equations.
The Morgenstern – Price method (1965) defines both moment and force equilibrium. To analyse the seepage of ground water, SEEP/W tool is used and also it helps to find the excess of pore water pressure dissipation problems within rock and soils called porous materials. Foundation material has a saturated hydraulic conductivity equal to $1\text{x}10^6$ m/sec. To define the hydraulic conductivity function over a range of positive and negative pressure to adequately reflect the decrease in

hydraulic conductivity that occurs as the soil becomes unsaturated. Ksat Upper soil = 1E-6 m/day, Ksat Lower soil = 1E-9 m/day.

According to IS 7894 – 1975, a) "steady seepage with the reservoir full on downstream side", the minimum factor of safety is **1.5** and (Duncan & Wright 2005, p.199) explains about a factor of safety provides a "quantitative indication of slope stability". They are:

(i) A calculated factor of safety value equal to 1.5 **(FOS = 1.5)** represents the forces on the slope being in equilibrium; that is the forces within the slope causing stability (resisting forces) are in balance with those which cause the slope to be unstable (driving forces).

(ii) A calculated factor of safety value greater than 1.5 **(FOS > 1.5)** represents the slope being stable under the given conditions (resisting forces > driving forces), and

(iii) A calculated factor of safety value less than 1.0 **(FOS < 1)** represents the slope is unstable (failing); that is the driving forces out the way the resisting forces.

According to IS 7894 – 1975, b) "sudden drawdown condition the maximum head water to minimum with tail water at maximum on upstream side", the minimum desired factor of safety is **1.3**

5. METHODOLOGY

5.1 Loading Conditions

In this study, two loading conditions studied like steady state seepage and sudden drawdown analysis. SEEP/W has been applied together with SLOPE/W. Two types of slip surface searching techniques: "Entry-exit" and "Grid-radius" were used. The most common limit equilibrium (LE) based method used is Morgenstern-Price Method (M-PM), which is incorporated in SLOPE/W to analyze the model with all four cases to find out the factor of safety on both upstream and downstream sides of the earthen dam contains over all height 10 m and maintained water level at 8 m on upstream side and other details shown in Figure no. 1

SLOPE/W uses the SOLVE process to calculate the FOS. Each slip surface is processed in 3 steps:

1. Initially, no forces are considered between the slices.
2. Normal forces are then considered, with no shear. An iterative process is used to calculate the FOS within a specified convergence
3. Then normal and shear force relationship is considered in Morgenstern-Price method.

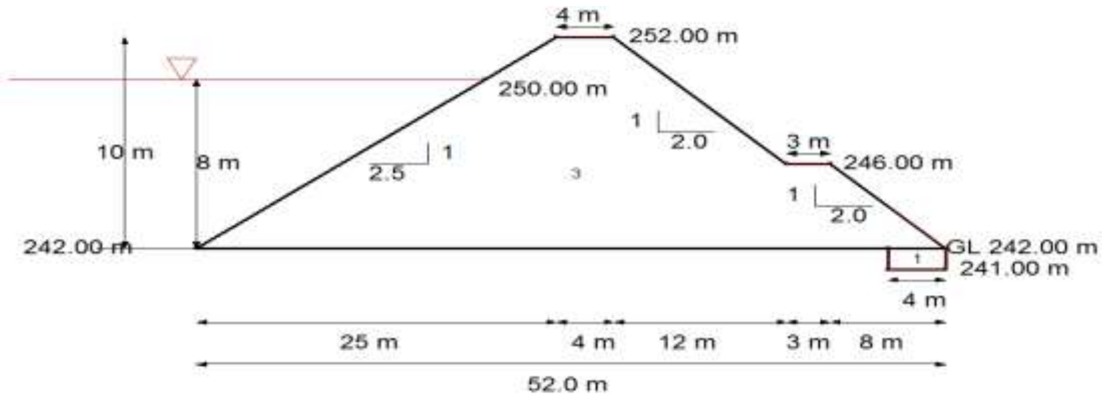


Fig No. 1 Earthen Dam Model

6. RESULTS AND DISCUSSIONS

6.1 Problem simulated using Software

In this paper, have cross checked all the four cases with loading conditions using the techniques to find out the factor of safety. But here, I have shown the improved factor of safety with their graphs for one simulation.

i) STABILITY OF D/S SLOPE DURING STEADY SEEPAGE ANALYSIS

a) "ENTRY AND EXIT": Cases (I to IV)

The simulation of **Case IV: With berm with drain case in steady seepage condition**

The berm is provided on the downstream side and also drainage filter is provided at the bottom of the toe on the downstream slope to improve the shear strength of the soil in the failure zone. After providing berm and drain on the downstream slope the factor of safety improved compared to above three conditions. The failure of slip circles was generated by specifying the entry of the slip circle at the toe and exit at the top bank of the embankment. The critical slip circle locates the corresponding factor of safety as shown in Figure 2 **(SLOPE/W with critical slip surface)** which is **1.64** and Figure 2.1 **(SEEP/W critical slip surface)** shows the magnitude contours of pore water pressures which are negative above phreatic line due to the suction and it is positive below phreatic line. The water flows from upstream slope to downstream slope of the earthen dam.

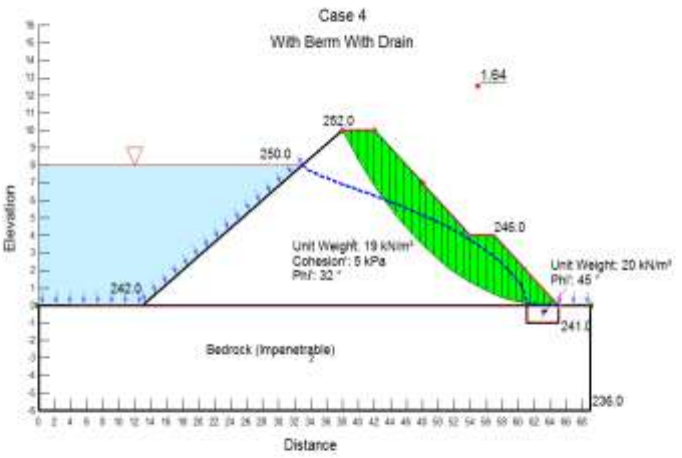
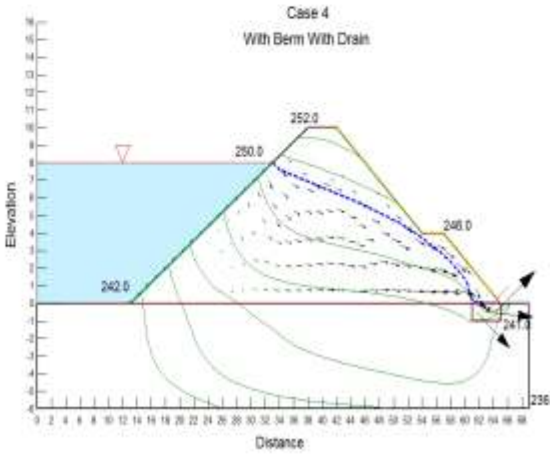


Fig. No: 2.0



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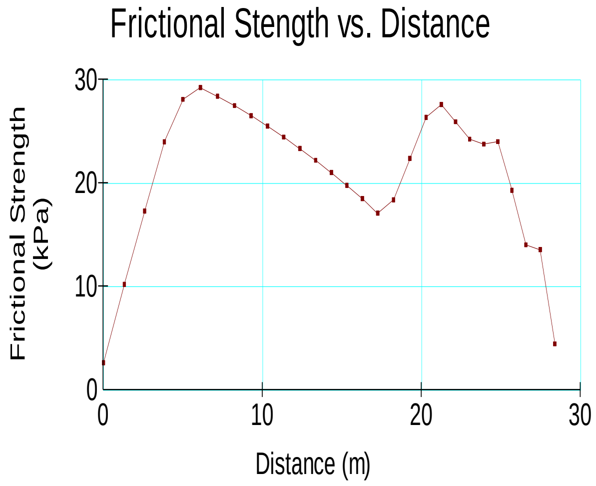
GRAPHS



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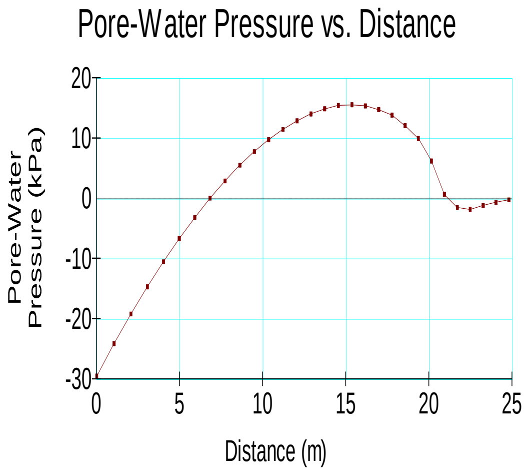


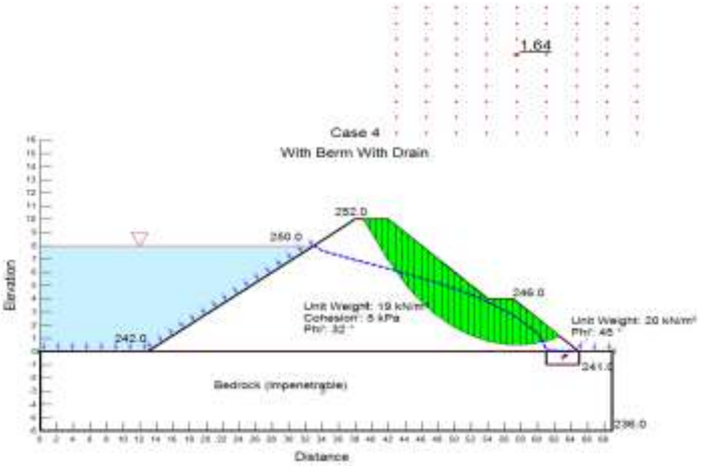
Fig. No: 2.3

Figure 2.2 shows the variation of frictional strength corresponding to distance along the critical slip surface from heel to the phreatic line (slice 6) and then it decreases the frictional strength and maintains constant from slice 7 to 17 again the strength increases from slice 18 to 21 and then decreases further up to till the last slice of the critical slip surface.

Figure 2.3 shows the variation of pore water pressure corresponding to distance along the critical slip circle on downstream slope, the graph depicts that the pore water pressure is negative at the heel of the downstream slope due to suction and it increases from the heel to the phreatic line and it becomes zero when the critical slip surface touches phreatic line and from the phreatic line the pore water pressure increases up to the maximum ordinate of the slices (slice 1 to 18) and it decreases further from slice 19 to 30 up to the toe of downstream slope.

b) "GRID AND RADIUS": Cases (I to IV)

The simulation of **Case IV: Stability analysis of an earthen dam with berm with drain-** Berm is provided on the downstream side and also drainage filter is provided at the bottom of the toe on the downstream slope to improve the shear strength of the soil in the failure zone. After providing berm and drain on the downstream slope the factor of safety improved compared to above three conditions. The failure of slip circles was generated by specifying the grid and radius of the embankment. The critical slip circle locates the corresponding factor of safety as shown in figure 3.0 which is **1.64.** Figure 3.1 shows the magnitude contours of pore water pressures which are negative above phreatic line due to the suction and it is positive below the phreatic line. The water flows from upstream slope to downstream slope of the earthen dam. The Graphs are generated same as like "Entry & Exit" technique.



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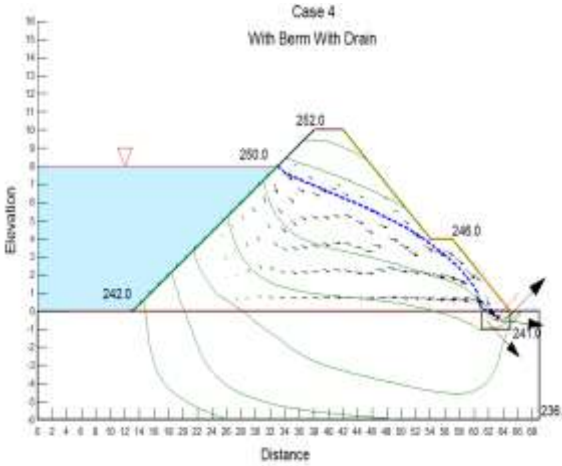


Fig. No: 3.1

ii) STABILITY OF U/S SLOPE DURING SUDDEN DRAWDOWN ANALYSIS

a) "ENTRY AND EXIT": Cases (I to IV)

The Simulation of **Case III: Without berm with drain -** Berm is neglected on the downstream side and drainage filter is provided at the bottom of the toe on the downstream slope to improve the shear strength of the soil and applied the drawdown condition on the upstream slope to find the critical slip surface. The failure of slip circles was generated by specifying the entry of the slip circle at the toe, and exit at the top bank of the embankment on the upstream side. The critical slip circle locates the corresponding minimum factor of safety as shown in figure 4.0 which is **1.35**.

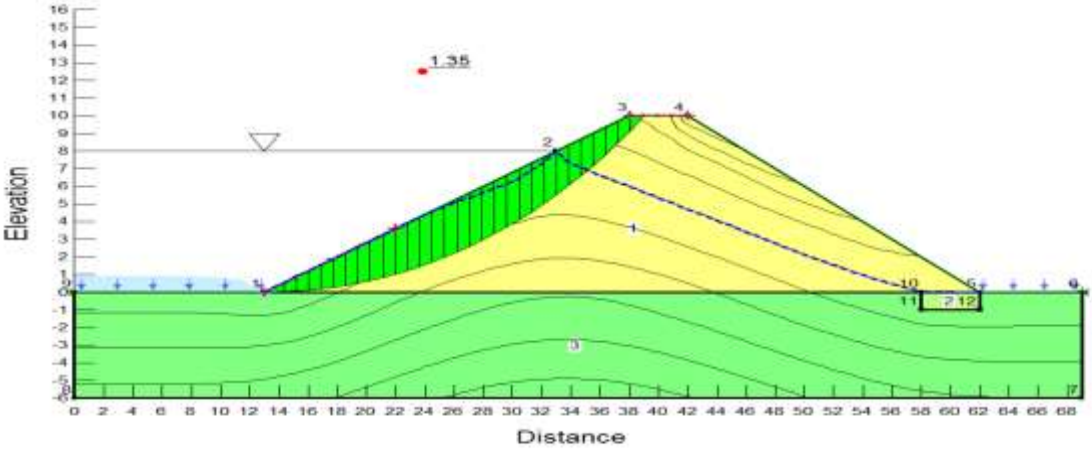


Fig. No: 4.0

b) "GRID AND RADIUS": Cases (I to IV)

The Simulation of **Case III: Without berm with drain -** Berm is neglected on the downstream side and drainage filter is provided at the bottom of the toe on the downstream slope to improve the shear strength of the soil and applied the drawdown condition on the upstream slope to find the critical slip surface. The failure of slip circles was generated by specifying the grid and radius of the embankment. The critical slip circle locates the corresponding minimum factor of safety as shown in figure 5.0 which is **1.30**

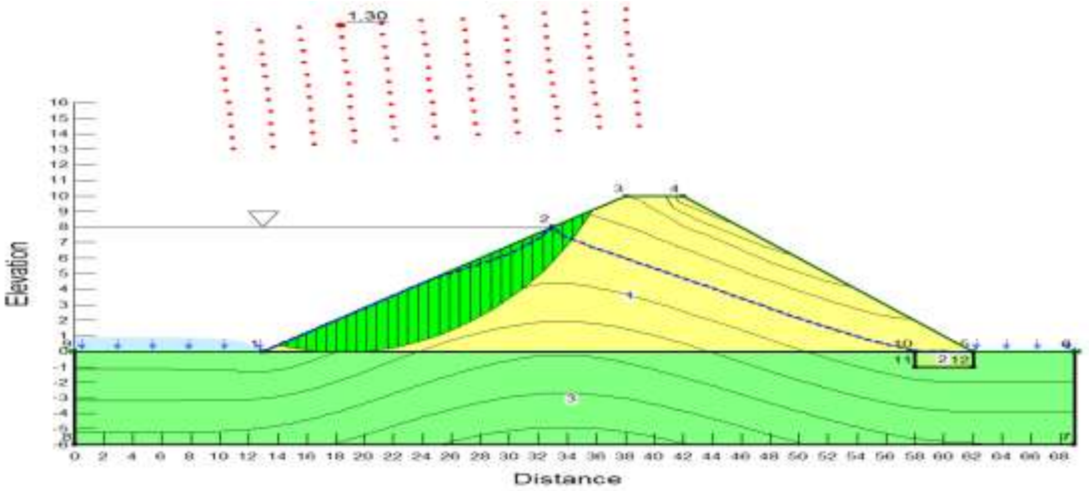


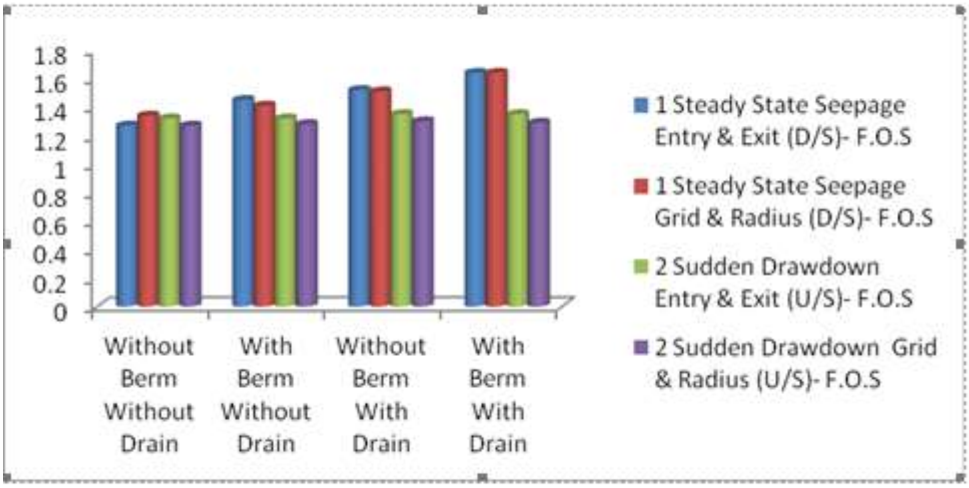
Fig. No: 5.0

7. RESULTS

SLOPE/W utilizes the limit equilibrium (LE) approach and as a result, the output is relatively simple. The typical cross section of homogeneous earthen dam is simulated using "Entry and Exit" and "Grid and Radius" technique of all the four cases showing the location of the critical slip surface, the corresponding vertical slices, and the critical FOS is displayed in Table 3.0

Table 3.0 Factor of Safety

Cases (I to IV)	**Steady State**		**Sudden Drawdown**	
	Factor of Safety		**Factor of Safety**	
	Entry & Exit	**Grid & Radius**	**Entry & Exit**	**Grid & Radius**
	Downstream Side		Upstream Side	
I. Without berm without drain	1.27	1.34	1.32	1.27
II. With berm without drain	1.45	1.41	1.32	1.28
III. Without berm with drain	1.52	1.51	1.35	1.30
IV. With berm with drain	1.64	1.64	1.35	1.29



8. CONCLUSIONS

- Steady state seepage and stability analysis on the downstream side are necessary for the homogeneous earthen dam.
  - The factor of safety is increased on downstream side after providing the berm and drain on the downstream side is **1.64** which is higher than a minimum factor of safety (FOS) specified by IS 7894 (1975) for steady seepage condition with a full reservoir.
  - Provision of drain increases the factor of safety on the downstream side.
  - In this analysis, the factors of safety values of all cases have been analyzed to find out the stability of the earthen dam. Out of all four cases, with berm with drain case is more suitable to stabilize the homogeneous earthen dam with a higher factor of safety (FOS).

- Sudden drawdown and stability analysis on the upstream side is necessary for the homogeneous earthen dam.
  - The factor of safety of upstream slope is increased to **1.35** by providing the drain on downstream side which is slightly more than a minimum factor of safety (FOS) of **1.3** as per IS: 7894 (1975) for sudden drawdown condition on the upstream side.
  - Provision of a drain on downstream side improves the factor of safety (FOS) on the upstream side.

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