Slope Stability Analysis of an Earthen Dam using GEOSTUDIO 2007 Software

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Abstract. Analysis of an earthen dam, especially its slopes, is very important these days as its failure may cause huge loss of lives and properties. These days numerical models are used to check the stability of an earthen dam. Numerical models simulate all the parameters, which affect the safety of an earthen dam. The most important parameters are properties of the soils used for the construction of an earthen dam. For the numerical modeling in this study, a finite element analysis software is used i.e., GEOSTUDIO 2007 (SEEP/W and SLOPE/W). The parameters considered in this analysis are the site and its foundation conditions, soil material characteristics and hazard potential associated with the particular site. To find the factor of safety, a numerical model of SLOPE/W and SEEP/W program of GEOSTUDIO software are tested for steady state condition and sudden drawdown. The Morgenstern-Price Method, based on limit equilibrium, which is incorporated in SLOPE/W to analyse the model for four cases, namely, earth dam without berm and without a toe drain, earth dam with berm without a toe drain, earth dam without berm with a toe drain and earth dam with berm with a toe drain. The results showed that out of four cases, the best case to improve the factor of safety of the slope is the fourth case i.e. earth dam with berm with a toe drain.

Keywords: Slope Stability Analysis; Steady State Seepage; Sudden Drawdown; Berm; Drained Blanket

1. Introduction

The construction of earthen dams has become more common as compared to other type of dams (i.e. concrete dam) in recent days, since earth dams are generally made up of locally available raw soil in their natural state with minimum of processing. The main purpose for this common usage is the construction method, which is based on easy techniques with utilization of cheap raw earth and subsurface materials. The advantages for the construction of earthen dams are that rigorous conditions are not required for the dam foundation, soil is easily available in most parts of the world close to possible dam sites, easy handling of soil and lesser cost of construction.

In olden days, designing of slopes were 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 huge loss of lives and properties. Now-a-days there is an increased demand for engineering cut and fill slopes in 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 in order to handle complex problems in the construction field. Embankments of earthen dams must be designed to construct stable slopes 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 has been carried out for the 14 m height of the homogeneous dam. The analysis has been performed using Mohr-Coulomb failure envelop. There are many methods of analysis such as Method of Slices, Bishop's method, Janbu's method and Morgenstern Method etc. using any of the methods one can determine the stability analysis.

GEOSLOPE is developed by GEO-SLOPE International, Canada, based on the principle of limit equilibrium which incorporates the finite element method, which is developed specially for determining the stability of an embankment. 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 have been used with "Morgenstern method" to do the stability analysis. SLOPE/W uses the theory of limit equilibrium of forces and moments to compute the factor of safety against failure. SLOPE/W solves two factor of safety equations; one equation satisfies force equilibrium and the other satisfies moment equilibrium. All the commonly used methods of slices can be visualized as special cases of the General Limit Equilibrium (GLE) solution.

One of the major factors for the failure of earthen dams is the seepage from their body and foundation. In order to prevent the failure of an earthen dam, it is necessary to control the seepage in dams. Therefore, seepage analysis for earthen dam is the main step and one of the major issues that has been considered in the present study and by many researchers. There are many commercially available softwares [1, 2] which provide the facilities of both seepage and stability analyses of an earthen dam. Zomorodian et al [3] studied the effect of horizontal drains on upstream side of earthen dams during rapid drawdown condition using finite element method and limit equilibrium methods. They determined the quantity of water seepage through the dam using the Seep/w program and factor of safety for the slope stability analysis by using the Slope/w program. Mula and Zhang [4] studied the effect of earthquake vibration on slope stability analysis using Geo-studio and Plaxis 2D software. The critical slip surface and factor of safety is calculated by using finite element method, limit equilibrium method and Morgenston – Price. They also studied the effect of dam height and its geometry on stability and liquefaction due to earthquake. Kamanbedast and Delvari [5] studied the behaviour of maroon soil dam with various parameters, which is situated at 19 km from North of Bahaman on maroon river . The stability analysis of maroon soil dam has been done using Ansys software and the results were compared with the result obtained from Geo studio Software. Karimi et al [6] studied the seepage analysis in Ilam earth fill dam using seep/w software. The four mesh size i.e. fine, medium, coarse and unstructured mesh was considered during the study. The results shows that average flow rate of seepage under the different mesh size for Ilam dam equal to 0.836 lit/sec for the whole length of the dam. Slope/w software is used with different methods such as Bishop, Janbu, ordinary method of slides and Morgenstern method for slope stability analysis. The minimum factor of safety obtained from each of the above method is considered as a factor of safety of the slope. Dodagoudar et al [7] studied the seepage and stability analyses of an earth dam using finite element method. The seepage analysis is divided into two categories i.e. steady state analysis and transient analysis. The study showed that with the increase in the value of young's modulus of core and shell, the maximum crest displacement decreases. Goswami and Borah [8] studied a case of a hydro-electric dam in the north-eastern region of India. The dam is an earth dam and section of the dam has been assumed as per the criteria and analysed using GEOSTUDIO software for the static case. Seepage analysis was conducted using seep/w software for the steady state and transient state. To determine the factor of safety of the upstream and downstream slopes, the slope stability analysis was performed using slope/w software. The slopes of the dam are considered to be reinforced with layers of geotextile. Devi and Anbalagan [9] studied the slope stability analysis of an earthen dams using GEOSTUDIO software. To derive factor of safety, a numerical model of SLOPE/W and SEEP/W program of GEOSTUDIO software was tested for steady state and sudden drawdown. Morgenstern and Price [10] reconstructed the method of slice, for circular and non-circular failure surface, by considering the inter-slice forces satisfying both moment and force equilibrium. Lowe [11] introduced a method satisfying only force equilibrium by considering both inter-slice normal as well inter-slice shear force with a difference in assumption for the inter-slice force function. Himanshu and Burman [12] studied the seepage and slope stability analyses of the earthen embankment dam of Durgawati reservoir project in the region of Kaimur–Bihar using geotechnical software GEOSTUDIO 2007.

2. Materials

For dam embankment, clay is used and for drain, sand is used. The properties like unit weight, cohesion and angle of internal friction for clay and sand are listed in Table 1 and Table 2.

Table 1. Embankment Properties

Type of Soil	Symbol	Property	Assumed Value
Clay	[illegible]	Unit Weight of Soil (kN/m^3)	16
	c	Cohesion of Soil (kN/m^2)	45
	ϕ	Angle of Internal Friction (^{0})	5
	k	Permeability (m/sec)	8.149×10^{-7}

Table 2. Drain Properties

Type of Soil	Symbol	Property	Assumed Value
Sand	[illegible]	Unit Weight of Soil (kN/m^3)	18
	c	Cohesion of Soil (kN/m^2)	0
	ϕ	Angle of Internal Friction (^{0})	38
	k	Permeability (m/sec)	9.65×10^{-6}

3. Methodology

The stability of slope is characterized by the term factor of safety (FOS), defined as the ratio of the summation of shear resistance and shear mobilized for individual slices:

$$FOS = \frac{\sum shear\ resistance}{\sum shear\ mobilized} \quad (1)$$

For steady- state seepage analysis, the mathematical formula associated with it, is expressed as:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = 0 \quad (2)$$

where H = total available hydraulic head difference, k_x = the hydraulic conductivity in the horizontal x-direction, t = time, Q = applied boundary flux i.e. discharge, k_y = the hydraulic conductivity in the vertical y-direction.

The earthen dam height is assumed to be 14 m with a free board of 2 m. The water level is maintained at 8 m on upstream side. The embankment section having upstream slope of 2.5 H: 1 V and downstream slope of 2 H: 1 V. The top width of dam is taken as 6 m. A berm of 4 m is provided on the downstream side at the height of 7 m and toe drain having 2 m depth and 4 m in length. In this study, two loading conditions i.e., steady state analysis and sudden drawdown analysis is used. SEEP/W has been applied together with SLOPE/W. "Entry-exit" type of slip surface are used. The Morgenstern-Price Method is based on limit equilibrium, which is incorporated in SLOPE/W to analyze the model with all the four cases to find out the factor of safety on downstream sides of the earthen dam . The four cases, namely, earthen dam without berm and without a toe drain, earthen dam with berm without a toe drain, earthen dam without berm with a toe drain and earthen dam with berm with a toe drain are illustrated in the figure below.

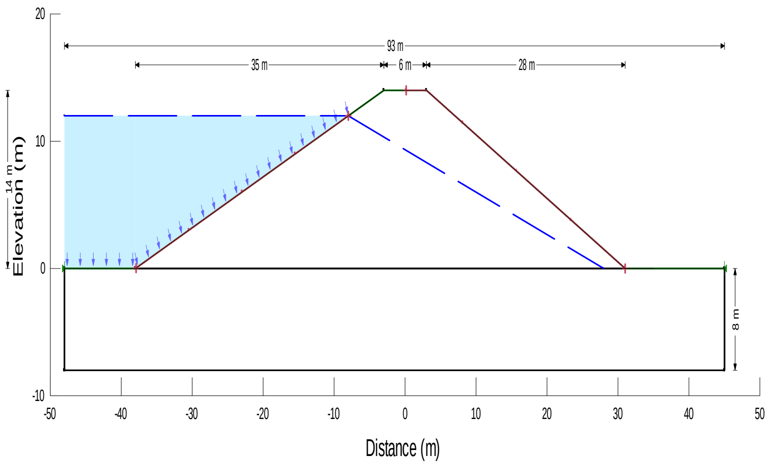

Fig. 1. Earthen Dam Model without Berm and without Drain

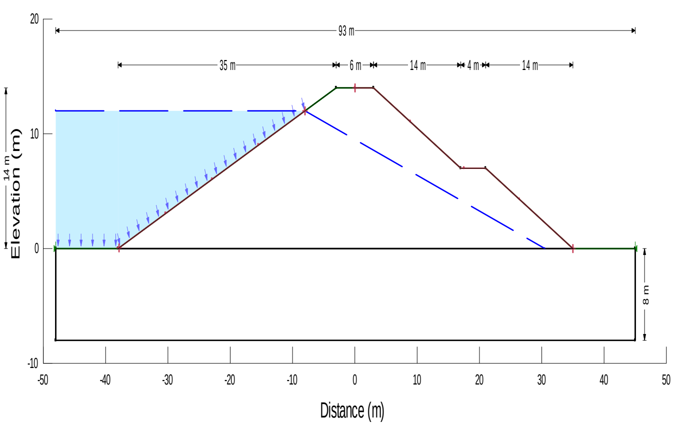

Fig. 2. Earthen Dam Model with Berm and without Drain

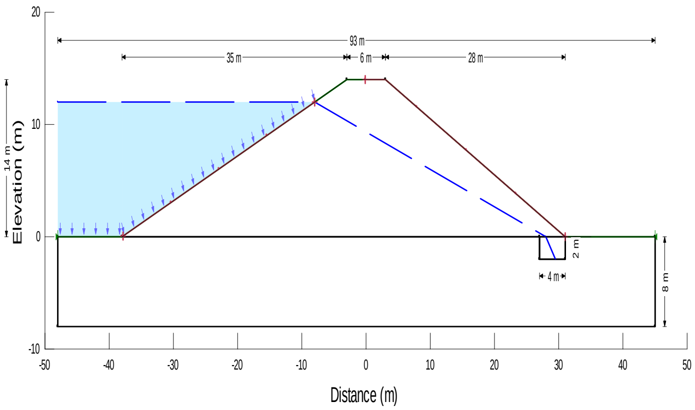

Fig. 3. Earthen Dam Model without Berm and with a Drain

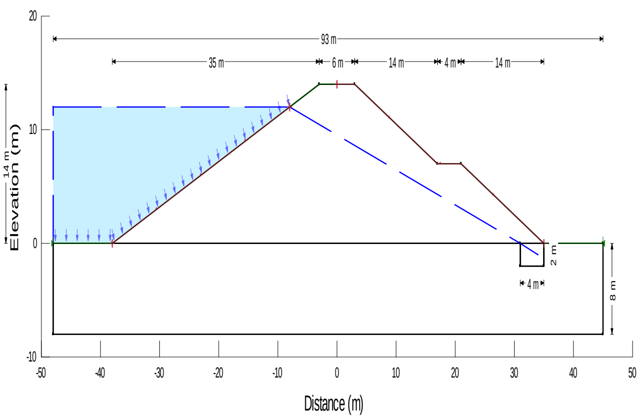

Fig. 4. Earthen Dam Model with Berm and with a Drain

4. Results and Discussion

The results were obtained for the four different cases i.e., the factor of safety for the earthen dam model without berm and without drain is found out to be **1.908** and **2.229 (**for downstream side and upstream side respectively) as shown in Figure 5 & 6, for the earthen dam model with berm and without drain is found out to be **2.069** and **2.220 (**for downstream side and upstream side respectively) as shown in Figure 7 & 8, for the earthen dam model without berm and with drain is found out to be **2.189** and **2.243 (**for downstream side and upstream side respectively) as shown in Figure 9 & 10 and for the earthen dam model with berm and with drain is found out to be **2.390** and **2.205 (**for downstream side and upstream side respectively) as shown in Figure 11 & 12.

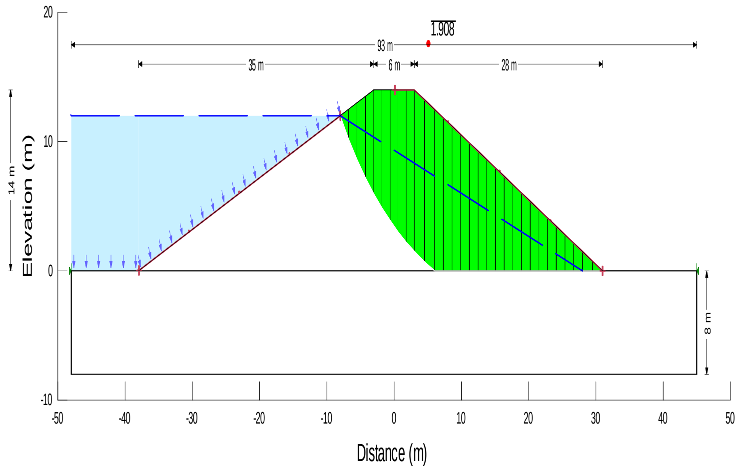

Fig. 5. Result obtained for Earthen Dam Model without Berm and without Drain for D/S

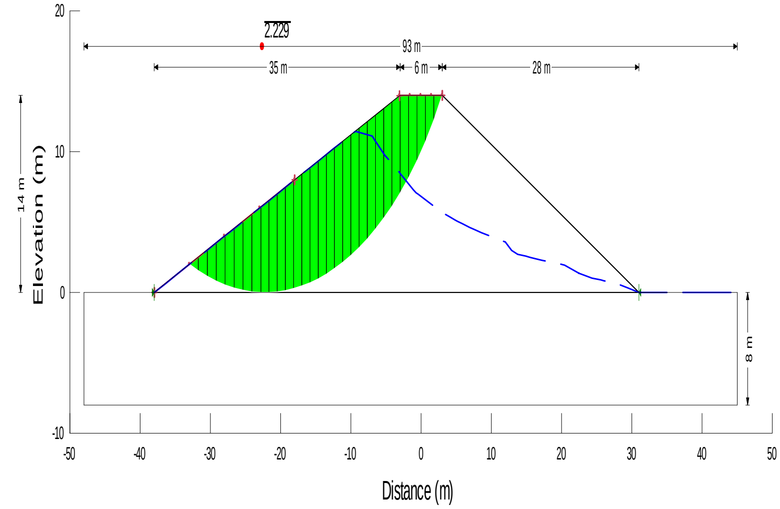

Fig. 6. Result obtained for Earthen Dam Model without Berm and without Drain for U/S

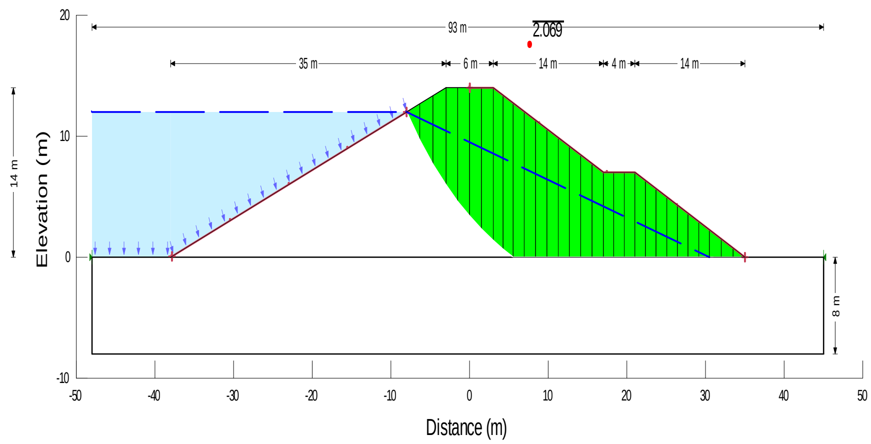

Fig. 7. Result obtained for Earthen Dam Model with Berm and without Drain for D/S

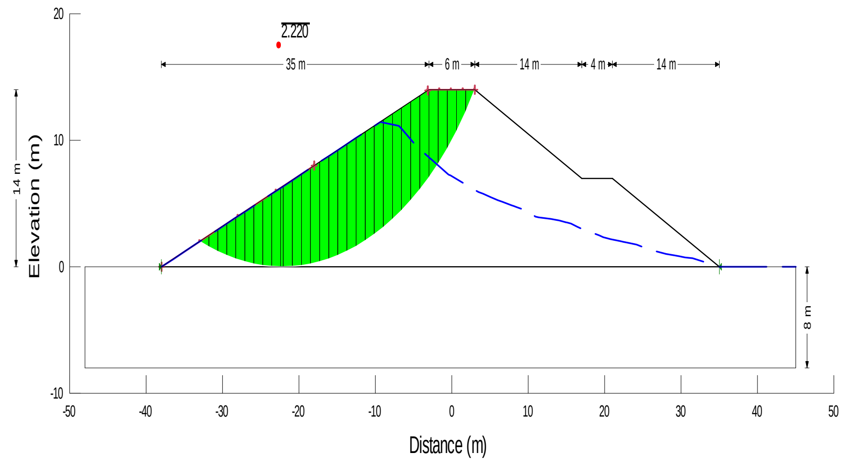

Fig. 8. Result obtained for Earthen Dam Model with Berm and without Drain for U/S

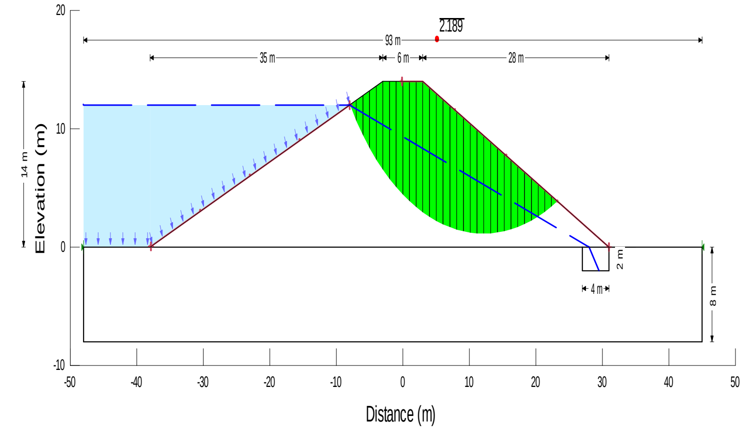

Fig. 9. Result obtained for Earthen Dam Model without Berm and with Drain for D/S

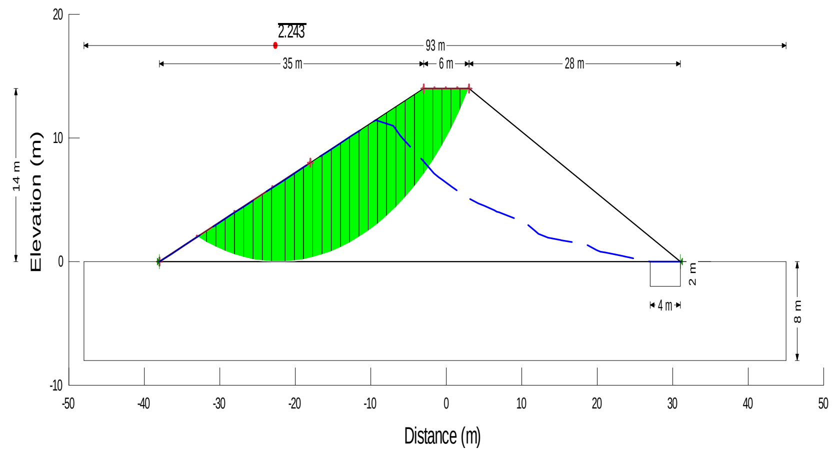

Fig. 10. Result obtained for Earthen Dam Model without Berm and with Drain for U/S

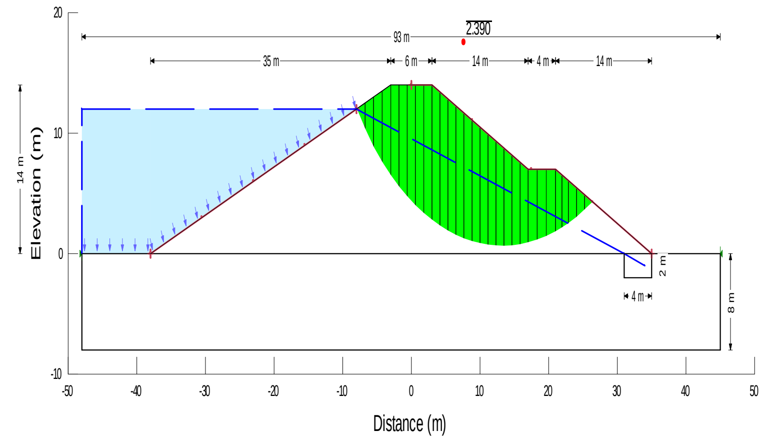

Fig. 11. Result obtained for Earthen Dam Model with Berm and with Drain for D/S

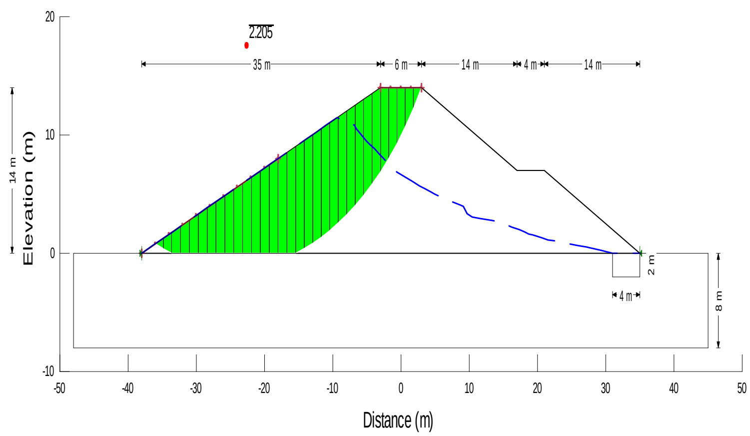

Fig. 12. Result obtained for Earthen Dam Model with Berm and with Drain for U/S

4.1 Stability of D/S Slope during 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 side to improve the shear strength of the soil in the failure zone. After providing berm and drain on the downstream side the factor of safety improved (Fig. 11) as compared to above three cases (Figs. 5,7,9). The failure slip circle was generated by specifying the entry of the slip circle at the toe and exit at the top of the embankment. The critical slip circle locates the corresponding factor of safety (Figs. 5, 7, 9, 11).

4.2 Stability of U/S Slope during Sudden Drawdown Condition

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 (Fig. 10). The critical slip surface for other three cases is also found out (Figs. 6,8,12). The failure slip surface is 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 factor of safety (Figs. 6,8,10,12). Finally, all the factor of safety values for different cases are shown in Table 3.

Table 3. Factor of safety for different cases

CASES	FACTOR OF SAFETY	
	Steady State	**Sudden Drawdown**
I. Without berm without drain	**1.908**	**2.229**
II. With berm without drain	**2.069**	**2.220**
III. Without berm with drain	**2.189**	**2.243**
IV. With berm with drain	**2.390**	**2.205**

5. Conclusions

Based on the above results, the following conclusions are made

1. The factor of safety is increased on downstream section after providing the berm on the d/s side.
2. The factor of safety is increased on downstream section after providing the toe drain.
3. Out of four cases, the best case to improve the factor of safety of the slope is the fourth case i.e. earthen dam with berm and with a toe drain.

References

1. SLOPE/W, Stability Analysis, Users Guide Version 5, GeoSlope Office, Canada, 2002, http://www.geoslope.com, last accessed 2019/08/27.
2. GeoStudio Tutorial Manual, GEO-SLOPE International Ltd, http://www.geo-slope.com, last accessed 2019/08/27.
3. Zomorodian, S., Abodollahzadeh, M.: Effect of Horizontal Drains on Upstream Slope Stability During Rapid Drawdown Condition. International Journal of Geology 42 (66), 29-34 (2010).
4. Zhang, L., Maula, B. H.: Assessment of Embankment Factor Safety Using Two Commercially Available Programs in Slope Stability Analysis. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, vol. 14, pp. 559-566. Elsevier (2011).
5. Delvari, A., Kamanbedast. A.: Analysis of Eath Dam: Seepage and Stability Using Ansys and Geo-Studio Software. World Applied Sciences Journal 17 (9), 1087-1094 (2012).

6. Hasani, H., Mamizadeh, J., Karimi, H.: Stability of Slope and Seepage Analysis in Earth Fills Dams Using Numerical Models (Case Study : IIam DAM-Iran).World Applied Science Journal 21 (9), 1398-1402 (2013).
7. Athani, S. S., Shivamanth, Solanki, C. H., Dodagoudar, G. R.: Seepage and Stability Analyses of Earth Dam Using Finite Element Method. ICWRCOE 2015, vol.4, pp. 876-883. Elsevier (2015).
8. Goswami, D., Borah, U.: ANALYSIS AND DESIGN OF EARTH AND ROCKFILL DAMS. Indian Geotechnical Conference IGC 2016.
9. Anbalagan, R., Devi, D.: Study on Slopes of Earthen Dam by Using GEOSTUDIO Software. IJARIIT 3(6), 408-14 (2017).
10. Morgenstern, N. R., Price, V. E.: The Analysis of the Stability of General Slip Surfaces. Geotechnique 15(1), 77-93 (1965).
11. Lowe, J.: Stability Analysis of Embankments. Journal of the Soil Mechanics and Foundations Division. ASCE 93(4), 1-33 (1967).
12. Himanshu, N., Burman, A.: Seepage and stability analysis of Durgawati earthen dam: a case study. Indian Geotechnical Journal 49(1), 70-89 (2019).