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EVALUATION OF STATIC STABILITY OF EARTH DAMS USING GEOSTUDIO SOFTWARE (CASE STUDY: NIAN DAM, IRAN)

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Abstract: In this paper, Nian earth dam static stability is investigated using slope/w software. Slope/w is one of thesoftwares of the geostudio collectionwhich is based on the finite element method. Downstream slope of the earth dam at the end of the construction phase and steady state phase is considered to be critical. Upstream slope of the earth dam at the end of the construction phase and a sudden drop in water level phase is also considered to be in critical condition. In these phases, the slope of the Nian dam is analyzed by Ordinary, Bishop, Janbu and Spencer methods and safety factors are calculated. It was found that the minimum factor of safety is related to the Ordinary method and the end of construction phase compared to the other phases has the most safety factor. The calculated safety factors are compared to minimum safety factors provided by United States army.
Keywords: earth dam, static stability, finite element method, safety factor

1. INTRODUCTION

Earth dam is one of the oldest building facilities that people need to build due to the basic needs in areas of agriculture and drinking water. The main body of earth dams are usually made without the use of mortar materials like rubble stones, rubbles, gravel, sand, silt and clay as either a mixture, separate, homogeneous or being zoned. Hence, the construction of earth dams are generallymore economical. Slope stability analysis of earth dam is very important to the ascertainof static stability of the structure. The purpose of static stability of earth dam is to maintain stability and prevent the movement of earth dam components against static forces. In other words, an earth dam is stable whentotal applied stress to any part of dam is smaller than the mobilized stress in that part. Thus the stability of earth dam is a relative issue and by relative changing the values of active and passive forces, there can be varying degrees of stability. Hence, in the design of earth dams the relative stability is measured with criterion which is called the safety factor. The higher the safety factor level, the more will be reflecting degree of stability [1].

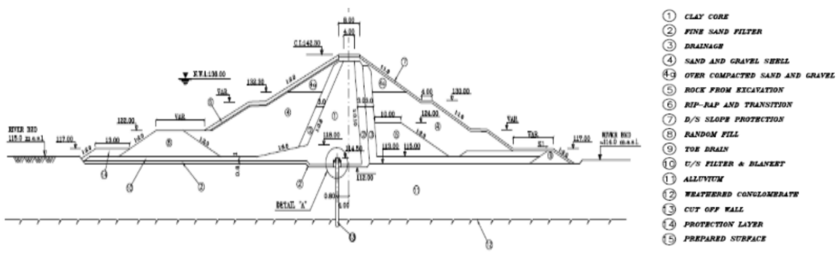

Figure 1. Cross section of Nian dam

2. MATERIALS AND METHODS

Nian dam is an earth dam with a clay core which is located at $55'$ and $39''$ degrees east and 28 and 16 degrees north in Hormozgan province in Iran.Cross section of Nian dam is shown in Figure 1. Material property related to slope stability analysis is shown in Table 1.

Table 1. Material property related to slope stability analysis

Material	Specific weight (KN/m³)		Resistance parameters	
	wet	saturated	Adherence (KPa)	Angle of friction (degree)
Shell	23.1	23.4	0	43
Core UU state CU state CD state	20.8	21.3	83 40 5	23 28 33
Weir mix	21	22	0	36
Foundation	21	22	0	30

There are several methods to evaluate the static stability of earth dams. They can be divided into two general groups, limit equilibrium and finite element method.

Limit equilibrium method: the limit equilibrium method is based on the determination of applied stress and stress mobilized in a hypothetical failure surface in a steep embankment and then determination ofsafety factor considering the ratio of these two quantities.

Finite element method: In the finite element method, the maximum and minimum principal stresses throughout the body and dam foundation are calculated and based on the results of principal stresses, shear stresses are determined. The resultant calculated shear stresses are compared with the shear strength across the dam and its foundation and as a result the safety factor will be obtained against failure. Finite element method was introduced for the first time for geotechnical issues by Clough and Woodward [2] in 1967 but using this method for the analysis of large soil structures such as earth dams was first presented by Duncan [3] in 1996.

Software introduction: In this paper, the finite element method is used to evaluate the static stability of Nian dam. Several softwares are used to verify the stability of structures are available in the market that uses the finite element method. One such software is slope/w which is among the geostudio software collection. This software was first introduced in 1997 and since the new features were added to it. One of the features of slope/w is that the analysis carried out in the other softwares of the geo studio collection cab ne easily added to it.

3. RESULTS AND DISCUSSION

Slope/w software was used to investigate the stability of Nian dam. Critical phases of upstream slope stability are the end of construction and sudden drop in water level phases, critical phases of downstream slope stability are the end of construction and steady state phases. Hence, these slopes in their critical phases are analyzed.

3.1. The study of upstream and downstream slope stability at the end of construction phase

Nian dam was built using sigma/w. Sigma/w is one of geostudiosoftwares, which uses finite element method for the analysis of stress and deformation of soil structures. Nian dam was built in 13 layers under its own weight. Then the upstream and downstream slope stability of Nian dam was assessed using the slope/w. Mohr-coulomb criterion was used to investigate the behavior of soil. Slip wedges in upstream and downstream slopes of Nian dam is shown in Figures 2 and 3, respectively.

3.2. The study of downstream slope stability at the steady state phase

Seep/w software is used to investigate steady-state phase of Nian dam. Seep/w is one of geo studio software collection which calculates the leakage using partial differential equations that shows the water flow. Differential equations governing the flow in two-dimensional mode to be the following:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial H}{\partial y}\right)=0 \tag{1}$$

where k_x, k_y are coefficient of permeability in (x,y) directions, and H is total head of water. Then the downstream slope stability of Nian dam was assessed using the slope/w. Mohr-coulomb criterion was used to investigate the behavior of soil. Slip wedge in downstream slope of Nian dam is shown in Figure 4.

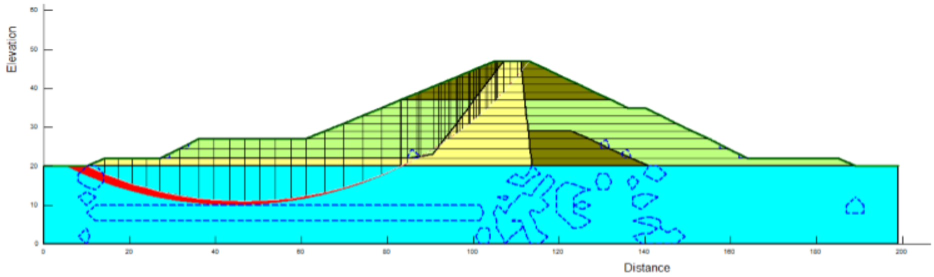

Figure 2. Slip wedge in upstream slope of Nian dam at the end of construction phase

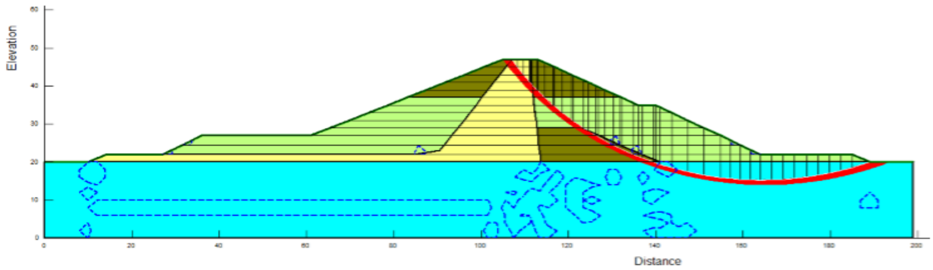

Figure 3. Slip wedge in downstream slope of Nian dam at the end of construction phase

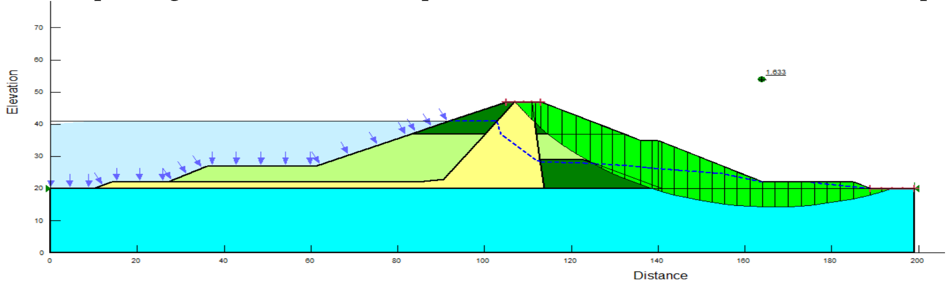

Figure 4.Slip wedge in downstream slope of Nian dam at the steady state phase

3.3. The study of upstream slope stability at the sudden drop in water level phase

Nian dam is modeled in steady state phase using seep/w, and then the sudden drop in transient state of water for a period of 30 days, using 10 exponential time steps.Figure 5 shows a pore pressure distribution 6 days after the sudden drop. As can be seen, flow in upstream is toward the tank while in downstream is toward a toe.

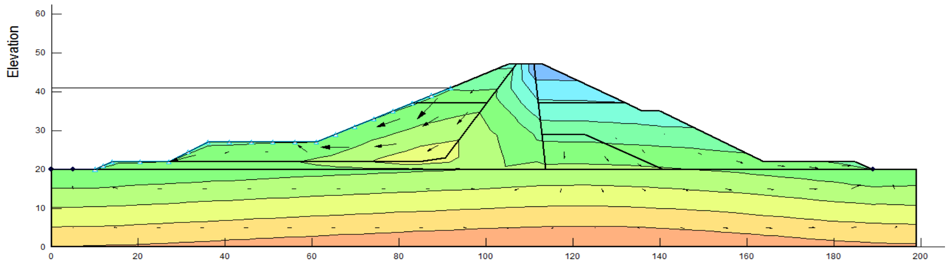

Figure 5. Pore pressure distribution 6 days after the sudden drop

In order to obtain safety factor and upstream slope stability analysis, the model built in the seep/w has been opened in the slope/w and using an appropriate method the slope stability is analyzed. Mohr-coulomb criterion was used to investigate the behavior of soil. Slip wedge in downstream slope of Nian dam is shown in Figure 6.

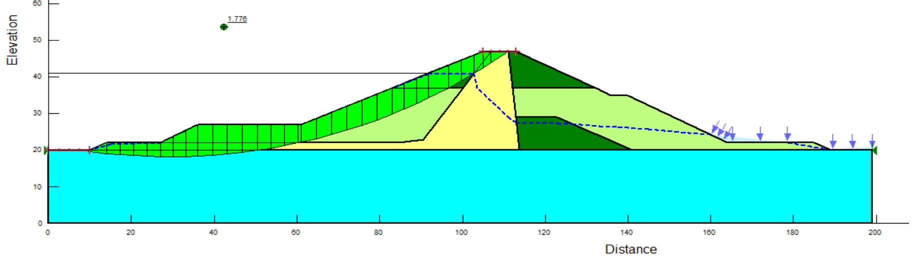

Figure 6. Slip wedge in downstream slope of Nian dam at the sudden drop in water level phase

Analyses in three previous phases with Bishop, Janbu, Ordinary and Spencer methodshas been calculated.The minimum safety factor in each of these methods, has been considered as a safety factor of slope stability as shown in Table 2.

Table 2. Summary results of safety factors for stability slope analysis

Analysis method	Downstream slope after construction	Upstream slope after construction	Downstream slope in steady-state leakage	Upstream slope in sudden drop in water level
Ordinary method	1.903	2.463	1.477	1.7
Bishop method	2.119	2.782	1.647	1.822
Janbu method	1.942	2.477	1.537	1.754
Spencer method	2.097	2.768	1.638	1.8

Comparison of different methods shows that Ordinary method gives lowest safety factor. Comparison of the phases of slope stability shows that the highest safety factor id obtained at the end of construction stage because pore pressure distribution is lower than other stages.

The United States army has provided the minimum acceptable safety factor in the stability analysis of earth dams as shown in Table 3 [4].

Table 3. The minimum acceptable safety factor in the stability analysis of earth dams.

Conditions for stability analysis	The minimum acceptable safety factor			
	Upstream slope		Downstream slope	
	No earthquake	earthquake	No earthquake	earthquake
End of the construction phase	1.25	1.0	1.25	1.0
Steady state, tank half full	1.5	1.25	-	-
Steady state, tank full	-	-	1.5	1.25
Sudden drop in water level	1.25	1.0	-	-

Safety factors obtained from different methods are compared with minimum acceptable safety factors provided by United States army.It is evident that the obtained safety factors of all phases using different methods are bigger than the minimum values and only in steady state with Ordinary Method the safety factor is 1.477 that it is lower than the minimum value of 1.5.

4. CONCLUSION

In this paper using the slope/w software, stability slope analysis in Nian dam is studied. Downstream slope of the earth dam at the end of the construction phase and steady state phase is considered to be critical. Upstream slope of the earth dam at the end of the construction phase and a sudden drop in water level phase is also considered to be in critical condition. In these phases, the slope of the Nian dam is analyzed by Ordinary, Bishop, Janbu and Spencer methods and safety factors are calculated. It was found that the minimum factor of safety is related to the Ordinary method and the end of construction phase compared to the other phases has the most safety factor. Safety factors obtained from different methods are compared with minimum acceptable safety factors provided by United States army. It is evident that the obtained safety factors of all phases using different methods are bigger than the minimum values and only in steady state with Ordinary Method the safety factor is 1.477 that it is lower than the minimum value of 1.5.

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