Slope Stability Analysis by Finit Element Methods (Case Study: Mandali Dam)

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Abstract— The slope stability is a very important problem in geotechnical engineering. In this work, by applying the Morgenstern-Price presented by the computer program SLIDE V.6.0 to define the potential slip surface and calculate the factor of safety of zoned earth dams (Mandali dam in Iraq) under Four main critical conditions considered in the analysis are end of construction, steady state(Maximum Reservoir Level for upstream and Minimum Reservoir Level), steady state with seismic loading ,which allow the user to get the Minimum safety factor of the dam, immediately, according to the material classification and the parameters of design, height and slope.

Keywords — Earth Dam, The finite element, Morgenstern-Price method, factor of safety, Seismic force, side slope stability

1 INTRODUCTION

Slope stability analysis using computers is an easy task for engineers when the slope configuration and the soil parameters are known. However, the selection of the slope stability analysis method is not an easy task and effort should be made to collect the field conditions and the failure observations in order to understand the failure mechanism, which determines the slope stability method that should be used in the analysis. Therefore, the theoretical background of each slope stability method should be investigated in order to properly analyze the slope failure and assess the reliability of the analysis results.Two dimensional slope stability methods are the most common used methods among engineers due to their simplicity. However, these methods are based on simplifying assumptions to reduce the three-dimensional problem to a two-dimensional problem and therefore the accuracy of the analysis results vary between the different analysis methods.

A stability analysis of earth dams and banks requires consideration of the coupled effects of:loads such as body weight, surcharge, and forces caused by sequential construction. Seepage forces due to steady or transient flow of water. Often, for simplicity, the effects of external and seepage forces are uncoupled and superimposed [Li and, Desai, 1983] Static slope stability method include Limit equilibrium analysis and stress deformation analysis. Limit equilibrium analysis consider force and/or moment equilibrium of a mass of soil above a potential failure surface (Patel and Sanghvi (2012))

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The computer program (SLIDE V.6.0) has been utilized to analyze the stability of the Mandali Dam. The loading conditions considered in the present analysis are minimum water level 172.0, maximum water level 182.5 and seismic forces0.07. The limit equilibrium method (LEM) according to Morgenstern-price presented by computer program (SLIDE V.6.0) is applied to define the potential slip surface and calculate the factor of safety of the dam slopes. The failure area is assumed and divided into a number of sections. The equilibrium of each section is considered and finally a factor of safety for the assumed slip surface is determined, considering the equilibrium of the whole mass. The potential slip surface and factor of safety are iteratively determined until a critical slip surface and minimum factor of safety have been found

2 SLOPE STABILITY ANALYSIS

Most of the methods currently utilized in slope stability analysis are based on the limit equilibrium approach. The essential assumption of this approach is the validity of well known Moher-Coulomb failure criterion which defines the shear strength of soil as follows:

$$S = c + \sigma \tan\varphi \qquad (1)$$

where (c) and (ϕ) are cohesion intercept and effective angle of internal friction, respectively, and (σ) is the normal effective stress The method of limit equilibrium assumes that the shear strength of the soil is partially mobilized along an assumed failure surface which my be a straight line, circular arc, logarithmic spiral curve or any other irregular surface. The method, however, defines the factor of safety (FOS) as the ratio of available shear strength (S) and the developed shear stress (τ):

$$\mathrm{FOS} = S / \tau \qquad (2)$$

Equation (3) is a form of definition introduced by Bishop (1955) which has gained fairly wide acceptance. The factor of

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safety (FOS) is taken as the ratio of the total shear strength available on the slip surface to total shear strength mobilized (τ) in order to maintain equilibrium [Spencer, 1967]. The interest lies in materials that are saturated with groundwater; in such a case, equation (2) takes the form:

$$S = c + (\sigma - u)\tan\varphi \qquad (3)$$

In which (u) is the pore water pressure. For the mentioned definition, the method of slices appears as a good approach for obtaining an accurate solution for any shape of failure [Whitman, and Bailey, 1967].

3 MORGENSTERN AND PRICE'S METHOD

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.The the Morgenstern-Price method was developed by Morgenstern and Price (1965), which considers not only the normal and tangential equilibrium but also the moment equilibrium for each slice in circular and non-circular slip surfaces. In this method, a simplifying assumption is made regarding the relationship between the interslice shear forces (X) and the interslice normal forces (E) as:

$$X = \lambda \cdot f(x) \cdot E \qquad (4)$$

where, f(x) is an assumed function that varies continuously across the slip, and (λ) is an unknown scaling factor that is solved for as part of the unknowns.

The unknowns that are solved for in the Morgenstern and Price method are the factor of safety (FOS), the scaling factor (λ), the normal forces on the base of the slice (P), the horizontal interslice force (E), and the location of the interslice forces (line of thrust). Once the above unknowns are calculated using the equilibrium equations, the vertical component of the resultant force on the interslice forces (X) is calculated from equation (4).

$$P = \frac{\left[W - (X_R - X_L) - \frac{1}{f}\left(c^{-} l \sin\alpha - ul\tan\phi^{-}\sin\alpha\right)\right]}{m_\alpha} \qquad \ldots (5)$$

where:

P: Normal force on the base of the slice

W: Weight of slice

XR : Vertical component of the resultant force on the interslice (from right side of slice)

XL : Vertical component of the resultant force on the interslice (from left side of slice)

Two factor of safety equations are computed, one with respect to moment equilibrium (Fm) and the other with respect to force equilibrium (Ff). The moment equilibrium equation is taken with respect to a common point as:

$$F_m = \frac{\sum\left[c^{-} l + (P - ul)\tan\phi^{-}\right]R}{\sum\left(Wd - P_f\right)} \qquad (6)$$

For circular slip surfaces: f = 0, d = Rsinα and R = constant;

$$F_m = \frac{\sum\left[c^{-} l + (P - ul)\tan\phi^{-}\right]}{\sum W\sin\alpha} \qquad (7)$$

The factor of safety with respect to force equilibrium is:

$$F_f = \frac{\sum\left(c^{-} l + (P - ul)\tan\phi^{-}\right)\cos\alpha}{\sum P\sin\alpha} \qquad (8)$$

On the first iteration, the vertical shear forces (X_R and X_L) are set to zero. On subsequent iterations, the horizontal interslice forces are first computed from:

$$(ER - EL) = P\sin\alpha - \frac{1}{f}\left[c^{-} l + (P - ul)\tan\phi^{-}\right]\cos\alpha \qquad (9)$$

where:

ER: Horizontal interslice force (from right side of slice)

EL: Horizontal interslice force (from left side of slice)

l: The inclined width of slice

u: Pore water pressure

P: Normal force on the base of the slice

This method of slope stability analysis, which is valid for slip surfaces of any arbitrary shape, is considered as the more general rigorous method [Baker, 1980]. It stems its generality from the fact that no stringent restriction is imposed neither on the direction or location of the interslice forces nor on the shape of the slip surface analyzed [Al-Jorany, 1996].

4 SEISMIC FORCE (EARTHQUAKE)

Dynamic loads generated by seismic disturbances must be considered in the design of all major dams situated in recognized seismic 'high-risk' regions. The possibility of seismic activity should also be considered for dams located outside those regions, particularly where sited in close proximity to potentially active geological fault complexes. Seismic activity is associated with complex oscillating patterns of accelerations and ground motions, which generate transient dynamic loads due to the inertia of the dam and the retained body of water. Horizontal and vertical accelerations are not equal, the former being of greater intensity. For design purposes both should be considered operative in the sense least favourable to stability of the dam. Horizontal accelerations are therefore assumed to operate normal to the axis of the dam.(Novak and Nalluri,(2007))

If seismic coefficients are defined, a seismic force will be applied to each slice as follows:

Seismic Force = Seismic Coefficient * Slice Weight (10)

From this definition it can be observed that the seismic force increases when slice weight increases.

5 CASE STUDY

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The Mandali Dam is one of an earth fill dams in Iraq, which had been designed by Directorate General of Dam and Reservoirs. Which is located on Harran Wadi, in the governorate of Diyala which is extends to the northeast of Baghdad. The dam site is situated upstream Koma sang pipe line headwork the area of the dam is bounded by the following coordinates (373700-378500) N, (554500-565000) E. The dam is a low dam, which acts in most of its parts as a submerged weir. The Wadi bed is gravely and permeable to some depth as it is clear from geological investigation

Mandali dam with a central core total length of the dam is about (1316 m) and its maximum height is about (14m). The shell, which is composed mainly of poorly graded gravel with high percentage of coarse gravel , and the central core, the investigation and laboratory testing show clay the available materials at site as a construction material for core (Directorate General of Dams and Reservoire,(2004)). Figure (1) shows a typical cross section of Mandali dam

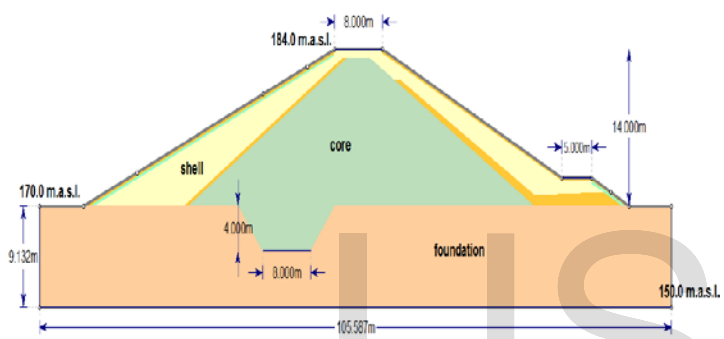

Figure (1) typical cross section of Mandali dam

6 MODELING AND ANALYSIS

The finite element mesh used in this analysis is as shown in figure (2); 3 node triangles elements are used to describe the domains. The mesh contains 2500 element and 1624 node; The first step in our analysis are concerning about selected the numbers of element and selected these value when the number of element became independents of solution, in this case any increment in the number of element dose not effected on the values of solution in domain of analysis the number of elements is selected from mesh generation from change in phreatic surface

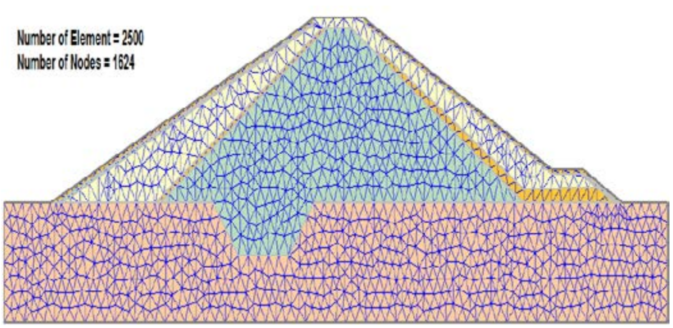

Figure (2) Finite Element Mesh for the Mandali Dam

7 ANALYSIS AND DISCUSSION

It is very important to define the techniques that are used to select the shape of the slip surface and location of the critical slip surface. The [U.S. Army Corps of Engineers, 2003a] recommended that the shape and location of the critical slip surface are subjected to the limitations: Shape of the slip surface and Location of the critical slip surface From these assumptions and limitation of (U.S. Army Corps of Engineers, 2003a) the slip surface types used in the present analysis are circular slip surfaces. The analysis method used is the limit equilibrium method (LEM) according to Morgenstern-price. The strength model used in the present analysis, is Mohr-Coulomb.

The loading conditions considered in the present analysis are minimum water level 173.0, maximum water level 182.5 and seismic forces0.07. The limit equilibrium method (LEM) according to Morgenstern-price presented by computer program (SLIDE V.6.0) is applied to define the potential slip surface and calculate the factor of safety of the dam slopes

Stability at the end of construction is most critical for embankments constructed of plastic materials. Immediately on completion of embankment there would be construction pore pressure due to consolidation of fill under the embankment load. There would be no water loads The values of factor of safety obtained by the designer based on the slip surfaces method and according to the circular slip surface method. the most critical slip surfaces in the upstream and downstream for these loading conditions for each possible slip surfaces are shown in table (1)

Table (1) Factor of safety due to end of construction

	results of the present	
	Method used	Type of slip surface
		circular
upstream	Morgen-stern-price	2.688
downstream		2.285

The FOS at the end of construction obtained for both upstream and downstream slope has a maximum value of 2.688 and a minimum value of 2.285

For steady state condition with maximum water level at182.5 m, the FOS obtained for both upstream and downstream ranges from 2.688 to 2.285as shown in table (2). The results showed that the FOS satisfied the minimum required FOS which is 1.5. During steady state condition, the ponded water will exert external force on the upstream surface to counter balance the internal force exerted by the pore water pressure. Hence, the FOS computed under this condition is higher indicating a stable slope.

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Table (2) Factor of safety due to steady state (maximum water level)

Condition	results of the present		
	Method used	Type of slip surface	
		Without seismic forces	with seismic forces
upstream	Morgenstern-price	2.670	1.783
downstream		2.281	1.866

For steady state condition with minimum water level water level172.0, the FOS obtained for both upstream and downstream ranges from 2.288 to 2.882as shown in table (3)

Table (3) Factor of safety due to steady state (minimum water level)

Condition	results of the present		
	Method used	Type of slip surface	
		Without seismic forces	with seismic forces
upstream	Morgen-stern-price	2.288	1.874
down-stream		2.882	1.887

seismic forces is also taken into consideration in the dam stability analysis. The value of 0.07g was adopted as the critical acceleration under steady state condition. The maximum and minimum FOS for the upstream and downstream under this condition is 1.783 and 1.866 maximum water level and 1.874. 1.887 minimum water level respectively.

Figures (3) and (4) show the most critical slip surfaces in the upstream for the minimum water level loading conditions with and without seismic forces for each possible slip surfaces

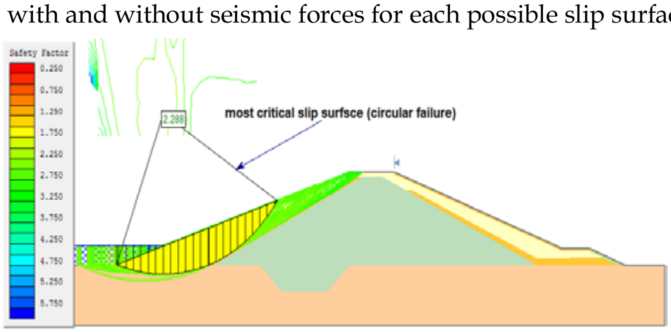

Figure (3) Location and value of the most critical slip surface FOS = 2.288

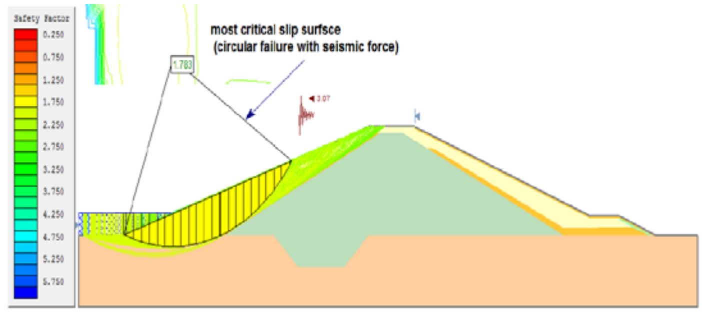

Figure (4) Location and value of the most critical slip surface seismic effect (0.07), FOS = 1.783.

Figures (5)and (6) show the most critical slip surfaces in the downstream for the maximum water level loading conditions with and without seismic forces for each possible slip surfaces

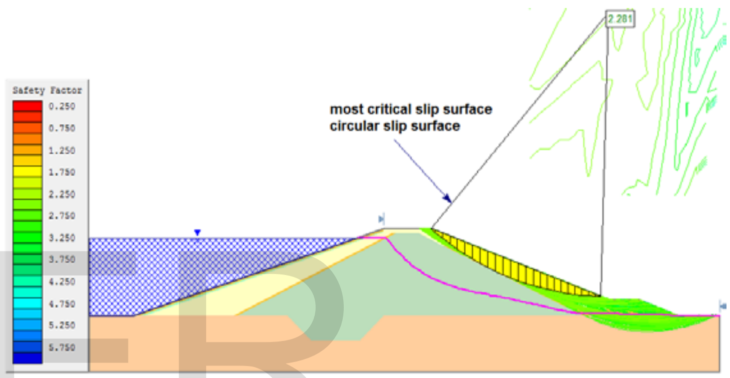

Figure (5) The most critical slip surface for maximum water level in reservoir FOS =2.281

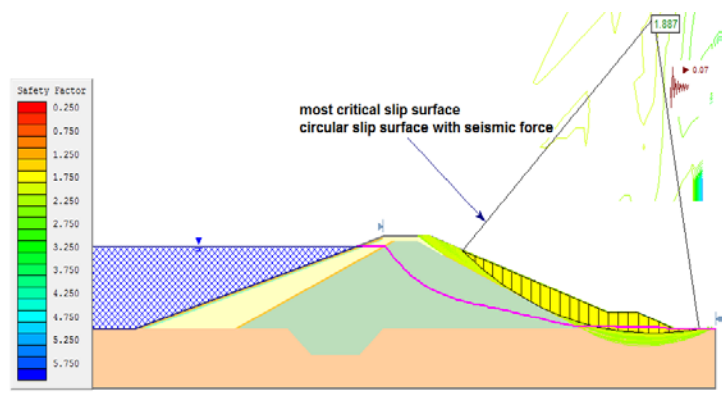

Figure (6) most critical slip surface for maximum water level in reservoir with seismic force (0.07), FOS = 1.887

8 CONCLUSION

In this study, a finite element software, SLIDE V.6.0 is used to determine the factor of safety under different load conditions Maximum Reservoir Level for upstream and Minimum Reservoir Level with seismic forces effects the results showed that Mandali zoned earth dam is safe against the danger of slope sloughing under the different load conditions also indicates that the factor of safety decrease prorate (22.071%) for upstream of Minimum Reservoir Level and prorate (17.273%) for downstream of Maximum Reservoir Level with seismic forces effects

REFERENCES

[1] Al-Jorany, A.N., (1996), "Slope Stability Analysis", Ph.D. Dissertation, Department of Civil Engineering, University of Baghdad.

[2] Baker R., (1980). "Determination of the Critical Slip Surface in Slope Stability Computations", International Journal for Numerical and Analytical Methods in Geomechanics, Vol.4.

[3] Directorate General of Dams and Reservoirs, (2004) " Mandali Dam Project- Geological Report" Ministry of water Resources.

[4] Li, G.C. and Desai, C.S., (1983), "Stress and seepage analysis of earth dams", Journal of Geotechnical Engineering, ASCE, Vol.109, No.7, pp.946-960.

[5] Novak P.A. Moffat and Nalluri C., (2007) "Hydraulic Structures", School of Civil Engineering and Geosciences University Upon Tyne, UK and Formerly Department of Civil and Structural Engineering, UMIST, University of Manchester, UK (Fourth Edition)

[6] Patel S.K. and Sanghvi C.S., (2012) "Seismic Slope Stability Analysis of Kaswati Earth Dam", Applied Mechanics Department and Prof. L.D. College of Engineering, Gujarat, India

[7] Spencer, E., (1967). "A Method of Analysis for the Stability of Embankments Assuming Parallel Inter-Slice Forces", Geotechnique, Vol. 17, March, pp. 11-26.

[8] Whitman, R.V. and Bailey, W.A., (1967), "Use of computers for slope stability", Journal of Geotechnical Engineering, ASCE, Vol.93, No.SM4, pp.475-498