Stability Analysis of Zoned Earth Dam under Effect of the Most Dangerous Conditions (Case Study: Khassa Chai Dam)

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Abstract: The most dangerous conditions of zoned earth dams for the upstream side slope is rapid drawdown condition and for the downstream side slope is the seismic load condition. In this work, Slope stability analysis of the case study (Khassa Chai dam in Iraq) under the most dangerous conditions is investigated. Also, the limit equilibrium method (LEM) according to (Simplified Bishop method) presented by computer program (SLIDE V.5.0) is applied to define the potential slip surface and calculate the factor of safety of the dam slopes, this analysis includes different values of water level of reservoir under different load conditions (rapid drawdown and seismic force). The result of side slope stability was investigated and analyses show that the upstream and downstream slopes are still stable under rapid drawdown condition or seismic load. However, the upstream slope is unstable under the other two cases considered (rapid drawdown condition with a seismic load effect 0.1), and the minimum value of safety factor recorded is about 0.857.

Keywords: Zoned Earth Dam, Finite Elements, factor of safety, Seismic Force, Side Slope Stability, Rapid drawdown

1 INTRODUCTION

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 those 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 favorable to stability of the dam. Horizontal accelerations are therefore assumed to operate normal to the axis of the dam (Novak et al. 2007).

The drawdown is known as one of the most dangerous conditions for the upstream slope. When the countervailing upstream water pressure has disappeared, it causes a danger to the upstream slope. The upstream shell cannot stay stable under the hydrodynamic pressure due to rapid drawdown. Soils inside the dam body remain saturated and seepage commences from it towards the upstream slope. Seepage and hydrodynamic pressures create downward forces acting on the upstream slope.

Generally, sudden drawdown stability computations are performed for conditions occurring when the water level adjacent to the slope is lowered rapidly. For the analysis purposes, it is assumed that drawdown is very fast, and no drainage occurs in materials with low permeability; thus the term "Sudden" drawdown. Materials with values of permeability greater than 10^{-4} cm/sec can be assumed to drain during drawdown, and drained strengths are used for these materials (U.S. Army Corps of Engineers 2003).

Events following a rapid drawdown may usefully, but approximately be divided into four stages as shown in Fig. 1.

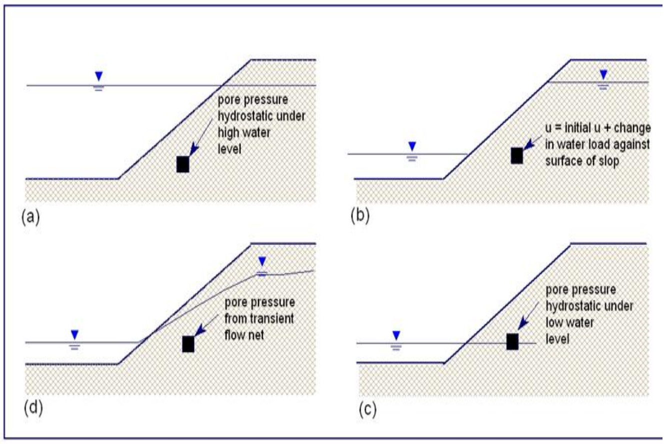

Fig. 1. Response of slope to rapid drawdown (Lambe and Whitman 1969). (a) Initial equilibrium condition. (b) After drawdown but before consolidation adjustment. (c) After consolidation adjustment. (d) Final equilibrium condition.

If the drawdown time is much less than the time in which consolidation adjustment can occur within the slope, the pore pressures immediately following the drawdown will equal the pore pressures before drawdown plus the change in pore pressure due to the change in water load against the slope. In time, consolidation adjustments will occur, but pore pressures will still remain high until the excess water drains from the slope and a new equilibrium is reached corresponding to the low level of water against the slope. With free draining soils, such as coarse sands and gravels, the consolidation time will generally be less than any actual drawdown time so that the stage depicted in figure (1b) never occurs and stability of slopes in such soils can be analyzed using a transient flow net as shown in figure (1c). With slowly draining soils, the situation depicted in figure (1b) is critical with regard to stability of slopes (Lambe and Whitman 1969).

Sarma (1973) developed a simple but accurate method of stability analysis of embankments and slopes to determine the critical earthquake acceleration that was required to bring a mass of soil, bounded by a slip line of any shape and free surface, to state of limiting equilibrium. It was based on the principle of limiting equilibrium and the method of slices. He found that in any solution, the physical acceptability of the complete solution must be checked before accepting the result. It was suggested to use the critical acceleration as a measure of the factor of safety.

Desai (1977) applied a numerical finite element scheme for development of guidelines and charts for analysis and design of slopes subjected to transient drawdown conditions. The physical problem considered concerns analysis of slopes at certain sections of the banks of the Mississippi River. An important answer adopted by this study as a part of the investigation, the factor of safety at the end of drawdown computed from the numerical procedure was compared with the factor of safety from conventional sudden drawdown analysis. A series of charts were obtained for various combinations of problem parameters, and comments and suggestions concerning the potential of the procedure for analysis of slopes were presented in this study.

Hoe et al. (1997) discusses the stability and permanent displacement of a slope subjected to combined horizontal and vertical accelerations. A long-spiral failure mechanism was used. During this study, they found that the seismic force has a significant effect on stability and permanent displacement of slopes, and the parametric study reveals that vertical acceleration may play an important role on stability and permanent displacement if the corresponding horizontal acceleration was large.

Tran (2008) developed a numerical model to analyze the stability of the Tieng main dam in rapid drawdown condition for two cases before and after rehabilitation, using limit equilibrium and finite element methods. Changes of stress-strain behaviours and pore pressure, failure mechanism, and factor of safety of the upstream slope were investigated. In this study he found that the stability of the upstream slope is dramatically decreased but still being stable during rapid drawdown condition.

Lakehal et al. (2011) applied the modified method of Bishop,when an attempt is made to construct sets of nomgrams for the calculation of the safety factor of homogeneous earth dams under long term stability. It allows the user to get the optimal safety factor of the dam immediately according to the material classification and the parameters of design, height and slope.

2 Simplified Bishop Method

As mentioned in Lambe and Whitman 1969, this method was first described by Bishop (1955); a simplified version of the method was developed further by Janbu et al. (1956). The simplified Bishop method neglects the inter-slice shear force since it assumes that the resultant of the inter-slice forces acting on each slice has a horizontal line of action. This method, associated with circular slip surfaces, violates the equilibrium equation of horizontal force so it is an approximate method.

Whitman and Bailey (1967) indicate that error in the values of factor of safety obtained by this method of analysis is usually less than 5%. The value of safety factor by using the simplified method, safety factor can be calculated from:

$$SF = \frac{\sum_{i=1}^{i=n}\left[\bar{c}\,\Delta X_i + \left(W_i - U_i \Delta X_i\right)\tan\bar{\phi}\right]\left[1/M_i(\theta)\right]}{\sum_{i=1}^{i=n} W_i \sin\theta_i} \qquad (1)$$

where:

$$M_i(\theta) = \cos\theta_i\left(1 + \frac{\tan\theta_i \tan\bar{\phi}}{FOS}\right) \qquad (2)$$

$\bar{c}$ and $\bar{\phi}$ are effective shear strength parameters for the soil at the base of the slice

n: number of slices

W_i : weight of the slice.

θ_i : slope of slice.

u_i : the average pore water pressure at the bottom of the slice is equal to $u_i = h_i * \gamma_w$

h_i: height of water in the piezometer placed at the bottom of the slice.

Equation (1) is to be solved by trial and error method since SF appears on both sides of the equation. However the convergence of trial is very rapid. $M_i(\theta)$ can be found from Fig. 2. The two methods above (ordinary method and simplified Bishop method) are presented in Fig. 3, which shows the differences between the two methods.

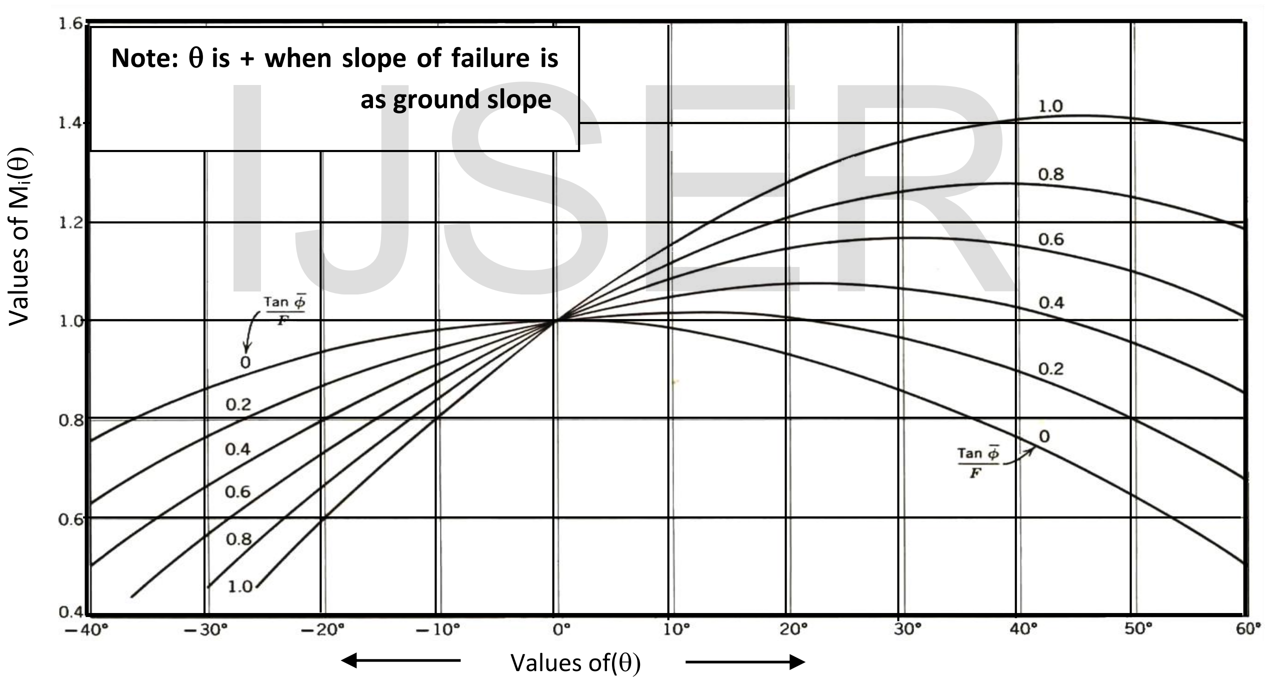

Fig. 2. Values of $M_i(\theta)$ (Janbu 1973)

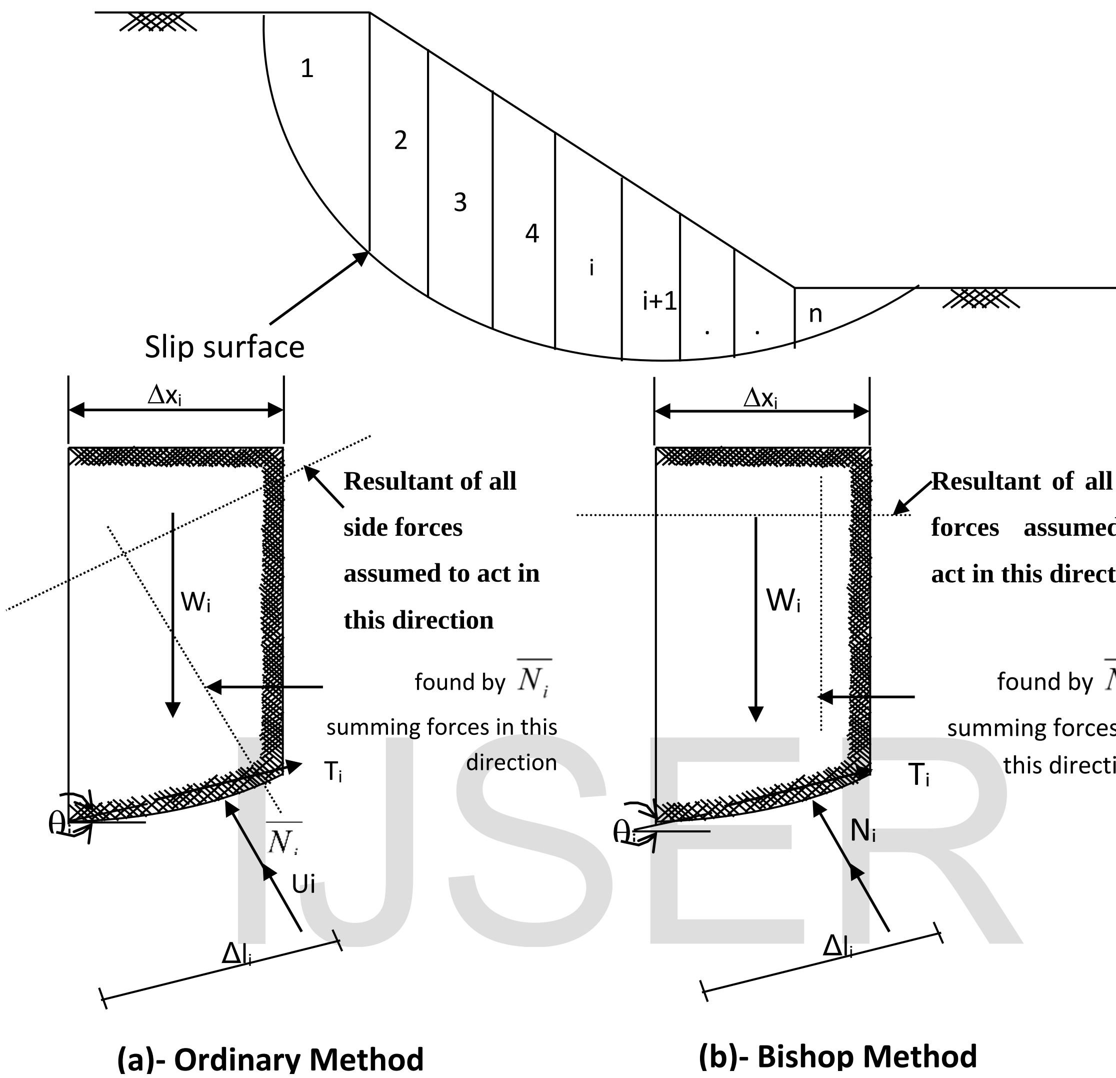

Fig. 3. General slip surface and forces acting on typical slice (Lambe and Whitman 1969).

3 CASE STUDY (KHASSA CHAI DAM)

The Khassa Chai dam is one of the important earth fill dams in North of Iraq; the dam is located on Khasa river upstream the town of Kirkuk. The Khasa Chai river is a tributary of Zaghitun river which is flowing into the existing Adhaim dam reservoir, The dam site is located near Kuchuk village,10 km northeast of Kirkuk Town. The dam is provided with a central core at its total length is about (2215m) and its maximum height is about (58m) as shown in Fig. 4, the dam consists of composite section of pervious and impervious materials, the shell (sand and gravel) of the dam will consist of pervious material, and a core (silty clay) of impervious materials. It is a multi-purpose structure designed to maintain a permanent minimum supply of water into the Khasa Chai river during all seasons for environment improvement and survival of fauna, supply irrigation water for gardens and green yards within the city of Kirkuk and Facilitate the maintenance of recreational water areas within the bed of Khasa Chai course through Kirkuk (Directorate General of Dams and Reservoirs 2005).

The finite element mesh used in this analysis is shown in Fig. 5. Three node triangle elements are used to describe the domains. The mesh contains 1743 element and 938 node.

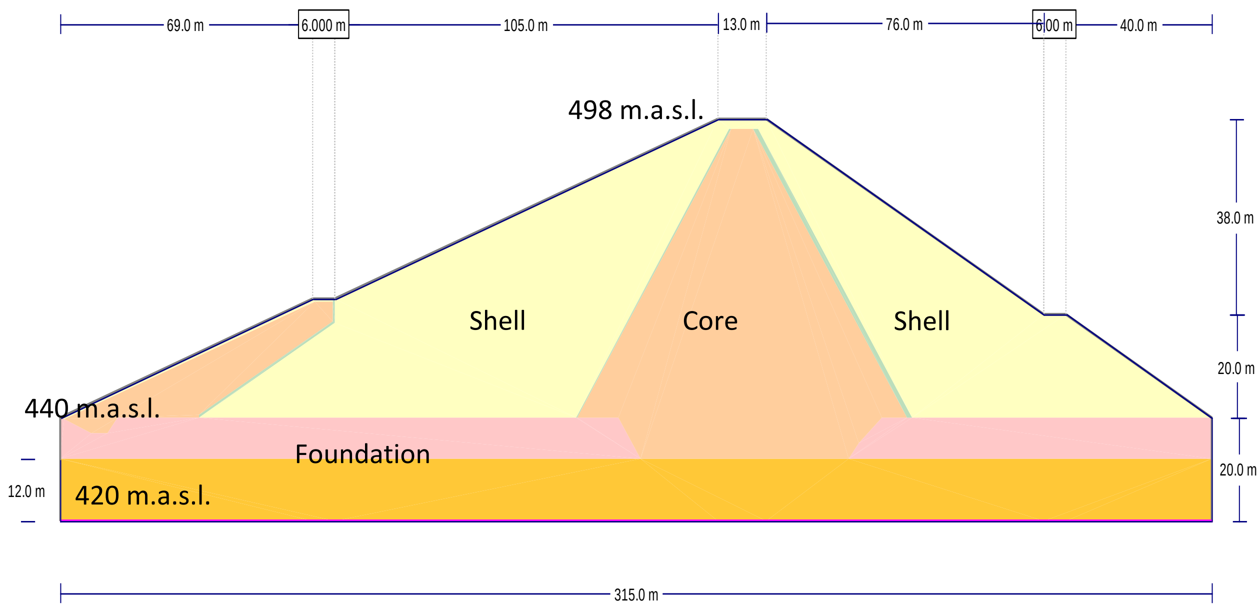

Fig. 4. Finite element mesh for Khassa Chai dam

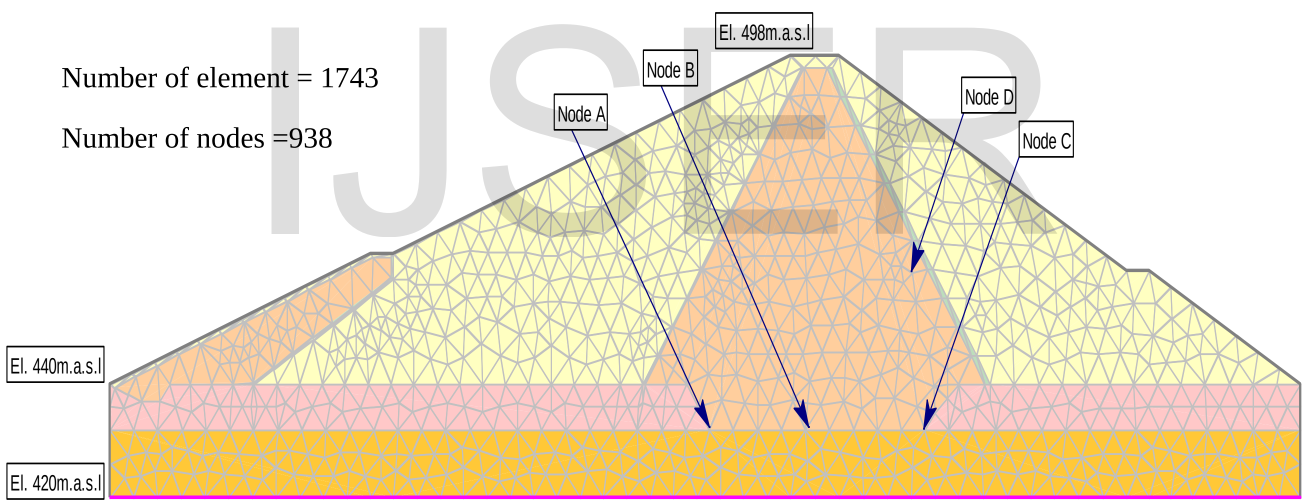

Fig. 5. Cross section of Khassa Chai dam by **SLIDE V.5.0** program

4 RESULTS AND DISCUSSION

4.1 Effect of the Seismic Load Conditions

To study the effect of seismic load coefficients, two different load coefficients (0.05 and 0.1) are considered, the seismic load coefficient used in this analysis is the same as that used by designer. If seismic coefficients are defined a seismic force will be applied to each slice as follows:

$$\text{Seismic Force} = \text{Seismic Coefficient} * \text{Slice Weight} \qquad (3)$$

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

Fig. 6 and Fig. 7 show the critical slip surface in the downstream side slope. When the seismic effect is increased from 0.05 to 0.1, it can be noticed that the value of factor of safety is decreased by about 10.33% at maximum water level.

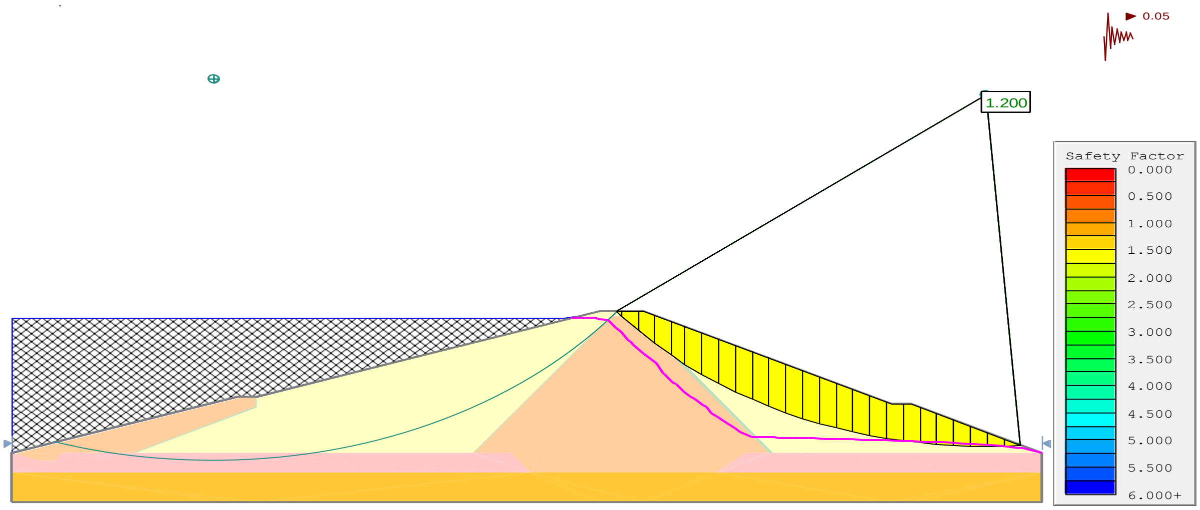

Fig. 6. Critical slip surface (circular slip surface) in downstream side for maximum water level in reservoir with seismic effect (0.05), SF=1.2

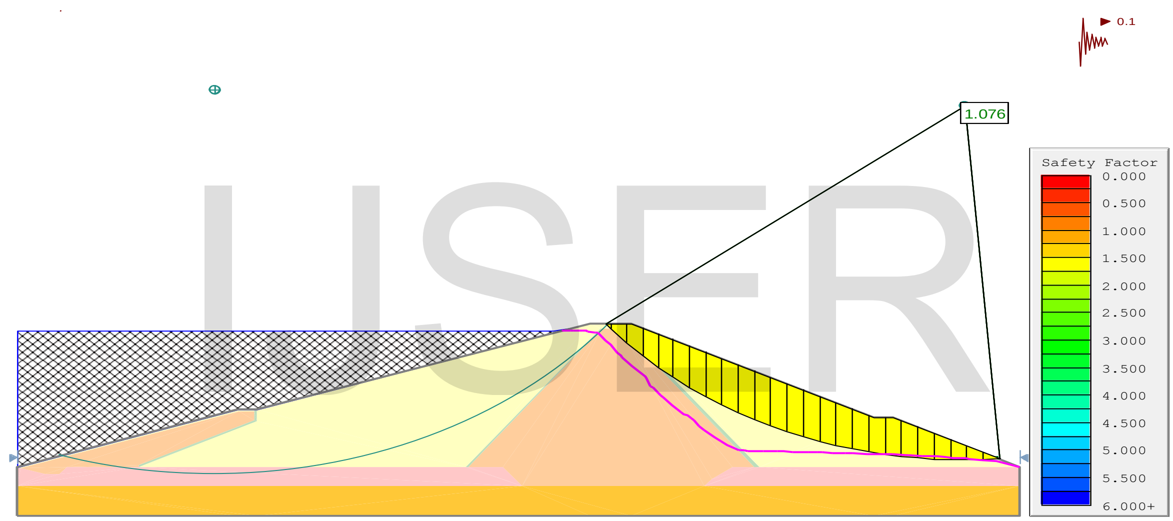

Fig. 7. Critical slip surface (circular slip surface) in downstream side for maximum water level in reservoir with seismic effect (0.1), SF=1.076

4.2 Effect of the Rapid Drawdown Conditions

The computer program (**SLIDE** V.5.0) is used to calculate the SF of upstream side under rapid drawdown condition.Excess pore pressure refers to short term (transient) changes in pore pressure within a soil due to rapidly drawdown of pounded water in upstream side conditions (undrained loading). Materials with low permeability such as clays, may exhibit this behavior. With the so-called "B-bar" method, the change in pore pressure is assumed to be directly proportional to the change in vertical stress. The excess pore pressure is given by:

$$\Delta u = \bar{B} \, \Delta \sigma_V \qquad (4)$$

where:

Δu = excess pore water pressure caused by drawdown condition.

$\bar{B}$ = (B-bar) overall pore pressure coefficient for earth fill material.

$\Delta \sigma_V$ = change in vertical effective stress.

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From equation (4), it can be observed that the value of the excess pore pressure is dependent on the value of (B-bar) coefficient. The value of (B-bar) coefficient is dependent on the type of soil and properties of soil. If (B-bar) coefficient is defined about 0, the soil is free to drain and no excess pore water pressure is developed in upstream side. If (B-bar) coefficient is defined about 1, the undrained condition is applied and excess pore pressure is developed in upstream side. The value of (B-bar) coefficient close to 1 represents critical condition of rapid drawdown in upstream side and should be selected to any soils which have low permeability.

Fig. 8 shows the value and location of most critical slip surface for steady state condition (before rapid drawdown). Fig. 9 shows the value and location of critical slip surface for rapid drawdown condition from EL. 495m.a.s.l to EL. 466 m.a.s.l, it can be observed that the value of factor of safety is decreased by about 35.5%.

From Fig. 10 and the value recorded for factor of safety in this part of analysis, it can be observed that the value of safety factor decreases dramatically with seismic coefficient under rapid drawdown condition, and minimum value of safety factor recorded is about 0.857 for rapid drawdown condition from EL. 495m.a.s.l to EL. 466 m.a.s.l with seismic load effect 0.1.

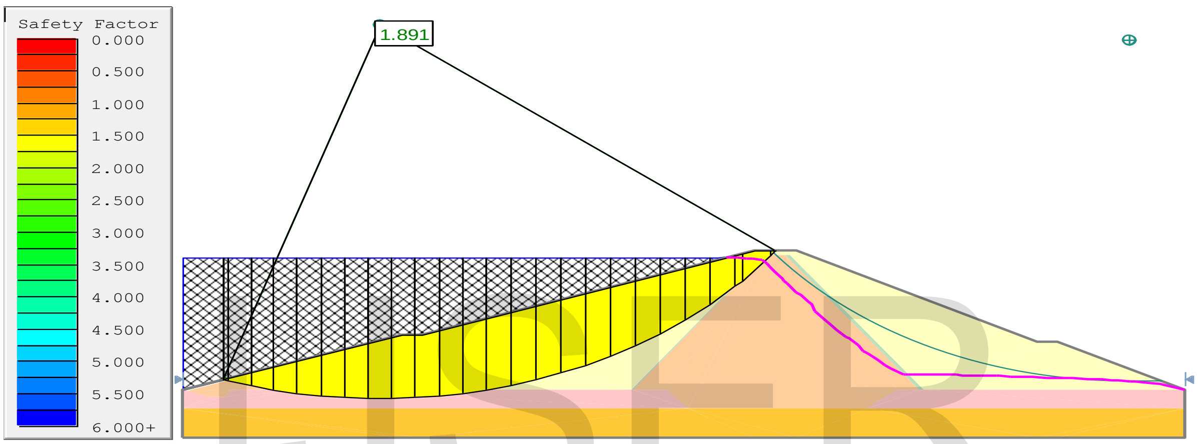

Fig. 8. Critical slip surface (circular slip surface) in upstream side for maximum water level in reservoir before rabid drawdown, SF = 1.891

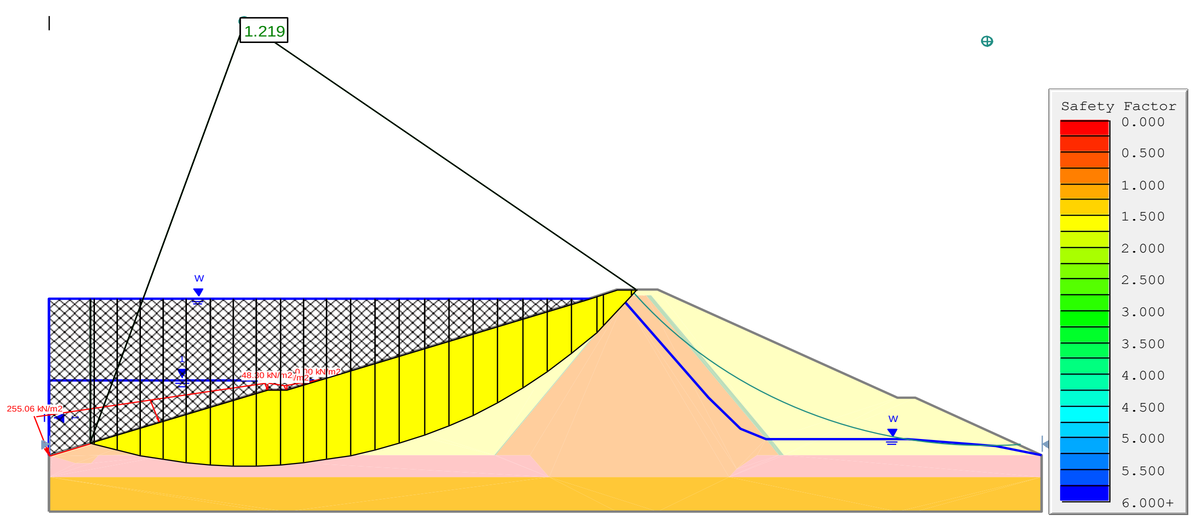

Fig. 9. The most critical slip surface for rapid drawdown condition from EL. 495 m to EL. 466 m, SF = 1.219

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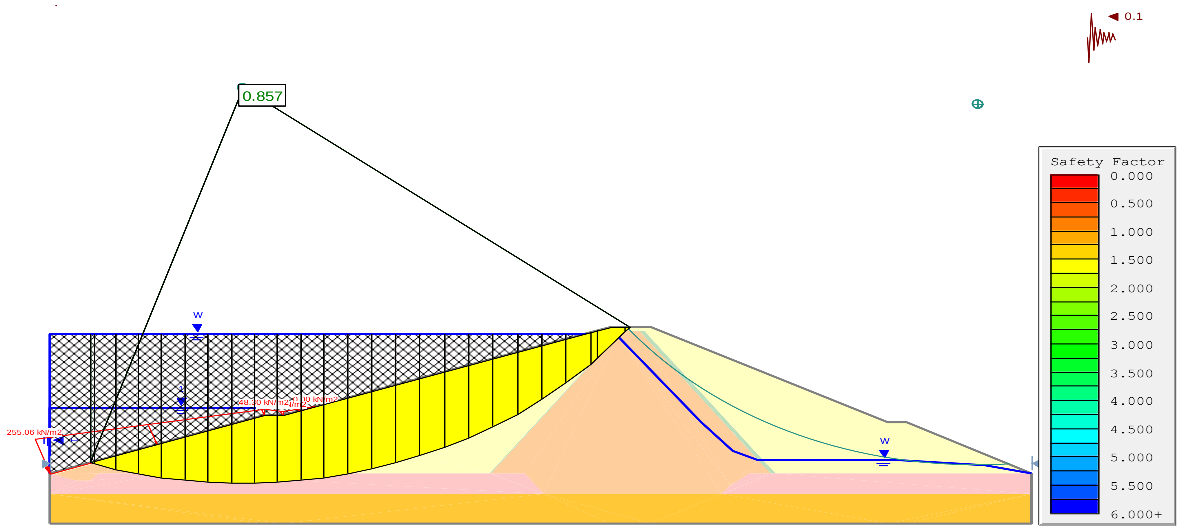

Fig. 10. The most critical slip surface for rapid drawdown condition from EL. 495 m to EL. 466 m with seismic load effect (0.1), SF = 0.857

5 CONCLUSIONS

Based on stability analyses In the case of zoned earth dams **(Khassa Chai Dam as a case study)** and the results obtained from this research work, the following main conclusions can be drawn.

1. The downstream slope is still stable under a seismic effect, and the minimum value obtained for factor of safety is about 1.2 and 1.07 in downstream with seismic effect 0.5 and 0.1, respectively.
2. The upstream slope is still stable during rapid drawdown condition from EL. 495m.a.s.l to EL. 466 m.a.s.l, and the minimum value obtained for factor of safety is about 1.219.
3. The upstream slope is unstable under rapid drawdown condition from EL. 495m.a.s.l to EL. 466 m.a.s.l with seismic load effect 0.1, and the minimum value of safety factor recorded is about 0.857.

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