Evaluation of the upstream slope stability of earth dams based on drawdown conditions - Khassa Chai Dam: a case study

Thair J M Alfatlawi¹,Yahyea K. Al-temimi⁴, Zeena M. Alomari²*
¹²University of Babylon, Department of civil Engineering, Babylon, Iraq.
Email: thairjm@yahoo.com, yaltemimi4@gmail.com & Zeena276z@yahoo.com

Abstract Sudden drawdowns may cause instability in slopes without adequate levels of protection against failure. In this paper, a numerical approach utilising the finite element method (FEM) was employed to examine the seepage and slope stability of a typical earth fill dam. Finite element software (GEOSTUDIO 2012) was used to carry out both steady-state and transient seepage analyses on Khassa Chai Dam in Iraq to study the seepage and upstream slope stability after various upstream drawdown scenarios. To include water levels during evacuation, variable linear water heads with time were identified as boundary states in the transient seepage analysis. The quantity and direction of water flux, existing gradient, and safety factor were calculated for all scenarios. The results revealed that the stability of the slope during drawdown is highly impacted by how fast its pore water pressure dissipates. The results also showed that a minimum F.S. was achieved within 10 hr in the case of a 1-day water drawdown, with the F.S. reduced by 60.66%; this becomes critical when the water level in the basin drops by about 41.67% of its original height.

Keywords: Finite Element Method (FEM), Khassa Chai Dam, Rapid drawdown, Seepage, Slope Stability

1. Introduction

Drawdown condition is a significant critical loading condition affecting the stability of the upstream slope whether it is in an initial or partial or totally submerged state. The drawdown of the level of water has two impacts: a decrease in stabilizing exterior hydrostatic pressure as a result of the unloading dropping water effect and pressure variation of the pore water in the embankment body. Where the lowering velocity reaches a peak, a delay is formed in the internal pore water pressure dissipation and residual excess pore water pressures may thus cause failure in the upstream slope. Figure 1 shows the collapse of the upstream slope of the Carsington Dam (1984), which occurred due to drawdown conditions.
The stability of the slope throughout a reservoir drawdown is affected by many factors, such as rates of drawdown, slope inclinations, and soil characteristics of the earth dam materials (Moregenstern, 1963; Desai, 1977; Viratjandr and Michalowski, 2006). Yan et al. (2010), Wang et al. (2012), Fathani and Legono (2012), and Sudardja (2012) investigated the impact of lowering on embankment dams’ stability using lab experiments, while Berilgen (2007) investigated the safety of submerged slopes subject to reduction of water by utilising a flow program to calculate transient seepage and a coupled program to examine deformation and stability. Lane and Griffiths (2000) and Huang and Jia (2009) used the shear strength reduction method to evaluate the stabilisation of slopes under drawdown loading.

Zhang et al. (2010) examined the fluctuations of water level in a reservoir, taking the Hefeng landslide as a case study, showing that these were the greatest cause of failure in the Hefeng landslide. Fredlund et al. (2011) adopted the Duncan (1990) three-stage strategy to investigate sudden drawdown conditions along with coupled transient analysis and slope stability analysis to determine the conditions under which that methodology produces results similar to those of more accurate analysis. Souliyavong et al. (2012) studied the impacts of saturated permeability of embankment soil and the emptiness velocity of the reservoir on the stability of the slopes of an earth fill dam exposed to reservoir drawdown with unsaturated soil characteristics. Gao et al. (2014) studied the effect of lowering water on the safety of 3D slopes by using the kinematic approach of limit analysis and a 3D rotational failure system. Significant stability charts were introduced to more accurately assess the factor of safety of 3D slopes during four unique kinds of drawdown scenarios.

Song et al. (2015) examined the impact of fluctuation of reservoir water level and hydraulic characteristics of the soil as characterised by the soil–water characteristic curve (SWCC), a saturated and unsaturated permeability coefficient function, through a string of numerical approaches with various fitting parameters. Kirra et al. (2015) used a finite element method with various operation conditions, and several slope stability methods # to investigate the slope safety of a zoned earth dam (Mandali Dam) in Iraq, showing that the dam was stable and safe against piping and slope deformation under different loading conditions. Alonso and Pinyol (2009; 2016) analysed various sudden drawdown scenarios to assess approaches for the estimation of pore water pressure distribution through and after a drawdown based on considering a numerical case in addition to real cases with in situ estimations.

Fattah et al. (2016) presented a movement analysis for the Khassa Chai Dam in Iraq that exposed it to an earthquake motion so that pore water pressure, effective stresses, and displacements could be estimated. For this analysis, they utilised the finite element method, and they concluded that the pore water pressure developed at the base of the core was greater than pore water pressure on the upper parts of the dam, and that the effective stresses continually decreased, indicating that the soil was continually

![Figure 1. The collapse of the upstream slope of the Carsington Dam (1984) (Twort et al. 2000).](image_url)
weakened. Further, the horizontal displacement increased with depth from the crest to the base of the dam. Fattah et al. (2015; 2017) also carried out a numerical simulation of the sudden drawdown condition on the DauTieng reservoir in Tay Ninh province in Southern Vietnam and the Al-Wand dam in Iraq using finite element software (GEOSTUDIO 2007). It was inferred that the slope stability safety factor of the dams’ slopes reduced slightly within a brief time period after the beginning of evacuation of the reservoir, then began to increment.

Abdulsattar et al. (2017) inspected the seepage and exit gradients through Kassa Chai Dam, studying the impact of changing in the dam structure via GEOSTUDIO software. It was concluded that the presence of core had a great impact on decreasing the seepage quantity through the dam body. In addition, the filters had a significant influence on reducing the exit gradient. Khassaf and Madhloom (2017) applied the finite element program SLIDE.5.0 to calculate the amount of seepage, existing gradient, hydraulic gradient, and pressure head of the Kassa Chai Dam in Iraq under the influence of the different values of core permeability and thickness.

The objective of the present study is to identify how the condition of rapid drawdown for the reservoir could influence an earthfill dam’s safety. This was done by modelling the Khassa Chai Dam as a real case and applying GEOSTUDIO (2012) and its subprograms SEEP/W and SLOPE/W.

2. General preliminaries

2.1 Seepage analysis:

SEEP/W is formulated based on water flow in both unsaturated and saturated soil following the law of Darcy

\[ q = ki \]

(1)

where: \( q \) = unit flux; \( k \) = hydraulic conductivity; and \( i \) = hydraulic gradient.

The governing differential equation utilised in the formulation of flow in the subprogram SEEP/W is thus

\[ \frac{\partial}{\partial x} [k_x \frac{\partial H}{\partial x}] + \frac{\partial}{\partial y} [k_y \frac{\partial H}{\partial y}] + Q = \frac{\partial \theta}{\partial t} \]

(2)

where: \( H \) = total head; \( k_x \) = hydraulic conductivity in the x-direction; \( k_y \) = hydraulic conductivity in the y-direction; \( Q \) = applied boundary flux; \( \theta \) = volumetric content of water; and \( t \) = time.

Under steady-state seepage conditions, the water flux entering and leaving an elemental volume is the same at all times. The equation thus becomes
\[
\frac{\partial}{\partial x} \left[ k_x \frac{\partial H}{\partial x} \right] + \frac{\partial}{\partial y} \left[ k_y \frac{\partial H}{\partial y} \right] + Q = 0
\]

(3)

The stress condition for both unsaturated and saturated soil can be described by two parameters, matric suction \((u_a - u_w)\) and pore air pressure \((-u_a)\). At atmospheric pressure, the pressure of pore water stays constant due to transient seepage, which implies that the effective stress \((\sigma - u_w)\) is constant and has no effect on the variation in the volumetric content of water. Thus, the variation in the volumetric content is based solely on \(u_a - u_w\), and the change in volumetric content of water is a function of the changes in pressure of pore water such that, when \(u_a\) stays steady,

\[
\frac{\partial \theta}{\partial t} = m_w \frac{\partial u_w}{\partial \theta}
\]

(4)

\(m_w\) = the slope of the storage curve.

The entire hydraulic head is given by

\[
H = u_w + y
\]

(5)

where: \(u_w\) = pressure of pore water; \(\gamma_w\) = water unit weight; and \(y\) = elevation.

\(u_w = (H - y)\gamma_w\)

By substituting into equation (2)

\[
\frac{\partial}{\partial x} \left[ k_x \frac{\partial H}{\partial x} \right] + \frac{\partial}{\partial y} \left[ k_y \frac{\partial H}{\partial y} \right] + Q = m_w \gamma_w \frac{\partial (H - y)}{\partial t}
\]

(6) As elevation \((y)\) is constant,

\[
\frac{\partial}{\partial x} \left[ k_x \frac{\partial H}{\partial x} \right] + \frac{\partial}{\partial y} \left[ k_y \frac{\partial H}{\partial y} \right] + Q = m_w \gamma_w \frac{\partial H}{\partial t}
\]

(7)

The equation of the finite element that follows the application of the Galerkin technique to the weighted differential equation is

\[
\int_B \left[ \left[ B^T \right] [C] \right] d_v \{H\} + \int_B \left[ \left( \lambda < N >^T < N > \right) d_v \{H\} \right] = \frac{q}{A} \int_A \left( < N >^T \right) d_A
\]

(8)

where: \(B\) = the matrix gradient; \(C\) = matrix of hydraulic conductivity of the element; and \(H\) = nodal head vector.
\[ \lambda = m_w \lambda_w \]
\[ <N >^T <N > = [M] = \text{matrix mass}; \]
\[ \{H\}_t = \frac{\partial h}{\partial t} \] is the changing in head against time; \( q \) = the flux unit across the element side, and \( <N> \) = the interpolating function’s vector.

For the subprogram SEEP/W’s two-dimensional analysis, the element’s thickness is considered constant over the whole element. The equation of a finite element can be therefore written as
\[
t_1 \int_v ([B]^T[C]) d_v[H] + t_1 \int_v (\lambda <N >^T <N >) d_v[H]_t = q t_1 \int_L(<N >^T)d_L
\]
(9)

where \((t_1)\) is the element thickness.

In shortened form, the equation of finite element is thus
\[
[K][H] + [M][H]_t = \{Q\}
\]
(10)

Equation (10) is the general equation for a finite element for analysis of transient seepage. When analysing a steady-state condition, the head is not subject to a time function and, accordingly, the term \([M], \{H\}_t\) vanishes, decreasing the finite element equation to
\[
[K][H] = \{Q\}
\]
(11)

2.2 Slope stability analysis:

SLOPE/W use the limit equilibrium theory for moments and forces to compute the safety factor against failure. A safety factor is defined as the factor by which the soil shear strength should reduce in order to bring the soil mass into a limiting equilibrium state along a selected surface of slip. In this work, three methods for slope stability analysis of embankment dam are utilised.

1. Ordinary (Fellenius) method (1936): This method neglects all interslice forces and considers only themoment equilibrium. The advantages of this method include that it is easy to calculate the factor of safety of an earth dam slope without the need to perform iteration of processes. The mobilised forces for this method are illustrated in Figure 2.

\[
FS = \frac{\sum cl + (w \cos \alpha - ub) \tan \phi}{\sum ws \sin \alpha}
\]
(12)
where $FS = \text{Factor of safety}; W = \text{weight of slice}; \alpha = \text{bottom slice inclination}; \varphi^\prime = \text{effective internal friction angle}; u = \text{pressure of pore water}; b = \text{width of slice}; l = \text{bottom slice length}; \tilde{N} = \text{effective normal force on the slice base (kN)}; \text{and } S = \text{the shear force on the slice base (kN)}.$

![Figure 2. Considered forces for the ordinary (Fellenius) method.](image)

2. The Simplified Bishop method (1955): The Simplified Bishop method is exceptionally basic in the application of circular shear surface; this technique considers only the equilibrium moment rather than the whole horizontal equilibrium force. The mobilised forces for this method are illustrated in Figure 3.

$$FS = \frac{1}{\sum W \sin \alpha} \left[ \frac{cb + wtan \varphi - cb \sin \alpha tan \alpha}{\cos \alpha \sin \frac{atan \alpha}{FS}} \right]$$

(13)

where $FS = \text{Factor of safety}; W = \text{weight of slice}; \alpha = \text{bottom slice inclination}; \varphi = \text{internal friction angle}; b = \text{width of slice}; l = \text{bottom slice length}; E = \text{inter slice normal force (kN)}; \tilde{N} = \text{effective normal force on the slice base (kN)}; \text{and } S = \text{the shear force on the slice base (kN)}.$

![Figure 3. Considered forces for the Simplified Bishop's method.](image)

3. Morgenstern-Price method (1965): This uses normal and shear interslice forces together, considering force and moment equilibrium, which allows for a variety of user-selected interslice force functions such as half-sine, constant, and data point specified. The mobilised forces for this method are illustrated in Figure 4.

$$FS = \frac{\sum c l + (N - u) tan \alpha \sec a}{\sum [w - (T_2 - T_1)] tan \alpha + \sum (E_2 - E_1)}$$

(14)
\[ F_m = \frac{\sum [c' + (N-ul)\tan\varphi]}{\sum W\sin\alpha} \]  

(15)

where \( c' \) =effective soil cohesion; \( l \) = bottom slice length; \( b \) = width of slice; \( u \) = pressure of pore water; \( W \) = slice’s weight; \( \alpha \) = bottom slice inclination; \( \varphi' \) =effective internal friction angle; \( E \) = inter slice normal force (kN); \( N' \) =effective normal force on the slice base (kN); \( S \) =the shear force on the slice base (kN); and \( T \) = the vertical interslice shear force (kN).

Figure 4. Considered forces for the Morgenstern-Price Method.

3. Khassa Chai Dam

The Khassa Chai Dam is one of the embankments in the north of Iraq, which has significant importance as a multipurpose project to maintain a permanent minimum supply into the Khasa Chai stream throughout all seasons to improve the environment. The dam was constructed on the Zaghaitun River’s seasonal tributary, which in turn flows into the existing reservoir of Al-Adhaim Dam (10km) in Kirkuk, north-east of Kuchuk village. Its composite section consists of a shell (sand and gravel) and a core of impervious materials (silty clay). The foundation of the dam consists of several formations that differ with depth, ranging from stiff brown silty-clay to very stiff brown silty-clay with a lot of coarse grain gravel and organic matter with black traces. A chimney discharge was adopted at the core downstream, with a thickness of 2m. Figure 5, shows a typical cross-section of Khassa Chai Dam, and the materials characteristics of Kassa Chai Dam’s components are shown in Table (1) (Center of Engineering Designs and Studies, 2007).

Figure 5. Typical Khassa Chai Dam cross-section (Center of Engineering Designs and Studies, 2007).
Table 1: Material characteristics of Khassa Chia Dam (Center of Engineering Designs and Studies, 2007)

| Materials  | Unit weight (KN/m³) | Permeability Coefficient (m/sec) | Water Content (%) | C (KN/m²) | Φ (degree) |
|------------|---------------------|---------------------------------|-------------------|-----------|------------|
| Shell      | 21.9                | 1.25x10⁻⁵                      | 15                | 0         | 38         |
| Core       | 17.52               | 2.25x10⁻¹⁰                     | 25                | 85        | 9.28       |
| Filter     | 18                  | 1.25x10⁻⁵                      | 15                | 0         | 35         |
| Foundation | 21.8                | 1x10⁻¹⁰                        | 30                | 173       | 21.76      |
| Drain      | 23                  | 1x10⁻²                         | 10                | 0         | 35         |

4. Methodology

Drawdown condition is particularly important during the early life of a dam, when full consolidation and strength of the material may not have been reached. It is also important where the need to pull down the reservoir level occurs in some emergency conditions such as for rehabilitation. Drawdown is here examined as a result of water drawdown from the reservoir in three cases, depending on the hydrological conditions at the embankment site and the designed water level of the reservoir, as shown in Table (2). The examined operation cases are a normal case over 11 days, a critical case over 5 days, and an urgent case over 1 day. The partially submerged slope faces a decline in the natural water level (51 m).

Table 2: Hydrological cases at the location of dam and design water level of the reservoir (Al-Simawee H., 2008)

| Property                      | Value                        |
|-------------------------------|------------------------------|
| Length of dam                 | 2200m                        |
| Type of dam                   | Earth fill with silty clay core |
| Operation level               | 51 m                         |
| Storage area at the operation level | 2.37km²                      |
| Height of dam                 | 58m                          |
| Outlet flow                   | 150m³/sec                    |

The GEOSTUDIO (2012) family of programs has several software tools that are applicable to the present study, such as SEEP/W for seepage modeling and SLOPE/W for the stability of slope. The seepage model utilizes the FEM for two-dimensional Darcy flows in saturated and unsaturated soils. The dam model is applied by sketching the cross-section of the earth dam, which is adopted in the grid of finite elements consisting of quadrilateral and trigonometric regions. The material models used for the shell, core and filter soils are part of a saturated/unsaturated system, while the fully saturated option is chosen for the foundation soil. The initial boundary condition for the seepage analysis in the state of steady is the water level in the upstream slope is about 51m. The boundary condition on the downstream slope face is not indicated, as the pressure of pore water depends on the location of the surface's phreatic; thus, the boundary condition on the downstream slope surface is a potential seepage surface. The conditions of boundary for transient analysis of seepage are water level vs. time variables. The analysis of stability is achieved for all the cases of evacuation by using the Morgenstern-Price method that considers both interslice normal force and shear force. The requirement for force and moment equilibrium is thus fully satisfied (SLOPE/W, 2012), though the results obtained from the Bishop and Ordinary methods are also examined and compared with the results of the Morgenstern-Price method.
5. Results and Discussion

5.1 Water Flux

The results of water flux from the study are presented in this section. Figure 6 presents the computed contour map of pressure head distribution and the flow line through Khassa Chai Dam at the initial steady-state seepage.

Figure 6. Contour map of pressure head distribution and the flow line through Khassa Chai Dam.

For various water levels through drawdown, a linear changeable head with time was indicated as the boundary case in the analysis of transient seepage, as illustrated in Figure 7.

Figure 7. Hydraulic boundary function during emptying of Khassa Chai Dam reservoir.

If the reservoir is emptied, the direction of water flux inside the body of the dam reverses toward the upstream slope, producing an instability slope in the earth dam upstream. Figure 8 illustrates the reversing and changing in water flux inside the dam body during the drawdown period.
Figure 8. Flow directions of the water flux during emptying of Khassa Chai Dam reservoir.

The most extreme velocity of water is found on the slope face at the slope toe and on the foundation surface, where the hydraulic gradient achieves maximum magnitude; thus, a specific point at the toe of upstream slope is taken to calculate the variation of the quantity of water flux during the different drawdown periods. The stability of the soil mainly depends on its unit weight, though seepage force may increase or decrease the soil stability depending on the seepage direction. When the seepage direction is upward (opposite to soil force), the stability of the soil is decreased. Figure 9 shows the change in the quantities of water flux under drawdown conditions, and negative magnitudes indicate that the flow takes place out of the dam.

Figure 9. Trend of water flux under drawdown conditions.

As shown in Figure 9, the exiting water flux increases with the drawdown of the reservoir level until it reaches a maximum value when the reservoir drawdown is stopped. This flux rate then starts to decrease until the seepage process is completed. The time period during which the water flows out the dam is affected by the drawdown rate, with the rate of seepage flow being slower during normal drawdown conditions than in the other two cases. Table (3) provides a summary of the water flux flows out of the dam through the slope at a selected point (m³/day) for all emptying periods of Khassa Chai Dam reservoir.
Table 3: Values of water flux at a selected point (m$^3$/day) for all periods of Khassa Chai Dam reservoir drawdown

| Time (days) | Water Flux (m$^3$/day) | Time (days) | Water Flux (m$^3$/day) |
|------------|------------------------|------------|------------------------|
| 0          | 0                      | 0          | 0                      |
| 0.25       | -0.0105                | 0.25       | -0.0105                |
| 1          | -0.0105                | 1          | -0.0105                |
| 2          | -0.0106                | 2          | -0.0106                |
| 3          | -0.0106                | 3          | -0.0106                |
| 4          | -0.0107                | 4          | -0.0107                |
| 5          | -0.0107                | 5          | -0.0107                |

The velocity of flow for water flux of a specific dam varies during different drawdown periods; the rate of seepage flow is slow during the normal drawdown condition compared with the other two cases. The linear dependence between the hydraulic gradient and the seepage velocity is the main influential in determining the characteristics of the change of the water flux; a temporary increase in the hydraulic gradient due to sudden drawdown may not be tolerated by the slope of an embankment. Other factors that may affect the characteristics of the change of the water flux include dam material, dam structure, permeability of the slope, and the amplitude and speed rate of the water level drawdown. Accordingly, the increase of water flux is considered an important factor in studying the effects of permeability of the shells of the dam with regard to dam safety.

5.2 Exit Gradient

As seen in Figure 8, seepage starts to appear on the slope face after drawdown. As a result, the maximum velocity of water is concentrated on the slope face, at the slope toe, where the hydraulic gradient reaches its maximum value. It is hypothesized that drawdown of the reservoir level at a significantly rapid rate may cause movement of the soil particles out the dam due to increased exit gradients, causing erosion of the soil inside the body of the dam that may result in piping. To investigate the influence of the outlet water flux on the stability of the soil at the face of the dam, the exit gradient is estimated at three different locations on the slope. Figure 10, shows the maximum recorded exit gradient under different drawdown conditions. Slowing the drawdown rate gives additional time for the excess pore water pressure to dissipate, which in turn decreases the exit gradient.

Figure 10. Maximum exit gradient on various locations of the upstream face due to the drawdown conditions.

5.3 Stability analysis of Khassa Chia Dam

To assess upstream dam slope stability, the limit equilibrium (slice technique) analysis of slope stability depending on FEM is used. Results can be obtained from the application of various techniques (Morgenstern-price, Bishop and Ordinary), though here Morgenstern-Price is considered in the greatest
depth, as this technique has the highest accuracy in terms of the equilibrium analysis limit. However, the results from the other techniques are compared with the Morgenstern-Price results. The estimation of F.S. in the present study is also compared to the limits of USACE (2003) and BDS (1994). Table (4) summarises the computed upstream F.S. for all cases of operations using limit equilibrium methods. Figure 11, Figure 12, and Figure 13 present the trend of F.S. for the slope of dam under various drawdown cases using the three analytical methods.

Table 4: Results of Khassa Chai Dam stability analysis by (SLOPE/W, 2012) with Limits of (USACE, 2003) and (BDS, 1994)

| Critical Stability Condition | Case1: 11 days | Case2: 5 days | Case3: 1 day |
|-----------------------------|---------------|--------------|-------------|
| USACE (2003)                | 1.2           | 1.2          | 1.2         |
| BDS (1994)                  | (1.3-1.2)     | (1.3-1.2)    | (1.3-1.2)   |
| Morgenstern-Price           | 1.156         | 1.154        | 0.897       |
| Bishop's                    | 1.123         | 1.121        | 0.897       |
| Ordinary                    | 1.138         | 1.135        | 1.079       |
| Remark                      | Questionable  | Questionable | Unstable    |

Figure 11. Trend of the safety factor during drawdown for period of 11 days.
6. Conclusions
In this research, the impact of drawdown conditions of a reservoir on embankment safety was numerically studied, and some conclusions can be inferred: Whenever the drawdown period is longer than the rate of seepage from the upstream face, due to the linear dependence between the hydraulic gradient and the discharge velocity, a temporary increase in the hydraulic gradient due to sudden drawdown might not be withstood by the earth dam slope. Under sudden drawdown conditions, the exit gradient may reach a critical level at the upstream face and cause failure of the dam.

The results also showed that a minimum F.S. is achieved within 10hr in the case of a 1-day water evacuation; the F.S. is reduced by 60.66% and becomes critical when the water level in the basin drops by about 41.67% of its original height (51m), giving a critical pool level equal to 29.75m. In the case of 5- and 11-day periods, the value of F.S. is reduced by 50.13% and 48.83%, respectively initially, and then increases at the end of the water drawdown time. This proves that the 1-day evacuation period is a much more critical condition than the two other cases, and that the F.S. values of upstream slope stability do not satisfy the minimum limits for all cases of drawdown conditions of Khassa Chai Dam. A match was also noted between the Morgenstern- Price, Bishop and Ordinary methods, in agreement with Duncan (as cited in Griffiths and Lane 1999), who mentioned that the variation between the values of a factor of safety estimated using several methods is commonly lower than 6%.

References
[1] Abdulsattar A. A, Faris M. R and Zedan A. J 2017 Seepage Analysis through an Earth Dam (Khassa Chai Dam) as a Case Study Engineering and Technology Journal.35(2 Part (A) Engineering) pp172-181.
[2] Alonso Pérez de Agreda E, and Pinyol Puigmartí N. M 2009 Slope stability under rapid drawdown conditions. In First Italian Workshop on Landslides. pp 11-27.
[3] Alonso E. E, and Pinyol N. M 2016 Numerical analysis of rapid drawdown: Applications in real cases. Water Science and Engineering. 9(3) pp175-182.
[4] Al-Simawee H 2008 Encyclopedia of Dams in Iraq,Republic of Iraq, Ministry of Water Resources, Directorate of Planning and Observation.
[5] BDS 1994 The British Dam Society at the Institution of Civil engineers, Great George Street, London, SW1P3AA. http://britishdams.org/conferences.
[6] Berilgen M.M 2007 Investigation of stability of slopes under drawdown conditions. *Comput. Geotech.* 34 pp81–91.

[7] Center of Engineering Designs and Studies 2007 Khassa Chai Dam Planning Report.

[8] Desai C. S 1977 Drawdown analysis of slopes by numerical method. *Journal of Geotechnical and Geoenvironmental Engineering*. 103 (ASCE 13054).

[9] Fathani T. F and Legono D 2012 Dynamics of earth dam stability caused by rapid rising and drawdown of water level.

[10] Fattah M. Y, Alwash H. H and Hadi S. A 2016 Behavior of Khassa Chai Earth Dam under Earthquake Excitation *Engineering and Technology Journal*. 34 (15 Part (A) Engineering) pp 2784-2795.

[11] Fattah M. Y, Omran H. A and Hassan, M. A 2017 Flow and stability of Al-Wand earth dam during rapid drawdown of water in reservoir. *Acta Montanistica Slovaca*. 22(1)

[12] Fattah M.Y, Omran H.A and Hassan, M.A 2015 Behavior Of An Earth Dam During Rapid Drawdown Of Water In Reservoir – Case Study *Int. J. Adv. Res.* 3 pp 110–122.

[13] Fredlund M, Lu, H, and Feng, T 2011 Combined seepage and slope stability analysis of rapid drawdown scenarios for levee design *in: Geo-Frontiers 2011: Advances in Geotechnical Engineering*. pp 1595–1604.

[14] Gao Y, Zhu, D, Zhang F, Lei G.H and Qin, H 2014 Stability analysis of three dimensional slopes under water drawdown conditions. *Can. Geotechnical J*. 51(11), 1355e1364.

[15] SEEP/W 2012 Seepage Modeling with SEEP/W: An Engineering Methodology (July 2012). GEO-SLOPE International Ltd., Calgary, Canada.

[16] Griffiths D. V and Lane, P.A 1999 Slope stability analysis by finite elements *Geotechnique*. 49 pp 387–403.

[17] Huang M and Jia, C. Q 2009 Strength reduction FEM in stability analysis of soil slopes subjected to transient unsaturated seepage *Computers and Geotechnics*. 36(1-2) pp 93-101.

[18] Khassaf S. I and Madhloom A. M 2017 Effect of Impervious Core on Seepage through Zoned Earth Dam (Case Study: Khassa Chai Dam) *Int J Sci Eng Res.* 8(2).

[19] Kirra M.S, Shahien M, Elshemy M and Zeidan B.A 2015 Seepage and Slope Stability Analysis of Mandali Earth Dam, Iraq: A Case Study *in: International Conference on Advances in Structural and Geotechnical Engineering, Hurghada, Egypt*.

[20] Lane P.A and Griffiths D. V 2000 Assessment of stability of slopes under drawdown conditions *J. Geotech. Geoenvironmental Eng.* 126 pp 443–450.

[21] Moregenstern N 1963 Stability charts for earth slopes during rapid drawdown *Geotechnique*. 13(2) pp 121-131.

[22] Song K, Yan E, Zhang G, Lu S and Yi Q 2015 Effect of hydraulic properties of soil and fluctuation velocity of reservoir water on landslide stability *Environ. Earth Sci.* 74 pp 5319–5329.

[23] Souliyavong T, Gallge C, Egodawatta P and Maher B 2012 Factors affecting the stability analysis of earth dam slopes subjected to reservoir drawdown *Second Int. Conf. Geotech. Constr. Mater. Environ.* 2012. pp 507–512.

[24] Sudardja H 2012 The effect of reservoir water level fluctuation to the seepage on earth dam *In Journal of the Civil Engineering Forum (JCEF)*. (Vol. 21, No. (1)).
[25] Twort A. C, Ratnayaka D. D and Brandt, M. J 2000 Water supply. Elsevier.

[26] USACE 2003 Slope Stability, Engineering Manual 1110-2-1902, Department of the Army, Corps of Engineers, Washington DC, United States of America, available at www.usace.army.mil/inet/usacoe-docs-eng-manuals/em1110-2-1902/entire.pdf.

[27] Viratjandr C and Michalowski R. L 2006 Limit analysis of submerged slopes subjected to water drawdown Canadian Geotechnical Journal. 43(8) pp 802-814.

[28] Wang J. J, Zhang H. P, Zhang, L and Liang Y 2012 Experimental study on heterogeneous slope responses to drawdown Engineering geology. 147 pp52-56.

[29] Yan Z. L, Wang J. J and Chai H. J 2010 Influence of water level fluctuation on phreatic line in silty soil model slope Engineering Geology. 113(1-4) pp 90-98.

[30] Zhang T, Yan E, Cheng J and Zheng Y 2010 Mechanism of reservoir water in the deformation of Hefeng landslide J. Earth Sci. 21 pp 870–875.

[31] SLOPE/W 2012 Stability Modeling with SLOPE/W: An Engineering Methodology (July 2012).GEO-SLOPE International Ltd., Calgary, Canada.