Seepage and Slope Stability Analysis of Haditha Dam using Geo-Studio Software

Mohammed Karim Malik 1, Dr. Ibtisam Raheem Karim 2

1, 2 Civil Engineering Department, University of Technology, Baghdad, Iraq

Abstract. The current study is designed to model seepage and slope stability analysis of Haditha dam (Iraq) using finite element method by GEOSTUDIO 2012 software. GEOSTUDIO software is capable to carry out analysis such as, stress-strain, seepage, slope stability, dynamic analysis. SEEP/W and SLOPE/W are sub programs of GEOSTUDIO which can simulate the movement and pore-water pressure distribution within permeable materials like soil and rock. In the present study Haditha dam, which is an earth dam constructed on the Euphrates River in the middle west of Iraq 7 km upstream from Haditha city in Al Anbar governorate with a total length of the barrier 9064 m was chosen as a case study to simulate the seepage and slope stability analysis. The input data given to the software are the geometry of the dam and its material properties. The flow net is generated by SEEP/W software showing phreatic line, equipotential line, and stream line. Also, the seepage influx is computed by the software. The dam at its actual design was investigated by inspected the water in the reservoir to be at maximum, minimum and normal water level. It was concluded that the dolomite core and the presence of asphaltic-concrete diaphragm and the grout curtain have an important effect on decreasing the seepage quantity through the dam body and the factor of safety values of upstream and downstream slopes stability satisfy the minimum limits for all levels of water.

1. Introduction

Any dam failure or accident to dam can cause potential hazard to property and lives of millions of people who dwell downstream of the dam and also other life stock. Also, the seepage failure and slope failure of an earth dam are considered among of the most common types of failures in earth dams. Therefore safety of the dams is very important side for preservation the national investment. So, several studies have dealt with the issue of dams’ safety. Irzooqi (1998)[1] studied and analyzed the seepage problem at the downstream area of Haditha dam in Al-Anbar governorate on Euphrates River especially in front of two stations on the right side. It was concluded that the main source of the seepage at the first site is a leakage of reservoir water through the foundation. At second site, the main source is reservoir water, which seeps under the foundation grout curtain through channels made by the dissolution of the gypsums formations. Ismaeel and Bahzad (2011)[2] used a finite element method through SEEP2D program, to determine the free surface seepage line, the quantity of seepage through the dam, the pore water pressure distribution, the total head measurements and the effect of anisotropy of the core materials of Duhok zoned earth dam. The analysis of the results of this study showed that Duhok dam is safe against the danger of piping and slope sloughing under the present operation levels. Kirra et al. (2015)[3] used GeoStudio software by employed Finite Element modeling. The model is verified, and then it is employed to analyze seepage and stability of Mandali Dam (Iraq). The results of the analysis confirm the safety of Mandali dam against combined seepage and slope stability under all cases of operation. The case of rapid drawdown is the most critical operating case; compared to other cases of operation. Kirra et
al. (2017)[4] studied three typical cases of failed earth dams; Fontenelle dam (USA), Carsington dam (England), and Walter F. George dam (USA). The obtained results confirm that for typical cases of failed dams, failure is attained due to either seepage or slope instability or combined seepage and slope instability. Scenarios for redesign of failed dams to prevent failure are presented and discussed. Ibraheem (2017)[5] analyzed seepage flow in Al-Adhaim earth dam using Geo-studio through its subprograms SEEP/W and SLOPE/W. The study is carried out through analyzing section in two cases, the first model was analyzed by the presence of plastic core instead of clay core in seven cases were selected depending on the position of plastic core in earth dam. The second was analyzed using clay soil and clay soil mixed with materials 5% lime and 6% silica-fume as core of earth dam. The results showed that in the first model the permeability was decreased and the phreatic line declined from the original in all cases that selected. In the second model, when clay soil mixed with improved materials the permeability of clay soil decreased in the cases of different water content, and the unconfined compression strength increased more than 70%. Mishal (2018) [6] used GeoStudio software to calculate the factor of safety against sliding under different soil conditions for Adhaim earth dam, using nine methods and taking into consideration the effect of change in the reservoir water level, seepage rate through dam body and the main soil properties such as the weight density, angle of internal friction and the cohesive strength. these variables were linked to the safety factor and the relationship is represented by a mathematical equation. the result obtained that the most effective variable on the factor of safety against sliding which is the angle of internal friction. the process of rapid drawdown of the Adhaim’s dam reservoir has also been studied. It has been noticed that the values of factor of safety increase along with the rapid drawdown until it is fixed at the dead storage reservoir level. Najeeb (2018) [7] studied and analysis of seepage through Al-Shahabi earth dam in Wasit Governorate, Iraq, by using Geo-Studio software with its sub-programs SEEP/W 2012 with two cases of water levels, which are: normal water level and maximum water level. It was concluded that the quantity and velocity of seepage when the steady state seepage analysis during maximum water level are increasing about 1.6 from the quantity and velocity of seepage during normal water level and the phreatic line declines throughout the dam then passes through horizontal drain and exit at the dam toe drain, which is safety for stability because the phreatic line not intersects with downstream face; therefore the sloughing phenomenon of downstream not occur. Al-Shamary (2019)[8] studied assessing the water seepage during the Haditha dam (Iraq) using the computer software (SEEP/W, 2012). The results obtained from the software were compared with the actual field data of the seepage amount for years (1989 - 2017) and with the water level in the dam reservoir for different periods. The results of comparison give an idea to the efficiency of the dam protection against the seepage. The results displayed that the asphaltic diaphragm in good condition and efficient on the right and left sides of the dam.

2. Governing Equations

Following partial differential equation (PDE) is the governing equation used for modelling of SEEP/W program, Lu and Likos, (2007) [9]:

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

Where,

- $H$ = Hydraulic head (L);
- $k_x$ & $k_y$ = hydraulic conductivity values in x and y direction, respectively, (L/T), $Q$ = applied boundary flux (L³/T); $t$ = time domain (T); $\theta$ = volumetric water content (%).

3. Case Study

Haditha dam is a multi-purpose hydro development designed to control the Euphrates River flow in interests of irrigation, electric power generation and for partial accumulation of extreme Euphrates River inflows into Haditha reservoir. The dam was constructed in the Middle west of Iraq 7 km upstream from ADDIN CSL_CITATION {"citationItems":[]}"id":"ITEM-1","itemData":{"abstract":"The Haditha reservoir in Iraq was selected as case study to be used in the numerical models, because it possesses the two relevant types of reservoir sedimentation processes (delta formation and density current). It represents a case where the reservoir storage capacity losses are substantial. In order to reduce capacity losses. The delta formation was simulated for fixed and fluctuating water level in the reservoir, including the simulation of the formation of channels in the delta. The model was a previous run for simulating delta formation, and by subsequently applying the gradual water drawdown procedure used
in the Haditha reservoir, the actual removing process of the accumulated sediment was simulated. In this study the different processes and phenomena related to reservoir sedimentation were simulated in successful way for a real and a schematized reservoir, whereas also flushing as mitigation measure was fairly well simulated when compared with the practice in Haditha reservoir. However more studies and a proper calibration and verification are needed to predict the sedimentation processes more accurately before using the model for design purposes.

The length of the barrier of dam is 9064 m (dam 8875 m and hydroelectric station 189 m). The right-bank stretch toward the right bank from the station has a length of 3310 m, the channel stretch of the dam 580 m, and the left-bank stretch 4985 m shown in Figure (2) and height of dam: 57 m, length of dam at top: 8923 m, width of dam base: 325 m, top width: 20 m, elevation at top: 154 m.a.s.l, Operational level: 147 m.a.s.l, storage size of operational level: 8.28 Billion \( m^3 \), surface area of storage at operational level: 500 km\(^2\), flood level: 150.2 m.a.s.l, storage size at flood level: 9.8 Billion \( m^3 \), surface area of storage at flood level: 567 km\(^2\), Min. operational level: 129.5 m.a.s.l and dead storage: 0.23 Billion \( m^3 \). Figure (3) shows the main materials of the dam.
simulating delta formation, and by subsequently applying the gradual water drawdown procedure used in the Haditha reservoir, the actual removing process of the accumulated sediment was simulated. In this study the different processes and phenomena related to reservoir sedimentation were simulated in successful way for a real and a schematized reservoir, whereas also flushing as mitigation measure was fairly well simulated when compared with the practice in Haditha reservoir. However more studies and a proper calibration and verification are needed to predict the sedimentation processes more accurately before using the model for design purposes.

Figure 2: Haditha dam layout [11].
3. Safety Criteria of Haditha Dam

The Geometric properties of Haditha dam were compared with those recommended by the British Dam Society (BDS, 1994) [13] in Table (1). Such comparison shows that the geometric design of the dam is acceptable based on the recommendations of (BDS,1994) [13]

Table (1). Comparison between Original Section of Haditha Dam and (BDS, 1994) [13] Safety Limits

| Parameter          | Haditha dam | (BDS) Safety limits | Safety of dam status |
|--------------------|-------------|---------------------|----------------------|
| Crest width        | 20 m        | Not less than 2m    | Acceptable           |
| Upstream slope     | 1:2.75-1:3  | 1:2.5               | Acceptable           |
| Downstream slope   | 1:2.25      | 1:2                 | Acceptable           |
| Free board         | 3.8 m       | Not less than 2m    | Acceptable           |
| Bed width of core  | 135 m       | Not less than H/3= (18m) | Acceptable |
| Core slope         | 1:1-1:2.5   | 1:12                | Acceptable           |

4. Seepage analysis of Haditha dam

Seepage through Haditha dam is controlled by a dolomite core and inside the core extends an asphaltic-concrete diaphragm that starts from the base of the dam to almost its top to cutoff the seepage lines. This core consists of dolomite rocks with hydraulic conductivity ranges from (0.1-1) m/day. Ninety cross sections are stated along the axis of the dam body on the right and left sides each of ninety meters length as shown in Figure (4). The cross section of station 32 was chosen to calculate the seepage because it is the most exposed to the pressure of the reservoir water due to its proximity to the river bed and the high depth of the water in it in addition to the availability of the piezometer reading and the seepage value of this station.
Figure 4: Locations of the stations on body of the Haditha dam, [8].

Seepage through and under the dam is analyzed using the program SEEP/W2012. The finite element mesh used for the analysis the maximum water level is shown in Figure (5). The mesh includes higher-order six-nodded triangular elements, with (3204 element) and (1695 nodes). The upstream boundary nodes are designated as head boundaries with total head equals to the water level in the reservoir. The bottom line at toe is designated as a zero discharge (no flow). Figures (6) and (7) present the water head variation and pore water pressure through the dam body, respectively. It is clear from Figure (6) that the central dolomite core, asphaltic-concrete diaphragm, and grout curtain causes significant lowering of the phreatic line and exit at the dam toe, which is safety for stability because the phreatic line not intersects with downstream face; thus the sloughing phenomenon of downstream not happen.

Figure (7) confirms that the pore water pressure in the internal surface of downstream side slope is far away from downstream and the seepage through the dam is within the historical cases of seepage failure in (Rice, 2007)[14] which ensures stability of the downstream against seepage failure.

Figure 5: Typical finite element mesh for seepage analysis by GeoStudio.
5. Results of the Stability Analysis of Haditha Dam

Seepage analysis is carried out first to establish the steady state seepage. The results of the steady state seepage are used as input for limit equilibrium analysis. Upstream and downstream slopes were checked at three different levels of water, as follows:

A. Maximum water level.
B. Normal water level.
C. Minimum operational level.

Figures (8) and (9) show the factor of safety (F.S) for the upstream at maximum water level using Bishop method and Corps of Engineers #1 method, respectively. Also, Figure (10) shows the F.S for downstream slope by Ordinary method for maximum water level. Figures (11) and (12) show the F.S for upstream slope at normal water level using Morgenstern-Price method and Corps of Engineers #1 method, respectively. Figure (13) shows the F.S for downstream slope by Ordinary method for normal water level. Figures (14) and (15) show the F.S for upstream slope at minimum water level using Bishop method and Corps of Engineers #1 method, respectively. The F.S for downstream slope by Janbu method for minimum water level is shown in Figure (16).
Figure 8: F.S for upstream slope by Bishop method for maximum water level.

Figure 9: F.S for upstream slope by Corps of Engineers #1 method for maximum water level.

Figure 10: F.S for downstream slope by Ordinary method for maximum water level.
Figure 11: F.S for upstream slope by Morgenstern-Price method for normal water level.

Figure 12: F.S for upstream slope by Corps of Engineers #1 method for normal water level.

Figure 13: F.S for downstream slope by Ordinary method for normal water level.
Figure 14: F.S for upstream slope by Bishop method for minimum water level.

Figure 15: F.S for upstream slope by Corps of Engineers #1 method for minimum water level.

Figure 16: F.S for downstream slope by Janbu method for minimum water level.

Results of Haditha dam stability analysis for the steady state with Limits of (USACE, 2003) and (BDS, 1994) are shown in Table (2).

Table 2. Results of Haditha dam stability analysis for the steady state with Limits of (USACE, 2003) [15] and (BDS, 1994) [13].
**6. Conclusion**

Finite element modeling was used in the present study to analyze the combined seepage and slope stability of Haditha earth dam. Maximum water level of steady seepage case was considered to evaluate seepage. Three different levels of water (maximum, normal, and minimum) were considered, and six different limit equilibrium slope stability methods were used to analyze the upstream and downstream slopes of the dam. The dam safety check was based on the minimum required F.S stated in (USACE, 2003) and (BDS, 1994). The results showed that the geometric design of the dam is acceptable according to (BDS, 1994) criteria and the seepage through the dam is within the historical cases of seepage failure in (Rice 2007) and It is noticed that the central dolomite core, asphaltic-concrete diaphragm, and grout curtain causes significant lowering of the phreatic line and its exit at the dam toe, which ensures stability of the downstream against seepage failure because the phreatic line not intersects with downstream face; thus the sloughing phenomenon of downstream not happen. The factor of safety (F.S) values of upstream and downstream slopes stability satisfy the minimum limits for all levels of water. It can be concluded that Haditha dam is safe against seepage failure and slope failure under the different levels of water presented in this paper.

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