Effect of Using Vertical Drainage Column in Hemrin Dam on Factor of Safety Under Seismic Load

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Abstract. Recent years have seen an increase in the use of computer-based numerical models to test the stability of earth dams and to simulate the impact of all the factors that affect their safety. Geo-Studio software and its sub-programs SLOPE/W, and QUAKE/W are used to determine the factors of safety and stability of dams, and investigations of dynamic analysis, a finite element serves as its base to do the numerical modeling for this study. The Hemrin Dam represents the case study and is regarded as the study's major focus. The results showed that the values of the safety factor increased from (1.439) to (1.583) when the water level is 8m, from (1.365) to (1.549) when the water level is 16 m, and from (1.084) to (1.317) maximum water level is 32m, without and with a vertical drainage column, because the pore water pressure is reduced and the effective stress is increased. In the case of a Rapid drawdown of water when a vertical drainage column is added, the value of the factor of safety decreases from 1.371 to 1.306 for the initial time, while decreasing from 1.406 to 1.363 for the second day of rapid drawdown. These reductions result from there is a delay between the process of the reservoirs' water level dropping and the water level lowering on the earthen dam's side. The vertical drainage column is crucial for the stability of the dam as the water is drained using the existing vertical and horizontal filters which eventually improve and increase the value of the effective stress.

Keywords: Hemrin dam, factor of safety, El-Centro earthquake, Geo-Studio.

1. INTRODUCTION

Dams are one of the oldest techniques people have used to regulate rivers and other natural waterways. It was organized and managed by humans to suit their demands for drinking water, agricultural water and avoid recurring dangers such as floods or torrents or accomplish both purposes at once. Stability and safety are crucial considerations when building dam structures. Any structure's performance and stability are always its top priorities, especially large structures like dams that can fail and cause serious property losses in addition to putting people's lives in danger. Seismic loads have been implicated in several embankment dam collapses. Many effects of earthquakes can be seen on embankment dams, such as settlement, instability, internal cracking, differential motions, or damage to nearby structures [1,2]. Several earthquakes that were categorized as moderate to relatively strong happened in some locations in light of the recent events in Iraq. This occurrence, which had a considerable impact on the dam body, is a key event in the history of facilities in general and dams in particular. It causes the dam to fail, which causes calamities to happen that destroyed infrastructure and human life.

Hemrin Dam, which serves as the case study, is situated in the steep Hemrin mountain range and is thought to be the current active seismic line, it is imperative to research the direct and indirect effects of earthquakes on Hemrin Dam. Studied [3] Analysis Seismic Response and Stability of the Slope of the Hemrin Dam in the Governorate of Diyala. Used the Geo-Studio program to examine the Hemrin Dam and determine the factor of safety. Three nodes were taken from various locations inside the dam body to test the dynamic response, and the safety factor was determined at various water levels. Used the El-Center earthquake scaled to 10 seconds. Results showed that the safety factor increases as the water level rises, but that the increase in the factor of safety size with water depths of (10 and 15) meters was more than that with other depths. Geo-Slope software was used [4] to analyze the seepage and stability of slopes in the Hemrin Dam. The SLOPE/W program is used to obtain stability of slopes evaluations for both upstream and downstream slopes. The results showed that the minimum safety factor was obtained at the maximum elevation of the water head for two cases without and with a horizontal drain filter. The value of the safety factor ranged from 1.37 to 1.48 at a water level of (92)m, from 0.94 to 1.37 at (104.5) m, and from 0.94 to 1.37 at (104.5) m without and with a horizontal drainage blanket. Used [5] PLAXIS 3D software it depends on the finite element method to establish the values of the safety factor for the upstream slope located in India. Used two components of the seepage analysis are the steady-state and transient analyses. In various instances, the stability of the earth dam's upstream slopes has been examined in several cases: (a) full water level (b) rapid drawdown in 5 and 10 days (c) slow drawdown during 50 days; and (d) minimum water level. studied [6] Investigated the earth dams' safety factor in drawdown situations using the geo-studio software. They conclude that the drawdown happens within a day and the after an hour, the safety of the factor has reached its minimum value. Also, they demonstrate how the decrease in where the pressure of pore water is in the slope, at sea level was released has a significant impact on the stability of the slope.

This section of the Hemrin Dam shown in Figure 1, which was taken, represents the reality of the condition of the Hemrin Dam (1. foundation, 2. shell, 3. core, 4. Fine filter, 5. Coarse filter, 6. Random fill, and 7. Cofferdam, 8. Vertical drainage column, 9. Horizontal drainage blanket). This section was also relied upon by previous researchers [3,4]. This study differs from the rest of the research. It studies the effect of the vertical drainage column on the stability of the Hemrin Dam In the event of an earthquake El-Centro, it was scaled to 20 seconds, without or with a vertical drainage column, and different water levels in the dam reservoir, which are (8 m, 16 m, and 32 m).

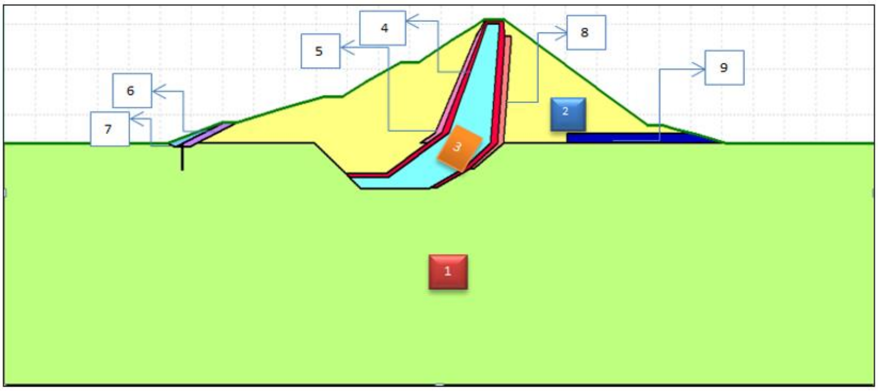

Figure 1: Hemrin Dam components.

2. STUDY OF CASE

2.1 Location of Hemrin Dam

One of the significant, important, and strategically important projects built on the Diyala River is the Hemrin Dam. The idea to build the dam originated from the damage caused by the river's frequent flooding during the rainy seasons. The Hemrin Dam is a sizable dam located 10 kilometers in front of the Diyala Dam and 120 kilometers northeast of Baghdad [7]. Hemrin Dam's location in Iraq is depicted in Figure 2.

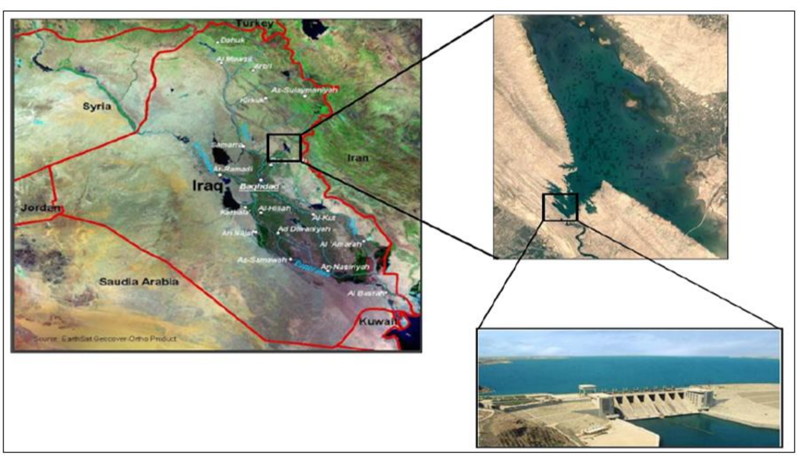

Figure 2: The location of Hemrin Dam.

2.2 Description of Hemrin Dam

Hemrin Dam's length is about (3500 m), and its maximum height is about (53 m) in the old Diyala River section. The highest level of the dam is (109.5) m above sea level. The advantages of the Hemrin dam project are managing floods in the Diyala River, reducing their volume from (14,000 to 4,000 m^3/sec), an increase in electricity production of (50) megawatts per hour, and Fisheries development [7]. The usage of both vertical and horizontal filters was done. They are in the downstream area. The material of the filter is loose sand, and it has a vertical filter that is 35.9 meters long and 2.5 meters wide and a horizontal filter that is 64 meters long and 2.5 meters wide as shown in Figure 1. Material properties for each part of the dam, permeability, unit weight, Angle of internal friction, and cohesion as shown in Table 1.

Table 1: Hemrin Dam's Material Characteristics [7].

No.	Properties of Material	Permeability (m/s)	Unit Weight (kN/m³)	Angle of internal friction (degree)	Cohesion (kPa)
1	Foundation	$1.46e^{-10}$	22	15	40
2	Shell	0.00169	21.5	38	0
3	Core	$3.5e^{-07}$	20.2	4	52
4	Fine Filter	$1.6e^{-05}$	22	35	0
5	Coarse Filter	0.0001	22	35	0
6	Random fill	0.0012	17	36	7
7	Cofferdam	$2.31e^{-07}$	18	30	15
8	vertical Filter	0.0019	18	33	0
9	horizontal Filter	0.0015	18	33	0

2.3 Earthquake Excitation

An El-Centro earthquake with a period of 20 seconds was used as the earthquake for the current study, shown in Figure 2 [8-12].

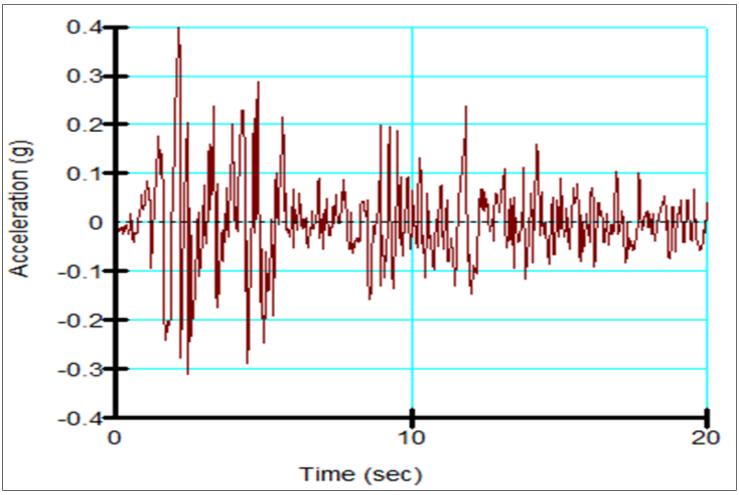

Figure 3: The El-Centro Earthquake's 20-second acceleration time record [8].

2.4 Modeling of Hemrin Dam Using Geo-Studio Software

Geo-Studio software is based on the finite element method to do the numerical modeling for this study [13], and its sub-programs SLOPE/W is used to do investigations on slope stability and calculated safety factor [14], and QUAKE/W is used to do analysis dynamics for Hemrin Dam [8]. Arranging the mesh for the Hemrin Dam is shown in Figure (4). Geo-Studio was used to analyze the Hemrin Dam and determine the value of safety factors with and without a vertical drainage column and at three different water levels as follows:

Case 1. The level of water in the reservoir is a quarter.

Case 2. The level of water in the reservoir is half full, and

Case . of water in the reservoir is full.

Four different types of elements—triangular, square, rectangular, and trapezoidal in various sizes make up the type of mesh, as shown in Figure 4. In dynamic conditions, the boundary condition is along the bottom of the foundation in the vertical and horizontal direction X/Y restrained. In contrast, the sides of the foundation are constrained and anchored in the Y direction, while the boundary nodes upstream are set as hydrostatic pressure, equal to the water level in the reservoir as shown in Figure 4**.**

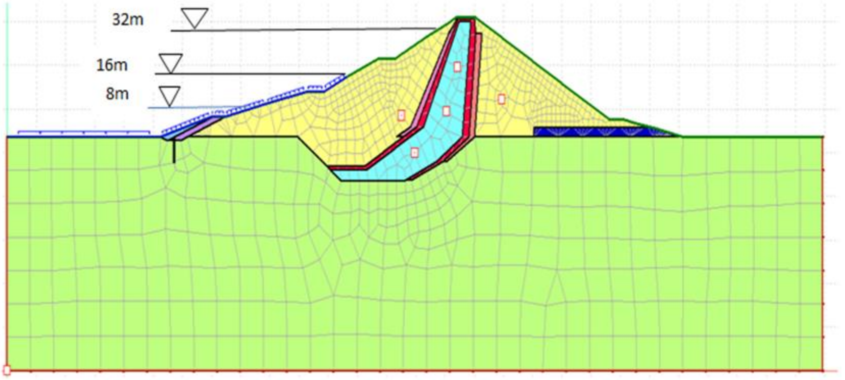

Figure 4: Arrangement of the mesh, boundary condition, and water levels of the Hemrin Dam.

3. RESULTS AND DISCUSSION

In this research, the stability of the Hemrin Dam, which represents the case study, was studied because it is located in a seismic activity area under the influence of the El-Centro earthquake for 20 seconds, with or without a vertical drainage column and different water levels in the dam reservoir, which are (quarter, half and full), the most important conclusions were reached by studying and analyzing the results of numerical models of the Hemrin Dam under the influence of earthquakes, which present in the following paragraph:

3.1 Factor of Safety

Adding the vertical drainage column causes pore water pressure to decrease and the effective stresses to increase; thus, the safety factor increases. Table 2 shows the safety factor values for the three cases (quarter, half full, and full) before and after the earthquake and with and without a vertical drainage column. The safety factor increases with the decrease in the water level in the dam reservoir. For example, it has been seen that the value of the factor of safety increased from 1.084 to 1.317 without and with a vertical drainage column for a full water level**.**

Table 2: Values of factor of safety

Case	**Without a vertical drainage column**		**With vertical drainage column**	
	Before earthquake	After Earthquake	Before Earthquake	After Earthquake
Quarter water level (8 m)	1.433	1.439	1.584	1.583
Half water level (16 m)	1.363	1.365	1.552	1.549
Full water level (32 m)	1.086	1.084	1.319	1.317

As shown in Figures 5 and 6, the Slip Surface at full water level under the seismic load before and after the addition of the vertical drainage column, the order of the Slip Surface following the addition of the vertical drainage column, and the increase in the safety factor's value.

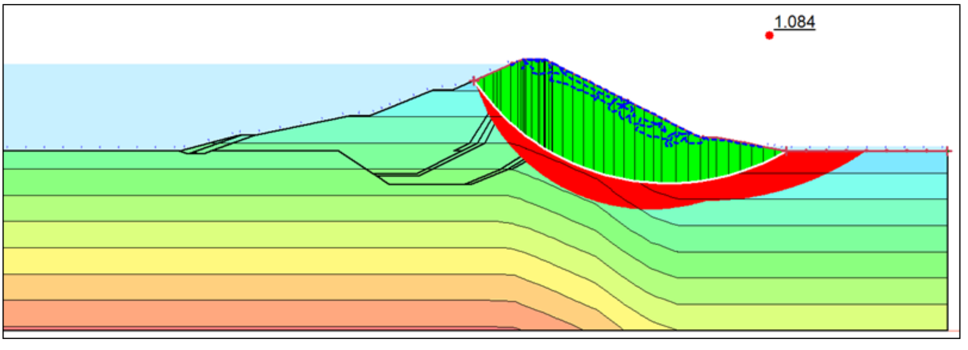

Figure 5: Slip surface without vertical drainage column at full water level after an earthquake.

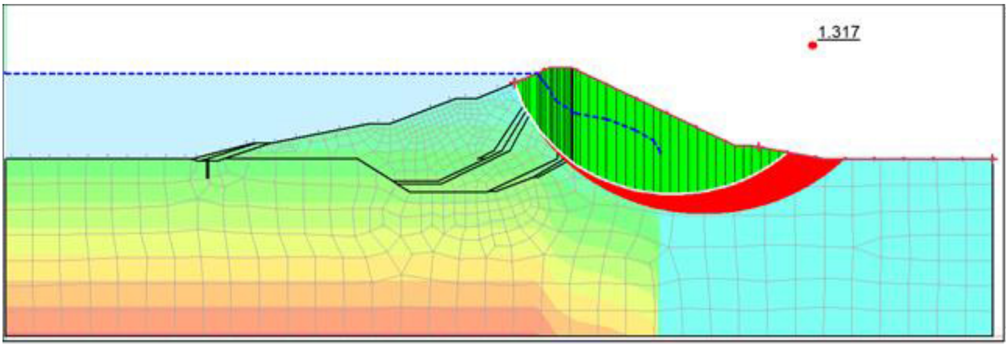

Figure 6: Slip surface with vertical drainage column at full water level before earthquake.

3.2 Rapid Drawdown

Rapid drawdown is dangerous, to conduct the analysis, the dam drained all of its water in just two days. There is a delay between the process of the reservoirs' water level dropping and the water level lowering on the earthen dam's side. Lowering the water level in reservoirs takes longer than the drainage procedure. This is the outcome displayed in Table 3.

Table 3: Values of factor of safety for a rapid drawdown for water.

Time (hr)	**Factor of Safety**	
	Without Vertical drainage Column	**With Vertical drainage Column**
Initial	1.371	1.306
12	1.394	1.339
24	1.400	1.354
36	1.404	1.356
48	1.406	1.363

The value of the safety factor decreases from 1.371 to 1.306 for the initial time, while decreasing from 1.406 to 1.363 for the second day, when the vertical drainage column exists. These decreases result from a delay between the process of the reservoirs' water level dropping and the water level lowering on the earthen dam's side as shown in Figures 7 to 10.

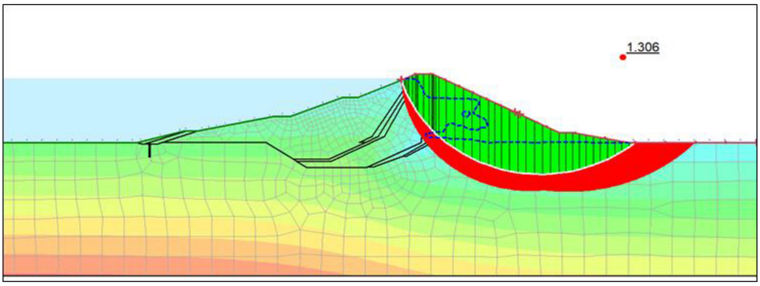

Figure 7: Value of factor of safety for a rapid drawdown for water with vertical drainage column at the initial time.

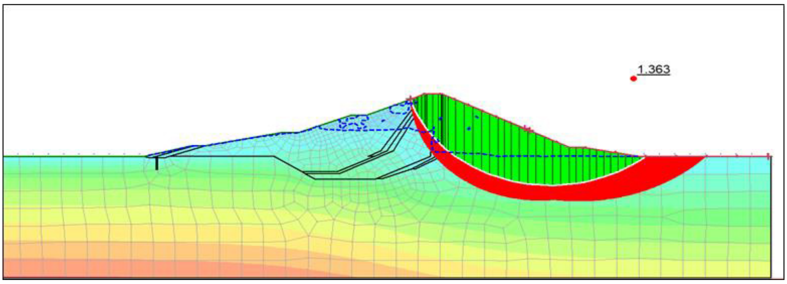

Figure 8: Value of factor of safety for a rapid drawdown for water with vertical drainage column at second day time.

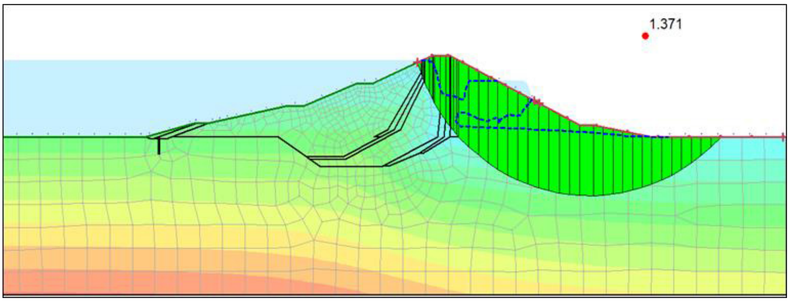

Figure 9: Value of factor of safety for a rapid drawdown for water without vertical drainage column at the initial time.

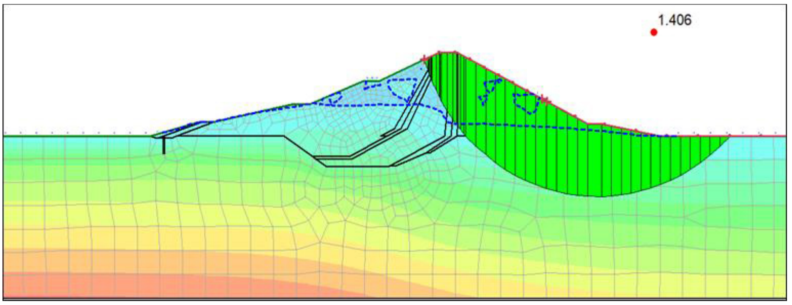

Figure 10: Value of factor of safety for a rapid drawdown for water without vertical drainage column at second day time.

4. CONCLUSIONS

- The values of the safety factor are increased from (1.439) to (1.583) when the water level is a quarter, from (1.365) to (1.549) when the water level is half full, and from (1.084) to (1.317) when the water level is full, without and with a vertical drainage column, as the pore water pressure is reduced and the effective stress is increased.
- In the case of rapid drawdown of water when the vertical drainage column exists, the value of the safety factor decreases from 1.371 to 1.306 for the initial time while decreasing from 1.406 to 1.363 for the second day of rapid drawdown. These decreases result from a delay between the process of the reservoirs' water level dropping and the water level lowering on the earthen dam's side.
- The vertical drainage column is crucial for the dam's stability as the water is drained using the existing vertical and horizontal filters, which eventually improve the value of the effective stress, and hence the stability of the dam is improved.

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