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Numerical Analysis of Earth Dam Subjected to an Earthquake Excitation

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ABSTRACT

A dynamic analysis of the Makhool dam using Geo-studio software is presented in this paper for the purpose of investigating the seismic behavior of earth dams. With emphasis on the dam's height, soil characteristics, and input motion, this study examines the effect of earthquake excitation on the dam's behavior. With input from the SEEP/W program, the analysis was conducted using the QUAKE/W program. In this study, the horizontal component of motion was taken at three different values: 0.04g, 0.06g, and 0.08g. In addition to total stress in x-direction and y-direction, pore water pressure, and x-displacement, the results were presented in figures. Study findings showed that the horizontal displacement and shear strain of the dam increased with dam height, with the maximum displacement of the dam equal to 94 cm at the end of the earthquake. Besides the type of dam soil, the acceleration of the dam was also affected by the strength of the soil, since weaker soil reduced the acceleration of the dam. The pore-water pressure at the dam's base was the highest, with the horizontal movement increasing with depth. In earthquake zones, seismic evaluation is vital for dam construction, and the research provides valuable advice for designing and building earth dams.

1. INTRODUCTION

Earth dams are indispensable designs that store water, control floods, and produce hydroelectric power. They are utilized universally, with many enormous dams worked during the twentieth hundred years. Nonetheless, earth dams are in danger from seismic hazards, which can cause significant damage or even disappointment. Accordingly, seismic evaluation is urgent, particularly in regions inclined to earthquakes. Dam disappointment can prompt death toll, financial damage, and extreme ecological mischief [1]. Various kinds of dams can be worked with different materials, and the decision relies upon site conditions, material accessibility, and the dam's motivation. Present day dams are fundamentally of two sorts: substantial dams and dike dams. Dike dams are additionally partitioned into rock-fill dams and earth-fill dams [2].

As of late, there has been a developing requirement for framework like interstates and dams. The development of huge dams has become more continuous, filling needs, for example, water supply, flood control, water system, and hydroelectric power age. Notwithstanding, the seismic way of behaving of earth dams is a critical variable to consider during plan and development.

This paper presents a powerful investigation of the Makhool dam utilizing Geo-studio programming to concentrate on the seismic way of behaving of earth dams. The review inspects the effect of seismic tremor excitation on the dam's way of behaving, zeroing in on the dam's level, soil properties, and information movement. The examination was performed utilizing the Shake/W program, with input from the Leak/W program. The discoveries offer significant bits of knowledge into planning and building earth dams in tremor inclined regions and highlight the significance of seismic evaluation for dam security.

2. LITERATURES REVIEW

Seismic evaluation for dam development is vital to guarantee the security and dependability of earth dams. Many investigations have analyzed the seismic way of behaving of earth dams, zeroing in on what quake excitation means for the dam. Field examination is a vital piece of seismic evaluation, remembering seismological investigations that show past quake events for the locale. These examinations assist with assessing the probability of future earthquakes, and the seismic history for the dam development region should be accessible. Another examination includes geotechnical studies, which inspect the dirt or rock development at the site and survey their way of behaving during a tremor, deciding what they mean for the design's obstruction. The geological condition likewise should be examined [3]. It is possible for earthquakes to increase pore water pressure within dams and cause extra stress to them. The main impact of earthquakes is slope instability, which can lead to dam failures [4]. The shaking from an earthquake can collapse an entire dam, and earthquakes are structural failures. There are two main types of earthquake-related failures: liquefaction of the dam's foundation and sliding or cracking of the dam's embankment [5]. Approximately 30,000 reservoirs are in a low safety condition, according to collected data [6, 7]. These statistics show a high risk of dam failure due to earthquakes.

Hosseini and Nasrollahi [8] determined the excess pore pressure after the earthquake for the Karkheh dam that consider the largest dam in Iran, the case study was modeling by FLAC2D. It was concluded from this study that the value of pore-water pressure decreases at the filter zones that existed on core sides. The maximum pore-water pressure happened at the middle level of the core and this value increases about 26% after earthquake.

Niu et al. [9] studied the seismic response of Shuangjiangkou earth-rock fill dam by using non-linear Pastor-Zienkiewic model that consider the materials of the dam as two-phase pours medium and consider the dam-reservoir-foundation as on system and called it interaction system. It was calculated from this study the maximum horizontal displacement that equal to 0.6 m and the maximum vertical displacement that equal to 0.3 m at the crest of the dam. Pore-water pressure increase at the base of the dam also the vertical stresses increase at the base of the dam.

A study by Khalil [10] examined the pore-water pressure in the Mosul dam under three accelerations: 0.2 g, 0.25 g, and 0.3 g. The sections varied in the degree of friction and the density of the core materials. With increasing acceleration value, pore-water pressure increases in the section above.

According to Bouaicha et al. [11], the variation of pore-water pressure and horizontal displacement of earth dams were studied using FLAC2D based on the finite difference method. The displacement with water was also compared with the displacement without water, and the displacement with water is greater and equal to 0.342 m.

Ebrahimian [12] made investigation of seismic behavior of earth dam by using numerical modeling. It was studied the effect of dam height, behavior of the soil, the characteristics of input motion on the seismic response of the dam, it was concluded that the horizontal displacement and shear strain increases with increasing of the dam height and the maximum displacement of the dam at the end of earthquake is equal to 94 cm. Also, the type of dam soil plays a major effect on seismic behavior of the dam, when the soil with less strength that reduce the acceleration of the soil when it was compared with the strong soil.

According to Fattah et al. [13], the Khassa Chai-zoned earth dam was dynamically analyzed under earthquake conditions. The earthquake El-Centro, with a duration of 10 seconds, was used as a basis for this study. Vertical accelerations of 0.05 g, 0.1 g, and 0.2 g were input. In addition to pore-water pressure, displacement, and stress, many dam parameters were measured. With depth, horizontal displacement increased with increasing pore-water pressure at the dam's base.

The Al-wand earth dam was numerically analyzed by Al-Hadidi and Abbas [14]. In their simulation, the 2017 Iraq earthquake was accelerated by 0.05 g, 0.02 g, and 0.03 g. For nodes 3 and 1, the maximum pore-water pressure was 80 Kpa and 110 Kpa, respectively. As the earthquake lasted, horizontal displacements and vertical displacements increased, whereas stresses gradually decreased, indicating soil weakening.

Bhosale and Deshmukh [15] made the numerical analysis of Ambad dam (zoned earth dam) located at India by using PLAXIS 2D to study the seismic response of the dam. Seismic behavior of Ambad dam can be expressed by the terms: pore-water pressure, stress and displacement.

It was used two cases in this numerical analysis: earthquake with full reservoir and the second case with empty reservoir.

For earthquake 5.4 magnitude the results of displacement as listed below:

-Total displacement 0.2 m, 0.45 for full and empty reservoir.

-Horizontal displacement 0.187 m, 0.1 m for full and empty reservoir.

-Stresses for full reservoir equal to 683.49 Kpa while for empty reservoir 515.47 Kpa.

-Pore-water pressure for full reservoir equal to 480 Kpa and for empty equal to zero.

Tosun et al. [16] researched numerical analysis of Bebekli dam that existed in the western part of Turkey to show the seismic behavior of the dam. It was observed from this analysis that the maximum value of horizontal displacement is equal to 58.5 cm on the crest of the dam while the deformation is about 7-15 cm and these results can be showed the problem of the sliding through the dynamic analysis.

Mazaheri et al. [17] studied the dynamic analysis of Doyraj Earth Dam that is located in Iran, seismic behavior can be expressed by vertical and horizontal acceleration and horizontal excel ration also it was adopted two models in this analysis Mohr model and Finn mode. Deformation can be showed that the maximum settlement at the dam is 61 cm and the horizontal deformation at the core is less than the dam upstream and the maximum horizontal happened at the downstream of the dam.

Soroush and Rayati [18] studied numerical analysis for Karkheh dam with central clay core and cut off wall on its foundation with finite element code PLAXIS, the studies shows that the peak acceleration for Karkheh dam is 0.4 g and it was used only the first twenty seconds. It was concluded from this study the effect of earthquake on cut off wall and the maximum horizontal deformation of cut off wall happens in higher elevation of cut off wall and this deformation at the top about 54 cm that means settlement in foundation that could be increase the displacement [19, 20].

3. METHODOLOGY

The dynamic analysis of the Makhool dam was conducted using the QUAKE/W program, which is a finite element method-based software for analyzing the seismic response of earth structures. A number of studies have validated the Shake/W program in geotechnical engineering. Break/W, a finite element method-based program used to analyze earth structures' drainage behavior, was used to generate data for the Shake/W program. When the dam was excited during a seismic event, the Break/W program simulated the distribution of pore-water pressures within it. Based on their ability to simulate earthquake loading conditions of earth structures, the Quake/W and Break/W programs were selected. In geotechnical engineering, finite element analysis has been extensively used to analyze the behavior of structures under dynamic loading conditions. Using Geo-studio software, a comprehensive seismic analysis of earth dams was conducted by integrating the Shake/W and Break/W programs. The item thinks about the showing of amazing estimations and material properties, and it gives a simple to utilize association highlight data and result. the choice of the Shake/W program, Hole/W program, and Geo-studio programming relied upon their ability to reproduce the perplexing approach to acting of earth structures under seismic stacking conditions and give a comprehensive examination of the seismic approach to acting of earth dams.

The two-layered model used for the strong assessment of the Makhool dam was made using Geo-studio programming. The model relied upon the authentic estimation and material properties of the dam, and it consolidated the foundation, barrier, and supply. The model was discretized into restricted parts, and the examination was driven using the Shiver/W program. The material properties of the dam were gained from research focused tests and field assessments. The limits used in the model consolidated the thickness, Energetic's modulus, Poisson's extent, and shear strength of the soil layers. The limits were endorsed against certified data, including the delayed consequences of exploration office tests and field assessments. The model was endorsed against the eventual outcomes of past assessments and authentic data. The consequences of the examination were contrasted and the aftereffects of past investigations that researched the seismic way of behaving of earth dams. The correlation showed great understanding between the consequences of the investigation and the aftereffects of past examinations. the two-layered model utilized for the powerful investigation of the Makhool dam depended on the genuine math and material properties of the dam. The parameters used in the model were validated against real-world data, and the model was validated against the results of previous studies and real-world data.

Geo-studio software was used to create the two-dimensional model presented in this paper. This analysis is carried out by finite element method and subjected to Makhool earthen dam as a case study to show the dam stability.

4. DESCRIPTION OF MAKHOOL DAM

Table 1. Properties of Makhool dam

Property	Value
Cresting	
Dam crest level	160 m.a.m.s.l.
Crest width	12 m
Core of clay	
Level of core	157.5 m.a.m.s.
Width at the top	l. 5 m
Width of core base	17.5 m
Dam length in total	3670 m
Dam height maximum	56 m
Maximum water level elevation (MWL)	150 m
Minimum water level elevation (NWL)	140 m

Makhool dam is being constructed on the Tigris River in Iraq. Approximately 3 km separate this mountain range from the eastern side of the Makhool anticline, approximately 16 km from the Al-Fatha bridge, and 30 km from Baijy town in the Salah Al-Din Governorate. It is approximately 15 kilometers downstream from the confluence of the smaller Zab and Tigris rivers from Baghdad, the Iraqi capital.

Located 3670 meters above mean sea level (m.a.m.s.l.), the dam reaches a maximum water level of 150 meters. This dam reaches its highest point at 56 meters above mean sea level (m.a.m.s.l.) with a crest height of 160 meters and a crest width of 12 meters.

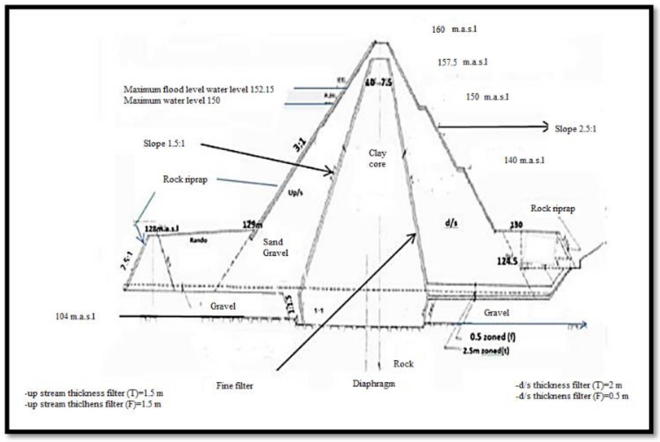


Figure 1. Makhool dam critical section (Based on State Committee on Dams and Reservoirs, Iraq 2021, unpublished report) (Scale 1:10000)

In addition to the clay core, downstream and upstream filter layers, containing fine and coarse gravels, are installed along the dam axis between Makhool Mountain fold in the west and the Khanukah fold in the east. Detailed information about dams and reservoirs in Iraq is provided in an unpublished report by the State Commission for Dams and Reservoirs (1921) as shown in Figure 1. Table 1 shows the Properties of Makhool dam.

4.1 Seepage analysis

Program SEEP/W is used for analyzing the seepage through the dam, the mesh includes about 2365 nodes and 3371 elements, the nodes that is located at upstream are be considered as head boundaries with total head equal to the level of water for the reservoir.

Figure 2 shows the seepage line of minimum water level.

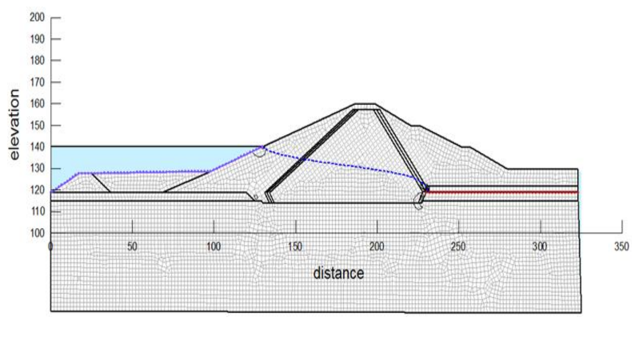


Figure 2. Seepage line

Table 2. Material properties of dam

Material Properties							
No.	**Zone Type**	**γ(kN/m^3)**	**Cohesion (kPa)**	**Permeability (m/sec)**	**Poisson Ratio**	**ϕ(°)**	**Modulus of Elasticity (MN/m^2)**
1	Clay core	17.8	36	3.5×10^{-10}	0.33	0	30
2	Filter F	16	-	1.69×10^{-3}	0.30	35	19
3	Filter T	61	-	1.69×10^{-3}	0.30	35	19
4	Gravel	20	-	1.20×10^{-4}	0.35	35	20
5	Shell	21	-	1.69×10^{-3}	0.20	38	19
6	Random Fill	17	-	1.10×10^{-5}	0.25	56	19

4.2 Dynamic analysis

Dynamic analysis is done by the QUAKE/W program depending on the imported results from the SEEP/W program. The analysis assumes that water level changes in two cases, with three values of 0.04 g, 0.06 g and 0.08 g.:

-Minimum water level 140 m.

The analysis results are shown in the form of figures that includes total stress in x-direction and Y-direction, pore water pressure, x-displacement for four nodes. Table 2 shows the material properties of dams.

A comparison will be made between the nodes (1, 2, 3 and 4) for different computed parameters in the program. Figure 3 shows the Nodes of dynamic analysis.

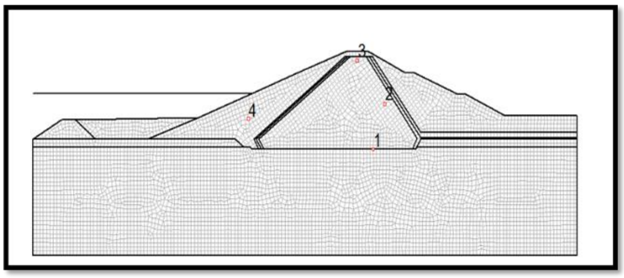


Figure 3. Nodes of dynamic analysis

5. RESULTS AND DISCUSSIONS

The mathematical examination of the earth dam exposed to a tremor uncovered a few significant discoveries that have huge ramifications for the plan and development of dams in quake inclined locales. In this segment, we will introduce and decipher the aftereffects of our review. First and foremost, the examination showed that the level part of movement altogether affects the way of behaving of earth dams during earthquakes. The dam experienced bigger removals and strains in the even heading than in the upward course. This tracking down features the significance of considering the even part of movement in the plan of earth dams to guarantee their security and unwavering quality during earthquakes. Also, the investigation discovered that the seismic reaction of the dam is exceptionally reliant upon its level and soil qualities. As the height of the dam increases, the displacement and strain values also increase. Similarly, the soil type affects the seismic response of the dam, with softer soils resulting in larger displacements and strains. These findings suggest that engineers should carefully consider the height and soil characteristics of the dam during the design phase to ensure its safety and reliability under seismic loading conditions. the study's results can be used to optimize the design of earth dams by considering the effect of dam height, soil characteristics, and input motion on the seismic response of the dam. By incorporating these factors into the design process, engineers can develop more effective strategies to mitigate the risks associated with earthquakes and ensure the safety and reliability of earth dams. Our study provides valuable insights into the seismic behavior of earth dams and highlights the importance of seismic evaluation for dam construction in earthquake-prone regions. The findings of this study can be used to improve the design and construction of earth dams and ensure their safety and reliability under seismic loading conditions. However, further research is needed to validate these findings and develop more accurate models for predicting the seismic response of earth dams. Figure 4 shows the Input acceleration of 0.04 g. Figure 5 shows the Input acceleration of 0.06 g. Figure 6 shows the input acceleration of 0.08 g.

Figures 7-12 show the horizontal and vertical total stresses for nodes 1, 4 for three values of earthquake.

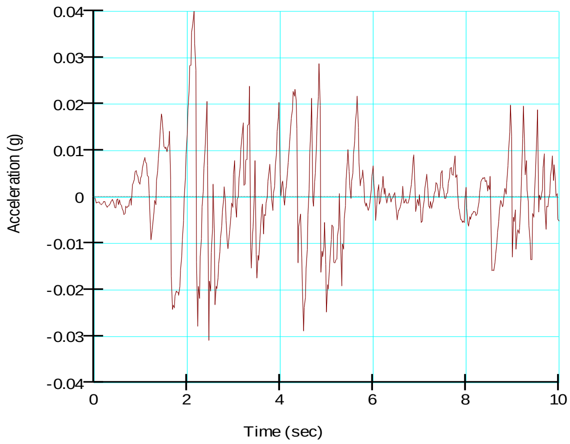


Figure 4. Input acceleration of 0.04 g

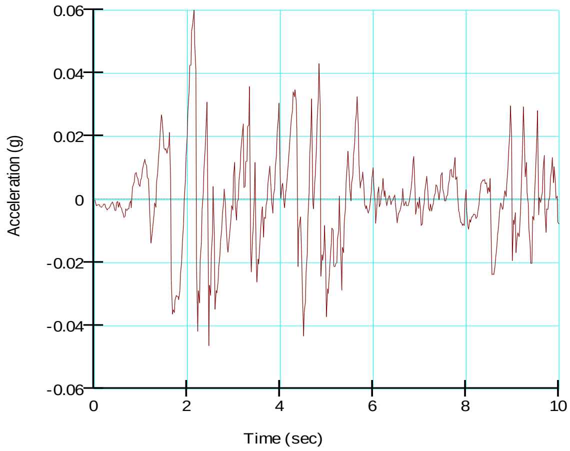


Figure 5. Input acceleration of 0.06 g

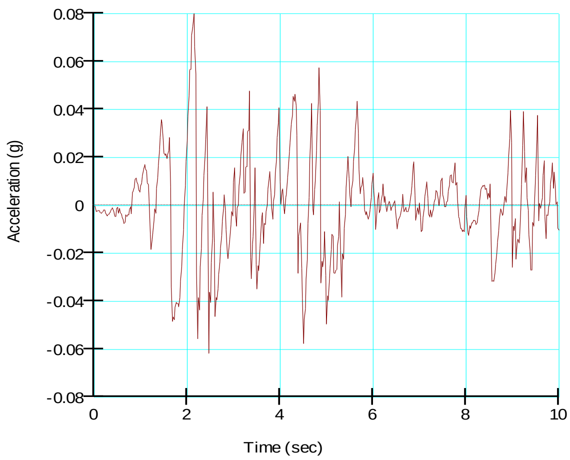
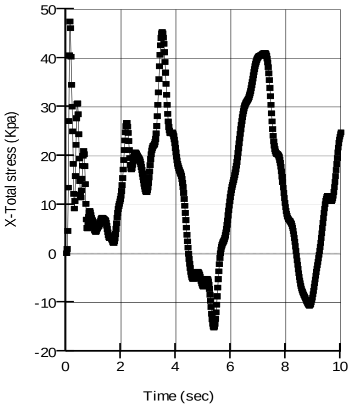


Figure 6. Input acceleration of 0.08 g



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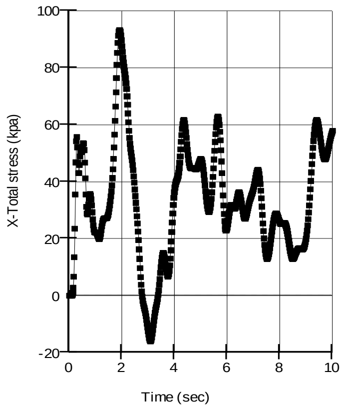
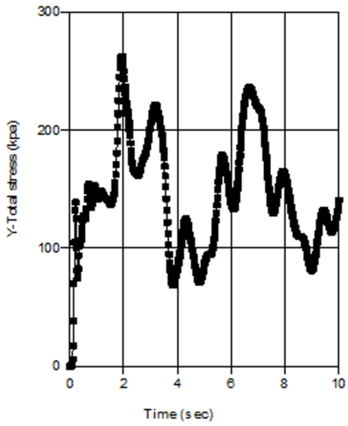


(b)

Figure 7. X-Total stresses of (a) node 1 (b) node 4 of 0.04 g



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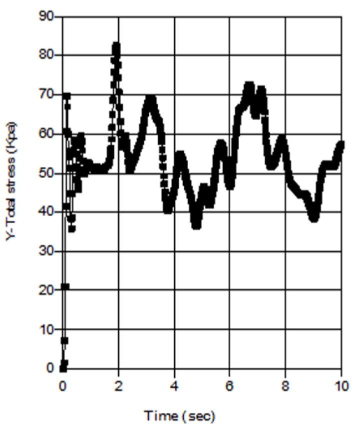

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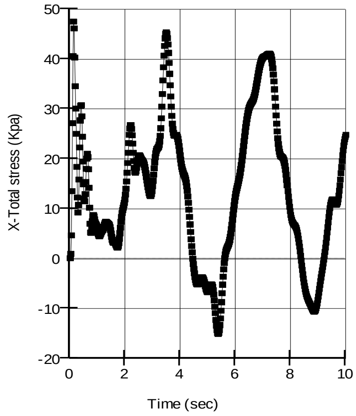
Figure 8. Y-Total stresses of (a) node 1 (b) node 4 of 0.04 g



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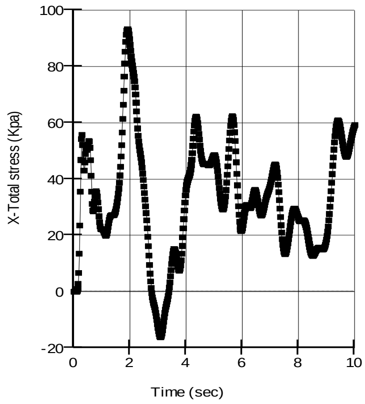
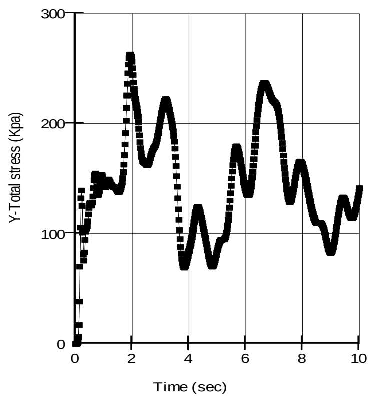


(b)

Figure 9. X-Total stresses of (a) node 1 (b) node 4 of 0.06g



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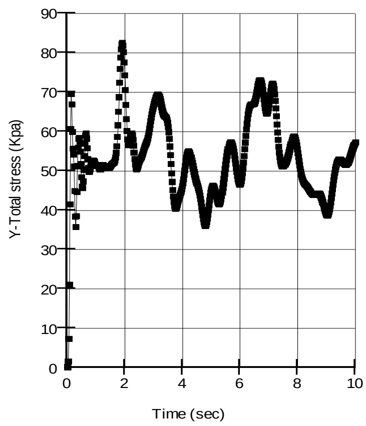
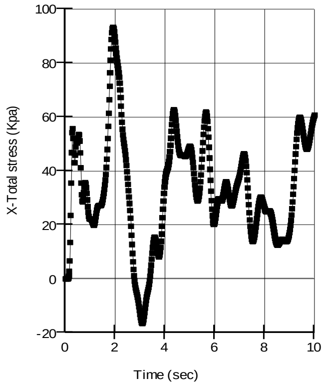


(b)

Figure 10. Y-Total stresses of (a) node 1 (b) node 4 of 0.06 g



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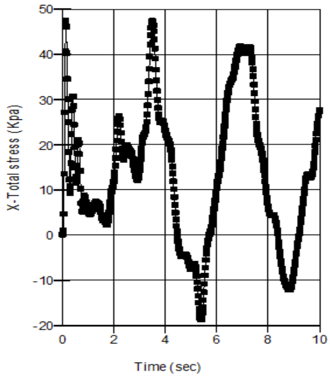
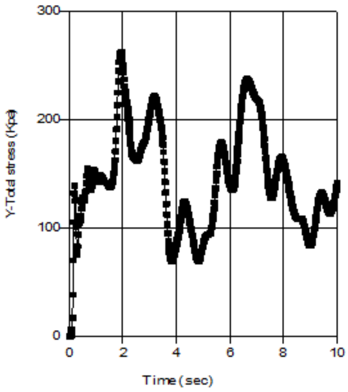


(b)

Figure 11. X-Total stresses of (a) node 1 (b) node 4 of 0.08g



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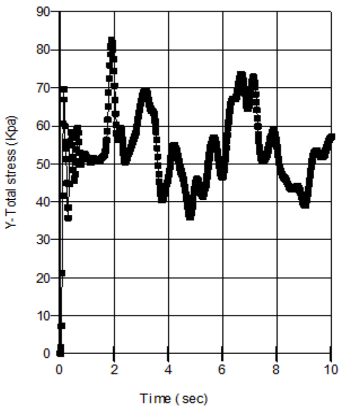


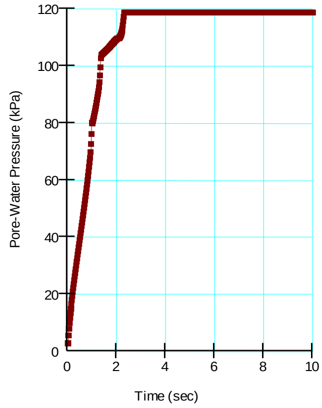
(b)

Figure 12. Y-Total stresses of (a) node 1 (b) node 4 of 0.08 g

Table 3. The max x-displacement of nodes 1 and 3 for three values of earthquake

Earthquake Value (g)	Max X-Displacement of Node 1 (m)	Max X-Displacement of Node 3 (m)
0.04	0.600	0.360
0.06	0.608	0.365
0.08	0.612	0.400

The x-total stress and Y-total stress for the two nodes started to decrease that affected the strength of the soil and led to soil weakness. Table 3 shows the max x-displacement of nodes 1 and 3 for three values of earthquake.



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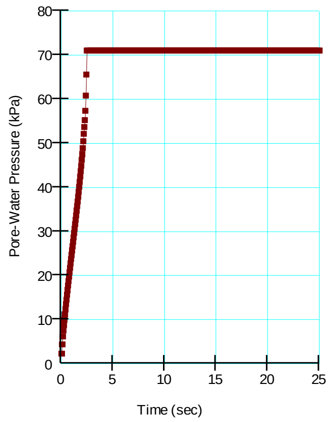
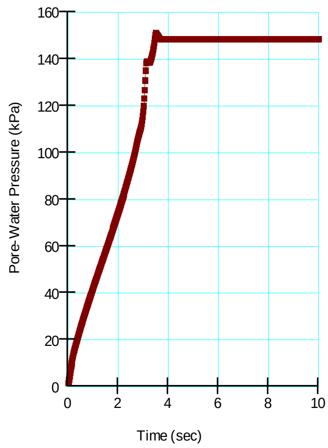


(b)

Figure 13. Pore-water pressure of (a) node 1 (b) node 3 of 0.06 g



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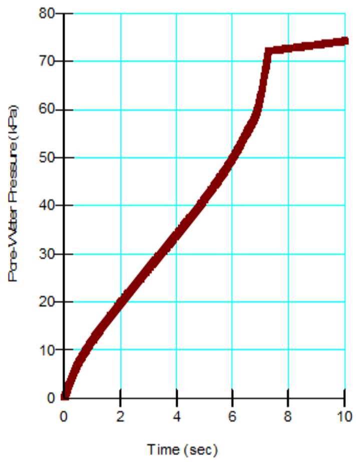

(b)

Figure 14. Pore-water pressure of (a) node 1 (b) node 3 of 0.08 g

According to the results, the x-displacement increases with the value of earthquake, as well as the displacement increases with the depth of the nodes. For earthquake values of 0.06 g and 0.08 g, Figures 13-14 show the pore-water pressure at node 1 and node 3, respectively, and it was concluded that pore-water pressure is greater at the base than at the crest and increases with earthquake value.

6. CONCLUSIONS

The aim of this study was to examine the seismic behavior of earth dams and assess how earthquake excitation affects the dam's performance. The researchers utilized the QUAKE/W program, a software based on the finite element method, to model the seismic response of the Makhool dam. Information for the Tremor/W program was made utilizing the Leak/W program, another limited component strategy based programming for breaking down drainage conduct in earth structures. Key discoveries show that dam uprooting ascends with expanding speed increase, pore-water pressure is higher at the foundation of the model contrasted with the dam peak, and info speed increase drops with expanding x-speed increase. The concentration additionally highlights the meaning of field examination and geotechnical reads up in seismic evaluation for dam development. All in all, this examination offers important bits of knowledge into the seismic way of behaving of earth dams and underscores the requirement for seismic evaluation in dam development in tremor inclined regions. The consequences of this study can be applied to improve the plan and development of earth dams, guaranteeing their security and unwavering quality under seismic stacking conditions.

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