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Analysis of Seismic on Earth Dam: A review

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ABSTRACT: One of the most crucial aspects of dam construction is stability under a seismic load. The breakdown of the dam could cause a catastrophic effect on downstream areas. For that, the safety of the facilities lies in their stability. Dams must be stable and withstand the loads placed on them. They are national security facilities. Because dam collapse causes unbridled humanitarian, economic, and social disasters, its construction must be scrutinized and strive to reach the best design with the best materials. The researchers sought to conduct several studies to know the dam's behaviour during earthquakes, the role of their geometric dimensions, and the technical condition of the soil on which the dam was founded or formed. The current study provide review on seismic analysis research. The simulation and the results indicated that the soil liquefaction state should be reduced, and the three-dimensional results should be analyzed to predict the locations and forms of deformations and the ability to deal with them.

Keywords: Earth dam, seismic, soil liquefaction, earthquakes, soil dynamic

1. INTRODUCTION

Geotechnical engineering is one of the most important fields of civil engineering. It is the primary science of soil studies. Earthquake loads, particularly seismic loads, must be considered in designs where the interrelationship between seismic load and earth dam is investigated. The effect of the seismic load is studied on different types of earth dams. The constant pursuit of researchers to evaluate the performance of earth dams and provide all the data necessary to make designs that simulate reality requires studies, research, and a continuous escalation to reach the best.

The facilities' stability and safety are among the most critical factors that structural design engineers are keen on. The stability and safety of dams, in general, and earth dams, in particular, are vital to preserve individuals' lives and avoid floods and landslides that could remove facilities and roads and uproot crops. Earthquakes and seismic loads are the primary threats to dam stability and safety. Therefore, it was necessary to study and analyze the static and dynamic performance, the size and number of earthquakes, and how they affect the dam.

The current investigation provide review to literature that search on seismic analysis. The properties of the soil and its cohesion and plasticity should also be studied. Many researchers traveled to conduct studies and research to obtain the best and most accurate results. The researchers used software and finite element analysis to create simulations in which results could be predicted and problems anticipated and addressed. Research has been conducted on many existing dams in many countries worldwide to ensure the procedures' correctness and to reach the desired goal. This paper reviews many studies to analyze the effect of seismic load on earth dams.

2. Seismic Analysis of Dam

Spyridis et al. investigated many factors that may negatively affect the dam's body. As the dynamic movement has a role in the movement of the soil forming the dams, the threat to the dams also threatens the downstream countries. The relationship between dynamic movement, the earth dam, and the extent of the dam's behavior in reality was studied. Finite element programs were used to prepare a model exposed to different seismic movements and to know the outcomes of these tremors. Figure 1 illustrates the analysis of the finite-element mesh. Two models were prepared and exposed to four ground motions for the linear and nonlinear studies, and the responses of the two models were compared. When

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studying the height of the dams, the type of soil used, and the components of the dams, it was found that the dam's foundation has a crucial role in resisting earthquakes affecting it, especially those of medium intensity. The type of soil material on which the earth dam is built has a significant impact on its earthquake resistance. The findings also demonstrated that the greater the resistance to earthquakes, the more impermeable the earthen dam components were [1].

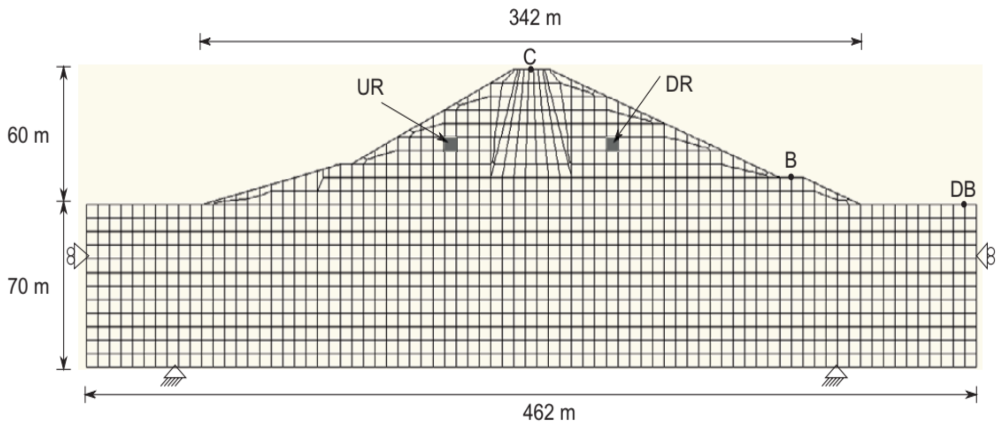

FIGURE 1. - Finite-element mesh used in the analysis of the La Villita dam [1]

Pelecanos et al. modeled the La Villita dam, and two earthquake waves of different intensities, extents, and magnitudes were conducted. The results were analyzed, and the dam's behavior was discussed under the influence of these seismic waves in the dynamic and static states and the extent of soil behavior with the earth dam. Finite element analysis was used to reach the most accurate results. The results proved that acceleration asymmetry and an apparent displacement should be assumed. The greater the soil material cohesion constituting the dam, the greater the structure's resistance to earthquakes. It also proved that the deformation volume decreases as the dam's hardness increases in harmony with its constituent materials [2].

Alaoua et al. conducted a numerically analytical study on the stability of the lateral tendencies of the soil during earthquakes. An earthen dam model was prepared, and tests were conducted on it. The researchers turned to this research for what was issued by the International Commission on Dams. This committee acknowledged the exposure of many earth dams to collapse when exposed to earthquakes. The committee also mentioned that it recognized the water pressure on the earthen dam during the earthquake, which was expected to be a significant factor in its collapse.

The prepared model studied the extent of the soil's reaction to the stresses placed on it. The seismic records of the real Loma Prieta earthquake were entered. The study proved that there are horizontal deformations located on the dam that affect the dam's foundation. The numerical analysis considered the effect of water on the dam during earthquakes. Also, the soil type and the dam's shape were realistic, leading to the most accurate results [3]. Table 1 list the properties of different soil types.

Table 1. - Properties of foundation and earth dam soils [3]

Properties	Soil 1	Soil 2	Soil 3	Soil 4
γ Dry density (Kg/m3)	2000	2000	1800	1900
E Young's modulus (MPa)	610	610	328	328
υ Poisson's ratio	0.3	0.3	0.3	0.3
C Cohesion (KPa)	4	8	6	6
Φ Friction angle ()	40	40	35	35
ψ Dilution angle	0	0	0	0
Porosity	0.3	0.3	0.3	0.3
Permeability (m/s)	10-6	10-7	10-6	10-7

Ebrahimian et al. followed the path of those who researched the earthen dam response to earthquakes numerically. They sought the same method by preparing a model for the dam, and this model was studied in a nonlinear numerical approach. This approach enables an accurate description of the stress and strain on the soil with the earth dam. The use of this model helped to predict the behaviour of the earthen dam during an earthquake. Some of the dam's properties and their effect on its height, composition, and geometric shape were also considered[4].

Deoda et al. investigated the behavior of two dams in India under the influence of earthquakes. The two dams were Chang Dam and Kaswati Dam. The GeoStudio program was used to model the two dams. Figure 2 displays the 2D section and the 3D segment of the GeoStudio program. A dynamic analysis applied a set of time histories with a study of seepage, the stability of the lateral inclinations, and the effect of water on the dam in the presence of seismic loads. The results expressed a linear relationship between dam level and seepage rate. The results showed the importance of considering the vertical response over the horizontal response, which can be neglected. CMS time histories are a real, tangible expression of a real earthquake with entirely realistic results [5].

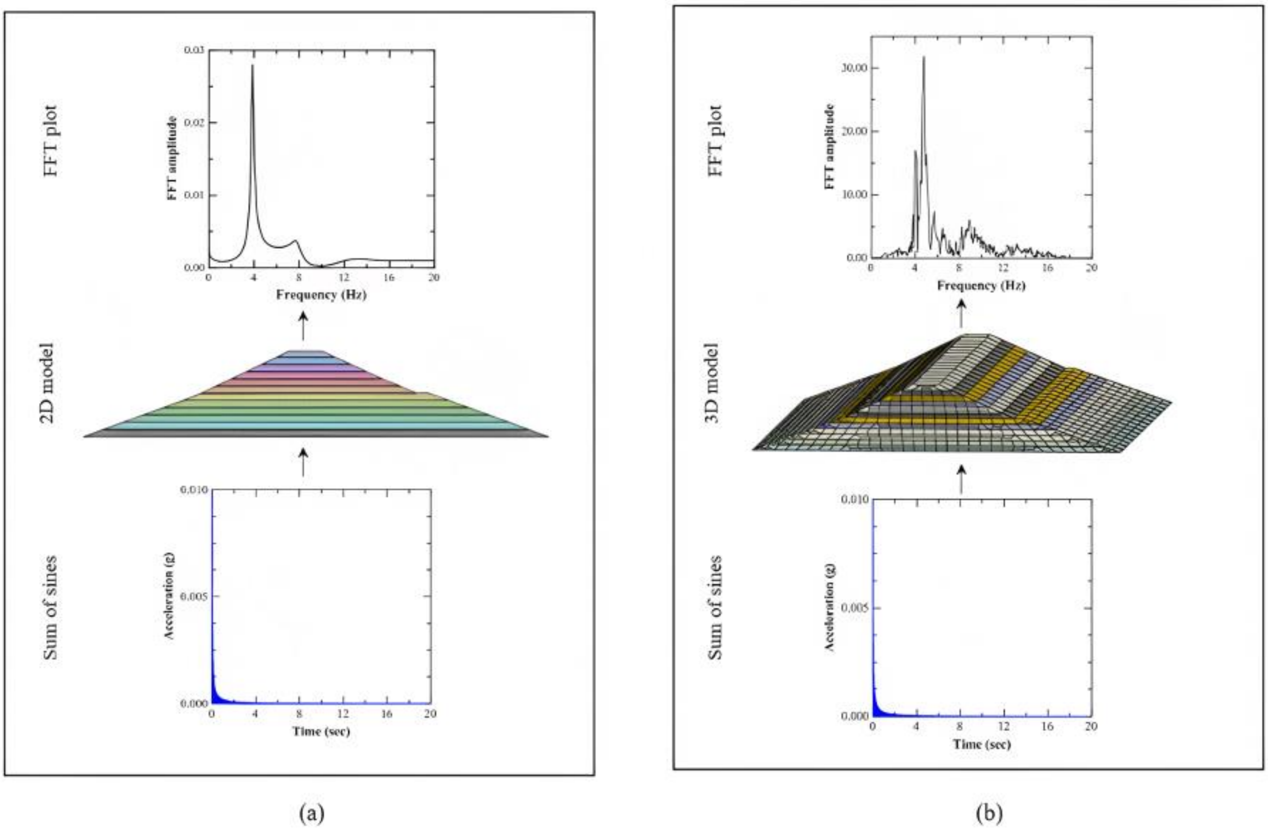

FIGURE 2. - Natural frequency estimation using the sum of sines' method for a typical (a) 2D section and (b) 3D segment [5]

Mosadegh relies on three-dimensional analysis instead of simple analyses in analyzing the seismic behaviour affecting the dam's foundation. Whether real or virtual, earthen dams were exposed to a sizeable seismic spectrum, considering each dam's engineering properties and components. The water pressure and dam deformations after the earthquake were taken into account to reach accuracy in the results. A comparison was made to study the horizontal lateral displacement on the dam. Some criteria have been developed on which many researchers can rely when selecting the appropriate analysis method for seismic loads located on dams. The study and experience have proven that in the case of the availability of data and site information about the dam, accurate results come from conducting a three-dimensional analysis. In the case of moderate earthquakes, the dam's lateral displacement is measured using simple linear analysis [6].

Castelli et al. analyzed in this research the effect of seismic load on the earth dam. This study was conducted on the Lentini site in Sicily, where the earthen dam was exposed to an earthquake, which caused deformations. The dynamic response of the dam as a result of the earthquake in 1990 was studied, and the results were compared with an earthquake simulation model on PLAXIS software using the codes EERA and MARTA. Figure 3 presents the normalized share modulus as a function of the share strain for different layers. The results showed a strong agreement between the results of the earthquake at the dam in 1990 and the simulation results on finite element software [7].

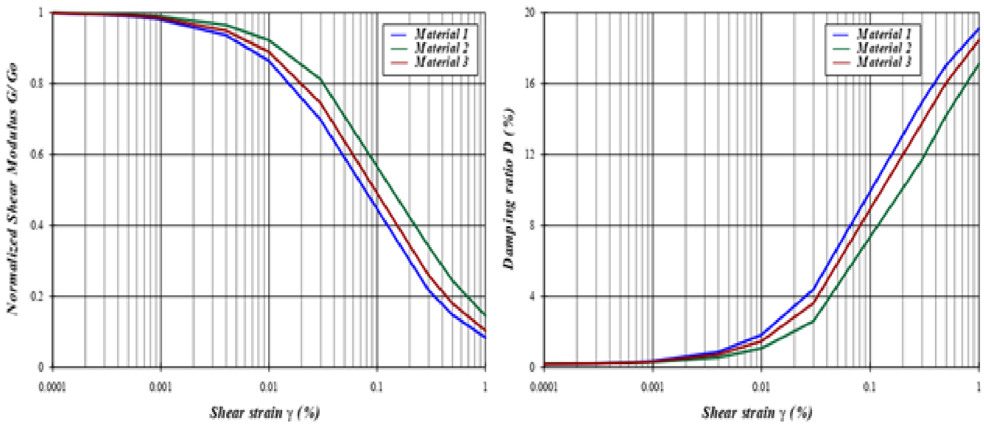

FIGURE 3. - G/Go-γ and D- γ curves of layers [7].

Zdravkovic et al. studied static and dynamic analysis. The response of the dam's two different types of earthquakes in terms of magnitude, duration, and frequency value was taken into account. It compared the dynamic analysis results with the recorded numbers of the dam's earthquake response. The behaviour and elasticity of the soil and its reaction to the dam's behavior during the earthquake were also studied. A comparison and link were made between the dam's recorded response and the results based on the hypotheses of the model used to simulate the dam and the earthquake. The study proved that it is possible to predict the dynamic behavior of the dam in the event of an earthquake, and the assumptions on which the various studies were built were proven correct. The researchers took them into account in their research. It also proved that the binary analysis produced acceptable approximate results, but the accuracy of the results came from the three-dimensional analysis. The study recommended that the materials that make up the dam should not be standardized, as they are, in fact, standardized [8].

Raja et al. used the Geo-Studio program to study and analyze the earthquake's impact on the earthen dam. This is for analysis using the finite element method. The stress on the embankment was conducted before and after the earthquake. Some characteristics and behaviors were used, such as the soil behaviour and materials, the soil under the dam's base layer, and the dynamic response of earthen dams. Data is entered into the program using a real earthquake record, and factors such as displacement and stress are considered. The experiment was conducted on the Nara Dam, and it was found that the horizontal and vertical stresses are less at the bottom of the dam. Table 2 lists the seismic analysis results of the Nara dam. In the static analysis, the soil behaviour was considered linear, but in the dynamic study, it was found that the soil has nonlinear behaviour [9]. Table 2 list the seismic analysis results of the Nara dam.

Table 2. - Results of the Nara dam for seismic analysis [9]

Parameter (Max values)	Linear soil model	Nonlinear soil model	%Increase (Nonlinearity effect)
Horizontal stress	753.69 kPa	808.94 kPa	7.33
Vertical stress	958.2 kPa	1031.5 kPa	7.59
Horizontal displacement	5.608 mm	11.470 mm	104.5
Vertical displacement	28.751 cm	30.526 cm	6.17

Jitno and Davidson studied the displacement of earthen dams due to earthquakes. They relied on the Newmark method, based on the dynamic analysis associated with stress. In this study, some assumptions were made, and the advantages and disadvantages of these assumptions were discussed. Static analysis was studied, as experiments proved that dynamic analyses are critical, as they correctly express failure and potential collapse. It shows the extent of the potential cracks in the dam, due to which beneficial facilities can be obtained for the individual and society [10].

Karami and Aminjavaheri researched earthquake analysis and its impact on the Goucham earth dam. Two 6.9 Richter earthquakes struck the heterogeneous Iranian dam. Newmark's linear method has been relied upon to study the stresses in the flat plane. The finite element method was used to study the response of the dam in a more general and comprehensive manner, taking into account the calculation of the displacement and the measurement of the deformation in the resulting dam when the earthquake occurred. It used two codes in the analysis to study the plasticity of soil materials and obtain the most accurate results, as illustrated in Figure 4. The results proved that the two methods used for analysis helped reach the same results in the case of earthquakes within a short period. Because the nonlinear analysis proves that the plasticity of the soil causes the displacement process, the nonlinear case helps obtain more results and more dynamic analysis [11].

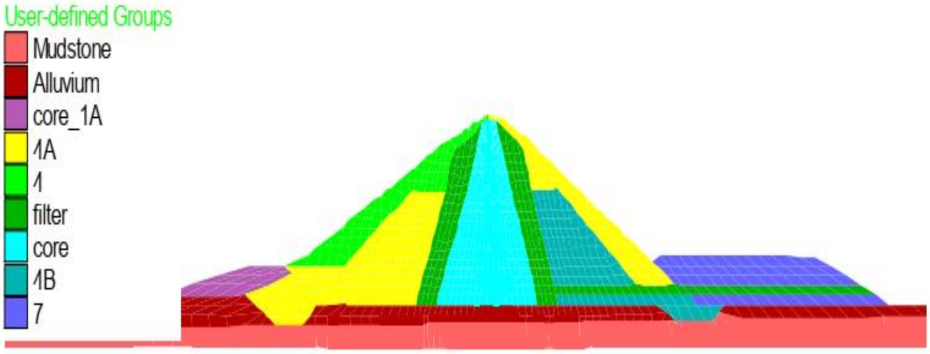

FIGURE 4. - Materials of the Goucham dam[11]

The study of soil plasticity is an essential and urgent priority. Studying the soil materials and analyzing the soil components makes it possible to predict the resulting behavior when exposed to specific loads. Esfahani Kan studied soil plasticity and its effect on dams in the case of earthquakes. A simulation was made to determine the shape of the stresses resulting from these loads as a reliable reference for other researchers and geotechnical engineers. A simulation was also done to predict dam deformations when the earthquake occurred. To ensure the accuracy of their results, simplified methods were tried to solve the results and predict the dam's behavior in the event of an earthquake. Studies have shown that soil plasticity has a vital role in resisting loads. Moreover, the linear methods are not accurate in all cases, but the triple analysis is more accurate [12].

The most famous type of dam is the earthen dam. So, studying and analyzing loads, whether they are on time or not, is the key to keeping the dam as a source of life. Hong Le et al. conducted a study of the behaviour of dams and their resistance to earthquakes, as shown in Figure 5. They also studied the best ways to predict the dam's deformations due to these earthquakes. This study proved that the expected deformations of dams due to earthquakes have several methods. However, it is challenging to reach accurate results because it is expected or uncertain. The three most popular methods for estimating deformities were presented. However, it was recommended that more and more studies should be conducted in order to be able to predict the most remarkable accuracy of possible distortions and thus be able to solve them [13].

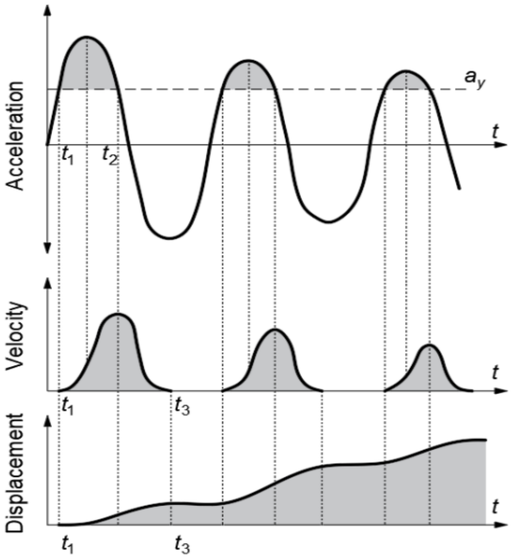

FIGURE 5. - Concept of Newmark approach [13]

3. Liquefaction in Dam

One of the risks affecting earthen dams is liquefaction. Therefore, researchers and dam engineers tend to study liquefaction, and its relationship to earthquakes, as earthquakes may cause liquefaction. A study was conducted on Sidi

Al-Barrak Dam. Many tests were carried out at the dam's base, aiming to set predictions for its liquefaction and how to deal with it. The state of liquefaction was also studied in conjunction with the earthquake affecting the dam. Experience has shown that if the dam is exposed to an earthquake of 5.25, 6, or 6.75 Richter, the liquefaction state appears in the sandy layer at a depth of 15 meters or less in the river and 7 meters on earth. A simulation model in Plaxis software has been made, and the numerical response of a sand layer when exposed to a seismic tremor with an acceleration estimated at 0.2g. The degree of liquefaction is expressed by the pore pressure ratio and denoted by the symbol r_u. The r_u value is calculated as shown in equation 1; the liquefaction factor is calculated in Equations 2, 3, and 4.

$$r_u = 1 - \frac{\sigma'_v}{\sigma'_{v0}} \qquad (1)$$

where:

σ'_v : The effective vertical stress at the end of the dynamic calculation.

σ'_{v0}: The initial effective vertical stress.

$$F_L = \frac{R(N_{SPT}, F_C)}{L(a_{max})} \qquad (2)$$

where:
R: The liquefaction resistance.
L: The dynamic load.

$$L = \frac{a_{max}\sigma_v}{980\sigma'_v} r_d \qquad (3)$$

where:
a_{max} : The peak ground acceleration of the dam.
σ_v: The total effective vertical overburden stresses.

$$r_d = 0.0004z^3 - 0.00062z^2 - 0.0036z + 1.0 \qquad (4)$$

For soil to be safe from liquefaction, the value of r_u must be less than 0.7. It was noted from the simulation results that they match the results recorded for earthquakes that occurred in previous periods [14] [15] [20].

Al-Adhaim Dam in Iraq was studied using Geo-Studio software. Aude et al. developed a model to simulate the dam's behavior when exposed to an earthquake. This model identified the reasons for the expected failure of the dam and the factors causing it. Some factors must be studied to get the most accurate results from soil liquefaction, seepage, and slope stability. Figure 6 displays the liquefiable zones of the dam, and Table 3 lists its properties. After analysis and study of the results, it was proven that the dam is safe and stable in its static state. However, after ten seconds of exposure to a seismic tremor with a 0.38 of the ground acceleration, the dam had moved by 12 cm. When comparing the output with the permissible one, there was an apparent decrease in the safety factor, as the minimum safety factor is 1.2, and reinforcement was recommended to preserve the soil from liquefaction. Therefore, after consolidation and study, the safety factor was increased to 1.95 [16].

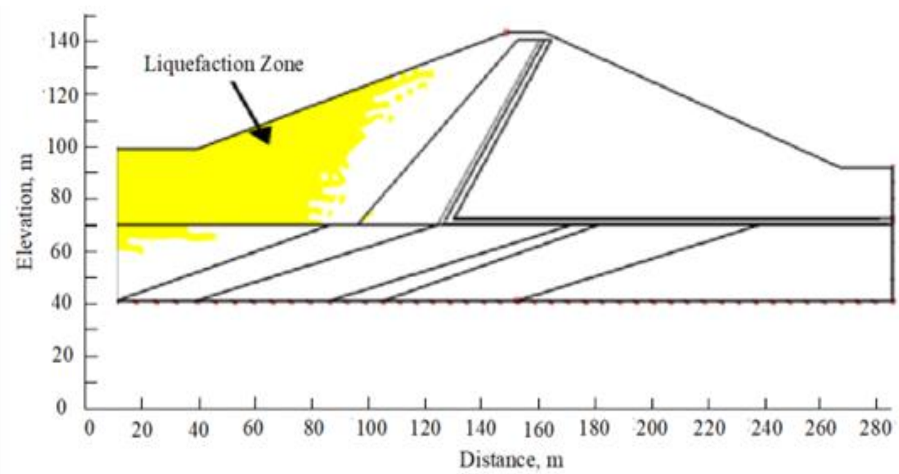

Figure 1. - Liquefiable zones of the dam. [16]

The thickness of the soil layer played an essential role in measuring the liquefiable value. [17] [18] The more incoherent the soil, the larger the voids between soil particles; thus, the ratio of voids in the soil increases. Results and experiments have proven that soil liquefaction increases with the ratio of voids. [19]. Sandy and gravelly soils are the most common types of soils that suffer from liquefaction. Therefore, they are severely affected by seismic load, affecting the dam's behavior and causing failure. [21] [22].

Table 3. - The properties of Al-Adhaim Dam soils [16]

Material Zone	Modulus of elasticity (MN/m^2)	Permeability (m/s)	Poisson's ratio	Unit weight (kN/m^3)	Cohesion (kN/m^2)	Angle of internal friction (degree)
Shell	19	1.25×10^{-3}	0.3	17.658	0	37
Core	30	2.25×10^{-10}	0.45	19.62	60	23
Filter F	19	1.2×10^{-5}	0.3	18.658	0	35
Filter T	19	1×10^{-4}	0.3	18.658	0	35
Foundation on Marl	350	1×10^{-10}	0.35	20.601	600	10
Foundation on sandstone	300	5.5×10^{-8}	0.35	20.601	0	38

The fact that the safety factor is less than one during an earthquake does not always imply that the dam has collapsed. However, what increases this expectation is the degree of soil liquefaction and its role in dam components [23]. The occurrence of liquefaction in the soil under the dam's foundation in the rear area is more significant than in the front area. It causes deformations in the horizontal direction, which results in rotation in the dam, which is the beginning of the collapse [24].

In order to find a clear and radical solution to the problem of liquefaction and consistently increase the safety factor, it was necessary to conduct studies and research in all forms to reach the best results. Guettaya et al. conducted a study on an earthen dam in Tunisia. Dynamic analyses were carried out on a dam simulation model, and some tests, such as SPT and CPT, were used. The results showed that the vibratory compaction significantly improved the soil's properties and reduced the incidence of liquefaction under the foundation of the dam, therefore increasing safety [24] [25] [26].

Table 1. - Minimum required FS for liquefaction hazard assessment for California [25].

Liquefaction consequences	N1,60cs	Fs
Settlement	≤15	1.1
	≥30	1.0
Surface manifestation	≤15	1.2
	≥30	1.0
Lateral spreading	≤15	1.3
	≥30	1.0

There were several researchers and scientists to help solve the liquefaction problem. The researchers turned to jet grouting to improve the soil's ability to resist liquefaction, as illustrated in Figures 7 and 8. This method allowed for a more cost-effective dam redesign as an appropriate solution in some cases where vibration compaction is impossible. This method is suitable for small soil sections subject to liquefaction. Jet-grouting is done with the same idea as pile casting, whereby slurry is pumped into paths under high pressure [26].

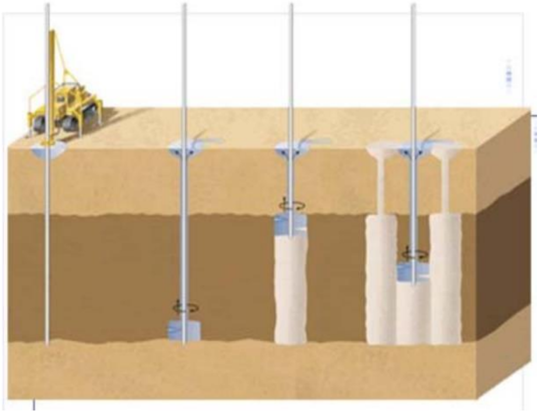

FIGURE 7. - **Jet grouting simulation [26].**

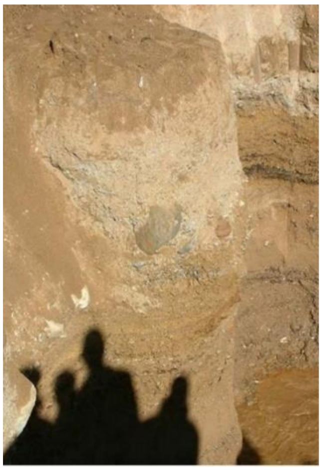

FIGURE 8. - **Jet grout column [26].**

4. Conclusion

Dams are crucial all around the globe because they are used to collect water, generate power, and preserve agricultural land and human settlements from flooding. Dams are found on all six continents, with either concrete or earthen dams. Structures, in general, and dams, in particular, are exposed to vertical and lateral loads, and earthquakes are among these forces. Dams' safety and stability are crucial to preserving crops, people, and public property. Dams are an essential pillar of any country's economy and national security. Therefore, it is essential to design dams accurately and ensure they are resistant to all possible loads.

Many researchers tended to analyze earthquakes and their impact on earthen dams and used applications, programs, and finite elements analysis. This analysis can predict the dam's deformation size likely to occur due to earthquakes, regardless of their frequency or size. It also helps to study the role of water and the permeability of dams during earthquakes. The soil was analyzed for its plasticity, composition, and the amount it was affected in response to earthquakes. This analysis was done regardless of whether the soil served as the dam's base or a component. The study also included the dimensions of the dam and its role in resisting loads.

The soil liquefaction due to the earthquake that strikes the dams has also been studied. The greater the distances between soil particles, the more susceptible they are to liquefaction. There was a clear relationship between liquefaction and the safety factor of dams. So, it was necessary to find a solution to liquefaction. Research has shown that vibratory compaction and jet grouting are two magic methods for reducing liquefaction. All these studies have shown that all these factors have a significant impact. Furthermore, the three-dimensional analysis is the most accurate and comprehensive in showing the results.

These studies are being conducted to provide clear and tangible evidence by which design engineers, particularly dam engineers, can be guided. Such studies give more confidence, more learning, and thus the ability to make the most accurate designs. The development of earthquake engineering has become rapid and must be kept up.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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