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Horizontal and Vertical Movement of Concrete Dam Erecting on Sandy Soil under Seismic Loading

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ABSTRACT

Concrete dams are the strongest dams, designed for flood control, electricity generation, and water management. They can become unstable due to ground shaking and earthquake impacts, resulting in stability loss due to embankment and foundation materials or severe deformations like slumping, settlement, cracking, and slope collapse. Where consider an earthquake one of the factors that pose a major threat to dams, especially if the earthquake is strong and if the soil under the dam is sandy soil, so that geotechnical designers should consider more than any other disaster when developing construction in seismically active areas. Therefore, a laboratory study was conducted on a model of concrete dam with dimensions (width =15 cm, high = 20 cm, and thick = 5cm) on fine sand soil. In order to study the stability of the concrete dam subjected to earthquake vibration, the model of the dam was subjected to different types of earthquakes (Halabja and El Centro). The main goal of the study is understanding the behavior and performance of concrete dam subjected to seismic load. It can be concluded that the stability of the concrete dam subjected to earthquake depends on the intensity of the earthquake. Thickness and width of the dam. According to the results, the El-Centro earthquake effect on concrete dams is 60% greater than the Halabja earthquake.

1. Introduction

For the most part, dams are among the most ancient methods of retaining water, and because of their many benefits, they are frequently constructed across the globe [1].

Dams built of concrete are known as concrete dams. Within this category are gravity dams, arch dams, and buttress dams. Although concrete dams are more expensive to build, they are stronger and more durable than embankment dams [2]. An earthquake is characterized as a sudden, strong shaking of the Earth brought on by the cracking and shifting of rock beneath the surface. Seismic waves produced by an earthquake can cause damage to and failure of man-made buildings built on the Earth's crust [3]. Large reservoirs and dams built in seismically active areas present a serious risk to downstream property and life. It's evident that active faults, which are found around dams, locations, due to the instability of the dam and the deterioration of the foundation materials, might cause detrimental embankment deformation. Numerous studies have been conducted by scientists to explain how earth formations respond to seismic forces.

A study by [4] examined the stability evaluation of small concrete gravity dam using FEM with the ABAQUS software program and

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the analytical 2-dimensional gravity approach to guarantee the dam's safe operation. According to the results a number of significant factors, including the dam's base width, inclination toward the downstream side, presence of a passive wedge that resists, cohesiveness of the material used to construct the dam, angle of failure plane friction, and others, affect the structural stability of small concrete gravity dams.

In the study and construction of dams, particularly in earthquake-prone locations, earthquake or seismic loads are the primary dynamic loads taken into account. Their kinematic origin is what makes them are a result of the earth's surface moving during an earthquake, which created vibrations in the building [5].

A study by [6] examined how a concrete dam would respond to a seismic load, A finite element model with non-linear analysis is used for the investigation. The proposed model is used with the Oued el Fodda dam in Algeria as an example. Two earthquakes, Northridge (1994) and Kocaeli Izmit (1999), were taken into consideration. According to the data, near-fault motion often results in larger displacements at the top of the dam than far-fault motion. According to [7], safety standards for concrete dams subjected to dynamic loadings should include an assessment of the structure's overall stability, including confirming that it can withstand induced lateral stresses and moments and avoiding excessive concrete cracking.

A study by [8] conducted an investigation on the concrete gravity dam's seismic performance in order to assess how the foundation affected the nonlinear response using the FEM. To simulate the foundation, they employed an elasto-plastic composition. For the foundation's yield and the dam body's yield, the Mohr-Coulomb model and the smeared crack model were used, respectively. The findings demonstrate that the dam's slope and crest are where fissures originate.

An experimental study of deformation and stability of dams built of phosphogypsum under seismic impacts, there was a consistent trend toward a particular reduction in the natural vibration periods of the models as the impact intensity increased. An increase in density could be the cause of this occurrence of the models' material and, as a result, a rise in their rigidity, [9].

A study by [10] analyzed seismic damage for concrete gravity dams using a numerical examination of the seismic damage for the Oued Fodda concrete gravity dam, which is situated in northwest Algeria. The findings of the study was suggested that, the frictional joints model can more effectively lessen the seismic response and damage hazard of the dam body.

A study by [11] conducted a number of linear dynamic evaluations of stiff gravity dams on a frictional base and created an empirical formula to estimate the gravity dams' permanent sliding displacement. The advanced analytical and numerical solutions in the subject of concrete dams have focused on the key seismic issues in gravity dams including 3D effects, [12].

A study by [13] carried out an investigation into the Koyna dam's parameters, in order to replicate the harm done to the dam during seismic activity in actual time. The concrete damaged plasticity model takes into account the nonlinear characteristics of the material. The reservoir and the foundation play a major role in how a dam will behave during an earthquake. The displacements increase as the foundation modulus decreases.

When a strong earthquake impacts the dam, the stresses under the dam can exceed its strength, pushing the dam over elastic limit and resulting in significant structural damage [14].

According to [15], a number of significant factors, including the dam's base width, inclination toward the downstream side, presence of a passive wedge that resists, cohesiveness of the material used to construct the dam, angle of failure plane friction, and others, affect the structural stability of small concrete gravity dams.

The magnitude and duration of the ground movements are primarily responsible for the seismic stresses that are present on the dam monolith. During the earthquake excitation, there are mixed effects from the interaction of the dam's bodies. They embody the reservoir and the contact between the foundation and the concrete dam, which might affect the structural reaction and cause excessive collapse. Huge variations in stresses are seen as a result of the quick changes in the maximum compression and tension stress magnitudes at the toe and heel of the dam during earthquakes. Therefore, it is crucial to research the many factors that affect the seismic reaction behavior of concrete gravity dams in order to ensure their safety [16].

A study by [17] found that the concrete dam had generated sliding for hydrodynamic pressure in addition to the non-linear base movement analysis that was based on sliding; sliding motion has the effect of absorbing energy on the dams that were built on stiff Strong ground motions cause base and sliding motion, yet the system stays stable.

Concrete dams depend on their shape and weight to secure their safety requirements. Usually, the design of this type of dam begins with the adoption of the preliminary shape, which is subject to analysis and check of safety factors for expected failure modes. The shape of the dam is often modified by adding a concrete part to its upstream side to increase the weight and through it increases its resistance to all negative forces that may cause the failure of the dam [18].

A study by [19], eight near-fault seismic excitations are used to quantify how a concrete gravity dam reacts to vertical ground motion (VGM). To determine the dam's damping, horizontal, and vertical time periods, a modal analysis was performed. With Abaqus software, the nonlinear dynamic analysis of the concrete gravity dam was conducted utilizing the horizontal earthquake component and the horizontal plus vertical component. The dam's response is assessed using a number of factors, including maximum principal stress in the vertical direction, tensile failure crack pattern in the dam, relative horizontal displacement, relative vertical displacement, relative horizontal acceleration, relative vertical acceleration, and response spectra for relative horizontal and relative vertical acceleration. These factors quantify the effect of vertical earthquake components on the safety and stability of the concrete gravity dam.

The prediction of concrete dam performance during earthquakes is a very complicated and demanding topic in the realm of structural dynamics. This is due to a number of elements, including the neighboring infinite reservoir and the soil mass. The interplay between the dam's movements and the imprisoned water has a significant impact on the dam [20, 21].

In [22], a broken concrete gravity dam was modeled, and the contact between the damaged sections of the dam and the main body was modeled using zero-thickness contact components. Non-linear studies were performed using the enhanced Lagrangian approach, which took frictional sliding and contact joint opening into account. The fluid-structure-interaction relationship was also taken into consideration, taking into account the reservoir's absorptive barrier and fluid compressibility. The "Konya" and "Manjil" dam damage models are case studies. Based on both models, non-linear dynamic assessments were conducted. The influence of stiffness and damping coefficients on the dam's seismic response was investigated. The interaction effects of the dam, foundation, and reservoir were also taken into consideration. These revealed sufficient similarities and indicated that the dam's stability is unaffected by aftershocks. It has been shown that the top block moves with every aftershock, eventually resulting in some irreversible sliding that might potentially collapse the dam.

A study by [23] investigated the deep sliding stability of a concrete gravity dam-foundation system using probabilistic seismic analysis. For the sliding stability analysis, a concrete gravity dam's typical nonoverflow monolith was chosen as a case study. Using a high sample number, the Monte Carlo technique is used to perform the probabilistic seismic analysis of a gravity dam-foundation system. In order to measure susceptibility in the event of an earthquake, seismic fragility analysis is therefore examined, and seismic fragility curves are produced. The seismic safety evaluation in the probabilistic framework is based on an assessment of the gravity dam's overall seismic stability. Due to the complexity of the engineering geological conditions and the lack of clarity surrounding the geological defects in the underlying dam foundation, focuses on the effects of parameter sensitivity and uncertainty and seismic fragility analysis of concrete gravity dams based on the sliding instability failure mode. The numerical modeling of infinite foundations is performed using the viscoelastic artificial boundary model. In order to address the nonlinearity contact issues in the entitling stability of concrete gravity dams, the dynamic contact force model is used. The modeling parameters of cohesion and friction coefficients are selected at random. Using a gravity dam foundation's average nonoverflow monolith as an example study. In order to determine the quantitative impact of each parameter on the seismic response of the concrete gravity dam, the parameter sensitivity analysis is carried out first. Next, using effective Monte Carlo simulation and moment estimation techniques, the probabilistic analysis is performed to transmit the uncertainty in the sliding parameters to the seismic performance assessed by IDA. Damage levels are established, and seismic fragility curves are generated for the failure probability calculation of the sliding stability under earthquake threats based on the outcomes of the probabilistic analysis.

A study by [24] examined the effect of various frequency contents on concrete gravity dams behave seismically. For this reason, an analysis is conducted on a finite element model of the Pine Flat concrete gravity dam under various seismic input movements with varied frequencies. Results show that the dam's response to the earthquake's frequency content ratio is highly dependent on it, as will be demonstrated. The findings show that frequency content has a significant impact on the structure's dynamic responsiveness. In passing, the same model has been examined under various modular ratios to investigate the impact of soil-structure interaction (modular ratio is the ratio of the modulus of elasticity of the foundation of the structure). Interaction effects may be incorporated into the study in one of the easiest methods possible. Variable modular ratios, and therefore varying involvement in soil-structure interaction, have a significant impact on the dam's dynamic response, according to the results.

A study by [25] conducted an investigation on the differences in the dam horizontal acceleration responses between the massless and massed foundation models. According to the findings, the model with the massless foundation produced a horizontal acceleration response at the dam crest that was around 1.5 times larger than the model with the mass foundation.

Therefore, in the present study focus on the stability and behaviour of concrete dam on fine sand soil under the influence of earthquakes are studied. Two types of earthquakes have been taken namely (El-Centro and Halabja).

2. Experimental work

2.1 Dam model

In this study, a concrete dam model was used that was cast with a mixing ratio of 1:1:1.5 and without reinforcement. The dimensions of the concrete dam were: length = 49 cm, width = 15 cm, height = 20 cm, and thickness = 5 cm, as shown in Figure 1.

2.2 Soil used

The sand used in this work was brought from Al-Khalis district in Diyala Governorate. A set of tests was carried out to determine the characteristics of fine sandy soil, as shown in Table 1.

Table 1: Characteristics of sandy soil

Characteristics	Values	Standards
Classification (USCS)	SP	ASTM D 422 and ASTM D 2487 (2006)
D_{10} in mm	0.07	ASTM D 422 and ASTM D 2487 (2006)
D_{30} in mm	0.095	ASTM D 422 and ASTM D 2487 (2006)
D_{60} in mm	0.15	ASTM D 422 and ASTM D 2487 (2006)
Coefficient of uniformity (Cu)	2.14	ASTM D 422 and ASTM D 2487 (2006)
Coefficient of curvature (Cc)	0.86	ASTM D 422 and ASTM D 2487 (2006)
Permeability coefficient (cm/sec)	0.00394	ASTM D - 2434
Field dry unit weight, γd ((kN/m^3)	0.00394	ASTM D 4253 – (2006)
γd (max.) (kN/m^3)	15.8	ASTM D 4253 – (2006)
Relative density, Dr.%	70%	ASTM D 4253 – (2006)
Angle of internal friction (Ø)	36	ASTM D3040-04(2006)

Figure 1. Concrete dam model

Figure 2. Container used in the test

2.3 Container used in the test

Rectangular container made of steel was manufactured locally, with three sides made of steel and the front side made of reinforced glass that dimensions are 850mm in length, 550mm in width, and 600mm in height. The container was painted with anti-corrosion paint and as shown in Figure 2.

2.4 Device Used in the Test

The device used in this test was called a shake table device. It included many parts of equipment, electrical instruments, and sensors, as shown in Figures 3 and 4.

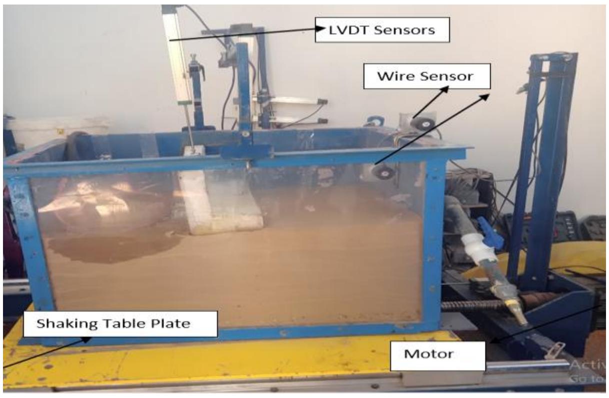

Figure 3. Shaking table with its add-ons

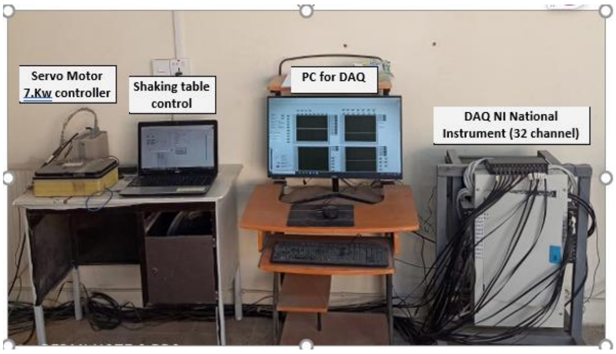

Figure 4. Digital shaking table

2.5 Model preparation and test

A steel container was installed on the plate of the shake table device used in the test. The soil is placed inside a steel container with dimensions of 850mm x 550mm x 600 mm. A 7-cm layer of gravel was placed, and then 6 layers of soil were added, each 50 mm, using the raining technique by rain device and compaction to reach a density of 70% (depth of soil 30cm). After completing the soil preparation process concrete dam (L = 490mm, B =150mm, H = 200mm, T=50mm) is placed on the soil surface. Using a tap, the soil is submerged in water until it is entirely saturated. There is a big water tank attached to it. The water level at the upstream side was 6 cm from the ground surface. Two Lvdt sensors were installed on the concrete dam at two different points to read the vertical displacement. Also, two wire sensors were installed on the concrete dam at two different points to read the horizontal displacement, as shown in Figure 5.

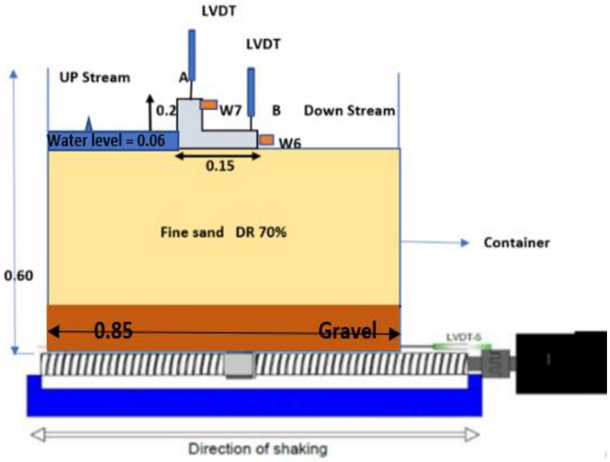

Figure 5. Schematic diagram of the model test

Prior to testing, all sensor values are calibrated using Lab VIEW interaction software on a desktop computer. A second laptop running a different Lab VIEW interface controls the shaking table simultaneously. As seen in Figure 6, the program was loaded with the temporal histories of the chosen historical earthquakes (1940 El Centro, and 2017 Halabja earthquakes); the data were downloaded as Excel sheet files onto the running computer. The answers of the test sensors are gathered using the desktop version of the data gathering system's Lab VIEW interface software following the completion of the shaking table test under various situations. DIAdem interaction software is used to store, display, and analyse these data. After that, two different types of earthquakes (Halabjah and EL-Centro) were tested on the model to study the stability of the concrete dam in the sandy soil.

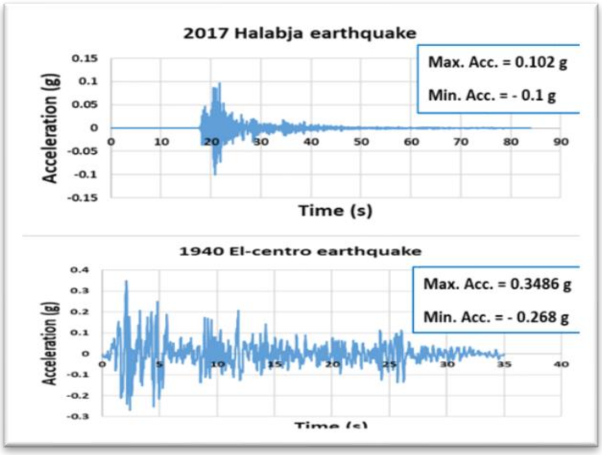

Figure 6. Time histories for Halabja and El-Centro earthquakes

3. Results and discussion

To understand the behavior and stability of a concrete dam, four LVDTs are erected at points A and B. In these two points, vertical displacement is recorded during an earthquake, and the others measure horizontal displacement. The earthquakes are applied to the concrete dam and the soil below it after the model reaches a steady state of seepage.

The two earthquakes are Halabja and El Centro. It is clear from figures 7 and 8 that the vertical displacement of points A and B was slightly oscillated during the first 23 seconds of the Halabja earthquake. During the time of 23 seconds, the vertical displacement jumped and dropped highly for points A and B. Beyond the time of 23 seconds, the vertical displacement begins to be low-frequency until it reaches the end of the earthquake at points A and B.

In general, the vertical displacement of point A is 92% more than that of point B. This means that the concrete dam is tilted to the left. This is because the part of the dam in which point A is located has a high weight as compared to the other part on which point B is located. The increase in vertical displacement at 23 seconds is due to that the time is near from the peak of Halabja earthquake.

Figures 9 and 10 show the horizontal displacement of points A and B during Halabja earthquake. The horizontal displacement is vibrated during the earthquake for points A and B. It is obvious that the horizontal displacement is moved slowly to the right at the first 23 second. After that, the point A is moved to the left, while point B is moved to the right. The movement of concrete dam is changed at 23 seconds which is near from peak acceleration of Halabja earthquake. The horizontal displacement of point A is 75% more than point B. It is clear that the point A is settled more than B that caused left tilting to concrete dam.

Figures 11 and 12 illustrate the variation of vertical displacement of points A ana B during El-Centro earthquake. It is obvious from figures 10 and 11 that the vertical displacement is small during the first 8 seconds for points A and B. After that the point A begins to settle downward and point B moved upward. The vertical movement of point A is to be nearly constant during the last 23 seconds while in point B is during the last 8 seconds of earthquake. The difference in vertical movement between points A and B is 0.45 mm. It is clear that the El-Centro earthquake caused total movement to the concrete dam 60% mor than Halabja earthquake.

Figures 13 and 14 depict the change in horizontal movement of concrete dam during El-Centro earthquake. In general, during the first 5 seconds of earthquake the horizontal movement is very small, after that begins to be more oscillated and then approximately to be fixed during the last 26 seconds of earthquake. The whole lateral movement of concrete dam is to the left and caused tilting of dam. The peak acceleration of El-Centro earthquake is almost at 2.4 second but the high lateral displacement of points A and B is near 5 seconds. The lateral displacement is nearly 0.58 mm and 0.30 mm for points A and B respectively. This mean that time delay is happened and the earthquake is resisted by sandy soil until the soil be with low resistance. After that the dam moved laterally in the left side. At the beginning of earthquake, the soil absorbed the energy of earthquake to limited time, after that the rise of pore water pressure may increase and caused reduction in effective stress of soil. Therefore, small settlement and lateral displacement happened in the whole body of concrete dam. The liquefaction phenonmenon is not happened during earthquake because of the relative density of sandy soil under concrete dam is dense. The liquefaction phenonmenon is occurred usually when the relative density of sandy is loose. In general, the concrete dam stability is not affected largely by these types of earthquakes: this may be due to that the peak of earthquake is not high especially Halabja earthquake. It is clear that the effect on stability of concrete dam of Elcentro earthquake is more than Halabja earthquake due to the cause mentioned above.

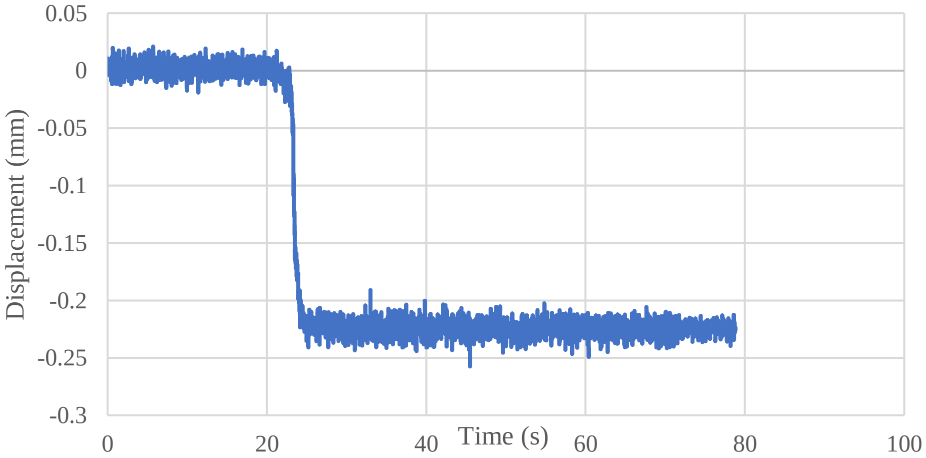

Figure 7. Vertical displacement of point A during Halabja earthquake

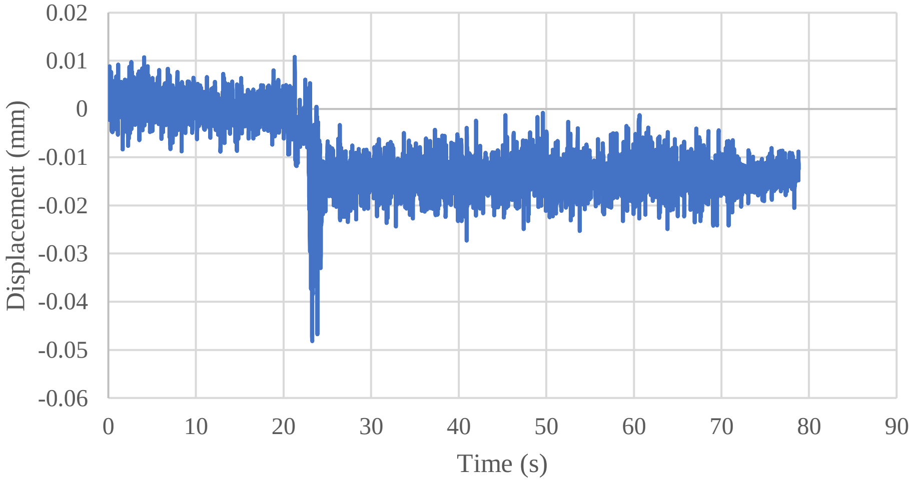

Figure 8. Vertical displacement of point B during Halabja earthquake

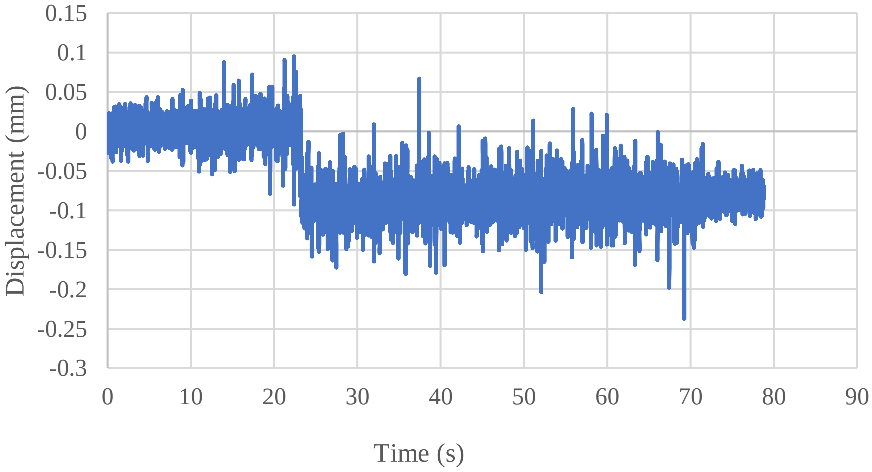

Figure 9. Horizontal displacement of point A during Halabja earthquake

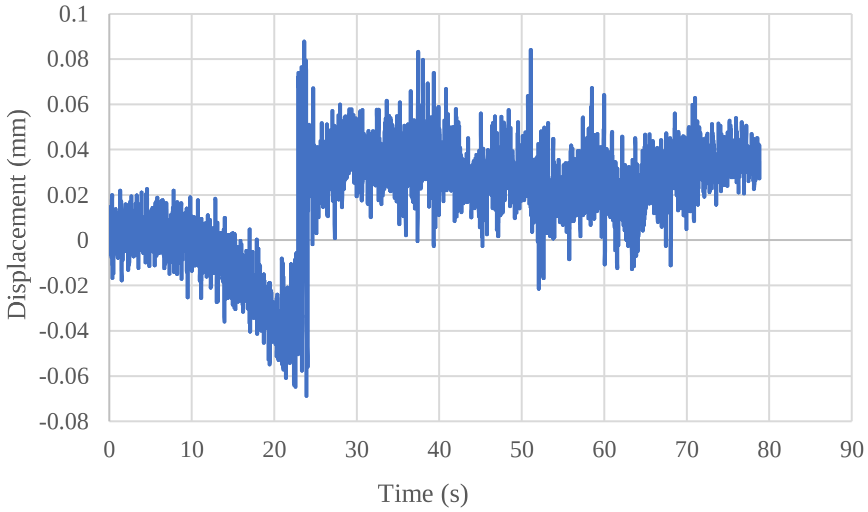

Figure 10. Horizontal displacement of point B during Halabja earthquake

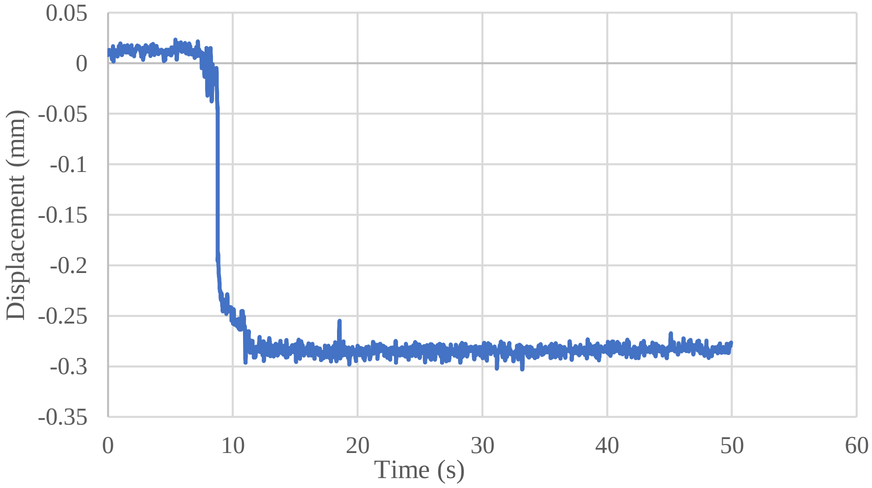

Figure 11. The vertical displacement of point A during El-Centro earthquake

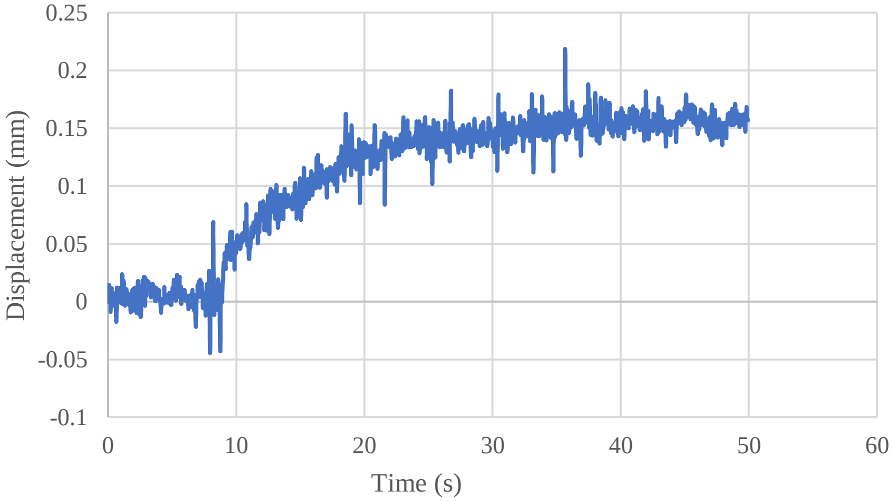

Figure 12. The Vertical displacement of point B during El-Centro earthquake.

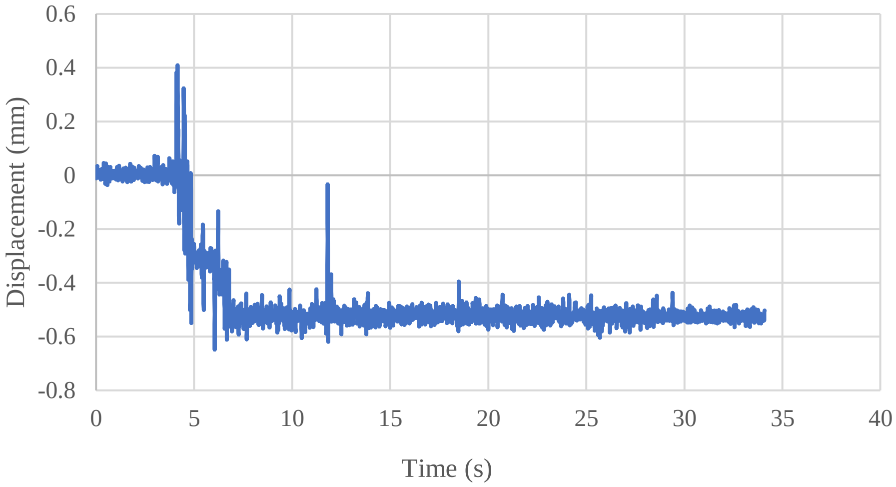

Figure 13. The Horizontal displacement of point A during El-Centro earthquake.

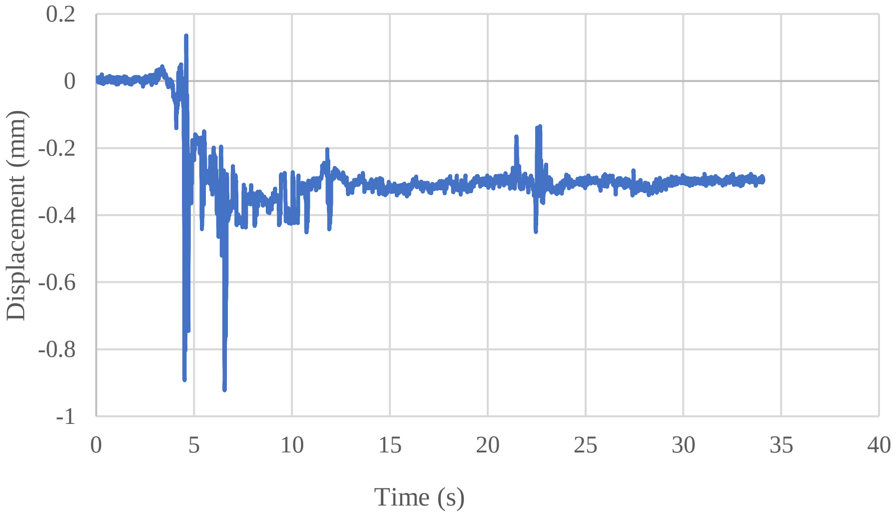

Figure 14. The Horizontal displacement of point B during El-Centro earthquake

4. Conclusions

- El-Centro earthquake effect on stability of concrete dam is 60% more than Halabja earthquake, this is due to differences in peak acceleration and intensity.
- The stability of a concrete dam subjected to an earthquake depends on: a. the intensity of the earthquake; b. the thickness and width of the dam. c. type of soil.
- The concrete dam tilting is to wards high thickness part of dam due to seismic load.
- The cross section of concrete dam in addition to intensity of earthquake play consequential rule in stability of concrete dam.
- The sandy soil below concrete dam is not caused liquefaction or piping in foundation of dam during earthquake due to high relative density of soil.

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