

Numerical Modelling of Behavior of Vertical Shaft Spillway Under Earthquake Effect (Case Study: Dukan Spillway)

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A spillway is a hydraulic structure that allows additional water to be released from a dam's upstream to downstream region. In the present study, 3D modeling of the Dukan flood system evaluated the effects of structure-water interaction on the dynamic responses to the flood using ABAQUS6.13 software. To determine the effect of the vertical column the acceleration of the earthquake in the Y direction was applied to the Dukan model with four different values of water height under the influence of the Halabja earthquake that occurred in 2018. Examination of the results of the numerical model shows that in the event of an earthquake, the height of the water around the column increases due to the increased displacement, but in the absence of an earthquake effect the displacement does not change and its value is very small. Investigations revealed that as the height of the vertical column increases, the maximum value of stress occurs when the water height is 30 meters and decreases when the water column decreases.

Keywords: Spillway, Numerical Modeling, Morning Glory, Earthquake, dukan

1. Introduction

Dams, as the most important source of water storage needed by human societies, include hydraulic side structures that affect the safety and performance of the dam. Various types of overflows, as one of the important hydraulic components of dams, are responsible for discharging excess water from reservoirs when necessary, especially during floods. Lotus overflows are one of the most common types of overflows, which are known as the best option for flood drainage systems in many cases. Spillway building has various components, which include a funnel-shaped spillway with a circular geometry in plan, a vertical shaft and sometimes an inclined shaft, a bend and a tunnel that leads to the outlet flow. Hydraulic performance and improper overflow devices can be a threat to the stability of dams, especially earthen dams, and create risks for the population living downstream of that area. Therefore, it seems necessary to pay attention to the safety of the dam by considering various design parameters. One of the most important issues discussed in the field of safety of dams is the behavior and performance of the structure in the face of ground disturbances, which doubles

the need to pay attention to seismic evaluations. Earthquake design of the underground parts of overflow is done by calculating shear displacement of the free field under the effect of seismic waves, calculating the actual displacement of the structure by taking into account the coefficient of flexibility of the structure and deformation of the free field and applying the actual displacement of the underground structure, but a more accurate evaluation of the vibrations of the overflow requires a proper analysis of the response. The dynamics of the overflow and its interaction with the foundation and surrounding tank. Therefore, the modeling of these structures should be in ways that express the real behavior of the structure-water-soil connection system. Investigations show that up to now few documented and focused studies have been conducted on the analysis of the dynamic response of lotus spillways, but the analytical modeling of the interaction of towers submerged in water (it has similar behavior to this type of spillways) has been proposed by researchers for a long time and has been completed over the years. Is. On the other hand, although the dimensions of the flood discharge system in overflows It depends on the hydraulic and flood parameters of the design, but in the matter of selecting the dimensions of the overflow and determining the height of the earthen dam, it is necessary to pay special attention to the possibility of changing the dimensions of the overflow and, as a result, changing the height of the dam. Therefore, it can be useful to know the dynamic behavior of the lotus overflow system by considering the change in its dimensions. In the following, a review of the studies and results of the researchers in this field and the analysis of the tremors of overflows is done.

Nohani and Mousavi,(2009) examined the influence of the number and width of vortex breaker blades on the intensity of spiral vortices and the effectiveness of the discharge system in a spiral spillway. To do this, A physical model of a shaft spillway was built by the researchers, who also conducted several experimental studies. The results indicated that the discharge coefficient of the morning glory spillway experienced a 20 % increase by increasing The total number of blades and a 9% increase by increasing both the number and width of the blades [1]. The study conducted by Nohani (2014) attempted to determine the discharge coefficient of shaft spillways, specifically under the geometric conditions of the spillway crest. This was achieved through the utilization of a physical experimental model. The research investigation was conducted on shaft spillways of varying diameters, both with and without the addition of vortex breakers in the morning glory spillway crest . It is important to acknowledge that the assessment of the crest edge type conducted in this study. This study evaluated two types of crest edges, namely flat-edged and sharp -edged crests[2]. In a study conducted by Nohani and Gheisi (2014), an experimental investigation was performed to examine the impact of vortex breaker length on the discharge coefficient in a shaft spillway [3].

In a study conducted by Nohani (2010), an experimental investigation was conducted to investigate how a glory hole spillway's discharge coefficient is affected by the anti-vortex plate's tilt. [4]. In a study conducted by Nohani (2016) The present study investigates the quantitative evaluation of the impact of anti-vortex plates on the inflow pattern in vertical shaft spillways by the utilization of FLOW3D software.

The findings of the study revealed that the inclusion of a vortex breaker in a structure with dimensions of $10 \times 8 \times 5$ has a substantial impact on the water flow at fixed water heights, as compared to a control condition. Furthermore, the discharge rate is observed to grow with the addition of more vortex breakers [4]. In a study conducted by Nohani (2014), an experimental

physical model was utilized to calculate the discharge coefficient for a morning glory spillway, specifically focusing on the spillway crest edge geometrical circumstances. This study examines the effects of different diameters of morning-glory spillways, both with / without anti-vortex elements at the top of the spillway. It is noteworthy that the investigation of the type of crest edge was extended in this study. This study examines two distinct types of spillway crest edges, namely sharp-edged and wide-edged crests [5]. The experimental investigation conducted by Petaccia and Fennochi (2015) examined the pressure variations and flow profile of the siphon spillways [6,7].

In 2015, Ebrahim Nohani attempted to investigate the shaft Spillway's hydraulic performance through numerical modeling. The numerical modeling of the morning glory spillway was conducted using the Flow 3D software, in accordance with the standards set by (USBR). A numerical model was used to determine the hydraulic parameters of the flow, such as the pressure distribution, water level profile, and coefficient of discharge. After that, these parameters were contrasted with information obtained from the USBR and USACE models. The comparison of these parameters revealed a strong agreement and consistency between the results [8]. Amir Reza Razavi , Hassan Ahmadi(2017) , This study used a physical model to calibrate and validate flow using FLOW-3D. Next, by increasing the flow's suspended load, The discharge values that go through the spillway known as morning glory were established. In this regard, flow discharge values were examined for different heads over the spillway using suspended load (3000, 6000, 9000, and 12000 ppm). such that suspended load has a significant impact on deceased values [9]. L.L. Ebner, S.K.Askelson,E.A.Thompson and N.C. Cox(2016) The proposed alterations involve the elevation increase of two high head dams, measuring 56.4 m (185 ft) and 30.5 m, by 4.88 m. Additionally, there are plans to modify a service spillway to enhance its flood capacity, as well as construct a new labyrinth weir emergency spillway. In order to facilitate the design process for both spillwaysfor the Isabella Reservoir and associated outlet operations, a number of three-dimensional (3D) models for computational fluid dynamics (CFD) have been created. The design process for the emergency spillway has been optimized by the utilization of a composite modeling approach, which incorporates both physical and computational fluid dynamics (CFD) modeling techniques to analyze the performance of the labyrinth weir. A useful tool for assessing various spillway design possibilities is the computational fluid dynamics (CFD) model of the main, auxiliary, and forebay dams at Isabella Dam, as well as the service and emergency spillways, offer a valuable platform for evaluating different design options for the spillways. These models also aid in the production of rating curves and the validation of data received from physical models. The hydraulic conditions within and downstream of the spillway chute were assessed using the computational fluid dynamics (CFD) model outcomes. The computation of velocity, water surface height, and stream power was conducted in order to determine the necessary steps for protecting the chutes against erosive damage [10]. Enjilzadeh and Nohani (2016) conducted a study in which they utilized FLOW3D numerical models to perform a three-dimensional numerical simulation of the flow in the morning glory spillway of Alborz dam. The accuracy of the numerical model was assessed by comparing it to experimental data, and the relative error of the numerical model was used as a measure of its accuracy. The aim was made to determine the flow pattern and control conditions of shaft spillways in various modes by considering boundary conditions, inlet conditions, grid spacing of the flow field, and the project rating curve of morning glory spillways. Based on the outcomes of the numerical

model, the relative error of the numerical modeling is determined to be 6.4% when estimating the discharge rate of the spillways. The numerical modelling error in calculating the depth parameter of the flow in the spillway crest is 7.6%, as observed in comparison with the corresponding experimental results [11]. In their study, Smyth and Smyth (2001) proposed a model to explain the formation of the morning glory cloud, which occurs due to the resonant flow of a two-layer fluid over the terrain represented by the mountains of Cape York Peninsula. In the scenario where the upper layer is significantly deep, the equations of motion can be simplified to a forced Benjamin-Ono equation. The modulation solution's predictions are then compared to observational data regarding the morning glory phenomenon. It is observed that there is a satisfactory agreement between the predicted and observed pressure jump caused by the lead wave of the morning glory. However, there is a lack of agreement regarding the speed and half-width of this lead wave [12].

In the present study, Parham et al. (2019) conducted a simulation of the flow via a sectoral morning glory spillway utilizing a three-dimensional numerical model. The present study aimed to analyze the key properties of flow in spillways of this particular type, with a subsequent proposal of a mathematical relation to determine the rate of water release. In order to accomplish this, the geometry of the spillway crest was analyzed by considering five sector angles. Additionally, the flow characteristics and drainage capacity of each sector angle were compared. A mathematical equation was presented to determine the discharge flow rate of sectoral morning glory spillways. The findings derived from the correlation reveal that the calculations conducted using the given relation exhibit a maximum inaccuracy of 7.77%, which is observed at a sector angle of 62 degrees. The mistake percentage serves as a validation of the dependability of the relationship [13].

2. Aim of study

The main purpose of the research is to study the effect of earthquakes on the vertical shaft spillway and to know the extent of its safety and integrity because it is a very important part of the dam body. As earthquakes can cause Earthquakes can lead to damage and collapses in dam facilities, while dams with large reservoirs can cause earthquakes. It is reported that the safety of dams from earthquakes is an important phenomenon in dam engineering and requires more comprehensive seismic studies to understand the seismic behavior of the structural parts exposed to severe earthquakes.

3. Location and description of Dukan spillway

The Lesser Zab River's Dukan Spillway was constructed between 1954 and 1959 and is situated about 220 kilometres upstream from the river's confluence with the Tigris. The location is roughly 295 km north of Baghdad and 65 km northwest of Sulaimaniyah city, next to the town of Dukan. The limestone and dolomite rocks that form the narrow, steeply inclined gorge where the spillway is situated. It's a circular block of concrete.[14]

The emergency spillway is a bellmouth spillway, also known as Morning Glory, with a circular 40.26 m diameter and a crest located at the reservoir's typical high water level. A 10.2 m diameter tunnel receives the bellmouth's discharge through a vertical drop shaft with a

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diameter of 12.5 m. The tunnel has steel lining at its downstream end, where its diameter is reduced to 9.9 metres and it is angled 30 degrees upward and 47 degrees downstream to allow for a free discharge into the river valley. The information about the dukan spillway is displayed in Table (1), with the emergency spillway having a maximum capacity of 1,860 m³/s.

Table (1) Details of Dukan shaft spillway

Type	Emergency Spillway
Diameter bellmouth	40.26m ('Morning Glory')
Crest Level at Ogee	El. 511.00 m.a.s.l
Discharge Capacity at El. 515.10	1,860 m ³ /s
Internal Diameter of Shaft	12.50 m
Internal Diameter of Tunnel	10.20 m
Outlet Details	Steel lined, reduced diameter 9.90m, inclined 30° upwards and 47° downstream for free discharge to river gorge

4. Materials and Methods

The geometric model is initially created in accordance with the dimensions of the Dukan shaft spillway employed in this study in order to analyse the structure using ABAQUS. The material characteristics are given after the model is created (Table 1). After that, the structures are put together using the assembly module, and the step module is used to select the necessary analysis type. By choosing the appropriate element type and mesh property type, the mesh is created. The base of the dam is regarded as stiff in order to do the modal and hydrostatic analysis of only the shaft construction. A boundary condition of the displacement/rotation type is used for the dynamic analysis. Since the shaft is only being examined for the earthquake's horizontal acceleration, both rotation and translational movement in the vertical direction are taken into account as zero.

5. Numerical modelling

Analysing pressure and displacement under various water levels and seismic effects was the goal of the numerical model. The behaviour of the vertical shaft spillway has been simulated in this study using the (ABAQUS 6.13) programme. A strong numerical tool with a long history of use in multiphysics domains, ABAQUS is typically used for simulating components and systems. It is applied to transient situations involving many degrees and multiple physics. ABAQUS offers a number of pre-built models to forecast material behaviour in addition to the ability to incorporate user-defined models. The model considers the elastic behaviour of the materials and uses three-dimensional (solid) parts, The model was discretized using the water's surface and the domain's border. The spillway's axisymmetric geometry was taken into consideration when creating the 3D model.

6. Result and Discussion

6.1 Displacement

The maximum horizontal displacements of Dokan spillway is shown in Figs.1(a,b,c and d) and 2 for with and without earthquake cases and different height of water. It is observed from Figs. 1 and 2 that the top shaft block undergoes a significant sliding during an earthquake, which attains the value of 62.2 cm in full height of water around reservoir case, while it is 19.3 cm in the 10 m height of water around reservoir case. Fig. 1, as below, presents the envelopes of maximum horizontal displacement of the shaft for different reservoir cases.

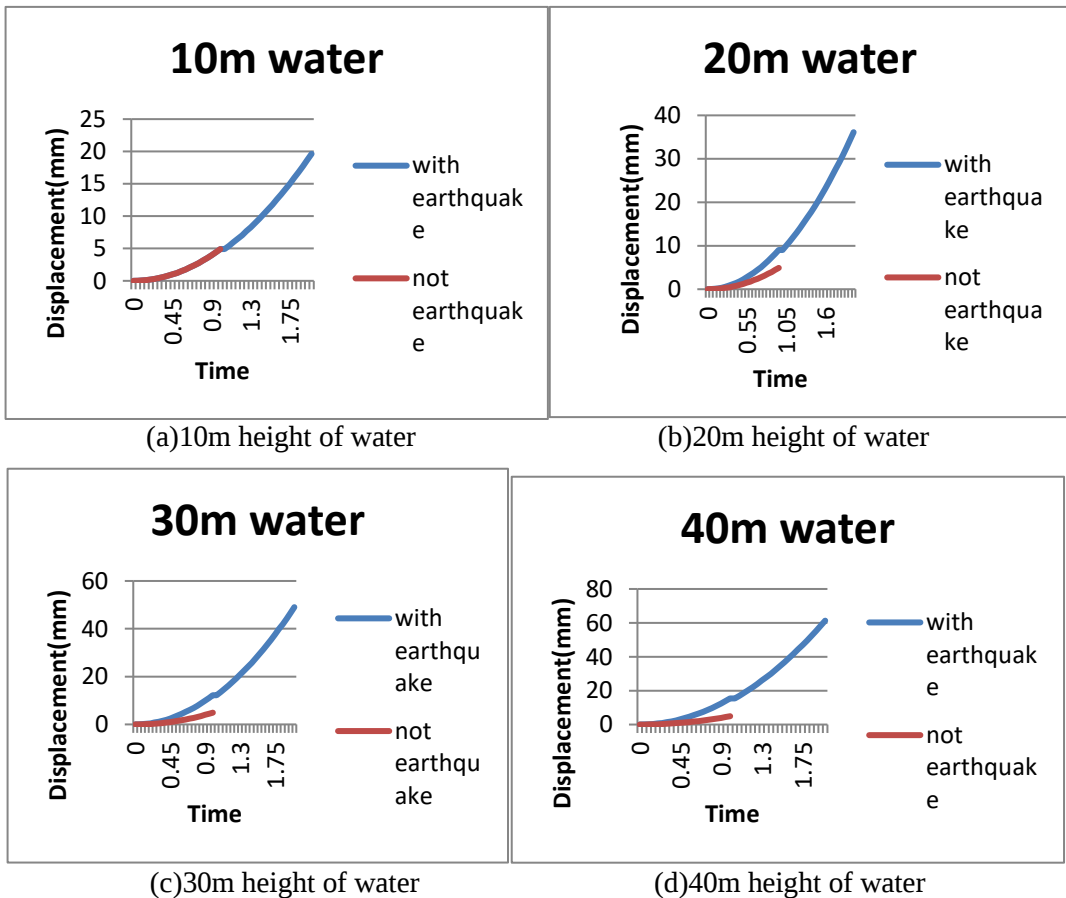


Figure (1) Displacement of spillway with and without earthquake for (a)10 m (b)20 m(c)30 m(d)40m height of water

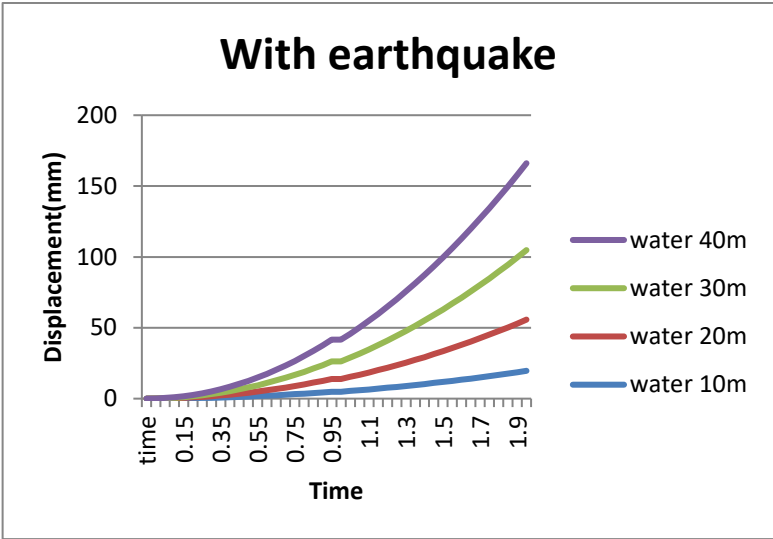


Figure (2)Max. Displacement of spillway under earthquake effect

According to the above figures, it is clear that when there is an earthquake, the displacement increases as a result of the formation of horizontal hydrodynamic forces, from which it is clear that there is a direct relationship between the height of the water and the force, which in turn causes moments that try to turn the body around the base, and it is also clear when there is no earthquake, there is a large difference in the amount of displacement as a result of the decrease in moments.

We also notice that when the height of the water increases, the displacement increases

6.2 Von Mises

Von Mises criterion is yield condition used in mechanics of materials to determine when a material will start to yield. Von Mises criterion takes into account both shear and normal stresses. These criteria are important in the design of structures as they help determine the maximum load a structure can withstand, and the Von Mises criterion is more suitable for brittle materials. When analysis the model of dokan spillway observed When there is no earthquake, the value of the von mises is very small and hardly changes, while when there is an earthquake, its quantity doubles to a very large value compared to the case when there is no earthquake. As its value is at the height of the water column from 10 to 40 metres, the value of the von mises ranges between 0.001 and 0.002, and its highest value is at a height of 10 metres. As the water column rises, its value decreases, while its value increases to 43MPa when there is an earthquake and at a height of 30 metres, which is It is also close to a height of 20 metres, and is lowest at a water height of 40 metres . As shown below(figure 3,4(a,b,c and d))

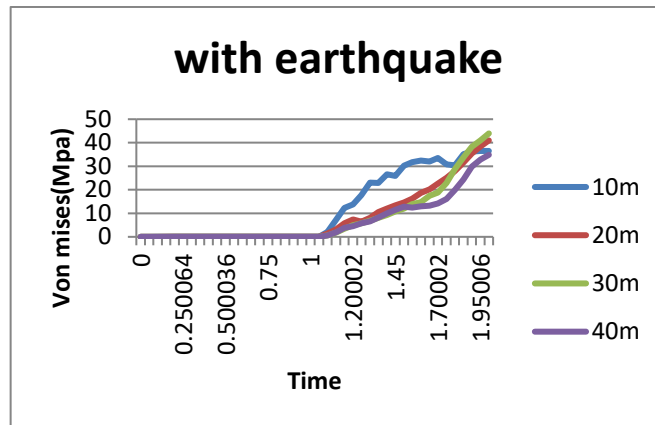
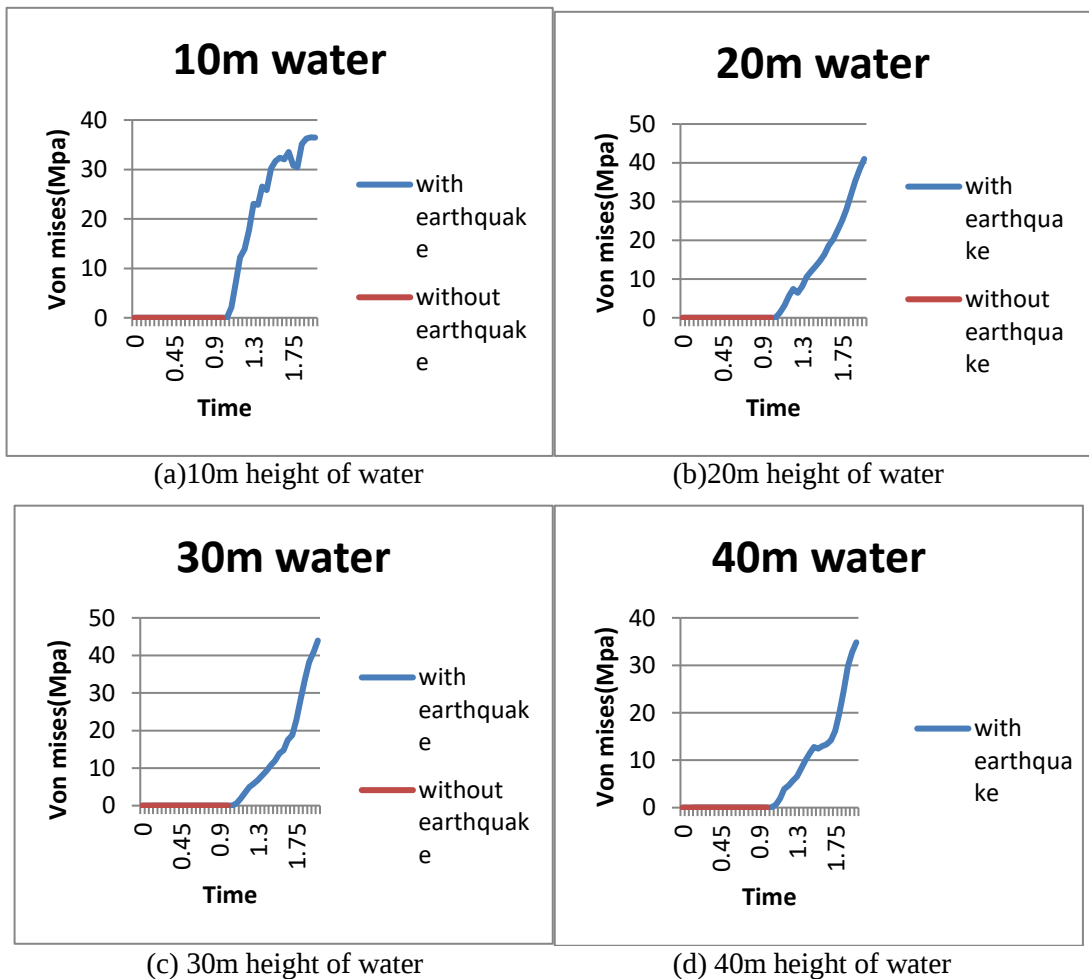


Figure (3) Max.Von mises under earthquake effect

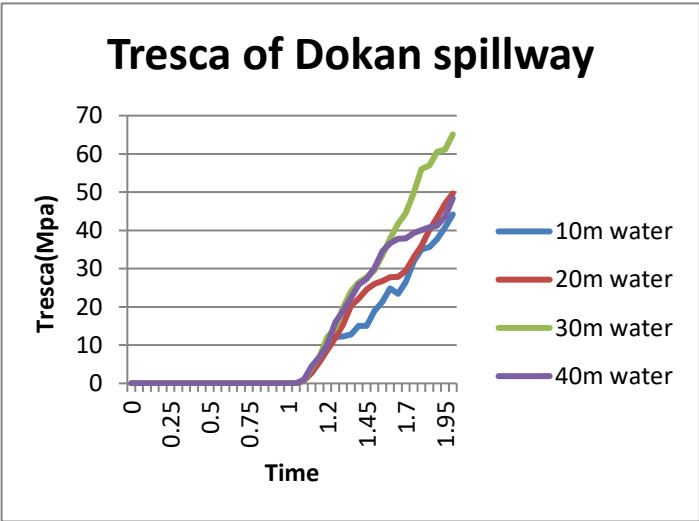


Figure(4) Von mises of spillway with and without earthquake for (a)10 m (b)20 m(c)30 m(d)40m hight of water

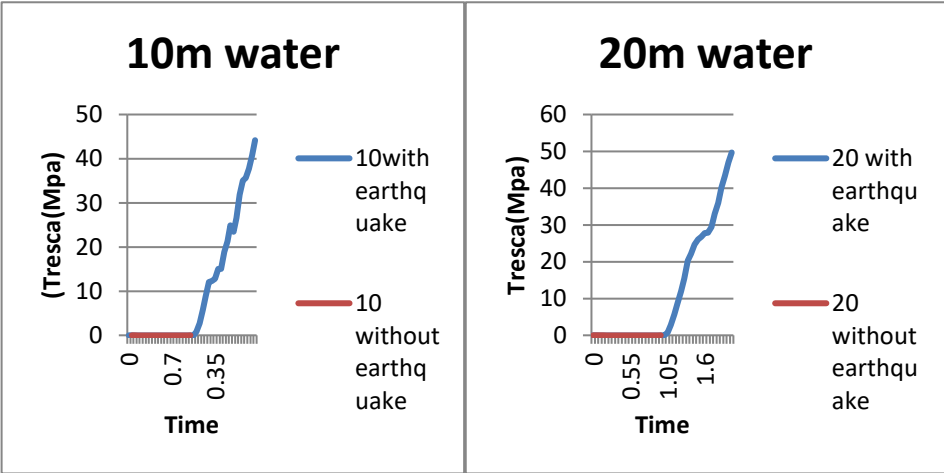
It is observed that the stress developed in the concrete was found to be almost same. so that it is observed the shaft spillway not affect by by displacement or stress under effect of water load or static load in case of not found earthquake .

6.3 Tresca

The maximum tresca that generated in the walls of shaft spillway of Dokan is shown in Figs.5 and 6 for with and without earthquake cases and different height of water.

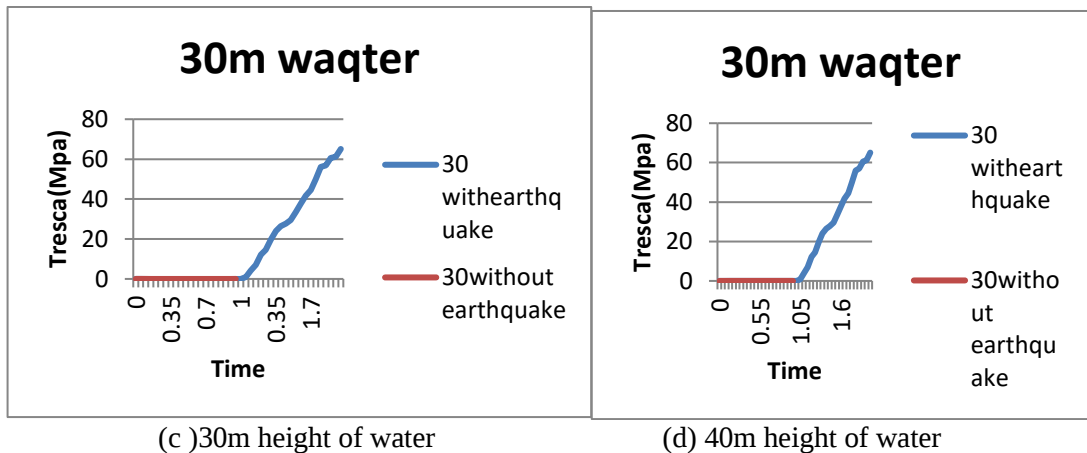


Figure(5):Max. tresca of dokan spillway under earthquake effect



(a)10m height of water

(b)20m height of water



Figure(6): Tresca of spillway with and without earthquake for (a)10 m (b)20 m(c)30 m(d)40m hight of water

The Abaqus model has different material failure criteria such as Von-Mises stress, Maximum principal stress, Tresca stress, etc. The Von-Mises stress is mainly used

for failure evaluation of ductile materials . On the other hand, the maximum principal stress theory is most of the time used for failure evaluation of brittle material such as concrete.

7. Discussion

In the current three-dimensional dynamic research of the reservoir system was carried out. Three-dimensional dynamic analysis of the system reservoir can be used to analyze the designs and estimate the seismic behavior of shaft spillway structures . The flood discharge system in Dokan spillway depend on the hydraulic and flood parameters of the design as well as the topographical conditions. In this study, the effects of the vertical overflow shaft displacement and stress on the dynamic responses of the complex were determined. For this purpose, eight different models of limited components in the softwareAbaqus 6.13Modeling and values of max. displacement and stresses (von mises) were conducted from the dynamic analysis. The results obtained from this research can be summarized as follows:

-Analysis of various models shows that the increase displacement of the column when the height of the water increases under the influence of the earthquake, and it remains the same value when there is no earthquake, which is a very small value due to the stability of the effect of the water as a result of its stagnation.

-The results of dynamic analysis show that the change height of water under earthquake effect is affect to stress in wall of structure and increases to a certain extent and then begins to decrease

The stress value before using the seismic effect is much higher than its value after using it. This is due to the various forces affecting the body of the spillway that are caused by the earthquake, such as hydrostatic and hydrodynamic water pressure, wave pressure, the pressure of river sediments placed in front of the dam which are effectively affected by the presence of

the earthquake, the force of the earthquake, and seismic water pressure. All of these factors affect the increase in stresses on the body of the spillway.

-The maximum horizontal displacement is (19 mm) when the water level is 10 m, (38 mm) when the water level is 20 m, and (49 mm) when the water level is 30 m, 62 mm when the reservoir is full, that is, at 40 meters when using the effect The Halabja earthquake is the result of the effect of lateral pressures on the body of the spillway and an attempt to dislodge it sideways. While when using only the water column without an earthquake, the maximum horizontal displacement is reduced to (4.7 mm), and there is only a very slight effect due to the stability of the water surrounding the spillway.

References

1. Nohani, Ebrahim. "An experimental study on the effect of vortex breakers thickness on discharge efficiency for the shaft spillways." *Science International* 27, no. 3 (2015).
2. Nohani, E., Heidarnejad, M. "Laboratory investigation into effect of angle of anti-vortex plates on discharge coefficient in glory hole spillway", 9th Iranian Conference on Hydraulics, Tehran, Iran Hydraulics Association, Tarbiat Modarres University, (2010).
3. Xianqi, Zhang. "hydraulic characteristics of rotational flow shaft spillway for high dams." , (2015).
4. Nohani, E., Heidarnejad, M. "Laboratory investigation into effect of angle of anti-vortex plates on discharge coefficient in glory hole spillway", 9th Iranian Conference on Hydraulics, Tehran, Iran Hydraulics Association, Tarbiat Modarres University, (2010.)
5. Petaccia, G., and A. Fenocchi. "Experimental Assessment of the Stage–discharge Relationship of the Heyn Siphons of Bric Measurement and Instrumentation 41 (March 2015): 36–40. doi:10.1016/j.flowmeasinst.2014.10.012. Zerbino Dam." *Flow*
6. Houichi L, Ibrahim G, Achour B. Experiments for the discharge capacity of the siphon spillway having the Creager Ofitserov profile. *Int J Fluid Mech Res* 2006; 33(5):395–406. <http://dx.doi.org/10.1615/InterJFluidMechRes.v33.i5.10>.
7. Gramatky G. Siphon spillway [Dissertation]. University of California; 1928 .
8. Ebrahim Nohani ,(2015).An experimental study on the effect of vortex breakers thikness on discharge efficiency for the shaft spillway .*Sci.Int. (Lahore)* ,27(3),2295-2299,2015
9. Amir Reza Razavi a*, Hassan Ahmadi,(2017). Numerical Modelling of Flow in Morning Glory Spillways Using FLOW-3D. *Civil Engineering Journal*.
10. Laurie L. Ebner,(2016). Numerical Modeling of the Spillways for the Dam Raise at Isabella Dam. *Hydraulic Structures and Water System Management* .ISBN 978-1-884575-75-4
11. Mohammad Reza Enjilzadeh a*, Ebrahim Nohani,(2016). Numerical Modeling of Flow Field in Morning Glory Spillways and Determining Rating Curve at Different Flow Rates .*Civil Engineering Journal*.Vol. 2, No. 9,September, 2016,448
12. ANNE PORTERy AND NOEL F. SMYTH ,(2001).Modelling the morning glory of the Gulf of Carpentaria. *J. Fluid Mech.* (2002), vol. 454, pp. 1{20. C 2002 Cambridge University Press .DOI: 10.1017/S0022112001007455
13. Parham Sabeti, Hojat Karami, Hamed Sarkardeh,(2019).Analysis of the Impact of Effective Length of Morning Glory Spillway on Its Performance (Numerical Study). *Instrumentation Mesure Metrologie*. <https://doi.org/10.18280/i2m.180217>
14. Lawa, F.A., Koyi, H. and Ibrahim, A. (2013) Tectono-Stratigraphic Evolution of the NW Segment of the Zagros Fold-Thrust Belt, Kurdistan, NE Iraq. *Journal of Petroleum Geology*, 36, 75-96. <http://dx.doi.org/10.1111/jpg.12543>
15. Dokan and Derbendikhan Dam Inspections,(2006). SMEC International Pty. Ltd.