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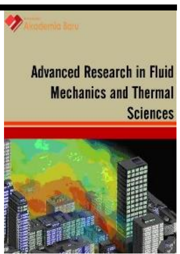

Stability Assessment of Zoned Earth Dam under Water Particles Fluidity Effect: Hemren Dam as Case Study

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ABSTRACT

Recently the numerical modeling using finite element method is take into account as a very effective tool to investigate the desired behavior of structures in geotechnical engineering. Earth dams are a water retention structures that are normally wide constructed around the world due to its significant features. These structures may be failed due to exposure to an earthquake and this will result in disaster. The main objective of this study is to assess the slope stability and the seismic response of an earthen dam. Since the matter of seismic response is still have a considerable lack of information for earth dams as a unique structure. Hemren zoned earth dam that is located in Diyala governorate, northeast of Iraq that considered as an active seismic zone has been considered as case study. Numerical modeling has been done in this study using Geo studio software. Factor of safety was calculated with different water levels in order to evaluate the dam safety with different operation water level. The excited earthquake is Elcentro while three values of peak ground acceleration were used which are 0.2, 0.25 and 0.3 g and the duration time is scaled to 10 seconds. In addition, three key points (at the core, the shell and the foundation) that represent the dam construction material are used to evaluate the dynamic response within the dam body. The results revealed that the factor of safety is increased when the water level is increase, but in the increasing in the magnitude of factor of safety with water depths of (10 and 15) m was more than the other depth. The zone of the dam core shows a negative pore water pressure value. That leads to an increasing in effective stress at the core of the dam.

Keywords:
Slope stability; Hemren dam; Earth dams; Earthquake analysis; Finite element method

1. Introduction

Dam could be defined as a barrier that stops or restricts the drainage of water or underground streams. Reservoirs that are created by dams do not only prevent floods but also provide water

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resource for activities such as watering, human consumption, power generation, and irrigation. A dam can also be utilized to collect water or for storage of water that may dole out among locations in a proper manner. As a matter of fact, dams serve the basic aim of preserving water, while other structures like floodgates or levees (also known as dikes) are utilized to control or direct water stream into particular land areas. Although of all the benefits that could be obtained from dams' construction, but on the other hand, it may be caused a catastrophic flood when they fail [1]. Therefore, the monitoring of dam safety is considering the most significant issue that should be focused by the engineers and decision makers.

As result of an earthquake status, Samarco tailing dam was failed in 2015. In the case of dynamic load related with horizontal seismic load along with the vertical load, that situation could result in an effective decreasing in the slope stability which may result to failure. The commercial software Geo-studio was used as a numerical endeavor two-dimensional analysis. The stability of the slope was assessed initially by taking into account the finite element stress analysis. The impact of factor of safety of tailing dam due to effect of both horizontal and vertical seismic loads were investigated by introduced a staged pseudo-static analysis [1].

Shanmugapriya and Jusoh [2] studied the soil nailing system from the perspective of inclination effect in. They consider the Genting Highlands in Malaysia as case study with different soil nail inclinations. They use Slope/w model in order to obtain the suitable rang for the efficient stabilization for soil slope. It concluded that the inclination of the soil nail has considerable impact on the slope stability. In addition, the results indicate that the soil nail inclination has a small impact of the value of factor of safety when the degree of inclination of the soil nails ranges within 5° - 20° to the horizontal.

Shole and Belayneh [3] preformed numerical analysis utilizing Geo-Studio 2012 software on the Gidabo rock fill dam. The dam has side slope of (2H:1V) and 22 m dam height from river bed level. The shape of clay core and side slopes impact on the stability of embankment dam was evaluated; also, the least earthwork exploitation with stable dam safety is specified. According to the analysis of the results, the values of factor of safety were 1.514 and 1.611 at end of construction for upstream and downstream respectively, and the values of factor of safety were 1.504 and 1.316 for the steady state condition and for rapid drawdown respectively. The flux through the dam was found to have a value of 1.95×10^{-7} $m^3s^{-1}m^{-1}$. The results also indicate that at normal pool level, the horizontal deformation is 0.023m and the vertical deformation is 0.192m, and these deformation values are within the permissible limits. Subsequently, the chosen clay core shape and side slope dam achieved all design requirements and decreased the used shell fill material.

Many recent contributions throughout the literature were studied the dynamic response of earth dams by numerical modeling in a serious concern. In addition, most of these contributions accounted such response in term of stability, pore water pressure development, liquefaction potential and the induced stresses and displacement [4]. Khattab and Khalil [5] study the factor of safety in the upstream and downstream of Badush Dam with the consideration of the seismic response and the rise of water level.

The geogrid earth dam behavior was also observed under dynamic load [6]. In addition, nonlinearity of soil was also included in term of seismic load [7]. The finite deference's method was also used in the past to conduct regarded analyses [8, 9]. Furthermore, software like 1D Plaxis was also used wholly to conduct the required numerical simulation to study and compare of some earth dam's failure after earthquakes [10], while the same software used also in term of 2D analyses in some similar cases [11]. In a related context, it is observed that some recent studies are extended to consider the unsaturated zones within dam body in the seismic response analyses [12].

Rockfill dams have a serious share in the scientific research within this field [13, 14]. Additionally, there are a considerable lack of information about the expected dynamic response behavior of zoned earth dams that located within Diyala governorate, Iraq that considered an active seismic area [15]. Khanmohammadi and Hosseinitoudeshki [16] in 2014 study the effect of water level on slope stability. They conclude that the factor of safety and durability of slope are increase when the water level is decrease and vice versa. While Taghizadeh and Vafaeiyan [17] explain that if the slope contains fine grain soil, then the soil will be swell with the increasing of water level; when the slope contains the coarse grain soil, the increaseing in water level may be reduce the bearing capacity.

Latief and Abdul Kareem [18] study the effect of water level on slope stability and construction cost of highway embankment using finite element analysis. They conclude that the decrease in water table could be improve the factor of safety and reduce the construction cost. Thair *et al.*, [19] use the geo-studio software to investigate the factor of safety of earth dam under drawdown conditions. They conclude that the minimum value of factor of safety was obtained when after 1o hours when the drawdown is occurred within one day. In addition, they show that the slope stability is highly affected by the drop of water level where the pore water pressure in slope was dissipate.

The focusing of this study was on the earth dam slope stability since the stability is one of the main issues in dams engineering. As of late, numerical models are utilized to evaluate the stability of earth dams and to simulate the impacts of the considerable factors that assumed to have a part of the dam’s slop stability soundness. Geo-studio software is considered as one of the commonly geotechnical software has been used for the analysis of slope stability and it is based on the finite element analysis. SLOPE/W is a branch of Geo-studio software is used under different conditions to evaluate slope stability [20].

2. Case Study

2.1 Description of Study Area

Hemren dam locate in the northwestern part of Iraq, about 150 km from the Baghdad city within Diyala governorate as shown in Figure 1. The main goal of the dam is flood management, irrigation and hydroelectric generation. The dam and the attached power house were built in years 1976-1981. The reservoir of Hermren dam has a full–pool operating altitude of 92 m above mean sea level and its boundaries extend between a latitude of 25º61' 34º14' N and a longitude of 30º12'- 44º09'E. The volume of water that stored by Hemren dam is 2.06 billion cubic meters with a surface area of about 327 km^2 at high level period. Figure 2 shows the cross section of Hemren dam [21].

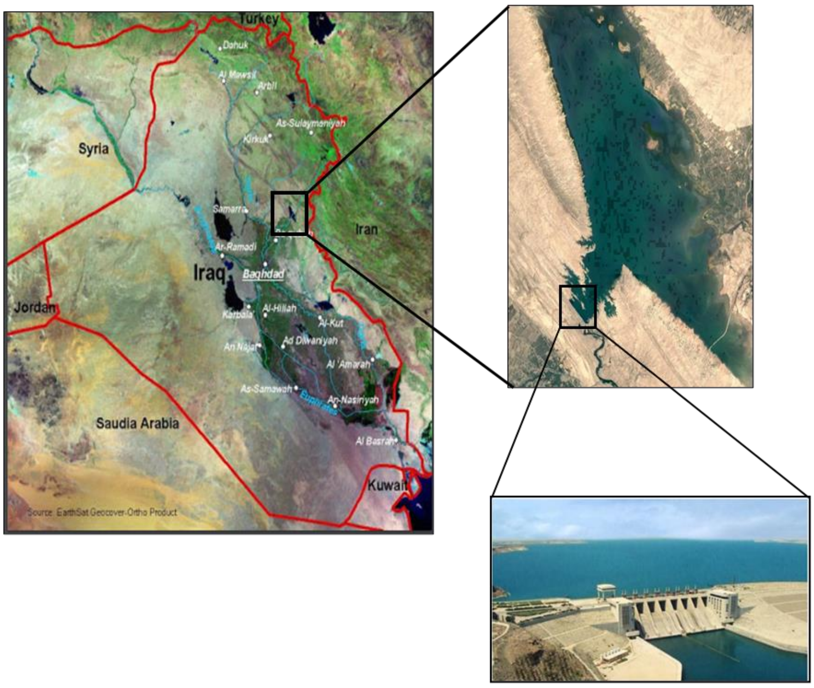


Fig. 1. Location of Hemren dam

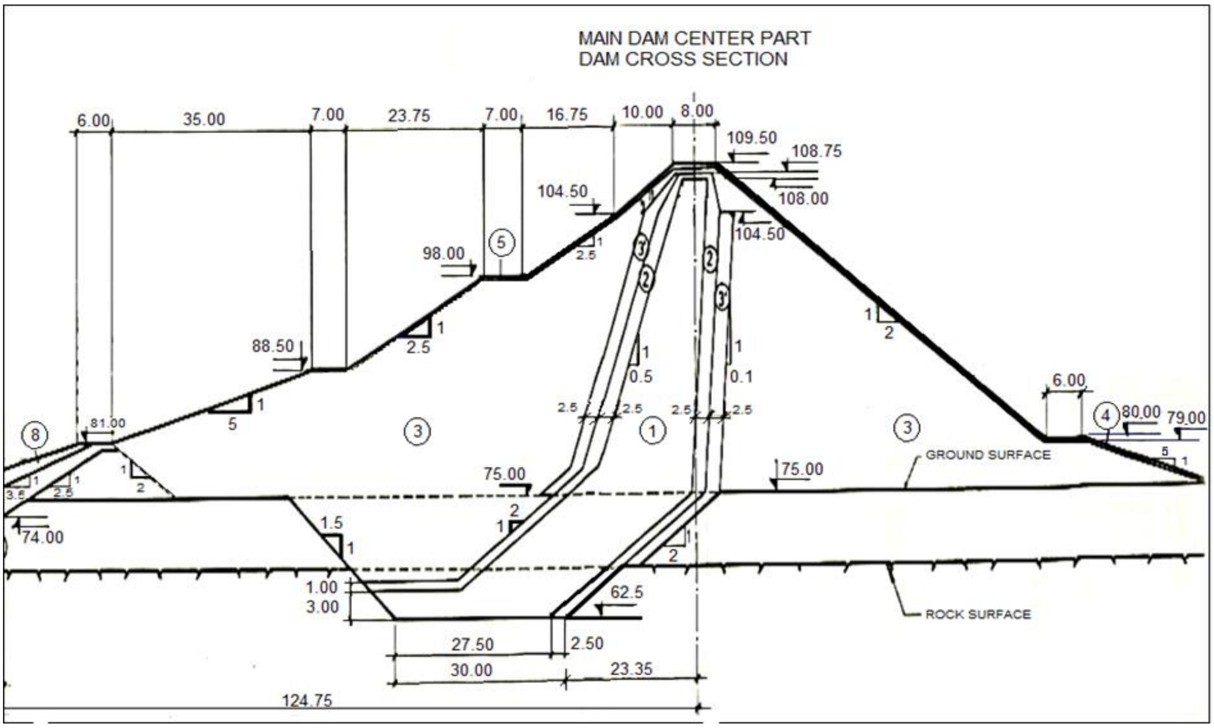


Fig. 2. Cross section of Hemren dam

2.2 Material Properties

The usual standard parameters of the materials that utilized in the dam body which are usually must be introduced to the numerical model and represent as material characteristics for selected case study are listed in Table 1.

Table 1
Material properties of Hemren Earth Dam

Layer properties	Shell layer	core layer	Foundation layer	Filter layer
Bulk density (kPa)	25	17	25.5	20
Φ (degrees)	33	18	35	28
C (kPa)	0	12	0	0
k (cm/hr)	6	$0.8*10^{-3}$	6.5	5

where Φ is angle of soil internal friction, C is the soil cohesion and k is the coefficient of permeability.

3. Methodology
3.1 Geo-Studio Software

Geo-studio software is a geotechnical program that based on the finite element scheme and can achieve studies, such as strain-stress, leakage, the stability of the slope, and dynamical investigation. It includes five sub-model namely SLOPE/W, SIGMA/W, QUAKE/W, TEMP/W and CTRAN/W. In this study, SLOPE/W and QUAKE/W were used [22].

3.2 Program SLOPE/W

A part of the well-known complete suite geotechnical products GeoStudio is SLOPE/W. The ability of analysis and presentation of wide range of complicated problems, which includes utilizing of finite element, computed pore-water pressures and stresses in a stability analysis make this part as one of the powerful aspects of this integrated approach. The integrated approach is not just expanding the analytical capability, but it helps to get control of some restriction of the purely limit equilibrium formulations. In spite of it is not essential to utilize these advanced features, there is certainly an enhancement in the analytical ability as SLOPE/W may be utilize as a singular product by utilizing it as a part of a full suite of geotechnical software program. SLOPE/W was designed and developed in order to be a general software tool to analysis and evaluation of the stability of earth structures. In additionally, the SLOPE/W software can be utilized to analyses and evaluate the wedge stability of a soil that has been reinforced with a structural element such as a pre-stressed anchor, a soil nail, geo-fabric or some other techniques and material [23].

3.3 Program QUAKE/W

QUAKE/W is a geotechnical finite element software that is a part of the well-known complete suite geotechnical products GeoStudio which is utilized for the dynamic analysis of earth structures exposed to earthquake and other instant impact loading. According to QUAKE/W is component of GeoStudio, it is fully incorporated with the other GeoStudio parts such SLOPE/W, SEEP/W, SIGMA/W. GeoStudio remarkably widen the sort and scope of issues that may be analysed. It goes beyond what may be made with other geotechnical dynamic analysis software due to incorporation of QUAKE / W and other products within GeoStudio. QUAKE/W may be utilized as a solo and independent product, but one of its essential desirability is the incorporation with the other GeoStudio products that give gives it a great advantage as a result of this integration with the rest GeoStudio products [24].

3.4 Numerical Modeling

Dynamic numerical modelling has been performed using three components SIGMA/W, QUAKE/W and SLOPE/W, in a full suite of geotechnical products named GeoStudio [25]. Dynamic analyses are done by utilizing QUAKE/W to evalute the dynamic stress conditions and are keyed in to SLOPE/W to evalute the factor of safety. During the analysis the FEM nodes keep records of information about the stresses. During dynamic analysis the nodes will contain dynamic stresses and static stresses. The relationship between the dynamic and static stresses is given by Eq. (1). The dynamic stresses are evaluated in QUAKE/W utilizing the following formulation.

$$\sigma_{dynamic} = \sigma - \sigma_{static} \tag{1}$$

where $\sigma_{dynamic}$ is dynamic stress, σ_{static} is static stress and σ is the total stress (static+dynamic) acting at a point. The factor of safety (F.O.S) is defined as

$$FOS = \frac{\sum S_r}{\sum S_m} \tag{2}$$

where Sr is the total available shear resistance and Sm is the total mobilized shear stress along the entire length of the slip surface. Dynamic stress levels for maximum and minimum earthquake accelerations have been computed and then keyed into SLOPE/W to evaluate a factor of safety. The modelling methodology adopted in GeoStudio is given in Figure 3.

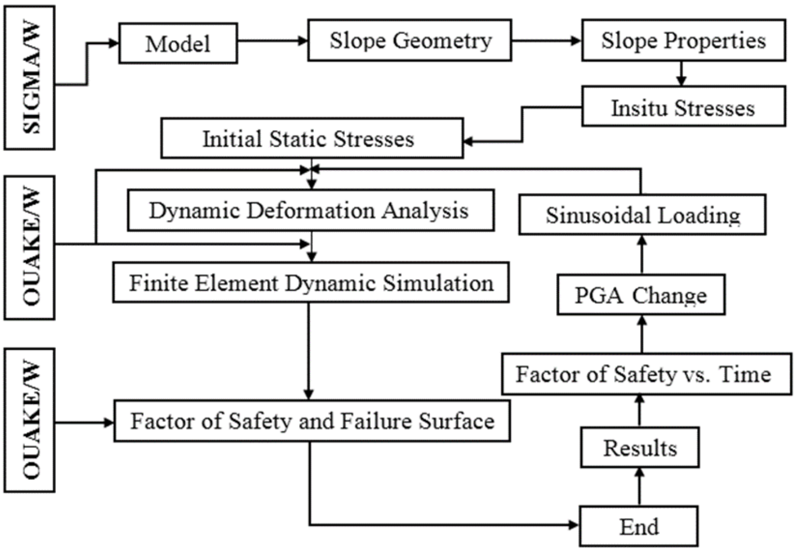


Fig. 3. Methodology of Numerical Modeling

The governing motion formulation utilized by Geo Studio software for dynamic response of a system in finite element may be represented as

$$[M]\{\ddot{a}\}+ [C] \{\dot{a}\} + [K] \{a\} = \{F\} \tag{3}$$

where [M] is mass matrix, [C] is damping matrix, [K] is stiffness matrix, {F} is vector of loads, {ä} is vector of nodal accelerations, {ȧ} is vector of nodal velocities, {a} is vector of nodal displacements.

In this research analyze Hemren zoned earth dam constructed by impervious core, filter, shell and foundation. The height of dam was 34.5m, we take different water levels (34.5, 30, 25, 20, 15, and 10) m to find slope stability factor for upstream and downstream. Figure 4 shows the three that selected as a key point to calculate the displacement. These points considered as key points of dam construction material where point (1) represent the represent the dam core material, point (2) represent the foundation material and point (3) represent the shell material. The displacement and pore water pressure was measured in X-and Y direction with different values of acceleration (g). Figure 5 shows the finite element mesh of Hemren earth dam.

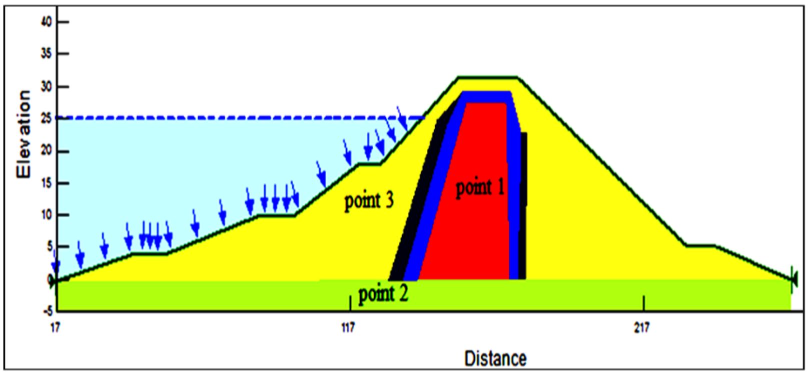


Fig. 4. Key points on Hemren earth dam body

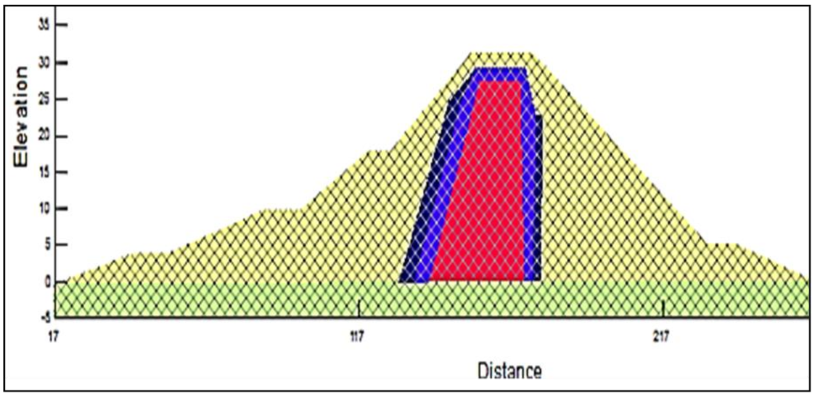


Fig. 5. Finite element mesh of Hemren earth dam

4. Results and Discussion

4.1 Slope Stability

Various water levels were considered in this research in order to obtain slope stability factor in upstream and downstream of Hemren earth dam as shown in Table 2.

Table 2
Factor of Safety (FOS) for Hemren earth dam

Water Level	FOS at Upstream	FOS at Downstream
34.5	4.69	1.592
30	2.9	1.726
25	2.559	1.62
20	2.3	1.559
15	4.337	1.559
10	4.228	1.559

Level 34.5m is the overtopping level, 25m is the spillway level (maximum working level), 30m is the level between the overtopping level and maximum working level, 10m is the empty level, 15m and 20m are the dam operation levels.

It can be noted that when the water level increased from 15 m (the initial operational level) to 20 m the factor of safety decrease from 4.337 to 2.3. This decreasing in the factor of safety is according to the initial water flow through the dam that decrease the angle of soil internal friction Φ in dam upstream construction material. After that and when the water level is continue increasing up to 34.5 the factor of safety is continue increasing. It is clear as presented in Table 2 that the factor of safety increase with increasing water depth because according to the slope stability formula Eq. (4) below, the increasing in cohesion was achieved by increasing the volume of submerged soil. In (10 and 15) m water depth for the upstream, there is an increasing in the factor of safety more than other depths because the increasing of the dry part more than the wet part.

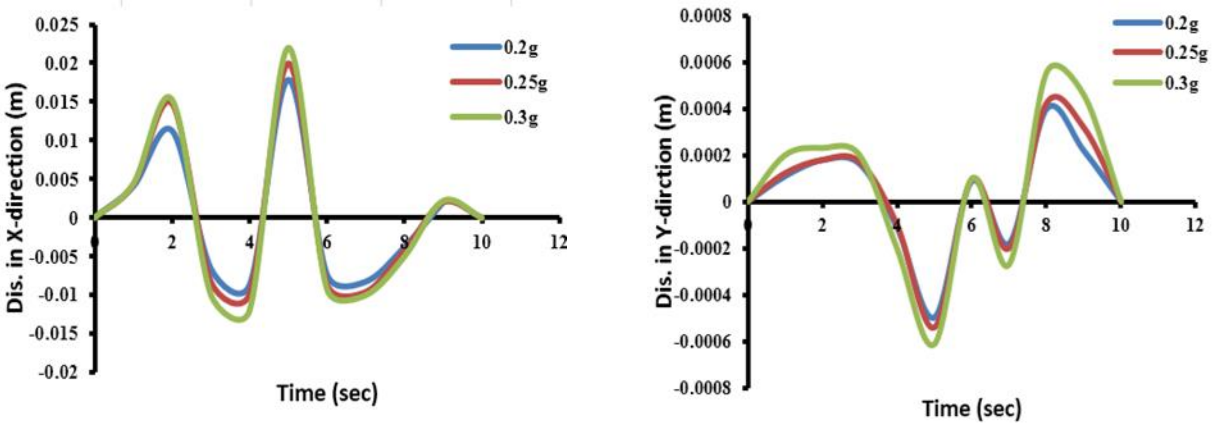
$$F.S=(\tau_f\ /\tau)=(C'/\ \gamma.\ Z\cos\beta.\ \sin\beta) \tag{4}$$

where τ_f is the maximum shear stress which the soil can afford at the magnitude of normal stress of σn, τ is the actual shear stress applied to the soil. C' is the cohesion, γ is effective unit weight, Z is the depth of soil and β is angle of slope. This finding agreed with [16, 17, 18, 19].

4.2 Displacement

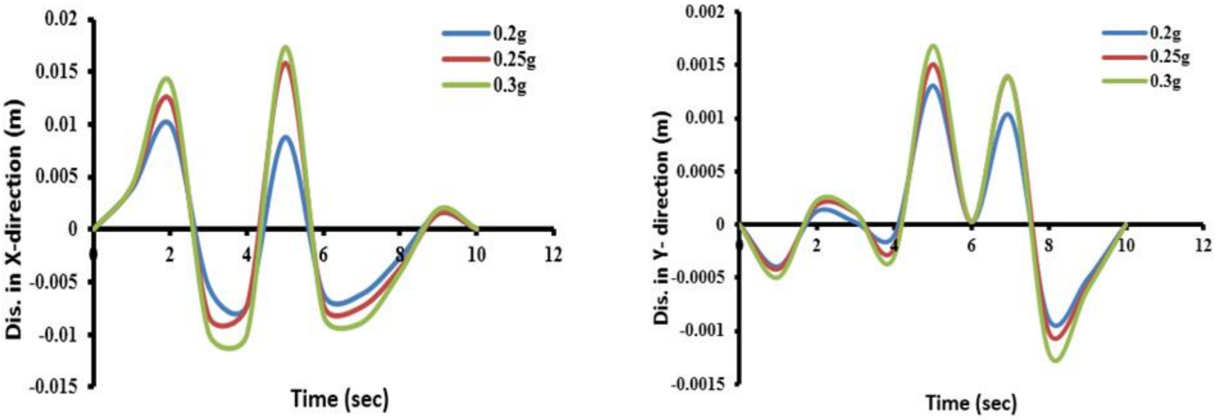
Figure 6(a) and 6(b) shows the resulted displacement due to the excited earthquake for core (point 1). Figure 7(a) and 7(b) show the resulted displacement due to the excited earthquake for foundation (point 2). Figure 8(a) and 8(b) shows the resulted displacement due to the excited earthquake for shell (point 3).

It is clear that the peck ground acceleration increases the expected displacement for the three points, and the rate percent of such increasing for these points from 0.2 to 0.3g calculated depending upon the maximum reported values. It can be also noticed that the displacement in x – direction illustrate generally more levels than those of y – direction due to the nature of the exciting earthquake load. In addition, the Y – displacement in point have the maximum rate of increasing in point 1 which represents a noticeable hazard indicator for the earth dam crest cone.



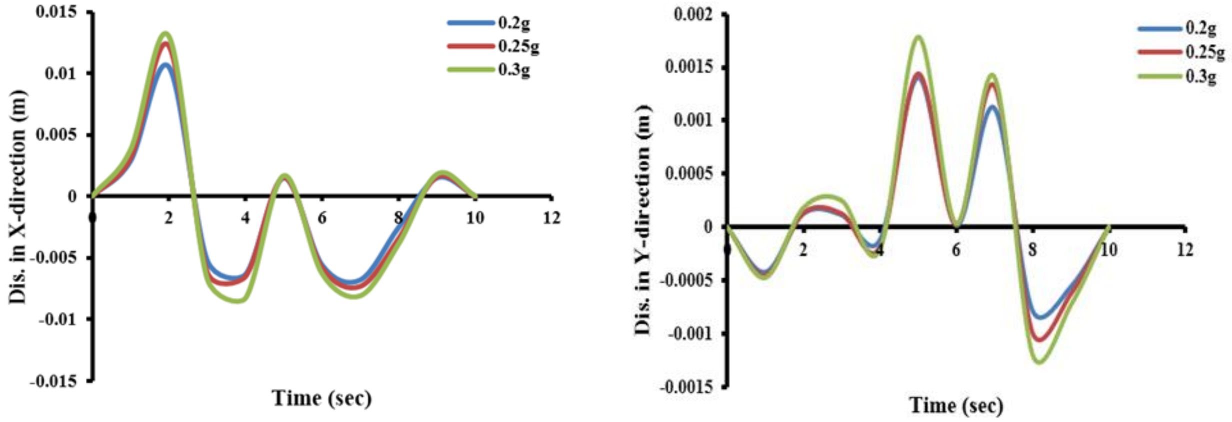
(a) (b)

Fig. 6. Calculated displacement in X and Y direction in the core



(a) (b)

Fig. 7. Calculated displacement in X and Y direction in the foundation

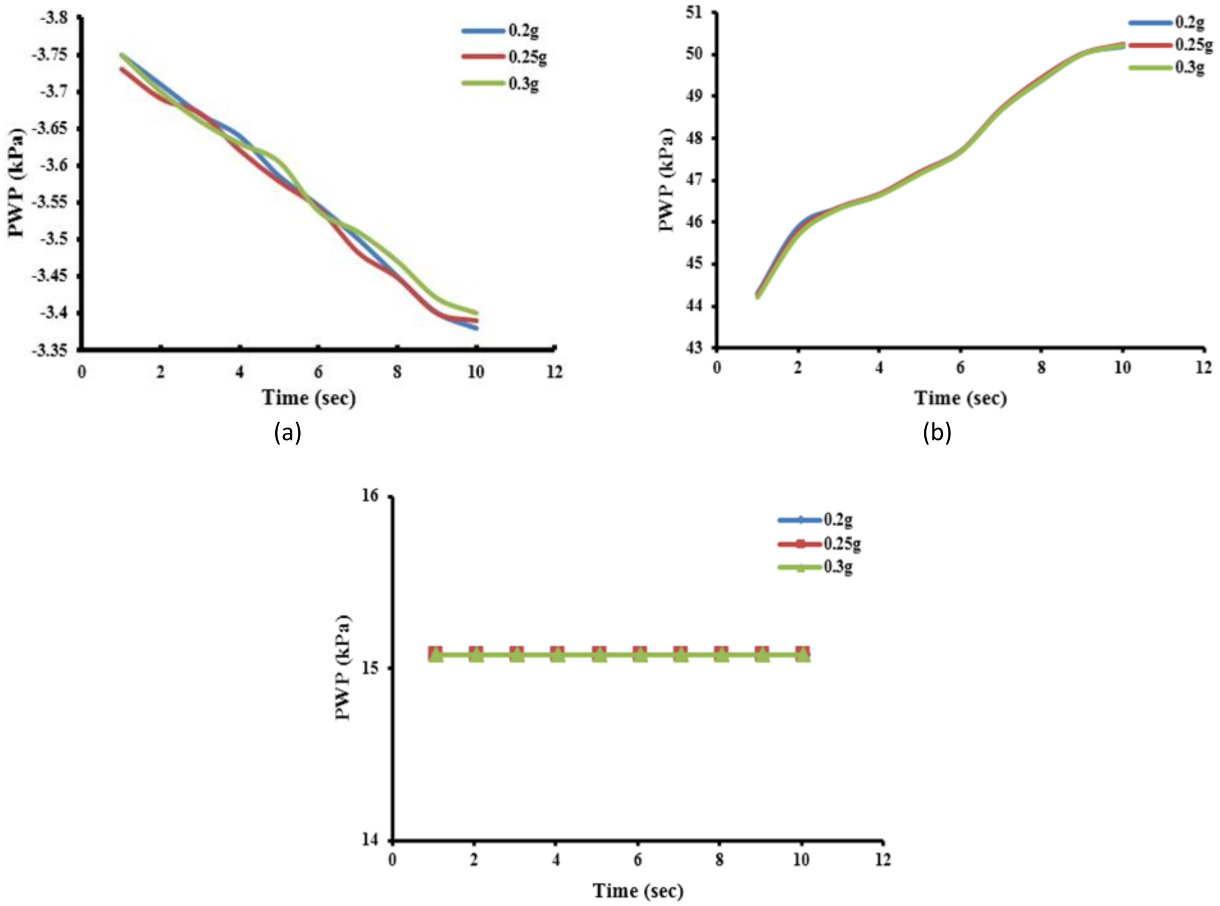


(a) (b)

Fig. 8. Displacement in X and Y direction in the shell

4.3 Pore Water Pressure

Pour water pressure development at points 1, 2 and 3 respectively are shown in Figure 9. Actually, since the inherent position of point 1 is located within the negative pore water pressure zone, increasing the positive pore water pressure potential dictated by the earthquake inhibit the negative phase of such pressure for the current point as shown in Figure 9(a) while the positive phase increment is evident in point 2 due to the same reason as in Figure 9(b). On the other hand, no effect is evident for increasing the peck ground acceleration within the 10 seconds, however, this effect may be appeared if the time of analyses takes longer values as reported in the literature. This dictates further research taking into accounts if a considerable can be recognized if the duration of the earthquake is more than 10 seconds.



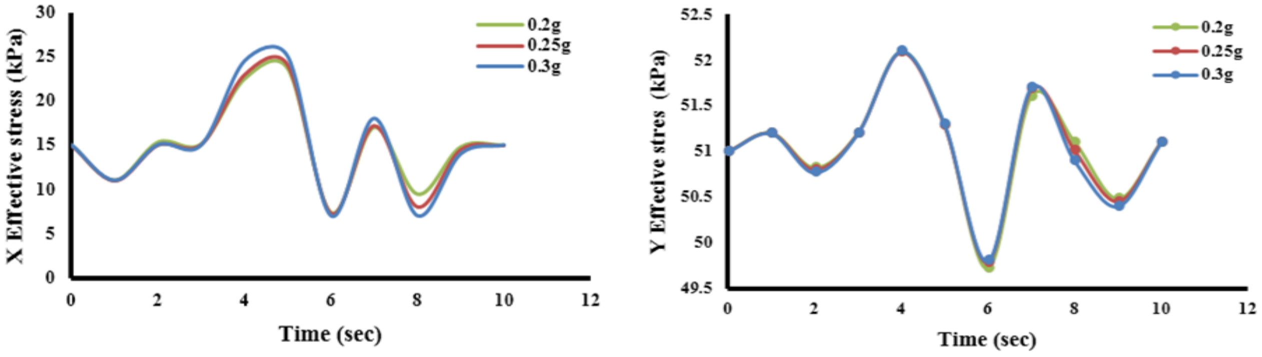
(a) (b)

(c)

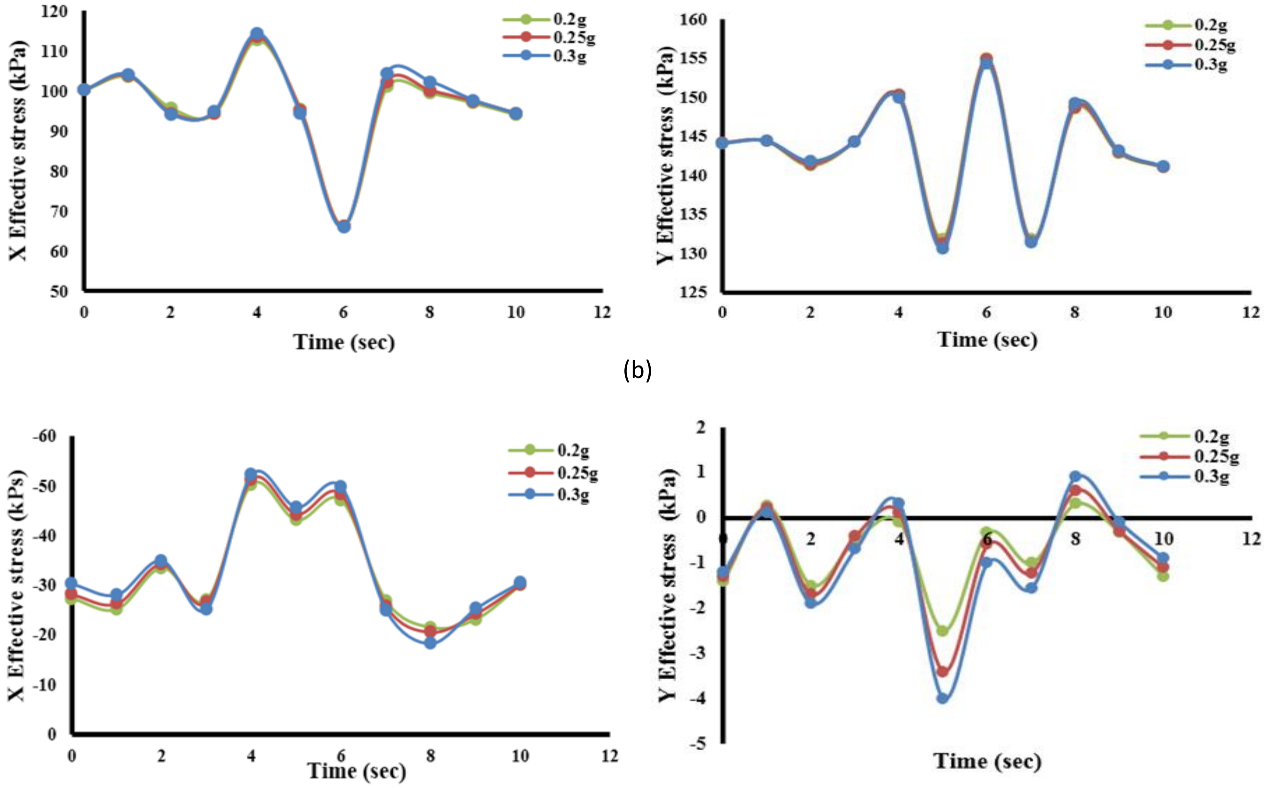
Fig. 9. Pore-water pressure at (a) point 1, (b) point 2, (c) point (3)

4.4 Effective Stress

The induced effective stresses in the selected points were shown in Figure 10. It can be recognized in Figure 10 that for points 2 and 3, the x effective stress levels tends to be more than those of y stresses. This behavior is expected due to the nature of the excited loads that are lateral inherently. On the other hand, such behavior does not exist for point 1 because it is located within a negative pore water pressure zone.



(a)



(b)

(c)

Fig. 10. Effective Stress at (a) point 1, (b) point 2, (c) point (3)

5. Conclusion

The following are some conclusions that can be included through this study.

i. For both U/S and D/S sides, the factor of safety of slope stability was increase with increasing of water depth.
ii. The factor of safety with (10 and 15) m water depths are increase more than other water depths.
iii. Due to the inherent mechanical properties of the dam construction materials, the response of displacement to the peak ground acceleration is high compare to the response of effective stress.
iv. There is no clear effect on the value of pore water pressure when the peak ground acceleration was increased to 10sec.
v. The negative pore pressure at the top of the dam has to be decreased due to the earthquake exciting to balance the excess potential of such pressure.

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