Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.4, No.3, pages: 39-49

Effect of Seismic Load on the Stability of Earth Dam Reinforced with Geosynthetic Material

Mohammad Hossein Khiyabani [1]***, Rouzbeh Dabiri*** [2*]

[1] *M.Sc. of Geotechnical Engineering, Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.*

[2*] *Assistant Professor, Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.*

(rouzbeh_dabiri@iaut.ac.ir)

(Date of received: 01/05/2022, Date of accepted: 22/09/2022)

ABSTRACT

Earth dams are sometimes built with large dimensions in order to produce electrical energy, control floods, supply drinking water and agriculture, etc. The failure of earth dams also causes irreparable economic and human losses, which increased the importance of designing and strengthening dams. The stability of earth dam mainly depends on the shear strength of the soil, and this resistance in earth dams is provided by the friction between soil particles. The greater the angle of internal friction between soil particles, the more the shear resistance of soil improves. As a result, the stability of dam increases. The issue of increasing the shear strength in the soil with using geosynthetics in the earth dam is the main goal of this research. The effect of geosynthetics and their arrangement, placement distance from each other, length, and materials used, including cohesion, unit weight and internal friction angle are the main research variables. In this research, by using geotextile in the earth dam body, the stability and safe and economical design of the dam in static and dynamic state under seismic load has been evaluated. For this purpose, Plexis software has been used.

Keywords:

Earth dam, Geosynthetic, Static loading, Dynamic loading, Stability analysis.

1. Introduction

Due to Iran's location in the arid and semi-arid region of the world and the country's need for growth and development, water, productivity policies in the water industry have been prioritized in the country's plans and purposes. One of the best ways to achieve this aim is water storage and proper productivity, which can be achieved by constructing earth dams. Considering the very high volume of earthworks related to the construction of earthen dams, as well as the economic losses and loss of life due to the failure of such structures, the importance of designing and safety of these types of structures and the lack of financial resources are becoming clearer. For this purpose, in the present research, the stability and safe and economical design of earthen dams using geotextile has been investigated. In general, it can be explained that the greater the internal friction angle between the soil particles, the more shear stress is tolerated by the soil and the stability of the dam increases. Geotextiles are synthetic materials and polymer elements that increase the mechanical resistance and load-bearing capacity of the material by placing them between soil particles. In order to increase the level of stability of dams and to further stabilize the upstream and downstream of the dams, they are used against earthquake and landslide damages [1]. Soil resistance is the most important factor in slop stability in earth dams. The problem of increasing the shear strength in coarse-aggregate soils with the help of geotextiles is the main goal of the present research. In which the effect of the type of geotextiles and their arrangement including the distance of the geotextiles from each other and the lengths of them in the soil are the main variables of the research. On the other hand, every year due to the happening of earthquakes, many human and financial losses are caused due to land slide in different regions of the world. Also, the location of Iran in seismic zone, the need to carry out various constructions in the vicinity of natural slopes, doubles the attention to the factors affecting the seismic stability of the slopes. Therefore, due to the importance of natural slopes, the effect of seismic loads on its stability is extremely important.

2. Literature Review

Nowadays, soil reinforcement is used as an effective and reliable technique to increase the strength and stability of soil masses. This method is used in various works such as stabilization of layers inside earth dams and under shallow foundations and pavement design. The new concept of reinforced soil was introduced by Henri Vidal in 1966. He used wide metal strips between layers of dense soil. The method of soil reinforcement in the stability of slopes is mainly based on the mutual effect of friction between soil and reinforcement elements [2]. The development of the using polymer products in embankments has led to the production of geotextiles, which are widely used in the reinforcement of embankments due to their many advantages. In a reinforced soil structure, there is often a lower tensile stress in the soil, therefore more stability is provided in the embankment, and since polymer reinforcements are also effective in the non-linear range of the stress-strain diagram, due to the strain tolerance, they do not break suddenly at one point and can show a lot of lateral deformation [3]. In general, because geotextiles produce a large friction area and have good drainage properties, therefore it can be used in coarse-soil particles [4]. These polymer or synthetic fabrics are more compatible with soils due to their low hardness. In addition, fabrics are more permeable and resistant to corrosion and are resistant to degradation, bacterial and acid attacks, and are non-toxic [5, 6 and 9]. Approximately 75% of the large dams built in the world are earthen. Today, earth dams have an increasing role in controlling ground water compared to concrete dams. Reinforced earth dams have advantages such as reducing the movement of soil particles, reducing the volume of embankments in the upstream and downstream areas, increasing the reliability coefficient of the stability of the upstream and downstream zone, speed in construction, flexibility during earthquakes, and the possibility of constructing a small head on They have on the crown in dam [10]. Considering the above advantages, since the early 1980s, many measures have been taken to use reinforced earth dams, which are mentioned in some practical examples of them that were built for different purposes. Reinforcing materials can be used to repair earth dam. An example of their use is in the Jamesville Dam in New York. The studied dam, which was facing erosion in the upstream part, was repaired with using reinforced materials. After the compaction of the previous face, reinforcing materials were added to that face of the dam to decrease the risk of erosion in the upstream area and maintain the stability of the dam [11, 8]. Another advantage of reinforced earth dams is the possibility of making a spillway on the crown of the dam. Therefore, instead of constructing a concrete spillway separate from the main body of the dam, the spillway can be implemented on the dam itself. For example, in the Estella Dam, which is 29.5 meters high and reinforced in France, the downstream of the dam is completely vertical and the spillway is built on the dam itself. In addition to saving cement consumption, this will reduce the volume of earthworks and eliminate the issue of covering and protecting downstream. In addition to the construction of the main body and side structures of the dam, an important issue in dams is the protection of the cover of the upstream and downstream slopes. In some cases, if the downstream side can be constructed vertically, a large amount of earthworks can be reduced and the problem of downstream protection will be solved, and there is no need to implement concrete cover. Therefore, the use of reinforced earth dams can save cement consumption and ultimately be effective in the design economy [12, 7]. The largest reinforced earth dam ever made is the Taylor Draw Dam, which was built in the city of Colorado in the United States in 1995. The length of the crown is 380 meters and the flow rate that can pass through its spillway is 1850 m3/sec. The construction of this dam using the reinforced method has saved about 1.5 million dollars compared to the construction of the common earth dam. In general, the construction of a reinforced earth dam can sometimes reduce costs by about 40% [13-14]. An example of a reinforced earth dam application is the Sherburne Dam in Montana, USA. After increasing the height to 7 meters with the help of reinforced elements, this dam was able to contain about 200 million m3 of water according to the length of the crown of 350 meters. In this project, the use of reinforced soil method resulted in saving about 35% in costs [15].

3. Numerical Analysis Method

In present study, for evaluating geosynthetic material effects on stability of earth dam under dynamic load due to earthquake, cross section models proposed in Figure 1. The geometric characteristics and materials of Alaviyan earth dam are considered in PLAXIS software model. Geotextile selected as a geosynthtic material in this research. Geotextile layers properties is seen in Table 1. Geotextile layers effects in two conditions have been assessed and replaced in slope of upstream in earth dam body. Mohr-Coulomb constitutive model used for material behavior in numerical analysis. Acceleration of Elcentro earthquake spectrum used for dynamic analysis. As seen in Figure 2, dynamic loading has been done in three different points of the numerical model. In analysis of per three points, The effect of the lack and placement of geotextile in two cases (distances of 5 meters and 10 meters from each other) and their effect on changes in effective stress, pore water pressure, and horizontal displacement center the core and the slope have been investigated.

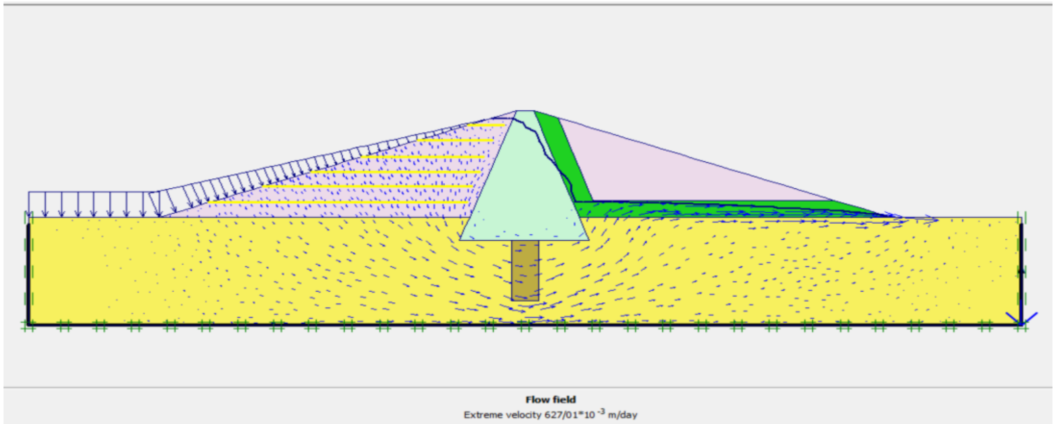

Figure 1. The section of earth dam in present study.

Table 1. Properties of geotextile layer in present research.

Positions	Height in maximum length of geotextile (m)	Height in minimum length of geotextile (m)	Maximum length of geotextile (m)	Minimum length of geotextile (m)	Distance of geotextile each other (m)	Elastic modulus (KN/m)
1	75	135	151	8	5	20
2	80	130	40	19	10	20

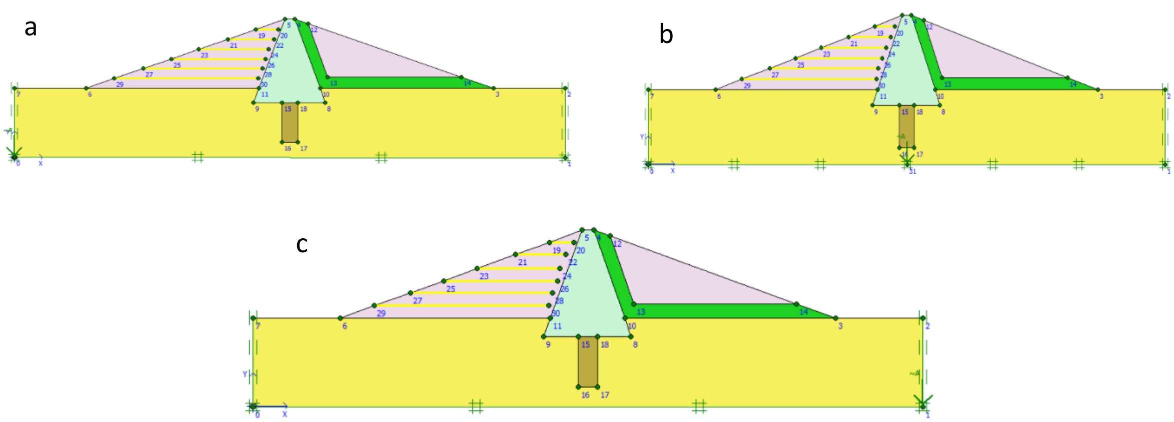

Figure 2. Effects of earthquake loading on earth dam with geotextile layers, a: upstream, b: below the core of earth dam, c: downstream.

4. Results

4.1. Clay Core Behavior

4.1.1. Horizontal Displacement in Center of the Clayey Core

The value of horizontal displacement in the center point in the clay core in earth dam while geotextile layers are used, under dynamic loading conditions in the three studied points can be seen in Figure 3. According to diagrams, it can be explained that graphs almost have a displacement trend. In the upper parts of the dam, the clay core has shifted to the upstream, and then at one point the displacements have become zero and moved again to the inside of the clay core. Due to the proximity of the lower parts of the clay core to the place of dynamic load effect, the maximum displacement occurred almost in the center of the height of the clay core, and by reducing the distance of the geotextiles, the displacements were reduced significantly.

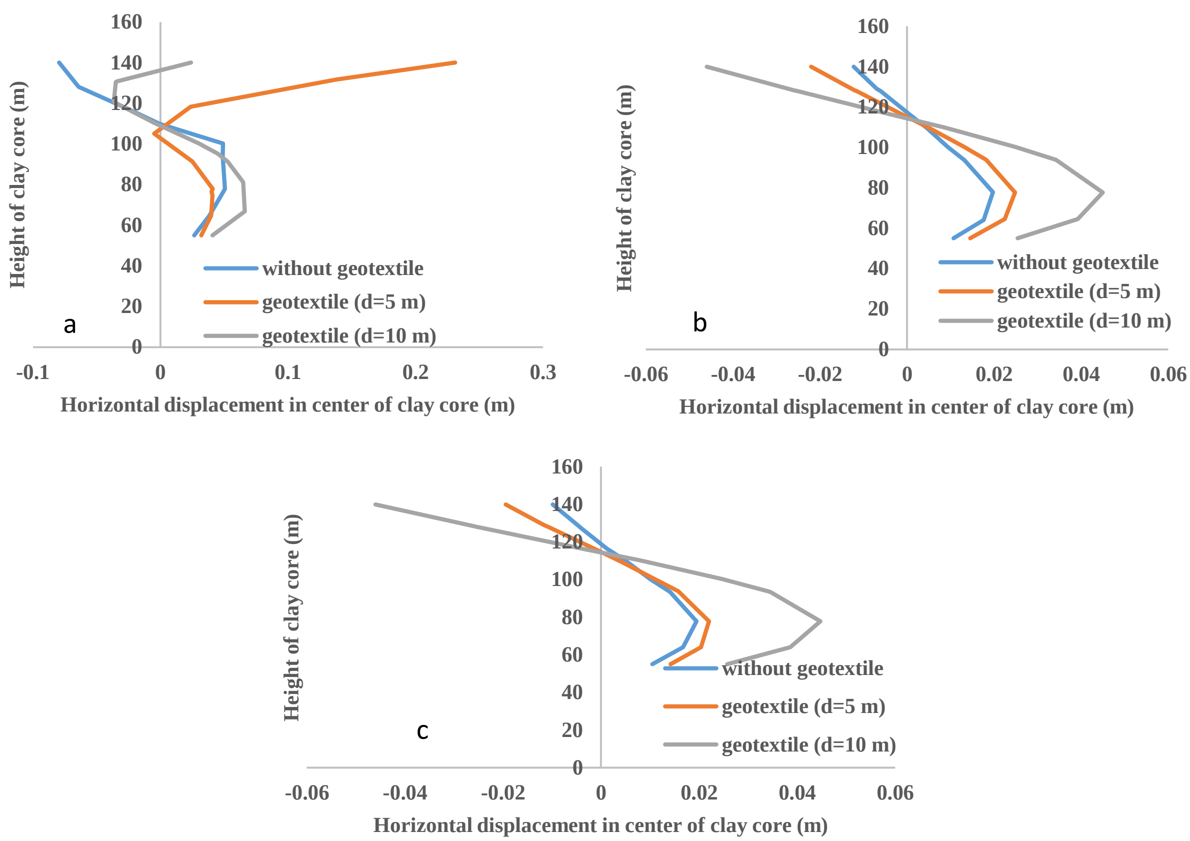

Figure 3. Effects of earthquake loading on horizontal displacement in clay core of earth dam with geotextile layers, a: upstream, b: below the core of earth dam, c: downstream.

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.4, No.3, pages: 39-49

4.1.2. Pore Water Pressure in Center of the Clayey Core

The pore water pressure in the center point in the clay core in earth dam while geotextile layers are used, under dynamic loading conditions in the three studied points can be seen in Figure 4. According to the diagrams, it is clear that the pore water pressure has increased with growing depth. Also, existing or lack of geotextile in the body of the earthen dam, there is no effect on the changes in pore water pressure, and in all three cases, the graphs have matched.

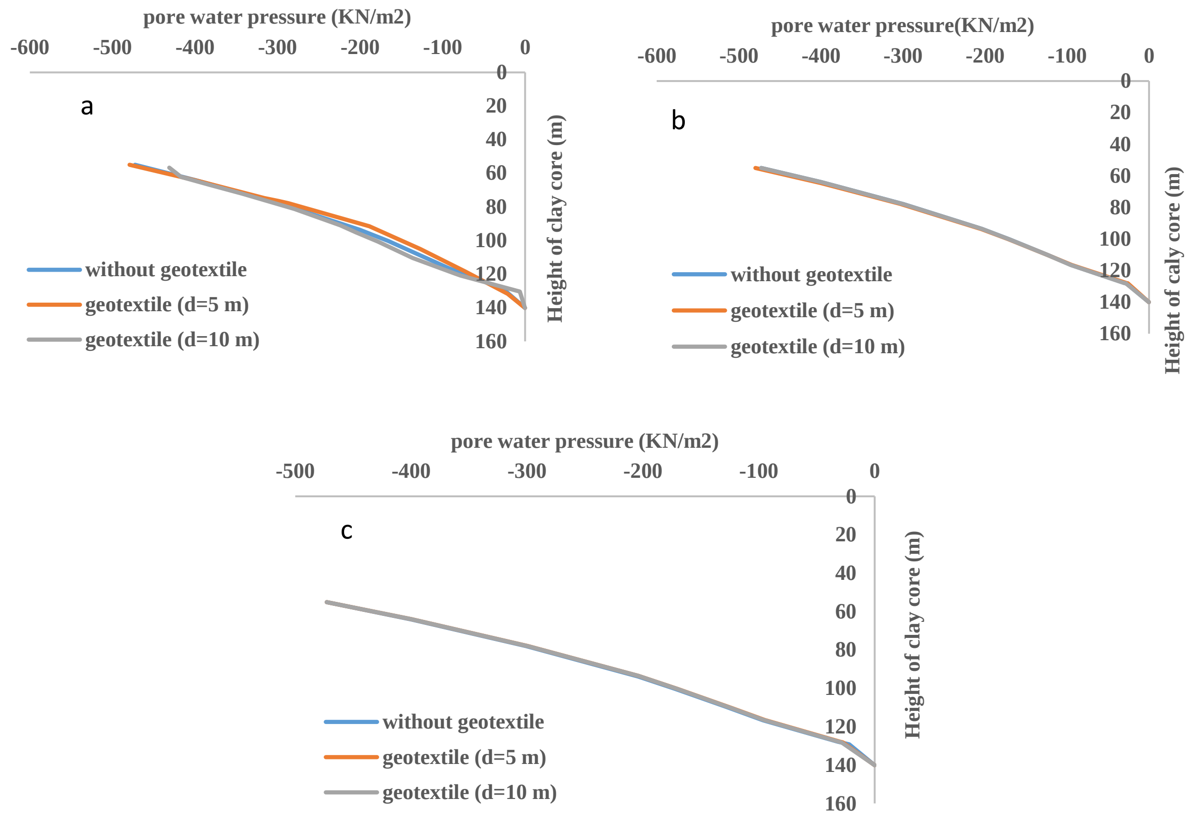

Figure 4. Effects of earthquake loading on pore water pressure in clay core of earth dam with geotextile layers, a: upstream, b: below the core of earth dam, c: downstream.

4.1.3. Variations of Effective Stress in Center of the Clayey Core

The effective stress variations in the center point in the clay core of earth dam with geotextile layers in upstream, under dynamic loading conditions in the three studied points can be seen in Figure 5. According to the graphs, it is clear that the effective stress increases with depth, and according to the compatibility of the graphs in all three selected loading points and the use of geotextiles in the upstream slope of the earthen dam, it is clear that the presence or absence of geotextiles has no effect on the stress changes.

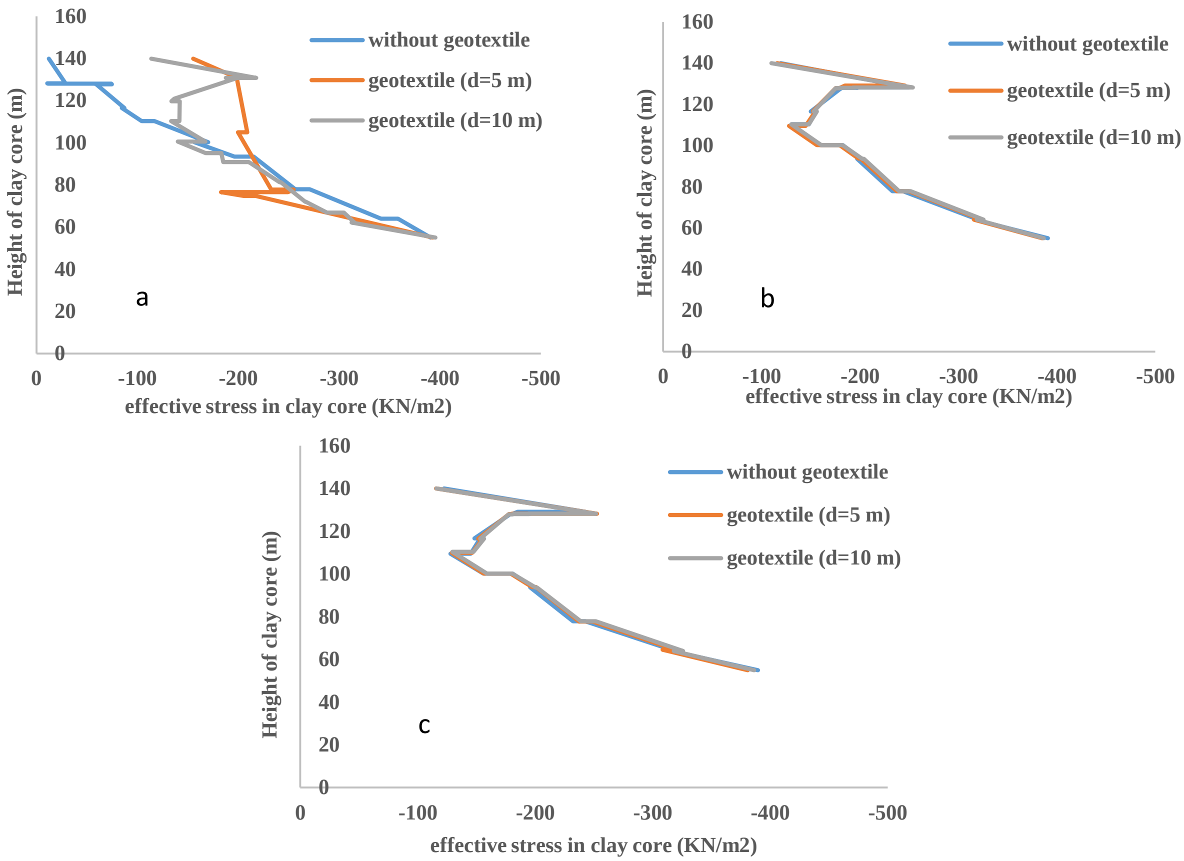

Figure 5. Effects of earthquake loading on effective stress in clay core of earth dam with geotextile layers, a: upstream, b: below the core of earth dam, c: downstream.

4.2. Upstream Slope Behavior

One of the important issues in the present research is the investigation of the effect of geotextile layers on the stability of upstream slope in earth dam, which is discussed below.

4.2.1. Lateral Displacement of Upstream Slope

It should be mentioned that at this stage, dynamic loading was done in the numerical model at two downstream and upstream points and the results were presented in Figure 6. According to the presented diagrams, it can be seen that the deformation process is the same in both loading points. So, at first the amount of displacements increases and then it reaches zero at one point. In the following, it increases again and gradually decreases significantly in the depth of displacements. The remarkable point of these two figures is that, the amount of displacement when dynamic loading is applied downstream, with the presence of geotextiles with 5 meter distances from each other, has the highest value compared to the other cases.

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.4, No.3, pages: 39-49

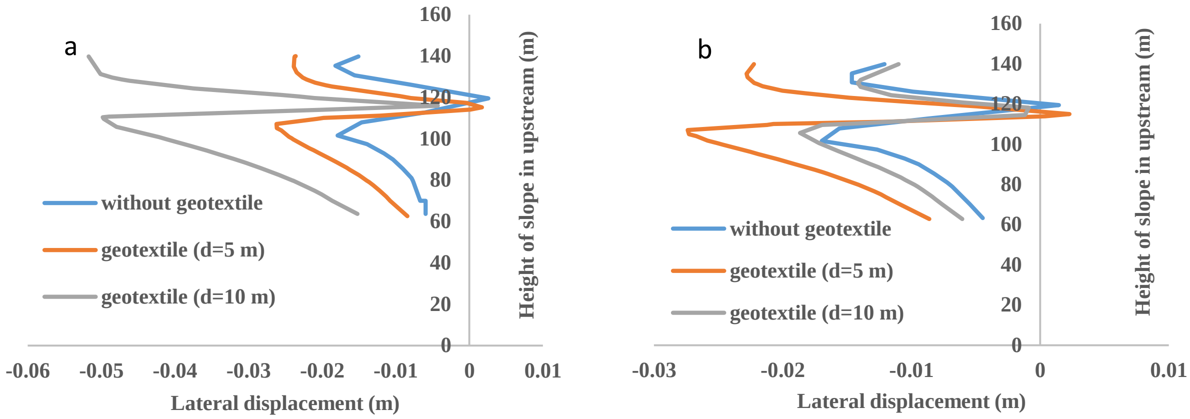

Figure 6. Effects of earthquake loading on lateral displacement in slope of upstream in earth dam with geotextile layers, a: upstream, b: downstream.

4.2.2. Vertical Displacement of Upstream Slope

According to the figures, it is clear that the vertical displacement of the slope decreases significantly with the increase of the horizontal distance from the clay core wall and approaches zero. The deformation process is the same in both loadings, but the significant point is that the amount of vertical displacement in the case where the geotextiles are located at a distance of 5 meters from each other is more than the other cases (the vertical displacement has increased by decreasing the distance of the geotextiles).

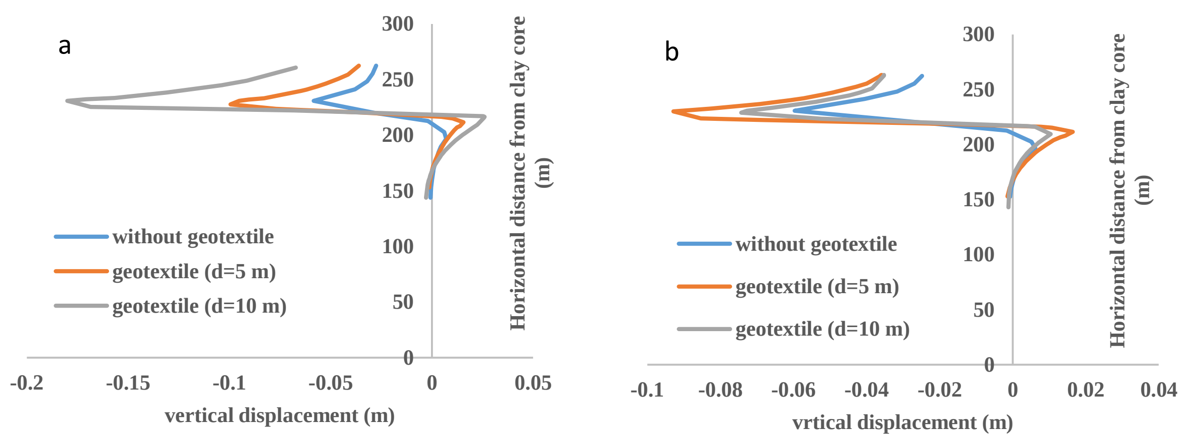

Figure 7. Effects of earthquake loading on vertical displacement in slope of upstream in earth dam with geotextile layers, a: upstream, b: downstream.

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.4, No.3, pages: 39-49

4.2.3. Variation of Pore Water Pressure in Upstream Slope

As it is clear from the Figure 8, the roof pore water pressure increases with increasing depth in both dynamic loading and geotextile placement situations, and the compatibility of the graphs shows that the presence or absence of geotextile has no effect on these changes.

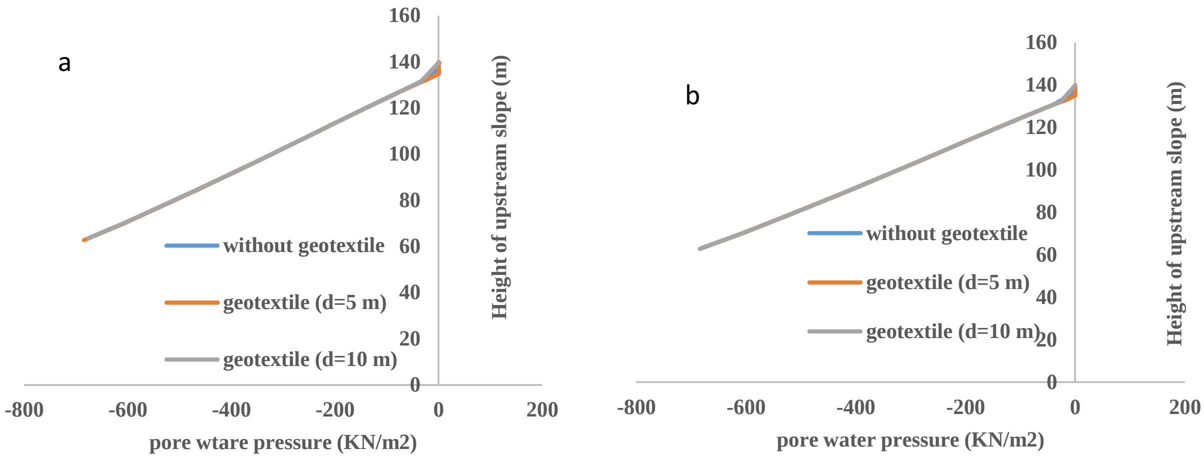

Figure 8. Effects of earthquake loading on pore water pressure in slope of upstream in earth dam with geotextile layers, a: upstream, b: downstream.

4.2.4. Variations of Effective Stress in Upstream Slope

According to the diagrams, it can be seen that the effective stress changes are more in the upper parts of the gable, and the diagrams are slightly different, but from a height of approximately 100 meters down, the stress changes are almost uniform, that is, it increases with a certain slope, which can be solved justified by increasing the horizontal distance from the clay core wall. Also, from this height onwards, the compatibility of the graphs shows the lack of effect of geotextile layers on stress changes.

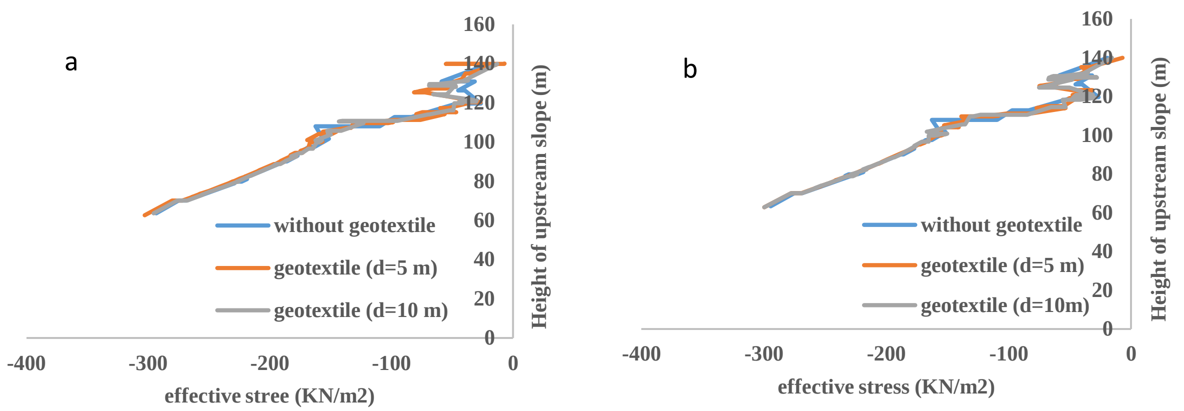

Figure 9. Effects of earthquake loading on effective stress in slope of upstream in earth dam with geotextile layers, a: upstream, b: downstream.

5. Conclusions

In general, results of present research can be explained in below:

1- The horizontal displacement of the clay core in the upper parts of the dam is towards the upstream slope and then moves to the inside of the core.

2-According to the location of the effect of dynamic load in the second type of loading, which is below the core, the maximum displacement of the core occurs almost in the center of the height of the core and decreases with the reduction of the displacement depth.

3- By reducing the horizontal distance of the geotextiles, the horizontal displacement of the clay core is significantly reduced.

4- By examining the changes in pore water pressure in the middle of the clay core and also in the slope, it was found that the pore water pressure increases with depth in all loadings and in all cases.

5- Examining the effective stress changes in the clay core shows that the effective stress in all geotextile loads and states increases with depth and the matching of the graphs shows that the geotextile has no effect on the effective stress changes.

6- The horizontal displacement of the slope is gradually reduced in depth, and the vertical displacement of the slope decreases significantly with the increase of the horizontal distance from the core wall.

7- In dynamic loading in the downstream, unlike other loading conditions, it was observed that the horizontal and vertical displacement of the slope is more when the geotextiles are located at a distance of 5 meters from each other.

8- By examining the effective stress changes of the slope, it was found that the variations of the effective stress changes is more in the upper part of the slope, and after a certain depth, the effective stress in all loadings and different states of the geotextile increases almost similarly.

6. References

[1]- Fellenius, W., 1936, **Calculation of stability of earth dams**, Transactions, 2nd International congress on large dams, Int. Commission Large Dams, 445-449.

[2]- Jiang, Y. S., 1990, **Slope Analysis using boundary elements**, New York: Springer-Verlang Publisher.

[3]- Matsui, T., and San, K., 1992, **Finite element slope stability analysis by shear strength reduction technique**, Soils and Foundations, 32, 59-70

[4]- Jaritngam, S., Chuchom, S., Limsakul, C., and Jaritngam, R., 2001, **Slope stability analysis using neural networks**, In: The 6th mining, metallurgical and petroleum engineering conference on resources exploration and utilization for sustainable environment (REUSE), 24-66

[5]- Janbu, N., 1954, **Application of composite slip surface for stability analysis**, In: Proceeding of European conference on stability earth slopes, Stockholm, Sweden, 21-29.

[6]- Lowe, J., and karafiath, L., 1960, **Stability of earth dams upon drawdown**, In: Proceeding of first pan-American conference on soil mechanics and foundation engineering, 2, 537-552.

[7]- Taylor, D. W., 1940, **Stability of earth slopes**, J. Boston Society of Civil Engineers reprinted in contributions to soil Mechanics. Boston Society of civil engineers, 337-386.

[8]- Bishop, A. W., 1955, **The use of slip circle in the stability analysis of slopes**, Geotecnique, 7-17.

[9]- Morgenstern, N. R., and Price, V. E., 1965, **The Analysis of the stability of general slope surfaces**, Geotecnique, 79-93.

[10]- Bore, H., 1999, **TELDYN – Users**, Manual, Lafayette, California.

[11]- Saravut, J., Somchai, C., Chusak, L., and Rittisak, J., 2002, **Neural Networks: a tool for the Slope Stability Analysis**, 3th International conference on Landslides, slope stability and safety of infrastructures, 11-12, Singapore.
[12]- Broms, B. B., 1977, **Triaxal Tests with Fabric-Reinforced Soil**, Proceeding of International Conference on Use of Fabrics in Geotechnics, Paris, France, III, 109-133.
[13]- Mc Gown, A., Andrawes, K. Z. and Al-Hasani, M. M., 1978, **Effect of Inclusion Properties on the Behaviour of Sand**, Geotechnique, 8, 3, 327-346.
[14]- Gray, D. H., and Ohashi, H., 1983, **Mechanics of Fiber Reinforcement in Sand**, Journal of Geotechnical Engineering Division, ASCE, 109, 3, 335-353.
[15]- Ameskamp, M., 1997, **Three dimensional rule-based continuous soil modeling**, Ph.D. dissertation, Technical Report, 9701, Faculty of Engineering, Kiel University, Kiel, Germany.