On the Effect of Clay Core Shape on Dynamic Response of Embankment Dams

Behzad Shakouri[1]*and **Mirali Mohammadi[2]**

[1] PhD Candidate, Water & Hydraulic Structures Eng., Department of Civil Eng., Faculty of Eng., Urmia University, Urmia, Iran.
[*]*corresponding author,* e-mail:*b.shakouri@urmia.ac.ir*

[2]Associate Prof. in Civil Engineering Hydraulics & Hydraulic Structures, Department of Civil Eng., Faculty of Eng., Urmia University, P O Box 165, Urmia 57561-15311, Iran
e-mail:*m.mohammadi@urmia.ac.ir*

Abstract

Although the issue of embankment dams' vulnerability has been taken into account since the past 8 decades, but the behavioral complexities of these types of structures in different geometric and physical conditions require more detailed studies used by more precious computing tools. In this research work, the effects of clay core shape on dynamic response of embankment dams is considered. Agh-Chai dam (located in the West Azerbaijan, Iran) is used as a case study. In order to achieve this goal, the parameters, which in dynamic conditions, can lead to instability and collapse of dam, are tested on different angles of the core slope by changing from 90-degree (vertical core) to 42-degree inclined cores. Dynamic analysis of Agh-Chai dam is done by using Geostudio-2004 and Plaxis2D 8.2softwares. The results of dynamic analysis show that by the inclination of the dam's core, the amount of maximum horizontal displacement, maximum vertical displacement and pore water pressure coefficient (*Ru*) approximately reducesto 63.54%, 63.91% and 67.25%, respectively, which leads to its improvement of performance against earthquake. This can therefore be a higher priority for embankment dams design. Regarding to the geotechnical specifications of the dam's construction site, of course, the inclination of dam's core can be increase until does not endanger the stability of dam body in other critical conditions, such as rapid draw down, etc.

Keywords: Embankment dam, Dynamic analysis, Clay Core shape, Geostudio-2004, Plaxis2D 8.2

1. INTRODUCTION

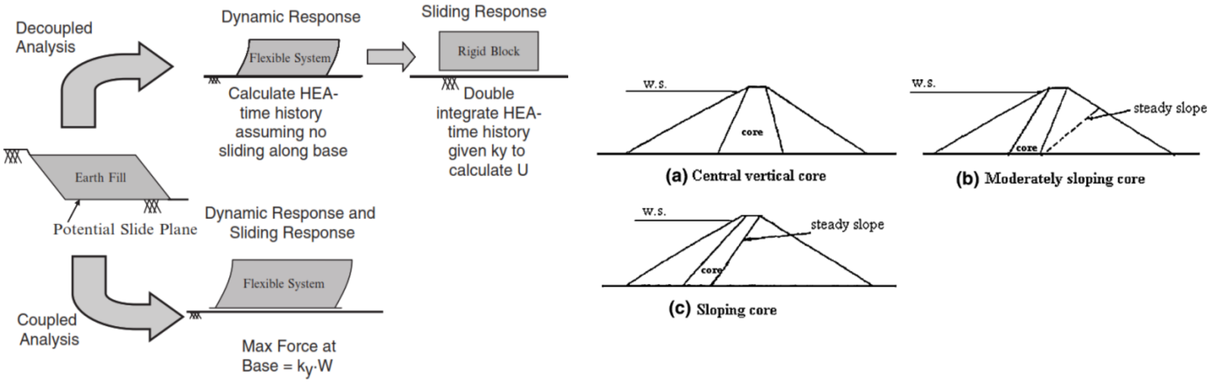
Earth dams are very important structure and provide renewable energy and agriculture facility to the country. As the dams' structure is very large and the dams store a tremendous amount of water, with respect to environmental and economic considerations, their safe performance is very important. Stability and performance are always primary concerns for any structure such as the huge structure of dams and the failure of it that causes disaster and loss of human being and properties in results. Despite significant development in geotechnical engineering, earthquakes continue to cause failure of many dams and result in the destruction of life and the damage of properties, so the stability of earth dams during earthquake is of primary concern [1]. Therefore, the issue of earth dams' vulnerability to earthquakes and other dynamic loads has long been a concern of engineers and researchers. However, because the earthquake damaged a few of large earth dams, the nature of the impact of the earthquake on earth dams was not seriously addressed[2]. Many engineers believed that earth dams were resistant to earthquakes. However, it is nowadays proven that these types of dams are more susceptible to destruction than other types of dams, and careful examination of their stability is one of the most complex issues of those dams[3]. The evolution of analytical methods in earth dams'seismic evaluation has started from the simplest method called the pseudo-static method and has led to sophisticated analysis with advanced behavioral models that necessarily require a computer. Earthquake engineers, based on advanced research, believe that the usual idea ofslip surface of a slope applied in a pseudo-static method does not correctly define the function of an earth dam under an earthquake; the best performance of a dam should be assessed by examining the relative displacements. Newmark (1965) first proposed the calculation of the deformation caused by an earthquake [4]. Sarma (1980), proposed a new analysis approach, based on the Newmark method, aims to determining the critical horizontal acceleration that is required to bring the soil mass to a state of limiting or critical equilibriumand the soil mass was calculated and considered as a block on the inclination surface [5-6]. Makdisi and Seed (1978) introduced the concept of equivalent acceleration to represent seismic loading on a slip prone mass that used by Cascone and Rampello (2003) as coupled and decoupled methods [7-8]. Figure 1.a showsdecoupled and fully coupled analysis, which performs in dynamic response analysis and computation of displacements. In the Geostudio-2004 and Plaxis2D 8.2softwares,decoupled and coupled methods have been used, respectively.

Increasing the pore pressure caused by the earthquake and remaining of itin this state is another reason for dam breaks. The increase in pore water pressure is due to the increase in irreversible volume strains. In addition, these volumetric strains themselves are augmented by the decrease in strength due to the increase in pore water pressure. The dependence of these two parameters on each other indents the importance of using a coupling mechanism to investigate the behavior of saturated porous media. This method also describes that classical and decoupled methods are not suitable for the dynamic analysis of earth structures because they do not take into account the decrease in strength of materials due to increasing of pore water pressure [9-10].Considering the increasing of pore water pressure during the earthquake, it is necessary to use advanced nonlinear models that considers the pore water pressure changes and their relationship with the effective stress in addition to dam's displacements [11].Some of researches that is done previously by several investigators about the seismic performance of earth structures can be mentioned asMakdisi and Seed, 1978; Seed, 1979; Lin and Whitman, 1983; Ambraseys and Menu, 1988; Yegian et al., 1991a, b; Marcuson et al., 1992; Jibson, 1993; Ambraseys and Srbulov, 1994; Ghahraman and Yegian, 1996; Kramer and Smith, 1997; Finn, 1998; Rathje and Bray, 2000; Rathje and Saygili, 2006; Bray, 2007; Vahedifard et al. 2013; Meehan and Vahedifard, 2013; Raja and Maheshwari, 2016; Shakouri and Mohammadi, 2019 and so on [1, 7, 12-28].

As the central core of the earth dams has the primary task of sealing and controlling the seepage through the dam body and by considering thatthe destructive damages due to earthquakes is overwhelmed the dam's core, therefore, it is important to investigate the effect of shape and location of clay core on the dynamic response of earth dams. For this purpose, in dynamic state, factors and phenomena that can cause instability and destructionof the dam have been investigated for different shapes of the core. These phenomena include horizontal and vertical displacements, pore water pressure, pore water pressure coefficient(*Ru*), and shear strains produced in the core.

2. SHAPE AND LOCATION OF THE CLAY CORE ON THE EARTH DAM CROSS SECTION

The main method of controlling seepage from the body of an earth dam is the use of a central core, which reduces the amount of water passing through it. The central core thickness must be sufficient to control the amount of water passing through the dam body.Technically, impermeable fine-grained (clayey-silty) aggregates have less shear strength compared to coarse-grained (sand) materials and are more prone to pore water pressure and leakage issues during construction. Therefore, the minimum dam body size and, naturally, the lowest cost of construction are achieved when the use of fine materials in dam body construction is minimized and confined to a thin clay core. Impervious clay core can be constructed in three main forms and positions at the cross-sections of earth dams. Figure 1.b shows the position of the core at the cross section of the earth dams. When core down stream slopes are at1V:0.5Hor more towards upstream, it is called moderately sloping core. It is called sloping (inclined) core, if the downstream shell and core contain a self-stable slope about 1V:1.25 Horless, This slopeis usually used in rock fill dams that down stream rockfill shellis constructed in the form independent and the post time, the upstream filter and coreareper formed[29-31].



(a) (b)

Figure 1. a) Decoupled dynamic response/rigid sliding block analysis and fully coupled analysis [25] b) Coreshapes andtheirlocationin embankmentdamssections [31].

3. INTRODUCTION TO THE CASE STUDY SPECIFICATIONS AND MODELING

3.1. GENERAL SPECIFICATIONS OF THE DAM

In this study, Agh-Chai dam, which is a clay core soil type, is selected as a case study. The dam is located in West Azerbaijan Province, 45 kilometers northwest of Khoy city. The length of the dam is 826 meters and its height is 86.5 meters from the riverbed and 105 meters from the bedrock. The riverbed is consisting of coarse alluvium that is about 18 to 20 meters in thickness[32]. All of the alluvial materials below the dam's core have been removed and the core has been constructedon the safe rock, but other parts of the dam have been constructed on the alluvium. The ratio of the length of the dam's crest to its height is such that the two-dimensional analysis is sufficient for the calculations. Because the Geostudio-2004 software package does not fully extend the energy-absorbing boundaries. Therefore, in order to prevent reflection of energy into the model, a range of one hundred meters upstream and downstream of the dam ismodeled.In Plaxis2D 8.2 software, the energy-absorbing boundaries proposed by Kuhlmeyer and Lysmer (1973) are used to absorb energy at the boundaries. This kind of boundary condition causes the waves to reach the boundary points not to be reflected inward, thus limiting the sides of the model without affecting the results [33]. To uniformize the model conditions, in this software also a range of one hundred meters upstream and downstream of the dam is modeled.

3.2. GEOTECHNICAL PROPERTIES OF MATERIALSUSED IN GEOSTUDIO-2004 SOFTWARE

To calculate the static stresses in the Geostudio-2004 software package performed by Sigma/w software, the hyperbolic strain stress relation proposed by Duncan and Chang (1970) is used [34]. This model is available in Sigma/w software as a nonlinear elastic model. In this formulation, the soil modules are a function of the confined stresses and the deviation stresses (σ_1-σ_3) that appliedto the soil [35]. The geotechnical parameters used in this analysis are in accordance with Table 1.Quake/w software is used to perform dynamic analysis in Geostudio software package. Quake/w software uses the equivalent linear method to perform dynamic analysis. In this method, a linear analysis is performed using the initial values of damping and shear modulus and then using the corresponding laboratory curves and the maximum shear strain value obtained, the new damping values and shear modulus are calculated. These values are prepared for a new analysis and the operation is repeated several times to change the properties of the other materials. To perform dynamic analysis by equivalent linear method, it is necessary to know the diagram of shear modulus reduction and the increase of damping ratio against shear strain changes [36].

Table 1. Geotechnical parameters of Agh-Chai dam based on hyperbolic modulus [32].

Type of materials	$\gamma_d\left({}^{t}/_{m^3}\right)$	K_L	K_b	K_{ur}	n	m	R_f	$C(Pa)$	$\emptyset$
Clay core	1.72	110	75	140	0.71	0.51	0.80	0.10	24
Filter	1.98	340	252	500	0.28	0.18	0.71	0.00	35
Shell	2.10	800	600	950	0.35	0.30	0.85	0.00	42
Alluvium	1.92	400	300	480	0.40	0.10	0.78	0.00	24

3.3. GEOTECHNICAL PROPERTIES OF MATERIALSUSED IN PLAXIS2D 8.2SOFTWARE

Hardening Soil Model (HSM), available in Plaxis software, was used to model the foundation materials and dam body. The hardened soil model is an advanced elastoplastic model to simulate the behavior of different types of soils including soft and hard soils. The soil exhibits a hardening during initial deflection loading and simultaneously develops irreversible plastic strains. In a particular case of a drained triaxial test, the relationship between axial strain and deflection stress can be approximated by a hyperbola. Such a model was first used by Kondner (1963) and then in the famous model of Duncan and Chang (1970) [34, 37]. The hardened soil model first replaces the theory of elasticity with the theory of elasticity, secondly by incorporating soil dilution and thirdly by introducing a ceylon cap, replacing the hyperbolic model [38-39].The geotechnical parameters that is used in the analysis are also presented in Table 2.

Table 2.Agh-Chai Dam and Body Material Properties Based on Hardened Soil Model[3].

Type of materials	E_{50}^{ref}	E_{oed}^{ref}	E_{ur}^{ref}	m	C	$\emptyset$	ψ	P_{ref}	R_f	γ_{unsat}	γ_{sat}
Clay core	28000	28000	88000	0.71	4	18	0	500	0.80	20.50	21.00
Filter	58000	58000	178000	0.28	1	35	5	500	0.71	18.50	19.50
Shell	105000	105000	360000	0.35	1	42	12	800	0.85	21.00	22.50
Alluvium	65000	65000	210000	0.45	1	24	0	500	0.78	20.00	21.00

3.4. INPUT ACCELERATION

Based on the results of the earthquake hazard analysis at the dam site, the MCL acceleration is proposed for the horizontal component of 0.52 g. In this study, the horizontal component of the Manjil-Rudbar earthquake accelerogramwith maximum acceleration of 0.514 g is used to perform the dynamic analysis, which is well in accordance with the design parameters. This accelerogramis applied for 53 seconds in the horizontal direction to the base of the dam. Figure 2 shows the horizontal component of time history of this accelerogram.

4. DYNAMIC ANALYSIS

To calculate the initial conditions of dynamic analysis, it is necessary to first analyze the dam in a static state. To do this, first, the phases of the dam construction, which consists of 10 steps, are modeled. By assuming that the dam experiences an earthquake after reaching a steady leak state, it is therefore necessary to determine the static conditions of the dam after reaching this state. Since in dynamic analysis, the purpose is to find the displacements caused by the earthquake, then it is necessary to set zero the static displacements of the dam in both x and y directions before continuing the dynamic analysis. Modal analysis results from Sap2000 software (10th version) are used to allocate the Rayleigh damping parameters. The frequencies of the five main modes are shown in Table 3. The f_{min} Riley parameter is considered asthe dam's mean first two frequencies modes.

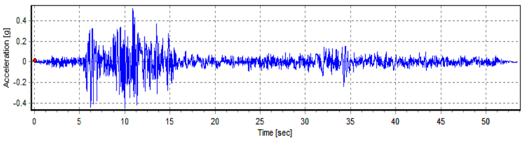


Figure 2. Horizontal component of the Manjil-Rudbar earthquake's time history.

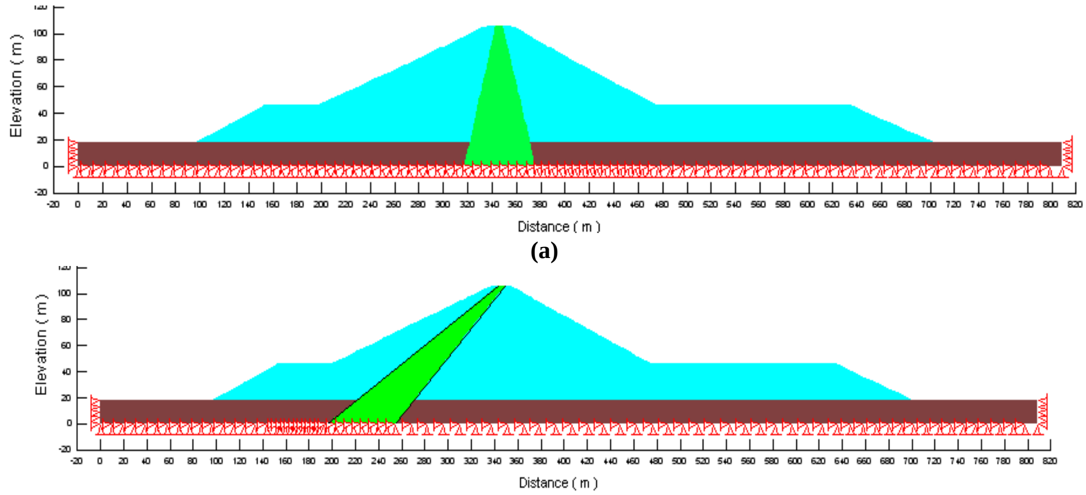
Table 3. Main frequencies of the dam [3].

Mode number	1	2	3	4	5
Frequency (HZ)	0.3940	0.6191	0.7854	0.8426	0.9765

5. METHOD OF DOINGRESEARCHWORK

In this study, to study the effect of core shape on the dynamic response of earth dams, different angles of the core slope is considered and to keep the core volume constant in all cases, its width at the contact location with the foundation and also in the dam crest remained constant. For this purpose, 5 different angles of slope for the dam core have been used, one of that is vertical core where the angle of the axis of the core is 90-degree (vertical core), and in other cases the angle is reduced to 75, 62, 54 and 42-degree inclined cores. As the slope angle decreases, the dam's core expands to upstream, and as clayey materials have less shear strength, this can be dangerous for the upstream slope. Figure 3 shows the cross section of thevertical and 42-degreeinclination of dam modeled in Geostudio software.In the steady state mode, the pressure of the dam reservoir acts as an upstream slope stability factor, but this problem does not seem to be serious. However, in the rapid draw down of the reservoir mode due to removal of the reservoir water pressure and also as reversal of the seepage forces from the core to the shell, the upstream slope becomes critical. In construction mode, it is also necessary to ensure the stability of the slopes when the upstream and downstream slopes are susceptible to slip and instability. For this purpose, to ensure the stability of all cores with different slopes in both the rapid draw down and the end of construction modes, the upstream slope safetyfactors were calculated using Geostudio-2004 software package. By comparing the results obtained from the analysis and safety factors provided by the USBR

Institute, that is concluded that all cores are stable [40]. Calculated safety factors for different angles of the core slope are presented in Table 4.



(b)

Figure 3. Dam section with different angles of core a) vertical b) inclined with 42-degree of slope

Table 4. Dam safety factor of stability in different modes.

Slope inclination angle of the core	**90-degree**	**75-degree**	**62-degree**	**54-degree**	**42-degree**	**USBR allowed**
Safety factor at rapid draw down state	1.920	1.833	1.707	1.440	1.251	1.1-2.3
Safety factor at end of construction state	1.939	1.850	1.790	1.652	1.485	1.1-3.4

6. DYNAMIC ANALYSISPERFORMEDBYGEOSTUDIO-2004 SOFTWARE

In this software, the damdynamic response analysis is performed using Quake/w software and the time history of shear and vertical stresses at different points of dam are calculated. Then, by transferring these stresses to the Slope/w software, displacements due to earthquakes at different points of the dam are calculated. Slope/w software calculates the displacements using the Newmark rigid sliding block concept.In this study, five different sliding surfaces were used to calculate the displacements using Slope/w software, three of them are in the upstream slope and the other two are in the downstream slope. These surfaces are located in areas where the greatest possible displacements occurs (based on the results obtained from Plaxis software as well as on the experiences of other researchers, such as Tani (2000)) onthe earthquake damages occur in earth dams [41]. In Slope/w software, using dynamic calculated stresses at the bottom of each piece and by integrating it along the slip surface, the total dynamic shear force is obtained. By dividing the total dynamic shear force to the mass of the slip prone, the mean acceleration value is calculated at different time steps, when the mean acceleration exceeds the acceleration value of $a_y$occurs on slip surfaces. The value of a_y corresponds to the acceleration that gives safety factor of one on the slip surface [42].

Figure4 shows the maximum values of horizontal and vertical displacements for the different angle of core inclinations for different slip surfaces. By examining the results of horizontal and vertical displacements, it is found that the overall dam displacements are represented by the settlement of the dam crest and the upstream shell movement toward the reservoir as well as the downstream shell movement toward downstream. As, the dam's coreinclination increases, the amount of maximum horizontal displacement reduces from 50.80cm to 32.28cm and the amount of maximum vertical displacement reduces from 32.70cm to 20.90cm. The pattern of these displacements is quite consistent with the pattern presented by Ambraseys (1962) regarding displacements due to an earthquake in earth dams [43].The values of safetyfactors before and after the earthquake for different sliding surfaces are presented in Figure 5. By examining the values of the safetyfactors observed at S1 to S3 surfaces, their values decreasesbyincreasing of the dam's core inclination. The reason is that by the core inclination of the dam most of it falls on the slip surface and because the strength of the dam's core material is lower than its shell, the safety factor decreases. At S4 and S5 surfaces, unlike surfaces at the upstream of the dam, the safetyfactors increases by increasing of the dam's core inclination. The reason is that as the core expands to the upstream side, smaller volumes of it fall into the slip surfaces, and most of the slip surface is composed of high-strength gravelly materials. Although these changes are not significant at these surfaces, they still change the values of the safety factor.

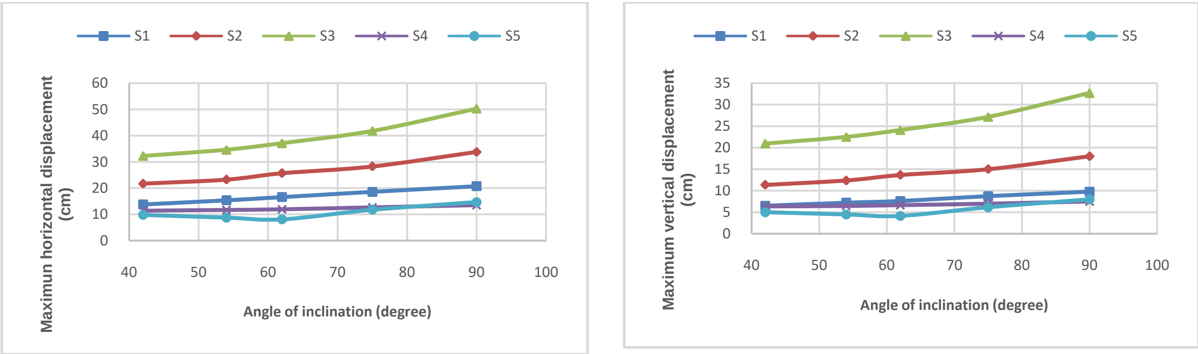


Figure 4. Maximum values of horizontal and vertical displacements at different sliding surfaces and angle of core inclination.

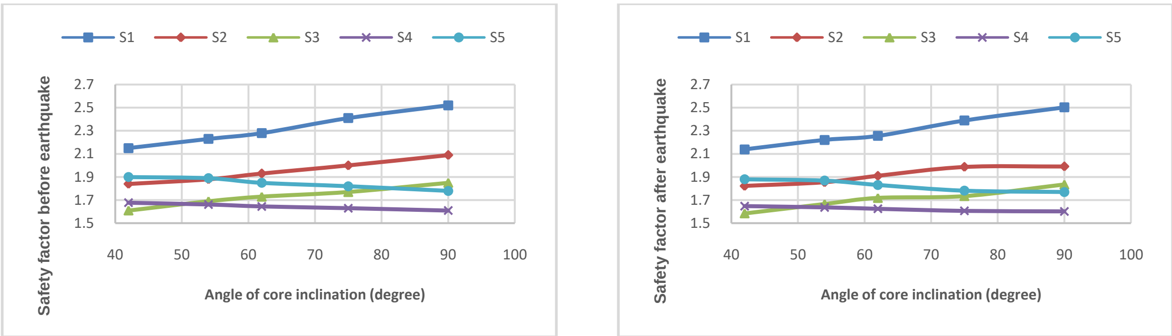
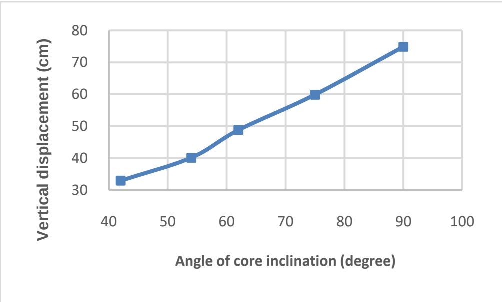


Figure 5. Safety factors before and after earthquake for different sliding surfaces and angle of core inclination.

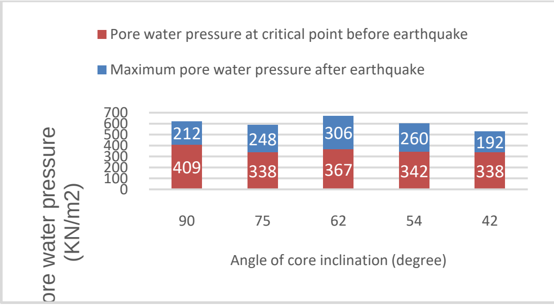
7. DYNAMIC ANALYSIS PERFORMED BYPLAXIS8.2 SOFTWARE

7.1. DISTRIBUTION OF DISPLACEMENTS

Plaxis software uses hardened soil, which is an advanced behavioral model for describing soil behavior, to perform static and dynamic analysis. This model can easily estimate the displacement caused by an earthquake by defining yield levels. It also calculates the pore water pressure due to earthquake caused by irreversible volume strains. The pore water pressure can be characterized by the possibility of cracking caused by the reduction of effective stresses. Therefore, in analyzing the results of this software, it is more focused on examining the displacements and pore water pressure due to earthquake, which are the most important criteria for assessing the stability of dams against earthquakes. By examining the pattern of displacements caused by the earthquake, it is concluded that the displacements created in the dam are in the form of settlement ofthe dam crest and upstream shell movement toward the reservoir and partial downstream shell movement. This type of instability is naturally acceptable and is consistent with the general pattern presented about the displacements due to an earthquake in earth dams. In addition, from isocurves of displacements, it is found that the horizontal displacements in the negative direction are more concentrated upstream of the core and toward the reservoir as thecoreinclination increase. The maximum values of the horizontal displacements in the positive direction are also on the downstream slope of the dam.In Figure 6.a, the changes of the vertical displacements for the different angle of core inclinationsis plotted. By examining this figure, it is found that with the core inclination of the dam the amount of vertical displacements decreases and this decrease in displacements follows a regular pattern. The maximum vertical displacement reaches from 75cm in the vertical core to 33cm in the maximumcore inclination.The maximum horizontal displacement of the dam with vertical core are 20cm in the positive (downstream) direction and 59cm in the negative (upstream) direction that reachesto 19cm and 62cm, for themaximumcore inclination, respectively. By examining the horizontal displacements for other sections, it should be noted that although the inclination or verticality of the core does not have much effect on the amount of maximum horizontal displacement, the pattern of displacement distribution in the dam body varies.



(a)



(b)

Figure 6. a) Diagram of changes of vertical displacements for the different angle of core inclinations. b) Pore water pressure before and after the earthquake for the different angle of core inclinations.

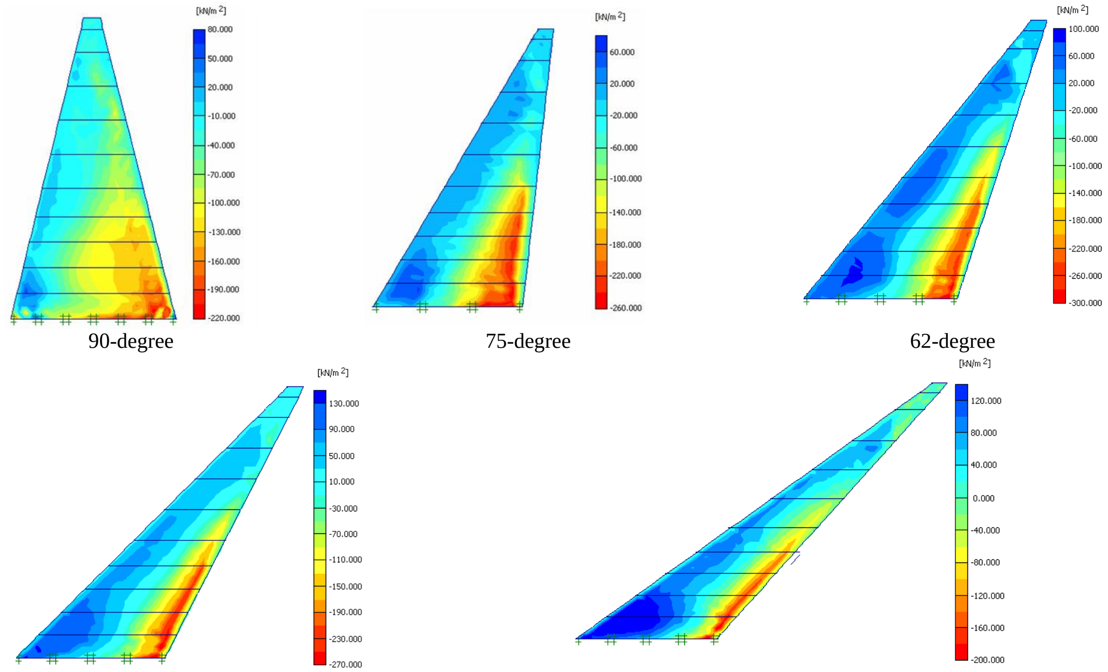
7.2. Pore Water Pressure Assessment at the End of the Earthquake

In this study, assuming non-drainage behavior, the changes of pore water pressure in the clay core were investigated. Figure 6.b shows the pore water pressure before and after the earthquake for the models that by increasing the pore water pressure, the stresses and strains of the earthquake can reduce the shear strength of the soil. The maximum amount of pore water pressure reached from 212kN/m^2 in the vertical core increases to 306kN/m^2 in the inclined corewith the angle of 62-degreeand then decreases to 192kN/m^2 by the inclined core with the angle of 42-degree. As shown in Figure 7, at all sections, the pore pressure is concentrated in the lower level of the core and downstream, and withincreasing of the inclination of the core, the pore pressure is initially reduced then increased significantly and finallyreduced again. In the pattern of pore water pressure distribution, it is also found that, although with the core inclination,the maximum pore water pressure reaches its maximum value in more below parts, in the greater part of the upstream core, the amount of pore water pressure decreases.The distribution of pore water pressure at the end of the earthquake can be attributed to the static stress conditions of the dam. As, in the upstream parts of the dam’s core that are more consolidated as a result of earthquakes, there is a negative pore water pressure, but in the lower parts of the dam’s core which havelower consolidation coefficient,positive pore water pressure is created. The validity of this claim can be substantiated by referring to research by previous researchers e.g.Amorosi and Chan (2008) [44].

In sandy and non-sticky soils, this increase in pore water pressure causes a liquefaction phenomenon, but sticky soils and clays are not susceptible to liquefaction. In clay soils, increasing pore water pressure reduces effective stress and hydraulic fracturing phenomenon, which can cause core erosion and consequently dam damage.One of the parameters used to evaluate the occurrence of hydraulic fracturing is to indicate the amount of pore water created in the core of earth dams; the pore water pressure coefficient(Ru) is the ratio of the pore water pressure created at each point to the vertical stress at that point. The percentages of pore water pressure and Ru values for the models are presented in Table 5.If the value of Ru reaches or exceeds 1.0, the hydraulic fracturing probability resulting from the internal erosion of the core material may occur. The value of Ru which is a criterion for assessing the occurrence of hydraulic fracturing in the dam's core, has decreased as the dam's core inclination decreases from 0.510 for the vertical core to 0.343 forthe most inclined core. Thus, with the core inclination of the dam, the safety factor against hydraulic fracturing probability increases. The values of this parameter indicate that the probability of any hydraulic fracturing within the dam core is eliminated and the core is within safe range against erosion. The process of changes in the Ruin the core is characterized by decreasing the amount of Ruas the core becomes smaller, and then the safety factor against hydraulic fracturing increases.

Table 5. Results of pore water pressure and hydraulic fracturingprobability.

Angle of core inclination (degree)	Percentage of pore water pressure increase (%)	R_u
90	52	0.510
75	73	0.430
62	84	0.464
54	76	0.397
42	57	0.343



90-degree 75-degree 62-degree

54-degree 42-degree

Figure 7. Porewater pressure distribution at the end of the earthquake with different angle of core inclinations.

8. CONCLUSIONS

In this research, the effect of clay core shape on the dynamic response of embankment dams is investigated using Geostudio-2004 and Plaxis2D 8.2softwares. Based on the analysis given in the previous sections, the main conclusionsare as follows:

In dynamic analysis, the displacements created in both softwares are represented by the settlement of the dam, the upstreamshell movement towards the reservoir, as well as the slight downstreamshell movement towards downstream. As Geostudio software results, byincreasing the dam's core inclination, the amount of maximum horizontal displacement reduces from 50.80cm to 32.28cm and the amount of maximum vertical displacement reduces from 32.70cm to 20.90cm. As Plaxis software results, the maximum vertical displacement reaches from 75cm in the vertical core to 33cm in the maximum core inclination. The maximum horizontal displacement of the dam with vertical core are 20cm in the positive (downstream) direction and 59cm in the negative (upstream) direction that reaches to 19cm and 62cm, for the maximum core inclination, respectively.

By examining the pore pressure created by the earthquake, the pore pressure is concentrated in the lower level of the core and downstream, and with increasing of the inclination of the core, the pore pressure is initially reduced then increased significantly and finally reduced again. The maximum amount of pore water pressure reached from 212kN/m^2 in the vertical core increases to 306kN/m^2 in the inclined core with the angle of 62-degree and then decreases to 192kN/m^2 by the inclined core with the angle of 42-degree.The value of pore water pressure coefficient(*Ru*) which is a criterion for assessing the occurrence of hydraulic fracturing in the dam's core, has decreased as the dam's core inclination decreases from 0.510 for the vertical core to 0.343 forthe most inclined core. Thus, with the core inclination of the dam, the safety factor against hydraulic fracturing probability increases.

By the inclination of dam core, its performance against the earthquake improves. However, for choosing slope of the core, it should be noted that decreasingofthe angle of core inclination slope is acceptable to some extent that the dam stability inthe any loading conditions that the dam will face during its useful life do not pose a risk. One of the most important part of these conditions is the rapid draw down mode in which the upstream slope becomes seriously critical.The results of dynamic analysis show that by the inclination of the dam's core, the amount of maximum horizontal displacement, maximum vertical displacement and pore water pressure coefficient (*Ru*) approximately reduces to 63.54%, 63.91% and 67.25%, respectively, which leads to its improvement of performance against earthquake. This can therefore be a higher priority for embankment dams' design. Regarding to the geotechnical specifications of the dam's construction site, of course, the inclination of dam's core can be increase until does not endanger the stability of dam body in other critical conditions, such as rapid draw down, etc.

9. REFERENCES

1. Raja, M.A. and Maheshwari, B.K. (2016),"Behaviour of Earth Dam under Seismic Load Considering Nonlinearity of the Soil", Open Journal of Civil Engineering, 6, pp. 75-83.

2. SeratiJannati, P., Mohammadi, M. and Manafpour. M. (2010), "The effect of Impervious Core Shape on Dynamic Stability of Soil Dams", 5th National Congress on Civil Engineering, Mashhad, Ferdowsi University, Mashhad, Iran. **(In Farsi)**

3. SeratiJannati, P. (2010), "The effect of Impervious Core Shape on Dynamic Stability of Soil Dams",Thesisof Master of Science in Civil Engineering, Hydraulic Structures, Faculty of Engineering, Urmia University. **(In Farsi)**

4. Newmark, N.M. (1965), "Effects of Earthquake on Dam and Embankments",Geotechnique, Vol. 15, No. 2.

5. Sarma, S.K. (1980), "A Simplified Method for Earthquake Resistant Design of Earth Dams", Design of Dam to Resist Earthquake, ICE, London.

6. Chowdhury, R., Flentje, P., and Bhattacharya, G. (2009), "Geotechnical slope analysis",Crc Press.

7. Makdisi, F.I., and Seed, H.B., (1978), "Simplified procedure for estimating dam and embankment earthquake-induced deformations", Journal of Geotechnical and Geoenvironmental Engineering, 104 (Proceeding).

8. Cascone, E. and Rampello, S. (2003), "DeCoupled seismic analysis of an earth dam", Soil Dynamics and Earthquake Engineering, no. 23, pp. 349–365.

9. Lacy, S.J. and Prevost, J.H. (1987), "Nonlinear Seismic Analysis of Earth Dams", Soil Dynamics and Earthquake Engineering, 6 (1), pp. 48-63.

10. Zerfa, F.Z. and Loret, B. (2003), "Coupled Dynamic Elastic-Plastic Analysis of Earth Structures", Soil Dynamics and Earthquake Engineering, 23, pp. 435-454.

11. Kramer, S.L. (1996), "Geotechnical Earthquake Engineering", Prentice-Hall.

12. Seed H.B. (1979), "Considerations in the earthquake-resistant design of earth and rockfill dams",Geotechnique 29(3): pp. 215-263.

13. Lin J.S. and Whitman R.V. (1983), "Decoupling approximation to the evaluation of earthquake-induced plastic slip in earth dams", Earthquake Engineering and Structural Dynamics 11: pp. 667-678.

14. Ambraseys N.N., Menu J.M. (1988), "Earthquake-induced ground displacements", Journal of Earthquake Engineering and Structural Dynamics 16: pp. 985-1006.

15. Yegian M., Marciano E. and Ghahraman V. (1991a), "Earthquake-induced permanent deformations: probabilistic approach", Journal of Geotechnical Engineering 117(1): pp. 18–34.

16. Yegian M., Marciano E. and Ghahraman V. (1991b), "Seismic risk analysis for earth dams", Journal of Geotechnical Engineering 117(1): pp. 35.

17. Marcuson W.F., Hynes M. E. and Franklin A.G. (1992), "Seismic stability and permanent deformation analysis: the last 25 years", Stability and Performance of Slopes and Embankments—II, Berkeley, California, pp. 552–592.

18. Jibson R.W. (1993), "Predicting earthquake induced landslide displacements using Newmark's sliding block analysis", Trans. Res. Rec, Nat. Acad. Press, 1411, pp. 9-17.

19. Ambraseys N.N. and Srbulov M. (1994), "Attenuation of earthquake-induced displacements", Journal Earthquake Engineering and Structural Dynamics 23: pp. 467-487.

20. Ghahraman V. and Yegian M.K. (1996), "Risk analysis for earthquake-induced permanent deformation earth dams", Proc. 11th World Conf. on Earthquake Engineering, Acapulco, Mexico. Paper 688. Oxford: Pergamon.

21. Kramer S.L. and Smith M.W. (1997), "Modified Newmark model for seismic displacements of compliant slopes", J. Geotechnical Geoenvironmental Engineering, ASCE 123(7): pp. 635-644.

22. Finn W.D. (1998), "Seismic safety of embankments dams: developments in research and practice 1988-1998", Proc. Geotech. Earthquake Engrg. Soil Dynamics III, ASCE, Geotechnical Spec. Pub. No. 75, Dakoulas, Yegian and Holtz (eds), Seattle, WA, pp. 812-853.

23. Rathje E.M., Bray J.D. (2000), "Nonlinear coupled seismic sliding analysis of earth structures", Journal of Geotechnical and Geoenvironmental Engineering 126(11): pp. 1002-1014.

24. Rathje E.M., Saygili G. (2006), "A vector hazard approach for Newmark sliding block analysis", Proc. Earthquake Geotech. Engrg. Workshop, University of Canterbury, Christchurch, New Zealand, Nov. pp. 20-23.

25. Bray, J.D. (2007), "Simplified Seismic Slope Displacement Procedures",Eartquake Geotechnical Engineering, 2007 Springer. pp: 327-353.

26. Vahedifard, F., Leshchinsky, D., and Meehan, C. L. (2013), “Displacement-based internal design of geosynthetic-reinforced earth structures subjected to seismic loading conditions”,Géotechnique, 63(6), pp. 451-462.

27. Meehan, C. L., and Vahedifard, F. (2013), “Evaluation of simplified methods for predicting earthquake-induced slope displacements in earth dams and embankments”, Engineering geology, 152(1), pp. 180-193.

28. Shakouri, B. and Mohammadi, M. (2019), “Evaluation of Penetration Depth for Cutoff Walls in the Core of Earth Dams”,GeotechGeol Eng. https://doi.org/10.1007/s10706-019-01004-x

29. French National Committee (1973), “International watertight cores”, Proceedings 11th ICOLD congress, vol III, Q42, R28, Madrid.

30. Reinus, E. (1973), “Some Stability Properties of Having an Inclined Core”, Proceedings 11th ICOLD Congress, Vol. II, Q42, R-2, Madrid, Spain.

31. Nayebzadeh, R., and Mohammadi, M. (2011), “The effect of impervious clay core shape on the stability of embankment dams”, Geotechnical and Geological Engineering, 29 (4), pp. 627-635.

32. MahabGhods Consulting Engineers (2001), “Studies of the Agh-Chai Reservoir Dam, Phase II”, Technical Reports, Volume 10. **(In Farsi)**

33. Kuhlymer, R.L. and Lysmer, J. (1973), “Finite Element Accuracy Method for Wave Propagation Problems”, ASCE, Journal of the Soil Mechanics and Foundation Division, Vol. 99, No. SM5, pp. 421-427.

34. Duncan, J.M. and Chang, C.Y., (1970), “Nonlinear analysis of stress and strain in soils”, Journal of Soil Mechanics and Foundations Division, ASCE, vol. 96, no. SM5, pp. 1629-1654.

35. Krahn, J., (2004a), “Stress and Deformation Modeling with SIGMA/W”, First Edition, SIGMA/W Engineering Book, May.

36. Krahn, J. (2004b), “Dynamic modeling with QUAKE/W: an engineering methodology”, GEO-SLOPE.

37. Kondner, R.L. (1963), “Hyperbolic stress-strain response: cohesive soils”, Journal of the Soil Mechanics and Foundations Division, 89 (1), pp. 115-144.

38. Schanz, T., Vermeer, P.A. and Bonnier, P.G. (1999), “Formulation and Vertification of the Hardening Soil Model”, In: R.B.J. Brinkgreve, Beyond 2000 in Computational Geotechnics, Balkema, Rotterdam, pp. 281-290.

39. Brinkgreve, R.B.J., Broere, W., and Waterman, D. (2008), “PLAXIS2D Manual, Version 9.0”, Delft University of Technology and PLAXIS.

40. USBR (2011), “Design Standards No. 13 Embankment Dam. Chapter 4: Static Stability Analysis”.

41. Tani, S. (2000), “Behavior of Large Fill Dams During Earthquake and Earthquake Damage”, Soil Dynamics and Earthquake Engineering, No.20, pp. 223-229.

42. Krahn, J. (2004c), “Stability modeling with SLOPE/W: An engineering methodology”, GEOSLOPE/W International Ltd. Calgary, Alberta, Canada.

43. Ambraseys, N.N. (1962), “The Seismic Stability Analysis of Earth Dams”, 2nd Symposiums on Earthquake Engineering, University of Roorkee, India.

44. Amorosi, A. and Chan, A.H.C. (2008), “Fully Coupled Dynamic Analysis of a Real Earth Dam Overlaying a Stiff Natural Clayey Deposit”, 12th International Conference on Association for Computer Method and Advances in Geomechanics, India.