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Evaluation of Seismic Performance of Earth Dams Due to the Level of Its Reservoir Using Finite Element Method

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Abstract **-** One of the challenges in engineering world is investigation on seismic behavior of earthdams during an earthquake. The complexity of this issue is lack of adequate information about the impact of the earthquake on earthdams behavior. Many scientists presented an important research in this area. Dam stability during the earthquake is one of considerable factors which can be estimated by various parameters. In this paper, as a reliable parameter, safety factor is estimated using finite element method in PLAXIS 2D software. In this paper, reservoir water level is considered as a noticeable parameter which affects on stability of earthdam and safety factor during an earthquake. For this purpose, two different water levels, %30 and %70 of earthdam height, is assumed for reservoir. Also, in order to consider effects of earthquake, a magnitude MW 6.8 earthquake is applied to model. Angle of internal friction of earthdam materials is 30 to 35 Degree and the side slopes are 1:2.7. Additionally, as isotropy has no enormous impact on results, isotropic materials are assumed for earthdam. Analysis results indicate reservoir water level increasing from %30 to %70 of earthdam height has direct impact on safety factor reduction up to %8.

Keywords: Earthdam, Reservoir Level, Finite Element Method, Seismic Performance, Safety Factor.

1. Introductions

It has been a long time since the construction of earth dams was used to control and store water. One of the issues that is important in earth dams is the seismic behavior of earth dams due to landslide of neighboring areas or earthquakes. Mostly failure due to an earthquake was not in areas where the dams are concentrated; however, to investigate this comment a few practical experiences are available. Earthquake-related failures can be sub-categorized and for each group the stability prediction can be considered:

1 .The earthquake shake causes cracks in the upper parts of the dam and these cracks may happen exclusively in the core and water can flow from cracks and if there are no precautionary measures, the piping will eventually lead to the destruction of the dam.

2 .The earthquake shake causes the body or foundation to subsidence, therefore the dam's crest moves. As a result of the free height reduction, the water flows above the dam and the dam will destroy.

3 .The reservoir shake causes the formation of oscillary waves which are large and slow at the surface of the water. If there is not enough free height, the water inside reservoir passes the crest of dam toward downstream and possibly destroys the dam.

4 .Slopes of dam in the both sides might reach to failure due to earthquake and the dam can be destroyed from the both sides. One of the attractive factors is the stability of dams. To measure the stability of dams, various parameters can be used which one of the most accurate and reliable is the Safety factor.

Shong-Loong Chen et al. [1] entitled the effect of upward water level on dynamic response of embankment dams conducted a dynamic survey on embankment dams according to seismic conditions of Taiwan in DIANA-SWANDYNEII with different water levels and numerical simulations. In this paper, the penetration and dynamic stability of embankment dams making by three different types of soil such as clay, silt and silty sand have been examined. Results obtained from dynamic survey on five different water levels indicate that areas above foundation line and membrane part of upstream silty link to dam height have seep ability; moreover, pore water pressure makes rapidly and increase in medium of upstream silty part. Also, results indicate that pore water pressure in more than one third of upward out membrane mostly be negative until water height reaches to 0.75% of the dam height which is indicative of area stability and any seepage is impossible in this passive time.

Yu-xin Jie et al. [2] in a study examined penetration, seepage and also stress and strain on different water levels in embankment dams. In this research, in order to perform numerical simulation for filling water in a rock embankment dam, a simple approach has been used for analysis of unsaturated soil stabilization. In addition to stress and movement in dam, pore water pressure and phreatic line have simultaneously obtained. Results indicate that according to simultaneous effect between deformation and pore water pressure, progress of phreatic line in body and core of dam is faster than analysis of unsaturated penetration and seepage without simultaneous effect of deformation. Changes of pore water pressure is not only related to unsaturated penetration due to water surface changes, but also related to cavity due to deformation.

2. Material and Methods

In order to examine the dynamic behavior of embankment dams, a model was designed and safety factor for two cases of friction internal angles of 30 and 35 degrees in top and bottom levels of reservoir was investigated. For this purpose, a dam with 70 meters height, sides slope 1:2.5 and 9 meters length of crest was assumed. Clay soil was used for a core and a sand for drainage and also a foundation consist of clayey-sand. The dam has also a cutoff consist of grout (Figure 1), and then was meshed by the program (see Figure2).

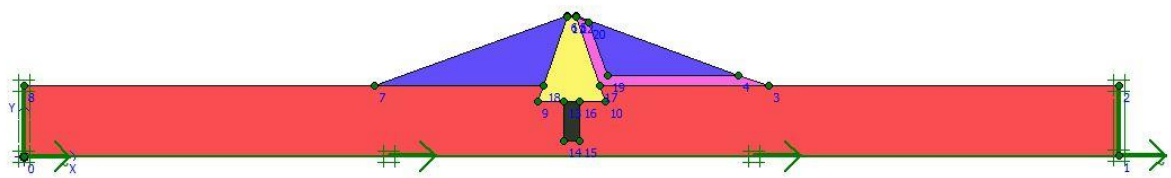

Fig. 1: soils cluster.

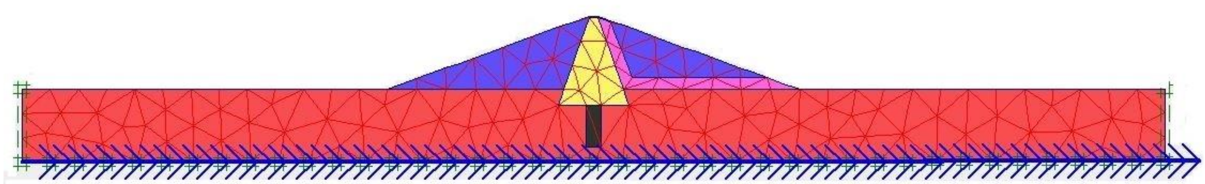

Fig. 2: mesh formation.

2.1. Soil Data

In this model, five soil specimens (grouted ground to seal the foundation by, clay soil for core, sand and gravel for soil draining, clayey sand for soil of and at last, silty sand for dam surface) ware used which properties of each of them separately shown in Table 1.

Table 1: soils specifications.

Soil	E(KN/m2)	C(KN/m2)	Φ	K(m/day)
Silty Sand	5500	30	35	0.2
Clay	2500	60	30	0.001
Clayey sand	3500	1	33	0.4
sand	30000	1	35	10
Grout	4000	1	33	0.05

The information above and also initial values of computations can be extracted by Allpile [3]program, Advance Soil Mechanic written by Das[4] and Foundation Analysis and Design written by Bowles[5] and other parameters can be computed. The table in this guideline and books has been taken for helping in selection of soils property.

Penetration of some soils has been mentioned in book of Advance Soil Mechanic from which can used for selecting the most appropriate soil. Test standard method for standard penetration test [6]and sampling soils by split rib tube (two scales sampling). This test method describes way of going forward two scales tubular sampling for obtaining definite soil specimen and measuring soil strength against sampling penetration, and generally it has been known as Standard Penetration Test (SPT).This standard do not express all safety cases related to its application, consumer of this standard account to provide appropriate health and safe instructions and define applicability of equality limitations before using. Values which is expressed in inches-pounds units as standard. This test provides both a sample in order to detection and appropriate experimental tests related to the soil, and another sample that it may lead to much touched shear deformations. This test has been widely used in exploratory geotechnical projects. There are any local and widely propagated relationships which number of SPT impact or N related to engineering behavior of earth works and foundations. Also, elasticity modulus of some soils can be determined by Foundation Design and Analysis book which is taken in the following using SPT.

Table 2: modulus of elasticity specifications.

Soil	Es(kN/m2)
Sand	Es=500(N+15) Es=18000+750N Es=(15200 to 22000)ln N
Clayey sand	Es=320(N+15)
Silty sand	Es=300(N+6)
Gravelly sand	Es=1200(N+6)

2.2. Earthquake Data

Magnitude (Richter) and amplitude logarithmic measuring of earthquake is in conjunction with released energy as earthquake waves in earthquake center. Earthquake magnitude do not have top and bottom limits; however, the most and least earthquake magnitude are 9.5 and -3.5. In this logarithmic scale, shallow earthquakes have been shown that elastic wave of earthquake with magnitude 6 Richter, has an energy about 30 times energy of an earthquakes with magnitude 5 Richter, and also more than 900 times one with magnitude 4 Richter and so on. Different factors are effective on determination of earthquake power including focus depth, distance of earthquake center to measure station, frequency of sampled energy and pattern of earthquake propagation (angle variety in vibration amplitude).

According to the statistics of earthquakes occurred in California[7], America between 1898 to 1989, at least 23 earthquakes with magnitudes between 6.5 to 7.2 are reported and also, so other earthquakes observed in less or more magnitudes. Measurement is done by the shaking caused by earthquake in any time. In whole, in three past decades in California, the scales which have had more strong shaking and acceleration during earthquake, have been measured by organization of coastal and geodetic of America. On the base of statistics, earthquakes are differed on different cases. Thus herein, an earthquake with the following characteristics has been considered which these cases can be accounted in possibility occurrence in an acceptable range among earthquakes which may cause damage. Earthquake characteristics used in this analysis, have been taken in Table 3 and also, acceleration in cm/s2, velocity in cm/s and displacement in cm versus time observed in the following Figures.

Table 3: Earthquake specifications.

Earthquake magnitude	6.8	Mw
The distance from the epicenter	77.7	Km
Peak value	-2.4	Cm
Sample rate	200	Hz
Acceleration	52.5	cm/s2
Velocity	3.12	cm/s

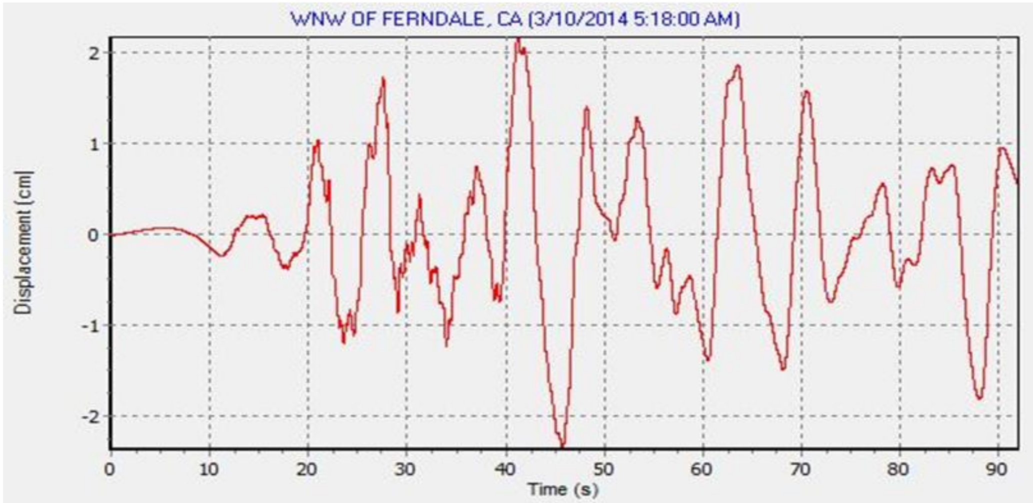

Fig. 3: Earthquake Displacement-Time diagram.

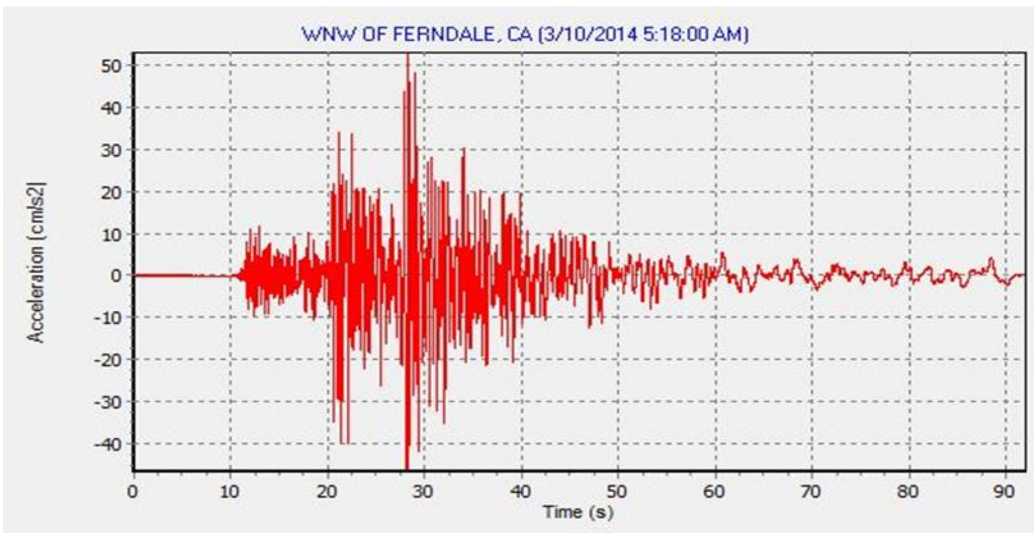

Fig. 4: Earthquake Acceleration-Time diagram.

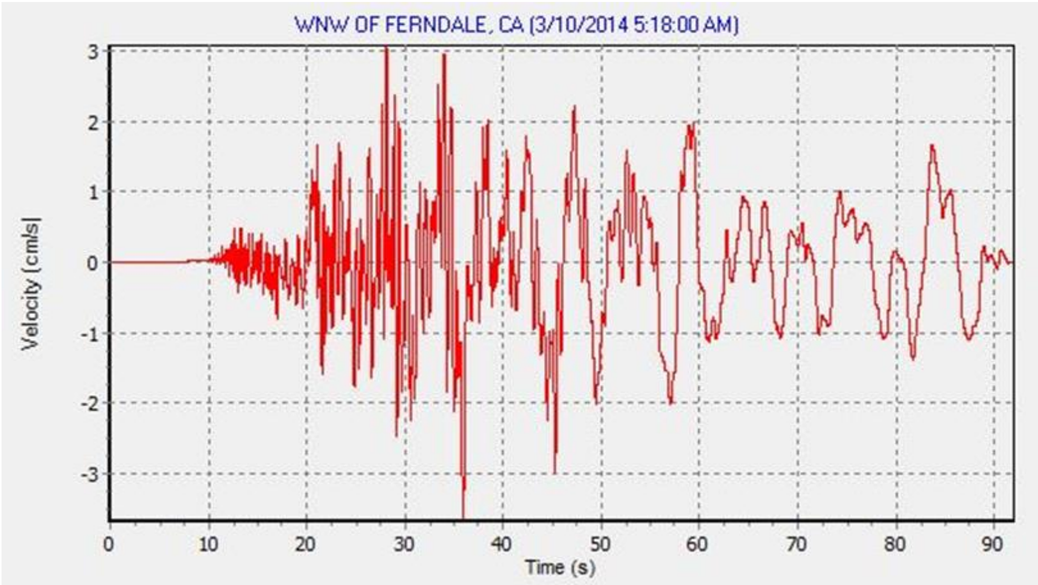

Fig. 5: Earthquake Velocity-Time diagram.

3. Results and Discussion

After modeling and applying initial conditions, seismic conditions of dam were considered according to two levels of water reservoir (30% and 70% of reservoir volume). These investigations were conducted in two different levels of water reservoir and each level by 3 times repetition. In the following, computation charts of safety factor were taken for different water levels with separation of reservoir water height that would be analyzed.

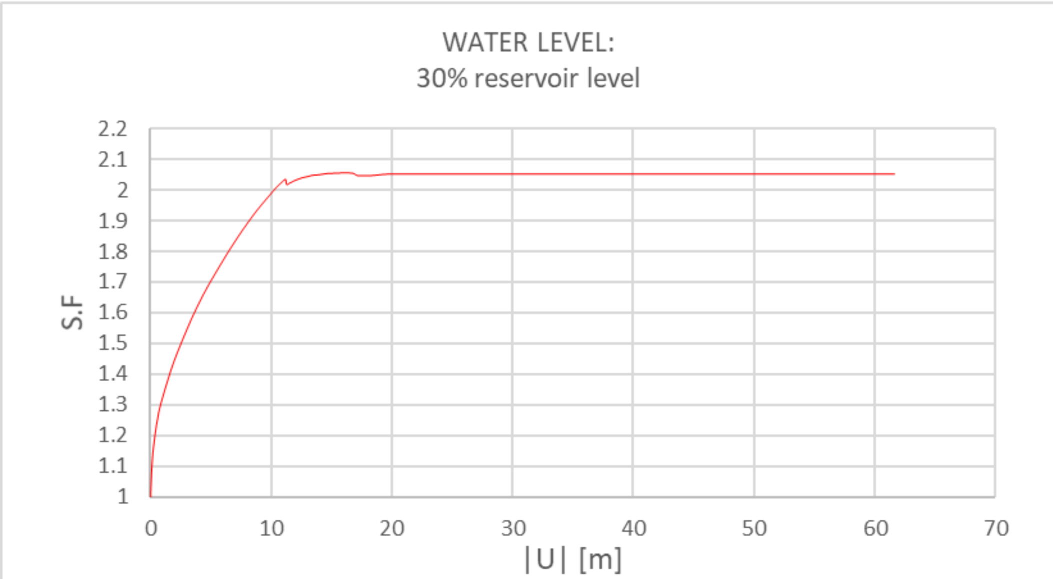

Fig. 6: Safety factor diagram-30% reservoir level.

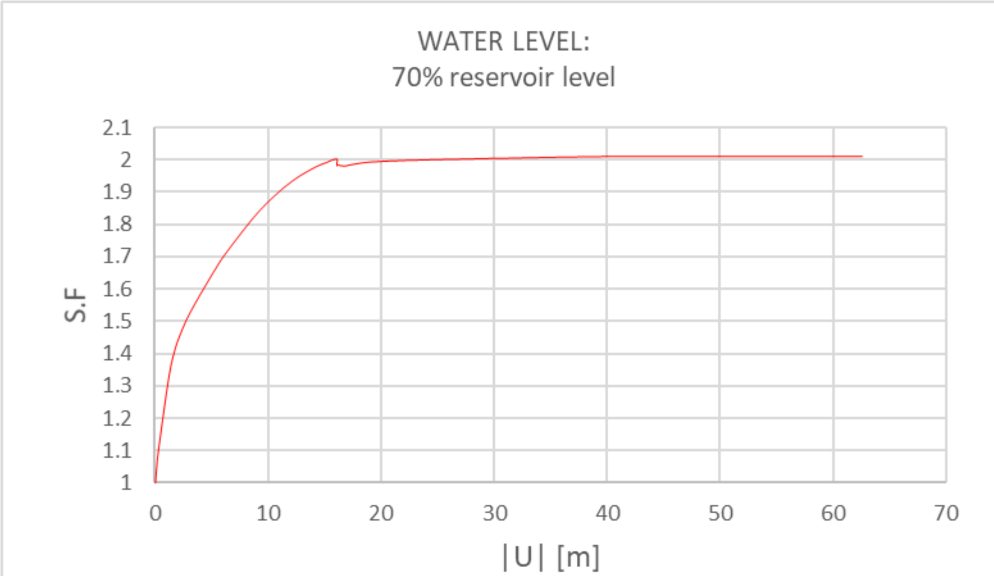

Fig. 7: Safety factor diagram-70% reservoir level.

Based on investigations and analysis of Tables and Figures in this research, it can be concluded that increase reservoir water level leads to reduced safety factor of dam. In the other word, dam reaches to high stability by increasing water level. Also, it can be found out by increasing water height in dam reservoir during earthquake, the program for dynamic computation of dam would later reach to the constant number and stability in factor of safety.

As it is observed in above charts, increasing water surface from 10% to 90% of reservoir height cause decreasing factor of safety.

4. Conclusion

Figures 6 and 7 indicates FS for two water levels. As it as it is obvious in these charts, curves slope reduced from level 30% to 70%. By drawing a tangent line between them to find safety factor, it's value becomes smaller. This means that, seismic stability of embankment dam is reduced by increasing water level of reservoir.

After conducted assessments about seismic behavior of embankment dams, results indicate that FS is decreased by increasing water level of reservoir; so that, dam stability is reduced by increasing water level of reservoir; one of the reasons can be the interaction between retaining water and dam structure. Also, according to the results, FS always have a value between 2 to 2.2. The Results shows that FS is reduced by increasing upward water level of dam; if water level is increased from 30% to 70% of upward water level, this reduction would be about 8%.

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