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DYNAMIC ANALYSIS OF STABILITY AS IMPORTANT PRINCIPAL OF EMBANKMENT DAMS AGAINST EARTHQUAKE

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ABSTRACT

Earthquake is one of the important risks in relation to our country's climate. In the range of faults and earthquake-strickenareas, the error of measurement, inappropriate and unsafe performance and wrong replacement of dams turned them into potential risky structures. During the present centuries, many of embankment dams built in the earthquake-stricken areas. The possibility of hitting an earthquake and tectonicsactivities resulted from the movement of faults exist both in the exploitation period in these dams that if happens, it will cause detrimental effects. What studied in this article after reviewing the risks of earthquake and destroys resulted from are the kinds of dynamic analysis and pseudostatic, which can guarantee the stability of different parts at the time of earthquake.

Key terms: embankment dams, earthquake, dynamic analysis, stability of dams.

INTRODUCTION

From A very long time ago, the embankment Dams were common to control and store the water supply. However, due to the constraint of facilities and lack of knowing the rules of earth mechanic and hydraulic, the height of dams and earth dams did not exceed from a limit although there were not such limitation in terms of width and length of dam. Today with the advancement of soil mechanic and the expansion of technological facilities and accurate studies, they could create a soil dam with significant height in a way that at present consider as the highest soil and rock dams of world. In addition to earths formerly recognized inappropriate for this purpose, now they can prepare them for building the infrastructure of embankment dams. Despite these advances, it is still hard to suggest firm mathematical solutions for the issues of designing the embankment dams. As a result, many of the dams' elements still design and create based on the experiment, motivation, and smartness of engineers. In other words, there is no complete design and exact type. In order to provide a precise and rational design in soil dams, it is required to completely study the primary situation of dam foundation and the constituent of it and perform controlled methods and exactly according to suggested programs of architect.

In the past, many of engineers and architects thought that soil dams were resistant inherently against the earthquakes but today it is proved that the behaviors of soil dams against the dynamic forces have special complexities and its evaluation needs an exact and scientific analysis of subject. As our country is located in the earthquake-stricken area of world and the increase of the number and height of soil dams under the construction and design, and also the approach of increasing the risks of building dams in this condition, the importance of a precise and scientific analysis of dams' stability appears during the earthquake occurrence. The design of dam is depended on the selection of methods for the analysis of earthquake condition and before it , the selection of a suitable method for static analysis eventually have the best dynamic analysis. The exact study of soil dams against the earthquake is from the most complex issues in the areas of soil structures. The diversity of dynamic features of soil dam body and the fundamental difference of earthquake features such as the content of frequency, the duration of earthquake effect and the maximum range are among the factors that play a role in dynamic response of dam. Fortunately, a number of soil dams that ruin in the earthquakes are rare, although we must not know this because of firm design but this is a lucky phenomenon.

The Ruins from Earthquake

In this case, there are not available much practical experiments but these ruins resulted can categorize into the groups and can recommend stability of designs for each group:

1. The movement of earthquake causes to cracking of the above parts of dams, which these cracks are exclusively in the core and the water stream, created from them and if there is no contingency measure, it can result into piping and finally the destruction of dams.
2. The movement of dams causes to the body leakage or foundation and the crown of dam and due to lowering the free height, the water

streams from the above of dam and destroys it.

3. The movement of reservoir can case the advent of big and slow waves but on the water surface in a way that the free height is not large, the water reservoir pours into the low range and cause into the destruction.
4. Because of earthquake, it can make landslides, if it is around the reservoir and the capacity of sliding elements is significant in relation to the reservoir, the overflow is not enough for the discharge and finally the extra water exceeds from the crown of dams and destroys it. Additionally, the earthquakes can cause to damage the plants of water emission or destroy or obstruct the course of overflow in which the water overflows from the top of dam.
5. If there is loose sand and to some extend event below the dam and in the foundation, because of earthquake reach to the extent of liquefaction that their resistance is completely trivial and cause side effects such as sliding, the cracking, horizontal movement or thorough destruction. In addition, the existence of saturated sands sensitive to the foundation can reach to a trivial resistance because of earthquake vibrations.
6. The loft of the sides of dam can reach to the stage of break due to the earthquake or destroy both ranges.
7. If an active fault is in the dam reservoir that cut the cross of the reservoir bed, if it is not the cause of earthquake by itself, it can raise an important part of reservoir that this phenomenon can reduce the capacity of reservoir and overflow the surplus of waters from the top.
8. If the fault is exactly under the foundation, not only what happened, it can also cause to break the body of dam that if the water crosses from the created hole, it causes the dam destruction.

The Prevention of Crack and Leakage of Soil Dam from Earthquake:

In ordinary lands, it means the lands that there is no possibility of earthquake happenings in them, several types of dams and for different points of a region is studied until the best , toughest and the most economical are selected in regards to the facilities of that region. In the earthquake lands, we must control every designs against the all-possible risks resulted from the earthquake. However, unfortunately, it is not still clear that how is the best method of treatment with the problem in quantitative. What an architect and engineer judgeaccordingly is the observation and examination of past effects of earthquake and a series of calculations based on the correct and logical assumptions usually achieved after the involvement of certainty coefficient related to different matters, that is not economical nor similar to what is in the land but to predict the required measures in the conditions without earthquake to prevent the risks related to each case. It is required to remember that the overflow and all channels of water existence should be from the courses that there is a minimum possibility of destruction and their blockage. In every land, there is a possibility of leakage of body and foundation of dam that this leakage cause to crack the dam and these cracks can be linear and latitudinal, width, or transverse. It is required that the prediction be in a way that created cracks are repaired and cannot cause to whole destruction. In the earthquake –stricken areas, the scopes created in low slope, and the free height exceeded considered as an extra calculation in the ordinary designs. Maybe the amount of exact surplus of free height is not capable due to the soil leakage and the effect of waves on the top surface of water resulted from earthquake but providing of an extra height does not bear a significant cost. Particularly,when the free height is higher, the cost of overflow is less creating in the ordinary conditions.

In this regards, we must predict the measures in order to prevent from resulted destruction of cracking. Although , we cannot present a general rule in this area and it only depends on the judgment and the method of design prediction that if it is the possibility of fast discharge of cracks of water flows it is hopeful that (if the authorities aware from them timely) to prevent from the destruction of dam.

Although in the areas without earthquake, it is common but in the earthquake-stricken areas, the existence of filter compatible with the drain with the enough capacity immediately on the head of dam in the low scope is required. This filtration must continue over the dam... clustering, the density, hit or permeability of filter must be selected with care and be from the materials without adhesive. The existence of this system unlike the main role of it in preventing the destruction resulted from the crack, because if in case of earthquake in the core of dam create a crack, the sand materials of head cannot block itself against the crack, then this micro lithic materials are washed and emitted from the crack. At the same time, in addition of advancement of concomitant crack with the fast movement, the water of body of dam destroys. If the filter is on the way, it is not remain it the crack due to the filtering material and the same time, prevent from the washing of materials reach to head.

Determination of possible risks after earthquake

Earthquake always been one of the concerning risks that can happen during a period of creation and exploitation of dam. In 6th of Jan, the earthquake of Bhuj in the Karaji, India, caused to the fundamental damage to several irritation of dam. The main damage is due to the stream-caused, the large meeting of Taj, the long longitude cracks in the top of the dam and across the crown of dam, the inflation over the dam and boiling sands happened in the surface of reservoir that not destroyed due to low level of water in the reservoir.

There are other cases of earthquakes caused to the damages in the soil dam as below:

1. Earthquake Santa Barbara, the dam Sheffield in 1925 in California – due to the flowing of sand close to the bottom of dam with the intention of earthquake.
2. The earthquake of San Fernando in 1971 is a phenomenon that proves the vulnerability of some kind s of soil dams and may examine as the starting point of advancement and development of researches in the security of sliding the big dams. The hydraulic dam of Lower Van Norman experienced the wide Liquefaction and main rupture of gradient. It prevented the rising compared to the top and flood in a region including more than 70 thousands of inhabitants downstream, due to low level of water in reservoir in a season, that earthquake occurred. The rupture near the dam of Lowe Van Norman has drawn the attention of authorities and safety engineers the potential vulnerability of soil dams build from the sand and soft saturated and compressed silt.
3. The dam of Hunadawa otani of Japan in 1939 and 1946 with the foundation of rock sand appeared the complete destruction and washing with a crack with the height of 75 meters across the top and the number of cracks with the heights of 10 to 50 meters on the uplifting gradient and probably resulted from the sliding of gradient.

According to the above matters which were the samples of earthquake incidents at time of exploiting the dams, although the earthquake is an event with the possibility of low incident but it is impossible and if it occurs, it can have many harmful effects. The event of earthquake is possible during the construction like the occurrence during the exploitation. And in case of occurrence can influence many areas of construction and place harmful effects.

Some effects of destroy from earthquake in the soil dams:

- ❖ The decline of resistance of foundation resulted from the vibrating movement of earthquake (liquefaction).
- ❖ The occurrence of leakage stream focused from the body of dam (in particular from the top part).
- ❖ The cross of fault from the foundation or its activity
- ❖ The considerablesliding or falling at place of side of supports
- ❖ The occurrence of leakage centralized from the foundation
- ❖ The reduction of material resistance from the body of dam(from the liquefaction)
- ❖ The reduction of dam height and free depth from the high leakage of body or lifting the surface of reservoir
- ❖ The creation of different cracks in the body of dam (particularly the linear cracks) that caused to the central leakage of water from the uplifting to downstream
- ❖ The creation of strong waves in the reservoir and supercharge of water from the body of dam.
- ❖ The damage from overflow and the exit valves of water and lack of possible and fast discharge of reservoir.

Methodsof Stability Analysis of Soil Dams in Condition of Earthquake Occurrence

Generally, in order to study and analysis the soil dams and natural soil gradients, different methods have been developed so far that is categorized into the following two main groups according to the nature and philosophy of work:

- Pseudo Static methods Of Analysis
- Dynamic Methods Of Analysis

Pseudo Static Analysis:

Pseudo static analysis of soil dams is a simple and ordinary method in the study of stability of soil dams while an earthquake occurs. The Seismic coefficient, in order to evaluate the certainty coefficient of soil dams, use under the shaking resulted from the earthquake. In this method, the multiplication of Seismic coefficient creates in the weight of the mass susceptible to landslide, with the maximum inertia force, is equal to the earthquake with the speed of ng in figure 1 created a mass force in horizontal direction with the intention of ng equals to the weight of land sliding mass. The vector of this mass force (ng.w) like the mass weight (w) passes from the center of gravity of part abc(o1). This force with the leverage of F caused the gravity that is switched the part around the center of O. Hence, due to the earthquake, the certainty coefficient of roof reduces against the slide.

$$Fs = \frac{S.l.R}{EW+Ng\ FW}$$

In the above relation also, E is the distance of effective mass weight to the center, O, S is the adhesiveness of mass. On the deduction, the resistant anchor is from the cutting mass resistance and in the exit; the stimulus anchor is from the mass weight and the speed of earthquake.

It is noteworthy that the pseudo static method is an approximate method , because the speed of earthquake happens in both horizontal and vertical directions and with various amounts in ratio with the time.so, in this method, it cannot consider completely a particular dynamic effect imposed on the embankment dams during an earthquake. For example, the precise analysis showed that during the earthquake the acceleration on the top of dam is more than from its base and more importantly, the pseudo static method cannot predict the effects made by the water pressure of extra holes from an earthquake on the quality of materials sensitive to the liquefaction. Therefore, it never should be applied to design the embankment dams consisted of sands or dams located on the sandy foundations.

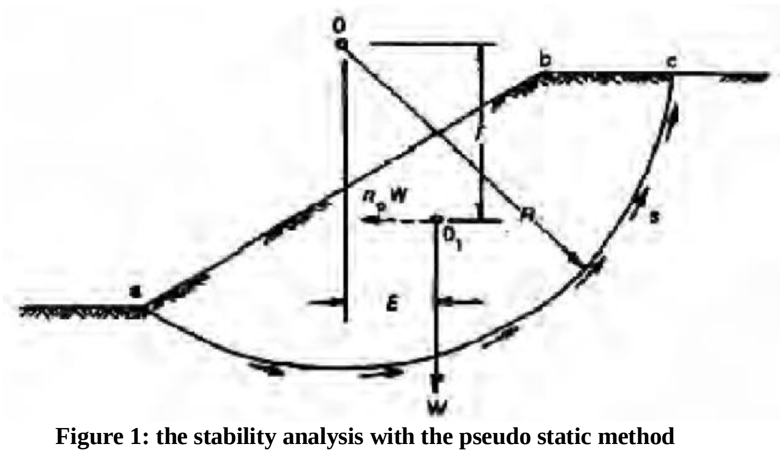

Figure 1: the stability analysis with the pseudo static method

The limitation of pseudo static methods:

1. In this method assumes that embankment dams treats like a solid object and therefore the accelerations are uniform and equals to the earth acceleration while the embankment dams or levees (except for the solid levees

in the thin valley) has a flexible treatment.

2. It is assumed that the acceleration entered on the body of dam changes with over time while the entire seismic phenomenon modifies compatible with time.
3. To prevent the complexities of problem and facilitate in applying this method, it is assumed that the equal force enterfrom a horizontal accelerate and in one direction while the direction of inertia force modifies from the acceleration with different directions.
4. Plasticity metamorphosis resulted from earthquake is considered in this method.
5. For the dams which made by the non-adhesive and saturated soil and exposed to the strong movement of earth, the first reason of damage or rupture is the increase of water pressure in the holes of levees and as a result of resistant reduction that there is not possibility to predict this kind of rupture by means of pseudo static analysis. In fact, the pseudo static analysis does not consider the process of producing the water pressure of holes, the redistribution of it and the prone to the resistance reduction in the different measurement levels.
6. The seismic coefficient constantly and ordinarily causes to achieve a conservative part or downstream for the levee.
7. In this method, the treatment of a variety of soils against the dynamic loading and their performance after theoccurrence of the earthquake plays no role in determination of seismic coefficient.

Despite Bolten Seyed concluded because of a dynamic analysis that the pseudo static method is applicable for the materials from the earthquake are not reduced the resistance or added the pore water pressure. However, some engineers argue because of mentioned limitations, originally, in no cases we should use this method in the stability analysis of soil dams.

Dynamic analysis

If the body of embankment dam treats as a solid object and no sliding happens, the amount of applied acceleration on the body of dam in all uniformed parts and in all equal states with the earth acceleration (foundation) in the location of construction. On this basis, we can consider the earthquake acceleration equals to the maximum acceleration of earth at place. Therefore, this assumption is not correct due to two reasons:

Firstly, different measurements showed that never the embankment dams actually treated as the solid object but it is flexible and shows different treatment compatible with the general specification against of earth movement.

Secondly, the maximum acceleration in the body of dam occurs only in a short period of time and tensions and metamorphosis made in the body of dam in a range of real earthquakes with cycles having different maximum acceleration is completely different from the inertia force resulted from the maximum acceleration.

The dynamic analysis of response, under the movement of earthquake including the determination of time history of acceleration or speed and the reaction of dam is estimated based on the behavior pattern. The behavior evaluation of metamorphosis of an embankment dam or levee in dynamic analysis is usually carried out by use of the limited method of elements or limited difference. An accurate dynamic analysis is required to have a wide informational database and special skills. For the big dams and also dams on the active faults, the accurate dynamic analysis is attended in order to evaluate the roof seismic stability, and we can apply the deforming-tension analysis. Apart from the deforming-tension of static stability of roofs which is done in general with the use of analysis of limited static elements. In some analysis, the durable measurements from the earthquake are calculated with achieving the constant deformation of roof in every limited element. The constant measurements inside the single elements are evaluated from different methods. In deforming-tension analysis, with the use of experimental results of lab, the roughness of soil is determined under the earthquake loading and then with the method of potential measurement and so on, the reducing roughness calculates the constant deformation.

To understand the real treatment of embankment dams under the influence of earthquakes, we must select a suitable dynamic model for dam and study its momentary time.Today, different dynamic analysis is applied to analyze the dynamic of soil dams by researchers that the most important ones are as below:

1. The methods based on solving the equations of dam movement
2. The separation methods of dam to parallel layers and dynamic analysis to numerical methods
3. Method of limited elements

Dynamic analysis with the help of limited element method

Dynamic analysis of soil dams can be done with the help of limited element method that the complexity of problem and accuracy is more in this case. The easiest form of dynamic equation for a plasticity material presented by the Zinkovich (1977) & Nillvar (1975) as below:

(1) Ma = ca + ka = f

M: matrix mass C: Matrix attenuation K: roughness of matrix f: vector of force a: the vector of nodes displacement

The points on the letters indicates the degree of derivation towards the time (it means... indicates the second derivation and symbol.. indicates the first derivation). The first expression in the left side of equation 1 related to the inertia forces from the earthquake acceleration. The second expression related to the specification of liquefaction of soil (the power of soil in distributing and amortization of seismic energy.) and the last expression is related to the required forces for creating the plasticity deformation of soil. The above equation shall be solved according to some boundary condition and this usually takes place with the consideration of specific acceleration in the foundation level. If the equation in this specific acceleration is ag, and no other external force applies in this system, so the equation 1 will be as the following:

Ma + ca + ka = 0

To solve the mentioned equation, it should apply the boundary condition in relation to the acceleration, speed and specific displacement. In this way, the mentioned equation would be solved with the help of method transformation to model amplitude (Zinkovich, 1977) or with the method of explicit time marching scheme (Klaf & Koopra, 1966).

If the foundation of dam consider in the analysis, the main problem will be the reflection of waves on the boundaries introduced on the limited element network. This will have fundamental effect on the way of analyzing the problem and considering the effect of boundary condition. The problem of studying the effects of boundaries and selection of their position in relation to main structure discussed by Lissmer & Koolmar (1969) and booker & Esmal(1981).

The stability determinations by use of the limited element method proposed by Seyyed (1966) for the first time and the following stages suggested:

- The time history identifies the provocation of base or foundation of desired dam.
- Calculate the application of limited element analysis create tensions by provocation of foundation in the body of dam.
- Place the material samples of the body of dam exposed to the combinational effects of primary

static tensions and dynamic tensions.

- With having the pore pressures made during the earthquake, estimate the characteristics of deformation and resistance of soil and certainty coefficient against the rupture within or after the earthquake.

In order to solve the soil case having non-linear features and according to the Time Marching Scheme by Zekovich, Chang & Hinton (1978) applied from the criteria method of Moher Kolmb. In these calculations, the pore pressures have been considered that these changes calculated with the use of predicted mass deformation of soil.

Another finding of dynamic analysis with method of limited element is that distribution of side acceleration and dynamic cutting tensions is not in the horizontal uniform level but reduces from the central axis to the gradients. Therefore, the average amount is close to the uniform amount given by the theory of cutting deformation. Further, the evaluation of tension distribution in different times has been shown during the earthquake that in the gradient of soil dams, created the wide elastic range. This actually implies the cracks made in soil dams after the earthquake. In addition of dynamic analysis with the method of limited element, it is shown that the vertical acceleration induced by the horizontal movements and vertical to earth in the soil dam can have considerable figures.

CONCLUSION

The stability of soil dam involving the roofs, foundation, the top of dam and so on always have been the important concern of designer and the occurrence of an earthquake can cause detrimental effects. We can say that dynamic analysis of soil dams against the earthquakes always have been a valuable parameter that secure the dams against the subsidence and all kinds of cracks. Besides, the evaluation of dam deformation by use of dynamic analysis with the method of limited element and limited difference has made a big contribution in developing to achieve a target to a dam without the reaction against the seismic implications.

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