Abstract

Behavior of Earth dams against dynamic forces has exclusive complications. In this situations, design of dams requests strict analysis and exact knowledge about effective parameters on dam operation. Existence of materials with variant types, thickness, physical characteristics, also especial essence of earthquake, all are parameters that complicate evaluation of dams behavior and stability analysis of upstream and downstream slopes in earth dams. In the past decades, slope stability analysis using pseudo static methods in several dams such as Sheffield, oshima and upper or under sanfernando dam, and observation of their failure in earthquake, despite of safety factors greater than one, caused doubts in utilizing of this method. In this research, by evaluation of several case studies, limitations of pseudo static methods were studied and in follow, results of them will be presented.

Key words: Earth Dams, Stability Analysis, Limitations, Pseudo Static Method, Dynamic Method, Safety Factor.

1- Introduction

Until now, variant solutions have been introduced for stability analysis of slopes in earth dams. These methods have been divided to two ways: limit equilibrium and stress-strain method. Base of limit equilibrium methods be determining of imposed stresses and mobilized strength on assumed surface of failure and then, determining of safety factory. Methods such as Fellenius, Bishop, Taylor, Spencer and Janbu are used for this matter [1].

But, in stress-strain method, after discretising of dam in cross section and foundation, also, assumption of rigid boundary in noticeable distance from slopes, stress and strain distribution are analyzed and safety factor are evaluated on the most liable surface of failure [2]. However, this analysis in earthquake situations could be done in pseudo static and dynamic ways that the later case, because of its simplicity and fast was more
usefull in the past. But, now there are doubts in use of this method that it has been studied in this research.

2-Principles of pseudo static methods
In this methods, effect of earthquake are considered by pseudo static accelerations that are caused by inertia forces ($F_H$, $F_V$) on center of slide mass.

\[ F_h = \frac{a_h W}{g} = k_h W \]  
\[ F_v = \frac{a_v W}{g} = k_v W \]

In these relations:
: Vertical and horizontal acceleration $a_v, a_h$
$K_v, K_h$: Non-dimensions coefficients of earthquake in Vertical and horizontal direction
$W$: weight of sliding mass

In classic pseudo static methods, at first, land slide mechanism is assumed in dam cross section and after that, safety factor is determined on this surface. It is clear that by repeating of calculations on other surfaces, the surface that has a lowest safety factory will be given [3]. If safety factor is greater than one, generally, slope is stable but observations demonstrate that this assumption isn’t correct always.

3- Case study
3-1- upper and lower sanfernando dam
In earthquake on 1971 in Los Angels that its magnitude rating was 6.6, until 40 Km from center of earthquake, there were 44 dams from height 9 to 58 m. Through them, upper and lower sanfernando dam were damaged during this occurrence. Both of them, were constructed by hydraulic filling way and an epicenter located approximately 10 Km from dam. In upper sanfernando dam, down stream shell slided but in lower sanfernando dam upstream slope slided.

In design procedure of lower sanfernando dam that stability analysis was done by pseudo static and slices method, safety factor (S.F) in earthquake with friction angle 35 and acceleration 0.15g and 0.1g determined 1.01 and 1.08.

Other calculations showed that for S.F=1, base on pseudo static method, $K$ is 0.22 to 0.34 [4]. Therefore, dam must be stable but, it damaged. Moreover, seed (1978) found out that S.F in strain 20% is 0.8. Thus, calculation of S.F regardless strain maybe makes a mistake [5]. A view of lower sanfernando dam after sliding in earthquake on 1971 are shown in fig.1.

![Figure 1. View of lower sanfernando dam after sliding](image_url)
3-2- Sheffield dam
The failure of the Sheffield dam in California, during an earthquake on June 29, 1925 marks one of the recorded cases in which a catastrophic slide failure of an earth dam. The Sheffield dam was constructed in 1917 by compacted method. The body of the dam was composed of silty sand and sandy silt containing some cobbles and boulders, but the upstream slope was faced with a 4 ft thick clay blanket which was extended up to 10 ft into the foundation. The foundation soil consists of a layer of terrace alluvium, 4 ft to 10 ft thick, and overlying sandstone bedrock. The earthquake has been assigned a magnitude rating of 6.3 with an epicenter located 11 Km from dam site. Maximum ground acceleration was 0.15g and duration of significant shaking was 15 to 18 second that caused slid downstream perhaps 100 ft. From analysis of the stability of the downstream slope before the earthquake, the S.F was determined 1.68 for effective stress strength parameters $c' = 0$ and $\phi' = 34.5$, but in pseudo static method, the S.F determined 1.31 for $K=0.1$ (see fig. 2).

<table>
<thead>
<tr>
<th>Factor of safety before earthquake</th>
<th>F.S = 1.92</th>
<th>F.S = 1.68</th>
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<tr>
<td>Factor of safety during earthquake</td>
<td>F.S = 1.21</td>
<td>F.S = 1.31</td>
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Figure 2. Computed factors of safety for pseudo-static analysis using seismic coefficient $K=0.1$ in Sheffield dam [6]

Clearly, by using a somewhat higher value of the seismic coefficient, the S.F could have been reduced to 1.0. A seismic coefficient of 0.17 would have led to this result. With regard to earthquake acceleration between 0.04g and 0.15g, this dam must be stable but, it damaged in earthquake [6].

4- limitations of pseudo static methods
eventually, with regard to results of two case studies and evaluations, we must note that pseudo static methods have a several limitations such as:

1-Assumption of constant acceleration in height of dam is opposite of real behavior of dams and it leads to errors in results. Because the earthquake acceleration imposes in both horizontal and vertical direction and their magnitudes varies with time, therefore, this method can't completely consider the dynamic effective of earthquake and thus, pseudo static methods are approximate ways. The exact analysis have shown that during the earthquake, the acceleration in crown of dam is more than bed [5].
2-The result of pseudo static method is strongly depended to seismic factor ($K$) that choose of a well factor is one of the most difficult procedures.
3-For using of this method is necessary that the design earthquake will be known with all of its characteristics for determining of dynamic reactions. Because, generated acceleration depends on earthquake contents completely.

4-The dynamic behavior of dam is a function of dynamic properties of materials that determining of them is very difficult.

5-Analysis by pseudo static method similar to all limit equilibrium ways, exhibits a index for stability [7], but it doesn’t represent any information about strains in failure mode.

6-Selection of effective parameters in calculations, lead to variant answers that benefit of one to others isn't known.

7-Concerning basic concepts of pseudo static methods, if S.F will be less than one, slope must be slide. In fact, inertia forces at a time distance less than one second, maybe it will makes S.F<1, however because its effects are immediately disappeared, it might not be accompanied with dam damage [8].

On the other hand, one of the biggest limitations of pseudo static methods is that this ways don’t relate $K_h$, S.F and failure.

The more the $K_h$, S.F reduces and as shown in fig.3, if S.F releases to less than one, this can't mean failure and instability in dam, because, pseudo static method applies forces as a permanent force on dam, while in earthquake situations, slopes are under this forces in a limited period.

![Figure 3. Reduction of safety factory with increases of $K$ [8]](image)

8-Pseudo static methods can't predict effects of increases in pore water pressure due to earthquake on deposits that have a liquefaction risk.

Dust, it better not use this method in design of earth dams on sandy deposits or consist of sand.

**4- Conclusions**

Concerning evaluations of two case studies, we should note that however, pseudo-static methods are easy and fast but, because of their limitations, it ought to not use this method for stability analysis of earth dams. In design procedure it is advised utilizing
dynamic methods, but if we want to use pseudo-static way, we should concern limitation of it, seismic characteristic of dam site, dynamic properties of soil, also amount of risk acceptation for downstream regions, before we start calculations.

6-References
[1]-Terzaghi, (1950), Mechanics of landslide.
[8]-Geoslope software manuals, Calgary, Alberta, Canada.