Earthquake Induced Landslide Potential in Maku Dam Reservoir (NW Iran)

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ABSTRACT:
Earthquake induced landslide potential is estimated for Maku dam reservoir located in northwestern Iran. Data sets used in the analysis include a comprehensive seismotectonic and seismic hazard analysis in Maku dam site, strong motion records of the 1976 Chaldiran earthquake at Maku city station and 2005 earthquake, and estimated engineering properties of rocks. Combining these data in the Newmark's dynamic model resulted to a critical acceleration estimation which yields to coseismic landslides. Spectral matching of these records with target spectra characterized that the Baroon-Bedavli fault, although with lower maximum magnitude, plays more significant role to induce landslide comparing to Chaldiran fault which has a higher seismogenic potential.

KEYWORDS:
Landslide potential, Earthquake hazard, Maku dam, Chaldiran earthquake

1. INTRODUCTION

Maku earth dam with a height of 78 m and reservoir capacity of 150 million m^3 was constructed on Zangemar River at the upstream of Maku city, northwestern Iran. Irrigating of the dam started in 1990. Field investigations show that the oligomiocene limestone in the left abutment of Maku dam reservoir has slided toward reservoir and it is still continuing. Geological evidences such as colluvial deposits show that slides in both banks are triggered many years ago although it was increased after impounding. Apart from climatic conditions, earthquakes are the main responsible for triggering landslides. Other geological conditions like layers dip direction, joints and fractures and presence of active Baroon fault in the dam base and reservoir increase sliding potential. Some earthquakes occurred in the near vicinity of Maku dam site before the dam construction and after impounding of the reservoir. The frequency of earthquakes confirms that the area of the dam site (northwestern Iran and eastern Turkey) is a high seismic zone.

In this study, a seismotectonic framework was modeled first. Then, a seismic hazard analysis of the dam site was carried out to asses a deterministic horizontal response spectrum. With regard to rock mechanics analysis and slope map, a FS (static safety factor) was estimated. After that, a critical acceleration for triggering of probable induced earthquake sliding was performed. Several strong motion accelerograms are recorded at Maku dam site in free field. Therefore, one of the recorded time histories was spectrally matched to the deterministic spectrum. Then, it was characterized whether or not landslides can be induced by larger earthquakes.

During the study, the seismic hazard analysis team of the project performed a comprehensive approach for the dam site and the uniform response spectrum was calculated for the Maximum Design Level (MDL). A probabilistic seismic hazard analysis of annual rate for magnitude was controlled by the slip rate of seismic sources. Considering the source and site roles, the accelerograms of the 2005 earthquake recorded at the Maku dam station was selected and spectrally matched to the maximum design level uniform response spectrum.

Following to this matching, the final time history was the criterion to compare the yield acceleration for failure.

2. TECTONIC AND GEOLOGICAL SETTINGS

Site locates in the Turkish-Iranian Plateau which has an average elevation of approximately 2000 m, composed of continental fragments accreted to the margin of Eurasia by the Late Cretaceous or early Tertiary, melanges, ophiolites, and a covering of volcanic rocks and Cenozoic sediments (Sengo¨r, 1990). In this region many active major faults separate various lithotectonic units.

Apart from the Bedavli-Baroon fault which is located in the near vicinity of the Maku dam, there are other capable faults like Gailatu-Siah Chesmeh-Khoy and Chaldiran faults. Total offsets on the faults in the Turkish-Iranian Plateau were estimated through observations of offset geomorphological features, restoration of pull-apart basins, and examination of geological maps by Copley and Jackson (2006). A summary of Copley and Jackson (2006) work is inferred slip rates of two faults as follows:
Gailatu-Siah Chesmeh-Khoy fault: 2-4 mm/yr
Chaldiran fault: 8 mm/yr

Berberian (1983) prepared a preliminary seismotectonics report for Maku dam site. This report was a good descriptive report of the known faults and historical and instrumental earthquakes. However, there is no investigation about ground movement and faulting in that report. During the first and second phases of this study, seismotectonics evaluations were developed by several comprehensive field study and morphotectonic evaluations by areal photo stereoscopy. The knowledge on seismotectonics of the region was improved after Giardini and Ballasanian (1997) published their book entitled "Historical and prehistorical earthquakes in Caucasus".

Slided region in the left bank of the Maku reservoir (Figure 1.a), dam foundation, and both abutments are all located on the southern limb of Baroon asymmetric anticline (Figure 1.b) which is covered by Oligomiocene Qum limestone. Qum formation is divided into three members which from base to top are as follow:
1- Thin bedding limestone member.
2- Thick bedding limestone member.
3- Greenish marls member.

Qum formation covers Permian dolomitic limestone (Ruteh formation) by an angular unconformity (Figure 1.c). Ruteh formation itself covers Devonian shales.

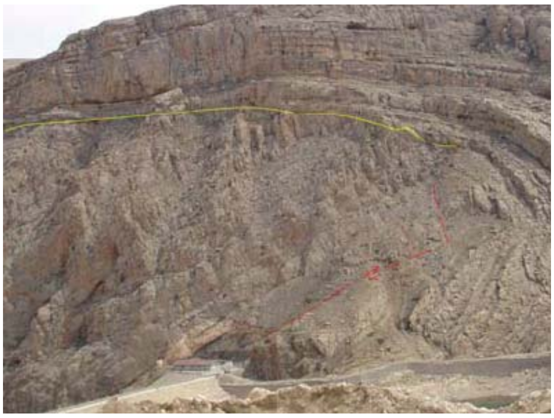
In the dam location Devonian shales is thrusted on the first member of the Qum formation by Baroon reverse fault (Figure 1.d). The major part of shortening released on the Baroon fault, which is located in the core of Baroon Anticline, leads to a displacement at Qum formation thin layers. The first member of Qum formation, dipping toward upstream, is being compressed by movement on the Baroon fault. This shortening causes sliding failure deformation in thin bedding limestone and marls and rockfalls in thick limestone of Qum formation. Two deformation phases is confirmed by angular unconformity without changing of principle stress axes. The southwestern limb of baroon anticline is luci of a reverse fault with the same name. Although its surface feature is obvious anticline sections but is not on the earth because of folding and covering by slope instability. Baroon fault reached to the Bedavli dextral fault in its north termination. The activity of Baroon fault is confirmed by many earthquakes in its hanging wall, some of the most recent ones are 2005.8.17 (mb 4), 2005.9.1 (mb 4) and 2006.5.9 (mb 4.2).

3. LANDSLIDES MORPHOLOGY

The investigation on the slides (Figure 1.e) shows that there are parts of larger landslides which occurred in both left and right banks of the dam reservoir, although the most recent slides belong to the left bank. The geometry

(a)

(b)



(c)

(d)

(e)

Figure 1- a) Maku damsite and slide surface in its left bank, b) Baroon Anticline and Maku dam reservoir, c) Unconformity between Premian and Oligomiocene (yellow line) and Baroon fault (Red line), d) Baroon fault in the core of Baroon, e) Landslide No. 1 in the left bank of Maku reservoir.

failure surface of landslides is radial and the material of landslides is the second member of Qum formation which is severely weathered and all of them are higher than the normal water level. Table 1 shows the morphological characteristics of four important landslides in the left bank of the Maku dam reservoir.

Table 1- Geomorphological characteristics of landslides in the near vicinity of the dam reservoir

Landslide No	Length	Width	Depth	Displacement
1	75	115	5	4-6
2	38	42	4	6
3	Not so much	Not so much	5	4
4	Not so much	Not so much	7	3

3.1. Modeling Method

The Newmark method (1965) was used to evaluate the earthquake induced landslide potential in the Maku dam reservoir. Wilson and Keefer model the dynamic behavior of landslides on natural slope leads to reasonable and useful results. Newmark (1965) showed that the critical acceleration of a potential landslide block is a simple function of the static factor of safety and the landslide geometry, expressed as:

$$a_c = (FS - 1)gSin\alpha$$

where a_c is the critical acceleration in terms of g, the acceleration of Earth's gravity; FS is the static factor of safety; and α can generally be approximated as the slope angle. Thus, conducting a Newmark analysis requires knowing the static factor of safety, the slope angle, and selection of an earthquake strong motion record. Unfortunately, in the Maku dam region a 3D topographic map was not available and therefore, it was not possible to produce digital landslide hazard maps similar to Jibson et al (2000) in California.

In the Newmark method, the dynamic stability is related to static stability. The static factor of safety can be obtained by the following relationship (Jibson et al, 2000)

$$FS = \frac{c'}{\gamma t \sin\alpha} + \frac{\tan\Phi'}{\tan\alpha} - \frac{m\gamma_w \tan\Phi'}{\gamma \tan\alpha}$$

where φ′ is the effective friction angle, c' is the effective cohesion, α is the slope angle, γ is the material unit weight, γ_w is the unit weight of water, t is the slope-normal thickness of the failure slab, and m is the proportion of the slab thickness that is saturated. For estimation of effective cohesion and effective friction angle, the rock mechanics team work did some back analyses with considering FS=1. With this approach a range presented by rock mechanics teamwork but we used the most conservative parameters as follow:

$$C = 15\ Kpa$$

$$\varphi' = 25^\circ$$

Slope angle in the region under study is about 10° and the most important factors controlling the slides are geological setting (dip direction of layers is toward reservoir), raining rate and its effect to pore-water pressure, rock mass quality and finally earthquakes intensity. With regard to water base level and raining rate, the saturated depth estimated to be 2 m and FS to be 1.42.

4. SLIDE POTENTIAL

After computing the static factor of safety (FS), the critical acceleration which can trigger initial sliding can be obtained through the Newmark's relationship. Based on the FS amount and Newmark approach, the critical acceleration is computed as 0.71g. Figure 2 shows the uniform response spectrum of Maku dam site in the Maximum Design Level (2000 years return period) at 50th percentile. In the analysis, an acceleration time history was selected and the critical acceleration of the slope to be modeled was superimposed. The time history of 2006.9.5 earthquake, whose characteristics are summarized in Table 2, was selected and spectrally matched to the response spectra. Figure 3 shows the acceleration time history of 2006.9.5 earthquake after spectral matching. It shows that Peak Ground Acceleration (PGA) may be exceeded to critical acceleration, and potential of sliding is probable in the case of earthquakes due to the movement on the Bedavli-Baroon fault.

Table 2- Characteristics of the selected earthquake for dynamic slope stability analysis

Station Name			Earthquake					Component (cm/s/s)		
	Lan	Lat	Date	Time	Lon	Lat	Mb	L	V	T
Maku dam(Free field)	44.48	39.19	2005/08/17	18:26:44	44.59	39.39	4	82	53	125

5. DISCUSSION ON THE 1976 CHALDIRAN EARTHQUAKE

A large earthquake occurred in eastern Turkey on November 24, 1976 in Van province where was very close to the Chaldiran Plane. The magnitude of this earthquake was Ms 7.3 and had 55 Km fault rupture related to the Chaldiran fault and had 42 Km epicentral distance to the Maku dam site which is impounded in the middle of 1995.

With regard to an 8 mm/yr slip rate for the Chaldiran fault, one can expect that a large earthquake may occur in the future. An accelerogram recorded in Maku city of Iran, presented by Moinfar (1980), was selected and matched to the target spectrum. In the latter analysis, the target spectrum was obtained by considering the role of Chaldiran fault only. Figure 4 shows the 1976 Chaldiran initial and final acceleration time histories before and after spectral matching. Taking into account the critical acceleration for triggering slide in Maku dam reservoir (0.71g), the probability of occurrence of landslide due to a large earthquake on the Chaldiran fault is minimal.

6. CONCLUSIONS

Earthquake induced landslide potential in the Maku dam reservoir was studied. According to this study, most of the old and recent landslides on the south limb of Baroon anticline, where the Maku dam lake is located, are due to the increase in pore-water pressure. Some of the landslides are seismically induced due to the trigerring caused by the movement of the Baroon-Bedavli fault. Because of the critical acceleration of 0.71g to cause sliding, seismically movement on the Chaldiran fault could hardly induce landslide. Artificial dip reduction was performed so that static factor of safety (FS) reached to 1.52. However, the probability of earthquake induced landsloide should be probable in the upper high angle thin and thick limestones layers if the baroon-Bedavli fault is seismically moved by its approximately maximum magnitude.

7. ACKNOWLEDGEMENT

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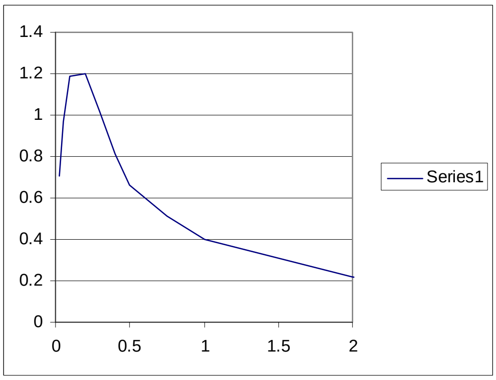

Figure 2- Uniform response spectrum of Maku dam site in the Maximum Design Level

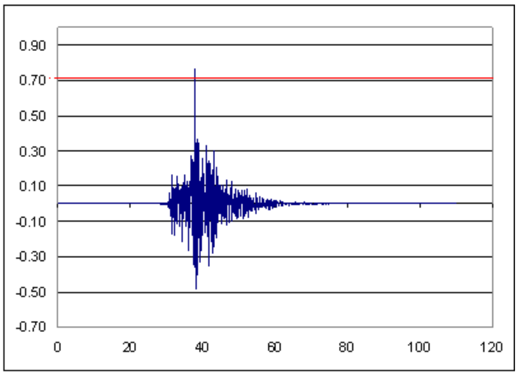

Figure 3- Acceleration time history of 2006.9.5 earthquake after spectral matching with target spectra. Red line shows the critical acceleration to yield slides in Maku dam site.

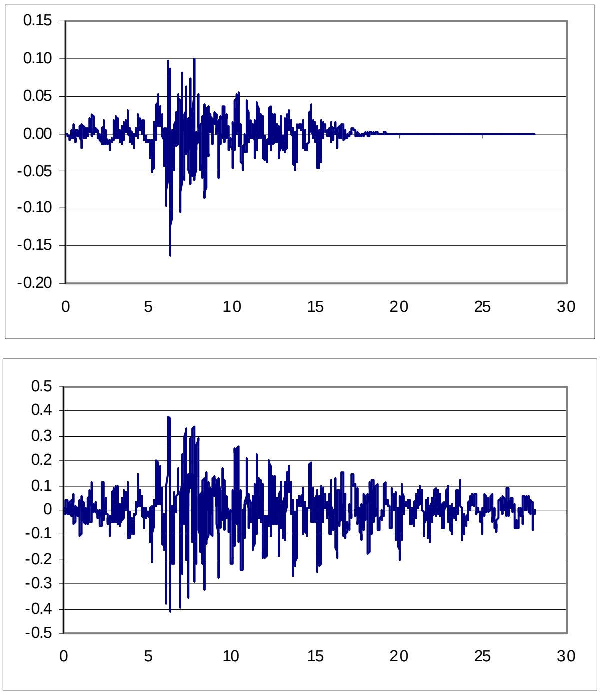

Figure 4- Initial and final Chaldiran 1976 acceleration time histories before and after spectral matching to the target spectrum.

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