Известия НАН РА, Науки о Земле, 2018, 71, № 2,30-37

SEISMIC ACTIVITY STUDIES AND SEISMIC RISK ASSESSMENT FOR SOME OPERATING DAMS IN ARMENIA

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Reclived by the editor 21.11.2017

The problem of induced seismicity related with operation of reservoirs is essential in geophysics and earthquake engineering, especially for the reservoirs, which are constructed in seismically active regions. As the whole territory of Armenia is situated in very high seismoactive zone seismic risk assessment of dams is very important task for Armenia. We have collected and analyzed the data on the current reservoir's and dam's situation and then pointed out the main factors that determine the risk's levels.

Our investigations, performed for the three most dangerous homeland large dams, are based on the main principles of total risk analysis for dams, presented in the recommendations of International Committee of Large Dams (ICOLD). In this paper it has been also shown, that the number of microearthquakes increase after reservoir operation, causing changes of seismic regime in observed regions.

Keywords: induced seismicity, dams, microearthquakes, seismic activity, risk assessment, ICOLD

Introduction

As it is known quick growth of the number of natural and technogeneous catastrophes has been noticed in recent years and as a result a population and economic losses in many countries and society, in general become more vulnerable to natural disasters.

The incidents at dams may happen due to seepage in foundation, body and abutment area, internal erosion of piping, overtopping, dam slumping, slides, construction drawbacks, problems at downstream toe, non-maintence of demands of exploration notes and earthquake impact (Flooding and Dam Failure, 1996).

Most of 83 dams (large and small) in Armenia are situated in highland areas of 1500-3000m altitude. The majority of dams are embankment ones. Armenian dams are mostly situated in an area with high litologic, tectonic and geomorphologic heterogeneities (Khondkaryan, 1998, Sargsyan, 2008).

Armenian Upland is one of the most active segments of Alpine-Himalayan seismic belt, which is related to the collision zone of Arabian-Eurasian plates. This region is seismically very active.

According to the new seismic zonation map of the territory of Armenia the level of seismic hazard is evaluated with expected ground accelerations of up to 0.5g and which is corresponding to 9-10 seismic impacts on MSK-64 scale.

However, almost all dams were mostly designed corresponding to seismic hazard level of 7-8 on the MSK-64 scale.

Today it is generally accepted that significant reservoir-triggered earthquakes can only occur in regions with high tectonic stresses in the earth crust, i.e. the causative fault that can produce an earthquake already in near failure conditions, so that added gravity stresses and pore pressure propagation due to reservoir impounding and can trigger the seismic energy release (ICOLD, 2003).

According to ICOLD Bulletin 72 for sites in hazard class IV (PGA>0.25g and active fault closer then 10 km from site) separate consideration of MDE (Maximum Design Earthquake) OBE (Operating Basis Earthquake) and RIE (Reservoir Induced Earthquake) are required (ICOLD 72, 2005).

For this task the following groups of factors are discussed: (1) geological and structural factors; (2) factors resulted from dam site (3) flooding. A risk-analyzing method identifies the weak element or elements of a complex dam system. Safety can be increased by means of improvement of these elements.

This paper outlines the main principles of total risk analysis of dams based on the recommendations of International Committee of Large Dams (ICOLD), discussed some issues of conventional methods and introduces the results of a study which was performed for the three large dams in Armenia: Azat, Akhuryan and Tolors.

1.Seismic activity around reservoirs area

Comparison of the pre-impounding and the post-impounding seismic activity is necessary in order to resolve the anthropogenic seismicity from background activity. The main difference between a reservoir-triggered earthquake and a natural earthquake is that the reservoir-triggered earthquake has a relatively high likelihood of occurring within the first few years after impounding of the reservoir or when the reservoir level has reached its maximum elevation. These earthquakes have often a shallow focus and their epicenters are relatively close to the dam sites or the reservoir (Ibrahim, 1989, Torcal, 2005). After dam construction the filling of the reservoir creates a gravity stress field, which is immediately added to the pre-existing tectonic stresses. The field of pore pressures follows, propagating in depth, gradually decrease the initial effective stresses due to the action of the primary tectonic stress field and of the added weight of water in the reservoir (ICOLD 72, 2005, ICOLD, 2003). In our studies we observed data which had been recorded within 20 km and 50 km regions around the reservoirs site during instrumental period (since 1962) using a new homogenized catalogue (with magnitude Ml) based on the National Earthquake Catalogue created in the National Survey for Seismic Protection (NSSP, www.nssp-gov.am), International Seismological Center Catalogue (ISC, http://www.isc.ac.uk/) and Catalogue of the Institute of Geological Sciences (IGS).

1.1Reservoir AZAT

The Azat reservoir is built on the Azat River. It is situated in Ararat region in the central part of Armenia. The Azat dam is embankment earthfill dam. Dam height is 76m. The reservoir impounding started in 1976. It is used for irrigation purposes. The downstream population is about 88.2 thousand. The design seismic resistance of the dam is I=8 in MSK scale. According to the new seismic hazard map the territory of reservoir is located in the zone with amax=0.4g (I≥9).

The study area is characterized as a very active seismic region,due to Garni-Elpin and Yerevan active faults. Azat dam is in the area where two historical strong earthquakes occurred: the Dvin earthquake in 893, M=6.8 and the Garni earthquake in 1979, M=7.0 (Karakhanyan, 2008).

For the pre-impounding period the mean number of earthquakes with M>3.5 per year occurring inside a 50 km radial zone is 5 events. The yearly average number of earthquakes that take place during the post-impounding period is 33 events (six of them with M>4.0). It is shown, that the number of microearthquakes increased after its operation, causing changes of a seismic regime in observed region (Fig. 1).

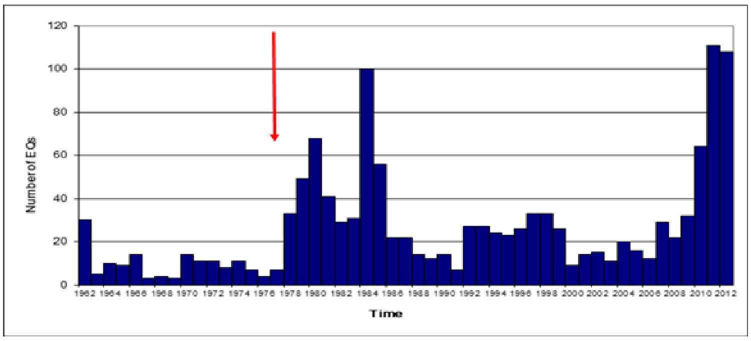

Figure 1.The time histogram of earthquakesin area 50 km around the Azat reservoir site.

1.2 Reservoir TOLORS

The Tolors reservoir is built on the Sisian River. It is situated in Syuniq region in the southern part of Armenia. The Tolors dam is rock fill dam with a central clay core. Dam height is 69 m. The reservoir impounding started in 1974. The downstream population is about 15 thousand. The design seismic resistance of the dam is I=8 in MSK scale. According to the new seismic hazard map the territory of reservoir is located in the zone with amax=0.4g (I≥9).

Tolors dam is in the area where two historical strong earthquakes occurred: the Syuniq earthquake in 1407, M=6.5 and the Zangezur earthquake in 1931, M=6.3.The largest earthquake recorded in the instrumental period was Zangezur II earthquake in 1968 with magnitude M=4.9.

For the pre-impounding period, the mean number of earthquakes per year occurring inside a 50 km radial zone is 2 events. The yearly average number of earthquakes that take place during the post-impounding period is 14 events.

During only one decade after the impounding of the reservoir several events with M>3.5 occurred. The largest one occurred in 1982 with M=4.2. After impounding of reservoir in study area the number of microeathquakes increased (fig.2), but with four years delay after impounding explained by the fact that the seismicity in this area is mainly associated with pore pressure diffusion (Sargsyan, 2009).

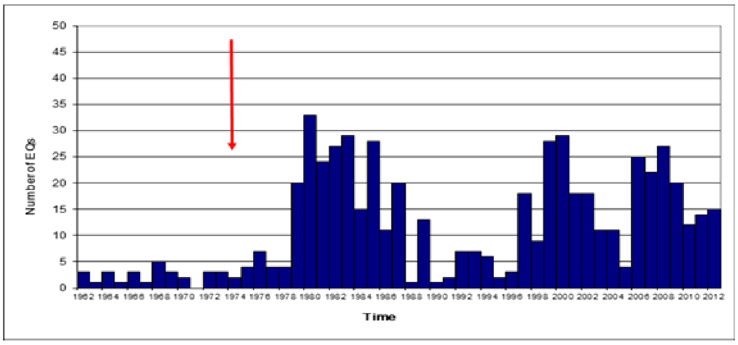

Figure 2.The time histogram of earthquakes in area 50 km around the Tolors reservoir site.

1.3 Reservoir AKHURYAN

The Akhurian reservoir is situated in Shirak region in the northern part of Armenia. The Akhuryan dam is gravity dam which height is 59m. The reservoir impounding started in 1982. The downstream population is about 100 thousand. The design seismic resistance of the dam is I=8 in MSK scale. According to the new seismic hazard map the territory of reservoir is located in the zone with amax=0.4g (I≥9).

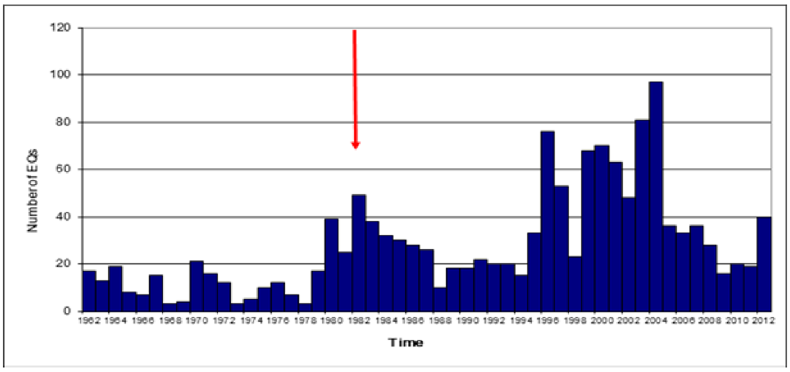

Figure 3.The time histogram of earthquakes in area 50 km around the Akhuryan reservoir site.

The main faults in study area are the following: Akhuryan, Pambak-Sevan, Jeltochenrensk and Spitak. In this area occurred the Leninakan earthquake in 1926, M=6.0 and during instrumental period the largest Spitak earthquake in 1988, M=7.0. For the pre-impounding period the mean number of earthquakes per year occurring inside a 50km radial zone is 10 events. After impounding of reservoir in study area the number of microeathquakes increased: average number per year is 37 (fig.3).

2.Seismic Risk Assessment of Azat, Akhuryan and Tolors dams

As the whole territory of Armenia is situated in very high seismoactive zone, the seismic risk assessment of dams is very urgent and important.The main principles of total risk analysis of dams is based on the recommendations of International Committee of Large Dams (ICOLD), discussed some issue of conventional methods and introduces the results of a study, which was performed for the Azat, Akhuryan and Toloros dams.

The total (potential) risk associated with dams consists of structural components and socio-economic components. The structural components of potential risk depend mostly on storage capacity and on the height of the dam, as the potential downstream consequences are proportional to the mentioned values. Socio-economic risk can be expressed by a number of the persons, who need to be evacuated in the case of danger and by potential downstream damage. It is possible to rate the total risk by weighting the mentioned components associating the larger weighting factor to the dams with larger storages and entailing larger potential downstream damage (ICOLD 72, 2005, ICOLD, 2003).

The following table 1 is convenient to rate the risk associated with dams. Four risk factors are separately weighted as low, moderate high or extreme ones:

Table1. Risk factors: weighting pointes

Risk factor	Extreme	High	Moderate	Low
Contribution to risk: weighting points				
Capacity	>120 (6)	120-1 (4)	1-0.1 (2)	<0.1 (0)
Height	>45 (6)	45-30 (4)	30-15 (2)	<15 (0)
Evacuation requirements (number of peoples)	>1000 (12)	1000-100 (8)	100-1 (4)	None (0)
Potential downstream demange	High (12)	Moderate (8)	Low (4)	None (0)

The weighting points of each of the 4 factors, shown in the parentheses in the table 1, are summed to provide the total risk factor as

Total risk factor = capacity + height +number of people+ downstream damage.

The risk class of the dam based on the total risk factor as followed (ICOLD 72, 2005, ICOLD, 2003).

Table 2. Classification of total risk of dams

Total Risk Factor	Risk class
(0-6)	Low
(7-18)	Moderate
(19-30)	High
(31-36)	Extreme

In the case of the possible disasters at reservoirs, it is necessary to do the following special calculations:

- the determination of the amount of peoples, who need to be evacuated in the case of danger;
- the assessment of possible economic damages (buildings, constructions, roads, bridges and others).

Table 3.Risk factors and corresponding weighting values for the Azat, Akhuryan, Tolors dams

Contribution to Risk (weighting points)	Values	Risk factor	The weight values	Risk class	Values	Risk factor	The weight values	Risk class	Values	Risk factor	The weight values	Risk class
	Azat				Tolors				Akhuryan			
Capacity, km^3	70	High	4		96	High	4		525	Extreme	6	
Height, m	76	Extreme	6		69	Extreme	6		59	Extreme	6	
Evacuation No of persons living downstream	82.200	Extreme	12		15 000	Extreme	12		100000	Extreme	12	
Potential Downstream damage	Extreme	Extreme	12		High	Extreme	8		High	Extreme	12	
Total Risk		Extreme	34	IV		High	30	III		Extreme	36	IV

There are the different methods for solution of the noticed tasks. For example, we used the “Volna-2” special calculation program for the assessment of the results of the failures of the dams and potential downstream damages. As it is shown in Table 3 the total risks for Azat, Tolors and Akhuryan dams depended on the structural components and socio-economical components having high-risk values.

3.Summary and conclusion

Sudden failure of a dam are result of earthquake, destroying of dams followed by inundation of population in downstream area, forces to pay special attention to the seismicity of the region the dams built in. Many of the large and small dams in Armenia are located in zones of high seismicity. It is shown that the number of microearthquakes increase after its operation causing changes of seismic regime in the observed region. In general, it is clear that a relationship exists between seismicity and reservoir water level, which probably modifies the pre-exiting tectonic stress field and pore pressures, but no specific mechanism for the induced seismicity has yet been identified.

According to the definition by International Commission of Large Dams (ICOLD), the dams with heights more than 15 meters and reservoirs with more than 3 million cubic meter water capacity, are considered as the large and are high risk objects.

Taking into account the high population density in Armenia and the fact that residential areas exist downstream from many of these reservoirs, makes the ensuring of reservoirs safety an urgent issue. The main reasons of the incidents on the dams in the world are based on the lack of information by the experts on regular monitoring of the dam's current technical parameters and some special characteristics of its condition.

Emerging from the fact that the earthquakes cannot be predicted in the near future, the most appropriate approach is the assessment of the dam risk will be to allow then install the special water alarm systems at the most dangerous dams. In this case a large number of people that could be saved from flooding caused by possible failure of a dam and economic damages will be decreased.

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Reviewer A. Araqelyan

ՍԵՅՍՄԻԿ ՌԵԺԻՄԻ ԵՎ ՍԵՅՍՄԻԿ ՌԻՍԿԻ ԳՆԱՀԱՏՈՒՄԸ ՀԱՅԱՍՏԱՆԻ ՈՐՈՇ ՇԱՀԱԳՈՐԾՎՈՂ ՋՐԱՄԲԱՐՆԵՐԻ ՀԱՄԱՐ

Լ. Ս. Սարգսյան

Ամփոփում

Ջրամբարների շահագործմամբ պայմանավորված հարուցված սեյսմիկությանը, երկրաֆիզիկայի և ինժեներային սեյսմոլոգիայի կարևորագույն խնդիրներից է, հատկապես այն ջրամբարների համար, որոնք կառուցված են բարձր սեյսմաակտիվ շրջաններում: Քանի որ Հայաստանի տարածքը գրեթե ամբողջությամբ գտնվում է բարձր սեյսմիկ վտանգի գոտում, պատվարների սեյսմիկ ռիսկի գնահատումը շատ կարևոր խնդիր է: Մենք հավաքել և վերլուծել ենք ներկայիս ջրամբարների և պատվարների վերաբերյալ տվյալները, այնուհետև բերել ենք այն հիմնական գործոնները, որոնք որոշում են ռիսկի մակարդակը: Այս աշխատանքում մեր կողմից ընտրված ՀՀ երեք ամենախոշոր ջրամբարների համար կատարվել է լրիվ ռիսկի գնահատում՝ հիմնվելով Խոշոր Պատվարների Միջազգային Կոմիտեյի (ICOLD) առաջարկությունների և պահանջների վրա: Ցույց է տրված նաև, որ ուսումնասիրվող ջրամբարների տարածքներում ջրամբարիների շահագործումից հետո դիտվում է թույլ երկրաշարժերի քանակական աճ, որը բերում է այս շրջաններում սեյսիկ ռեժիմի փոփոխության:

ОЦЕНКА СЕЙСМИЧНОСТИ И СЕЙСМИЧЕСКОГО РИСКА ДЛЯ НЕКОТОРЫХ ЭКСПЛУАТИРУЕМЫХ ВОДОХРАНИЛИЩ АРМЕНИИ

Л.С. Саркисян

Резюме

Проблема наведенной сейсмичности, связанной с эксплуатацией водохранилищ, имеет важное значение в геофизике и инженерной сейсмологии, особенно для плотин, которые строятся в сейсмически активных областях. Поскольку вся территория Армении расположена в зоне высокой сейсмоактивности, оценка сейсмического риска плотин является одной из важных задач. Мы собрали и проанализировали данные о текущем состоянии водохранилищ и плотин, а затем указали основные факторы, определяющие уровни риска.

Наши исследования, проведенные для трех самых опасных плотин, основаны на принципах общего анализа рисков для плотин, представленных в рекомендациях Международного комитета крупных плотин (ICOLD). В этой работе также показано, что количество микроземлетрясений возрастает после наполнении резервуара, вызывая изменения сейсмического режима в наблюдаемых областях.