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THE INVESTIGATION OF MORPHOTECTONICAL INDEXES AND SEISMOTECTONIC ACTIVITY IN BAHJATABAD DAM –IRAN

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Abstract. Determination of Neotectonics activity rate imperative in dams and related structures studies. The results of Neotectonics and active tectonics investigation along with the results of seism tectonics studies have an essential role in the selection of the dam site, type, details of design and dam construction and related structures. Generally, morphotectonic Indexes are significant tools for identifying and determining the level of tectonic activity, especially around the river drainage basin. Thus, tectonic active areas can be reasonably identified and distinguished from areas with lower activity, using the said indexes. By determining the rate of tectonic activities, the results can be used in the design of the dam body and other structures. According to the investigation conducted on morphotectonic Indexes around the river drainage basin and site of "Behjatabad Dam" in Qazvin province, especially Index of relative active tectonic, it was determined that reservoir area and construction site of the dam and other related structures are located in a region with a very high tectonic activity. According to the conducted studies about this dam, the relative activity factor (Laf) for the area of Behjatabad dam is equal to 1.38, which in terms of tectonic activity rate is in an area with very high activity. Based on the tectonic seismic studies in the area of this dam, there is possibility of earthquakes with a magnitude greater than 7 Richter

during the useful life of the dam (100 years), which is in accordance with the study of morphotectonic indexes. The vertical and horizontal acceleration values for the design surfaces are equal to 0.34 and 0.48.

Keywords: neotectonics, morphotectonic indexes, dam, river drainage basin, active tectonic, seismotectonic, credible earthquake

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БАХДЖАТАБАД БӨГЕТІ (ИРАН) АЙМАҒЫНДАҒЫ МОРФОТЕКТОНИКАЛЫҚ ИНДЕКСТЕР МЕН СЕЙСМОТЕКТОНИКАЛЫҚ БЕЛСЕНДІЛІКТІ ЗЕРТТЕУ

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Аннотация. Неотектоникалық белсенділіктің жылдамдығын анықтау бөгеттер мен онымен байланысты құрылыстарды зерттеудің маңызды кезеңі болып табылады. Неотектоника мен белсенді тектониканы зерттеу нәтижелері сейсмотектоникалық талдау деректерімен бірге бөгеттің орналасқан жерін, оның түрін, дизайн ерекшеліктерін және құрылыс параметрлерін таңдауда шешуші рөл атқарады. Морфотектоникалық индекстер тектоникалық белсенділік деңгейін анықтаудың және бағалаудың, әсіресе өзен бассейндерінде тиімді құралы ретінде қызмет етеді. Мұндай индекстерді қолдану тектоникалық белсенділік аймақтарын сенімді түрде анықтауға және оларды аз белсенді аймақтардан ажыратуға мүмкіндік береді. Өзен бассейнінде және салыстырмалы тектоникалық белсенділік индексін қоса алғанда, Бехджатабад бөгетінің (Казвин провинциясы) учаскесінде жүргізілген морфотектоникалық көрсеткіштерді зерттеуге сәйкес, су қоймасының ауданы мен бөгеттің тұрғызылған жері тектоникалық белсенділігі жоғары аймаққа жатады. Бөгет аймағы үшін салыстырмалы белсенділік коэффициенті

(Laf) 1,38 құрайды, бұл өте жоғары тектоникалық белсенділігі бар аймаққа сәйкес келеді. Сейсмотектоникалық зерттеулер негізінде бөгет аймағында құрылыстың пайдалану мерзімі ішінде (100 жыл) Рихтер шкаласы бойынша магнитудасы 7-ден асатын жер сілкінісі болуы мүмкін екендігі анықталды, бұл морфотектоникалық көрсеткіштерді талдау нәтижелеріне сәйкес келеді. Есептелген тік және көлденең үдеулердің мәндері сәйкесінше 0,34 және 0,48 құрайды.

Түйін сөздер: неотектоника, морфотектоникалық көрсеткіштер, бөгет, өзен бассейні, белсенді тектоника, сейсмотектоника, тектоникалық белсенділік

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ИЗУЧЕНИЕ МОРФОТЕКТОНИЧЕСКИХ ИНДИКАТОРОВ И СЕЙСМОТЕКТОНИЧЕСКОЙ АКТИВНОСТИ В РАЙОНЕ ПЛОТИНЫ БАХДЖАТАБАД – ИРАН

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Аннотация. Определение скорости неотектонической активности является важным этапом при изучении плотин и связанных с ними сооружений. Результаты исследований неотектоники и активной тектоники, совместно с данными сейсмотектонического анализа, играют ключевую роль при выборе местоположения плотины, её типа, проектных особенностей и параметров строительства. Морфотектонические индексы служат эффективным инструментом для выявления и оценки уровня тектонической активности, особенно в пределах речных бассейнов. Использование таких индексов позволяет надёжно определять зоны тектонической активности и отличать их от менее активных участков. Согласно исследованию морфотектонических показателей, проведённому в бассейне реки и на участке Бехджатабадской плотины (провинция Казвин), включая индекс относительной тектонической

активности, установлено, что район водохранилища и место возведения плотины относятся к зоне с высокой тектонической активностью. Коэффициент относительной активности (Laf) для района плотины составляет 1,38, что соответствует области с очень высокой тектонической активностью. На основе сейсмотектонических исследований выявлено, что в пределах района плотины возможно возникновение землетрясений магнитудой более 7 по шкале Рихтера в течение срока эксплуатации сооружения (100 лет), что согласуется с результатами анализа морфотектонических показателей. Значения расчётных вертикального и горизонтального ускорений составляют 0,34 и 0,48 соответственно.

Ключевые слова: неотектоника, морфотектонические показатели, плотина, речной бассейн, активная тектоника, сейсмотектоника, тектоническая активность

Introduction

Neotectonics and dams is of great importance that the International Commission of Large Dams (ICOLD) has dedicated the bulletin No. 112 (1998) to this matter. In the process of dam construction studies, the survey of active tectonic is usually undertaken within the scope of seismotectonic studies and taken little heed to morphotectonic indexes separately and decisively. However, in the same bulletin (Chapter 3) it is mentioned that the study of morphotectonic is also important and is considered as an auxiliary tool. Seismic studies basically lead to the extraction of earth acceleration coefficients, which are used directly in design as a major parameter, but the morphotectonic indexes simply express the activity or inactivity of tectonic in an area.

Therefore, during the tectonic studies of a dam site in order to carry out structural design more accurately, the results of Neotectonics studies that can be feasible by examining the aforementioned indicators, should be used in accordance with seismic data.In recent years, morphotectonic indexes, as Keller and Pinter (2002) and Lone (2017) have stated, have been an important tool for identifying and determining the amount of tectonic activity in the study area. By using these indicators, active tectonic can be distinguished from areas with less activity. Since any tectonic motion with any rate affects the earth's Landscapes surface, therefore the study of effects on the landscapes that can be identified by the morphotectonic indexes[11], can show the movements and even the extent of these tectonic movements. Morphometry and morphotectonic properties are important in geomorphology are important in geomorphology, which provide considerable information about the subsurface topography and earth surface structure (Barman, et al 2021). As several studies suggest, the analysis of morphotectonic indexes enables a reliable assessment of

[11] The indexes are: SL: (Stream Length Gradient Index), Vf: (ratio of valley-floor with to valley height), Af: (Asymmetry factor), BS: (Drainage Basin shape Raito), T: (Transverse topographic symmetry factor), Smf: (Mountain front sinuosity), S: (River sinuosity index), Hc: (Hypsometric curve), Hi: (Hypsometric integral).

tectonic activity intensity and distribution across a landscape. In particular, such indexes are crucial in regions like the Behjatabad Dam basin, where drainage patterns and landform evolution are shaped by both lithological composition and ongoing tectonic processes (Bhatt et al., 2020). In this context GIS enhances morphotectonic studies by integrating and analyzing these indices, providing a comprehensive understanding of tectonic activity across the basin (Giri, et.al, 2020).

Therefore, in dam construction studies, the study of morphotectonic indexes, along with studies of other sectors, will determine the active areas of tectonic and their activity rates with higher accuracy. Ultimately, this leads to the design and construction (Execution) of more stable structures in more suitable construction sites. Therefore, in this circumstance, the structure and site will be designed and executed in safer conditions. In regions where active tectonism influences landscape features, geomorphometric analysis of drainage networks can reveal significant anomalies. For instance, higher-altitude watersheds often exhibit variations in morphometric indices, a phenomenon that can be attributed to the tectonic activity in the region. This highlights the critical role of tectonic processes in shaping the evolution and characteristics of river basins (Sajjadi, et.al, 2020).

In the following, according to the above explanations as an example, the method of evaluating this index, especially in a schematic and visual way, is presented in the area of "Behjatabad Dam" river basin.[22]

The method of carrying out this study is as follows: firstly, the area of the river drainage basin and its axis and reservoir are carefully identified and found on the maps. Secondly, at the same time as seismic studies, the investigation of morphotectonic indexes is done. If the study of morphotectonic indexes shows the high tectonic activity in the area of the dam and its reservoir, the designs will be based on the results of the morphotectonic indexes even if the seismicity indexes show a low rate. In this article, the morphotectonic indexes along with the summary of conducted seismic studies and the results have been presented.

1- **Specifications of Behjatabad project**

The construction site was selected for the construction of the Behjatabad Reservoir Dam with a longitude of 50° 20′ east and 36° 10′ north latitudes, in the northwestern part of Iran, in Qazvin province and at a distance of 23 Km northwest of Abyek city (northeast of Qazvin province). And 2.5 Km upstream of Behjatabad village, is located on a river with same name. (Figure 1).

[22] Usually, elevation levels that is base of this study is provided from topographic maps scaled 1:50000 and “Dem 45m” maps of river drainage basin from United States Geological Survey (USGS) website. In this study Global Mapper software has been used for data analysis.

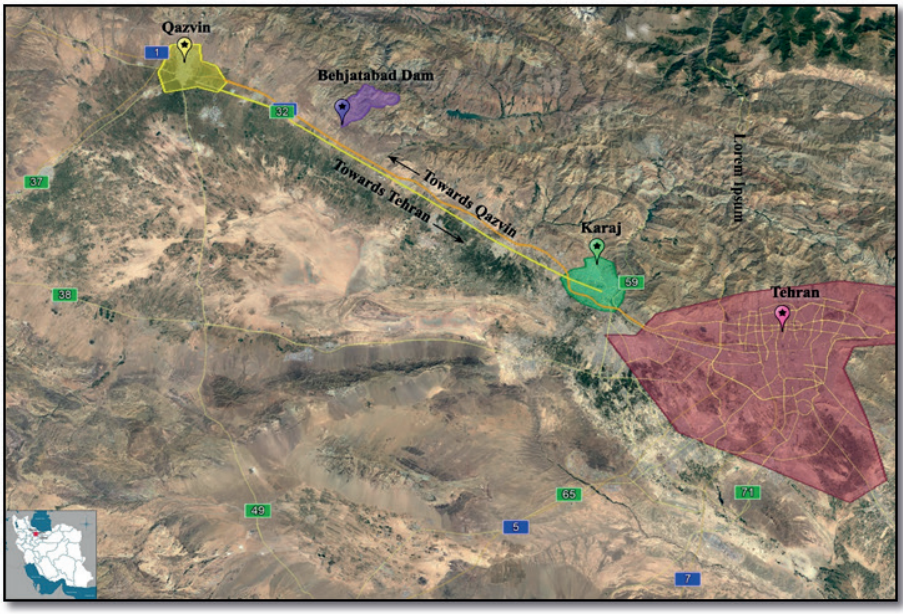

Figure 1- Geographical location of Behjatabad dam

For the purpose of regulate and control the floods and runoffs of this basin to provide part of the drinking water required of Abyek city an earth dam with a clay core having an approximate height of 48 m, from the bed has been designed for implementation in the aforementioned construction site. (Figure 2) The access road to the dam site is accessible through the Tehran-Qazvin highway. In order to reach the dam construction area, on the Tehran-Qazvin highway, after passing

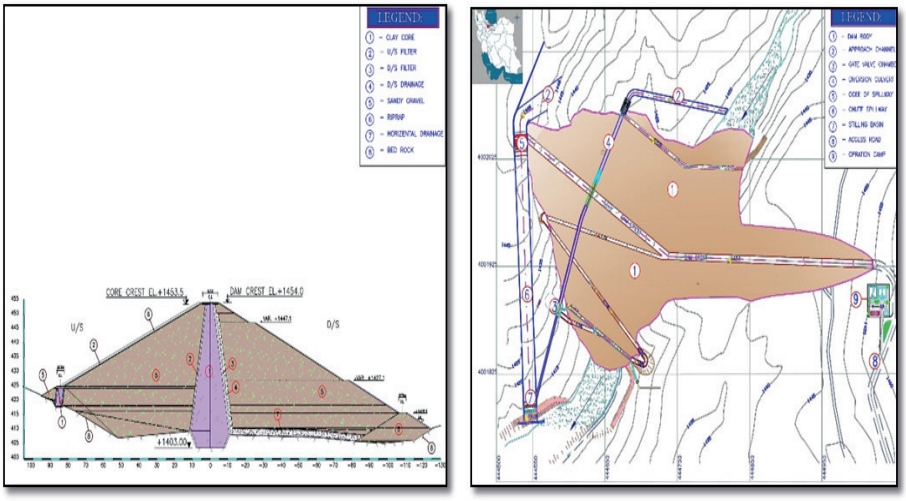

Figure 2- Plan & Profile of the Behjatabad Dam

Abyek city and about 35 Km from Qazvin city, an asphalt road branches off the highway, which is the access road to Behjatabad village. (Figure 1) shows the location of the Behjatabad Reservoir Dam.

(Figure 3) shows the area of the dam river drainage basin on the main faults of the basin are identified (Golabtounchi 2013)[6].

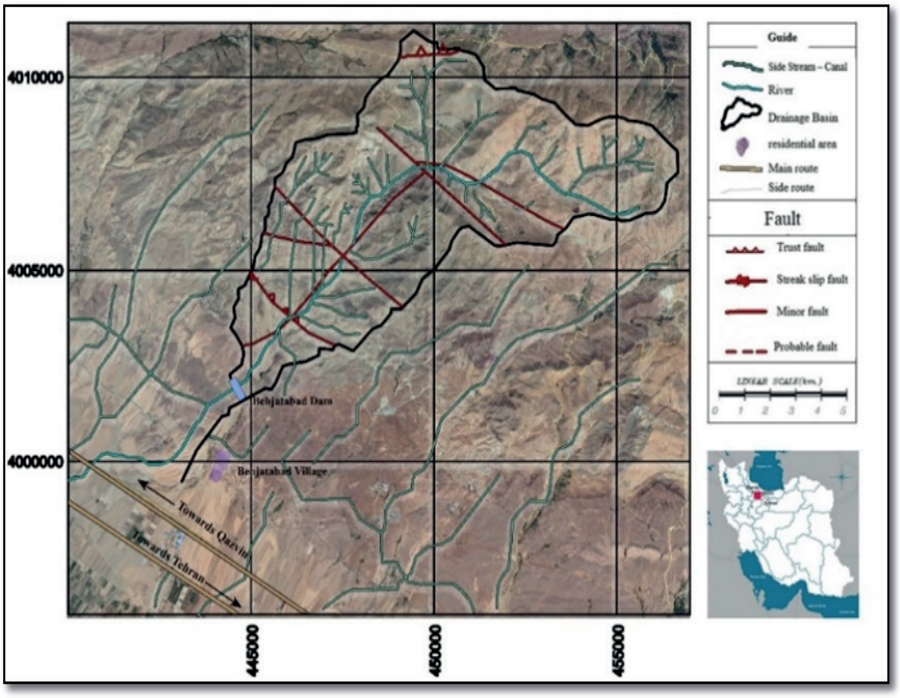

Figure 3- The dam and the main faults in this basin

2- **An abstract of general geology of Behjatabad dam area**

The area of the Behjatabad Dam project is located in the Central Alborz Geological Unit in terms of the Geological division of Iran. The valleys within the river drainage basin of Behjatabad Dam are generally V-shaped. In the construction site of Behjatabad dam, the valley where the dam is located is almost V-shaped too.

The direction of the river is in the northeast-southwest direction. The mountains of the dam river drainage basin have a general northwest-southeast trend. The geometric characteristics of Behjatabad Dam River drainage basin are presented in (Table 1).

The bedrock of the Behjatabad Dam construction site is composed of "Andesite" and "Eocene Andesite Basalts" belonging to the Karaj Formation. The color of these rocks is mostly gray. The porphyry texture of these stones is well recognizable in hand specimens. The outcrops of the foundation stone can be seen on all right and left sides of the dam axis up to the MASL of 1438.

Quaternary deposits within the dam axis and related structures of Behjatabad include alluvial terraces, slope debris and river alluvium. The oldest part of the Quaternary deposits in the area of Behjatabad Dam is composed of alluvial terraces mostly fine-grained alluvial deposits, which are shown on the Geological map of the dam axis marked Qt (Figure 3). The alluvial terrace of the left side of the dam, which is approximately 1438 m, from the level of the dam crown, from a geotechnical perspective is very important in sustainability analysis and dam foundation waterproofing. The maximum depth of these sediments in this faction, according to the excavations, reaches about 40 m, (Figure 4).

Table 1- Geometric characteristics of river drainage basin

The height of the dam from the bed (m)	The width of the valley floor (m)	Basin area (Km^2)	Minimum height (m)
48	25	51	1414
Maximum height (m)	Average height (m)	Main Branch length (Km)	Basin width (Km)
2638	1934	15	5/3

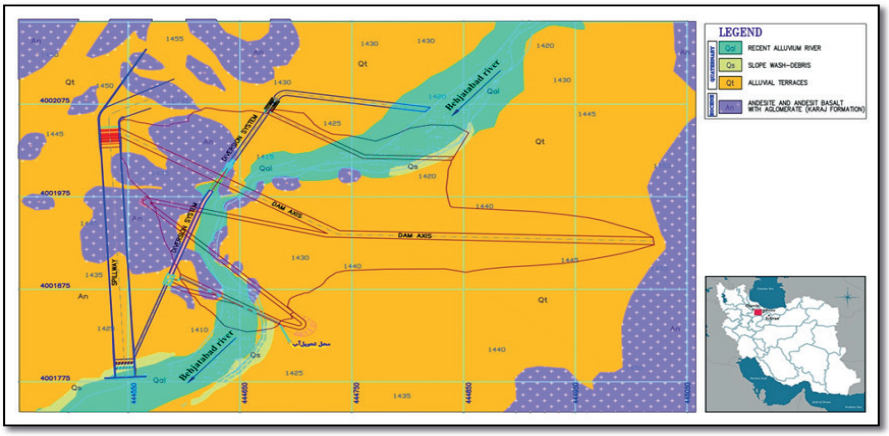

Figure 4- Geological map of Behjatabad dam area and related structures

4- Investigation of morphotectonic indexes (analysis method)

In the following, the results of the survey of morphotectonic indexes in the river drainage basin of Behjatabad Dam are presented.

4-1- Stream length gradient index (Sl)

This index is used to determine local gradients ($^{\Delta H}/_{\Delta L}$) along a river in a specific area or specific cross section (L). In this case, the local gradient or the ratio of the difference in height at a given specific cross section (ΔH) to the difference in horizontal distance at that cross section (ΔL), according to the length of the river from the central point of the measured section to the river headwaters or the place

of river division from the beginning of the river drainage basin (L) is determined as the stream length gradient index (SL) (Figure 5).

According to the above explanations, the determination of this index is obtained from the following equation (Keller 1980)[12]:

$$SL = L \times \frac{\Delta H}{\Delta L}$$

(Figure 5) also shows an assessment of this index for the Behjatabad Dam River drainage basin, for example.

(Table 3) shows the results of the calculations related to the SL index in the Behjatabad Dam basin, along with the evaluation of the tectonic activity class according to the contents of (Table 2). Also, the longitudinal profile of the river is presented for performing the calculations present in (Figure 6). Based on the above explanations and the contents of (Table 3), the SL index for the Behjatabad Dam River drainage basin shows the semi-active tectonic activity rate.

Table 2- Determining the rate of tectonic activities in relation to the amount of SL (Hamdouni et al, 2008)[9]

Gross amount	The rate of Tectonic activity
>500	active
300-500	Semi-active
<300	Inactive

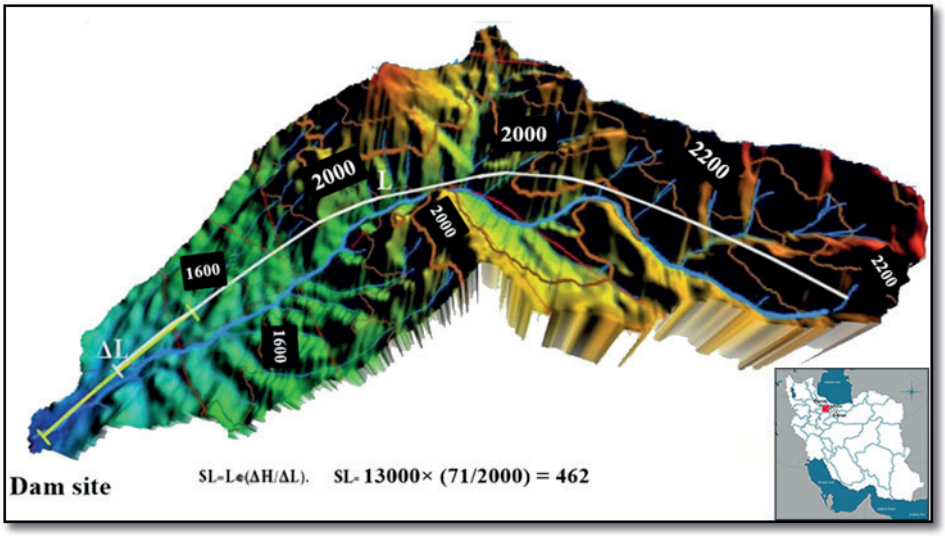

Figure - 5 Schematic view of the components of SL index in the river drainage basin

Table 3- Index calculations SL in the main gully of river drainage basin

Height (m)		ΔH (m)	ΔL (m)	L (m)	SL	Activity class
Min	Max					
2029	2115	86	2000	1000	43	3
1919	2029	110	2000	3000	165	3
1825	1919	94	2000	5000	235	3
1731	1825	94	2000	7000	329	2
1608	1731	123	2000	9000	554	1
1523	1608	85	2000	11000	468	2
1452	1523	71	2000	13000	462	2

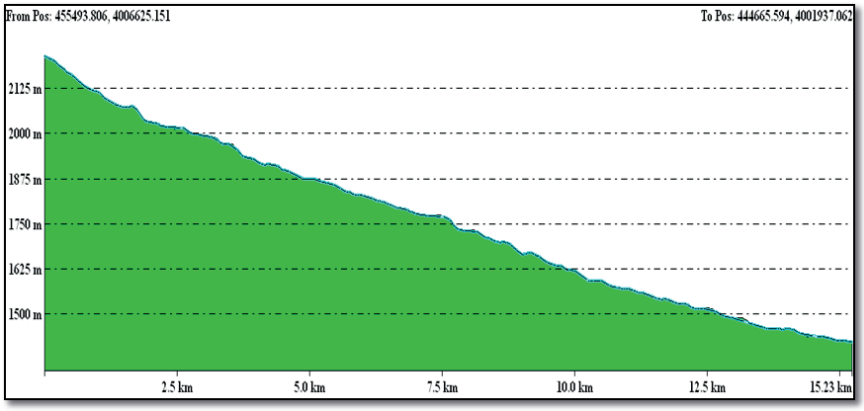

Figure 6- Longitudinal River used in index calculation of SL

4-2 The ratio of valley-floor width to valley height (Vf)

This index was first introduced by Bull (1978)[3] based on the following equation.

(1) $Vf = 2Vfw / [(Eld-Esc) + (Erd-Esc)]$

In the above equation, Vfw: width of valley floor, Eld: height of the left side of the valley, Erd: height of the right side of the valley, Esc: average height of the valley floor. Since valleys are generally V-shaped or U-shaped, the ratio of the width of the valley floor to the height can vary, and this may be related to the tectonic activity and the high altitude of the area due to these movements. Also, (Figure 7) shows how to evaluate this index, for example, in the river drainage basin of Behjatabad Dam.

In (Table 5), based on the evaluation method mentioned above, the results of the study of the ratio of valley-floor width to the valley height of Vf in the river drainage basin of Behjatabad Dam are presented. Considering the Vf index numbers and the shape of the valley where the river passes and the construction of Behjatabad dam site, which is V-shaped, it can be stated that the low value of this index for Behjatabad dam indicates the active tectonic of this basin.

Table 4. The amount of tectonic activity according to the amount of Vf

the amount of Vf	Tectonic condition
Less than 1	active
1 to 2	Semi-active
2 <	Inactive

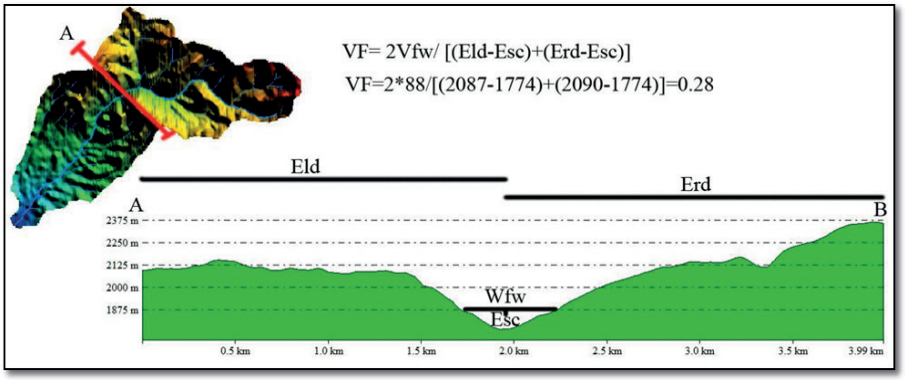

Figure 7- Evaluation of the ratio of the width of the valley floor to the height in the river drainage basin

Table 5- The results of the study in valley floor width ratio to its width (Vf)

Design name	Section number	Earth (m)	Eld (m)	Esc (m)	Vfw (m)	Vf	Activity class
Behjatabad	The beginning of the basin	2438	2250	2211	99	0.74	1
	Middle section	2090	2087	1774	88	0.28	1
	The axis of the dam	1440	1436	1422	25	1.56	2

4-3- Basin asymmetry factor (Af)

The asymmetry factor can be used in the Dam River drainage basin scale. In this case, examining the geometric shape of the streams network (gullies) in the basin is the basis for determining this index and proportionally examining the rate of tectonic activity. In areas with high tectonic activity rates, asymmetry in the geometry of gullies as well as the river drainage basin can be traceable and identifiable. Therefore, by using this index, the deviation and asymmetry due to tectonic activities in the river drainage basin can be identified. The basin asymmetry factor (Af) is defined as the following equation according to Keller (1980) proposal:

In this equation:

$$f=100\left(\frac{Ar}{At}\right)$$

Ar: The area of the basin to the right of the river (Km^2).

At: The total area of the river (Km^2).

It is important to note that basically using this indicator in basins where the rock type is almost the same will provide better and more appropriate results. (Figure 8) illustrates the evaluation of the mentioned index for the sample.

Considering that Af = 50 is the criterion for the symmetry of the basin, so determining the rate of tectonic activities related to the value of the Af-50 relationship according to the work of Hamdouni et al (2008)[9] is as described in (Table 6). (Table 7) shows the results of the study of the asymmetry factor of the basin for the Behjatabad dam basin based on the criteria set out in (Table 6).

Based on the above results, it can be stated that the impact of the tectonic forces on the Behjatabad Dam basin is almost estimated high. In this dam, the number of symmetry index greater than 50 or in other words, Af-50 = 15 shows that the rise and tilt index of the basin is to the right.

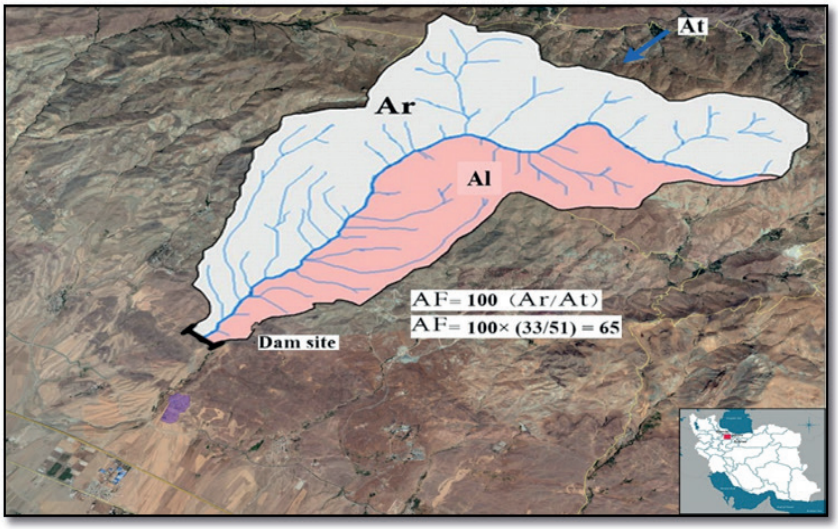

Figure 8- Evaluation of asymmetry factor in the river drainage basin

Table 6- Criteria for determining the rate of tectonic activities in relation to the amount obtained from the relation Af-50

Af-50	Rate of Tectonic condition
>15	active
7-15	Semi-active
<7	Inactive

Table 7- Results from the survey of the drainage basin asymmetry factor (Af)

Design name	At (Km^2)	Ar (Km^2)	AF	[AF-50]	Activity class
Behjatabad	51	33	65	15	1

4-4- Drainage Basin Shape ratio (BS)

The shape of the river drainage basin or drainage basin of the study area can also be a tool for evaluating tectonic activities. Basins that are tectonically active, usually have an elongated shape. Reducing the rate of tectonically activity and

subsequently stopping the rate of uplift and thus overcoming erosive processes, causes the shape of the basin to gradually become circular over time, the index of the basin shape decreased based on following equation:

(2) BS = BL / BW

In this equation, BL is the length of the river drainage basin, which is calculated from the outlet of the basin (the location of dam's construction) to the end of the river drainage basin (place of entry into the river drainage basin of the dam). BW is the width of the river drainage basin in the widest part.

In Behjatabad dam, this index is equal to 2.8, which indicates that the number of tectonic movements in the river drainage basin of this dam is active, or in other words, the high activity of tectonic factors in this basin. In (Figure 9), the evaluation of this index for the Behjatabad Dam River drainage basin has been done for example.

The results of the study of the shape index for the Behjatabad dam drainage basin are listed in (Table 8).

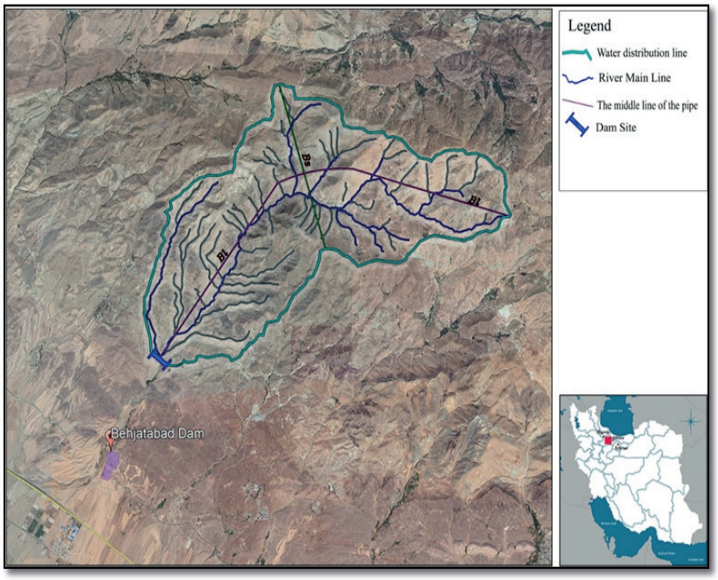

Figure 9- Evaluation of Drainage Basin Shape ratio (BS)

Table 8- Results from the survey of the Drainage Basin Shape ratio (Bs)

Design name	Bw (Km)	BL (Km)	Bs	Activity class
Behjatabad	5.3	15	2.8	1

4-5- Transverse topographic symmetry factor (T)

By this index, it is possible to evaluate the asymmetry of the basin and finally the active or inactive area of the project area. This index is calculated from the

relation

$$T=\frac{DA}{Dd}$$

in which:

DA: The distance of the middle line of the river drainage basin to the main gully.

Dd: The distance between the middle basin of the river drainage basin and the boundary.

The numerical value of the index is between 0 and 1. In (Table 9), a criterion can be proposed for evaluating the inverse topographic symmetry index in terms of the rate of tectonic activities.

(Figure 10) shows how to calculate this index for example within the river drainage basin of Behjatabad Dam.

In order to calculate the symmetric topographic symmetry index (T) of the basin, 10 sections on the basin (from the top of the basin to the dam structure) were identified and the values of each of them were calculated based on the above relation and listed in (Table 10). Also, the average of the obtained results is mentioned as the index indicating the basin in the previous table. According to the numbers obtained for index T for Behjatabad Dam basin, which indicates that the Neotectonics is semi-active in this basin.

Table 9- Tectonic activity rate according to the amount (Golabtounchi 2023)

Activity Class	the amount of T	Tectonic Activity rate
3	0	Inactive
2	0 - 0.5	Semi-active (moderate activity)
1	0.5 - 1	Active

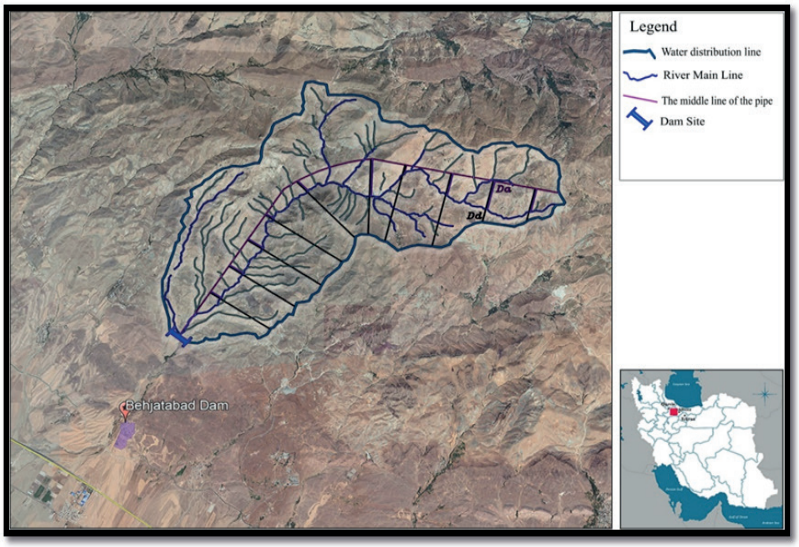

Figure 10- Reversal of symmetric topography symmetry index in river drainage basin

Table 10- Results from the inverse topographic symmetry index (T)

Evaluated sections	D_a	D_d	T	Activity class
1	775	1055	73/0	1
2	940	1375	68/0	1
3	730	2435	30/0	2
4	300	2555	12/0	2
5	1220	2465	5/0	1
6	435	2330	19/0	2
7	260	2635	10/0	2
8	520	2570	20/0	2
9	485	2315	21/0	2
10	370	3000	12/0	2
Average	604	2273	27/0	2

4-6- River Sinuosity Index (S)

The River Sinuosity Index can be measured based on the

$$S = \frac{C}{V}$$

equation (Ramasht et al. 2012)[17].

In the above equation, C: the length of the river and V: the length of the valley in a straight line. The higher S values, the closer river is to equilibrium, and therefore the lower rate of tectonic activity in the area, and conversely, the smaller S, the higher rate of tectonic activity in the area.

State to evaluate the above mentioned for the Behjatabad Dam River drainage basin is shown in Figure 10. Also, the results of the review and evaluation of this index are listed in (Table 11).

Considering the S index number for Behjatabad River, it can be concluded that the rate of tectonic activities of this basin is high.

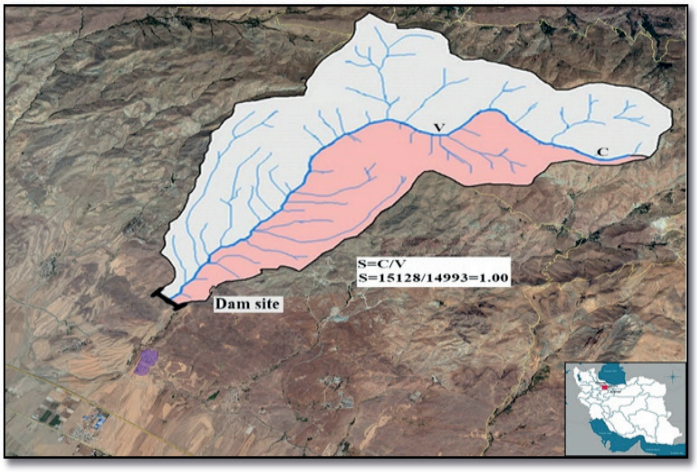

Figure 11- Evaluation of river sinuosity index in Behjatabad Dam River drainage basin

Table 11- Results from the River Curve Index (S)

Design name	C	V	S	Activity class
Behjatabad	15128	14993	1	1

4-7- Mountain Front Sinuosity factor (smf)

This index is basically marked with a smf sign and is calculated based on the following formula: Smf=Lmf/Ls

In the above equation, Lmf: the length of the mountain front at the point of mountain collision with the plain and Ls: the direct length of the mountain front.

Based on the above equation, the lower Smf rate, the more active tectonic forces are in the study area, or in other words, the more active area in terms of the rate of tectonic activity.

In order to get better results in calculating and determining the Mountain Front Sinuosity factor, the use of aerial and satellite images is preferable to topographic maps. It is worth mentioning that when examining this index, whenever Smf =1, it indicates a completely active tectonic structure. (Table 12) presents the criteria for measuring the rate of tectonic activities in relation to the smf index based on the work of Hamdouni et al. (2008)[9] quoted by Karami (2012)[11] (Figure 12). also shows the smf rating in the Behjatabad Dam area. Also, the results of the study of the Mountain Front Curve (Smf) in the area of Behjatabad Dam Basin are presented in (Table 13). Based on the results of this table, the Behjatabad dam basin shows an almost high rate of tectonic activities.

Table 12- Tectonic activity rate measurement criterion in relation to the smf index

Index value smf	Tectonic Activity rate
<1.1	Inactive
1.1 – 1.5	Semi-active
>1.5	active

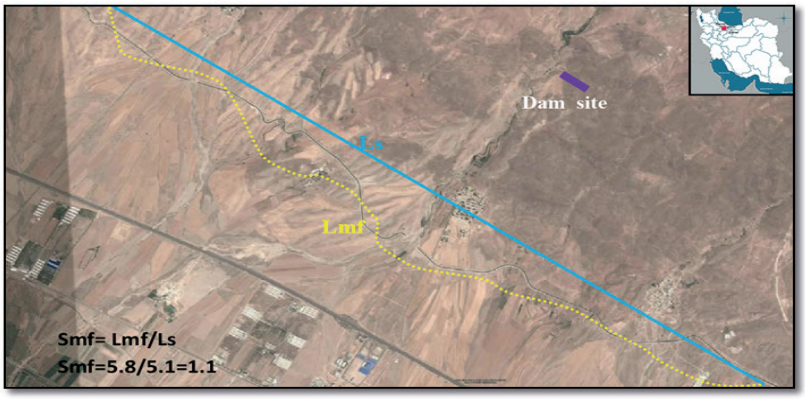

Figure 12- Evaluation of the sinuously (meander) index of the mountain front

Table 13- Results from the Mountain Front Twist Index Smf in the basin

Design name	Ls	Lmf	Smf	Activity class
Behjatabad	1/5	8/5	1/1	1

4-8- Basin hypsometric curve index (HC) and hypsometric integral (Hi)

In the calculation of this index $\frac{h}{H}$ and $\frac{a}{A}$ are measured from topographic maps. In these calculations, "H" is the height of the basin, which is obtained from the difference between the maximum and minimum heights in the basin. And "A" is the total area of the basin. The numerical value of $\frac{a}{A}$ ratio is variable between 0 and 1. Three stages of youth, middle or adulthood for hypsometric curves has been designated by Strahler.

It is worth mentioning that hypsometric curves are usually plotted on the vertical axis based on the $\frac{h}{H}$ ratio and $\frac{a}{A}$ ratio on the horizontal axis. Analyzing these curves is one way to identify the rate of tectonic activity. These analyses are usually conducted by calculating the integral of the area under the curves, called the hypsometric integral index, or Hi.

For this purpose, the following equation can be used:

$$Hi = \frac{Hint - Hmin}{Hmax - Hmin}$$

In this equation: H max: Maximum height H, min: Minimum height and Hint is the average height of the basin. It should be noted that these heights can be easily and simply extracted from the topographic maps of the river drainage basin or study area.

The result of the hypsometric integral index in Behjatabad Dam basin is calculated based on the above interface and its result is listed in (Table 14). Based on the results, the Hi class index shows a high rate of activity for the Behjatabad Dam basin.

Table 14- Results from the hypsometric integral index Hi

Design name	max	min	And	Hi	Activity class
Behjatabad	2638	1414	1934	0/4	1

5- Index of relative active tectonic (Iat:)

The index of relative active tectonic (Iat) is obtained by averaging the class of tectonic decay index. Then the total number of classes is divided by the number of indicators. The Iat index is calculated from the following formula.

$$Iat = \frac{s}{n}$$

In this equation, the sum of the both morphotectonic indexes classes and the number of indicators is examined. To classify this index, the following categories

are suggested according to the work of Hamdouni et al. (Hamdouni et al, 2008)[9] in (Table 15).

The results of the study and calculations related to the relative index of active tectonic (Iat) are listed in (Table 16). Based on these results, the Behjatabad Dam basin with an Iat index of 1.38 is in terms of the standard of tectonic activity rates in a region with very high activity or a very active land construction rate region.

Table 15- Criteria for the rate of tectonic activities in relation to the index Iat (Hamdouni et al, 2008)

Level Iat	Tectonic activity rate
1 – 1.5	Very active
1.5 - 2	active
2 – 2.5	medium
>2.5	Inactive

Table 16- Results from the scrutiny of Iat and tectonic rate in Basin Studies

Design name	Sl	Vf	Af	Bs	T	Smf	S	Hi	I at	Tectonic Activity rate
Behjatabad	2	1	1	1	2	1	1	2	1/38	Very active

6- The Study of Seismotectonic

In Behjatabad dam project, the studies have been done on active faults until 50 Km radius. 25 active and seismic faults have been identified in this area. The results of the study regarding all 25 faults in the area of this dam are presented in Table 17. Also, the map of the historical earthquakes' epicenter and the map of recorded epicenters by seismometer along with active faults until 150 Km of the dam site has been shown respectively in figure 14 and 15.

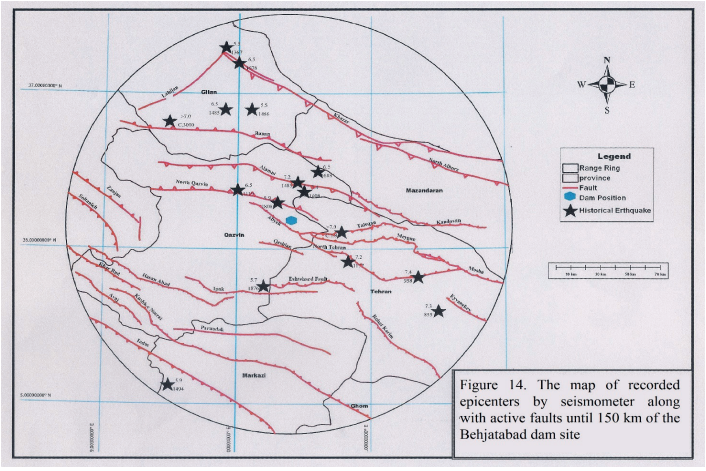

Figure 14. The map of recorded epicenters by seismometer along with active faults until 150 km of the Behjatabad dam site

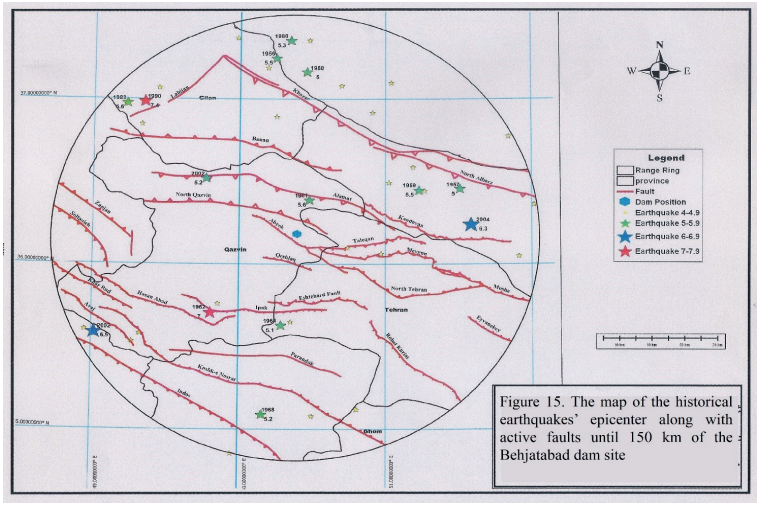

Figure 13,14- the map of the historical earthquakes epicenter and recorded epicenters

In Figure 16, all the mentioned fractures have been shown on the Quick Bird satellite image. It is worth mentioning that according to numerous field surveys in the area of the dam site and its surroundings, no structural connection between these fractures and the Abyek fault (the closest fault to the dam site) has been observed, and therefore the mentioned fractures will probably not have seismic activity.

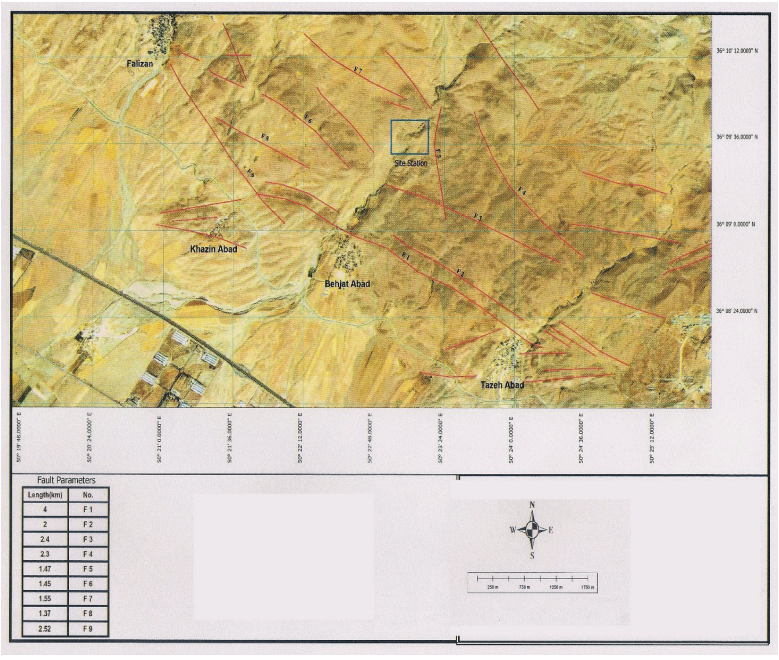

Figure 15- Distribution map of auxiliary faults in the area

6-1- Estimations of parameters with seismicity coefficients in the studied dams

The studied results are presented in Table 18. Generally, Behjatabad Dam is in a high seismic activity condition in terms of both seismicity and the rhythm of the annual event.

Table 17- The results of calculation of Gutenberg-Richter seismic coefficients in Behjatabad Dam

Correlation coefficient R	Standard Error SE	Seismicity Coefficients		Study Plan
		b	a	
0.94	0.40	0.4	3.8	Behjatabad

6-2- the study of the return period index of earthquake magnitudes

Commonly, two methods are mostly used for the return period of earthquake magnitude. These methods include the Gutenberg-Richter (1956)[8] elementary method and the more advanced Kijko-Sellul (1989,1992)[14,15] method. The results of this study and calculations are presented in Table 19.

Based on these results, there is possibility of earthquakes with a magnitude greater than 7 Richter in Behjatabad Dam in the return period of 100 years (equivalent to the useful life of the dam).

Table 18- The results of the Gutenberg Richter (1956)[8] and Kijko-Sellul (1989)[14] methods for the return period of various magnitude

Magnitude of Behjatabad Dam	Return Period (Year)	Method
7.6	75	Gutenberg-Richter (1956)[8]
>8	175	
>8	475	
>8	975	
6.6	75	Kijko-Sellul (1989)[14]
7.0	175	
7.2	475	
7.4	975	

6-3- Acceleration calculations at different design levels

The maximum horizontal and vertical acceleration values at different design levels for Behjatabad Dam are presented in Table 20. It is worth mentioning that in the mentioned plan, the most important seismic source or sources that play the main role in determining the values of the ground movement parameters, especially the calculation of the maximum acceleration values are the Abyek, Taleghan, North Qazvin, and Qeshlaq faults respectively with lengths of 49, 81, 76 and 33 Km and the distance from the dam site is 2, 10, 15 and 17 Km and magnitude scales (MS), 6.5, 6.8, 6.8 and 6.2 are the most important seismic sources and create the most acceleration at the dam site.

Table 19- The results of calculation of proposed maximum acceleration for the earthquake and different design levels

Behjatabad Dam		Calculation Method	Return Period (Year)	Probable Earthquake	Seismic Design Level
Horizontal	Vertical				
0.23	0.21	probabilistic	500	DBE	DBL
0.37	0.23	probabilistic	2000	MDE	MDL
0.48	0.34	deterministic	10000	MCE	MCL

According to the aforementioned paragraph, the maximum magnitude scale (Ms): 7.4 is reasonable for the largest possible earthquake in the studied area in connection with the activity of a bedrock fault.

Therefore, given conducted studies, it is clear that the Behjatabad dam area is very active in terms of tectonics, and the structures in this area should be designed and analyzed more sensitively.

Conclusion. Morphotectonic Indexes can have an appropriate role as an important tool in assessing and determining the rate of tectonic activity within the river drainage basin of the dam and the associated structures. Since the results of examining these indicators and analyzing these results have a significant impact on the dam site and design of the required structures in this site. Therefore, these results should be considered in the structural design of dams.

It is worth mentioning that the results of assessing morphotectonic indexes in dam construction areas could be taken as a very suitable complement and verifier for seismotectonic investigations results.

25 active and seismic faults have been detected within 50 Km of Behjatabad dam. Among them, the four faults consisting of Abyek (2 Km), Taleghan (10 Km), Qazvin (15 Km) and Qeshlaq (17 Km) are very important. The magnitude of earthquakes that these faults can cause is 6.5, 6.8, 6.8 and 6.2 Richter respectively. According to the calculations, the largest possible earthquake in Behjatabad dam site has a magnitude of 7.4 Richter.

The evaluation and analysis of morphotectonic indexes and the relative index of active earth tectonic (Iat) in the Behjatabad Dam River Basin indicate high level of tectonic activities.

In other words, the river drainage basin area and the construction site of Behjatabad dam is located in an area with a very active tectonic rate. Thus, high tectonic activities shall be taken into account in the design of Behjatabad Dam and the related structures.

The studied morphotectonic indexes for Behjatabad dam are Hi, S, smf, T, BS, Af, Vf and SI respectively with the values of 2, 1, 1, 2, 1, 1, 1 and 2 and the Iat index is equal to 1.38 which indicates the high rate of tectonic activities in this region.

Based on this issue, you should be accepting the designs for the maximum credible earthquake) MCE (And in terms of maximum vertical and horizontal acceleration at the maximum credible level) MCL (To be done.

Therefore, in applying different seismic levels, the impact of morphotectonic indexes should be considered. For example, in an area that has little seismic data or existing data shows low seismotectonic activity, but the calculation of morphotectonic indexes indicates high tectonic activity, the results of these indicators should be given more importance and related dams and structures should be designed based on high seismic parameters.

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