A Review: The Tectonic Perspective and seismic response of Darbandikhan Dam Stability and potential solutions

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Abstract.
Darbandikhan dam is a rockfill dam constructed northwest of Iraq in the early sixties. Even though the dam is located in a mountain zone with high seismic influence, the dam was not designed to resist a high seismic motion. This study is a review of Darbandikhan dam current situation and the possible factors of its potential failure. The dam can be regarded as a vulnerable condition. Due to the unstable geologic formations and the existence of limestone and anhydrite which can impact the dam stability. On the other hand, rainfall dwindling and the temperature rising affected the hydrological system in the area. Climate change causes drought, desertification followed by a flood in a very short period. Therefore, the dam reservoir elevation has been diminished due to the reduction of the inflow. The dam has experienced a strong seismic motion in November 2017, it causes serious fissures on the dam road, failure on the left side slope and rocks toppling. The sliding of soil and the falling rocks in the dam lake when the earthquake hit the dam location, lead to clay accumulation which has prevented the gates to be opened. Serious and fast maintenance have to be implemented to fix the landslides and dam safety against earthquakes.

Keywords: Darbandikhan dam, Seismic response, Climate change, Sirwan river

1. Introduction:
Darbandikhan dam was constructed on Diyala river during (1956 to 1961) (Cordell 2006, Tofiq and Guven 2014). It is a rockfill dam with a clay core and 128m height. The downstream and upstream slopes of the embankment are 1:1.75 (V: H) from the upper side and 1:2 (V: H) from the lower side, and the width and length of the embankment crest are 17m and 535m, respectively (Cordell 2006). The embankment clay core’s volume is $1.3 \times 10^6 m^3$, includes filters with grainy materials which allows the water through and prevents sediments. To prevent the sliding and stabilize the right and left banks of the embankment, a remedial effort was accomplished. The area contains a power station with 249 MW which was installed in 1985. The spillway was installed on the western side with an elevation of 470 m to control the emergency flow which allows the flow of $(5700-11400) m^3/s$ (Tofiq and Guven 2014). The reservoir volume is $3 \times 10^8 m^3$ at a water level of 485 m. Live storage volume is $2.5 \times 10^9 m^3$ while the dead storage is $0.5 \times 10^9 m^3$ at 434 m of water level. The reservoir experienced rockslides more than once. Therefore, a maintenance was carried out to prevent a potential overtopping break (Al-Ansari and Knutsson 2011). Figure 1 shows the dimensions of the dam. Darbandikhan dam’s lake is considered one of the main lakes in the Kurdistan region, north of Iraq. It is basically fed by two tributaries: The Diyala river which stems from Iran and the Tanjero river which comes from the north (Jafir, Ahmed et al. 2017). The dam was constructed essentially for irrigation
and generating power. Rather than that the lake is a source of drinking water and agricultural benefits for the neighbouring area (Ararat, Mehti et al. 2008). The dam lake is encompassed with mountains and hills, and water elevation is usually decreasing during the summer season however, it increased again due to rain in winter. The lake witnessed frequent changes in water level between (1984-2018), whereas a piecemeal drought started to appear gradually due to the variation of the precipitation. Also, considering the constructed dams on Diyala river tributaries by Iran, this was an essential cause to reduce the water level in the dam lake (Azeez, Ahmad et al. 2020). The dam foundation sits on different tectonic formations with various characteristics which behave differently with the seismic response. The dam was exposed to a strong seismic effect with MW 7.3, on November 12, 2017. The earthquake affected the area around the embankment, and also the formation properties of the foundation. Landslides occurred in the region of the dam structure. Furthermore, some of the massive rocks in the area became unstable due to the landslides on the location (İmamoğlu, Bedirhanoğlu et al. 2018). Cracks have shown around the embankment core, and it gets bigger up to 21 cm towards the middle of the dam structure.

In this paper, an extensive review of the Darbandikhan dam condition has been illustrated showing the geological perspective of the dam and vicinity, climate change impact, seismic influence on the dam, and general evaluation of the dam safety.

![Figure 1. Darbadikhan Dam dimensions](image)

**Figure 1. Darbadikhan Dam dimensions**

1.1 Diyala river and the catchment area

Diyala river is considered as the main tributary of Tigris which stems from Iran mountains and runs through Sulaimaniyah city in Iraq. The total length of the river is 445 km, and it flows into Darbandikhan lake with a daily maximum inflow of 5816 m³/s (Tofiq and Guven 2014). The total catchment area is around 32600 km², 59% of it in Iran while the rest flows in Iraq. The river fountains are located in Zagros mountains in Iran, and it has three essential tributaries: Tanjeru, Wand, and Sirwan (Al-Faraj and Scholz 2014). The river basically runs through three regions, the first is between Zagros Mountain and Darbadikhan dam, the second lied between Darbandikhan lake and Himreen Dam, whereas the third region located between Himreen dam and Tigris river. It runs from east to west until it meets with Tigris 5 km from Baghdad (Abbas, Wasimi et al. 2016, Al-Khafaji and Al-Chalabi 2019).

Darbandikhan dam is an earth dam located between (45°51′23.512″E 34°27′10.021″N) about 285 km north of Baghdad and 65 km from Sulaimaniyah city (Tofiq and Guven 2014). Figure 2 shows the dam location in Iraq (Tofiq and Güven 2015). It was the first conducted dam in Iraq with a 128m height.
and 17m crest width (Al-Husseinawi 2019). The catchment area covered by the Darbandikhan dam is around 17850 \(km^2\) while the area covered by the reservoir is 113 \(km^2\). During the hot summer, the area affected by the high temperature which can get to 40°C. Also, semi-orbital and pressure belts influence the region. Whereas in winter, the temperature can get to zero. The area is also affected by the Mediterranean wind and tornadoes from the Arabian sea which can cause heavy rain. Precipitation is impacted by the Mediterranean Sea as well (Azeez, Ahmad et al. 2020).

![Figure 2. Darbandikhan Dam location using GIS mapping](image)

### 2. Geologic and Tectonic characteristic of the area:

The dam lied between Eurasian and Arabian geologic plates in the Zagros area (Sadeghi and Yassaghi 2016). There are different types of formations around this zone. These formations are Bai Hassan, Mukdadiya, Injana, Fatha, Khurmala, Kolosh, Sinjar and Tanjero (Sissakian and Fouad 2015). Figure 3 shows the tectonic characteristics in the region.
2.1 Bai Hassan formation
The essential geology of these layers is Clastic. These formations match the geology layers in the southeast of Turkey and Northern Syria (İMAMOĞLU, BEDİRHANOĞLU et al. 2018). Basically, these rocks are widespread in the north of Iraq especially in Khanaqeen, Badra, Darbandikhan area and Qara Dagh (Sissakian and Fouad 2014).

2.2 Mukdadiya formation
These geologic layers are implicating claystone, siltstone, sandstone and mudstone. The thickness of these layers around (100-230) m. it belongs to the late Miocene age. Most of the sandstone forms the riverbeds. These forms can be seen in the Darbandikhan area most apparent. These rocks are usually settled easily in rivers. It covers Darbandikhan, Qara Dagh and Khanaqeen (İMAMOĞLU, BEDİRHANOĞLU et al. 2018).

2.3 Injana formation
These formations consist of claystone, siltstone and sandstone. These rocks tend to be brown-reddish in colour. It can be found in Qara Dagh and Darbandikhan dam area. Its depth ranges between (200-330) m (Sissakian, Al-Ansari et al. 2015).

2.4 Fatha formation
These layers include gypsum, limestone, red claystone and green marl. Also, it is considered the most widespread geology in Iraq. These geologic materials are majorly implicating anhydrite which can be converted into limestone and marl. The thickness of these layers varies from one region to another, it ranges between (600-900) m. A part of the Darbandikhan dam foundation settled on these geologic layers (Sissakian, Al-Ansari et al. 2015, İMAMOĞLU, BEDİRHANOĞLU et al. 2018).

2.5 Khurmala formation
These rocks consist of gypsum, anhydrite and limestone. The average depth of it is around 185 m. it settled near the south of downstream side of Darbadikhan dam.

2.6 Kolosh formation
This geology consists of calcareous, marl, shale and sandstone with 410 m depth. These rocks can be found transitioning between Kolosh and Sinjar formation. Its depth can reach to 1000 m in some regions around Darbandikhan area (İMAMOĞLU, BEDİRHANOĞLU et al. 2018).

2.7 Sinjar formation
These layers are identified in Sinjar city and can be indicated by containing algae reefs and lagoonal calcareous. The typical depth of these geologic layers is usually around 176 m. These layers are spread in the Darbandikhan dam area with 120 m thickness (İMAMOĞLU, BEDİRHA.NOĞLU et al. 2018).

2.8 Tanjero formation
These formations implicate siltstone, limestone and marl which located mainly south of Sulaimaniyah city. The biggest depth of these geologic materials is around 2000 m and can be indicated between Chuwarda and Rowarduz (İMAMOĞLU, BEDİRHA.NOĞLU et al. 2018). These forms covered enormous areas in Darbandikhan and the south-east of the Dam (Sissakian and Fouad 2015). Figure 3 shows extensively the formations in the Darbandikhan dam area.

3. Climate change impact on Darbandikhan area:
The climate effect is regarded as a main challenging factor that the world has to resolve. Temperature and precipitation patterns are parts of this system that influence the hydrological system (Mimikou, Baltas et al. 2000). This variegation in hydrological patterns causes a drought pursued by inordinate flood in a very short time (Owor, Taylor et al. 2009). In recent years, Iraq witnessed serious water issues including pollution, water shortage, and desertification (Abbas, Wasimi et al. 2016). The variety of climate in the region led to form aquifers, fountains and rivers which born in the mountains area and find their way to the plains. Because of that, the Tigris river basin flooded many times, whereas the river flow can reach 300 mm/hour (Jaradat 2003).

During the last decades, a fast alteration in climate change pattern has been taken place because of the continuous rising of temperature and dwindling of rainfall. This rapid variation in climate has occurred due to natural and manmade factors (Stocker 2014). Climate effect can be reflected directly on the sediment yield and streamflow characteristics (Owor, Taylor et al. 2009). For instance, precipitation has been diminished by 12.5% in the Tigris basin in Turkey during 2021 because of climate impact in the area and it is expected that rainfall in Tigris river will be decreased by 26% in 2030 (Şen 2019). In recent years, Iraq has witnessed an extreme change in the climate. For instance, from 2007 to 2009, extreme drought has been taken place in the area and followed by severe rainfall in the southern regions of Iraq which was double the normal percentage of precipitation (Al-Khafaji and Al-Chalabi 2019). The geographical information system has been utilized to evaluate the climate influence in Jordan and Iraq (De Pauw, Saba et al. 2015). This research showed that the climate will tend to be arid, the land cover will be diminished with the decreasing of water resources, and the temperature will be rising. Due to that, Diyala river witnessed an unordinary shortage in the inflow rate and increasing in sedimentation (Adamo, Al-Ansari et al. 2018). Therefore, an extensive study for the rapid change in climate and its influence on Diyala river is required (Issa, Al-Ansari et al. 2014). The temporal and spatial distributions of sediment yield and streamflow are influenced by precipitation characteristics such as soil type, land cover, topography, and intensity (Chakravarti, Joshi et al. 2015). Another element is the scarcity of land cover to stabilize the soil which may cause soil erosion by runoff. SWAT model has been utilized to assess the influence of watershed management on runoff, chemical yields in a complicated hydrological system, and sediments (Gassman, Reyes et al. 2007). SWAT is considered an effective tool to quantify and simulate the water quality and quantity in watersheds under various climate conditions (Neitsch, Arnold et al. 2011). Li and Gao (2015) , Principe (2012) indicated that the data of the weather which refers to the fluctuation of the climate is regarded as an essential factor to control sedimentation rate in the watershed. A connection between the watershed scale and climate variation indices has been conducted by providing a crucial insight of water balancing dynamics and the impact of seasonality on estimating the drought in the watershed (Sehgal and Sridhar 2019). The variation of climate in Iraq have been investigated by utilizing five hydrological models: EUROSEM, AGNPS, WEPP, CREAMS, and SWAT. SWAT model has been
utilized for its efficiency in modelling the variation of climate data and water resources (Tomy and Sumam 2016). The recent study that addressed the influence of change in climate on the sediment yield and streamflow of the Diyala basin have utilized the SWAT model to predict the future influence of climate on the inflow. The results showed that the watersheds in the Darbandikhan area will be reduced to 49% in 2050. The reduction in watershed percentage can be basically because of the precipitation shortage and air temperature rising. Furthermore, sediment yield will be diminished to 43.7% in Darbandikhan watersheds. Also, because of the scarcity of the landcover which can catch the soil against the force of the flow, this can cause a negative impact on the sediment gates operation. This study has investigated an extreme hydrological events such as peak sediment and streamflow in Diyala basin (Al-Khafaji and Al-Chalabi 2019).

3.1 Influence of climate change on Darbandikhan lake:
To estimate the variation in elevation of Darbandikhan dam lake, a remote sensing method has been applied based on Landsat images to predict the drought affection on the lake levels. Firstly, the area is about to witness a water shortage in the near future because the Iranian part has constructed several dams on the tributaries which affect the inflow to the lake. This causes a manifest decrease in the lake water levels, affecting the environmental life of the area (Abdullah and Abdullah 2013, Toma 2013). Satellite analysis showed a noticeable variation in the lake surface during recent years. A manifest fluctuation has taken place in the lake as its levels were been increased or decreased of the normal percentage (Azeez, Ahmad et al. 2020). Figure 4 illustrates the variations in Darbandikhan lake’s elevation in different years according to Landsat satellite images.

The surface flow from the Sirwan river, rainfall, and the runoff from the adjacent areas are the main sources of Darbandikhan lake. Therefore, the hydrological situation in the area effects directly on the climate state in the lake especially the temperature and precipitation.

In order to predict the drought impact on the lake levels, the 12 months’ time scale SPI values have been utilized for the years of 1984-2017. The results revealed that the lake elevation has witnessed a periodic variation during these years. Also, extreme drought was indicated in 1995,2000,2015,2017. The resulted percentage of drought in the study is 47% which is almost half of the considered years in the study, and that reveals a manifest drought (Azeez, Ahmad et al. 2020).
4. Darbandikhan dam evaluation:
Rockfill and earth-fill dams varied with their behaviour when a seismic motion takes place and mainly depends on the velocity and acceleration of that motion (Newmark 1965). Furthermore, the geological beds are an essential factor that has a huge impact on the dam’s stability (Anastasiadis, Klimis et al. 2004). The motion can cause a 1.5m downslope when it has a strong acceleration (Serff, Seed et al. 1976). Also, the compaction degree is another factor that can influence the dam stability when an earthquake occurs. The dam crest is the utmost vulnerable side during the earthquake, it can break and slide to the toe. The dam failure can cause displacements in the slope sides which can be extended to the surface (Al-Husseinawi, Li et al. 2018).

The stability of Darbandikhan dam is investigated by the Water Resources Ministry to inspect any abnormal issue. A network of pillars has been installed on the surface of the dam, whereas a levelling inspection and GPS were conducted. Also, the seepage of water in the body of the dam was monitored within nine installed piezometers to indicate the dam behaviour (Cordell 2006). Because of the
limestone beds (Khurmala formation) which form 535 m along the dam body, it is eroded easily with water seepage under the dam. Moreover, the dam sits entirely on siltstone-claystone beds. Figure 5 shows the formations in the dam site.

Both left and right banks require proper compacting and stabilization. Investigation shows the existence of cracks on the right bank road of the dam because of failing the underneath beds of siltstone-claystone under the dam foundation. Therefore, dam hillsides are representing a manifest danger due to the activeness of rockfall and landslides. An extensive investigation must be conducted to indicate the landslides and the unstable parts of the dam (İMAMOĞLU, BEDİRHAĞANOĞLU et al. 2018).

4.1 Seismic impact on rockfill dams

One of the infrastructure safety factors is the quality of construction. Several dams were failed due to seismic motion with Mw > 6, such as San Andreas dam (1906), Sheffield dam (1925) in California, USA. Some cases of dam distortion following seismic motion were investigated considering the history of earth dams all over the world (Sêco e Pinto 2010). One of the worst dam breaks occurred in the history of mankind during 1786 in Kangding, China, and lead to 100000 deaths due to the landslide resulted from Mw 7.7 earthquake (Dai, Lee et al. 2005).

4.1.1 History of seismic response in the area

The Middle East has become an active seismic region that can have an intense earthquake. Indian, Arabian and African plates are moving to the Eurasian plates towards the north. In 1945, it has recorded the most destroying earthquake during the last 100 years with Mw 8.1. The seismic motion hits the Makran area, north of Oman Gulf causing a tsunami in Oman Gulf and the Arabian sea and lead to 4000 deaths. During May 1935 in Pakistan, an earthquake occurred with Mw 7.6 leading to 30000 deaths approximately. The collision between Eurasian and Arabian plates lead to crust distortion along the Iranian mountains. Therefore, the eastern parts of Iran can be considered as a vulnerable region due to the seismic activity in the region. For instance, Dasth-E-Lut area was experienced a strong earthquake with Mw 7.8 during 1978 and causing around 15000 deaths. Furthermore, the previous earthquakes show seismic activity on the Iran-Turkey border. In 1930, Mw 7.2 earthquake hits Hakkari city causing 2514 person deaths and a lot of destruction. Also, 2385 people died in 1975 due to an earthquake that hits Diyarbakir with a magnitude of Mw 6.6. The latest seismic activity has taken place in Turkey was during 2011 in Van city, causes a lot of destruction in
many cities and 604 deaths. Figure 6 illustrates the history of the devastating earthquakes which have occurred in the area (İMAMOĞLU, BEDİRHAOĞLU et al. 2018).

Figure 6: shows the history of earthquakes in the area between 1900 to 2016 (İMAMOĞLU, BEDİRHAOĞLU et al. 2018)

4.1.2 Seismic impact on Darbandikhan dam

Dams can be influenced by an earthquake with different deformations such as: overtopping resulted from the water waves in the dam reservoir, slope sliding, longitudinal and cross-sectional cracks, seepage under the foundation, reduction of the freeboard and dam body liquefaction (Sêco e Pinto 2010).

Despite the fact that Darbandikhan dam is located in the active zone of high seismicity, there are not enough instruments to check the dam safety during and after the seismic motion (Cordell 2006). During (2006-2010), some implemented maintenance was carried out to fix the landslide in the left side bank and rock stability in the left and right abutments.

During November 2017, the dam was hit by an earthquake from Sarpol e- Zahab area on the Iraqi – Iranian borders with a magnitude of Mw 7.3, it was considered as one of the strongest earthquakes that occurred in the Zagros regions since 1900 (Alsinawi and Ghalib 1975). Causing 396 deaths and around 7000 injuries in the impacted area (Al-Husseinawi, Li et al. 2018). Although the majority of destructions have occurred in the Iranian cities, Darbandikhan area was the most influenced by the earthquake. The earthquake hits the northern parts of Iraq, around 30 km from the dam territory. Figure 8 shows the earthquake event location and the intensity of seismicity in the area. Previously, the dam has been evaluated to be safe seismically under shaking of Mw 6.5 (Cordell 2006). Currently, there are some concerns about the stability of the dam. The reservoir water level has been decreased as a precaution to keep the dam safe. The distortion in the dam body is manifest after the earthquake.
Several cracks on the crest of the dam have been observed (as it is shown in figure 7). The region has witnessed 53 earthquakes with a magnitude Mw>4. Utilizing Sentinel-1, levelling and GPS (the global positioning system) to evaluate Darbandikhan dam safety after the Mw 7.3 earthquake and estimating the dam subsidence after, before and throughout the seismic motion. Levelling and GPS data have been collected between March and November 2017 to calculate the subsidence of the dam. Also, Sentinel-1 data images were collected during (October 2014-March 2018) to create a time series of the dam body displacement. Sentinel-1 data are considered as a sufficient method to evaluate the subsidence of the dam body, whereas 68 sentinel-1 images have been harnessed for this study between 2014 to 2018. The results revealed that the dam was comparatively stable with a displacement of 4 mm/year. While after the earthquake has occurred, the crest has displaced at a rate of 70 mm/year until March 2018. Sentinel-1 data showed a continuous displacement between November 2017 to March 2018 (Al-Husseinawi, Li et al. 2018). The fissures on the downstream slope can be riskier than those on the upstream or the crest. Despite the maximum subsidence concentrated in the centre of the dam body, different sides of the dam body displaced with different values in both horizontal and vertical directions. Such attitudes are expected during seismic motion (R.I. 1990). Shaking the dam body can cause non-uniform subsidence on different sides of the dam depends on the acceleration of the seismic motion. The earthquake direction may affect the value of the subsidence, whereas the motion must be on the longitudinal side slope despite the direction of the motion, due to gravity.

Figure 7: Cracks observed in the area of the dam after Sarpol e- Zahab earthquake
Darbandikhan dam can be considered as a vulnerable dam because of the followings (AL-Rahal, Khattab et al. 2020):

a- The dam region lies in a tectonic fault area which is more likely to threaten the dam stability when an earthquake occurs.

b- The existence of cracks on the dam road and the surrounding area, and failure of the left side slope.

c- The sliding of soil and falling rocks in the dam lake which causes an accumulation of clay prevented the gates to be unlocked.

These reasons put the dam in a vulnerable situation of failure. Therefore, it is crucial to assess the safety of the soil slope shoulders under various conditions as static load, rainfall and earthquakes.

Rainfall is an essential element that influences the stability of slopes. The soil in the side slopes tends to be unsaturated generally, and when it attached to rainfall, its pores will be impacted and its shear strength can be reduced. Subsequently, the slope side stability will be influenced directly (Rahimi, Rahardjo et al. 2010, Ji-Cheng, Xiao-Nan et al. 2014). On the other hand, the dynamic load can be manmade such as railways and machines or natural as earthquakes. There are many tools and types of equipment to estimate the stability of side slopes when it’s under earthquake load. Also, softwares as GEO-SLOPE can be utilized to analyze numerically the slope stability (Vyas, Rukhaiyar et al. 2014).

A centrifuge and shaking tables were applied as a laboratory technique to predict and simulate the
behaviour of the slopes during seismic motion (Viswanadham and Mahajan 2007, Giri and Sengupta 2010).

To analyze the left side slope’s stability of Darbandikhan dam (which implicates low plasticity clay and unsaturated soil) with respect to earthquake and rainfall, Geo-Studio software has been harnessed. Laboratory tests have been performed on the soil samples which have been taken from the field to indicate the soil characteristics. The model has been exposed to an earthquake and 24 mm/ day as rainfall intensity with varied periods (10, 20, 30, 40, 50, and 60) days. For each period of time, an analysis has been implemented. The results showed that the model condition was critical when it was exposed to a seismic motion with a magnitude Mw 7.3 for 30 seconds and 20 days of rainfall with an intensity of 24 mm/ day. Moreover, the earthquake causes an amplifying in the stresses of soil particles which cause a decreasing in slope stability, while the rainfall causes a reducing in the shear values after 60 days of rain (AL-Rahal, Khattab et al. 2020).

4.3 Structural and rock stability assessment

Rock slope’s failure is the falling of rocks with different sizes downslope due to their own mass (Blyth 1984). Usually, the rock mass work as a strengthening tool to stabilize the slope but by the time it can fail and move to the downslope (Hoek and Bray 1981). Aziz, Al-Samarrai et al. (2019) implemented engineering and structural research to evaluate the rock slope safety in six stations whereas a rock failure has been taken place. These stations located along Sirwan road, south of Baranan mountain, near Darbandikhan dam. Rock slopes have been investigated in every station and the failure zones have been indicated. GEOFPRINT 9.5 software was utilized to create a stereographic projection by representing the field data to analyze the six stations condition separately. Sliding, toppling and rockfall were the indicated failures of rock slope in the study area. The slope angle, dip of strata and height were the essential elements that influence the slope stability. Most of the indicated failures in the area have been occurred due to the existence of rock masses without strong support. And due to the weather effect and erosion, these masses can become a source of danger. The model presented 60% of the conducted failures were rockfall, 10% by sliding and 30% due to toppling (Aziz, Al-Samarrai et al. 2019).

5. Conclusion:

Darbandikhan dam’s condition is critical because of its location which is close to the Zagros region and due to the seismic activity in the area. The dam foundation sits on different formations of limestone, siltstone, marl and anhydrite. These geologic materials can cause dissolution under the dam due to the anhydrite conversion when it is attached to water, and this can cause a stability issue to the dam. Also, the dam lake affected by the climate change impact in the area such as the high temperature and the decreasing in precipitation which has been reduced by 12.5%, and this lead to inflow reduction in Diyala river. It is expected that the dam watershed will be decreased to 49% by 2050 because of the continuous shortage of rainfall and the rising of air temperature. Therefore, drought is spreading in the area, whereas the drought percentage reached 47%. Moreover, the dam banks lacked the appropriate compaction which is an important factor to stabilize the huge embankments. The crest of Darbandikhan dam is the most vulnerable parts during seismic motions which can fail and slide to the toe causing a dam failure. Cracks have shown up on the road banks because of the eroded formation beds of siltstone-claystone underneath the road. Also, the subsidence of the dam body after the earthquake of Saporal e-Zahab has become 70 mm/year while it was 4 mm/year. The scarcity of landcover cause soil erosion when the soil exposed to rainfall, this can lead to landslides easily when seismic motion takes place. A huge unstable rock masses may slide easily to downslope due to the erosion or weather effect. An outstanding effort has to be made to avoid a possible disaster that may occur to Darbandikhan dam and the neighbouring region.
6. Recommendations:
a- A quick maintain on the dam location should have been taken place to avoid an extra fail which may threaten the dam safety.
b- Removing all the unstable blocks and rock masses that may slide or move downslope.
c- A periodic survey and monitoring of the dam must be conducted to indicate its displacement and maintaining it.
d- wrapping the slopes with stabilizing material as gabions are preferable to create more safety during seismic motions.
e- To reduce risk and protect the slope, a retaining wall can be constructed to provide a more safe location.
f- Spreading awareness in the area by warning the people who live near the dam and close to the riverbank in case the dam fail. Moreover, a warning sign in the dangerous locations shows people the riskiest locations.

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