Design of Large Dams on Active Fault

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SUMMARY:
One of the initial procedures for design and construction of dams is available site selection. Iran country lies on a very active region from seismicity point of view, therefore Construction of dam in such areas must be considered with a required safety factors. Existence active fault on dam site is one of the most effective factors in the selection of dam type. The Shirvan dam with a height of 83 m is the first concrete dam designed on an active fault. This active fault, F_2, is a branch of long active fault that is named Baghan-Garmab fault. Displacement rate of F_2 fault was recommended maximum 20 cm. Rudbar Lorestan with height exceeding 150 m was the second concrete dam that was studied and designed on active faults. One of them is F1 fault. The F_1 fault with a length about 2 kms passes from the dam site and is related to the Main Zagros Recent Fault. Measured maximum displacement along the F_1 fault on the dam site is about 6 m with strike slip mechanism. Therefore, for this site rock fill dam with clay core was recommended. Mangol dam located in the north of Iran was concrete face rock fill dam that was designed on active faults in studies stage. Beheshtabad dam is located in Kohkeloyeh-Boyerahmad province. Although there are several active faults in this site, the double arch dam was designed and it seems that if doesn't affect on changing the dam type should be chenged. International codes always recommend that to avoid constructing dams on active fault. If it is impossible to select another site, a flexible dam will be recommended.

Keywords: Dam site, Active Fault,Concrete dam,Seismicity

1. INTTRODUCTION

Iran lies on a very active region from seismicity point of view, since a shallow destructive earthquake (M>6.8) and several moderate earthquakes take place at least every ten years. Construction of dam or any other major structures in such areas must be considered with a required safety factors. Since 20 years ago many dams have been constructed in Iran. So with respect to the past time the convenience region for constructing of these structures is limited. Therefore, these structures must be designed in a region with low qualification. To design and construct a dam in a seismic zone, the seismotectonic and seismic hazard studies are very important and inevitable.

The Shirvan (Barezu) dam with a height of 83 m was the first arch concrete dam that designed and constructed on an active fault. Rudbar Lorestan dam with a height of more than 150 m is the second concrete dam that is being studied and designed on an active fault and very close to capable Zagros Main Recent fault (ZMRF). In this study, the effects of faults reactivations for four dams Shirvan, Rudbar Lorestan, mangol, and beheshtabad will be discussed.

2-The Shirvan dam

The Shirvan dam is a double arch dam with 83 m height. This dam is located at 50 km of Shirvan city in the Khorasan province. The Shirvan dam is located within the Kopeh Dagh folded belt at northwest of Iran. The most important and closest active structure to the dam is the Baghan-Garmab earthquake fault (F1). This right-lateral strike-slip fault with a strike N30W is lied on south of Iran-Torkmanestan Boundary at 2 km of the dam.

There is another fault (F_2) that cut lithological units at both sides of dam valley and extend toward F_1 fault (figure 1). Strike of this fault is E-W and its dip is 45-55^o toward south-southwest. With regards to previous investigations, this fault has been cut alluvial deposits and displaced those about 20 cm. On the other hand, this fault is joined to the F_1 earthquake fault (Baghan-Garmab fault). But termoluminescence tests were indicated the last motion (activity) of the fault was belong to 16000 years ago. Therefore, with regards to definition of active fault, this fault (F_1) is active. Dam construction was done without attention to F_2 fault in the site [1].

Figure 1. Baghan-Garmab fault and F_2 fault on shirvan dam

3-The Rudbar Lorestan dam

The Rudbar Lorestan power plant and dam site is located within the Zagros fold and thrust belt at south of Aligudarz city (about center of Iran). The height of this dam is 158 m and its reservoir has about 2×10^8 m^3.
Dam site has two active structures: one of them is Zagros fault that is located in northeast of dam, and other structure is Saravand-Baznavid fault (a segment of Zagros main active fault)that is located in south of dam (figure 2).
The Zagros main fault is seismically active and following destructive earthquakes have occurred along it: The Dinawar earthquakes of May 912 and April 1008 (Ms 7.0), the Lake Irene earthquake before 1889, the Silakhor earthquake of 23 January 1909 (Ms 7.4; associated with over 40 km of surface faulting along Dorud fault), the Farsinaj earthquake of 13 December 1957 (Ms 6.7), the Nahavand earthquake of 16 August 1958 (Ms 6.6; with a surface faulting between 5 and 15 km along Garun fault), the Karkhaneh earthquake of 24 March 1963 (Ms 5.8), the 1987 and 1998 earthquakes and other shocks [6].

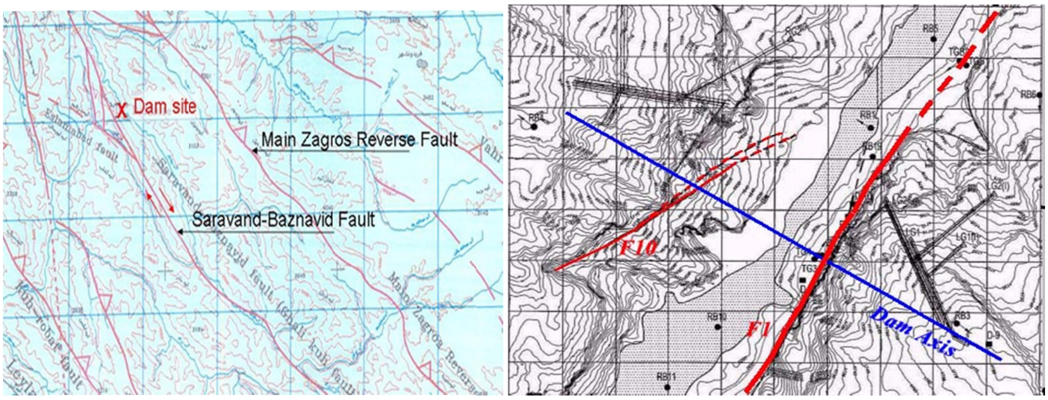

Figure 2. The Rudbar Lorestan dam site and main active fault

The Saravand-Baznavid fault is the closest seismically active structure to the dam site. The Saravand-Baznavid fault with 100 km long is a recent fault, that due to following characteristics can be recognized as an active fault:

1) The fault at the north slope of Ghali Kuh has been displaced drainages as right-lateral about 500-1000 m.
2) Based on dating (Termoluminescence method) of one sample from the fault plane above outlet portal of access tunnel (T1), age of last fault motion has been estimated 3600±400 years. On the basis of ICOLD recommendations (Bulletin 112), the SBF is recognized as an active fault.
3) The fault is lied along the Dorud fault (a segment of the Zagros main fault). The Dorud fault was ruptured during the 23 January 1909 Silakhor earthquake (Ms 7.4). Location of the Saravand-Baznavid fault along this seismogenic trend and outcrop of fault plane with right-lateral strike-slip slicken side can indicate activity of this fault as a capable fault.

This fault passes from 1600 m of the dam site. The most important fault at the dam site is the F_1 fault. This strike-slip fault forms east wall of the dam site valley and due to outcrop of a fault plane in axis area has been recognized very well. Dip of the fault plane is very much (about 90^o) and measured displacement along it is about 6 m (figure 3). This fault does not have a considerable length (less than 1 km) and located at effective bound to the Saravand-Baznavid fault [2].

Figure 3. Outcrop of a fault plane (F1) in the Rudbar Lorestan dam axis

following reasons the F_1 fault can be considered as an active fault:

1) Adjacency of this fault to one segment of the Zagros main fault (the Saravand-Baznavid fault segment) and location within its deformation zone.
2) Dating of samples from the F_1 fault plane indicate that F_1 is an active fault, as based on these tests (dating two samples), age of the last fault motion have been gained 6100±700 and 6500±650 years ago.

With respect to above information and lack of enough queries in the area, we recommend to design a Rock fill dam or a RCC dam instead of a double arch concrete dam [4].

4-Beheshtabad dam

Beheshtabad dam with 184 m height and reservoir volume about 18×10^8 m^3 is located close to Ardal city in Chaharmahale Bakhtiary province. Adviser first design for this dam is a double arch dam. Beheshtabad dam site is located within the Zagros fold. Dam site have several faults, that longest of faults is 7 km. Some of faults located near dam body and lateral structure, that due to following faults can be mentioned:

(1)F_1 fault located in left side of dam body, (2) F_2 fault passes from right side of dam body, (3) F_3 fault located under of dam body, (4) F_4 fault is existed in right side of dam site, (5) F_2, F_3, and F_6 located near dike, (6) F_4, F_2, F_6, F_8, and F_{11} influenced to diversion tunnel (figure 4).

Despite there are several active faults in this site, the double arch dam was designing and it seem that don't perform any change on dam type. International codes always recommend that avoid constructing dams on active fault. If it is impossible to select another site, a flexible dam will recommend for this site [7].

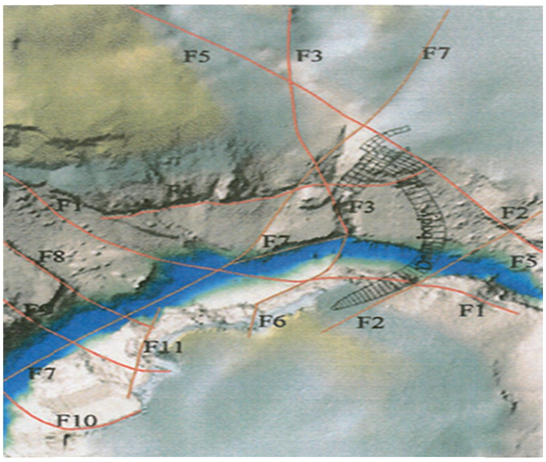

Figure 4. the faults is existing in Beheshtabad dam site

5-Mangol dam

Type of Mangol dam is predicted rockfill dam. The height of dam is 124m and its reservoir has 23×10^7 m^3. Dam site is located at 23 km south of Amol city. This dam lied on Haraz river in north of Iran.

Seismicity investigation show that Khazar fault and Alborz north fault were active faults.

Unfortunately, Mangol dam site is located at close to two segments of Alborz north fault. These fault are Kelerd and Chelav faults, and Kelerd fault is located at 2 km Chelav fault (figure 5).

The left-lateral strike-slip fault (F_1 fault) is existed At near of dam axis (figure 6).

measured displacement of fault is about 8 m. F_1 fault passes from 200 m downstream of dam axis. This fault has been cut Kelerd fault.

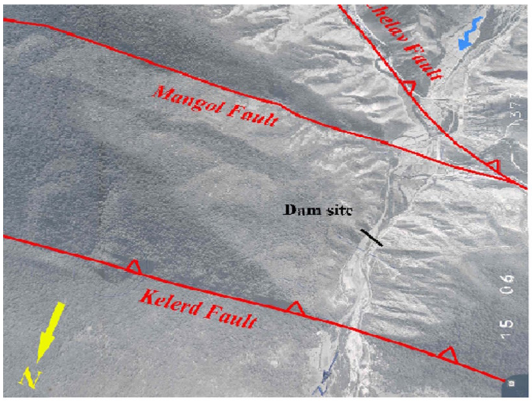

figure 5. Kelerd fault, Chelav fault, and Mangol fault

figure 6. Dam site and F_1 fault in downstream of dam axis.

Measured displacement a long of F_1 fault is 50 cm. Although, this displacement for another faults will be more 1 m [8].

6. RESULTS

To design and construct a dam in a seismic zone, the seismotectonic and seismic hazard studies are very important and inevitable. The main goal of this study is the knowledge of active faults. For example, the sun fernando earthquake of 1971 in USA indicated that faulting due to destruction of resistant structure. For this reason, it is forbidden to construct a structure close to active faults. With respect to importance of structure, they recommend to construct structures at distance 200 m to 2 km of active fault.

In this study, it is tried to describe four dams that active faults pass from the structures.

1. The Shirvan dam is a double arch dam with 83 m height located in the north east of Iran. The most important and closest active structure to the dam is the Baghan-Garmab earthquake fault (F1). There is another fault (F_2) that cut lithological units at both sides of dam valley and extend toward F_1 fault. We recommended maximum displacement about 20 cm for this fault.

The designer: 1) creating a convex reinforced concrete pad with thickness and width more than the thickness of dam body in the foundation, 2) creating several joints with parallel plates with fault plate inside the pad, 3) the lower half of vertical joints of the dam body, adjacent to the fault should have short shear crowns to make it possible that the inductive relative displacements from low levels to high levels of dam body take place.

2. The Rudbar Lorestan power plant and dam (with height about 150 m) are located within the Zagros fold and thrust belt in the center of Iran. The most important and closest active structure to the dam site is a segment of the Zagros main fault system that named the Saravand-Baznavid fault with

minimum distance between 1-2 km. For this reason, suggested to design a Rock fill dam instead of a double arch concrete dam.

3. Beheshtabad dam with 184 m height is located within the Zagros fold. The designer recommended a double arch dam. Dam site has several faults, that longest fault is 7 km. Some faults are located near dam body and lateral structure. Since, we recommended to avoid construct concrete dam on active fault.

4. Mangol dam with 124 height is located at 23 km south of Amol city. This dam lied on Haraz river in north of Iran. Mangol dam site is located at close to two segments of Alborz north fault. Because, we recommended to constructing rock fill dam for this site.

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