Rudbar Lorestan Dam Design and local Faults

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Abstract

The Rudbar Lorestan Dam area is located in the High Zagros Seismotectonic province of Iran. The access to the area especially the dam site for tectonically mapping is rather difficult. The dam site is close to two main structures. Main Zagros Reverse fault to the Northeast of dam and a segment of the Main Zagros Recent Fault (Saravand-Baznavid) on the Southwest of the dam site. Several big earthquakes occurred along the Main Recent Fault. One of the most important one was Silakhor earthquake with Ms7.4. A strike-slip local fault (F1) is passing from the dam site. Measured maximum displacement of the F1 fault on the dam site is about 6 m. This displacement can be due to several movements.

On the right abutment another local fault is located by the name F10 and which appear shearing of the bedding plane. Based on the Termoluminescence method of samples from the fault planes motion estimated about 3-8 thousand years. The F1 Fault surface is smooth, and there are very prominent striations ranging in scale from fine slickensides to CM scale grooves, tool marks and corrugations. Besides the fault F1 and F10 there are a number of other local faults which may also be removed during the reactivation of Main Recent Fault. For dynamic analysis of dam body an earthquake with Ms7.4 is selected for reactivation of Saravand-Baznavid fault.

KEYWORDS: Rudbar Lorestan, active, fault, dam

1. INTRODUCTION

I love Iran, but this country located on a very active region from seismicity point of view, since a shallow destructive earthquake (M>6.8) and several moderate earthquakes will be occur at least every ten years. Then, because we live in this country, we should try to protect the lives of people against the earthquake and, so their properties. Construction of major structures in such area must be considered with a required safety factors. So with respect to the past time the convenience region for constructing of dam structures is limited. Therefore these structures must be designed in a region with low qualification. To design and construct a dam in a seismic active zone, the seismotectonic and seismic hazard studies are very important and inevitable. The Rudbar Lorestan dam site has the same conditions. This site is located in the seismic active zone in the Zagros Seismotectonic Province that lies in the center of Iran. There are several active faults in this zone. A segment of the major active fault (**Zagros Main Recent Fault** (ZMRF)) with the name of Saravand-Baznavid (SBF) and with the length about a hundred km is passing from 1.6 km southwest of the dam axis. There are many small faults in the deformation zone of ZMRF. Dam foundation located on the number of these small faults. Figure 1 shows the location of Dam site. Seismotectonic investigations of the project suggest a maximum magnitude 7.4 along the ZMRF could result movement along the small faults of blocks under the dam foundation. Therefore the site has more complex geological condition. The main task of this paper is to convince the young engineers and clients to avoid of establish concrete dam at the same condition sites with Rudbar Lorestan in the world.

Figure 1; location of dam axis

2. ACTIVE FAULTING IN THE IRANIAN PLATEAU

1. The Zagros is active fold-thrust mountain belts in the SW of Iran, one of the active borders of Iran. Tectonic studies indicate that the Iranian plateau has a very high density of active and recent faults and that reverse faulting dominates the tectonics of the region (Berberian 1976, 1979).
2. Some of the Iranian Quaternary faults are directly associated with known large magnitude earthquakes, and are capable of generating future earthquakes (Berberian 1976, Berberian and Mohajer-Ashjai 1977). Due to the lack of historical earthquake data or adequate micro-earthquake surveys, it is impossible to deduce the activity of most Iranian faults. Paleoseismology studies help us in order to recognize the faults activities.
3. In this study, it is tried to describe one dam foundation that active faults pass from the near and under structures.

2. Geology and Seismotectonics

The Rudbar Lorestan power plant and dam site is located within the Zagros fold and thrust belt at south of Aligudarz city (center of Iran) Mahdavian et. al, (2005). The height of this dam is about 148 m and its reservoir has about 2×10^8 $m^{3.}$ Dolomites of Dalan formation (Late Permian) have formed both of walls.
The dam site is close to two major structures recognized to be currently active (Figure 2) such as:
-The Main Zagros Reverse Fault, a NE-dipping reverse thrust about 10 km to the Northeast of the dam site.
- A segment of MZRF (right lateral fault) called Saravand-Baznavid Fault (SBF).
-Also related to the SBF a second important regional fault, the Eslam-Abad Fault lies to the Southwest and crosses the location of the power house. Two samples for thermoluminescence dating suggest recent movements (13800±800 y; and 14000± 950 y). This fault is also considered as a seismogenic source, but for the dam site importance than the SBF.
The SBF is the closest seismically active structure to the dam site. The dam site is located within a tight valley with very steep walls (Figure 1). The ZMRF is a Quaternary right-lateral wrench fault (with NW-SE strike) that situates between the southwestern part of central Iran and the northeastern part of the Zagros active folded belt, in the west of the country. The ZMRF is not a single structure but a narrow one formed by a succession of individual fault segments, often arranged in a right-lateral en echelon pattern. Horizontal slip rate along this fault is estimated at least 10-17 mm yr^{-1} that could be the source of frequent earthquakes

of Ms 6-7 (Talebian & Jackson, 2002). Figure 3; shows fault lane and slickensides belong to the Saravand-Baznavid Fault.

The ZMRF 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.

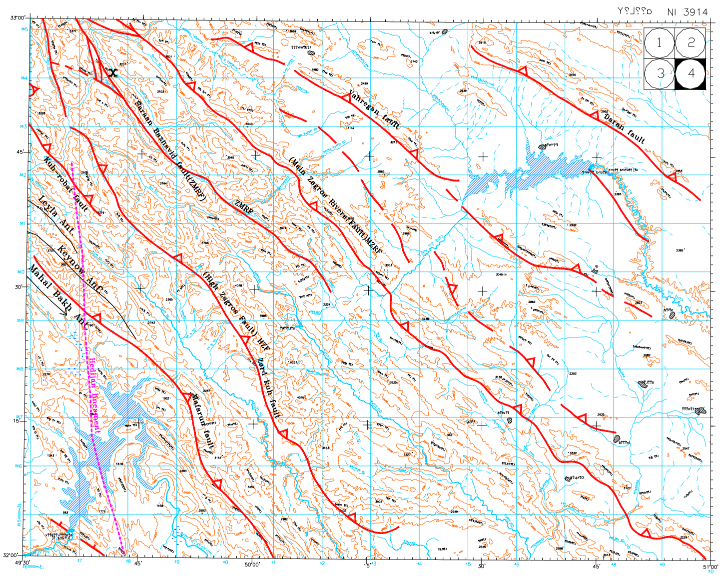

Figure 2, Tectonic Setting map of the area around of the dam site.

The mapping of geology of site was very difficult for geologist because of the topography access. We applied geological map as representative of the dam site as the principal discontinuities are shown with sufficient precision (figure 4). The discontinuities cross the dam foundation and abutment area are F1, F48 and F10 (J10) and several normal faults. In addition there a number of normal faults, lateral faults and faults of unknown nature as well and open or sheared bedding planes which are mainly oriented NW-SW. The measure length of the F10 on the rock is about less than 100 m. From the roadway near the dam axis there is detectable 1-2m displacement across prominent bedding in the limestone across F10 (Mr. Berryman from Poyre Company, 2007).

The SBF with 100 km length is a recent fault that due to following characteristics can be recognized as an active fault:

1) The fault at the north slope of Saravand-Baznavid Fault 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 (SBF) 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.

Figure 3 ; Fault plane and slickensides of Saravand-Baznavid Fault

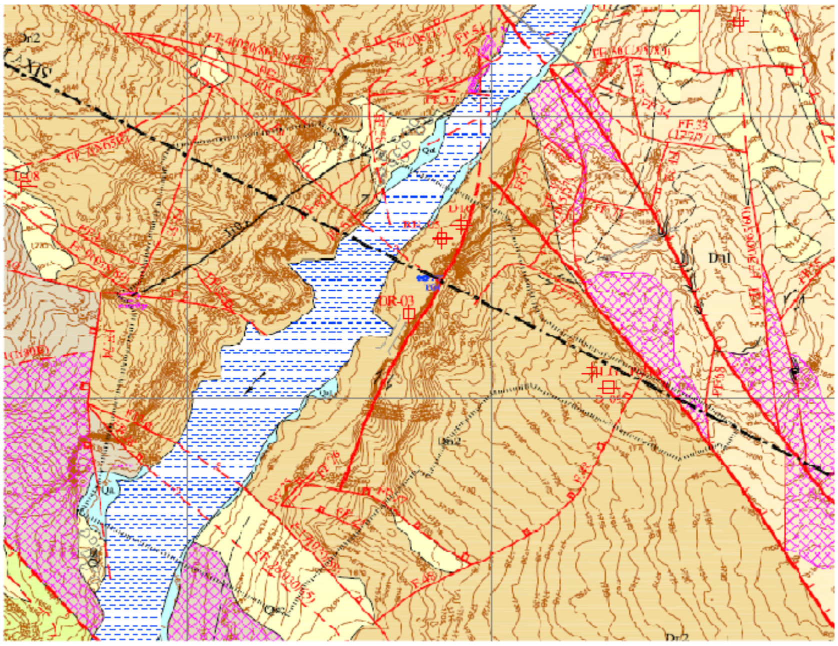

Figure 4, Geological map and faults of dam site (after geological report). Black dash line shows dam axis.

3) The fault is lie along the Dorud fault (a segment of the ZMRF). The Dorud fault was ruptured during the 23 January 1909 Silakhor earthquake (Ms 7.4). Location of the SBF 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 SBF passes from 1.6 Km of the dam site with an average displacement 2.5m and maximum displacement about 5-6m.

The seismogenic layer is within crust sediment at expected 8-12 km.

3. LOCAL FAULTS ON DAM FOUNDATION

A number of small faults there are on dam foundation. One of the important small faults at the dam foundation 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 about 90^o and measured maximum displacement along it is about 6-8 m. This fault does not have a considerable length and located at effective bound to the SBF (ZMRF). The fault surface is smooth, and there are very prominent striations ranging in scale from fine slickensides to cm scale grooves, tool marks and corrugations (Figure 5).

Figure 5, Outcrop of a fault plane (F1) in the Rudbar Lorestan dam axis. Grooves and tool marks on fault surface

The length of individual grooves and tool marks are a meter or more and it is possible that the length of these individual grooves represent single event fault displacement. The length of F1 is several ten meters. Then we cannot consider a capable or seismogenic fault, and it is not possible to estimate its possible single event displacement from main seismic fault or capable fault scaling relationships (Mr. Berryman from Poyre Company, 2007).

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.

In spite of small length of the F_1 fault, with regards to considerable displacement (6-8m) along it, we expect that its length be more than outcropped length of this fault. Due to existence numerous shear zones that crossed this fault, following of it on the field is very difficult and almost impossible. In this respect, according to Figure 6; two following models can be considered:

The F1 fault has been continued toward north and south, but displacement along it, transfer from one segment to another segment with an en-echelon pattern, so, we can not see trace of this fault as a continuous line. Existence of many strike-slip faults at south of dam axis can confirm this model. These types of discontinuous ruptures have been observed on many Iranian earthquakes for example: The 26 December 2003 Bam earthquake (Talebian et al. 2004).

The F1 fault does not have considerable length and in fact, it is movement transferor (or displacement) from one shear zone to another one. In this case, the shear zones have preserved thrust movement equal to strike-slip movement of this fault. Existence of many shear zones around the dam site can confirm this model.

Then we reported that in the vicinity of the SBF and along a pre-existing active the maximum displacement along F1 may reach about 10% of the movements on the SBF. Therefore maximum displacement expected for F1 is 50 cm.

Mr. Greco from Poyre Company (2007) believes:

-During a strong earthquake (Ms 6.5 or more) the deformation is transferred from the SBF to F1.

-The “tectonic” length of the fault should be considered rather than the length exposed, therefore according to direct experience an average of 20 cm to maximum 50 cm displacement along F1 is suggested for the MCE at SBF.

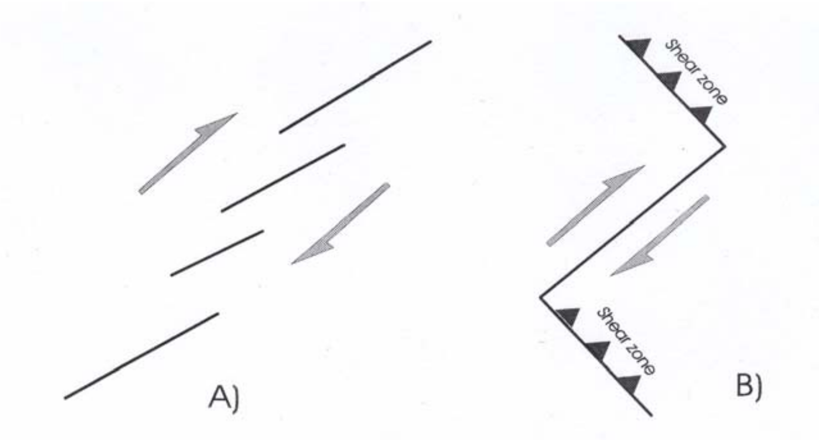

Figure 6, Two models can be considered for F1 fault

-This movement will be partially absorbed by the F1-"sheared zone" (there are uncertainties about the real appearance of F1).
-There will be a relative displacement of the blocks in contact with F1: the differential movements of the past suggest also important vertical displacements to be expected in the range of centimeters.
-Joint J10 to NW and Fault F48 to SE are the outermost boundaries of the movements, unless they may also be directly reactivated by a major earthquake themselves.
-According to the complicated geometry, it is not possible to account for a reliable kinematic model. Nevertheless we expect at least an area of several m width around F1 in which cm-displacements (vertical and lateral) can take place.

Mr. Berryman from Poyre Company (2007) believes:
-A single slip-joint to accommodate movement on Fault 1 is probably insufficient to confidently mitigate possible block motions at the site.
-The amount of movement on each of the components of the block movement model cannot be estimated except that on Fault 1 there is the possibility that tool marks and grooves on the fault surface, which appear to be at least 1m in length, may represent single event movement.
- Movement of blocks in the dam site triggered by major earthquake ground motions on the SBF appear to be the much more likely scenario for movement in the dam site, than secondary faulting. This is because Fault 1 is poorly oriented for strike-slip secondary rupture, and would require simultaneous rupture of another faults at the site.
- J10 (F10) appears to have displacement – approximately 1 m in a dextral strike-slip sense;
- The length of individual grooves/tool marks on the F1 surface appear to be at least 1 m long - this may be a measure of single event displacement.

4. Conclusion

Now considering the above mentioned items, all studies, report and technical discussions, following points are deduced:

1. Various displacement in the beginning and also the end of F4 active fault indicates that occurred displacements cannot be produced as a result of two blocks movement (separated from basement by F4 fault) and along F4 fault plane, but different displacement is resultant of a group of movement with complicated design and scenario along fault and/or discontinuities in the site.

2. Considering above items, displacement in Rudbar Lorestan dam foundation is a result of sever earthquake in more than one direction and occurs on faults and discontinuities (with different quantities)

3. In case of concrete dam, it is not enough to improvise one special slip joint in dam structure, assuming that movement happens in one direction and along F4 fault, so other slip joints should be prepared and designed in the structure of dam with different directions.

4. Most suitable solution against displacement on discontinuity in dam site while occurrence of sever earthquake is to use flexible and clay self-repair material including the building of clay core and filter.

5. There is no published source of concrete dam building on more than one active fault and/on a fault with displacement potentiality.

6. The ICOLD have been always indicated that the building of concrete dam on active fault should be avoided.

7. Concerning above mentioned items, building of concrete dam on this area is not recommended, all young engineers must be obliged to follow these recommendations because of their job commitments and are responsible for people lives and properties.

8. Consequently just clay core dam is the right option for these kinds of area even if it brings about more costs.

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