Geomorphologic hazards for Vanyar Dam with emphasis on the reactivation of Tabriz fault, northwest Iran

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Abstract: Shahid Madani or Vanyar Dam is being construction on Aji Cahy River, to the north of Tabriz. It has been built on the upper red formation of Miocene. This lithology generally consists of sandstones, conglomerates, clays, and gypsum. Salt domes are also located underneath the reservoir area behind the dam. The slopes beside the reservoir are not stable. Unexpected events, such as subsidence, could occur after the reservoir is filled causing destruction to infrastructure. However, the most serious event could be the infiltration of water into the Tabriz fault. This fault has not been reactivated for over 220 years and it is thought that the infiltration of water from the reservoir could cause the two sides of the fault plane to move. It is thought that the displacement of the fault could cause an earthquake of more than 6.5 on the Richter scale. To try and prevent this fault reactivating, filling of reservoir is proposed to be undertaken gradually.

Résumé: Shahid Madani ou barrage de Vanyar est construction sur le fleuve d'Aji Cahy, au nord de Tabriz. Il a été construit sur la formation rouge supérieure de miocène. Cette lithologie se compose généralement des grès, conglomérats, argiles, et gypse. Des dômes de sel sont également situés dans le réservoir du barrage. Les pentes près du réservoir ne sont pas stables. Quelques événements inattendus, comme l'affaissement des terres, pourrait se produire après que le réservoir soit rempli causant la destruction à l'infrastructure. Cependant, l'événement le plus dangereux est l'infiltration de l'eau dans le défaut de Tabriz. Ce défaut n'a pas été réactivé pendant plus de 220 années. On le pense que l'infiltration de l'eau du réservoir pourrait causer les deux côtés de l'avion de défaut au mouvement. On le pense que le déplacement du défaut pourrait causer un tremblement de terre plus de de 6.5 sur l'échelle de Richter. Pour essayer et empêcher ce défaut dangereux réactivant le remplissage du réservoir est proposé d'être entrepris graduellement.

Keywords: Shahid Madani, Tabriz, Dam, subsidence, reactivating, earthquake

INTRODUCTION

Dams were first constructed more than 5000 years ago and the regulation of rivers for water security has been at the heart of the advancement of human civilizations.

Huge artificial water reservoirs are created all over the world for generation of hydroelectric power, flood control and irrigation purposes. Triggering of earthquakes by artificial water reservoirs was for the first time pointed out by Carder (1945) at Lake Mead in the United States of America. Damaging earthquakes exceeding M 6 occurred at Hsinfengkiang, China in 1962; Kariba, Zambia–Zimbabwe Border in 1963; Kremasta, Greece in 1966; and Koyna, India in 1967. The December 10, 1967, Koyna earthquake of M 6.3 is so far the largest and most damaging reservoir triggered earthquake. It claimed about 200 human lives, injured about 1500 and rendered thousands homeless. Civil works at Koyna town suffered major damage. The Hsinfengkiang and Koyna earthquakes caused damage to dams themselves. Other reservoir triggered earthquakes such as those at Kariba, Zambia; Kremasta, Greece; Oroville, CA; Aswan, Egypt; and Srinagarind, Thailand caused damage in nearby towns and villages. The occurrence and potential of triggered earthquakes has caused major modifications of civil works and engineering projects indeed the possibility of triggered seismicity was one of the major factors in terminating the construction of Auburn Dam in California (Allen, 1978).

Earlier, as pointed out by Allen (1982) and Simpson (1986), there is a general reluctance on the part of the Engineering Committee, globally, to accept the significance or even existence of the phenomenon of reservoir-triggered seismicity. However recently there has been some change in this attitude. The US Committee on Large Dams (USCOLD, 1997) concluded that there can be an increase in occurrence of reservoir-triggered seismicity (RTS) during the period of reservoir water level changes and the possibility of RTS should be considered for every reservoir deeper than 80–100 m.

Most of the work carried out on various aspects of artificial-water-reservoir-induced seismicity till 1990 has been reviewed by Gupta (1992).

Natural and human-induced subsidence due to the dissolution of evaporites is a significant geohazard in some areas of Iran. Some of the areas where evaporite dissolution subsidence hinders development include the Miocene and Plioquaternery evaporitic terrain of NW Iran, the town of Tabriz.

The most cost-effective way of planning in these areas lies in avoiding the existing sinkholes and the most subsidence prone areas (Pauksˇtys et al., 1999). The application of this preventive philosophy requires the recognition of the areas affected by subsidence and the production of hazard maps. However these tasks are generally difficult, especially in extensively developed areas where evidence of recent subsidence activity is obliterated by human activities. In addition to the traditional geomorphological and geotechnical investigation approaches, the paleokarst features found in the geological record can help to understand the subsidence processes and locate problematic locations (Guerrero and et al, 2004).

This work analyses the past and recent subsidence in the Aji Chay River valley. The paleosubsidence features found in the stratigraphical record are used to understand the processes involved in the current subsidence phenomena and to identify hazardous locations that could affect highly vulnerable transport routes.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The study area corresponds to a small portion of the end sector of the Aji Chay Basin, which constitutes the southern Tertiary foreland basin of the Azerbaijan in the NW of Iran (Fig. 1). The study area was located at 38° 07′ N latitude and 46° 22′ E longitude.

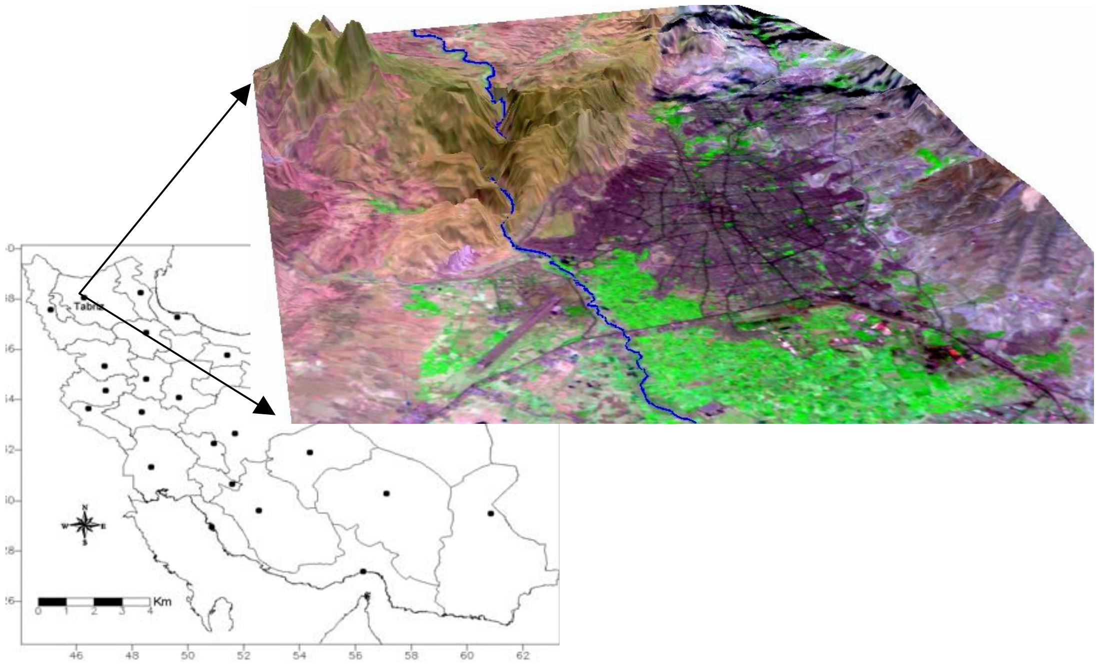

Figure 1. Geographical location of the study area

The basin fill is primarily composed of Palaeogene and Neogene continental sediments deposited in alluvial that pass distally into lacustrine environments. The conglomeratic facies at the margins of the basin grade progressively into sandstones, clays, marls and evaporite–carbonate facies towards the sedimentary axis of the basin.

Several evaporitic formations were deposited as the most subsiding areas migrated to the south of the basin. In general, the Palaeogene formations are affected by folding structures while Neogene strata remain sub horizontal. From the lower Miocene, an extensional stress regime has operated in the central sector of the Aji Chay Basin generating different main joint families with WNW–ESE, N–S and E–W trends and so on. Once the basin became exorheic, presumably in the late Miocene–early Pliocene, a new drainage network started to dissect the endorheic infill. These alluvial systems have developed stepped sequences of mantle pediments and terraces that partially cover the Tertiary infill.

The study area is characterised by a semiarid climate. At Tabriz meteorological station, the mean annual precipitation and temperature are 314 mm and 14.6 °C, respectively. The Aji Chay River valley is an extensively developed area with a rapidly growing population.

The construction Dam of SHAHID MADANI is placed on alluvium covered evaporite bedrock susceptible to subsidence.

NORTH TABRIZ FAULT ACTIVITIES

Along the international border between NW Iran, eastern Turkey and south Armenia, there is quite a high level of seismic activity. Here, repeated strong earthquakes have destroyed many cities, most notably Tabriz in 1042 (M= 7.3), 1641 (M= 6.8), 1721 (M= 7.3) and 1780 (M= 7.4), Ararat in 1319 and 1840 (both M = 7.4) and Chalderan in 1976 (M= 7.1) (Ambraseys and Melville, 1982; Berberian, 1994, 1997; Berberian and Yeats, 1999). Historical data indicate that the maximum seismic hazard threatens the city of Tabriz. The high seismic hazard is linked to the activity of the North Tabriz fault (NTF), the North Mishu fault, the Tasuj fault and the Sufian fault. The information available on these faults is fragmentary and scanty(fig 2).

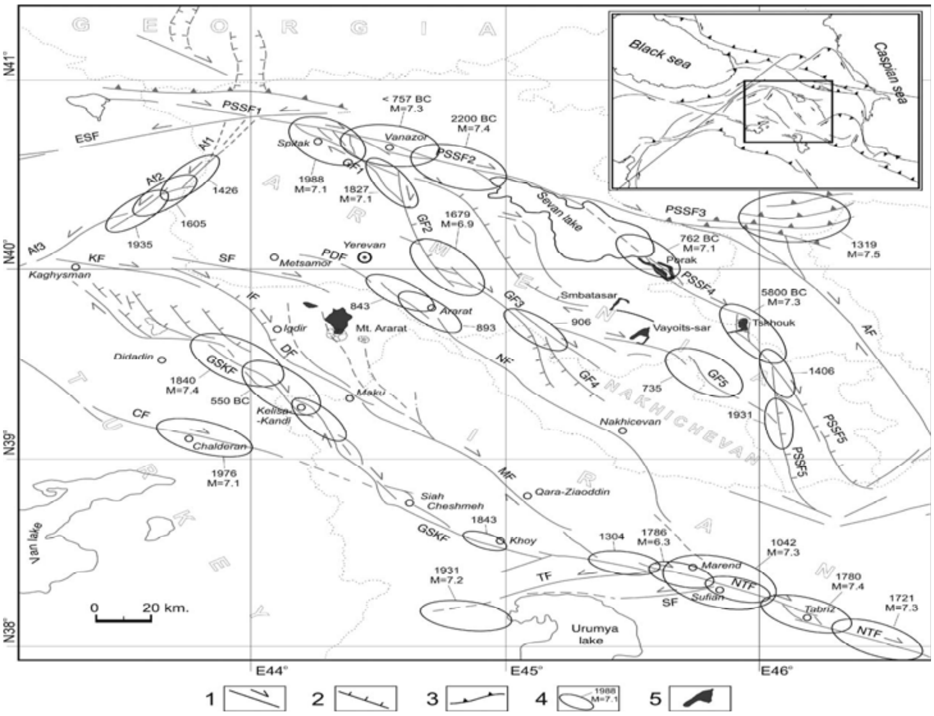

Figure 2. Active faults of Armenia, Eastern Turkey and NW Iran. 1 –strike –slips; 2 – normal faults; 3 –thrusts; 4– strong earthquake epicenters; 5 – Earthquake-triggered volcanic eruptions in the Holocene-historical time. (Karakhanian and etal, 2004)

Berberian (1997) divides the NTF into several segments that have a combined length of 210 km. The segments are identified according to a series of surface ruptures from the earthquakes of 1721, 1780 and 1786 AD. According to Berberian (1997), in the northwest, the NTF merges with a reverse fault zone that bends W–SW north of Lake Urmia (Fig. 2) (the Sufian and Tasuj faults); in the southeast, it merges into another zone of reverse faults that bends E–NE (South and North Bozqush, Duzduzan and South Sarab). On the Tabriz segment, Berberian (1976, 1997) observed vertical reverse-fault uplift of the northern side and inferred from air photo surveys signs of right-lateral strike–slip motion. Our field studies of 1996 and our interpretation of satellite images indicated considerable strike–slip motions along the NTF. The geometry of the NTF zone is characterized by multiple right-stepping en echelon segments. Two fault segments, one to the west and one to the east of the Tabriz city, are of particular importance for seismic hazard assessment.

The western fault segment strikes from Tabriz to the city of Sufian and bears clear signs of right-lateral strike–slip motions. Right-slip amplitudes range from 100 m for large valleys (e.g., village of Zebarlu) to 25–30 m for young valleys (e.g., villages of Tazeh Kand, Ovil) to 3–5 m for minor streams (e.g., village of Khajeh Mardjan and Cheleh Khaneh Pain). The vertical displacements vary from 2–3 to 10 m, but are always between two and seven times less than the horizontal ones. The northern and southern sides of the en echelon segments are uplifted alternately, a typical characteristic of strike–slip faults. Small pull-apart depressions are formed at the sites of fault segment overlap (e.g., village of Tazeh Kand). To the east of the village of Khajeh Mardjan,

The NTF separates the Upper Red Formation of a Miocene age in the north from Quaternary deposits in the south. Small gullies of probable late Holocene age are right-laterally displaced by 8 m along the main branch of the fault. This observation leads to a very rough estimation of the minimum slip rate on this fault segment, which is at least 1.5–2 mm/year (Karakhanian et al., 1996). The eastern segment is shifted southwards with respect to the western one and strikes from the city of Tabriz to the village of Basmedge. These two segments define the intervening Tabriz pull-apart basin. Young ruptures on the flanks of both segments branch in a NW direction and have right strike–slip offsets, which form a graben-shaped stepped depression in the centre of the pull-apart. These young ruptures have clear scarps and can be traced through the northern part of the city of Tabriz. Today, these scarps cross the runways of the old and new Tabriz airports and the new highway line. Apparently, these are seismogenic surface ruptures produced by the 1780 (M= 7.4) earthquake and by earlier events, which are clearly visible on the 1955 air photo (no. 1875).

Many strong historical earthquakes were recorded along the North Tabriz and North Mishu faults (Ambraseys and Melville, 1982; Berberian, 1994, 1997). All these earthquakes caused rather heavy damage to the city of Tabriz. The earthquakes of 1042 (M= 7.3) and 1721 (M= 7.3) alone killed about 40,000 of people each, while more than 50,000 died during the event of 1780 (M= 7.4) (Ambraseys and Melville, 1982; Berberian, 1994, 1997). The earthquakes were often accompanied by large landslides, extensive liquefaction and lengthy surface ruptures. According to Ambraseys and Melville (1982) and Berberian (1997), the SE Shebli segment of the NTF had ground breaks of 50–35 km during the 1721 (M= 7.3) earthquake, and the NW Tabriz segment ruptured for 45–42 km, with a vertical displacement of 2–4 m, during the event of 1780 (M= 7.4). Berberian (1997) describes earthquakes clustering in time along the NTF, the first cluster including three strong earthquakes in 1721– 1786, and the second including two events of 1273 and 1304.

One important fact for the seismic hazard assessment is that the North Tabriz fault, North Mishu fault and Gailatu–Siah Cheshmeh–Khoy fault are contiguously linked with each other, to form a single 550-km-long system of the North Tabriz– Gailatu fault (NTGF, Fig. 2). This fault system controls the main seismic hazard in the territory of NW Iran, SE Turkey and partly southern regions of Armenia and Azerbaijan. The zone of strong seismic impact from the North Tabriz–Gailatu fault includes the large cities of Maku, Khoy, Marand, Sufian and Tabriz, numerous villages in NW Iran, as well as the cities of Dogubayazit, Igdir and numerous villages in SE Turkey. Cities and villages in Nakhichevan (Azerbaijan), including Nakhichevan and Ordoubad, and in Armenia (Artashat, Yerevan, Armavir, Metsamor and others) fall in the zone of more moderate seismic impact.

A distinct episode of 60-year periodicity of strong earthquakes along the system of North Tabriz–Gailatu fault system is of particular interest. The SE segment of this system (Tabriz–Shebli NTF segment) ruptured in 1721 (M= 7.3). Fifty-nine years later, the 1780 (M= 7.4) event produced rupture on the central segment (NTF segments, Tabriz–Sufian and North Mishu faults), and 60 years after that, the NW segment (GSKF) ruptured in the event of 1840 (M= 7.4).

The North Tabriz fault system poses particularly high hazard for the city of Tabriz for thefollowing reasons.

1. Tabriz is in the system of North Tabriz fault, which has 12 historical earthquakes of

M= 6.2–7.4 on the NTF segments within 960 years (from 858 to 1819). The earthquakes caused severe destruction in the city, killed more than 130,000 people and produced surface ruptures that pass beneath the NW part of the modern city, Airport area, highway and railway lines.

2. There are weak soils and landslide-prone areas in the city.

3. There are creep-like motions (at the rate of 15 mm/ year) on the western NTGF segment, weak and medium-size seismicity on the western and central segments of the NTGF in contrast to the seismic quiescence on the eastern flank (NTF) in the Tabriz city region. An important note is that, as of today, the strong earthquake quiescence period has already lasted for more than 200 years, which can be considered a factor increasing the threat. All these factors together make Tabriz (a city with the population of 1.5 million) one of the most seismically hazardous cities of the world, with high probability of strong earthquake on the eastern flank of the NTGF in near future. Since the North Tabriz–Gailatu fault system also poses a high seismic hazard to the adjacent territories of NW Iran, SE Turkey, Nakhichevan (Azerbaijan) and southern Armenia, it therefore requires further study.

CONCLUSION:

The Aji Chay River longitudinally crosses the Aji Chay Depression following in its central sector which is the axis of a very gentle NW–SE trending synclinal structure.

At outcrop, the Aji Chay Formation comprises of gypsum, marls and clays with an evident increase in the proportion of gypsum in a downstream direction.

The entrenchment and lateral migration of the Aji Chay River throughout its evolution has generated an asymmetric valley with stepped terraces on the northern margin and a prominent gypsum escarpment on the east side. The asymmetric configuration of the valley and the existence of a scarp are common features of fluvial systems that cross the Tertiary evaporitic formations in Aji Chay. An outstanding geomorphic feature is the long and E–W trending Khajeh Depression located on the east margin of the Aji Chay Valley. This recently captured depression with a flat bottom mantled with a thin veneer of gypsiferous silts has been interpreted as a salt karst developed in gypsum bedrock.

Dam building on the river may cause increasing solution of salt in the foundation materials. With respect to new studies about Tabriz North Fault that introduces it as a thrust fault we think its plane may be elongated toward the beneath of the dam Shahid Madani. Therefore, infiltrated water may cause sliding at the fault plane. Consequently, displacement at the two sides of fault could be caused to induced earthquake in Tabriz city. For preventing this dangerous fault reactivating , filling of reservoir is proposed to be undertaken gradually.

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