Fault-zone properties and earthquake rupture

INTRODUCTION

Geological structures, specifically faults play a substantial role in the qualitative and quantitative aspects of hydrogeological processes (Bense, et al., 2006). Fault zones in the earth shallow crust (<1 km) influence a suite of hydrogeological processes and groundwater flow patterns in aquifers (Levens et al., 1994; Mayer et al., 2007; Bense et al., 2008; Burbey, 2008; Folch and Mas-Pla, 2008). Faults in the earth crust formed at distinct scales and influence the geological unit permeability that is an important factor in the movement of groundwater (Geraud, et al., 2006).

A first-order description of fault zones commonly includes a fault core, which is surrounded by a damage zone from the hydrogeological perspective. The fault core, as the zone of the most intense strain, is generally found in the center of the fault zone, and identified the most of the displacement within the fault zone. Fault cores in different rocks are commonly zones of fault gouge and breccias (Evans and Chester, 1995; Caine et al., 1996; Evans et al., 1997). The damage zone has secondary structures such as minor faults and fractures extending into the foot wall and hanging wall, which take up the rest of strain within the fault zone (Bense, et al., 2013). The fault core and damage zone are surrounded by protolith that is relatively undeformed units which may contain joints not primarily related to the fault zone, and exists as a background deformation pattern (Forster and Evans, 1991; Caine and Forster, 1999).

The main hydrogeologic properties of fault zones are believed to be highly anisotropic. Vertical or near-vertical faults are commonly described as being either conduits for horizontal flow along the fault, barriers to horizontal flow across the fault, or a combination of the both respect to the fault core conditions (Anderson and Bakker, 2008).

The faulting mechanism and movement type is a significant parameter in the hydrogeological behavior of faults. Normal faults with tension mechanism have a greater ability to groundwater movement and conversely, reverse faults with compressive mechanism, are not proper pathways for groundwater flow. Reverse faults and strike slip faults generated by compression forces, so can act as an impermeable barrier against groundwater movement across the fault (Goldscheider, 2008).

Various fault processes can reduce the permeability of the fault core and cause fault to behave as an impermeable barrier against groundwater flow in unlithified sediments. Tectonic sediment mixing in fault zones generally leads to a notable reduction of permeability (Faerseth, 2006; Rawling and Goodwin, 2006; Caine and Minor, 2009; Balsamo and Storti, 2011). The physical mixing of sediments with contrasting grain-size distributions can be expected to result in a more poorly sorted sediment mixture than any of the source beds, and for this reason sediment mixing leads to the efficient reduction of pore space and permeability in the fault zone. The degree to which permeability is reduced as a result of sediment mixing in unlithified sediments will depend on the contrast in permeability between the end-member beds. Heynekamp et al. (1999) report a reduction in permeability of up to six orders of magnitude as compared to the original sand layer, where sandy clay form in the fault zone as a result of mixing between sand and clay layers along the Sand Hill fault zone in New Mexico, USA. The latter study further illustrates that mixing, from relatively homogeneous source layers, causes strong permeability heterogeneity in the fault zone because of incomplete sediment mixing. In addition to permeability heterogeneity, permeability anisotropy can be expected to be present in fault zones as a result of rotation of bladed sediment grains. Grains aligning preferably with the main fault dip have been observed in both lab-experiments on loose sands, and in naturally faulted sediments ranging from sand to gravel (Bense, et al., 2013). At the grain scale, the increased tortuosity of flow paths across the fault as a result of the realignment of oblate grains in the direction of the fault dip results in permeability anisotropy so that perpendicular to the shear zone, permeability can be up to two orders of magnitude lower than along it (Arch and Maltman, 1990).

Where clay minerals are present in the sediment matrix, phyllosilicate framework bands will develop along which platy clay minerals orient in the direction of the fault zone andwill so facilitate the sliding of grains past one another possibly reducing grain breakage (Fossen et al., 2007). Clay smears often develop along fault zones cutting through clay beds. The focus onclay smear exists mainly because of their potential to efficient block across fault fluid flow (Bense and Van Balen, 2004). Clay smears have been described in stratigraphies characterized by unlithified sediments consisting of sand–clay alternations (Yielding et al., 1997).

Cataclasis in unlithified sediments is the pervasive brittle fracturing and commination of grains (Engelder, 1974; Chester and Logan, 1986; Blenkinsop, 1991; Davis and Reynolds, 1996). The effectiveness of cataclasis occurring in unlithified sediments varies as function of grain composition, relatively weaker grains such as feldspars can be entirely crushed while stronger quartz grains show low intensity cataclasis characterized by the flaking of grains rather than their entire disintegration by crushing (Loveless et al., 2011; Exner and Tschegg, 2012).

Permeability along cataclastic deformation bands in unlithified sediments with clay content is typically reduced more strongly, as compared to undeformed sediments, which is demonstrated by many field and laboratory permeability tests (Antonellini and Aydin, 1994; Fisher and Knipe, 2001). Permeability along cataclastic deformation bands is often anisotropic with the largest reduction in permeability perpendicular to the deformation band (Antonellini and Aydin, 1994; Sigda et al., 1999).

Fluids carrying reactive solutes circulating through fault zones potentially can reduce permeability as a result of water–rock interaction and cementation (Zhang et al., 2008).

To study the influence of the North Tabriz Fault (NTF) on the adjacent groundwater aquifer in Ammand area, the geologic information reported by the Geological Survey of Iran (1996), along with the hydrostratigraphic characteristic of aquifer drives from 57 well logs, were investigated. Well log data employed to correlate the sedimentary layers in order to clarify the type and structure of the region aquifers. Groundwater level and electrical conductivity (EC) of the groundwater samples have been measured in site. Finally, groundwater level isopotential lines along with flow directions and some hydrochemical analysis of 57 water sample were employed to prepare suitable maps which revealed the impact of the fault on the surrounding aquifer.

THE STUDY AREA

The Ammand area is located in the northwest of Iran and in the northwest of Tabriz City (Fig. 1). The Tabriz City is one of the large cities of Iran with more than 1. 5 million inhabitants (Moradi, et al. 2011). The study area with 297 mm of average annual precipitation and 12. 5 ^{o} C of average annual temperature has a cold and dry climate according to Emberger classification method. Groundwater of this area as the main source of water supply was exploited for drinking and agriculture purposes. This area was crossed by a large and active fault (North Tabriz Fault) which belongs to the complex system that connects the North Anatolian fault system, located in Turkey, to the Alborz mountain range in Iran and accommodates both the northward motion of Arabia and the westward motion of Anatolia plates relative to Eurasia plate (Moradi, et al. 2011).

The purpose of this study is to investigate the influence of the North Tabriz fault on the hydrogeological characteristic of the surrounding aquifer.

GEOLOGICALSETTING

The present-day tectonics of Iran is mainly the result of the complex tectonic system due to motion between the Arabian and Eurasia plates (Djamour, et al., 2011). The Tabriz area is part of the complex tectonic system result of the interaction between Arabia, Anatolia and Eurasia plates and comprising the complex system of faults (Sengoret al., 2005; McKenzie, 1972; Jackson, 1992).

The North Tabriz Fault (NTF) is the most outstanding tectonic structure in the northwest of Iran with right lateral fault mechanism (Fig. 1). It is one of the most active faults in Iran which has a clear surface expression in most part of its length (Hesami, et al., 2003). It has an average strike of NW-SE over a length of more than 150 km and appears to be generally close to vertical in dip (Vafaei, et al., 2011). Right-lateral movement along this fault, documented by Berberian and Arshadi (1976) from the study of aerial photographs, which also can be seen clearly in the field (Karakhanian et al., 2004). NTF lineament in the area is easily recognizable in Miocene units (Fig. 2).

Variety of geological formations around the study area according to their rocks composition and the effects of geological phenomena such as North Tabriz fault have contributed as the main role in the appearance of the area current morphology and hydrogeological characteristics of the area aquifers.

Geological units of the area are consists of Pliocene gray Dacite in the north, Miocene gypsiferous red marl and sandstone layers that surrounding the area, Quaternary Travertine deposits in central part, which all of these formations have been covered by Quaternary alluvial fan deposits in most part of the area (Fig. 2).