Revista Geoaraguaia
ISSN:2236-9716
Barra do Garças – MT
v.11, n.2, p.21-48. Dez-2021

EVALUATION OF SEISMOTECTONIC AND SEISMICITY IN BUIN ZAHRA AREA WITH AN EMPHASIS ON BUIN ZAHRA CITY

AVALIAÇÃO DA SISMOTECTÔNICA E SISMICIDADE NA ÁREA DE BUIN ZAHRA COM ÊNFASE NA CIDADE DE BUIN ZAHRA

Moslem Jahangirbakht[1]

Mehdi Zare*[2]

Bahram Akasheh[3]

Arezoo Dorestian[4]

ABSTRACT

In this paper, we study the seismotectonic and seismicity status of the Buin Zahra region, in Qazvin province. The studied area has experienced two catastrophic earthquakes in 1962 and 2002 such that more than 12,450 people were killed and about 4,280 people were injured. However, the exact status of human and financial injuries of historical earthquakes is not clear and only the occurrence of earthquakes is confirmed by the ruins and archaeological studies in this area. The emphasis of this work is on the city of Buin Zahra because it is the center of the considered area. In this work, geological and quaternary geological status, seismotectonic, and seismicity of the region are investigated. In this study, geological maps and reports, satellite images, and other researches were used to assess seismic sources, faults. Regarding the seismicity history of the study area, various scientific sources reporting the characteristics of earthquakes were utilized considering the occurrence of numerous earthquakes and the geological and seismological importance of the region. To obtain seismic parameters, common methods such as the Kijko-Slevolle were employed. the results showed that this region, with multiple active faults and a history of various earthquakes, is highly seismically active such that there is the probability of earthquakes with magnitudes of 5-6 and even more than 7 in certain periods.

Keywords: Buin Zahra; Earthquake; Fault; Seismotectonic; Seismicity; Seismicity parameters.

[1]PhD Candidate, Department of Geophysics, North Tehran Branch, Islamic Azad University Tehran, Iran. *Corresponding Author j_moslem@yhoo.com ORCID: https://0000-0001-9900-4084

[2]International Institute of Seismology and Earthquake Engineering, Tehran, Iran. mzare@iiees.ac.ir ORCID: https://orcid.org/0000-0002-2106-7752

[3]Department of Geophysics, North Tehran Branch, Islamic Azad University, Tehran, Iran. akashe@ut.ac.ir ORCID: https://orcid.org/0000-0002-5698-0787

[4]Department of Geophysics, North Tehran Branch, Islamic Azad University, Tehran, Iran. dorostian382@yahoo.com ORCID: https://orcid.org/0000-0002-6239-2789

RESUMO

Neste artigo, estudamos o status sismotectônico e sismológico da região de Buin Zahra, na província de Qazvin. A área estudada sofreu dois terremotos catastróficos em 1962 e 2002, que mais de 12.450 pessoas foram mortas e cerca de 4.280 pessoas ficaram feridas. No entanto, a situação exata das lesões humanas e financeiras de terremotos históricos não é clara e apenas a ocorrência de terremotos é confirmada pelas ruínas e estudos arqueológicos nesta área. A ênfase deste trabalho está na cidade de Buin Zahra por ser o centro da área considerada. Neste trabalho, são investigados o estado geológico e quaternário, sismotectônico e sismológico da região. Neste estudo, mapas e relatórios geológicos, imagens de satélite e outras pesquisas foram usados para avaliar fontes sísmicas, falhas. Em relação ao histórico da sismicidade da área de estudo, várias fontes científicas relatando as características dos terremotos foram utilizadas considerando a ocorrência de inúmeros terremotos e a importância geológica e sismológica da região. Para obter parâmetros sísmicos, métodos comuns como o Kijko-Slevolle foram empregados. os resultados mostraram que esta região, com múltiplas falhas ativas e uma história de vários terremotos, é altamente sismicamente ativa de tal forma que há probabilidade de terremotos com magnitudes de 5-6 e até mais de 7 em determinados períodos.

Palavras-chave: Buin Zahra; Terremoto; Falta; Sismotectônico; Sismicidade; Parâmetros de sismicidade Geoquímica, Petrogênese, Plutonic, Sonqor, Irã.

INTRODUCTION

Earthquake as one of the most important natural events is considered also as a natural hazard owing to the damages imposing to humans and the environment. The effects and consequences of this phenomenon on human life can be studied from different aspects. Earthquakes along with some phenomena can hugely cause a widespread crisis in an area. Among such phenomena are liquefaction in plains and loose soils, landslides, and rockfalls in foothills and valleys, heterogeneous settlement of structures built on manual embankments, widespread fires caused by failures in high-pressure pipes of gas, oil, and electrical connections. Such events will reoccur in the future in an area that has previously experienced them. However, it is not presently possible to predict the location, time, and impacts of these events exactly and only the danger lurking in such areas is clear. Being located on one of the most important seismic belts in the world, i.e the Alpine-Himalayan belt, the Buin Zahra region and its surroundings in Iran are prone to earthquakes that is confirmed by the historical history of the area. Based on the setting of historical earthquakes, it is indicated that the region was affected by earthquakes several times in the last century, moreover, the region and its surroundings were influenced by four relatively strong and severe earthquakes directly or indirectly(Ambraseys, Melville, 1982). Among the most important earthquakes that occurred in Buin Zahra and its surroundings is Kolah Darreh Buin Zahra earthquake in 1919, with the magnitude of Ms = 5.7 (Ambraseys, Melville, 1982), Buin Zahra earthquake in 1962 (figure:1), with the magnitude of Ms = 7.2 (Berberian et al., 1992), Rudbar and Manjil earthquake in 1991 with a magnitude of Mw = 7.3 (Berberian et al., 2010), Changooreh and Abdreh in 2002 with a magnitude of Mw = 6.4 (Walker et al., 2004; Yazdi et al., 2017), and Mallard earthquake in 2017 with a magnitude of Mw = 5.2 (Ehteshami Moinabadi et al., 2017; Baratian et al., 2020). Studies on geology, seismotectonic, and seismicity history of the study area are the most basic works on the earthquake event. It is essential to update these studies in the region to appropriately change the behavior of the residents regarding earthquakes by creating more comprehension of the faults' activity while making culture. Furthermore, with increasing the policymakers' awareness, proper measures should be taken in this region to optimize important, vital, and normal structures. It is worth noting that the existence of the distressed urban area in the city of Buin Zahra along with new constructions requires further attention to the issue of culture-making. Considering the enhancement of building materials compared to 1962 or even 2002, it is hoped that compliance with national building codes and regulations in the design and implementation phases will guarantee the resistance of structures built in the study area against probable future earthquakes.(figure 2, 3 and 4) This important aspect requires public awareness, responsibility sense of executives, supervisors, and appropriate policy-making of decision-makers and policymakers.

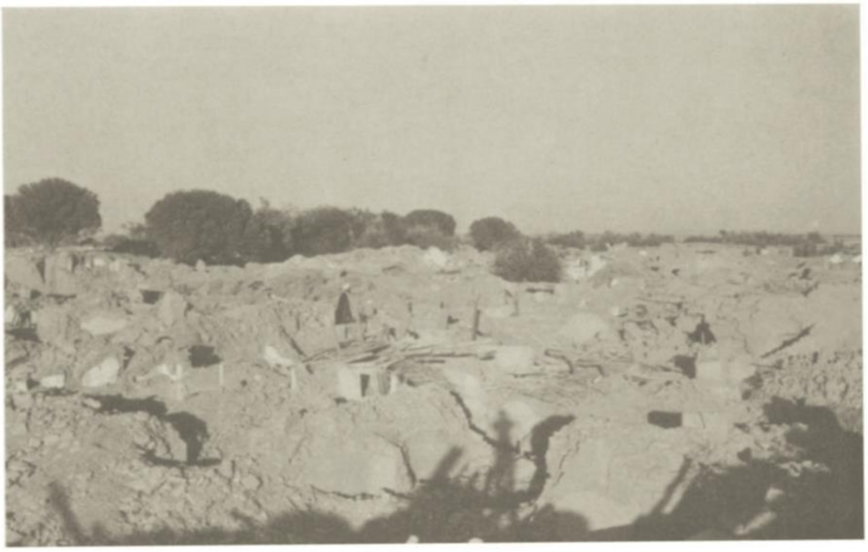

Figure 1. Buin Zahra after the earthquake in 1962
Source: Adapted from Ambersys (1963)

Figure 2. The structures being constructed of reinforced concrete along with the almost a complete and usable steel structure
Source:Photo by Jahangirbakht, M.(2019). Farhang Street, Buin Zahra

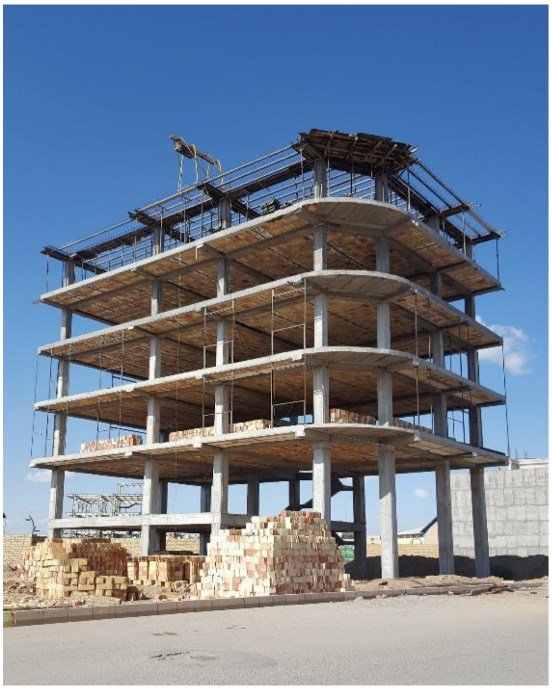

Figure 3 A residential structure with new materials and novel construction methods
Source: Photo by Jahangirbakht, M.(2019). Takhti Street, Buin Zahra

Figure 4. A structure with a bolted steel frame
Source: Photo by Jahangirbakht, M.(2019). Takhti Street, Buin Zahra

RESEARCH PURPOSES

The present study deals with the investigation of geological status, quaternary geology, seismotectonic, seismicity, and estimation of seismicity parameters of the study area. The following questions are responded to in this work:

-What is the status of influencing faults in the region?

-What is the seismic history of the region?

-How is the seismicity status and what are the seismicity parameters?

RESEARCH METHOD

In the present study, the sources and references related to the geology and quaternary geology were studied and the information regarding the geology of the region was gathered taking into account the general geological position of the Middle East and the country (Iran). Moreover, the geological maps were reviewed prepared for the region to achieve the geological site status of the area. Considering the geological maps and studies conducted in recent years, the seismic sources of the region were investigated, the most important of which are faults in the study area. The information regarding earthquakes in the region was collected using the catalog of historical and systemic earthquakes as well as the scientific sources in this field. Fortunately, there are several studies in this regard. Ultimately, the seismicity parameters of the region were estimated focusing on Buin Zahra city through popular methods.

RESEARCH PRINCIPLES

ELASTIC-REBOUND THEORY

Reid's elastic-rebound theory (1911, Reid) explains the process of storing and releasing energy in the rocks of both sides of a fault. The stress stored and released during the faulting process has a very complicated physical nature. On the other hand, faults have no uniform and homogeneous properties in their overall structure, either in terms of geometry or their constituent materials' properties. Moreover, there are strong and weak areas in a fault. The strong areas of a fault are called “hard areas” by some scientists, such as Kanamori and Stewart (Kanamori, Stewart, 1978), they are also termed “barrier areas” by Aki (1979), and some others. In the stiffness model for fault rupture, it is assumed that the shear stress before an earthquake is not uniform over the fault surface owing to the release of stress in the weak zone as a result of creep or foreshock. The main shock is caused by the release of residual stress in the hard section of the fault. In the barrier model, it is presumed that the foreshock stresses in the fault are uniform and are released from all parts of the fault except the barrier and stronger areas when occurring the main earthquake. When new uniform stress reaches rock strength, the aftershocks occur. Since both foreshocks and aftershocks are mainly observed during an earthquake, some strong areas act as hard and some act as barrier areas (Aki, 1984). Nevertheless, the importance of hard and barrier areas in the site is based on the earthquake since, within a nearby site, stronger vibrations are experienced compared to the site beyond these areas.

Gutenberg-Richter relation on the earthquake recurrence

An extensively used method for determining the seismic parameters a and b is the Gutenberg-Richter technique (Gutenberg, Richter, 1954). Generally, the distribution of earthquakes in any region of the earth follows the classical Gutenberg-Richter relationship.

$$Log10[N(>M)]=a-Bm$$

where N is the accumulative number of earthquakes with a magnitude higher than M, a and b are constant values (Ishimoto, Inda, 1939; Gutenberg, Richter, 1944). a is a criterion of the seismicity level and b is normally close to one (Richter, 1958). The value of b is obtained by the slope of the above equation, the high value of b indicates the relatively higher number of small earthquakes, and the lower value of b denotes the lower ratio of smaller earthquakes in a range. This relation is a power relation and is almost linear since M is proportional to the logarithm of the energy. The relationship reveals that seismic physics does not specifically follow the law of elasticity not surprisingly. Generally, it is accepted to explain the seismic catalog of a region based on the Gutenberg-Richter relation. This relationship is applied practically both by seismologists and engineers.

ESTIMATING THE SEISMIC PARAMETERS

The Kijko-Slevolle method is used to estimate seismic hazard parameters using a mixed and heterogeneous catalog of earthquakes in a region. The maximum probable magnitude for an area is defined as the maximum magnitude of a probable earthquake for that region, which means the magnitude of the largest probable earthquake in a region (Kijko, Slevolle, 1992). The maximum probable magnitude (Mmax) of an area is required for seismologists, the earthquake engineering community, accident management agencies, and the insurance industry. Despite the importance of the Mmax value, fewer studies have been surprising performed to establish appropriate techniques for estimating this parameter (Andrzej, Mayshree, 2011). Presently, there is no universally accepted exclusive technique to estimate Mmax. However, the present procedures for achieving Mmax are divided into two important categories of the definitive method (Wells, Cooper Smith, 1994; Weller, 2009; Moliere, 2010) and the probabilistic method (Kijko, Samuel, 1988, 1998, 2011). Mmax is considered a maximum limit and the intersection of an earthquake’s magnitude, and an earthquake with a magnitude higher than Mmax is not expected. To estimate the seismicity parameters, two Gutenberg-Richter and Kijko-Slevolle methods, are mainly used, of which the latter is commonly used as a result of its advantages. It was used in the present paper as well. In 1989, Kijko developed a method for estimating seismicity parameters using a heterogeneous list of earthquake events. Then in 1992, he corrected and completed this method using the exponential distribution of two boundaries. Furthermore, in this method, historical earthquakes are also utilized along with instrumental earthquakes, in the study area. Other advantages of this method are as follows:

1. Taking into account large errors of earthquakes with two different uniform and normal distributions

2. Calculating non-recording of earthquakes at certain intervals for incomplete lists
3. Using the distribution of the largest values for the historical earthquakes

RESEARCH BACKGROUND

Considering the seismicity of Buin Zahra and the occurrence of several important earthquakes in this area, several studies have been conducted on geology, seismotectonic, and seismicity of the Buin Zahra area. By feeling the requirement to identify geological structures in the country, the oil company was initially responsible for these studies. Then, by establishing the Geological Survey of Iran, this task was granted to this organization, subsequently, investigation of geological affairs was initiated by various groups throughout Iran. Among the most important fields studied and researched in the country were neotectonic and seismotectonic. In this regard, the experts of the Geological Survey reported the results of their surveys and published them along with geological maps, fault maps, and seismic hazard zoning. Report No. 52 (Barbarian et al., 1992; Gharib-Gorgani et al., 2017; Bina et al., 2020) was published about the Neotectonic and seismotectonic of Qazvin plain in 1992. There are several research studies conducted by students and professors of the Institute of Geophysics, University of Tehran, and the International Institute of Seismology and Earthquake Engineering, for which the results have been published by these institutes.

RESEARCH DATA AND RESULTS

BUIN ZAHRA 57 YEARS AFTER THE EARTHQUAKE

Buin Zahra county with 4 districts, 9 rural districts, 5 cities, 128 villages with a population of 178 total residents is located in the center of Buin Zahra city in the south of Qazvin province(figure 5 to 7). The relative population density in Qazvin province in the 2016 census is 82 people per km2, much higher than the relative density in the whole country (49 people per km2). Buin Zahra town with 36814 residents and a population of 122994 is one of the most populous cities of the province. In this town, there are five cities with 16,476 households and a population of 56,082 people. Buin Zahra city with 6298 residents has a population of 20823 people.

Figure 5. The location of the study area (Buin Zahra county).
Source: Designed and drawn by Jahangirbakht, M.(2020).

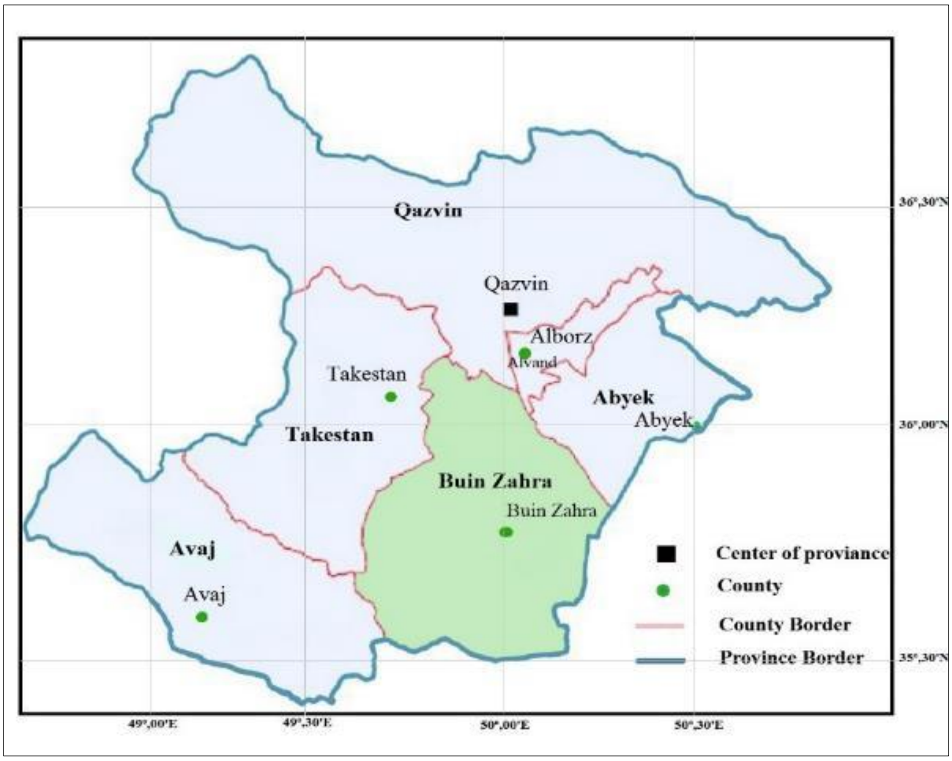

Figure 6. The map of the political divisions of Qazvin province and Bu in Zahra county
Source: Designed and drawn by Jahangirbakht, M.(2020).

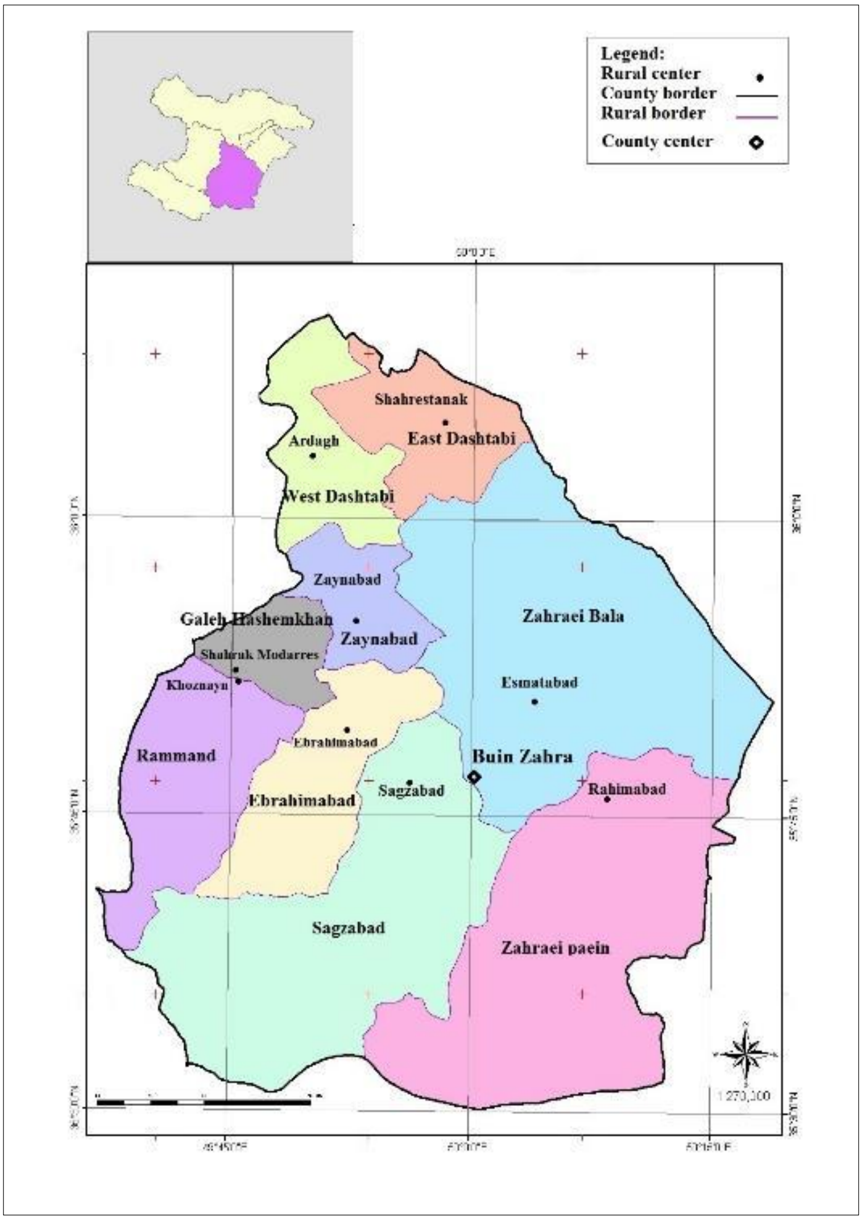

Figure 7. The map of rural districts of Buin Zahra county
Source: Designed and drawn by Jahangirbakht, M.(2020).

GEOLOGY AND QUATERNARY GEOLOGY OF BUIN ZAHRA REGION

The geology of the study area is one of the fundamental aspects, which should be studied regarding seismicity investigations. The importance of geology is both based on the seismic source effects as well as the direction of earthquake waves and the impact of the site. It is especially important to recognize the characteristics of faults as seismic sources and their types in terms of activity and inactivity within seismic studies. Studying and considering the geological maps and geological studies are among the tools for determining the existence and types of faults. Characteristics of seismic source and its effects include several aspects such as the nearfield effects, fling step, forward-directivity, backward-directivity, and low hanging wall effects. Proximity or distance of the site to the fault is the most important feature resulting in the mentioned effects. Normally, the accelerograms recorded at distances less than 10 to 20 km from the earthquake-causing fault are considered as the near field records (Howard et al., 2005; Loko, Cornell, 2007; Huang et al., 2008). Considering the expansion of cities and villages in mountainous areas and river valleys as a result of their environmental attractiveness, humans have been directed toward high-risk areas in terms of earthquakes, liquefaction, and floods. Hence, it is increasingly important to take into account the near-field and site effects of the earthquakes. The flood in April 2017 in the center and north of Iran and the Rudbar-Manjil earthquake in 1990 are examples indicating the risk of floods and earthquakes concerning the population centers location. Therefore, it is essential to perform precise geological studies and investigate the structure of the ground for resistance to the mentioned phenomena in all development projects. There are different behaviors for the ground structure within which the earthquake waves pass, as well as the site facing the earthquake waves, which affect the structures' destruction rate. The phenomenon of amplification, geometric damping, elastic and non-elastic damping can be mentioned in this regard.

Buin Zahra region is located in the geological zone of Central Iran and has unique geological features. This region is located in the southern part of the folding of Central Iran's northern border. The study area is a wide plain gradually ending to the foothills of central and partly western Alborz. On the east, it is bordered by Eshtehard salt marshes and by the Ramand Mountains drifts on the Qazvin plain on the west. The heights in the south and west of this region are affected by the operation of several known faults, the most important of which are Ipak, North Qazvin, Haji Arab-Seminyak, North Eshtehard, Avaj, and Hassan Abad faults. Eshtehard North and South as well as Jaroo faults with a seismicity history are located in the east, along the parallel to Ipak active fault. The Alborz Geological Unit is placed as a complex anticline in the northern margin of Central Iran. This east-west unit is generally extended from the region of Azerbaijan to North Khorasan. This unit is limited in the southern part by Mosha Fault (Barbarian, 1983), North Tehran Fault (Chalenko et al., 1984) and it is separated by Semnan Fault from Central Iran. The northern boundary of this structural unit is the Caspian reverse fault. Its western border is separated from Talesh mountains along the Lahijan fault, moreover, its eastern border is unknown and vaguely connected with Kopet Dag and Binalud. In the dynamic tectonics of the Iranian plateau, the deformation of the Alborz mountain range is the product of a strain separation caused by shortening the slope of this zone (Berberian, Yates, 1999). This strain causes a reverse strike-slip mechanism for the faults in the area. An instance in this regard is the faults of the Buin Zahra region such as Ipak, northern and southern Eshtehard, Avaj, and Hassan Abad.

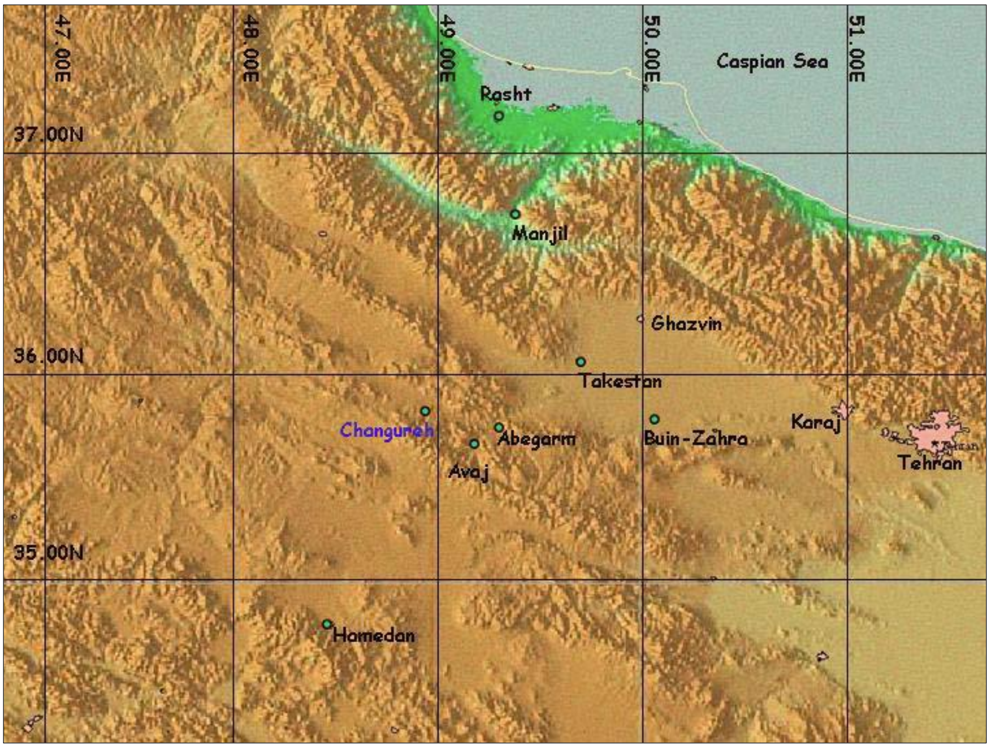

Figure 8. The topographic map of the studied region (Earth digital map, 2002).
Source: Zaré (2002).

The city of Buin Zahra is located on the southern end of the Qazvin plain(figure 8), which is a trapezoidal region observable in the satellite images. The fertile soil of this plain causes the prosperity of agriculture and animal husbandry. Such fertility has been originated from the alluviums washed by rivers such as Haji Arab, Khorrood, and Rud Shoor from the heights to the plain and precipitated in the lower areas. The fan shapes at the end of the river can be observed in simple satellite images. The height difference between this city (with an altitude of 1225 m above sea level) and the closest heights related to the folds of the northern margin of central Iran (height of 1320 meters) is caused by the operation of the Ipak fault as one of the most operating faults in the region and even Iran. This topographic change will have a significant impact on the interaction of earthquake waves and the site. The impact is greater in high-frequency waves as the dominant frequencies of the close field (Bohr, 1972). The city of Buin Zahra is located over not much stiff river alluvium. There are no detailed studies on the thickness of these alluviums and the status of the bedrock in the region. According to the topography of the region, the maximum thickness of the alluvium should be in the center of the Qazvin plain in the Allahabad region. The thickness of the alluvium decreases gradually to the northern and southern areas, and the outcrops of the bedrock appear ultimately. The runouts of the Eocene Formation of Karaj in the north and south of Qazvin plain may reveal that this formation forms the bedrock of Qazvin plain (Barbarian et al., 1992). Manuel Berberian believes that the Ipak fault occurred in the Eocene volcanic rocks (Barbarian, 1976.d). According to geophysical studies conducted by the Irrigation Organization in 1965, the maximum thickness of alluvial deposits in the Qazvin plain including the Buin Zahra region within 300 and 350 m. These studies reveal that owing to the lower special resistance abnormalities in the region, there is a strong possibility of a Miocene Formation at the bottom of the region or high-clay alluvial deposits. However, the existence of volcanic rocks in the bottom of the plain is also expected, which is confirmed by the presence of high special resistance anomalies along the Kharrood (Irrigation Organization, 1965).

SEISMOTECTONIC OF THE BUIN ZAHRA REGION

As mentioned above, seismotectonic and seismicity surveys are among the most fundamental studies that are essential in any small or large construction project, to guarantee the safety and stability of structures and, thus, human and financial resources. The Iranian plateau is located at the intersection of the Eurasian-Arabian plate (Berberian, King, 1981). The collision between the Arabian and Eurasia plates has changed an area of 3 million km2 of oceanic crust (Berberian, 2014). The position of Iran between two old continental plates, Eurasia in the north and Africa-Saudi Arabia in the south is like a fragile plate affected by the tensions caused by the movements of the Arabian Plate over the past several million years. This has made a particularly important status for the Iranian plateau in terms of tectonics (Berberian, 2014). Iran's active seismotectonic has been originated by the northward movement of the Arabian Plate relative to the Eurasian plate. In Iran and at a longitude of 49 °E, there is an annual shortening of about 20 cm along the north-south. About half of this amount occurs in the Zagros Mountains and the rest in the Alborz Mountains and the southern Caspian Basin in northern Iran.

Active faulting and folding, volcanic activity, the presence of mountain ranges, and variable crust thickness are among the characteristics of the Iran plate. This plate has been intermittently damaged by devastating earthquakes, resulting in numerous life losses, many homeless people, and the rupture of vital agricultural and industrial arteries (Barbarian, 1995, 1996). Buin Zahra area is situated in the zone of inverted and driven faults and parallel folds of the Alborz mountain range. This area of faulting and folding has caused several earthquakes throughout history, especially in the last century. Faults are important tectonic structures that their identification as the seismic source is a key factor in seismic hazard analysis. It is important to investigate the faults because of the possibility of releasing the energy stored in them in the form of earthquakes. Furthermore, it is also necessary to evaluate the morphological effects of the formation and re-operation of faults and determine their age, if possible (Pourkermani, Adib, 2011). The need for more attention to the earthquake phenomenon becomes inevitable by the presence of several faults in the study area and their seismic history. The occurrence of large and medium earthquakes over the past decades and the historical seismicity in the Buin Zahra area and Qazvin plain have caused a huge deal of human and financial losses. The seismicity of this region is resultant by the operation of reverse strike-slip faults within a complex convergent plate tectonic system (Barbarian, Yates, 1999). Convergence with a velocity of about 35 mm per year between the Eurasian and Arab continental plates in Iran is absorbed by strike-slip and reverse faults (Jackson et al., 1995). By this convergence, the Iranian plateau fold is caused in the two main axes of the Alborz and Zagros mountains. The seismic areas with higher activity are respectively, Zagros, Alborz, and the eastern part of central Iran (Barbarian, 1976; Tekin, 1972). Most earthquakes have greater depth along Zagros. Central Iran is characterized by scattered seismicity with large earthquakes, long return periods, and interruptions along several Quaternary faults. Generally, the earthquakes in this area are superficial and normally associated with superficial faults (Barbarian, 1976). The faults generated in this range have a seismicity history. However, active deformations are not uniformly distributed and it is not possible to match a fault to a large percentage of convergence (Berberian, Yates, 1999).

All physiographic parts of Qazvin plain, such as Tehran and its suburbs including Buin Zahra, are restricted to Quaternary faults and the elevations and heights in this area have been generated by the function of these faults (Barbarian et al., 1992; Yazdi et al., 2021). Considering the multiplicity of faults in this zone, the division of faults can be effective in future studies to differentiate them and investigate their effects on other seismic parameters. In the present work, taking into account the importance of long faults (more than 10 km) in an area with an approximate radius of 150 km, geological maps were extracted and their characteristics were determined using other studies and surveys.

It is worth noting that the lines drawn in these studies as faults were prepared based on the existing geological maps confirmed by geomagnetic maps of fault trends. In a more general view, these fractures in the earth's crust and Quaternary sediments coincide with the direction of the faults in the northern end of Central Iran and western Alborz. Concerning the important faults such as the Ipak fault, the existence of seismicity has been deeply studied providing reliable features. Nonetheless, further seismic, geomagnetic, and geoelectric studies are required to extract the full outline of the fault and the three-dimensional shape of the fractures. There are two general conditions for occurring any earthquake with seismotectonic. First, the fracture has been caused by a newly generated tectonic force, second, the existing fracture has been displaced due to these forces. This can be determined by geological surveys and geological maps, moreover, the two states can be also distinguished by seismology and fracture surface surveys for a fault. It was difficult to judge in this regard at least in the case of the study faults, and no results were obtained from the researchers' investigations. The important parameter of fault's length is closely related to the magnitude of the earthquake. It should be stated that the entire length of the fault is not broken during an earthquake.

The important point in estimating earthquake risk is the faulting and the fault's behavior during an earthquake. A fault is introduced as a slope-slip or strike-slip fault or their combination. However, there are subcategories in each case as well, for instance, a compressive or reverse strike-slip or a normal strike-slip are in this regard. A fault may not show the behavior in faulting, which is expected during an earthquake. The Lome Prieta earthquake surprised the geological community when behaving differently despite occurring in the San Andreas Fault. It showed a significant compressive component not crossing the classical behavior of the surface strike-slip (Anderson, John, 1991; Yazdi et al., 2019). It is more worrying that during the 1980s, two major earthquakes occurred in California (Coalinga and Whittier Narrows) on thrust faults with no intersection with the ground, they were therefore not mapped by geologists (Hauksson, Stein, 1989). There is a similar case in Iran, where the generated fault was unknown and invisible in the 2002 Changooreh and

Abdreh earthquakes according to some researchers. Numerous of such faults are likely under the residential areas.

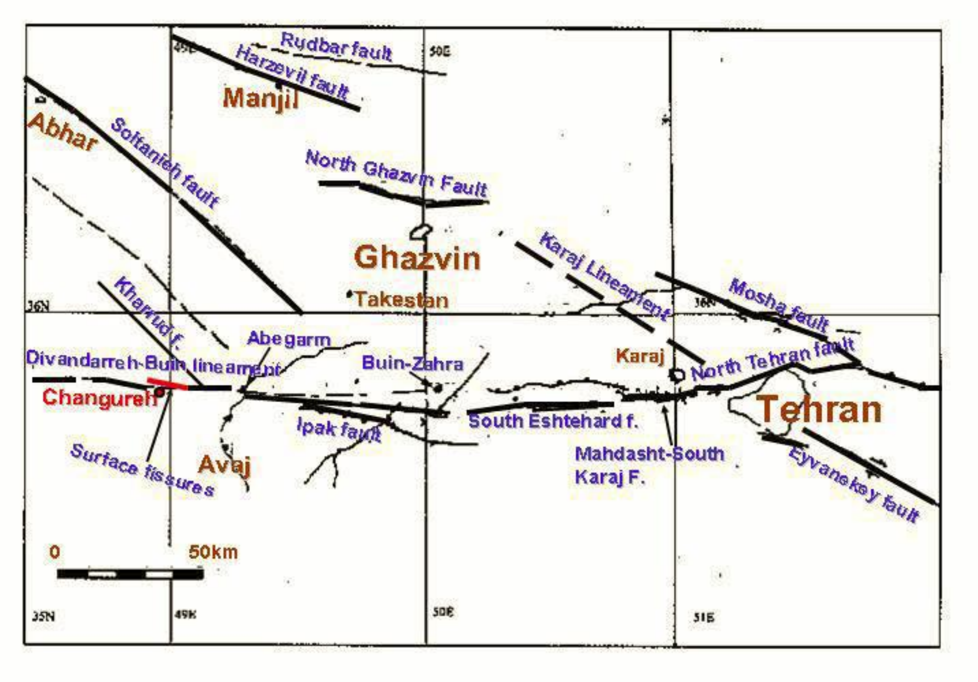

Figure 9. The fault map of the western Tehran-South Ghazvin region.
Source: Zaré (2002).

The tectonic activity of the region is complicated so that different judgments were made about the faults and faulting in both earthquakes of the last century. Ambraseys believes that within the 1962 Buin Zahra earthquake and its aftershocks, faulting occurred gradually at least 64 miles along the fault line into two stages (Ambraseys, 1963). One of these faultings has been most likely originated from Rudak, where the fracture started and continued toward the east to Ipak. There is also deeper faulting with weak surface evidence from Indergin continued toward the east to Toofak (Ambraseys, 1963). The epicenter was reported 10 km south of Rudak village. Whether the earthquake occurred in two stages or such a conclusion was led by the researcher's perception of field studies and the effects of surface faults are not clear. It was possible to perform more detailed studies based on the available maps recorded in at least three stations of the Geophysical Institute of the University of Tehran, Manjil Dam, and Shiraz. Unfortunately, such studies were not possible due to no cooperation of the Geophysical Institute and the Seismology Department.

The faulting mechanism in the Buin Zahra earthquake was compression or reverse with a small component of left-lateral strike-slip. Regarding the Changooreh earthquake, a compressive faulting system has been experienced with a small and partial component of left-lateral strike-slip (Zare, 2003). It seems that both earthquakes occurred in the same fault system.

IMPORTANT FAULTS IN THE STUDY AREA AFFECTING THE CITY OF BUIN ZAHRA

Based on several investigations on geological maps of the study area, several faults have been identified and introduced on geological maps by various researchers. In the present study, a hypothetical circle was drawn with the center of Buin Zahra city and a radius of 150 km, and most of the faults in this area were identified from various sources. There are 52 important faults with a length of more than 10 km among the identified faults. The reason is the impact of the movement of each fault on the city of Buin Zahra, which varies from mild shocks to severe destruction of the city's structures. Another effective factor in selecting these faults is the seismicity history causing the feeling of shakes or the destruction of structures in the city of Buin Zahra. The parameters related to the seismicity of faults were calculated in this regard for 39 faults in the study area. Among the important faults in the area with a seismicity history are Ipak, North Qazvin, North Eshtehard, Hassan Abad, Avaj, and Haji Arab-Seminak faults.

SEISMICITY POTENTIAL OF FAULTS

The seismicity potential of a fault is the magnitude of the earthquake that can be considered when it is reactivated. This feature is associated with the length of the faulted segment and the displacement of the fault surface. This relationship has been one of the research topics of seismologists and technologists including Albee, Smith, Slemmons, Tacher, Press, Housner, Mohajer Ashjaei, Amberaseys, Melville, Nowroozi, Bonilla, Wells, and Coppersmith. They presented empirical relationships based on the seismic properties of specific areas. The type of fault and its mechanism have been rarely considered. However, the features such as seismotectonic zone, type of fault and its mechanism, and geometric appearance of the fault (fault length, bending, branching, etc.) should be considered in the experimental relations and their preparation.

Determining the extend of faulting of a considered length in an earthquake event is one of the important challenges in obtaining the seismicity of the fault. The values between almost 20 to 75% of the fault length have been proposed by various researchers.

In the present work, the experimental comments of Ambraseys-Melville (1982), Nowruz (1985), and Mohajer Ashjaei-Nowruz (1978) for the earthquakes in Iran and the Middle East were used to achieve the seismicity of the faults.

Ambraseys & Melville experimental instruction

$$Ms=1.429\log L+4.629$$

Noroozi experimental instruction

$$Ms=1.259+1.244\log L$$

Mohajer-Ashjae & Noroozi experimental instruction

$$Ms=5.4+\log(L/2)$$

Table 1 represents the seismic potential of major and important faults in the study area that their reactivation can affect Buin Zahra county and Buin Zahra city.

Fault No	Fault Name	Fault length(km)	Magnitude				Magnitude of Experienced earthquake	I_0	$a_h(m/s^2)$
			M.A.N	A.M	N	AERAGE			
1	Masuleh	48	6.7	7.0	7.1	6.9		IX$^+$	354
2	Khazar	600	7.7	7.7	7.7	7.7	7.7	X	501
3	Sulehsara	40	6.7	7.0	7.0	6.9		IX$^+$	299
4	Benaksar	45	6.7	7.0	7.0	6.9		IX$^+$	335
5	Javaherdasht	75	6.9	7.3	7.3	7.2		IX$^+$	491
6	Keleshom	62	6.9	7.2	7.2	7.1		IX$^+$	376
7	Harzevil	120	7.2	7.6	7.6	7.5	7.4	IX$^+$	473
8	Chalakrud	49	6.8	7.0	7.1	7.0		IX$^+$	335
9	Asanmahalleh	44	6.7	6.8	7.0	6.8		VIII$^+$	335
10	Nusha	42	6.7	6.9	7.0	6.9		IX$^+$	335
11	Banan	67	6.9	7.2	7.3	7.1		IX$^+$	376
12	KeShachal	85	7.0	7.4	7.4	7.3		IX$^+$	491
13	Soltaneeh	106	7.1	7.5	7.5	7.4		IX$^+$	473
14	Zevardasht	57	6.9	7.1	7.2	7.1		IX$^+$	376
15	Shahrud	60	6.9	7.2	7.2	7.1	7.6	IX$^+$	376
16	Kandovan	76	7.0	7.3	7.3	7.2		IX$^+$	491
17	Alamutrud	53	6.8	7.1	7.1	7.0	7.6	IX$^+$	354
18	Aftabru	49	6.8	7.0	7.0	7.0		IX$^+$	354
19	Shekarnab	41	6.7	6.9	7.0	6.9		IX$^+$	335
20	North Qazvin	61	6.9	7.2	7.2	7.1	6.5	IX$^+$	376
21	Taleghan	48	6.8	7.0	7.1	7.0	5.9	IX$^+$	354
22	Mosha	200	7.4	7.7	7.7	7.6	7.1	X	473
23	Gheshlag	18	6.4	6.4	6.6	6.5		VIII$^+$	237
24	North Tehran	90	7.1	7.4	7.4	7.3	7.7	IX$^+$	447
25	North Eshtehard	40	6.9	7.2	7.2	7.1		IX$^+$	354
26	Hassan Abad	85	7.0	7.4	7.4	7.3		IX$^+$	421
27	Ipak	87	7.0	7.4	7.4	7.3	7.2	IX$^+$	421
28	Avaj	80	7.0	7.3	7.4	7.2		IX$^+$	422
29	Parandak	110	7.1	7.5	7.5	7.4		IX$^+$	473
30	Khoshkrud	87	7.0	7.4	7.4	7.3		IX$^+$	422
31	Kushk Nosrat	66	6.9	7.2	7.3	7.1		IX$^+$	376
32	Alborz	300	7.6	7.7	7.7	7.7		X	501
33	Indes	19	6.4	6.5	6.6	6.5		VIII$^+$	237
34	Tafresh	54	6.8	7.1	7.1	7.0		IX$^+$	354
35	Talkhab	40	6.7	6.9	7.0	6.9		VIII$^+$	299
36	Qom	72	7.0	7.3	7.3	7.2		IX$^+$	422
37	Qezel Ozan	65	7.0	7.2	7.2	7.1		IX$^+$	376
38	Perkuh	40	6.7	6.9	7.0	6.9		VIII$^+$	299

Fault No	Fault Name	Fault length(km)	Magnitude				Magnitude of Experienced earthquake	I_0	$a_h(m/s^2)$
			M.A.N	A.M	N	AERAGE			
39	Zard Gholi	18	6.4	6.4	6.6	6.5		VIII+	224

Table 1 Seismic potential of faults around Buin Zahra

SEISMICITY HISTORY OF BUIN ZAHRA REGION

Without the seismic history of an area, it is not possible to understand its seismic status. For any area, the seismic history can be obtained through historical sources and documented reports of scientific earthquake-recording centers. The seismic history of a range is normally assessed in two periods, in scientific sources and research reports on seismicity in the different areas of the world. The first one is before installing the seismic network and the second other is followed by the seismic recording of earthquakes in the world. This categorization was also considered in the study area including historical and ancient earthquakes (before 1900 AD) and earthquakes recorded by the global or local seismic network. Here, a brief description of the two periods along with the earthquakes that occurred in the region is provided. The earthquakes were selected in this regard based on their location, which is an area with Buin Zahra city as the center and an approximate radius of 150 km. They had the greatest impact on Buin Zahra city or surrounding villages. In the following, we will denote the historical and systemic earthquakes that occurred in the region.

HISTORICAL AND ANCIENT EARTHQUAKES IN THE STUDY AREA INCLUDING:

1. Possibility of settlement or generation of Qazvin plain during ancient earthquakes, Barbarian et al., in Report No. 61, citing the writings of Emil Trinker (1930), denote an earthquake triggering the plain surface during the reactivation of an operating fault.

2. The earthquake of the third millennium BC in Sagzabad, for which the magnitude and the extent of the associated damage are not known, however, it seems that

the Sagzabad civilization was destroyed by it (Ambraseys and Melville, 1982; Moinfar, 1996; Marlik 1, 1973; Negahban, 1971).

3. Earthquake of 864 AD in Rey occurred in the Ray region with a magnitude of about 5 on the surface and an approximate epicenter intensity of 7 (Golriz, 1958; Ambraseys and Melville, 1982, Barbarian et al., 1985).

4. Earthquake of 1119 AD in Qazvin with an approximate magnitude of 6 and epicenter intensity of more than 8 (Barbarian et al., 1992).

5. Earthquake of 1177 AD Shahrerey-Qazvin with a magnitude of about 7 and an epicenter intensity of approximately 8 (Barbarian et al., 1992).

6. Earthquake of 1876 in Kolah Darreh, Buin Zahra with a magnitude of more than 5, the intensity of which has not been estimated by researchers (Barbarian et al., 1992).

Instrumental earthquakes or the earthquakes after 1900 AD in this range are:

1. Earthquake of Saturday, September 1, 1962, with a magnitude of 7.3 and an epicenter intensity of about 9 (Barbarian et al., 1992) and (Akasheh and Berkhamar, 1983) and (Petrescu and Purcaru, 1964; Wu and Ben-Menahem, 1965, Mackenzie, 1972).

2. Rudbar-Manjil 1990 earthquake with a magnitude of 7.7 at the scale of mass waves, Torque magnitude of 7.3 and an epicenter intensity of 10 (Barbarian et al., 1992), (Qureshi et al., 1991) and (Barbarian et al., 2010).

3. Changooreh and Abdreh 2002 earthquakes with a torque magnitude of about 6.5 and an epicenter magnitude of between 8 to 9 (Ghasemi et al., 2006) and (walker et al., 2005) and (Hosseini et al., 2002).

4. Mallard 2017 earthquake with a torque magnitude of about 2.5 was followed by an aftershock with a magnitude of about 4.2 on the same scale. The epicenter magnitude of this earthquake was not reported (Ehteshami-Moinabadi et al., 2019).

CONCLUSION

Geological, Quaternary geological and seismotectonic surveys of the region reveal a higher risk for the region. Considering the passage of several faults through the study area, most of which with a history of seismicity, the residential, industrial, and agricultural centers in this area are mainly at earthquake risks. Based on the history of at least two historical earthquakes and five devastating instrumental earthquakes with great financial and human losses in the last century in the study region, the seismic capacity and potential for re-seismicity of faults are indicated passing through this area. Considering the maximum magnitude of 7.2 on the surface waves scale for the earthquake experienced in the region, one can not ignore the important issue of the earthquake in this area. Moreover, the accumulation of population and newly established industrial centers in this area will highlight this importance.

The maximum probable magnitude (Mmax) for the region was determined as 7.9±023 using the Kijko-Slevolle method. Considering the experimental relationships for the seismicity potential of the faults in the region, the largest earthquake caused by the reactivation of the faults was a maximum of 7.7 and there was relatively good consistency between these values. Based on the calculations, the probability of an earthquake greater than 7 in this zone with a return period of about 65 years is 78%. Moreover, the acceleration caused by such an earthquake in the city of Buin Zahra is about 421 cm/s2. These numbers are acceptable considering the magnitude of the earthquake in 1962 and the calculations based on the relation between acceleration and intensity.

REFERENCES

AALIMANESH, N., TAHERI, M., SADEGHI, A. **Abstracts of the results of the 2016 General Census of Population and Housing in Qazvin Province, Qazvin Management and Planning Organization**, 2017

AKASHEH, B., & BERCKHEMER, H. Focal Mechanism of Earthquake in Iran with Special Emphasis to Small Shock in the Tehran Region, Geodynamic Project in Iran, Final Report, Rep. No. 51, **Geol. Sur. Of Iran**, 1983.

AKI, K. Asperities, barriers, characteristic earthquake, and strong motion prediction. **Journal of Geophysical Research**. 89, 1984. p. 5867-5872.

AKI, K. Characterization of barriers on an earthquake fault, **Journal of Geophysical Research**. 86 : 1979. p. 6140-6148.

AMBRASEYS, N. N. The Buyin-Zahra (Iran) earthquake of September, 1962 a field report. **Bulletin of the seismological society of America**. 53(4). 1963. p. 705-740.

AMBRASEYS, N. N.; MELVILLE, C. P. A **History of Persian Earthquakes**. Cambridge University Press, Cambridge, 1982.

ANDERSON, J. Review of geophysics, Supplement, April 1991 **U.S. national report to international union of geodesy and geophysics 1987-1990**, 1991. p. 700-720

Baratian, M., Arian, MA., Yazdi, A. Petrology and Petrogenesis of Siah Kooh Volcanic Rocks in the Eastern Alborz. **Geosaberes**, 2020. 11: 349-363

BEKPOUR, Sh., POURKERMANI, M. SAEEDI, A., QITANCHI, M. Structural analysis of Ipak fault (south Buin Zahra), abstract of articles of the 21st Earth Sciences Conference, 2004.

BERBERIAN M. **Earthquake and coseismic surface faulting on the Iranian Plateau; a historical, social, and physical approach**. 1st Edition, Elsevier, Publishing June 2014, ISBN :9780444632920, 2014.

BERBERIAN, M. Contribution to the seismotectonics of Iran (part II), **geological survey of Iran, Rep. No. 39**, 1976.

BERBERIAN, M. Earthquake faulting and bedding thrust associated with the Tabas-e-Golshan(Iran) earthquake of September 16, 1978. **Bulletin of seismological society of America**. 69, 1979. p. 1861-18887.

BERBERIAN, M. Master "blind" thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics. **Tectonophysics**, 241(3-4), 1995. p. 193-224.

BERBERIAN, M. The Historical Record of Earthquakes in Persia, **Encyclopaedia Iranica**, VII F. 6, Drugs-Ebn al-Atir, Mazda Publishers, Costa Mesa, CA, 1996. p. 635-640.

BERBERIAN, M., KING, G. C. P. Towards a paleogeography and tectonic evolution of Iran**, J. Earth Sci**, 18, 1981. p. 1764-66.

BERBERIAN, M., YEATS, R. S. Patterns of historical earthquake rupture in the Iranian plateau. **Bulletin of the seismological society of America**. 89: 1999. p. 120-139.

Bina, M., Arian, MA., Pourkermani, M., Bazoobandi, MH., Yazdi, A. Study of the petrography and tectonic settings of sills In Lavasanat district, Tehran (north of Iran), **Nexo Revista Cientifica**, 2020. 33(2), 286-296, DOI: https://doi.org/10.5377/nexo.v33i02.10768

BOLOURCHI, M. H**. Etdue geologique de la region d' Avaj (NW de I'Iran), statigraphie et tectonique**, G.S.I., 1975. https://tel.archives-ouvertes.fr/tel-00564667/fr/

BOOR, D. A not on the effect of simple topography on seismic SH waves. **Bulletin of the Seismological Society of America**. 62(1), 1972. p. 275-284.

DEMETS, C., GORDON, R.G., ARGUS, D.F., STEIN, S. Effects of recent revision to the geomagnetic reversal time scale on estimates of current plate motions. **Geophys. Res. Lett**. 21, 1994. p. 2191-2194.

DUTTA, A., MANDER, J. B. Energy based methodology for ductile design of concrete columns, **J. Struct. Eng**. 127(12), 2001. p. 1374-1381.

EGLIMI, B., **Geological map of Danesfahan**, scale 1: 100000, Geological Survey of Iran, Sh. 5961. 1998.

EHTESHAMI-MOINABADI, M., ZARE, M., KAMRANZAD, F. The Malard M 5.2 Earthquake (west Tehran, Iran) a moderate earthquake with important active tectonic results, February 2019, **Conference: NHAQ97, At: Geographical Organization of Iran**, Volume: 1, 2019.

GALAMGASH, J. **Geological map of Saveh**, scale 1: 100000, Geological Survey of Iran, Sh. 6060, 1998.

Gharib-Gorgani, F., Ashja-Ardalan, A., Espahbod, MR., Sheikhzakariaee, SJ., Yazdi, A., Petrology of Mg-bearing Meta Ophiolite Complexes of Qaen-Gazik, Eastern Iran, **National Cave Research and Protection Organization**, 2017. 4(1), DOI:10.21276/ambi.2017.04.1.ga01

GHASEMI, H.; KAMALIAN, N.; HAMZELOO, H. Stochastic finite-fault simulation for the 2002 Changureh-Avaj Earthquake, NW Iran**. Journal of the Earth and space Physics**. 32(1), 2006. p. 25-35

GOLRIZ, M., **Minoodar or Bab al-Jannah of Qazvin**. University of Tehran Press, No. 467, 1958

GUTENBERG, B.; RICHTER, C. F. Earthquake magnitude, intensity, energy and acceleration. **Bulletin of Seismological Society of America**. 46: 1954. p. 105-145.

GUTENBERG, B.; RICHTER, C. F. Magnitude and energy of Earthquake. **Annali di Geofisica**. 9: 1956. p. 1-15.

HAUKSSON, E.; STEIN, R. D. The 1987 Whittier Narrows California Earthquake A metropolitian shock. **J. Geophysics. Resm**. 94: 1987. p. 9545-9547.

HOSSEINI, S. K.; SUZUKI, S.; FUJII, Y.; SADEGHI, H.; FATEMI AGHDA, M. Aftershock observation of the 22 June 2002 Changureh-Avaj Earthquake (Mw6.5), NW Iran., **Abstracts of AGU fall meeting, S71B-1091**. 2002

HOWWARD, J. K.; TRACY, C. A.; BURNS, R. G. Comparing Observed and Predicted Directivity in Near-Source Ground Motion. **J. Earthquake Spectra**. 21(4), 2005. p. 1063-1092.

HUANG, Y. N.; WHITTAKER, A. S.; LUCO, N. Maximum Spectral Demands in the Near-Fault Region, **j. Earthquake Spectra**. 24(1), 2008. p. 319-341.

ISHIMOTO, M.; LINDA, K. Observations sur les seismes energistres parle microsismographe construit dernierement (1). **Bulletin of the Earthquake Research Institute**., Tokyo Imperial University. 17: 1939. p. 443-478.

JACKSON, J. A.; HAINES, J. HOLT, W. The accommodation of Arabian-Eurasian plates convergence in Iran. **Journal of Geophysical Research**. 100: 1995. p. 15205-15219.

JACKSON, J., PRIESTLY, K., ALLEN, M.; BERBERIAN, M. Active tectonics of the south Caspian basin, **Geophys. J. Int.** 2002. 148: 214-245.

JACKSON, J.; MCKENZIE, D. P. Active Tectonics of the Alpine Himalayan Belt between western Turkey and Pakistan, Geoph, **J. R. Astron. Soc**. 77, 1984. p. 185-264.

KANAMORI, H.; STEWART, G. S. Seismological aspect of the Guatemala earthquake of February 4, 1976, **Journal of geophysical research**. 83, 1978. p. 3427-3434.

KIJKO, A.; SLEVOLLE, M. A. Estimation of Earthquake Hazard Parameters From Incomplete data File Part II.Incorporation of Magnitude Heterrogeneity, **Bull. seis. Soc. Am**.,Vol.82,No.1, 1992. p.120-134.

LUCO, N.; CORNELL, C. A. Structure-Speci c Scalar Intensity Measures for Near-Source and Ordinary Earthquake Ground Motions**. J. Earthquake Spectra**. 23(2): 2007. p. 357-392

MCCLUSKY, S. et al., Global Positioning System constrains on plate kinematics and dynamics in the eastern Mediterranean and Caucasus, **J. Geophys. Res**. 105, 2000. p. 5695-5719.

MENDER, J. B., PECKAN, G.; CHEN, S. S. Low-cycle variable amplitude fatigue modeling of top-and-seat connections, **Eng. J. AISC**. 32(2): 1995. p. 54-63

MENDER, J. B.; PANTHANKI, F. D.;, & KASALANATI, A. Low-cycle fatigue behaviour of reinforcing steel, J. **Mater. Civ. Eng**. 6(4): 1994b. p. 453-468.

MOHAJER-ASHJAI, A.; NOWROOZI, A. A. Observed and probable intensity zoning of Iran. **Tectonophysics**. 49, 1978. p. 149-160.

MOINFAR, A.; MAHDAVIAN, A.; & MALEKI, E. **A collection of basic information on Iran Earthquakes**. 1994.

MOINFAR, A.; MAHDAVIAN, A.; MALEKI, E. Historical and Instrumental Earthquake Data Collection of Iran, **Mahab Ghods Consultant Engineers**, Iran (in persian). 1994

MUELLER, C. S. The influence of maximum magnitude on seismic-hazard estimates in the central and eastern United States, **Bull. Seism. Soc. Am**. 100 (2): 2010. p. 699-711.

NOWROOZI, A. A. Empirical Relation between magnitudes and fault parameters for earthquakes in Iran. **Bull. Seism. Soc. Am**. 75, 1985. p. 1327-38.

POURKERMANI, M., ADIB, A. **Structural Geology**, Payame Noor University Press, 2011

RICHTER, C. F. **Elementary Seismology.** W. H. Freeman and co., San Francisco, 1958

SELLA, G. F.; DIXON, T. H.; MAO, A., Revel a model for recent plate velocities from space geodesy, **J. geophys. Res**. 107, 2002. DOI:10.1029/2000JB000033.

TAKIN, M. Iranian geology and continental drift in the Middle east. **Nature** 235 No. 5334, 1972. p. 147-150.

TATAR, M.; HATZFELD, D.; MARTINOD, J.; WALPERSDORF, A.; GHAFORI-ASHTIANY, M.; CHERY, J. The present-day deformation of the central Zagros from GPS measurements, **Geophys. Res. Lett**. 29: 2003. p. 1927-1930.

TAVAKOLI, F. **Present-day deformation and kinematics of the active faults observed by GPS in the Zagros and east of Iran**, PHD Thesis. 2007

TRINKER, E. Geophysical and archaeological exploration in the Takla-Makan desert of Chinies Turkestan. **J. Central Asian Soc**. 5-18, 1930.

VERNANT, Ph. Et al. Contemporary crustal deformation and plate kinematics in Middle East constrained by GPS measurements in Iran and nort Oman, **Geophys. J. Int**. 157: 2004. p. 381-398.

WALKER, R. T.; BERGMAN, E.; JACKSON, J.; GHORASHI, M.; TALEBIAN, M. The 2002 June Changureh(Avaj) earthquake in Qazvin proviance, northwest Iran: epicentral relocation, source parameters, surface deformation and geomorphology, **Geophys. J. Int**. 160: 2005. p. 707-720.

WANG, Q., ZHANG, P., FREYMUELLER, J., BILHAM, K., LAI, X., YOU, X., NIU, Z., WU, J., LI, Y., LIU, J., YANG, Z. & CHEN, Q. Present-day crustal deformation in China by Global Positioning System measurements. Science 294, 2001. p. 574-577.

WELLS, D. L.; COPPERSMITH, K. J. New empirical relation among magnitude, rupture length, rupture width, rupture area, and surface displacement, **Bull. Seism. Soc. Am**. 89(4), 1994. p. 974-1002.

WELLS, L. D.; COOPERSMITH, J. K. New empirical relationships among Magnitude, rupture length, rupture width, rupture area and surface displacement, Bull. Seism. Soc. Am. 74 (4): 1994. p. 974-1002.

WHEELER, R. L. Methods of Mmax estimation east of the Rocky Mountains, **U.S. Geological Survey open-File Report** , 2009.

Yazdi, A., Ashja-Ardalan, A., Emami, MH., Dabiri, R., Foudazi, M. Chemistry of Minerals and Geothermobarometry of Volcanic Rocks in the Region Located in Southeast of Bam, Kerman Province. **Open Journal of Geology**, 2017. 7(11): 1644-1653. DOI: 10.4236/ojg.2017.711110

Yazdi, A., Shahhosini, E., Dabiri, R., Abedzadeh, H. Magmatic differentiation evidences and source characteristics using mineral chemistry in the Torud intrusion (Northern Iran). **Revista Geoaraguaia**, 2019. 9(2): 1-21

Yazdi, A., sharifi teshnizi, E. Effects of contamination with gasoline on engineering properties of fine-grained silty soils with an emphasis on the duration of exposure, Springer, **SN Applied Sciences**, 2021. 3:704 DOI: https://doi.org/10.1007/s42452-021-04637-x

ZARE, M. A seismological Overview on the Changureh (Avaj, Iran) Earthquake of 22 June 2002, Mw=6.3 (**published on ORFEUS Newsletter**, September 2002), 2002. http://orfeus.kmni.nl/newsletter/vol4no2/iran.html.

ZARE, M. Seismotectonic of South Ghazvin Plain and Stress Situation in the Buin-Zahra 1962 and Changureh 2002 Earthquake prone Areas, Fourth International conference of Earthquake **Engineering and Seismology**. 2003