Analysis of Location of Villages in Relation to Rupture Zone (Case Study: North Qazvin Fault)

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Abstract

This paper studies the shear zone of North Qazvin fault and investigates the location of rural settlements in this area. In selected sections, the presence of transverse valleys along the fault made it possible to investigate the evidence of shear zones in which we can see severe crushing in igneous rocks of andesitic and trachyandesitic type, and cataclastic. Moreover, traces of faulted and fractured zones (Damage zone) including fractures and small and minor faults were observed. The study also found Intact green tuffs at the end of the shear zone of the North Qazvin fault, which was considered as the healthy wall next to the shear zone. According to the field studies and observations of the shear zone of the North Qazvin fault in this section, the width of the shear zone was measured at 320 m on the hanging wall of the fault. After that, we used common software to compare the location of villages with the rupture zone of the North Qazvin fault. The results showed that the villages of Barajin, Hesamabad, Kherman-Sokhteh, Dastjerd-e Olia, Ahvarak, Khoran, Tazarkesh, Kikhanan, Najmabad, Razjerd, Qutbi Miyan, Sperno, Ange, Mazraeh Lat and Mazraeh Kharmanlough are located on the rupture zone of the North Qazvin fault. Moreover, 45 villages are located less than 2 km away from the North Qazvin fault. Therefore, it is necessary to relocate the villages that are on the rapture zone or change the direction of future developments of these villages outward, away from the rupture zone. For those villages that are located less than 2 km away from the North Qazvin fault, with regard to the acceleration of earthquakes around the fault and the phenomenon of rock fall in villages, the study proposes retrofitting in future construction.

Keywords: Rupture zone, North Qazvin Fault, Village, Vulnerability, Fault Damage Zone

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Introduction

The study area is located in Qazvin province, in the structural zone of Alborz (Map 1). Construction in safe places is one of the basic requirements for the development of rural and urban settlements. In this regard, respecting the fault rupture zone is an issue that has been neglected in locating settlements. For this reason, during an earthquake, many homes are destroyed by fault displacement and surface fault rupture. This paper is an attempt to investigate the location of villages in the shear zone of the North Qazvin fault.

Literature Review

Given that the construction process is increasing near faults regardless of their boundaries, one of the most important preliminary studies to prevent seismic vulnerability of settlements is to observe such boundaries. In areas near the fault, ground motion is strongly influenced by the fracture and surface rupture mechanism of the fault and the permanent displacement of the ground. Faults in mountainous and sloping areas causes phenomena such as landslides and rock falls. Therefore, it is necessary to investigate seismic faults in terms of the fault zone and potential displacement. Construction is of special importance in fault zones, and buildings should have a safe distance with them. Fault engineering boundary is the boundary that is considered for a seismic fault so that structures are less affected by the effects of fault, such as surface rupture and displacement (Mojarb and Zare 2009).

Regarding the designation of fault rupture zone, since there is insufficient information on the exact location of faults in urban and rural areas, officials designate the boundary up to two thousand meters instead of conducting detailed studies to determine the location of the fault. It is worth mentioning that fault rupture studies help to accurately identify the location of faults and provide investors and property owners with information needed for designation of boundaries according to valid scientific and acceptable criteria (Nestle & Lem, 2010; Batatian, 2002).

In most studies on fault boundaries, important factors such as fault geometry and displacement associated with fault seismicity play an important role in the latest seismic activity, fault slope, and depth of the foundation. However, the amount of rupture width has not been properly considered based on the width of the fault zone and fault joints. By entering this factor in the formula $S = U (2D + F / \tan\theta)$ and considering the special coefficient or safety coefficient obtained from field studies of multiple faults and combining transverse parameters (perpendicular to the fault) with the longitudinal parameters of the faults, the minimum width of different types of faults can be calculated. This way, many points that were previously considered as safe areas are considered to be at risk by applying the new method, which was first introduced by Bafti et al. The important point in this method is that it is necessary to conduct studies in the field of neotectonics and to scrutinize quaternary movements in field studies. Finally, civil engineers can use it to set up various engineering structures and estimate the amount of stylization. Studies have shown that with increasing the slope of the fault surface, the width of the fault area decreases (Bafti et al., 2010).

One of the most important seismic hazards is the risk of surface rupture of faults during an earthquake, the only solution to which is to observe the fault boundaries. Fault observance is still not considered in new cities and new rural settlements, as well as in developing areas adjacent to metropolitan areas. Field and telemetry surveys in Pardis indicate the existence of several important and active faults in the city on which construction has been carried out. The city is home to important faults such as Pardis, Hesa and Ferdows, which have clearly cut Quaternary deposits. The minimum area, especially in the sub-wall section for Pardis, Ferdows and Hesa faults, is 40, 21 and 28 meters. In addition, Roodehen fault in a distance of three kilometers north of the city, North Tehran fault and Mosha fault can be the causes of destructive earthquakes in this city. Observance of the fault boundary is the only solution to deal with the risk of surface rupture. This requires structural studies and urban geology in order to identify active faults before the implementation of urban development plans (Ehteshami Moinabadi 2016).

The south of Tehran is adjacent to the faults of Pishva, Kahrizak and Ivaneki. If these three faults become activated, the resulting earthquake will cause many human and financial losses. In this regard, one can pay attention to the methods based on the type of fault and field observations (Barbarian et al. 1985) or based on the International Building Code (IBC) which includes fault slope, displacement rate, factors of structure type and foundation and structure sensitivity. A combination of these methods and consideration of geotechnical issues may lead to a better designation of boundaries. In determining the construction area in the vicinity of earthquake-prone areas, first the active fault map and soil type map of the area should be prepared based on geotechnical studies with a scale of 1: 500 and based on computational formulas, depth, shape and importance of the structure. After that it is possible to build the new buildings in accordance with obtained information (Iranbadi and Zare 2014).

With regard to the rapid growth of urbanization in the cities of Iran, which are mostly located in the hillsides of the country and the fact that Quaternary faults can be found on the border between mountains and plains, the issue of determining fault boundaries has become important. One of the ways to determine the fault boundary is to obtain the density of faults in the study area by which areas can be classified in terms of fault risk. Denser faults are more likely to move (Mojarb and Zare 2009). In this study, the shear zone of the North Qazvin fault has been investigated, and the vulnerability of villages located in the fault rupture area has been determined. According to the theories (Kim, 2004), the shear zone of a fault can be tabular, sheetlike or curviplanar in which the amount of strain is much higher than the surrounding rocks and has a non-axial shear component. There are two types of shear zones: ductile shear zone and brittle shear zone. Ductile shear zones are narrow and long zones formed by relative displacements. They are like fault zones but occur without fracture (unless reactivated). The reason is that deformation of such zones often results in the concentration of a larger amount of strain in the shear zones. The development of shear zones is generally accompanied by a sharp decrease in granule size and results in the formation of rocks with linear and band-shaped characteristics called mylonite. Shear zones typically record a non-axial deformation and range in size from a granule or particle size to thousands of kilometers in length and width. The strain gradient from mylonite to deformed rocks is the scale and reference that researchers used to detect large-scale shear zones compared to regional deformations. Brittle shear zones are shear zones that occur where the walls of the shear zone are often not deformed or may be sheared. These zones often contain fractures and phenomena caused by a brittle deformation mechanism. Moreover, they form in the shallow parts of the crust, generally at depths of 5 to 10 km above the earth's surface, where deformation with a brittle mechanism predominates, such as faults and fractures (Choe & et al. 2016).

A brittle shear zone consists of the following parts (Figure 1):

1. A fault core (the area in which the most displacement occurs): It contains cataclasites, gouges and the shear zone.
2. Transitional zone
3. A damage zone on both sides of the fault core and consists of mechanical structures including fractures, veins, folds and smaller faults.
4. Wall rocks of brittle shear zone which are without deformation.

Research Method

In order to protect the villages from earthquake damage, it is necessary to conduct detailed studies, which help us to determine the location of the faults and to determine their surface rupture. This will also help to accurately identify the location of the fault and select the area according to valid scientific and acceptable studies for future development of villages. In order to conduct this research, fault rupture area has been determined by geological surveys, field

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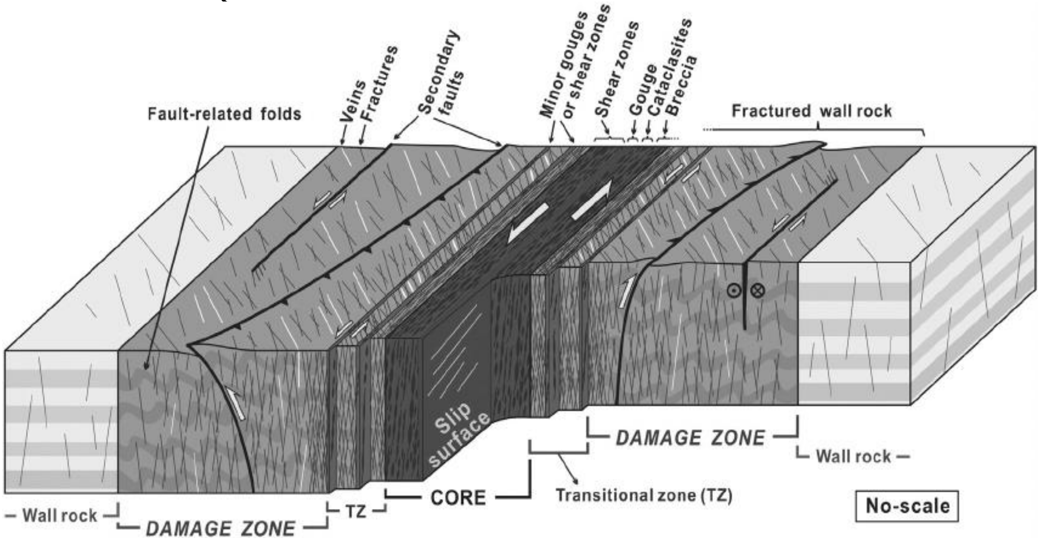
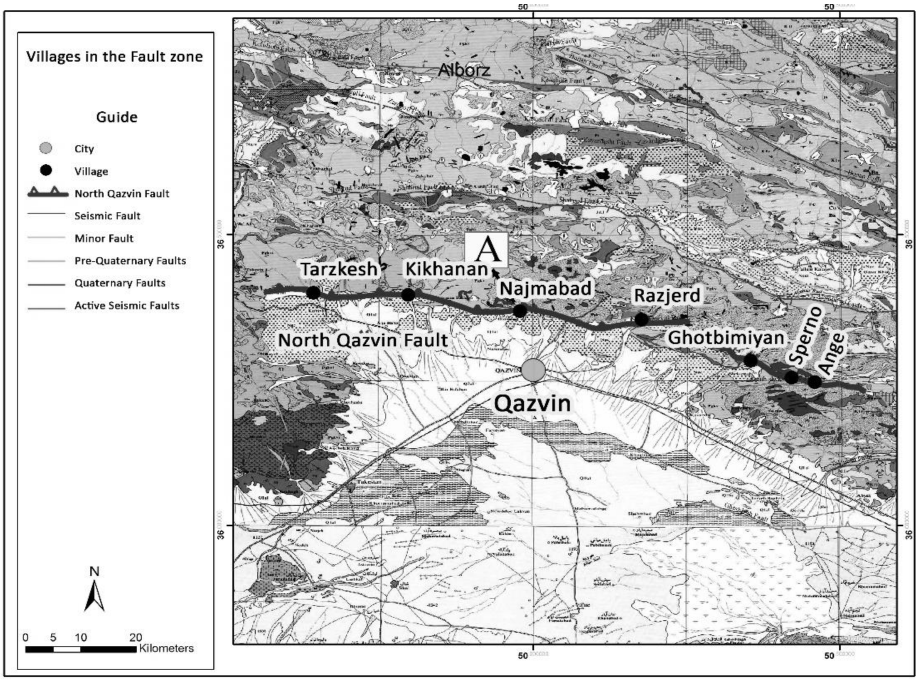
studies and necessary measurements. Moreover, the vulnerability of the studied villages has been determined.

The research questions are as follows:

- How many villages are located in the rupture zone of North Qazvin fault?
- What are the characteristics of the fault damage zone in North Qazvin fault?
- In what way villages would be developed in the fault zone?
- What is the extent of vulnerability of existing settlements and facilities in the study area?



F1. Major parts of a shear zone (Choe et al. 2016)



F2. The study area and the location of the North Qazvin fault

Geology of the Case Study

From a geological point of view, Qazvin province is located at the junction of western Alborz and the northern edge of central Iran. According to the studies, the northern heights of the province in the southern margin of Alborz and most of the province, which includes Qazvin plain and southern highlands, belong to the structural-sedimentary zone of central Iran. It seems that the border of these two zones coincides with the thrust fault of north Qazvin, which separates the northern heights from the Qazvin plain. However, this border is certainly estimated so that it is impossible to determine a real line of separation between Alborz and central Iran, and these two (Central Alborz-Iran) are two bodies of the same basin.

From a morphological point of view, the mountains of the north Qazvin are made up of a series of east-west ridges and drifts that are driven south. The intensity of metamorphism is highest in the mountains and plains and has mountainous heights that gradually reach the flat area of Qazvin plain, which is covered with young alluvial deposits and sometimes with desert formations such as salt crust and clayey hills. The southern border of the province has a mountainous physiography in which Paleozoic and Mesozoic rocks, especially Cenozoic volcanics, play an essential role.

Tectonostratigraphic units in the northern part (Alborz) and the southern part (central Iran) of the province are not clearly different and everywhere rocky sequences begin with the Late Precambrian platform deposits (Soltanieh Formation) which more or less continue with a few small and large sedimentary stops to the middle Triassic. Upper Triassic rows are middle Jurassic units of tectonostratigraphic that is limited to two Upper Cimmerian (Upper Triassic) and Middle Cimmerian (Middle Jurassic) orogenic events, mainly composed of shale and sandstone (Shemshak Formation) and sedimentary in Iran. The former Cimmerian canvases have been piled up. Everywhere in Qazvin province, the Middle Jurassic-Upper Cretaceous rocks are rows of carbonate marl plateaus with small outcrops in the north and south (peak) of the province. Cenozoic rocks begin with Eocene detrital igneous assemblages (Karaj Formation) into which granite intrusions related to the Pyrenean orogenic event have sometimes been injected. Most of the Cenozoic rocks of Qazvin province are rows contemporaneous with the Cenozoic orogeny, which are mainly accumulated in the intermountain basins and have limited outcrops at the foot of the heights.

The study area is located in the Alborz structural zone. Alborz is a series of open V-shaped mountains on the southern edge of the Caspian Basin. Although (Alavi, 1996) has considered the structure of Alborz in the form of duplex structures of the Antiformal stack based on its observations, but other geologists such as Allen et al. (2003), believe in a model such as mud structures for this structural zone in northern Iran. Therefore, various structural sections have been reconstructed and presented with some changes compared to Stocklin's original model. Accordingly, these mountain ranges consist of folds and thrust faults with two directions of movement (towards the southern Caspian basin in the north and towards the central Iran block in the south). Accordingly, the thrust faults in the northern part have a slope to the south, and conversely, the faults in the southern part have a slope to the north, which indicates a positive mud structure. Right-slip and thrust faults are frequently seen in the Alborz mountain range. These faults are more parallel to the mountain range and most of the folds have been formed by the reactivation of these faults. The main thrust and slip faults have east-west to northeast-southwest trend, which are located in the west-central and eastern parts of the mountain range, respectively. These faults have a steep slope parallel to the mountain range. This steep slope indicates that most of the thrust faults are the same old normal faults that have been reactivated during the Neogene and Quaternary periods (Sabouri 2018).

North Qazvin Fault

The North Qazvin Fault (Map 1) is a fault with an east-west direction and a length of

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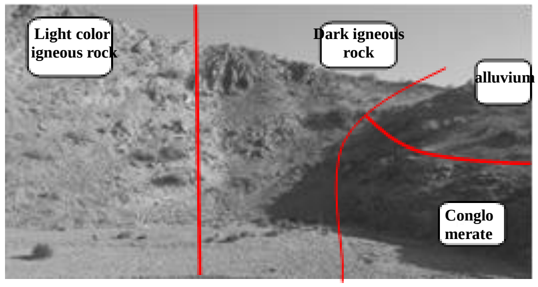
more than 60 km, which passes a short distance from the north of Qazvin. This fault is similar to the thrust fault of north Tehran (Barbarian et al., 1985). The sudden difference in altitude between the city of Qazvin (with an average altitude of 1250 meters above sea level) and the nearest ridge at a distance of 30 km northeast of Qazvin (Qezler Qalasi ridge with a height of 2700 meters) is one of the most prominent topographic features of Qazvin. Ghaem is along the north Qazvin fault. This fault has formed the boundary between volcanic-pyroclastic rocks of Karaj Formation (in the north) and Quaternary alluvial sediments (in the south) for most of its length. In most geological sections, the North Qazvin fault in the foothills of Qazvin can be seen (Barbarian et al. 1992).

The young thrust fault in the north of Qazvin is a seismic fault, but due to little data, its seismic history is not well understood. It is probable that the earthquake of December 10, 1119 AD in Qazvin with magnitude (Ms = 6.5 and I0 = VII), occurred due to the fault movement in the north of Qazvin (Barbarian et al. 1371).

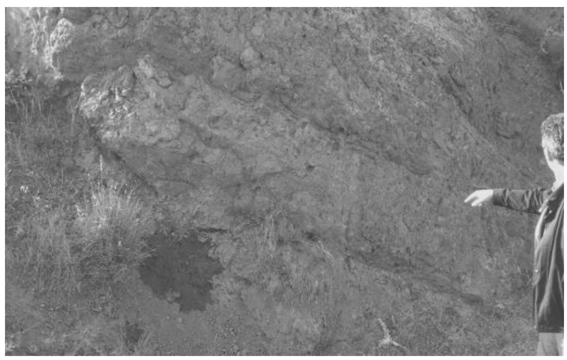
Discussion and Analysis

Considering that the North Qazvin fault has a length of more than 60 km and is a seismic fault, it is of special importance to identify the shear zone of the fault. The location of many villages in the area of North Qazvin fault increases the importance of this fault. Some of the villages that are located near the fault are Najmabad, Razjerd, Barajin, Chenask, Hesamabad, and Astalak. Several sections were studied to investigate the shear zone. In these sections, due to the presence of transverse valleys along the North Qazvin fault, studies related to the evidence of shear zones were well possible. At this point, the North Qazvin fault has driven Cretaceous igneous rocks on the Pliocene conglomerate (Figure 3). Severe fragmentation and deformation were observed in these dark and gray andesitic rocks. It seems that this part can be considered as the core of the shear zone. In fact, severely crushed catalastics were observed as another evidence of the core of the shear zone in this section (Figures 4 and 5). Fractured rocks and smaller faults were also observed which can be considered as the fault damage zone (Figure 6).



F3. Location of the shear zone of the North Qazvin fault near the village of Najmabad. At this section, crushed igneous rocks (right) are thrusted onto the conglomerate (left). (east view)

F4. Location of the shear zone of the North Qazvin fault near the village of Najmabad. At this section, crushed igneous rocks (right) are thrusted onto the conglomerate (left). (east view)



F5. Crushing and faulting in the shear zone of the North Qazvin fault near Najmabad village. (west view)
The location of the image is marked A on map 1

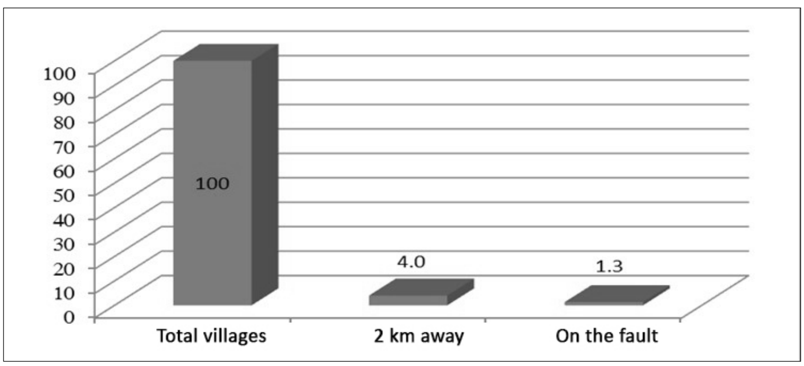
F6. Crushed rocks in the shear zone of the North Qazvin fault near Najmabad village. (west view) The location of the image is marked A on map 1

Moreover, green tuffs of Karaj, which suffered a slight fracture, were observed. This part, which can be seen in a healthy and relatively intact part, was considered as a retaining wall along the shear zone of the North Qazvin fault. According to the field observations in this section (marked on map No. 1 with the symbol A), the shear zone of the north of Qazvin fault in the fault wall was measured at 320 meters.

According to the determination of the shear zone of the North Qazvin fault and using ArcGis software, the location of the villages in the study area was compared with the shear zone of the fault and out of 875 villages of Qazvin province, 15 villages are located on the fault zone (Table 1 and figur No. 7). Therefore, due to the seismicity of the North Qazvin fault, in the event of an earthquake, these villages will suffer serious damages. Also, 45 villages are located less than 2 km away from the North Qazvin fault (Table 2 and figure 8) where issues related to the area near the fault, including high seismic acceleration, the possibility of landslides and rock falls in sloping areas are possible. Chart 1 shows the percentage of villages located on the fault and the percentage of villages located within 2 km.

Row	Village	Row	Village	Row	Village
1	Barajin	6	Dastjerd-e Olia	11	Najmabad
2	Hesamabad	7	Ahvarak	12	Razjerd
3	Kherman-Sokhteh	8	Khoran	13	Qutbi Miyan
4	Mazraeh Lat	9	Tazarkesh	14	Sperno
5	Mazraeh Kharmanlough	10	Kikhanan	15	Ange

T1. Villages on the Fault (Figur 7)



Ch1. Frequency of villages located on the North Qazvin fault and located within 2 km of Qazvin province

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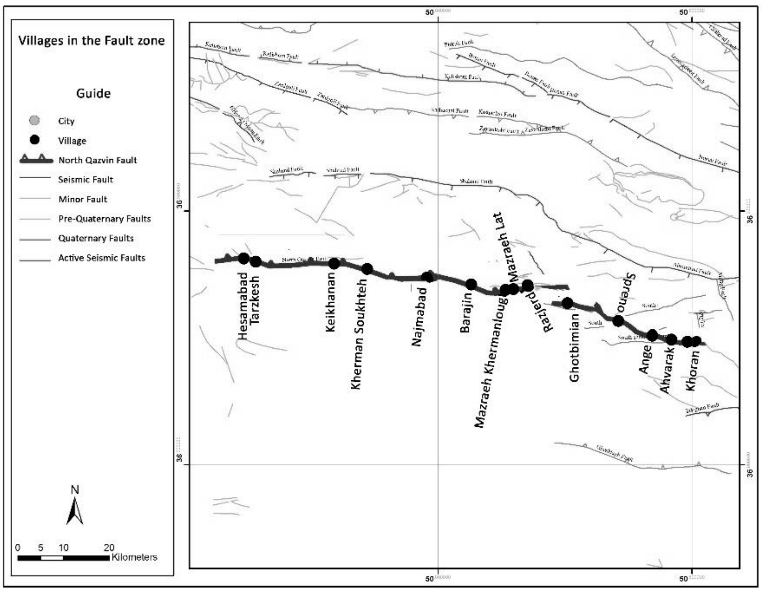
Row	Village	Row	Village	Row	Village
1	Estalk	16	Shadkouh	31	Arousabad
2	Soukhtehchenar	17	Kiadeh	32	Naderabad
3	Morteza Abad	18	Gharib Mazrae	33	Akbarabad
4	Pirmardound	19	Morghdari Ange	34	Mazraeh Zavareh
5	Asadabad Khorin	20	Kalaroud	35	Hosseinabad Eghbal
6	Cheshmeh Gholamali	21	Kajiran	36	Abdolabad
7	Dareh Malgeh	22	Amirnan	37	Esmaeilabad
8	Soltanabad	23	Rashghoun	38	Mazraeh Mohandes Shiba
9	Bakkendi	24	Markaz Ferestandeh Telo	39	Shafieabad
10	Doudeh Taj	25	Bandzaviar	40	Ouzoun Dareh
11	Rahdarkhaneh Kouhi	26	Emam Zamen	41	Madan Sang
12	Kourbolagh	27	Chenasak	42	Joudaki
13	Zarjeh Bostan	28	Charis	43	Shahghadam
14	Shekarnab	29	Veres	44	Dodaheh
15	Khouneh Doush	30	Ghazgaleh Bozorg	45	Taratan

T2. Villages located within 2 km of the Fault (Figur 8)

For the villages located on the North Qazvin fault, in order to prevent deaths due to surface rupture during the earthquake and to save human lives, it is necessary to move the village to another point or correct the future development direction of the village outside the rupture of the North Qazvin fault. For this purpose, in preparing or reviewing the master plan of these villages, the designated shear zone for the northern Qazvin fault can be considered as a criterion for future development of villages and in determining the future development of these villages, new construction on the shear zone of the northern Qazvin fault can be prohibited.



F7. Location of 15 villages located on the North Qazvin fault

To minimize earthquake damage in villages located less than 2 km away from the fault, due to the hazards of the area near the fault, a resistant structure is recommended. Moreover, the distance from the areas with the possibility of landslides and rockslides in the villages should be observed in the future construction. For this purpose, in preparing and reviewing the guide plans of these villages, the development of the village in the area of surface rupture of the fault, which is located in sloping areas and at the foot of slopes, should be prevented.

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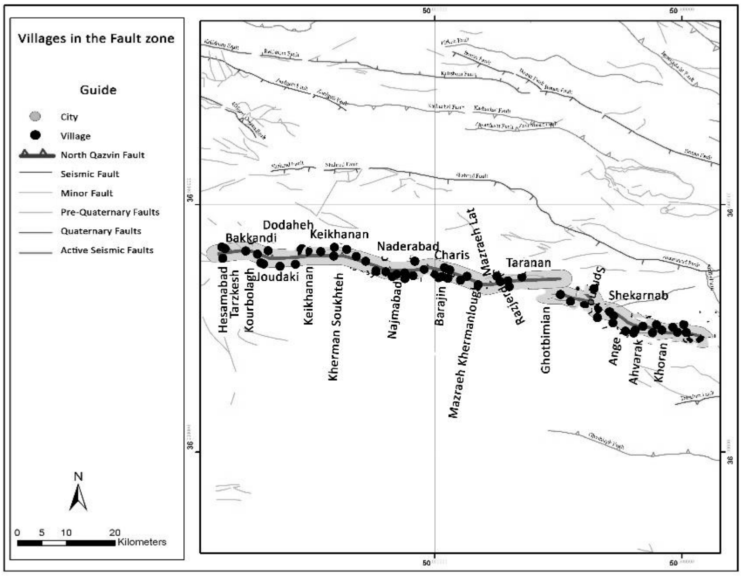

F8. Location of 45 villages located less than 2 km of fault

Conclusion

According to the studies performed on the North Qazvin fault in different sections including severe fragmentation in igneous rocks of andesitic type and trachyandesite, there are fragmented Cataclastics that were analyzed. Also, traces of faulted and fractured zones including fractures and small and sub-faults were observed. Furthermore, green tuffs that were intact and relatively intact were observed at the end of the shear zone of the North Qazvin fault, which was considered as a healthy wall next to the shear zone. According to the field studies and observations of the shear zone of the North Qazvin fault in this section, the width of the shear zone was measured at 320 m on the meta wall of the fault. Since there are many villages in the area that are located on the shear zone of North Qazvin fault, the villages were compared with the rupture area of North Qazvin fault. As a result, the villages of Barajin, Hesamabad, Kherman-Sokhteh, Dastjerd Olia, Ahvarz, Khavar , Kikhanan, Najmabad, Razjerd, Ghotbi Miyan, Sperno, Ange, Mazraeh Lat and Mazraeh Khermanluq are located on the rupture zone of the fault. Also, 45 villages are located less than 2 km of the fault. For the villages located on the North Qazvin fault, in order to prevent deaths due to surface rupture during the earthquake, it is necessary to move the village to another point or correct the future development direction of the village outside the rupture of the North Qazvin fault. For this purpose, in preparing or reviewing the master plan of these villages, the designated shear zone for the North Qazvin fault can be considered as a criterion for future development of villages and in determining the future development direction of these villages, new construction on the shear zone of North Qazvin fault can be prohibited. For villages located less than 2 km, to prevent earthquake damage, a resistant structure should be considered due to the earthquake acceleration near the fault and also the distance from areas with the possibility of landslides and rockslides in the villages in future construction.

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