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An Investigation on Borojerd as a Vulnerable Area against Earthquake: A Case Study of Borojerd Houses

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Abstract- *Iran is one of the countries which is always struck by quake and its location on Himalayan-Alpine belt has enhanced this condition such that in the previous century it has experienced more than 130 quakes with magnitude 7.5 in Richter scale. This phenomenon is not destructive in itself but lack of structures' tolerance against forces caused by quake devastates and ruins them for different reasons. Iran is one of the ten natural disaster-prone countries and it is known as the sixth earthquake stricken country which causes high death toll. Based on this, urban security has great importance in this land. In this regard, this study has used a survey and analytical method based on qualitative and quantitative characteristics of Borojerd houses with the aim of identifying the amount of vulnerability using national statistics and random sampling. The results of this study indicated that seismic risk is high in Borojerd and confirmed low level of material resistance and high density of families in houses and lack of facilities and important services like hospitals, fire-fighting and rescue centers in critical situation.*

Keywords: *Earthquake, Houses Vulnerability, Borojerd*

I. INTRODUCTION

Danger is an indispensable part of the human society and in this regard, danger and its related aspects should be considered and not ignored but its range is different from one country to another. What under developed or developing countries have suffered from is risk management and crisis management in these conditions (*Smith*, 2003) and it is not unexpected that we say inefficient urban planning of the third world countries is a defective planning to resist problems not planning for preventing urban problems. It is clear that problems of modern cities are not only social, economic, political and cultural problems but natural factors, which constitute cities, have significant influence in this trend (*Zangiabadi*, 2006). One of the important natural factors influencing cities are faults which have a unique role in earthquakes and its disasters.

This phenomenon is not limited to a certain place or time; sometimes it influences eastern part of world and sometimes western part of world. The more powerful the released power and energies are, the more destructive effects will remain unless man takes actions to reduce it.

Table 1 shows the most destructive quakes in recent decade while statistics demonstrate influence of man's ability in managing this phenomenon. Mortality comparison in *Japan* and *Haiti* verifies this because regarding the high quake magnitude and high population density in *Japan*, its casualties is more lower than *Haiti*, such that human casualties in *Haiti* is 15 times of *Japan* and this means that man suffers from mismanagement. (See Table 1: Earthquakes with 1,000 or more deaths since 2001). Iran is not safe from earthquakes and its effects and consequences and always encounters this phenomenon such that from 1900 to 2010 more than 13000 earthquakes have stricken this country that among this number, 117 earthquakes have magnitude 6-7 and 1354 earthquakes with magnitude 4-5 in *Richter* scale and it can be said that on average one 7 *Richter* scale quake has occurred every ten year (Seismology and earthquake engineering international institute). Result of this natural disaster is death of 126000 individuals in the recent 100 years.

Aside from earthquake and faults, forming cities and manner of construction should be considered because it can heavily influence the vulnerability range. Unfortunately, most Iranian cities have founded along with faults without special monitoring and what intensifies this condition is the weakness of structures and buildings against earthquake such that 80% of buildings have not significant resistance against this phenomenon and among 12 million residential units, more than 7.2 million lack required standards against this phenomenon and 4 million rural houses have old texture constructed with mud which has least resistance against quake. In addition, low quality aggregates, house types, lack of suitable and resistant construction model and erosion of buildings add to the problem (*Negaresh*, 2003).

Establishment of *Borojerd* in latitude $33^{0}55'$ and longitude $48^{0}48'$ in *Zagros* Mountain hillside along with metamorphic *Sanandaj*-*Sirjan* zone in north and in south, in one hand (figure 1), and increasing non-standard skeletal and spatial growth without considering the required infrastructures and increase in population from 49000 in 1959 to 337000 in 2011, on the other hand, can transform least natural crisis to a great human disaster.

Therefore cases like, Violating constructions and irregular physical urban expansion; Not considering faults limits and soil type; Undesired aggregates used in cities; Not following construction standards and finally Constructing town with large population near faults, will significantly accelerate crisis range in this city. (See **Figure 1:** *Borojerd* location of the major tectonic boundaries.)

Based on this, present research tries to analyze vulnerability of *Borojerd* houses by earthquake using skeletal-spatial and anthropologic-social factors with a systematic view.

II. BACKGROUND

It is quite clear that earthquake is one of the most dangerous natural phenomena which strikes in one part of world in each year and this has led researchers to evaluate and study this phenomenon from different views due to damages imposed to vital arteries of cities. In this regard, we can mention following papers:

One of the papers relevant to earthquake and its damages on *Iran* urban systems is *Faraji* and *Shadab Far* paper titled "the position of water supply transmission systems in management of urban area against earthquake" which is published in 2013. This paper studies earthquake condition of *Qazvin* city and conditions of vital arteries like water supply transmission and manner of encountering it by urban management (*Shadab Far*, *Faraji*, 2013).

Another paper is "engineering management of lifeline systems under Earthquake risk" by *Hiroyuki Kameda* which is concerned with special characteristics of engineering earthquake vital arteries and vital elements in earthquake engineering. It particularly dealt with seismic reliability in a plan with analytical method and has considered directions for future of earthquake engineering and training a third generation for this field (*Kameda*, 2012).

Professor *Masakatsu Miyajima* has published an article in the international symposium of lessons learnt from great earthquake 2011 in East Asia in 2012. This paper studied damages imposed to water supply transmission facilities of East *Japan*, especially *Sendai* city in 2011 earthquake and analysis of abrupt increase and decrease in water pressure through field study (*Miyajima:2012).*

Another paper is *Chen* and *Ji-Hao Lin* paper titled "Earthquake damage scenario simulation of a water supply system in *Taipei*" which is published in 2008 in SPIE articles book in volume 7143. This paper has considered influence of earthquake on water transmission system in *Taipei* and role of urban management in regulating its problem. Then, damages caused by earthquake on water supply system of *Taipei* were simulated and estimated using software (*Ji-Hao Lin*: 2008).

One of the other studies is *Amjad Maleki* et. al article titled "earthquake risk zoning and prioritizing improvement of houses in *Kurdistan*" which is published in 2007. This paper studies seismic position of different parts in *Kurdistan* and condition of aggregates and finally, zoning model was obtained considering buildings conditions in each province (*Maleki. 2007: 115*).

For the next, the extensive number of earthquakes in the *Lorestan* province and its seismicity can be noted. According to the results, most of the earthquakes which happened in the *Lorestan* province have a magnitude between 4 to 5 Richter and have mostly occurred in 1973, 1997 and 2004. Specifically, the *Borojerd* city and its suburbs have always experienced earthquakes that the oldest might be the *Silakhor* earthquake in 11,000 years ago and Seymareh earthquake in 872 AD which resulted in the death of 20-thousand people (*Shahrabi*& *Javan Doloee*, 2009: 697)). The most recent ones are a 6.1 Richter earthquake in 2006, a 4.7

Richter earthquake in 2008, and finally a 3.6 Richter earthquake in 2012.

In this context, *Shahrabi* and *Javan Doloie* has published an article in 2009 titled "Seismic characteristics of *Borojerd* floodplain based on seismic data registered in a temporary seismology network" which is published in 2009. This paper studies seismic characteristics of *Silakhor* based on the seismic events registered in temporary seismology network established in this plain in 2005 and aftershock characteristics of March 2006 earthquake in this area (*Shahrabi*& *Javan Doloee*, 2009: 697).

Another paper about *Borojerd* geology is a paper by *Akbari* et. al titled "heavy minerals and litho-geochemical studies for gold exploration in *Mohsen-Ibn-Ali* in *Borojerd*" in 2008 in which geological studies have been conducted to identify surrounding environment and minerals in this region.

Regarding conducted studies and references about earthquake and seismic condition of *Borojerd* and its risks, there is no comprehensive study about condition of houses and its interaction on vulnerability of human space in this area. Therefore, this study tries to provide an in-depth view about seismic condition of this area regarding its seismic condition and structures.

Seismicity in *Iran* and *Borojerd*

Zagros seismicity belt has high frequency regarding earthquake and more than half of quakes in *Iran* in recent century have occurred in it. This zone is divided into three zones "inferior *Zagros*, folded *Zagros* and high *Zagros*". Earthquake statistics show that folded *Zagros* is seismically more active than other zones. (See **Figure 2:** Architecture and urban fabric in *Borojerd)*

Almost all quakes have concentrated in west and south-west belt of *Iran* in folded *Zagros* and indicates relationship between folded and faulted zones with active seismic areas. Among most important seismic areas in this belt we can refer to north-east of *Bandarabbas*, west of *Kohnoj*, East of *Lar*, *Qir* and *Karzin* area, *Kazeroon* to *Booshehr*, *Gachsaran*, north of *Dezful*, West of *Hamadan*, *Kermanshah* and *Borojerd* (*Negaresh*, 2003). Opening plate of *Red Sea*, in one hand, and movement of *Saudi Arabia* plate with mean 2cm in each year toward *Iran*, on the other hand, has added to problem and transformed it to one of the causes for frequent earthquakes in *Iran* (*Negaresh, 2012)*.

Borojerd, which is located in the foots of *Zagros* 4km away from *Zagros* fault and near to *Dorood* faults, main *Zagros* reverse fault (MZRF) and high *Zagros* fault (HZF) has witnessed quakes and aftershocks which cause much damages (fig 3) (*Negaresh*, 2003). More than 807 seismic events have occurred in the recent century in this faulted area among them 124 cases had 5.4 *Richter* and higher magnitude and this shows active seismic condition of area (Fig 4). The most important and large earthquake is *Silakhor* earthquake (south-east *Borojerd*) in 1980 with magnitude 7.4 which devastated 128 villages and killed 6000 people and 2006 earthquake in south of *Borojerd* (*Darbe Astaneh*) with magnitude 6.1 with more than 60 aftershocks. In addition, less severe earthquakes have reported like 2008 earthquake with magnitude 4.7 Richter caused by *Nahavand* fault and 2012 earthquake with magnitude 4.7 in *Richter* scale (*Iran*'s international seismology and earthquake engineering). Therefore, it is important to consider position of urban structures in this city. [See **Figure 3:** *Zagros* fault map and other sub-faults; **Figure 4:** Seismicity of area in recent century. Asterisk shows earthquake position in 2010 in east of *Dorood* and **Table 2:** Number of rooms in residents regarding area of each residential unit (2011)].

Necessities of investigating and analyzing earthquake in *Borojerd*

1) Skeletal-spatial indicators analysis

1-1) Density analysis

The first studied indicator is density indicator. In this regard, population density in residential unit (family dimension), number of residential units, and number of rooms in each residential unit and area of each residential unit were the most important studied variables.

In 2011, population of *Borojerd* was 337641 and the number of resident households was 99308 and the number of residential units in the city was 93681; therefore, residential unit indicator is 0.27 per individual, individual in residential unit indicator is 3.6, family in residential unit is 1.06 and residential unit indicator per family was 0.94 (Table 2).

In the case of density indicator, relation of number of rooms in each unit with vulnerability is that the freer unit in residential units, the less vulnerabilities.

Among total residential units in this city, 17797 units are apartments and 75884 units are common houses and more than 30000 units have an area less than $70m^2$ and this $70m^2$ space has more than 26000 residential units with more than two rooms which limits free space and increases risk factor. On the other hand, family dimension in this city is 3.6, while most houses in this city have one or two rooms which show high risk.

Therefore, by considering this, we can feel density condition of homes and risk dimensions in city in crisis time.

2.1) Aggregates indicator

This indicator is the most important studied indicator that its variables include year of construction, aggregates used in building, type of appearance and skeleton. Regarding types of aggregates and based on standard indicators of aggregate resistance, it has divided into four groups' weak, less durable, semi-durable and high durable. (See **Table 3:** Resistance and resistance frequency of *Borojerd* building aggregates)

Analyses indicate that more than 46% of residents are constructed with weak, less durable and semi durable aggregates and 51.2% are constructed with durable aggregates. It should be mentioned that regarding the other factors, these buildings with durable aggregates may have vulnerabilities because this ratio is only related to vulnerability caused by aggregates.

Total number of buildings constructed in *Borojerd* is 93681 which 54548 are built in city and 16323 in villages. More than 50% have steel or reinforced concrete frame and other buildings have used aggregates like (brick, steel, stone, cement, block, wood, mud, etc) that used aggregates are shown in the below table. (See **Table 4:** Estimating common residential units based on skeleton and aggregates, 2011).

As above table shows the number of all buildings constructed by reinforced concrete is 2258 and by steel frame is 47200 while more than half of the residents have not even this standard and most of them are constructed from less durable and quality aggregates and this is only threat and risk for residents and vulnerability against earthquake is high.

Among all residential units in this city, 17797 units are apartment which 10738 have steel frame and 1029 are constructed from reinforced concrete and 75884 are other buildings which 36462 cases have steel frame and 1229 have reinforced concrete frame. 66226 residential units have suitable construction aggregates. (See **Table 5:** Building construction based on year and aggregates).

Because construction year has an important and considerable role in solidarity of building, it should be considered in vulnerability of building. In this regard, usual residential structures and steel frames which date back to 1981, has lost their useful life and place in less durable and semi durable buildings while buildings and structures that have built after 1980s have not required standards and are in these conditions, especially structures which lack steel or reinforced concrete frames. Regarding this, considerable parts of structures are placed in this group which their vulnerability and destruction risk in the case of earthquake is evident.

3.1) Area seismicity index

Table (6) shows distribution of numbers and type of buildings in *Borojerd*. As seen, most structures are of steel structure frames or with brick aggregates. (See **Table 6:** Number and type of buildings in *Borojerd)*

In this regard, more than 80% of these buildings have a height lower than 9m or less than three floors. Therefore, based on suggested equation of Regulation 2800 in calculating the vibration period of buildings with steel frame (equation 1) we can say that most structures in city have a vibration period equals to 0.4s.

$$T = 0.08H^{\frac{3}{4}} = 0.08 \times 9^{\frac{3}{4}} = 0.415692\,s \qquad (1)$$

In which H is the height of building (m) and T is the dominant period of structure (s).

On the other hand, Since *Borojerd* is located in the foot of the *Zagros* Mountains, in most areas, has a soil equivalent to the soil type II of Regulations 2800 and depending on the soil profiles has a dominant period about 0.3 to 0.4 s (BHRC).

Therefore, we can say that because of proximity between soil natural period and structure, area structures are subjected to intensification phenomenon i.e. even in the case of earthquake with not high magnitude, it is likely to have more than usual destruction.

4.1) analyzing accessibility to rescue centers

This index which encompasses width of passages, dead ends and access to rescue centers can be described as below.

Borojerd is an old historical city with a traditional and old texture that allocated more than 260hr of central space of city to it as its indispensable part. Narrow streets and dead ends are frequent which can increase vulnerability factor in critical conditions. Aside from it, part of peripheral urban spaces which is attached to the main city by the development of city, has organic and irregular texture without required systematic order for encountering risk and it has narrow streets without required urban standards.

Healthcare and service conditions in *Borojerd* should be added to this problem, a problem which should be studied from different views like geographical distribution, access radius, facilities, number of hospitals, emergency, etc. Geographical distribution of hospitals shows amount of giving service in crisis condition (Fig. 5). This map shows that major part of city in a wide radius has not considerable access to hospital and emergency equipments and this will increase vulnerability. Besides, low number of hospital beds which are lower than 1000 bed and three emergency units which are extremely low for its 400000 population and in the case of least risk, vulnerability range will be transformed to disastrous number. (See **Figure 5:** Geographical position of *Borojerd* hospitals)

Regarding the number of fire-fighting stations, city is in critical condition because four stations are very low for this city and limited number of employees and machines should be added to this issue such that only one advanced fire-fighting machine with 20 steps ladder is available in this city which portrays vulnerability of this city.

2) Analyzing social-human indicators

2.1) analyzing equipments condition in critical conditions

One of the important and considerable indicators in recognizing the amount of human vulnerability is exploiting primary equipments in crisis. Equipments like first aid and fire extinguishers are very important in the first hours of earthquake. Earthquake insurance is an important indicator for mental confidence in crisis.

In order to get required data, random statistical range was selected and data were gathered. Obtained results were very disappointing such that more than 87% of houses have not first aid as primary things in emergency conditions and more than 90% of houses lack fire-extinguisher. Regarding earthquake insurance, less than 10% of families have used this because of ignorance and financial problems. (See **Figure 6:** Percent of residents' exploiting primary equipments in crisis).

2.2)Analyzing training and awareness situation

Another indicator which can be referred in social-human indicators is citizens training and awareness in *Borojerd* which encompasses education, first aid trainings, natural disasters training and awareness of resident resistance.

Studies have shown disappointing statistics in this regard such that in studied cases less than 20% of families have exploited training for resisting against natural events which this statistics is more desired for urban students such that more than 80% of urban students get familiarized with earthquake primary trainings in the first minutes of it in schools. Regarding the first aid, less than 17% of families and less than 50% of urban students were aware of it and more than 55% were aware from buildings' resistance and those who were in buildings with lower resistance knew it but they stated lack of financial power in providing costs of buildings.

III. CONCLUSION

Increasing urbanization and urban population are considered as factors for high damages during earthquake. Development of communication networks and urban infrastructures, in one hand, and lack of observing first aid points in urban constructions and unplanned growth and development of city, on the other hand, cause high damages during earthquake (*Zangiabadi*, *2006*).

Studies about *Borojerd* confirmed increasing skeletal growth and lack of harmony between skeletal development and spatial development. Therefore, regarding these discussions and obtained results, we can say that high seismic capacity of area, high destruction likelihood and lack of crisis management system and severe shortage of required infrastructures in *Borojerd* can intensify problem and change it to crisis. Results of indicators verified that *Borojerd* has undesired conditions regarding density, aggregates, seismicity and social-cultural indicators.

Indeed, the results of these indicators clarified the warning in the *Borojerd* city and showed the need of additional attention of city managers into the earthquake issues. In this regard, the high-density of residential, in one hand, and spatial compactness of the building, on the other hand, and also poor construction, especially in the rural areas, stated that the urban management system of *Borojerd* requires more attention to the safety of humans rather than focusing on selling rate for getting higher income.

Therefore, civil projects and construction operation should enhance urban infrastructures and vital arteries i.e. even though there is not required time and budget to improve and enhance all buildings in city but by enhancing infrastructures like electricity network, water supply system, urban access roads and vital centers like hospital and crisis management systems, provide seismic risk control and management. On the other hand, determining destruction distribution in city caused by earthquake, estimating amount of urban demand for vital elements like water and energy and locating backup structures based on destruction maps should be part of work priorities. Efficient and comprehensive planning for physical development and growth considering required standards can prevent risks and minimize it.

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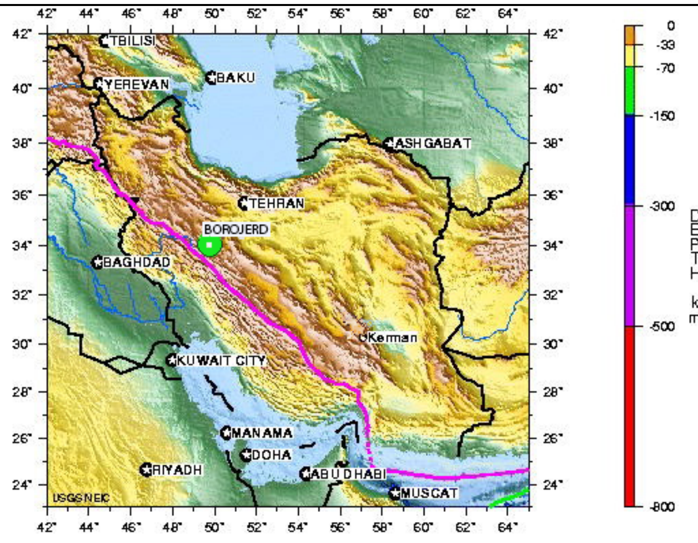

Figure 1: *Borojerd* location of the major tectonic boundaries (Source: USGS)

Figure 2: Architecture and urban fabric in *Borojerd*

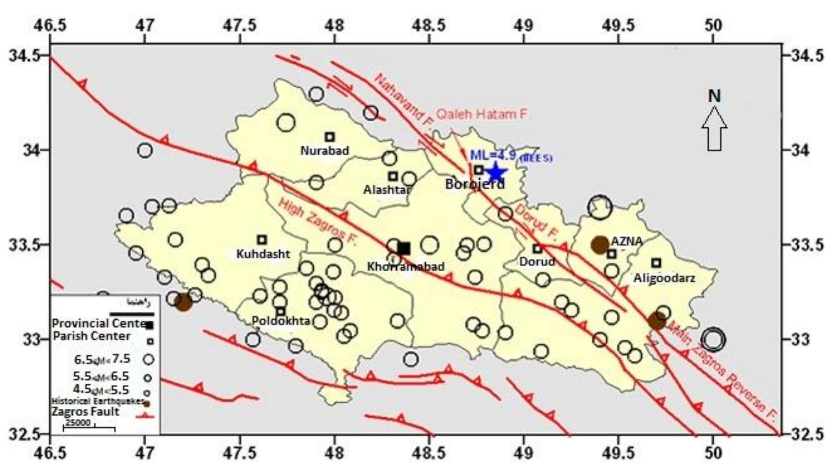

Figure 3: *Zagros* fault map and other sub-faults

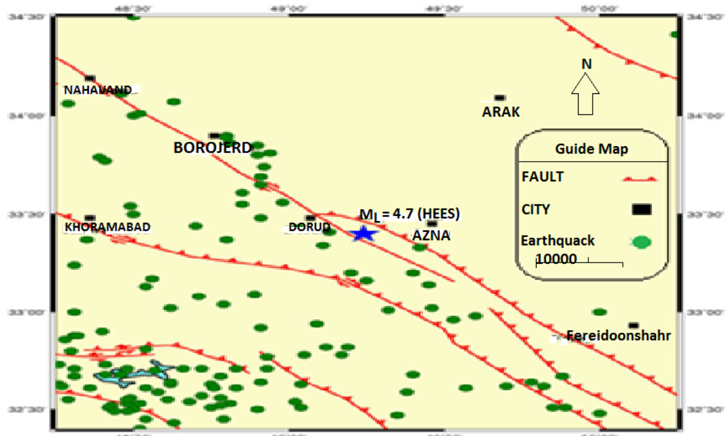

Figure 4: Seismicity of area in recent century. Asterisk shows earthquake position in 2010 in east of *Dorood.*

Figure 5: Geographical position of *Borojerd* hospitals

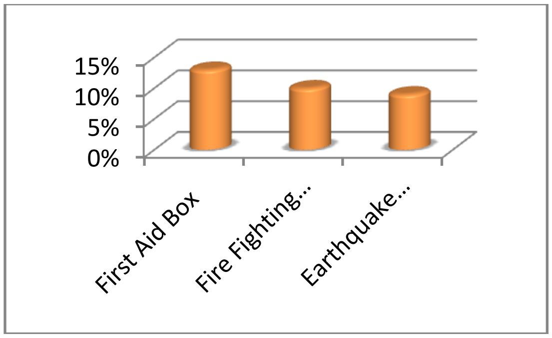

Figure 6: Percent of residents' exploiting primary equipments in crisis

Tables

Table 1: Earthquakes with 1,000 or more deaths since 2001

Date	location	Magnitude	Death
2001	Gujarat India	7.6	20085
2002	Hindu Kush Afghanistan	6.1	1000
2003	southeastern Iran	6.6	31000
2004	Sumatra	9.1	227898
2005	Pakistan	7.6	86000
2006	Indonesia	6.3	5749
2008	eastern Sichuan	7.9	87587
2009	southern Sumatra Indonesia	7.5	1117
2010	Haiti region	7	316000
2011	Japan	9	20896

Source: earthquake.usgs

Table 2: Number of rooms in residents regarding area of each residential unit (2011)

Rooms	Apartment	Simple building	<75	75- 100	100-150	150-200	>200
1	794	4740	4265	809	275	85	46
2	6703	33879	19223	15824	4673	1225	431
3	6885	23969	5736	10185	8912	4514	1245
4	2383	8537	1243	3057	3429	2073	1039
5	709	2495	190	657	1008	824	506
6	168	1296	114	211	328	335	437
total	17797	75884	30771	29645	18627	9056	3704

Source: Statistical Center of Iran

Table 3: Resistance and resistance frequency of *Borojerd* building aggregates

Aggregates' resistance	Frequency	Percent
Weak	1923	2.05
Less durable	3087	3.2
Semi-durable	38417	41
Highly durable	47958	51.2

Table 4: Estimating common residential units based on skeleton and aggregates, 2011

Aggregates type	Urban	Rural	Total
Steel frame	34142	13058	47200
RC*	868	2011	2258
Others	36435	10046	46481

*reinforced Concrete

Source: national statistics organization

Table 5: Building construction based on year and aggregates

year	Steel	RC*	other	Total
2006-2011	28848	24387	3132	56367
1996-2005	11470	377	6908	18831
1986- 1995	5655	184	11268	17245
1976-1985	4250	111	13748	18178
1966-1975	830	210	5104	6159
before 1966	361	185	2348	2900

*reinforced Concrete

Source: Statistical Center of Iran

Table 6: Number and type of buildings in *Borojerd*

Aggregates type in urban areas	Num.	Aggregates type in rural areas	Num.	Total 2011
Steel frame	34142	Steel frame	13058	47200
RC*	2011	RC*	868	2258
Brick-iron and stone-iron	30908	Brick-iron and stone-iron	5920	36828
Brick-wood	1440	Brick-wood	144	2883
Cement block	52	Cement block	37	89
Brick or stone	136	Brick or stone	68	204
Wooden	117	Wooden	26	143
Wood brick	460	Wood brick	1087	1547
Mud brick	96	Mud brick	137	233
Unknown	0	Unknown	0	221
Unexpressed	857	Unexpressed	256	1113
Total	70577	Total	23104	93681

*Reinforced Concrete
Source: Statistical Center of Iran