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Designing Roudbar Residential Complex with the Approach of Earthquake Resistant and Taking Advantage of the Features of Form and Structure

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Abstract: *Because the earthquake is one of the harmful factors that damages properties and human lives annually, statistics of injuries shows that over 130000 people have lost their lives during the past 100 years in Iran. Thus, according to Khazar and Alborz Faults existence which caused great damage in north of Iran, it is necessary to design a residential complex with an earthquake-resistant form, appropriate landscape design, and interior design and anti-seismic technologies. Therefore, the study aimed to design earthquake-resistant buildings. Present study is a descriptive-analytical approach carried out on a mixed method platform. The study focuses on designing Roudbar Residential Complex based on an anti-seismic approach. It is a cross-sectional research since its findings can be used to solve the safety problems of Roudbar building with respect to earthquakes of the regions. The causality relationship in this research can be formulated as follows: the novel anti-seismic technologies increase safety and reduce damages caused by earthquakes.*

Keywords: *residential complex, earthquake resistant, structure, form, Roudbar*

1. INTRODUCTION

Due to its proximity to earthquake-prone belt in Alps – Himalayas, Iran is among the most earthquake prone countries in the world. In a 5-7-year period, different cities of Iran have experienced earthquakes with a Richter magnitude of 6 to 7 and sometimes even more. According to geological studies, almost 97% of Iranian cities and villages are exposed to the earthquake threats (Zafari et al., 2007). As a matter of fact, what makes casualty is not the earthquake itself but non-resistant buildings. Therefore, there is an urgent need for constructing earthquake-resistant buildings. The technologies and guidelines used in developed countries can be used as an appropriate model.

The application of architectural procedures to buildings can be a useful solution to increase safety against earthquake while at the same time maintains the buildings' beauty. Such procedures use lightweight interior and exterior materials and elements, and also exploit new technological solutions in designing forms, sites and landscape. Since structural design approach is divided into two forms, namely designing based on forces shift and designing according to the performance in this research, the emphasis is laid on designing based on performance. In performance design, buildings' performance is positive and predictable. The owner of such buildings is ensured that the level of damage will be low and controllable in the case of the occurrence of an earthquake. This designing approach can provide us more economically suitable options. Roudbar's soil and urban density system necessitates the use of performance-based structural designing. Therefore, this approach was adopted in our research. In this article, we will first evaluate the regional features, obstacles, potential for seismic design, requirements and needed applications, and then the features of the selected region and site are analyzed.

1.1 Research questions and hypotheses

According to the theme of the study, the following questions were formulated, the answers to which could play a significant role in fulfilling the goal of the research.

- Have the structural design patterns changed in the region after the occurrence of an earthquake?
- How should neighbor units be located in an earthquake-resistant building?
- How should the landscape of an earthquake-resistant building be designed?

It is also assumed that Roudbar's architectural plan and pattern type is designed by analysis. This complies with the culture of Roudbar people and also conform to earthquake safety maxims. It is assumed that the synthesis of this pattern with earthquake-resistant techniques would lead to appropriate results.

2. Introducing Roudbar climatic conditions

Roudbar is the capital of Roudbar province. It is located at 65 kilometers far from Rasht on the entrance of Rasht-Ghazvin route (Rahmatian, 2009) Looking at the urban structure of the city reveals that since Roudbar is in the proximity of nature and High Mountains, it includes a highland structure. Buildings are located on small lands less steep than the others are. The existence of Sefidrood River and roads has given a linear structure to Roudbar. Due to its climatic conditions, sun radiation and heat, the type of housing plan has also changed. The occurrence of climatic phenomena such as tornados and Monsoon storms has led to high financial damages and casualties. Therefore, there is an overwhelming need that researchers fight against these catastrophes. The following factors are essential to consider while designing buildings in this region.

- Southern and northern winds are favorable winds in this region;
- In buildings' western walls, the use of resistant coating is necessary, and no aperture should be allowed in the walls;
- To reduce the moisture of walls, the units should be separated from each other allowing the air flow between them;
- The ceiling should be steep;
- To reduce the penetration of surface moisture, it is advised that the building is constructed higher above the ground using basements and catwalks;
- The building of porches is useful for using air current. The best way to design porches is to plan it southward.
- The thoroughfares should be continued southward;
- To let air flows inside the building in hot seasons, the building of labyrinthine spaces should be avoided;
- Less resistant elements such as doors and windows should be small;
- Air should not be allowed to enter from seams of doors and windows;
- The design of doors and windows should be done with utmost care. The pressure of wind on buildings' front should be minimized;
- The design of shadow masks can prevent sun radiation through transparent windows into the house. The outer layer of buildings can be colored bright to block sun radiation absorption in building's walls.
- The selection of raw materials in traditional houses depended much on the environment and regional ecology. Materials such as mud and clay, stone and clay, and wood and clay are all non-resistant and are used most often in Gilan villages.

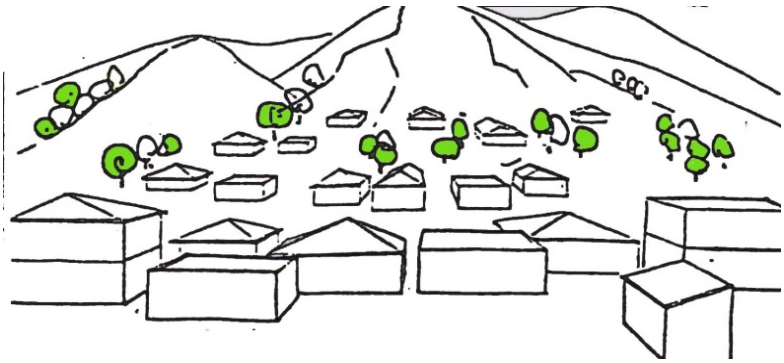


Figure 1. The lack of dispersal and spatial incoherence (Reorganization Plan of Rostamabad, 2014)

3. Roudbar housing before and after the earthquake

In an earthquake in Roudbar in 1990, according to the information given by Budget Planning Organization, more than 14000 people died. Almost 100000 houses were completely destroyed, and 200000 units were affected with constructional damages. Almost 400000 people became homeless. Most of the casualties were those living in buildings built with traditional materials such as stone, brick, clay, wood and mud. It should also be noted that buildings had been built with girders and concrete. Substandard materials, improper connections and incorrect implementation were the causes of such sever damages. Manjil was the most damaged city in that disaster. Ninety percent of the city's buildings, which were mostly single-floor and brick-made, were destroyed (Analytical et al., 1990).

Considering the severe damage in Roudbar and its small distance with Manjil, it can be considered as parallel to Manjil. It can be concluded that these cities were located on meizoseismal (the area of maximum damage in an earthquake). However, lack of a larger city with engineering structures has made it difficult to determine the central region since the destruction of village houses could not be merely a criterion for the determination of this region. Such structures can be easily ruined even if they are far located from the earthquake.

The way brick houses were destroyed in Manjil and Roudbar indicated the spectrum power of seismic energy at high frequencies, which was probable since these two cities were adjacent to the meizoseismal and the released energy was great (Analytical et al., 1990).

After Roudbar and Manjil earthquake, the residential pattern type was changed. For example, 2-floor buildings changed to single-floor, which was due to the fear among Roudbar people. In renovation stage after the earthquake, gender and age of Roudbar population changed, which consequently affected the architecture of the buildings. After the renovation, the residents started to expand their buildings. A central space was made in all buildings, which acted as living room as well as connecting other spaces of the buildings. Porches also lost popularity. The changes also redefined the borders and the habits of Roudbar residents. It should be noted that since living rooms were at the center and other rooms surrounded them, the airflow was blocked in the house and the moisture increased in the summer leading to an unpleasant condition for the citizens.

3.1 Roudbar buildings after the earthquake

Experienced engineers and architectures using strong durable materials built new buildings in Roudbar. The designs of new buildings are inspired by urban architecture.

Different types of buildings before and after the earthquake were:

- Buildings renovated before the earthquake, which were influenced by the ordinary change of cultural, social and architectural trends.
- Buildings that were innovated after the earthquake with or without the government's aids by the people. These buildings often easily fulfilled the needs of families and were in compliance with the cultural and social structure. However, sometimes they lacked proper technical requirements.
- During designing some buildings, people's opinions were not completely considered. In a majority of cases, due to the abundance of debris collection and the shortness of temporary accommodation, the movement of some villages was not logical. There was not conformity between the given lands and the people's needs(Sartipi, 2009).

4. Results

The most important feature of Roudbar is its urban structure. An overall look at the city shows that some points of the city are connected to each other through roads, and the buildings are located on small lands less steep than the others are.

Figure 2. Images of Roudbar urban structure (Source: Author)

Types of materials used in a building define the durability and strength of the building. A majority of buildings are those built with brick and iron. Some of buildings are also made out of steel.
Nowadays, buildings made by traditional materials (mud and clay, stone and mortar etc.) are less observed. The reason behind this is the weak strength of these materials against earthquake. Horizontal force against earthquake generates a strong force and thus destroys the vertical elements made with traditional materials.

4.1 A review of renovated buildings

The analysis of renovated buildings shows that the renovated buildings were not according to the life pattern of Roudbar citizens. We will elaborate on some cases of such discrepancies in the following.

- In new designed buildings, the life of citizens has been ignored, and urban life patterns have been more often taken as a model for building design. Occupations such as agriculture have been also ignored (Akramiand etal, 2008).
- The width of passages is proper. In building's passage walls, light-weighted materials should be used to achieve an appropriate implementation. In the renovation plan, passages are built in such way that each passage is connected to several other passages, and if one passage is blocked, only a small percentage of the plan is troubled.
- The renovated building units are in average adjacency. Due to low density of the buildings, the units will not face specific problems.

Many houses in the renovation plan are made out of iron (Bahreini et al., 2000).

4.2 Traditional housing

- The houses are in proper position with respect to sun radiation.
- Houses are built in accordance with the culture and life patterns of people.
- In traditional buildings, hierarchy is taken into consideration while in renovation; no attention is paid to this issue.
- The width of passages is not proper and it may lead to the blockage in earthquakes.
- Traditionally built passages are long and can not be multiply accessed. This can decrease the speed of help and relief distribution.
- Eaves and surpluses abound in traditional housing construction plans. These factors can be very dangerous during an earthquake occurrence.
- On the sides of traditional passages, the walls are full, which cause difficulty in earthquake especially with the existence of narrow width of the passages.
- Small doors and windows reduce damages caused by earthquakes (Bahreini et al., 2000).
- The construction system and the way materials were connected in Roudbar increased the damage in 1990 earthquake.
- The selection of construction techniques that were respectively in compliance with regional and national independence.
- The improvement of building units and environment compared with pre-earthquake conditions.
- The engineering system respected what people did as a value and esteemed phenomenon.

- The engineering system aimed at using past techniques. Therefore, any change had to conform to the existing facilities and conditions.
- The engineering system also aimed at the integration of building units. Any synthesis and movement without necessary technical reasons was doomed to failure (The Management et al., 2006).

4.3 Renovation policies and principles

Principles that are effective in securing buildings against earthquakes and possible damages are:

- Considering the earthquake safety principles;
- Considering issues related to entering, exiting and escaping to open space, yards and adjacent spaces;
- Avoid using materials and elements that block the exits.
- Increasing the number of exits (Figure 3. B)
- The possibility of escaping from windows in the case of emergency (Regulation 2800, earthquake)

4.4 Findings of the comparison between traditional and renovated buildings

After the analysis of the renovated and traditional buildings, five features of the renovated buildings were in contradiction with those of traditional houses that are listed as follows:

1. The expansion of units in a single floor
2. The expansion of units regardless of the climate and non-linear pattern
3. The removal of porches synthesized into the houses
4. The use of Zgali (wood and mud) in all parts of the building structures

After the detection of differences between the traditional and renovated buildings, five total influential factors were identified as follows:

1. The need for life spaces and changes in the residential patterns of the people

1. The improvement of problems derived from the lack of attention to climatic conditions in renovation and temporary accommodation stage.

2. Urban culture and the tendency of the people to change their own rural residential patterns

3. Changes in the people's life patterns including the removal of cattle, agriculture and the change, and taking to urban professions

4. The local carpenters' lack of knowledge about constructing two-floor buildings with Zgali (wood and mud).

5. Designing earthquake-resistant houses in Roudbar

It is necessary to search for a solution to design and build earthquake-resistant buildings. The goal of this section is to design buildings and form Roudbar housing patterns with respect to the people's life style, their current needs and resisting the earthquakes. An attempt is made to achieve an optimum solution.

5.1 Basic principles in designing earthquake-resistant buildings

Any design developed for building Roudbar houses should conform to the climate culture and life of the people, and it should also be expandable. Therefore, the following advices and procedures are suggested.

- The buildings should be in the direction of favorable winds.
- Native plants could be used to block the unpleasant winds.
- Semi-open spaces should be given to the buildings.
- The interior spaces should be flexible without violating designing principles.
- The direction of houses and the replacement of different building sections should be in accordance with the regional climatic conditions.
- The entry boundaries and the interior visibility of the houses should be taken into consideration.
- The materials used in building the houses should conform to the regional climate.
- Dominance in the buildings
- A direct access should be provided from the entry to the kitchen.
- Living rooms should be connected to open and semi-open spaces so that it could be easily expanded to these open spaces.
- Proper form, the choice of proper lands, the proper combination of lands, adjacencies etc. are the important factors in designing buildings.
- Entries and exits should be given the easy access to the adjacent open spaces.
- The use of elements, which lock the exits, should be avoided.
- Using more exits as an escaping way in emergencies
- Using windows as an emergency exit (unknow,1987; unknow, 2011)
- Avoiding the use of spaces which delays escape (such as steps etc.)

- In buildings with more than one floor, terraces and roofs can be used for sleeping in warm seasons of the year.
- Designing short escape routes for children and elders, and also providing emergency exit for bedrooms [8]

5.2 Effective design principles to reduce earthquake damage

The effective design principles to reduce earthquake damage are listed in the following:

- Use of indigenous materials with good thermal capacity
- The number of windows (minimum or maximum)
- The direction of windows
- Attention to dominance in housing design
- Considering semi-private and private spaces.
- Considering effective elements like porches (semi-open space)
- Attention to the vegetation in yards and open space (in Building Safety Regulations, 1987 and 2011)
- Complying to the allowed distance between buildings
- Less residential proximity of the building units
- Avoiding the proximity of yards with walls of other buildings
- Lack of proximity arc roof and appendages such as the volume of the adjacent yard

5.3 Damaging factors in Roudbar

The hazardous factors of Roudbar should be detected and hence reduced. With respect to this issue, a number of economic, social, and physical factors exist which are briefly listed in the following section:

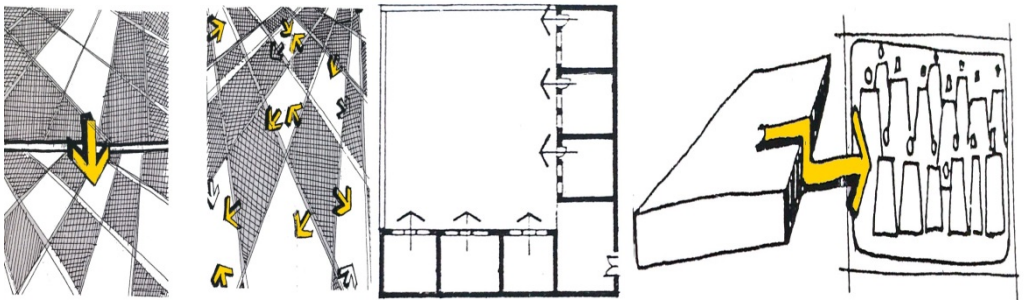
Density: the population density should be reduced in earthquake prone regions. The population should be properly and equally distributed in the city. Building density should also be controlled. Open spaces should be provided between different housing units leading to the reduction of density.

Access: walking, driving. The access of buildings to different passages should be easy (Figure 3- A).

The existence of service centers and their transmittance in the city;

The proper transmittance of open spaces among buildings and the provision of easy access and emergency aids;

Changing open spaces to several small-dispersed spaces (Figure 3- C).



A B C

Figure 3-A. The access of buildings to different passages should be made easy

Figure 3-B. Increasing the number of exits

Figure 3-C. Changing open spaces to several small dispersed spaces

6. Anti-seismic technologies

Anti-seismic technologies that will be discussed in this section include a rather wide range. Table 1 shows a few examples of new structural systems that are recently used in building industry with the goal of providing safety against earthquake. In what follows, Figures 4-9 show a view of these systems. After introducing the new systems, seismic isolator will be discussed.

Table 1. A few examples of new structural systems

System type	Performance	example	Impact
Horizontal construction	Transmitting a part of the force path, resistance	Horizontal Coil	Load gravity and horizontal forces

system	against earthquake lateral force		
Vertical construction system	Tolerating the forces by using pressure	Vertical structures such as beams, columns and shear walls	The retrofitting of vertical structures by one of three methods of shear wall, braced frame and moment frame. Each of the systems could bear load gravity
Braced Frames	Alternative for shear walls and moment frames	Typical materials of braced frames: wood and steel	Bracing increases the security of buildings
Horizontal Coil	Transmitting inertial force to lateral braces	Horizontal coil in terrace and ceiling	Resisting the horizontal inertial fore that is applied to diaphragms
Shear wall	The absorption of seismic force. Consistent building from the foundation to the highest ceiling diaphragm	Shear walls made of reinforced concrete	To oppose horizontal forces
Foundation		Strip foundations and individual Shallow foundation	Preventing any relative horizontal movement during an earthquake
Non-structural elements	Tolerating no additional seismic force on their mass	Covering panel, roof, glass and splitter blades, lifts, air conditioning equipment building materials	Applicable for the building
Non-structural elements	Hazardous during earthquake	Infill walls (non-load-bearing) Staircase	Structurally damaging
Secondary structural elements	Hazardous during earthquake	Windows, false ceilings Dry plaster panels	The time of earthquake, an unbraced false ceiling, moves like a pendulum
Seismic isolation	Increasing seismic security		Reducing the impact of earthquake forces
Plaster walls	Fire resistant Foundations that could be installed on wood Metal profiles and common walls, An integrated system with proper coverage of the seams of connections	Plaster-coated plates	Besides reducing the dead load of the building, it decreases the destructive effects of earthquakes preventing financial loss and casualties [9] Voice control, light-weight, sensible price, fast installation

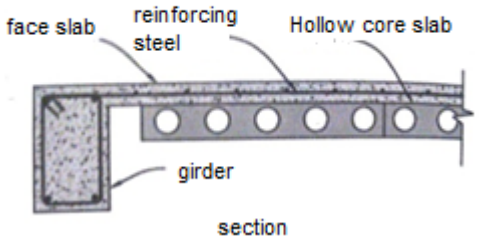


Figure 4. Wall connections and diaphragm (Golabchi,2010)

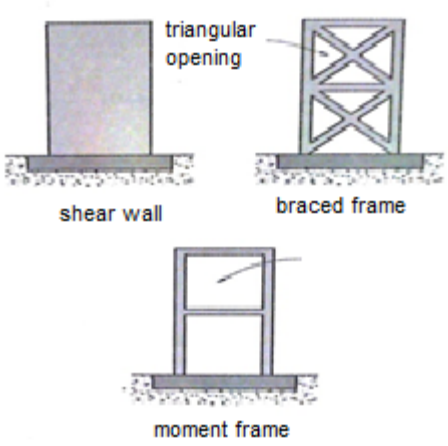


Figure 5. The performance of different frames (Golabchi,2010)

Figure 6. the details of implementing shear walls (source author)

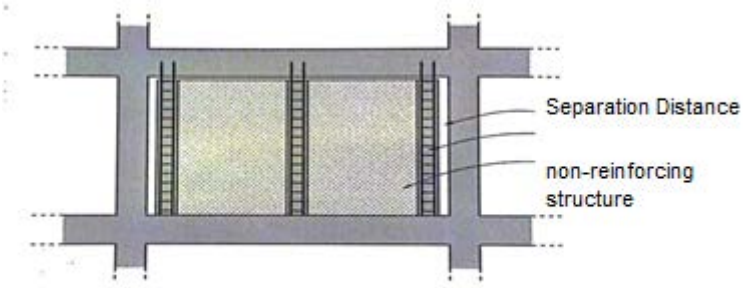


Figure 7. pores of non-load-bearing walls (Golabchi,2010)

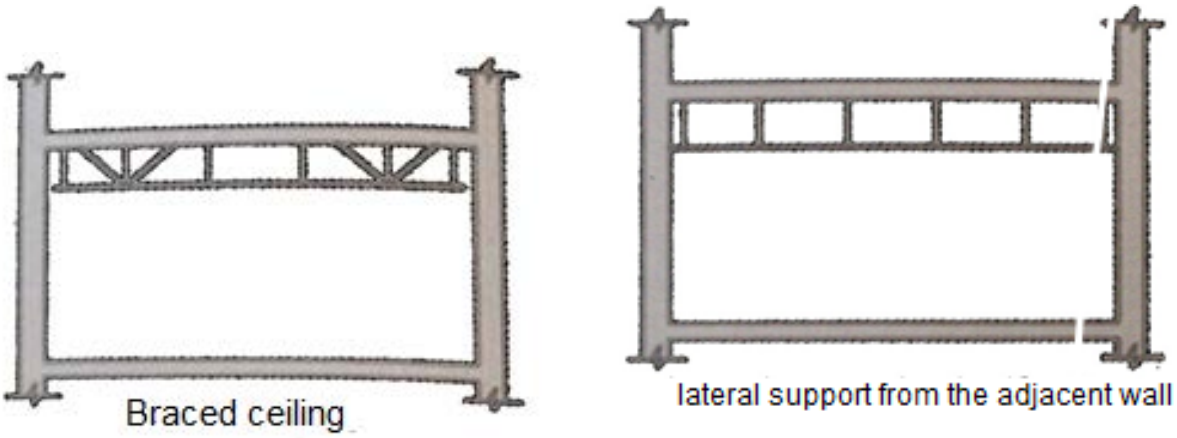


Figure 8. Non-structural elements of anti-seismic walls (Golabchi,2010)

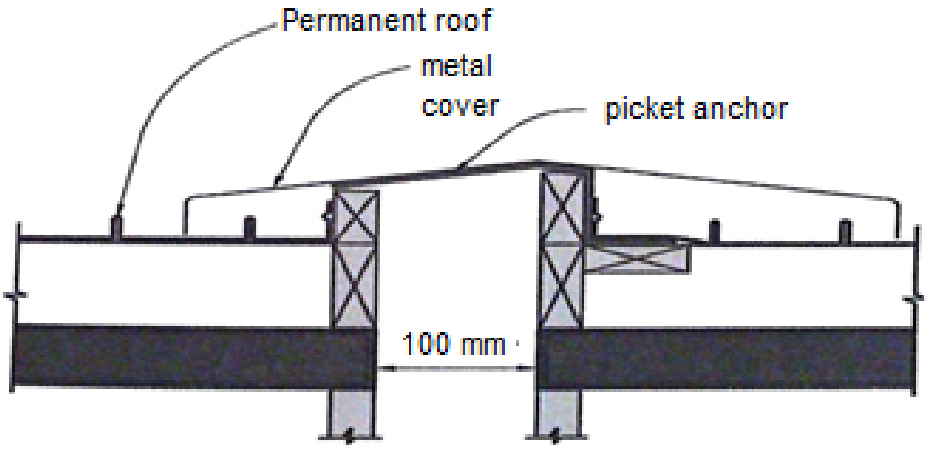


Figure 9. Separation distance source: (Golabchi,2010)

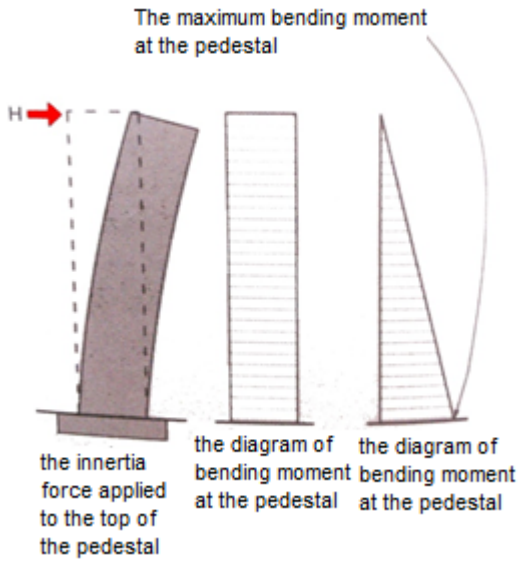


Figure 10. the condition of pedestal during an earthquake (Golabchi,2010)

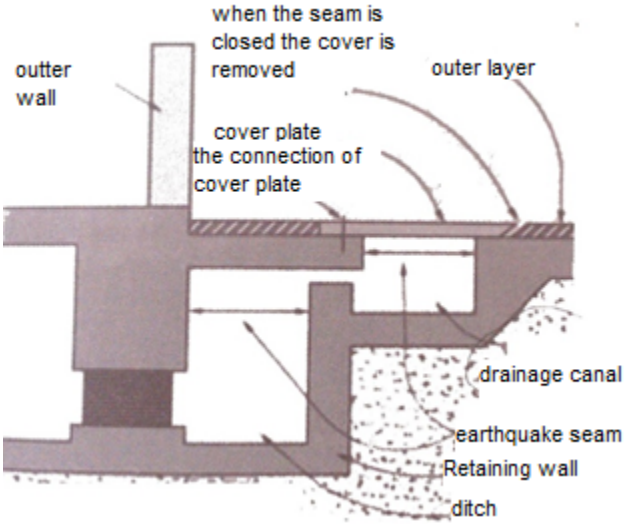


Figure 11. Possible level of seismic isolated buildings (Golabchi,2010)

7. proposal: using earthquake resistant systems in building Roudbar houses

Traditional building system of Roudbar is not capable of fulfilling the needs of the people thus newer systems should be used for this purpose. From a formalist point of view, the buildings are made with simple geometrical shapes (quadrangular and rectangular), and the building conforms to an acceptable level of order. The low height of the buildings (at most three floors) is a factor in reducing damage during an earthquake. The simplicity of the building form and its acceptable size has resulted in less expenses and troubles.

Given the great number of natural disasters, accidents, financial loss and casualties of earthquake in Roudbar (especially 1990 earthquake), more than ever, it is necessary to deliver research with the goal of minimizing damages using anti-seismic systems and native architectural procedures.

7.1 Site analysis

The site in question was located in Rostamabad in Roudbar with 57 hectares. In comparison with other areas, Rostamabad is more distant from the dangerous fault. We tried to choose a smooth ground and slightly steep. The main passages and streets are located in the north of site. The surrounding lands are mainly used to build houses, mosques and elementary schools.

Figure 12. The location of the site (Google Earth)

7.2 Designing Process

To have an optimum design, first we considered the population and started to make divisions. Then we defined the hierarchy of such divisions. We also determined the requirements of each division including important elements, population capacity, the radius of each distributive elements, and type and quantity of network. According to the results, local requirements are neighbor units, housing units, building block and building unit. Then the respective diagram is depicted (Figure 13 and 14).

According to anti-seismic architectural and urban disciplines, the relationship between the adjacent buildings and a collection of earthquake resistant buildings will be designed. In this design, we attempt to consider the diversity, direction of sun radiation and climatic conditions.

During designing the buildings, a few points were considered, which are listed as follows:

Considering the main features of Roudbar and its organic architecture;

Creation of plants;

Using native materials (wood); using such materials in steep roofs;

East-west direction of the buildings;

Using central plans as a pattern for designing plots;

Moisture present in substructures;

Considering exist and emergency escape routes;

Using anti-seismic materials;

Considering the safety if there are non-structural elements;

Considering the location of game space, congregation, pedagogy and health care centers in the site.

7.2.1 Designing stages

1. The analysis of structural information including symmetry and static forms avoids the increase of block length, relational diagram of spaces, etc.
2. The analysis of the site access spaces and routes (Entries and exits should provide the easy access to the adjacent open spaces)
3. Considering the adjacency, boundaries and shading in the blocks
4. Considering the housing types and plans of Rostamabad-Roudbar (the proposal should include boundaries and maintain the life patterns of the residents with an easy access to surrounding open spaces. Therefore, designing of the plans should include easy access ways to the staircases and terraces. Other notable features were the provision of interior invisibility and sun radiation. Northern and southern sunrays were taken as the proper radiation).
5. Considering the native architecture of Roudbar

7.3 Reasons behind choosing lands with different sizes during divisions

- Freedom of different social strata to choose their favorite building according to the different sizes of houses
- Easy access to different elements
- Proper transmittance of the people in the city and avoiding crowd congestion in one location
- The necessity of creating diversity

Figure 13. using native materials; considering the location of health and recreational centers; using the open space and considering correct size of passages used for emergency exit (source author)

Figure 14. the location of entries to the buildings (source author)

8. Conclusion and suggestions

After designing, given the condition previously stated in this article as well as the existing construction principles (structure method, and type and strength of required materials), technical guidelines of the buildings were put forward which are stated as following:

- Using reinforced concrete and steel structure which are more resistant to earthquake
- Wooden structures; due to their simple connections, light weight and the least danger (in some parts of the buildings without any structural use- merely for maintaining the beauty of the buildings)
- Suggested for opposing lateral forces of moment space frame
- Using seismic isolation and considering separation distance between two blocks
- Using non-structural elements and securing them, such as securing the windows and using braced false ceilings.
- Providing open spaces in front of each block to make temporary accommodation
- Isolating the blocks from the main passages to prevent destruction and debris fall
- Using dry plaster panels in interior spaces due to their weight and fire-resistance
- Securing the building foundation using strip (since the building is not that high)- strengthening the pedestals
- According to the form of blocks, it was concluded that the best form can be used in Roudbar climatic condition is rectangular since it is in east-west direction which is in accordance with the regional climate.
- To gain the best result, blocks were dispersed with compact space.

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