Architectural Design of Irregular Buildings in Turkey

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According to experiences from past earthquakes of Turkey, collapses or damages of buildings were directly or indirectly related to the architectural design. Since the irregularity of a building is one of the main causes of heavy damages, there has been a title called “Irregular Buildings” in Turkish earthquake code since 1998. Under this title, some types of buildings are defined as irregular, and architects and engineers are advised to avoid these kinds of irregular configuration designs. In this study, reasons that would lead to irregularities in buildings are explained with figures, and precautions should be taken to avoid from these irregularities are presented.

**Index Terms**— Code Standards, Construction, Earthquakes

**I. INTRODUCTION**

Humankind has faced challenges of nature (earthquake, flood, hurricane etc.) many times in history, and most suffering losses have been resulted from earthquakes. Like most of the countries located on active fault line, Turkey has faced with destructive earthquakes. Besides destroying the socio-economic substructure earthquakes have caused physiological effects on human lives lasting for years and these effects prevent development of civilizations.

Turkey is in the third place in the world in terms of relative risk of earthquakes. In the last 58 years, 58,202 people were killed, 122,096 were injured due to earthquakes in Turkey. Moreover nearly 411,465 buildings were collapsed or heavily damaged. In brief, almost 1003 people die and 7,094 buildings collapse per year in Turkey [1]. The reasons behind the poor seismic performance of buildings in Turkey are several, and Karaesmen [2] makes a general classification of these factors as follows:

- The universal lack of knowledge in the sciences related with earthquake engineering.
- The indifference of the public and some members of the engineering and architecture community towards the earthquake threat.
- The ignorance of geological and geo-technical conditions in the choice of location for urban settlements in countries with fast and undisciplined city growth.
- The structural defects in masonry buildings due to the general lack of understanding of this structural system and poor construction quality.
- The structural defects in reinforced concrete buildings, which are built on every scale and everywhere from the remote villages to large urban settlements.

According to the observations after the past earthquakes, damages are mostly due to architectural design. At this point earthquake codes play a crucial role to lead the designer. In Turkey there is an earthquake code that is used to determine the behavior and the earthquake resistance of the buildings. In this study, damages of past earthquakes are investigated in the scope of Turkish Earthquake Code.

**II. PAST EARTHQUAKES IN TURKEY**

Earthquakes occur as a result of breaking of faults which are formed due to compressing of plates on earth’s crust each other. There are a lot of broken faults on Anatolian plate on which Turkey is situated. Turkey, which is squeezed by the movement of Eurasia, Africa and Arabian plates, has major active fault zones such as North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ) (Fig.1).

The North Anatolian Fault (NAF) with a length of 1500 km is one of the most active and largest strike-slip faults in the world, which causes destructive earthquakes by slipping at an average rate of 20–25 mm/yr. NAF is the most active component in the tectonic evolution of Anatolia. Within this century more than 25 earthquakes have occurred along the fault ruptured over 900 km of its length [4].

As it was seen from the Table 1, catastrophic consequences were observed after recent severe earthquakes in Turkey leading thousands of casualties.
dedicated to architectural design and it is most important that we have to take to protect human life. There are various architectural audience is the “Definition of Irregular Buildings”. Irregular buildings are defined in this part as “buildings whose design and construction should be avoided because of their unfavorable seismic behavior”. In this section, various types of geometric arrangements and structural behavior patterns in plans and elevations of buildings are identified as irregularities in terms of seismic design (Fig. 2).

The code’s main advice for the designers is to avoid these irregularities altogether if possible. However, the code also defines the structural calculation assumptions and precautions to be taken in case such irregularities exist in the building. The authors believe that an adequate verbal definition supported by the suitable graphic material will be more meaningful for an architect than a set of formulas. In the following part, irregularities are shown schematically.

### III. BASIC ARCHITECTURAL DESIGN PRINCIPLES OF TURKISH EARTHQUAKE CODE

Earthquake codes are legal documents, the aim of which is to determine the minimum conditions for the production of seismically safe and functional buildings. The object of these rules is to prevent architects and engineers from making critical design mistakes that will endanger the life of their buildings’ occupants.

The first seismic design codes for buildings was published in 1940 in Turkey after the great Erzincan Earthquake in 1939. Because of the earthquake 32,962 people were killed and 116,720 buildings collapsed or were damaged. Thus, the government of that time felt the need for a legal enactment. On 17th January 1940, Law No.3773 “Law Related to Aids for Erzincan Earthquake Area” was decreed [5]. This law was the first disaster law of the republic but it was basically about post-event response. In Turkey, seismic codes have changed as a result of big destructive earthquakes. However, the effects of architectural design on the damage caused by earthquakes came up as an issue in the code of 1968.

Turkish Earthquake Code focuses on the earthquake resistant design of R/C, steel and masonry structural systems, and also strengthening of existing buildings. At the beginning of this code it is mentioned about earthquake resistant buildings under the chapter of “Analysis Requirements for Earthquake Resistant Buildings”. This chapter is generally dedicated to architectural design and it is most important section for architects.

<table>
<thead>
<tr>
<th>Year</th>
<th>Place of Occurrence</th>
<th>Magnitude</th>
<th>Loss of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>Hakkâri</td>
<td>7.2</td>
<td>2514</td>
</tr>
<tr>
<td>1939</td>
<td>Erzincan</td>
<td>7.9</td>
<td>32962</td>
</tr>
<tr>
<td>1944</td>
<td>Bolu-Gerde</td>
<td>7.2</td>
<td>3959</td>
</tr>
<tr>
<td>1953</td>
<td>Yenice, Gönen</td>
<td>7.4</td>
<td>265</td>
</tr>
<tr>
<td>1957</td>
<td>Fethiye</td>
<td>7.1</td>
<td>67</td>
</tr>
<tr>
<td>1966</td>
<td>Varto</td>
<td>6.9</td>
<td>2394</td>
</tr>
<tr>
<td>1970</td>
<td>Gediz</td>
<td>7.2</td>
<td>1086</td>
</tr>
<tr>
<td>1975</td>
<td>Lice</td>
<td>6.9</td>
<td>2385</td>
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<tr>
<td>1976</td>
<td>Çaldıran, Muradiye</td>
<td>7.2</td>
<td>3840</td>
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<tr>
<td>1992</td>
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<td>6.8</td>
<td>653</td>
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<tr>
<td>1995</td>
<td>Dinar</td>
<td>6.3</td>
<td>94</td>
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<tr>
<td>1998</td>
<td>Ceyhan, Adana</td>
<td>5.9</td>
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<tr>
<td>1999</td>
<td>Kocaeli</td>
<td>7.4</td>
<td>17408</td>
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<td>1999</td>
<td>Düzce, Kaynaşlî İzmit</td>
<td>7.2</td>
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<td>2002</td>
<td>Sultandağ, Çay</td>
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<td>2003</td>
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<td>2005</td>
<td>Seferihisar-İzmir</td>
<td>5.9</td>
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<tr>
<td>2005</td>
<td>Hakkâri</td>
<td>5.4</td>
<td>3</td>
</tr>
<tr>
<td>2010</td>
<td>Başyurt - Elâzığ</td>
<td>6.0</td>
<td>42</td>
</tr>
<tr>
<td>2011</td>
<td>Van</td>
<td>7.2</td>
<td>604</td>
</tr>
</tbody>
</table>

The main section of the part that addresses the most to the architectural design is the “Definition of Irregular Buildings”. Irregular buildings are defined in this part as “buildings whose design and construction should be avoided because of their unfavorable seismic behavior”. In this section, various types of geometric arrangements and structural behavior patterns in plans and elevations of buildings are identified as irregularities in terms of seismic design (Fig. 2).

![Fig. 2. Irregularities According to 2007 Turkish Earthquake Code [6]](image-url)
considered as the center of vertical elements of the structural system. The center of rigidity of a building should coincide with the center of mass. When the center of a building mass does not coincide with the center of rigidity, torsion and stress concentrations occur in the building when it is subjected to seismic loads (Fig.3). Eccentricity between the centers makes the building rotate due to seismic forces.

The Turkish earthquake code mentions the torsion eccentricity as follows: "The case in which the Torsion Irregularity Factor ($\eta_{bi}$), which is defined as the ratio of the maximum story drift ($\Delta_{i}^{\text{max}}$) to the average story drift ($\Delta_{i}^{\text{ort}}$) at any story, exceeds 1.2 in any one of the two perpendicular earthquake directions".

$$\eta_{bi} = \frac{\Delta_{i}^{\text{max}}}{\Delta_{i}^{\text{ort}}} > 1.2 \quad (1)$$

In order to avoid torsional deformation (Fig.4), it is desirable to have symmetry both in the building configuration and structure. The vertical structural elements of the lateral resistive system should be arranged in order to approach the centers of mass and rigidity to each other and in order to produce high resistance to torsional effects on the building [7, 8].

A. 2. Floor Discontinuities

Diaphragms, which transfer forces between vertical structural elements, are needed to connect them and to make them resist to the seismic forces as one body. Architectural Institute of Japan (1970) states that they behave like columns when the lateral forces are considered as the horizontal forces [9].

Architectural requirements such as necessities for vertical traffic within a multistory building, visual integration of stories, and other purposes result in a variety of diaphragm penetrations such as staircases, elevators, atriums, duct shafts, skylights, and so on. The size, location, and even shape of the penetrations are critical to the effectiveness of the diaphragm. Diaphragm penetration and their geometrical irregularities weaken the load carrying capacity and the lateral rigidity leading to torsion and stress concentration.

The Turkish earthquake code describes floor discontinuity as follows: “The cases (Fig.5). in which:
1. The total area of the openings ($A_b$) including those of stairs and elevator shafts exceeds 1/3 of the gross floor area ($A$) of any story.
2. Local floor openings making the transfer of seismic loads to the vertical structural members difficult or even impossible.
3. Abrupt reductions made in the in-plane stiffness and strength of the floors.”

$$A_b = A_{b1} + A_{b2}$$

This irregularity is not strictly forbidden in code but it is obligatory to show with calculations that the transformation of lateral loads to the vertical elements is safely achieved.

If the relative size of the penetration in a diaphragm is a reasonable one, placement of reinforcement for the edges and corners of the opening and adequate diaphragm width at the opening may be sufficient for the integrity of the continuous diaphragm. However, if the penetration in a diaphragm is quite large, the diaphragm should be separated into small and regular parts for maintaining the continuity of the whole diaphragm [7].

A. 3. Projections in Plan

Architectural form determines the strength of the building because the building behavior depends on this form. If plan of the building is not consisted of simple and regular geometries there will be big stresses especially at corners of the building during an earthquake.

The Turkish earthquake code describes the projections in plan irregularity as follows: “The cases where projections beyond the re-entrant corners in both of the two principal directions in plan exceed the total plan dimensions of the
building by more than 20% in the respective dimensions (Fig.6)."

Seismic behavior is related with the mass of the building and every molecule creates loads of inertia proportional with the earthquake energy. If a structure consists of too many building blocks with different natural periods and lateral rigidities, these blocks will move individually during an earthquake (Fig.7).

It is not always possible or architecturally desirable to design a building having a symmetrical plan. In fact, most of the time, due to the requirements of the building program, functional and aesthetical concerns the architects decide to create more complex building forms. Even so, if the projections are absolutely necessary, the structural engineers should be consulted for additional reinforcements. If possible, the structure should be divided into several sections with structural joints (Fig. 8) [11].

B. Seismic design faults in elevation

B. 1. Weak Storey and Soft Storey

Weak storey is related with the total cross section areas of columns and shear walls. Weak storey configuration describes structure where one storey of a building is more flexible and/or weaker than the one above it from the perspective of seismic forces. On the other hand soft storey is a ratio about the relative displacement of the building. If there is a soft storey in a building, total displacement of building that should be in upper floor, occurs only in one floor where soft storey is. These two irregularities are similar to each other (Fig. 9).

If there is a soft or weak storey in a building, more displacements occur in one floor where it is. This unexpected displacement in these wrong applications causes the collapse of the whole building (Fig. 10).

Ambrose and Vergun stated that if relatively open ground floor is necessary there are some possible solutions to reduce soft and weak story effects [7]:
1. Bracing some of the open bays. If designed adequately for the forces, the braced frame (truss) should have a class of stiffness closer to a rigid shear wall, which is the usual upper structure in these situations. However, the soft or weak story effect can also occur in rigid frames, where the “soft” story is simply significantly less stiff.
2. Keeping the building plan periphery open, while providing a rigidly braced interior.
3. Increasing the number and/or stiffness of the ground-floor columns for an all rigid frame structure.
4. Using tapered or arched forms for the ground-floor columns to increase their stiffness.
5. Developing a rigid first story as upward extension of a heavy foundation structure.

B. 2. Discontinuity of Vertical Structural Elements

Forces applied to buildings must travel from their points of origin through the whole system and into the ground, in the design for lateral loads. The force paths must be complete. Where there are interruptions in the normal flow of the forces,
problems occur. In a multi-story building, columns and shear walls must be stacked on top of each other. If a column is removed in a lower story, a major problem is created, requiring the use of a heavy transfer girder or other device to deal with the discontinuity (Figure 11) [7].

The Turkish earthquake code describes Discontinuity of Vertical Structural Elements as follows: “The cases where vertical structural elements (columns or structural walls) are removed at some stories and supported by beams or gusseted columns underneath, or the structural walls of upper stories are supported by columns or beams underneath”

Although these items of this irregularity were not forbidden in 1998 earthquake code, structural elements like columns or shear-walls must be continuous through the entire building height according to 2007 earthquake code. Discontinuity of the structural elements of the buildings may make a storey weak or create torsional effects.

C. Common seismic design faults by configuration of structural elements

It is an important subject that structural elements should be well placed and sized besides their sufficiency in numbers.

Poor decisions may increase the stresses in structural elements and cause damages. In this section two major configurations mistake that architects should be aware of are mentioned.

C. 1. Short columns

If both long and short columns exist in the same story, instead of distributing the loads equally among all of the columns, the columns experience different shear forces due to their height differences (Fig. 12). The lateral loads are passed from the longer and more flexible columns to the shorter and the stiffer ones, and concentrated on the short columns. As short columns are not designed for overloading, failure occurs along the line of short columns before the longer and more flexible ones, which simply deflect without cracking [13]

There exist solutions in order to avoid short column formation. These are:

- It is necessary to keep the heights of columns around a facade approximately equal. If the unequal heights of the columns are needed, horizontal bracing can be inverted to equalize the stiffness of the columns of varying height. Another solution is to obtain the visual effect of unequal heights of the columns with the help of non-structural architectural elements where the column heights remain same, actually [14].
- Short columns may turn into a shear wall
- Non-structural walls should be isolated from columns by developing architectural details. Placement of elastic or flexible material in between the infill walls and the structural members is necessary to obtain independent displacement of the frames system from the infill walls [15].
- As an engineering attribution, proper arrangement of reinforcing for short column solves the problem.

An architect should be aware of the reasons of the short column formation. Therefore, coordination between the architect and the structural engineer is important and is needed to avoid the problem in the architectural design process [15].

C. 2. Strong beam–weak column configuration

In case of an earthquake, the structure must be able to absorb the maximum energy by ductile deformations in column–beam connections, while the lateral stability of the building is preserved. If the beams of a building are more rigid than the columns, ductile deformations will occur at the top and bottom ends of the columns. Excessive displacements will cause additional moments and the columns will easily loose their lateral stability. Since the greatest earthquake forces occur at these columns, they will collapse first, probably causing the destruction of the entire building (Fig. 13).
If the columns are more rigid than the beams, ductile deformations will occur at the ends of the beams. Beams can absorb a lot of energy by ductile deformations without an important loss in the load carrying capacity. In this system, all the beam–column connections in the building have to fail before the collapse of the ground floor columns. Architects should know that strong column–weak beam design is not only advisable but also obligatory according to Codes.

**V. CONCLUSION**

Architects who form man made environment should combine structure and esthetics effectively. Especially for countries on very active seismic zones, it is architects and engineers’ responsibility to secure human lives. However architects leave all the responsibilities for earthquake safety to engineers. By the past earthquakes, it was understood that there was a strong relationship between architectural design and building resistance. Unfortunately there are too many casualties as a result of not being able to connect this relation well. To prevent these casualties, architects should design the structural system correctly and understand the dynamic behavior. To do that, the seismic codes which are important keys should be used actively when designing structures.

The most significant part of earthquake code for architects is “irregular buildings”. In this part, designing regular and symmetric buildings are advised to architects and engineers. Architects should know that regular and symmetrical buildings are stronger against earthquake forces, and irregular buildings have weak parts that may not resist earthquakes. Thus, these weak parts may cause damages even collapse of buildings. It should be noted that because the earthquake code is not prepared with an architect-friendly approach, especially the irregularity types created by geometric arrangements such as projections in mass and gallery openings are widely misunderstood and often undeservedly objected by architects. The earthquake code does not forbid the existence of such architectural elements but simply calls for attention to the consequences of using these elements in terms of the seismic behavior of the building.

In conclusion, earthquakes will not affect human’s lives negatively as a result of buildings designed and constructed according to earthquake-resistant design principles. For preventing negative effects of earthquakes, following topics must be taken into consideration immediately.

- Basis of earthquake codes must be taken in architecture students’ undergraduate program.
- Existing buildings must be reinforced and repaired according to the regulations given in earthquake codes.
- During the construction period, the new structures must be inspected attentively to be adapted to the earthquake code.

As a further inspection, the success of education of earthquake resistant structure design should be questioned and to evaluate and improve, a common commission should be organized.

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