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Investigation of Structural Irregularities in Malatya Province After the February 6 Kahramanmaraş Earthquakes in Turkey

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ABSTRACT

Turkey is located on a seismically active region and expose to various earthquakes frequently that cause many lots of life and property. Turkey is situated on Anatolian Peninsula on the Alp Himalayan earthquake belt that is seismically active region in the world. As a result of the 7.7 and 7.6 magnitude earthquakes that took place in Kahramanmaraş on February 6, 2023, buildings were seriously destroyed in 11 provinces in Turkey. In the examinations carried out in the destruction areas after the earthquake, it was observed that there were structural irregularities in the buildings and that most of the buildings with these structural irregularities collapsed, while those that remained standing received moderate or severe damage. In this study, the reasons for the collapse of buildings in Malatya, one of the provinces most affected by the Kahramanmaraş earthquakes in Turkey, were examined through structural irregularities. The purpose of this research is to reveal significant factors which should be taken into consideration on the architectural design stage by investigating destroyed and heavily damaged buildings. It was obtained that the significant factors causing destruction or affecting earthquake performance of structures are: building geometry, structural configuration, inadequacy in the cross sections of structural members, heavy overhangs, rigidity and strength differences between floors, short columns, pounding effect. In the examination, it was determined that soft floors and torsional irregularities play an important role in building demolitions, since most buildings are not designed appropriately for the ground on which they are located.

Keywords: earthquake, structural irregularity, building damage.

1.INTRODUCTION

Turkey is situated in a seismically active region and suffers from earthquakes at frequent intervals, which cause considerable loss of life and property, and has negative impacts on the national economy (Inan, 2011). In Turkey, 11 provinces were affected by the 7.7 and 7.6 magnitude earthquakes that occurred in Pazarcık-Kahramanmaraş at 04.17 and Elbistan-Kahramanmaraş at 13.24 on February 6, 2023. Kahramanmaraş-centered earthquakes earthquakes were described as the disaster of the century, as they caused the most loss of life and destruction in Turkey in the last century, affected the largest area, caused the collapse of the largest number of buildings and caused the greatest economic loss and nd more than 50000 people lost their life. These provinces are Kahramanmaraş, Malatya, Hatay, Osmaniye, Adıyaman, Diyarbakır, Şanlıurfa, Kilis, Adana, Gaziantep, Elazığ. Earthquakes affected millions of people. Turkish Statistical Institute (TUIK). According to data, the registered population for 2022 in 11 provinces where the earthquake was effective will be 10 989 944 people has been detected. On February 6, 2023 the second earthquake, which occurred at 13.24 with a magnitude of 7.6 and centered in Elbistan (Kahramanmaraş), caused serious building destruction and loss of life in Malatya province. In Malatya, one of the provinces most affected by the earthquakes centered in Kahramanmaraş, according to the statement made by the Malatya governorship, 5000 buildings were directly destroyed by the earthquake and 36500 buildings were seriously damaged. Accordingly, it is too significant to design earthquake resistant buildings in order to defend the structures against significant earthquake loads. Architectural design decisions have a significant effect on earthquake behaviour of structure that influences the seismic performance of the building due to the particularly building and structural system configuration issues. According to Erman (2002), earthquake resistant architectural principles are not the provisions that could be inserted by the structural engineer after the completion of architectural design. They should be applied to the project during the architectural design phase.

In literature, the causes of damage after any earthquake have been examined by many researchers focusing on different points (Koç, 2016; Caglar et. al., 2020; İlerisoy 2019;Doğan et al., 2021; Korkmaz, 2015;.Özkan et. al., 2023; Aytis, 2023;İnan Günaydın, 2023, Kırıcı and Soyluk, 2024; Tozlu and Gürsoy, 2024; Coşkun et al., 2024; Arslan et al., 2024).

This study examines the main structural irregularities that cause destroying in buildings or taking heavily damage in Malatya province. The significant architectural defects are revealed by examining the collapsed and heavily damaged buildings in Malatya province. Structural irregularities observed in damaged buildings will be explained in detail.

2.STRUCTURAL IRREGULARITIES IN TURKISH BUILDING EARTHQUAKE CODE (TBEC)

In the Turkish Building Earthquake Code (TBEC), irregular buildings are described as buildings whose design and construction should be avoided due to their poor earthquake behavior. Structural irregularities are grouped under two headings in the Turkish Building Earthquake Code (TBEC) as irregularities in plan and irregularities in vertical direction. Structural irregularities in plan are torsional irregularity denoted as A1, floor discontinuities denoted as A2, projections in plan denoted as A3. Irregularities in vertical direction are weak storey denoted as B1, soft storey denoted as B2, discontinuity of structural elements denoted as B3. Apart from the described structural irregularities in the TBEC, short column effect, weak column-strong beam irregularity, seismic pounding effects, soil type related damages and material-related damages are commonly observed in buildings after the Kahramanmaraş earthquakes in Turkey. These irregularities are coded from C1 to C5, respectively adapted from the study of İnan and Korkmaz. (İnan and Korkmaz, 2011). Irregularities in plan and vertical direction are described in Table 1 and 2, respectively. Moreover, most commonly encountered irregularities in buildings after the Kahramanmaraş earthquakes except defined in the TEBC are entitled as other irregularities (Table 3).

Table 1: Irregularities in Plan (TBEC)

A1) Torsional Irregularity:
The case where Torsional Irregularity Factor ηbi which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum storey drift at any storey to the average storey drift at the same storey in the same direction, is greater than 1.2 [ηbi = (ηi)max / η i)ort > 1.2]
A2) Floor Discontinuities:
In any floor; I. The case where the total area of the openings including those of stairs and elevator shafts exceeds 1/3 of the gross floor area, II. The cases where local floor openings make it difficult the safe transfer of seismic loads to vertical structural elements, III. The cases of abrupt reductions in the in-plane stiffness and strength of floors.
A3) Projections in Plan:
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 in the respective directions by more than 20%.

Table 2: Irregularities on Vertical direction (TBEC)

B1 – Interstorey Strength Irregularity (Weak Storey) :
In reinforced concrete buildings, the case where in each of the orthogonal earthquake directions, Strength Irregularity Factor η_{ci}, which is defined as the ratio of the effective shear area of any storey to the effective shear area of the storey immediately above, is less than 0.80. $[\eta_{ci} = (\Sigma A_e)_i / (\Sigma A_e)_{i+1} < 0.80]$ Definition of effective shear area in any storey : $\Sigma A_e = \Sigma A_w + \Sigma A_g + 0.15\ \Sigma A_k$ ΣA_w sum of shear wall areas at any storey in line with earthquake direction ΣA_g sum of shear wall areas at any storey in line with earthquake direction ΣA_k sum of infill wall areas at any storey in line with earthquake direction
B2 – Interstorey Stiffness Irregularity (Soft Storey) :
The case where in each of the two orthogonal earthquake directions, Stiffness Irregularity Factor η_{ki}, which is defined as the ratio of the average storey drift at any storey to the average storey drift at the storey immediately above or below, is greater than 2.0. $[\eta_{ki} = (\Delta_i/h_i)_{ort} / (\Delta_{i+1}/h_{i+1})_{ort} > 2.0$ or $\eta_{ki} = (\Delta_i /h_i)_{ort} / (\Delta_{i-1}/h_{i-1})_{ort} > 2.0]$
B3 - Discontinuity of Vertical Structural Elements :
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.

Table 3: Other Irregularities

Other irregularities
C1) Short column effect C2) Weak column-strong beam irregularity C3) Seismic pounding effects, C4) Soil type related damages C5) Material-related damages

3.EARTHQUAKE DAMAGES IN MALATYA PROVINCE

3.1.Seismicity Of The Region

From the year 1900 to the Kahramanmaraş earthquakes of 06.02.2023, There were 224 earthquakes of M ≥ 4.0 in the region, the largest of which was 6.8 magnitude. The Eastern Anatolian Fault went through a seismically active period, especially in the 19th century. It created a series of earthquakes that starting with the 1789 Palu earthquake, continuing with earthquakes in 1822, 1866, 1872, 1874, 1875, 1893 and completed finally with the 1905 Malatya earthquake at the beginning of the last century. Although it seems to have entered a relatively calmer period after this earthquake until today, the 22 May 1971 Bingöl (Ms: 6.8), 5 May 1986 (Ms: 5.8) and 6 May 1986 (Ms: 5.6) Doğanşehir earthquakes were intermediate earthquakes generated by the Eastern Anatolian Fault in the last century. A total of 13 earthquakes (Ms > 5.0) that caused damage on the Eastern Anatolian Fault occurred even during this period, when the North Anatolian Fault had no earthquakes larger than 7 in the 20th century and was quieter in terms of producing large earthquakes compared to the 19th century. However, none of these were larger than Ms: 6.8. On the Eastern Anatolian Fault, which entered a more active period in the 2000s, respectively; 01.05.2003 Bingöl (Mw: 6.3), 14.03.2005 Karlıova (Bingöl) (Mw: 5.8), 21.02.2007 Doğanyol (Malatya) (Mw: 5.7), 08.03.2010 Kovancılar (Elazığ) (Mw: 6.1), 24.01.2020 Sivrice (Elazığ) (Mw: 6.8), 14.06.2020 Karlıova (Bingöl) (Mw: 5.7) damaging earthquakes have occurred (Fig.1). After the 6 February Earthquakes, many aftershocks with different magnitudes occurred in the region (Fig. 2).

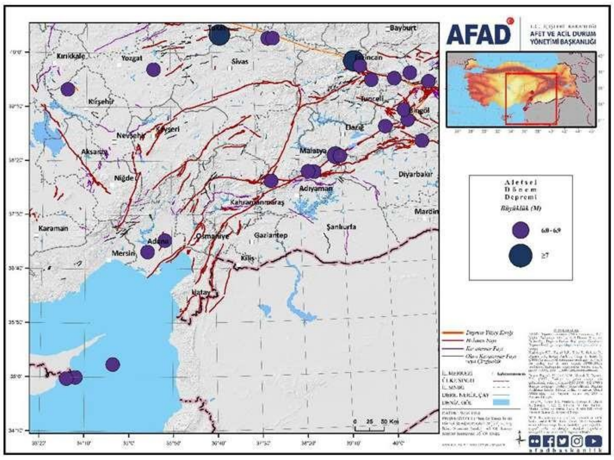

Figure 1: Earthquakes greater than magnitude 6 occurred in the region where the Kahramanmaraş earthquake occurred from the 1900s to February 6, 2023(AFAD,2023)

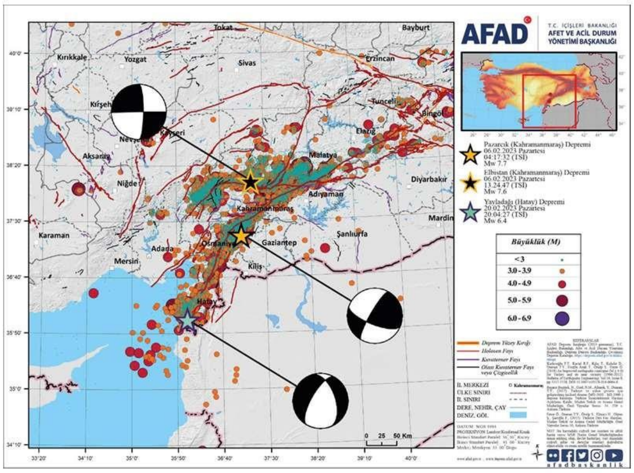

Figure 2: Aftershocks after the February 6 Kahramanmaraş earthquakes between 6 February 2023 and 6 May 2023 (AFAD, 2023)

3.2.Structural Damages In Malatya After Kahramanmaraş Earthquakes

3.2.1.Torsional Irregularity (A1)

Torsional irregularity, which causes the most damage in all earthquakes in Turkey, manifested itself in the last earthquake of February 6, 2023. Many buildings in Malatya collapsed due to torsional irregularity. Various factors cause torsional irregularity in buildings. The most significant ones are irregularity in plan and structural discontinuities, complex building forms, insufficient or non-existent earthquake joints, insufficiency of shear walls, location of rigid cores, creating rigid and flexible regions in the structure, rigidity not being distributed homogeneously, large overhangs, pounding effects, strength differences between floors, number of floors and poor soil type. The building in Fig. 3 was severely damaged due to torsion caused by the adjacent buildings and heavy console.

Figure 3: Torsional irregularity damages in Malatya

3.2.2.Floor Discontinuity (A2)

The floor discontinuity is described in the TEBC as the case where the total area of the openings including those of stairs and elevator shafts exceeds 1/3 of the gross floor area or the cases where local floor openings make it difficult the safe transfer of seismic loads to vertical structural elements and or the cases of abrupt reductions in the in-plane stiffness and strength of floors. Floor discontinuity caused less damage than other irregularities, especially when heavily damaged or collapsed buildings were examined. The building in Fig. 4 was severely damaged due to the distribution of structural elements between floors and floor discontinuity due to the local floor openings that make it difficult the safe transfer of seismic loads to vertical structural elements.

Figure 4: Floor discontinuity damages in Malatya

3.2.3.Projections in Plan (A3)

The projection irregularity is defined in the TBEC as 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 in the respective directions by more than 20%. Open and closed heavy cantilevered buildings caused serious destruction after the Kahramanmaraş earthquakes in Malatya. These type of cantilevers creates projection irregularity in that floor and cause various irregularity such as torsional irregularity, pounding irregularity, stiffness differences between floors, etc. The buildings in Fig. 5 were severely damaged due to the overhangs and projection irregularity.

Figure 5: Projection damages in Malatya

3.2.4.Weak Storey (B1)

The weak storey irregularity is defined in the TBEC that in reinforced concrete buildings, the case where in each of the orthogonal earthquake directions, Strength Irregularity Factor ηci, which is defined as the ratio of the effective shear area of any storey to the effective shear area of the storey immediately above, is less than 0.80. If the ratio is between 0.8 and 0.6, there exists weak storey irregularity in structure. But, if it is less than 0.6, the structure must be redesigned until appropriate range of values are gained. This irregularity is related on vertical configuration issue in which there is a major reduction in strength between storeys. Although it is so dangerous when it occurs at ground storey due to the greatest load accumulation at this storey, it can be observed at any storey of a building. This irregularity generally occurs due to the lesser strength or major flexibility between stories. If all stories of the building are nearly equal in terms of strength or stiffness, earthquake forces can be distributed nearly equal to each storey under earthquake loading. The buildings illustrated in Fig. 6 were severely damaged due to the weak storey problem.

Figure 6: Weak storey damages in Malatya

3.2.5.Soft Storey (B2)

Soft storey irregularity is defined in the TBEC as the case where in each of the two orthogonal earthquake directions, Stiffness Irregularity Factor ηki , which is defined as the ratio of the average storey drift at any storey to the average storey drift at the storey immediately above or below, is greater than 2.0. There are various parameters that cause soft storey irregularity. For instance, a discontinuity between the ground and first floor cause critical conditions on earthquake behaviour of building. The height difference between the floors is a remarkable one among them. The ground floor of a building is generally designed as higher than the upper floors due to the user requirements. This causes stiffness losses and more displacement in the ground storey. Because, the cross sections of the columns are kept in same size in the ground floor even though there is a height difference is created between the two floors. Therefore, it causes a difference in rigidity or stiffness between the floors. This type of floors is called as the soft storey. It usually occurs due to the architectural requirements. For instance, using open ground storey such as shops, showrooms, banking halls create severe damage. Because, while a great storey drift occurs in the ground floor, the upper floors move like a diaphragm. High stress concentration occurs along the connection line between the ground and first floor that leads to distortion or collapse in structures (Arnold, 2002). The buildings displayed in Fig. 7 were severely damaged due to the weak storey problem.

Figure 7: Soft storey damages in Malatya

3.2.6. Discontinuity of Vertical Structural Elements (B3)

In the TBEC Gusseted columns or the columns which rest on cantilever beams are prohibited. Besides, in no case the shear walls should be allowed to rest under the columns and in no case the shear walls should be allowed to rest on the beams. Some of the vertical structural element problems observed after the Kahramanmaraş earthquakes were illustrated in Fig. 8 and 9. It is a significant issue that must be designed by carefully considering the location of the structural elements in the plan and the adequacy of their cross-sections. If it is not designed symmetrically and with sufficient cross-section in plan, the building will begin to collapse in the area where the structural system elements are insufficient, which are designed to be flexible.

Figure 8: Discontinuity problems in vertical structural elements

Figure 9: Insufficient design of structural elements

3.2.7.Short Column Effect (C1)

Short columns are defined as the columns that are shorter than the columns on the same floor. When a building has both long and short columns in the same storey, the columns expose to different shear forces due to their height differences. The lateral loads firstly come to the long and flexible columns, after go towards to the short column and accumulate in there. Due to the excessive accumulation of the seismic energy, shear cracks occurs at both ends of the columns. The damage in these short columns is often in the form of X-shaped cracking that occurs due to shear failures. Mezzazine floors, mechanical floor, hillside sides, graded foundation, ribbon windows, partial openings adjacent to the structural elements and stair landings are the most commonly encountered design problems caused short column effect. Short column effects in Malatya after the Kahramanmaraş earthquakes were illustrated in Fig. 10.

Figure 10: Short column effect

3.2.8.Weak Column-Strong Beam (C2)

During an earthquake in a building, beams are expected to deform primarily instead of columns. Damage to any column seriously affects the earthquake resistance of the entire building. Plastic hinging at both ends of the columns may initiate a storey displacement or even leading to the overall collapse of the building (Arnold and Reitherman, 2002). The beams should have weakest coupling instead of columns to prevent plastic hinging in columns. This condition can be provided by correctly sizing the structural members and using sufficient amount of steel in them. The building shown in Fig. 11 exposes to great damage in earthquake due to the hallow-tile slab. Hollow-tile slab is usually used in projects to prevent visibility of beams. But, it increases the building weight. Thus, it increases the earthquake forces simultaneously due to the direct proportion between the building mass and earthquake forces.

Figure 11: Weak column-strong beam damages

3.2.9.Seismic Pounding Effect (C3)

Seismic pounding is a significant design problem that causes serious damage and destruction in buildings under earthquake loads. It commonly occurs due to the insufficient seismic gap or no gap between two adjacent buildings. A sufficient amount of earthquake joints should be left to prevent buildings from colliding, taking into account the floor drifts of the building during an earthquake. If the size of the seismic gap is insufficient based on the expected storey drifts, pounding between adjacent or nearest structures may occur. Some of the seismic pounding problems observed after the Kahramanmaraş earthquakes in Malatya were illustrated in Fig. 12.

Figure 12: Seismic pounding damages

3.2.10.Soil Type Related Problems (C4)

Many buildings are damaged in earthquakes due to poor ground structure in Turkey. Local soil types are divided into six main groups in the TEBC, named from ZA to ZF, from good ground to poor soil. The soil type ZA consists of solid hard rock and ZB consists of slightly weathered, medium- solid rocks. Besides, ZC comprises of considerable dense layers of sand, gravel and hard clay or weathered, highly fractured weak rocks. ZD consists of medium firm, firm sand, gravel or considerable stiff clay layers. Moreover, ZE comprises of loose sand, gravel or soft-solid clay layers. ZF refers to grounds that require site-specific research and evaluation. Buildings with ground liquefaction generally have this soil type. Some of the soil type related damages noticed after the Kahramanmaraş earthquakes in Malatya were shown in Fig. 13. In examinations carried out in areas where collapsed or heavily damaged buildings are located, the fact that there are slightly damaged neighboring buildings on the same ground layer shows that the demolitions are not only caused by the ground.

Figure 13: Soil type related problems

3.2.11.Material Problems (C5)

Poor quality of concrete and column-beam connections, failure to tighten the stirrups at the column ends, rusting of reinforcement, damage caused by reinforcement and the usage of coarse aggregates caused heavy destruction of buildings after the Kahramanmaraş earthquakes. The use of coarse aggregates in buildings has been widely observed, and it has been realized that concrete burns and brittle fractures occur because it is not watered (Fig. 14).

Figure 14: Material problems

4.GENERAL ANALYSIS OF BUILDING DAMAGES IN MALATYA AND FINDINGS

In this section, the main structural irregularities that cause destroying in buildings or taking heavily damage in Malatya province were summarized. The heavily damaged or collapsed buildings presented in Section 3 are examined in this section in terms of all structural irregularities they contain. Because the structures were not destroyed just because of a single structural irregularity, but because they contained many structural irregularities, the structure was the cause of heavy destruction. Examined thirty buildings are presented in Fig. 15 Arnol with all the structural irregularities it contains.

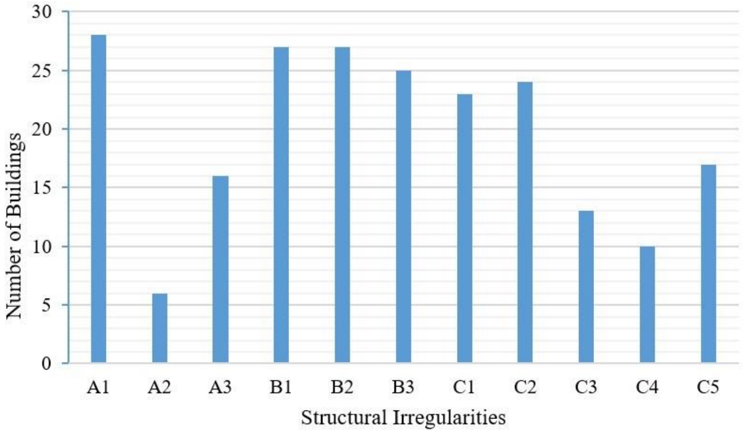

Figure 15: Structural irregularities on investigated buildings in Malatya

5.CONCLUSIONS

In this study, the main structural irregularities that cause destroying or taking heavily damage in buildings in Malatya province after the Kahramanmaraş earthquakes has been examined. In this study, the structural irregularities, which are observed to cause the most loss of life and property after the Kahramanmaraş earthquakes, were analyzed and evaluated comprehensively on 30 building samples selected from the province of Malatya. Additionally, apart from the structural irregularities specified in the Turkish Building Earthquake Code (TBEC), irregularities that cause destruction were also categorized and evaluated in detail. It was obtained that the significant factors causing destruction or affecting earthquake performance of structures are: building geometry, structural configuration, inadequacy in the cross sections of structural members, heavy overhangs, rigidity and strength differences between floors, short columns, strong beam-weak column, pounding effect, soil and material related problems. In the examination, it was determined that soft floors, weak floors and torsional irregularity play significant role in building demolitions, since most buildings are not designed appropriately for the ground on which they are located.

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