A Study on the Determination of Damage Levels in Reinforced Concrete Structures during the Kahramanmaraş Earthquake on February 06, 2023

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Abstract. Planning for settlement and urban redevelopment following disastrous earthquakes depends on the early detection and control of structural damage. The first damage assessment to be made immediately after the earthquake should be done as practically and quickly as possible. Within the scope of the study, the general causes of damage to the reinforced-concrete buildings in the region affected by the Kahramanmaraş earthquake couple dated 06 February 2023, which can be called the disaster of the century for Türkiye, and the first damage assessments were made using the European Macroseismic Scale (EMS-98) for 30 different reinforced concrete structures. This method gives six different building examples for each of the five different damage levels. Considering the buildings used in damage level, information is given about the causes and consequences of the damage. In general, it is the main cause of insufficient reinforced concrete frame damage as well as the effects of structural negativities such as soft storey, short columns, etc.

Keywords: Türkiye, Kahramanmaraş earthquakes, destruction, damage, EMS-98

1. Introduction

Türkiye is located on a very high seismic risk region. The earthquakes that occurred in the historical process in the country caused great loss of life and property. More than 50,000 people lost their lives after the Kahramanmaraş (Turkey) earthquakes, which were much more destructive than the 1939 Erzincan earthquake, in which 33,000 people lost their lives, and occurred independently of each other at nine-hour intervals. Even this is a sufficient indicator to show how great the destruction of earthquakes is. The first earthquake occurred on February 6, 2023, at 04:17 local time, with a magnitude of Mw=7.7 in the Pazarcık district of Kahramanmaraş. On the same day, 9 hours later, at 13:24 local time, an earthquake with a magnitude of Mw=7.6 occurred, the epicenter of which was in the Elbistan district of Kahramanmaraş. The focal depth of the first earthquake is 8.6 km, while the focal depth of the second earthquake is 7 km.
The fact that these earthquakes were very close to the surface and that a large earthquake occurred soon after, greatly affected the damage levels.

As in every residential unit affected by earthquakes, the first structural damage should be determined after destructive earthquakes. The first damage assessment, which is an important stage of modern disaster management after an earthquake, should be done as quickly and practically as possible. This requirement is made both for the continuation of social life after the earthquake and for deciding whether the structures located in the earthquake zone will be used immediately or whether they need repair and strengthening [1, 5]. The size of the area affected by the earthquake and the amount of existing building stock in that area negatively affect the rapid assessment of damage. Sufficient number of expert personnel, public resources, difficult terrain conditions as well as climatic conditions directly affects this process [6, 7]. After the Kahramanmaraş earthquake couple, which caused great destruction in approximately 16% of the country's surface area, the first damage assessments were carried out very quickly and practically by the relevant Ministry. The Ministry moved as fast as possible and reached the maximum number of buildings in the minimum time. QR code application was carried out in the examined buildings and the data obtained were made available to the building owners. In this context, the criteria that will be the basis for the first damage assessments after the earthquake should be chosen correctly. Providing information on which type of structure, which criteria to choose, and how these criteria will be applied in the field will significantly speed up the initial damage assessment process. The first damage assessments to be carried out systematically will significantly affect the loss of life and property in a possible second earthquake [8, 9].

Within the scope of this study, damage levels were made by considering the effects of the earthquake couple, which occurred on 06 February 2023 in Turkey and whose epicenter was Pazarcık-Elbistan in Kahramanmaraş province, on reinforced concrete structures. Damage classification was carried out for 30 different reinforced concrete buildings using the European Macroseismic Scale-98. Six different concrete building examples are given for five different damage levels recommended for reinforced concrete buildings at this scale. As a result of the damage data obtained and the observations made in the site, the main causes of the damages in reinforced concrete structures were tried to be determined.

2. The 6 February 2023 Earthquakes

The first earthquake occurred on February 6, 2023, at 04:17 local time, with a magnitude of Mw=7.7 in the Pazarcık district of Kahramanmaraş. On the same day, 9 hours later, at 13:24 local time, an earthquake with a magnitude of Mw=7.6 occurred, the epicenter of which was the Elbistan district of Kahramanmaraş. On February 20, 2023, at 20:04 local time, another earthquake with a magnitude of Mw=6.4 occurred in Hatay Yayladağı. Earthquakes have caused massive destruction in about 16% of the country's land area. These earthquakes are unprecedented disasters in recent history in terms of intensity and area covered. As a result of the earthquakes, more than 50,000 people lost their lives, more than five hundred thousand buildings were damaged, energy, and communication infrastructures were damaged and significant financial losses occurred. As of 6 March 2023, damage assessment studies were carried out for almost 1,700,000 structures in 11 cities affected by the earthquake by the Turkish Ministry of Environment, Urbanization and Climate Change. The damage levels obtained are given in Table 1.
Table 1. Number of Buildings for which Damage Assessment was carried out (6 March 2023) [10]

<table>
<thead>
<tr>
<th>Damage Levels</th>
<th>Number of buildings</th>
<th>Independent section</th>
</tr>
</thead>
<tbody>
<tr>
<td>None-damaged</td>
<td>860,006</td>
<td>2,387,163</td>
</tr>
<tr>
<td>Slightly damaged</td>
<td>431,421</td>
<td>1,615,817</td>
</tr>
<tr>
<td>Moderately-damaged</td>
<td>40,228</td>
<td>166,132</td>
</tr>
<tr>
<td>Heavily damaged</td>
<td>179,786</td>
<td>494,588</td>
</tr>
<tr>
<td>Demolished</td>
<td>35,355</td>
<td>96,100</td>
</tr>
<tr>
<td>Will be demolished immediately</td>
<td>17,491</td>
<td>60,728</td>
</tr>
<tr>
<td>Could not detect</td>
<td>147,895</td>
<td>296,508</td>
</tr>
<tr>
<td>Total</td>
<td>1,712,182</td>
<td>5,117,036</td>
</tr>
</tbody>
</table>

The two significant earthquakes' focal mechanism solution, the specifics of which are provided in Table 2, revealed that the Pazarçık and Elbistan segments' earthquakes are associated with strike-slip faulting (Figure 1). Over 9000 aftershocks were recorded during this time.

Table 2. The source parameters of the two main shocks [11]

<table>
<thead>
<tr>
<th>No</th>
<th>Date (UTC+3.00)</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Depth (km)</th>
<th>Magnitude Type</th>
<th>Location</th>
<th>S/D/R (°)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>06-02-2023 04:17:32</td>
<td>37.288</td>
<td>37.043</td>
<td>8.6</td>
<td>Mw 7.7</td>
<td>Pazarçık (K.Maraş)</td>
<td>233/74/18</td>
<td>AFAD</td>
</tr>
<tr>
<td>2</td>
<td>06-02-2023 13:24:47</td>
<td>38.089</td>
<td>37.239</td>
<td>7.0</td>
<td>Mw 7.6</td>
<td>Elbistan (K.Maraş)</td>
<td>90/86/13</td>
<td>AFAD</td>
</tr>
</tbody>
</table>

Figure 1. Epicentre distribution of Pazarçık earthquake (Mw = 7.7) and Elbistan earthquake (Mw = 7.6) and their aftershocks from 06.02.2023 to 10.02.2023 [11]
3. Damage Levels in Reinforced Concrete Structures

The earthquake couple, which caused enormous structural damage and destruction in 11 different provinces, clearly revealed the importance of the earthquake-resistant building design principles of the existing building stock features. In general, the existing building stock in urban areas affected by earthquakes is reinforced concrete structures. Irregularities that will adversely affect the earthquake resistance of reinforced-concrete structures (RC) have directly affected the structural damage levels. The first of these irregularities is the soft/weak storey. The strength and stiffness differences between the stores in the building caused significant destruction and damage when the relative storey drift between the floors exceeded the prescribed limit values. In particular, the main reason for such damages was that the ground floors were designed as a commercial enterprise with a large area and built without infill walls, and the upper floors were designed for residential purposes with infill walls. Examples of buildings in which the ground floors partially or completely collapsed due to the difference in strength and stiffness between floors are shown in Figure 2.

![Fig. 2. Examples of soft-storey damage](image)

Different levels of damage have been caused to the short columns formed due to the variation of column heights in the building or the changes in column lengths due to applications such as band-type windows. Examples of the short-column damage are shown in Figure 3.

![Fig. 3. Examples of the short-column-induced structural damage](image)

Insufficient accordance and lack of clamping between the structural members that make up reinforced concrete frame systems prevent the load transfer from occurring correctly. Examples of damage observed in the form of the collapse of storey slabs (pancake type of collapse) called insufficient reinforced concrete frame, are given in Figure 4.

![Fig. 4. Samples of the pancake-type damage](image)
Examples of damage in closed heavy overhangs built outside of reinforced concrete structural frames are given in Figure 5.

![Fig. 5. Samples of the heavy overhang damage](image1)

The inadequacy of concrete and reinforcement used in reinforced concrete structures directly and significantly affects the damage levels. The fact that the transverse reinforcement spacing, the concrete strength, the granulometry of the aggregate used in the concrete, the number of longitudinal reinforcements and the reinforcement strength are insufficient according to the earthquake-resistant building design principles cause damages. In addition, not using the required concrete cover thickness causes corrosion of the reinforcement, reducing both the bearing capacity and the adherence between the concrete and the reinforcement. Damages caused by insufficient concrete and reinforcement are shown in Figure 6.

![Fig. 6. Damages due to insufficient concrete and reinforcement](image2)

The magnitude of the earthquake, local ground conditions, and the structural characteristics of the existing building stock in the earthquake region affected by the earthquake directly and significantly affect the losses to occur. Accurate and timely acquisition of structural damage information will guide both the reduction of casualties and the effective implementation of emergency rescue [12,13]. In order to make the first damage assessments quickly and practically, it requires an observational decision on damage levels. It is not possible to make damage assessments in this process by making detailed structural analyze. An important factor here is to have a correct and detailed inventory of buildings and exhaustive damage data [14]. Damage information on structures is necessary for rescue, humanitarian and reconstruction operations in the earthquake region. Damage scales can be used in the site to grade structural damages [15].

There are many different evaluation methods to evaluate and classify structural damage after an earthquake more rapidly [16,17]. Modified-Mercalli (MM-31 and MM-56), Mercalli-Cancani-Sieberg (MCS), and Medvedev, Sponheuer-Karnik (MSK-64 and
Taking into account the security vulnerabilities in this scale, the European Macroseismic Scale (EMS-98) scale was developed by the European Seismological Commission with wider damage levels [16-19]. Within the scope of this study, 50 different reinforced concrete building damage classifications were made by using five different damage levels specified for RC structures in the European Macro-seismic Scale-98. The damage grading of the reinforced-concrete structures in EMS-98 is shown in Figure 7.

<table>
<thead>
<tr>
<th>Classification of damage to buildings of reinforced concrete</th>
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<tbody>
<tr>
<td><strong>Grade 1: Negligible to slight damage</strong> (no structural damage, slight non-structural damage)</td>
</tr>
<tr>
<td>Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.</td>
</tr>
<tr>
<td><strong>Grade 2: Moderate damage</strong> (slight structural damage, moderate non-structural damage)</td>
</tr>
<tr>
<td>Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.</td>
</tr>
<tr>
<td><strong>Grade 3: Substantial to heavy damage</strong> (moderate structural damage, heavy non-structural damage)</td>
</tr>
<tr>
<td>Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.</td>
</tr>
<tr>
<td><strong>Grade 4: Very heavy damage</strong> (heavy structural damage, very heavy non-structural damage)</td>
</tr>
<tr>
<td>Large cracks in structural elements with compression failure of concrete and fracture of rebar’s; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.</td>
</tr>
<tr>
<td><strong>Grade 5: Destruction</strong> (very heavy structural damage)</td>
</tr>
<tr>
<td>Collapse of ground floor or parts (e. g. wings) of buildings.</td>
</tr>
</tbody>
</table>

Fig. 7. The grades of damage according to EMS-98 for RC buildings

Six different examples of reinforced concrete structures with negligible to slight damage (no structural damage, light non-structural damage) are shown in Figure 8. In the six different buildings examined, thin plaster cracks at different levels and especially fine cracks occurred in the infill walls constructed from materials with low-strength properties. No damage was observed in the members that make up the frame system in these buildings.
Examples of reinforced concrete buildings for moderate damage (slight structural damage, moderate non-structural damage) are shown in Figure 9. In the buildings examined at this damage level, hairline shear cracks were commonly encountered, especially in the beam members located on the ground floors. Cracks were observed in many partition and infill walls.

Grade 3 damage of this assessment method refers to substantial to heavy damage (moderate structural damage, heavy non-structural damage). Examples of reinforced concrete buildings for this grade are shown in Figure 10. In the sample buildings used in this classification, large and abundant cracks and separations were observed at the floor and at the joint of the walls. In addition, cracks occurred in columns and beams due to the impact of the collision.
Grade 4 damage classification indicates very severe damage (heavy structural damage, very heavy non-structural damage). Examples of these damage classifications are shown in Figure 11.

Example reinforced concrete buildings, which became completely unusable after the earthquake and reached the mechanism of total or partial collapse, are shown in Figure 12.
Total collapse, soft-story damage, cracks in structural system members, infill wall damage, and damage in column-beam joints are the damages observed in the investigated buildings. In addition, poor workmanship, lack of inspection, low material strength, and design errors also negatively affected the damage situation. The probability of damage is higher in structures with soft/weak floors, strong beams-weak columns, short-columns, and irregularities in plan and vertical, which adversely affect the behavior of structures under earthquake effects. Insufficient use of reinforced concrete shear walls and inadequate lateral rigidity can also negatively affect the behavior of structures under earthquake effects and increase the amount of damage. In addition, similar mistakes that are usually made regarding reinforcement workmanship (insufficient wrapping, inadequate or incomplete reinforcement arrangements, insufficient or incorrect clamping, etc.) also affect the level of damage.

4. Conclusions

Within the scope of the study, the impact of the Kahramanmaraş earthquake of 06 February 2023, which caused great destruction in 11 different cities of Türkiye, on reinforced concrete structures, was taken into account. In the study, first of all, examples of commonly encountered reinforced concrete damage examples are given. Afterwards, in the EMS-98 evaluation method, which is widely used for initial damage assessment, five different damage level classifications specified for reinforced concrete structures were taken into account. Six different reinforced concrete building samples were selected for each damage level. Considering the examined buildings, it can be stated that the damages occurred as a result of not being constructed in accordance with the earthquake resistant building design principles.

Modern disaster management includes a rapid and practical damage assessment following an earthquake to ensure that social life can continue. At this time, training on how to conduct damage assessments should be given to those who will perform earthquake damage assessments. This method will make fieldwork more efficient and dependable. This planning is often crucial for effective data collection. Otherwise, field studies need to be renewed to collect data. All kinds of data to be obtained as a result of any damage assessment and rating to be made after the earthquake are valuable data in terms of...
earthquake and structural engineering. These data can be used to determine the area's seismicity as well as the traits of the building stock, including their strong and weak points. In addition, by using these data, it is able to make the essential adjustments to earthquake-resistant building design principles.

References


