



Post-earthquake structural damage assessment, lessons learned, and addressing objections following the 2023 Kahramanmaraş, Turkey earthquakes

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Abstract

This paper provides a comprehensive examination of post-earthquake structural damage assessment efforts following the Kahramanmaraş, Turkey, earthquakes that occurred on February 6, 2023. Drawing on global damage assessment protocols, the study compares and analyzes the methods implemented in the aftermath of the earthquakes, offering insights into lessons learned and challenges faced. The analysis of objections raised regarding the assessment efforts reveals significant changes in structures with moderate and severe damage, emphasizing the need for continuous improvement in assessment strategies. The paper advocates for a realistic and two-stage application method, consideration of crack type and cause, and active involvement of local communities in the assessment process. Furthermore, the study identifies key issues in the current earthquake damage assessment methodology and proposes solutions, including a more precise classification system, regular volunteer training, consideration of secondary disaster risks, and effective communication methods. The paper concludes by underscoring the importance of effective damage assessment in disaster management, addressing objections from the affected population, and continual enhancement of strategies to improve resilience in earthquake-prone regions.

Keywords Post-earthquake damage assessment · Structural resilience · Disaster response · Objections in damage assessment · Kahramanmaraş earthquakes

1 Introduction

In the aftermath of a destructive earthquake, assessing structural damage becomes critical for various stakeholders, including government agencies, emergency responders, engineers, and researchers. The condition of buildings and infrastructure is evaluated to determine the

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extent of damage and the safety of structures for occupation or use, forming a foundation for informed decisions regarding evacuation, repair, or demolition. Devastating consequences can result from earthquakes, such as the loss of human lives, extensive property damage, and significant disruptions to communities and economies. The assessment of structural damage in the aftermath of such events plays a crucial role in understanding the earthquake's impact, prioritizing response efforts, and planning for future resilience.

Several studies in the literature investigate the seismic response of structures after catastrophic events. Among them, Moghadam and Eskandari (2004) developed a procedure for quickly inspecting buildings in earthquake-damaged areas of Bam following the Bam Earthquake of December 26, 2003. Experiences from the post-earthquake evaluation of damaged buildings in Christchurch following the 2010–2011 Canterbury earthquake sequence were shared by Galloway et al. (2014). Furthermore, observations and recommendations for post-earthquake building safety evaluations for the $M_w=7.8$ Gorkha Earthquake in the Kathmandu Valley were reported by Surana (2015). Lulić et al. (2021) conducted a case study to investigate the post-earthquake damage assessment of the educational building after the Zagreb earthquake. Similarly, Mouloud et al. (2023) conducted a case study for post-earthquake damage classification and assessment of residential buildings after the earthquake in Mila City, Northeast Algeria, on August 7, 2020.

Turkey and its neighboring regions, positioned on the highly seismically active Anatolian plate, influenced by the Eurasian, Arabian, and African plates, are situated in an area prone to compressional tectonic activity. Significant earthquakes have been observed in this region (McKenzie 1972; Sengor and Yilmaz 1981). According to records from the Disaster and Emergency Presidency of Turkey (AFAD), two earthquakes with moment magnitudes of $M_w = 7.7$ and $M_w = 7.6$ were struck on February 6, 2023, approximately 9 h apart. The epicenters were in the Pazarcik and Elbistan districts of Kahramanmaraş. Substantial damage across the provinces and districts of Kahramanmaraş, Hatay, Gaziantep, Adiyaman, Malatya, Kilis, Adana, Diyarbakir, Osmaniye, and Sanliurfa resulted from these earthquakes, collectively affecting a population of more than 15 million. Remarkably, these earthquakes were documented as Turkey's second and third largest. An aftershock with a moment magnitude of 6.6 occurred at the epicenter in the Nurdagi District of Gaziantep between these two major earthquakes. Subsequently, on February 20, 2023, another aftershock with a magnitude of $M_w = 6.4$ transpired, with its epicenter in the Yayladagi district of Hatay (TADAS 2023; GEER-EERI 2023).

The February 6, 2023, events were yet another reminder of the region's vulnerability to seismic activity. Understanding how structures respond to such events, the effectiveness of damage assessment protocols, lessons learned from previous earthquakes, and objections raised by people regarding the assessment process are essential for improving preparedness and mitigating future risks. A comprehensive examination of the post-earthquake structural damage assessment efforts undertaken in the region after the devastating earthquakes of February 6, 2023, is the focus of this paper. By analyzing the methods, challenges, and outcomes of these assessments, as well as the objections raised by people regarding the assessment results, a contribution is made to the broader understanding of disaster response and recovery, focusing on enhancing resilience in earthquake-prone regions.

This paper investigated the widely used damage assessment protocols in the world and the one implemented in the region for that purpose after the 2023 Kahramanmaraş earthquakes, along with their comparisons. Moreover, the lessons from post-earthquake dam-

age assessment efforts during these earthquakes are evaluated. Furthermore, the strategies employed, the coordination between various agencies, the role of technology in assessment, and the objections and concerns voiced by the affected population will be delved into. The involvement of local communities and their feedback, recognized as essential components of effective disaster management and recovery, is considered. Thus, the analysis encompasses the objections raised by individuals and communities regarding the damage assessment efforts, aiming to provide a more holistic view of the post-earthquake response. Ultimately, the goal is to shed light on the significance of effective damage assessment in disaster management, emphasize the importance of addressing objections and concerns raised by the affected population, and promote the continuous improvement of strategies and practices in the face of seismic hazards.

2 Existing post-earthquake damage assessment protocols

In 1989, the ATC-20 report, titled “Procedures for Postearthquake Safety Evaluation of Buildings,” was released by the Applied Technology Council. This report was designed for utilization by qualified professionals tasked with conducting immediate on-site assessments and making decisions concerning the ongoing use and occupancy of buildings damaged by earthquakes. Since its inception in 1989, the ATC-20 methodology has been applied globally in response to earthquakes of different magnitudes. Over time, a series of ATC-20 documents have been developed, including the 2005 release of a second edition of the field manual (ATC-20-1). Comprehensive information on various topics, such as safety evaluation procedures, guidelines for assessing the safety of damaged buildings, methods for evaluating the structural integrity and livability of buildings, guidelines for determining the safety of non-structural components, and procedures for evaluating the safety of building systems, is provided in the ATC-20-1 Field Manual. Moreover, a detailed procedure for assessing the safety of damaged buildings, involving steps such as visual inspection for visible damage, evaluating structural integrity, assessing livability through examination of electrical, plumbing, and HVAC systems, appraising the safety of non-structural components, and scrutinizing the safety of building systems like elevators and fire protection systems, is outlined in the ATC-20-1 Field Manual (FEMA P-2055 2019).

The ATC-20 documents are specifically crafted for use by qualified professionals tasked with making immediate evaluations and decisions regarding the continued use and occupancy of damaged buildings. The Evaluation process of the ATC-20-1 Field Manual is illustrated in Fig. 1. The current methodology outlines procedures for swift and detailed assessments, resulting in categorizations as INSPECTED (green placard), RESTRICTED USE (yellow placard), or UNSAFE (red placard). Special provisions are included for evaluating essential buildings, non-structural elements, geotechnical hazards, and limited guidance on post-earthquake human behavior. The document has three evaluation methods: rapid, detailed, and engineering evaluation. The rapid evaluations, typically lasting 10–30 min per building, offer an initial general assessment of damage and safety, primarily from the exterior, involving personnel like building inspectors, civil and structural engineers, architects, and disaster workers. The rapid evaluation criteria of ATC-20-1 are given in Table 1. On the other hand, detailed evaluations, taking one to four hours per building, provide a more thorough visual examination, often following an initial Rapid Evaluation,

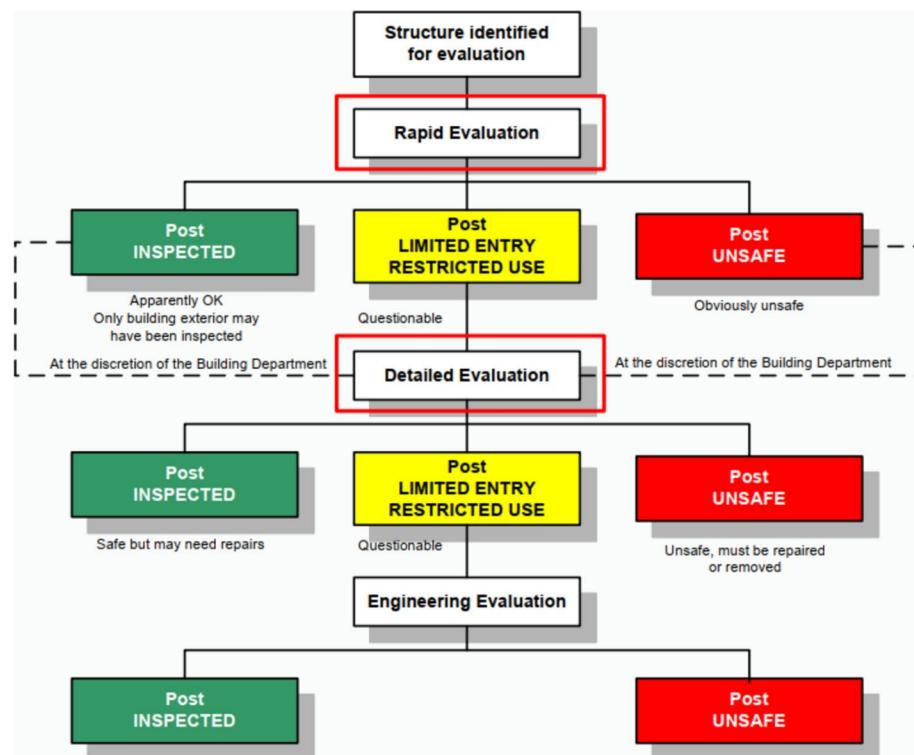


Fig. 1 Evaluation process of ATC-20-1 Field Manual (ATC-20 2005)

with structural engineers recommended for this stage. A third level, Engineering Evaluation, is mentioned but not extensively discussed, involving structural engineering consultants hired by the owner (ATC-20 2005; Lizundia et al. 2017).

In its latest effort, the ATC-20-1 Bhutan Field Manual was released in 2014, specifically tailored to accommodate Bhutan's vernacular buildings and consider its cultural and governmental context. This adaptation involved several enhancements to the presentation of content from the ATC-20-1 Field Manual, introducing a graphical format with numerous images to assist architects, engineers, and building officials in more accurate evaluations of damaged buildings. The procedures also integrate valuable insights from recent post-earthquake building safety evaluations following the 2010 Maule, Chile Earthquake, and the 2010–2011 Canterbury Earthquake Sequence in New Zealand, as documented in ATC-109 (2014).

The ATC-20 methodology was initially applied in New Zealand in 1998 and underwent revisions in 2004 and 2009 (NZSEE 2009). Although an unpublished draft existed in 2010 (NZSEE 2010) during the Christchurch earthquakes, it was generally not utilized (ATC-109 2014). The official document (NZSEE 2009) employed during the Christchurch earthquakes incorporated a three-placard system, akin to ATC-20, with two evaluation levels, Level 1 and Level 2, equivalent to ATC-20's Rapid and Detailed Evaluations, respectively. Furthermore, this methodology, used during Level 2 evaluations, introduced the assessment of usability categories to offer more detailed information on the building's structural condition

Table 1 ATC-20-1 Rapid evaluation criteria (ATC-20 2005)

Condition	Action ^a
1. Building has collapsed, partially collapsed, or moved off its foundation	Post UNSAFE
2. Building or any story is significantly out of plumb (i.e., leaning)	Post UNSAFE
3. Obvious severe damage to primary structural members, severe racking of walls, or other signs of severe damage and distress present	Post UNSAFE
4. Obvious parapet, chimney, or other falling hazard present	Post RESTRICTED USE and barricade the unsafe area
5. Large fissures in ground, massive ground movement, or slope displacement is present	Post UNSAFE
6. Other hazard present (e.g., toxic spill, asbestos contamination, broken gas line, fallen power line)	Post UNSAFE and/or barricade unsafe area ^b

^aIn completing the Rapid Evaluation form, the evaluator will be asked to determine the degree of damage (minor/none, moderate, or severe) and to determine the posting. The posting or action recommended above is for the severe situation

^bRESTRICTED USE posting may be applicable in certain situations

and continued use. Drawing from the Christchurch experience, New Zealand updated its procedures in 2014, detailed in (MBIE 2014).

Lastly, Japan, one of the earthquake-prone countries, has developed a rapid inspection method and damage classification system through the project “Development of the Restoration Techniques for Damaged Buildings due to an Earthquake” (1981–1985), funded by the Ministry of Construction. The resulting manual for post-earthquake rehabilitation techniques, published in 1986, outlines the rapid inspection for assessing collapse and non-structural element risks, categorizing buildings as “Unsafe”, “Limited Entry”, or “Inspected”. The method, employed swiftly to identify vulnerable structures against aftershocks, relies on visual observations from outside the buildings, assessing both structural and foundation risks. Structural damage is classified into five classes based on crack patterns and residual crack width. Buildings with Damage Class III, IV, or V in any member are labeled as “Rank B”, with further considerations for column damage ratio, inclination due to settlement, and risks to neighboring buildings and foundations. If any evaluated rank is C or higher, the building is deemed “Unsafe”; if all risks are Rank A, it is labeled “Inspected,” while others are categorized as “Limited Entry.” The inspector must hold a 1st or 2nd class architect license or be a licensed timber building architect residing in the affected area. They are required to attend training provided by the local government and register for the task. The rapid inspection is intended to commence shortly after an earthquake and conclude within seven days. Non-structural risks are assessed, including window and frame, wet and dry finishing, signboard/machinery, outdoor staircase, and others. If all risks receive a Rank A evaluation, the building is labeled “Inspected,” while others are marked as “Limited Entry.” Ultimately, the building is tagged with the more severe category among structural and non-structural damage classifications (JBDPA 2015; Kusunoki 2021).

3 The post-earthquake damage assessment protocol implemented following the 2023 Kahramanmaraş earthquakes

In the aftermath of the devastating earthquakes that struck Kahramanmaraş in 2023, the Ministry of Environment, Urbanization, and Climate Change (MoEUCC) has officially taken a leading role in overseeing efforts to assess structural damage post-earthquake. While it is preferable to engage experienced structural engineers for post-earthquake safety evaluations, it has long been recognized that there is a shortage of engineers to meet the demand following a significant event. Additionally, it is believed that a structural engineer may not be indispensable for many buildings undergoing rapid evaluations. What is crucial, however, is that the evaluator possesses an understanding of local building construction techniques and has received sufficient training in evaluating earthquake damage. Proper training provides context and clarity regarding the rationale and criteria underpinning the methodologies (Lizundia et al. 2017).

A similar situation unfolded in the aftermath of the Kahramanmaraş earthquakes. Given the extensive and destructive nature of the earthquake's impact across a large area, the MoEUCC's trained personnel proved insufficient. Consequently, support was sought from volunteer construction engineers and architects in various public institutions, researchers from universities and research institutes, as well as professionals from the private sector. The individuals conducting damage assessments are required to be either architects or civil engineers. Each assessment is carried out by teams consisting of two people. Following rapid training, these collaborative initiatives have led to the implementation an assessment procedure developed by the MoEUCC. The combined efforts of these individuals have been directed towards contributing their expertise to the assessment and recovery process, exemplifying a cooperative and well-coordinated response to the aftermath of the earthquake. The author of this article has participated in post-earthquake reconnaissance efforts, and also actively contributed to the post-earthquake damage assessment efforts of governmental buildings in the region. The MoEUCC's implemented assessment procedure is summarized below, and further details can be accessed through AFAD (2014) and HTED (2023).

The flowchart for the assessment procedure details is presented in Fig. 2. The assessment procedure devised by the MoEUCC entails two key stages. Firstly, an "External Inspection"

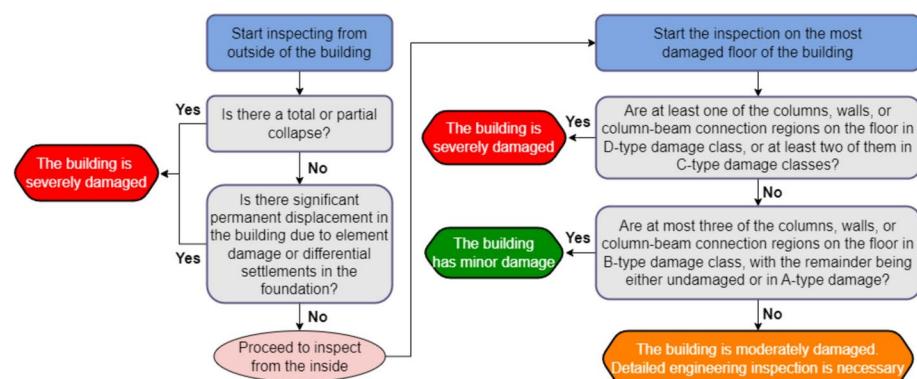


Fig. 2 Flowchart for post-earthquake structural damage assessment procedure developed by the MoEUCC (Adapted from HTED 2023)

Table 2 Determining structural component damages

Damage type	Crack width (w)	Compression damage
O-type damage	—	—
A-type damage	$w \leq 0.5 \text{ mm}$	—
B-type damage	$0.5 < w \leq 3 \text{ mm}$	Crushing of cover
C-type damage	—	Spalling of cover
D-type damage	—	Reinforcement buckling, core crushing

**Fig. 3** Structural component damage types (HTED 2023)

is performed, involving an initial assessment of the building's exterior. If there are evident indicators of substantial structural displacement (whether partial or complete), significant permanent story drift, or rigid rotation, the extent of damage can be ascertained exclusively through this external examination. In cases where the external inspection does not yield a definitive conclusion, the second stage, termed "Internal Inspection," comes into play. In this stage, a thorough examination is carried out, primarily focusing on the most severely affected floor, typically the ground floor. Only vertical load-bearing members such as columns, shear walls, etc., and column-beam joints are evaluated during the damage detections.

The determination of structural component damage is conducted based on the classification provided in Table 2 below. It mainly depends on crack width and compression damage on the members. As it progresses from "O-type damage" to "D-type damage" within the damage type classification, the level of damage within the structural component increases. An example of structural component damage types is illustrated in Fig. 3. As a result of these inspections, structures are categorized into five different damage levels based on the classification provided in Table 3. The classification of buildings' damage level during this phase adheres to the following criteria:

- If a minimum of one column, shear wall, or column-beam joint area on a given floor is categorized as D-type Damage, or if a minimum of two of these areas fall into C-type Damage, the building is promptly labeled as "Heavily Damaged."
- Conversely, should, on a floor, a maximum of three column, shear wall, or column-beam joint areas be identified as B-type Damage, and the remaining areas be either unscathed or designated as A-type Damage, the building is promptly categorized as "Lightly Damaged."

Table 3 Damage classification (DAI 2023)

Damage category	Damage level
None	A building that has not incurred any damage due to the earthquake (Pre-existing damage and defects in the building before the earthquake are not assessed)
Minor	Buildings with minor earthquake-induced damage, such as small cracks in the paint, plaster, and walls, as well as instances of plaster falling from the walls. (Pre-existing damage and defects in the building before the earthquake are not assessed). The use of the building is allowed
Moderate	Buildings with earthquake-induced damage, including cracks in the walls and minor cracks in load-bearing elements. Pre-existing damage and defects in the building before the earthquake are not assessed. A building with “moderate” damage should not be used until the potential decrease in load-bearing capacity is addressed (without repairing the building) or strengthened
Major	These are buildings with extensive and widespread shear failures or separations in the load-bearing elements of the building. “Heavy” damaged structures are defined as buildings with irreparable loss of load-bearing capacity and irrecoverable damage in terms of strength and economics
Collapse	These are buildings in which the load-bearing elements of the structure have undergone significant permanent displacement, partially or completely collapsing due to an earthquake. It is impossible to enter these buildings under any circumstances, and the evacuation of belongings cannot be carried out

- Without meeting either of these conditions, the building is classified as “Moderately Damaged,” necessitating a comprehensive engineering assessment.

Moreover, while a similar approach has been implemented for masonry structures, there is no evaluation protocol for other structures, such as steel, precast concrete, timber structures, etc.

After the earthquakes, a mobile damage assessment application designed by the ministry has been utilized to expedite the damage assessment process and enhance data accuracy. The application can be used on mobile phones or tablets, enabling field inspection teams to collect and record damage assessment data. Assessments are conducted offline by damage assessment teams using this application on the damaged structure. When devices are brought online, the entered data is transferred to a central database (Gurbuz and Aslan 2023).

After the evaluation is completed, a QR code containing information about the condition of the buildings is attached to the entrance of the structures. This QR code can be scanned with a mobile phone to access the building’s damage status information. Some examples of QR codes attached to buildings after post-earthquake damage assessment are depicted in Fig. 4.

Additionally, people can inquire online about the damage status of their buildings by using their information through Turkey’s e-government portal (turkiye.gov.tr) or the damage assessment inquiry (DAI 2023) webpage of MoEUCC. After the damage assessment results



Fig. 4 QR code examples attached to structures after their post-earthquake damage assessment (Cnnturk 2023)

Table 4 Number of total buildings in earthquake-affected provinces (TERRA 2023)

Province	Residential	Work-place	Public	Other	Overall total
Adana	404,502	29,920	8916	7779	451,117
Adiyaman	107,242	5765	4370	3119	120,496
Diyarbakır	199,138	11,412	11,964	3165	225,679
Elazığ	106,569	7221	2872	7051	123,713
Gaziantep	269,212	22,829	5480	8162	305,683
Hatay	357,467	33,511	10,382	5489	406,849
Kahramanmaraş	219,351	12,358	6879	4565	243,153
Kilis	33,399	1526	1651	736	37,312
Malatya	159,896	8370	6670	4051	178,987
Osmaniye	128,163	9428	3105	2384	143,080
Şanlıurfa	347,902	18,847	11,790	4089	382,628
Total in 11 Provinces	2,332,841	161,187	74,079	50,590	2,618,697

are announced in neighborhood municipalities, there is a one-month objection period. During this period, individuals can submit objections through the e-government portal or communication offices, and based on these objection applications, a re-evaluation of the damage will be conducted by the experienced staff of the relevant ministry, and the results will be finalized. After finalizing the results, any further objections can only be made through the administrative judiciary (DAI 2023).

4 Observed damage following the earthquakes

The earthquakes in question caused great destruction in the earthquake-affected eleven provinces. The total number of buildings in those provinces is 2,618,697, and the distribution of the buildings according to their occupancy types is reported in Table 4. The structural system of buildings in the region is as follows: 86.7% are reinforced concrete, 2.4% are steel, 3.5% are masonry, 3.6% are precast, and 3.8% have other structural systems. These earthquakes are unprecedented disasters in recent history regarding intensity and area cov-

ered. As a result of the earthquakes, more than 50,000 people lost their lives, more than half a million buildings were damaged, communication and energy infrastructures were heavily damaged, and significant financial losses occurred. The collapsed or severely damaged buildings also include historical and cultural structures, schools, administrative buildings, hospitals, hotels, and residential buildings (TERRA 2023). As of June 12, 2023, the damage assessment studies carried out by the MoEUCC have been conducted on 2,197,000 structures. The damage distribution results of these buildings are presented in Fig. 5a. According to this, it was determined that 60,109 buildings (2.7%) collapsed, 202,366 buildings (9.2%) were heavily damaged, 44,346 buildings (2.0%) were moderately damaged, and 627,805 buildings (28.6%) were slightly damaged and lastly remaining (57.5%) were determined undamaged. On the other hand, reassessment works have been conducted in some regions following the aftershocks. Despite this, the overall definitive damage assessment has taken 45 days, with 20 days for objection assessments. (Gurbuz and Aslan 2023; Ilki 2023).

The Kahramanmaraş earthquakes have also adversely affected the structures under construction in the region. Due to the high peak ground accelerations measured by seismic stations (TADAS 2023; Demir et al. 2024) and the significant damage and destruction caused by the earthquakes in existing structures (Fig. 5a), there is a need to assess the post-earthquake damage status of these buildings and evaluate whether construction should continue. For this purpose, collaboration has been established between the Ministry of Environment, Urbanization, and Climate Change and the Council of Higher Education. Post-earthquake damage assessments of the structures under construction were carried out by faculty members at universities nationwide. The assessments categorized the buildings under construction into four different categories: Undamaged, in need of Element-Based Strengthening, in need of System-Based Strengthening, and Beyond Strengthening due to severe damage. As of June 12, 2023, a total of 27,060 structures under construction in the region have been examined, and the findings are presented in Fig. 5b. According to the assessments, 247 buildings (0.9%) were determined as beyond repair due to severe damage, 733 buildings (2.7%) required system-based strengthening, 1,202 buildings (4.4%) needed element-based strengthening, and the remaining structures (91.9%) were found to be undamaged and could continue construction (Gurbuz and Aslan 2023).

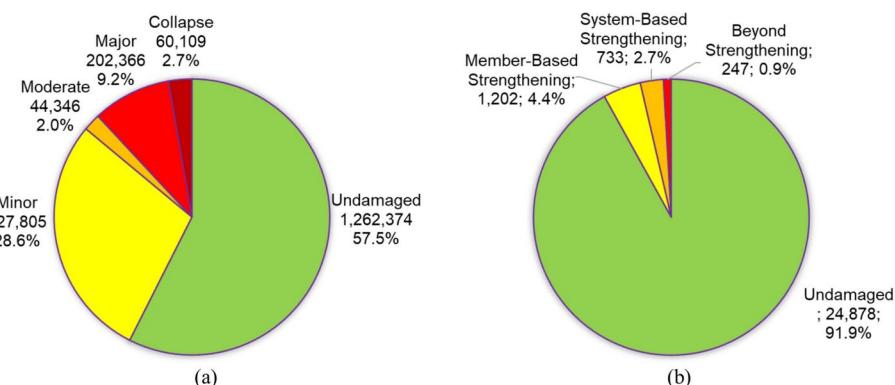


Fig. 5 Damage distribution of existing structures (a) and existing incomplete structures (b) after post-earthquake damage assessment as of June 12, 2023, reflecting the level of required intervention for each structure

5 Raised objections regarding the post-earthquake damage assessment efforts

This section delves into the objections raised by individuals concerning the initial post-earthquake damage assessments of their buildings. The objections submitted and the outcomes of the subsequent damage reassessments have been publicly disclosed through the Damage Assessment Inquiry system of the Ministry of Environment and Urbanization and Climate Change (DAI 2023). This dataset is crucial for gaining insights into the effectiveness and realism of the initial damage assessments, offering valuable information on the number of objected buildings and the extent to which these objections lead to assessment changes. Moreover, it provides an opportunity to refine the existing evaluation method and facilitates the possibility of conducting more accurate assessment studies in the future.

Two possible outcomes emerge upon raising an objection and conducting a reassessment of a structure. First, there may be no change in the initial damage assessment, indicating the accuracy of the initial evaluation. In the second scenario, the initial damage assessment may be altered, revealing an error in the initial evaluation. Furthermore, in cases where the initial damage level is revised, it may be upgraded to a more severe category (e.g., from moderate to severe damage) or downgraded to a milder category (e.g., from moderate to minor damage). The terms “upgraded” and “downgraded” are used to refer to the increase or decrease in the severity or extent of damage, respectively.

This study meticulously investigates the post-earthquake damage assessment of 541,341 structures located in 18 districts within the 11 provinces most affected by the 2023 Kahramanmaraş earthquakes, carried out by the MoEUCC. The analysis encompasses the initially identified earthquake damage levels in these structures, objections lodged against the assessments, and the results of subsequent damage reassessments prompted by these objections. The summarized results are presented in Table 5 in the Appendix and visually depicted in Fig. 6. However, data on dispute rates between assessments conducted by experienced versus less experienced assessors, as well as objection rates in regions more heavily affected by aftershocks, are not available.

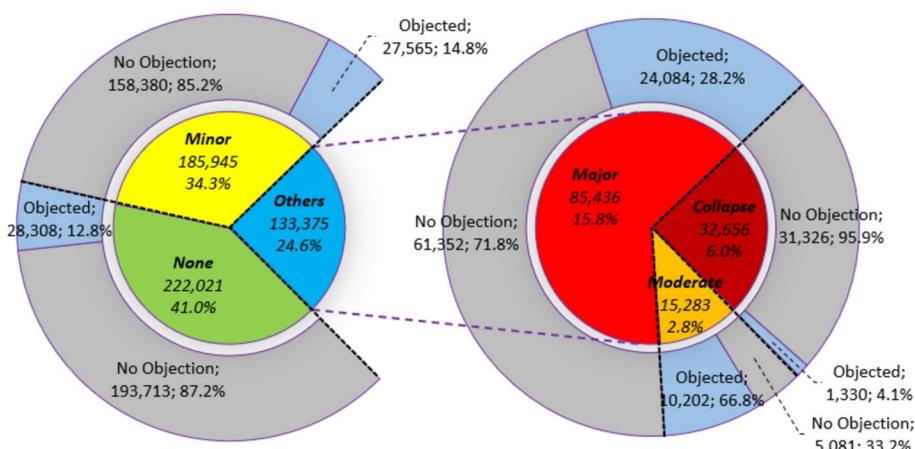


Fig. 6 Damage assessment results and the objections made to initial damage assessment results of eleven provinces

As can be seen from Fig. 6, out of the total assessed 541,341 structures, 15,283 (2.8%) were determined to have moderate damage, 85,436 (15.8%) were identified as heavily damaged, and 32,656 (6.0%) were found to be collapsed. The remaining 407,966 structures were either undamaged (41.0%) or had suffered minor damage (34.3%), as depicted in Fig. 6. Objections were raised for 28,308 cases (12.8%) among structures identified as undamaged, and for structures with minor damage, objections were made in 27,565 cases (14.8%). Additionally, objections were lodged for the damage assessment of 10,202 structures (66.8%) with moderate damage, 24,084 structures (28.2%) with severe damage, and 1,330 collapsed structures (4.1%). In summary, objections have been raised for 91,489 buildings (16.9%) out of a total of 541,341 structures where post-earthquake damage assessment has been conducted. As Fig. 6 illustrates, objections are predominantly raised for structures with moderate damage and then severe damage, with collapsed buildings receiving the least ratio of objections.

The results of objections are detailed in Table 6 in the Appendix and Fig. 7. Examining the data reveals that 53.6% of objections to structures identified as undamaged resulted in no change in the damage assessment, while objections to the remaining structures (46.4%) led to an increase in the damage level to a more severe category. Regarding structures with minor damage, 71.7% of objections resulted in no change in the initial damage assessment, 10.3% were downgraded to a lower damage level, and in the remaining cases (18.0%), the damage level was increased to a more severe category. Moreover, in structures with moderate damage, 29.2% remained unchanged, 57.0% downgraded, and 13.8% upgraded in damage level. Among severely damaged structures, 46.6% remained unchanged, 46.6% had a downgrade, and 6.8% had an upgrade in damage level. Finally, 70.7% of structures in collapsed buildings had an unchanged damage level, while 29.3% had a downgraded damage level.

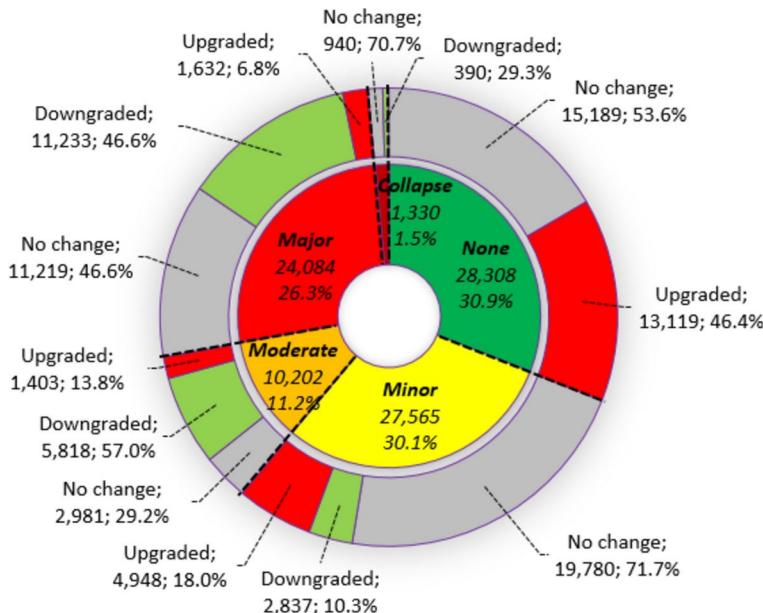


Fig. 7 The results of objections to the damage assessment findings

In summary, the reassessment of building damage reveals significant changes in structures with moderate and major damage, where the results are often downgraded to a less severe damage level. Minimal changes are observed in objections to structures with minor damage and collapsed buildings. However, for structures initially identified as undamaged, approximately half have undergone an upgrade to a more severe damage level (see Fig. 7).

There appears to be a correlation between the highest number of objections and the most substantial changes in buildings with moderate and major damage. Furthermore, it has been observed that initial damage assessments in these buildings were significantly reduced upon re-evaluation. This suggests that the most notable errors in damage assessment occur primarily in buildings with moderate and severe damage. Upon examining the reasons for this, it is likely attributed to the inherent difficulty and complexity of the assessment method, leading to incomplete understanding and, consequently, inaccurate application by some assessors, particularly those lacking experience. Additionally, evaluators may lean towards making decisions at higher damage levels to err on the side of caution due to the extensive damage caused by the earthquake's magnitude and intensity. This inclination may also be particularly pronounced in regions frequently experiencing intense aftershocks.

6 Lessons from the post-earthquake evaluation of damaged buildings following the 2023 Kahramanmaraş earthquakes

This section emphasizes the need for improvements in the current earthquake damage assessment methodology applied by the relevant ministry, addressing various challenges and proposing solutions to enhance the accuracy, efficiency, and comprehensiveness of the assessment process.

The method employed for damage assessment relies on crack width and compression damage in vertical load-bearing system elements. Accurate measurement of crack width at the correct location in the member is crucial, necessitating the removal of cover concrete and measurement of crack width in the core area. These processes are time-consuming and pose challenges for inexperienced evaluators in correctly applying the specified criteria. Furthermore, ongoing aftershocks during damage assessment make working in damaged buildings a significant safety risk for evaluators. Consequently, assessing damaged buildings realistically and adequately from the inside becomes challenging for evaluators' safety.

The assessment method does not consider the type and cause of cracks (bending, shearing, torsional behavior, etc.). Particularly, the Turkish Earthquake Code 2018 (TEC 2018), like commonly used seismic codes, seeks to prevent brittle shear damage in elements under the influence of horizontal loads. In contrast, it is assumed that concrete in the tension zone will crack due to tensile stresses, and the effective flexural stiffnesses of cracked sections are used in the design phase (Wight and MacGregor 2012). Therefore, shear damage in an element is more critical than bending damage. Consequently, conducting an examination without determining the type and cause of damage in members can lead to incorrect assessments. That is evident in numerous objections made for moderately and heavily damaged buildings during damage assessment, resulting in a reduction of damage levels to those corresponding to lower damage levels after re-evaluation by expert engineers.

Structures, whether or not they have received adequate engineering services, exhibit a variety of damage types in both structural and non-structural elements due to earthquake

effects. This damage might occur for various reasons in different locations. Individuals without expertise or insufficient prior training in this subject may find it challenging to gain experience through short post-earthquake training and apply the desired damage assessment method. Therefore, instead of applying the assessment method as a one-time definitive damage assessment, a two-stage application, as seen in ATC-20 (2005) and Japanese (JBDA 2015) methods, would be more realistic. In the first stage, a simple, understandable, and easily applicable method that can be applied even by non-expert engineers or architects with brief training should be developed. For the second stage, the existing method should be applied by expert engineers after addressing its shortcomings. This method would allow for rapid assessments by trained personnel, crucial for immediate decision-making, while subsequent detailed inspections could resolve disputes and provide deeper insights into complex cases. Furthermore, integrating local community participation acknowledges their unique knowledge of local construction practices and building conditions, potentially improving initial assessments' accuracy and fostering community trust in assessment outcomes.

Non-structural elements, such as infill walls, also experienced significant damage in the aftermath of earthquakes. In the assessment method, if no damage occurs in the vertical load-bearing system components, advanced damages in non-structural elements are disregarded, indicating the structure as lightly damaged. However, due to a lack of awareness among many individuals about the difference between structural and non-structural elements, there have been questions about the assessment results and the process of evaluating damaged buildings. Mainly, objections to undamaged or lightly damaged buildings have been attributed to this situation. Upon re-evaluation following objections, the damage levels of these buildings mostly remain unchanged (see Fig. 7). On the other hand, in buildings with no significant damage to structural members but considerable damage to non-structural elements, there are significant challenges for people to live again. Therefore, in the applied damage assessment method, the damage situation in non-structural elements should be considered in terms of the occupancy status of the structure, and people should be informed accordingly.

The official post-earthquake damage assessment of the structures in the hazard-effected regions can only be carried out under the authority and coordination of MoEUCC. The completion of post-earthquake damage assessment studies and the subsequent re-evaluation of structures following objections take a long time. To expedite that process, individuals should be allowed to have competent engineers conduct damage assessments for their own structures. The relevant ministry can also issue a competency certificate for this purpose.

After damage assessment studies conducted by the authorized ministry and the finalization of objection results, a new objection can only be made through administrative judicial means. Due to the heavy workload of Turkish courts, cases heard in courts can take a very long time to conclude, leading to grievances. To accelerate these processes, methods such as forming expert teams affiliated with the relevant ministry or re-evaluation by expert engineers authorized by the ministry, as mentioned above, could be developed.

During the assessments, priority has been given to the damage assessment of structures that need immediate use after earthquakes, such as hospitals, fire stations, etc. However, structures like grocery stores, hardware stores, and pharmacies located within regular buildings, should be included in the high-priority inspections list, and damage assessments for these structures and the normal buildings they are in should be carried out by specialized teams as soon as possible.

In the region, there are many structures used for industrial purposes. Some of these structures have been used for stockpiling and distributing the materials sent to the region for needs and aid. Therefore, accurate damage assessments of these structures were crucial. The damage assessment method provided by the relevant ministry can only be applied to reinforced concrete and masonry structures. However, no assessment method exists for steel, prefabricated, substandard structures, etc. Only the post-earthquake damage assessments of these structures are ensured to be conducted by expert engineers, leaving the evaluation entirely to the experience of technical personnel conducting the examination. This situation can significantly decrease the standard evaluation level for assessing these types of structures, leading to significant differences in results. Additionally, no criteria have been explained for expertise in the evaluation of these structures. Therefore, evaluation criteria should be established for post-earthquake damage assessments of these structures.

One of the significant problems after earthquakes has been the occurrence of aftershocks with large magnitudes and frequent intervals. In the region, these aftershocks have advanced the existing damage in many buildings, causing some damaged buildings to collapse and resulting in significant losses (TERRA 2023). The repetition of damage assessment for a structure exposed to these aftershocks raises the question of whether the damage assessment needs to be renewed. Considering that more than 2.5 million structures in the region were affected by the earthquakes and aftershocks, renewing the damage assessment after every aftershock is impossible. Some regions have renewed damage assessment studies after certain aftershocks. However, conducting this renewal process after every aftershock may not be feasible. Therefore, similar to the methods recommended in the literature (ATC-20-1 Bhutan 2014; Lizundia et al. 2017), practices such as renewing damage assessment studies in some regions or using indicator buildings after significant aftershocks can be considered for necessary cases. As a result, if damage has progressed in the identified region or indicator buildings after an aftershock, the damage assessments conducted in other areas can be renewed.

After damage assessment, some difficulties have been experienced in understanding the barcodes attached to the entrances of structures, as shown in Fig. 4, to learn the damage status of the building. These barcodes did not provide visual information directly about the damage status of the structure but required the barcode to be scanned, access to an intelligent mobile phone, an internet connection, and the presence or installation of a barcode reader application on the respective telephone to access the information it contains. Some people do not have smartphones, while others may not have had the opportunity to retrieve their phones after urgently evacuating the building following the earthquakes. Moreover, some individuals may lack experience using smartphones and installing and using such a barcode application. Moreover, after earthquakes, telecommunication infrastructure in many regions has suffered significant damage, causing disruptions in internet access for an extended period. At the same time, the electrical infrastructure has also been damaged, resulting in difficulties in charging phones. On the other hand, due to the small size of the attached barcodes, it is necessary to approach them closely for scanning. Primarily due to significant and frequent aftershocks in the region, approaching damaged buildings poses a considerable risk. For these reasons, it has been observed that the applied barcode system has created significant challenges and risks in informing people about the damage situation of structures. To prevent this situation, as suggested in ATC-20 (2005), more easily

understandable, simple, differently colored, and easily visible signs should be placed on the structures.

In the region, it was not possible to take measures to prevent entry to many severely damaged, collapsed, and structures at risk of collapse for a long time. In addition to the damage assessment signs, structures of this kind should be quickly cordoned off after their damage assessments are conducted.

Significant difficulties were observed in understanding the damage categories given in Table 3 by people living in the region. Primarily, there has been significant confusion regarding the occupancy status of the structure based on this classification. Therefore, this classification should be clearer and more understandable, and people should be informed about it.

Especially considering the possibility that the quick training provided to inexperienced architects and engineers before damage assessment may be insufficient, the number of civil engineers and architects in the country should be determined, and volunteers should be regularly trained for post-earthquake damage assessment studies.

In the applied evaluation method, there are no assessment criteria for secondary disaster risks such as fire, leakage of toxic substances, rockfall, and flood. However, the rate of life and property losses due to secondary disasters has been high in the region (TERRA 2023). Therefore, evaluation criteria for secondary disasters should be added to the assessment criteria.

7 Conclusions

In conclusion, the comprehensive examination of post-earthquake structural damage assessment efforts following the devastating earthquakes of February 6, 2023, in the seismically active Anatolian region sheds light on critical disaster response and recovery aspects. The paper has explored widely used damage assessment protocols globally and compared them with the methods implemented in the region. Lessons drawn from the post-earthquake evaluation of damaged buildings have identified challenges and proposed solutions to enhance the assessment process's accuracy, efficiency, and comprehensiveness.

The analysis of objections raised regarding the post-earthquake damage assessment efforts reveals a correlation between the highest number of objections and significant changes in structures with moderate and severe damage. That emphasizes the inherent difficulty and complexity of the assessment method, leading to incomplete understanding and, consequently, inaccurate application by some assessors. The objections may also arise due to broader considerations such as socio-economic impacts, legal ramifications, and challenges in effectively communicating assessment results to stakeholders. The study advocates for continuous improvement in strategies and practices, acknowledging the need for realistic and two-stage application methods, considering the type and cause of cracks, and involving local communities in the assessment process.

Furthermore, the paper highlights several crucial issues and proposes solutions to address challenges in the current earthquake damage assessment methodology. These include the need for a clearer classification system, regular training for volunteers, consideration of secondary disaster risks, and efficient communication methods to inform the public about the damage status of structures.

In the face of seismic hazards, the events of February 6, 2023, underscore the region's vulnerability to seismic activity. The paper concludes by emphasizing the importance of effective damage assessment in disaster management, the significance of addressing objections and concerns raised by the affected population, and the continuous improvement of strategies and practices. By learning from the experiences of the 2023 Kahramanmaraş earthquakes, the broader understanding of disaster response and recovery is enriched, focusing on enhancing resilience in earthquake-prone areas.

Appendix A

See Tables 5 and 6.

Table 5 Final damage categories and change in damage status after re-evaluation of the buildings as of August 10, 2023

Province	District	Investigated buildings	Damage Category of Buildings						Objected buildings						Change in Damage Status of Buildings						
			None			Moderate			Major			Collapse			No Change			Downgraded			
			#	#	%	#	#	%	#	#	%	#	#	%	#	#	%	#	#	%	
Hatay	Antakya	60,366	9319	15.4	19,634	32.5	3283	5.4	18,322	30.4	9808	16.2	9624	15.9	4030	41.9	3314	34.4	2280	23.7	
	Defne	21,897	4880	22.3	8137	37.2	1451	6.6	5745	26.2	1684	7.7	4557	20.8	1939	42.5	2041	44.8	577	12.7	
Adiyaman	Center	44,372	10,141	22.9	20,227	45.6	2352	5.3	8168	18.4	3484	7.9	10,814	24.4	5793	53.6	3268	30.2	1753	16.2	
Kahraman-	Dulkadi-	45,294	18,176	40.1	16,551	36.5	1213	2.7	6819	15.1	2535	5.6	9265	20.5	5156	55.7	1712	18.5	2397	25.9	
maraş	iroylu																				
Oniki-	Oniki-	50,703	21,734	42.9	21,229	41.9	1278	2.5	5250	10.4	1212	2.4	10,727	21.2	5898	55.0	2061	19.2	2768	25.8	
subat	subat																				
Elbitistan	25,557	14,518	56.8	6317	24.7	447	1.7	2883	11.3	1392	5.4	5463	21.4	3309	60.6	645	11.8	1509	27.6		
Pazarcık	18,943	6240	32.9	6487	34.2	696	3.7	3764	19.9	1756	9.3	3106	16.4	1669	53.7	693	22.3	744	24.0		
Turk-	18,663	6477	34.7	6782	36.3	588	3.2	2905	15.6	1911	10.2	4060	21.8	2298	56.6	790	19.5	972	23.9		
oglu																					
Gaziantep	Nurdagi	10,907	2065	18.9	3003	27.5	315	2.9	3150	28.9	2374	21.8	1725	15.8	942	54.6	287	16.6	496	28.8	
	İslahiye	15,349	5550	36.2	4761	31.0	595	3.9	2821	18.4	1622	10.6	2341	15.3	1196	51.1	440	18.8	705	30.1	
Malatya	Yesily-	42,686	12,898	30.2	16,786	39.3	945	2.2	10,028	23.5	2029	4.8	6212	14.6	3894	61.2	1448	23.3	960	15.5	
urt	Dogan-	13,690	2484	18.1	4112	30.0	297	2.2	4926	36.0	1871	13.7	1653	12.1	935	56.6	408	24.7	310	18.8	
şehir	Center	49,613	31,998	64.5	13,283	26.8	420	0.8	3385	6.8	527	1.1	7347	14.8	4332	59.0	812	11.1	2203	30.0	
Osmancıye	Center	24,176	14,254	59.0	8410	34.8	240	1.0	961	4.0	311	1.3	2462	10.2	1492	60.6	355	14.4	615	25.0	
Kilis	Baglar	19,859	12,040	60.6	6851	34.5	483	2.4	468	2.4	17	0.1	2389	12.0	1496	62.6	458	19.2	435	18.2	
Diyarbakır	Haliliye	39,582	24,085	60.8	14,624	36.9	323	0.8	476	1.2	74	0.2	3299	8.3	2079	63.0	249	7.5	971	29.4	
Sancıurfa	Adana	18,161	15,683	86.4	2248	12.4	150	0.8	65	0.4	15	0.1	1662	9.2	835	50.2	712	42.8	115	6.9	
Cukurova	Elaçığ	Center	21,523	9479	44.0	6503	30.2	207	1.0	5300	24.6	34	0.2	4783	22.2	2804	58.6	585	12.2	1394	29.1
Total and ratios in 11 provinces		541,341	222,021	41.0	185,945	34.3	15,283	2.8	85,436	15.8	32,656	6.0	91,489	16.9	50,007	54.7	2078	22.2	21,204	23.2	

Table 6 Results of the objections as of August 10, 2023

Province	District	Investigated buildings	Objected buildings	None				Minor				Moderate				Major				Collapse			
				Upgraded		No change		Upgraded		No change		Downgraded		Upgraded		No change		Downgraded		Upgraded		No change	
				#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Hatay	Antakya 60,366	9624	15,9 300	39,9 451	60,1 798	56,5 46	3,3	568	40,2 575	36,0 770	48,2	253	15,8 2276	40,2 2,389	42,2 998	17,6 91	45,5 109	17,6 91	45,5 109	54,5	54,5		
Defne	21,897	4557	20,8 141	39,7 214	60,3 231	57,5 40	10,0	131	32,6 356	37,9 467	49,7	117	12,4 1191	42,4 1,505	53,6 112	4,0 23	44,2 29	55,8	55,8				
Adiyaman	Center 44,372	10,814	24,4 1109	53,8 952	46,2 3,250	79,5 378	9,2	460	11,3 440	20,2 1,511	69,4	227	10,4 912	39,2 1,329	57,1 85	3,7 111	68,9 50	31,1	31,1				
Kahramanmaraş	Dulkadiç 45,294	9265	20,5 1799	48,8 1,884	51,2 1,636	77,8 106	5,0	361	17,2 198	26,8 420	56,8	122	16,5 1411	54,6 1,144	44,3 27	1,0 115	73,2 42	26,8	26,8				
Onikritus	50,703	10,727	21,2 2225	51,1 2,133	48,9 2,584	76,1 314	9,2	498	14,7 265	24,0 720	65,2	119	10,8 759	42,7 1,004	56,4 16	0,9 67	74,4 23	25,6	25,6				
Elibistan	25,557	5463	21,4 1629	62,3 986	37,7 1,179	64,5 190	10,4	458	25,1 50	26,2 103	53,9	38	19,9 336	48,2 3,34	47,9 27	3,9 115	86,5 18	3,9 115	86,5 18	13,5	13,5		
Pazarcık	18,943	3106	16,4 382	49,6 388	50,4 780	68,7 43	3,8	312	27,5 95	39,6 124	51,7	21	8,8 388	42,3 508	55,3 22	2,4 25	58,1 18	41,9	41,9				
Turkoglu	18,663	4060	21,8 815	54,7 675	45,3 830	74,1 61	5,4	229	20,4 101	32,0 173	54,7	42	13,3 496	47,2 531	50,5 24	2,3 58	69,9 25	30,1	30,1				
Gaziantep	Nurdagi 10,907	1725	15,8 114	32,9 233	67,1 435	69,7 19	3,0	170	27,2 34	24,1 60	42,6	47	33,3 264	52,5 196	39,0 43	8,5 98	89,1 12	10,9	10,9				
İskilip	15,349	2341	15,3 280	43,8 360	56,3 472	67,9 42	6,0	181	26,0 90	24,2 197	53,0	85	22,8 285	53,1 189	35,2 63	11,7 85	87,6 12	12,4	12,4				
Malatya	Yesilova 42,686	6212	14,6 445	53,0 395	47,0 1,499	75,1 92	4,6	404	20,3 275	45,0 251	41,1	85	13,9 1554	57,8 1,087	40,4 49	1,8 58	76,3 18	23,7	23,7				
Dogancı	13,690	1653	12,1 64	45,1 78	54,9 337	77,5 3	0,7	95	21,8 57	41,0 77	55,4	5	3,6 409	47,7 319	37,2 129	15,1 71	88,8 9	11,3	11,3				
Osmaniye	Center 49,613	7347	14,8 2314	55,9 1,829	44,1 1,449	75,0 211	10,9	273	14,1 108	27,1 215	53,9	76	19,0 447	52,8 374	44,2 25	3,0 14	53,8 12	46,2	46,2				
Kilis	Center 24,176	2462	10,2 876	63,0 514	37,0 544	70,4 142	18,4	87	11,3 22	16,5 104	78,2	7	5,3 50	32,3 100	64,5 5	3,2 2	18,2 9	81,8	81,8				
Diyarbakır	Bağlar 19,859	2389	12,0 577	63,1 338	36,9 726	67,8 284	26,5	61	5,7 119	38,8 152	49,5	36	11,7 74	77,1 22	22,9 0	0,0 0	0,0 0	0,0 0	0,0 0				
Sanlıurfa	Hailiye 39,582	3299	8,3 1158	56,4 895	43,6 805	82,2 118	12,1	56	5,7 82	40,2 108	52,9	14	6,9 29	52,7 20	36,4 6	10,9 5	62,5 3	37,5	37,5				
Adana	Cukurova 18,161	1662	9,2 278	75,3 91	24,7 493	52,3 436	46,3	13	1,4 59	18,0 257	78,6	11	3,4 5	20,8 19	79,2 0	0,0 0	0,0 0	0,0 0	0,0 0				
Elazığ	Center 21,523	4783	22,2 683	49,3 703	50,7 1,732	65,7 312	11,8	591	22,4 55	21,0 109	41,6	98	37,4 333	67,0 163	32,8 1	0,2 2	66,7 1	33,3	33,3				
Total		541,341	91,489	16,9 15,189	53,7 13,119	46,3 19,780	71,8 2,837	10,3	4948	18,0 2981	29,2 5818	57,0	1403	13,8 11,219	46,6 11,233	46,6 1632	6,8 940	70,7 390	29,3	29,3			

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