Düzce University
Journal of Science & Technology

Review Article

Identifying Infill Wall Failures in Kahramanmaraş Earthquakes and Strategies for Performance Improvement

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DOI: 10.29130/dubited.1405720

ABSTRACT

Non-structural walls play a very important role in buildings, as they are used to create partitions and provide aesthetic appeal. However, their failures during earthquakes have been a recurring issue. Damage to the infill walls that occurred due to the Kahramanmaraş earthquake on February 6, 2023, was observed in residential and industrial buildings and especially in transformer structures that provide vital electricity distribution. This article presents the findings of field surveys conducted in Kahramanmaraş after recent earthquakes, focusing on non-structural wall collapses that obstructed mainly residential building entrances-exits and structures of particular importance. Within the scope of this study, deficiencies in the certification process in the field of infill walls were seen as the root of workmanship defects. Recommendations were made for the deficiencies in the certification process and for improving the process for the future. Infill walls shouldn't exhibit out-of-plane behavior, causing loss of life and property and for escape routes to be blocked due to falling walls. With today's technology and engineering, it is possible to positively improve the energy consumption capacity and out-of-plane behavior of infill walls. In this context, a detailed literature review was conducted, and the different techniques used were explained in the article. In addition, explanations were given regarding the force of regulation in Türkiye. Within the scope of the study, the compatibility of regulations and national qualifications in the direction from the design to the production of infill walls is revealed.

Keywords: *Non-structural walls, Infill Wall, Wall, Earthquake, Building failures, Construction practices, National qualification system, TBDY 2018*

Kahramanmaraş Depremlerinde Dolgu Duvar Hatalarının Belirlenmesi ve Performans Geliştirme Stratejileri

ÖZ

Yapısal olmayan duvarlar, bölmeler oluşturmak ve estetik çekicilik sağlamak için kullanıldıklarından binalarda çok önemli bir rol oynamaktadırlar. Ancak deprem sırasındaki başarısızlıkları sürekli tekrarlanan bir sorun olmuştur. 6 Şubat 2023 Kahramanmaraş depremi sonucu konut, sanayi binaları ve özellikle hayati öneme sahip elektrik dağıtımını sağlayan trafo yapılarındaki dolgu duvarlarda hasarlar gözlemlendi. Bu makale, Kahramanmaraş'ta meydana gelen son depremlerden sonra yapılan saha araştırmalarının bulgularını, özellikle konut binalarının giriş-çıkışlarını kapatan ve özel önem taşıyan yapıların işlevselliğini kaybetmesine neden olan yapısal olmayan duvar göçmelerine odaklanmaktadır. Bu çalışma kapsamında dolgu duvar alanındaki sertifikasyon sürecindeki eksiklikler işçilik kusurlarının kökeni olarak görülmüştür. Sertifikasyon sürecindeki eksikliklere ve geleceğe yönelik sürecin iyileştirilmesine yönelik önerilerde bulunulmuştur. Dolgu duvarların düzlem dışı davranış sergileyerek can ve mal kaybına yol açması, göçen duvarlar nedeniyle kaçış yollarının kapanması istenmez. Günümüz teknolojisi ve mühendisliği ile dolgu duvarların enerji tüketim kapasitesini ve düzlem dışı davranışlarını olumlu yönde iyileştirmek mümkündür. Bu bağlamda detaylı bir literatür taraması yapılmış ve kullanılan farklı teknikler çalışmada irdelenmiştir. Buna ek olarak konu hakkında Türkiye'de

Geliş: 16/12/2023, Düzeltme: 15/01/2024, Kabul: 24/04/2024

yürürlükte olan mevzuata ilişkin açıklamalarda bulunulmuştur. Çalışma kapsamında, dolgu duvarların tasarımından üretimine kadar olan süreçte kullanılan mevzuat ve ulusal yeterliliklerin eşgüdümün önemine vurgu yapılmıştır.

Anahtar Kelimeler: *Yapısal olmayan duvarlar, Dolgu Duvar, Duvar, Deprem, Yapısal Göçmeler, İnşaat uygulamaları, Ulusal yeterlilik sistemi, TBDY 2018*

I. INTRODUCTION

Earthquake is one of the leading causes of structural or non-structural damage in reinforced concrete (RC) buildings [1]. Earthquakes are a phenomenon that shakes the environment, and the vibrations that occur suddenly due to the fractures in the earth's crust spread as waves. Depending on the earthquake's type, effect, severity, and/or size, severe damage may occur to the structure [2]. During the earthquake, the energy released on the structure by the oscillation of the structure must be consumed by the load-bearing elements such as columns, beams, and shear walls. With the dissipation of energy, these carrier elements are damaged. The extent of the damage is directly related to the design, material quality, and workmanship [3]. Making mistakes in these headings causes total collapse of the structure and causes loss of life and property. In non-structural elements, the most significant damage is generally observed in infill walls [4]. The infill walls move with the oscillation during the earthquake. Infill walls: Since they are in direct contact with load-bearing elements such as columns, beams, and slabs, they show the behavior of acting together during an earthquake. However, these elements suffer severe damage in the first vibrations due to their low energy dissipation capacity. At the same time, contact with carrier elements is lost, and as a result, it causes loss of life/property. For these reasons, the design is made by ignoring the bearing capacities of these walls in the building design guides worldwide [5]. Thus, it can be said that the design is on the safe side.

Most partition wall systems available in Türkiye are produced with brick, lightweight concrete briquette, and aerated concrete materials [6]. Since the mechanical properties of these materials are quite low, these elements are expected to be damaged during the earthquake [7]. Some numerical and analytical studies have shown that the effect of the infill wall on the building systems cannot be neglected [8-9]. Shing and Mehrabi (2002) conducted a study to predict the behavior of brick partition walls within the frame. In their research, they revealed that brick partition walls act as a pressure bar within the frame and that the strength of these walls is not merely the sum of the strengths of the frame and the brick infill separately. In addition, they classified the possible failure mechanisms observed in the walls [10]. These failure mechanisms are bending, mid-height crack, horizontal slip, diagonal crack, and corner crush. These damages represent a behavior called in-plane. The in-plane failure mechanism is the favourable one in terms of ductility and energy dissipation. Apart from this, out-of-plane behavior is an undesirable failure on infill walls. Out-of-plane mechanisms represent the most dangerous source of local collapse. Such deficiencies lead to the need to subsequently strengthening/repairing the infill walls. Many methods are applied in the literature to strengthening/repairing infill walls [11-14]. However, during the application of these methods, building owners cannot benefit from the building. The important issue here is that the infill walls are manufactured with high performance during the construction of the building and that there is no need for strengthening/repairing in these walls.

On February 2023, at 04.17 and 13.24, according to GMT+3 time zone, two earthquakes occurred in Pazarcık/Kahramanmaraş and Elbistan/Kahramanmaraş epicentre. The first earthquake occurred at a depth of 10 km and M_w= 7.8. The second earthquake occurred at a depth of 10 km and M_w=7.5 [15]. These earthquakes affected eleven city centres and rural areas, with approximately 10 million people living. As a result of the earthquakes, more than 50.000 people lost their lives, and about 212.000 buildings collapsed or were severely damaged in 10 cities affected. Türkiye announced that the financial loss was approximately 104 billion dollars [16]. Unfortunately, most RC structures were built after the 1970s, and many buildings were reported to have been seriously damaged or entirely collapsed by the earthquake sequence [17]. After the Kahramanmaraş earthquakes, fieldwork was also conducted by the authors to observe the damages on the infill walls. Heavy shear damage, crushing at the corners, and the most out-of-plane behavior were observed on the infill walls of the damaged structures in the region. In the earthquake that occurred on the night of February 6, it was observed that the infill walls fell on people while they were sleeping, resulting in severe injuries and deaths. As another observation, it was observed that the infill walls were toppled towards the building's main exits and stairwells. For this reason, it was determined that people could not get out of the building because the escape routes were blocked, and they were injured/died by falling on the walls in mass during the escape. Finally, it has been observed that the infill walls have been knocked down, preventing the opening of the interior and exterior doors and causing people's escape routes to be blocked. While such problems are experienced in residential areas, it has been determined in the field study that there are also infill wall problems in energy transformers that provide electricity to cities with vital importance. In post-earthquake search and rescue efforts, energy is important in ensuring the continuity of public services such as hospitals. However, in the Kahramanmaraş earthquake, it was determined that many single-storey energy transformers, previously installed in the region, either collapsed altogether or the infill walls were overturned. The equipment with high material value was damaged. As a result of these damages, it was seen that vital needs could not be met.

This article presents the findings of field surveys conducted in Kahramanmaraş after recent earthquakes, focusing on non-structural wall collapses that obstructed especially residential building entrances-exits and structures of special importance. For this, field work was done by the authors. Observed damages were noted and categorized on the basis of structure. The field study reveals significant deficiencies in the production process, including poor installation techniques, inadequate anchorage and connections, and the use of low-quality materials. These failures pose hazards to occupants and hinder rescue efforts. The second chapter focuses on the infill wall damages observed in the structures during the field work and the out-of-plane behavior in the infill walls. Seismic resistance of buildings can be significantly increased by preventing out-of-plane behavior with correct construction techniques, material selection and structural connections. In addition, the training processes and awareness of the personnel involved in the production process of infill walls are very important. In the third section, determinations were made regarding the qualifications within the scope of the training of individuals involved in the production process of infill walls and the reasons for the workmanship defects. In the fourth chapter, current studies in the literature on how to design infill walls with high-performance levels are included, rather than the individuals who produce infill walls. These studies have been evaluated comprehensively. The article emphasizes the need for improved construction practices, stricter quality control measures, and enhanced awareness among stakeholders to enhance building's seismic resilience. This study aims to improve construction practices and stricter quality control measures and increase awareness among stakeholders to eliminate the risks of infill walls in buildings. Taking proactive measures will ensure the safety and well-being of building occupants and mitigate risks in earthquake-prone regions, ultimately contributing to the overall resilience of the built environment.

II. INFILL WALL DAMAGES OBSERVED IN KAHRAMANMARAŞ EARTHQUAKES

In RC structures, masonry walls are employed for structural and functional requirements. An infilled frame is a composite construction that consists of infill walls and a moment-resistant RC frame. In Türkiye, infill walls are frequently employed owing to a need for both aesthetics and functionality [18]. Brick is one of the most significant building materials commonly used to make walls, particularly in the construction sector. It is also used in materials such as aerated concrete, pumice brick, and fire brick. These materials have different mechanical properties. Apart from these materials used in infill walls, wall productions are made with plasterboard wall systems. When the structures in the earthquake-affected areas are examined, hollow core clay bricks are the most popular type of filling material. These materials have a lower tensile strength and a much lower capacity to absorb energy during earthquakes [19-20]. Damage to the infill wall included diagonal cracking, crushing, and interface cracking at frame-boundary contacts [21]. Shear cracks (diagonal cracks) brought on by shear stresses are the most frequent kind of damage in buildings made of RC [22]. In addition, out-of-plane behavior is also undesirable in infill walls. A field study is planned to examine the damages on the infill walls in the affected city after the Kahramanmaraş earthquakes. In this field study, the damages in the infill walls were classified, and the deficiencies that caused these damages were tried to be determined. The most common diagonal cracks in the infill walls occurred in most buildings due to the Kahramanmaraş earthquakes. Photographs of buildings with this damage type are given in **Figure 1**.

Figure 1. *Diagonal cracks in infill walls after Kahramanmaras earthquakes.*

The infill walls within the reinforced concrete frame are first tried to limit the movement of the frame. Then, with the increasing load, the infill wall and the frame begin to separate. After this weathering, X-shaped shear cracks occur in the infill walls with high earthquake movements, and the width of the cracks increases. At higher damage levels, the X-cracks expand excessively, break apart, and the wall moves out-of-plane and shows a tipping behavior. These behaviors are seen in **Figure 1**. The main subject of this study is the examination of out-of-plane behavior, which is almost non-existent behavior compared to the energy dissipation in in-plane behavior. The probability of observing out-of-plane behavior is very high in the walls that rest on cantilever projections on the exterior, the walls that are attached to the floor and do not reach anywhere and do not extend to the ceiling, the lack of workmanship, material, and poor quality infill walls that are in a reinforced concrete frame. Out-of-plane behavior in the infill walls occurred in buildings due to the Kahramanmaraş earthquakes. Photographs of buildings with this damage type are given in **Figure 2**.

__Figure 2.__ Out-of-plane behavior in the infill walls occurred after the Kahramanmaraş earthquakes,(a),(b),(c),(d)brick infill walls, (e) aerated concrete infill wall and (f) briquette infill wall.

Figure 2 shows the overturning of the infill walls in structures extended with cantilever beams, the overturning of the infill wall in reinforced concrete carcass along the ground outside the building, not using girders in the infill wall in high frames, workmanship Errors, manufacturing of aerated concrete used as infill wall in a fragmented-fractured hospital building, manufacturing defects of infill walls. In **Figure 3**, pictures are shared showing the infill walls toppling towards the building's main exits and stairwells. In addition, pictures of the buildings, which were rendered useless by overturning the filling walls of single-storey energy transformers, were shared.

Figure 3. *(a) The closing of the building exits with the overturning of the infill walls, and (b) the infill walls in the energy transformers being inoperative by overturning after the Kahramanmaraş earthquakes*

Suddenly and unexpected collapse of infill walls can be prevented. For this, many regulations contain compelling rules and recommendations for designers. However, there are many compelling provisions regarding training personnel who implement the designer's wishes on-site and produce infill walls. In the third chapter, details about these issues are shared.

III. TRAINING OF MASONRY WORKERS AND PREVENTION OF WORKMANSHIP DEFECTS

This section will address the knowledge, skills, and competencies that these masters must possess, and the infill/partition walls, which are commonly used in almost all frame building systems produced for residential purposes and serve to divide the interior space into spaces. Masons are the main players in the production of these walls. It has been demonstrated in the earlier portions of this research that, in the event of destruction or damage to the wall structural element, there may be a loss of life and/or property due to numerous scholarly investigations and on-site observations. While this fact is obvious, it is necessary to examine in full detail what kind of measurement-evaluation process the people involved in producing this building element are qualified to do this job and the adequacy and applicability of the existing legislation throughout this process.

Mould making, blacksmithing, plastering, masonry, etc., in the Turkish construction industry. Some of the employees employed in professions consist of people who have completed (or think they have completed) their professional development with what they have learned as a result of the master-apprentice relationship. Since this process is not subject to any supervision or control, it cannot be said that there is an environment where the level and quality of work of people who have reached their current professional skills in this way can be visible or measurable. For this reason, in our country, The

Vocational Qualifications Authority (MYK) was established in 2006. To recognize and level past "unofficial" learning and to carry out all measurement-evaluation processes and the relationship between different achievements. MYK emerges as the leading authoritarian unit in Türkiye in terms of creating National Vocational Standards (UMS), which reveal the detailed analysis of a profession, and National Qualifications (NQ), which can be described as the curriculum that people follow to certify in an official environment that they are successful in their work in the light of these standards. These processes, which take place under the control of MYK, are called National Qualification System (UYS). National Qualification System: It is defined as a system in which career candidates in the construction branch are certified as a result of theoretical and practical exams, and the comparability of the documents received is ensured at national and international levels. As can be clearly understood from the definition, in Türkiye, people now have the opportunity to certify their knowledge and skills on an official level after being exposed to a specific measurement-evaluation process. Although no deficiencies in the quality of workmanship produced by employees are expected in such a system, it seems a reasonable expectation that no profound differences will be observed. This part of the study, first the conceptual framework for introducing the country UYS will be presented. Afterward, it will be examined to what extent these studies carried out by MYK, specific to the masonry profession, are sufficient for a sector employee who is a candidate to receive a certificate in the mason qualification of the current UYS and UY. An attempt will be made to reveal aspects of the subject that are open to improvement.

A. CONCEPTUAL FRAMEWORK

A. 1. European and Turkish Qualifications Framework

The European Qualifications Framework (EQF) emerged with the recommendation decision numbered 2008/C/111/01 of the European Commission and the European Parliament in 2008. The EQF is in an inclusive position, providing a common reference point for the national qualification frameworks of member countries and allowing different qualification levels in these countries to be compared with each other [23]. With this framework, which is the basis of the Lifelong Learning philosophy, and by the recommendation, the national qualification systems of all other countries should be associated with the EQF. At this point, Türkiye has prepared the Turkish Qualifications Framework (TQF) and has become one of the countries that have completed the referencing process to the 8-level EQF. As of today, 30 countries, including 25 European Union (EU) countries and five non-EU countries, including Türkiye, have associated their national qualification systems with the EQF [24].

A. 2. Vocational Standards

Vocational standards can be defined as descriptions and classifications of the jobs people do. In many countries, occupational standards are defined as a collection of competencies needed in the work environment related to the job performed. Another critical point about professional standards is that they form the basis of qualifications related to the profession [25]. MYK has defined UMSs in parallel with the definition of professional standards in the recommendation of the European Parliament in 2008 [26]. The prioritization process for professions that require professional standards is carried out by MYK, considering the needs of the business world and educational institutions.

A. 3. National Qualifications

National qualifications (NQ) are qualifications that emerge within the scope of each country's unique national qualifications framework. The profile of authorities, institutions, and organizations in the process preparing of these qualifications referenced to the EQF to their acceptance as official documents varies. Many countries prioritize stakeholders from the education and training sector in the national qualification preparation and implementation processes. However, in some countries such as Germany, France, and Türkiye, especially the business world and civil society, stakeholders seem essential for the system's sustainability and play an active role [27]. In Türkiye, UY's are defined as documents that contain expressions of skill-competence and knowledge at a level that will allow it to be measured whether an individual can perform his profession correctly or not [28]. As can be inferred from the definition, national qualifications are tools used to measure the level of success of an individual practicing a profession in that profession. Although UMSs, which are the framework of the profession, have a much broader information content, UYs are prepared in a more limited, short, and measurement-oriented manner in order to be able to conclude that an individual has officially fulfilled the requirements of that profession.

A. 4. Authorised Certification Bodies

After the measurement-evaluation process, successful candidates are issued a document that proves their current knowledge, skills, and competencies. Ministries, chambers of commerce, qualification institutions, etc. provide these documents. It is arranged by the authorities and delivered to its owner. In Türkiye, this responsibility falls on Authorised Certification Bodies (YBKs) authorized by MYK. YBKs are private organizations that stand at perhaps the most critical point in the certification industry and organize measurement-evaluation processes according to existing UYs. These organizations have essential duties, such as managing the examination processes for candidates who aspire to receive a certificate and determining whether the candidates are entitled to receive a certificate within the relevant qualification framework.

B. NATIONAL QUALIFICATION SYSTEM SPECIFICALLY FOR MASONRY

A mason in UMS is defined as a person who carries out his work by occupational health and safety rules, practices masonry units and masonry, also carries out applications such as stone walls, chimneys, and fireplaces, ensures sufficient quality conditions while performing these works and carries out studies for his professional development [29]. Its place in national classification systems is defined in ISCO 08: 7112. This document contains information such as the conditions under which the profession should be performed and what theoretical and practical knowledge, skills, and competencies the personnel who do this job must have. In parallel with this information, it is also included in the UMS in force in Türkiye. UMS is updated over time with relevant organizations and participants. UY, created by adhering to the content of this UMS, is, in a sense, the most crucial measurement-evaluation step that candidates must overcome on the way to certification. In other words, in order for a bricklayer to be able to introduce his previous learning after the application of the certification obligation begins, he must be subject to the measurement-evaluation process designed within the scope of this UY and carried out by YBKs and only after he can create a profile that overlaps with this UY, should he be included in the certification process and take his place in the sector. Mason UMS document describes the masonry job under 9 task headings. These;

- Implementing occupational health and safety, environmental protection and quality measures,
- Preparation before wall and chimney application,
- Applying wall building,
- Building a stone wall,
- Knitting a chimney,
- Building a fireplace/barbecue,
- Building a wall with glass bricks,
- Performing post-application procedures,
- Participating in professional development activities is included in the Mason (Level 3) UMS document code 11UMS0157-3.

Within these nine headings, there are steps "Preparing the application area-C1" and "Building a wall with masonry materials-C2 (brick, briquette, pumice block, aerated concrete and similar)" under the main heading of "Making the wall building application". The part that includes brick, pumice, and aerated concrete and wall building sub-processes, which we encounter in most of the constructions in the sector, is expressed here. When considered together with the steps of preparing the area to be applied, constructing a wall according to the standard, by the technique and with quality conditions is a process that takes place in a total of 21 steps. When we exclude the two steps containing conditional expressions, it becomes clear that a bricklayer must have a skill-competence set of 19 steps to prove his competence. However, when it comes to the necessary steps to ensure that these walls remain stable under the influence of lateral loads without compromising their integrity and without risking life safety, they have been observed to match some application steps. These;

- It places the gaps between the screed bricks, pumice blocks, briquettes, and aerated concrete at both corners, following the rope, paying attention to the knitting rules and joint spacing, and using knitting mortar or ready-made masonry mortar,
- In practice, care is taken to ensure that vertical joints are staggered and that horizontal and vertical joints are of appropriate thickness and continuity,
- It makes the wall corners and joints threaded/interlocking,
- It ensures the connection of the wall to columns and beams when necessary,
- It makes beams in high and long wall applications,
- It places the ready-made lintel suitable for door or window openings,

are steps that directly affect life safety under lateral loads such as earthquakes.

In Türkiye, proving the candidate's mastery within the scope of the relevant UY consists of two stages. Within the scope of these stages, candidates must demonstrate that they have the necessary theoretical knowledge in the qualification they apply for, and they can be entitled to receive a certificate by successfully carrying out a business scenario created by YBK in practice. In the theoretical exams, candidates are expected to verbally answer correctly the questions measuring the knowledge statements (BG) specified as examples in **Table 1**. Similarly, they are expected to demonstrate their competence and skills (BY) in the jobs presented as examples in **Table 1**. Candidates are scored separately for these steps (BG and BY). There are a total of 20 BG statements in the theoretical exam and a total of 39 BG statements in the Practical exam.

Table 1. *Some BG and BY expressions are required for candidates in the theoretical and practical exams of bricklayer qualification*

BG/BY	Qualification Explanation	Relevant Section of UMS
BG 5	Explains the reasons for grating in aerated concrete applications.	C.2.7
BG 8	Explains the points to be considered in joint construction.	C.2.10
BG 9	Explains the points to be considered in chimney construction.	E.2.1
BY 8	It moistens/wets the wall element or the area where the application will be made (the wall will be built).	C.1.1
BY 19	It makes wall corners and joints threaded/interlocking.*	C.2.11
BY 24	It places the ready-made lintel suitable for door or window openings.*	C.4.6
BY 29	According to the project, the first row of the chimney is placed with the help of knitting mortar by the technique.	E.2.1

Different findings emerge when the expression/address matches shared above are examined. It is important to include six specifications in the UY document, which are thought to be much more essential in the measurement and evaluation processes, especially in ensuring resistance to horizontal loads in wall applications. However, when the current mason UY document is examined, it is seen that the skill and competence expressions coded C.2.7, C.2.8, C.2.16, and C.2.17 are not included in the list of skills and competencies that the candidates must achieve. Tasks C.2.7 and C.2.8 are not among the six items that are critical for the stability of the walls. However, it is a significant deficiency that the steps of column-beam connection (C.2.16) and beam manufacturing (C.2.17), which are the most essential items, are not included among the skill and competence expressions.

Candidates who want to be certified as masons are given a specific masonry project during the practical exam. It is expected that the walls specified in this project will be manufactured by the rules and with different materials specified in the project. It has been published as an example of how the proficiency practice exam project published by MYK can be. It is expected that YBKs will conduct a practical exam similar to this project. Details of the project are presented in **Figure 4**.

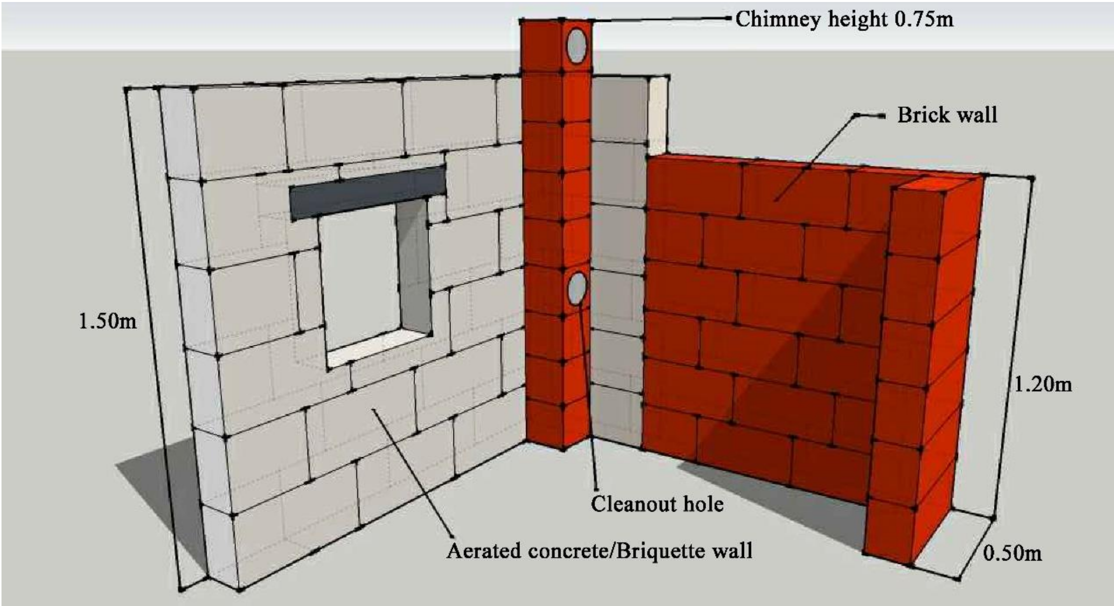


Figure 4. *The scenario required to be produced by mason candidates*

As seen in **Figure 4**, candidates are expected to manufacture the wall using aerated concrete/briquette and brick materials, paying attention to the details of the project. Infill walls are expected to be manufactured within a framework (such as columns and beams) or between two floors, as defined before. However, the project has no load-bearing elements such as columns and beams. In addition, even though it is a scenario, there are no details about which materials and how to connect these elements to the carrier elements. Due to these deficiencies, candidates are certified without this information. These individuals then carry out actual practices in the field in this direction. Similarly, there needs to be details on how to manufacture beams on high and wide walls. It is also seen the wall that the candidate is asked to build is different from the size of an actual wall.

IV. DESIGN OF INFILL WALLS WITH HIGH PERFORMANCE

Infill walls are a structural technology with outstanding load-bearing capability that is frequently used in low-rise structures all over the world. Beginning in the middle of the 1950s, laboratory and analytical studies were conducted on the seismic response of infills in terms of in-plane and out-of-plane behaviors [30, 31]. Numerous studies have been performed in recent years investigating in plane and out-of-plane responses of infills with various height/length ratios, infill unit strengths, openings, and perimeter frame characteristics, etc. [32-34]. Also, there exist several experimental tests investigating the effect of prior in plane damage on the out of plane performance of infills. Confined infill wall (CM), reinforced infill wall (RM), and unreinforced infill wall (URM) are the three primary forms of wall construction. In URM, the load-bearing walls are not surrounded by any vertical structural elements, such as columns. In addition, the wall's high inertia, broken masonry units, and insufficient deformation capacity make it earthquake-prone without horizontal reinforcement. This construction is usually used in areas with relatively minimal seismic risk for structures that are not taller than three storeys [35]. Typical URM building types include solid and cavity walls, which are combined with mortar. Understanding the failure hierarchy and structural flaws is essential to comprehending the seismic behavior of URM structures. The geometrical characteristics of the wall, boundary constraints, and material quality all affect how URM barriers collapse [36]. Reinforcements are added to RM walls vertically and horizontally to strengthen them against in-plane and out-of-plane failure modes. Because the masonry units used in RM walls are usually hollow, steel bars can be inserted into the vertical cells. These cells must be filled with mortar or grout to allow stress transmission between the steel bars and the masonry. Based on these factors, two primary failure processes in RM walls subjected to in-plane lateral stress may be recognized [37]. The first of them is a flexural failure, often indicated by masonry crushing at wall toes and tensile yielding of flexural reinforcement. The second failure mechanism is the shear failure mode, primarily marked by diagonal tensile cracking. Generally speaking, analytical models may be used to forecast an RM wall's flexural capacity with accuracy [38]. Because the mechanisms involved in the shear failure mode are complicated, predicting the shear strength can be a challenging. These methods may involve increased frictional strength along diagonal cracks, the dowel effect of vertical reinforcement, and the tension of lateral reinforcement [39].

All cells in fully grouted reinforced wall (FG-RM) [40], including the ones without reinforcement, are grouted. On the other hand, only the cells with vertical steel bars grouted in partly grouted reinforced masonry (PG-RM) [41] result in significant cost savings. The shear resistance is usually provided by horizontal reinforcement bars, which may be classified into bond-beam (BB) or bed-joint reinforcement (BJR). An example of a wall produced in the BB and BJR types is illustrated in **Figure 5**.

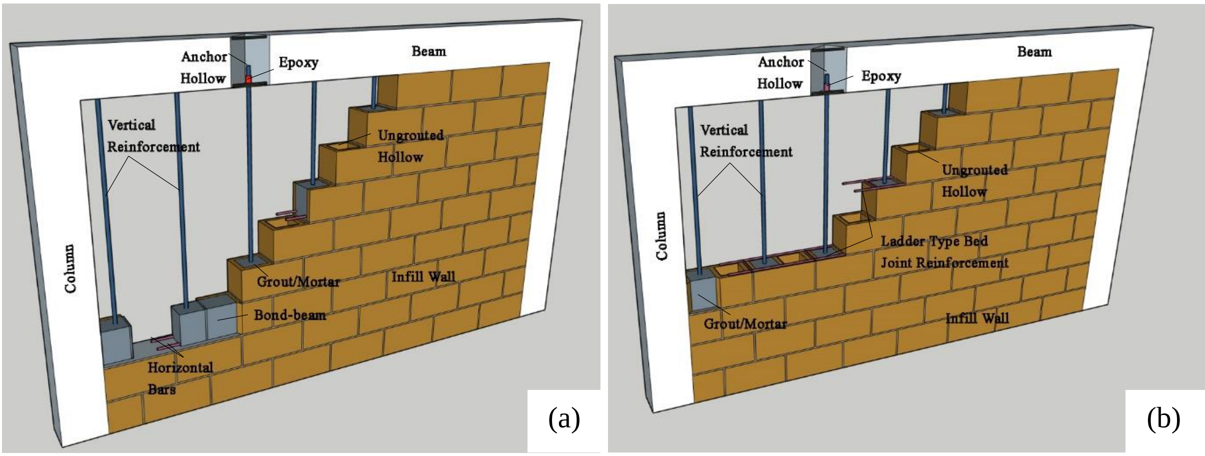
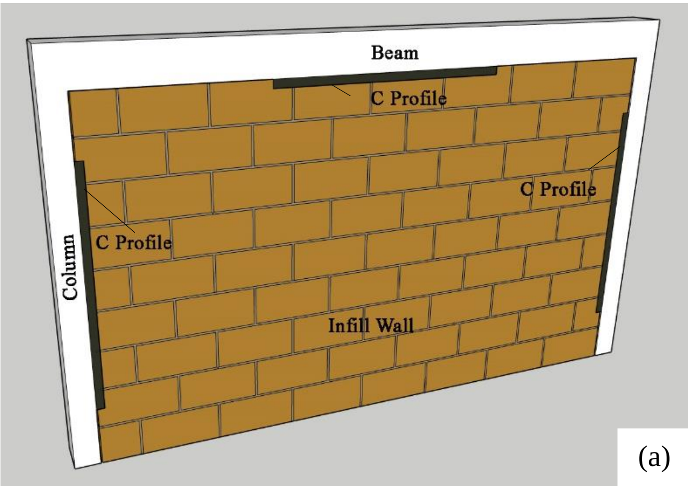


Figure 5. *An example of a wall produced in (a) BB and (b) BJR types*

In BB, which is used in the USA [42], Canada [43], New Zealand [44], and Mexico [45], RM beams made of grout-filled hollow rectangular units have horizontal reinforcing bars inserted into them. It has been demonstrated that these reinforcements may provide the brickwork with both high strength and appropriately ductile behavior. Specifically, the steel reinforcing makes the increased wall deformation capability possible. However, because the distribution of seismic activities depends on the stiffness ratio between the two materials, the reinforcement's contribution may be eliminated if it prematurely separates from the masonry [46]. Regarding the effect of the vertical reinforcement ratio, it has been shown that shear strength improves with an increase in this ratio [47]. However, because diagonal cracking predominates at medium to high levels of vertical pre-compression, the advantage of the vertical reinforcement ratio on the lateral strength is not apparent [48]. Conversely, a higher vertical reinforcement ratio does not have an impact on the walls' rigidity or displacement ductility [49]. The presence of BJR augments the in-plane deformation and ductility capacity, as well as the resistance to out-of-plane horizontal bending of the masonry wall. Aerated concrete infill walls' seismic performance was examined in a study by Halici et al. [50]. It highlighted how critical bed-joint reinforcing is to improving the out-of-plane seismic performance for both cord-type and flat truss constructions. Faridmehr et al. [35] applied the BJR technique on briquette walls. These walls contain vertical reinforcement and bed-joint reinforcement. Within the scope of the study, the inside of the wall elements through which the vertical reinforcements pass were filled with mortar. In addition, the vertical reinforcement within the infill wall is embedded in the upper and lower load-bearing reinforced concrete elements. The parametric study demonstrates that BJR significantly impacts the shear strength of walls.

A few experimental studies on masonry walls reinforced with textile-reinforced mortar coatings or prefabricated composite meshes demonstrated how these reinforcement systems can improve masonry's out-of-plane resistance while also markedly increasing its capacity to withstand plastic deformation [51-54]. Still, a crucial subject for a successful material design is the masonry-matrix bonding capabilities [55]. Shear bond tests [56, 57] are commonly based on tiny masonry samples (single bricks, stone units, or masonry wallets) to which the reinforcement is placed on one or both sides for a predetermined area. These tests evaluate the interaction between the composite material and the masonry substrate. Therefore, it is essential to provide a strong bond for painting or repointing (such as by cleaning, saturating, or treating the masonry surface mechanically or chemically) and, if required, appropriately size connections [58]. Flexible joint connections applied between the infill wall and frame are a technique being researched to increase frame ductility. However, the gaps left between the infill wall's and the frame do not affect the out-of-plane behavior. This may cause the walls inside the frame to topple out of the plane under horizontal loads. Researchers have reported that the experiments with frames using angle iron or sliding connectors filled with flexible material in columns positively affected the performance values of the wall [59]. In the Turkish Building and Earthquake Regulation (TBDY 2018) [60], the "flexible joint connection" option was first introduced to prevent damage to infill walls and to prevent any adverse effects it may cause in structural behavior. If the 2018 TBDY infill wall is isolated from the frame system with flexible joints, the allowed relative storey drift in the building increases by two times. The flexible connection detail example presented in Information Annex 4C in the 2018 TBDY is shown in **Figure 6**.



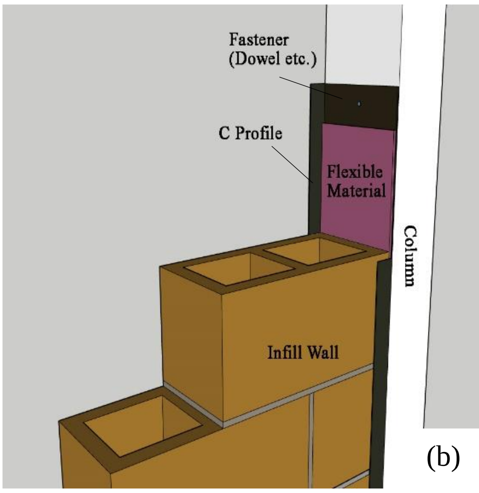


Figure 6. *Infill wall-column flexible connection detail (a) general view (b) detailed view*

In the system shown in Figure 6, the flexible material between the infill wall and column continues along the length of the vertical and horizontal carriers. Flexible materials are placed inside the C-profile, connected to the inner surfaces of the carrier elements with anchors. This system prevents interaction between the infill wall and the column in structures subject to lateral load. The flanges of the C-profile anchored to the surfaces of the load-bearing elements prevent the out-of-plane movement of the infill walls. There are some studies that examine the effect of such anchors placed in infill walls on the infill wall and reinforced concrete frame [61]. It has been stated that applying this technique significantly contributes to the rigidity of the walls. In addition, it has been reported that epoxy-based adhesives will be useful in anchoring such additional profiles to carrier elements.

V. CONCLUSIONS

Infill walls in buildings are widely used worldwide for partitioning and separating rooms, as well as for architectural and commercial purposes. As a result of earthquakes, in addition to the load-bearing systems of buildings, damage may also occur to elements that are not considered load-bearing. One of the damages that occur in buildings after earthquakes is these infill wall damage. As a result of the out-of-plane behavior of the partition walls, direct or indirect loss of life and/or property may occur. Damage to the infill walls that occurred due to the Kahramanmaraş earthquake on February 6, 2023, was observed in residential and industrial buildings and especially in transformer structures that provide vital electricity distribution. The damage observed on the walls was found to be workmanship and design defects. Within the scope of this study, deficiencies in the certification process in the field of masonry were seen as the root of workmanship defects. Recommendations were made for the deficiencies in the certification process and for improving the process for the future. Infill walls shouldn't exhibit out-of-plane behavior, causing loss of life and property and for escape routes to be blocked due to falling walls. With today's technology and engineering, it is possible to positively improve the energy consumption capacity and out-of-plane behavior of infill walls. In this context, a detailed literature review was conducted, and the different techniques used were explained in the article. In addition, explanations were given regarding the force of the regulation in Türkiye. Within the scope of the study, the compatibility of regulations and national qualifications in the direction from the design to the production of infill walls is revealed.

It has been observed that the exam project used as a scenario by MYK has no similarities with the actual wall production in the field. In particular, it has been observed that the walls were built on any flat ground and were manufactured without any frame systems around them. It has been observed that the dimensions of the walls requested from the candidate are far from the actual dimensions. The candidates are not supervised while performing the application directly on the construction site. There needs to be instruction showing candidates how to manufacture a wall higher than the generally used floor height. There is no information regarding the production of lintels used in window and door openings by the candidates in the relevant regulations. In the exam project given to the candidates, there are no details on how the infill walls will be connected/clamped to the reinforced concrete elements. Due to this lack of knowledge, deficiencies occur in the field practices of certified masons.

When international standards on masonry are examined, there are many methods to delay undesirable out-of-plane behavior in infill walls and increase the bearing capacity of in-plane behavior. Within the scope of this study, it has been seen that the reinforcement used in vertical and horizontal directions in wall production, especially the techniques anchored to the carrier system, are benefical. While these techniques increase construction and labour costs, they also improve infill wall behavior. It is known that this type of reinforcement is used in areas at risk of earthquakes. It is understood that the system recommended within the scope of TBDY 2018, which is in force in Türkiye, does not provide sufficient benefit.

As a result of these findings, it is thought that workmanship defects and design errors can be prevented with the following recommendations;

- Candidates who want to get a bricklayer certificate must take their exams in their work area, and the wall to be produced must be of actual size.
- Constructing the application exam specifically to be held within a reinforced concrete frame and including techniques that improve the in-plane and out-of-plane behavior of reinforced concrete elements in the exam project,
- Replacing the connection type recommended in TBDY 2018 with the reinforced infill wall technique is essential.
- There is a need to establish national competence in Türkiye for reinforced infill wall manufacturing and to certify candidates.
- Especially in buildings built in regions with high earthquake risk, the manufacture of infilled and reinforced infill walls on the walls facing escape halls should be made mandatory by regulation. Epoxy injection of anchors should be used in reinforced wall manufacturing.
- It should be mandatory to design the walls surrounding vital structures, which will be used to meet needs such as energy after the earthquake, or the walls surrounding the compartments where vital equipment is located, as reinforced concrete shear walls. The walls of such buildings in earthquake-prone areas should be strengthened as soon as possible or converted to reinforced concrete shear walls.

They are reviewing the regulations and national qualifications to keep the application and designer on the same denominator. People who have reached a certain level of professional qualification must take their place in the construction industry by obtaining a certificate, and therefore, each stakeholder in the sector must pass through a measurement-evaluation system with a confident quality assurance and have a share in this severe organization. People who have already successfully completed these processes must be periodically inspected by the relevant institutions.

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