Journal of Architectural Sciences and Applications
JASA 2023, 8 (Special Issue), 222-240
Research article
e-ISSN: 2548-0170
https://dergipark.org.tr/en/pub/mbud

A Graphical Ontology-Based Method for Rapid Damage Assessment of Stone Cultural Heritage Structures After an Earthquake: A Case Study of Mor Petrus and Mor Paulus Church, Adıyaman/Türkiye

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Abstract

To prevent further damage to historical structures and elements after an earthquake, it is important to implement temporary interventions that aim to stabilize and support the affected area. Within this scope, it is crucial to promptly identify the areas in historical buildings that require urgent intervention. The aim of this study is to design a standardized assessment method that provides an objective evaluation for post-earthquake damage detection in stone cultural heritage structures, independent of subjective assessments, and can be easily and quickly implemented in the field. For the proposed method, the heavily damaged Mor Petrus and Mor Pavlus Church in Adıyaman, which was affected by the 2023 earthquakes centered in Kahramanmaraş, is used as a case analysis. The results of the study demonstrate that the presented method is beneficial for detecting damages in masonry church structures after an earthquake. The graphical ontology-based method followed in the study allows for the identification of damages at the level of structural elements and focuses on areas with urgent damage.

Keywords: *Earthquake, rapid damage assessment, ontology, post-earthquake interventions, stone cultural heritage.*

Deprem Sonrası Taş Kültürel Miras Yapılarının Hızlı Hasar Tespiti İçin Grafiksel Ontoloji Tabanlı Bir Yöntem: Mor Petrus ve Mor Paulus Kilisesi Vaka Çalışması, Adıyaman/Türkiye

Öz

Deprem sonrası tarihi yapıların ve elemanlarının daha fazla zarar görmesini engellemek için, hasarlı alanı stabilize etmeyi amaçlayan müdahalelerin uygulanması önemlidir. Bu kapsamda tarihi yapılarda acil müdahale gerektiren alanlarının kısa sürede tespit edilmesi gerekmektedir. Çalışmanın amacı taş kültürel miras yapılarında deprem sonrası hasar tespiti için sübjektif değerlendirmelerden bağımsız, standartlaştırılmış bir değerlendirme sağlayan, sahada uygulanabilen kolay ve hızlı bir yöntem tasarlamaktır. Önerilen yöntem için, Adıyaman'da bulunan ve 2023 yılı Kahramanmaraş merkezli depremlerde ağır hasar alan Mor Petrus ve Mor Pavlus Kilisesi, vaka analizi olarak kullanılmıştır. Çalışma sonuçları araştırmada sunulan yöntemin, deprem sonrası kagir kilise yapılarında hasarları tespit edebilmekte faydalı olduğunu göstermektedir. Çalışmada izlenen grafiksel ontoloji tabanlı yöntem, hasarın yapı elemanları bazında tespit edilebilmesi ile acil hasarlı bölgelere odaklanmayı sağlamıştır.

Anahtar kelimeler: Deprem, hızlı hasar tespiti, ontoloji, deprem sonrası müdahaleler, taş kültürel miras.

Citation: Karataş, L. & Dal, M. (2023). A graphical ontology-based method for rapid damage assessment of stone cultural heritage structures after an earthquake: A case study of Mor Petrus and Mor Paulus Church, Adıyaman/Türkiye. *Journal of Architectural Sciences and Applications*, 8 (Special Issue), 222-240.
DOI: https://doi.org/10.30785/mbud.1310031

Received: *05/06/2023 –* ***Accepted:*** *11/09/2023*

1. Introduction

The earthquakes centered in Pazarcık and Elbistan, which occurred in Kahramanmaraş in Türkiye in 2023, were characterized by high peak points in the low-period range on the spectra (Mw7.7, focal depth=8.6 km, and Mw7.6, focal depth=7 km), indicating vertical directional forces. As a result, masonry structures, which constitute a significant portion of the cultural heritage inventory, were subjected to high forces, leading to one of the most severe and extensive damage scenarios in the history of earthquakes in Türkiye. The earthquakes with significant vertical forces caused extensive damage and even the collapse of numerous historical monuments in the affected areas (AFAD, 2023).

After the earthquakes, historical structures in the region underwent rapid visual inspections by various expert teams. However, the damage assessments conducted during these inspections relied entirely on the subjective views of the examining team, leading to a lack of effective and rapid post-earthquake damage detection in cultural heritage structures. In this regard, the Assessment and Evaluation Committee for the February 6, 2023 Earthquakes, organized by the Chamber of Architects of TMMOB (Union of Chambers of Turkish Engineers and Architects) in Hatay, expressed the following drawbacks resulting from the lack of emergency temporary interventions in monumental structures: "The Government Building in Hatay was still standing after the initial earthquake, although it had suffered severe damage. Almost all four walls were still intact. However, after the recent earthquake with a magnitude of 6.4, we witnessed that two walls of the structure had completely collapsed. If we had been able to support the remaining sections of the building with emergency protection interventions, perhaps we could have prevented that destruction. Even with any subsequent tremors, we could have kept the parts that were still standing preserved until potential future restoration works. These statements emphasize once again the necessity of developing new methodologies to enable rapid and objective damage assessment for the protection of cultural heritage structures from additional harm in the aftermath of earthquakes" (TMMOB Mimarlar Odası 6 Şubat 2023 Depremleri Tespit ve Değerlendirme Heyeti, 2023).

After an earthquake, it is important to have a field-applicable, easy, and rapid method that provides a standardized evaluation independent of subjective assessments. This allows for the swift implementation of emergency safety measures for the affected structures (D'Ayala, 2011; Fodde, 2017). Such a method facilitates the ability to halt ongoing damage during aftershocks and determine the most suitable temporary interventions (Alkan & Orman, 2016; Aybek, Ayan & Kuzgun, 2018; Karacabeyli & Çelik, 2015). Various studies have been conducted in the literature to achieve rapid post-earthquake damage detection. D'Ambrisi & Castellazzi (2016) developed a method based on fieldwork and visual inspections, where structures were classified into different damage levels based on criteria such as damage types and severity. They also prepared forms and checklists for rapid assessment. According to Coïsson, Ferretti & Lenticchia (2017) a damage mechanism table specifically for stone fortifications, which included graphical explanations and selections. They reported that this method significantly expedited the damage detection process. It has been explained that the proposed tables with graphical explanations focus on damage mechanisms rather than the entire building, enabling the establishment of a priority list. This prioritization allows for a focus on the most urgent elements for interventions, enabling the strengthening of more structures within a specific budget. Numerous studies in the literature emphasize the necessity of creating these rapid assessment damage forms for different types of structures in different geographical locations (Slejko, Riuscetti, & Cecić, 2018; PCM-DPC-MiBAC, 2006; Guidelines, 2007; Coïsson & Ottoni, 2012).

The motivation of the research stems from the emphasized need in the literature and the expressed urgency by the Assessment and Evaluation Committee for the February 6, 2023 Earthquakes, organized by the Chamber of Architects of TMMOB, for the development of methods that accelerate emergency protection practices following earthquakes. In this context, the aim of the study is to design a field-applicable, easy, and rapid method that provides a standardized evaluation independent of subjective assessments for post-earthquake damage detection in stone cultural heritage structures. The proposed method focuses on masonry church structures and is based on observing recurring damage mechanisms. Within this scope, the damage mechanisms of masonry church structures have been investigated, classified, and encoded in the literature. These damages have been transformed into graphical outputs and used to create an ontological-based schematic damage assessment form.

For the proposed method, the heavily damaged Mor Petrus and Mor Pavlus Church in Adıyaman, affected by the earthquakes centered in Kahramanmaraş in 2023, was used as a case study. It is hoped that the presented method will provide guidance to expert teams in determining the temporary emergency intervention needs, planning for repairs, and strengthening structures against seismic risks, thereby resulting in significant time and cost savings.

1.1. Mor Petrus and Mor Paulus Church: History, Architectural Features, and Importance

Mor Petrus and Mor Paulus Church located in Mara Mahallesi, Adıyaman city center. Also known as St. Paul Church, it is currently used by the Syriac community and is the only active church in Adıyaman. The Syriac Metropolitan Center is based in Adıyaman, covering the provinces of Gaziantep, Şanlıurfa, Malatya, Elâzığ, Adana, Mersin, and Antakya. For this reason, Adıyaman Mor Petrus and Mor Paulus Church is referred to as the "Metropolitan Church of the Surrounding Provinces." The church is utilized as a place of worship by the Syriac community in the neighboring provinces and serves the Christians in the region (Öztürk, 2019; Altuğ, 2018).

The church, estimated to have been built in the 4th or 5th century, has a spatial layout of a three-aisled basilica extending in the east-west direction. The wooden altar located in the apse was constructed by Syriac craftsmen from Urfa in 1890 and has recently undergone restoration. The upper floor of the narthex, located in the west, opens into the interior space. According to the Syriac inscriptions found on the entrance door and inside the church, it underwent repairs in 1888 and 1905. The church was restored in 1905 and 1953. Starting from the late 19th century and the beginning of the 20th century, the dwindling number of Syriacs in Adıyaman resulted in disruptions in religious services at the church. The significant decrease in population since 1964 has had a negative impact on the church. Remaining vacant for a long time, the church was reopened for worship in 2001. In 2001, both the interior and exterior restoration of the church, the construction of the Metropolitan Administrative Building, landscaping, and cemetery maintenance and repairs were completed (Dursun, 2016). Adıyaman, which was affected by the earthquakes centered in Kahramanmaraş, also suffered severe damage to the Syriac Ancient Metropolis Mor Petrus and Mor Paulus Church (Figure 1).

Figure 1. Adıyaman Mor Petrus and Mor Paul Church before (left) and after (right) earthquake (Karataş photo album, 2023)

2. Material and Method

The research was conducted in three stages: literature review, field study, and office phase. Within the scope of the literature review, a detailed investigation was conducted on the types of structural components in stone masonry church buildings constructed with stone as the building material in different geographical regions worldwide, as well as the types of damages that occur in these components after earthquakes. Based on the literature data, the classification of post-earthquake damage mechanisms was carried out on a structural element basis. In the next step, the classified damages were encoded to prepare visual damage assessment forms necessary for the rapid evaluation of post-earthquake damages in stone masonry church buildings in the field. Subsequently, the codes representing the types of damages that occur in stone masonry church buildings after earthquakes were transformed into visual schemas. As part of the conversion of codes into visual schemas, graphical representations were created based on the pre-earthquake images of the structure to illustrate the encoded damage mechanisms.

The graphical schemas were created and colored using Archicad 26, an architectural drawing software program. Based on all the collected data, a graphical ontology-based damage assessment form was developed to enable the rapid detection of post-earthquake damages in stone masonry church buildings. The generated post-earthquake damage assessment forms are based on a problem classification derived from a literature review conducted at the structural element level.

This approach is grounded in the existence of recurring damage mechanisms at the level of structural elements, which serves as a basis for understanding the seismic behavior of masonry church buildings. The graphical ontology-based damage assessment form prepared within the scope of this study is a tool that can be utilized for identifying post-earthquake damages in stone masonry church buildings in different geographical regions (Table 1). In the second stage, field visits were conducted to assess the current condition of the Adıyaman Mor Petrus and Mor Pavlus Church, where the prepared form would be implemented for post-earthquake assessment. The researchers themselves carried out the documentation of the church, systematically photographing the structure. Additionally, the building was observed in the field, and the identified post-earthquake damages were marked on the graphical form prepared in the previous stage. The processed damage assessment form is presented in Table 1.

The structural elements observed in the stone church building in the form include: (1) foundations, (2) walls, (3) columns (4) floors, (5) roofs, and (6) auxiliary elements (arches, decorative elements, chimneys, corbels, muqarnas, Turkish triangles, etc.). The observed seismic damage mechanisms in rubble stone church structures were examined within six subgroups based on the components of the structure. The damage mechanisms are defined as follows:

I. Damages Observed in Foundations

- Settlement of the foundation soil (1a);

II. Damages Observed in Walls

- Crumbling or loss of stone walls (2a);
- Deterioration of the cladding (2b), especially in double-walled stone structures;
- Damage between perpendicular walls caused by different material usage, inadequate connections, previous insufficient reinforcement interventions, or lack of maintenance (2c);
- In-plane sliding cracks in the main body of the wall (2d);
- Shear cracks in the main body of the wall (2e);
- Toppling of the entire wall or a portion of it out of the plane (2f);

III. Damages Observed in Columns

- In-plane sliding cracks (3a);
- In-plane torsion or shear cracks (3b);

• Toppling (3c);

IV. Damages Observed in Floors

• Crumbling or loss of the stone layer

V. Damages Observed in Roof

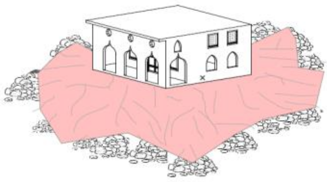
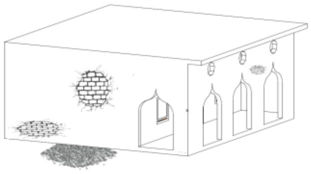
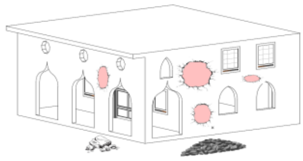
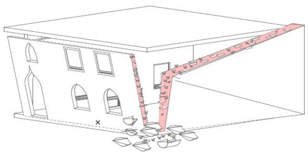
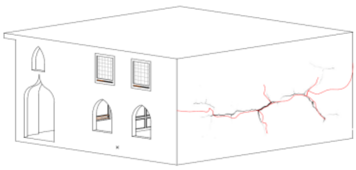
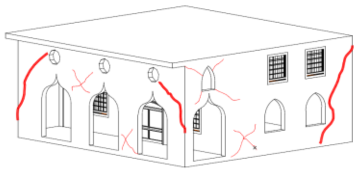
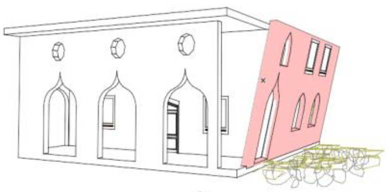
• Damage caused by the roof at wall corners or on top of the main wall (5a)

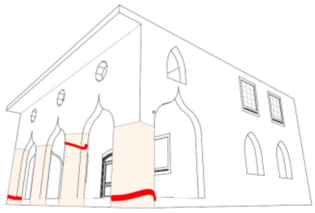
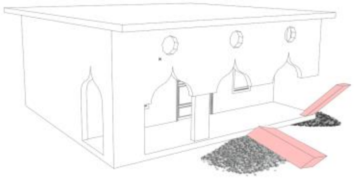
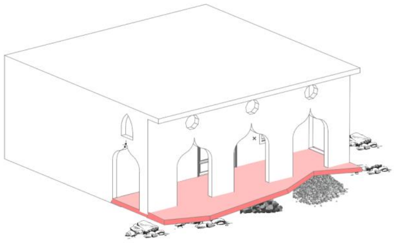
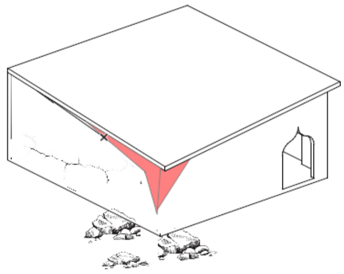
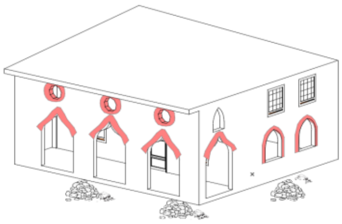
• Shear damage between the roof and walls (5b), especially due to previous insufficient reinforcement interventions or lack of maintenance

VI. Damages Observed in Auxiliary Elements

• Crumbling or loss of stone elements

Table 1. A graphical ontology-based post-earthquake damage assessment form designed for stone church structures

Code	Components	Definition	Schema	Yes/No
(1)	**Foundation**	Settlement of the foundation soil		**X**
		Deterioration or loss of stones in stone walls (2a);		**+** **+**
		Weathering of the surface coating (2b), especially in double-walled stone walls.		**+**
(2)		Different material usage, inadequate connections, or insufficient strengthening interventions in the past, or damages caused by neglect, between perpendicular walls (2c);		**x** **+**
	Walls	In-plane sliding cracks in the main body of the wall (2d);		**+**
		Shear cracks in the main body of the wall (2e);		
		Toppling of the entire wall or a portion of it out of plane (2f).		

(3)	**Columns**	In-plane sliding cracks (3a);		+ +
		In-plane torsion or shear cracks (3b);		X
		Toppling (3c).		
(4)	**Slabs**	Deterioration or loss of stone layer in the slab.		+
(5)	**Roof (Vault, dome, flat roof)**	Damage caused by the roof at wall corners or on top of the main wall (5a);		+
		Cutting damage between the roof and walls (5b), especially when strengthening interventions have been performed in the past.		+
(6)	**Auxiliary Elements (Arch, Decorations, Chimney, Cornices, etc.)**	Fracturing or loss of stone elements		+

The findings of the research are presented in the form of damage descriptions based on the observed damages marked on the form during field inspections. Examples from the post-earthquake images obtained in the field are provided to illustrate the identified damages. These damages are further explained using the encoded damage graphics included in the form.

3. Findings and Discussion

3.1. Damage Observed in the Foundation

During the field research, no instances of settlement of the foundation soil (1a) were encountered in the foundation of the structure, as indicated in the prepared damage assessment form within the scope of the study (Table 1).

3.2. Damage Observed in the Walls

The earthquake-induced damages observed in the walls during the field research are detailed as follows:

During the field investigations, numerous instances of fragmentation or loss of stone in the wall elements of the structure (2a) were identified. The stone elements of the structure exhibited joint voids resulting from poor maintenance prior to the earthquake, leading to inadequate adhesion between the stones and mortar. Particularly, this condition indicates that the empty spaces formed as a result of voids observed in the vertical joints of the walls, caused by poor maintenance, reduced the out-of-plane bending stiffness of the walls during the earthquake, thereby increasing the extent of damage (Figure 2).

Figure 2. Fragmentation or loss of stone materials in the wall (2a)

During the field investigations, it was determined that the load-bearing walls of the rubble masonry structure were constructed using a double-walled construction technique with different types of stone materials. Observations revealed a significant amount of pre-earthquake deterioration, primarily due to neglect. In particular, surface damages on the walls were frequently encountered in the worn-out sections. Additionally, due to the use of the double-walled construction technique, the weakened cut stones at the top have separated from the outer cladding, which consists of the less resistant rubble stones. The combination of different types of materials, such as rubble stones and cut stones, along with the wear and tear the structure has undergone over the years, has led to insufficient adhesion within the wall structure. As a result, the differential behavior of the materials on the inner and outer surfaces of the walls has caused extensive damage (Figure 3).

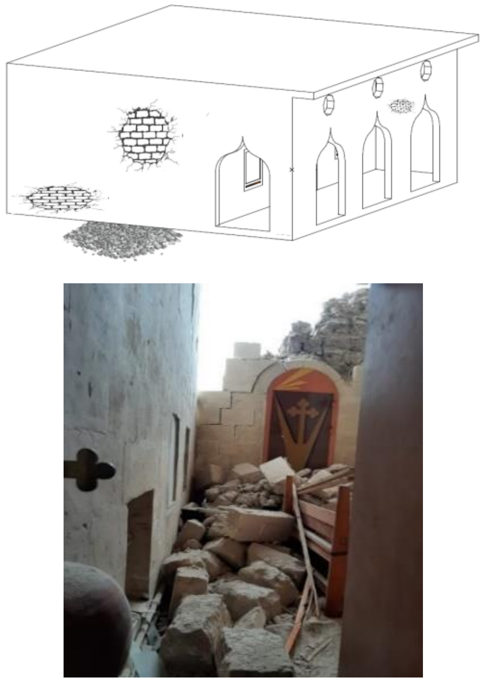


Figure 3. Weathering of the surface coating (2b), especially in double-walled stone walls

The separation of perpendicular walls with weakened adhesion due to neglect and the use of different types of materials, such as rubble stones and cut stones, has resulted in collapse (Figure 4). The main cause of this type of damage is generally attributed to the tensile stresses generated when the tensile strength of the walls is exceeded (Giuffrida & Deodatis, 2013; Speranza, 2019; Galán-Marín et al., 2020).

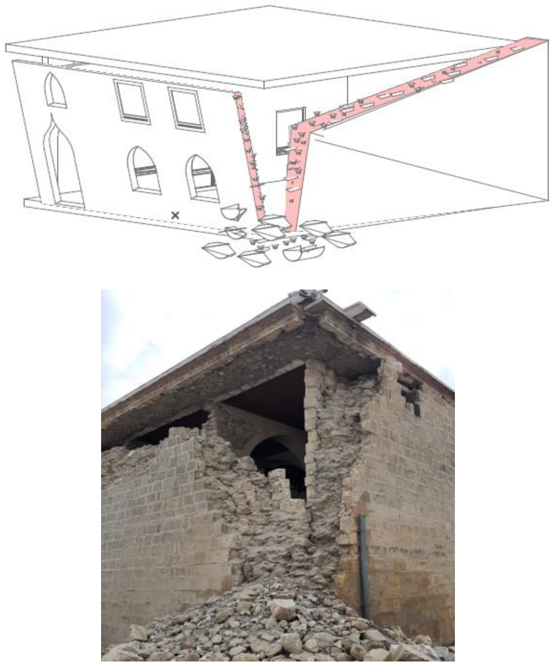


Figure 4. The damage observed between perpendicular walls due to the use of different materials or inadequate connections (2c)

During the field investigations, numerous instances of diagonal shear damage were identified in the wall elements of the structure. The stone elements of the structure exhibited joint voids resulting from poor maintenance prior to the earthquake, leading to inadequate adhesion between the stones and mortar. In particular, the empty spaces formed as a result of voids observed in the vertical joints of the walls, during the earthquake, reduced the out-of-plane bending stiffness of the walls, resulting in increased damage. Prior to the decrease in lateral resistance during the earthquake, characteristic diagonal cracks, also known as diagonal tensile damage, form in the walls. These diagonal cracks can propagate along the joints or directly affect the masonry units, or both. In rubble masonry walls, shear-in-plane damage is common, and when this type of damage occurs in an X shape, it is referred to as double diagonal shear cracks (Figure 5). No in-plane sliding cracks were observed in the main body of the walls.

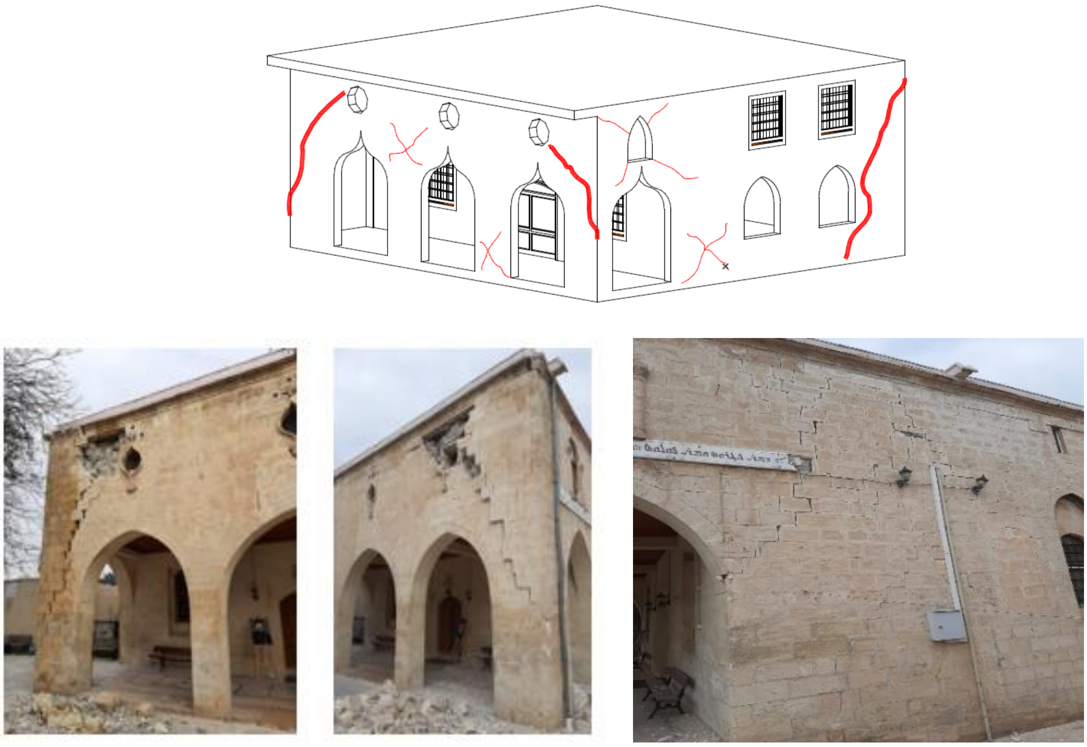


Figure 5. Shear cracks in the facade wall (2e)

During the post-earthquake damage assessment conducted in the earthquake-affected region, bending damage was also identified in some of the load-bearing walls of the masonry structure. Due to increased lateral forces or displacement demands, the lower sections of the masonry panels experience tensile cracks, and until crushing occurs in the compression zone at the base, overturning is detected due to lack of rotational restraint (Figure 6).

In masonry structures, when vertical loading and axial compressive stresses are within normal limits, a wall will collapse either by shear failure or by bending. Shear collapse occurs when the principal tensile stress in the wall exceeds the tensile strength, resulting from combinations of vertical and horizontal loads (Gülkan & Türker, 2012; Lourenço & Roca, 2006).

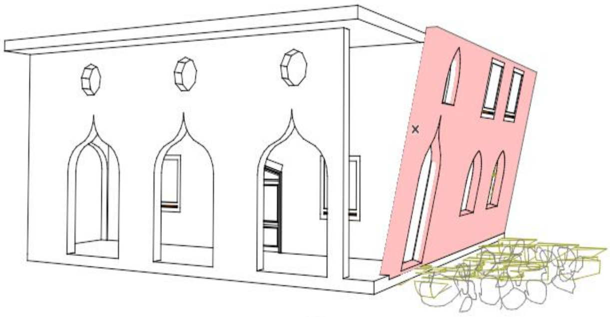


Figure 6. The out-of-plane overturning of the entire wall or a portion of it (2f)

In the Figure 7, the shear failure observed at the column bases is primarily caused by the shear stress resulting from exceeding the tensile strength of the structural element (Figure 7).

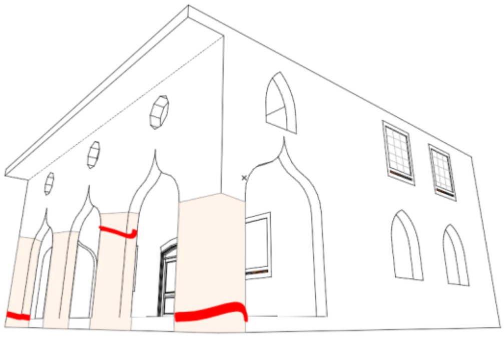


Figure 7. In the column bases, in-plane sliding cracks (3a) are observed

Additionally, improper material connections or material deterioration over the years due to neglect in maintenance lead to structural elements being more vulnerable to horizontal loads from earthquakes (Figure 8).

Figure 8. In the column bases, in-plane torsion or shear cracks (3b) are observed

During the field investigations, no evidence of overturning (3c) damage was found in the column bases of the structure.

3.4. Damage Observed in Floors

No damage was found in the intermediate floorings, wall corners, or on top of the main wall caused by the roof (Figure 9).

Figure 9. Example images of intermediate floor surfaces after an earthquake

However, it has been determined that there is fragmentation and loss of pieces in the ground floor surface of the structure where it comes into contact with the ground soil, due to various heavy parts falling from the structure (Figure 10).

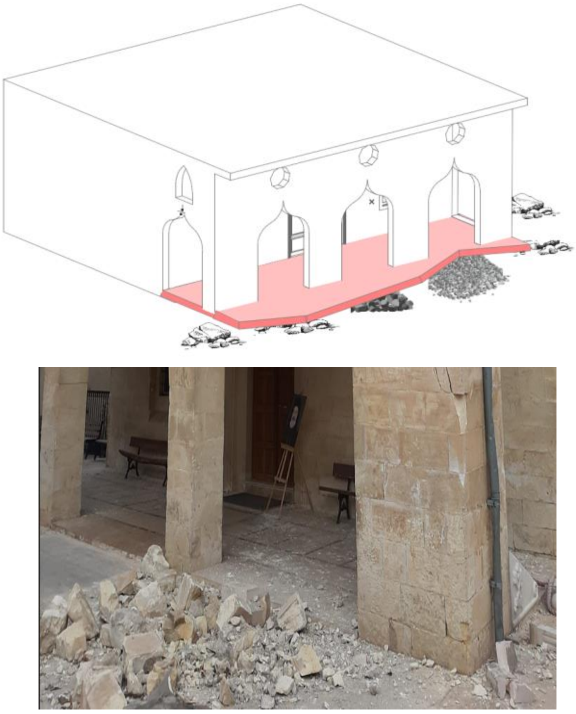


Figure 10. Fragmentation and loss of pieces (4a)

3.5. Damage Observed in Roof

Damage caused by the roof is observed on top of the structural wall and at the corners of the walls (Figure 11).

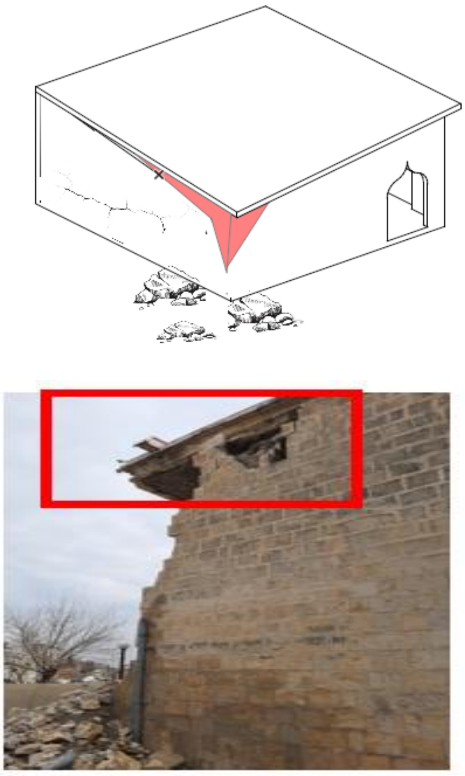


Figure 11. Damage caused by the roof at wall corners or on top of the wall (6a); Shear damage between the roof and the walls (6b), particularly due to inadequate reinforcement interventions in the past or lack of maintenance

3.6. Damage Observed in Auxiliary Elements

In the structure, it has been determined that inadequate reinforcement interventions in the past or the weakening of material strength due to lack of maintenance have resulted in damage to some decorative elements, such as flaking or loss of parts (2a), caused by the effects of the earthquake (Figure 12).

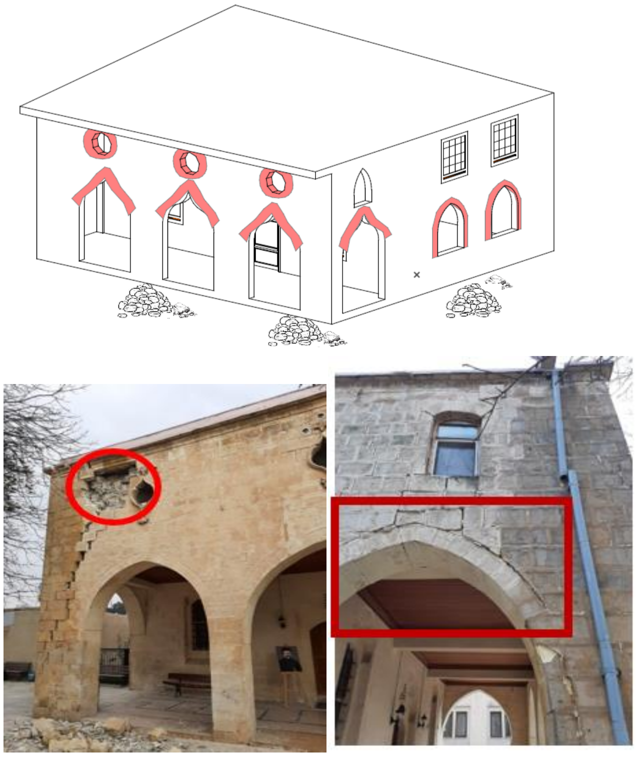


Figure 12. Damage caused by flaking or loss of parts (2a) in the element; particularly resulting from past insufficient reinforcement interventions or weakening of material strength due to lack of maintenance, and occurred during the earthquake

4. Discussion

The aim of the research is to design a standardized assessment form that provides an objective evaluation of the level of earthquake damage in church-type structures, using the Adıyaman Mor Petrus and Mor Pavlus Syriac Church as a case study. This assessment form aims to be significantly independent from subjective evaluations and to facilitate easy and rapid data collection in the field.

Based on the findings of the research, it has been determined that the most significant damage in the masonry structure occurs as a result of out-of-plane behavior, also known as the first mode of damage. In the majority of the damaged structures, it was observed that the weakening of material adhesion due to neglect and lack of maintenance contributed to the damage. In the case of walls constructed with double layers and using different types of materials in their layers, it was observed that the mortar in the cladding sections deteriorated, resulting in a loss of strength. This weakened outer layer of the walls detached from the wall surface and fell off due to the seismic effects. Cracks were also observed in the areas where stress accumulation was most intense as a result of the out-of-plane behavior of the masonry walls, leading to displacements perpendicular to the direction of seismic motion. Immediate intervention is required for the areas where there are loss of parts and out-of-plane overturning of walls. Urgent action is necessary in these areas.

Within the scope of the study, with the classification of structural elements in the building, it was possible to determine the areas that require immediate intervention and prioritize them. The results of the study show that the proposed method of prioritizing interventions based on damage mechanisms, focusing on the most vulnerable elements, allows for the strengthening of more structures within a specific budget. This approach enables a more efficient allocation of resources by targeting specific areas in need of reinforcement, rather than addressing the entire structure as a whole. The obtained results of this study support the findings of D'Ambrisi & Castellazzi (2016), who demonstrated the effectiveness of their classification based on criteria such as structural elements in providing ease of use in rapid assessments through forms and checklists. It confirms that the approach used in this study, which focuses on damage mechanisms and prioritizes them, allows for a quick identification of the post-earthquake condition. Additionally, the inclusion of graphical illustrations in the study enables a targeted analysis of specific damage mechanisms and the establishment of a prioritized list. This finding aligns with the observations made by Coïsson et al. (2017), who highlighted the significant time-saving benefits of incorporating graphical representations in post-earthquake damage assessments.

The results obtained in this study are specific to churches. This finding highlights the need to tailor the method to different types of structures in different geographical areas, considering that it provides ease and speed in determining the types of damage that occur after an earthquake. This finding reiterates the importance emphasized in many studies in the literature, which suggest the necessity of developing and testing damage assessment forms specifically designed for different types of structures in different geographic locations (Slejko et al.,2018; PCM-DPC-MiBAC 2006, Guidelines, 2007; Coïsson & Ottoni, 2012; Fuentes et al., 2019)

Furthermore, another significant finding identified during the field surveys conducted in the region is the deterioration of mortar material in the masonry structure's stone joints over the years, resulting in inadequate adhesion between the stones and mortar in certain parts of the structure. It has been observed that under the influence of earthquakes, the mortar elements lose their strength before the stones, particularly due to this condition. It has been concluded that the weakness of the material in these areas leads to a greater impact of seismic behavior on the structure. Typically, it has been observed that masonry walls start to lose their strength due to shear, resulting in the loss of stone elements.

According to the literature, there are many studies that identify and emphasize the importance of this issue. In a study by Casolo & Uva (2012), which examined the seismic response of two Italian churches, it was found that the observed damaged mechanisms were predominantly crack forms along mortar joints. Bailey,Dizhur, Trowsdale, Griffith & Ingham (2015) highlighted that in masonry structures, various connection behaviors, including the behavior of materials and structural systems, significantly affect seismic performance. The study strongly emphasizes the consideration of connections between architectural elements and material-material interactions in the evaluation of seismic behavior, and suggests that researchers should develop more effective strategies for strengthening masonry structures by understanding these factors. Alkenanee & Alrudaini (2023) addressed the impact of factors such as the strength of local materials and the quality of mortar on the seismic performance of masonry structures. The results demonstrated that the strength of stone and mortar significantly affects the seismic performance, showing that using cement-sand mortar with a strength of 15.2 MPa instead of lime mortar with a strength of 3.1 MPa can increase the building's shear capacity by 20%. Additionally, several studies explain that the seismic vulnerability of masonry structures in cities with low to moderate seismic intensity can be reduced by using relatively high-strength mortar and bricks and adhering to regular plan layouts. Our study confirms the observation, as described in many studies in the literature, that the weakness of inter-material connections in masonry structures has a greater impact on seismic behavior. This finding is among the observed issues in masonry structures worldwide after earthquakes (Mistretta, Stochino & Sassu, 2019; Lourenço, 2018; Oyguc, 2017; Öztürk, 2023; Koç, 2016). In this regard, our study highlights the importance of considering the connection and consolidation of different architectural elements and materials in repair and strengthening works in historic churches.

The loss in the connection between the masonry materials has significantly contributed to the formation of diagonal cracks and, subsequently, collapse, especially in certain walls and junctions. This situation emphasizes the urgent need, as highlighted in numerous studies in the literature regarding the sustainability of historical structures (Karkaş & Acun Özgünler; 2022; Karataş at al.,2023; Usta, 2019), to establish monitoring plans such as HBIM (Historical Building Information Modeling) for controlling the progression of damage, analyzing the structural behavior of buildings after earthquakes, and implementing temporary interventions. This finding underscores the necessity of such measures for ensuring the preservation of monuments in the face of seismic events.

4. Conclusion and Suggestions

The research utilized the Adıyaman Mor Petrus and Mor Pavlus Ancient Syriac Church as a case study to develop a standardized assessment form that provides an objective evaluation of building damage, independent of subjective assessments. The damage assessment form designed in this study is easy to fill out in the field and offers a quick and efficient way to identify earthquake-induced damages in masonry church structures worldwide.

The methodology employed focuses on identifying damages at the level of structural elements, enabling a targeted approach to prioritize urgent areas requiring intervention. The identification of areas in need of immediate attention is expected to provide significant time and cost savings for expert teams in the field, allowing for prompt intervention in order to minimize further losses to the buildings.

The observed damage mechanisms in the structure primarily include the collapse of certain facade walls due to external movements, partial wall collapses, shear cracks, loss of elements in auxiliary components, and crushing of supports. Urgent intervention is required for the building elements that have experienced loss of parts, partially collapsed walls, and out-of-plane overturning. Immediate action is necessary in these areas to prevent the original values of the structure from being lost within the debris piles and to avoid further losses in these severely damaged regions. Failure to address these issues promptly could lead to even greater losses in those areas.

To prevent further losses in the structures, temporary interventions should aim to stabilize and support the buildings and their components. Traditional wooden bracing can be employed intensively to prevent the collapse of facades and walls. Wooden braces provide direct load-bearing effects on the structural elements, partially restoring their structural stiffness, and can be removed later if necessary.

Alternatively, where feasible, connecting sections or even entire buildings can effectively prevent out-of-plane overturning. For this purpose, steel cables or more modern polyester straps can be used. Bands and cables connect orthogonal walls to each other and facilitate the distribution of loads from orthogonal walls to parallel walls in the direction of lateral seismic forces. From a logistical standpoint, they allow for the preservation of accessibility around the building. Additionally, they are both practical and can be removed more quickly compared to traditional supports (Karataş & Bayhan, 2023; Caglar et al., 2023).

When collapse and out-of-plane damage are prevented, shear cracks in the walls can be reinforced with wooden grids and bands. Especially for supporting structural elements in the field, wood elements or metal profiles, strips, or cables can be used and should be performed by firefighting personnel. More complex applications, such as the use of stabilizing grout, should involve the participation of expert teams (Modena et al., 2011).

In the subsequent stage of permanent interventions, the following types of applications are necessary for the structure (Dal & Ayhan, 2020):

• Improving connections to activate box behavior of the structure

• Enhancing adhesion in stone material joints

• Increasing the strength and compactness of the walls

• Establishing a structured monitoring policy specific to the structure, such as HBIM (Historical Building Information Modeling).

The aim of the research is to design a standardized assessment form that provides an objective evaluation of the level of earthquake damage in church-type structures, using the Adıyaman Mor Petrus and Mor Pavlus Syriac Church as a case study. This assessment form aims to be significantly independent from subjective evaluations and to facilitate easy and rapid data collection in the field.

Acknowledgements and Information Note

We would like to express our gratitude to the people of Adıyaman who were greatly affected by the 2023 earthquake centered in Kahramanmaraş for their cooperation during the data collection and photography process. We extend our best wishes for a speedy recovery to the entire community of Adıyaman.

Author Contribution and Conflict of Interest Declaration Information

The first author contributed 50% and the second author contributed 50%. There is no conflict of interest.

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