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CRITERIA AFFECTING STRENGTHENING OF STRUCTURES AND A CRITICAL DISCUSSION REGARDING THE ROLE OF CURRENT TECHNOLOGIES IN DETERMINING THE DAMAGES CAUSED BY EARTHQUAKES

ABSTRACT

Buildings suffer from disasters such as earthquakes, floods and fire over time. These disasters cause deterioration and damage to structures. Different techniques are applied according to reinforced concrete, masonry and prefabricated building types. In addition, different strengthening application techniques are used in historical and cultural masonry structures. It should be implemented in a manner that will make the least intervention in building types with historical and cultural heritage and will not harm the identity of the building. Thanks to today's technological possibilities, determining the damage to existing structures becomes faster. Therefore, the aim of the study is to present a comprehensive review of the role of today's technologies in determining the damages caused by earthquakes and the criteria that affect the strengthening of buildings. Appropriate strengthening is applied according to the magnitude of the building damage caused by the possible earthquake. Destructive and non-destructive testing methods are used to determine the damage to the buildings. Especially for buildings with historical and cultural heritage, non-destructive testing methods are used to determine the damage. Thanks to these methods, it is ensured that major damages that may occur in the future are prevented.
Keywords: Reinforcement, Earthquake, Non-Destructive Testing, Advanced Technology

1. INTRODUCTION

The reliability and protection of structures with disasters for years has become an important issue for researchers. As a result of these disasters, the loss of life and property was inevitable due to the lack of durability of the buildings. In 2019, at least 396 natural disasters occurred, in which 11,755 people died, affected 95 million people and cost about the US $ 130 billion (Anonymous 1, 2020). Strengthening applications are made for the reliability and protection of the buildings as a result of the disasters experienced, and the strengthening applications in buildings differ according to the type of building. In this context, different techniques are applied for strengthening studies and damage assessment in reinforced concrete, masonry and prefabricated structures.

In the masonry structures important in terms of historical cultural heritage, strengthening works and damage assessment should be made in a way that the least intervention will be made and will not harm the historical identity of the building. Preservation of historical buildings provides socio-economic benefits for countries as it strengthens cultural identity and revitalizes tourism (Modena, Porto, Valluzzi and Munari, 2013). Buildings with historical cultural heritage should be protected against events such as deterioration over time and natural disasters. In addition, besides preserving the architectural value of the building, the repair and strengthening of immovable artistic assets such as frescoes, balustrades, balconies, etc. are carried out according to the principle of least intervention (Lagomarsino and Cattari, 2015).

Most of the old buildings were not built as earthquake resistant (Thermou and Elnashai, 2006). Causes of damage in these structures; errors may be given due to architectural design, detailing and workmanship (Tesfamariam and Saatcioglu, 2010).

It has been an important issue for many researchers regarding the strengthening and repair applications applied in buildings. Some of the researches on this subject are as follows: Korkmaz (2007), used waste auto tires in retrofitting rural dwellings. She investigated the strengthening of the masonry structure wall by post-tensioning with a rubber band formed by being attached to each other. Caterino, Iervolino, Manfredi and Cosenza (2008), developed the appropriate strengthening strategy for strengthening structures. They examined the application of suitable reinforcement both economically and technically for the reinforced concrete structures that are insufficiently designed against earthquakes, using the multi-criteria decision method. Tekin, Alsancak, Demir and Şeker (2008), in their study, strengthened the beams damaged by the earthquake with prefabricated plates. The 80 mm thick prefabricated plate with longitudinal and transverse reinforcement was bonded to the lower face of the beam with epoxy and the increase in the bearing capacity of the beam was calculated. Peker (2005), investigated the reinforcement applications of masonry and historical buildings with fibre reinforced composite materials. She explained the advantages of fibre reinforced composites applied in the reinforcement of historical buildings over other strengthening methods. Yıldırım, Kalyoncuoğlu, Erkuş and Tonguç (2015), reinforced prefabricated reinforced concrete structures with seismic dampers. They compared seismic damping reinforcement with other reinforcement methods and determined that reinforcement with seismic dampers is more advantageous. Valluzi (2016), studied the effects of composite materials on both the protection of historical buildings and the strengthening of their walls. In addition, he explained the importance of technical developments in the strengthening of historical assets in this study.

In this article, the criteria affecting the strengthening of buildings and the issues regarding the role of today's technologies in determining the damages caused by earthquakes are explained. For this purpose, strengthening techniques in reinforced concrete, masonry and prefabricated building types were investigated. The criteria affecting the strengthening of these structures are determined as architectural, engineering design and repair costs. In addition, in this study, the role of destructive and non-destructive inspection methods and today's technologies in determining the damages caused by the earthquake is included.

2. STRENGTHENING TECHNIQUES

It is important to strengthen structures against earthquake risks and other disasters. By repairing such damages, serious damages of those who use the building are prevented. In addition, strengthening the structure against earthquake risks allows it to be used for a longer period of time. However, high occupancy public buildings such as schools and hospitals pose a greater risk to human life (Caterino, Iervolino, Manfredi and Cosenza, 2008; Thermou and Elnashai, 2006).

Strengthening techniques in buildings differ in reinforced concrete, masonry and prefabricated structures. Strengthening techniques in reinforced concrete structures; strengthening the carrier system elements, reinforcing with steel wrap, reinforcing with fibre reinforced elements, repair with epoxy resin, repair with shotcrete, reinforcement with cast-in-place reinforced concrete curtains and use of repair mortars. Strengthening techniques in historical masonry structures; repair of cracks, strengthening of bearing elements, strengthening of the ground, seismic insulation, reinforcement with carbon-based fibre-reinforced polymer, removal of excess masses, partial or complete renewal of the structure. Strengthening techniques in prefabricated buildings; reinforcement with seismic dampers, reinforcement with fibre-reinforced polymer, reinforcement with steel braces, reinforcement with reinforced concrete filler shear between the columns, reinforcement with external shear wall and diaphragm application. Strengthening techniques of reinforced concrete, masonry and prefabricated building types are summarized in the table below (Table 1) (Aköz, 2008; Gülmez, 2010; Kaplan and others, 2009; Tekin, Alsancak, Demir and Şeker, 2008; Yıldırım, Kalyoncuoğlu, Erkuş and Tonguç, 2015).

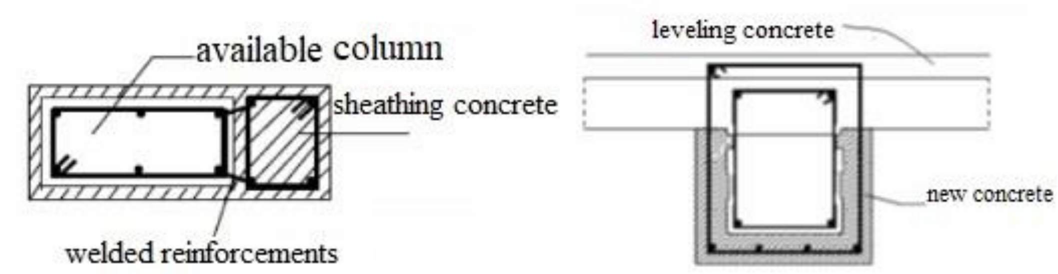
Table 1. Strengthening Techniques

Strengthening Techniques in Reinforced Concrete Structures	• Strengthening the Structural System Elements • Reinforcement with Steel Coil • Reinforcement with Fibre Reinforced Elements • Repair and Strengthening with Epoxy Resin • Repair and Strengthening with Shotcrete • Strengthening with On-Site Cast Reinforced Concrete Shears • Repair Mortars
Strengthening Techniques in Historical Masonry Structures	• Crack Repair • Strengthening Carrier Elements • Strengthening the Ground • Seismic Isolation • Reinforcement with Carbon-Based Fibre Reinforced Polymers (FRP) • Removal of Excess Masses • Partial or Complete Renovation of the Building
Strengthening Techniques in Prefabricated Structures	• Strengthening with Seismic Dampers • Reinforcement with Fibre Reinforced Polymer • Strengthening with Steel Crosses • Strengthening with Reinforced Concrete Filled Shear Between Columns • Strengthening with External Shear Wall and Diaphragm Application

Source: Aköz, 2008; Gülmez, 2010; Kaplan and others, 2009; Tekin and others, 2008; Yıldırım and others, 2015.

2.1. Strengthening Techniques in Reinforced Concrete Structures

Repairs and strengthening are carried out in order to compensate for the damages that occurred after earthquakes and other disasters. In reinforcing the carrier system of the building in reinforced concrete structures; sheathing, cross section, reinforcement with steel cross, fibre reinforced polymers are used. Bearing elements such as columns, beams and shears with insufficient load carrying capacity is strengthened using these methods. While reinforcing the beams, strong beams and weak columns should be prevented (Figure 1). It is important to distribute them properly within the building in reinforcing reinforced concrete shears. The walls that are not properly distributed cause torsion in the building against earthquake forces (Gülmez, 2010).



(a) **(b)**

Figure 1. (a) Jacket strengthening plan of the column, **(b)** Strengthening section of the beam, **Source:** Gülmez, 2010.

In reinforcement works applied to walls in reinforced concrete structures; fibre reinforced polymer (FRP) composites, epoxy resins, repair mortars and shotcrete are applied. Fibre reinforced polymer composites increase the mechanical performance of materials that do not have ductility and tensile strength. In addition, columns and beams are reinforced with carbon or glass textile fabrics (Figure 2). Repair of small cracks and damage in buildings are repaired with epoxy resin mortar (Figure 3a) (Balsamo and others, 2011). Repairs such as large cracks in buildings and the appearance of reinforcement in concrete are made with repair mortars. Repair mortars can be used in elements such as the structural system of the building and flooring. These mortars must be resistant to negative external effects. In order to detect the damages of the structures, the gaps formed due to the cores taken are filled with repair mortars. Repair mortars can be applied with a trowel or sprayed (Figure 3b). Shotcrete is applied where concrete is difficult or uneconomical to place, compress and mould. In addition, shotcrete is used where the concrete should be in thin layers (Figure 4) (Gülmez, 2010).

(a) **(b)**

Figure 2. (a) Fibrous polymer application in beams, **(b)** Fibrous polymer application in columns, **Source:** Canbay, 2020.

(a) **(b)**

Figure 3. (a) Reinforcement application with epoxy resins, **(b)** Reinforcement application with repair mortar, **Source:** Canbay, 2020.

Figure 4. Shotcrete application, **Source:** Anonymous 2, 2020.

2.2. Strengthening Techniques in Historical Masonry Structures

It is important to restore historical buildings taking into account their cultural identity. There are differences between the retrofitting applications of these structures in the past and today. Metal bars were used to prevent the opening of vaults, domes and arches in the restoration of historical buildings in the past (Figures 5 and 6). In addition, reinforcements were made to prevent the facades from falling over. Such preventive measures are effective and correct solutions for repairs performed at that time (Valluzzi, 2016).

(a) **(b)**

Figure 5. (a) External and internal view of Milan Cathedral, **(b)** Iron crossbars inside the church, **Source:** Angjeliu, Coronelli, Cardani and Boothby, 2020.

Figure 6. Notre Dame Cathedral supported by flying buttresses, **Source:** Anonymous 3, 2020.

Today, fibre reinforced composites, carbon and glass textile fabrics are used in the reinforcement applications of historical masonry structures, which increase the mechanical performance of the walls (Figure 7). These reinforcement applications have some advantages. These;

- Easy and fast to install,
- Increases the performance of the building element,
- It is a corrosion resistant material,
- Not adding excessive mass in repairs (Valluzzi, 2016).

Figure 7. Reinforcement with fibre reinforced composites in historical buildings, **Source:** Peker, 2005.

Fibre-reinforced composites and steel-connected elements are used to repair wide cracks in masonry structures (Figure 8). In the repair of small cracks, it is applied by injecting into the cavity with an appropriate mortar and original material (Figure 9). Another reason for the cracks in the walls of the historic masonry structure is due to the settling in the ground. As a result of the leakage of water into the underground, it causes the foundation to weaken and to settle in the historical structure. Another protective measure against earthquake effects in the historical building is seismic isolation. Seismic isolation decreases the interaction between the ground and the structure and reduces the damage caused by ground motion (Figure 10-12). The excess masses added to the building may cause damage to the bearing system in the historical building. Covering heavy soil on structural elements such as arches and vaults causes extra force in the building. These excess loads can be removed and light material can be placed to protect the climatic conditions. The restoration of historical buildings should be done in a way that does not harm the integrity of the building and the materials should be compatible with this. The materials should not be damaged in the partial or complete renewal of the building (Aköz, 2008).

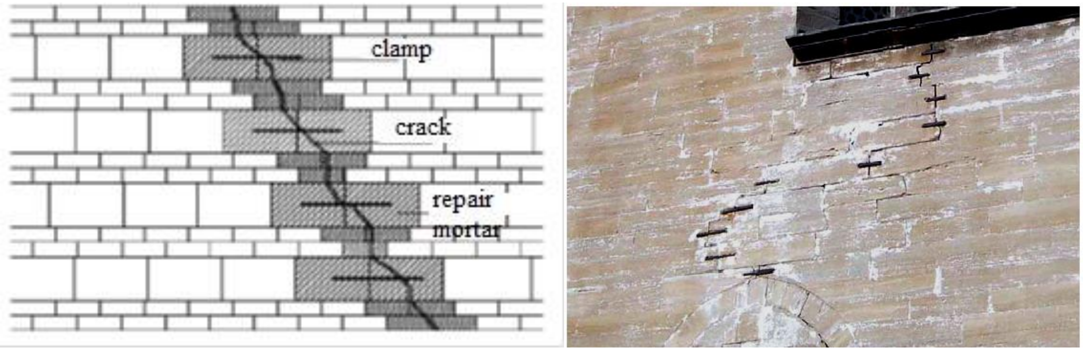


Figure 8. Repairing wide cracks by sewing, **Source:** Aköz, 2008.

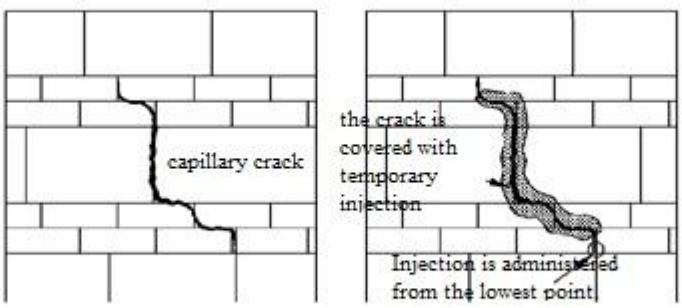
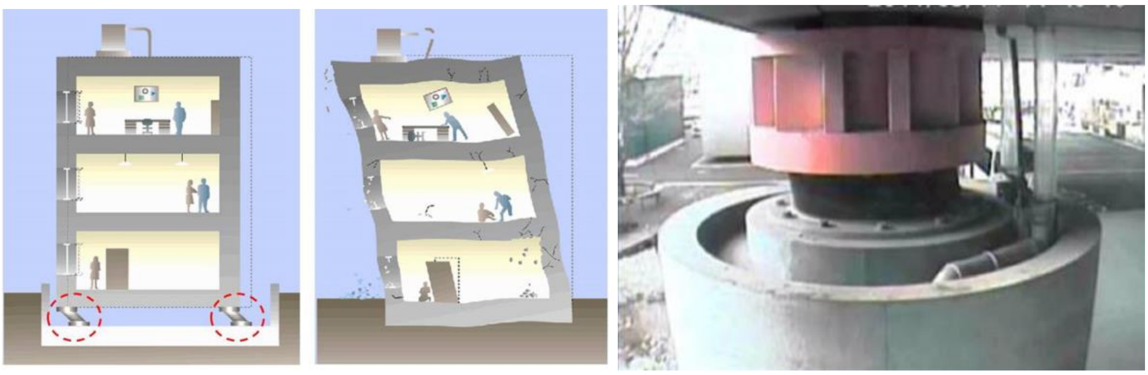


Figure 9. Injection repair of small cracks, **Source:** Aköz, 2008.



(a) **(b)** **(c)**

Figure 10. (a) Resistance of the seismic isolated structure against earthquake force, **(b)** Resistance of the structure without seismic isolation against earthquake force, **(c)** Seismic isolation application in the building, **Source:** Nakamura and Okada, 2019.

(a) **(b)**

Figure 11. (a) Seismic isolation devices, **(b)** Laminated rubber isolator detail, **Source:** Nakamura and Okada, 2019.

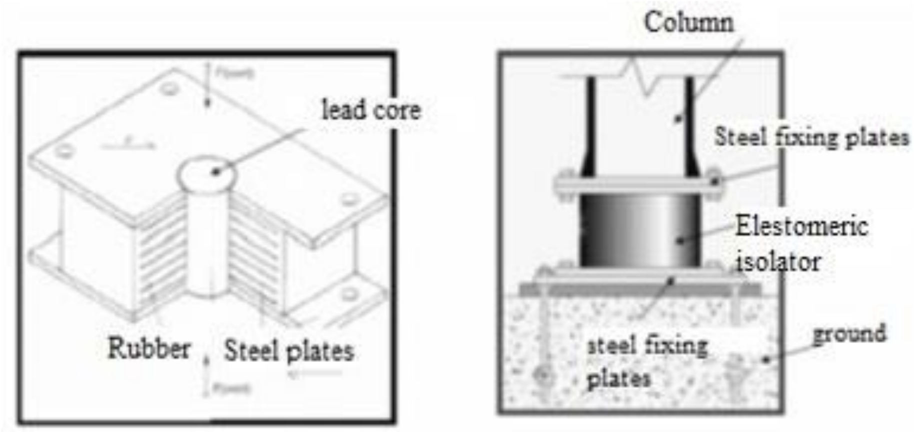
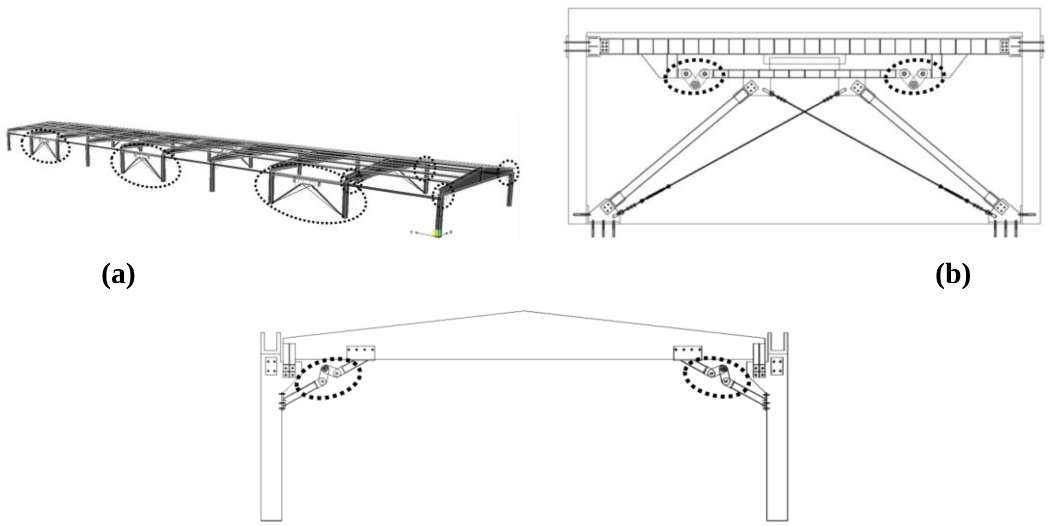


Figure 12. Detail of lead core rubber isolator, **Source:** Gülmez 2010.

2.3. Strengthening Techniques in Prefabricated Structures

There are difficulties in the reinforcement of prefabricated buildings due to errors in their designs compared to other building types. In strengthening methods of reinforced concrete structures; Methods such as sheathing or adding new carrier elements are used. In prefabricated buildings, these strengthening methods are not applied because it is not economical to strengthen the nodes. For this reason, frictional seismic damping elements are used in the reinforcement of prefabricated structures. These structures are supported with steel elements to increase resistance against earthquake forces. Frictional seismic dampers are placed in the places where displacement is high in the structure, converting the resulting seismic energy into heat energy, allowing it to move away from the building elements (Figure 13) (Yıldırım and others, 2015).

In strengthening techniques applied in prefabricated buildings such as factories, reinforced concrete fillings, shear or steel braces are applied to the vertical bearing system of the building. However, these techniques prevent the use of buildings. It prevents the different behavior of the prefabricated building at the roof level on the shear wall with the application of external shear and reinforcement in prefabricated buildings. With this method, elements with high horizontal stiffness are placed in order to reveal the diaphragm effect of the structure (Figure 14) (Kaplan and others, 2009).



(a) (b) (c)

Figure 13. (a) Layout of frictional seismic dampers, **(b)** Inverse V type friction seismic damper placement, **(c)** Corner junction friction seismic damper placement, **Source:** Yıldırım and others, 2015.

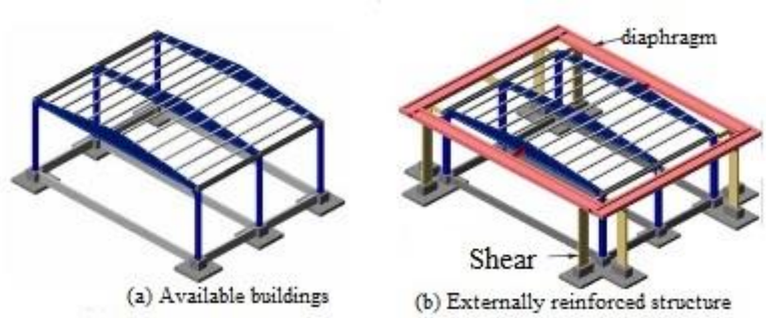


Figure 14. Building models reinforced with external shear diaphragm with the existing structure, **Source:** Kaplan and others, 2009.

3. CRITERIA AFFECTING STRENGTHENING OF STRUCTURES

Many scientific studies have been presented on the criteria that affect the strengthening of structures. Some of the studies on this subject are as follows: Modena and others (2013), investigated new materials and techniques in the repair and strengthening of historic buildings. As a result of these researches, they developed techniques on fibre-reinforced composites and steel-reinforced polymers to strengthen historical buildings. Hurol (2014), determined the criteria that earthquake resistant buildings should have. These criteria explained how it should be in terms of architectural and engineering design. Maio, Ferreira and Vicente (2018), conducted a comprehensive review of disaster risk reduction of urban cultural heritage assets located in historical sites. Bradshaw, Rajeev and Tesfamariam (2011), determined engineering and socio-economic factors as criteria in earthquake risk assessment in their study. They used the OWA operator, a decision-making tool that takes these criteria into account in the selection of retrofits. Margues, Lamego, Lourenço and Sousa (2018), studied the techniques used in retrofitting old houses in Lisbon city from a technological and economic perspective. They compared these structures before and after the application of strengthening the earthquake resistance. They determined the effect of the building with reduced earthquake damage on the retrofit and repair cost. Valluzzi, Calò and Giacometti (2020), examined the structural elements of historical masonry buildings and the occurrence of damage to immovable artistic assets. They determined the appropriate intervention type for the reinforcement of the historical masonry building by comparing the building elements and immovable artistic assets according to the damage levels in taking earthquake preventive measures. Slak and Kilar (2008), explained the parameters affecting the construction of structures in their study. They examined these factors in terms of architectural and engineering design. They also defined that earthquake resistant structures should have a good architectural and engineering design and this was defined as earthquake architecture. In the studies, the criteria affecting the strengthening of the structures; It is classified into three categories like architecture, engineering design and repair cost (Figure 15) (Bradshaw and others, 2011; Hurol, 2014; Maio and others, 2018; Marques and others, 2018; Modena and others, 2013; Slak and Kilar, 2008; Valluzzi and others, 2020). Good architectural and engineering design is effective in the earthquake resistance of the buildings. In architectural design, criteria such as artistic impression, harmony, architectural innovation, context, composition and building form, aesthetics and functionality affect the strengthening of buildings. In engineering design, the earthquake resistance and reliability of the building system, the local dominant material of the structural system, the plan of the building system, the horizontal and vertical plane irregularities, the structural system and its ability to withstand horizontal loads, column-beam ratios, foundations and the ability to transfer loads to the ground, and seismic isolations It is among the criteria (Slak and Kilar, 2008). The cost of repair has an effect on the space solutions of the designer's decisions in strengthening the structures. Therefore, the reinforcement application criteria of the buildings should be taken into consideration (Bradshaw and others, 2011; Caterino and others, 2008; Slak and Kilar, 2008).

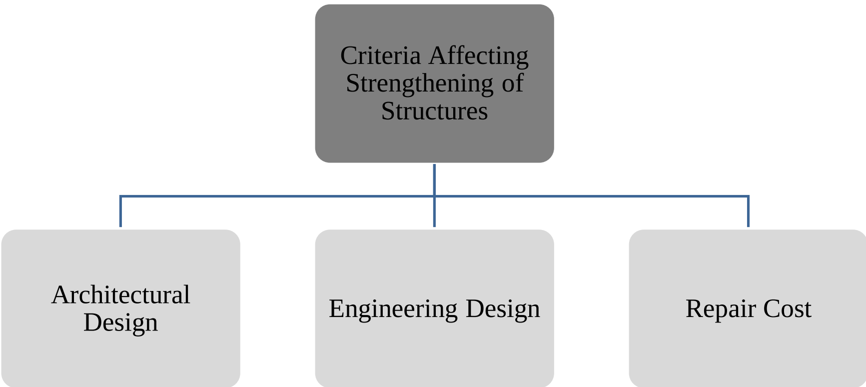


Figure 15. Criteria Affecting Strengthening of Structures, **Source:** Bradshaw and others, 2011; Slak and Kilar, 2008.

3.1. Architectural Design

In Vitruvius's work titled "Ten Books on Architecture", he stated that the architect should consider robustness, functionality and aesthetics in order to design a successful building (Vitruvius, 1960). According to these values, the architectural design solutions made vary depending on the customer's request. According to the customer's budget, aesthetic and economic needs can be met at the same time. This means that some adjustments have to be made in the architectural design of the building. The economic necessity in the architectural design should not override aesthetics. If it is not possible to produce an architectural solution for these two values, the economic necessity in building design takes precedence over aesthetics. However, this situation leads to unsuccessful project design. For this reason, the architect should develop designs that combine safety and aesthetics in the design of buildings (Hurol, 2014). In architectural design, the strengthening of buildings can be done by considering the following parameters.

3.1.1. Artistic Impression and Harmony

While making an architectural design, the design is made by considering the needs of the user. In addition, the sizes of the spaces are determined according to the needs of the user. Artistic impression and harmony are important in the solution of architectural design. The materials, colors and details used in the building provide this harmony (Slak and Kilar, 2008).

3.1.2. Architectural Innovation, Originality and Context

The use of materials is effective when making new and original designs in constructions. The materials used in architecture are one of the factors that determine the magnitude of damage in buildings. Improvement techniques such as textile fabrics or fibre-reinforced polymer wraps that affect the appearance of the exterior at least in the reinforcement applications of the buildings can be made. Other techniques such as steel support in such original designs may cause significant changes in the architecture and exterior of the building (Bradshaw and others, 2011; Slak and Kilar, 2008).

3.1.3. Building Form and Aesthetics

Building form gains importance in strengthening structures. When the buildings are in regular form, they provide earthquake resistance. Since the irregular form changes the mass center positions of the structures, the strength feature of the structures also decreases. Therefore, irregular form structuring should be avoided (Şirin, 2006). The continuity of the building from the ground to the upper floors makes it resistant to earthquakes. For example, additional spaces such as garages, shops on the ground floors and adjacent structures have an effect on the decrease in earthquake resistance (Gülmez, 2010).

Aesthetics is the change in the physical appearance of a building. For many buildings, it is important to protect the interior and exterior architectural elements of the building. The applied strengthening technique also affects the appearance of the building. For example, while fibre reinforced composites change the appearance of the structure to a small extent, the reinforcement made with steel braces causes a great change in the architecture and physical appearance of the structure (Slak and Kilar, 2008).

3.1.4. Functionality

As a result of the changes and new needs in the society over time, the design of the buildings is shaped and different spaces need to be added. The structures that cannot carry their past functions to the present can be used by giving a new function. By re-functioning, the historical buildings that cannot meet the needs, the destruction and collapse of the buildings are prevented (Gazi and Boduroğlu, 2015).

3.2. Engineering Design

Engineering design has an impact on the seismic evaluation of structures and analysis of potential earthquake risk. Evaluation of the system integrity and resistance of structures against horizontal loads can be made by considering the following parameters (Slak and Kilar, 2008).

3.2.1. Earthquake Resistance and Reliability of the Building System

The positions of the structures with respect to the center of mass are among the factors affecting their reliability and durability. In the strengthening of the structures, the cross-section of the carrier elements such as columns, beams and curtains is increased and shear walls are placed in the frame gaps. The rigidity of the structure is ensured by increasing the reinforcement percentage of the carrier elements. In this application, the reinforcement percentage should provide ductility while increasing the cross-section dimensions in the carrier elements. It increases the ductility with transverse reinforcements in the column-beam joints (Altın, 2008). Increasing the ductility helps to increase the strength of the structure and to reduce permanent deterioration. It also increases the strength of the building system and reduces deformations. Increasing the strength or ductility to the required level ensures that the structure is resistant to earthquake. The reliability of the building, the openings between the load-bearing systems, and the distribution of load-bearing elements affect the durability of the building (Bradshaw and others, 2011; Slak and Kilar, 2008).

3.2.2. Local Dominating Material of the Structural System

Factors such as the transportation of materials and the required amount of materials are effective in the reinforcement of buildings. If the necessary materials are not available in the area, it causes the transportation costs to increase (Bradshaw and others, 2011).

3.2.3. The Plan of the Building System and Its Irregularities in the Horizontal and Vertical Plane

The fact that the ground floors of the buildings are not built with filling walls for shops and trade causes weakening of earthquake resistance. In addition, geometric irregularities in the building plan cause damage to the buildings.

3.2.4. Structural System's Ability to Withstand Horizontal Loads

The transfer of the load of the structures to the ground is provided by columns, beams and shear elements. Errors in the proportions of columns, beams or irregularities in the plan such as columns and shears cause damage to the structure during an earthquake.

3.2.5. Seismic Isolation

Seismic isolation devices, such as shock absorbers, reduce the earthquake-induced loads on structures. This method can be applied to all structures. Seismic isolation enables the earthquake energy to be absorbed by damping oscillations between the foundation and the upper floor. If the damping of the structure is increased, the acceleration and translation to the structure decrease (Gülmez 2010).

3.3. Repair Cost

In the strengthening of structures, the repair cost is among the factors that determine the designer's decisions and space solutions. When deciding whether to demolish and rebuild or strengthen a building, the ratio of retrofitting cost / demolition + construction cost is taken into consideration. In addition, the number of floors affects the cost of building reinforcement such as the earthquake class of the area where the building is located, the total area of the building (m^2), ground type and building age (Yılmaz, Çankaya and Karakaya, 2018).

4. THE ROLE OF CURRENT TECHNOLOGIES IN DETERMINING THE DAMAGES CAUSED BY EARTHQUAKES

Damages occur in buildings after earthquakes and other disasters. The causes of damage vary according to the types of reinforced concrete, masonry (historical) and prefabricated buildings. Damages observed in reinforced concrete structures; Entrance floor without filling the wall, ground liquefaction, reinforcement placement errors, console problems, irregularity of the structure in horizontal and vertical planes can be listed. In masonry (historical) buildings; damage caused by the ground, errors in the design of the carrier system, incorrect use of materials, poor workmanship and detail, long-term natural factors, damage caused by people, traffic, air pollution damage are observed. In prefabricated buildings; Damages occur in panel systems and framed systems. The causes of damage caused by reinforced concrete, masonry and prefabricated building types are summarized in the table below (Table 2) (Durakoğlu, 2006; Gülmez, 2010; Mahrebel, 2006).

Table 2. Causes of Damage in Reinforced Concrete, Masonry (Historical) and Prefabricated Buildings

Reinforced Concrete Building	Masonry (Historical) Building	Prefabricated Building
Ground Floor Without Infill Wall	Damage Caused by Ground	Damages in Panel Systems
Ground Liquefaction	Errors in Carrier System Design	Damages in Frame Systems
Reinforcement Placement Errors	Incorrect Material Use	
Console Issues	Poor Workmanship and Use of Detail	
Irregularity of the Building in the Horizontal or Vertical Plane	Long Term Natural Factors	
	Human Damages Caused	
	Air Pollution	
	Traffic	

Source: Durakoğlu, 2006; Gülmez, 2010; Mahrebel, 2006.

Pre-detection of damage to buildings increases the usage time. Detection of these damages is determined by destructive and non-destructive testing methods. The compressive strength of the material used in the building can be determined by the destructive inspection method. The core sample is taken without damaging the bearing system of the building and the mechanical properties of the material can be determined by pressure tests (Figures 16 and 17) (Kanıt and Altın, 2008).

(a)

(b) **(c)** **(d)**

Figure 16. (a) Taking the core sample to determine the compressive strength of concrete, **Source:** Kanıt and Altın, 2008, **(b)** Coring tool, **Source:** Altın 2008, **(c)** The tool used for cutting the core, **Source:** Altın 2008, **(d)** Extracted and cut core samples, **Source:** Altın 2008.

Figure 17. Determination of the mechanical property of the material by pressure tests, **Source:** Kanıt and Altın, 2008.

The non-destructive testing methods applied in historical buildings determine the damage without damaging the building. Digital image processing, ultrasonic examination tests, georadar tests (GPR), fibre optic microscopy and thermographic tests are used to determine the damage in such structures (Adriaens, 2005; Cortella, Albino, Tran, and Froment, 2020; Modena and others 2013; Moropoulou, Labropoulos, Delegou, Karoglou and Bakolas, 2013; Pérez-Gracia, Caselles, Clapés, Martinez and Osorio, 2013). The characteristics of architectural surfaces in historical cultural buildings are determined by digital image processing. With this method, its structural character is revealed with different light levels reflected by the surface (Figure 18). Infrared ray is a non-destructive inspection method with a wide application that helps to obtain flaw detection on architectural surfaces from improving the appearance at night. The working principle of this method can determine the properties of the materials, microstructure and surface morphology since all objects at absolute zero temperature (0 K) emit infrared rays (Figure 19). It is a non-destructive inspection method used in georadar (GPR) tests to visualize the examined surface. This method is used to determine the infrastructure properties of highways and railways in transportation, the properties of the soil, the characteristics of the bearing system of structures such as bridges and tunnels, and the errors of historical cultural structures (Figure 20). The ultrasonic method is a non-destructive testing method used to determine the size and location of damage to the material with high frequency sound waves sent to the surface. This method determines the discontinuities and cracks on the material surface (Figure 21). It is a non-destructive inspection method used to obtain magnified images with the fibre optic microscope method. With this method, structures with cultural heritage are protected. In addition, fibre optic microscope method is used to define the decay events occurring in the structure, defects in the material and texture differentiation on the surface (Figure 22) (Moropoulou and others, 2013). With these methods, it ensures that the damage caused by the earthquake is determined and precautions are taken according to this damage. Since these structures are masonry technique, that is, the walls are bearing, the integrity of the building is preserved. This method can also be applied in damage assessment in reinforced concrete, prefabricated and masonry structures. The non-destructive testing method is faster and more accurate in determining the damage and quality of the material compared to the destructive testing method. For this reason, the non-destructive testing method is used in damage assessment, especially in buildings with cultural heritage. In such structures, repair and strengthening works are carried out in a way that the structure is least intervened and that it is compatible with the material.

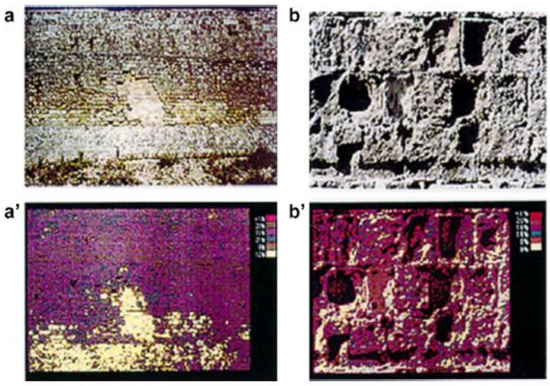


Figure 18. Determination of the structural character of the medieval city walls of Rhodes by digital image processing, **Source:** Moropoulou and others, 2013.

Figure 19. Left: Walls facing the National Heraklion Stadium in Crete; Right: Infrared thermography of the same wall, **Source:** Moropoulou and others, 2013.

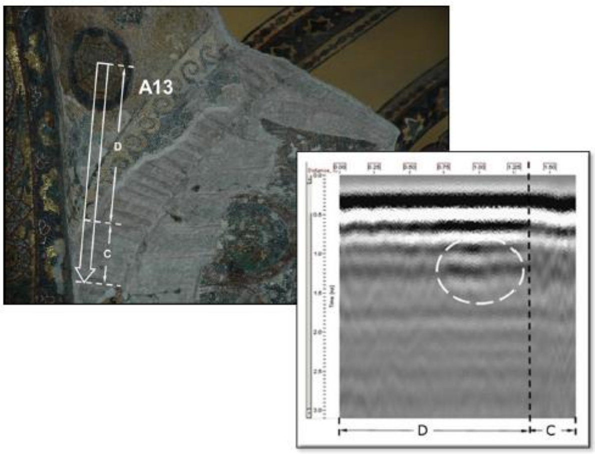


Figure 20. GPR scan of the mosaic area unearthed in Hagia Sophia (The target shown by the dashed white curve corresponds to an interior space filled with mortars and bricks), **Source:** Moropoulou and others, 2013.

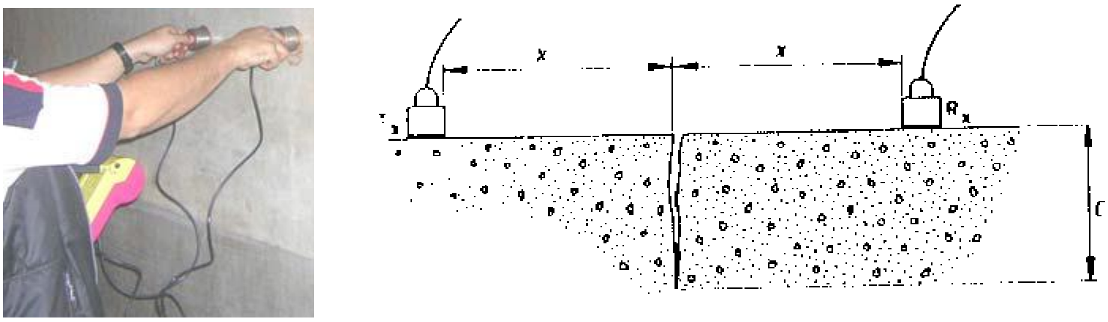


Figure 21. Determination of damage to the building by ultrasonic examination, **Source:** Aköz and Yüzer, 2009.

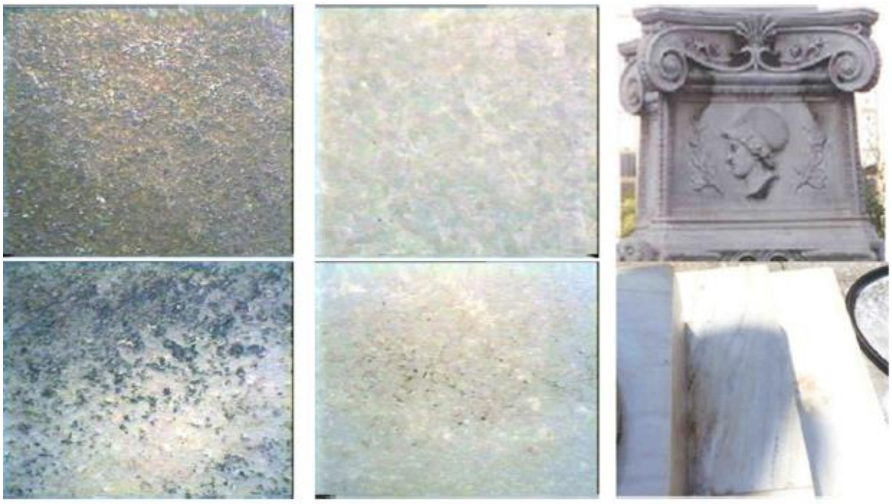


Figure 22. Evaluation of the cleaning interventions of the Athens Academy historic building using the fibre optic microscope method, **Source:** Moropoulou and others, 2013.

Science and Technology Research Partnership for Sustainable Development (SATREPS) is conducting research on the reduction of disaster risks in Peru. This research in Peru aimed to predict earthquake and tsunami disasters and take preventive measures against them. They tried to develop preventive technologies for them (Yamazaki and Zavala, 2013). The Central American Earthquake Center has taken measures to reduce earthquake risks using advanced technological methods. Advanced technologies include a range of software including image processing, data storage, visualization and data analysis (Tralli, 2000). It is aimed to reduce the risks of earthquakes and other disasters by using technological methods such as radar, lidar and photogrammetry. These methods are used to create data about the environment of buildings, the infrastructure of buildings, detect the regional vulnerability, rapid loss detection and damage assessment during an earthquake (French and Muthukumar, 2006).

Radar works by sending microwave pulses towards a target and measuring the return time and intensity reflected back to the sensor. Pulse frequencies range from about 300 MHz to 30 GHz with about 1500 high power pulses per second. The duration of each pulse is approximately 10-50 microseconds. Only amplitude information is used in recording radar echoes. The pulses are not frequency coded, so it is not possible to uniquely identify them. It is generally used for mapping cities by creating aerial photographs. Lidar is a laser light for measuring the distance to certain points like radar. This technology is used to calculate building height or building inventory of cities. Photogrammetric technologies are used in mapping cities. By using these techniques, the characteristics and analysis of the structures of cities are provided (French and Muthukumar, 2006).

5. CONCLUSIONS

Buildings are repaired and reinforced against earthquakes and other disasters. There are criteria applied in these strengthening studies. Architectural design, engineering design, and repair costs affect the designer's decisions and space solutions in strengthening structures. In addition, different strengthening works are carried out in reinforced concrete, masonry (historical) and prefabricated structures. Damage detection and deterioration of the structures should be determined in retrofitting works. Destructive and non-destructive testing methods are used for damage detection. The integrity of the building should not be damaged in the damage assessment of the buildings with historical cultural heritage. For this reason, non-destructive testing methods are used in such structures. In addition, the reinforcement of these structures should not impose any load on the building and the material used should be compatible with the historical structure. Metal bars were used in the reinforcement application of historical buildings in the past to prevent arches, vaults and dome damages, and their walls were supported with buttresses. Such practices damage the visual integrity of historical buildings. Today, fibre reinforced composites, carbon and glass textile fabrics are used in the reinforcement applications that increase the mechanical performance of the walls. These composite fabrics do not impose a heavy burden on historical buildings and do not harm the visual integrity of the building. In addition, the structures are more resistant to earthquakes with seismic isolation devices.

Destructive and non-destructive methods are used to determine the damages caused by earthquakes. In the non-destructive testing method; Ultrasonic tests, georadar tests, thermographic tests, digital image processing and fibre optic microscopes are used. In the destructive testing method, the mechanical properties of the material are determined by pressure tests. The non-destructive testing method can determine the damage to the buildings without damaging the structure according to the destructive testing method. The non-destructive testing method is used especially in determining the damages in historical buildings. It enables the mapping of cities and analysis of the properties of buildings with advanced technologies such as radar, lidar and photogrammetry used today. With these technologies, preventive measures are taken against earthquakes and other disasters.

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