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Assessment of Seismic Hazards for Unreinforced Masonry Structures in Turkey

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ABSTRACT: *Many people are living in unreinforced masonry (URM) structures, which constitute an important percentage of the building stock in Turkey. URM structures located on seismically active regions of Turkey are mainly non-engineered, deficient buildings. In this paper, earthquake damage to the buildings built using locally obtained materials, the material properties, and the architectural and load-bearing systems of these buildings were investigated and the sources of damage were determined. In addition, damage types which may occur in masonry structures are considered by reviewing the previous studies, causes of damages are investigated and solutions are suggested. Many researchers have been carried out on masonry buildings and strengthening methods for these buildings have been developed. The main purpose of the seismic strengthening is to upgrade the seismic resistance of a damaged building in order to make it becomes safer under future earthquake occurrences.*

Keywords: *Unreinforced masonry, earthquake, damage types, seismic strengthening.*

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I. INTRODUCTION

Stone masonry is a traditional form of structure that has been practiced for centuries in the world where stone is locally available. It has been used for the construction of many masonry structures in Turkey. The masonry structures are constructed from vertical walls made of different materials such as brick and natural stones [1]. Many people are living in unreinforced masonry (URM) structures, which constitute an important percentage of the building stock in Turkey [2]. The kind of structures is highly vulnerable to seismic which gives rise to unacceptable losses, even in moderate earthquakes [3]. Most of the losses are caused by bad builder of URM structures so these kinds of buildings have exhibited poor performance during many previous earthquakes [4]. Therefore, damages to the buildings have caused many casualties and economic losses [5]. Masonry buildings are preferred for reasons such as their ease of production, low cost and of obtaining materials in Turkey. Yet, almost none of these buildings exhibit enough resistance to earthquakes [6-8].

Former studies have demonstrated that many researchers have focused on reinforced concrete structures. There isn't enough research in this field although URM is one of the most popular research subjects In Turkey. In this study, earthquake damage to masonry buildings built using locally obtained materials in Turkey, the material properties, and the architectural and load-bearing systems of these buildings were investigated and the sources of damage were determined. The damage types which may occur in masonry structures are considered by reviewing the previous studies, causes of damages are investigated and solutions are suggested. In addition, the structures research into strengthening and rehabilitation methods of masonry structures, advantages and drawbacks have been evaluated.

Turkey is located on the Mediterranean seismic belt, one of the most important seismic belts of the world. For this reason, the seismicity of this belt has been the subject of many studies and has attracted the attention of researchers [9]-[11]. Turkey have been confronted with varying seismic shocks most of them caused enormous casualties and loss of property. Figure 1 shows seismic zoning map of Turkey. North Anatolian Fault Zone, East Anatolian Fault Zone and Aegean Graben System are the main earthquake generating sources in Turkey. According to the seismic zoning map, more than 70% of Turkey's lands are located on 1st and 2nd degree earthquake zones. Turkey is divided into the 5 zones. Zone 1 colored in red illustrates the highest hazard, whereas Zone 5 colored in white illustrates the lowest hazard zone.

There are many historical and masonry buildings in Turkey. While the masonry structures are dominant in the middle and eastern regions in Turkey, it is seen that the reinforced concrete structures are usually found in the in the western and northern regions [15]. The highest risk of the losses are found to be in the eastern part of Turkey, because of the both high seismic hazard in the region and poor quality of structures, particularly resulting in a highly vulnerable physical environment. Seismic risk map of Turkey are predicted very important results for masonry buildings. Researchers are generated a seismic risk map of Turkey for bearing wall buildings. Indices obtained for cities are plotted on the map of Turkey, which should be taken into account for determining the priority in seismic performance improvement studies for masonry buildings. As a result, both the eastern part of Turkey and Marmara region should be prioritized for future risk mitigation schemes.

II. EARTHQUAKE HAZARD IN TURKEY

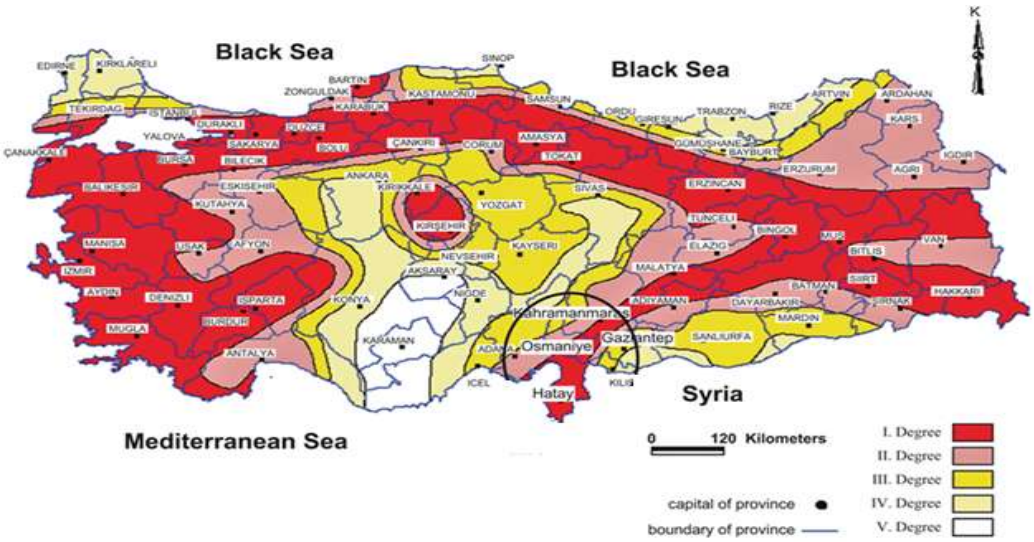

Figure 1. Seismic zoning map of Turkey

Many destructive earthquakes occurred in Turkey up to now. Many researchers have studied on the performances or damages of masonry buildings during the earthquakes in Turkey [8-14]. Damage assessment results for all buildings subjected to the earthquakes in Turkey are given in Table 1. Earthquakes on fault occurred between 1939 and 1999, resulting in more than 90,000 deaths, 175,000 injuries, and the destruction of 650,000 residential and office buildings. The M7.9 Erzincan earthquake, 1939, in north eastern Turkey, was the largest earthquake in Turkey in the 20th century. The city of Erzincan was devastated and approximately 32,000 people died also, in the table some information behaviours of masonry structures during the earthquakes were given.

Table 1. Damaged Assessment for Buildings in the History of Turkey

Year	Event	Magnitude	Damage of Buildings	Damage Level
1939	Erzincan	7.9	116720	Heavily
1983	Erzurum	6.9	3241	Heavily
1986	Malatya	5.9	824	Medium
1992	Erzincan	6.8	8057	Heavily
1995	Dinar	6.1	4909	Heavily
1998	Ceyhan	6.2	63646	Heavily
1999	Gölcük	7.8	132892	Heavily
2002	Sultandağı	6.3	15676	Heavily
2003	Bingöl	6.4	12758	Heavily
2004	Erzurum	5.1	-	Medium

III. EARTHQUAKE DAMAGE ON MASONRY STRUCTURES

Non-reinforced masonry structures are among the most vulnerable type of buildings during an earthquake. They are normally designed for vertical loads and, as masonry has adequate compressive strength, the structures behave well as long as the loads are vertical. When such a masonry structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. The strength of masonry under these conditions often depends on the bond between stone and mortar. The following paragraphs give the description of the behaviour of masonry buildings in some of the places visited in Turkey.

General structural type of stone masonry and especially random rubble debris stone are used in Turkey. Structure of stone building is easy since they do not require reinforcement workmanship. Therefore, these buildings can enough be damaged. The damage is likely to occur in the unrestrained walls. The probable failure mode is out-of-plane collapse of the walls. Furthermore, in Figure 2, it is seen that, it is rolled and failed in the living space of the historical structure.

Figure 2. Out-of-plane collapse

The problem of unconnected intersecting walls is very common in Turkey. Because of bad connection detail of the intersections, safety of the connections relied on strength of the mortar used for connection. Unconnected walls were more tendencies to out-of-plane failures. Figure 3 demonstrated damages observed at intersection of outer walls. Damage, generally was concentrated around the opening area.

Figure 3. Corner failure in the presence of unconnected intersecting walls

A major portion of the mostly single-story adobe buildings that were constructed in the traditional style entirely collapsed in Turkey [16-18]. The primary reasons for collapse in adobe buildings can be listed as the absence of masonry beams and columns which would protect the out-of-plane rigidity of the walls and the inadequacy of in-plane rigidity of the floors which connects the walls. Several cracks formed along the mortar and stone blocks on the sides during the earthquakes. Severe cracks and stone dislocations were observed at several critical locations. The wall damage was beside exposed inside the structure as it covers and plaster fell down at those critical locations.

Figure 4. Stone dislocations and collapse

IV. RETROFITTING METHODS FOR UNREINFORCED MASONRY STRUCTURES

In the last decades numerous studies have been conducted concerning ways for strengthening and rehabilitation assessment for masonry structures. Many researchers investigated into retrofitting methods to improve the structures around the world [19–37]. Numerous conventional techniques used for retrofitting of unreinforced masonry structures in Turkey. Figure 5 shows that the use of the shotcrete method seismic strengthening applications for old construction. Shotcrete method called has been used repair for old construction for many years. Application of the shotcrete to surface of a masonry wall is a common method for strengthening both in-plane and out-of-plane strength of the walls. The strengthening using shotcrete significantly increases both shear and flexural capacities ultimate load of the retrofitted walls. The method have improves in-plane inelastic deformation capacity and dissipates high-energy due to successive elongation.

Figure 5. Shotcrete method

Re-pointing is a traditional retrofitting technique commonly used in the old masonry structures. This technique offers some advantages as reduced surface preparation and preservation of aesthetics. It might be provided as low cost and application of implementation. On the other hand, the method is not sustainable and the success of the lies with the compatibility of the new mortar. It demonstrated to sharply improve the shear and bending moment capacities of masonry improving decrease of deformation in Figure 6. The technique can integrate other repair technique as grout injection; in this case it may be applied so as to better confine the injected material.

Figure 6. Re-pointing strengthening method

Center Core method is improved method for strengthening of masonry buildings. The technique is successfully used to enhance the resistance of URM wall under cyclic actions, and lateral maximum lateral displacement. The method is also related to the possibility to preserve the architectural aspect of the structure. However, the main disadvantage is given by the fact that highly qualified personel, high tech equipment and strict quality control are needed. Moreover, the method tends to create zones with widely varying stiffness and strength properties.

The study aims to investigate repair and strengthening methods of masonry structures, advantages and disadvantages in Turkey. The selected method must be consistent with aesthetics, strength and the cost requirements. The strengthening using method significantly increases both shear and flexural capacities ultimate load of the retrofitted walls [38–45]. The FRP method has been successfully used to enhance the strength and ductility for seismic retrofitting of the masonry structures. Furthermore, grout injection is a popular strengthening technique, as it does not alter the aesthetic and architectural features of the historical buildings. Re-pointing is traditional retrofitting technique commonly used in the historic masonry structures. The technique provides as low cost and application of implementation. However, the main disadvantage is given by the fact that highly qualified personal, high tech equipment and strict quality control are needed. As a result, the choice between "traditional" and "innovative" techniques should be weighed up on a case-by-case basis and preference given to those that are least invasive and most compatible with heritage values, bearing in mind safety and durability requirements.

V. CONCLUSION

In this paper, masonry buildings were investigated and sources of damage were determined during earthquake in Turkey. In addition, the damage types which may occur in masonry structures are considered by reviewing the previous studies, causes of damages are investigated and solutions are suggested.

-In order to retrofit existing buildings, it is important to understand the seismic performance of the building and therefore to identify the reasons for poor seismic capacity.
-Strengthening techniques must be improved for earthquake behavior of existing masonry structures.
-The selected retrofitting method should be consistent with aesthetics, strength, ductility, stiffness and the cost requirements.
-The seismic strengthening is to upgrade the seismic resistance of a damaged building while repairing so that it becomes safer under future earthquake occurrences.
-The cracked may be repaired by epoxy grouting and could be strengthened by epoxy or polymer mortar application like shotcreting, jacketing in the masonry structures.

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