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SOME OF RECOMMENDATIONS AND LEARNED LESSONS FROM BUILDINGS' PERFORMANCE DURING THE RECENT TURKEY-SYRIA EARTHQUAKE

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ABSTRACT

This paper reviews the performance of the buildings in Syria and Turkey during the February 6, 2023, Turkey-Syria earthquake. The damage and performance levels of buildings in the earthquake zones varied from minor or no damage to complete collapse. The damaged buildings are classified as seismic and non-seismic-designed buildings according to the earthquake codes. It has been found that there are many reasons for building collapses, such as non-consideration of seismic requirements in design or construction, poor quality of used materials, the possibility of exceeding the earthquake intensity than the design intensity level, insufficient foundations, and soil-related collapses. Based on the reasons mentioned above, general recommendations and future visions are highlighted to avoid the recurrence of such damages and collapses in future earthquakes.

KEYWORDS: Building Performance; Damage; Collapse; Seismic Design; Materials; Foundations; Soil.

1. INTRODUCTION

The two disastrous earthquakes that hit both Turkey and Syria on February 6, 2023, with 7.8 and 7.5 magnitudes, caused damage and destruction of many buildings and structures, killing more than 50,000 people (including at least 45,968 people in Turkey and 7,259 people in Syria), and injuring many thousands more. The response and vulnerability of the buildings in these affected regions are different and varied, and their damage levels vary from minor or no damage to major damage in destroyed buildings according to many factors relating to material quality, conditions of the structural design and construction, soil conditions, and so on.

Several reports and papers, such as (Alhawamdeh et al., 2023; EMSC - European-Mediterranean Seismological Centre, 2023; Lekkas et al., 2023; Mertol et al., 2023; OZTURK et al., 2023; Qu et al., 2023), have studied the casualties and damage individually or collectively.

The results obtained by (OZTURK et al., 2023) indicate that a significant amount of the

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extensive damage caused by earthquakes is due to design and execution mistakes.

According to the findings of (Papazafeiropoulos & Plevris, 2023), the buildings were subjected to loads that were far higher than those required for regular design. This, together with the significant vertical seismic components, had a role in the area's many buildings collapsing. Higher spectral acceleration values must be indicated in the Turkish seismic code; this is especially true in earthquake-prone areas.

(Ahmed, 2023) showed that the extensive collapse of buildings could be related to several causes, such as the old age of the buildings, some of which were constructed according to earlier versions of the code, and the insufficient application of the latest version.

The study of (Mertol et al., 2023) strongly recommended that all buildings near major fault lines, particularly those built between 1975 and 2000, undergo a structural performance assessment. It is also advised that any other PGAs along major fault lines be reevaluated because these earthquakes produced substantially greater PGAs, which are thought to be one of the primary causes of severe damage.

One of the tasks of the Newsletter of Environmental, Disaster and Crisis Management Strategies (Lekkas et al., 2023) was to review the most important results of post-event field surveys on the impact of the earthquake on the natural environment and building stock that were conducted in the earthquake-affected area and published in different sources mentioned in each case.

Buildings constructed before the year 2000 are expected to be risky, but those constructed afterward are anticipated to be safer, particularly with updated versions of the codes in both Syria and Turkey. These upgrades and modifications are based on the knowledge gained from earthquakes that have happened locally and globally. The new codes have taken into account the requirements for ductility and capacity design.

The versions of the Syrian Arab Code with its annexes for earthquakes are as follows: (1977, 1992, 1995, 1996, 1997, 2004, 2005, 2012, 2013, 2018), while the versions of the Turkish Building Earthquake Code are as follows: (1947, 1953, 1961, 1968, 1975, 1998, 2007, 2018).

To avoid repeating past mistakes, this study reviews the effects of the 2023 Turkey-Syria earthquake on the response and performance of the buildings in the affected areas in Syria and Turkey, by making use of the information provided in several sources and references. This makes it easier to draw attention to and pinpoint the most important lessons learned from the tragedy, apply them to enhance and improve the sustainability and safety of structures and lessen the potential damage that future similar disasters could cause.

2. Classification of building collapses and damages

Buildings in the areas affected by the Turkey-Syria earthquake responded differently, ranging from complete or partial collapse, to severe, moderate, or minor damage, or just cracks, while other buildings remained intact without any damage. Structures can be classified according to the date of their construction and their dependence on seismic codes in their design into old structures and newer structures (Lekkas et al., 2023). Figure 1 shows an example of buildings that were not damaged as a result of the good quality of both design and construction, which is Kahramanmaraş Chamber of Civil Engineers building (indicated by an arrow), while damaged buildings with completely collapse were appeared beside it.

Fig.(1):- The difference in the seismic response and damage of adjacent buildings, Kahramanmaraş (OZTURK et al., 2023).

The most important forms and causes of collapse and damage to those buildings will be reviewed in the following sections:

2.1 Poor Quality of Structural Elements Materials

Non-conformity of materials to specifications, whether in terms of resistance or quantity, is one of the most important reasons for earthquake-affected building collapses (Alhawamdeh et al., 2023; Lekkas et al., 2023; Mertol et al., 2023; OZTURK et al., 2023). These materials include concrete, longitudinal and transverse rebars. Poor concrete quality and low compressive strength of concrete are caused by a number of issues, including the uncontrollable production of hand-made concrete, irregularly sized aggregates, river-extracted, shiny and smooth aggregates and gravels, and inadequate compacting during concrete placement. As well as the reinforcing steel bars, which did not have any trace of cement paste left on their surface, which can be explained by the poor quality of the concrete with the insufficient amount of cement. The effect of reducing the compressive strength of concrete is more significant in columns compared to slabs and beams, where the axial forces dominate the behavior of the columns. Because of the poor quality of the concrete, many of buildings are completely collapsed and become like piles of gravel and sand (Lekkas et al., 2023; OZTURK et al., 2023), as shown in Fig. 2.

Fig.(2):- Wreckages of destroyed buildings resemble heaps of sand and gravel (Lekkas et al., 2023; OZTURK et al., 2023).

In addition, the minimum concrete strength requirements were not applied in the structural designs of old buildings executed before the dates of issuance of modern seismic codes (Mertol et al., 2023). Figure 3 shows that most of the concrete of the ruins of collapsed and severely damaged buildings contains round aggregates, large aggregates with diameters ranging between 50 and 100 mm, in addition to the presence of materials such as wooden pieces within the concrete. All of these observations reduce both the resistance of the concrete and the bonding between concrete and reinforcements (Mertol et al., 2023).


(a) (b) (c)

Fig.(3):- Poor quality of concrete: (a) aggregates having round shapes; (b) oversized aggregates; (c) Woodcuts in concrete. (Mertol et al., 2023)

It was also found that the amount of longitudinal and transverse bars was smaller than what is required to achieve strength and ductility, the spacing of the stirrups and the type of used steel do not conform to the requirements in the seismic codes (Lekkas et al., 2023). Another significant problem with steel reinforcement is corrosion. Due to material loss, it decreases the cross-sectional area of the reinforcement, which decreases the steel reinforcement's ability to withstand tensile loads. Corrosion also reduces the bond strength between steel and concrete, which greatly affects the durability of RC structures (Apostolopoulos & Koulouris, 2020) and leads to deterioration of structural performance under static and dynamic loads (Yu et al., 2017). Extensive corrosion was seen in the longitudinal and transverse reinforcements of some of the severely damaged or collapsed buildings (Mertol et al., 2023). The cause of corrosion may also be because the owner of the building does not pay enough attention to its structure. For instance, not taking proper corrosion precautions in a building subject to corrosion (OZTURK et al., 2023). Figure 4 shows corrosion in stirrups, longitudinal rebars, and beam-column joints which reduce the connection ductility during earthquake sequence.


(a) (b)

Fig.(4):-. Corrosion in: (a) longitudinal and transverse reinforcements (Mertol et al., 2023); and (b) beam-column connection (Alhawamdeh et al., 2023).

2.2 Poor Structural and Execution Details

In buildings that did not collapse into heaps of sand and gravel, significant failures were distinguished in terms of the configuration of the load-bearing system. In addition to the inadequacy of the columns (small cross-sections and/or poorly reinforced), they were also incorrectly positioned, in terms of both their location and orientation in the building plan. The joints between the columns and the horizontal elements (beams or slabs) were also insufficient, which canceled their supposed resistance, resulting in structural deficiencies (Lekkas et al., 2023). The reason for column collapses in many buildings may be due to a lack of achievement of the concept of a weak beam and strong column using the capacity design concept. See Figures 5 and 6 for more details.

Fig.(5):- collapse and damage due to strong beam and weak column (Mertol et al., 2023; OZTURK et al., 2023).

Fig.(6):- Extensively damaged RC columns (marked by arrows) in a building adjacent to ruins of a collapsed building in Hama (Alhawamdeh et al., 2023).

The phenomenon of converting balconies (cantilevers) on the perimeter of buildings into closed habitable rooms adversely affects the seismic behavior of the entire building due to the prevailing vertical seismic vibration in the epicentral area without providing any provision for the placement of reinforcing steel bars in the lower level of the supporting areas (Lekkas et al., 2023).

Mezzanine floors, stairway slabs, or spaces between columns in infill walls are some of the reasons for the appearance of the short column problem. Shear damage is unavoidable because this column is subjected to a higher shear force than was anticipated during the design phase (Fig. 7). The design of these short columns must be based on the approach of capacity design and take into account the requirements of the transverse reinforcement (OZTURK et al., 2023).

Fig.(7):- Damage due to the short column formation in some buildings (OZTURK et al., 2023).

As shown in Figure 8 inadequate lap splice and anchor lengths, transverse reinforcement, and beam-column joints with insufficient shear capability cause building collapses and considerable damage (Alhawamdeh et al., 2023; Mertol et al., 2023; OZTURK et al., 2023).

(a) (b) (c) (d)

Fig.(8):- Examples of inadequate: (a) anchorage length in beam (OZTURK et al., 2023); (b); transverse reinforcement (OZTURK et al., 2023); (c) stirrup ends' bend (Mertol et al., 2023); and (d) beam-column joint (OZTURK et al., 2023).

2.3 Soft Story and Weak Story

One of the most important causes of collapse and damage to reinforced concrete structures during earthquakes in all countries of the world is the soft story and the weak story problems (see Figure 9). The ground stories are generally used for commercial purposes or parking garages, and the heights of the ground stories are higher than the other stories. Lateral displacements are increased in soft stories due to the removed backfill walls and depending on the decrease in the lateral stiffness of the columns due to the height of the floors. In addition, sudden changes in the strength and stiffness of stories adversely affect the performance of buildings during an earthquake (OZTURK et al., 2023). Many buildings collapsed with a soft story mechanism or out-of-plane (OOP) construction failure, as displayed in Figure 10 (Alhawamdeh et al., 2023; OZTURK et al., 2023) and Figure 11 (Alhawamdeh et al., 2023). Where the collapse of infilled or masonry walls during the first earthquake can lead to the formation of weak and soft stories, which can lead to building collapse during the second earthquake or the aftershocks between them.

Fig.(9):- Collapses resulting from soft or weak stories in RC buildings (OZTURK et al., 2023).

(a) (b) (c)

Fig.(10):- Collapse of masonry or infilled walls of buildings in: (a) Aleppo (Alhawamdeh et al., 2023); (b) Adana (Lekkas et al., 2023); and (c) Latakia (*EMSC - European-Mediterranean Seismological Centre*, 2023).

Before earthquake After earthquake

Fig.(11):- Soft story failure of a 5-storey RC building with masonry infill walls in Elbistan (Alhawamdeh et al., 2023).

2.4 Torsion Effects

Irregularity in the building plan, irregular distribution of infill walls around the perimeter of the building, or collapse of some of these walls can all lead to an increase in torsional response during ground shaking, as shown in Figure 12 (Alhawamdeh et al., 2023).

(a) (b)

Fig.(12):- Torsion damages due to: (a) plan torsion irregularity; (b) plan with an L-shape. (Alhawamdeh et al., 2023)

The torsion effect can also occur at the level of certain structural elements, such as the joint area between the flat slab and the column, which does not reach its capacity due to the insufficient torsional rigidity of the flat beams. Columns narrower than flat beams can also cause beam reinforcements to be located outside of the column. This situation also creates a bonding problem in the connection region (see Figure 13) (OZTURK et al., 2023).

Fig.(13):- Severe damage to RC buildings with infilled ribbed or flat slab (OZTURK et al., 2023).

Inadequate strengthening procedures in existing buildings have also caused significant damage in these retrofitted buildings, due to both design and construction mistakes. Some columns suffered severe torsional shear damage as a result of separation between the old columns and the new added shear walls (see Figure 14) (OZTURK et al., 2023).

Fig.(14):- Earthquake-damage to a retrofitted high school building in Kahramanmaraş (OZTURK et al., 2023).

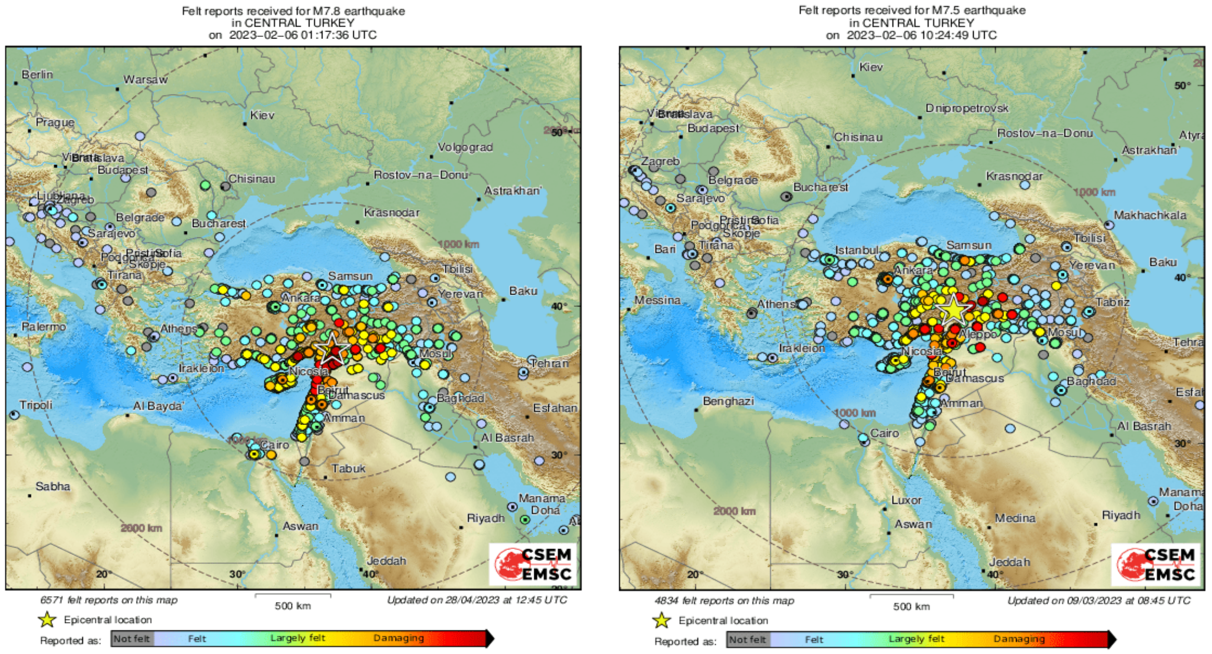
2.5 Insufficient Seismic Gaps

The lack of sufficient seismic gaps between adjacent buildings can lead to significant damage that may lead to collapse due to pounding effects, especially if these buildings differ in their dynamic characteristics, periods, and story heights. Neglecting the displacement and rotation of the foundations resulting from the soil-structure interaction leads to giving the lateral displacement values of the structures less than the realistic values. Figure 15 shows damage and collapses of buildings due to pounding effects.

Fig.(15):- Damage and collapses of buildings due to pounding effects (Alhawamdeh et al., 2023; OZTURK et al., 2023).

2.6 Sequential Earthquakes with High Intensity

Figure 16 displays the felt reports' maps provided by the European-Mediterranean Seismological Centre (EMSC) for both the main shock (M7.8) and the second shock (M7.5), using observations from the public to gather data on the extent and intensity of shaking felt by people during the earthquake.



(a) (b)

Fig.(16):- Maps of felt reports, which are collected for: (a) mainshock (M7.8); and (b) secondshock (M7.5). (EMSC - European-Mediterranean Seismological Centre, 2023)

The response spectra calculated at the site exceed the Design Basis Earthquake (DBE) levels with a 475-year recurrence period (10% probability of exceeding in 50 years) according to code-generated PGA (Alhawamdeh et al., 2023; Mertol et al., 2023), and also exceed levels of the Maximum Considered Earthquake (MCE) which have a 2475-recurrence period (2% probability of exceeding in 50 years) for some sites (Alhawamdeh et al., 2023).

Both earthquakes had total durations that were substantially longer than those of prior major earthquakes that had happened nearby. It is likely that the increased level of damage seen across most of the buildings in the area was affected by these longer duration values (Alhawamdeh et al., 2023).

Another important factor related to the observed collapses is the demand generated by the first earthquake with magnitude (Mw 7.8) followed by the second earthquake (Mw 7.5) of similar magnitude, and high-intensity aftershocks in between (Alhawamdeh et al., 2023).

Because the vertical accelerations of the earthquakes exceeded the criteria set forth by the codes, compression failures resulting from the already inadequate concrete strength and pancake-style structure collapses occurred (OZTURK et al., 2023). And the non-compliance and inadequacy of the load bearing systems may play a major role in the occurrence of this phenomenon. Figure 17. Presents the pancake-style of building collapse.

Fig.(17):- Damage to the load-bearing system with complete building collapse (Lekkas et al., 2023).

2.7 Soil Collapses and Insufficient Foundations

The level of the groundwater level inside the soil is an important factor in studying the soil influence on seismic vibration properties, by distinguishing between two areas according to the hypocentral distance (R): an epicentral area (in which the vertical component of seismic motion dominates) and an area outside of the epicentral (in which the horizontal component of seismic motion dominates). The vertical seismic component is caused by (P) waves, which are easy to propagate through water, while (S) waves, which are mainly responsible for the propagation of horizontal seismic motions, do not travel through water. So, in several cases, where the underground water table even reached the ground surface, the observed damage was greater by one (I) or two (II) degrees of the Macroseismic Intensity Scale (EMS-98) due to the dominance of the vertical component of seismic motion in the epicentral region. Additionally, it was noted that the buildings collapsed at the level of the soil foundation, as though the liquefaction phenomenon had taken place. This occurred as a result of the increased water pressure in the pores, which reduces or even stimulates the friction between the interfaces of the elements of the soil-bearing structure. Other than that, no significant differences were observed in seismic intensity or in the characteristics of ground motion where the vertical seismic component dominated (i.e., in the central region), due to any difference in soil quality or its general properties or formation. This conclusion is based on a comparative study and analysis of the seismic behavior of the structures and considering them to act as seismoscopes, since it is not possible to install seismic vibration recording tools (i.e., accelerometers) everywhere, and even more so because it happens that the vertical seismic component decomposes, with the distance from the epicenter, much faster than the horizontal component. In the regions outside the epicenter, the horizontal component of seismic motion dominates. Contrary to the above observations, what works for soil effects on seismic vibration properties was confirmed once again (Lekkas et al., 2023).

Many locations that now have high-rise buildings over them were once soft fields that were once used for agriculture. The water table was practically at the surface in these irrigated areas of the land, but it was often noted that the water was still emerging from the surface. These high-rise buildings' foundation systems can be safely categorized as "unsuitable" since they are too shallow (indicative, noted to be (where possible) between 0.50 and 0.60 meters), lacking the appropriate surface area for soil quality/conditions, and inadequately designed. A basic estimate of the foundation soil's strength predicts a tolerable bearing pressure of 40 to 50 kPa, whereas seismic excitation imposes 400 to 600 kPa or around 10 times the pressures that the specific type of earth can withstand (Lekkas et al., 2023). Figure 18 presents the liquefaction phenomenon that erupted in the February 6, 2023 earthquake.

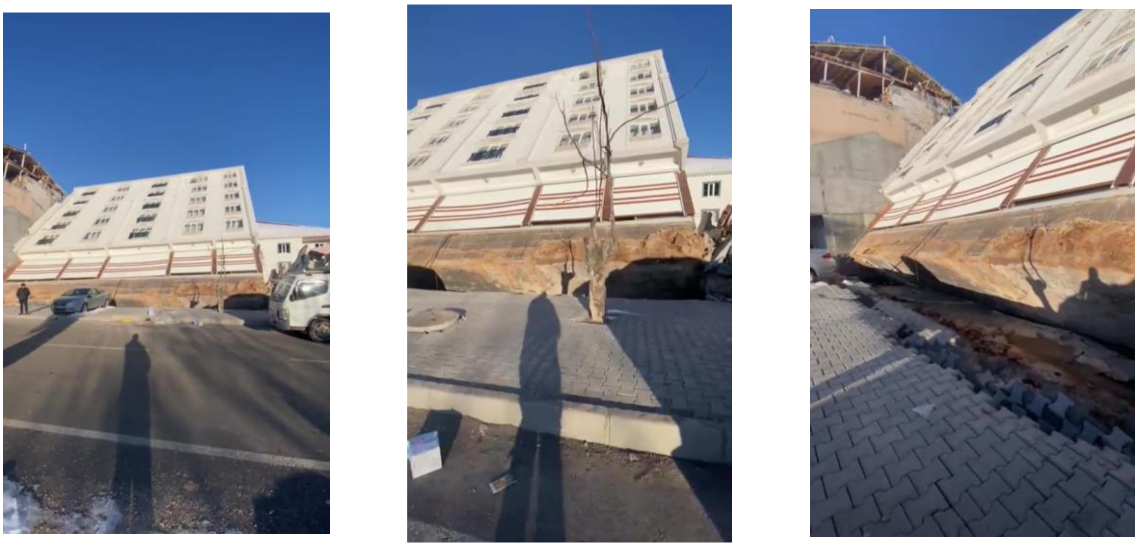


Fig.(18):- Liquefaction phenomenon tilted the building with no damage on the upper floors (Lekkas et al., 2023).

Finally, the main damage patterns mentioned in this paper and their causes can be summarized in Table 1.

Table (1):- Main damage modes and their reasons for earthquake-affected buildings

Main damage mode	Reason of damage
Total collapse of the building or/and piles of gravel and sand	Poor Quality of Structural Element Materials
Severe damage or/and Partial collapse of building	Poor Structural and Execution Details
Partial or/and total collapse of the building	Soft Story and Weak Story
Severe damage or/and Partial collapse of building	Torsion Effects
Severe damage or/and collapse	Insufficient Seismic Gaps
pancake-style of building collapse	Sequential Earthquakes with High Intensity
Partial or/and total collapse of the building	Soil Collapses and Insufficient Foundations

3. CONCLUSIONS

According to the current review, it can be found that building collapse due to earthquakes has many reasons. One of the most common reasons is poor material, poor construction, and the fragility of the structures, as many buildings were built of concrete with insufficient seismic reinforcements, inadequate development lengths, and non-compliance with the requirements of the seismic code, whether in design or implementation, in addition to the lack of maintenance of buildings by the owner and their rehabilitation in an inefficient manner. Another reason is the possibility of exceeding the intensity of the earthquake by more than the levels incorporated in the structural design, as well as the sequence in which multiple earthquakes of similar intensities occur on the same day. Likewise, soils with low bearing capacity, their liquefaction, and foundation failure are among the important reasons for buildings collapsing. In conclusion, building collapse is related to the characteristics of the building itself and its periodic maintenance, earthquake intensity, foundation, and soil type.

It is best to always adhere to the latest seismic codes for designing and constructing buildings in each country, such as the Syrian Arab Code and its Annex for Earthquake 2018 and the Turkish Building Earthquake Code 2018, and to constantly amend these codes to keep pace with global developments and based on the lessons learned from earthquakes.

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