Behavior of Unreinforced Masonry Structures During the 1992 Erzincan, Turkey, Earthquake

by Michel Bruneau[1] and Murat Saatcioglu[2]

INTRODUCTION

The Richter Magnitude 6.8 earthquake which struck Erzincan, a city of 100,000 population in eastern Turkey, on March 13, 1992, was one of the deadliest in this decade, so far. Its epicenter was only 7.7 kilometers north of the city. Officially, more than 525 died and over 700 were seriously injured, but the unofficial death toll, based on estimates of the survivors in the region, was in excess of 3,000. Approximately 300 buildings were destroyed, and another 500 damaged. These buildings were similar in form and structural system to those of the same vintage found across Europe and North America, largely because the city, after being flattened by another devastating Richter Magnitude 8.0 earthquake in 1939 (6600 buildings destroyed out of an inventory of 7200), had to be slowly rebuilt in compliance with Turkish aseismic design codes largely inspired from others used elsewhere in the world.

As masonry is the most universally available and economical construction material, unreinforced masonry (URM) structural or non-structural components are used widely throughout Erzincan, in spite of the fact that URM structures have long been recognized as most damage-prone during earthquakes. Not surprisingly, catastrophic failures of such structures were observed, but the survival of numerous URM buildings also was noted. A review of this seismic performance is worthwhile in view of the growing interest in the mitigation of seismic hazard in existing URM buildings worldwide.

Another predominant structural system used for buildings in Erzincan consists of reinforced concrete frames with unreinforced masonry infills. This structural form is used for all building heights and occupancy, from single story commercial to multi-story residential and office buildings. As these URM infill

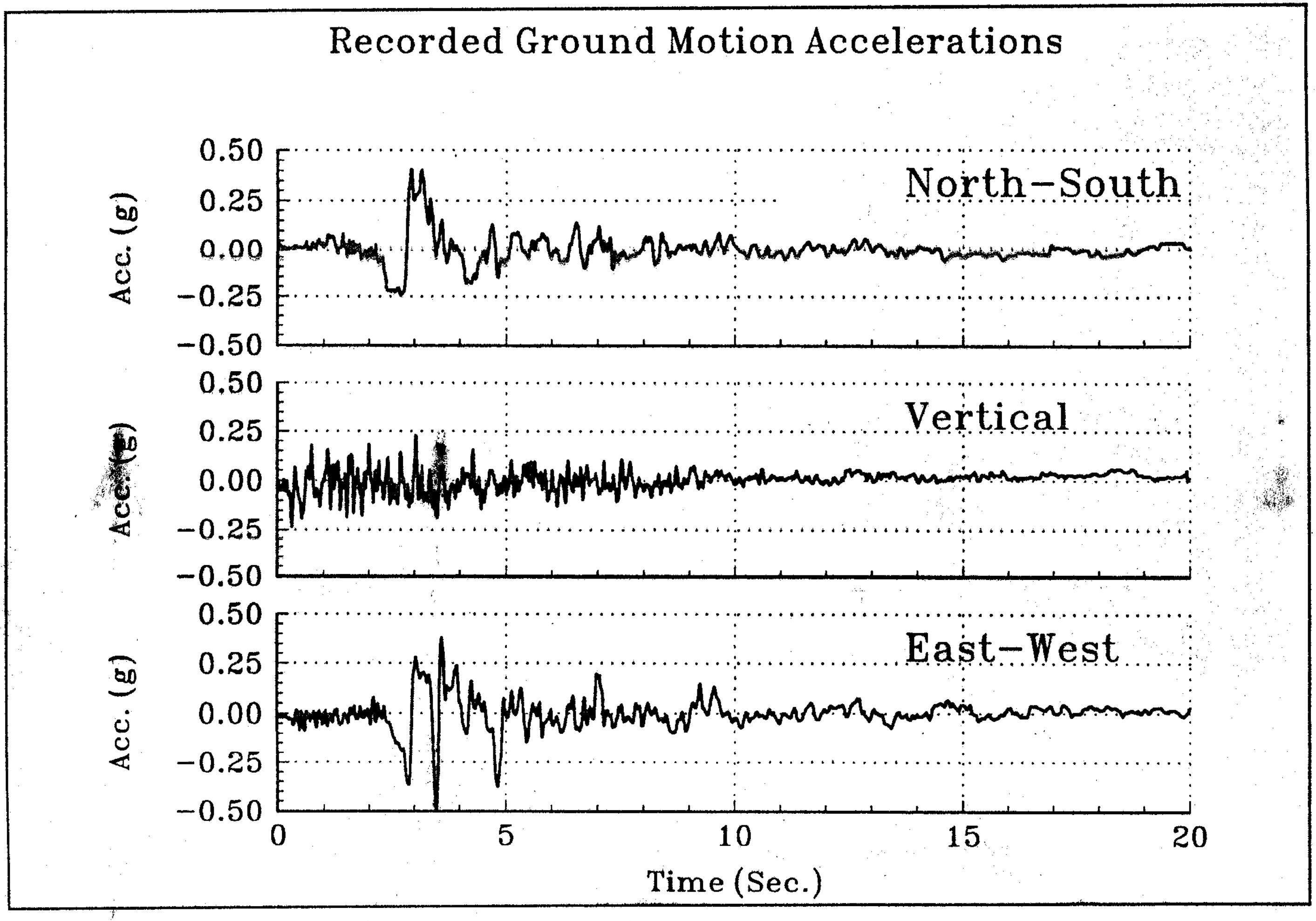

FIGURE 1. Strong motion accelerograms

---

[1] Department of Civil Engineering, 161 Louis Pasteur, University of Ottawa, Ottawa, Ontario, K1N 6N5, Tel.: (613) 564-3432, Fax.: (613) 564-9860, TMS Member.

[2] Department of Civil Engineering, 161 Louis Pasteur, University of Ottawa, Ottawa, Ontario

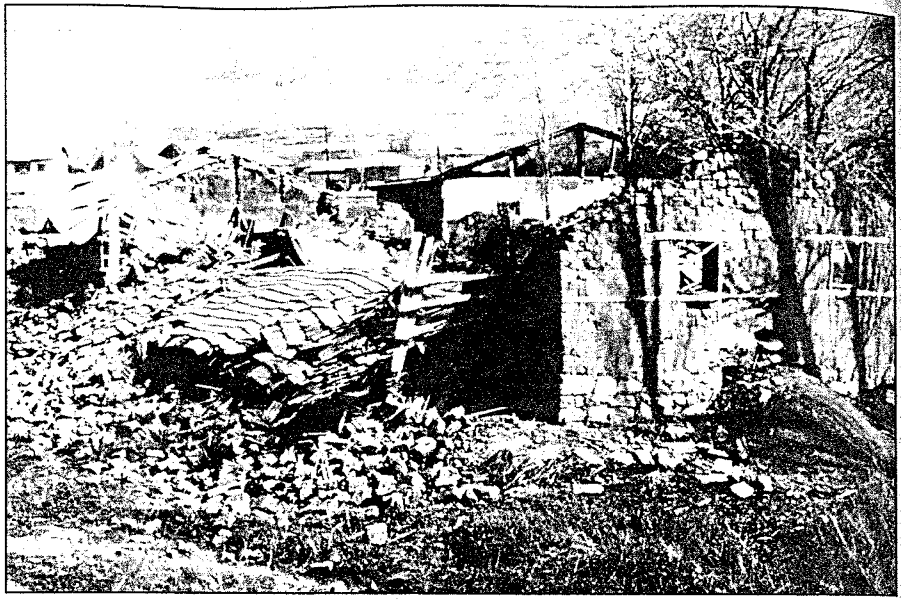

FIGURE 2. Example of collapsed mud-brick masonry construction

partitions had a dominant influence on the performance of the main structural system, a brief overview of this seismic performance also is noteworthy.

This paper focuses on reporting the seismic performance of buildings in which unreinforced masonry was the dominant structural system or played a major role as an unintentionally interacting non-structural element. Most lessons learned and relearned from this review are broadly applicable and believed to have direct implications for seismic resistant design practice, even though some masonry construction materials and systems used in Erzincan are not common to North America. A detailed review of the seismological and societal aspects of this disaster, as well as the seismic performance of non-masonry structural systems, is available elsewhere (1, 2, 3).

BASIC SEISMOLOGICAL DATA

A single strong motion instrument was present in Erzincan at the time of the main shock. It was located in the Meteorological Services Building, approximately in the center of the town, situated above a deep soil deposit. The three digitized acceleration time histories recorded by this instrument along its orthogonal axes were obtained by the writers, and are plotted in Figure 1. The values of horizontal PGA recorded, 0.39g and 0.49g in the N-S and E-W directions respectively, are compatible with those anticipated at such a close epicentral distance for an earthquake of this magnitude as per the existing applicable attenuation relationships (4).

A visual inspection of the ground acceleration time histories reveals that several large pulses of acceleration occurred early in the record. Such damaging acceleration pulses, often present in near source records, are known to translate into large energy demands on structural systems. Local soil conditions may be held partly responsible for the presence of these pulses but, in the absence of accelerogram records on rock, and until further geotechnical investigations are conducted, this can only be speculated.

UNREINFORCED MASONRY STRUCTURES

The spectrum of RUM construction types and practices varied greatly in Erzincan. Mud brick construction of low quality was used widely in the poorest neighborhoods on the outskirts of the city; while some have collapsed (Figure 2) or suffered major damage, others survived somewhat intact. The individual seismic performance of these non-engineered dwellings is an intricate function of wall thickness, internal subdivisions, roof mass, nature of the continuity with adjacent dwellings, etc. Even though these dwellings are of no engineering significance, it was sad to see their resourceless occupants rebuilding with exactly the same techniques and materials following the earthquake, often re-using surviving parts of severely damaged walls, in spite of the demonstrated poor seismic performance and high life-safety hazards of these constructions.

The URM construction type most commonly used in Turkey consists of reinforced concrete slab floors poured on top of URM bearing walls. The high in-plane rigidity of the floors allows a good distribution of seismically-induced forces to walls as a function of their respective rigidity, but reliance on the brittle URM to resist lateral forces ensures that once the strength threshold is exceeded, severe damage and/or dramatic collapse is likely. In-plane, out-of-plane, and combined in-plane/out-of-plane failures have all been observed, as normally expected from URM buildings.

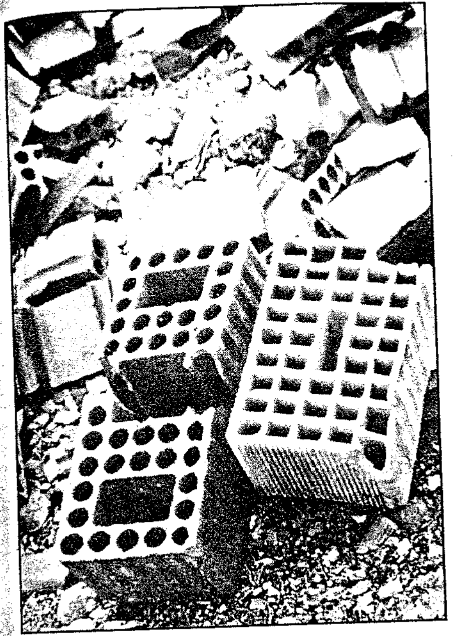

FIGURE 3. Examples of types of non-bearing masonry brick commonly encountered

Brick quality has a major influence on the in-plane performance of such structures. This is well demonstrated in cases in which non-bearing masonry has been substituted (as a cost-cutting measure or out of ignorance) for the bearing masonry normally required for this type of construction. In Turkey, a variety of brick-masonry units is available, and the Turkish standards TS-4377 (5) and TS-705 (6) differentiate between bearing and non-bearing units and their corresponding types of applications, the latter being allowed for partitioning purposes only.

Two types of non-bearing masonry were commonly encountered: multi-cell clay blocks with large rectangular holes or smaller circular holes, manufactured in Erzincan and Tokat (Turkey) respectively (Figure 3). Although the usage of both types is improper in a bearing wall application, even such a slight variation in shape had repercussions on seismic behavior. This was most forcefully illustrated in the neighboring town of Uzumlu, 30 kilometers east of Erzincan, where an entire residential complex of URM buildings was under construction at the time of the earthquake. Although the seismic intensity in this town already was less than in Erzincan, being attenuated by distance, a number of those new URM buildings collapsed. While others have alleged that a local soil effect was solely responsible for the damage sustained by the buildings built on the valley side of the Uzumlu complex, the writers believe that, in light of the

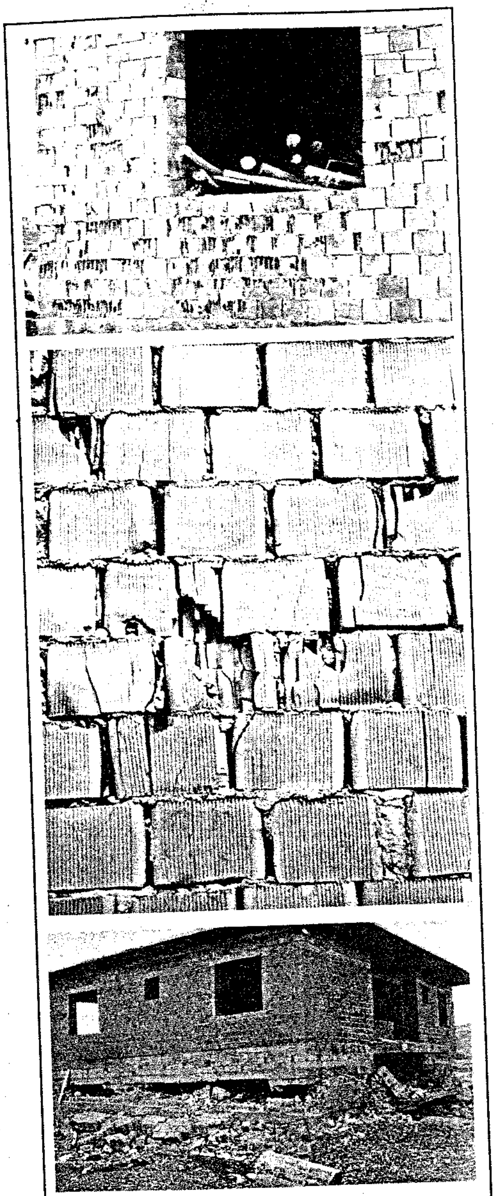

FIGURE 4. (a) Partially delaminated brick of the thin cell-walls type; (b) Close-up view of same; (c) Collapse of a URM building due to diagonal crushing of non-bearing masonry brick

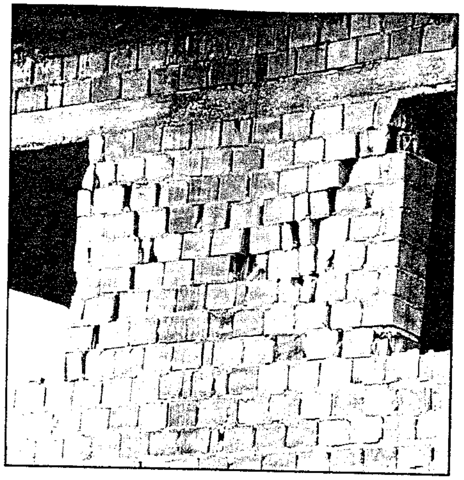

FIGURE 5. Large diagonal cracking in URM walls built with circular-cell non-bearing masonry blocks

severe difference in seismic performance observed over only a few hundred feet and a subjective evaluation of the local topography, such a soil effect can be, at best, only partly accountable for this damage. A closer observation revealed that, invariably, the walls built of the rectangular-cell URM blocks were severely damaged. This can be attributed to the poor resistance of these URM walls to seismically-generated compressive diagonal stresses. The very thin cell walls of these bricks proved unstable as soon as the compressive capacity was exceeded, producing an effective "delamination" accompanied by a rapid drop in strength, often leading to overall collapse (Figure 4). By comparison, vary large diagonal cracking was observed to occur in walls built with circular-cell masonry blocks; a lower void ratio and thicker average brick-cell walls both contributed to an enhanced block stability under compression, and allowed some structures to survive in spite of very large diagonal in-plane cracking (Figure 5). In-plane failures dominated in this case.

The out-of-plane behavior, being dependent on height-to-thickness (h/t) ratios, appears adequate for this type of URM construction. The connectivity bond forces at the reinforced concrete floors, the very low relative story heights, and the wide bricks used, partly explain why very few out-of-plane failures were observed.

In spite of these numerous failures, many residential URM masonry structures were observed to have survived this earthquake intact (Figure 6). This excellent behavior is largely attributable to the high structural redundancy of the older structures; the typical living area of residential apartments in Erzincan averages 70 m² per unit, subdivided by masonry-block partitions into two or three bedrooms, living room, kitchen, and restroom. A number of other URM structures also were present in Erzincan, and their performance was similar to that observed worldwide in similar circumstances. For example, a URM warehouse completely collapsed at the Rural Services Affairs (Figure 7). Constructed of 325 mm thick masonry walls of near-solid bricks, coated by more than 25 mm of stucco, for a height-to-thickness ratio of 11.5, the out-of-plane failure of this practically solid-wall rectangular enclosure occurred largely as a consequence of the absence of anchorage at roof level. Also as a consequence of a similar lack of anchorage, the out-of-plane failure of gable roofs, made of various types of masonry units, was extensive throughout Erzincan (Figure 8).

Double-layer URM walls constructed with sandwiching insulation (or sawdust used as insulation) also performed poorly: the presence of insulation prevented bond between the layers, leading to increased height-to-thickness ratios and out-of-plane damage (Figure 9). For similar reasons, other cavity walls performed

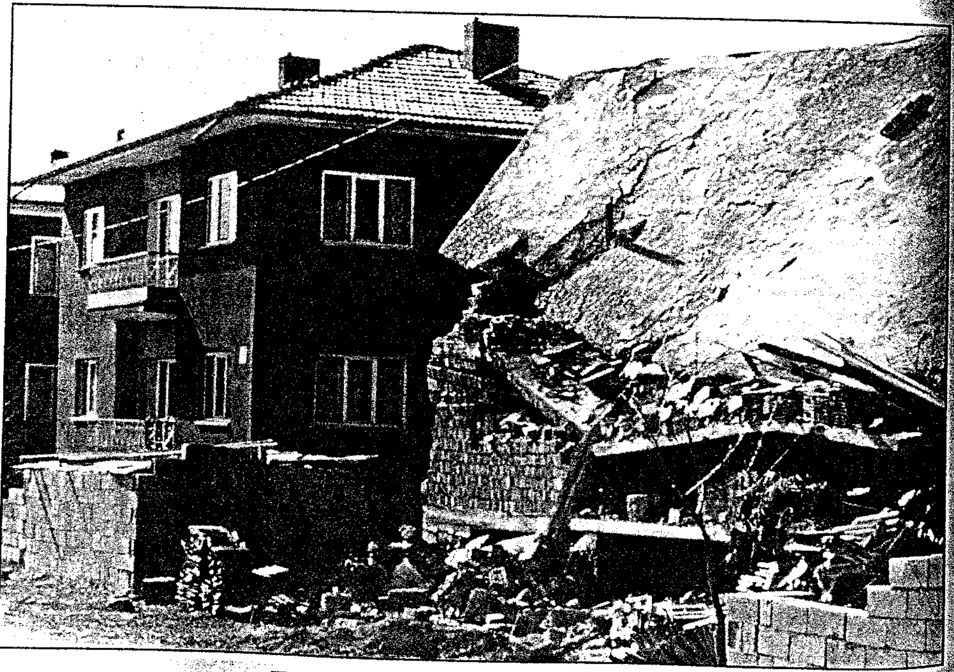

FIGURE 6. Example of older residential URM masonry buildings that have survived intact, next to a new building collapsed while under construction

FIGURE 7. (a) Completely collapsed warehouse due to out-of-plane failure of near-solid brick masonry at the Rural Services Affairs, and (b) close-up view of the brick masonry

FIGURE 8. Typical out-of-plane failure of unanchored gable roofs

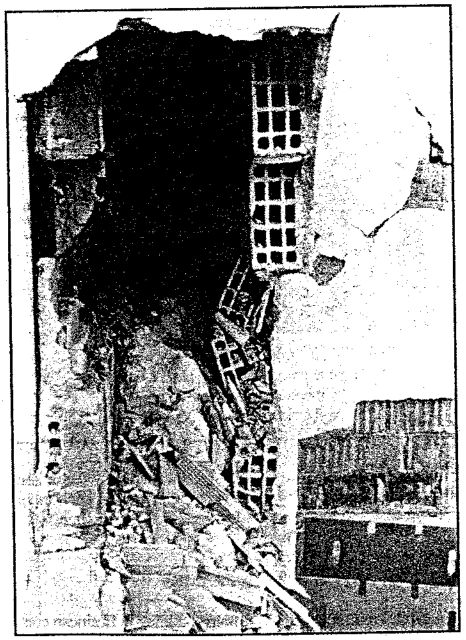

FIGURE 9. Damaged double-layer URM walls sandwiching insulation

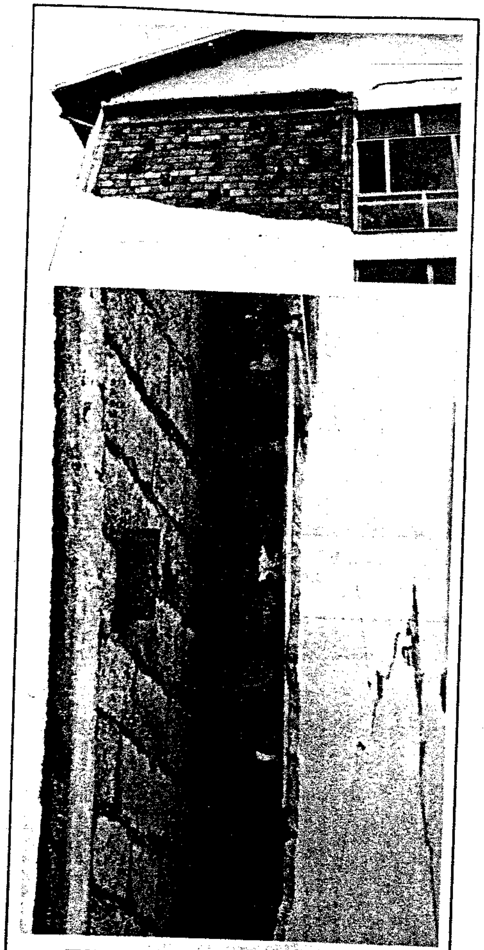

FIGURE 10. (a) Damaged cavity walls where sparse transverse cross-blocks were intended to act as anchors; (b) close-up view of same

equally poorly, regardless of the type of masonry used, and sometimes in spite of the presence of a few metal anchors or transverse cross-blocks intended as anchors (Figure 10).

MASONRY INFILLS IN REINFORCED CONCRETE FRAMES

A typical reinforced concrete frame building in Erzincan consists of a regular, symmetric floor plan, with square or rectangular columns and connecting beams. The exterior enclosure, as well as interior partitioning, is comprised of non-bearing URM infill walls. In some cases, double layers of masonry with insulation in between, are used for the exterior walls. These masonry infills were largely built out of unreinforced brick masonry; the use of concrete masonry was limited. The brick units were either solid or hollow brick. The solid bricks were used essentially as load-bearing units, although occasionally they were used as infills in some of the older buildings as well. Many different types of hollow, multi-cell bricks were used, both as load-bearing, and non-load-bearing units.

FIGURE 11. Typical (a) diagonal tension and (b) compression failures in masonry infills

Although these walls increased the overall building mass and seismically-induced inertia forces, they also contributed significantly to the lateral stiffness of buildings during the earthquake and, in many instances, controlled the lateral drift, and resisted seismic forces elastically. This was especially true in low-rise buildings, older buildings where wall-to-floor area was very high, buildings constructed mostly of solid bricks, and buildings located close to the firm soil near the mountains—especially when the masonry walls started from the ground level and continued along the building height. Where structural response and deformability demands were high, the masonry walls were not able to remain elastic, particularly when non-bearing hollow brick was used as infill. These non-bearing hollow bricks did not have the strength to withstand diagonal compression generated during the earthquake, and high deformability demands of frame structures. Therefore they developed diagonal tension and compression failures as shown in Figure 11. Crushing of the cells of the hollow brick units led to the separation of the infills from the frame, as shown in Figure 12. In one of the buildings of the Sumerbank Textile Factory, this separation was followed by out-of-plane movement of the infill, as illustrated in Figure 13. In some cases, failure of individual brick units triggered more conventional out-of-plane failures of infills.

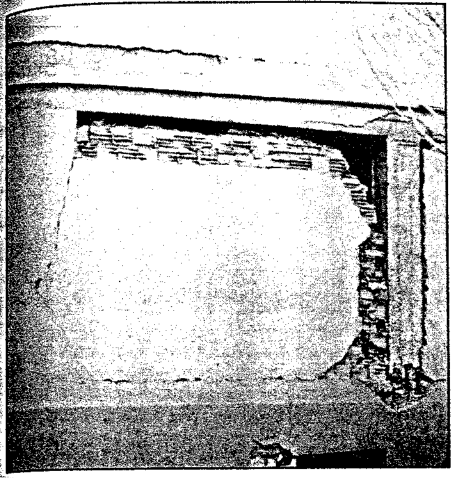

FIGURE 12. Crushing of hollow brick masonry and separation of infills from the frames

It is noteworthy that severe infill failures produced a considerable amount of falling debris which not only acted as life hazards during the earthquake, but also obstructed stairwells and passageways preventing subsequent safe egress of occupants (Figure 14). These observations partly explain why even minor separation cracks between infills and reinforced concrete frames, in otherwise sound buildings which survived the earthquake, became a major cause of concern to scared owners and tenants—most refused to re-occupy the premises, afraid that collapse was imminent.

Unreinforced concrete masonry infills were used in some of the commercial buildings as well as the State Hospital. Their performance appeared to be slightly better than those of the brick masonry.

Once the brick infills failed, the lateral strength and stiffness had to be provided by the frames alone, which then experienced significant inelasticity in the critical regions. At this stage, the ability of reinforced concrete columns, beams, and beam-column joints to sustain deformation demands depended on how well the seismic design and detailing requirements were followed both in design and construction. A review of the seismic performance of reinforced concrete frames during this earthquake is beyond the scope of this paper.

FIGURE 13. (a) Separation of URM infills from reinforced concrete frames and out-of-plane movement of part of the infill in Sumerbank textile factory; (b) close-up view of same

FIGURE 14. Emergency exit obstructed by debris from URM infill failures

Finally, as an indirect consequence of discontinuous infill walls, a large number of residential and commercial buildings were built with soft stories at the first-floor level. First stories in Erzincan often are used as stores and commercial areas, especially in the central part of the city. These areas as enclosed with glass windows, and sometimes with a single masonry infill at the back. Heavy masonry infills start immediately above the commercial floor. During the earthquake, the presence of a soft story increased deformation demands very significantly, and put the burden of energy dissipation on the first story columns. Many failures and collapses can be attributed to the increased deformation demands caused by soft stories, coupled with lack of deformability of poorly-designed columns. Figure 15 illustrates an example of apartment building with a soft story.

CONCLUSIONS

The extensive structural damage that occurred in Erzincan forcefully demonstrates the potential catastrophic seismic performance of non-ductile structural systems. A large number of URM structures collapsed during this earthquake. Many buildings with non-structural URM infills also performed poorly: either severe structural damage was produced by the unintentional interaction of these infills with the reinforced concrete frames (e.g., soft stories), or the falling debris from damaged infills created life safety hazards during the earthquake.

However, in some instances, the behavior of such systems was surprisingly satisfactory if enough over-strength was present to ensure elastic response. This was observed in older URM buildings with numerous thick walls and good quality, more-solid brick, and in most of the reinforced concrete frame structures with URM infills that survived the earthquake. URM infills used in these structures added considerable strength and stiffness to the system, ensuring elastic behavior of the frames.

In light of the observed damage in Erzincan, decision-makers should be fully aware of the catastrophic nature of non-ductile structural systems when weighing options in seismic risk mitigation strategies. This is particularly important in North America because of the large inventory of existing structures built prior to the enactment of ductile design guidelines.

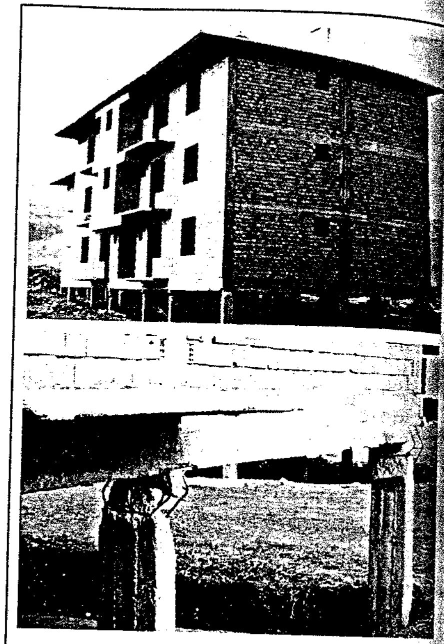

FIGURE 15 (a) A reinforced concrete frame building with a soft story, under construction; and (b) close-up view of first-story column failures

ACKNOWLEDGMENTS

The writers are most grateful to the Faculty of Engineering of the University of Ottawa for funding this reconnaissance visit, the Ministry of Reconstruction and Resettlement of the Republic of Turkey, and the Middle East Technical University (METU), Ankara, Turkey, for their generous on-site assistance, hospitality and support. Appreciation is extended to METU President Professor O. Saatcioglu, and Professor A.R. Gunbak, also of METU, for making all the necessary arrangements for the trip. The writers thank the METU structural engineering faculty members, in particular Professors Ersoy, Tankut, Gulkan, and Sucuoglu, for sharing some of their findings, and providing background information regarding the site visit. The kind assistance of the deputy-governor, police chief, and other officials of the province of Erzincan, as well as from building owners, plant directors and residents of Erzincan, too numerous to name here, is acknowledged. The findings and recommendations in this paper, however, are those of the writers alone.

APPENDIX I – REFERENCES

1. Saatcioglu, M., & Bruneau, M., 1993. *Performance of Structures During the 1992 Erzincan Earthquake*, Canadian Journal of Civil Engineering, Vol.20, No.2, pp. 305-325.
2. Earthquake Engineering Research Institute, 1993. *Erzincan, Turkey Earthquake of March 13, 1992 Reconnaissance Report*, Earthquake Spectra, Supplement to Volume 9, 210 p.
3. Gulkan, P. 1992. "A Preliminary Field Reconnaissance Report on the Erzincan Earthquake of 13 March 1992," Department of Civil Engineering Report, Middle East Technical University, Ankara, Turkey.
4. Naeim, F. 1989. *The Seismic Design Handbook.* New York: Van Nostrand Reinhold, 450 pp.
5. Turkish Standards Institute 1985. *TS 705 Solid Bricks and Vertically Perforated Bricks.* Ankara, Turkey.
6. Turkish Standards Institute 1985. *TS 4377 Vertically Perforated Lightweight Bricks.* Ankara, Turkey.