

4. BUILDINGS, DWELLINGS AND BRIDGE

A large number of engineered as well as non-engineered buildings were severely damaged and collapsed during the earthquake. This chapter reports the damage on building structures and describes their possible causes. Unreinforced masonry (URM) structures were damaged commonly due to poor construction practice of bearing walls. The seismic performance of brick masonry infills was catastrophic in URM structures. Adobe buildings completely collapsed or suffered heavy damages; the damage level depended on the distance from ruptured surface faulting.

Most of the destroyed villages were subjected to the full intensity earthquake motion without attenuation since they were very near to the ruptured fault, which extended from west to the east along the foot of mountains. The site effects amplified the earthquake motion in some areas and caused excessive damages. In general, villages near the epicenter and ruptured fault suffered larger damage.

Building team (to survey building damage) consisted of Dr. Masakatsu MIYAJIMA (vice team leader), Professor of Kanazawa University; and Dr. Reza Alaghebandian, Assistant Professor of The University of Tehran.

Since the stricken areas were very vast and damaged villages were scattered, the building team decided to visit most damaged area to cover more damages. This team investigated some major affected villages during three effective days till Friday, 26th June. The locations of investigated villages, measured through satellite using a GPS unit. The reconnaissance team held a meeting in Interior Ministry to explain their findings on 27th June (Saturday) and left Tehran for Japan on Sunday, 28th July. The following report is based on the two-week reconnaissance visit.

4.1 CHARACTERISTIC OF THE BUILDING INVENTORY

Traditionally, single-story adobe buildings have been used for construction in majority of the region. The adobe buildings were also used as warehouses or sheepfolds. The second most widely used type of construction in the villages was masonry building. New construction materials such as concrete and brick masonry were widely spread in the region. The predominant structural system used for buildings in villages consisted of unreinforced brick masonry (URM) bearing walls, which support steel-masonry (Jack-arch) floor slabs. This type of construction is used for most of residential units with a nearly identical detailing. While the majority of new buildings are of single-story, there are some two and even three-story buildings in relatively big villages. Steel frames as well as reinforced concrete frames were rarely used in the regions.

4.2 ADOBE BUILDINGS

The old adobe buildings were used not only as residential units but also as warehouses or sheepfolds. The construction of low quality adobe buildings consisted of mud-brick bearing walls, which supported a flat slab or arch floor slab. Stone was also used as an alternative material of a bearing wall in villages near mountain. Flat slabs were constructed with wooden beams thatched with mud-straw materials, while arch slabs were built by mud-brick bonded with mud-grout. The seismic performance of non-engineered dwellings is a function of wall thickness, internal subdivisions, roof mass, nature of the continuity with adjacent dwellings, distance to the fault, site effects, etc. **Figure 4.1** shows the failure of adobe buildings with arch floor slabs and/or wooden floor slabs.



(a) Adobe dwellings with arch roof and/or timber roof (Abdareh)



(b) A timber roof thatching with asphalt (Changureh)

Figure 4.1 Damaged adobe dwellings

4.3. UNREINFORCED MASONRY STRUCTURES

Unreinforced masonry (URM) structures suffered severe damage during the earthquake. Unfortunately, as masonry is the most universally available and economical construction material, individual owners used it widely around the regions. The URM is most commonly used in Iran together with steel-masonry (Jack-arch) floors poured on top of URM bearing walls. The high in-plane rigidity of the Jack-arch floor system led to a good distribution of seismically induced forces to bearing walls. However, reliance of floor on brittle URM bearing walls to resist lateral forces ensures that once the strength threshold is exceeded, severe damage and/or dramatic collapse are likely to occur. In-plane, out-of-plane, and combined in-plane and out-of-plane failures have been observed, as normally expected from URM structure buildings. **Figure 4.2** shows a collapsed URM structure building with steel-masonry Jack-arch slab.

Revised Iranian Seismic Code (1988) has a chapter for URM structure buildings. The design of new constructed governmental buildings like schools conformed to the Iranian Seismic Code detailing in their construction. In-plane failure of bearing walls was frequently observed in these types of URM structures. **Figure 4.3** shows an example in which the horizontal and vertical R/C ties are constructed following the Iranian Seismic Code.



Figure 4.2 Collapse of a URM structure (Abiz)



Figure 4.3 Newly constructed URM structure (Esfad)

Brick and mortar quality have major influence on in-pane performance of URM structures. Employing solid-bricks bonded with mortar in URM bearing walls with a thickness of 350-mm, seems to be sufficient to prevent out-of-plane failure in typical single-story URM structures. However, out-of-plane failure of URM bearing walls was the principal cause of collapse of URM structures. The use of poor mortar resulted in an unstable wall when subjected to out-of-plane seismic force. Moreover, the absence of any anchorage at the roof levels between bearing walls and slabs compounded the

problem and caused more damages. A number of owners used URM structure to enlarge their R/C buildings. Generally, the expanded wings collapsed while R/C structures suffered no damages.

4.4 SEMI-STEEL STRUCTURES

Because of high economic reason, structural steel was rarely used as a lateral resistance system in a structure. On the other hand, the use of steel was limited to the steel-masonry Jack-arch floors. **Figure 4.4** shows a two-story semi-steel structure with steel columns and beams. The building consisted of one interior and two exterior wings. URM bearing walls supported the roof slabs of exterior wings while steel columns were used to support the roof slab of the interior wing. The URM bearing walls collapsed and supported roofs fell down but the four relatively slender columns supported the interior wing without collapse.



Fig. 4.4 A typical collapsed URM structure (Esfeden)

4.5 DAMAGE TO BRIDGE

Most of bridges consisted of stone piers supporting an arch masonry slab or reinforced concrete slab. Only one bridge in the investigated area suffered damage from the earthquake. This was a single-span reinforced concrete overpass located between Abdareh and Changureh. The stone pier at one side collapsed and the settlement of slab caused a horizontal crack at the stone pier of the other side. **Fig. 4.5** shows the damaged bridge, which was closed to traffic.



Figure 4.5 Damaged bridge between Abdareh and Changureh

4.6 CONCLUSIONS AND RECOMMENDATIONS

The use of non-ductile structural systems such as adobe and unreinforced masonry (URM) structures resulted in the catastrophic damage. The URM structure, conformed to the Revised Iranian Seismic Code (BHRC), suffered heavy damage but survived from collapsing. Other URM structures commonly collapsed due to out-of-plane failure of infills. The absence of anchorage as well as the use of poor mortar was the cause of out-of-plane failure of infills. Beyond the elastic limit, seismic survival of the building depended heavily on ductility of the structural components. The use of slender columns can be noted as another primary cause of failures.

In general, the following points can be recommended:

- The owner of traditionally constructed adobe buildings should warn and encourage substituting their house with new construction seismic resistant structural systems.
- Existed reinforced concrete framed structures should analyze again and retrofit in a proper manner.
- Proper reinforcement detailing sketches should distribute between constructors as well as owners and house makers in a simple manner including clear sketches in detail.
- Construction of brittle URM structures should limit and using ductile members substitute.
- The villagers should be warned of using heavy construction materials especially in roof and particularly while thatching the roofs.

Villagers should encourage removing and reconstructing their houses in sites far from fault.

ACKNOWLEDGMENT

The authors greatly appreciate the Japan Society of Civil Engineering Ministry of Education (JSCE) for funding the reconnaissance visit. Building and Housing Research Center (BHRC) and Earthquake Engineering Research Center of Tehran University (EERC), Tehran, Iran, for their on-site assistance, hospitality, and support is also appreciated. The cooperation of local governor, police, and other

officials of local regions, as well as good-hearted building owners and residents are acknowledged. The findings and recommendations in this paper, however, are limited to those of the author.

(4.1, 4.2, 4.3, 4.4, 4.5 and 4.6/ *Reza ALAGHEBANDIAN*, Earthquake Engineering Research Center, Tehran University)

REFERENCES

- Building and Housing Research Center (BHRC) (2002). "Preliminary Report of Avaj-Changureh Earthquake", Ministry of Housing and Urban Development, Iran, in Persia.
- Otani *et. al*, (1993). "Damage Report on 1992 Erzincan Earthquake, Turkey", Joint Reconnaissance team of AIJ, JSCE, and Bogazici Univ., Istanbul, Turkey.
- Building and Housing Research Center (BHRC) (1988). "Iranian Code for Seismic Resistant Design of Buildings", Ministry of Housing and Urban Development, Iran.