Damage to Building Structures Caused by the 1999 Athens Earthquake in Greece

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This report presents the field investigation results on damage to building structures caused by the 1999 Athens earthquake. A total of 135 buildings were investigated during the field investigation, and severe structural damage including totally and partially collapsed building structures, especially reinforced concrete (R/C) building structures, were observed. The present report is a draft for Appendix of the AIJ (Architectural Institute of Japan) Report on Damage Investigation of the 1999 Kocaeli Earthquake in Turkey which will be published within the year of 2000.

Key words: 1999 Athens earthquake, Greece, earthquake damage, R/C buildings, masonry building, historical structures

1. INTRODUCTION

At 14:56 local time (11:56 GMT) on Tuesday of the 7th of September 1999, an earthquake of Magnitude of $M_w=5.9$ occurred with the epicenter of Northern Athens District of Menidi (also called Aharnes), and 143 people were killed and about 2,000 people were injured [1].

Authors of the present report, who were the members of the 1999 Turkey Earthquake Reconnaissance Team from the Architectural Institute of Japan (AIJ) moved from Istanbul to Athens on the 11th of September 1999, which was four days after the occurrence of the main shock of this Athens Earthquake, and left Athens on the morning of the 13th of September 1999. The two members spent two nights in Athens, and investigated a total of 135 damaged buildings.

This report presents the field investigation results on damage to building structures caused by this earthquake.

2. BRIEF DESCRIPTION OF EARTHQUAKE

The main shock of this earthquake occurred at 14:56 local time (11:56 GMT) on Tuesday of the 7th of September 1999, and Magnitude of the earthquake was $M_w=5.9$. Location of the main shock was 38.09N and 23.63E, which is located about 15 km to the north of the downtown of the City of Athens. The depth of the main shock of this earthquake was about 11 km. The fault plane solutions indicate WNW-ESE trending, almost south-dipping normal fault [1, 2].

Long before the main shock of this earthquake, the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) installed three analog accelerographs, belonging to the permanent strong motion network of ITSAK, in the City of Athens as being observed in Figure 1. Accelerograms of the main shock recorded at these three observation stations, which were located at distances of 15 km to about 17 km from the epicenter of the main shock, are respectively shown in Figures 2(a), 2(b) and 2(c). Among these, maximum horizontal ground acceleration of 0.30g was recorded at the ATH-3 Station. The peak horizontal ground accelerations at the other two Stations, ATH-2 and ATH-4, were 0.16g and 0.12g, respectively.

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addition, acceleration response spectra for 5% damping are shown in Figure 3. Unfortunately, no accelerograph was installed at around the epicentral area as shown in Figure 1. However, maximum peak ground acceleration near the epicenter field was predicted as about 0.60g by normalizing for distance [1].

3. RESULTS OF RAPID DAMAGE EVALUATION FOR BUILDING STRUCTURES

After the main shock of this earthquake, rapid damage evaluation was conducted by the state inspectors by using the three-color system, each color is meaning as follows;

- **Red**: Dangerous structure. Do not enter. Demolition will be required.
- **Yellow**: Damaged structure. Do not use as a dwelling. Repairs are required before reoccupation.
- **Green**: Minor damage may have occurred. Building can be occupied.

As of the 14th of September 1999, approximately
56,000 dwelling buildings had been investigated by the state inspectors. The investigation result was as follows [3];

- **Red**: 11%
- **Yellow**: 39%
- **Green**: 50%

### 4. FIELD INVESTIGATION

#### 4.1 Scope and Method of Field Investigation

A field investigation by the authors was conducted in two areas of Ano Liosia and Menidi, both of which were close to the epicenter of this earthquake and were reported to suffer relatively severe damage in the rapid damage evaluations (see Figure 1). In this field investigation, damaged buildings were recorded by photograph, and size and shape of the damaged elements were measured carefully in some buildings. A total number of the investigated buildings including the dwelling and non-dwelling buildings was 135, in which 92 buildings were reinforced concrete (R/C) structures and 43 buildings were masonry wall structures. There were no steel structures in the investigated area except for some low-rise industrial buildings. In addition, major historical structures such as Parthenon and Olympic Zeus, which are located near the downtown of the City of Athens, were also investigated.

#### 4.2 Damage to R/C Structures

R/C moment resisting frame structure with masonry infill walls as being observed in Photo 1 is one of the popular structural system in the investigated area, which is also widely accepted all over the world. Construction procedures of this structural system are, moment resists frames which are composed of R/C columns and beams are completed first, and then all the non-structural exterior and partition walls are filled with unreinforced masonry brick or block units and mortar. Typical structural damage to this type of structures are presented as follows;

(a) **Total Collapse and Partial Collapse of Low- and Medium-rise Buildings**

Photo 2 shows one of the totally collapsed residential buildings with four or five stories, where five people were reported to be killed during this earthquake. Photo 3 is another residential building collapsed totally toward the road, and the road was being occupied by the rubbles of this collapsed building. Also, Photo 4 shows total collapse of a three-story warehouse, whose perimeter walls were constructed by using the pre-cast R/C panels. In addition, Photo 5 is partial collapse of a three-story residential building. In most of the collapsed buildings, their columns were severely damaged such as crushing, shear and/or flexural failures or spalling of longitudinal reinforcing bars at their lap joints. On the contrary, their beams suffered smaller damage than the attached columns. In the damaged columns shown in Photo 4, rectangular hoops using $\phi 8$ were provided from the top through the bottom in spacing of about 25 cm and 90 degree hooks were adopted at the ends of all the hoops, and crushing of the concrete at the top and bottom of the columns were observed remarkably.

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**Photo 1.** An R/C moment resisting frame structure with masonry infill walls under construction

**Photo 2.** Total collapse of a four- or five-story R/C residential building
(b) Collapse of Distinctive Story

Another typical damage pattern was observed in a four-story residential building. The first story of this building collapsed totally. On the contrary, the upper stories suffered quite slight structural damage as shown in Photo 6. Since a parking space (or garage) was located in the first story of this building, smaller amount of infill walls shown in Photo 7 were provided in the first story than the upper stories.

The similar damage as being shown in Photo 8 was observed in the R/C bell tower of a church located in the center of the Town of Ano Liosia.
(c) Brittle Shear Failure of R/C Short Columns

Brittle shear failure of R/C short columns were observed in low- and medium-rise buildings for both dwelling and non-dwelling building structures. Photo 9 shows the damaged short columns of the two-story warehouse. Also, Photo 10 is a first-story short-column of the residential building.

Photo 9. Brittle shear failure of short columns (warehouse)
Photo 10. Brittle shear failure of a short column (residential building)

4.3 Damage to Unreinforced Masonry Wall Structures

Unreinforced masonry wall structures using the concrete block or clay brick units were usually adopted in one- or two-story houses. Photo 12 is a typical damage pattern observed in this type of building structures using hollow concrete block units. Also, Photo 13 shows an unreinforced masonry wall structure using hollow clay brick units. Severe shear cracks were observed in their bearing walls, especially in the walls with small horizontal effective length due to large openings.

Another typical damage pattern was observed in a two-story masonry house. Shear cracks were observed in its bearing walls in only one direction as shown in Photo 14. This seems to be caused by the pounding of the adjacent R/C building.

Photo 12. Shear cracks of an unreinforced masonry walls using hollow concrete block units

(d) Failure (or Spalling Off) of Infill Walls in Out-of-plane Direction

Even in the buildings suffered quite slight damage in their R/C moment resisting frames, the failure of infill walls in their out-of-plane directions were observed as being shown in Photo 11. The perimeters of those masonry wall panels were not connected firmly to the attached R/C column- and beam- (or floor slab-) members by using the connecting pieces such as small size of reinforcing bars.
4.4 Damage to Adobe Structures

Unreinforced masonry wall structures using adobe brick units with much lower strengths were observed in some of the one-story houses in the Town of Ano Liosia. In these structures, collapse of the masonry walls in in-plane or out-of-plane directions and failure of the timber members which supported tile roof structures were observed as shown in Photos 15 and 16.

4.5 Damage to Masonry Garden Walls

A large number of masonry garden walls using concrete block or clay brick units were observed during the field investigation. In those concrete block masonry garden walls, relatively thick hollow concrete block units were used, however, any reinforcing bars were not provided in these walls. Some of those were collapsed in out-of-plane direction as shown in Photo 17.

4.6 Damage to Historical Structures

Many historical structures are existing in and around the City of Athens. Among those, Parthenon, Erechtheion, Propylaea, Hadrian’s Arch, Olympic Zeus and Olympic Stadium, which are located near the down town of the City of Athens, were visited to investigate the affect of this earthquake. All the historical structures visited seemed to be not damaged by this earthquake as shown in Photos 18 through 21.
5. CONCLUSIONS

A total of 135 buildings, which were damaged by the 1999 Athens earthquake in Greece, were investigated by authors of the present study, and severe structural damage including the totally and partially collapsed building structures, especially the R/C building structures, were observed. Followings seem to be some of the principal causes to the earthquake damage observed in R/C building structures;

(a) Inadequate arrangements of lateral load resisting elements,
(b) Inadequate lateral confinement for columns due to large spacing of hoops and 90 degree hook at end of the hoops, which resulted in a poor ductility of the major load resisting columns,
(c) Soft story effect due to unbalanced arrangement of infill walls along the height of the building,
(d) Short column effect due to infill walls,
(e) Structural system of weak-column and strong-beam.

Since there are a large number of building structures which have the similar structural systems and details with the severely damaged buildings by this earthquake in Greece, seismic strengthening for those building structures will be expected to improve the resistance against coming big earthquakes.

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REFERENCES

[2] The Earthquake Research Institute of University of Tokyo, EIC Note No. 64, Sept., 1999 (Source: http://www.eri.u-tokyo.ac.jp/EIC/EIC_News/990907.html)