

# RESULTS OF FIRST RECONNAISSANCE ON DAMAGE TO REINFORCED MASONRY BUILDINGS AND GARDEN WALLS CAUSED BY THE GREAT EAST JAPAN EARTHQUAKE IN 2011

Kenji KIKUCHI<sup>1</sup>, Toshikazu HANAZATO<sup>2</sup>, Masayuki KUROKI<sup>3</sup>, Kazuya KOGA<sup>4</sup>,  
Katsuya KAWAKAMI<sup>5</sup> and Noriyuki MITA<sup>6</sup>

<sup>1</sup> Professor, Department of Architectural Engineering, Oita University,  
Oita, Japan, kikuchi@oita-u.ac.jp

<sup>2</sup> Professor, Department of Architecture, Mie University,  
Mie, Japan, hanazato@arch.mie-u.ac.jp

<sup>3</sup> Assistant Professor, Department of Architectural Engineering, Oita University,  
Oita, Japan, mkuroki@oita-u.ac.jp

<sup>4</sup> Lecturer, Department of Architecture, Tokyo University of Science,  
Chiba, Japan, koga@rs.noda.tus.ac.jp

<sup>5</sup> Associate Professor, Department of Architecture, Oyama National College of Technology,  
Tochigi, Japan, kawakatu@oyama-ct.ac.jp

<sup>6</sup> Associate Professor, Department of Architectural System Engineering, Polytechnic University,  
Kanagawa, Japan, mitanori@uitech.ac.jp

**ABSTRACT:** This paper reports results of the first reconnaissance on the damage to reinforced masonry buildings and garden walls. Along the Miyagi coast, some partially grouted masonry buildings were observed that had fallen over or collapsed as a result of tsunami, or tilted as a result of wash out of soil under the foundation. Partial collapse of concrete masonry nonbearing walls was also observed. Concrete masonry garden walls were observed that had collapsed due to the ground motions and the tsunami. Much damage to unreinforced stone masonry garden walls was observed.

**Key Words:** Great East Japan earthquake, damage reconnaissance, reinforced masonry buildings, masonry garden walls

## INTRODUCTION

This paper reports results of the first reconnaissance on the damage to reinforced masonry buildings including the concrete masonry nonbearing walls used in the reinforced concrete moment resisting frame, and masonry garden walls. One of the authors, Hanazato, has been investigating the damage to historical masonry structures. Its results will be reported somewhere.

There are two types of reinforced masonry structures. One is partially grouted masonry structure called as Reinforced Hollow Concrete Masonry Structure (Architectural Institute of Japan (hereafter

AIJ 2006). The other is fully grouted masonry structure called as Reinforced Fully Grouted Concrete Masonry structure (AIJ 2006) or Reinforced Masonry (RM) Structure (Japan Association for Building Research Promotion 2004). A reconnaissance on the damage to those reinforced masonry buildings including concrete masonry nonbearing walls was carried out in Sendai City, Minami-Sanriku Town and Kesennuma City on 23th, 24th and 28th to 30th of April in 2011.

While, a reconnaissance on the damage to concrete masonry garden walls was carried out in Natori City and Shiroishi City on 25th to 30th of March. Also, another reconnaissance was carried out in Natori City, Watari Town, Sendai City, Higashi-Matsushima City and Ishinomaki City on 2nd to 4th of April in 2011.

**DAMAGE TO PARTIALLY GROUTED MASONRY BUILDINGS**

The partially grouted concrete masonry building system, which is one of the boxed-wall structures, is composed of partially grouted masonry walls, reinforced concrete (hereafter R/C) collar beams, R/C floor slabs, and R/C footing beams as shown in Fig. 1. Usually, only the hollows of masonry units that have reinforcing bars are filled with concrete or mortar.

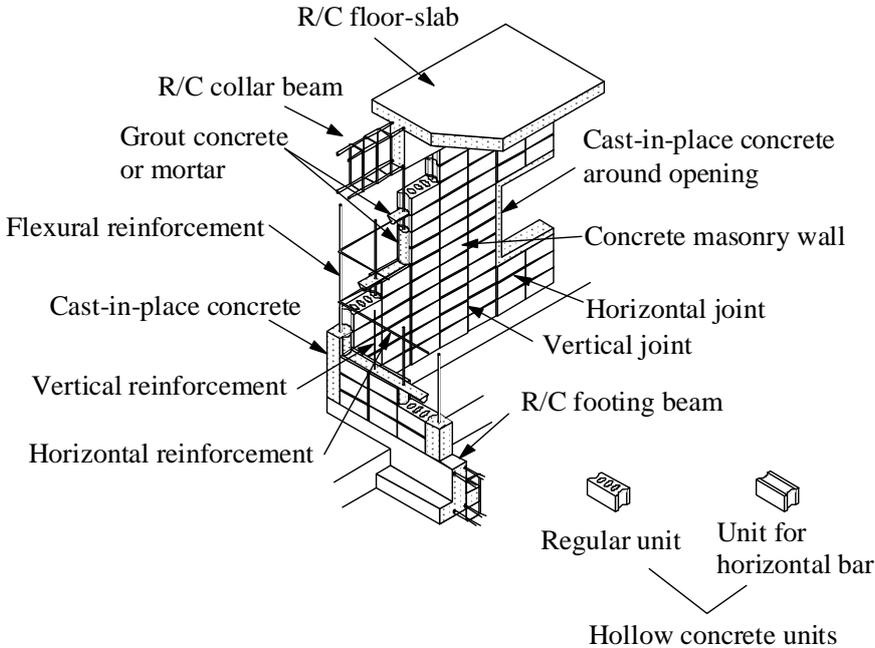


Fig. 1 Typical example of partially grouted masonry building system (AIJ 2006)

A one-story building of this type with plan dimensions of 14.2 m by 7.4 m in Wakabayashi Ward in Sendai is shown in Photo 1. It is a building for boiler room in a junior high school. The thickness of the hollow concrete block is 150 mm and no obvious damage to the masonry structure was observed. This building also survived the 1978 Miyagiken-oki earthquake without damage (AIJ 1980).

Two buildings of partially grouted concrete masonry stand side by side in Arahama district in Sendai located 100 meters from a coastal seawall (Photo 2). Plan view dimensions of the building in the front on the figure are 6.0 m by 5.6 m, while the masonry units are decorative. Dimensions of the masonry units are 450 mm in length, 150 mm in height and 150 mm in thickness. Although the building was rotated because the foundation was washed away, there were no cracks observed on the masonry wall.

The building that can be seen behind the mentioned one on Photo 2 is a reinforced masonry with hollow concrete blocks with finishing mortar. Dimensions in the plan view are 14.8 m by 9.4 m. This building suffered inundation and the soil beneath it was partially washed away, but no rotation or structural damage was observed in this case. Most probably, the building of front of this one took almost all the impact from the tsunami waves.



Photo 1 A partially grouted concrete masonry building without any damage



Photo 2 Damaged two-story partially grouted concrete masonry houses

A partially grouted masonry building with hollow concrete blocks (150 mm thick) in northern Minami-Sanriku, shown in Photo 3, was also affected by the tsunami. The building is located 400 m from the inclined embankment. Base dimensions of the building are 7.5 m by 3.9 m. Tiled roof is formed from timber truss elements. There is an interior wall on the first floor in the span direction, while there is no wall on the second floor. Although its foundation is 6.0 m above the sea level, the tsunami affected the building up to the height of the second floor ceiling. Cracks occurred in the wall on the first floor. Collapsed timber buildings in the vicinity of the present structure suggest better performance of concrete block buildings in tsunami attacks.



Photo 3 A partially grouted concrete masonry building slightly damaged by tsunami

### DAMAGE TO FULLY GROUTED MASONRY BUILDINGS

Fully grouted concrete masonry building system, which is one of the boxed-wall structures, is composed of grouted masonry walls, R/C or grouted masonry wall girders, R/C floor slabs, and R/C footing beams as shown in Fig. 2.

Photo 4 shows a two-story fully grouted masonry residential building built in 1980 in Taihaku Ward in Sendai. Plan view dimensions of the building are 15.0m x 12.4m. Thickness of concrete masonry units is 190 mm. Although this building is located in the area that experienced seismic intensity of 6-upper on JMA (Japan Meteorological Agency) scale, the building remains undamaged.

Photo 5 shows a three-story commercial building, which is located in Aoba Ward in Sendai. Plan dimensions of the building are 11.5m x 6.1m, while the thickness of concrete blocks is 190 mm. Earthquake ground motion with seismic intensity of 5-upper did not cause structural damage on this building.

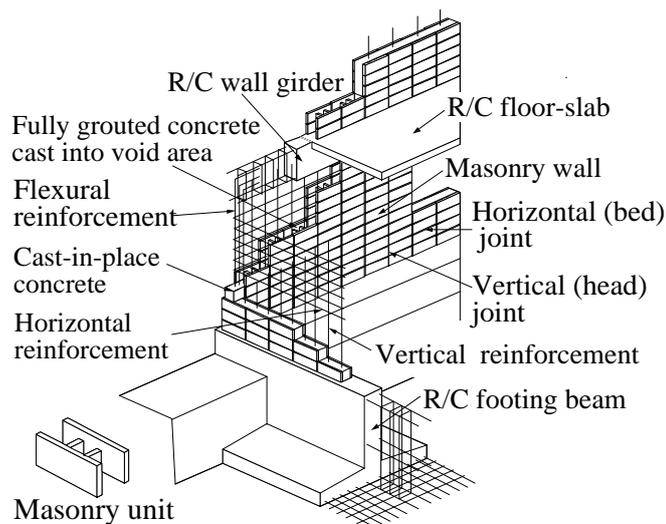


Fig. 2 Typical example of fully grouted masonry building system (AIJ 2006)



Photo 4 A fully grouted concrete masonry house without any damage



Photo 5 Undamaged fully grouted commercial building

### **DAMAGE TO CONCRETE MASONRY NONBEARING WALLS**

Photo 6 shows a two-story building in Izumi Ward in Sendai. The building has infilled concrete hollow masonry in the R/C frames. Although this area experienced seismic intensity of 6-upper, damage on the infilled masonry as well as R/C frames was not observed during the investigation.

Structures with concrete masonry nonbearing walls affected by tsunami are considered in the following. Photo 7 shows a bank building located on the intersection of National Road Route 398 and National Road Route 45 in the Minami-Sanriku. The whole residential area in the seaside plain was heavily impacted by tsunami and almost all buildings located around this building had been destroyed. The structural system of this two-story building is reinforced concrete frame with four columns and with infill walls of nonbearing concrete masonry. The building had a reinforced masonry extension at the first floor made of hollow concrete blocks without R/C columns. The concrete masonry units are

concrete hollow blocks with dimensions of 400x200x190 mm. This extension had collapsed and been washed away. It was observed on the reinforcing round bars (8 mm) that they were significantly deteriorated by corrosion.



Photo 6 Undamaged R/C building with concrete masonry nonbearing walls



Photo 7 Damaged R/C building with concrete masonry nonbearing walls

### **DAMAGE TO CONCRETE MASONRY GARDEN WALLS**

According to the current Building Standard Law (hereafter BSL) in Japan, masonry garden walls are defined as one of the buildings which must be designed and constructed in accordance with the provisions given by the BSL Enforcement Order and/or AIJ standard (AIJ 2006). Fig. 3 shows a typical masonry garden wall which is designed based on the current AIJ Design Standard, where hollow concrete masonry are reinforced with vertical and horizontal reinforcing bars.

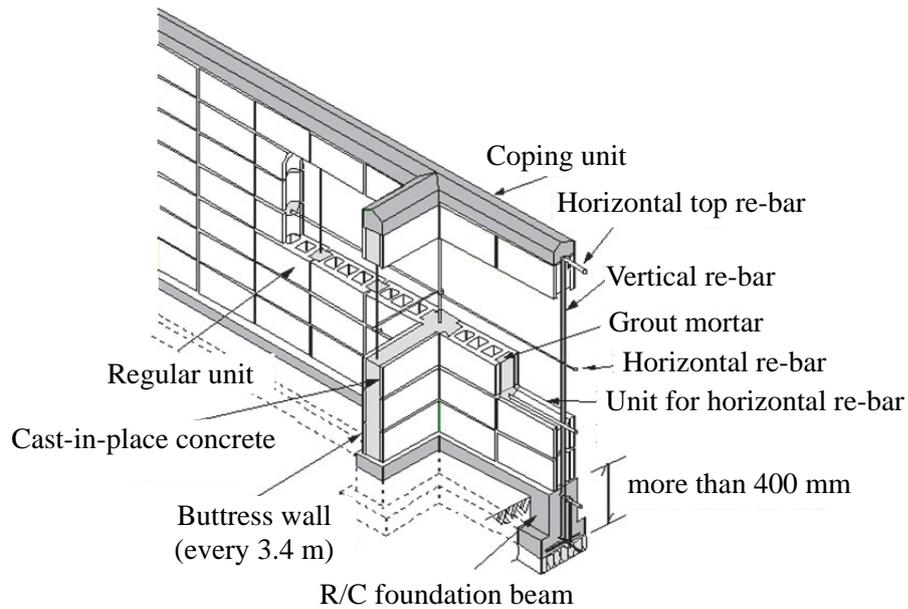


Fig. 3 Typical example of concrete masonry garden wall designed by current AIJ standard (AIJ 2006)

After the Miyagiken-oki earthquake (June 12, 1978), a variety of measures have been taken in Miyagi Prefecture, ahead of other prefectures, regarding prevention of damage to concrete masonry garden walls. An investigation has been conducted in order to investigate effectiveness of these measures.

Photo 8 shows a concrete masonry garden wall in Aoba Ward in Sendai. The wall partially collapsed due to significant deformation of the ground, while the part of the wall next to the entrance gate has relatively minor damage. It is made of six layers of decorative concrete masonry with unit dimensions of 190 (height) x 490 (length) x 100 (thickness) mm. The wall was connected to an intersecting wall with horizontal reinforcing bars spaced at 600 mm.



Photo 8 Collapse of concrete masonry garden wall due to bad soil conditions

Photo 9 shows another concrete masonry garden wall located in Aoba Ward in Sendai. The wall is facing the street which is inclined about 30 degrees in east-west direction. Due to the inclination of the ground, six layers of concrete blocks (190x390x100 mm) are stacked in a staircase formation to fit the slope. Vertical reinforcement is placed at spacing of 800 mm. However, the vertical reinforcement did not extend into the upper two layers. Furthermore, there were no horizontal reinforcing bars at the top of the wall. Therefore, these blocks fell down.



Photo 9 Falling of concrete blocks

Photo 10 shows a concrete masonry wall overturned and collapsed completely. This wall was located in Natori, where the recorded seismic intensity was 6-upper. The reasons of the collapse are 1) no anchorage into foundation for vertical reinforcing bars, and 2) insufficient length of the buttress wall as well as insufficient depth of the embedment of the foundation. This wall did not meet the criteria of the current provisions of the BSL Enforcement Orders.



Photo 10 Collapse of concrete masonry garden wall due to bad construction

Photo 11 shows a concrete masonry wall located at Shinden district of Miyagino Ward in Sendai. The collapse of the wall was caused by soft soil conditions and insufficient anchorage length of vertical reinforcements. Decorative concrete blocks (with dimensions of 140x490x100 mm) were placed on the continuous footing of 300 mm height in six layers. There was no horizontal reinforcement in the wall. While the wall's vertical reinforcement consisted of 9 mm round bars spaced at 1000 mm.



Photo 11 Insufficient anchorage of vertical reinforcing bars

Photo 12 shows a long concrete masonry wall at Uematsu district in Natori. The wall consists of concrete blocks (190x390x100 mm) stacked in 5 layers. Since height of the wall was not over a limit of 1.2 m, buttress walls were not provided. Observed diagonal cracks are the result of insufficient length of lap splice of top reinforcing bars under seismic action. Thickness of the concrete cover around top horizontal bars was about 10mm. These observations suggest that it is necessary to improve details of top of the walls including coping unit.



Photo 12 Cracks on concrete masonry garden wall

In the following text the summary of damage to concrete masonry walls caused by tsunami is presented. Photo 13 shows masonry wall composed of hollow concrete blocks (190x390x100 mm) with incorporated metal fence located in Naruse district in Higashi-Matsushima. Total height of the wall is about 1.0 m. Although wall remained in one piece, it was overturned by tsunami wave. There are many similar walls in the same area that remained undamaged. Cause for the collapse of this wall is a short anchorage into the ground.



Photo 13 Concrete masonry wall overturned by tsunami

Photo 14 shows concrete masonry garden wall located in Yuriage district in Natori, where is seriously damaged by tsunami. Part of the wall made of concrete masonry blocks remained undamaged, but the metal fence is missing. This shows that intersecting walls perform better in the tsunami attack.

This paragraph presents the summary of damage on concrete masonry garden walls in Miyagi Prefecture. The level of damage was difficult to estimate because it also included the damage caused by tsunami. Miyagi Prefecture conducted investigation on safety of 8193 masonry garden walls in 2002. As a result of the investigation, 79% of concrete masonry walls were classified as safe. The rate of destroyed walls in Natori is 16% (4/25). In the 1995 Kobe earthquake, 25% of concrete masonry walls collapsed in Kobe (AIJ 1998). While during the 2007 Niigataken Chuetsu-oki earthquake 17.6%



Photo 14 Undamaged concrete masonry garden wall by tsunami wave

of concrete masonry walls collapsed in Kashiwazaki (AIJ 2010). This situation shows that measures based on lessons learned from the 1978 Miyagiken-oki earthquake reduced damage of concrete masonry walls.

**DAMAGE TO STONE MASONRY GARDEN WALLS**

The Tohoku is a famous production district of tuff stone. There are a number of garden walls built from high quality tuff stone.

Photo 15 shows collapsed stone masonry garden wall which was built with only unreinforced mortar located in Masuda district in Natori. Strength of this wall comes from adhesive strength of mortar and the resistance of dowels used in the wall construction. The earthquake significantly damaged many walls of this type.

On the other hand, Photo 16 shows stone masonry garden wall retrofitted with a steel structure. It can be observed that the wall remained undamaged.



Photo 15 Damage to stone masonry garden wall



Photo 16 Stone masonry garden wall retrofitted with steel structure

## CONCLUSIONS

In the coastal area of Miyagi Prefecture several hollow reinforced concrete masonry buildings had fallen over or collapsed as a result of tsunami, or tilted as a result of wash out of soil under the foundation. Also, partial collapse of concrete masonry nonbearing walls was observed.

As a result of the investigation in Sendai City, in the areas distanced from the coastline, notable damage was not observed on partially grouted concrete masonry buildings, fully grouted concrete masonry buildings, and concrete masonry nonbearing walls.

The following conclusions were made after the investigation of concrete masonry garden walls in Miyagi Prefecture. The observed types of damage were the following: collapse due to ground deformation, collapse of unreinforced portions of walls due to poor construction, tip-over and collapse due to insufficient anchorage of vertical reinforcing bars into foundations or due to insufficient embedding of the foundation into ground, collapse due to reinforcing bar corrosion, major cracking at lap splice joints along the horizontal top reinforcing bar, and tsunami-induced overturn and collapse. The investigation of a certain district in Natori showed that 16% of concrete masonry garden walls and many non-reinforced stone masonry garden walls collapsed.

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## REFERENCES

- Architectural Institute of Japan (1980). “*Report on the Damage Investigation of the 1978 Miyagiken-oki Earthquake.*” 687-688 (in Japanese).
- Architectural Institute of Japan (1998). “*Report on the Hanshin-Awaji Earthquake Disaster, Building Series Volume 2.*” 613-621 (in Japanese).
- Architectural Institute of Japan (2006). “*AIJ Standards for Structural Design of Masonry Structures.*” (in Japanese).
- Architectural Institute of Japan (2010). “*Report on the Damage Investigation of the 2007 Noto-Hanto Earthquake and the 2007 Niigataken Chuetsu-oki Earthquake.*” (in Japanese).
- Japan Association for Building Research Promotion (2004). “*Guidelines for Structural Design of Reinforced Masonry (RM) Structures.*” (in Japanese).