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DAMAGE TO CONCRETE MASONRY GARDEN WALLS CAUSED BY 1994 NORTHRIDGE EARTHQUAKE IN USA AND 1995 HYOGOKEN-NANBU EARTHQUAKE IN JAPAN

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ABSTRACT

A large number of concrete masonry garden walls were severely damaged during the 1994 Northridge earthquake in California, USA and the 1995 Hyogoken-nanbu earthquake in Kobe, Japan. This type of earthquake damage must be prevented because two-third of the total human damage (dead people) was caused by the structural damage to masonry garden walls during the 1978 Miyagiken-oki earthquake in Japan. After the occurrence of the Northridge and Hyogoken-nanbu earthquakes, field investigations were conducted by authors to investigate the cause of the structural damage to masonry garden walls. Herein, results of these field investigations are presented first, and then some discussions on design and construction methods for masonry garden walls are made.

KEYWORDS

Earthquake damage; USA and Japan; Masonry garden walls; Seismic safety; Design standards; Construction methods;

INTRODUCTION

Every time when strong motion earthquakes occurred in Japan, a large number of structural damage to masonry garden walls have been reported. Current structural wall systems such as reinforced masonry wall buildings and masonry garden walls, which are composed of hollow concrete-block masonry units, were imported from the United States to Japan after the World War II (1940's), and have become popular all over Japan. Human damage caused by the collapse of masonry garden walls was firstly reported after the 1962 Miyagiken-hokubu earthquake. During the 1978 Miyagiken-oki earthquake, however, 20,898 masonry garden walls were damaged, and 28 people were killed and 11,028 were injured. Among these, more than 14,000 hollow concrete-block masonry garden walls were structurally damaged and 18 people were killed due to the structural failure of the masonry garden walls and gate-piers. Similar kind of earthquake damage to the masonry garden walls was also reported in the United States, and one example can be seen in the preliminary report on the 1971 San Fernando California earthquake, (1971).

Herein, structural damage to hollow concrete-block masonry garden walls caused by the 1994 Northridge earthquake, California is introduced first, then results of field investigation on damage to the masonry garden walls caused by the 1995 Hyogoken-nanbu earthquake are presented. Some discussions are made based on the design and construction methods for these masonry garden walls in the United States and Japan, and finally field investigation results on existing masonry garden walls in Oita City, Japan is briefly described.

CURRENT DESIGN STANDARDS FOR MASONRY GARDEN WALLS IN JAPAN AND USA

According to the current Building Standard Law (BSL) in Japan, all the masonry garden walls are defined as one of the building structures, which must be designed and constructed in accordance with the provisions given by the BSL Enforcement Order and/or Structural Design Standards of the AIJ (Architectural Institute of Japan). Fig. 1 shows a typical masonry garden wall which is designed based on the current AIJ Design Standard, where hollow concrete-block masonry units are reinforced by vertical and horizontal reinforcing bars (Re-bars).

Among the design provisions specified in the current BSL and AIJ Standard for masonry garden walls, important provisions for seismic safety are;
(1). Maximum height of the wall is limited up to 2.2 meters above ground level:
(2). Masonry walls shall be placed on continuous and deep reinforced concrete (R/C) foundation beam with sufficient embedment depth of 40 cm or more below ground level:
(3). Use continuous vertical Re-bars without any intermediate joint(s):
(4). Top and bottom of vertical Re-bars shall be anchored into R/C foundation beam and horizontal bars placed along top of the wall using hooks and sufficient anchorage lengths or splices:
(5). Maximum spacing of vertical and horizontal wall Re-bars is 80 cm or less:
(6). Sufficient wall-thickness and installation of buttress walls are effective against earthquakes:

According to the provisions specified in the current Uniform Building Code (UBC) in the United States (1994), however, there is no design standards for masonry garden walls less than six feet (or 1.8 meters) in height.

Finally it can be noted that masonry units for horizontal Re-bars and units for vertical Re-bars as shown in Fig. 1 are available in Japan, size and shape of which are specified in the Japanese Industrial Standard (JIS:A5406). On the contrary, there are no masonry units being effective for horizontal and vertical Re-bars in the United States and other Latin American countries. It can be understood for Japanese authors why there is no masonry units being effective for vertical wall Re-bars in the Western earthquake countries, because most of the masonry walls in these countries have been historically constructed by running bonds. Since horizontal wall reinforcement is also effective for seismic masonry wall structures, development and adoption of the masonry units for horizontal Re-bars are expected.

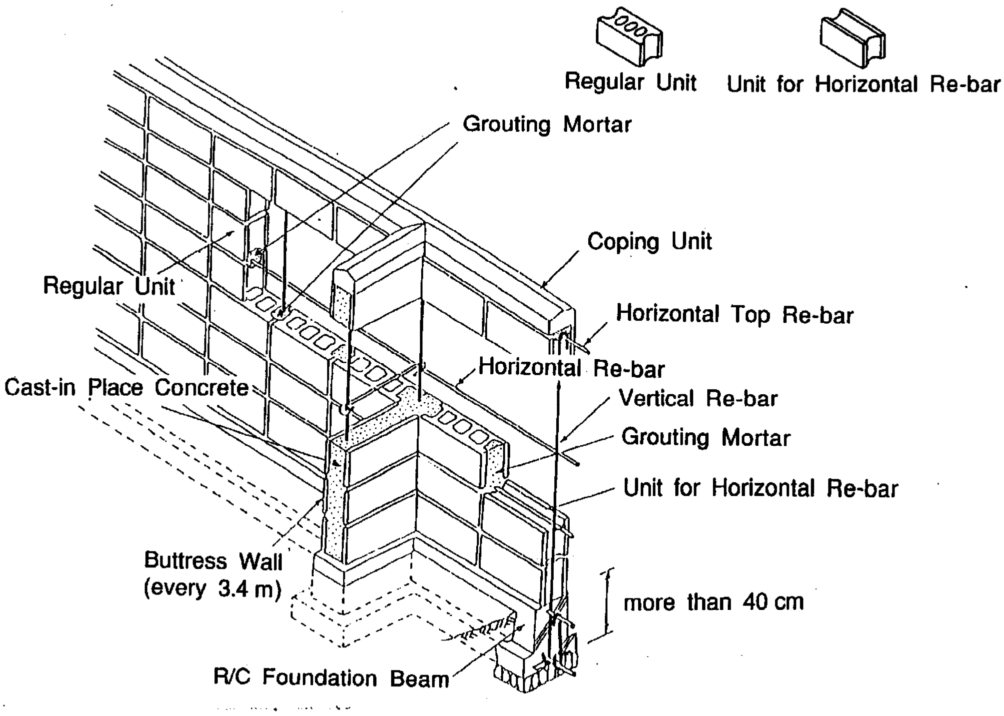

Fig. 1. A hollow concrete-block masonry garden wall designed by current Japanese design standards.

DAMAGE TO MASONRY GARDEN WALLS BY 1994 NORTHRIDGE EARTHQUAKE

After the occurrence of the Northridge earthquake of January 17, 1994, field investigations were conducted by authors during the periods from 28th of January to 1st of February by Kikuchi and from 5th to 9th of February by Yoshimura. These investigations were mainly for investigating the damage to building structures caused by this earthquake (Mikumo *et al.*, 1994, and Yoshimura 1994). During these field investigations, considerable earthquake damage was observed in various structures and damaged structures were widely spread in wide regions. It can be noted, however, that the severe structural damage to masonry garden walls was concentrated in relatively restricted narrow regions such as Northridge, Granada Hills, and Mission Hills through San Fernando, and almost no severe damage to masonry garden walls was observed in Santa Monica, Hollywood and West Los Angels, where many building structures were extensively damaged. Followings are brief description of the damage to masonry garden walls caused by this earthquake:

(1). Most of the damaged masonry garden walls were composed of hollow concrete-block units as shown in Fig. 2, and dimensions of the masonry units, (t)x(h)x(l), were (9 to 13 cm)x(20 cm)x(40 to 55 cm), where (t), (h) and (l) represent the thickness, height and length of the masonry units, respectively.
(2). Heights of the walls damaged were from 1.5 meters (7 layers) to 2.6 meters (13 layers) above the ground surface, and horizontal lengths of the walls were generally longer than Japanese ones. Most of the walls were constructed by running bond.
(3). Most of the damaged garden walls did not have any effective foundations such as R/C foundations, but bottom of the walls were buried into ground as shown in Fig. 3.
(4). Masonry wall in Fig. 4 had insufficient anchorage lengths in vertical Re-bars, where bottom ends of the vertical Re-bars were pulled out from the R/C buttress wall (or foundation).
(5). All the damaged masonry walls which were subjected to horizontal earth-pressure turned over toward the road-side (see Fig. 5).
(6). There were no effective buttress or pilasters observed in damaged masonry garden walls. Fig. 6 shows one of the partially survived walls due to the presence of effective pilasters composed of double H-shape masonry units with wide thickness.
(7). Most of the structurally damaged masonry walls were completely un-reinforced or not reinforced by the effective reinforcement such as vertical and horizontal Re-bars with sufficient anchorages. In case when the effective masonry units for horizontal Re-bars are not available as shown in Fig. 7, it is difficult to construct the seismic masonry walls which are monolithically reinforced by wall Re-bars. If the masonry walls without any monolithic reinforcement are subjected to strong earthquake, masonry units are expected to be scatted as shown in Figs. 2 and 5.
(8). Corrosion of Re-bars, inadequate anchorage for reinforcement, insufficient mortar grouting around Re-bars and large spacing for vertical Re-bars were other causes of the damage to masonry garden walls during this earthquake.

Fig. 2. Damaged wall and masonry units.

Fig. 3. Masonry wall without foundation.

Fig. 4. Inadequate anchorage for vertical Re-bars.

Fig. 5. Damage due to earth pressure.

Fig. 6. Locally survived wall due to pilasters.

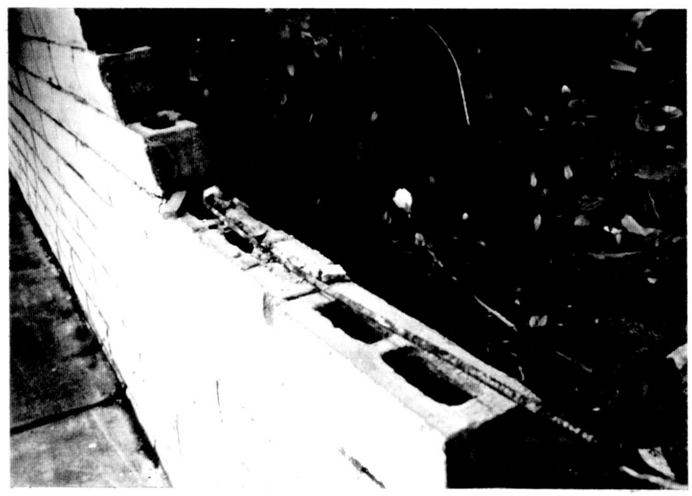

Fig. 7. Masonry units not for horizontal Re-bars.

DAMAGE TO MASONRY GARDEN WALLS BY 1995 HYOGOKEN-NANBU EARTHQUAKE

Field investigations were conducted approximately two weeks after the occurrence of the earthquake. Since damage to masonry garden walls were widely spread even within the City of Kobe, one restricted investigation area in Higasi-nada Ward of Kobe City was selected for the field investigation. As being reported already, the worst earthquake damage was concentrated in Higashi-nada Ward both in human and building structures. The investigation area was approximately 2,400 meters long in South-North direction and 50 to 250 meters wide in West-East direction, and within this belt-zone, damage to all the masonry walls and building structures located along the selected roads were investigated. Total distance of the roads was more than six kilometers (four miles), and total number of walls and buildings investigated were 236 and 603 respectively.

During the field investigations, followings were mainly investigated for all the masonry garden walls:
(1). Scale of walls including height above street level, horizontal length and thickness of walls.
(2). Size and shape of masonry units.
(3). Foundation system adopted.
(4). Reinforcing details within the masonry walls including location and spacing of vertical and horizontal wall reinforcements.

Investigation results are shown in Fig. 8, where damage to the masonry garden walls were classified into three

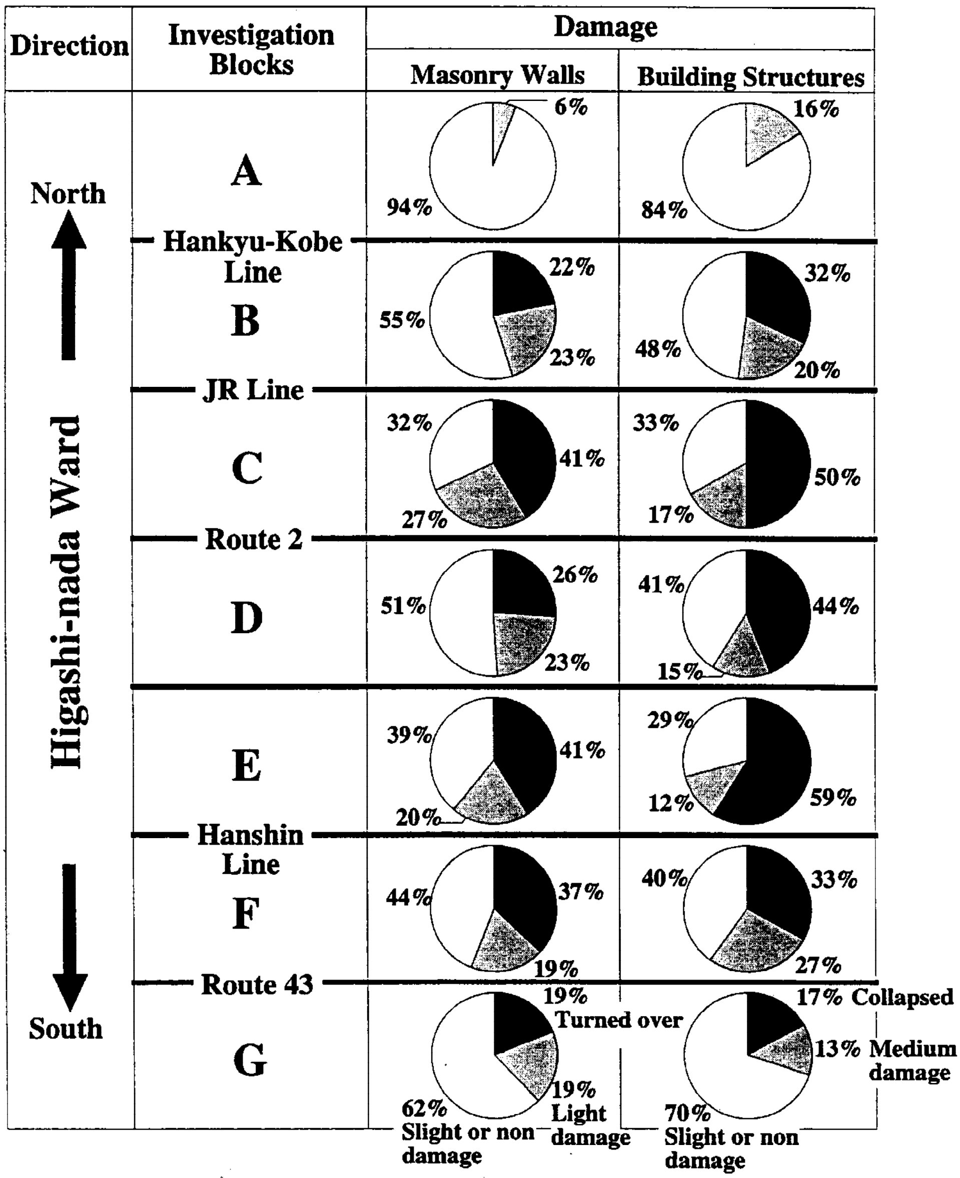

Fig. 8. Field investigation results in Kobe City.

grades, "turned-over", "light-damage" and "slight- or non-damage", and damage to the buildings were classified into "collapse", "medium-damage" and "slight- or non-damage". Among the building structures investigated, timber buildings were 76 percent, reinforced concrete (R/C) and steel buildings were 14 and 7 percent respectively, and others were 3 percent. In the figure, circle diagrams in left column show the damage statistics in masonry garden walls and right ones are for building structures. It can be seen from Fig. 8 that damage statistics in masonry garden walls is well corresponding to that of the building structures. In this area, however, damage to the building structures was more significant than that of the masonry garden walls. In masonry garden walls, total of completely collapsed (or turned over) walls was approximately 25 percent, but in the worst Investigation Blocks (C and E) in Fig. 8, completely collapsed masonry walls were more than 40 percent. On the contrary, damage to the building structures was 33 percent in total, but in Block (E) in Fig. 8, about 60 percent buildings were completely collapsed.

It is noted that, among the masonry garden walls collapsed completely, more than 91 percent walls were turned over toward the adjacent road (see Figs. 9, 10 and 12). Such kinds of damage to masonry walls must be prevented for saving human lives as well as for emergency vehicles. If this earthquake had occurred in the day-time, then more significant human damage would have been estimated to occur. According to a rough estimation by authors, approximately more than 20,000 masonry garden walls were completely collapsed during this earthquake.

Fig. 9. Masonry wall without foundation.

Fig. 10. Shallow depth for embedment in foundation.

Fig. 11. Masonry wall without wall Re-bars.

Fig. 12. Insufficient wall reinforcement.

Fig. 13. Insufficient anchorage for vertical Re-bars.

Fig. 14. Inadequate joint between wall and buttress.

Summarizing the main causes of the damage to masonry garden wall:
(1). No foundations to give an effective anchorage for vertical Re-bars (Fig. 9):
(2). Shallow depth for embedment in foundations (Fig. 10):
(3). No or small amount of vertical wall Re-bars (Figs. 11 and 12):
(4). Insufficient anchorage for bottom of vertical Re-bars (Fig. 13):
(5). Poor reinforcement details:
(6). Inadequate reinforcement for buttress and/or wall-to buttress joint (Fig. 14):
Investigation results indicated that most of the damaged masonry walls had not been designed and/or constructed in accordance with the design provisions as presented in this paper. It can be noted, however, that there were no damage to masonry garden walls designed and constructed based on the BSL and AIJ Standards.

HISTORICAL REVIEW OF DESIGN STANDARDS FOR MASONRY GARDEN WALLS IN JAPAN

The first design standard for masonry garden walls in Japan was established in 1950 in the BSL (Building Standard Law) Enforcement Order, where following three provisions were specified:
(1). Wall height: (h_{max}) ≤ 3 meters.
(2). Wall thickness: (t_w) ≥ (h_{max})/10.
(3). Buttress walls: every 4 meters or less.
These provisions (in Article 61) seems to be probably for un-reinforced masonry garden walls.

In 1971, above height limit for masonry garden walls in Article 61 was reduced from 3.0 to 2.0 meters, and new design provisions for reinforced masonry garden walls were newly established (in Article 62-8) in the BSL Enforcement Order. According to this new design standard for reinforced masonry garden walls, following seven provisions were specified in Article 62-8:
(1). Maximum wall height: (h_{max}) ≤ 3.0 m.
(2). Wall thickness: (t_w) ≥ 15 cm; with (t_w) ≥ 10 cm in case of (h_{max}) ≤ 2 m.
(3). Reinforcement along wall top, foundation beam, wall-edge and intersections.
(4). Vertical and horizontal wall reinforcement: every 80 cm or less in spacing.
(5). Buttress walls: every 3.2 m or less, and horizontal length ≥ (h_{max})/5.
(6). Anchor all Re-bars into wall top, foundation, wall-edge and intersections.
(7). Depth of foundation beam: more than 35 cm with embedment of 30 cm or more.

In 1981, most of the seismic design provisions for building structures in BSL Enforcement Order were drastically revised, which is so-called "A New Aseismic Design Standard", but most of the design provisions for masonry garden walls were unchanged except that;
(1). maximum height of walls was reduced from 2.0 to 1.2 meters, and
(2). minimum embedment depth for foundation beam with 20 cm or more was newly established in Article 61.
In addition to these revisions, Article 62-8 for reinforced masonry garden walls was slightly revised as;
(3). maximum height of wall was reduced from 3.0 to 2.2 meters, and
(4). spacing of buttress wall was changed from 3.2 to 3.4 meters.

In addition to those design provisions specified in the Building Standard Law (BSL) Enforcement Order, more detailed and strict design standards have been published from the Architectural Institute of Japan (AIJ). The newest design standard for reinforced masonry garden walls was published in 1989 (1994), which is briefly described in the former section and Fig. 1 of the present paper.

FIELD INVESTIGATION ON EXISTING MASONRY GARDEN WALLS IN OITA CITY, JAPAN

In order to investigate the seismic safety for existing masonry garden walls, field investigations were conducted by authors (Yoshimura *et al.*, 1987). During the investigations, more than 2,300 masonry walls were selected, and approximately thirty investigation items were investigated for each masonry wall. All the walls are existing along through the school roads for primary school students in Oita City, Japan.

Followings are main investigation items:
(1). Scale of wall including height and length of wall:
(2). Size and shape of masonry units including wall-thickness:
(3). Presence of reinforcement along wall-top, wall-edge and intersections:
(4). Spacing of vertical and horizontal wall-reinforcement:
(5). Buttress walls:
(6). Anchorage methods of vertical Re-bars into foundation:
(7). Size and shape, and type of foundation:
(8). Cracking on wall-surface:

Investigation results obtained were compared with the provisions specified in the current BSL Enforcement Order as mentioned above. Summarizing the investigations, incredible results were obtained; that is; "more than 95 percent of the existing masonry garden walls are unlawful against the current Building Standard Law in Japan, and well designed and constructed masonry walls are only less than 5 percent". This field investigation results conducted against the existing masonry garden walls indicate that a large number of unlawful masonry garden walls are still existing and constructing all over Japan, which are expected to failed in dangerous manner during the next coming earthquakes.

CONCLUSIONS

According to the field investigation results on damage to masonry garden walls caused by recent two representative earthquakes in USA and Japan, main cause of the earthquake damage to the masonry garden walls was that the damaged masonry walls had not been well designed and constructed. We cannot forget the facts that both of these two earthquakes occurred at early in the morning, that is, the 1994 Northridge earthquake occurred at 4:30 am., and the 1995 Hyogoken-nanbu earthquake occurred at 5:46 am., and thus there were no extensive loss of human lives. If these two earthquakes had occurred in the day-time when many people were walking around the streets, then more significant human damage would have been estimated to occur.

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