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SEISMIC SAFETY OF EXISTING CONCRETE MASONRY GARDEN WALLS

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SUMMARY

In order to investigate the seismic safety of masonry garden walls, five different field investigations have been conducted. Among them, two were on masonry garden walls damaged during the 1995 Hyogoken-nanbu earthquake and the 1997 Kagoshimaken-hokuseibu (Northwestern region of Kagoshima Prefecture) earthquake, and the other three were on masonry garden walls survived during the 1995 Hyogoken-nanbu earthquake, design and construction methods adopted in the existing masonry garden walls in Oita City, and strengthening methods of adopted for existing masonry walls. By comparing the earthquake damage to the masonry garden walls with their structural details, it is indicated that vertical reinforcing bars, reinforced concrete foundations and intersecting walls play very important roles for seismic safety of the masonry garden walls. It is also indicated that the seismic resistance of most of existing masonry walls in Oita City was very poor. Furthermore, results of the field investigation on strengthening methods used for existing walls indicate that the improvement is insufficient. As a results, it is concluded that the connecting masonry walls to intersecting walls is a very effective strengthening method and this strengthening method can be applied to various kinds of existing masonry garden walls.

INTRODUCTION

Garden walls are widely constructed surrounding housing lots all over Japan. Hollow concrete-block masonry units were introduced from the United State after World War II, and garden walls using these masonry units have been popular in Japan. Every time when strong motion earthquakes occurred in Japan, however, a large number of structural damage to the masonry garden walls have been reported. Human damage caused by the collapse of the masonry garden walls firstly reported after the Miyagiken-hokubu earthquake in 1962. During the 1978 Miyagiken-oki earthquake, more than 14,000 masonry garden walls and gate-piers were damaged in Sendai City, and eighteen people, which was two-third of the total death, were killed by the complete collapse or extensive structural damage to the masonry garden wall structures. About five years ago, the 1995 Hougoken-nanbu earthquake caused tremendously severe damage to human lives, building structures, and many other urban facilities. A large number of masonry garden walls were also completely collapsed or severely damaged during this earthquake as shown in Figure 1, but fortunately there were almost no significant human damage due to the collapse and/or failure of those masonry walls because this earthquake occurred very early in the morning. Similar kind of earthquake damage to the masonry garden walls were also reported after the 1971 San Fernando earthquake [U. S. Government Printing Office, 1971] and the Northridge earthquake [Kikuchi et al., 1996] in the United States.

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In order to investigate the seismic safety of existing masonry garden walls, five different field investigations were conducted in Kobe City, Kagoshima Prefecture and Oita City. The final goal of these investigations are to propose a new design method for the masonry garden walls and to propose the effective seismic strengthening methods for existing masonry walls with poor seismic resistance in order to prevent severe earthquake damage, especially overturning failure. In this paper, before discussing the seismic safety of the existing masonry garden walls, the current Japanese Codes and Standards for structural design of masonry garden walls is described. On the basis of the results of the field investigations for the damaged and undamaged (or survived) masonry garden walls, relations between earthquake damage and structural details of the masonry garden walls are discussed. In addition, the results of field investigation on strengthening methods adopted in the existing masonry walls are presented, and a practical strengthening method by connecting the wall itself to the intersecting walls is proposed finally.

Figure 1: Structural damage to a masonry garden wall by the 1995 Hyogoken-nanbu earthquake

2. CURRENT DESIGN STANDARDS FOR MASONRY GARDEN WALLS IN JAPAN

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) [AIJ, 1994 and 1997]. Figure 2 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 Standards for masonry garden walls, important provisions for seismic safety are:

(1) maximum height of the wall is limited up to 2.2 meters above the ground level;

(2) spacing of vertical and horizontal wall re-bars is 800 mm or less;

(3) use continuous vertical re-bars without any intermediate joint(s);

(4) sufficient wall thickness and installation of buttress walls are needed against earthquakes and wind pressure;

(5) bottom of vertical re-bars shall be anchored into a continuous reinforced concrete (R/C) foundation beam, while top of vertical re-bars shall be anchored into horizontal bars placed along the top of wall using hook and/or sufficient anchorage length or splice; and

(6) masonry walls shall be placed on continuous and deep R/C foundation beam with sufficient embedment depth of 400 mm or more below the ground level.

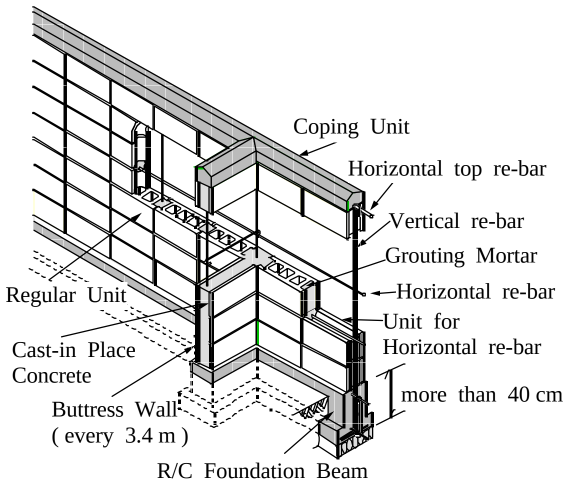


Figure 2: A reinforced concrete masonry garden wall designed by current AIJ standard

DAMAGE TO MASONRY GARDEN WALLS AND STRUCTURAL DETAILS

Field Investigations on Earthquake Damage to Masonry Garden Walls

Early in the morning of 17 January 1995, the Hyogoken-nanbu earthquake (the Kobe earthquake) occurred in the southern part of Hyogo Prefecture in the main island of Japan. The magnitude of this earthquake was 7.2 on the Richter scale. Just after the occurrence of this earthquake, a total of 236 masonry garden walls located in a restricted area in Higashi-nada Ward of Kobe City were investigated by authors [Kikuchi et al., 1996]. Those walls investigated were all of the masonry garden walls which were located along the roads shown by solid lines in Figure 3. During this earthquake, the above restricted area selected was severely affected by strong ground shaking with a peak ground acceleration of 400 Gals (cm/s^2) or more, and 30 % or more of the building structures located in this area collapsed completely or severely damaged. Totally collapsed masonry garden walls were approximately 25 % of all the walls located in the same area. About two years after the occurrence of the Kobe earthquake, another field investigation was conducted in Higashi-nada Ward of Kobe City in order to investigate the seismic resistance of masonry garden walls which survived this severe earthquake. Figure 3 shows the areas where a total of 1,220 masonry garden walls which survived were investigated [Yoshimura et al., 1998b]. They had been subjected to a seismic intensity scale of VII on the Japan Meteorological Agency scale. The results of this filed investigation for the survived walls are presented in Section 4 of this paper.

On the 26th of March and 13th of May, 1997, other severe earthquakes (the 1997 Kagoshimaken-hokuseibu earthquake) occurred on the northwestern region of Kagoshima Prefecture which is located in the southwest island of Japan. The magnitude of these earthquakes were 6.5 and 6.3 on the Richter scale, respectively. During these two earthquakes, a large number of masonry garden walls were also collapsed or severely damaged as shown in Figure 4. The authors conducted post-earthquake investigations within the damaged area just after the occurrence of each earthquake. Sixty-one masonry garden walls were investigated in a residential areas. Among those walls, 23% had collapsed [Yoshimura et al., 1998a].

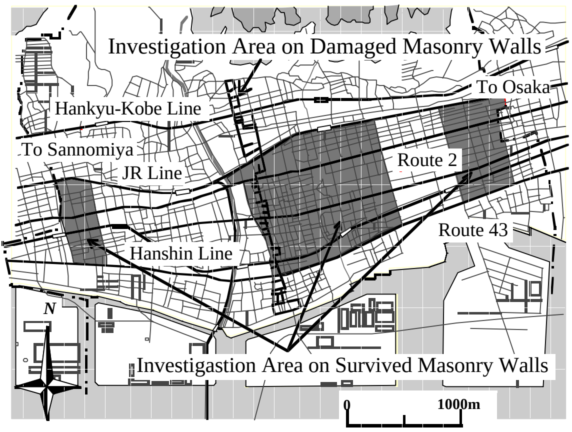


Figure 3: Investigation areas of damaged and survived masonry garden walls in Kobe City

Figure 4: Structural damage to masonry garden walls by the 1997 Kagoshimaken-hokuseibu earthquake

Patterns of Overturning Failure

Investigation results are shown in Figure 5, where damage to the masonry walls are classified into three grades, "Collapsed (or overturned)", "light-damage" and "non-damage", and foundation systems adopted for the investigated walls are also classified into three types, "R/C foundation", "hollow concrete-block foundation" and "no foundation". In addition, the collapsed walls are classified into three types according to the portions of masonry walls that were overturned. In this figure, numerals shown by bold and italic letters represent the number of walls investigated in Kobe City and Kagoshima Prefecture, respectively. As mentioned in Section 2, the BSL and AIJ Standards require that the masonry walls shall have the R/C foundation. However, it can be seen from Figure 5 that the masonry walls having R/C foundation were only 60% and 11% of the investigated walls in Kobe City and Kagoshima Prefecture, respectively, and other walls had shallow foundation by using hollow concrete-block units or did not have any foundation. In case of the overturned walls, the number of walls that were overturned from the bottom of wall panels was larger than other overturning patterns. Some of the walls having the R/C foundations were collapsed. The main cause of this damage is that vertical re-bars in the walls were not insufficiently anchored into the R/C foundation or were not provided.

Relations between Structural Details and Earthquake Damage

The installation of buttress walls is required in the BSL and AIJ standards for the masonry walls of longer than 3.4 m and higher than 1.2 m. Masonry walls having buttresses were only 29% of the walls required to install the buttresses in Kobe City and none of the investigated walls in Kagoshima Prefecture had buttresses. Furthermore, in case of the masonry walls with buttresses, the buttress walls did not have effective influence on the earthquake damage to the masonry walls, because there were only a few walls with adequate foundations to these buttresses

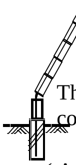
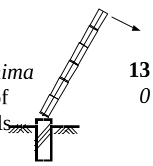
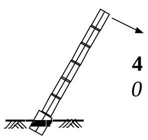
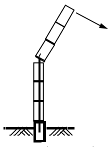
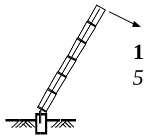
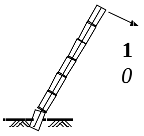
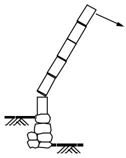
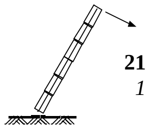
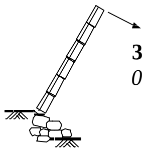
		Collapsed (or overturned)				Light-damage	Non-damage	Not clear	Total
		Overturned portion							
		(1) A part of wall panel	(2) Whole of wall panel	(3) Wall panel and foundation	(4) Not clear				
Foundation system	(A) R/C foundation	 **5 : Kobe** *0 : Kagoshima* The number of collapsed walls (A-1)	 **13** *0* (A-2)	 **4** *0* (A-3)	**4** *0*	**25** *1*	**80** *4*	**0** *0*	**131** *5*
	(B) Hollow concrete-block foundation	 **1** *2* (B-1)	 **1** *5* (B-2)	 **1** *0* (B-3)	**1** *0*	**6** *14*	**14** *8*	**0** *0*	**24** *29*
	(C) No foundation	 **1** *5* (C-1)	 **21** *1* (C-2)	 **3** *0* (C-3)	**2** *0*	**10** *4*	**27** *2*	**0** *0*	**64** *12*
	(D) Not clear	**0** *0*	**1** *1*	**0** *0*	**2** *0*	**4** *8*	**9** *6*	**1** *0*	**17** *15*
Total		**7** *7*	**36** *7*	**8** *0*	**9** *0*	**45** *27*	**130** *20*	**1** *0*	**236** *61*

Figure 5: Damage statistics and patterns of overturning failure of masonry walls investigated in Kobe City and Kagoshima Prefecture

and/or joints of the buttress walls. On the contrary, 64% of the walls investigated in Kobe City and Kagoshima Prefecture have intersecting walls, where the intersecting walls are defined as the walls connected at right angles in plan to each horizontal edge of the investigated walls as shown in Figure 6.

Relations between the structural details of the investigated walls and their damage levels are summarized in Figure 7, where the investigated masonry walls are classified into four types in accordance with their adopted structural details. Type 1 Walls have both of vertical wall reinforcements and R/C foundations as well as intersecting wall(s) at the wall edge(s). Type 2 Walls do not have any intersecting walls, although they have both of the vertical re-bars and R/C foundations. Types 3 and 4 Walls, have either vertical re-bars or R/C foundations are provided, or neither of them. The difference in Types 3 and 4 Walls is that the former have the intersecting walls and the latter do not have those. It is noted that all of the walls investigated in Kagoshima Prefecture did not have any R/C foundations. It can be seen from Figure 6 that, in case of the investigated walls in Kobe City, the ratio of collapsed walls to the total number of walls in Type 1 is 16 % smaller than that in Type 2 and the ratio of undamaged walls in Type 1 is 6 % larger than that in Type 2. In addition, similar tendency can be seen in comparison between results of Types 3 and 4 Walls. These facts mean that the presence of intersecting walls as

Figure 6: A wall having intersecting wall

well as vertical re-bars and R/C foundations give large effects on the mitigation of earthquake damage to the masonry walls. Many of the connections between the investigated wall and its intersecting walls were observed to be inadequate during the field investigations. Therefore, by connecting more firmly the masonry wall to its intersecting wall(s), then the seismic resistance of masonry garden walls are expected to increase much more.

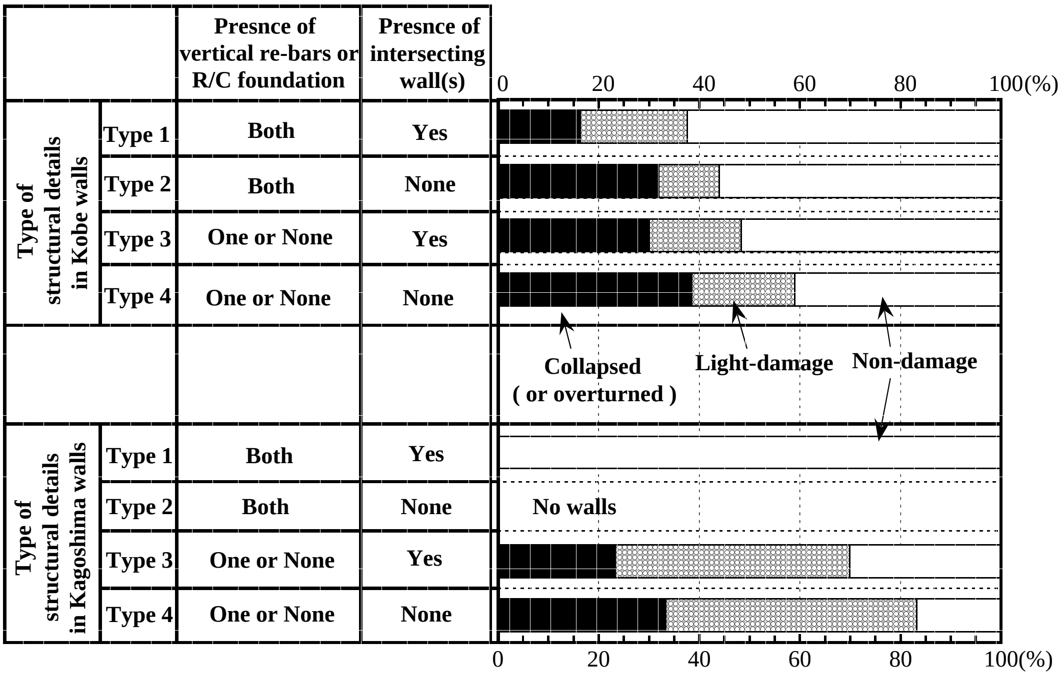


Figure 7: Relations between structural details and earthquake damage

SEISMIC SAFETY OF EXISTING MASONRY GARDEN WALLS

In order to investigate the seismic resistance of the existing masonry walls, a field investigation was conducted on a total of 1,032 existing masonry walls in school districts of four different elementary schools selected in Oita City, Japan [Kajimura et al., 1997]. The representative results of the field investigation in Oita City are shown in Figure 8, together with the results of the collapsed walls in Kagoshima Prefecture and the collapsed walls and the survived walls in Kobe City. In Figure 8, the percentages of the walls having vertical re-bars, horizontal re-bars, top horizontal re-bars, buttress walls, R/C foundations and intersecting walls are shown against the total number of investigated walls. In the post-earthquake field investigation on the damaged walls in Kobe City, the presence of horizontal re-bars and top horizontal re-bars were not investigated. Representative results are as follows:
(1) With regard to the ratio of the walls having vertical re-bars, the results from the collapsed walls in both of Kobe and Kagoshima were 14-38% lower than those from the undamaged walls or the survived walls. The ratio of the walls with vertical re-bars in Oita was as high as those of the undamaged walls and survived walls in Kobe.
(2) None of the masonry garden walls in Kagoshima had buttresses. In Kobe on the contrary, approximately 40% of the collapsed walls and 30% of the survived walls had buttresses. It is noted that there were only a few walls with adequate foundations of these buttresses and/or joints of the buttress wall. The walls having the buttress walls in Oita were only 4%.
(3) Collapsed walls in Kagoshima did not have any R/C foundations. On the contrary, 29% of the undamaged walls in Kagoshima had R/C foundations. In Kobe, 66% of the undamaged walls had R/C foundations, while only 46% of the collapsed walls had R/C foundations. For most of the collapsed walls with R/C foundations, shallow embedment depth of foundations and insufficient anchorage of vertical re-bars were observed. Only 16% of the walls in Oita had R/C foundations.
(4) In both Kobe and Kagoshima, approximately 70% of the undamaged and survived walls had intersecting walls at their horizontal edges, while about 50% of the collapsed walls did not have any intersecting walls. Most of the collapsed walls with intersecting walls had inadequate joints between wall edges and intersecting walls. In Oita, 78% of the investigated walls have the intersecting walls.
It can be understood that most of the investigation results in Oita City are scattered or fall within the results obtained from investigations of collapsed and survived walls in Kobe City. As a result, severe structural damage

to the masonry garden walls is expected during next big earthquakes in Oita City, and thus the structural inspection and seismic strengthening for existing masonry garden walls are urgently required.

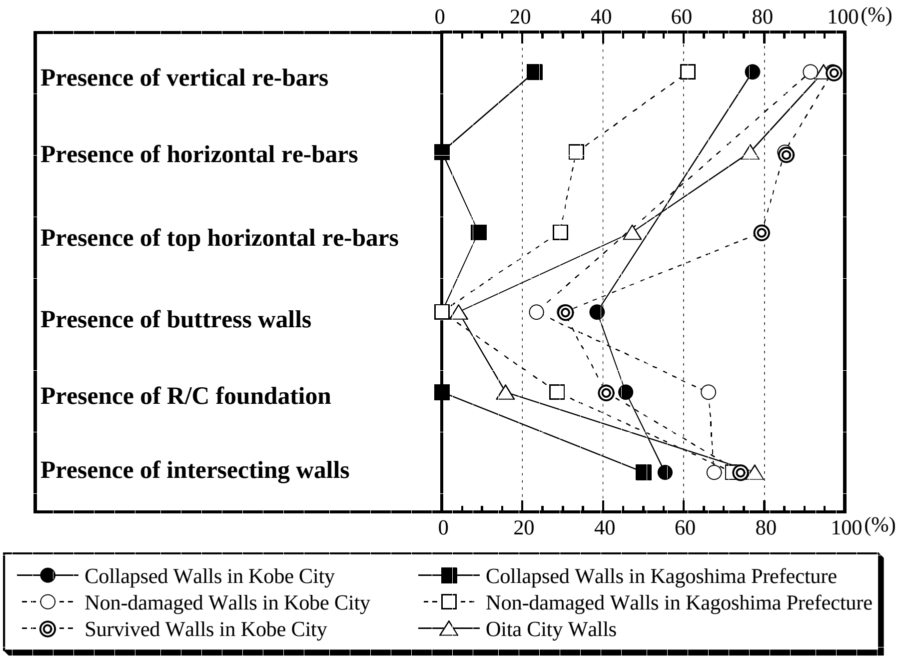


Figure 8: Results of four field investigations on seismic resistance of masonry walls

SEISMIC STRENGTHENING METHODS FOR EXISTING MASONRY WALLS

Field Investigation on Strengthening Methods Adopted for Existing Masonry Walls

In order to develop more effective strengthening methods for existing masonry garden walls with poor seismic resistance, strengthening methods adopted in the existing walls were investigated. These were all of the strengthened masonry garden walls which were located in the field investigation areas in Kobe and Oita Cities, and Kagoshima Prefecture. There were 35 strengthened walls, and the strengthening methods can be classified into the following six types:

(1) Add reinforced concrete block buttresses. This type of strengthening was used on five walls among those investigated. In Figure 9 the additional buttresses are connected to the existing wall by using bolts or other connecting materials. The buttresses should have massive foundations to prevent the wall from overturning toward the opposite side to the buttress during a severe earthquake.

(2) Add steel pillars. As shown in Figure 10, new steel pillars are anchored into ground soil or their foundations newly constructed, and are connected to the existing wall by using bolts or other connecting materials. This type of strengthening method was used on seven existing walls.

(3) Add buttresses composed of steel members. This strengthening method was composed of a steel pillar and a steel diagonal member as shown in Figure 11. A total of 11 walls were strengthened by this type of strengthening method. If these strengthening elements are anchored into massive foundations and are connected to the masonry wall firmly, then this type of strengthening seems to be effective. However, wide space is necessary between a building structure and a masonry garden wall.

(4) Connect walls to intersecting walls. As shown in Figure 12, this strengthening method is to connect the existing wall to the intersecting walls with connecting materials such as steel plates. It was adopted on five existing walls.

(5) Connect walls to adjacent structures. Four of the strengthened masonry garden walls were connected to the adjacent structures such as a residential building.

(6) Combine different strengthening methods mentioned above.

Some strengthened masonry garden walls may not be able to develop their seismic resistance sufficiently during severe earthquakes because of the poor seismic resistance of the strengthening elements such as lack of the massive foundation of the strengthening members.

Figure 9: Existing wall strengthened with concrete block buttress wall

Figure 10: Existing wall strengthened with steel pillar

Figure 11: Existing wall strengthened with steel pillar and diagonal member

Figure 12: Existing wall connected to intersecting wall with steel plates

A Proposal of Seismic Strengthening Method for Existing Masonry Walls

The number of existing masonry walls investigated in Oita City were listed in Table 1, where the walls classified into four types in accordance with their structural details. It can be understood from Table 1 that the walls having the R/C foundations were very few. On the contrary, the intersecting walls were provided into more than three fourth of the walls in Oita City. As these results, it is noticed that the strengthening method by connecting the masonry walls to the intersecting walls can be applied to a large number of the existing masonry walls. Figure 13 shows an example of the strengthened masonry wall by connecting to the intersecting walls. In the case when the masonry wall are long, buttress walls or steel pillars would need to be installed in the center of the masonry wall as shown in Figure 13.

Table 1: Structural details of existing walls in Oita City

Type of structural details	Presence of vertical re-bars or R/C foundation	Presence of intersecting wall(s)	Number of walls (%)
Type 1	Both	Yes	106 (12.1)
Type 2	Both	None	29 (3.3)
Type 3	One or None	Yes	560 (64.4)
Type 4	One or None	None	176 (20.2)
Total			871 (100.0)

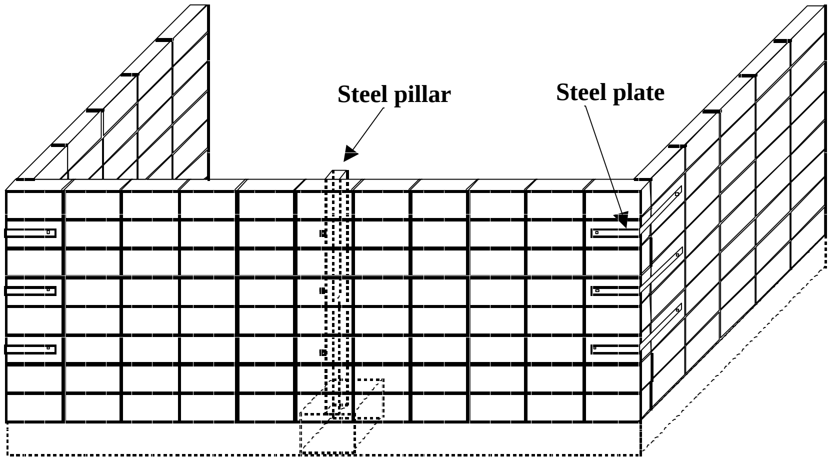


Figure 13: An example of strengthening method by connecting masonry wall to intersecting walls

CONCLUSIONS

In order to investigate the seismic safety of the existing masonry garden walls and to examine the strengthening methods for the existing walls with poor seismic resistance, five different field investigations were conducted in Kobe and Oita Cities, and Kagoshima Prefecture in Japan. The results obtained from these field investigations demonstrated the following conclusions.

(1) The presence of intersecting walls and vertical wall reinforcement as well as the reinforcing methods and details adopted are very important for the seismic safety of masonry garden walls.

(2) Severe structural damage to the masonry garden walls is expected during the next big earthquakes in Japan, because the seismic resistance of most of the existing masonry walls is very poor.

(3) Some strengthening methods adopted for the existing masonry walls are insufficient on the improvement of seismic resistance.

(4) Structural inspection and more effective seismic strengthening for existing masonry garden walls are urgently required and it is necessary to develop more effective strengthening methods and details for the existing masonry walls.

(5) Strengthening method by connecting masonry walls to intersecting walls is effective and can be applied to various kinds of existing masonry garden walls.

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