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RESEARCH ARTICLE

STUDY ON THE RISK OF COLLAPSE OF BLOCK WALLS IN JAPAN DURING EARTHQUAKES

Kensuke Goto[1], Takehiro Goto[2] and Keinosuke Gotoh[3]

1. Health and Safety Sciences, Osaka Kyoiku University, Japan.
2. Department of Business and Economics, Nippon Bunri University, Japan.
3. Professor Emeritus, Nagasaki University, Japan.

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Abstract

The earthquakes in Kumamoto (2016) and Osaka (2018) in Japan revealed grave repercussions of collapsed block walls, causing fatalities and severe damage. These incidents underscored the need for understanding and mitigating the risk posed by these structures. In response, this study focused on assessing block walls' collapse risk. Surveys across Nagasaki, Tokyo, and Chiba scrutinized various factors like rebar presence, wall appearance, and maintenance status using a Japan Concrete Block Association chart. Results revealed alarming statistics: 38% of block walls in Nagasaki posed a danger, with factors like lack of rebar and wall age significantly impacting collapse risk. Comparing regions, earthquake-experienced Kanto had 19% risky block walls versus 38% in less-experienced Kyushu, emphasizing the influence of earthquake awareness on residents' perception of block wall risks. Lack of rebar emerged as a primary risk factor across all areas. Considering block walls have a lifespan of 20-30 years, deteriorating rebar due to corrosion poses imminent risks. Urgent surveys and awareness campaigns, especially along school routes, are crucial to prevent tragedies like the young girl's death in Osaka. The study emphasizes scholars' responsibility to disseminate accurate information about block wall risks during earthquakes. However, challenges persist, such as unclear property ownership, hindering countermeasures even after identifying high-risk walls. Looking ahead, national diagnostic surveys are essential to address the looming danger, especially considering potential seismic events like the Nankai Trough Earthquake. Disaster education must prioritize teaching children about the risks of block walls during earthquakes to ensure their safety.

Introduction:-

The 2016 Kumamoto Earthquakeshook the Kumamoto area with foreshocks on April 14, 2016 and the main shock on April 16; there were not only two major earthquakes at a seismic intensity of 7 but also repeated aftershocks, causing major damage that included 273 fatalities and the complete destruction of 8642 buildings (Fire Department Emergency Response Office, 2023; Kawase et al., 2017; Mukunoki et al., 2016; Kiyota et al., 2017).In addition to the two major tremors, the repeated aftershocks of this major earthquake caused considerable damage to numerous buildings such as general residences, important cultural properties such as Kumamoto Castle, administrative and

Corresponding Author:- Kensuke Goto
Address**:-** Health and Safety Sciences, Osaka Kyoiku University, Japan.

school facilities, as well as loss of many precious human lives. This earthquake brought to the fore several issues regarding disaster risk reduction, including the likelihood of major earthquakes in areas where earthquakes have rarely occurred in the past, as well as a fresh awareness of the importance of earthquake-proofing buildings.Among the one who lost their lives in this tragic event, there was a man in his twenties who was crushed to death after being buried under a block wall that collapsed during the earthquake. Among the results of field studies conducted by us, one remarkable point was the high frequency of the collapse of block walls in the Kumamoto Earthquake, similar to that of entirely destroyed residential buildings.

The Osaka Earthquake of June 18, 2018, with its hypocenter in northern Osaka, was observed in Osaka City(Kita Ward), Takatsuki City, Ibaraki City, Minoh City, and Hirakata City just two years after the Kumamoto Earthquake. The Osaka Earthquake occurred at a maximum seismic intensity of 6, causing damage including 6 fatalities and 21 completely destroyed buildings (Cabinet Office and Government of Japan, 2022; Kiyono et al., 2021; Hirata and Kimura, 2018; Japan Meteorological Agency, 2018).Of the five people who lost their lives, two were crushed by collapsed block walls; one was a nine-year-old girl on her way to elementary school. This disaster prompted the Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2018)to promote safety measures and to conduct a survey of the safety of block walls in 51,082 national, public, and private kindergartens, integrated centers for early childhood education and care, elementary schools, junior high schools, compulsory education schools, high schools, secondary education schools, and special support schools nationwide.However, although safety surveys of block walls have been conducted in public facilities, the surveys are not being proactively conducted in privately-owned properties.

The average block used in block walls weighs approximately 7 kg, prone to collapsing en masse. Therefore, there are high chances of a sudden collapse of a block wall killing or injuring passers-by in event of an earthquake. For dailyroutine activities, such as being on the way to work or school, shopping, going home, delivering items, going out for a walk, or conversing on the street, people are often close to block walls. Considering this fact, anyone may be injured, be it a small child or an elderly,or even a person with some disability (including wheelchair-bound people who cannot move quickly). The risk is particularly high for children who pass by the same places every day on the way to/from school.

Collapsed block walls also hinder evacuation, support/rescue, restoration and transportation during disasters; moreover, non-collapsed block walls, despitestill standing after the main shock, may collapse during aftershocks. Grasping the status of the risk of collapse of block walls during normal times is crucial to earthquake countermeasures.Although there are some existing studies into structural damage using concrete block walls (Ravikumar et al., 2014; Kabeyasawa, 2017; Uebayashi et al., 2016), there are limited studies investigating concrete block wall damage and the risk thereof; they include Nakano (2008) and Mochizuki et al. (1980) who have studied damage to block walls from tsunamis caused by earthquakes. In Japan, these fact-finding studies on risk are rare, and fact-finding with regard to risks from block walls is likewise uncommon, having only been conducted in a few municipalities.

In Japan,being an earthquake-prone country, rebar is commonly used; the use of rebar in other countries is almost non-existent as block walls are still widely used throughout Asia, with concerns that the risk during earthquakes exceeds that of Japan. Therefore, in these countries, in addition to the risk to structures, the risk from block walls during earthquakes is an even more urgent issue than it is in Japan.

In this study, to grasp the risk of the collapse of block walls as part of everyday disaster preparation/disaster risk reduction, field studies were conducted regarding the current status of still standing block walls where no earthquake has occurred yet, and the level of risk was quantified.

Overview of the 2016 Kumamoto Earthquake and 2018 Osaka Earthquake 2.1 2016 Kumamoto Earthquake

Two major tremors at the seismic intensity of 7 were observed in the major earthquake that struck the Kumamoto area in 2016 (Fire Department Emergency Response Office, 2023; Kawase et al., 2017; Mukunoki et al., 2016; Kiyota et al., 2017; Mashiki Town, 2016). Since the revisions of Earthquake Observation Act in 1949, this was the first earthquake where seismic intensity of 7 occurred twice within the same earthquake. Of these two major seismic events, the Kumamoto City region in Kumamoto Prefecture was the hypocenter of the initial foreshock, which struck at 9.26 PM on April 14, 2016; the depth of this hypocenter was 11 km (provisional value). It was a 6.5-magnitude (provisional value) earthquake.Seismic intensity of 7 was observed in Mashiki Town, Kumamoto

Prefecture. The hypocenter of the second main shock, which struck at around 1:25 AM on April 16, 2016, was also the Kumamoto City region in Kumamoto Prefecture; the depth of this hypocenter was 12 km (provisional value). It was a 7.3-magnitude (provisional value) earthquake. Seismic intensity of 7 was observed in Mashiki Town and Nishihara Village in Kumamoto Prefecture. The former was struck twice with seismic intensity of 7 tremors, leading to severe damage. In addition to the major tremors in this earthquake, there were many aftershocks that had a huge impact, including the collapse of buildings that were still standing after the main shock.

In terms of human damage, there were 272 fatalities (50 confirmed in police autopsies, whereas remaining were earthquake-related deaths), and 2737 injuries of various degrees.There was also massive residential damage, including 8657 completely destroyedhouses, 34,491 partially destroyed, and 155,143 partially damaged (all including earthquake-related damage). In this earthquake, the extent of residential damage was remarkable. As of July 12, 2016, around three months after the earthquake, Mashiki Town (where two tremors with a seismic intensity of 7 were observed) had 2665 completely destroyed houses, accounting for about 30% of all residential damage in the town, whereas houses suffering partial destruction or more accounted for more than half of all the residential damage. Older houses, in particular, were noteworthy for the collapse of block walls, in addition to many houses that were completely collapsed (Fig 1). A man in his twenties was crushed to death after being buried under a collapsed block wall.

2018 Osaka Earthquake

The hypocenter of the earthquake that struck Osaka at 7:58 AM on June 18, 2018 was located in the north of the prefecture(Cabinet Office and Government of Japan, 2022; Kiyono et al., 2021; Hirata and Kimura, 2018; Japan Meteorological Agency2018; 2019). The depth of the hypocenter was 13 km (provisional value), and the earthquake itself was a 6.1-magnitude (provisional value) earthquake.A maximum seismic intensity of 6 was observed in five cities in Osaka Prefecture—Osaka City's Kita Ward, Takatsuki City, Hirakata City, Ibaraki City, and Minoh City. The earthquake struck at a time when many people were on their way to work or to school. The paralyzed transportation infrastructure made it difficult for many people to find transport or take any other measures, revealing numerous issues with emergency response in central urban areas.

In terms of human damage, there were 6 fatalities and 462 injuries of various degrees. Residential damage included 21 completely destroyedhouses, 483 partially destroyed, and 61,266 partiallydamaged. In this earthquake, two of the six fatalities (an 80-year-old man and a 9-year-old girl) were due to the collapsing block walls. The girl was crushed to death by a block wall that collapsed next to the pool of her elementary school. Therefore, MEXT issued a notice to Boards of Education across Japan urging them to take action with regard to block wall safety inspections at schools, etc. Ministry of Land, Infrastructure, Transport and Tourism (MLIT) requested local governments to issue alerts nationwide to owners of walls, etc. Moreover, the law was partially revised to require seismic diagnosis of block walls, etc., along evacuation routes in the same manner as buildings. Additionally, support was to be provided to help with the costs in the case of removal as a result of the seismic diagnosis of block walls, etc.

Damage from the collapse of block walls in earthquakes in Japan in the past

In addition to the two earthquakes mentioned above, there have been several damages caused in the past due to collapse of block walls during earthquakes in Japan. Particularly, of the 28 fatalities in the Miyagi Earthquake (M7.4) occurred on June 12, 1978, 18 were caused by the collapse of block walls: 64% of the total number of fatalities was due to the collapse of block walls.People with functional needs in times of disaster, such as children and the elderly,requiring support for evacuation during disasterswere particularly affected. Considering these facts, the alarm was raised with regard to the risk of the collapse of stone walls and block walls during earthquakes (Lu and Miyano, 1993). Although surveys were conducted in Miyagi at one time, there were almost no risk surveys in other regions thereafter, until the issue once again was highlighted following the Great East Japan Earthquake.

In addition to the Miyagi Earthquake, other deaths due to collapsing stone/block walls included 3 out of 28 total fatalities in the Niigata Earthquake (M7.5) of June 16, 1964, 4 out of 48 total in the Tokachi Earthquake (M7.9) of May 16, 1968 (Lu and Miyano, 1993), and 1 (elderly) in the Fukuoka Earthquake (M7.0) of March 20, 2005.

In the 2016 Kumamoto Earthquake as well, many sidewalks were obscured by collapsed block walls (Fig 1), and many houses had almost all their block walls collapsed. In most cases, these block walls were not reinforced or had suffered corrosion (Fig 2).

Block wall risk surveys were conducted for a certain time in Miyagi after the Miyagi Earthquake and drew attention following the Great East Japan Earthquake; however, ultimately, there were almost no national studies till the Osaka Earthquake in 2018. As for the collapse of the block wall that caused the death of the young girl in the Osaka Earthquake, of the block walls of approximately 3.5 m high facing the school route around the elementary school pool, the upper section (about 1.6 m high), an eight-tier concrete block assembly, collapsed along an approximately 40m stretch along the school route (Fig 3).This tragic incident led to studies of block walls in public facilities in many cities, including Takatsuki City; however, as stated above, there have been almost no studies of block walls in private houses.

Block wall collapse risk surveys

Survey technique

This survey of the risk of the collapse of block walls involved door-to-door home visits selected through random sampling. The details of the survey and this study were explained to owners before the survey for their consent. The JCBA (Japan Concrete Block Association) "Block Wall Diagnosis Chart" was used to conduct diagnoses by quantifying the risk of collapse. This diagnosis chart provides a comprehensive score based on four values/factors: basic performance (basic performance value), wall appearance (external appearance factor),wall resistance (resistance factor), and maintenance status (maintenance factor). A higher total score (55 points or more) indicates a safe block wall, and a lower score (less than 55 points) indicates the risk of collapse. A score of less than 40, particularly, indicates the need to take urgent collapse prevention measures or to completely remove the wall.

The basic performance diagnosis refers to a score based on reference points for items that include year of construction, presence of additional height construction, usage (lone wall/exterior wall, etc.), location of the wall (presence of retaining wall underneath), height and thickness of the wall, presence of openwork (Fig 4), presence of rebar, presence of buttresses or buttress posts, presence of a top rail (Fig 5), etc. The presence of rebar in the wall was investigated using a sensor (Fig 6). For wall external appearance, the reference coefficient is based on overall tilt, cracks, damage, or significant dirt, and the minimum score provides the external appearance factor. For wall resistance, the reference coefficient is based on the extent of instability of the wall, and that value is used as the resistance factor. For maintenance status, the reference coefficient is based on whether or not the wall is reinforced or has measures to prevent collapse, and that value is used as the maintenance factor. A diagnosis covering a total of 16 items, including the year of construction, height and thickness of the wall, presence of openwork, presence of rebar, and presence of buttresses, enabled evaluation of not only appearance and construction standards but also the risk of the collapse of the block wall based on its current status.

The survey targeted Nagasaki City and Omura City in Nagasaki Prefecture, which have not experienced any major earthquakes in recent years, as well as Taito Ward in Tokyo and Funabashi City in Chiba Prefecture, which have experienced many earthquakes, comparing the risk of the collapse of block walls in the Kyushu area (Nagasaki Prefecture) and the Kanto area (Tokyo/Chiba). In Kyushu, surveys were conducted at a total of 85 locations: 58 in Nagasaki City and 27 in Omura City. In the Kanto area, surveys were conducted at a total of 52 locations: 31 in Taito Ward and 21 in Funabashi.The survey period was from May 2016 to November 2019.

All the analyses in this study were conducted using BellCurve for Excelversion 3.20 (Social Survey Research Information Co., Ltd.).

Survey results and discussion

Chi-squared tests were conducted to investigate the impact of the basic performance of block walls on the risk of collapse. Fisher's exact test was used when expected cell values were less than 5.The results for each area are shown in Table 1 and Table 2.

In the Kyushu area, 38% of block walls were dangerous or required caution. As a result of the chi-squared testand Fisher's exact test, it was observed that the lack of rebar ($p<0.01$), the presence of openwork ($p<0.01$) (Fig 7), and the age of the wall (20 years or more) ($p<0.01$)have a significant impact on danger or caution concerning block walls. On the contrary, in the Kanto area, 19% of block walls were dangerous or required caution. As a result of the chi-squared test and Fisher's exact test, it was found that lack of rebar ($p<0.01$), and lack of top rail ($p<0.01$)have a significant impact on danger or caution concerning block walls.

Based on this survey, in comparison to the Kanto area, which has suffered many major earthquakes, the Kyushu area, which has less experience of major earthquakes, has roughly 200% more block walls that are dangerous or require caution. This shows that experiences of earthquakes among residents impact disaster awareness with regard to block walls. In both the areas, block walls without rebar had a significant impact on collapse risk. This was considered to be the main factor that heightens the risk of block wall collapse. In surveys of the risk of collapse of block walls, in addition to visual inspection, it is extremely important to use sensors to study the presence of rebar.

Majority of the owners in this survey were unaware of the fact that the block walls were not reinforced. It was found that the block walls were in state of collapsing due to poor workmanship by the contractors. In the Kumamoto Earthquake, where many block walls collapsed, it is thought that most of the residential block walls that fell either had no rebar or had become corroded. Considering this, surveys are urgently required with regard to the presence of rebar in particular. Moreover, there were many block walls that will undergo greater deterioration in the future, including those with major cracks, etc. (Fig 8).

Block walls have a durable life of about 20 to 30 years (Ravikumar et al., 2014; Kabeyasawa, 2017). However, as rebar corrodes due to the neutrality of the block as it deteriorates, block walls must be repaired or reinforced for houses which are 20 years old. Therefore, it is important to conduct diagnostic surveys of block walls such as those conducted in this study.

Following the Osaka Earthquake, many studies of block walls in public facilities were conducted; however, but there is an urgent need for surveys on the block walls facing the school routes used by children every day. When the authors investigated the 2016 Kumamoto Earthquake, the number of collapsed block walls stood out alongside the complete destruction of houses. Therefore, the authors began a survey on the dangers of block walls and worked to raise awareness about the dangers of block wall collapse, especially along school routes. The tragic accident in which a young girl was crushed to death by a collapsed block wall on her way to school in the Osaka Earthquake was an indicator that there is still a long way to go with the transmission of this information, evoking a strong sense of our own inadequacy as researchers. We intend to conduct further surveys of the risk of the collapse of block walls along school routes and raise further awareness about these risks.

Conclusion:-

This survey clarified that 38% of block walls in Nagasaki Prefecture are dangerous or require caution, and that many block walls are at a high risk of collapse during earthquakes. This figure was 42% in the 2006 study by the authors. Nearly 40 years have passed since the Miyagi Earthquake, raising an alarm about the danger of the collapse of block wall during earthquakes, and since then the Great Hanshin-Awaji Earthquake (1995), Fukuoka Earthquake (2005), which also affected Nagasaki Prefecture, and Great East Japan Earthquake (2011), with its terrible damage, have occurred. Although the awareness of residents regarding the dangers of earthquakes is thought to have increased thereby, the lack of awareness of the dangers of block walls has been highlighted here, indicating that the lessons of the past are not being applied. Being natural disasters scholars, we have not sufficiently made residents aware of the risks of block walls during earthquakes; it is our responsibility to provide accurate information on this issue from now on and make people fully aware about this problem.

Although block walls are no longer used in many houses due to recent residential issues, they are still found in many houses as a familiar sight. Until now, there have been only a few major earthquakes during school commuting hours, but they may occur in the future. Therefore, to protect the lives of children, who have functional needs in times of disaster, it is important to understand the collapse risk of block walls along school routes in collaboration with schools and local areas before earthquakes occur, and to investigate earthquake countermeasures.

Currently, Japan is facing an issue of an increased rate of vacant houses; land and home ownership are often unclear. Therefore, even if block walls are diagnosed as being at a high risk of collapse as a result of a survey on block wall collapse risk, it is often difficult to take countermeasures. Likewise, our survey found that there were cases at sites with unknown owners where diagnosis revealed a high risk of collapse due to lack of rebar, etc. While it is difficult to take measures if the owner is unknown, there were cases in which children walk alongside those block walls as the land is located along a school route (Fig 9).

Currently, in Japan, there are great concerns about the Nankai Trough Earthquake (Hirose et al., 2022; Hirano et al., 2023). Even though the alarm has already been raised about the dangers of these walls, to save lives, whether one or many, the current situation has not been clearly grasped and the dangers have not been well publicized, calling for diagnostic surveys nationwide regarding these walls. Moreover, in disaster prevention education, the awareness of disaster risk must be increased by teaching children about the risks of block walls during earthquakes and teach them to stay away from block walls in an event of earthquake.

Table 1:- Influence on collapse vulnerability in various fundamental performance aspects of block walls (Kyushu area).

Fundamental performance	P-value
Lack of rebar	＜0.01
Presence of openwork	＜0.01
Lack of top rail	＜0.05
Age of the wall (20 years or more)	＜0.01
Lack of buttress	0.47
Height of the wall (2.2 m or more)	＜0.05
Thickness of the wall(10cm)	＜0.05
presence of additional height construction	-
Usage (retaining wall/outer wall)	＜0.05
Location of the wall (presence of retaining wall underneath)	＜0.05
Crack	＜0.05
Damage	0.126
Significant dirt	＜0.05

-: non-existence

Table 2:- Influence on collapse vulnerability in various fundamental performance aspects of block walls (Kanto area).

Fundamental performance	P-value
Lack of rebar	＜0.01
Presence of openwork	＜0.05
Lack of top rail	＜0.01
Age of the wall (20 years or more)	0.57
Lack of buttress	0.71
Height of the wall (2.2m or more)	-
Thickness of the wall (10cm or more)	0.21
presence of additional height construction	0.19

Usage (retaining wall/outer wall)	-
Location of the wall (presence of retaining wall underneath)	＜0.05
Crack	0.28
Damage	0.72
Significant dirt	0.16

-: non-existence

Fig 1:- Collapsed block wall on the sidewalk.

Fig 2:- Collapsed block wall with corroded rebars.

Fig3:- The collapsed elementary school block wall in the 2018 Osaka Earthquake.

Fig 4:- Openwork block wall.

Fig 5:- Block wall with buttress and top rail.

Fig 6:- Investigation of presence or absence of rebars using sensors.

Fig7:- Block wall with openwork.

Fig 8:- Block wall withmajor cracks.

Fig 9:- Elementary school children passing beneath block walls diagnosed as high-risk for collapse and with unknown owners.

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