A Study of Disaster Mitigation for Non-Engineered Construction in Developing Countries

-Bridging the Gap between Experiments and Practices-

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論文の要旨

A Study of Disaster Mitigation for Non-Engineered Construction in Developing Countries
-Bridging the Gap between Experiments and Practices-

（和訳）開発途上国における組積造の耐震性向上のための研究
－実験研究と普及方策－

今井　弘

開発途上国では地震の度に甚大な被害を被っている。人的被害の主要な原因は、建物の倒壊によるものであり、特に被害が甚大になる原因として、途上国の庶民住宅の一般的な建設工法である組積造の脆弱性があげられる。これらの庶民住宅の多くは、地域の職人あるいは住民自身によって建設され、技術者が関与していないノンエンジニアドと呼ばれる。

途上国での地震被害軽減に向けて、ノンエンジニアド建設の耐震性向上は喫緊の課題である。

本論文は、地震多発地域のノンエンジニアド建設の庶民住宅の主要工法である組積造を対象として、実験研究による耐震補強工法の開発と、耐震性向上の工法の普及に向けた現地活動を通した方策を研究したものである。

本論文は 5 章で構成されている。

第 1 章においては、研究の背景と目的を述べた。

2001 年インドブジ地震、2003 年イランバム地震、2005 年パキスタン北部地震、2006 年インドネシアジャワ島中部地震等など、組積造の脆弱性により甚大な被害がでている。一概に組積造といっても、焼成レンガ、アドベ（日干しレンガ）、石、コンクリートブロック等と様々な材料があり、組積方法も各国（地域）の違いがある。地震多発地域の近年の主要なレ

ンガ組積造建築物を、南アジア型レンガ組積造と、東南アジア型レンガ組積造と分類し研究対象とした。また 2010 年ハイチ地震で甚大な被害がでたコンクリートブロック組積造も、フィリピンやヒマラヤ地域での主要工法であるため研究対象とした。

途上国のノンエンジニアド建設に関するガイドブックや、実験研究の既往文献を参照し、各国での耐震性向上の取り組みをまとめた。ノンエンジニアド建設は、工学的研究の対象となることが少なく、また各国での地域性あるため、これまで十分な取り組みがなされていない。更に、地震被害調査や実験研究と、現地での復興住宅再建事業などは、単独事業で行われることが大半のため、連携が少なくギャップが生じている。

このことから実験研究による耐震補強工法の開発と、耐震性向上の工法の普及に向けた現地活動を通した方策の両者の連携を通して、実践的な耐震性向上の手法の確立を目的としている。

第 2 章では、実大振動台実験を通して、対象とした各主要組積造の地震時の挙動、破壊時の挙動、耐震性能の検証を行った。南アジア型レンガ組積造モデルの振動台実験では、パキスタンから輸入したレンガを使用し、一般的なノンエンジニアド庶民住宅と同等の壁厚がレンガ長手幅の 23cm 壁で構成された試験体により実験を行った。倒壊に至る破壊時の挙動は、開口部からの面内せん断クラックが発生した後、窓上の臥梁の崩落により、全壊に至った。東南アジア型レンガ組積造モデルは、昨今インドネシアで主要な建設工法である枠組み組積造（Confined Masonry）であり、壁厚がレンガ短手部分の 10cm 壁に RC フレームで囲われたモデルである。破壊は、面外挙動によりレンガ壁が崩壊した後、RC フレームの損傷により全壊に至っている。コンクリートブロック組積造実験は、フィリピンの建築基準法に則ったモデル（モデル A）と、現地で一般的に建設されているノンエンジニアドモデル（モデル B）の 2 体の比較実験を実施した。ノンエンジニアドモデルは、入力波 JMA 神戸 NS100%により妻壁の崩落と面外壁の損傷など被害が大破し、その後の入力 JMA 神戸 110%では、ノンエンジニアドモデルは全壊に至った。一方、建築基準に則ったモデルは、壁面に損傷はあるものの、倒壊に至っていない。この実験では、建築基準の遵守の重要性、妻壁の脆弱性、またコンクリートブロック内部に充填するモルタルの施工法による耐力の違いを検証することができた。これらの振動台実験を通して、各組積造の典型的な脆弱破壊のメカニズムの検証をすることができた。

第 3 章では、第 2 章の振動台実験を通して検証した組積造の脆弱破壊を防ぎ、耐震性能を向上させるための耐震補強工法の開発を実施した。現地で普及しうる既存建物にも適応できる耐震補強工法を、Affordability（安価な経済性）、Feasibility（簡易な施工性）、Adaptability（既存建物への適応性）という観点で開発し、実験研究を行った。

組積造が脆弱破壊を起こす一因として、組積壁の引張強度の低さがあげられる。この弱さを補うために、耐震補強としてワイヤーメッシュで組積壁を覆い、モルタル仕上げを施す工

法である。ワイヤーメッシュは、現地で入手しやすい材料として、鳥かごで使用されている亜鉛メッキ溶接メッシュを採用した。これまでのフィールド調査では、地方の建材屋でも入手可能で安価である。これまでもワイヤーメッシュをモルタルで覆った工法は、フェロセメントと呼ばれ使用されているが、組積造の耐震補強としての研究は数例あるのみであり、振動台実験での耐震性能の実証は例がない。振動台実験では、同材料をした組積壁全面を覆うジャケッティングと部分的補強のバンデージングの実験を実施した。インドネシアから輸入したレンガを使用し、補強なりモデルと補強ありモデルの 2 棟の比較実験では、補強ナシモデルが入力波 JMA 神戸 NS100%で、妻壁と組積面の面外崩壊したのに対し、補強モデルは特に損傷は見られなかった。振動台実験を通して、補強効果を実証することができた。

第 4 章では、途上国における耐震補強工法の普及方策の検討を行っている。まずインドネシアの 2006 年ジャワ島中部地震での復興住宅の継続的調査をもとに耐震補強工法の必要性と実用可能性に関して述べている。また 2009 年スマトラ島沖地震で被災したパダンパリアマンにて職人トレーニングや住民の意識向上ワークショップの実施事例として、職人の技術の向上のみならず、住民の防災意識の向上が不可欠であることの特性を明らかにした。第 3 章で開発した組積造の耐震補強工法に関して、パダンにて職人トレーニングを実施し、現地での普及と、より簡易に実施するための施工性の改善を行った。フィリピンにおいて、庶民住宅向けの簡易耐震診断ツールの開発をおこなった。まず住民の防災意識向上のための、自らが住宅の耐震性を診断する 12 項目の耐震診断チェックリスト、そして次のステップとして技術者と住民が共同で簡易耐震診断ソフトウエアを使用して、診断を行う。この課程を通して、ノンエンジニア建設に欠如していた工学的知見との接点を持つことを目的としている。そしてこれらの簡易耐震診断ツールのフィリピン全土への普及に向けて実施したワークショップを普及方策の一事例として挙げている。

第 5 章において、本論で得られた耐震補強工法の効果と、普及に向けた現地活動を通した知見を、今後の展開可能性と課題に関して述べている。これまで工学的配慮がすくないノンエンジニアド建設は、工学的研究の対象になりづらく研究が進んでいない分野である。しかし地震の度に多くの人々が犠牲になっているノンエンジニアド建築物の耐震性向上に向けて、各関係者が一丸となって取り組む必要があり、各関係者の必要な行動として提案を示した。

今後、耐震補強工法の経年劣化等の耐久性の分析、また他地域への展開する上で工学的、定量的な解析の構築が必要である。

本論で得られた知見は、インドネシアでは現場へ還元され、職人トレーニングや政府へのワークショップが開始され始めたことからも、実施可能な耐震補強工法の一工法として、提案できたと考えている。

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Chapter 1 Introduction

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1.1 Background

Each year, disasters caused by earthquakes around the world have devastating effect on people. Past earthquakes revealed the vulnerability of human life in developing countries. For examples, the 2001 Gujarat earthquake in India resulted in approximately 20,000 fatalities; the 2003 Bam earthquake in Iran resulted in approximately 30,000 fatalities; the 2005 Kashmir earthquake in Pakistan resulted in approximately 80,000 fatalities; and the 2010 Port-au-Prince earthquake in Haiti was presumed over 300,000 fatalities. (See Fig.1 and Table 1)

Most of the human casualties in past earthquakes were caused because of the collapse of buildings, particularly masonry constructions in developing countries. Most of these buildings are categorized into “Non-Engineered Construction”. “These buildings are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design.”[1]

Figure 2 shows the damage of non-engineered construction by recent earthquakes.

Unfortunately, these type of buildings are widely constructed in most seismic prone areas. These types of buildings in developing countries are not as safe as engineered construction. As described above, these are mostly constructed with locally available materials. Furthermore, the construction workers are either non-skilled or only semi-skilled and without technical knowledge in construction.

The improvement of safety of non-engineered construction against earthquake is one of the most urgent issue.

Since 2001, the author has been working as a humanitarian aid and in a research institute for the improvement of earthquake safer design of non-engineered construction. The author is involved in activities such as damage survey, shelter program, masons technical training, awareness seminar for house owners, and laboratory testing of material as well as full scale shaking table tests. The author proposed retrofitting methods for non-engineered construction and practical tools for vulnerability and safety evaluation as awareness tool for non-engineered construction in developing countries, these were proven through lessons learned from experiments and practices.

[1] IAEE, Anand S. Arya, Teddy Boen, Yuji Ishiyama, et al., GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION, 1986, p1

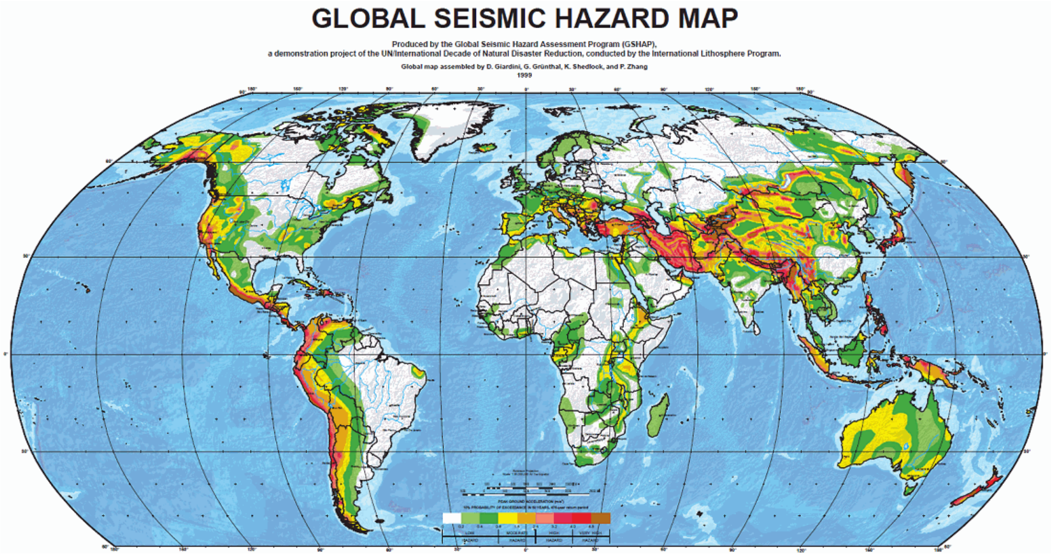


Fig.1 Global seismic hazard map[2]

Table 1 List of recent earthquake 1990-2014[3]

Earthquake	Year	Date	Time	Magnitude	Fatalities
1991 Uttarkashi earthquake, India	1991	19-Oct		6.8	768
1992 Flores earthquake, Indonesia	1992	12-Dec		7.8	2,519
1993 latue earthquake, India	1993	29-Sep	3:56	6.2	9,748
1994 Paez river earthquake, Colombia	1994	6-Jun		6.8	1,100
1995 Great Hanshin earthquake, Japan	1995	16-Jan	5:46	6.9	6,434
1996 Lijiang earthquake, China	1996	3-Feb	19:14	6.6	322
1997 Qayen earthquake, Iran	1997	10-May	7:57	7.3	1,567
1998 Afghanistan-Tajikistan Border Region	1998	30-May		6.9	4,000~4,500
1999 Izmit earthquake, Turkey	1999	17-Aug	3:02	7.6	17,127
2000 Bengkulu, Sumatera, Indonesia	2000	4-Jun	23:30	7.9	103
2001 Gujarat earthquake, Bhuj India,	2001	26-Jan	8:46	7.7	20,023
2002 Hindu Kush earthquake, Afghanistan	2002	25-Mar	19:08	6.1	1,166
2003 Bam earthquake, Iran	2003	26-Dec	5:26	6.6	31,000
2004 Indian ocean earthquake and tsunami	2004	26-Dec	7:58	9.1	227,898
2005 Kashmir earthquake, Pakistan	2005	8-Oct	8:50	7.6	80,361
2006 Central Java earthquake (Yogyakarta)	2006	26-May	5:53	6.3	5,749
2007 Peru earthquake (ICA)	2007	15-Aug	23:40	8.0	514
2008 Sichuan earthquake, China	2008	12-May	14:28	7.9	87,587
2009 Sumatra earthquake, Indonesia	2009	30-Sep	17:16	7.5	1,117
2010 Port-au-Prince earthquake, Haiti	2010	12-Jan	16:53	7.0	316,000
2011 Christchurch earthquake, New zealand	2011	22-Feb	12:51	6.3	185
2011 Tohoku earthquake and tsunami, Japan	2011	11-Mar	14:46	9.0	20,896
2011 Van earthquake, turkey	2011	26-Oct	13:41	7.1	604
2012 Visayas earthquake, Philippines	2012	6-Feb	11:49	6.7	113
2013 Bohol earthquake, Philippines	2013	15-Oct	8:12	7.2	222

* Color parts which are most damage were non-engineered construction.

[2] Source: Global Seismic Hazard Assessment Program http://www.seismo.ethz.ch/static/GSHAP/
[3] Author made based on Source: USGS web site,
http://earthquake.usgs.gov/earthquakes/eqarchives/year/byyear.php

(A) 2001 Bhuj earthquake in India, adobe and brick masonry were damaged

(B) 2003 Bam earthquake in Iran, adobe and brick masonry were damaged

(C) 2005 Kashmir earthquake in Pakistan, stone and CB masonry were damaged

(D) 2006 Central Java earthquake, 2008 Sumatra earthquake (Padang) in Indonesia, brick masonry and confined masonry were damaged

Fig.2 Damage of non-engineered construction by recent earthquakes

1.2 Research objectives

The non-engineered construction in developing countries is very vulnerable to earthquake, however, these construction exists and is still being built in earthquake prone areas.

The objective of construction methods of this research were brick and concrete block masonry structure which are the ordinary construction methods found in developing countries.
The classified masonry types on hazard map in Asia is shown in Fig.3.
Basically, brick masonry construction methods in Asia are able to classify into two types of construction methods, these are the South Asian model and the South-East Asian model.

One of major construction methods in Asia, the method of South Asia, the Himalayan belt included, these are totally different from the method of South-East Asia, even though brick masonry is generally used.

Figure 5 shows the classification according to brick laying in each country.

The brick masonry construction In the South Asia and the Himalayan belt areas, the walls are approximately 230 mm thick that is equal to the length of the brick and is called to “One-brick-thick wall”, shown in Fig.5 (A). The use of Flemish-bond is very common in India and Nepal. Similarly the use of British-bond is common in Pakistan.
In addition, taking the situation in West Asia or Middle East, brick masonry in Iran and westward consists of 350 mm thick walls, which is called “One and half-brick-thick wall”, shown in Fig.5 (C).

On the other hand, in South-East Asia, the most common type of construction has small a dimension of reinforced concrete frame with load-bearing brick wall being almost 100 mm thick width that is same as dimension of end of brick, called “Confined masonry with a half-brick-thick wall”. In particular, these type of masonry construction had suffered serious damage during recent past earthquakes in Indonesia, shown in Fig.5 (B).

The common construction methods are related to the vernacular because they are close in correlation to the environment and local culture. Hence, there are different characteristics of each brick masonry construction in each country.
In addition, the concrete block masonry construction have recently become common residential structures in developing countries.

A review of common housing types in the Philippines shows that many non-engineered houses exist and these are mostly using concrete hollow blocks (CHB). On the Himalayan belt, Kashmir area in Pakistan and India, the CHBs is also commonly used as a construction material. Furthermore the devastating damages of concrete block structures in 2010 Port-au-Prince earthquake in Haiti is still fresh in our memory. (See Fig.4)

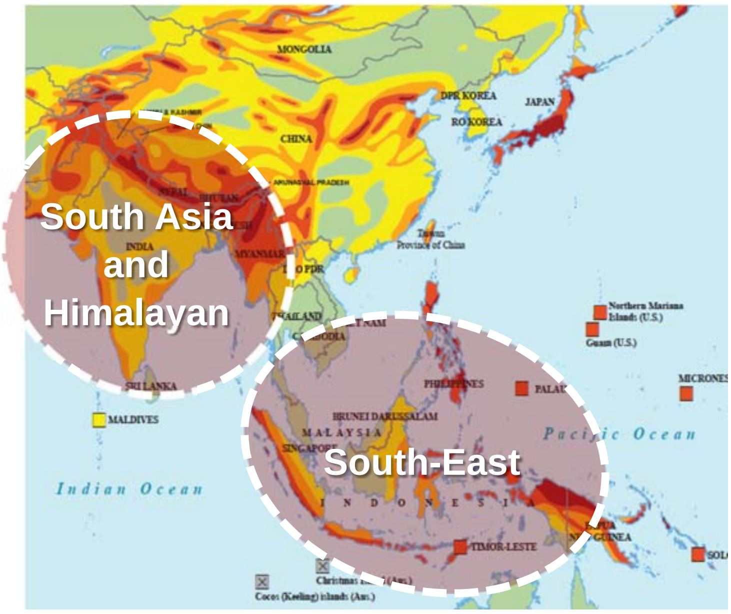


Fig.3 Classified masonry type on hazard map in Asia[4]

Fig.4 Damage in 2010 Port-au-Prince earthquake in Haiti[5]

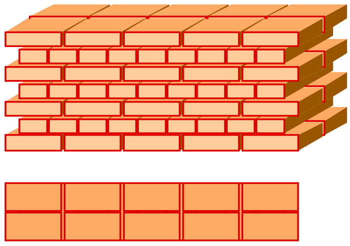
[4] Source: Author made on Hazard map from OCHA: http://reliefweb.int/sites/reliefweb.int/files/resources/map
[5] Source: The telegraph: Haiti earthquake: aerial and satellite photos of Port-au-Prince from the air and space: http://www.telegraph.co.uk/news/picturegalleries/worldnews/6987916/Haiti-earthquake-aerial-and-satellite-photos-of-Port-au-Prince-from-the-air-and-space.html

(A) One-brick thick wall

[British Bond]

The common brick laying in South Asia.

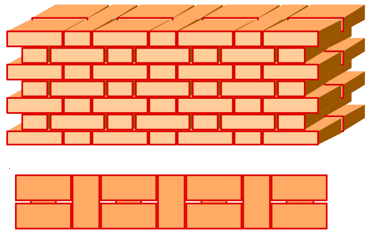
Thickness of wall is approximately **230 mm.**



[Flemish Bond]

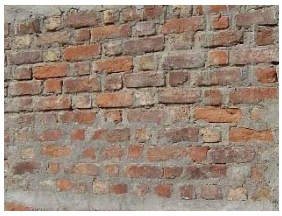
The common brick laying in South Asia.

Thickness of wall is approximately **230 mm.**



in Pakistan

in Nepal



in India

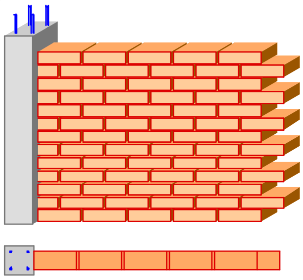
in India

(B) A half-brick-thick wall + RC frame

[Confined masonry]

The common brick laying in South-East Asia.

Thickness of wall is **100 mm**.



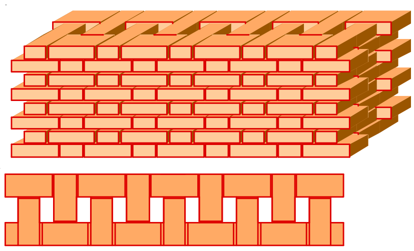
in Indonesia

in Indonesia

(C) One and a half-brick-thick wall and more.

The common brick laying in Middle-East.

Thickness is more than **350 mm.**



in Iran

in Iran

Fig. 5 Classification according to brick laying in each country

1.3 Review of past studies and literatures

First of all, it would not be an exaggeration to say that the “Guidelines for Earthquake Resistant Non-Engineered Construction[6]” is a starting point in considering earthquake safer construction in developing countries, shown in Fig.6. The first edition of the book was published by the International Association for Earthquake Engineering (IAEE) in 1986. This book consisted of a revised and improved version of the original document, “Basic Concepts of Seismic Codes, Vol.1, Part 2, Non-Engineered Construction”, also published by IAEE in 1980. The revision resulted from the work of a committee, integrated by Anand S. Arya (Chairman, India), Teddy Boen (Indonesia), Yuji Ishiyama (Japan), et al. These efforts were guided by the objectives, scientists and other professionals in the field of earthquake engineering through the exchange of knowledge, ideas and the results of research and practical experiences. This “Guidelines for earthquake resistant non-engineered construction” consists of diverse issues that are derived from structural performance of building during earthquakes, general concepts of earthquake resistant design and strengthening of buildings. Recently, a new revised version was published by UNESCO[7], shown in Fig.7.

Since then, in particular, Anand S. Arya, India and Teddy Boen, Indonesia made vast contributions to the study of non-engineered construction.

Many manuals[8], guidelines[9,] and building codes are published based on their activities in the world. For examples, in the Nepal building code[10], the chapter of non-engineered construction was included. Furthermore, Gujarat State Disaster Mitigation Authority and Indian Institute of Technology Kanpur made some guidelines[11] for non-engineered construction are referred to this guide book.

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6 IAEE, Anand S. Arya, Teddy Boen, Yuji Ishiyama, et al., GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION, 1986.

7 Download site: UNESCO: http://www.unesco.org/new/en/natural-sciences/about-us/single-view/news/new_guidelines_to_improve_the_safety_of_informal_buildings/#.VCZqhmdxmeQ

8 Guidelines for Earthquake Resistant Non-Engineered Construction, NICEE, India,2004

9 Shaw R. and Okazaki K., Guidelines for earthquake resistant design, construction and retrofitting of buildings in Afghanistan, UNCRD-MUDH Publication, 2003

10 The Nepal National Building Code, 1994

11 GUIGELINES for STRUCTURAL USE of REINFORCED MASONRY, IITK-GSDMA, India, 2005

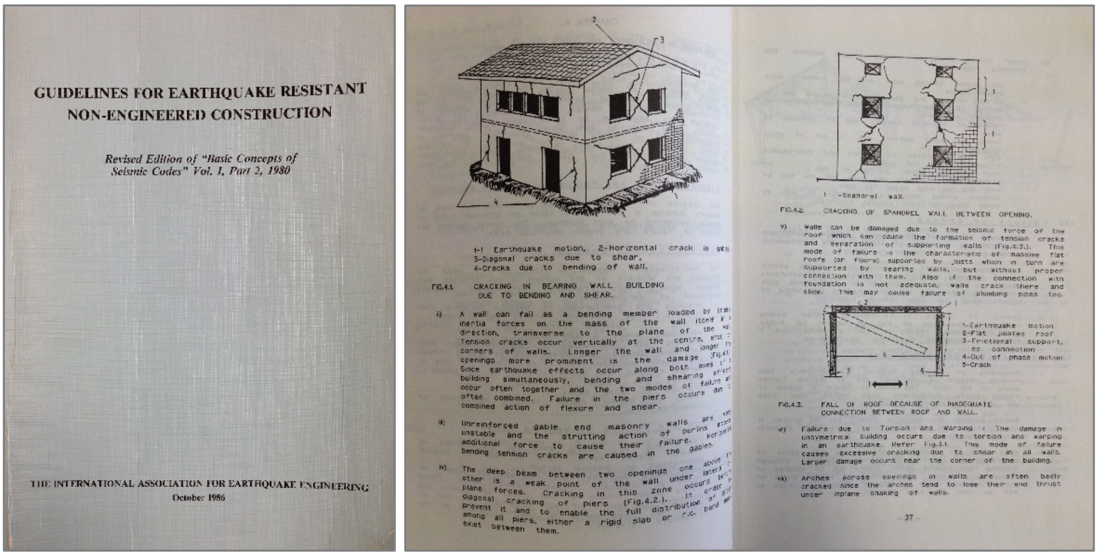

Fig.6 Guideline for earthquake resistant non-engineered construction, 1986, IAEE[6]

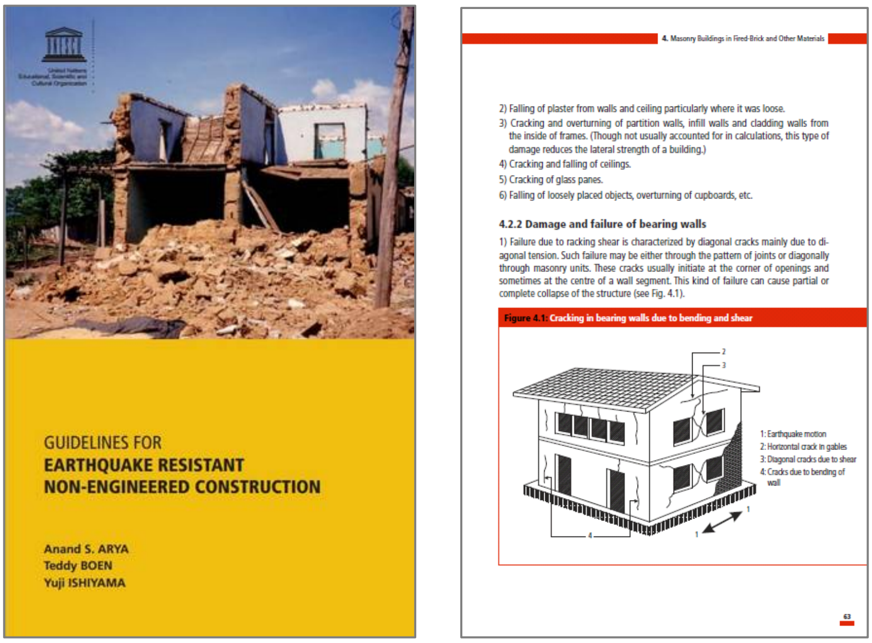

Fig.7 Revised version of guidelines for earthquake resistant non-engineered construction, 2014[7]

[6] IAEE, Anand S. Arya, Teddy Boen, Yuji Ishiyama, et al., GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION, 1986.

[7] Download site: UNESCO: http://www.unesco.org/new/en/natural-sciences/about-us/single-view/news/new_guidelines_to_improve_the_safety_of_informal_buildings/#.VCZqhmdxmeQ

In case, when a devastating earthquake occurs, many researchers survey failure processes and patterns by observation and learned from the damaged buildings and remaining debris. These studies identify and the recorded the behavior of buildings during shaking motion and their failure mechanism. These surveys in Japan constitute mainly on the works of the Architectural Institute of Japan (AIJ). Disaster investigation, damage case of construction method in developing countries, and damage factors have been reported, shown in Fig.8.

Fig.8 Report on the damage investigation of the 2006 Central Java Earthquake, 2006, AIJ[12]

Since many masonry buildings had been damaged by the 1923 Great Kanto Earthquake, masonry construction has not been a major construction method in Japan. In comparison to other structures, the research work on masonry structures are much less than other structural methods. And in addition, there have been only a few studies regarding earthquake safety of non-engineered construction in developing countries.

Regarding experimental studies, some studies have been conducted for masonry construction in developing countries.

[12] AIJ, Report on the damage Investigation of the 2006 Central Java Earthquake, 2006.

In Japan, Yoshimura, Kikuchi, Kuroki et al. in Oita University in 1991 conducted a series of studies which focused on confined masonry[13,14]. Their studies related to a JICA project incorporated with CENAPRED[15] in Mexico. These experimental studies have shown the comparison with different wall-to-wall connection details, shown in Fig.9.

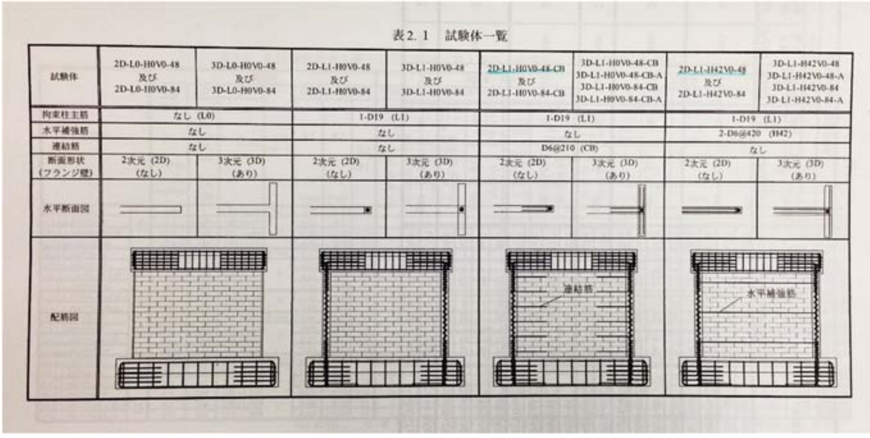

Fig.9 List of specimens by Oita University[16]

Osamu Jo in Hokkaido University also conducted research studies on static experiments and analysis of masonry structures in cases of Peru and Chile. These studies demonstrates the effectiveness of masonry wall with different sizes and location of openings in Fig.10.[17]

In other studies, Mizuno et al. in Building Research Institute (BRI) carried out dynamic and static experiments, specimens with horizontal reinforced bars, the study had confirmed that the reinforcing bars has a strength increasing effect.[18]

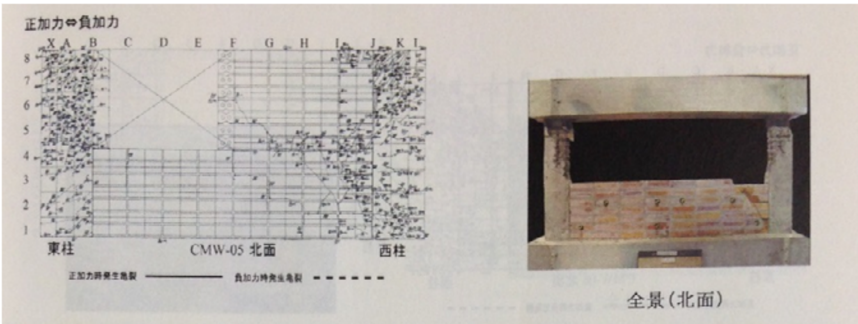

Fig.10 Static experiments by Hokkaido University[18]

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[13] Yoshimura et al., Experimental Study on Effects of height of lateral Forces, Column Reinforcement and Wall Reinforcements on Seismic Behavior of Confined Masonry Walls, 13WCEE, 2004.
[14] K. Kikuchi et al., Experimental Study for developing Higher Seismic Performance of Brick Masonry Walls, 13WCEE, 2004.
[15] Sitio Oficial del Centro Nacional de Prevention de Desastres; http://www.cenapred.unam.mx/es/
[16] K. Yoshimura, 開発途上国の地震国における煉瓦組積造建物の耐震性向上と補強法の開発研究, 2003, p17
[17] Jo Osamu, International Contribution of Proposal of Techniques Improving Seismic Performance on R/C Buildings with Masonry Walls used in Developing Countries, 2008.
[18] Mizuno et al. Technology Transfer of Housing Technology for the Third Would. Improvement of Structural Design of Confined Masonry Structure, 1994.

Overseas, there are some well-known text books for earthquake resistant design of masonry buildings. For example, one is "Earthquake-Resistant Design of Masonry Buildings[19]" by Miha Tomazevic (Slovakia), 1999, shown in Fig.11. The other is "Seismic Design of Reinforced Concrete and Masonry Buildings[20]" by Tom Paulay (New Zealand) and M.J.N. Priestley (USA), 1992, shown in Fig.12. They established that some structural calculation formulas for masonry structures. Although these studies target the masonry structures in Europe or America, they do not target the non-engineered construction in developing countries.

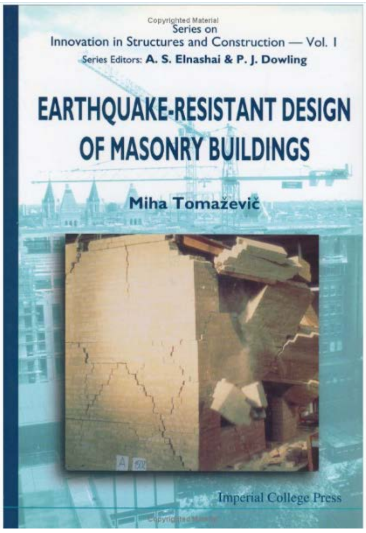


Fig.11 Earthquake-resistant design of masonry buildings[19]

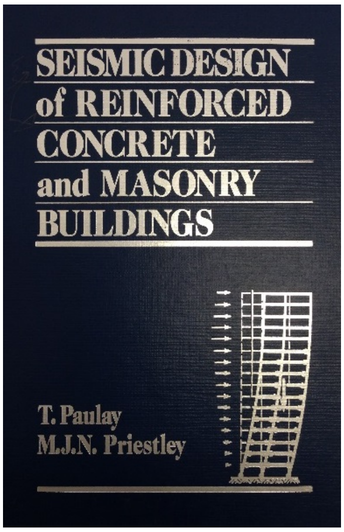


Fig.12 Seismic design of reinforced concrete and masonry buildings[20]

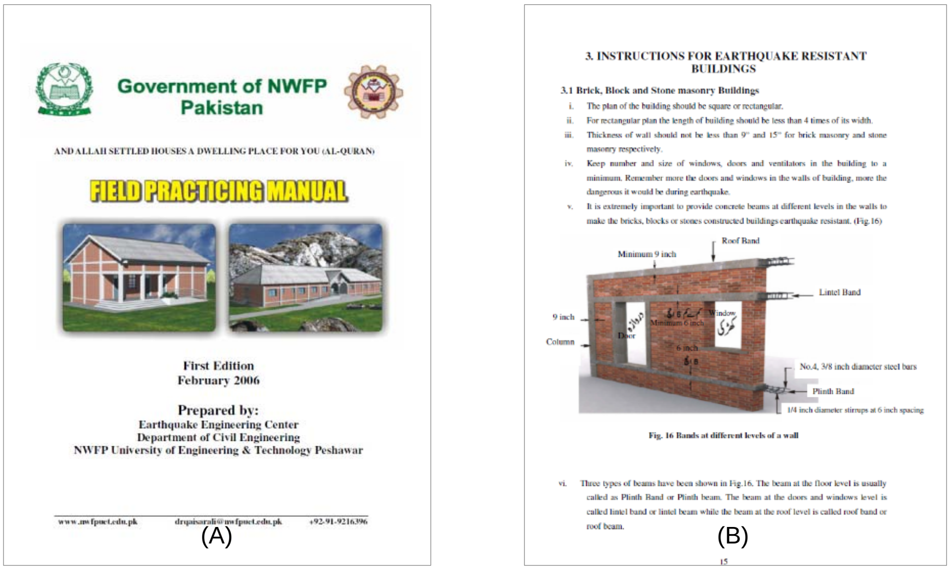
Regarding retrofitting methods, the "Guidelines for Earthquake Resistant Non-Engineered Construction"[1] introduced general techniques of repair, restoration and strengthening of buildings, but its description is not in detail.

[19] Miha Tomozevic, Earthquake-Resistant Design of Masonry Buildings, 1999.
[20] Tom Paulay, M.J.N.Priestley, Seismic Design of Reinforced Concrete and Masonry Buildings, 1992.

In the last few years, considerable research on retrofitting of masonry structures had been carried out in some countries.

After the 2005 Kashmir earthquake, Qaisar Ali in the University of Engineering & Technology, Peshawar, Pakistan studied and adapted steel mesh on masonry wall for avoiding collapse in Pakistan[21,22]. This proposal was focused mostly on the strengthening of non-structural masonry wall, shown in Fig.13.

Since the author had some projects with Qaisar Ali Pakistan in 2006, the author's research on retrofitting method for masonry structure in developing counties was started.



Government of NWFP
Pakistan

AND ALLAH SETTLED HOUSES A DWELLING PLACE FOR YOU (AL-QURAN)

FIELD PRACTICING MANUAL

First Edition
February 2006

Prepared by:
Earthquake Engineering Center
Department of Civil Engineering
NWFP University of Engineering & Technology Peshawar

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(A)

3. INSTRUCTIONS FOR EARTHQUAKE RESISTANT BUILDINGS

3.1 Brick, Block and Stone masonry Buildings

i. The plan of the building should be square or rectangular.
ii. For rectangular plan the length of building should be less than 4 times of its width.
iii. Thickness of wall should not be less than 9" and 15" for brick masonry and stone masonry respectively.
iv. Keep number and size of windows, doors and ventilators in the building to a minimum. Remember more the doors and windows in the walls of building, more the dangerous it would be during earthquake.
v. It is extremely important to provide concrete beams at different levels in the walls to make the bricks, blocks or stones constructed buildings earthquake resistant. (Fig.16)

Fig. 16 Bands at different levels of a wall

vi. Three types of beams have been shown in Fig.16. The beam at the floor level is usually called as Plinth Band or Plinth beam. The beam at the doors and windows level is called lintel band or lintel beam while the beam at the roof level is called roof band or roof beam.

(B)

15

Fig.13 Field practicing manual by University of Engineering & Technology Peshawar[22]

In South-East Asia, Teddy Boen is a pioneer in the study of earthquake-resistant design for non-engineered construction[23]. His activity is based on observations of past earthquake damages[24,25,26,27,28], surveys and computer analysis and design. He mentioned "Until now there are very few architects or engineers who pursue expertise and commit to learn non-engineered constructions because most of them will not receive adequate material rewards

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21 Qaisar Ali, et al., Seismic Behavior of Unreinforced and Confined Brick Masonry Walls before and after Ferro cement Overlay retrofitting, 2012
22 NWFP University of Engineering & Technology Peshawar, Field Practicing Manual, 2006.
23 Teddy Boen, Detailer's Manual for small Buildings in Seismic Areas, 1978.
24 Teddy Boen, Reconstruction of Houses in Aceh, Seven Months after the Earthquake & Tsunami, 2005.
25 Teddy Boen, Building A Safer Aceh, Reconstruction of Houses, One Year After The Dec. 26, 2004 Tsunami, 2006.
26 Teddy Boen, Yogya Earthquake 27 May 2006, Structural Damage Report, Jakarta, 2006.
27 Teddy Boen, Non-Engineered Buildings – Learn from Past Earthquake Damages. Yogyakarta, 2000.
28 Teddy Boen, Bengkulu & West Sumatra Earthquake September 12 2007, Structural Damage Report, Jakarta, 2007.

and must even make sacrifices. It can be seen from the amount of literatures that discusses the earthquake engineering problems for non-engineered constructions are only less than 5% of all literatures for different methods of construction, whereas, the victims caused by the collapse of these non-engineered buildings will be account to more than 60%"[29]. Recently, Boen introduced a retrofitting method for non-engineered construction which uses ferrocement with wire mesh as strengthening layers and uses sandwich construction analogy[30,31]. These retrofitting method uses ferrocement skin layers on walls as bandaging or jacketing. The author has been worked closely with Teddy Boen for a safer of non-engineered construction through sharing, exchange of information and discussion of experiments and field trainings since 2002. (See Fig.14, Fig.15)

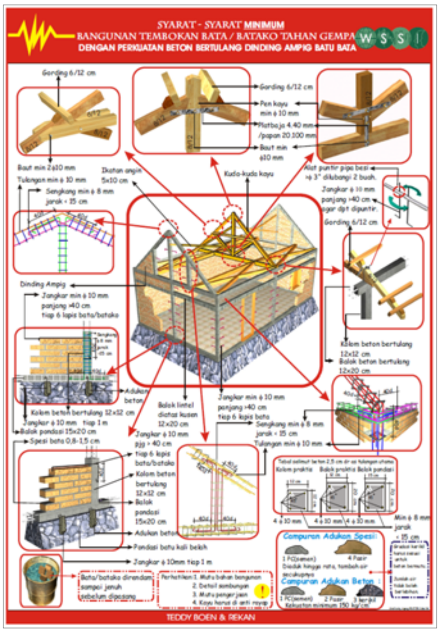

Fig.14 Poster Minimum Requirement for Earthquake Resistant Masonry Building by Teddy Boen, 2005

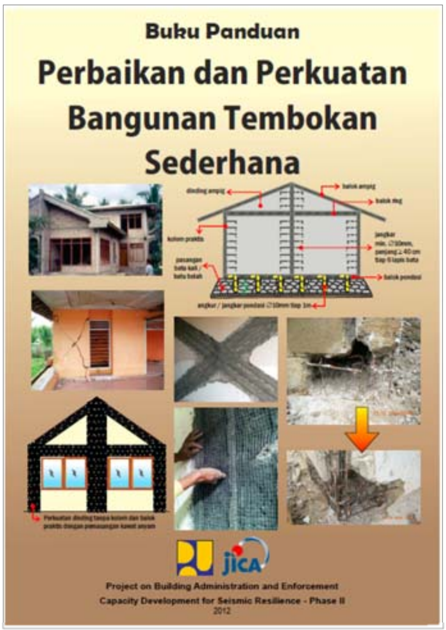

Fig.15 Guidelines for Retrofitting Simple Buildings in Indonesia, 2012[30]

[29] Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, The University of Kyoto, Ph.D. thesis, 2014, p34
[30] Teddy Boen et al., Buku Panduan Perbaikan dan Perkuatan Bangunan Tembokan Sederhana, published by JICA, 2012
[31] Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, The University of Kyoto, Ph.D. thesis, 2014

In other countries, some studies on retrofitting can be found, Marcial Blondet et al, Peru proposed external wire mesh and external polymer mesh called “Geogrid mesh” for strengthening adobe structure[32]. Daniel Torrealca performed static and dynamic simulation test carried out at Catholic University of Peru[33,34]. (See Fig.16)

(A) Geogrid mesh

(B) Construction model

Fig.16 Geogrid mesh for adobe structure in Peru

In Japan, Kimiro Meguro et al, proposes using poly propylene band (PP-band) for strengthening method for in developing countries[35,36]. In this method, masonry walls are wrapped by PP-band meshes on both sides as jacketing and the meshes are connected by PP-strings or wires and embedded in cement or mud mortar overlay, shown in Fig.17.

(A) PP-band mesh

(B) Construction model in Pakistan

Fig.17 PP-band mesh retrofitting by K.Meguro

32 Marcial Blondet et al., Seismic Protection of Earthquake Buildings, Conferencia Internacional en Ingenieria Sismica, 2007,

33 Daniel Torrealva, Seismic Design Criteria for Adobe Building Reinforced with Geogrids, 15WCEE, 2012.

34 D.Torrealva et al., Shear and Out of Plane Bending Strength of Adobe Walls Externally Reinforced with Polypropylene Grids, 14WCEE, 2008.

35 K. Meguro et al. A Step towards the Formulation of a Simple Method to Design PP-Band Mesh Retrofitting for Adobe/Masonry Houses, 2008.

36 K. Meguro et al. Development of Promotion Systems for PP-Band Retrofitting of Non-Engineered Masonry Houses, 15WCEE, 2012

All above mentioned past studies for strengthening masonry structures, have the same target in common.

In general, the failure mechanism of a masonry structure is very brittle fracture during earthquakes. In order to save people's lives against earthquakes, it is critical to increase the ductility of brick masonry structure. Therefore, this strengthening method for masonry building expect effectiveness for avoiding the possibility of brittle failure mode by adding mesh as tension reinforcement, and also strengthen the bond for proper connection between its resisting elements, so that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them.

Several studies by Kenji Okazaki have reported that earthquake risk perception in developing countries is included in disaster education and policy making. These are corroborated by researchers in each countries, such as Indonesia, Nepal, Pakistan, Turkey, Philippines, and Fiji. The strategy on dissemination of disaster mitigation were suggested through questionnaire survey.[37, 38]

Tatsuo Narafu as a leader, conducted collaborative research and development project[39,40] for disaster mitigation on network of research institutes in Asia, 2006-2008. Figure 18 shows outline of collaborative R&D project for disaster mitigation on network of research Institutes.

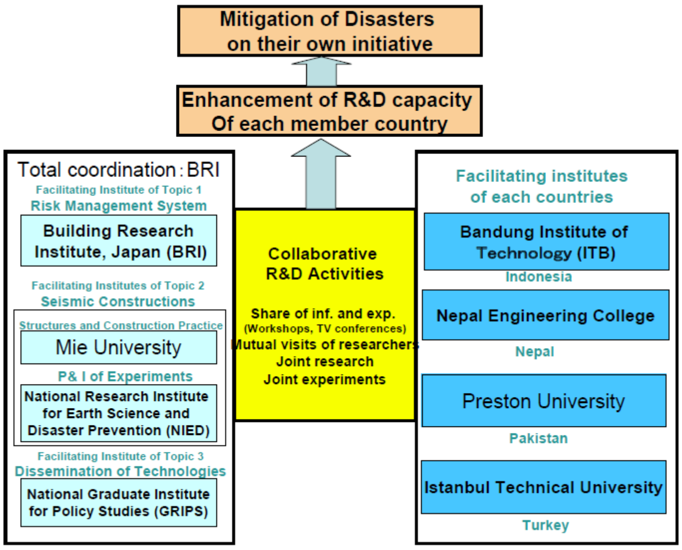

Fig.18 Outline of collaborative R&D project for disaster mitigation on network of research Institute

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[37] Kenji Okazaki et al., Earthquake Risk Perception and Policy Making, ERRA, Islamabad, 2010.
[38] Kenji Okazaki et al., New Strategy for Earthquake Risk Management, Keynote Paper, K5, First European Conference on Earthquake Engineering and Seismology, 2006.
[39] Tatsuo Narafu et al., Collaborate Research and Development for Safer Housing against Earthquakes, APRU/AEARU Research Symposium, 2007.
[40] Tatsuo Narafu et al., Basic Study for Bridge between Engineering and Construction practice of Non-Engineered houses. 14 WCEE, 2008.

There were three research topics as risk management system, feasible and affordable seismic constructions, and strategies for dissemination of technologies to communities. The author jointed this project as a special researcher. The project was a comprehensive approach to earthquake risk reduction, and due to this project, a network of researchers from developing countries was developed, which is very important.

From the viewpoint of practical activity in the field, Amod Mani Dixit and staffs from NSET (National Society for Earthquake Technology) in Nepal are challenging themselves vigorously for safer housing construction in Nepal and South Asia[41,42]. The demonstration using small scale shaking table was one of the practical methods for awareness delivered to the people, shown in Fig.19. NSET is try to change the risk perception of people by showing images of safety of construction directly to people.

(A) in Pakistan (B) in Iran

Fig.19 Shaking table demonstration by NSET

41 Amod Mani Dixit, Promoting Safer Building Construction in Nepal, 13WCEE, 2013.
42 Amod Mani Dixit, NSET, Challenges of Building Code Implementation in Nepal, International Symposium 2008 on Earthquake Safe Housing, 2008.

1.4 Positioning of this study and contents

An earlier mentioned, each study have focused on masonry structure in developing countries. However, there seems to be little implementation on field and the strengthening of existing building had been less studied.

In seismic prone area in developing countries, many inadequate buildings exist and these are still being built. The development of a retrofitting method to be applicable to existing buildings is needed.

This study aims to accomplish the improvement of safety of non-engineered construction against earthquake, this study proposes affordable, affordable and feasible retrofitting methods for masonry construction in developing countries that is proven through lessons learned from experimental studies and field trainings.

Furthermore, the seismic evaluation tools for awareness were developed. Because, the connection between experiment and practice is the critical missing link as a gap for non-engineered construction. This study try to bridge the gap between experiment and practice for the dissemination of safety of non-engineered construction against earthquake.

The present thesis composes of five chapters as:

Chapter 1 introduces the present study. The background, purpose, research objectives, and past studies with literature survey were presented through observations from field experience.

Chapter 2 describes the investigation of the seismic performance of non-engineered construction of three typical methods of masonry structures as mentioned in Chapter 1. As the first step, it was necessary to find out the actual behavior during earthquake. Therefore, three series of shaking table tests of masonry construction were carried out to understand the actual behavior until the tested structure collapsed.

Chapter 3 presents the retrofitting method that is proposed for non-engineered construction. The proposed retrofitting methods for non-engineered construction in developing countries take into consideration affordability, feasibility and adaptability for existing situations. The retrofitting method use wire mesh which is available in local market in these area. Furthermore, the retrofitting method was developed using feasible techniques which is possible to construct without the specific techniques.

Chapter 4 discusses about the challenges for dissemination of earthquake safety construction to the people. It is necessary to make a bridge between engineering and actual field conditions and situations. Workshops and seminars were held in Indonesia after the devastating earthquakes. Moreover, for raising awareness on disaster mitigation, two practical tools for vulnerability and safety evaluation for non-engineered houses were developed in the Philippines.

Chapter 5 concludes the present study, explaining the approach to improve earthquake safer construction in developing countries that have similar masonry construction.

Figure 20 shows action-task of contents of each chapter of the dissertation on the disaster management circle.

The flow and relations of each chapter is shown in Fig.21.

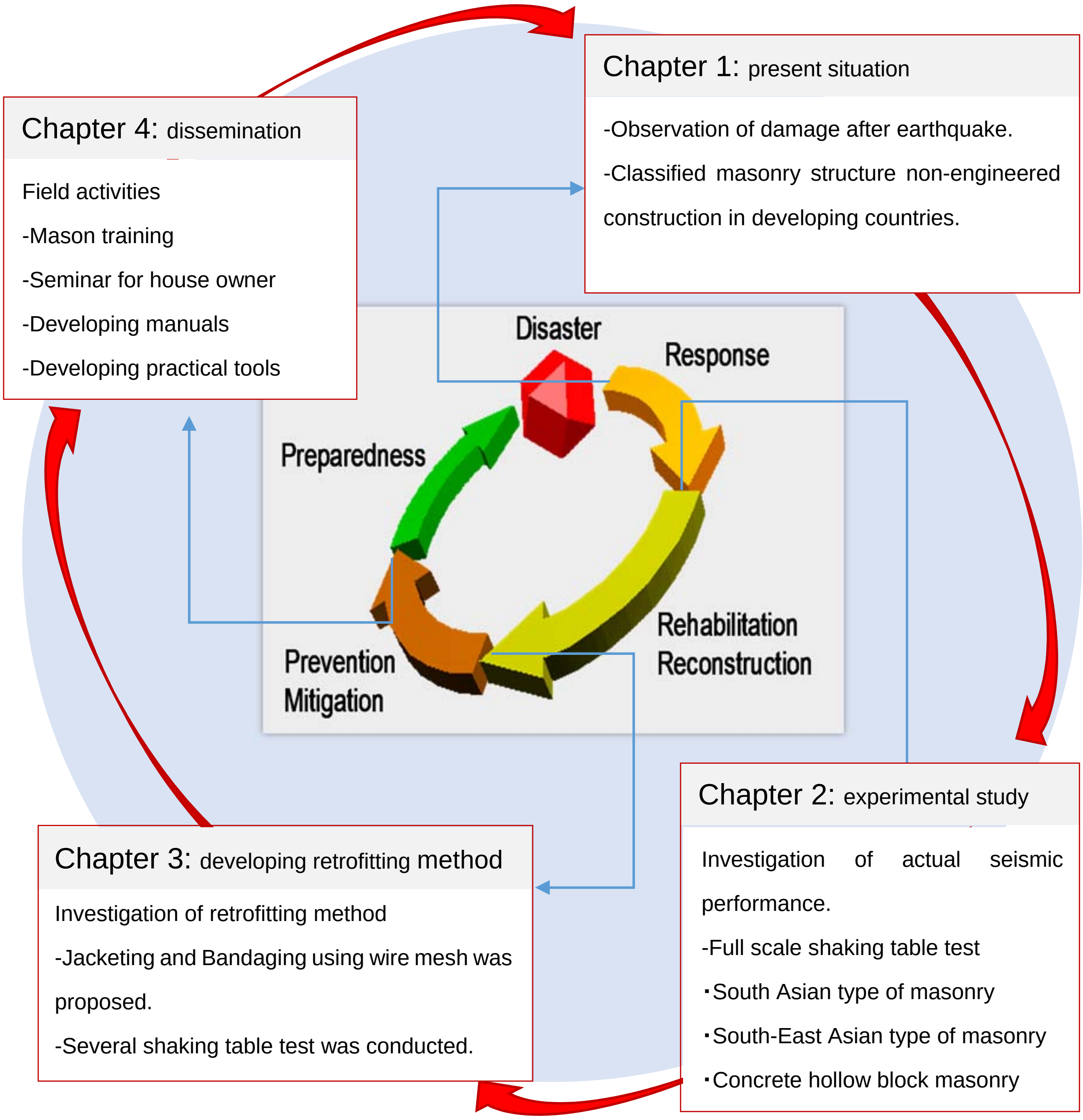


Fig.20 Action-task of contents on disaster management circle

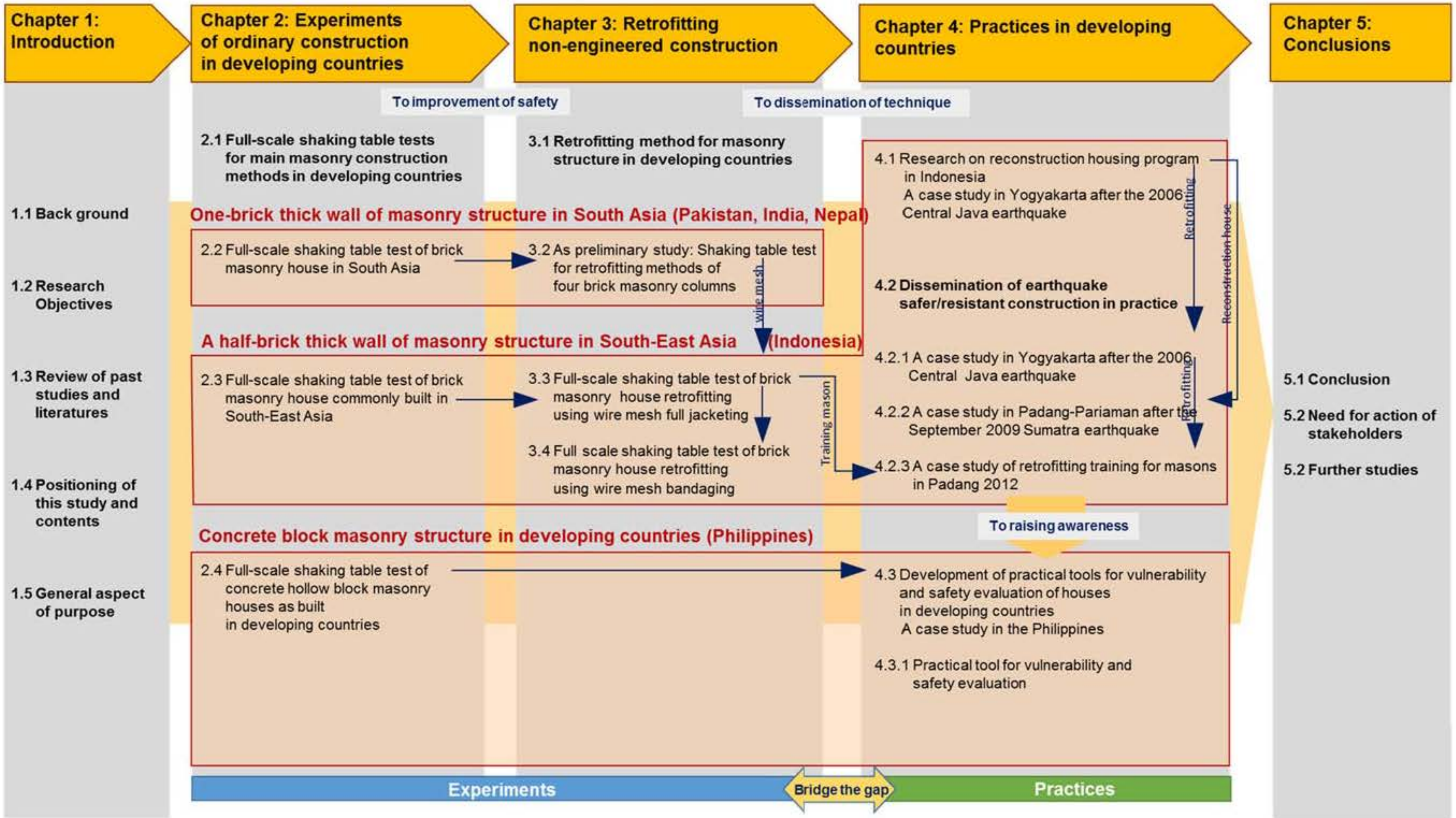


Fig.21 Each chapter of relations and flows

1.5 General aspect of purpose

In the task of the improvement of safety of non-engineered construction as disaster risk reduction, this study proposed retrofitting methods for non-engineered construction and the practical tools for vulnerability and safety evaluation for non-engineered houses as awareness in developing countries, these were proven through lessons learned from experimental studies and field trainings.

For earthquake safer construction, all individual buildings need to be designed for earthquake resistance. However, in developing countries, it is not realistic to design structurally all buildings because of financial problems, lack of engineer and trained construction worker for earthquake resistant design. Furthermore, existing non-engineered buildings are mostly not followed building code as noncompliant building.

A) Retrofitting method for non-engineered construction

In general, brick masonry construction is vulnerable of brittle fracture behavior when shaken by earthquakes. In order to save peoples' lives against earthquake, the ductility of brick masonry construction should be improved. Therefore, the retrofitting method for masonry construction should be aimed to avoid the possibility of a brittle failure mode, and strengthening of the unity of construction by providing proper connection between its resisting elements, in such a way that inertia forces generated by vibration of the building can be transmitted to the members that have the ability to resist them. Typical important aspects are the strengthening of the connections between roofs or floors and walls, and between walls and foundations.

The importance of the retrofitting method for non-engineered construction in developing countries should be evaluated according to the following:

1) Affordability (Economic aspects)

   To ensure the retrofitting method is capable of providing enough strength improvement at low cost in the society.

   It is needless to say that regards to financial matters, the house owners of non-engineered houses are normally low to middle income people. Therefore, economical aspects is most important. To try to make low cost, the ordinary available material in local market of these area should be used, and construction should be done without the specific techniques of using special tools. (See Fig.22 and 23)

In the developing countries, the construction cost tends to be higher in the ratio of material cost than labor cost. Therefore, the material selection is one of key for dissemination of retrofitting methods.

Fig.22 Construction materials and equipments in local market

Fig.23 Ordinary tools of local construction worker

2) Feasibility (Technical aspects)

To ensure the retrofitting method may be easily applied using ordinary materials and tools as well as local worker's skill.

Non-engineered construction are usually constructed by local masons, petty contractors or residents/house owners who are not formally trained in construction work. (See Fig.24 and 25) The approach should be concerned that retrofitting is also conducted by unskilled worker.

In order to do that retrofitting method should be simplified which is possible of being done without the specific techniques used in conducting particular construction. The techniques of retrofitting method should be possible to acquire through a few days training or explanation of textbooks. In other words, the proper information is indeed one of important point of retrofitting, because it is easily applied using ordinary construction techniques.

Fig.24 Non-engineered construction in Indonesia

Fig.25 Non-engineered construction in Philippines

3) Adaptability (Developmental or Flexible aspects)

To ensure the retrofitting method may be applied range as wide as the building type diverse in the society.

Non-engineered construction are mostly constructed by informal process without drawings or professionals. The meaning of it is an infinite diversity of existing situations. Therefore, retrofitting method should correspond to a variety of construction methods, shape of buildings and deterioration levels. (See Fig.26 and 27)

Fig.26 A variety of materials used

Fig.27 A variety of shapes and deterioration levels

B) Seismic evaluation tool for non-engineered construction

In the task of the dissemination of safety of non-engineered construction, it is necessary to acquire the state of the raising awareness is the first step.

The educational seminars regarding safer construction for residents/house owners (See Fig.28 (A)) and vocational training for masons (See Fig.28 (B)) were conducted. Through these seminars and trainings, their needs of current situation and their problems were assessed.

(A)

(B)

Fig.28 Seminar for residents/house owners and vocational training for masons

It is not only with masons, but it is also needed to raise the awareness of residents/house owners needed for earthquake safer construction. To promote of safety of non-engineered construction, the residents/house owners must understand the vulnerability of their own houses, and must take necessary actions as their responsibility, with the technical advice from the professionals.

To further assist the residents/house owners, we developed a simple seismic evaluation method as an awareness raising tool for non-engineered construction. These seismic evaluation tools provide much importance to bridging residents/house owners and engineers to communicate, because it is critical missing link for non-engineered construction.

As outcome, these developing retrofitting methods of non-engineered construction and seismic evaluation tools for residents is meant for bridging the gap between experiments and practices.

Chapter 2 Experiments of ordinary construction in developing countries

Chapter 2 Experiments of ordinary construction in developing countries

2.1 Full-scale shaking table tests for main masonry construction methods in developing countries

As mentioned in Chapter 1, two types of masonry construction, brick masonry and concrete hollow block masonry as non-engineered construction have recently become common structures in earthquake prone areas in developing countries. Several reports on investigations and observations on damaged buildings and remaining debris after earthquakes have concluded that devastating damages were caused by the vulnerability of such types of construction.

As the first step in disaster mitigation, it is the most important to record actual behavior of buildings during earthquakes and to investigate their seismic performance.

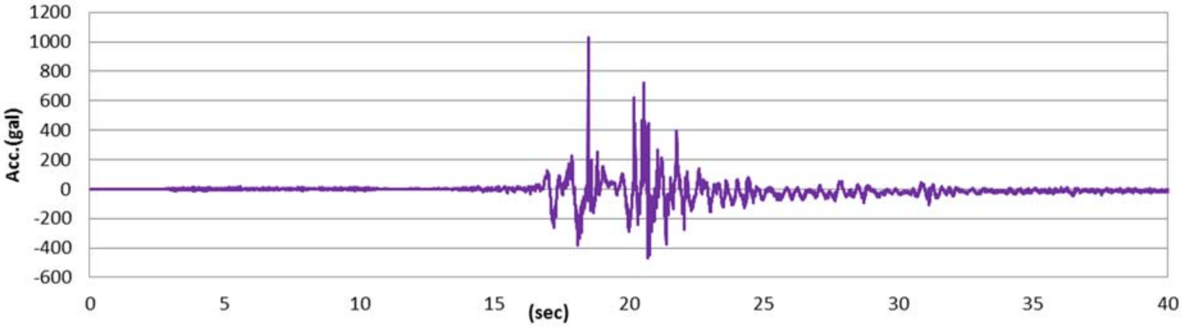
For these purposes, three shaking table tests of masonry construction were carried out to understand the actual behaviors until collapse, as well as, to verify the analysis methods to evaluate the seismic performance. Table 2 shows the list of shaking table test and detail of three models. Following are matters that are common to each shaking table test.

1) **Venue**: All tests were conducted at National Research Institute of Earth Science and Disaster Prevention (NIED), Tsukuba. NIED has two shaking tables. One is E-Defense which is the biggest shaking table in the world, completed in 2005. The other in Tsukuba is a one-direction horizontal with displacement ± 22 cm (44 cm of stroke), velocity 100 cm/s and excitation force of 3.6 MN. Test weight capacity is 500 tons, and the table dimension is 14.5 m by 15.0 m.
2) **Input motions**: Input motions used were based on JMA Kobe NS which was recorded at the JMA (Japan Meteorological Agency) Kobe observatory in the Great Hanshin Earthquake of 1995; this wave is referred to as JMA Kobe NS. Also the input motions recorded recently in the world were used. For example, Iran suffered heavy damage during the magnitude 6.7 Bam Earthquake that occurred on 26th December 2003 in Bam city. The Iranian government Building and Housing Research Center (BHRC) in Bam city recorded strong movements. Ground motions of the ICA Peru Earthquake 2007 were also used for the shaking table tests. Figures 29 and 31 show the comparison of each of the input motion.
3) **Measurement systems**: Accelerometers that are servo acceleration sensors were installed. Displacements were measured by 3D image processing, shown in Fig.31. And after each input, the distribution and size of cracks on the model were sketched.

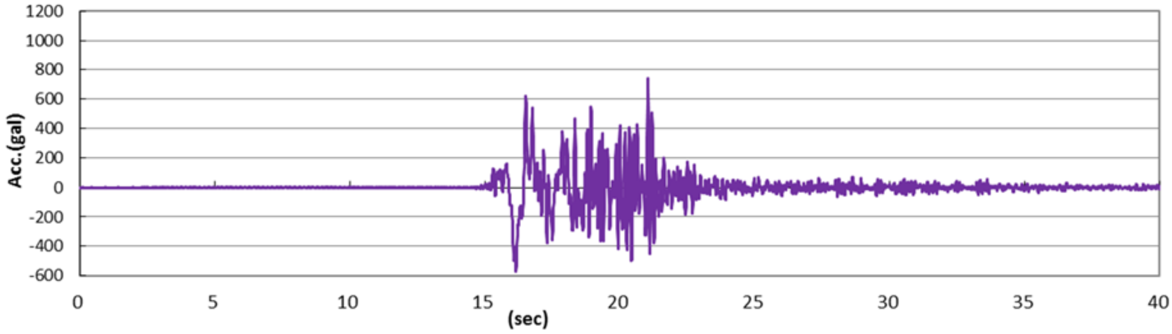
Table 2 List of shaking table test and detail of the models

Classification		South Asian type of masonry construction	South-East Asian type of masonry construction	Concrete hollow block masonry construction	
				Model A	Model B
Characteristics		One-brick thick wall	Half-brick-thick wall +RC frame	Full filling mortar into the hollow	
Size of specimens (WxDxH), (mm)		2650 x 2650 x 3165	2680 x 2680 x 3270	3700 (3750) x 3700 (3750) x 2900+gable wall	
Structure	Material	Brick from Pakistan	Brick from Pakistan for three walls and Japanese brick for one wall	Block from Philippines	
	Size of brick or block (W x D x H), (mm)	230 x 110 x 70	230 x 110 x 70 (Pakistani brick) 210 x 100 x 60 (Japanese brick)	400 x 100 x 200	400 x 150 x 200
	Wall thickness	230mm (length of face)	100mm (length of end)	100mm (4inch)	150mm (6inch)
	Reinforcement	none	RC column and beam	Reinforcement in the wall	
				6mm (Plane Bar)	10mm (Deform bar)
	Mortar				
	Cement:Sand (by volume)	1 : 8	1 : 10	1 : 4	
	Water:cement (by volume)	-	-	1.2 : 1.0	
	W/C ratio*1 (by weight)	88%	171%	80%	
	Soaking brick	done (min 30min)	none	none	none
	others	-	-	not compacted	compacted
	Gable wall	none	none	Gable wall: height is 1200mm	
	Roof	Flat roof by corrugated sheet with Wooden beam	none	Slope roof by corrugated sheet with wooden frame	
Specimen					
Curing period		21days	15days	24days	
Date of test		26-27 Dec, 2007	1-4 July, 2008	23-24 Feb, 2011	
Related project		Collaborative R & D project for disaster mitigation on network of research institute in Asia, 2006-2008	Collaboration project of NIED and Mie university in cooperation with BRI and Mitsuishi Fire Brick Co.Ltd	JST-JICA Enhancement of earthquake and volcano monitoring and effective utilization of disaster mitigation information in the Philippines, 2010-2014	
Author's position		Member, Design, Supervising Construction	Member, Design, Supervising Construction	Management, Design, Supervising Construction	

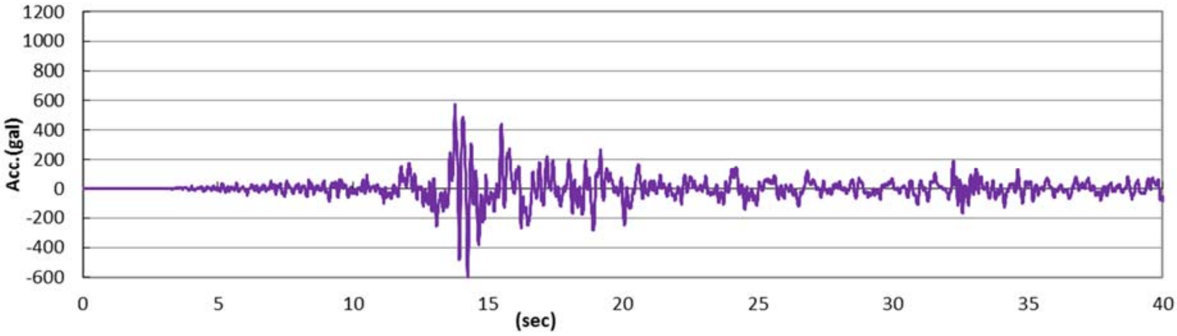
*1: Calcurated by using a bulk specific gravity of cement is 1.5.



(A) JMA Kobe NS, Japan

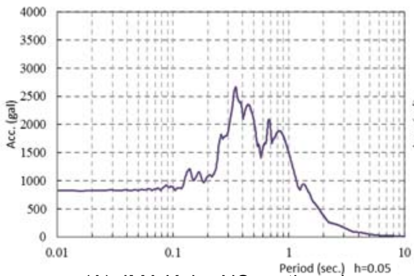


(B) Bam EW wave, Iran

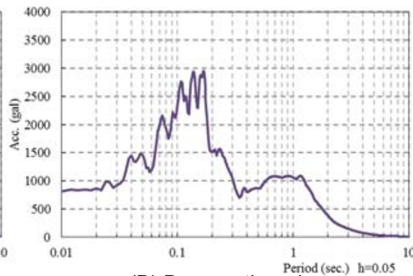


(C) ICA wave, Peru

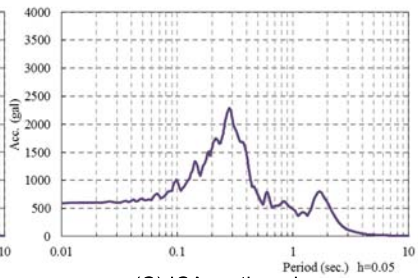
Fig.29 Input motion of main waves



(A) JMA Kobe NS earthquake



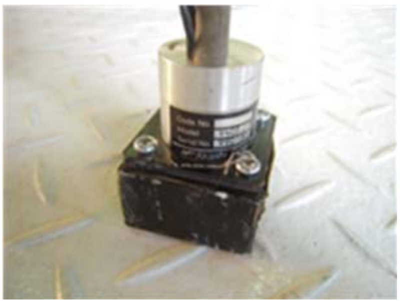
(B) Bam earthquake



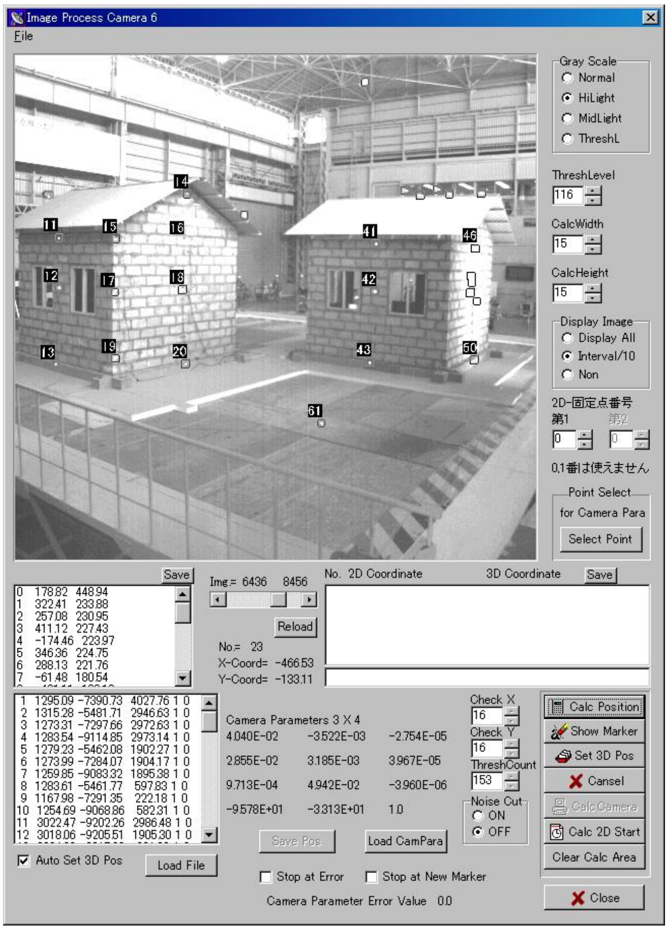
(C) ICA earthquake

Fig.30 Acceleration response spectra of main inputs[43]

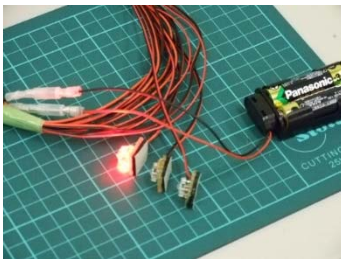
[43] T.Nakagawa, Collapse behavior of a brick masonry house using a shaking table and numerical simulation based on the extended distinct meshod, Bull Earthquake Eng(2012), 2012, p269-283



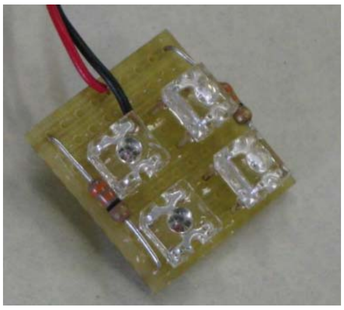
(A) Servo type acceleration sensors



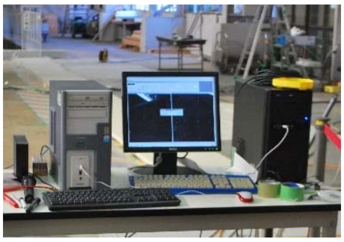
(B-1) Monitor screen on PC



(B-2) LED system



(B-3) Detail of LED



(B-4) Work station of 3D image

(B) 3D image processing

Fig.31 Measurement systems

2.2 Full-scale shaking table test of brick masonry house in South Asia

2.2.1 Outline of specimen

At first, shaking table test of South Asian type of brick masonry house was conducted for investigation of seismic performance, under Project of "Collaborative Research and Development Project for Disaster Mitigation on Network of Research Institute in Asia, 2006-2008" by BRI, NIED, GRIPS, Mie University and research institute of collaborating countries[44].

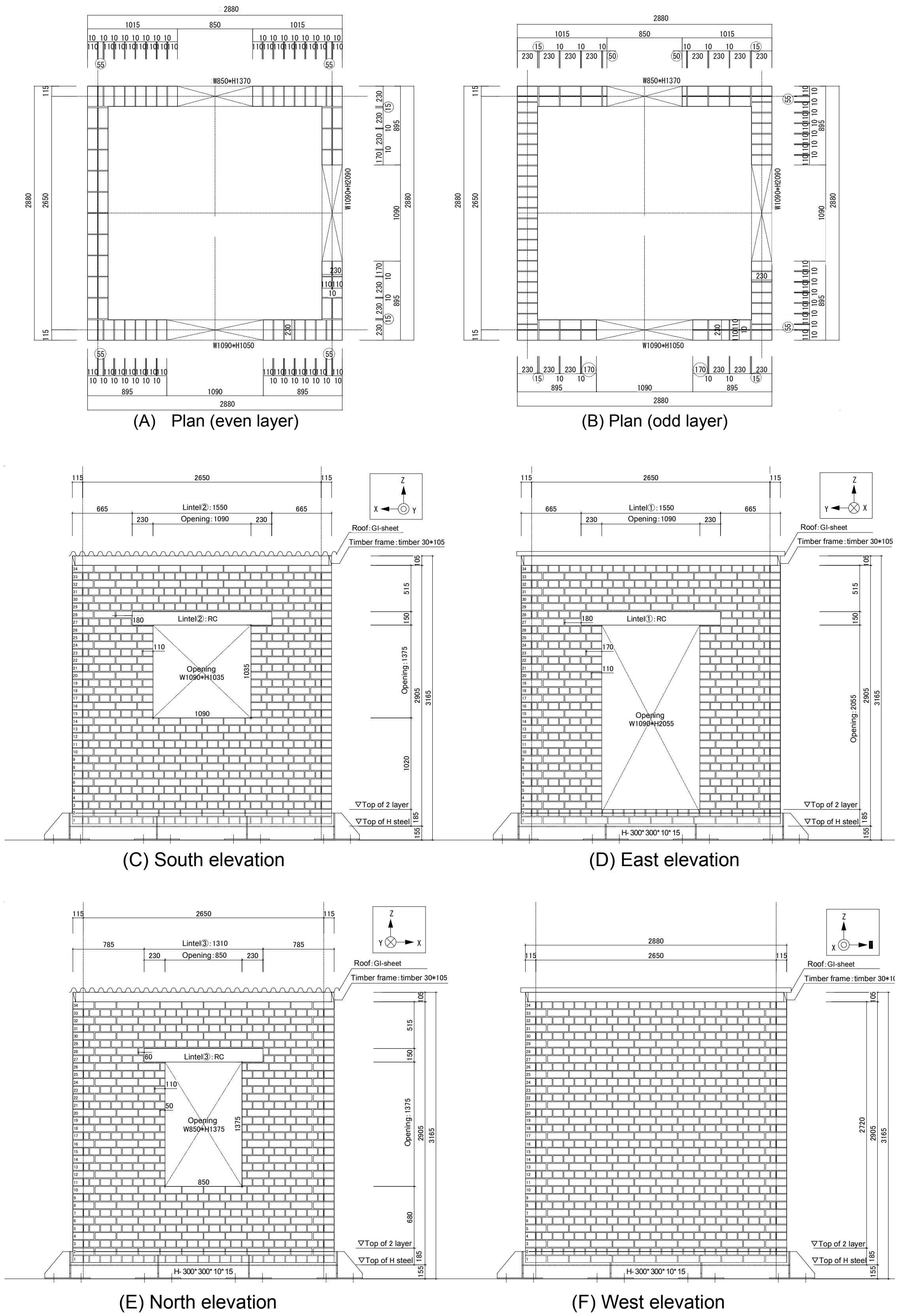
The model was designed through discussion with Dr. Qaisar Ali of the University of Engineering & Technology, Peshawar, Pakistan. The model was laid by British-bond that is common in Pakistan, and the wall thickness is 230 mm and is called "One-brick-thick wall", shown in Fig.32.

The bricks were imported from Pakistan, near Peshawar. These bricks are commonly used to construct houses in Pakistan. The strength of mortar, and the method of laying the bricks were done following the common practice for non-engineered construction in Pakistan.

The overall dimensions of the model are 2650 mm x 2650 mm in plan and 3165 mm in height without a gable wall. Figure 33 shows drawings of model structure.

Fig.32 Model on the shaking table

[44] Tatsuo Narafu et al., Collaborate Research and Development for Safer Housing against Earthquakes, APRU/AEARU Research Symposium, 2007.



(A) Plan (even layer)

(B) Plan (odd layer)

(C) South elevation

(D) East elevation

(E) North elevation

(F) West elevation

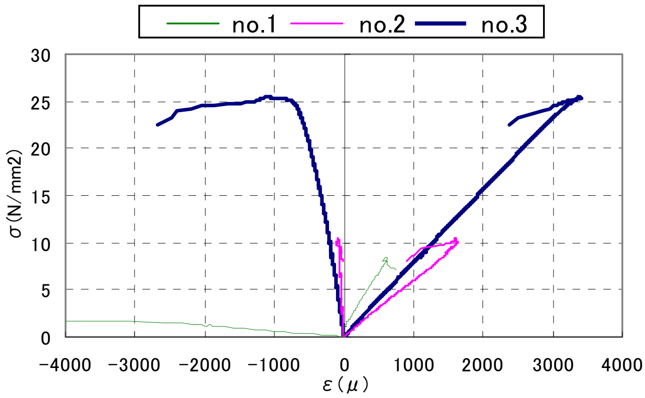
Fig.33 Plan and elevation of the model

2.2.2 Material properties

1) Brick

Figure 34 shows brick which were produced in Pakistan, near Peshawar. Size was 210 mm x 110 mm x 70 mm. The average compressive strength was 14.73 N/mm^2. The photo of the test and the stress-strain (σ-ε) curve are shown in Fig.35.

Fig.34 Pakistani brick



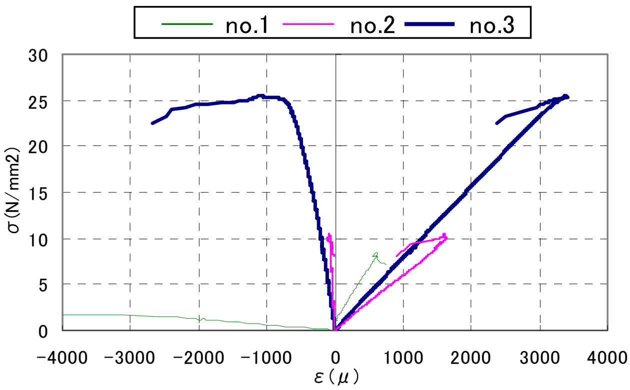
(A) σ − ε curve

(B) Specimen after test

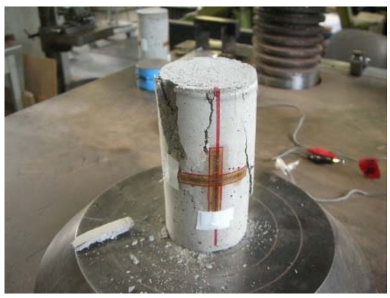
Fig.35 Properties of brick

2) Mortar

The ratio of cement and sand was 1 / 8 by volume and the water cement ratio was 88 % which followed the common practice in this area, discussed with Dr. Qaisar Ali. The average compressive strength was 9.96 N/mm^2. The photos of the test and the stress-strain (σ-ε) curve are shown in Fig.36.



(A) σ − ε curve



(B) Specimen after test

Fig.36 Properties of mortar

Table 3 List of input motions

Date	No.	Input wave(*1)	Time scale	Scale (%)	Displacement (± mm)	Acceleration (gal)	Velosity (Kine)	Time (Sec)	Recording Acc.	Recording 3D image	Recording video cam	situation of damage
26th Dec, 2007	1	Test	-	-	-	-	-	-	✔	-	-	none
	2	Zero	-	-	-	-	-	-	✔	-	-	none
	3	Step 01	-	-	1	-	-	60	✔	-	-	none
	4	Bam EW	0.79(*2)	5	9	42	5	100	✔	✔	✔	none
	5	failed	-	-	-	-	-	-	✔	-	-	none
	6	Sweep	-	-	-	-	-	-	✔	-	-	none
	7	failed	-	-	-	-	-	-	✔	-	-	none
	8	Step 02	-	-	1	-	-	60	✔	-	-	none
	9	Bam EW	0.79	10	18	70	10	100	✔	✔	✔	none
	10	Step 03	-	-	1	-	-	60	✔	-	-	none
	11	Bam EW	0.79	20	36	140	20	100	✔	✔	✔	none
	12	Step 04	-	-	1	-	-	60	✔	-	-	none
	13	Bam EW	0.79	5	54	300	30	100	✔	✔	✔	none
	14	Step 05	-	-	1	-	-	60	✔	-	-	none
	15	Bam EW	0.79	5	72	343	40	100	✔	✔	✔	none
	16	Step 06	-	-	1	-	-	60	✔	-	-	none
	17	Bam EW	0.79	5	90	370	50	100	✔	✔	✔	none
27th Dec, 2007	18	Step 07	-	-	1	-	-	-	✔	-	-	none
	19	Bam EW	0.79	5	135	560	75	100	✔	✔	✔	none
	20	Step 08	-	-	1	-	-	-	✔	-	-	none
	21	Bam EW	0.79	100	180	762	100	100	✔	✔	✔	none
	22	Step 09	-	-	1	-	-	-	✔	-	-	none
	23	JMA Kobe NS	1	110	200	1030	100	100	✔	✔	✔	none
	24	Step 10	-	-	1	-	-	-	✔	-	-	none
	25	sin 15Hz	-	-	4	1150	-	60	✔	✔	✔	none
	26	sin 1Hx	-	-	100	430	-	60	✔	✔	✔	none
	27	Pulse shock ±10mm	-	-	10	1730	-	40	✔	-	✔	Cracks occurred
	28	Zero	-	-	-	-	-	-	✔	-	-	-
	29	Cal	-	-	-	-	-	-	✔	-	-	-
	30	Bam EW	0.79	100	180	742	100	100	✔	✔	✔	Cracks increased
	31	JMA Kobe NS	1	110	200	1020	100	100	✔	✔	✔	Totally collapsed

*1. Input waves were based on Bam earthquake and Kobe earthquake. (F

*2. Bam EW earthquake was adjusted about time scale, because capacity of spec of shaking table.

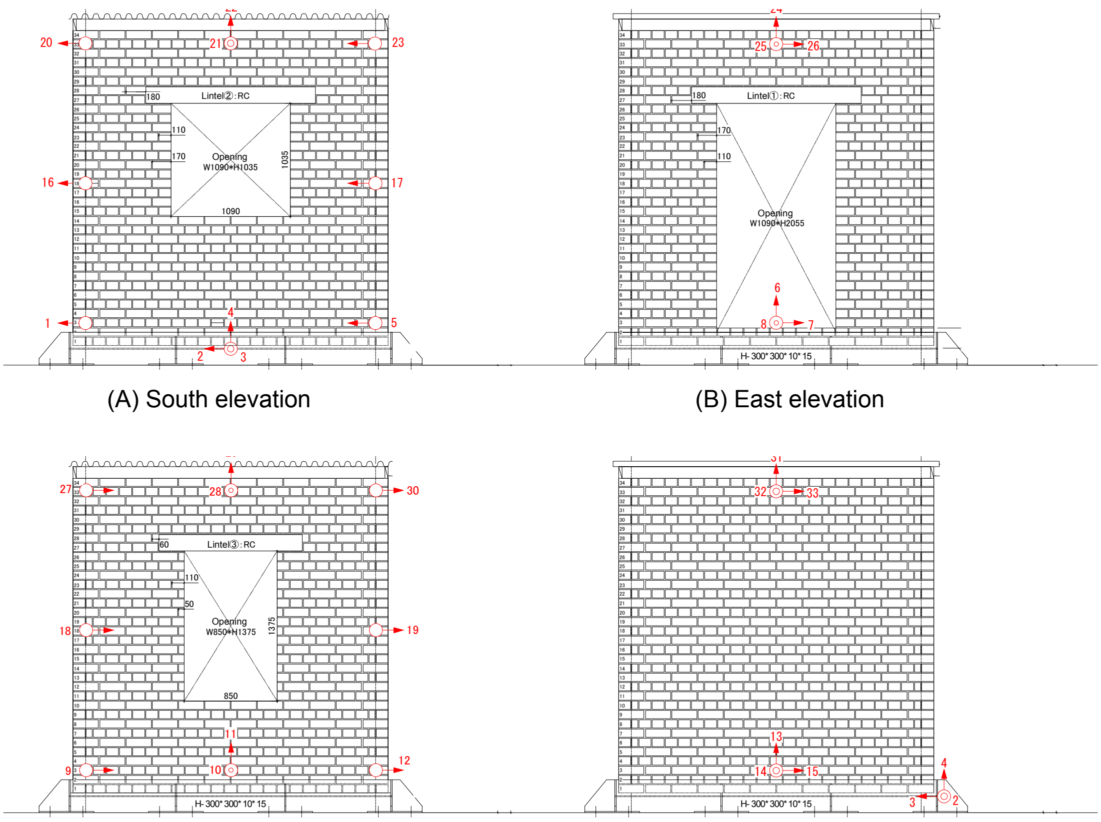
✔ Recording done

2.2.3 Input motions

Table 3 shows the schedule of excitation with input motions. These input motions were based on the 2003 Bam Earthquake (Bam EW) and 1995 Kobe Earthquake (JMA Kobe). For the Bam record in this test, it was necessary to modify the amplitude and the timescales of the shaking table inputs. In this case, the maximum Bam EW record displacement of 35 cm was changed to the maximum shaking table displacement of 22 cm. This displacement reduction led to a timescale reduction factor of 0.79 which was used in the test.

2.2.4 Measurement systems

Accelerometers were installed at 33 points on the specimen and on the shaking table. (See Fig.37) Shown in Fig.31, response displacement was measured by 3D image processing. LED makers as the point of measurement were installed at 53 points on the specimen and on the shaking table. (See Fig.38) And after each input, the cracks on the specimen were sketched for recording the progress of cracks development.



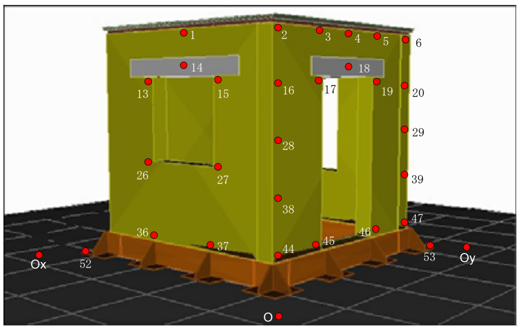
(A) South elevation

(B) East elevation

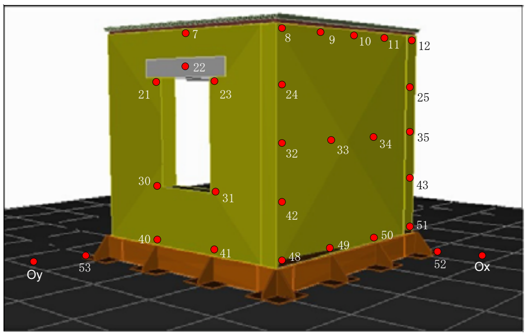
(C) North elevation

(D) West elevation

Fig.37 Location of accelerometers



(A) South-East view



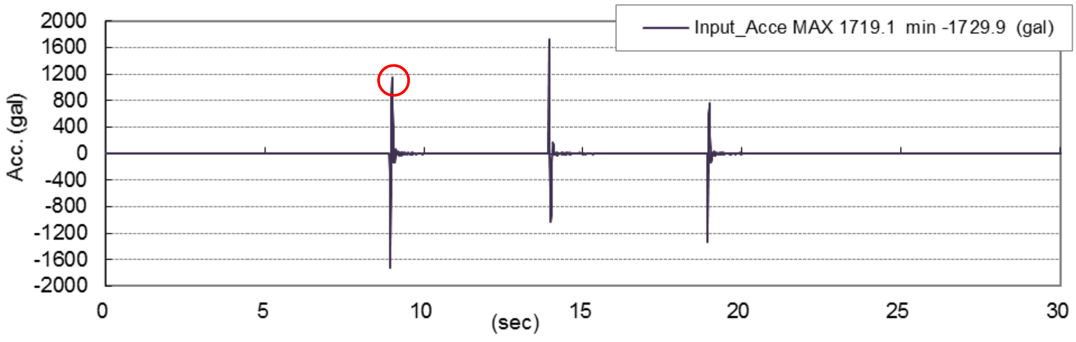
(B) North-West view

Fig.38 Location of LED markers for 3D measurement

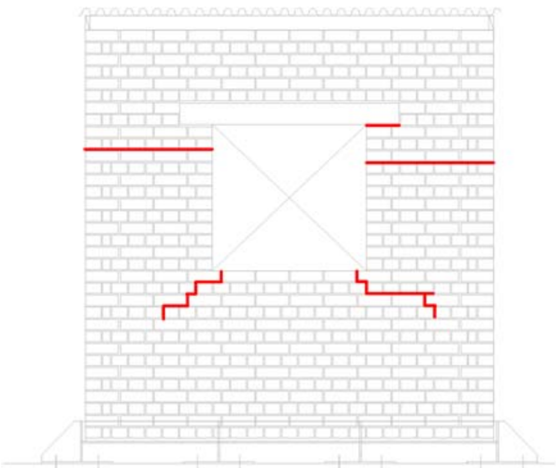
2.2.5 Observations of main inputs

First of all, in order to check the vibration characteristics of the model structure, a rectangular wave with 1mm amplitude was inputted.

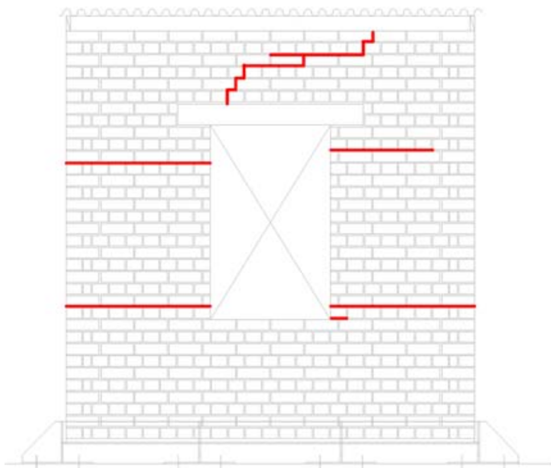
- **Up to input No.23:** The model was able to withstand the input Bam Earthquake (Input No.21) and Kobe Earthquake (Input No.23) with no cracks. Some points of reason why the house behaved accordingly for this earthquake inputs will be described at conclusion of this section. The results of the shaking table test are significant in investigating the behavior of the structure from the cracks of damaged as well as collapsed building.
- **Input No.27:** Strong pulse shock was inputted. The first pulse shock caused cracks from openings on the North and the South walls, shown in Fig.39. Horizontal cracks were found on the joint mortar and diagonal cracks at the openings. In the second pulse shock, minor cracks occurred on the East wall, shown in Fig.40.
- **Input No.30:** The existing cracks expanded and generated on each wall. The concrete lintel beams at the openings separated from the brick walls, shown in Fig.41.
- **Input No.31:** Finally, the model structure building having totally collapsed. The North and South walls were separated into some segments of walls, mainly four segments on both sides, upper part and bottom part by diagonal cracks, and the model was rocking during the beginning of shaking. The falling lintel beam led to the totally collapse of the building model, shown in Fig.42 and 43. It was caused by the loss of support due to large displacements. Figure 44 shows sequence of totally collapse during JMA Kobe NS.



(A) Input No.23: Pulse shock ±10 mm wave



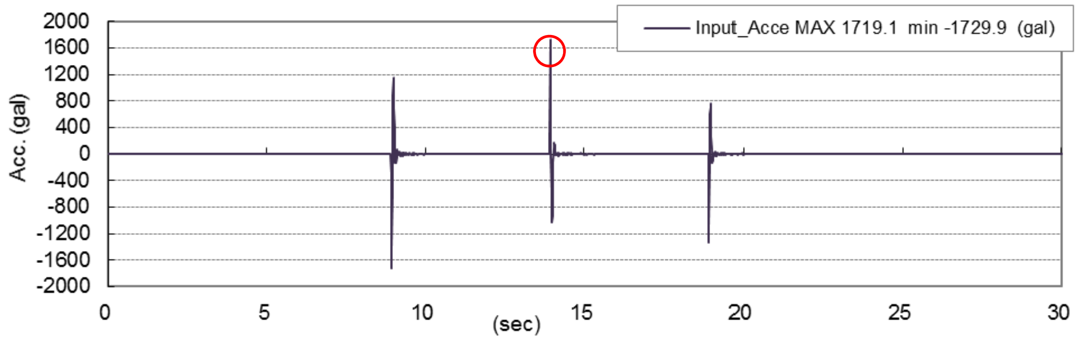
(B) South elevation



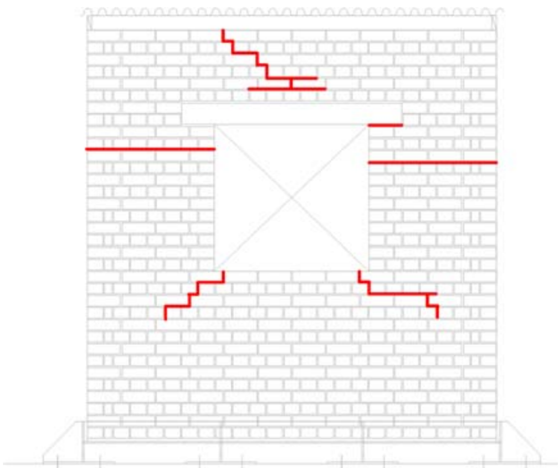
(C) North elevation

(D) East elevation

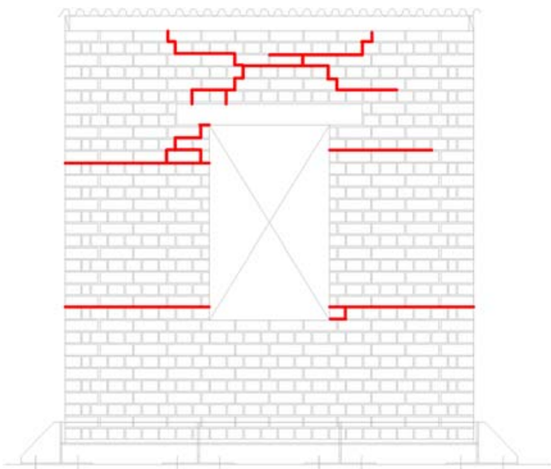
Fig.39 Crack pattern of Input No.23 (1st Pulse shock, red circle on (A))



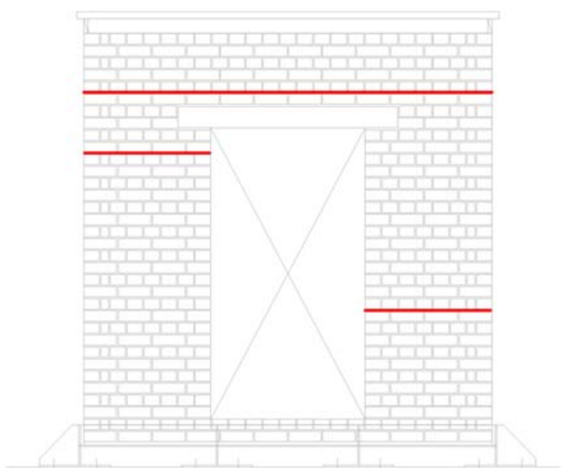
(A) Input No.23: Pulse shock ±10 mm



(B) South elevation

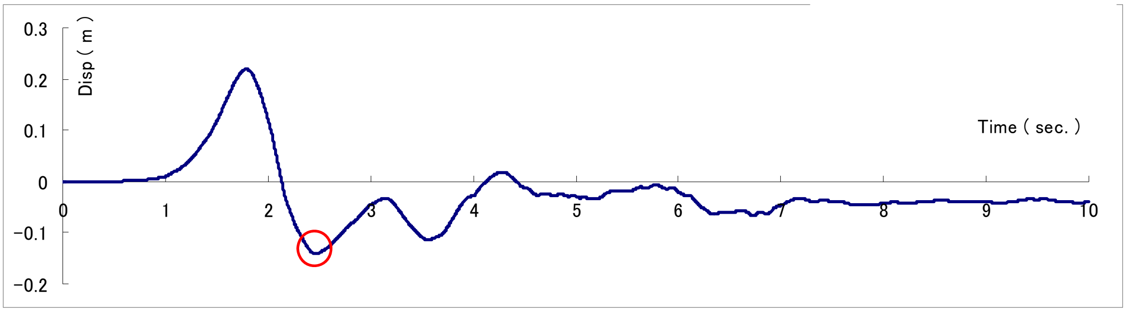


(C) North elevation

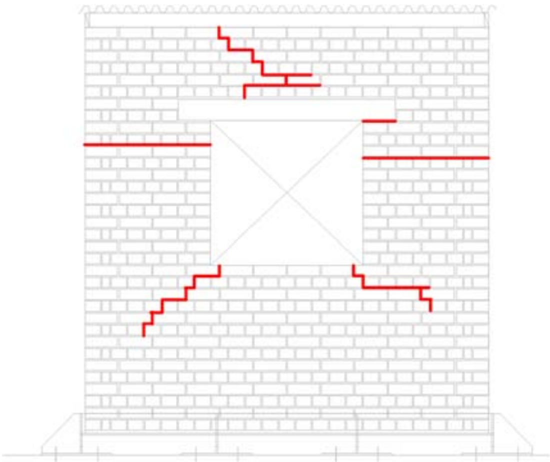


(D) East elevation

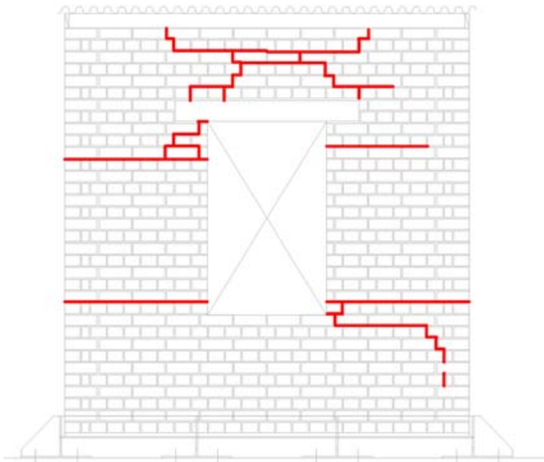
Fig.40 Crack pattern of Input No.23 (2nd Pulse shock, red circle on (A))



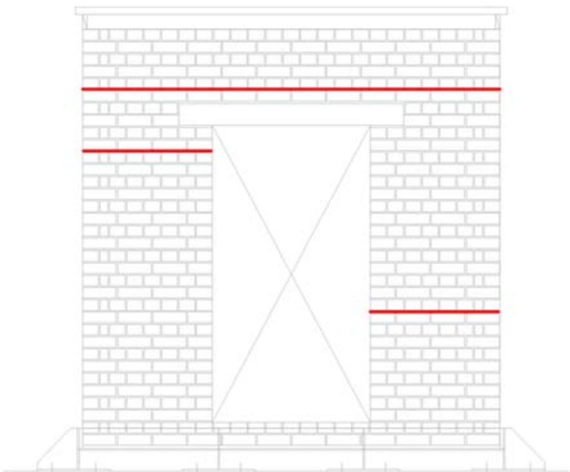
(A) Input No.30: Bam EW



(B) South elevation

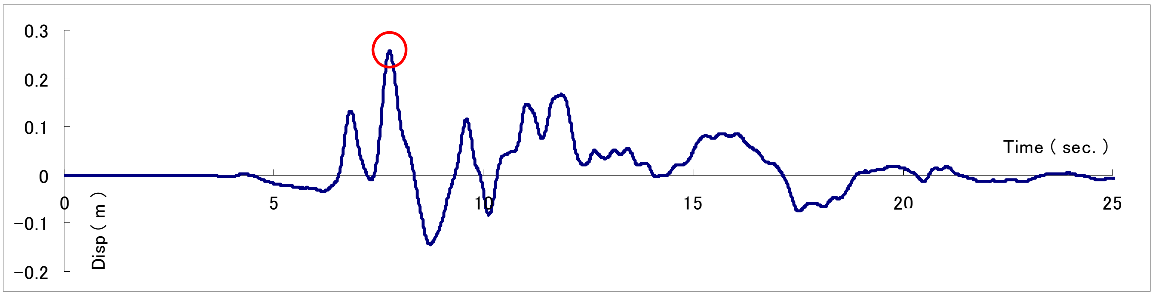


(C) North elevation

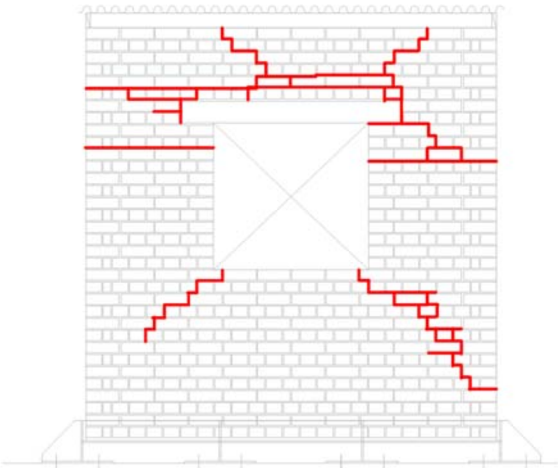


(D) East elevation

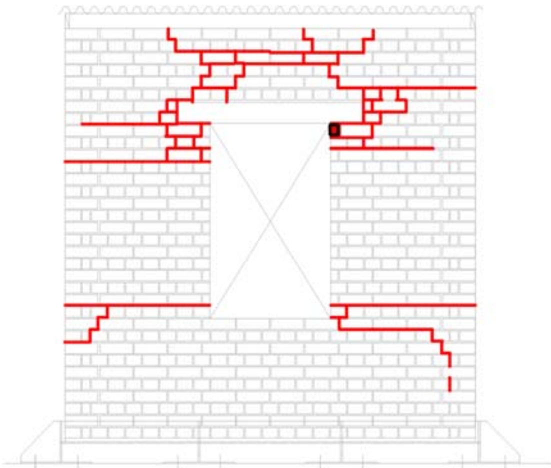
Fig.41 Crack pattern of Input No.30 (Red circle on (A))



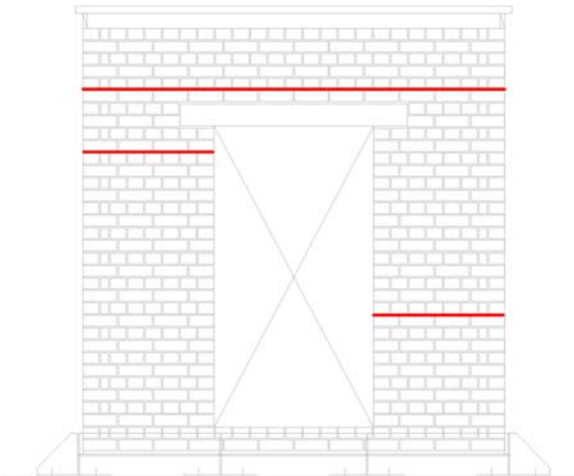
(A) Input No.31: JMA Kobe NS



(B) South elevation

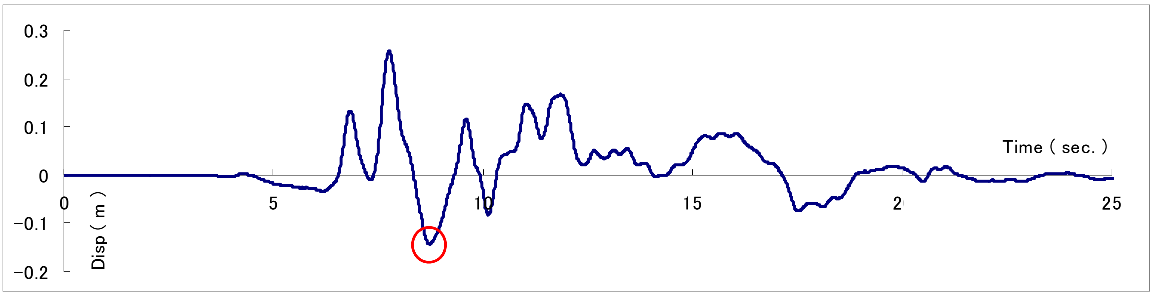


(C) North elevation

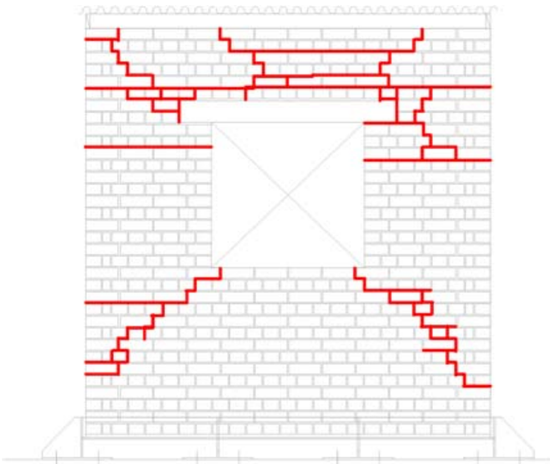


(D) East elevation

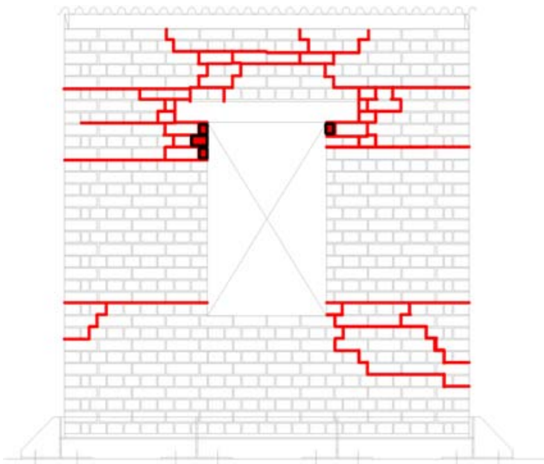
Fig.42 Crack pattern of Input No.31 (1) (Red circle on (A))



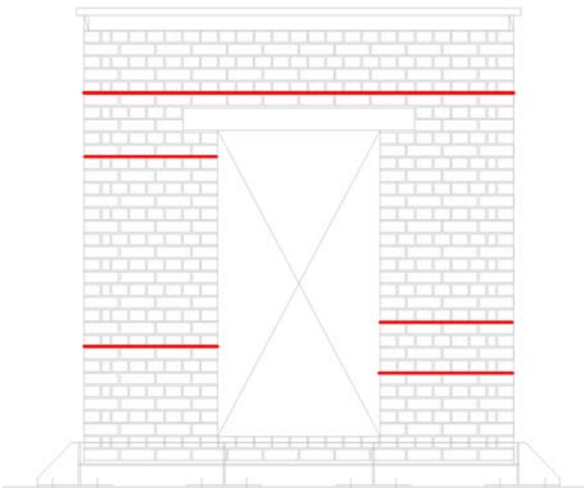
(A) Input No.31: JMA Kobe NS



(B) South elevation

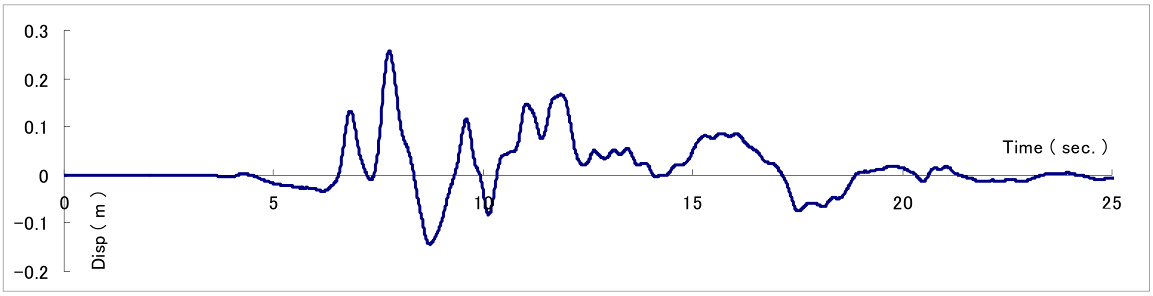


(C) North elevation

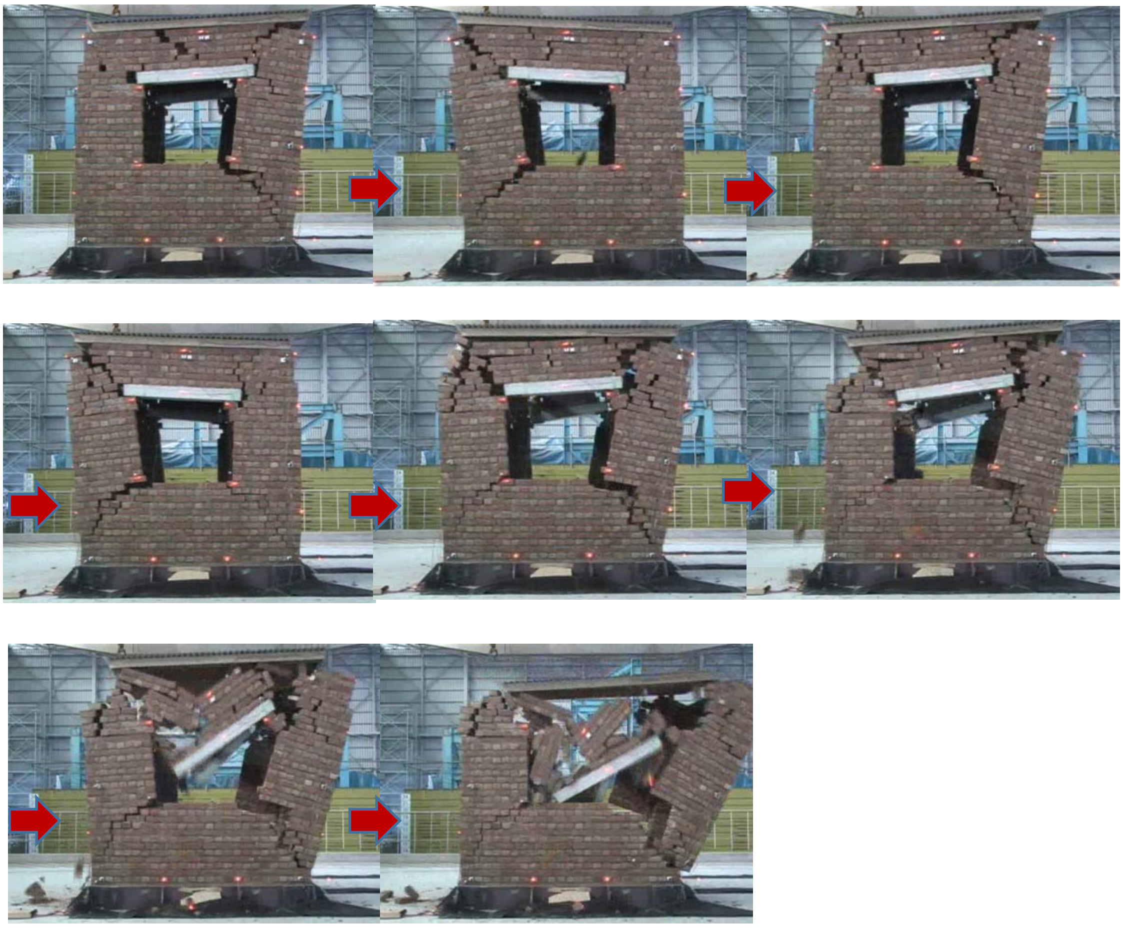


(D) East elevation

Fig.43 Crack pattern of Input No.31 (2) (Red circle on (A))



(A) Input No.31: JMA Kobe NS



(B) Sequence of collapse from South view

Fig.44 Sequence of collapse of input No.31

The result of this shaking table test of South-Asian type of brick masonry house clearly showed that cracks started from openings in the South and North walls. These walls were subjected to in plane loading. Then, the East wall collapsed by following an out-of-plane failure pattern. Before total collapse, the wall segments fell down towards the inside of the house, shown in Fig.45. This behavior of failure pattern is the critical point which loss of lives are imminent.

Fig.45 South-West view during input No.31

2.2.6 Conclusions

Table 4 shows characteristic of model structure and failure pattern. The failure was started in plane diagonal cracks.

Table 4 Characteristic of model structure and failure pattern

Chapter 2.2 South Asian type of masonry construction	
Wall thickness	230 mm
Span of wall	2650 mm
Ratio of Span/thickness of out-of-plane direction	2650 / 230= 11.52 **11times** of wall thickness
Area of floor	7,022,500 mm2
Area of wall of shaking direction	878,600 mm2
Ratio of wall density of shaking direction	878,600 / 7,022,500=0.125 **12.5%**
Failure pattern	**In plane failure**
Input motion of collapsing	JMA Kobe NS 100 % wave
Sequence of collapse	The North and South walls were separated into some segments of walls, mainly four segments on both sides, upper part and bottom part from diagonal cracks, and the model was rocking during beginning of shaking.

The observations and points of this shaking table test are shown below:

- The size of the model was smaller than actual houses. Therefore, the ratio of span/thickness and wall density of model were higher than ordinary houses in developing countries.

- The model was one-story building. Therefore, there was no weight to cause additional inertia force to the building other than the weight of the walls.
- The strength of mortar was produced to follow in the actual field condition, however, workmanship of masons in Japan was better than the actual field condition, and it was a new construction, therefore no deterioration.
- Through observation of debris, fallen bricks still formed in segments of brick walls. It was different as observed from debris after an actual earthquakes where the walls are shattered into pieces of bricks. It was concluded that bonding strength was much better than in the actual condition, shown in Fig.46.

Fig.46 Debris of bricks

The shaking table test indicated that the tested model are stronger compared to the actual ordinary houses built in developing countries. That was why masonry construction in these areas were vulnerable and suffered devastating damage during the past earthquakes such as the 2003 Bam Earthquake and the 2005 Kashmir Earthquake. It is considered that the damages of brick constructions in developing countries were defective caused by low standards of workmanship. Poor workmanship is often observed in developing countries.

2.3 Full-scale shaking table test of brick masonry house commonly built in South-East Asia

2.3.1 Outline of specimen

The second shaking table test of the South-East Asian type of brick masonry house was conducted for the investigation of seismic performance, under "Collaboration Project of NIED and Mie University in cooperation with BRI and Mitsuishi Fire Brick Co.Ltd.

According to Teddy Boen, in general, non-engineered construction in Indonesia can be summarized as follows; "Most of the buildings in the earthquake stricken area are masonry non-engineered constructions consisting of half-brick-thick masonry walls. This type of buildings are earthquake resistant if built based on earthquake resistant principles. However, from past 40-year surveys of significant damaging earthquakes in Indonesia, many masonry non-engineered constructions were damaged and/or have collapsed during earthquakes."[3]

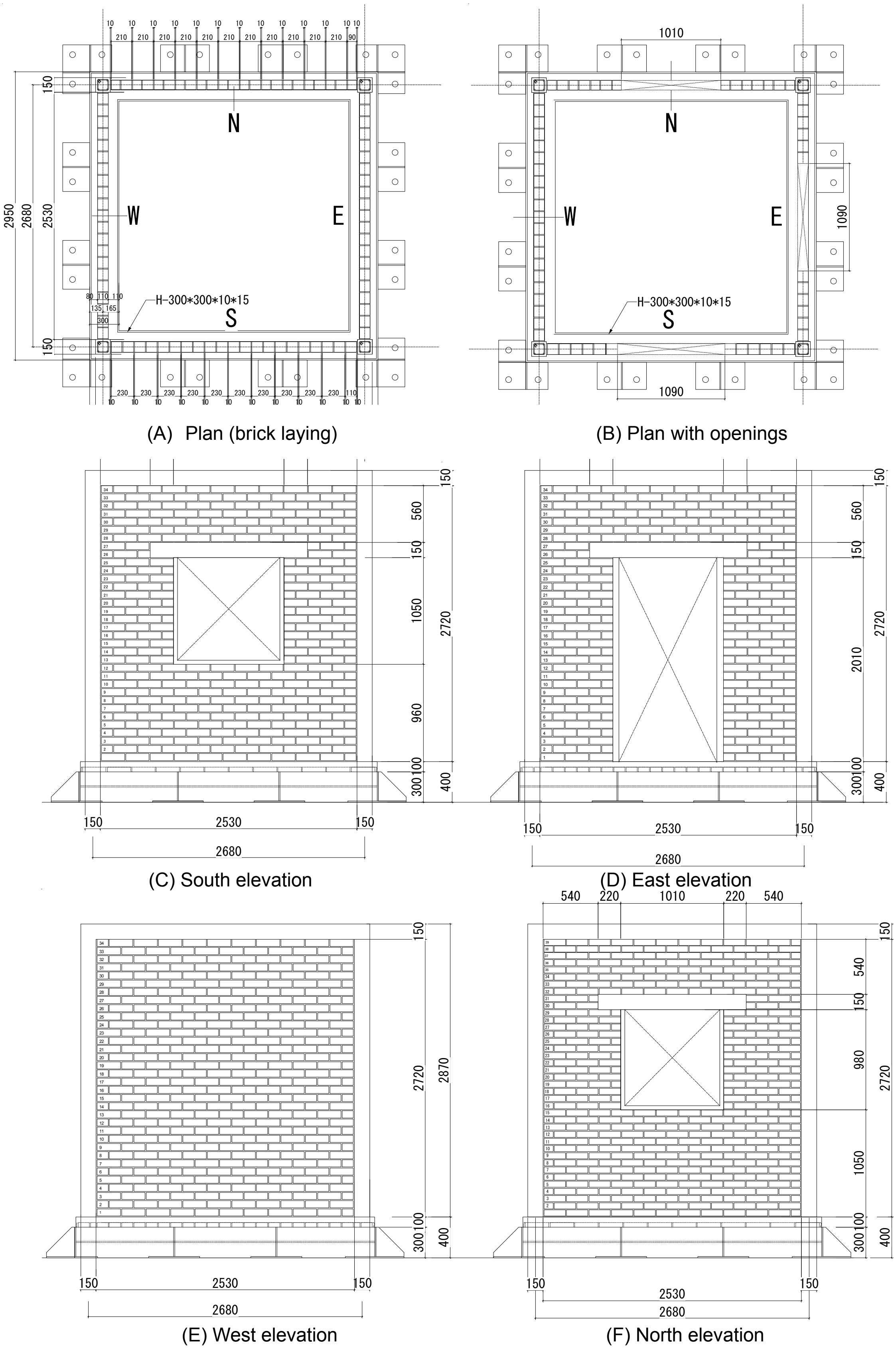
Such construction is called "Confined masonry with a half-brick-thick wall".

The confinement consist of reinforced concrete framing, consisting of the tie columns and tie beams. These RC frame is 120 mm x 120 mm and 150 mm x 200 mm with four 10 mm or 12 mm in diameter bars as main reinforcement and 8 mm in diameter stirrups spaced at 150 - 200 mm. Most of houses have timber roof trusses with galvanized iron sheets roofing. Few buildings used clay tiles for roofing.

The overall dimensions of the model were 2680 mm x 2680 mm in plan and 3270 mm in height without gable wall, shown in Fig.47. Figure 48 shows drawings of model structure.

Fig.47 Model on the shaking table

[3] Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, The University of Kyoto, Ph.D. thesis, 2014, P23.



(A) Plan (brick laying)
(B) Plan with openings
(C) South elevation
(D) East elevation
(E) West elevation
(F) North elevation

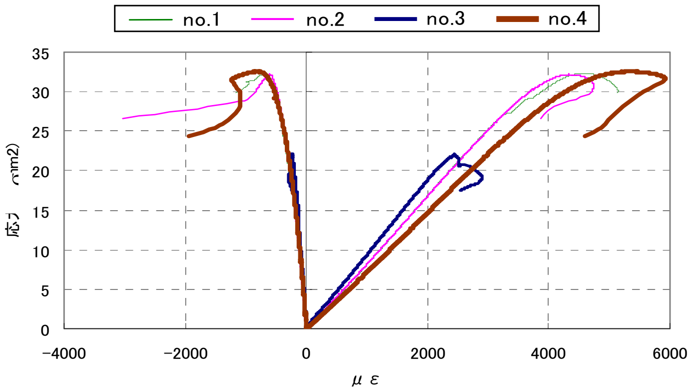
Fig.48 Plan and elevation of the model

2.3.2 Material properties

1) Brick

The East, South and West sides of the wall were made of Pakistani brick same as mentioned in Chapter 2.2. The North wall was made using Japanese brick. Because this was an additional test, remaining materials of the last shaking table test were used, shown in Fig.49. The average compressive strength was 29.79 N/mm^2. The photo of the test and the stress-strain (σ-ε) curve are shown in Fig.50.

Fig.49 Pakistani brick and Japanese brick



(A) σ — ε curve

(B) Specimen after test

Fig.50 Properties of brick

2) Mortar and Concrete for column and beam

The ratio of cement and sand was 1 / 10 by volume and the water-cement ratio was 171 % which followed the common practice in this area. The average compressive strength is 2.58 N/mm^2. The average compressive strength of concrete was 28.43 N/mm^2. The photos of the test are shown in Fig.51.

(A) Specimen of mortar

(B) Specimen of concrete

Fig.51 Specimens after test

Table 5 List of input motion

Date	No.	Input wave(*1)	Time scale	Scale (%)	Displacement (± mm)	Acceleration (gal)	Velosity (Kine)	Time (Sec)	Recording Acc.	Recording 3D image	Recording video cam	situation of damage
1st Jul, 2008	1	Test	-	-	-	-	-	-	✔	-	-	none
	2	Zero	-	-	-	-	-	-	✔	-	-	none
	3	Step 01	-	-	1	-	-	60	✔	-	-	none
	4	JMA Kobe NS	0.6	-	10	113	9	60	✔	✔	✔	none
	5	Step 02	-	-	1	-	-	60	✔	-	-	none
	6	Bam EW	0.5(*2)	-	10	84	9	60	✔	✔	✔	none
	7	Step 03	-	-	1	-	-	60	✔	-	-	none
	8	ICA	0.6(*2)	-	10	38	4	130	✔	✔	✔	none
	9	Step 04	-	-	1	-	-	60	✔	-	-	none
	10	ICA	0.6	-	50	194	20	130	✔	✔	✔	none
	11	Step 05	-	-	1	-	-	60	✔	-	-	none
	12	ICA	0.6	-	100	400	40	130	✔	✔	✔	none
	13	Step 06	-	-	1	-	-	60	✔	-	-	
	14	ICA	0.6	100	140	587	55	130	✔	✔	✔	
	15	Step 07	-	-	1	-	-	60	✔	-	-	none
4th Jul, 2008	16	Test	-	-	-	-	-	-	✔	-	-	none
	17	Zero	-	-	-	-	-	-	✔	-	-	none
	18	Step 08	-	-	1	-	-	60	✔	-	-	none
	19	ICA	0.1	-	10	782	20	30	✔	✔	✔	none
	20	Step 09	-	-	1	-	-	60	✔	-	-	none
	21	ICA	0.1	-	15	1200	30	30	✔	✔	✔	none
	22	Step 10	-	-	1	-	-	60	✔	-	-	none
	23	ICA	0.1	-	30	2240	57	30	✔	✔	✔	Cracks occurred
	24	Step 11	-	-	1	-	-	60	✔	-	-	none
	25	ICA	0.58	100	140	600	62	130	✔	✔	✔	Cracks increased
	26	Step 12	-	-	1	-	-	60	✔	-	-	none
	27	JMA Kobe NS	1	110	200	1274	100	100	✔	✔	✔	Totally collapsed

*1. Input waves were based on ICA earthquake, Bam earthquake and Kobe earthquake.

*2. ICA and Bam EW earthquakes were adjusted about time scale, because capacity of spec of shaking table.

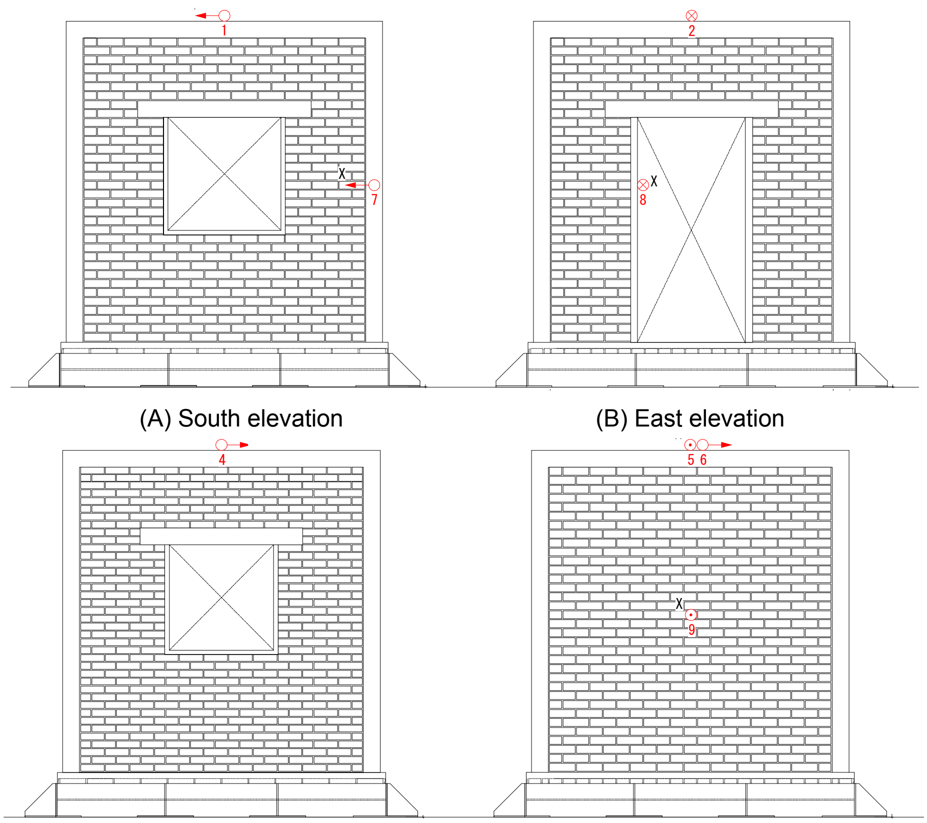
✔ Recording done

2.3.3 Input motions

Table 5 shows the schedule of excitation with input motions of the shaking table test. These input motions were based on the 2007 Peru Earthquake (ICA), 2003 Bam Earthquake (Bam EW) and 1995 Kobe Earthquake (JMA Kobe). The maximum capacity of displacement of the shaking table was less than the ICA and Bam records. Therefore, in tests using those records, it was necessary to modify the amplitude and the timescales of the shaking table inputs. In this case, the maximum ICA record displacement was approximately 41 cm and was adjusted to 14 cm in accordance with the capacity of the shaking table displacement. This displacement reduction led to a timescale reduction factor of 0.58 which was used in the test.

2.3.4 Measurement systems

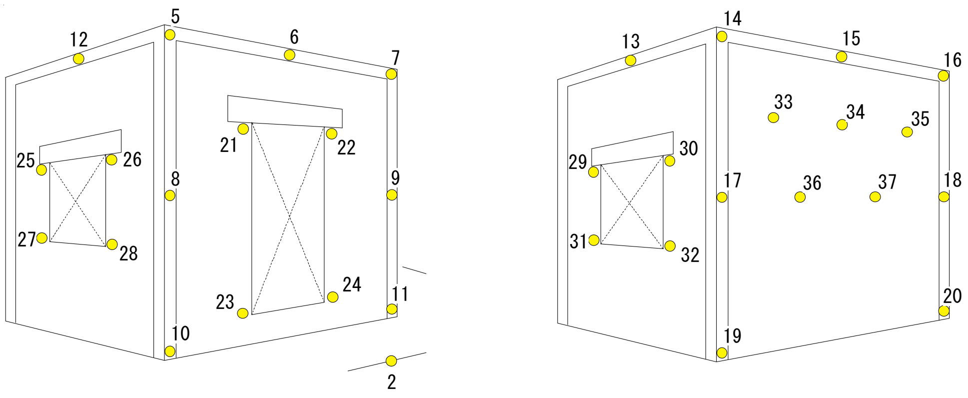
Accelerometers were installed at 12 points on the specimen and on the shaking table. (See Fig.52)　Response displacement was measured by 3D image processing. LED makers as point of measurement were installed at 37 points on the specimen and on the shaking table. (See Fig.53) And after each inputs, the location and size of cracks on the specimen were sketched to record the progress of crack development.



(A) South elevation　(B) East elevation

(C) North elevation　(D) West elevation

Fig.52 Location of accelerometers



(A) South-East view (B) North-West view

Fig.53 Location of LED markers for 3D measurement

2.2.5 Observations of main excitation tests

・**Up to input No.21:** The model was not damaged until input motion of 1200 gal based on ICA, shown in Fig.54. This model was also very strong compared to actual buildings in developing countries.

・**Input No.23:** In order to investigate the damage on the model. Input No.23 with displacement 30mm based on ICA, time scale was 0.1 was used for the shaking table test. The maximum acceleration was approximately 2200 gal, shown in Fig.55. This shaking caused several damage on the South and East walls of the model. Figure 56 shows crack patterns. One column at the South-East corner, height around 800 mm + GL was damaged.

・**Input No.25:** After cracks occurred, the cracks were generated by ICA input with a displacement 140 mm. However, the model did not collapse. (See Fig.57 and 58)

・**Input No.27:** After input No.27, the model totally collapsed. First, the middle part of West wall fell towards the inside of the house as out-of-plane failure pattern. Subsequently, from South-East corner, the collapse spread until the model totally collapsed. (See Fig.59)

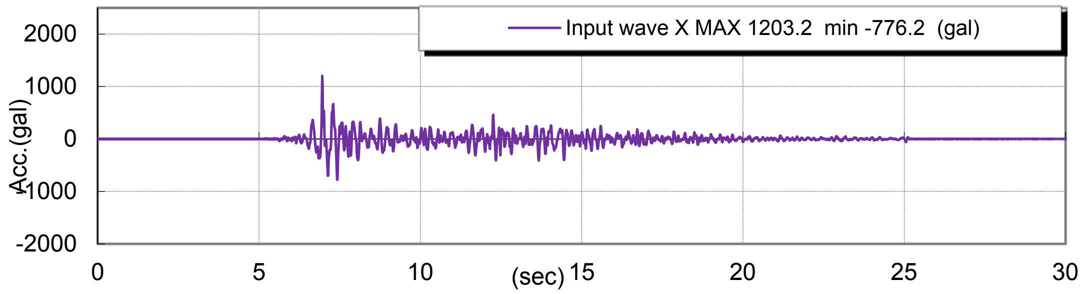


Fig.54 Input No.21: ICA displacement 10 mm wave, timescale 0.1

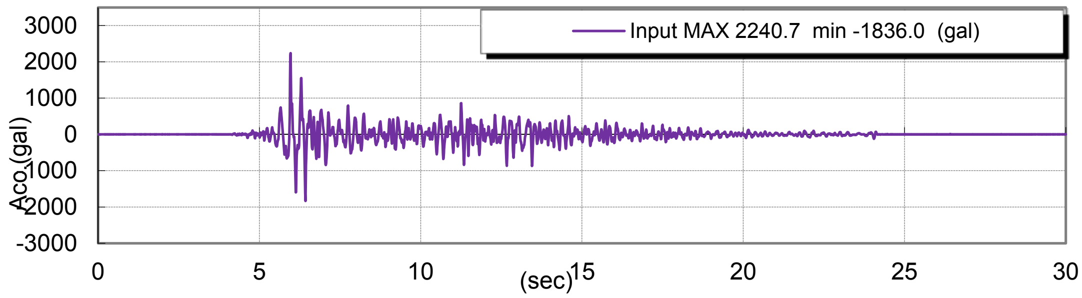
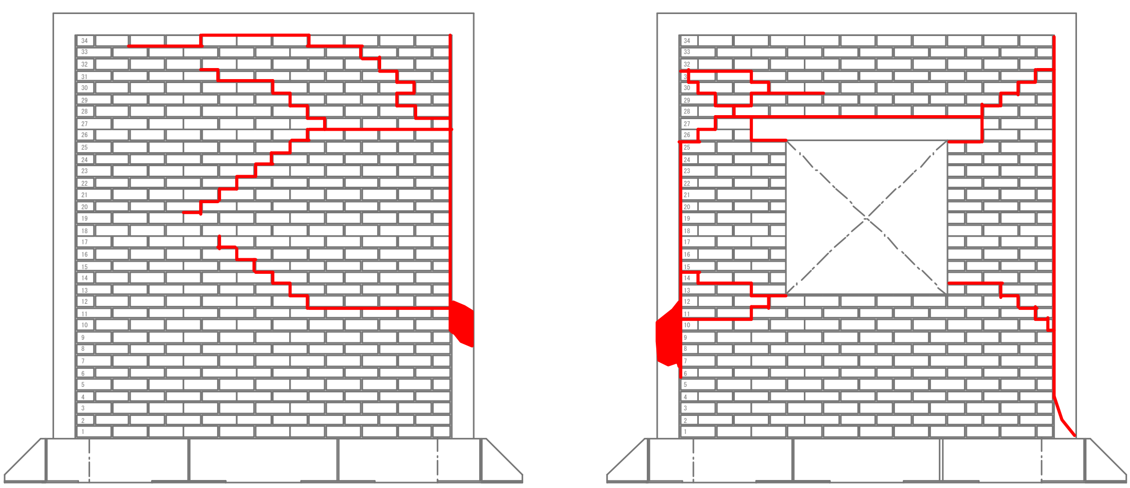


Fig.55 Input No.23: ICA displacement 30 mm wave, timescale 0.1



(A) West elevation

(B)South elevation

Fig.56 Crack pattern after input No.23 (ICA displacement 30 mm, timescale 0.1)

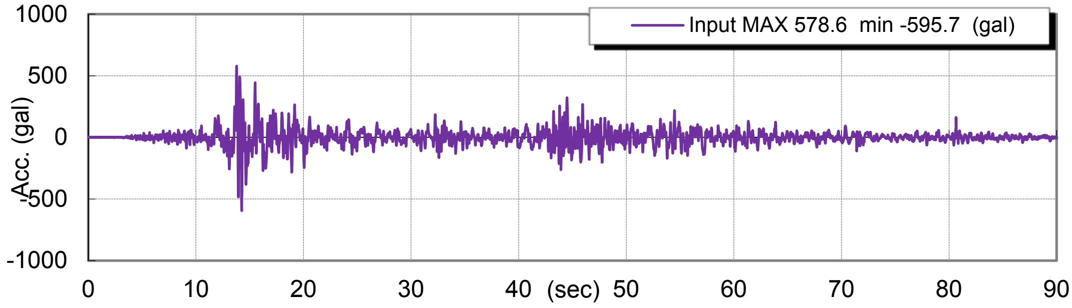
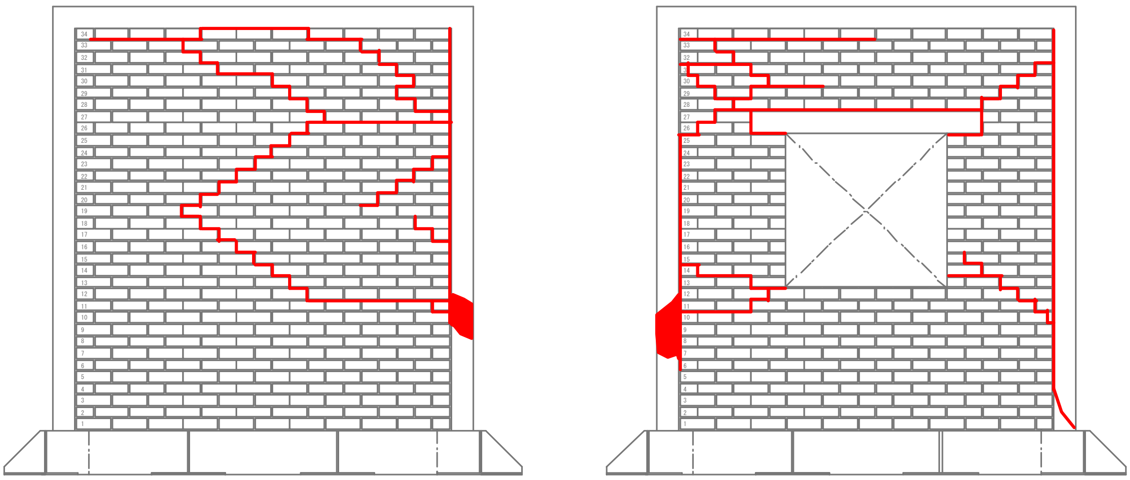


Fig.57 Input No.25: ICA displacement 140 mm wave, timescale 0.58



(A) West elevation (B) South elevation

Fig.58 Crack pattern after input No.25 (ICA displacement 140 mm, timescale 0.58)

1. First, collapse of walls occurred in the West wall.

2. The RC column started to collapse.

3. Collapse of the South wall started.

4. The part of the South wall, side of opening fell down.

5. Separated RC column from RC beam.

6. Collapse of two wall s with two ring beams

7. Falling down of two ring beams

8. Falling down of East wall

Fig.59 Sequence of failure pattern until totally collapsed by input No.27

2.2.6 Conclusions

Figure 59 shows pattern of failure until up to total collapse by input No.27.

The result of this shaking table test of the South-East Asian type of brick masonry house clearly showed that cracks started at the East wall as an out-of-plane behavior.

Table 5 shows characteristic of model structure and failure pattern. The failure was started in plane diagonal cracks.

Table 5 Characteristic of model structure and failure pattern

Chapter 2.3 South-East Asian type of masonry construction	
Wall thickness	100 mm
Span of wall	2680 mm
Ratio of Span/thickness of out-of-plane direction	2680 / 100 = 26.8 **26times** of wall thickness
Area of floor	7,182,400 mm2
Area of wall of shaking direction	346,000 mm2
Ratio of wall density of shaking direction	346,000 / 7,182,400 = 0.048 **4.8%**
Failure pattern	**Out-of-plane, then in plane failure**
Input motion of collapsing	JMA Kobe NS 100% wave
Sequence of collapse	The middle part of West wall fell to inside of the house as out-of-plane failure pattern. Subsequently, from South-East corner, the collapse spread until totally collapsed.

The total collapse started from separation of RC tie columns and walls, which allowed large deformation of the South-West corner of the West wall and lead to the out-of-plane collapse. Subsequently, failure and falling down of RC tie column occurred, which caused the collapse of south wall by buckling outward.

The cause of the failure of the column was due to the poor concrete mix which was placed when pouring the joint(cold joint) and reinforce bars are also jointed in this place, shown in Fig.60. If concrete at the joint was of good quality, failure of the column might not have occurred and RC frame remained just like the building in Fig.61. This implies that defects of RC tie members could cause serious damages to the overall structure.

(A) Joined part

(B) Failure of column

Fig.60 Failure of concrete column

Fig.61 Damaged house in Yogyakarta after 2006 Central Java Earthquake

In comparison with the South wall which was constructed with Pakistani brick and the North wall which was constructed with Japanese bricks, the North wall remained standing until the final stage of the shaking table test. There could be some possible reason for the difference of performance of the two walls such as:

- No defects in RC columns which are connected to the North wall.
- The North wall that is made of Japanese bricks itself was much stronger than Pakistani bricks, therefore, the strength of wall unit in bonding and shear were increased, even by using the same joint mortar.

While in plane shear cracks in the South wall caused the first stage of damage by Input No.23. In this shaking table test, the South wall was able to withstand the shaking of Input No.25 in spite of large shear cracks and rocking motion of the segmented walls. The collapse of the South wall seemed to be triggered by the failure of the adjacent column. This behavior of the wall might be different if the shaking excitation motion was not in one-direction. The wall probably collapse even when there were no failures of columns just like the building in Fig 62.

Fig.62 North wall did not collapsed in this test

2.2.7 Analysis using Simplified Evaluation Equation

1. Estimation of shear force of model structure of shaking table test

The shear forces induced by the earthquake wave in the shaking table tests are roughly estimated. Equation of dynamic motion for earthquake is:

$$m\ddot{x} + c\dot{x} + kx = -m\ddot{y}$$ [4]

where:
m= mass of the model structure
c= damping ratio
k = stiffness
x= displacement of the model structure
y = displacement of ground motion

The result of wave on shaking table tests was showed that damping force ($c\dot{x}$) was small enough to neglect. The above equation was derived:

$$m\ddot{x} + m\ddot{y} = m(\ddot{x} + \ddot{y}) = -kx$$

Q (kN) is shear force induced in the model structure. It can be roughly estimated as,

$$Q = Ma$$

where:
M = upper half of the model structure (t)
a= response acceleration of model structure (m/s^2 = 100gal)

Q is defined as the inertial force. a denotes the maximum response acceleration in middle or upper section of the specimen. Q before and at collapsing were estimated

Table 5 Rough estimation of shear force of model structure

Model structure		state	Mass of upper part	Response Acc. of upper part	Rough estimate of shear force
			M(t)	A(m/s^2)	Q(kN)
Chapter 2.3	South-East Asian type of masonry construction	Before failure	2.5	24.05	60.13
		At the failure	2.5	32.66	81.65

[4] A. Shibata, “最新建築学シリーズ　最新耐震構造解析　第 2 版,” Morikita Publication, pp.97-108, 2010

2. Ultimate Shear Strength of Each Model Structure using Simplified Evaluation Equation

In order to assess the shear strength in in-plane direction, three equations were employed for calculation. Where, h' is half of height of the specimen. It can be assumed that $N_w = \sigma_o = 0$.

Equation for calculation of ultimate shear strength:

$$H_{s,w} = \frac{f_t A_w}{C_I b}\left[1+\sqrt{C_I^{\,2}\left(1+\frac{N_w}{f_t A_w}\right)+1}\right] \qquad (1)$$ [5]

where,

$H_{s,w}$ = ultimate shear strength (N)

f_t = tensile strength (N/mm²)

A_w = horizontal cross section of wall (mm²)

$b = \frac{h}{l}$ = shear force coefficient, h = the height of wall (mm), l = the length of wall (mm),

$C_I = \frac{2\alpha b l}{h}$ = interaction coefficient

$\alpha = \frac{5}{4}$ = parameter of shape and distribution of interaction forces

N_w = vertical load imposed on wall (N)

$$V_s = \left(f_v \frac{1}{1.2}\sqrt{1+0.45\frac{\sigma_o}{f_v}}\right)A_w \qquad (2)$$ [6]

where,

V_s = ultimate shear strength of wall (N),

f_v = average of shear strength of wall ($= 0.125\sqrt{F_z}$) (N/mm²)

F_Z = compression strength of joint mortar (N/mm²),

σ_o =vertical load imposed on wall (N),

A_w = horizontal cross section of wall (mm²)

[5] Miha Tomazevic, "Earthquake-Resistant Design of Masonry Buildings," pp.109-159

[6] National Standards of P.R. China、Seismic Design Standards for Building Structures (GBJ11-89)

Table 6 Rough estimation of ultimate lateral shear strength of model structure

Model structure		state	Eq.(1) Ultimate shear strength (kN)	Eq.(2) Ultimate shear strength (kN)
Chapter 2.3	South-East Asian type of masonry construction	South wall	131.85	28.75
		North wall	181.70	27.12
		South + North walls	313.55	55.87

Eqs. (1) and (2) were proposed to evaluate the ultimate shear strength of the wall under vertical load. It should be noticed that Eq. (1) depends on the tensile strength of wall (: f_t). Eqs. (2) depend on the compression strength of joint mortar (: F_Z).

As results of the present assessment, the theoretical value by Eq. (1) was much higher than experimental value of South-East Asian type of confined masonry construction. The calculation value by Eq. (2) for un-reinforcement masonry wall corresponds approximately to experimental value of South-East Asian type of confined masonry construction.

2.4 Full-scale shaking table test of concrete hollow block masonry houses as built in developing countries.

2.4.1 Outline of specimen

Recently, a review of common housing types in the developing countries shows that concrete hollow block are increasing[7]. In the Himalayan belt, Kashmir area, and in the Philippines, concrete hollow blocks are usually also used for building houses. It is important to note that the catastrophic damage of concrete block structures in the 2010 Port-au-Prince Earthquake in Haiti is still fresh in our memory.

The shaking table test of concrete hollow block (CHB) masonry houses was conducted for investigation of its seismic performance, under project of "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines[8], 2010-2014 by NIED and PHILVOCS[9], funded by JST-JICA.

Two house model structures for comparison study were built on the shaking table, shown in Fig.63.

Figures 64 and 65 show drawings of the model structures. The overall dimensions of these two models were 3600 mm x 3600 mm in plan and 2900 mm in height and a 1200 mm gable walls. The structure of both models were load-bearing walls without RC frame and the walls were constructed with CHB that were imported from areas near Manila in the Philippines. These are commonly used types of CHBs that are produced as a home industry, these are called "Backyard Factory made". Both models have the same roof specification made of galvanized iron sheet with wooden frame. Furthermore, the foundation was constructed by reinforced concrete which was fixed by anchor bolts to the shaking table.

Fig.63 Model structure on the shaking table

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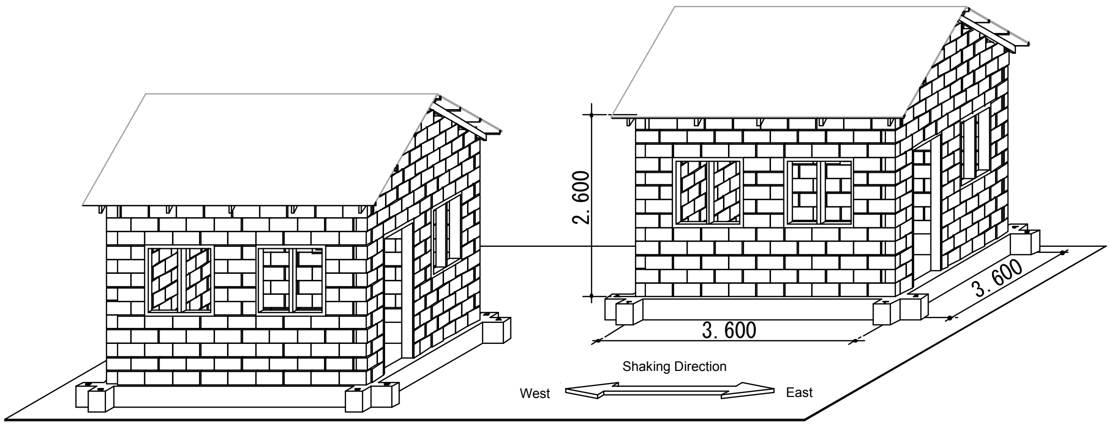
7 Ayako, MAESHIMA. A study on the Concrete Block housing supply in urbanizing Africa -Case study Lusaka, ZAMBIA-. The University of Tokyo, 2011(ver.2012), Ph.D. thesis, p1

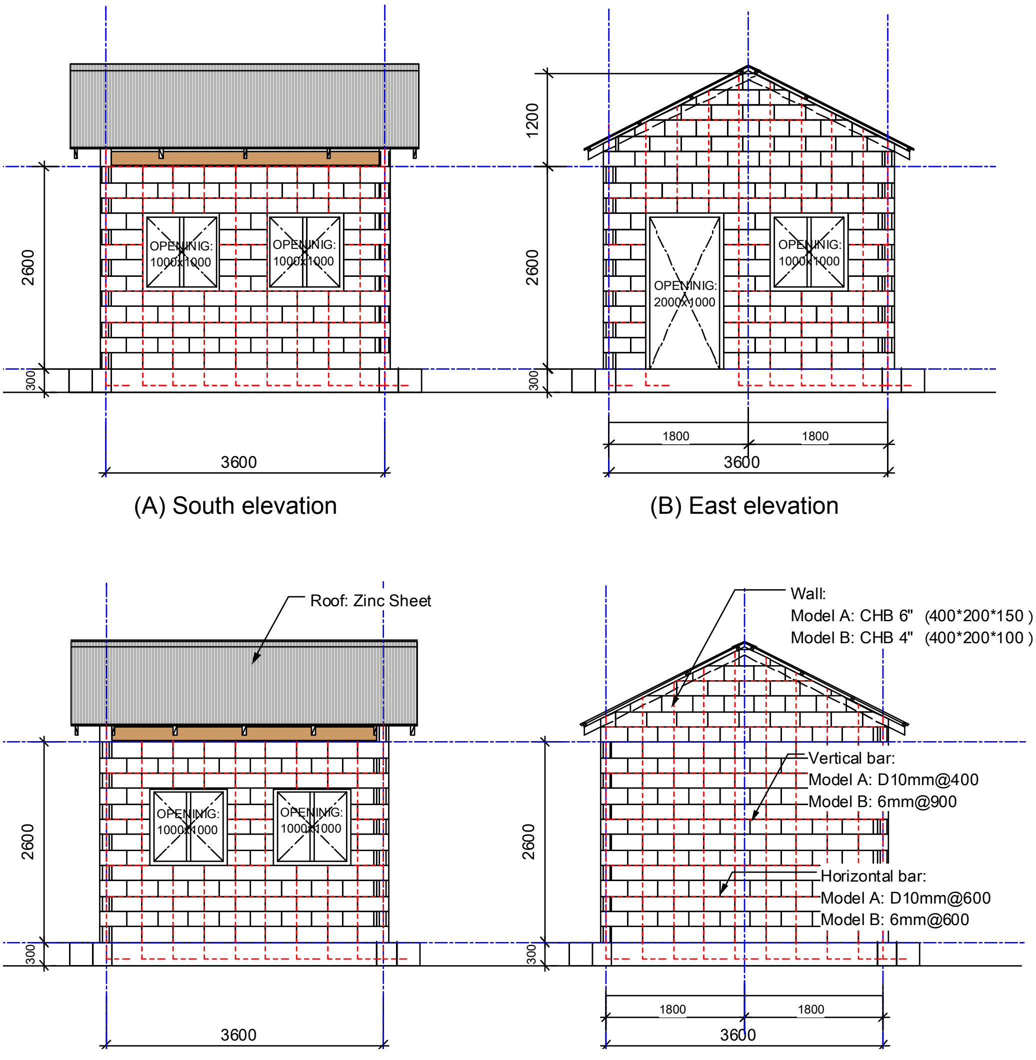
8 JST-JICA (SATREPS) 2010-2014, Enhancement of earthquake and volcano monitoring and effective utilization of disaster mitigation information in the Philippines

9 The Philippine Institute of Volcanology and Seismology (PHIVOLCS): http://www.phivolcs.dost.gov.ph/



Model B: Non-engineered model　　　Model A: Engineered model

Fig.64 Isometric of the models



(A) South elevation　　　(B) East elevation

(C) North elevation　　　(D) West elevation

Fig.65 Elevation of the model structure

One of the specimens was Model A. This model follows by the standards listed in Chapter 7 on Masonry of the National Structural Code of the Philippines 2010 (NSCP 2010)[10]. The other specimen is called Model B and represents the non-engineered house that is found to exist in different places in the Philippines, shown in Fig.66. Table 7 shows the specifications of two model structures.

Table 7 Specification of two model structures

Specification	Model A	Model B
Wall (CHB)	6 inches (400 mm x 200 mm x 150 mm)	4 inches (400 mm x 200 mm x 100 mm)
Longitudinal Bar	D10 mm@400 mm	6 mm@900 mm
Horizontal Bar	D10 mm@600 mm (each 3layers)	6 mm@600 mm (each 3layers)
Mortar (Cement : Sand)	1:4 (by volume) with compaction	1:4 (by volume) without compaction
Roof	galvanized iron sheet	galvanized iron sheet

Fig.66 CHB house near Manila, Philippines

2.4.2 Material properties

1) Concrete Hollow Block

The CHBs were imported from near Manila. There are two types of CHBs, one with thickness of 4 inches (100 mm) and the other 6 inches (150 mm), which were backyard factory made. For comparison, Japanese concrete blocks were also tested.

2) Prism specimens of masonry unit of Concrete Hollow Blocks

The specimens composed of three layers of CHBs stacked vertically, the holes and the joints filled with mortar. Vertical reinforcing bars are not provided/installed. Tests shows that the compressive strength of the mortar used for the prism specimens ranges from 9.5 N/mm^2 to 15.2 N/mm^2. Figures 67 and 68 show properties of materials.

[10] ASEP, (2010) National Structural Code of the Philippines 2010

(A) Compressive strength of full block *Use net area

Specimens		Maximum Load (kN)	Compressive Strength (N/mm2)	Ave. of Compressive Strength (N/mm2)
Philipppine CHB	4 inches	24	1.0	**1.0**
	6 inches	33	1.0	
Japanese Concrete Block JIS A 5406	Type-B 100mm	284	11.6	**12.0**
	Type-B 150mm	423	12.9	
	Type-C 100mm	476	20.6	**19.7**
	Type-C 100mm	563	18.7	

(D) Specimen of full block

(B) Compressive strength of cut models

Specimens		Maximum Load (kN)	Compressive Strength (N/mm2)	Ave. of Compressive Strength (N/mm2)
Philipppine CHB	4 inches	0.6	0.9	**1.5**
	6 inches	1.1	1.7	
Japanese Concrete Block JIS A 5406	Type-B 100mm	7.6	12.8	**15.9**
	Type-B 150mm	14.8	19.0	
	Type-C 100mm	11.0	25.4	**23.6**
	Type-C 100mm	13.1	20.8	

(E) Specimen of cut model

(C) Water absorption and air density

Specimens	Philippine CHB	Japanese Concrete Block JIS A 5406	
		Type-B	Tyepe-C
Water absorptopm rate [%]	17.6	11.5	6.6
Dry air dinsity [g/cm3]	1.6	1.7	2.2

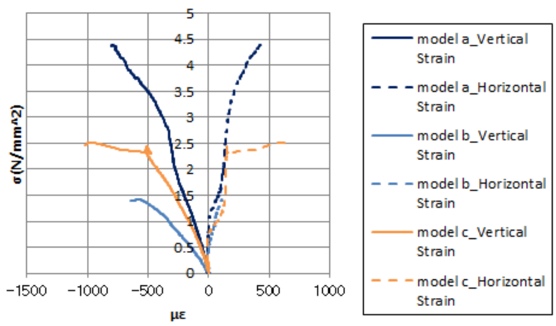
Fig.67 Properties of concrete hollow blocks

(A) Specification of models

	CHB		Reinforcing bar	Mortar	
	Thickness	inch, (mm)		Mixing ratio	Compaction
Model A	Philippine	6inch, (150)	none	1 cement : 4 sand	Compacted
Model B	Philippine	6inch, (150)	none	1 cement : 4 sand	Not compacted
Model C	Philippine	4inch, (100)	none	1 cement : 4 sand	Compacted

(B) Compressive strength of masonry unit

Prism of masonry unit	
Compressive strength	(N/mm2)
Model A	4.40
Model B	1.42
Model C	2.52



(C) σ − ε curve

(D) Specimen of prism

Fig.68 Properties of prism of CHBs

Table 8 List of input motion

Date	No.	Input wave(*1)	Time scale	Scale (%)	Displacement (± mm)	Acceleration (gal)	Time (Sec)	Recording: Acc.	Recording: 3D image	Recording: video cam	situation of damage: Model A	situation of damage: Model B
23rd Feb, 2011	1	Test	-	-	-	-	-	✔	-	-	none	none
	2	Zero	-	-	-	-	-	✔	-	-	none	none
	3	Step 01	-	-	1	-	60	✔	-	-	none	none
	4	JMA Kobe NS	1	20	35	166	60	✔	✔	✔	none	none
	5	Step 02	-	-	0.5	-	60	✔	-	-	none	none
	6	JMA Kobe NS	1	50	87.5	392	60	✔	✔	✔	none	none
	7	Step 03	-	-	0.5	-	60	✔	-	-	none	none
	8	NZ (sample input)	1	-	-	-	-	✔	✔	✔	none	none
	9	Step 04	-	-	0.5	-	60	✔	-	-	none	none
24th Feb, 2011	10	Test	-	-	-	-	-	✔	-	-	none	none
	11	Zero	-	-	-	-	-	✔	-	-	none	none
	12	Step 05	-	-	0.5	-	60	✔	-	-	none	none
	13	JMA Kobe NS	1	100	175	833	60	✔	✔	✔	Cracks occurred	Gable wall collapsed
	14	Step 06	-	-	0.5	-	60	✔	-	-	none	none
	Adding weight (4 tons) on Model A											
	10	Step 07	-	-	0.5	-	60	✔	-	-	none	none
	15	JMA Kobe NS	1	100	175	833	60	✔	✔	✔	Cracks occurred	Cracks increased
	16	Step 08	-	-	0.5	-	60	✔	-	-	none	none
	17	JMA Kobe NS	1	110	200	980	60	✔	✔	✔	Cracks increased	Cracks increased
	18	Step 09	-	-	0.5	-	60	✔	-	-	none	none
	19	NZ (sample input)	1	-	200	-	-	✔	✔	✔	Cracks increased	Cracks increased
	20	Step 10	-	-	0.5	-	60	✔	-	-	none	none
	21	JMA Kobe NS (reverse)	1	110	200	980	60	✔	✔	✔	Cracks increased	Totally collapsed

*1. Input waves were based on Kobe earthquake.

✔ Recording done

2.4.3 Input motions

Table 8 shows the schedule and list of input motions of the shaking table test. These input motions were based on the 1995 Kobe Earthquake (JMA Kobe NS).

2.4.4 Measurement systems

Accelerometers were installed at 15 points (See Fig.69) on the specimen and on the shaking table. Response displacement was measured by 3D image processing. LED lamp as point of measurement were installed at 54 points (See Fig.70) on the specimen and on the shaking table. And after each inputs, the cracks on the specimen were sketched for the development of cracks.

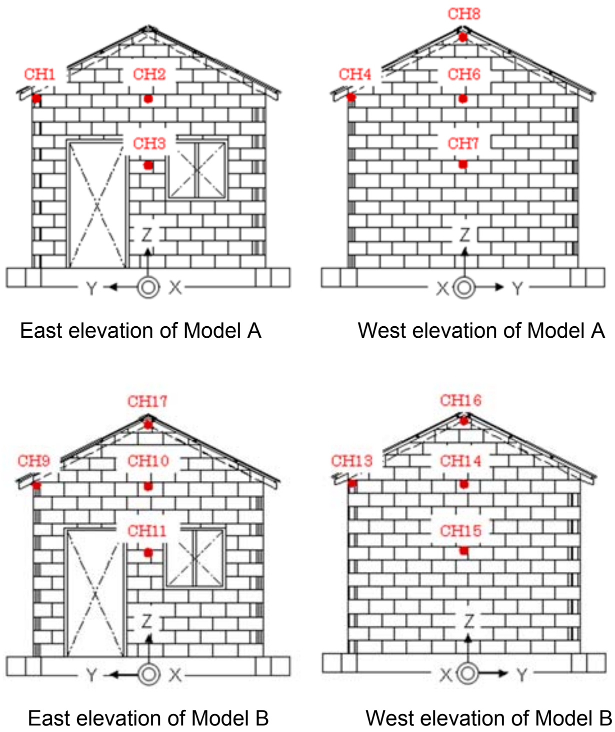


Fig.69 Location of accelerometers

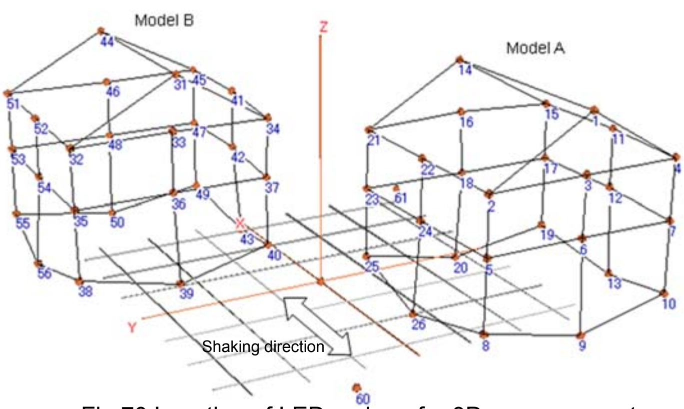


Fig.70 Location of LED makers for 3D measurement

2.4.5 Observations of main inputs

・ No.13: JMA Kobe NS 100% (Crack pattern are shown in Fig.73)

Model A (Engineered)

・The top of East walls reached to large displacements of 203 mm by 3D measurement, however, the wall did not collapse.

・Horizontal cracks were found on the bottom of the gable wall of East and West walls.

・East-South corner of wall started to separate.

Model B (Non-Engineered)

・East and West walls reacted to large displacement, then upper part of the gable wall fell down as an out-of-plane behavior. Maximum displacement is shown in Fig.71.

・North and South wall has minor diagonal cracks which started to appear.

Figure 72 shows comparison data of displacement of top of gable wall of both models during input No.13 JMA Kobe NS 100% in shaking direction.

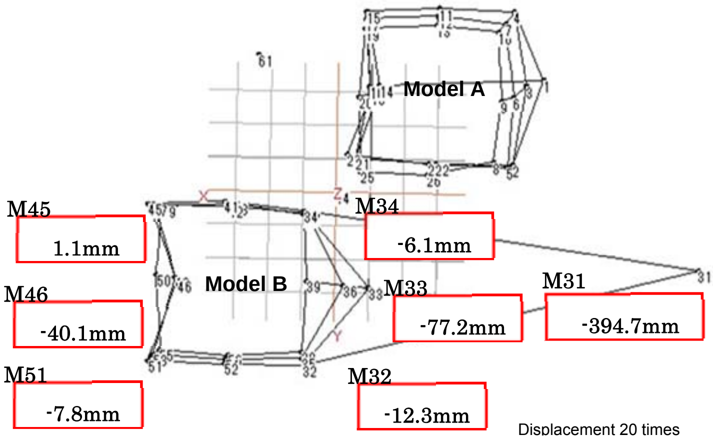


Fig.71 Maximum deflection of out-of-plane direction on Model B during input No.13

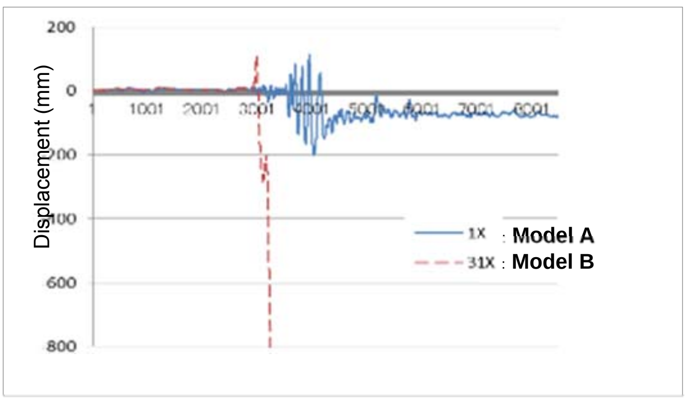
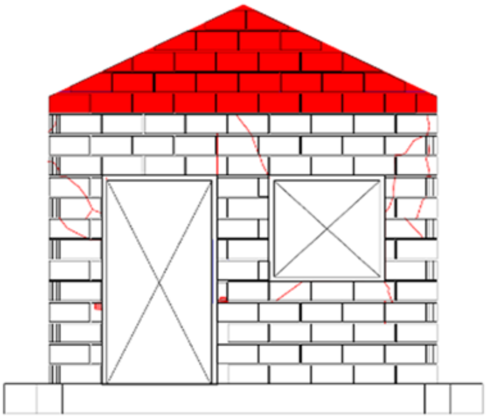
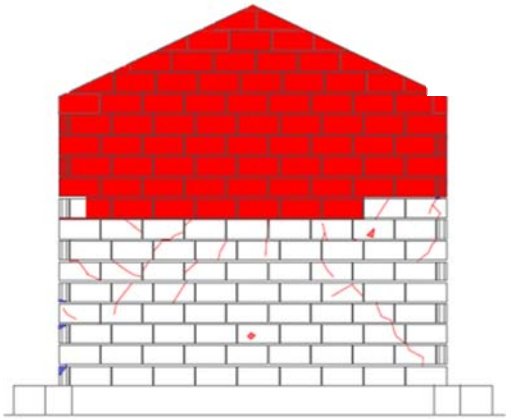


Fig. 72 Displacement data of gable walls of both model structures



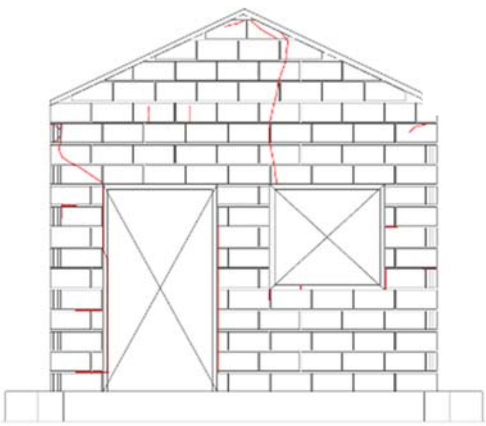
(A) East elevation of Model B



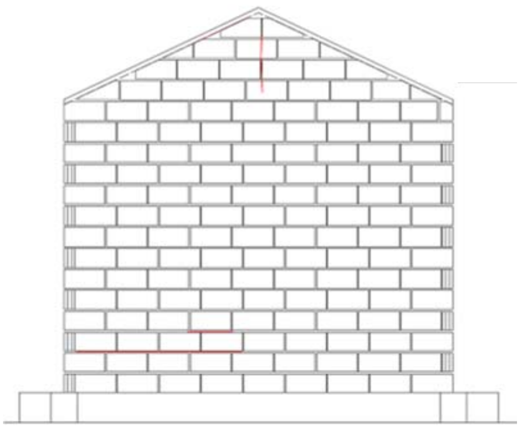
(B) West elevation of Model B

(C) East wall of Model B

(D) West wall of Model B



(E) East elevation of Model A



(F) West elevation of Model A

Fig.73 Crack pattern of Model A & B and Photos of Model B after input No.13 (JMA Kobe NS 100%)

The following findings were drawn from the observations during the full-scale shaking table experiment, shown in Table 9.

Table 9 Damage conditions of two models after main inputs

Input No'	Input motion	Scale	Acc	Situation	
		%	gal	**Model A**	**Model B**
23rd Feb, 2011					
No.4	JMA Kobe NS	20	166	No damage	No damage
No.6	JMA Kobe NS	50	392	No damage	East Wall: There was a horizontal crack at the bottom of the gable wall.
24th Feb, 2011					
No.13	JMA Kobe NS	100	833	West wall: There was a horizontal crack on the bottom of gable wall. East and West wall had large displacement. The East-South corner (3layers of upper part) separated.	East wall: Gable wall collapsed (fell). Upper part of opening had large displacement. West wall: Gable wall and upper part of wall was collapsed (fell). North and South wall: Miner cracks started to appear in diagonal direction.
Adding weight (4 tons) on Model A					
No.15	JMA Kobe NS	100	833	East wall: Gable wall and upper part of opening wall was collapsed (fell). West wall: Gable wall was collapsed. North and South wall: Minor cracks started to appear in diagonal direction.	East wall: Opening part had large displacement, and separated from South wall. West wall: large displacement, and wall separation occurred. North and South wall: Diagonal cracks were developed.
No.17	JMA Kobe NS	110	980	North wall: Diagonal cracks were developed.	East and West walls were collapsed, and then This model was totally collapsed.
No.21	JMA Kobe NS	100 (reverse)	833	East wall: Cracks were developed. Upper part of corner on South wall was separated. This model had partial damage, but still standing.	Already collapsed.

Table10 Characteristic of model structure and failure pattern

Chapter 2.4 CHB masonry construction	**Model A: Engineered**	**Model B: Non-engineered**
Wall thickness	150 mm (6inches)	100 mm (4inches)
Span of wall	3600 mm	3600 mm
Ratio of Span/thickness of out-of-plane direction	3600/150=24 **24times** of wall thickness	3600/100=36 **36times** of wall thickness
Area of floor	12,960,000mm2	12,960,000mm2
Area of wall of shaking direction	510,000mm2	340,000mm2
Ratio of wall density of shaking direction	510,000/12,960,000=0.039 **3.9%**	340,000/12,960,000=0.026 **2.6%**
Failure pattern	**Minor damaged**	**Out-of-plane, then in plane failure**
Input motion	JMA Kobe NS 100% wave	JMA Kobe NS 100% wave
Sequence of collapse	West wall: There was a horizontal crack on the bottom of gable wall. East and West wall had large displacement. The East-South corner separated.	East wall: Gable wall collapsed (fell). Upper part of opening had large displacement. West wall: Gable wall and upper part of wall was collapsed (fell). North and South wall: Miner cracks started to appear in diagonal direction.

2.4.6 Conclusions

Table 10 shows characteristic of model structures and failure pattern. The model B (Non-engineered) started to collapse which was caused by out-of-plane failure. In the Table 10, the ratio of span/thickness of wall is 36 times, it was longer than requirement of NSCP. The minimum thickness of load-bearing CHB walls as indicated in the NSCP shall be 150 mm and the ratio of the width (lateral unbraced length) of the wall to this thickness shall not exceed 32.

Other observations and points of this shaking table test are shown bellows:

- For Philippine CHB masonry structures, the application of mortar is also a critical and important aspect of construction because the CHB itself has poor strength. Therefore, correct standards of construction must be followed. Mortar fill should be properly compacted, shown in Fig.74, and should be homogeneous. Figure 75 shows differences of mortar in the hollow of CHB on both model structures. Left was from Model B which was not compacted, right was from Model A which was well compacted.

Fig.74 Face-shell of CHB fell down of Model A after shaking

Fig.75 Differences of core mortar

- Gable walls of both models were the most vulnerable parts of the whole structure, showing large movement/displacement compared to other parts.
- Gable walls of Model B (Non-engineered) collapsed easily, and would be dangerous for its residents when evacuating from the house to the outside, shown in Fig.72. The top of photo in Fig.76 related Fig.71 when maximum displacement happened.
- The gable wall of Model A (engineered) did not collapse after input No.13 JMA Kobe NS 100%; using the correct size and proper construction for this model may have a significant effect against bending failure of the gable wall.
- Model A survived 100% of JMA Kobe input motion with only minor damage; good compaction of mortar filling improved CHB-mortar bonding and the use of standard size

and spacing of steel reinforcement bars improved wall strength and ductility.

- Model B showed consistent failure between joint and upper fill mortar of the next upper level of CHBs, indicating poor bonding of the joints.

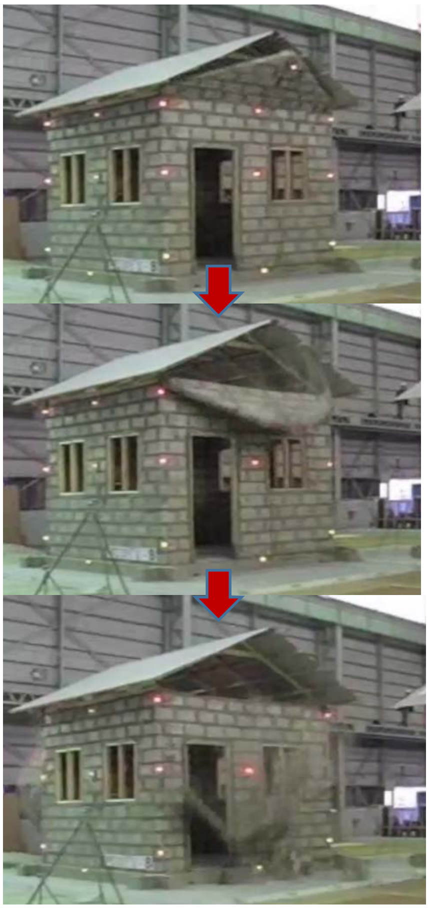


Fig.76 Sequence of the gable wall of Model B of input No.13

Fig. 77 Out-of-Plane failure on Model B before totally collapse

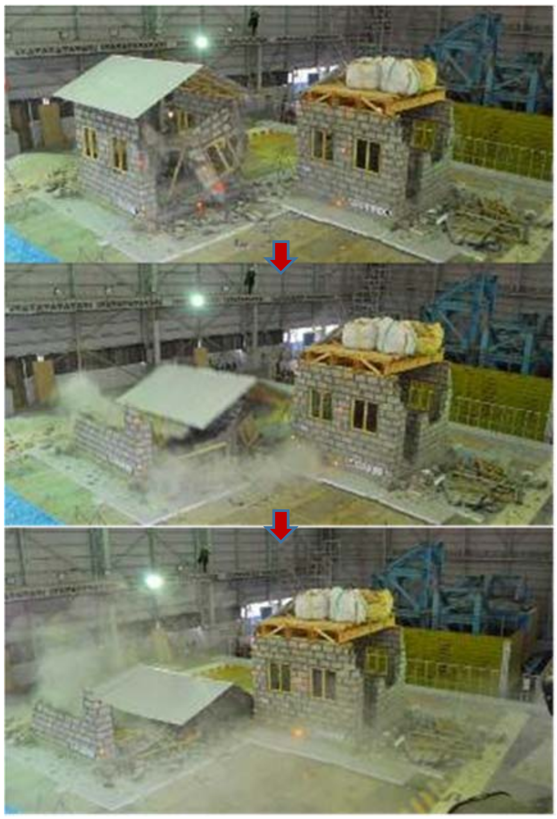


Fig.78 Sequence of total collapse of Model B of input No.17

Figure 77 shows heavy damaged and as out-of-plane failure pattern of Model B before input No.17 JMA Kobe 110 %.

Figure 78 shows behavior until totally collapse during input No.17 JMA Kobe 110 %. Both East and West walls of Model B collapsed of out-of-plane behavior, therefore, North and South walls were became free standing, then walls could not support upper part by shaking.

Through the full-scale shaking table test, the important findings for CHB construction are as follows:

1) Construction materials

- The construction should follow the minimum requirements set in the NSCP 2010.
- Use correct sizes of CHBs - The external walls should be made of fabricated 400 mm x 200 mm x 150 mm CHB (called 6 inches CHBs).
- Use correct sizes and spacing of reinforcing bars - The vertical and horizontal reinforcing bars should use 10 mm deformed bars in the CHB wall.

2) Standard construction implementation

- For Philippine CHB masonry structures, the application of filling mortar is a critical and important aspect of construction because the backyard factory-made CHB itself has poor strength. Therefore, correct standards of construction must be followed. Mortar fill should be properly compacted, mixing and pouring should be homogeneous and properly timed for good bonding of mortars.
- The vertical and horizontal reinforcing bars should use standard size and spaced at 400 mm on vertical and 600 mm horizontal as each three layer of blocks.

Through the shaking table test, the actual behavior until collapse, as well as critical vulnerable points of CHB masonry structure were demonstrated.

2.5 Conclusion

In this Chapter 2, three types of commonly built masonry construction were tested by shaking table tests to investigate the actual behavior until the structure collapsed.

The typical failure mechanism[11] were demonstrated through in this Chapter 2, as follows:

1) In plane failure mode (See Fig.79, 80, 81,82)

Wall is termed a shear wall. Shear walls are the main lateral earthquake resistant elements in many buildings. The damage modes of unreinforced shear wall is cracks diagonally due to shear stress. The sections at the level of the top and bottom of opening are found to be the worst stressed in tension as well as in compression.

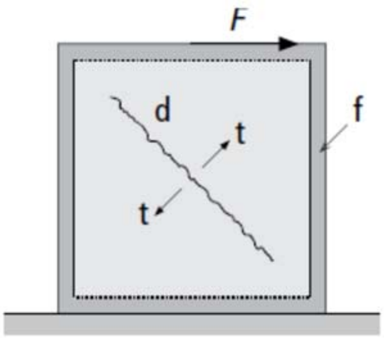


Fig. 79 Failure mechanism of free standing walls
Wall with moderate aspect ratio in guidelines[53]

Fig. 81 Diagonal cracks on actual building in Pakistan

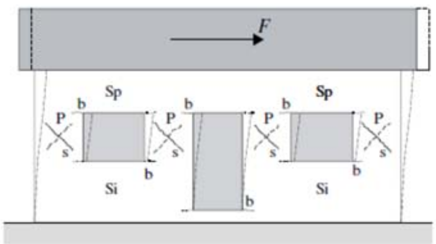


Fig. 80 Cracks and stress of a shear wall with openings
deflection and cracks
in Guidelines[53]

Fig. 82 Diagonal cracks in shaking table test of South-Asian model structure in Chapter 2.2

[11] Guidelines for Earthquake Resistant Non-Engineered Construction, IAEE, 2014, p36-38

2) Out-of-plane failure mode (See Fig.83, 84, 85,86)

The combination of walls as enclosure, the one direction of force act as shear walls, there are resistance against the collapse of wall. However, the other direction, the walls are subjected to the inertia force on their own mass. Near the vertical edges, the wall will carry reversible bending moments in the horizontal plane for which the masonry has little strength. A wall that is too wide or too high in comparison to its thickness (the ratio of the width of the wall to this thickness) ratio of the width are vulnerable.

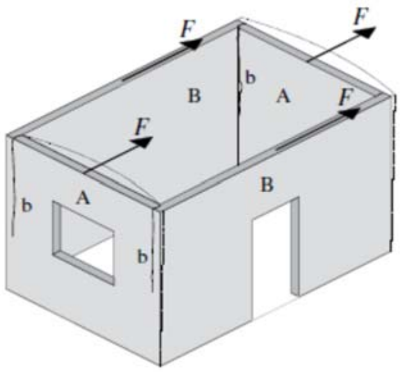


Fig.83 Failure mechanism of wall enclosure without roof in guidelines[53]

Fig. 84 Out-of-plane failure in shaking table test of South-East Asian model structure in Chapter 2.3

Fig. 85 Out-of-plane failure on actual building in Indonesia

Fig. 86 Out-of-plane failure in shaking table test of CHB model structure in Chapter 2.4

3) Overturning as out-of-plane of top of wall as Gable wall (See Fig.87, 88, 89, 90)

The force acting on the mass of the wall tends to overturn. The seismic of the wall is related to its weight and tensile strength of mortar and it is obviously very small. If the top of wall does not get much support, in this case, may overturn unless built strong enough in the vertical bending as a cantilever.

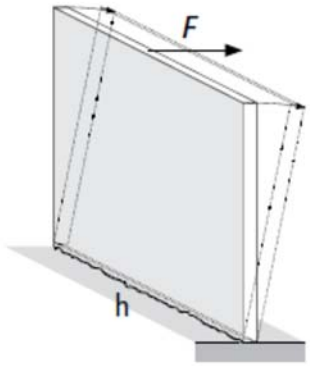


Fig. 87 Out-of-plane failure in guidelines[53]

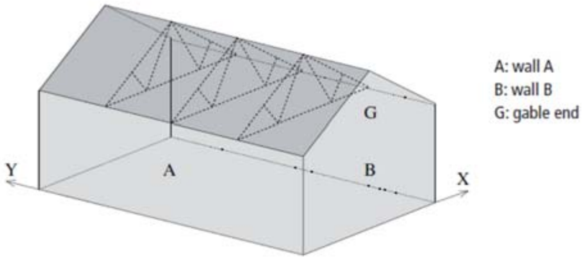


Fig. 88 Gable wall in guidelines[53]

Fig. 89 Out-of-plane failure of gable wall on actual building in Indonesia

Fig. 90 Out-of-plane failure of gable wall in shaking table test of CHB model structure in Chapter 2.3

These critical points of vulnerability of masonry structure were reconfirmed through this Chapter 2. Furthermore, for the improvement of seismic performance of masonry structures, the retrofitting methods were proposed in Chapter 3.

Chapter 3 Retrofitting non-engineered construction

Chapter 3 Retrofitting non-engineered construction

3.1 Retrofitting method for masonry structure in developing countries.

In Chapter 2, the critical points of vulnerable of commonly masonry structure as non-engineered construction were figured out through a study of shaking table tests.

This chapter explains the development a retrofitting method which considered Affordability, Feasibility and Adaptability, as described in Chapter 1.5.

Target are existing and new construction of low-rise building as one or two stories, mostly ordinary houses in developing countries.

Since 2006, the author has been studying wire mesh retrofitting method as jacketing and bandaging using wire mesh for brick masonry constructions in several countries where brick masonry is commonly used. In this chapter, the effectiveness of these wire mesh retrofitting method through experimental studies is discussed. Figure 91 shows type of wire mesh.

The proposed retrofitting method is using galvanized wire mesh which is easily available in developing countries, even in rural areas. These kind of mesh is used for chicken cage, which is available in local market. That being the case, it is not expensive material to common people in developing countries.

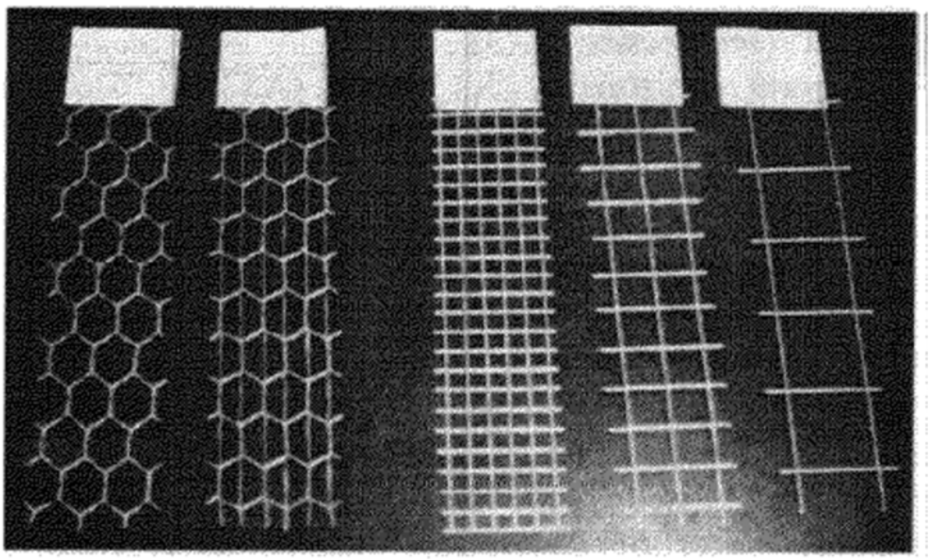


Fig. 91 Types of wire mesh[54]

[54] ACI549, Guilde for Design, Construction, and Repair of Ferrocement, Reapproved 1999, p549.1R-6

3.2 As preliminary study: Shaking table test for retrofitting methods of four brick masonry columns

3.2.1 Outline

As preliminary study, the comparative study of shaking table test for retrofitting methods for masonry structure was conducted at NIED, by NIED and Mie University in 14^{th} January, 2011.

The purpose is to investigate the behavior of the proposed retrofitting method for masonry construction using wire mesh.

Four models of brick masonry columns were constructed on the shaking table, shown in Fig.92.

- **Model A**: Unreinforced brick masonry column.
- **Model B**: Brick masonry column inserted 10 mm diameter rebar in the middle of column.
- **Model C**: Brick masonry column wrapped by hexagon-stitched wire mesh, it is called "Chicken-wire mesh".
- **Model D**: Brick masonry column wrapped by grid-stitched wire mesh, it is similar the wire mesh used in Indonesia.

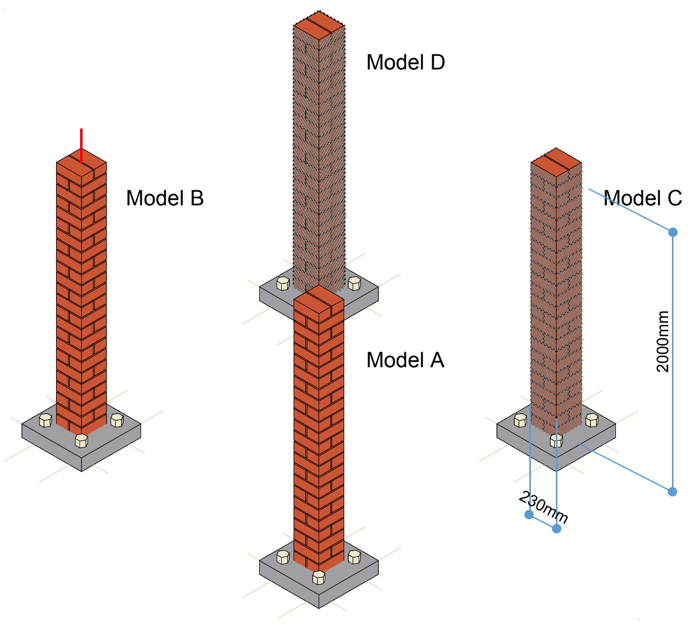


Fig.92 Isometric of four columns

The overall dimensions of the columns were 230 mm plan and approximately 2000 mm height, as 26 layers using Japanese bricks which dimension was to be 230 mm x 110 mm x 60 mm. The ratio of cement and sand was 1 / 4 by volume with 15 mm thickness.

Model A: Unreinforced brick masonry column	**Model B**: Brick masonry column inserted 10 mm diameter rebar in the middle
 	 
Model C: Brick masonry column wrapped by hexagon-stitched wire mesh, it is called chicken wire mesh	**Model D**: Brick masonry column wrapped by grid stitched wire mesh, it is similar used in Indonesia.
  Mesh fixed by screw plug @ 30 cm.	  Mesh fixed by screw plug @ 30 cm.

Fig. 93 Details of four column models

Figure 93 shows detail of each models. The models were not covered by finishing. In particular, Model C and Model D were only “Wrapping with wire mesh”. This test aims to investigate effectiveness of wrapping with wire mesh for strengthening the unity/confinement and increasing ductility.

3.2.2 Inputs motions

Table 11 shows the schedule of excitation test with input motions of the shaking table test. These input motions were based 1995 Kobe earthquake (JMA Kobe NS).

3.2.3 Measurement systems

Accelerometers were installed at 5 points on the specimen and on the shaking table. Response displacement was measured by 3D image processing. LED makers as point of measuring were installed at 22 points on the specimen and on the shaking table. After each inputs, the location and size of cracks on the specimen were sketched for recording the progress of cracks development.

Table 11 List of input motions

Date	No.	Input wave(*1)	Time scale	Scale	Displacement	Acceleration	Time	Recording		
				(%)	(± mm)	(gal)	(Sec)	Acc.	3D image	video cam
14th Jan, 2011	1	Test	-	-	-	-	-	✔	-	-
	2	Zero	-	-	-	-	-	✔	-	-
	3	Step 01	-	-	1	-	60	✔	-	-
	4	JMA Kobe NS	1	14	25	117	60	✔	✔	✔
	5	Step 02	-	-	1	-	60	✔	-	-
	6	JMA Kobe NS	1	28	50	235	60	✔	✔	✔
	7	Step 03	-	-	1	-	60	✔	-	-
	8	JMA Kobe NS	1	42	75	373	60	✔	✔	✔
	9	Step 04	-	-	1	-	60	✔	-	-
	10	JMA Kobe NS	1	57	100	470	60	✔	✔	✔
	11	Step 05	-	-	1	-	60	✔	-	-
	12	JMA Kobe NS	1	71	125	588	60	✔	✔	✔
	13	Step 06	-	-	1	-	60	✔	-	-
	14	JMA Kobe NS	1	85	150	706	60	✔	✔	✔
	15	Step 07	-	-	1	-	60	✔	-	-
	16	JMA Kobe NS	1	100	175	833	60	✔	✔	✔
	17	Step 08	-	-	1	-	60	✔	-	-
	18	JMA Kobe NS	1	110	200	980	60	✔	✔	✔

*1. Input waves were based on Kobe earthquake.

3.2.4 Observations of main inputs

First of all, in order to check the vibration characteristic of the models, a rectangular wave with 1mm amplitude and 0.05 Hz was inputted into the shaking table.

・**Input No.4**

Model A: The joint mortar between 4th layer and 5th layer separated.

Model C: The joint mortar between 9th layer and 10th layer separated.

・**Input No.6**

Model A: Locking from 5th layer.

Model C: Locking from 10th layer.

・**Input No.8**

<u>Model A: Totally collapsed</u>. Overturning from 5th layer was occurred after large locking.

Model B: The joint mortar between 1st layer and 2nd layer separated.

Model C: Severe rocking was observed close to overturning, but it did not overturn.

・**Input No.10**

Each remaining models were rocking, the displacement became increased.

・**Input No. 12 and No.14**

Displacement of each columns increased.

・**Input No. 16**

Model B: Displacement increased.

<u>Model C: Collapsed.</u> Overturning occurred slowly.

Model D: Displacement increased.

・**Input No. 18**

<u>Model B: Collapsed.</u> Displacement increased, then, overturned from 2nd layer.

<u>Model D: Collapsed.</u> Displacement increased, then, overturned from 3rd layer.

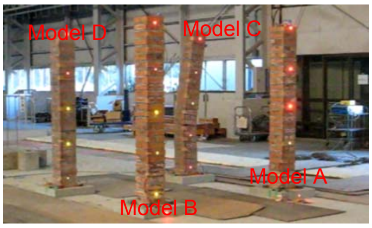
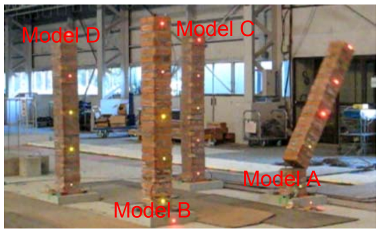
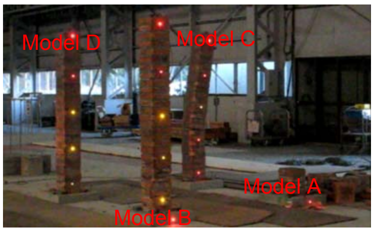
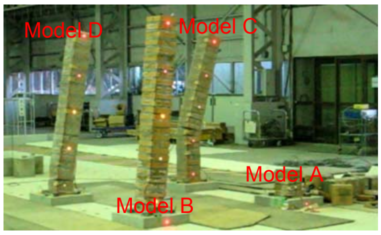
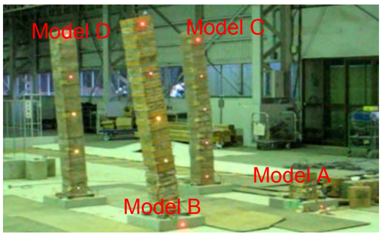
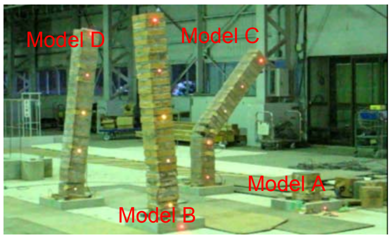
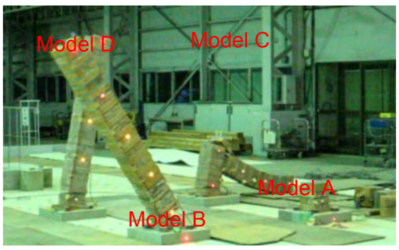
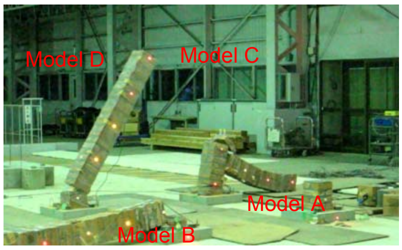
<table>
<tr><td></td><td></td></tr>
<tr><td>Input No.8 (JMA Kobe Scale 42 %, Disp. 75 mm)
Model C had large displacement.</td><td>
Then, Model A was overturned from 5th layer.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Input No. 10(JMA Kobe Scale 57 %, Disp. 100 mm)
Each models were rocking.</td><td>Input No. 12(JMA Kobe Scale 71 %, Disp. 125 mm)
Displacement of each columns increased.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Input No. 14(JMA Kobe Scale 85 %, Disp. 150 mm)
Displacement of each columns increased.</td><td>Input No. 16(JMA Kobe Scale 100 %, Disp. 175 mm)
Model C was over turned slowly.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Input No.18(JMA Kobe Scale 110 %, Disp. 175 mm)
Model B was collapsed from 2nd layer.</td><td>
Then, Model D also overturned from 3rd layer.</td></tr>
</table>

Fig.94 Sequence of each columns of main inputs

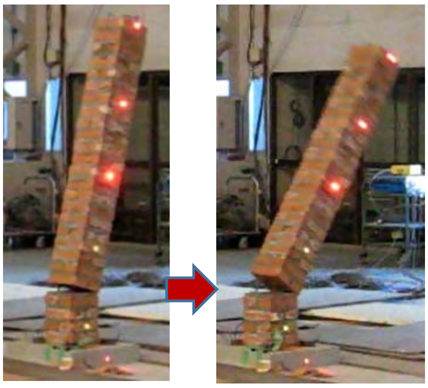
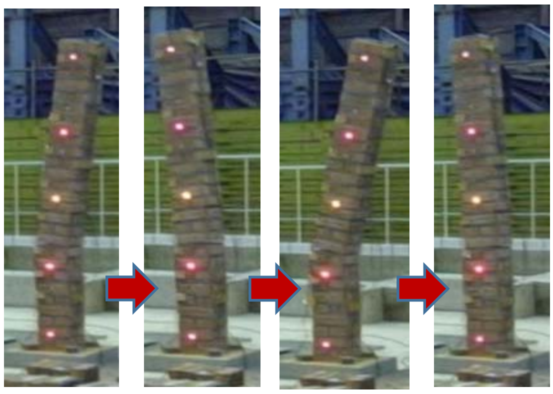
Model A: Unreinforced brick masonry column	**Model C**: Brick masonry column wrapped by hexagon-stitched wire mesh, it is called chicken-wire mesh
	

Fig.95 Sequence of Model A and Model C during input No.8

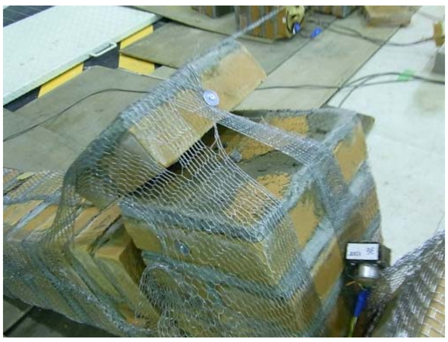
Model A: Unreinforced brick masonry column	**Model B**: Brick masonry column inserted 10 mm diameter rebar in the middle
	
Model C: Brick masonry column wrapped by hexagon-stitched wire mesh, it is called chicken-wire mesh	**Model D**: Brick masonry column wrapped by grid-stitched wire mesh, it is similar used in Indonesia.
	

Fig.96 Condition of each model after test

3.2.5 Outcomes

The result of the test clearly shows that wire mesh jacketing as retrofitting provide elastic effectiveness for brittle brick masonry construction, that was similar in effectiveness to inserting reinforcing bars, shown in Fig.94, 95 and 96.

These retrofitting is able to avoid the possibility of a brittle failure mode of brick masonry construction, and the ductility of brick masonry was improved by wire mesh jacketing.

Furthermore, an important part of this argument is that delaying collapse provides time to escape to get out of the house, meaning saving a person’s life.

3.3 Full-scale shaking table test of brick masonry house retrofitted using wire mesh full-jacketing

3.3.1 Outline

In order to investigate the seismic behaviors of Indonesian brick masonry construction with or without retrofitting using wire-mesh jacketing, the shaking table test was conducted as a collaborative research between NIED and Mie University in 25th June, 2012. In particular, the aim of this study is to assess the effects on seismic performance of the retrofitting method which using ferrocement overlay with galvanized wire mesh based on proposed method.

The retrofitting method taken from guild books "Retrofitting Simple Buildings Damaged by Earthquakes" by Teddy Boen, 2010[55]. The author and Dr. Teddy Boen decided model of this test as below:

The overall dimension of the model were 3600 mm x 3600 mm in plan and 2900 mm in height with concrete foundation, shown in Fig.97. The model made of bricks with mortar joints, the bricks were imported from Padang, Indonesia, to produce the typical brick houses. The size of these brick was defined to be 210 mm x 100 mm x 50 mm.

Two sides of South and West walls were retrofitted, both faces inside and outside of brick walls were covered with mortar as full jacketing. The wire mesh of 25 mm grid galvanized iron mesh was imported from Indonesia. The other sides of East and North walls were not retrofitted, only mortar finishing. Figures 98 and 99 show drawings of model. And the construction process is shown in Fig.100.

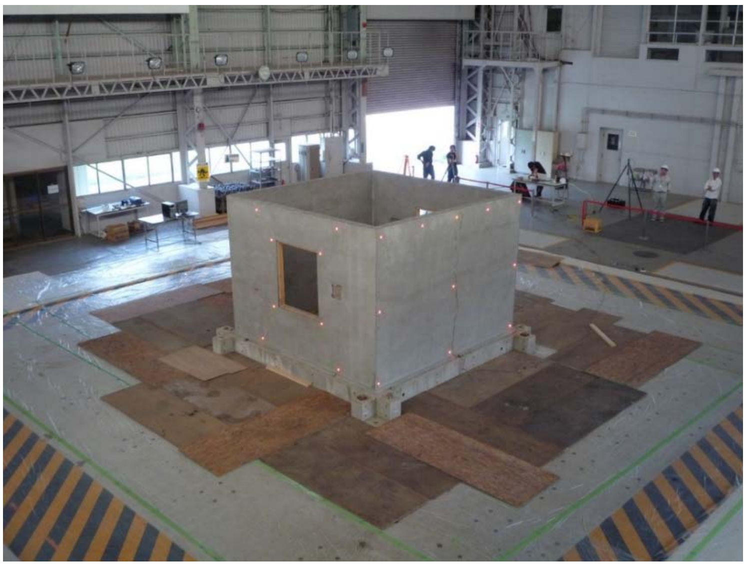


Fig.97 Model on the shaking table

[55] Teddy Boen, Publish by UNCRD, Retrofitting Simple Buildings Damaged by Earthquakes, 2010.

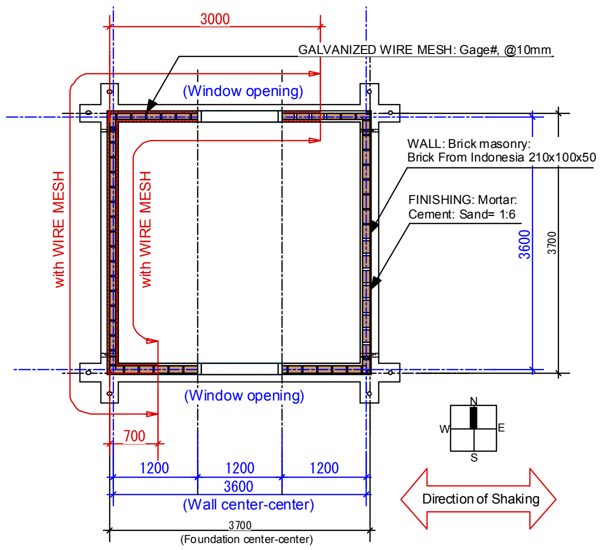


Fig.98 Plan of Model

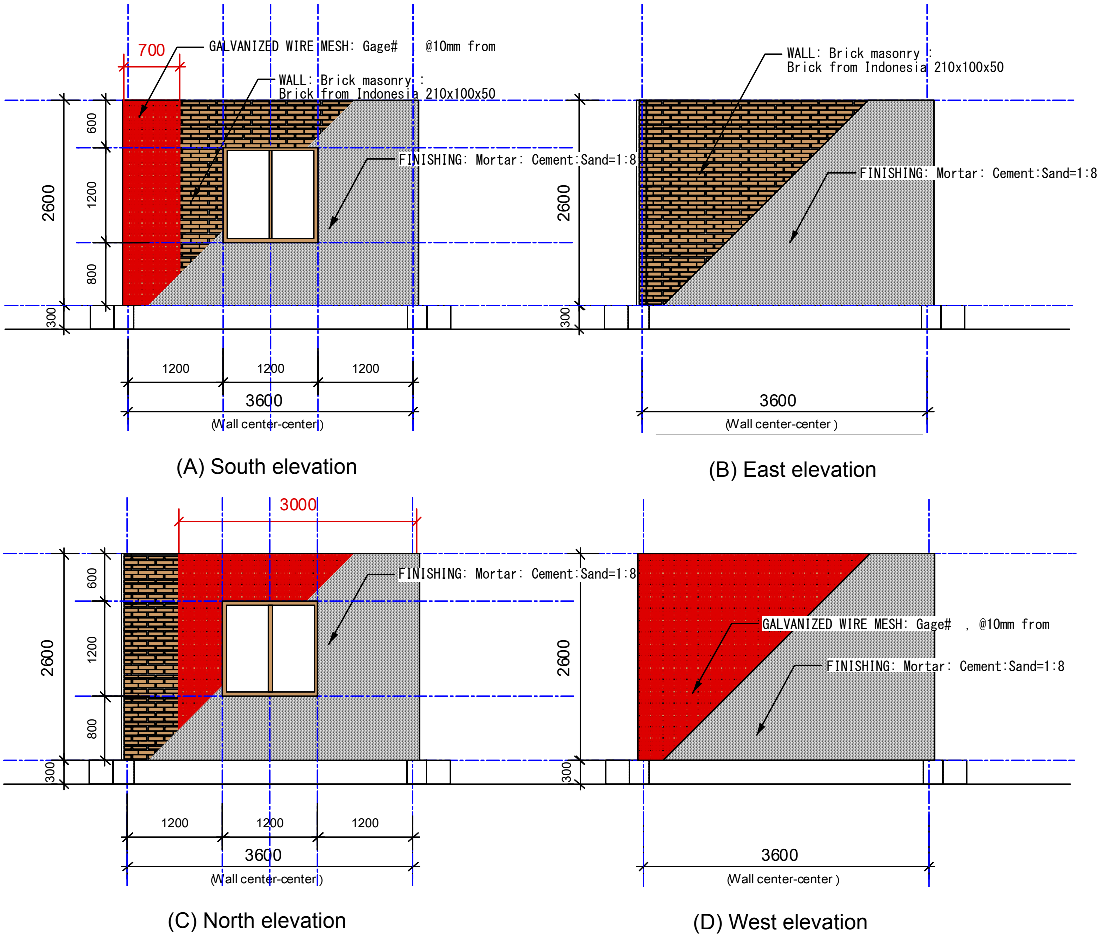


Fig.99 Elevation of Model

(A) Process of construction

(B) Four walls were almost complete

(C) Start to install wire mesh

(D) Wire-mesh tied by 1 mm tie wire inside and outside

(E) With wire mesh on South and West walls

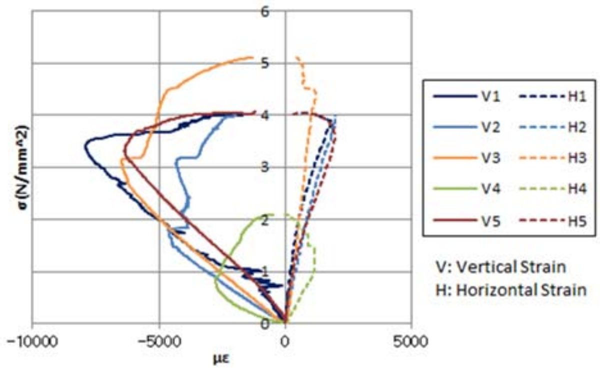
(F) No wire mesh on North and East walls

Fig.100 Process of construction of Model

3.3.2 Material properties

1) Brick

The dimension of Padang's brick was defined to be 210 mm x 100 mm x 50 mm, however, the results of measurement of ten bricks showed that the average was 196.1 mm x 98.6 mm x 53.5 mm. The average compressive strength was 3.9 N/mm^2. The photo of the test and the σ-ε curve are shown in Fig.101.



(A) σ − ε curve

(B) Specimen during test

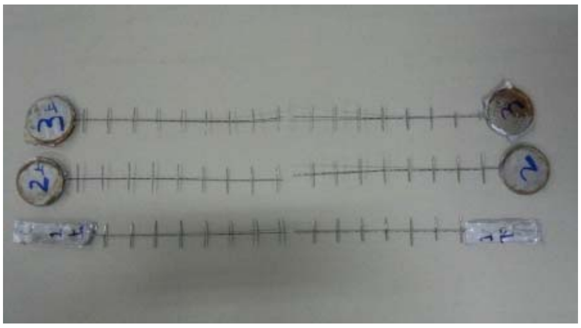
Fig. 101 Properties of brick

2) Mortar

The ratio of cement and sand was 1 / 8 by volume and the water cement ratio was 120 % which followed common practice in these area. The average compressive strength was 7.7 N/mm^2.

3) Wire mesh

The galvanized wire mesh imported from Indonesia. The dimension was 1mm diameter. The average tensile strength was 767.1 N/mm^2 which area of cross section was 0.785 mm^2. (See Fig.102)



(A) Specimen after test

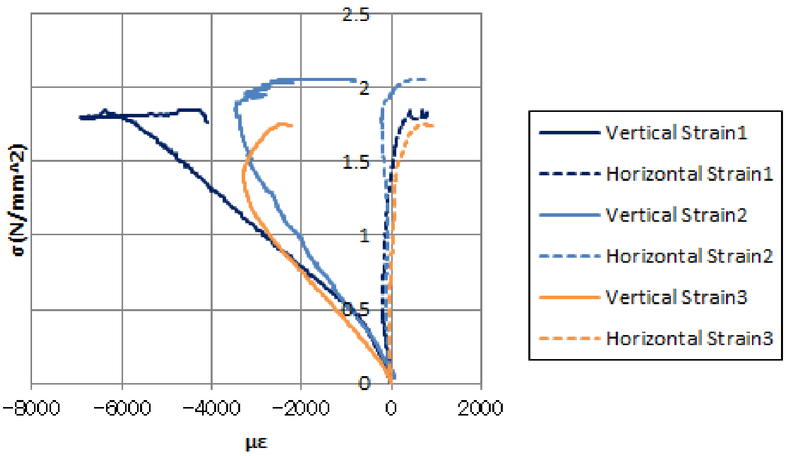
(B) Specimen during test

Fig.102 Photos of wire mesh tensile test

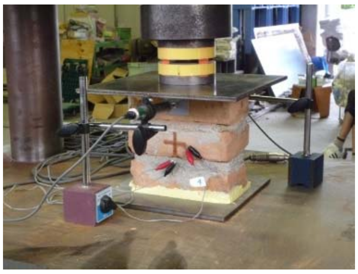
4) Prism of masonry units

To know the strength of the prism composed of three layers of the brick and joint mortar. Compressive and shear tests were conducted in specimens were examined in each test.

The average compressive strength was 1.9 N/mm^2. The shear strength was 0.65 N/mm^2. The tensile strength was 0.37 N/mm^2. The photos of the test and the σ-ε curve are shown in Fig.103.



(A) σ − ε curve



(B) Compressive test

(C) Shear test

(D) Tensile test

(E) Specimen of tensile test

Fig.103 Properties of masonry units

3.3.3 Inputs motions

Table 12 shows the schedule of excitation with input motions of the shaking table test. These input motions were based on 1995 Kobe earthquake, such as JMA Kobe NS and JR Takatori (See Fig.105), and 2011 off the Pacific coast of Tohoku Earthquake, such as K-NET Ojiya. (See Fig.104) Figure 106 shows the acceleration response spectra of K-NET Ojiya and JR Takatori wave.

Table 12 List of input motions

Date	No.	Input wave(*1)	Time scale	Scale (%)	Displacement (± mm)	Acceleration (gal)	Time (Sec)	Recording Acc.	Recording 3D image	Recording video cam
25th Jun, 2012	1	Test	-	-	-	-	-	✔	-	-
	2	Zero	-	-	-	-	-	✔	-	-
	3	Step 01	-	-	1	-	60	✔	-	-
	4	Sweep 3-15Hz	-	-	1	-	60	✔	✔	✔
	5	Step 02	-	-	1	-	60	✔	-	-
	6	Sweep 9-14Hz	-	-	1	-	60	✔	✔	✔
	7	Step 03	-	-	1	-	60	✔	-	-
	8	Sweep 13-17Hz	-	-	1	-	60	✔	✔	✔
	9	Step 04	-	-	1	-	60	✔	-	-
	10	Sign 10Hz	-	-	1.5		60	✔	✔	✔
	11	Step 05					60	✔		
	12	JMA Kobe NS (*1)	1	50	87.5	410	60	✔	✔	✔
	13	Step 06	-	-	1	-	60	✔	-	-
	14	JMA Kobe NS	1	100	175	833	60	✔	✔	✔
	15	Step 07	-	-	1	-	60	✔	-	-
	16	K-NET Ojiya	1	110	-	-	60	✔	✔	✔
	17	Step 08	-	-	1	-	60	✔	-	-
	18	JR Takatori	1	100	-	-	60	✔	✔	✔
	19	Step 09	-	-	1	-	60	✔	-	-

*1. Input waves were based on Kobe earthquake. (

✔ Recording done

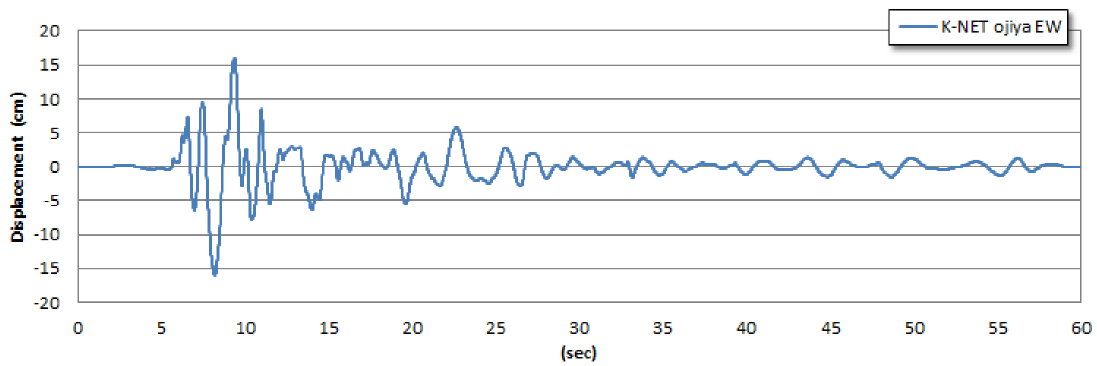


Fig.104 Input motion of K-NET Ojiya wave, Japan (Input No.16)

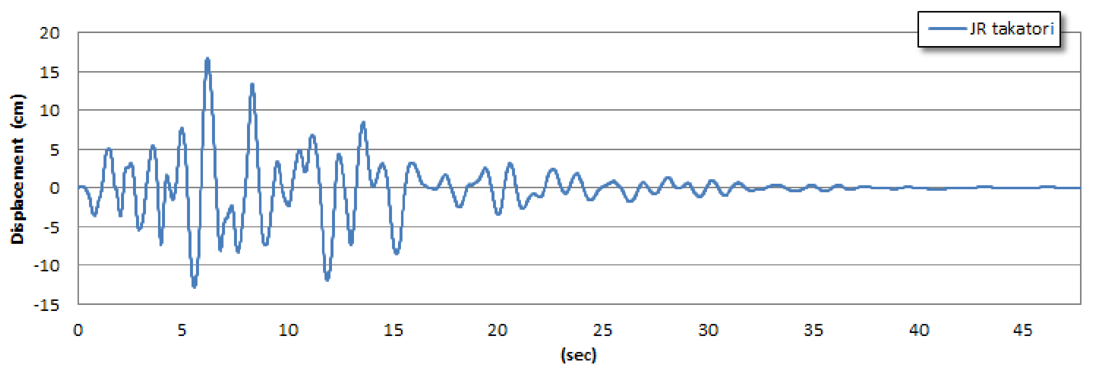
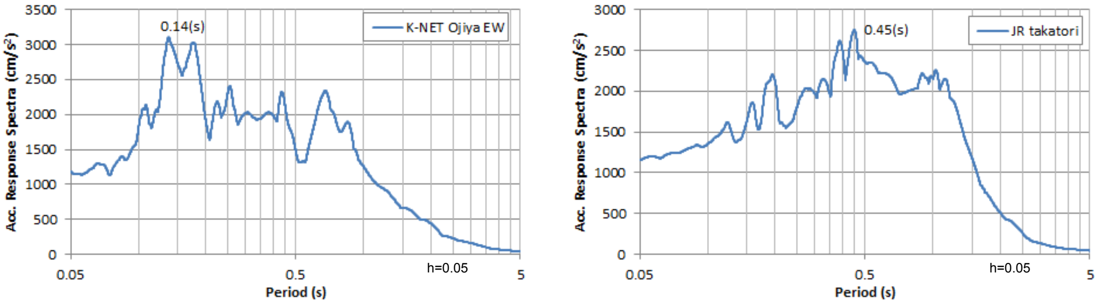


Fig.105 Input motion of JR Takatori wave, Japan (Input No.18)



(A) (B)

Fig.106 Acceleration response spectra of K-NET Ojiya (A) and JR Takatori (B) wave

3.3.4 Measurement systems

Accelerometers were installed at 3 points on the specimen and on the shaking table. Response displacement was measured by 3D image processing. LED makers as point of measuring were installed at 41 points on the specimen and on the shaking table. After each inputs, the location and size of cracks on the specimen were sketched for progress of developing cracks.

3.3.5 Observations of main inputs

At first, in order to check the vibration characteristic of the models, some sweep waves with 3-15 Hz, 9-14 Hz, and 13-17 Hz were inputted into the shaking table. However, it was difficult to find natural period of mode.

- **Input No.4 (Sweep 3-15Hz)**

  East wall (Non Retrofitting: NRF): Not damaged.

  South wall (Non Retrofitting: NRF): Minor cracks were initiated at the corner of opening.

  West wall (Retrofitted: RF): Not damaged.

  North wall (Retrofitted: RF): Minor cracks were initiated at the corner of opening.

- **Input No.12 (JMA Kobe 50%)** Crack pattern shown in Fig.107.

  East wall (NRF): Minor crack occurred.

  South wall (NRF): Cracks increased.

  West wall (RF): Minor crack occurred.

  North wall (RF): A part of the East side of the wall had vertical cracks.

- **Input No.14 (JMA Kobe 100%)** Crack pattern shown in Fig.108.

  East wall (NRF): Totally collapsed. Part of the East side collapsed.

  South wall (NRF): Non retrofitted wall, the corner of the East wall collapsed.

  West wall (RF): Minor crack were visible.

  North wall (RF): A part of the East wall collapsed.

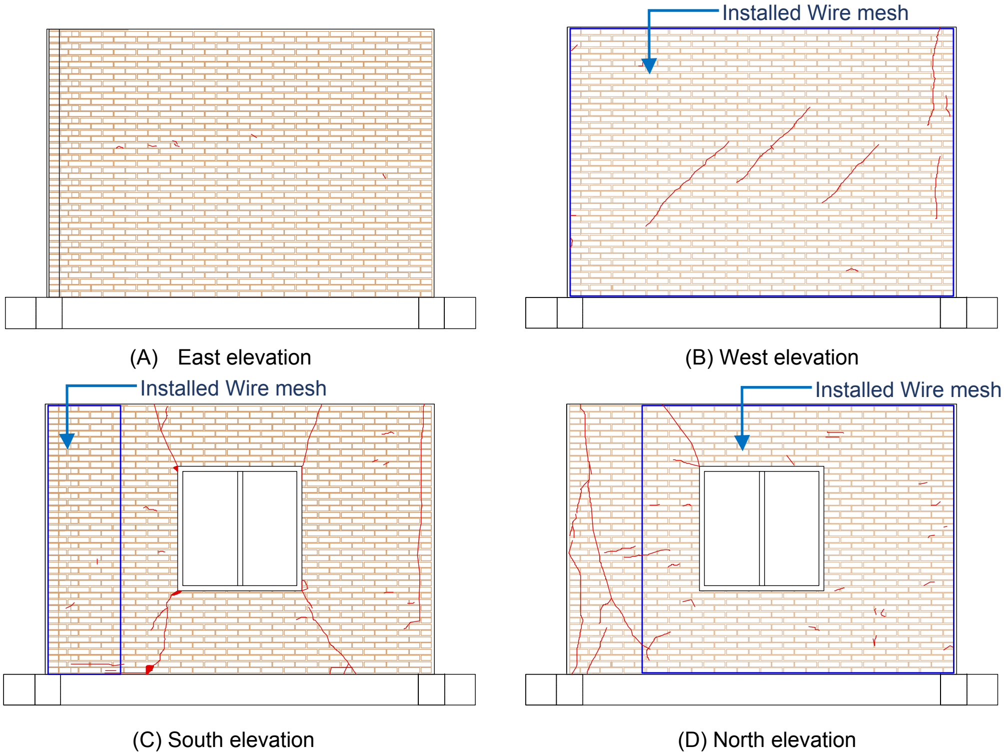


Fig. 107 Crack pattern of input No.12 (JMA Kobe NS 50%)

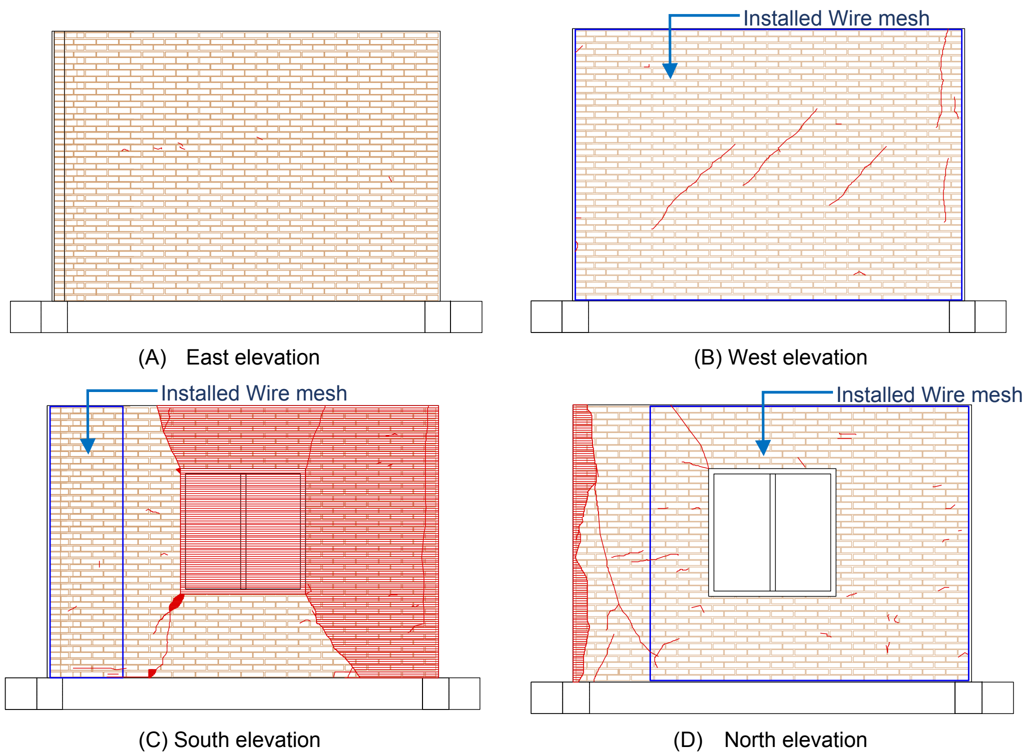


Fig. 108 Crack pattern of input No.14 (JMA Kobe NS 100%)

3.3.6 Outcomes

The shaking table tests clearly showed that the retrofitting using wire mesh was effective in preventing the collapse of the wall.

It was considered that this kind of collapse of the model structures was affected by the overturning motion. Predominant cracks in in-plane direction (the same direction as the shaking) were initiated from the corner of the opening, shown in Fig.109. Furthermore, cracks occurred easily in the unreinforced wall due to in-plane loading (North and South walls).

The natural frequency became lower on both model structures retrofitted with wire mesh and without wire mesh as the input level was larger and the cracks were developed. Such phenomenon was caused by stiffness reduction due to the development of cracks.

The maximum deformations in out-of-plane direction were 125 mm and 55 mm at the non-reinforced wall and at the reinforced wall, respectively, shown in Fig.110.

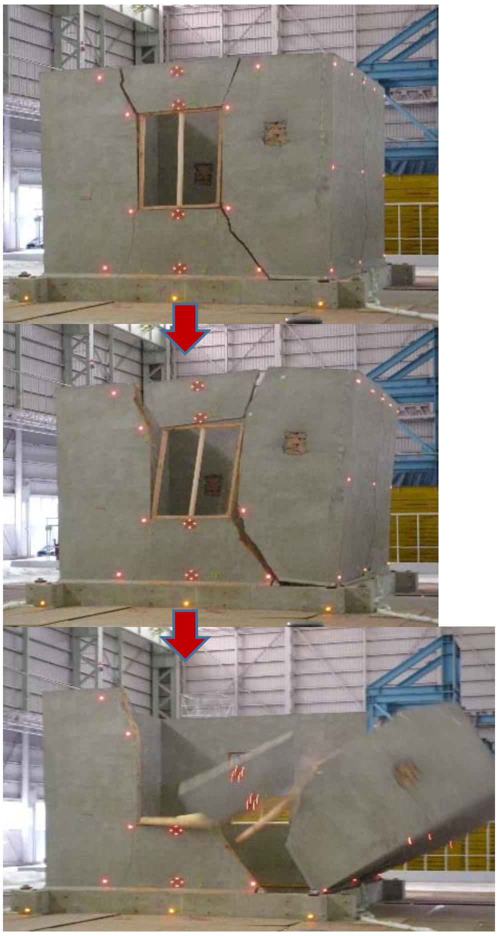
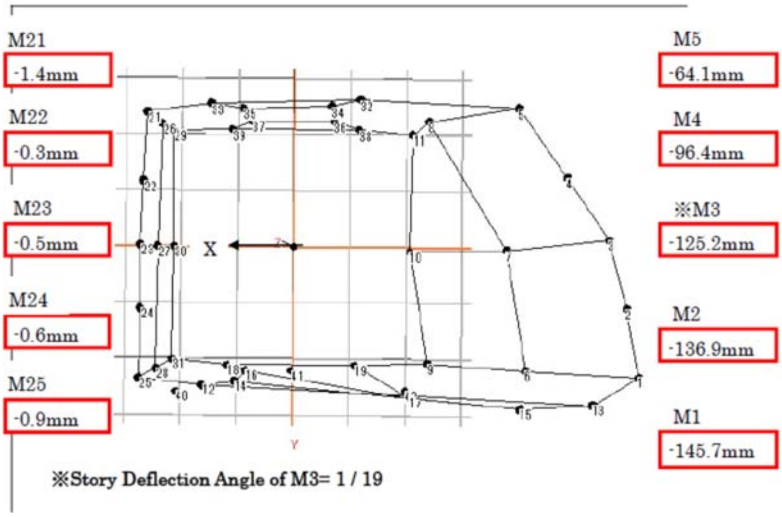
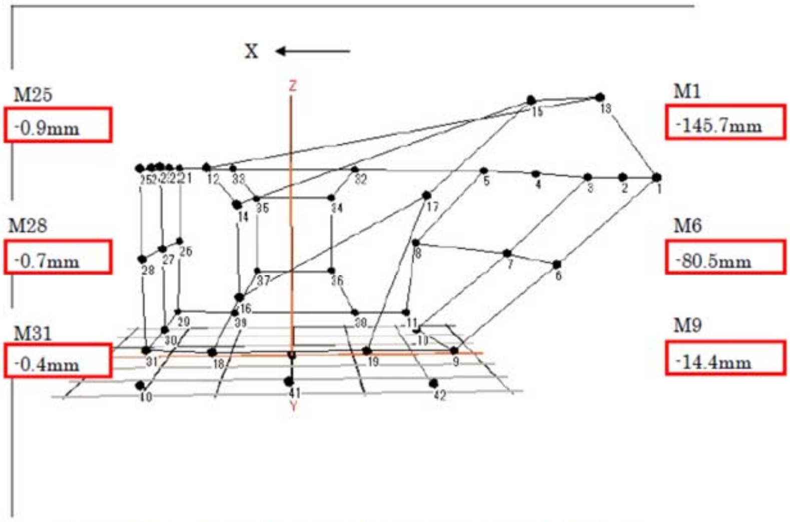


Fig.109 Sequence of collapsing of input No.14 (JMA Kobe NS 100%) from South view



The maximum relative deformation (M3: The maximum deformation)



The maximum relative deformation (M3: The maximum deformation)

Fig.110 Maximum deflection of out-of-plane of input No.14 (JMA Kobe NS 100%)

3.4 Full-scale shaking table test of brick masonry house retrofitted using wire mesh bandaging

3.3.3 Outline

In order to investigate the seismic behaviors of Indonesian brick masonry construction with using wire-mesh bandaging or without retrofitting, a shaking table test was conducted as a collaborative research between NIED and Mie University in 4th and 5th June, 2014.

The main aim of this study is to assess the effects of the retrofitting by bandaging with wire mesh when shaken by earthquakes and to demonstrate to the people the effectiveness of such retrofitting method.

The retrofitting model was decided through discussion in collaboration with Dr.Teddy Boen, and the method of this model was also based on the guidebook "Retrofitting Simple Buildings Damaged by Earthquakes" by Teddy Boen, 2010[56] and "Manual for Retrofitting Brick Masonry House for Seismic Safety" by author, 2008[57].

The overall dimension of the models were 3700 mm x 3700 mm in plan and 2600 mm in height. (See Fig.111) The walls of model consists of bricks with mortar joints. The bricks were imported from near Jakarta, Indonesia, the similar bricks used to construct houses in Indonesia. The size of brick was to be 210 mm x 100 mm x 50 mm. Figures 112 and 113 show isometric and drawings of model structures.

[56] Teddy Boen, Publish by UNCRD, Retrofitting Simple Buildings Damaged by Earthquakes, 2010
[57] Hiroshi Imai, Published by SNS International Disaster Prevention Support Center, Manual for Retrofitting Brick Masonry House for Seismic Safety 2008.

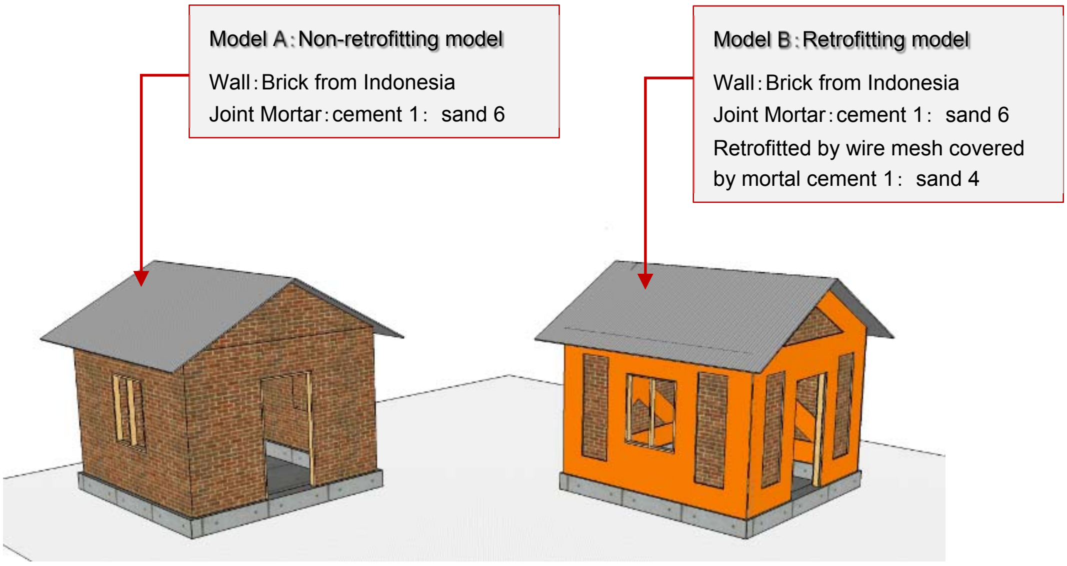


Fig.112 Isometric of models

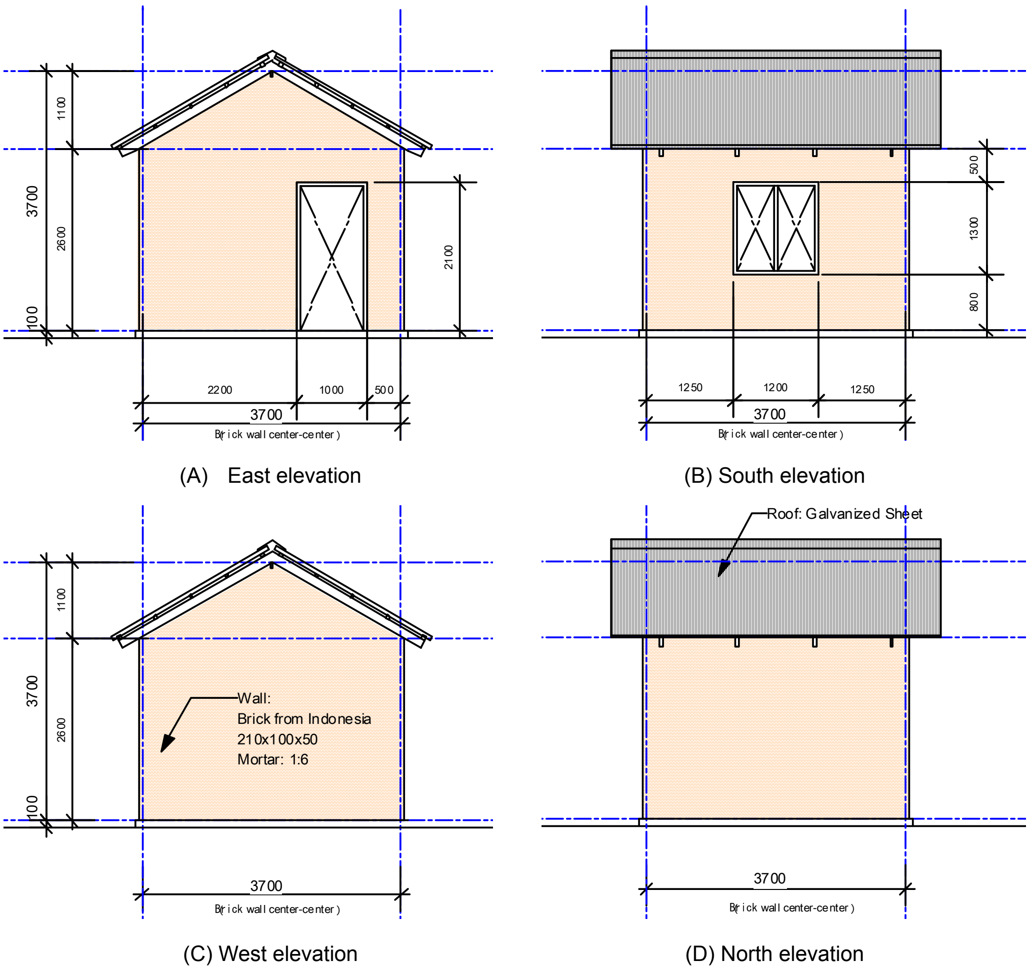


Fig.113 Elevation of Model A

3.3.4 Retrofitting method

In chapter 3.2, the effectiveness of retrofitting method which using ferrocement overlay as full jacketing with galvanized wire mesh were demonstrated. Moreover, in order to raise an affordability, the retrofitting method which using ferrocement overlay as bandaging with galvanized wire mesh was selected. The bandaging were proved the both side (outside and inside) of walls as sandwich and these were stitched by wire. (See Fig.114 – 117)

1) Placing of bandaging

Through the full-scale shaking table tests in Chapter 2, the typical failure mechanism of ordinary masonry constructions were investigated. The bandaging placed in consideration of the vulnerable points of masonry structure.

A) Diagonal on the walls

The shear strength of wall is main lateral earthquake resistant elements in masonry building, therefore, the bandaging was provided diagonals on the walls to improve shear strength.

B) Around openings

The stresses in tension as well as in compression are concentrated in the openings during shaking.

C) Top and Bottom of walls

The bandaging was provided horizontal as tie at the top as well as the bottom level of walls, in order to make a one box that helps to make them behave as a single unit.

D) Corner of walls

To avoiding separation of walls, the bandaging were provided vertical at the corner of walls that helps to hold the wall together.

E) Gable walls

The gable wall is one of vulnerable parts of masonry structure. To avoiding to overturning failure, the bandaging were provided from bottom to top of wall as vertical tie.

2) Materials

The wire mesh was imported from Indonesia. Wire mesh was made by galvanized welded iron. The size was 25 mm grid 1 mm diameter. The material properties shown in 3.4.3-3). Usually, the wire mesh is being sold as rolled that size is 1 m X 23 m in market. With consideration to the size of wire mesh and scale of building, the bandage width was decided to be 500 mm tie. The finishing mortar only placed in the bandaging area with wire mesh.

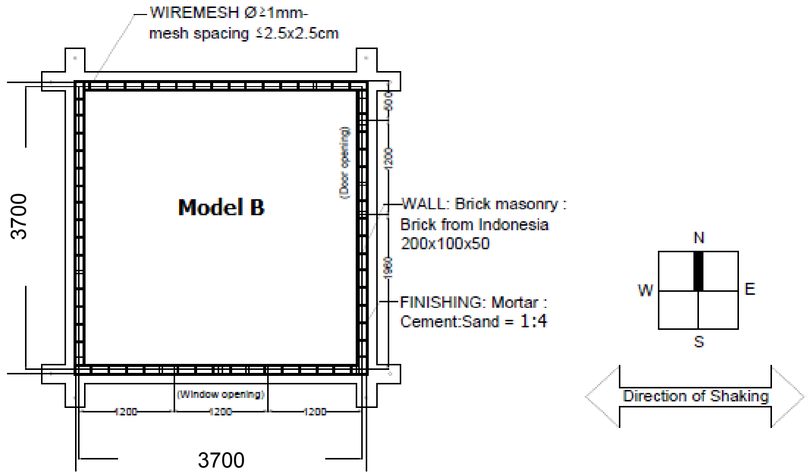


Fig. 107 Plan of Model B

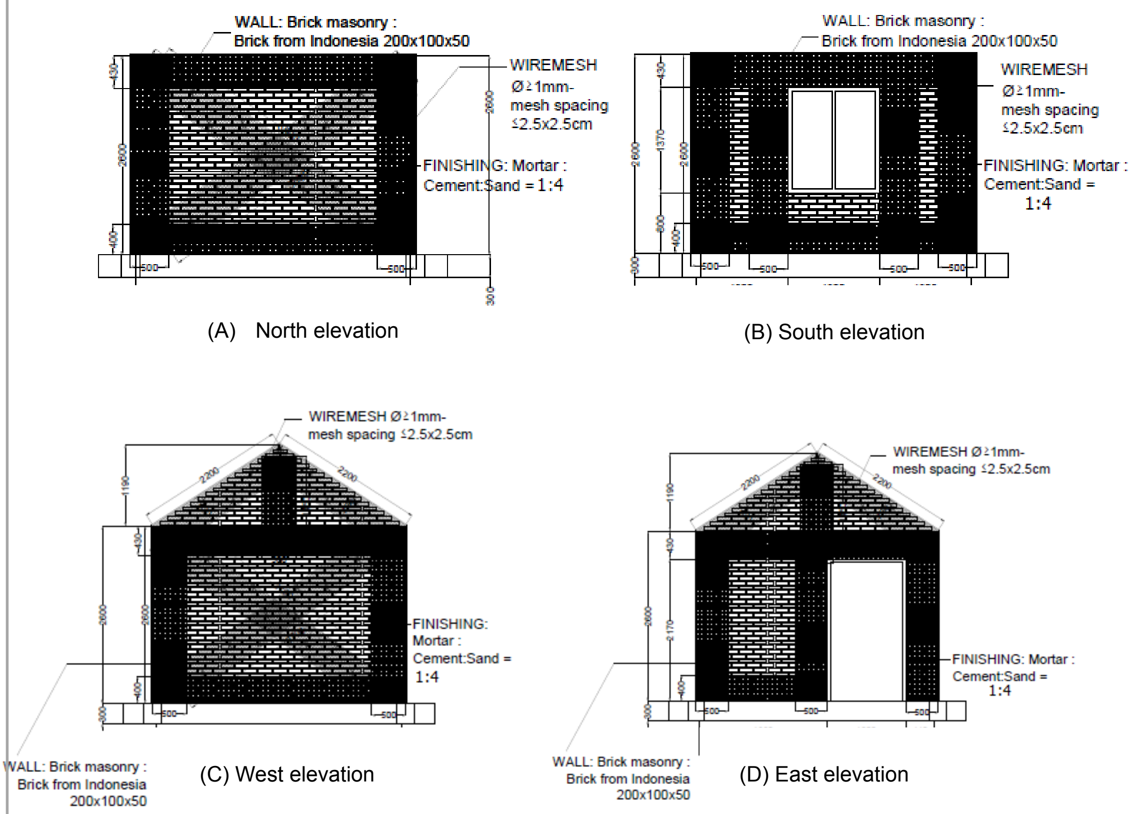


Fig.114 Elevation of Model B: Retrofitted using wire mesh[58]

[58] Drawn by Teddy Boen, 2014,

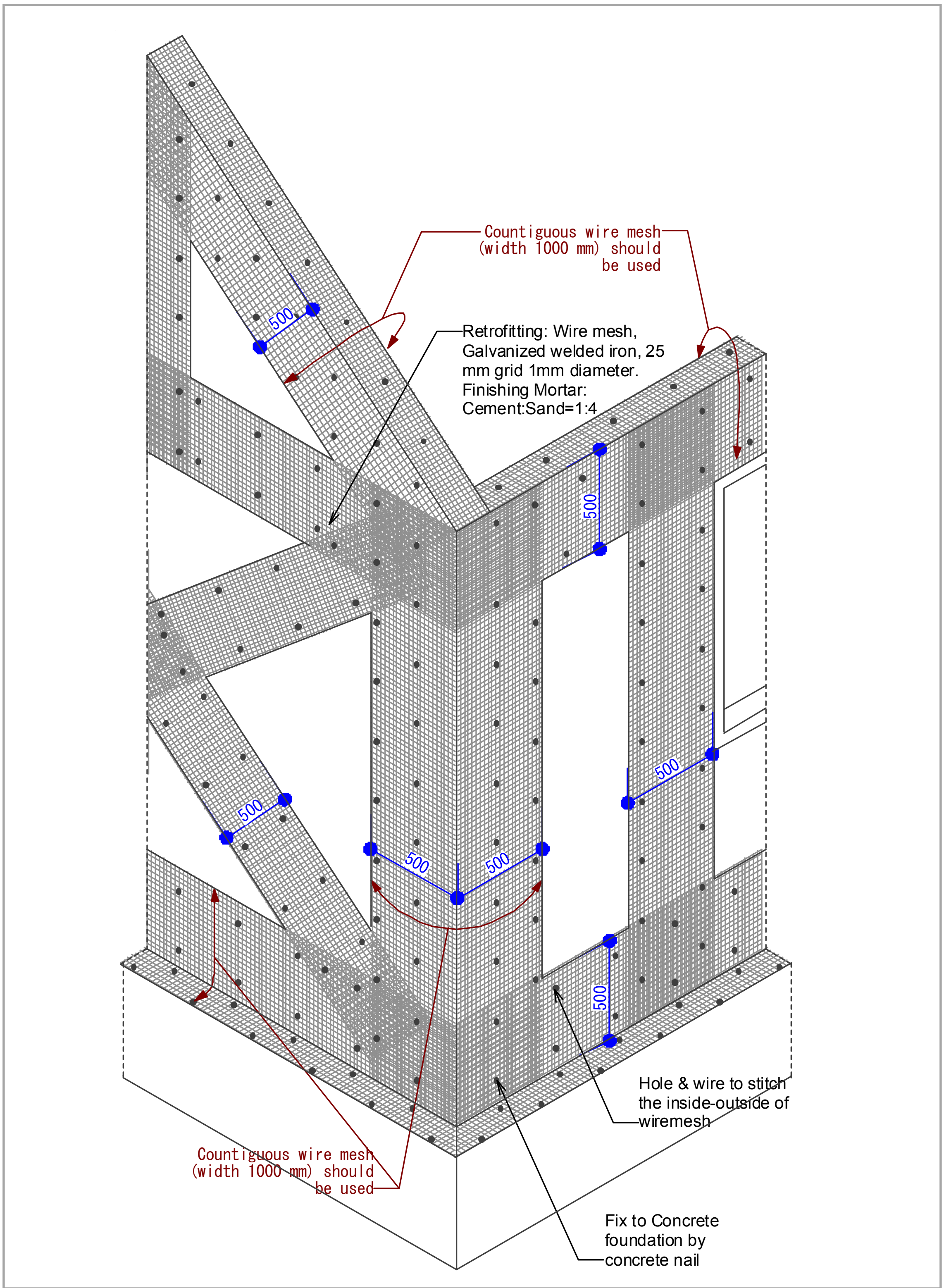


Fig.115 Detail of installing wire mesh on Model B[59]

59 Drawn by Author based on drawing by Teddy Boen, 2014,

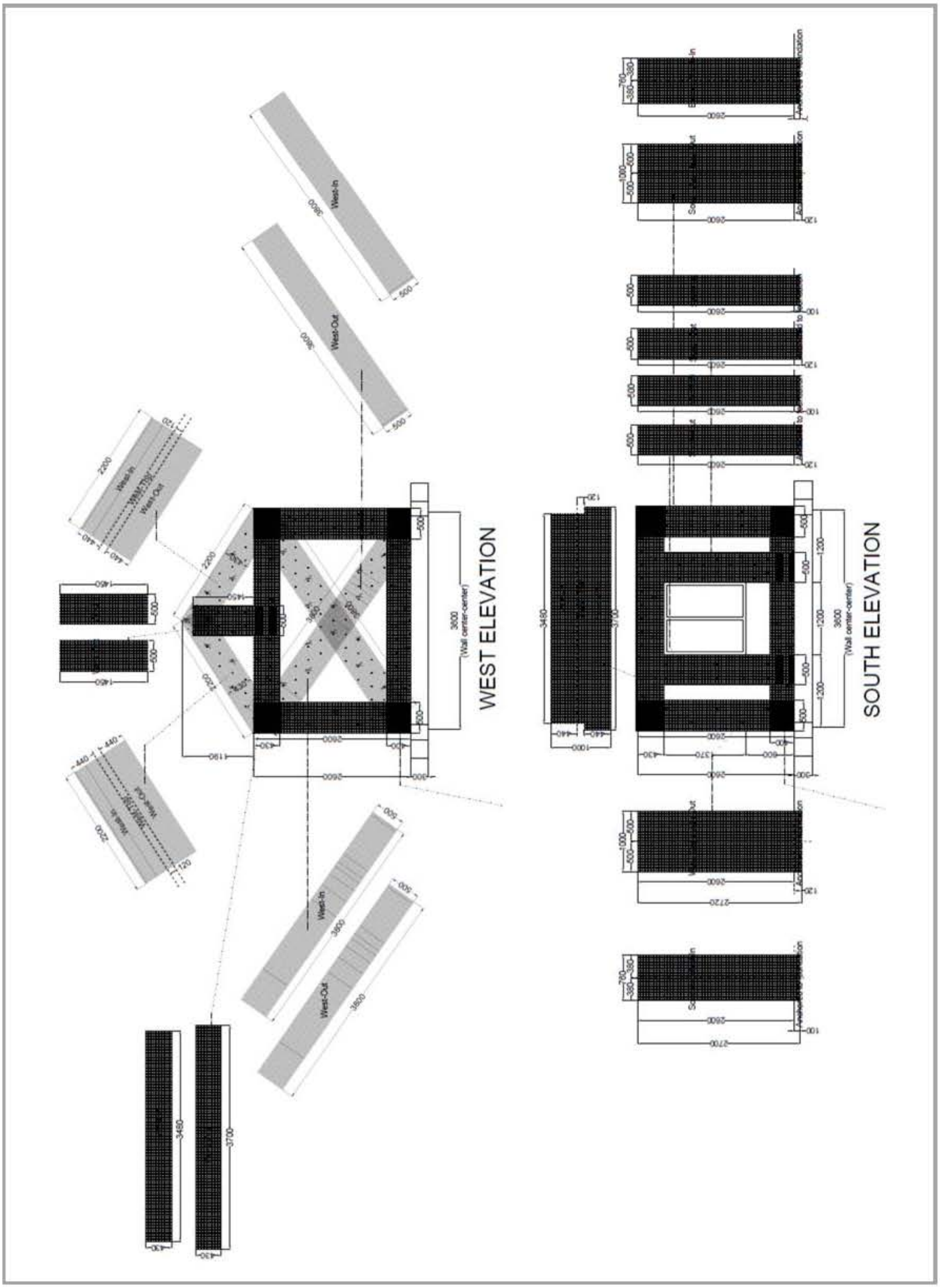


Fig.116 Arrangement of wire mesh on Model B[60]

60 Drawn by Teddy Boen, 2014,

3) Construction procedure

Figure 117 shows detailed section of retrofitting with wire mesh covered by mortar. Furthermore, the construction procedure is shown in Fig.118.

(A) In case of new construction, tie wire for connection of inside to outside wire mesh and roofing nail for keeping apart from brick surface were inserted on bed joint mortar. In other case for inserting to existing building, a through hole is made by using an electric drill. Tie wires should be placed at 300 mm pitch.

(B) Wire mesh was fixed to tie wires and roofing nails by wire such as bending wire etc. wire mesh should be continued, if wire mesh is short, it should be overlapped at least 200 mm. Wire mesh should extend and covered at the top of wall for making uniform structure.

(C) Wire mesh should be covered by mortar with a minimum thickness of 20 mm at least for making sandwich structure.

(D) At the corner and top of brick wall, wire mesh should be covered by continued mesh (one piece of mesh).

(E) In case of shortage of wire mesh, wire mesh should be overlapped at least 200 mm.

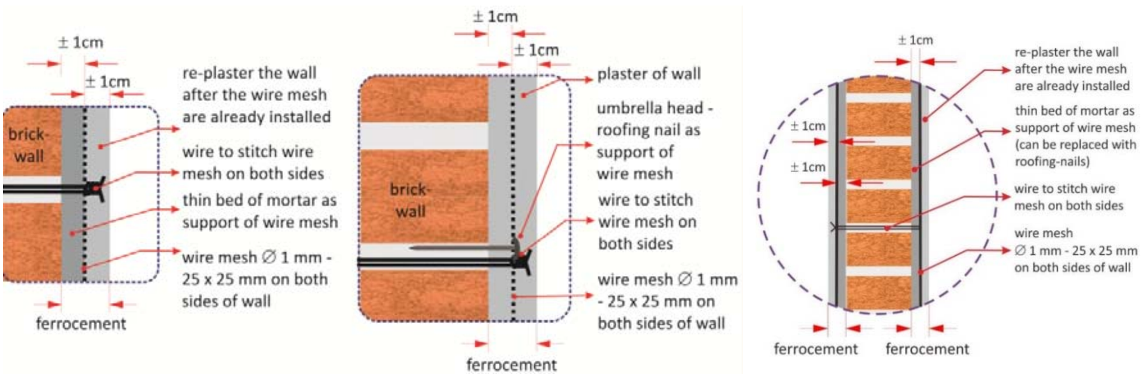


Fig.117 Details of retrofitting with wire mesh covered by mortar[61]

[61] Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, 2014, p125

(A) Insert tie wire and roofing nail for wire mesh

(B) Fixing wire mesh by tie wire between inside and outside

(C) Plaster: mortar thickness2cm

(D) Retrofitting work done on the North wall

(E) Retrofitted inside walls

Fig.118 Process of retrofitting on Model B

3.4.3 Material properties

1) Brick

The dimension of Indonesian brick was defined to be 210 mm x100 mm x 50 mm. The average compressive strength was 4.57 N/mm^2 by cut model to be 45 mm x45 mm x90 mm, shown in Fig.119.

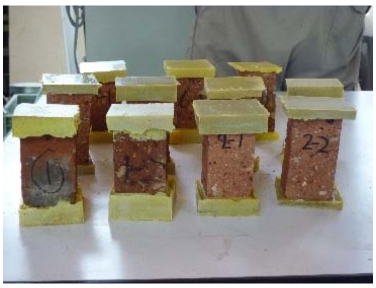


Fig.119 Specimens after test

2) Mortar

The ratio of cement and sand was 1 / 6 by volume and the water cement ratio was 120 % which followed the common practice in this area, discussed with Dr. Teddy Boen. The average compressive strength was 4.59 N/mm^2. The σ-ε curve are shown in Fig.120. On the other plastering mortar, the ratio of cement and sand was 1 / 4 by volume and the water cement ratio was 67 % which followed the common practice in this area. The average compressive strength was 27.58 N/mm^2. The σ-ε curve are shown in Fig.121.

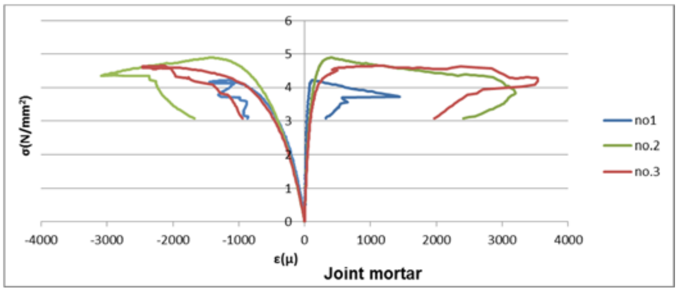


Fig.120 σ － ε curve of joint mortar

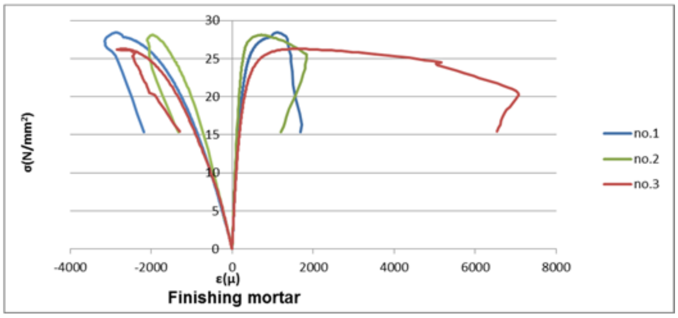


Fig.121 σ － ε curve of plaster mortar

3) Wire mesh

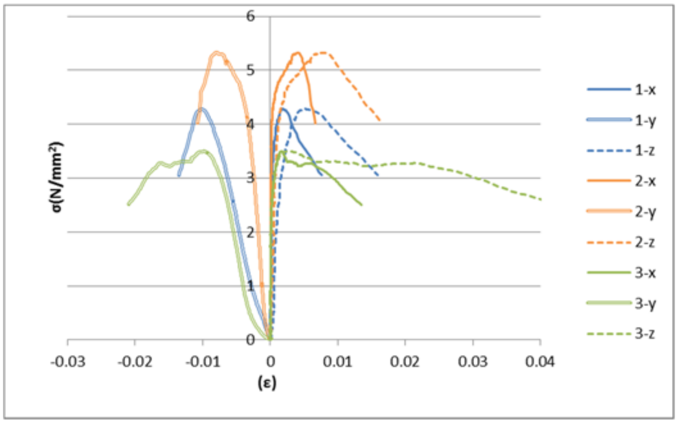
The galvanized wire mesh was imported from Indonesia. The diameter is 1 mm and 25 mm spacing. The tensile strength of wire mesh was 770.3 N/mm^2, shown in Fig.122.

Fig.122 Specimen during test

4) Prism of masonry units

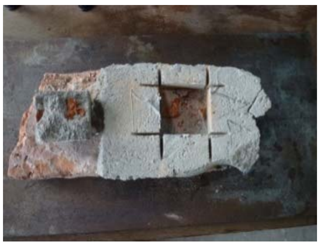
To know the strength of the brick wall a prism composed of three layers of the brick and joint mortar was tested. Compressive and shear tests were conducted, each test had three specimens. And tensile strength test between brick and mortar were conducted.

The average compressive strength was 4.35 N/mm^2. The shear strength was 0.50 N/mm^2. The tensile strength of joint mortar was 0.35 N/mm^2 and the tensile strength of plaster mortar was 1.21 N/mm^2. The photos of the test and the σ-ε curve are shown in Fig.123.



(A) σ − ε curve

(B) Compressive test



(C) Tensile test

Fig.123 Properties of Prism of masonry units

3.4.3 Inputs motions

Table 13 shows the schedule excitation with input motions of the shaking table test. These input motions were based on 1995 Kobe earthquake, such as JMA Kobe NS wave. The input motion was increased gradually as shown in Table 13.

Table 13 List of input motions

Date	No.	Input wave(*1)	Time scale	Scale	Displacement	Acceleration	Time	Recording		
				(%)	(± mm)	(gal)	(Sec)	Acc.	3D image	video cam
4th Jun, 2014	1	Test	-	-	-	-	-	✔	-	-
	2	Zero	-	-	-	-	-	✔	-	-
	3	Step(*2) 01	-	-	0.5	-	60	✔	-	-
	4	JMA Kobe NS	1	20	35	172.6	60	✔	✔	✔
	5	Step 02	-	-	0.5	-	60	✔	-	-
	6	JMA Kobe NS	1	35	61.25	291.9	60	✔	✔	✔
	7	Step 03	-	-	0.5	-	60	✔	-	-
	8	JMA Kobe NS	1	50	87.5	397.7	60	✔	✔	✔
	9	Step 04	-	-	0.5	-	60	✔	-	-
	10	JMA Kobe NS	1	60	105	469.3	60	✔	✔	✔
	11	Step 05	-	-	0.5	-	60	✔	-	-
5th Jun, 2014	12	Test	-	-	-	-	-	✔	-	-
	13	Zero	-	-	-	-	-	✔	-	-
	14	Step 06	-	-	0.5	-	60	✔	-	-
	15	JMA Kobe NS	1	85	148.75	675.2	60	✔	✔	✔
	16	Step 07	-	-	0.5	-	60	✔	-	-
	17	JMA Kobe NS	1	100	175	859.9	60	✔	✔	✔
	18	Step 08	-	-	0.5	-	60	✔	-	-
	19	JMA Kobe NS	1	110	192.5	1086.4	60	✔	✔	✔
	20	Step 09	-	-	0.5	-	60	✔	-	-
	21	JMA Kobe NS	0.5	-	87.5	2607.4	60	✔	✔	✔
	22	Step 010	-	-	0.5	-	60	✔	-	-

*1. Input waves were based on Kobe earthquake. (

*2. Step wave 0.05Hz

✔ Recording done

3.4.4 Measurement systems

Accelerometers were installed at 10 points on the specimen and on the shaking table. Response displacement was measured by 3D image processing. LED makers as point of measuring were installed at 58 points on the specimen and on the shaking table. And after each inputs, the location and size of cracks on the specimen were sketched for the development of cracks.

3.4.5 Observations of main inputs

At first, in order to investigate characteristic of the models, a rectangular wave with 0.5mm, 0.05 Hz was inputted.

- **Up to input No.15:** Both models survived when shaken by 60 % JMA Kobe and also 85 % JMA Kobe. There were no significant cracks or damage.
- **Input No.17:** Significant damage in Model A (Non-retrofitting model) occurred due to 100% JMA Kobe. The West gable wall and the East gable wall collapsed at the same time. Meanwhile Model B, the structure that was retrofitted using wire mesh still survived without any damage.(See Fig.125, Fig.126 and Fig.127)
- **Input No.19:** There were no significant changes.
- **Input No. 21:** Figure 124 shows input motion. Finally, both models were shaken by about 2G based on JMA Kobe NS. All of the West wall in Model A collapsed due to out-of-plane loading and almost at the same time large cracks from opening in South wall occurred as in-plane failure, then, Model A was totally collapsed. Model B still survived with minor cracks.(See Fig.128)

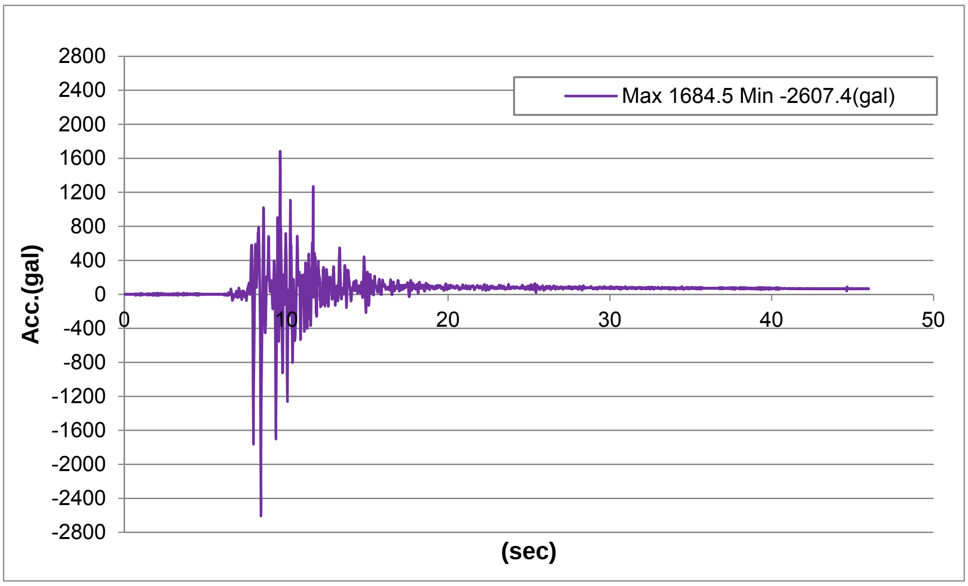
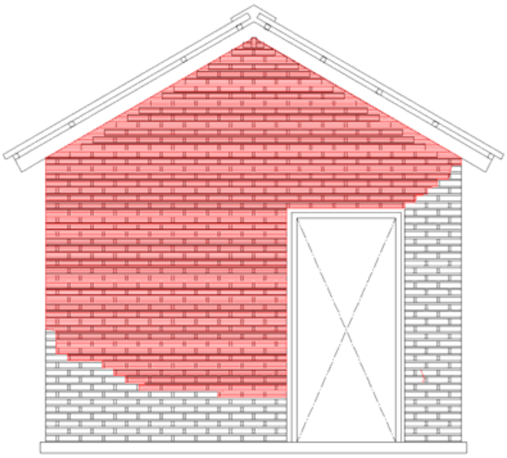
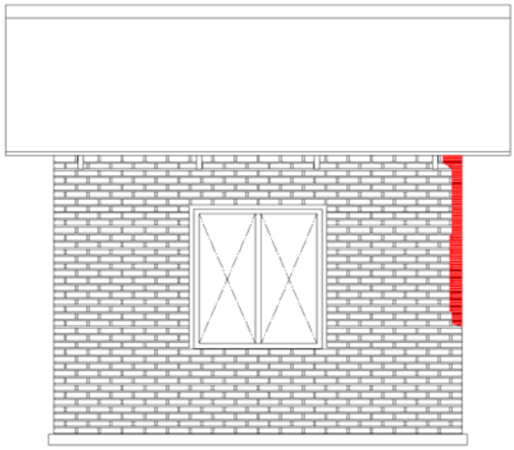


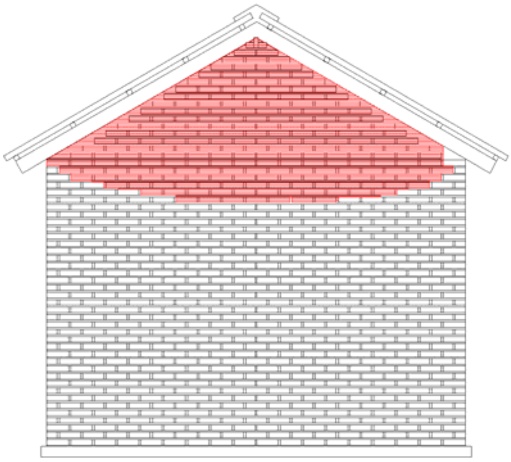
Fig.124 Input No.21 based on JMA Kobe NS wave



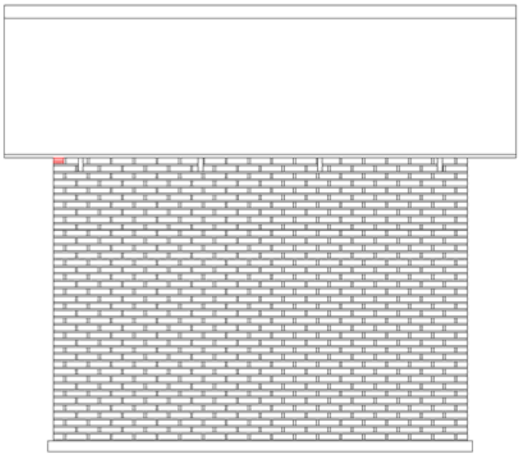
(A) East elevation of Model A



(B) South elevation of Model A



(C) West elevation of Model A

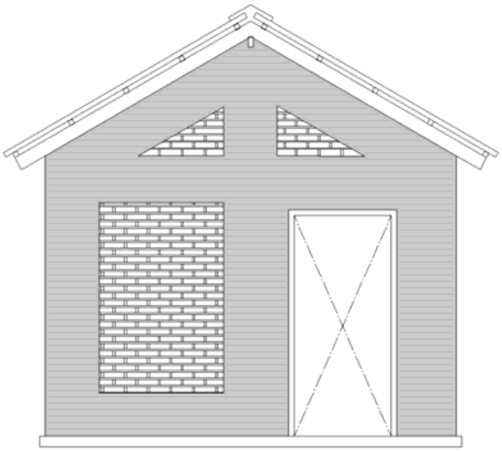


(D) North elevation of Model A

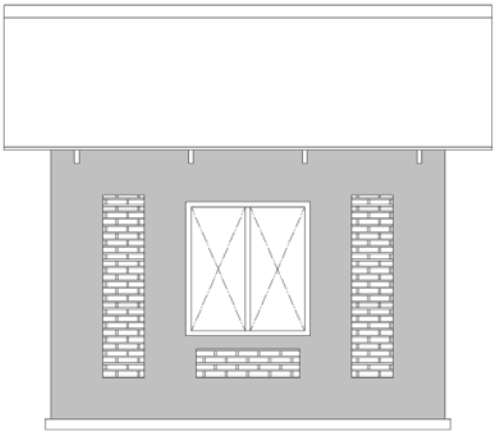
(E) Model A - East wall after input No.17 from South-East view

(F) Model A -West wall after input No.17 from South-West view

Fig.125 Crack pattern and condition of Model A after input No.17

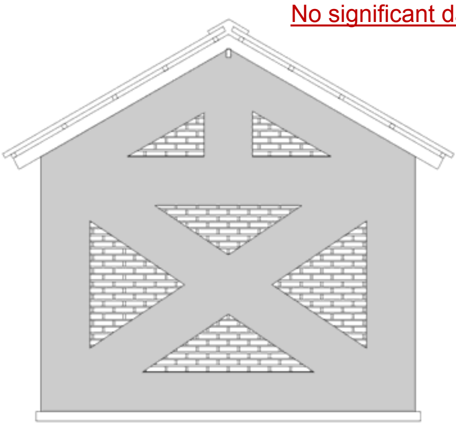


(A) East elevation of Model B

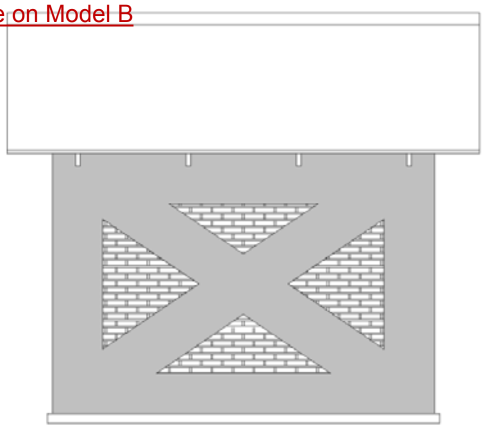


(B) South elevation of Model B

No significant damage on Model B

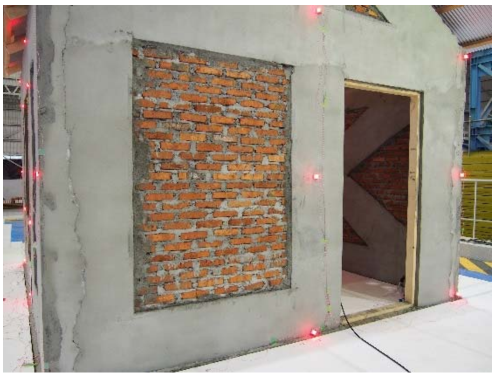


(C) West elevation of Model B



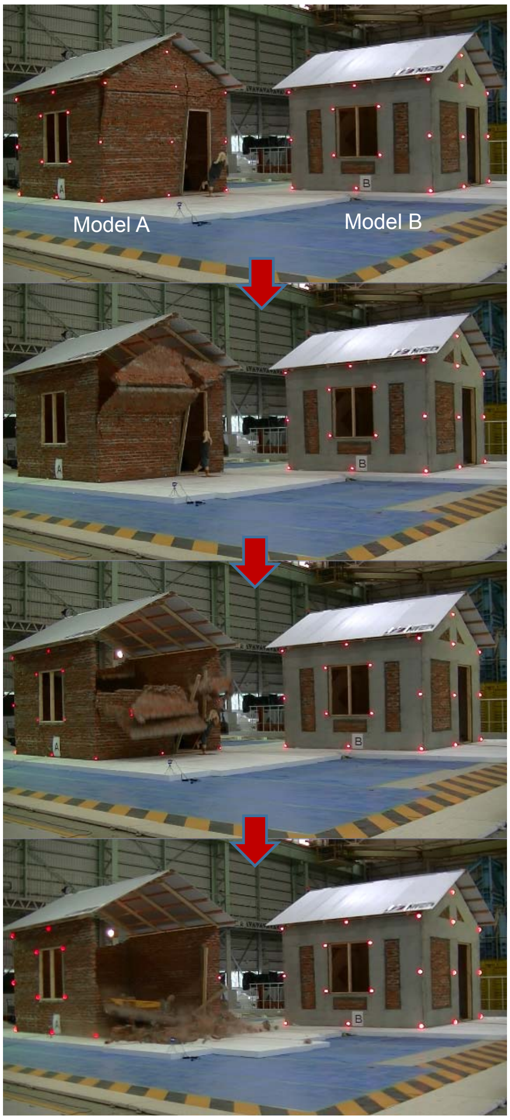
(D) North elevation of Model B

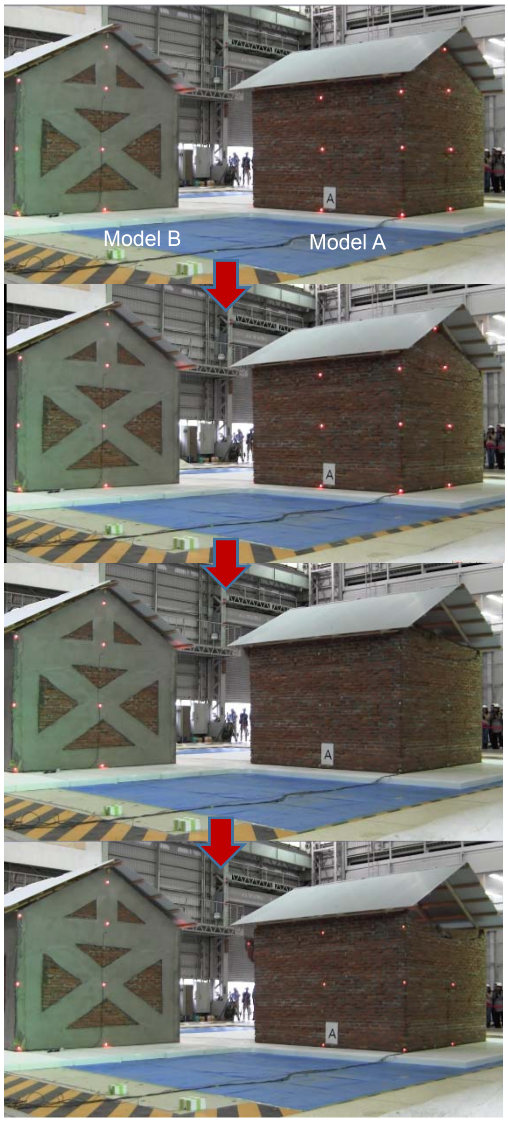
(E) Model B - South wall after input No.17



(F) Model B - East wall after input No.17

Fig.126 Crack pattern and condition of Model B after input No.17

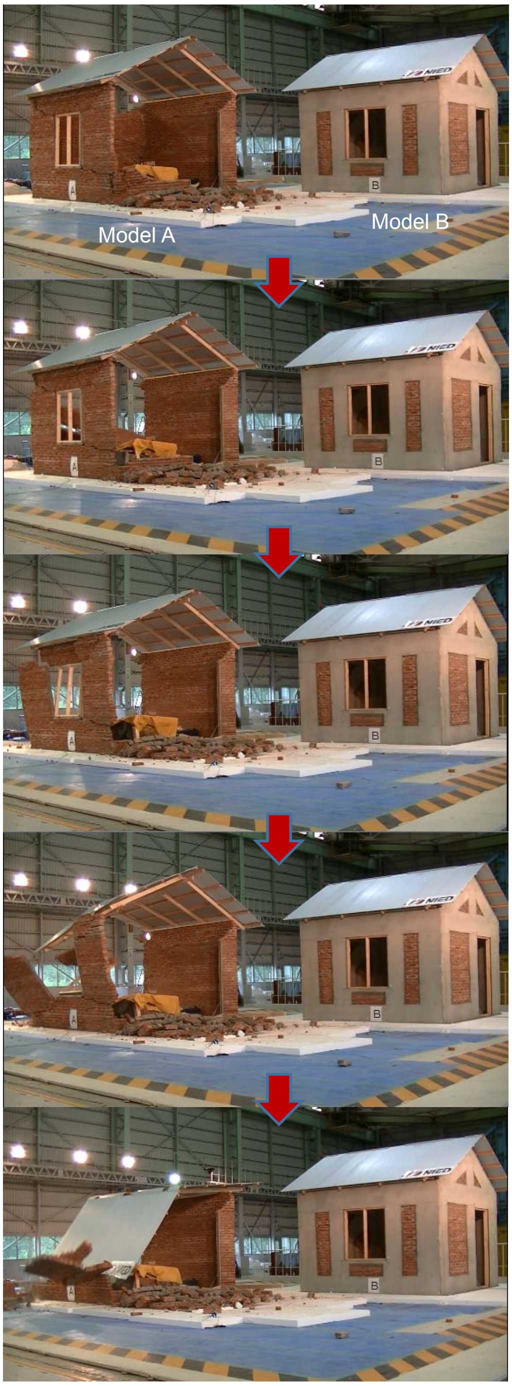




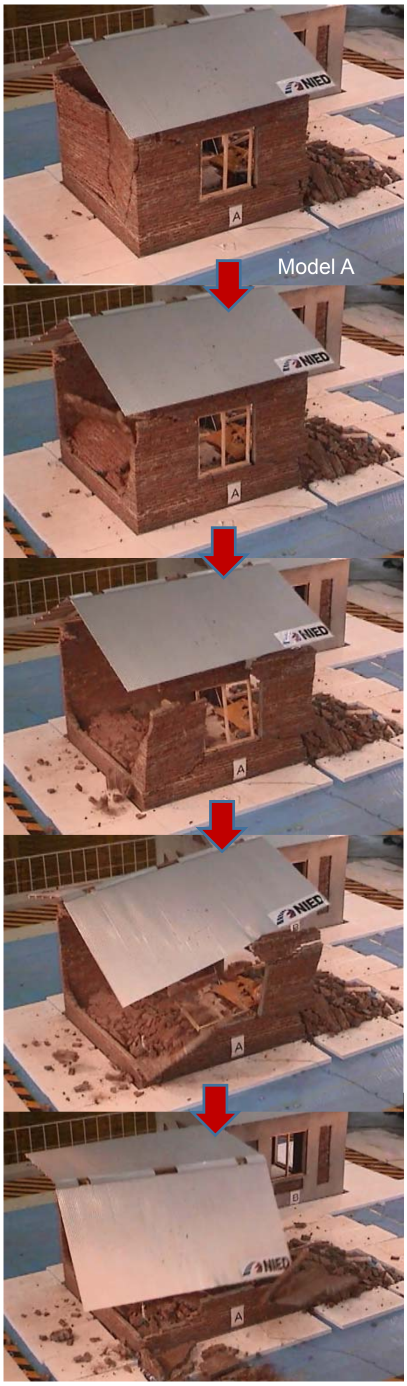
(A) View from South-East

(B) View from South-West

Fig.127 Sequence of gable wall collapsed due to input No.17



(A) View from South-East



(B) View from South-West above

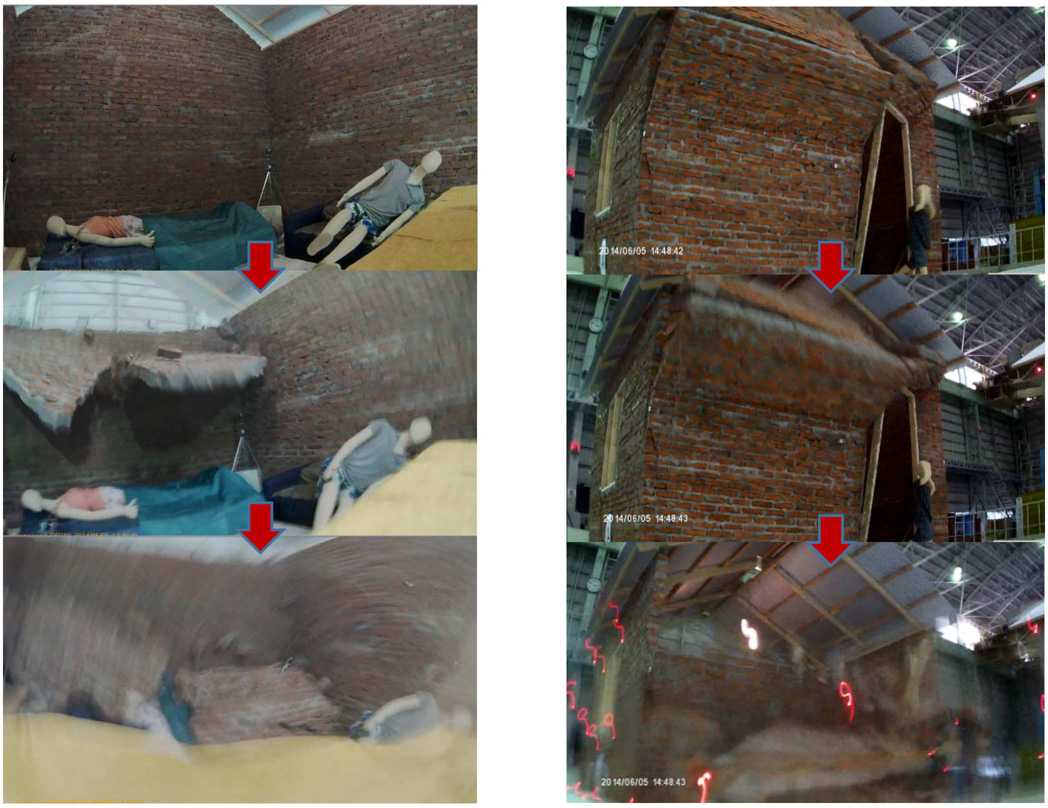
Fig.128 Sequence of totally collapsed Model A due to input No.21

3.4.6 Outcomes

The significant effect of retrofitting using wire mesh was successfully demonstrated by the shaking table test. The shaking table test made it clear that the retrofitting using wire mesh, even only partial strengthening as bandaging was effective in preventing the collapse of the house.

The behavior of the out-of-plane loading in Model A was the same as a Chapter 2.3 and Chapter 2.4, this behavior is most critical and may kill people. In particular, the gable wall made by masonry construction is dangerous for residents. Through this experiments, the author recommend not to construct gable walls using masonry. If masonry gable walls already exists, it should be retrofitted or demolished and replaced with light material as soon as possible. Figure 129 shows sequence of out-of-plane failure from residential view.

In Indonesia, there is a minimum requirement[62] about size of wall, the area of wall should be smaller than 9 m^2. The area of Model B is 9.62 m^2 from 3.7 meter in length of wall x 2.6 meter in height of wall as exceed the maximum size of walls. Most probably, the out-of-plane failure will occur in Model A even if there is no gable wall. The requirement of wall size also must be followed.



(A) Inside of house (Model A) (B) Entrance of house (Model A)

Fig.129 Sequence of out-of-plane failure of Model A due to input No.17

62 JICA, Key Requirements for Safer Housing for reconstruction in central Java, 2006.

3.5 Conclusion

In this chapter, the author conducted several experiments of proposed retrofitting method using galvanized wire mesh. The experiments as discussed in this chapter have shown the effectiveness of the method to strengthen for Indonesian brick masonry structure.

Retrofitting as strengthening should be apply for improvement over the original strength that is affected by their original structural inadequacy, such as material deterioration due to time, damaged structural elements by earthquake, buildings poorly built without considering seismic resistance.

The objective of this retrofitting method is to avoid brittle failure by providing additional tensile strength to the masonry walls. Furthermore, by unifying or tying all elements together, so that the building acts as one integral unit. In such a way that the inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them. Therefore, retrofitting should be such as, increasing the lateral strength in one or more directions, providing unity to the structure by providing proper connections between its resisting elements. Typical important aspects are the connections between walls and foundations, between intersecting walls, and avoiding the possibility of brittle mode of failure.

In addition, retrofitting method should consider inertia force that is related to the mass of walls and roofs. Therefore, the type of wire mesh should be selected as tensile strength requirements depends on the mass of the structure.

In regards to the retrofitting method which were examined by shaking table test for Indonesian masonry structure, aspects of affordability, feasibility and adaptability was observed.

1) Affordability (Economic aspects)

The proposed retrofitting method was using cement, sand, and wire mesh. The wire mesh by galvanized iron is easily available the country, even in rural areas. Because these kind of mesh is available in local market, usually used for chicken cage. That being the case, it is not expensive to the common people. Usually these kind of wire mesh is made in China, which is sold in a roll, such as 1 meter x 23 meter in the market.

The cost of one roll of mesh is approximately US$16. (at Indonesia, 2012). Ordinary size of house need 5 to 10 rolls for retrofitting, therefore the material cost would be US$80 to US$150.

Fig.130 Wire mesh in local market in Indonesia

Fig.131 Wire mesh in local market in Nepal

Figures 130 and 131 show wire mesh in local market in Indonesia and Nepal.

2) Feasibility (Technical aspects)

The method of using wire mesh covered by mortar is not a new technique, it is called "Ferrocement". Ferrocement has been widely studied and used and developed from experiments[63]. The idea of using ferrocement for strengthening was introduced in 1980 Monograph of Non-engineered Constructions[64]. In fact, this is a sandwich panel with masonry wall as core and ferrocement as skin facings. However, the retrofitting of masonry structure as non-engineered construction by ferrocement had very few studies in the past. Through shaking table test, the effectiveness of these retrofitting method was proven.

In the Chapter 3.3, the full jacketing of ferrocement for retrofitting and in Chapter 3.4 bandaging were constructed without using the special techniques and equipment used.

These techniques were done by ordinary hand and circumstances. In the next Chapter 4, practical training for retrofitting was held in the site will be discussed.

[63] ACI549, Guilde for Design, Construction, and Repair of Ferrocement, Reapproved 1999.
[64] IAEE, Monograph Non-Engineered-Guidelines for Earthquake Resistant Non-Engineered Construction, 1980.

3) Adaptability

The proposed retrofitting method is like a skin. Non-engineered construction has infinite variety of situations, however, non-engineered masonry structure is a load bearing wall structure, therefore, retrofitting method as a skin structure well be able to adapt to a variety of situations.

The retrofitting method introduced is not only one. The people are able to choose between these methods which among them are affordable, feasible, and adaptable to their own needs and situations.

For disaster risk reduction, it is important to understand the disaster risk, or damage estimate of the house. The residents/house owners must be able to check the risk by themselves. Therefore, these video/movie of the shaking table test can be utilized for disaster education purposes in developing countries.

Chapter 4 Practices in developing countries

Chapter 4 Practices in developing countries

4.1 Research on reconstruction housing program in Indonesia
-A case study in Yogyakarta after the 2006 Central Java earthquake-

4.1.1 Outline

The metamorphosis of reconstruction of houses after a disaster indicates the demand of owners. The purpose of this study is to investigate the possibility of dissemination of retrofitting for ordinary houses and to find out strategies of dissemination for disaster mitigation.

4.1.2 Background

The central Java earthquake occurred in DI Yogyakarta Province on 27th May, 2007, there were 175,687 houses that totally collapsed, 101,082 houses were heavily damaged, and 151,919 houses were slightly damaged. The number of casualties was 5,716 people dead and 18,702 people were injured.[65]

The Government of Indonesia conducted housing reconstruction recovery program, these are divided into three main activities as follows:

1. Grant-in-aid program for reconstruction of housing
2. Key requirements for safer construction
3. Building certification application system

The fund for the housing reconstruction grant system was IDR15,000,000 (approx.US$1,500) for heavily damaged, IDR4,000,000 (approx.US$400) for moderate damaged, IDR1,000,000 (approx.US100$) for minor damaged of houses. However, the cost of reconstruction of a simple house is around IDR30,000,000 (aprox.US$3,000).

The Government required standard construction as a prototype of reconstruction models. The prototype of reconstruction housing model was created by the Government based on a standard type for post-earthquake. The area of this prototype house was proposed 36 m^2 (6 m x 6 m plan) and reinforcement concrete column and beam as confined elements were included. It was obvious that the reconstruction program for housing in Yogyakarta followed a process of reconstruction from designing, certification, and construction with grand support. These reconstruction program was implemented as participatory and community-based, and was reported as a successful case for reconstruction in developing countries[66]. The housing reconstruction recovery program by the government was completed in December, 2007.

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[65] Bappenas, 2006

[66] International Recovery Platform, The Yogyakarta and Central Java Earthquake 2006 Recovery Status Report, 2009.

4.1.3 Research objective and method

Since 2006, the survey of the reconstruction of houses has been conducted in relation to the quality of construction.

The survey was conducted in Trimulyo village of Bantul, Jetis, shown in Fig.132. In these areas, the ratio of collapsed house was over 60% of 4,277 existing houses before the earthquake. The 300 houses were selected for survey as samples, it corresponds to about 1/14. The number of surveyed villages is listed and is shown in Table 14.

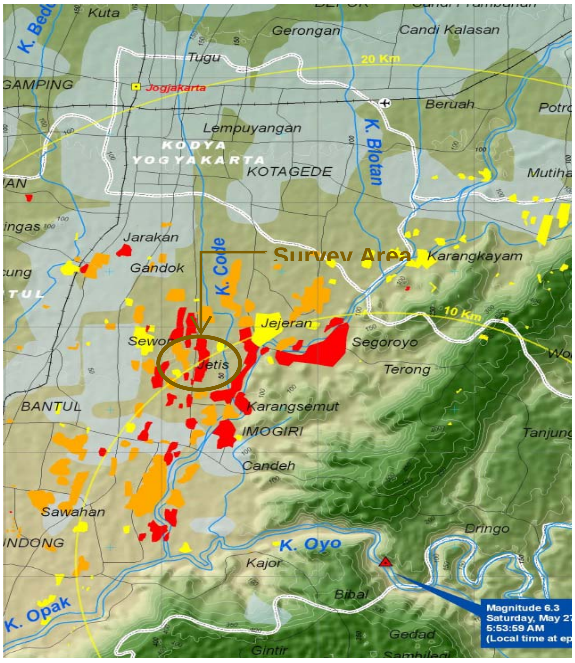


Fig.132 Area of survey in Bantul[67]

Table 14 Survey target area and numbers

Kabupaten District	Kecamatan Sub-district	Desa Village	Dusun Sub-village		Number of house before EQ	Number of house surveyed
Buntul	Jetis	Trimulyo	1	Bembem	320	25
			2	Blawang 1	380	25
			3	Blawang 2	410	23
			4	Bulu	416	26
			5	Cembing	310	24
			6	Denokan	250	22
			7	Karangsemut	205	23
			8	Kembang Songo	585	24
			9	Ponggok 1	340	25
			10	Ponggok 2	475	30
			11	Puton	360	23
			12	Sindet	226	30
Total number					4277	300

67 Web site: www.unosat.org (Peta Kerusakan Daerah Trimulyo, Jetis, Bantul)

4.1.4 Condition of reconstruction houses

1) Extension work of reconstruction houses

As mentioned in Chapter 4.1.2, the standard size of floor was 36 m^2. Figures 133 and 134 show the changing floor area by extension work in 2007, 2009, and 2013. Seven years after reconstruction, the area of floor become around 60 m^2. 65.3% of houses were constructed floor extension work. The average extension area of houses was 17.87 m^2. It is established that most residents/family demand a floor area of house of to be 60 m^2 in these area.

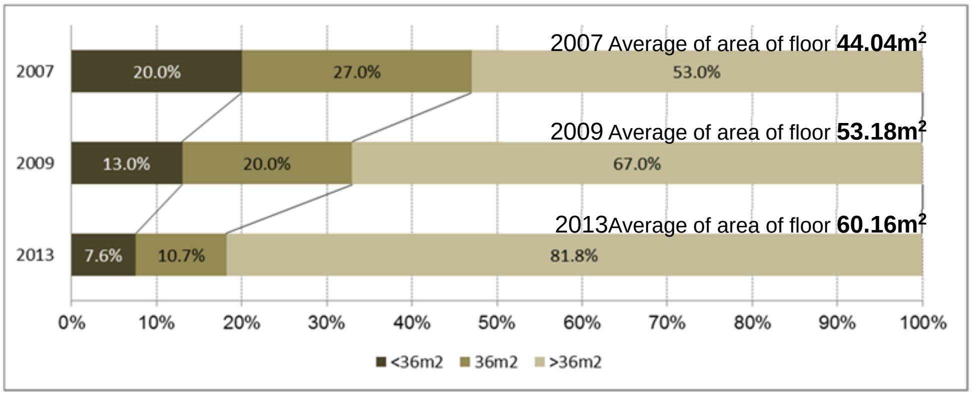


Fig.133 Area of floor of reconstruction houses

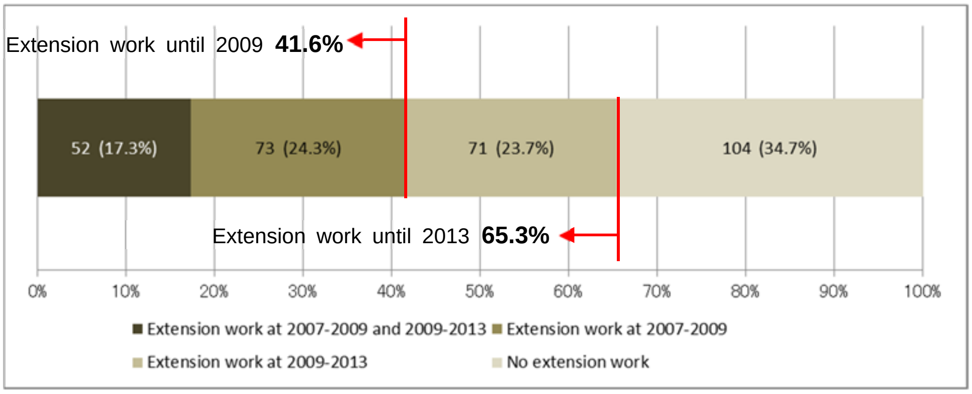


Fig.134 Period and percentages of extension work

2) The quality of construction for new houses in 2007

Figure 135 shows the quality of construction of new houses.

A survey was conducted to check whether the quality of construction followed the “Key Requirement” prepared by JICA, namely:

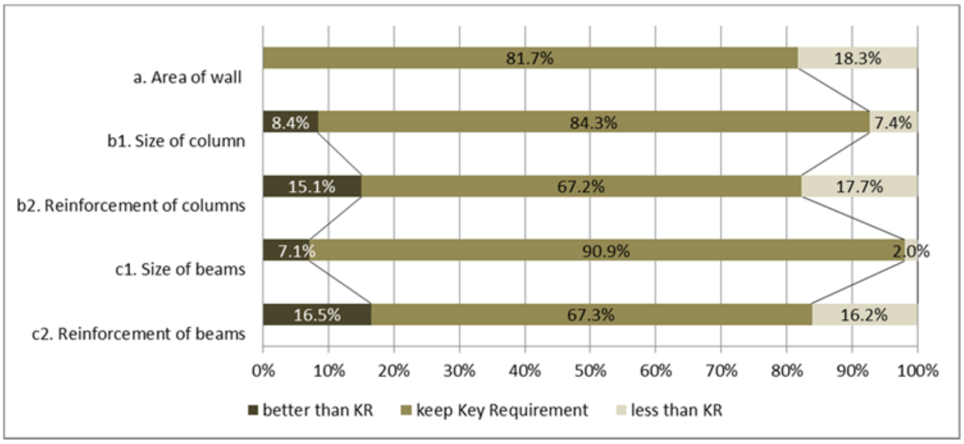
a. Area of wall of confined by RC columns and beams. –Key Requirement (KR): It should be smaller than 9m^2.

b. Size of RC columns. –KR: 150 mm x 150 mm, main reinforcement bar should be 10 mm diameter.

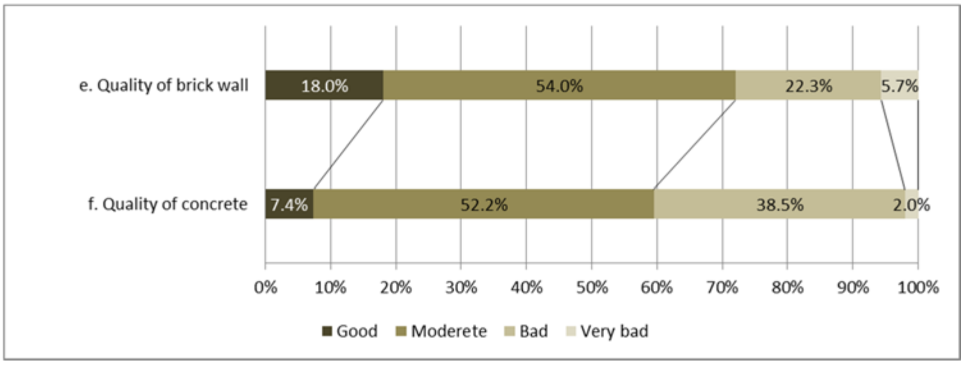
c. Size of RC beams. –KR: 150 mm in height and 120 mm in width, main reinforcement bar should be 10 mm diameter.

d. Laying brick work. –Uniformity and condition of filling mortar by observation.

e. Quality of concrete. –Uniformity of surface and quality itself by observation.



(A) Material and design items



(B) Workmanship items

Fig.135 Quality of reconstruction houses, 2007

The results of these surveys indicate the following information:

- The quality of construction regarding to materials such as reinforcing bar, was good compared to construction quality standards. It was considered that the materials were purchased by community units and distributed during the reconstruction.
- The result of the quality of concrete and assembling of reinforcing bars were worse compared to construction quality standards. In Yogyakarta, same as in most areas of Indonesia, construction works were done by individual masons. Besides that, there were insufficient equipment such as concrete mixer, vibrator, and a lack of knowledge of proper construction.
- During the period of reconstruction phase, the government employed supervisors, called “Facilitators” for the reconstruction of houses. However, these facilitators were new university or college graduates that did not have experience of actual construction works. Hence, most of supervision for the construction work was not effective. The survey indicated that it should be necessary to teach technical matters regarding construction in universities and colleges.

3) The quality of construction compared to new construction period and extension period.

Figure 136 shows existence of RC gable beam as an indication of observing the Key requirement. In newly constructed houses, more than 80% were following standard of construction, however, for the extension parts, only less than 50% were constructed by using RC beams for the brick gable walls. As mentioned in Chapter 2 and Chapter 3, these gable walls of house were the most dangerous parts and RC confined elements should be constructed.

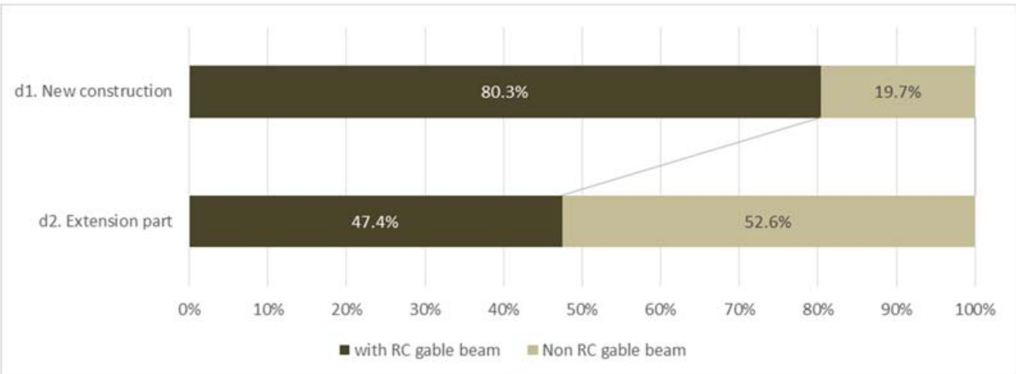


Fig.136 Existence of RC gable beam

4) Finishing work of reconstructed houses (Plastering and Painting works)

According to the observation, the process of construction was as follows:

Step 1: foundation, wall as structure part and roof were constructed with the government grant-aid, to provide shelter and decent living environment such as avoiding rain, wind, sunlight, insect as basic human needs.

Step 2: Extension work or finishing work of interior were constructed funded by residents themselves to raise the quality of living environment.

Step 3: After the above two steps, finishing work of exterior was started.

Figure 137 shows the existence of exterior finishing works at 2009 and 2013. In the new construction period, very few houses had finishing such as plastering or painting.

About two years after the new construction (2009), 30 % of houses were constructed finishing works, subsequently, up to 2013, almost 60 % of the houses were done with exterior finishing works.

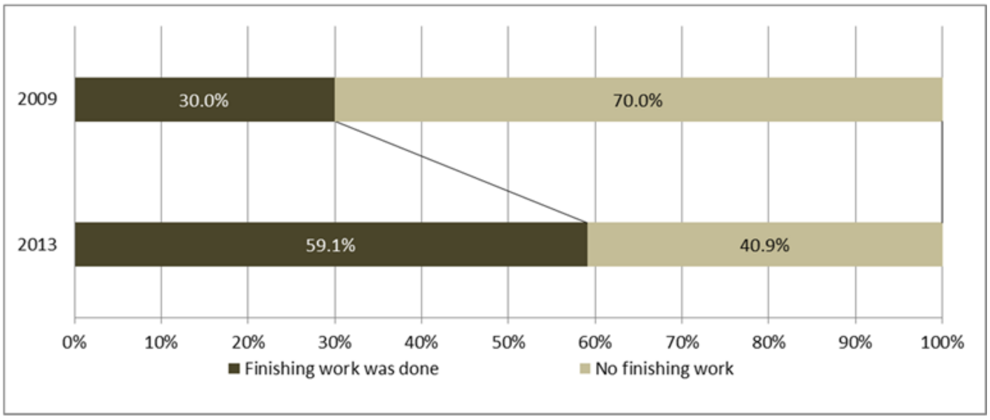


Fig.137 Existence of finishing work (plastering or painting) * Included only one side of walls

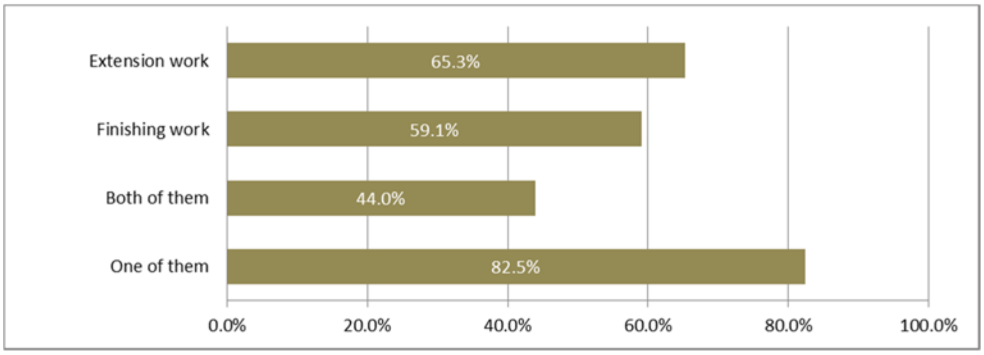


Fig.138 Existence of finishing work and extension work

4.1.5 Cost estimation

As shown in Fig.138, more than 80 % of the reconstructed houses constructed extension or finishing works, residents spent own funds to do that. In other words, residents spent own funds for upgrading their living environment. However, these additional works did not take into account seismic performance.

Table 15 Estimation of additional work (Rate US$1 = IDR 11,000, 2014)

	Cost / m^2(IDR)	Average Area(m^2)	Total cost(IDR)	(US$)
Extension work	830,000*1	17.9*1	14,857,000	1,350
Finishing work	28,720*1	72.0*2	2,067,840	188
*1 from survey in 2009, *2 from survey in 2013				

According to the survey, extension works were done for 65.3 % of the houses, average area of extension was 17.9 m^2. The average cost of extension works was US$1,350. The finishing work, the average cost was US$188, shown in Table 15.

Figure 139 shows example of the metamorphosis of reconstruction of houses.

(A)2009 Same situation of new construction

(B) 2013 Exterior plastering and painting work was done

(C) 2009 Exterior work was done.

(D) 2013 Exterior painting work was done.

(E) 2009 Extension work was done.

(F) 2013 Exterior plastering and painting work was done

(G) 2009 Same situation of new construction

(H) 2013 Extension work / Exterior plastering were done.

Fig.139 Example of the metamorphosis of reconstruction of houses

4.2 Dissemination of earthquake safer/resistant construction in practice

4.2.1 A case study in Yogyakarta after the 2006 Central Java earthquake

As mention Chapter 4.1, the survey about reconstruction and additional work was conducted in 2009. This activity was one of the component of a project called “Architectural Mobile Clinic” which visited construction sites to provide advice for proper constructions. The author visited 300 reconstruction sites during the project duration, and discussed with construction workers and house owners earthquake safer/resistant construction.

4.2.1.1 Practical masons training for retrofitting of inadequately constructed houses

Based on the result of condition of reconstruction houses, it was apparent that construction sites need to improve quality and strengthening of existing houses.

Training workshops were conducted for masons including community leaders in Bantul.

The purpose of the workshop was,

- Training for community leaders and masons to provide appropriate knowledge of basic construction methods for community capacity building.
- Training for masons to provide practical knowledge of retrofitting of existing houses.

In the workshop, they used the “Manual for Retrofitting Brick Masonry House for Seismic Safety”[68], shown in Fig.140.

Seven existing houses were retrofitted by practical training as examples and 266 participants joined in the 13 workshops.

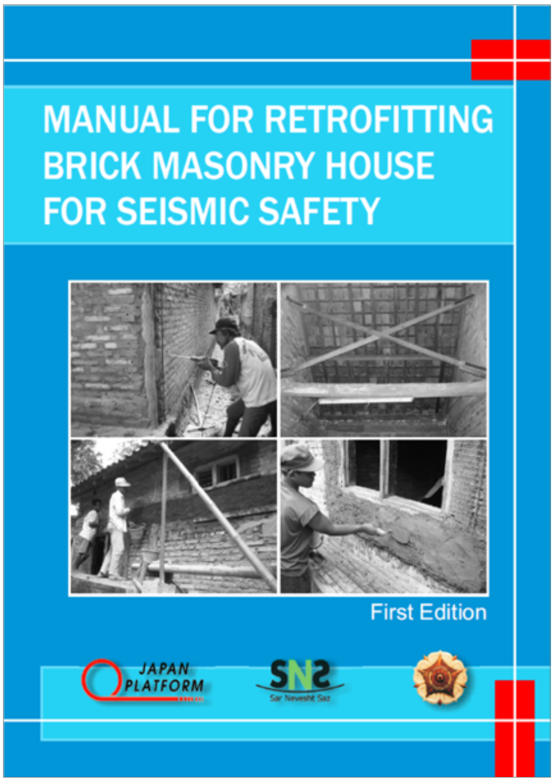


Fig.140 Manual for retrofitting brick masonry house for seismic safety 2008

English Ver.

[APPENDIX B-1]

[68] Hiroshi Imai, SNS, Gadjamada University, funded by Japan Platform, 2008.

4.2.2 A case study in Padang-Pariaman after the September 2009 Sumatra earthquake

A magnitude 7.6 earthquake occurred on 30th September, 2009 in West Sumatra, Indonesia. There were 279,432 buildings that were damaged. It was also recorded that 114,797 houses totally collapsed or were heavily damaged, and 67,198 houses were moderately damaged, and 67,839 houses were slightly damaged[69].

Most of these houses were constructed by un-reinforced brick masonry and confined brick masonry. Thus, it was very important to conduct disaster mitigation program for safer construction of houses to reduce the impacts of earthquakes in the future. It was needed to improve the practical knowledge of masons in reconstruction sites of houses that are using confined brick masonry construction, which is following the Key Requirement recommend by the government.

4.2.2.1 Practical masons training for reconstruction of houses following the Key Requirements

The manual “WHY and HOW? for safer housing, implementing construction work in field”[70], shown in Fig.135 was compiled according to the survey of the damage of houses and observations in Architectural Mobile Clinic Program in the villages of Padang-Pariaman, namely, Nagari Pakandangan, Sub-district of Enam Lingkung.

This manual was made in the local language version and English version.

The practical trainings for masons that were conducted for 110 masons before and during reconstruction program by the government that is being implemented in West Sumatra in 2009, are as follows:

- The practical training for masons, aims to share the knowledge of

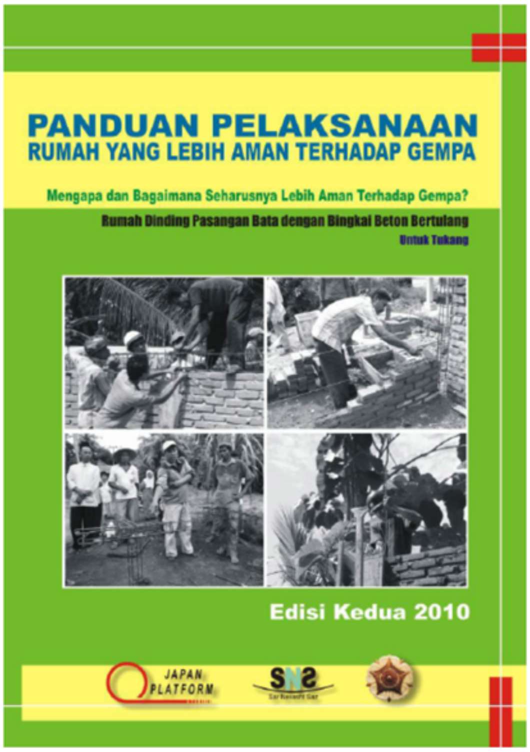


Fig.141 WHY and HOW? for safer housing, implementing construction work in field 2009 Indonesian language ver. **[APPENDIX B-2]**

69 The center of study for Disasters, Andalas University
70 Hiroshi Imai, SNS, Gadjamada University, funded by Japan Platform, 2009.

appropriate construction for earthquake safer/resistant confined masonry construction.

・ Five houses were reconstructed during the trainings.

110 masons attended the on the job trainings.

The manual “WHY and HOW?” for safer housing, implementing construction work in field” was used in the trainings.(See Fig.141) These training are two day workshop that consist of lecture and practical training.

The main sessions of the trainings contained the following:

1. Materials for housing construction
2. Foundation
3. Plinth Beams
4. Brick Masonry
5. Column and Ring Beam
6. Gable Wall
7. Wind Bracing

The possibility of damage/failure pattern and how to make appropriate earthquake safer/resistant houses were noted in each topic. Figure 142 shows damage/failure pattern is on the left, the correct construction procedure is on the right side in the Manual.

Fig.142 “WHY and HOW? for safer housing” implementing construction work in field 2009

In order to easily understand proper construction, several methods, such as computer graphics, small model, and actual materials were made. (See Fig.143)

1) Process of construction by computer graphics

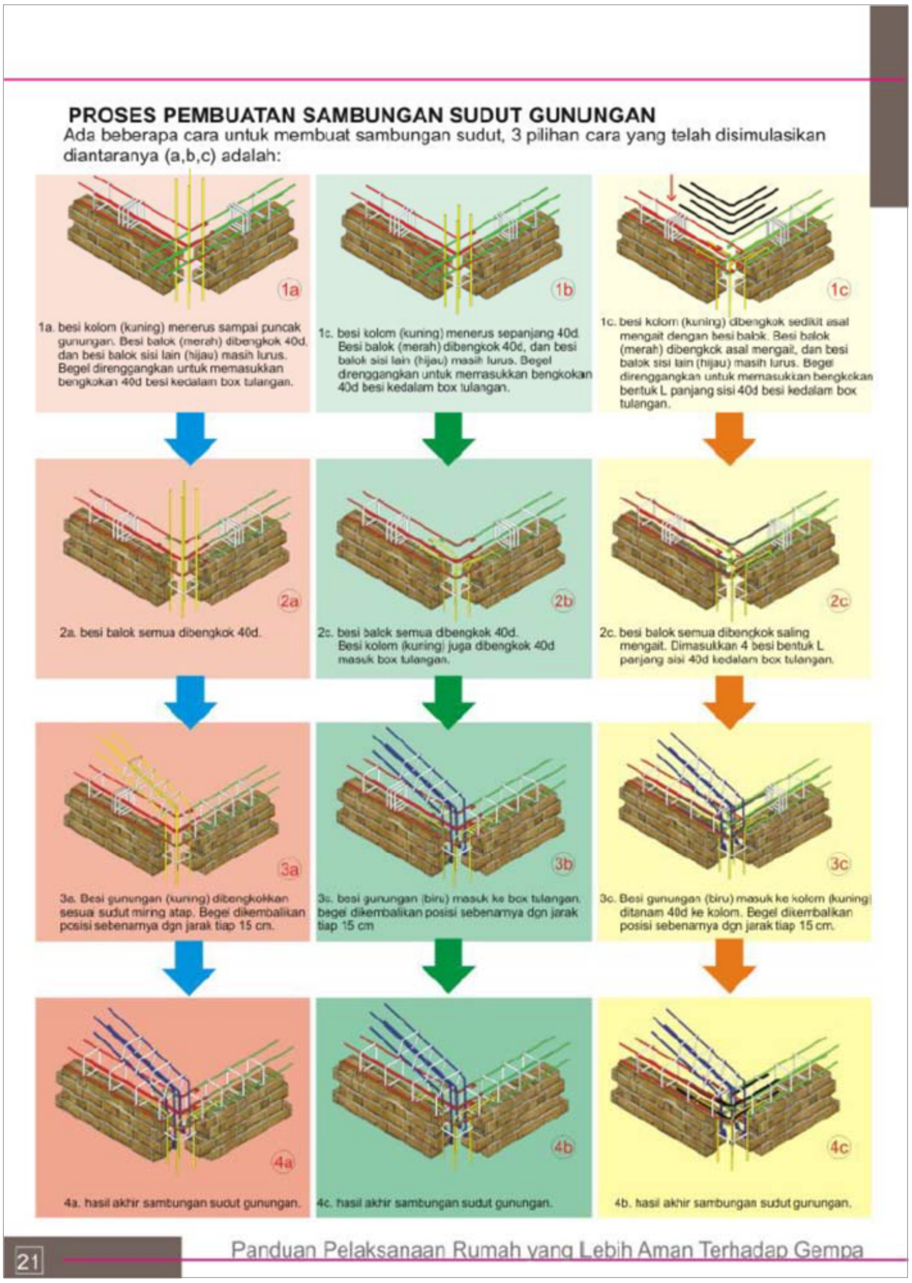


Fig.143 Process of assembling ring beam and gable beam in the manual.

2) Using small scale models

In the training, small-scale model of assembling reinforcement bar in the corner of house and actual reinforcement bars were distributed, then participants (masons) tried to construct the same object as small-scale model, shown in Fig.144 and Fig.145

The participants found very difficult to make the model by themselves, because they did not assemble the reinforcing bars piece by piece in the construction site, usually, they buy assembled units from the market. (See Fig.146)

However, using these assembled units of reinforcement bar, it was almost impossible to make proper connection at the joint between columns to beams, and beams to beams. Through the training workshop, finally, they could make these connection using actual reinforcement bars.

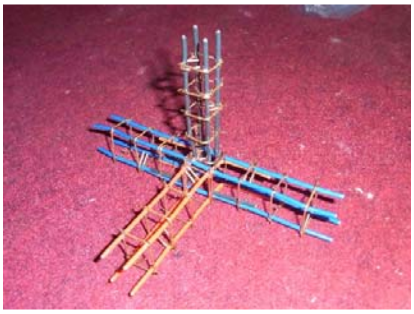


Fig.144 Model of assembling reinforcement at the corner

Scale 1/10, made by Build Change

(A) (B)

Fig.145 Assembling reinforcement bar in the training

Fig.146 Assembled reinforcement units

The staff made a complete reinforcement assembled model of scale 1/10. This model was used for lecture and practical trainings, shown in Fig.147. By making this model, our staff were able to learn how to assemble for proper construction. Therefore, it was education for the trainers of the training.

Fig.147 Making reinforcement model, scale 1/10

4.2.2.2 Workshops for residents/house owners about reconstruction houses following the Key Requirements

Through the training of masons conducted since 2009, just after earthquake, it was recognized that it is not only masons, but also residents/house owners who are to raise awareness of earthquake safer construction.

Because it is needless to say that apart from financial matters, residents/house owners will be around construction site for the most time. In other words, if the resident/house owner has some knowledge of proper construction, they become best supervisor of construction site.

The seminar of earthquake safer construction, held in 2010, for residents/house owners including community leader totals to 242 participants in 13 workshops. A guide book was published for residents/house owners on the basic points of safer constructions. The tradition in this area, Minangkabau, the house owner is a woman. Therefore participants were mostly women, but, they enjoyed the practical training. (See Fig.148)

(A) Lecture

(B) Q &A in the lecture

(C) Checking brick

(D) Mixing concrete

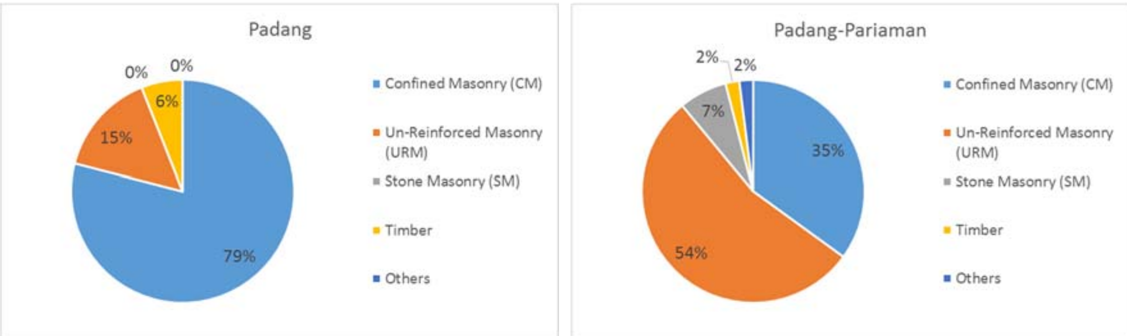
Fig.148 Seminar for residents/house owners

4.2.2.3 Data analysis from the interviews

The interview of 242 residents/house owners who attended seminar of Chapter 4.2.2.2.

1) What kind of construction method was used before the 2009 earthquake?

In Padang city, around 80 % of house were confined masonry construction, however in Padang-Pariaman, more than 50 % of the houses were un-reinforced masonry structures, shown in Fig.149.

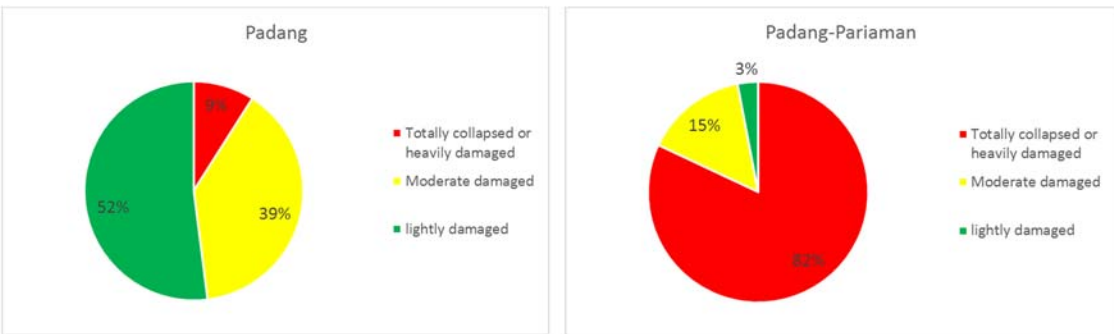


(A) Padang (B) Padang-Pariaman

Fig.149 construction method of before 2009 earthquake

2) What was the damage situation of the houses by the 2009 earthquake?

The result was largely different between Padang and Padang-Pariaman, It is caused by construction method of houses in these areas as described above. (See Fig.150)



(A) Padang (B) Padang-Pariaman

Fig.150 Damage situation of houses by 2009 earthquake

3) What kind of construction are you planning to build for reconstruction after earthquake?

The selection of the construction methods was as follows:

1. Confined masonry (CM) as reconstruction
2. Half masonry with timber as reconstruction, which is called Semi-permanent house
3. Others as reconstruction
4. Confined masonry (CM) as rehabilitation
5. Half masonry with timber as rehabilitation
6. Repairing of existing house

Figure 151 shows that more than half (28 % of 42 %) of reconstruction, people wanted to live in a new confined masonry house as permanent living environment. Moreover, more than half of the houses would be rehabilitated.

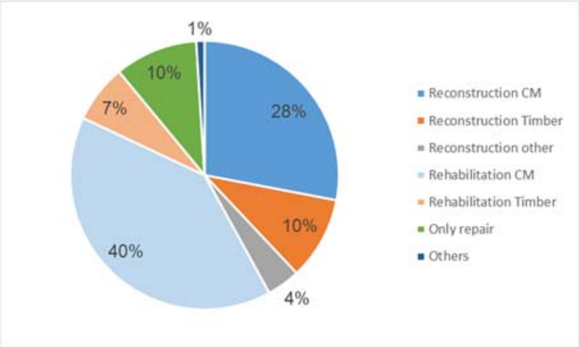


Fig.151 Construction methods after earthquake

4) Fund of reconstruction (grant-aid from the government*1 not included)

The housing reconstruction grant system in Padang-Pariaman was the same as in the Yogyakarta reconstruction program. Figure 152 shows the 32 % did not spend money and 40 % is more than IDR 20 million would be used for reconstruction. There is economic bipolarization.

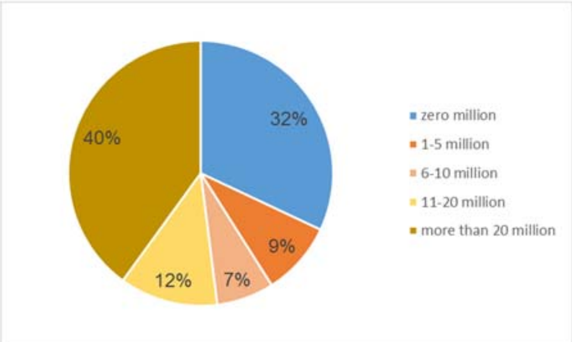
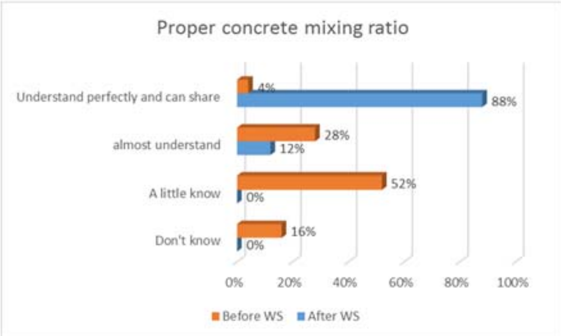


Fig.152 Fund of reconstruction

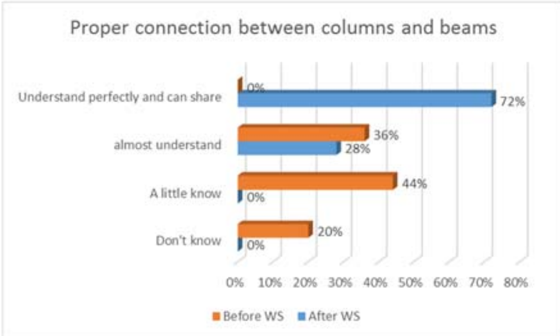
*1: IDR 15,000,000 (approx.US$1,500) for heavily damaged, IDR 4,000,000 (approx.US$400) for moderately damaged, IDR 1,000,000 (approx.US$100) for minor damaged of houses

The interview about knowledge of construction of 242 residents/house owners who attended workshops as explained in Chapter 4.2.2.2.

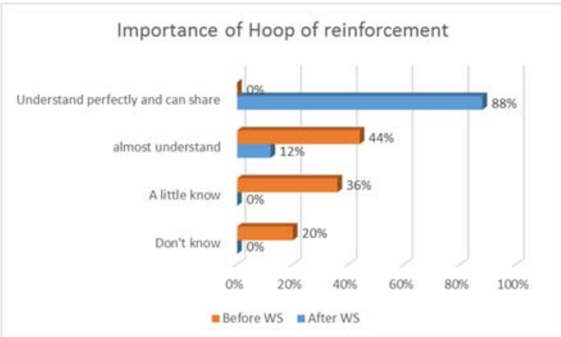
The interview was conducted before and after the workshops, workshops were concentrated on basic technique of earthquake safer construction. The result of comprehension of the main topics is as follows: (See in Fig.153)



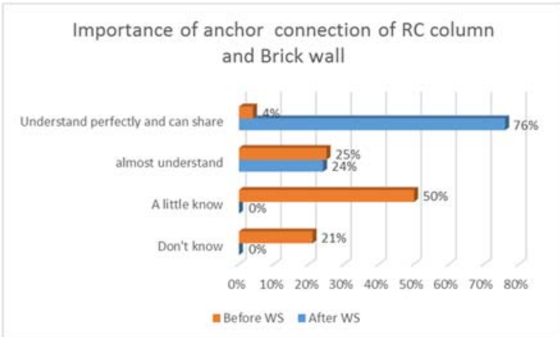
(A) Knowledge of concrete



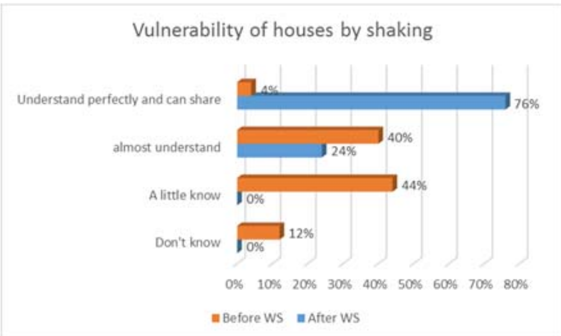
(B) Knowledge of connection



(C) Knowledge of hoop



(D) Knowledge of anchoring



(E) Knowledge of vulnerability of house

Fig.153 Result of comprehension of main topics

4.2.2.4 Focus Group Discussion (FGD)

As an evaluation of practical trainings and workshops for house owners in Padang-Pariaman were discussed, the focus group discussion were conducted for future strategy, shown in Fig.154.

According to Focus Group Discussion, there were some important comments, which are considered for the dissemination of earthquake safer construction in the future, as follows:

1) The awareness about house rehabilitation of the people changed after WS. For example, the people understands house safer construction techniques through WS. (by masons)
2) Before WS, when people constructed their houses, they didn’t care about earthquake safety. However, after they join WS, they follow the Key Requirements and construct a foundation. (by masons)
3) After WS, most of the people in the community understand the process of proper house construction.
4) After WS, more than 90 % of the people know earthquake safer construction techniques and sometimes they can give the masons some suggestions about earthquake safer construction. (by masons)
5) After WS, if they don’t have enough fund, most of the people prefer to build small house with high quality rather than big house with low quality. (by masons)
6) After training WS, the house owners have good communication with the masons about earthquake safer construction. (by house owners)
7) When the house owners buy the materials, they discuss about the material quality with the masons and buy the materials. (by house owners)
8) Most of the women, who were a house owner, participated in their house construction or rehabilitation and gave some advice to the masons because they usually were home. (by house owners)
9) When the masons don’t follow some requests from the women, the women explained the situation to their husband and/or father. Based on the explanation, the husband and/or father strongly emphasis their suggestion to the masons. Finally, the masons follow their suggestion.(by house owners)

Table 16 shows matrix of earthquake safer construction. Through this Focus Discussion Group, in order to build an earthquake safer house, one of key point of dissemination that was recognized is that the close cooperation between construction workers and house owners is necessary and important.

Table16 Matrix of earthquake safer construction about joining Workshop

	People joined WS	People did not joined WS
Mason trained	**It is possible to construct earthquake safer house** ・ The same goal between mason and house owner ・ House owner can understand to mason's technique for safer construction. ・ Earthquake safer technique can share. ・ They can discuss about construction.	**It is difficult to construct earthquake safer house** ・ There is some Gap between them ・ House owner have to follow mason's construction ・ Mason have to follow budget from house owner.

Fig.154 Focus Group Discussion of residents/house owners

4.2.3 A case study of retrofitting training for masons in Padang, 2012

This case study was based on actual practice in Padang, and Padang-Pariaman which suffered a lot of damage during the September 2009 earthquake. In those areas it was evident that existing buildings needed to be strengthened.

In December 2012, the retrofitting training[71] for masons was conducted in compliance with proposed method in Chapter 3.

4.2.3.1 Outline

In the order to disseminate the retrofitting method in Indonesia, practical training was conducted in Padang-pariaman. Through on the job training, masons were learned knowledge and technique. The existing house was retrofitted by training with 50 masons. Furthermore, construction procedure was improved with reconsideration about affordability, feasibility and adaptability.

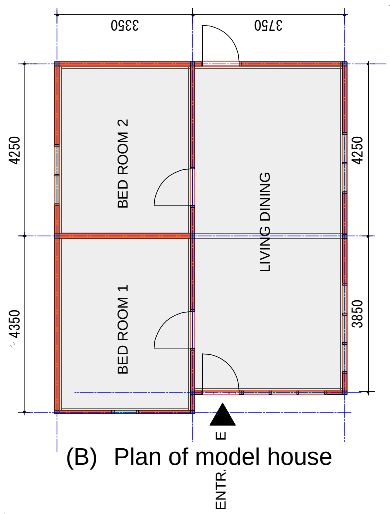
4.2.3.2 Retrofitting method

The method of retrofitting using wire mesh covered by mortar which described in Chapter 3 was applied. (See Fig.157)

1) Situation of existing house for training (See Fig.155)

This model house was built in 1991, and was shaken by the 2007, 2009 earthquakes. There were no visible damage, however improper construction was detected. The houses was made of confined masonry with half-brick-thick walls as non-engineered construction.

(A) Front side of model house



(B) Plan of model house

Fig.155 Model house

71 The project on building administration and enforcement capacity development for seismic resilience Phase 2" by JICA, 2012

Figure 156 shows findings about the model house, as follows:

(A) The building was standing on soft soil. However, the plinth beam was strong enough, because there were no damage on the plinth after being shaken by two large earthquakes.

(B) The gable wall should be strengthened.

(C) The walls and confinement elements should have good connections, such as between brick walls and columns and beams, between intersecting walls and between walls and foundations.

2) Materials and equipment (See Fig.158)

(A) Wire mesh: Galvanized welded wire mesh, Spacing 25 mm, Diameter 1 mm purchased in local market in Padang-pariaman.

(B) Fixing tools and Materials: Electric drill for making hole on the existing wall, Bending wire, Nail for temporary fixing.

(C) For Plastering: The ratio of cement and sand was 1 / 4 by volume and the water cement ratio was 70 %.

3) Procedure of retrofitting construction (See Fig.159)

(A) Preparation of wire mesh: Cutting size and bending for corner, it was better to prepare before assembling for corner and top of walls.

(B) Making through holes for fixing wire was made by drilling, 10 mm diameter on the joint mortar.

(C) Setting umbrella nail for fixing and keeping distance 1 cm from brick surface around with spacing of 30 cm.

(D) Inside and outside wire mesh was stitched by using tie wire inserted through holes in the wall.

(E) Wire mesh should be installed from bottom to top of wall.

(F) The top of wall also should be covered by wire mesh.

(G) Connection is very important using a wire of 2 mm diameter or four of bending wires.

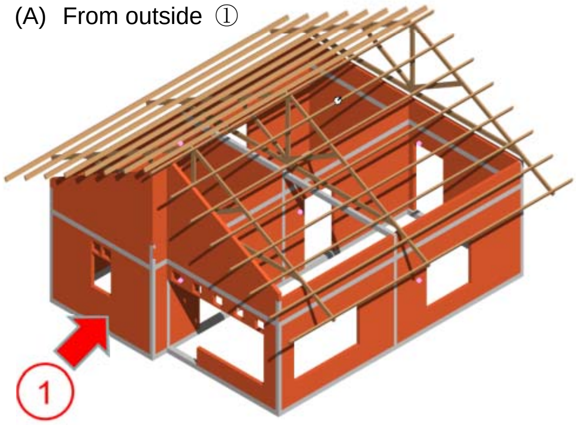
(H) Connecting hole should be filled up by grouting cement water.

(I) The ratio of cement and sand was 1 / 4 by volume was used.

(J) Thickness of plastering on wire mesh required minimum 2 cm.

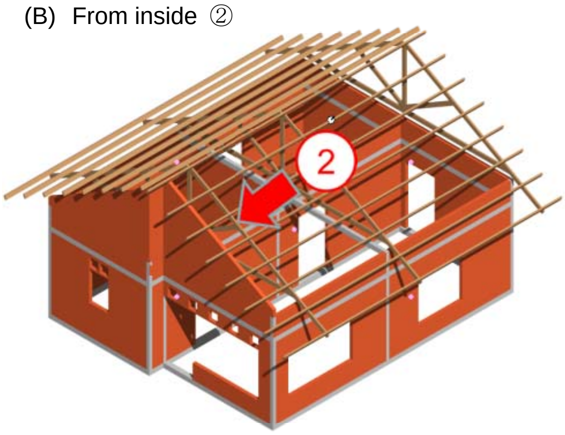
(K) Interior was also plastered.

(A) From outside ①



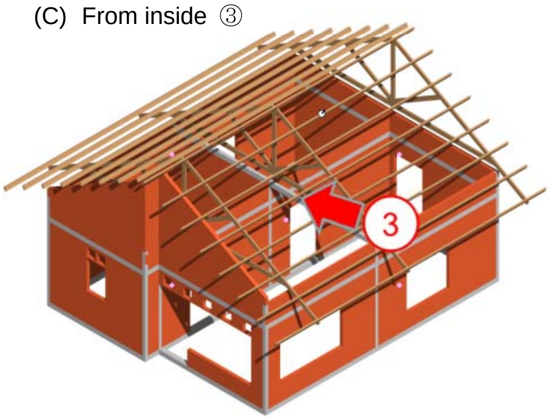
- This house has plinth beam. Concrete condition is not bad.
- The soil condition of site is very soft. (we insert on grand, 10mm steel bar reached until 6meter)

(B) From inside ②



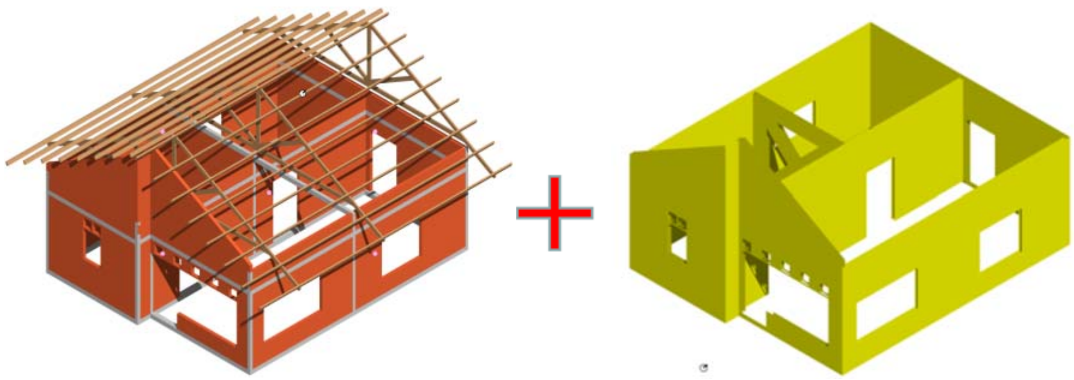
- The gable wall is only front side.
- There are no gable beams.
- There are no columns in the gable wall. The gable wall has cross wall at the center.
- Highest part is 2700 mm from RC beam
- Roof wooden truss is set back from brick wall 1m.

(C) From inside ③



- The beam was constructed on difference levels.
- Most walls do not have beams on top.
- There are free standing brick masonry walls on the lintel beams.

Fig.156 Condition of model house

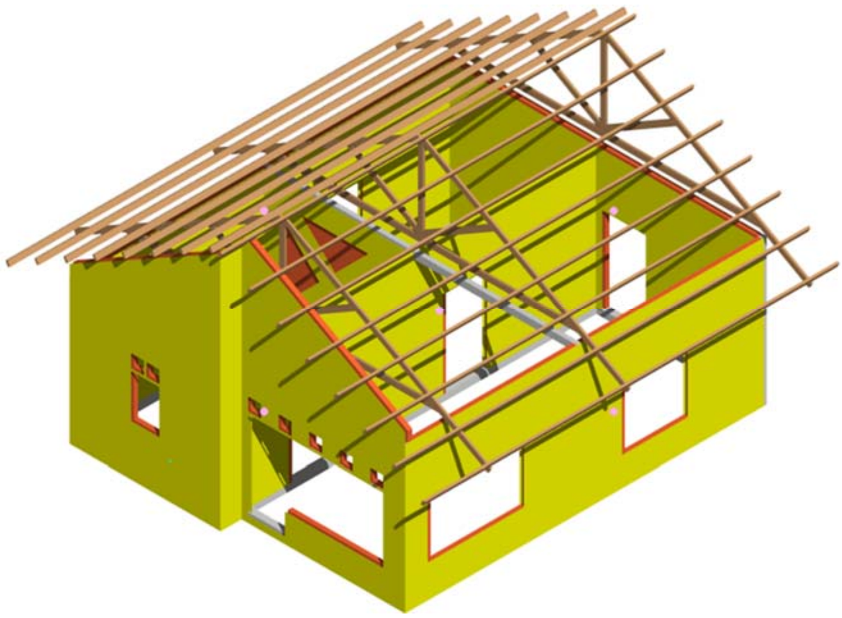


Existing House

Jacketing/bandaging

- All wall covered by wire mesh with mortar as ferrocement.

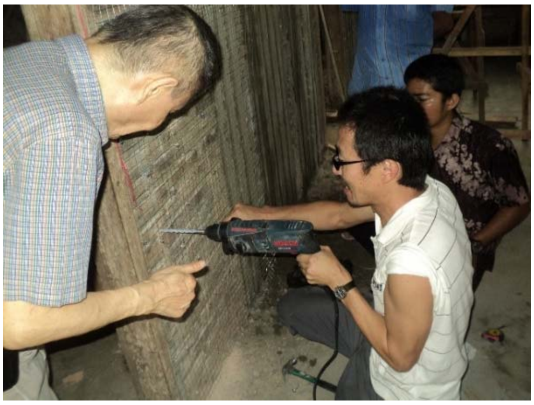
(A) Image of retrofitting method for existing building



(B) Image of retrofitting method for existing building

- This Retrofitting method provide increasing lateral strength in both directions (especially increasing tensile strength), giving unity to the structure by providing a proper connection and avoiding the possibility of brittle failure pattern.

Fig.157 Retrofitting method for existing building



(A) Training of masons (B) During training with Dr. Teddy Boen

Fig.158 Retrofitting training for masons

(A) Wire mesh: Galvanized Welded Wire mesh, Spacing 25 mm, 1 mm Diameter

(B) Fixing tools and Materials: Drill, Bending wire, Nail for temporary fixing.

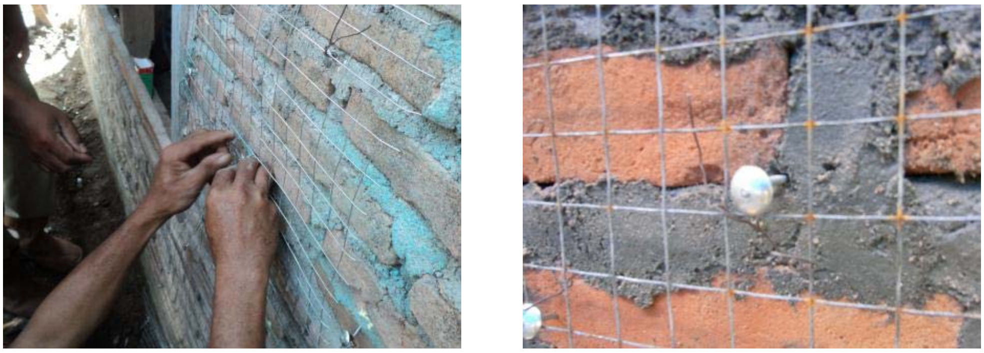
(C) For Plastering: Mortal Ratio is cement 1 : sand 4 by volume

Fig.159 Materials and equipment

(A)Setting wire mesh (cutting and bending): It is better to bend before assembling for corner and top of walls.

(B) Making through holes for fixing wire is made by drilling, diameter 10 mm on the joint mortar.

(C) Setting umbrella nail for fixing and keeping distance 1cm from brick surface around with spacing of @30 cm.



(D) Inside and outside wire mesh is stitched, using tie wire inserted through holes in the wall.

(E) Wire mesh should be installed from bottom to top.

(F) The top of wall also should be covered by wire mesh.

Fig.160 (cont'd) Sequence of retrofitting work during training


(G) Connection is very important using wire dia. 2 mm x 1 or bending wire x 4.
(H) Connecting hole should be filled up by grouting cement water.


(I) Plastering : mortar ratio cement 1 : sand 4 by volume.
(J) Plastering on wire mesh, thickness around 20 mm.


(K) Retrofitting works almost completed.

Fig.160 (cont'd) Sequence of retrofitting work during training

4) Outcome

This retrofitting work as practical training was conducted by around 50 participants in the two weeks workshop. Through this training, the construction procedure with affordability, feasibility and adaptability was checked by discussion with Dr. Teddy Boen and Dr. Iman Satiyarno. The guidebook was published by JICA through outcome of this training.

5) Cost estimation of retrofitting work

Table 17 shows the approximate retrofitting cost of the house.

The market price of new construction is approximately IDR 1,500,000 / m^2. The cost to build a new house with 59.185 m^2 footprint similar to the house in those area is approximately IDP 89,000,000. Therefore, the retrofitting cost is approximately 23.6 % if compare with the cost to build the new house. The average retrofitting cost should be in range of 15-20 %. In this particular case, the wall height is above normal. (Teddy boen, 2014)

The material cost of one roll of wire mesh (1 meter x 23 meter) was IDR 180,000. This house used ten rolls of wire mesh. Therefore, the material cost of wire mesh for this retrofitting house was IDR 1,800,000 (approximately US$160).

This increase was the result that the construction was used as training, therefore, the cost became a little bit high. The cost should be reduced to 20 %.

Table 17 Approximate retrofitting cost in training[72] (Rate: US$ 1 = IDR 11,000, 2014)

No	description	unit	volume	unit price (IDR)	total cost (IDR)
1	Cement water mix	Ls	1.00	200,000	200,000
2	Installation of wire mesh	m2	280.46	28,066	7,871,501
3	Plastering on brick walls	m2	280.46	45,966	12,981,689
				total cost	20,963,190

[72] Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, The University of Kyoto, Ph.D. thesis, 2014, p162

4.3 Development of practical tools for vulnerability and safety evaluation of houses in developing countries -A case study in the Philippines-

4.3.1 Practical tool for vulnerability and safety evaluation of houses

The first step for disaster risk reduction is to understand the disaster risk. In order for earthquake disaster risk reduction, it is critical that the stakeholders such as government officers, masons and contractors, community leaders, and residents/house owners should understand the earthquake risk, or damage estimate of their house, community and city. To promote earthquake disaster risk reduction of residents/house owners must understand the earthquake risk and be concerned, and must take necessary actions at their own expense with the technical advice from the professionals. For such purpose, a simple seismic evaluation method as awareness tool for non-engineered houses in the Philippines was developed.

The Philippine geographic location makes it prone to earthquake occurrences. For the last 35 years, the Philippines had been affected by 10 earthquakes greater than M7.0. A survey of common housing types in the Philippines shows that many non-engineered houses are mostly made of concrete hollow blocks, shown in Fig.161.

The practical tools for vulnerability and safety evaluation for non-engineered houses in the Philippines as awareness tools were developed as part of the project of "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines[73], 2010-2014 by NIED and PHILVOCS[74], funded by JST-JICA.

Fig.161 Non-engineered construction houses in Manila

[73] JST-JICA (SATREPS) 2010-2014, Enhancement of earthquake and volcano monitoring and effective utilization of disaster mitigation information in the Philippines
[74] The Philippine Institute of Volcanology and Seismology (PHIVOLCS): http://www.phivolcs.dost.gov.ph/

These practical tools for seismic evaluation for house are to raise awareness among the stakeholders, simply evaluate safety/vulnerability of houses as educational tools.

Through project, we developed two tools:

1. Tool 1 - 12-point Questionnaire: How Safe is My House? Self-check for earthquake safety.
2. Tool 2 - Software to evaluate safety and vulnerability of houses: Quick Quake Quality check of your house.

Target users for Tool1 are the residents/house owners with one or two stories concrete hollow blocks (CHB) masonry and wooden houses. This tool 1 is able to answer the 12-point questionnaire using a paper copy and hardcopy or in the website via the internet. Tool 2 is a computer simulation program that is based on the data from the field, experimental data and the National Structural Code of the Philippines 2010[75] (NSCP 2010).

Two practical tools were developed. Tool 1 is "Questionnaire which resident/house owner's self-check for earthquake safety", through this test, house owner is able to understand and realize that the earthquake risk is their own concern. Then, next Tool 2 is a "Software for evaluate of safety and vulnerability of houses" which is able to be conducted by resident/house owner and engineers who are trained to use the evaluation program. After that, they take action as their own task with technical assistance. These practical tools is important connect house owners and engineers as making a bridge between them, because such connection is a critical missing link for non-engineered construction. (See Fig.162)

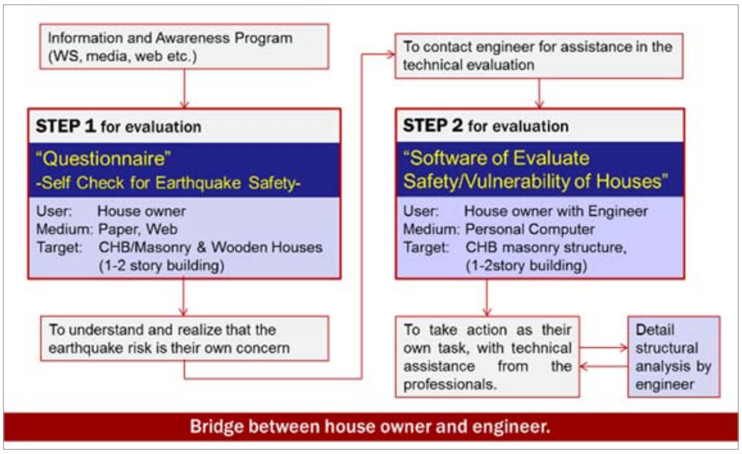


Fig.162 Concept of developing practical tools

75 ASEP, the National Structural Code of the Philippines2010,2010.

4.3.1.1 Tool 1 - 12-point Questionnaire: "How Safe is My House? Self-check for earthquake safety"

The 12 questions in the material include details about the house's history (who, when it was built), and structural details (shape, walls, materials, foundation, deterioration, etc.) based on "Let's check your house for Japanese Wooden house[76]. The simplified checklist has a scoring system that provides an evaluation of the integrity of one's house and its vulnerability to strong earthquakes. The initial result would help the house owner to be able to verify whether a house was properly built and have followed appropriate construction procedures and recommended measures or requiring necessary strengthening. The material also provides recommendations for safer houses. (See Fig.163)

The tool was developed for the concrete hollow block (CHB) structure and wooden structures in English and Filipino (Tagalog) as the local language.

This evaluation was intended for a one or two stories house, including those residence with small shops, offices, garages and the like. This tool help the resident/house owner of this type of buildings to evaluate their buildings by themselves and understand the likely behavior of their houses being damaged during a strong earthquake.

The 12 questions as safety evaluation tool intends to provide more understanding and guidance whether a CHB house conformed to the minimum construction requirements.

User: Resident/House owner
Medium: Paper, Website
Target: CHB masonry, Wooden structures

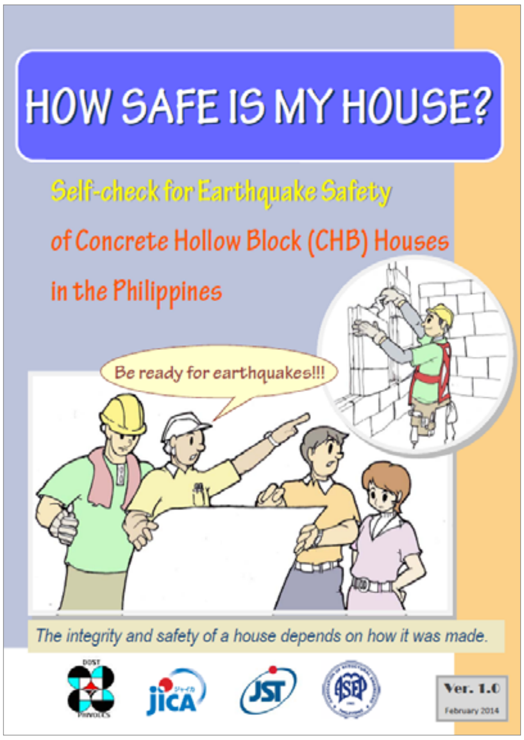


Fig.163 Tool 1: How Safe is My House?

[76] The Japan building Disaster Prevention Association, Let's check your house for Japanese wooden house.

Each questions are follows: (See Fig.164)

Question 1: It is assumed that building construction standards were most likely observed if authorized people took charge of the construction.

Question 2: It rates the chance that your house was built compliant to the recent earthquake-resistant building standards similar to special seismic detailing introduced in 1992.

Question 3: If damaged by previous earthquakes and disasters and not repaired, the structure is weakened making it vulnerable to partial or total collapse during a strong ground shaking.

Question 4: The shape of the house influences its behavior during strong ground shaking. Box-type or rectangular-shaped houses behave better than those with irregular or unsymmetrical configurations.

Question 5: It is assumed that supervised expansion or extension leads to safer and stronger structures.

Question 6: The use of standard 6 inches (150 mm) CHB for external walls produces more stable and stronger structures. The code prescribes the use of at least 6" thick CHB. This was evident in the Full Scale Shaking Table Test conducted for CHB houses on two models on Feb 2011 in Tsukuba, Japan. Avoid using sand and gravel taken from the shorelines and beaches as materials for CHB, mortar, plaster, and concrete mix for foundation for they will cause corrosion to the steel bars over time resulting in thinner diameter and loss of bond.

Question 7: Steel bars embedded in CHB walls, concrete columns, floors and foundation are meant to resist the impact of ground shaking. The use of the standard 10 millimeters diameter steel bars spaced at 40 centimeters from side to side and properly connected and tied to steel bars laid every three layers of CHB (60 centimeters) prevent collapse of walls during earthquakes.

Question 8: Walls wider than 3 meters span without any perpendicular walls or supports are susceptible to collapse in a strong ground shaking.

Question 9: The shaking table test for CHB houses exhibited that the unanchored gable part of the wall shows larger horizontal movement during strong ground shaking. It is recommended that well-reinforced and well-anchored CHBs or light-weight materials be used for the gable wall.

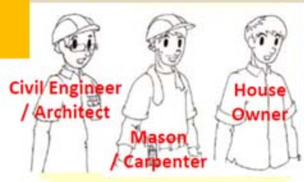
Question 10: Reinforced concrete wall foundation resists shaking, slipping and tilting better than stone-foundation.

Question 11: Rock or stiff-soil provides better support. Soft soils usually amplify strong ground shaking and tend to spread and subside the ground which may worsen damage to structures. For houses on slopes, tie beams or continues wall foundation prevent uneven settlement during strong ground shaking.

Question 12: It is important to observe the state of our house over time. Regular house maintenance must be done to prevent deteriorations like sagging of roof, chipped-off plasters and cracks on walls. It is also highly recommends that all CHB cells and joints are filled and compacted with cement mortar using correct mixture of 1 part of cement to 4 parts (1:4) by volume of washed river sand.

QUESTION 1

Who built or designed my house?



Items		point
A: Built or designed by a licensed civil engineer/architect.	-	1
B: Not built by a licensed civil engineer/architect.	-	0
C: It is not clear or unknown.	-	0

This question refers to the person who supervised the building of the house.

QUESTION 2

How old is my house?

Items		point
A: Built in or after 1992.	-	1
B: Built before 1992.	-	0
C: It is not clear or unknown.	-	0

This checks if your house was built under more recent earthquake-resistant building standards.

QUESTION 3

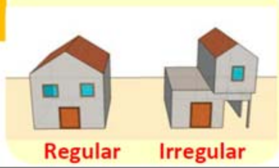
Has my house been damaged by past earthquakes or other disasters ?

Items		point
A: NO or YES but repaired.	-	1
B: YES but not yet repaired.	-	0
C: It is not clear or unknown.	-	0

This checks if the house sustained structural damage and had undergone repair works.

QUESTION 4

What is the shape of my house?

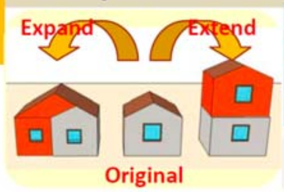


Items		point
A: Regular (symmetrical, rectangular or box-type)	-	1
B: Irregular or complicated.	-	0
C: It is not clear or unknown.	-	0

This checks the shape of your house which influences behavior during strong ground shaking. .

QUESTION 5

Has my house been extended or expanded?

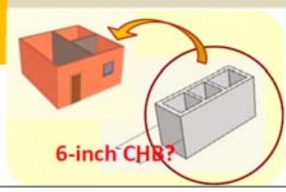


Items		point
A: NO or YES but supervised by a civil engineer/architect.	-	1
B: YES, but not supervised by a civil engineer/architect.	-	0
C: It is not clear or unknown.	-	0

This checks if additional construction was properly executed and correctly attached to the original structure.

QUESTION 6

Are the external walls of my house made of 6-inch (150mm) thick CHB?



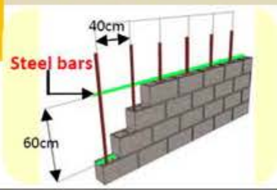
Items		point
A: YES, it is 6-inch CHB.	-	1
B: NO, it is thinner than 6-inch.	-	0
C: It is not clear or unknown.	-	0

This checks if the standard size of at least 6" thick CHB was used.

Fig.164 (cont'd) Contents of tool 1: How Safe is My House?

QUESTION **7**

Are steel bars of standard size and spacing used in walls ?

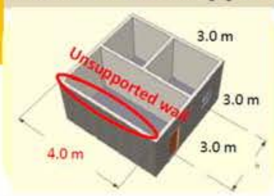


Items		point
A: YES (10mm diameter, tied and spaced correctly) .	-	1
B: NO, fewer and smaller than 10mm.	-	0
C: None or unknown.	-	0

This checks if standard size and spacing of steel bars were used as reinforcement.

QUESTION **8**

Are there unsupported walls more than 3 meters wide?



Items		point
A: NONE, all walls are less than 3m wide.	-	1
B: YES, at least one unsupported wall is more than 3m wide.	-	0
C: It is not clear or unknown.	-	0

This checks if the wall is properly supported from falling down.

QUESTION **9**

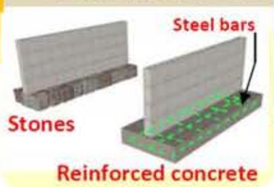
What is the gable wall of my house made of ?

Items		point
A: Light materials, properly anchored CHBs or no gable wall.	-	1
B: Not properly anchored CHBs, bricks or stones.	-	0
C: It is not clear or unknown.	-	0

This checks if the gable wall is properly supported by sufficient steel bars or by a lintel beam.

QUESTION **10**

What is the foundation of my house?



Items		point
A: Reinforced concrete.	-	1
B: Stones or unreinforced concrete.	-	0
C: It is not clear or unknown.	-	0

This checks if the foundation is properly constructed to support the walls.

QUESTION **11**

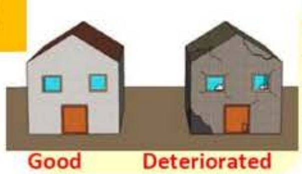
What is the soil condition under my house?

Items		point
A: Hard (rock or stiff soil).	-	1
B: Soft (muddy or reclaimed).	-	0
C: It is not clear or unknown.	-	0

This checks if the house was built over a stable or stabilized ground.

QUESTION **12**

What is the overall condition of my house?



Items		point
A: Good condition.	-	1
B: Poor condition.	-	0
C: It is not clear.	-	0

This describes the overall physical state of the house and checks defect or any deterioration.

Fig.164 (cont'd) Contents of Tool 1: How Safe is My House?

Figure 165 shows the scoring classified to three categories.

Score	Please sum up the points of question 1 to 12.		
	Total		Evaluation and Next steps
	11 - 12 points	➡	Though this seems safe for now, please consult experts for confirmation.
	8 - 10 points	➡	This requires strengthening, please consult experts.
	0 - 7 points	➡	This is disturbing! Please consult experts soon.

Fig.165 Scoring of questionnaire

The scoring was set based on the National Structural Code of the Philippines (NSCP) emphasizes adherence to design standards and proper construction implementation for CHB type of structures in the Philippines. Taking into account from the result of the full-scale shaking table test for the Philippine CHB masonry houses, some questions were selected to design standards and proper construction implementation for CHB type of structures in the Philippines. This safety evaluation tool intends to provide more understanding and guidance whether your CHB house conformed to the minimum construction standard.

As mentioned above, through this test of Tool 1, house owners is able to understand and realize the earthquake risk is for their own safety. The score for non-engineered construction might not be less than 10 points. Next step will be to contact and to consult engineers. This action is important to connect house owners and engineers and to bridge the gap between them, an action of solving the critical missing link for non-engineered construction.

4.3.1.2 Tool 2 - Software to evaluate vulnerability and safety of houses: "Quick Quake Quality check of your house"

Focusing on the CHB masonry structures, a computer simulation program as a practical tool for understanding and evaluating vulnerability/safety of houses was developed based on the data from the field, experimental data and the National structural code in the Philippines2010 (NSCP2010), shown in Fig.166.

With the input of ground conditions, foundation, floor plan, allocation of walls, roofing, reinforcement, age, etc., the tool shows the reasons of vulnerability and then how to improve the house's safety against earthquakes. A visual and user-friendly interface is also developed, so that resident/house owner, who are computer users, together with engineer are able to use the tool. The output includes the scoring of the house, and the reasons of vulnerability, and advice to strengthen the house.

User: Resident/House owner with Engineer
Medium: Personal Computer
Target: CHB masonry (1-2 story building)

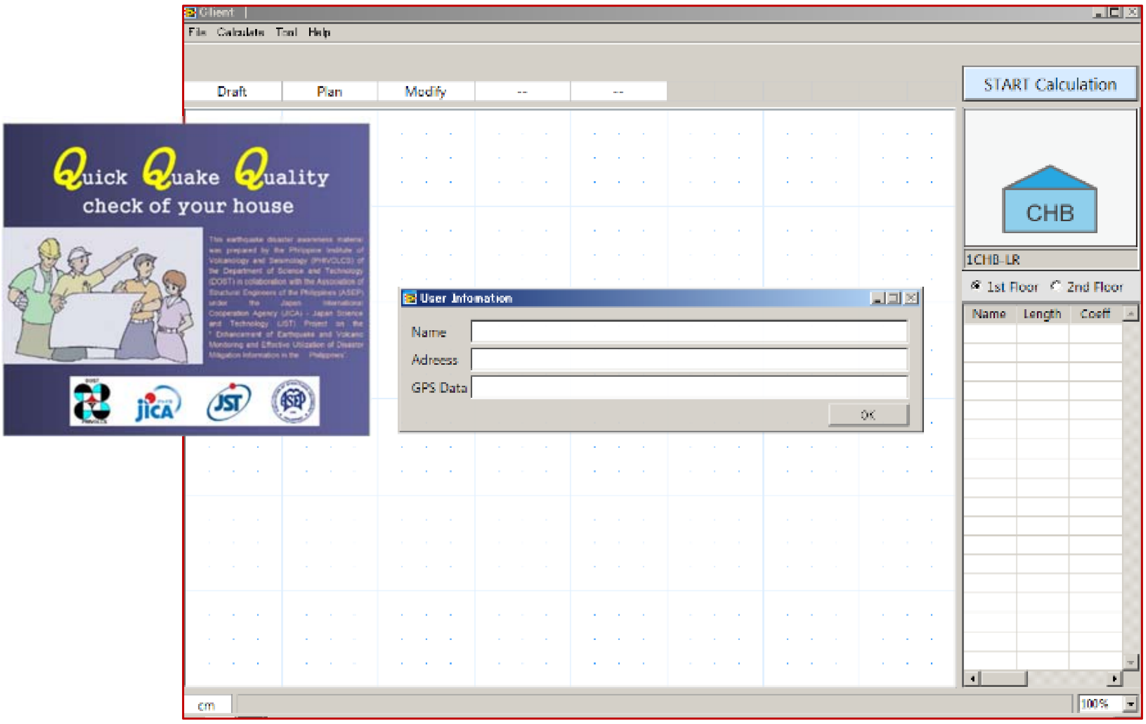


Fig.166 Tool 2: Software to evaluate vulnerability and safety of houses

1) Evaluation criteria

Structural walls, which are the basic resisting elements to seismic loads, load bearing walls such as shear walls which are the main lateral earthquake resistant element in masonry buildings. Therefore, the wall ratio is one of the parameters of seismic performance. Simplified evaluation method based on the wall ratio for masonry structures for un-reinforced masonry and confined masonry houses in developing countries were developed.

The calculations of ultimate strength are used to confirm the safety against earthquake and in accordance with NSCP2010. Basically, each X and Y direction of total ultimate shear strength is evaluated based on the wall ratio and considers a reduction factors and safety factors depending on situation and condition.

Figure 167 shows flow chart of evaluation criteria.

Apart from in-plane shear capacity, according to the result of the full-scale shaking table test for Philippine CHB masonry houses, the most critical failure mode was out-of-plane failure and is found in walls and the gable walls. Therefore, the following points will be evaluated by NSCP2010.

- Solid masonry walls in one-story buildings may be of 150 mm nominal thickness when not over 2.7 m in height, provided that when gable construction is used, an additional 1.8 m is permitted to the peak of the gable.
- Lateral support of masonry may be provided by cross walls, columns, pilasters, counterforts or buttress in the horizontal direction or by floors, beams, girts or roofs in the vertical direction. The clear distance between lateral supports of a beam shall not exceed 32 times the least width of the compression area.

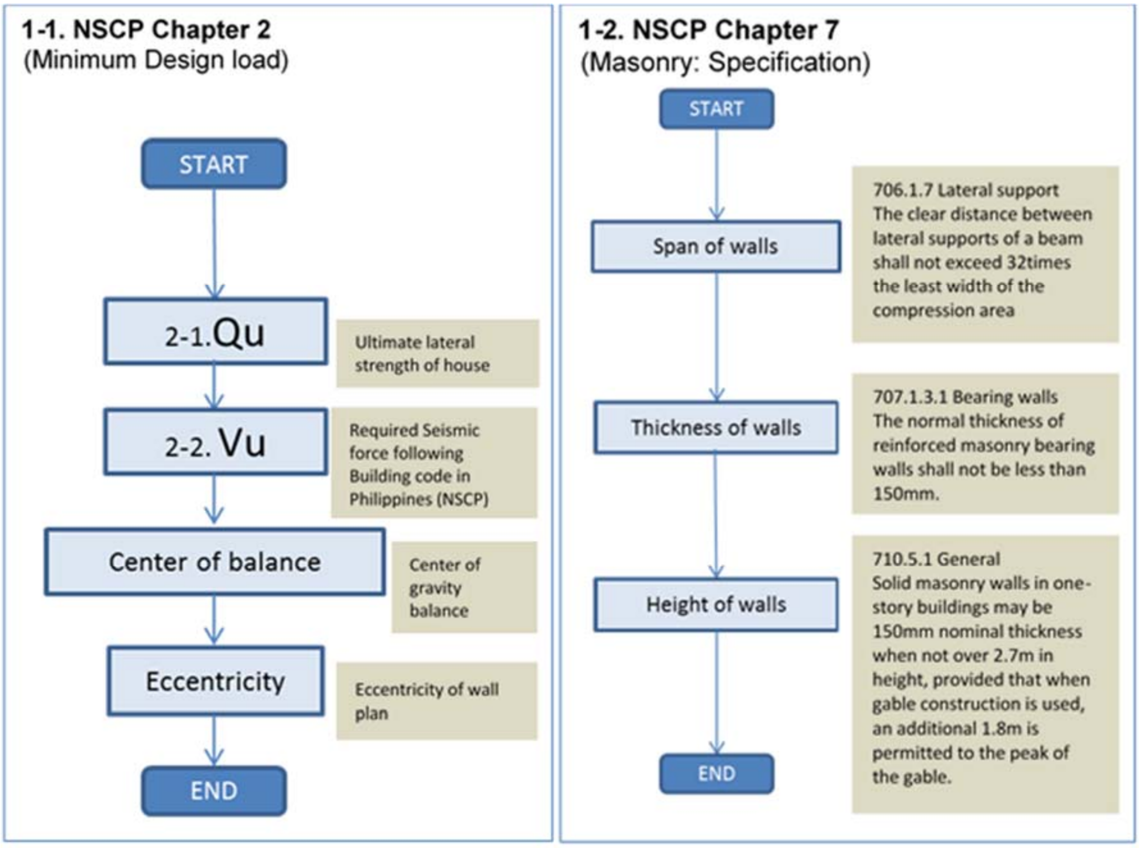


Fig.167 Tool 2: Evaluation criteria

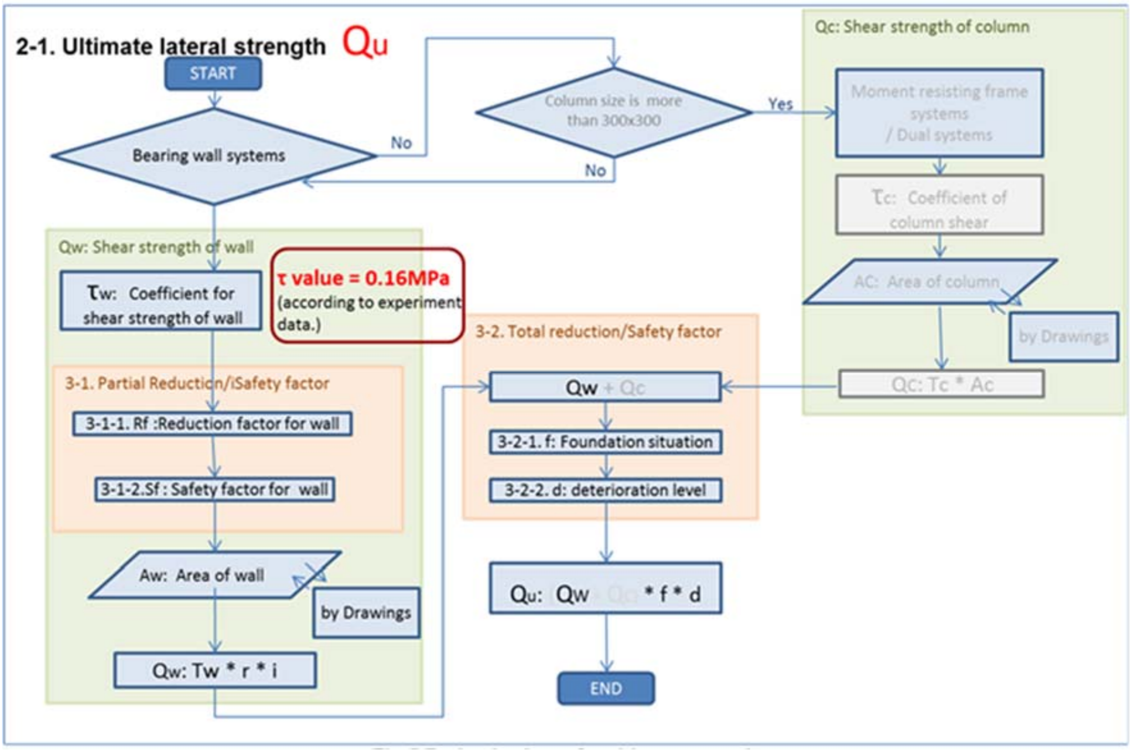


Fig.168 Tool 2: Ultimate lateral strength of house

2) Ultimate lateral strength of house

The calculations of ultimate strength are calculated based on the flow chart is shown in Fig. 168.

The Ultimate strength is calculated Shear coefficient of CHB wall depend on condition of wall which value has five ranges, highest value is in accordance with NSCP 2010 and lowest is a half of half of highest value based on shear test of CHB prisms in Japan, 2012. In addition, reduction factor (e.g. situation of reinforcement, foundation condition, Deterioration level) and safety factor (e.g. finishing effect, confinement effect) are considered.

3) **Required Seismic Force in the Philippine for Ordinary Houses**

The National Structural Code of the Philippines 2010 (NSCP 2010) requires a minimum design load as stipulated in Chapter 2. According to NSCP 2010, Ordinary houses such as masonry structure must follow as below formula:

Required seismic force

$$V = \frac{2.5CaI}{R}W$$

(208-5 in NSCP 2010)

Where;

Ca = Seismic coefficient

I = Importance factor

R = Numerical coefficient representative of the inherent over-strength and global ductility capacity of lateral-force –resisting systems

For example, Base shear value as Required for seismic force Ordinary CHB masonry structures in the Philippines (Zone 4) is around V=0.26W (R=4.5, I=1.0, Nv=1.2, Ca=0.40*1.2=4.8).

4) **Interface and inputs for the software**

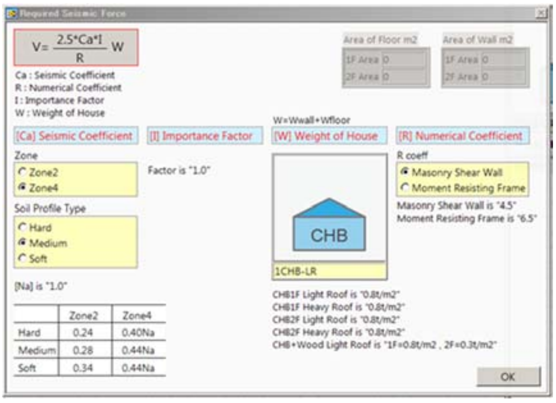
The software has visuals and has a user-friendly interface so that any user with the assistance of engineers can easily use this Tool. The steps of input is shown as follow:

Step 1: Input Information following pop-up window, shown in Fig.169 (A) and (B).

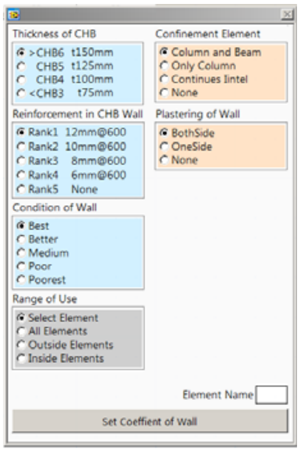
- To input name, address and GPS data if it is possible.
- To input related required seismic force.
- To input related ultimate lateral strength.
- To input related wall situation.

Step 2: Drawing house plan, shown in Fig.169(C).

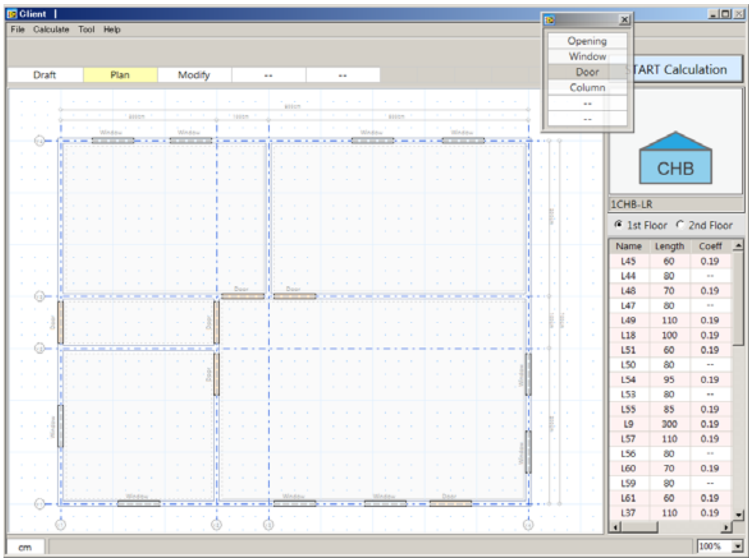
To draw location of wall as plan by line, then automatically, convert to into an architectural drawing.



(A) Pop-up window of required seismic force



(B) Pop-up window of wall conditions

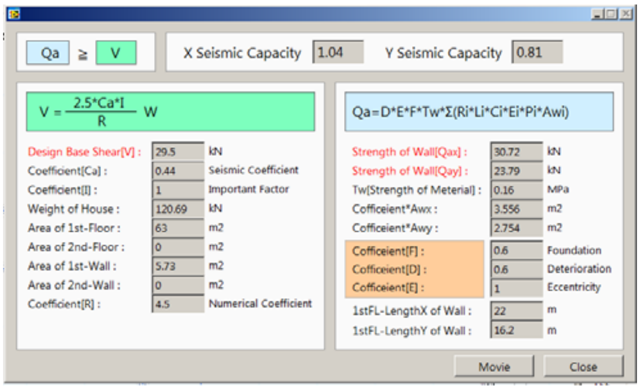


(C) Window of drawing of floor plan

Fig.169 Interface and input of software

5) Results and Comments

Results provided by the tools may not be accurate as a detailed analysis, however these will help increasing the awareness of users about the safety and vulnerability of their houses. As the required seismic force of this evaluation tools is based on the National Code, consequently most non-engineered houses might not followed clear requirements, but this evaluation will provide substantial and useful comments for their houses, thus house owners will get an understanding about the earthquake risk of their houses and which parts of the house are critical and important for safety. (See Fig.170)



(A) Result of evaluation

If one of direction is less than 0.8. Movie show heavy damage.	If score is 0.8 – 1.0. Movie show partially damage.	If score is more than 1.0. Movie show no damage.

(B) According to score, movie of damage is pop-up

Fig.170 Result and comments

4.3.1.3 Test run of practical tool for evaluation in Bohol, Philippines

An earthquake with 7.2 magnitude occurred in Bohol, Philippines on 15th Oct 2013. The National Disaster Risk Reduction and Management Council, Philippines reported 14,512 houses were totally damaged and 58,490 houses were partially damaged. Our team conducted damage survey and test run using the developed practical tool.

The scoring of houses which was evaluated by Tool 1: 12-point Questionnaire: How Safe is My House? Self-check for earthquake safety based on each items are shown below;

No	Sample houses	Negative points	Scoring
1		· Non-engineered · 4inch CHB · Undersized steel bar · Wide walls · Improper foundation	7
2		· Non-engineered · Irregular shape · Expanded · 4inch CHB · Wide wall · Undersized steel bar · Improper foundation · Located on slope · Poor condition	3
3		· Non-engineered · 4inch CHB · Wide wall · Undersized steel bar · Improper foundation · Located on slope · Poor condition	5

Fig.171 (cont'd) Scoring on test run in Bohol

4		· Non-engineered · Irregular shape · 4inch CHB	**9**
5		· Non-engineered · 4inch CHB	**10**
6		· CHB gable wall	**11**

(A) Scoring of each houses

Initial result of tested house in Bohol, 2013			
Point	Evaluation	No'	%
11 – 12 points	This seems safe	3	14
8 – 10 points	This requires strengthening	8	36
0 – 7 points	This is disturbing	11	50

(B) Scoring on test run of questionnaire in Bohol

Fig.171 (cont'd) Scoring on test run of questionnaire in Bohol

Initial result of test run of Tool 1 in affected area by Bohol earthquake is shown in Fig .171. Our impression of this scoring was almost accurate if compared to the actual damage by the earthquake. It was verified by test run using Tool 1, the questionnaire.

The software to evaluate safety and vulnerability of houses was also used for evaluating some houses. Through the test run, the scoring of some houses was better (safer) than the actual damage therefore, the reduction and safety factors of the software were revised. (See Fig.172)

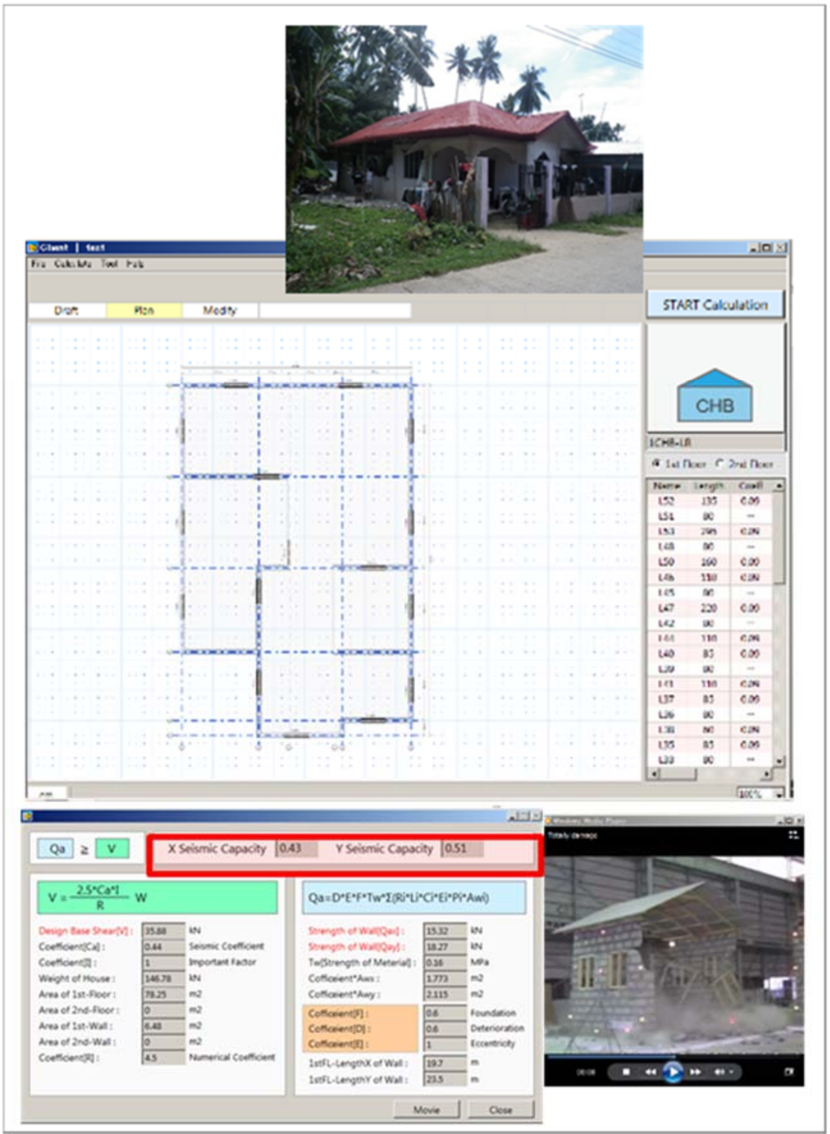


Fig.172 Test run of software in Bohol

4.3.1.4 A case study of dissemination strategy

A) Dissemination to people

These tools was launched to media in the Philippines (See Fig.173). Moreover, these tools, the hardcopies were freely distributed to the public and soft copies are available on PHIVOLCS website.(See Fig.174).

Fig.173 Launching of tool 1 to Media in the Philippines

Fig.174 Two tools be able to download from PHIVOLCS website

B) Training of engineer

1) Target Participants

Target users of the tools are residents/house owners and engineers, however, both the 12-point questionnaire and the software need to be understood by the local government engineers as one of the implementers of the law.

2) Lectures(See Fig.175(A))

The first session as introduction of the two tools aimed to provide orientation to the participants about its development, content, and use. This helps the participants to get familiarized on how the tools would work. Basically, this session was for the acquiring of the knowledge, while the subsequent sessions was for the development of skills.

The second session as practice aimed to develop the skills of the users. For Tool 1, the participants were allowed to score them by merely looking at the photos. The session furthered to develop their skills on how to utilize the questionnaire. Tool 2 is a software that requires the use of personal computer; lectures and introduction with practice. A copy of the software was distributed to all participants and with the facilitators' guidance the trainee installed the software. Hands-on exercises were provided on how to use the software.

3) Field tests (See Fig.175(B),(C),(D))

The last session was enhancing the skills of the users. In this session, a pre-coordinated survey was done to select sample houses where the participants survey. Participants were divided into groups and facilitators were assigned to each group. In the field, participant task was to utilize the two tools, for the 12-point questionnaire, interviews were done to house owners where they also took note related to the level of difficulty while conducting the interview. For the software, participants are provided with materials to measure parts of the house that were required for inputs of the software. Subsequently, results of surveys for both tools were processed.

(A)

(B)

(C)

(D)

Fig.175Lecture and field training of tools

4.4 Conclusion

The lessons learned regarding dissemination of earthquake safer technology for common people are important. The techniques should reach to the people in need of this information. The workshops and seminars were conducted in Indonesia after devastating earthquakes. The possibility of dissemination of the proposed retrofitting method was presented through interval research in Yogyakarta. The author observed technical problems in actual practice and subsequently improve the techniques. The dissemination training workshop of the proposed retrofitting method was held in Padang. Through training workshop, the construction procedure was improved with reconsideration about affordability, feasibility and adaptability.

Simultaneously, seminars for residents/house owners were conducted. To build an earthquake safer house, close cooperation between construction workers and house owners was necessary and important. The practical tools for vulnerability and safety evaluation of houses in the Philippines were developed: (1) 12-point Questionnaire: How Safe is My House? Self-check for earthquake safety of Concrete Hollow Block (CHB) in the Philippines (Tool 1) and software to evaluate safety and vulnerability of houses (Tool 2). These tools aim to raise the awareness of the stakeholders, such as the residents/house owners, local engineers, building officials, and the local government units. The Tools are disseminated in order to reach the specific users and achieve its goal of effective utilization of the disaster risk reduction. Various dissemination strategies were developed and implemented in order to reach the specific users and achieve its goal of effective utilization of disaster risk reduction.

Chapter 5　Conclusions

Chapter 5 Conclusions

5.1 Conclusions

To achieve its goal of effective utilization of disaster mitigation, the study aimed to improve safety of non-engineered construction against earthquake for saving human life by ensuring that non-engineered constructions do not collapse and do not kill people when shaken by earthquakes.

Through this study of experiments and practices, the author tried to bridging the gap between engineers and the common people. The techniques must reach the common people and not only kept in the laboratory.

Heading toward to the implementation of safety for non-engineered construction, the retrofitting methods with affordability, feasibility, and adaptability was proposed through laboratory test and field activities. Furthermore, the seismic evaluation tools for awareness were developed for dissemination of safety of non-engineered construction against earthquake.

In Chapter 1, the present study is introduced. The background, purpose, research objectives, and past studies with literature survey were presented through observations from field experience.

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In Chapter 2, describe is the investigation of the seismic performance of non-engineered construction of three typical methods of masonry structures in developing countries. Three series of shaking table tests of masonry construction were carried out to understand the actual behavior until the tested structure collapsed. The typical failure mechanism were demonstrated through series of shaking table tests. The experiments showed that in plane failure and out-of-plane failure, in particular, masonry gable walls were recognized as vulnerable elements in comparison with other elements. The importance of quality of construction was also demonstrated by experiments.

In Chapter 3, presented are the retrofitting method that is proposed for non-engineered construction. The proposed retrofitting methods for non-engineered construction in developing countries take into considerations as affordability, feasibility and adaptability for existing situations. One of the retrofitting methods uses wire mesh which is available in local market in these area. Furthermore, the retrofitting method was developed using feasible techniques which is possible to construct without the specific or special techniques. Also, several studies using shaking table tests of the proposed retrofitting methods demonstrated its effectiveness for masonry structures. The main aim of this study is to save human lives by preventing collapse of buildings. Through the experiments, the superiority of the method was demonstrated. From the videos of the shaking table tests, it can be seen the difference in behaviors between the building with and without reinforcement. The videos would be important as an information and be able to serve as an awareness tool for the people.

In Chapter 4, discussed are the challenges in the disseminating of earthquake safety construction information to the people. It is necessary to make a bridge between engineering and actual field conditions and situations. Workshops and seminars were held in Indonesia after the devastating earthquakes. The possibility of dissemination of the proposed retrofitting method was presented through research in Yogyakarta. Heading towards to implementation, the techniques of retrofitting were improved through vocational workshop in actual practice. At the same time, seminars for residents/house owners were held in Padang. To build an earthquake safer house, collaboration between construction workers and residents/house owners was essential and critically important. This chapter presents lessons-learned on how to improve affordability, feasibility and adaptability of retrofitting methods through workshop activities in Indonesia. Moreover, for raising awareness on disaster mitigation, two practical tools for vulnerability and safety evaluation for non-engineered houses were developed in the Philippines. Tool 1 is “Questionnaire which resident/house owner’s self-check for earthquake safety”, through this test, house owner is able to understand and realize earthquake risk. Tool 2 is “Software for evaluating the safety and vulnerability of houses” which is able to be conducted by residents/house owners and engineers who are trained. These procedures from Tool 1 to Tool 2 were able to connect residents/house owners and engineers, thus making a bridge between them. These tools aim to raise the awareness of the stakeholders, such as the residents/house owners, local engineers, and government. The tools were disseminated through workshops for local government engineers in the Philippines.

The outcome of this study was reported in a panel discussion of the Scientific Committee of Performance of Masonry Constructions in Foreign Countries in activity of Architectural Institute of Japan in 2009 and 2014.

5.2 Need for action of stakeholders

This study was meant for the bridging of the gap between experiments and practices, since disaster risk reduction is not an easy task, all stakeholders such as government, professionals as architect/engineer, construction worker and resident/house owner should act towards a comprehensive approach to disaster risk reduction.

Top down approach

The top down approach consists of the implementation of the building code.

1) Government

In order to improve earthquake safety, every building should be follow the building code in these countries. However, in the developing countries, non-engineered construction as an informal method of construction exists and is still being built in earthquake prone areas. Therefore, government should constitute simple building code as minimum requirement for the ordinary houses which are using simple techniques. These implementation of requirement needs to assist and monitor by government at field level. During the reconstruction phase, the government shall employed supervisors, called “Facilitators” for the reconstruction of houses. However, if these facilitators are new university or college graduates that did not have experience of actual construction works, it would be necessary to teach technical matters regarding construction in universities and colleges.

Bottom up approach

The bottom up approach consists of the implementation of the field activities.

2) Architect/Engineer

As mentioned Chapter 1, most human casualties by earthquake were due to collapse of non-engineered construction in developing countries. Full-scale shaking table tests as in Chapter 2 are very effective for evaluating, for raising awareness, and to get suggestions and advice from earthquake engineering experts. The importance is not only important in the design using new technology for building but also considering field implementation. Moreover engineering should be useful to societies. In order for technology to be utilized, engineer should be considered field implementation. In addition, the standard design for each area should be developed with linkage to local professionals on disaster preparedness.

3) Construction worker

Mason is the key personnel for improving earthquake safety of non-engineered constructions. Most mason are following knowledge based on their experiences. The masons need to be aware of the technology in order to ensure optimum, efficient and effective use of the building materials and the construction processes.

It is necessary to train them about technical matters regarding earthquake safer design and construction with simple and basic text books, as discussed in Chapter 4.2.

4) Resident/House owner

Earthquake safety will not achieved unless a bottom up approach in which resident/house owner and common people. The first step for disaster risk reduction is to understand the disaster risk. In order for earthquake disaster risk reduction to be effective, it is critical that house owners should understand the earthquake risk, or damage estimate of their houses. To promote earthquake disaster risk reduction, house owners must understand the earthquake risk and be concerned and must take necessary actions.

Through activity in Chapter 4.2, it was recognized that it is not only the masons, but also resident/house owner needs to be taught technical matters regarding earthquake safer design construction in trainings. Because it is needless to say that apart from financial matters, resident/house owner will be around construction site for the most time. In other words, if the resident/house owner have some knowledge of proper construction, house owners shall become the best supervisor of the construction site.

For the all stakeholders, it is necessary to promote better communication among them for disaster risk reduction. The author hopes through this study, developing countries will start to take a step forward to safer construction in their respective countries.

5.3 Further studies

In this study, some experiments of the retrofitting methods were carried out in laboratory, hence, the effectiveness of the retrofitting method to strengthen for existing building were founded.

However, the condition of non-engineered construction is an infinite diversity of existing situations. From a practical perspective, in the considering of these conditions, further study which is related to be bonding strength of a variety of wall conditions would be necessary. For example, pull down test which is using actual existing building and static tensile bonding test for variety of condition of walls.

Moreover, the proposed retrofitting method in this study was demonstrated for Indonesian masonry construction. In order to increase a possibility to apply to other type of masonry, additional experiments and analysis are necessary.

The proposed method is just being started for study, hence data is deficient for factors such as durability and dying shrinkage of mortar and wire mesh as ferrocement under the local environment in these countries.

In chapter 3, affordable, feasible and adaptable retrofitting method for brick masonry construction in Indonesia was introduced. Furthermore, in chapter 4, the practical tools for vulnerability and safety evaluation of houses were developed in the Philippines.

Linkage of retrofitting methods and practical tools for vulnerability and safety evaluation would be necessary for widely disseminating in other developing countries with similar problems.

For example, it is necessary to develop evaluation tools for brick masonry and confined masonry in Indonesia. Furthermore, retrofitting method for concrete block masonry structure also need to develop.

The effort should be continued and made sustainable, because earthquakes will always occur.

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72. Teddy Boen, Challenges and Potentials of Retrofitting Masonry Non-Engineered Construction in Indonesia, The University of Kyoto, Ph.D. thesis, 2014, p162
73. JST-JICA (SATREPS) 2010-2014, Enhancement of earthquake and volcano monitoring and effective utilization of disaster mitigation information in the Philippines
74. The Philippine Institute of Volcanology and Seismology (PHIVOLCS): http://www.phivolcs.dost.gov.ph/
75. ASEP, 2010, the National Structural Code of the Philippines, 2010
76. The Japan building Disaster Prevention Association, Let's check your house for Japanese wooden house.

Appendix

Appendix A: Simplified Strength analysis of non-engineered construction

1. Estimation of shear force of model structure of shaking table test.

The shear forces induced by the earthquake wave in the shaking table tests are roughly estimated. Equation of dynamic motion for earthquake is:

$$m\ddot{x} + c\dot{x} + kx = -m\ddot{y}$$ [1]

where:

m = mass of the model structure
c = damping ratio
k = stiffness
x = displacement of the model structure
y = displacement of ground motion

The result of wave on shaking table tests was showed that damping force ($c\dot{x}$) was small enough to neglect. The above equation was derived:

$$m\ddot{x} + m\ddot{y} = m(\ddot{x} + \ddot{y}) = -kx$$

where Q (kN) is shear force induced in the model structure. It can be roughly estimated as,

$$Q = Ma$$

where:

M = upper half of the model structure (t)
a = response acceleration of model structure (m/s^2 = 100gal)

Q is defined as the inertial force. a denotes the maximum response acceleration in middle or upper section of the specimen. Q before and at collapsing were estimated

[1] A. Shibata, "最新建築学シリーズ　最新耐震構造解析　第 2 版," Morikita Publication, pp.97-108, 2010

Table.1 Rough estimation of shear force of model structures

Model structure			state	Mass of upper part M(t)	Response Acc. of upper part A(m/s2)	Rough estimate of shear force Q(kN)
Chapter 2.2	South Asian type of masonry construction		Before failure	5.1	10.75	54.83
			At the failure	5.1	25.09	127.96
Chapter 2.3	South-East Asian type of masonry construction		Before failure	2.5	24.05	60.13
			At the failure	2.5	32.66	81.65
Chapter 2.4	CHB masonry construction	Model A (engineered)	Before failure	5.12	7.86	40.26
			At the failure	5.12	48.64	249.01
		Model B (non-engineered)	Before failure	2.87	5.00	14.37
			At the failure	2.87	11.69	33.59

2. Ultimate Shear Strength of Each Model Structure using Simplified Evaluation Equation

In order to assess the shear strength in in-plane direction, three equations were employed for calculation. Where, h' is half of height of the specimen. It can be assumed that $N_w = \sigma_o = 0$.

Equation for calculation of ultimate shear strength:

$$H_{s,w} = \frac{f_t A_w}{C_I b}\left[1 + \sqrt{C_I{}^2\left(1 + \frac{N_w}{f_t A_w}\right) + 1}\right] \quad (1)\ [2]$$

where, $H_{s,w}$ = ultimate shear strength (N)

f_t = tensile strength (N/mm^2)

A_w = horizontal cross section of wall (mm^2)

$b = \frac{h}{l}$ = shear force coefficient, h = the height of wall (mm), l = the length of wall (mm),

$C_I = \frac{2\alpha bl}{h}$ = interaction coefficient

$\alpha = \frac{5}{4}$ = parameter of shape and distribution of interaction forces

N_w = vertical load imposed on wall (N)

$$V_s = \left(f_v \frac{1}{1.2}\sqrt{1 + 0.45\frac{\sigma_o}{f_v}}\right)A_w \quad (2)\ [3]$$

where, V_s = ultimate shear strength of wall (N),

f_v = average of shear strength of wall ($= 0.125\sqrt{F_z}$) (N/mm^2)

F_Z = compression strength of joint mortar (N/mm^2),

σ_o =vertical load imposed on wall (N),

A_w = horizontal cross section of wall (mm^2)

[2] Miha Tomazevic, "Earthquake-Resistant Design of Masonry Buildings," pp.109-159
[3] National Standards of P.R. China、Seismic Design Standards for Building Structures (GBJ11-89)

Table.2 Rough estimation of shear force of model structures

<table>
<tr><td colspan="3" rowspan="2">Model structure</td><td rowspan="2">state</td><td>Eq.(1) Ultimate shear strength</td><td>Eq.(2) Ultimate shear strength</td></tr>
<tr><td>(kN)</td><td>(kN)</td></tr>
<tr><td rowspan="3">Chapter 2.2</td><td colspan="2" rowspan="3">South Asian type of masonry construction</td><td>South wall</td><td>171.27</td><td>90.93</td></tr>
<tr><td>North wall</td><td>194.23</td><td>107.66</td></tr>
<tr><td>South + North walls</td><td>365.50</td><td>202.59</td></tr>
<tr><td rowspan="3">Chapter 2.3</td><td colspan="2" rowspan="3">South-East Asian type of masonry construction</td><td>South wall</td><td>131.85</td><td>28.75</td></tr>
<tr><td>North wall</td><td>181.70</td><td>27.12</td></tr>
<tr><td>South + North walls</td><td>313.55</td><td>55.87</td></tr>
<tr><td rowspan="6">Chapter 2.4</td><td rowspan="6">CHB masonry construction</td><td rowspan="3">Model A (engineered)</td><td>South wall</td><td>269.3</td><td>176.6</td></tr>
<tr><td>North wall</td><td>269.3</td><td>176.6</td></tr>
<tr><td>South + North walls</td><td>538.6</td><td>358.2</td></tr>
<tr><td rowspan="3">Model B (non-engineered)</td><td>South wall</td><td>56.9</td><td>115.7</td></tr>
<tr><td>North wall</td><td>56.9</td><td>115.7</td></tr>
<tr><td>South + North walls</td><td>113.9</td><td>231.3</td></tr>
</table>

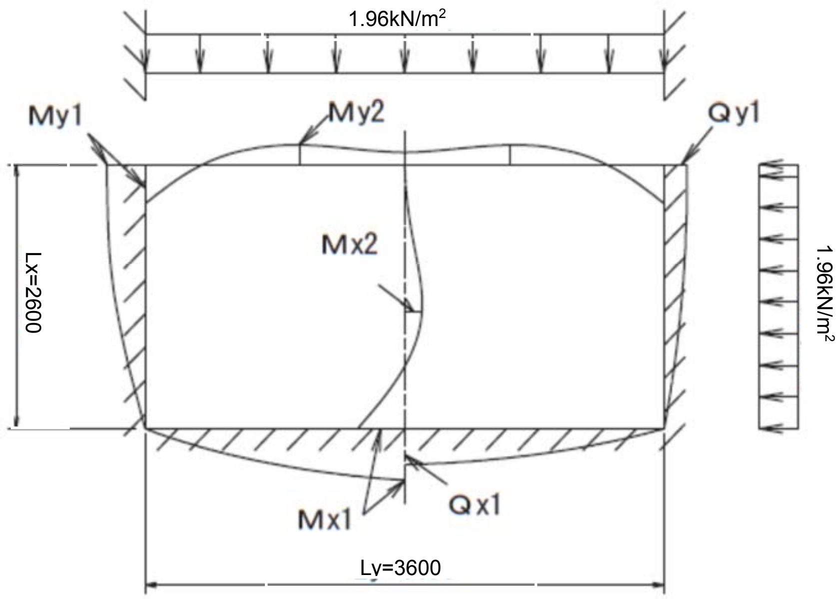
Eqs. (1) and (2) were proposed to evaluate the ultimate shear strength of the wall under vertical load. It should be noticed that Eq. (1) depends on the tensile strength of wall (: f_t). Eqs. (2) depend on the compression strength of joint mortar (: F_Z).

As results of the present assessment, the calculation was quite larger than the experiments data.

3. Calculation of out-of-plane of brick wall (Simplified method)

A case of Chapter 3.4

Height of wall: Lx=2,600mm
Length of wall: Ly=3,600mm
Thickness of wall: t=100mm (brick wall)
t=140mm (retrofitting wall)
Weight of density of wall γ_b =19.613kN/m^3 (brick wall)
γ_b =19.613kN/m^3 (retrofitting wall)



Stress diagram of one end free, three fixed, uniform load by AIJ[4]

1) Nominal allowable stress

W=(3.6*2.6*0.1)* γ_b /(3.6*2.6) = 1.96kN/m^2

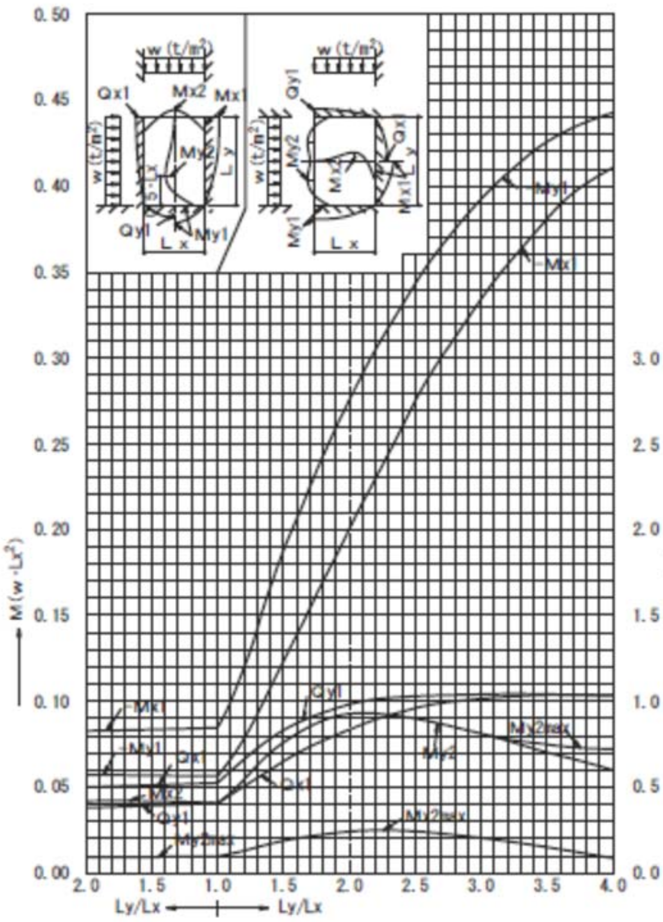
M=W * Lx^2

=1.96 * 2.6^2 =13.25kN

Mx2=0.017 * 13.25 = 0.225kN

My2=0.069 * 13.25 = 0.914kN

[4] Architectural Institute of Japan



Stress diagram of one end free, three fixed, uniform load by AIJ[5]

Ly/Lx = 1.38

Sectional force

$Z= 1/6 * 1000 * 100^2 = 1,666,666\ mm^2$

$\sigma t=M/Z =0.914 *10^6 / 1,666,666 = 0.54$ N/mm2

[5] Architectural Institute of Japan

2) The weight of mass of wall

Weight of Brick wall

W=(3.6*2.6*0.1)* γ_b = 18.35kN (brick wall)

Weight of Retrofitting wal

W=(3.6*2.6*0.14)* γ_b =25.70 kN (retrofitting wall)

Assumed acceleration 1G

The inertia force

$$F = \frac{w}{G} \cdot Accelataion$$ = Weight of mass of wall

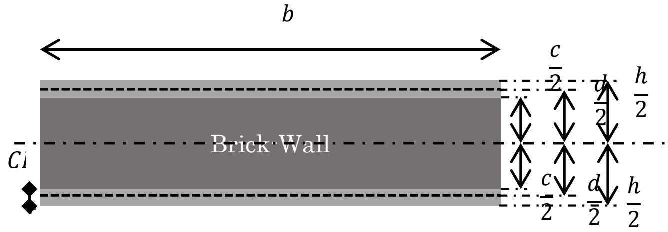
3) The distributed force

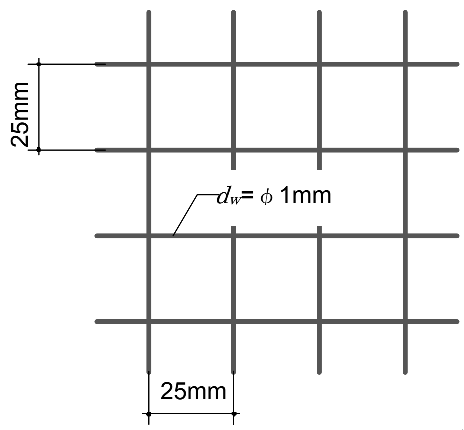
$$q = \frac{F}{L}$$

q =1.96kN/m^2 (brick wall)

q =2.74kN/m^2 (retrofitting wall)

Retrofitting method consists of mortar with 2cm thickness (*h*) and single wire mesh with 1mm diameter (*dw*) spaced at 25mm (*D*) as ferro cement in both directions.





Modulus elasticity of ferrocement from the following expressions taken from (ACI committee 549, 1999; Sandwich structures, Howard G. Allen) as follow;

Volume fraction of mesh in longitudinal direction

$$V_{rL} = \frac{N \cdot \pi \cdot d_w^2}{4 \cdot h} \frac{1}{D}$$

$$= \frac{1 \cdot \pi \cdot (1)^2}{4 \cdot 20} \frac{1}{25}$$

$$V_{rL} = 0.001571 \qquad = 0.15\%$$

Volume fraction of mortar

$$V_m = 1 - V_{rL}$$

$$= 1 - 0.001571$$

$$V_m = 0.998$$

- Elasticity modulus of ferro-cement:

$$E_f = E_m V_m + E_r V_{rL}$$

$$= (6{,}995) \times (0.998) + (205{,}000) \times (0.001571)$$

$$E_f = 7{,}303 N / mm^2$$

E_m =elasticity modulus of mortar matrix (=6,995N/mm^2)
E_r =elasticity modulus of reinforcement (=205,000N/mm^2)
N =number of layers of mesh (=1)

- Flexural rigidity of retrofitted wall (brick wall as core and ferrocement as skin facings) from Howard Allen[6], p217 (10.1)

$$D = E_f \frac{b \cdot t^3}{6} + E_f \frac{b \cdot t \cdot d^2}{2} + E_c \frac{b \cdot c^3}{12}$$

$b = 1000$ Assumed length of panel for calculation
t = 2cm mortar thickness,
d = 12cm Distance between wire mesh,

- Tensile stress of maximum flexural moment at retrofitted wall (brick wall as core and ferrocement as skin facings, from Howard Allen[7], p11 (2.7)

$$\sigma_f = M \cdot \frac{H_t}{2} \cdot \frac{E_f}{D}$$

$\sigma_f = 1.1333$ kN/mm^2

[6] Howard G. Allen Analysis and Design of Structural Sandwich Panels, p217 (eq.10.1)
[7] Howard G. Allen Analysis and Design of Structural Sandwich Panels, p11 (eq.2.7)

MANUAL FOR RETROFITTING OF BRICK MASONRY HOUSES FOR EARTHQUAKE SAFETY

Yogyakarta, Indonesia

1st Edition, August 2009

JAPAN PLATFORM

SNS

MANUAL FOR RETROFITTING OF BRICK MASONRY HOUSES FOR EARTHQUAKE SAFETY

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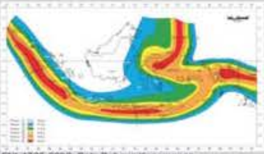
introduction

Yogyakarta's geotechtonical position, which is on the north side of the Australian plate and the Indo-Eurasian plate meeting point, possesses high seismicity levels. Subduction activities that occur in the ocean can activate the fractures that exist in the land and can cause shallow earthquakes which expand northward.



SNI-1726-2002: Peta Bahaya Kegempaan

Besides that, the seismicity level of Yogyakarta is quite high because most of the area's geological formations are formed of aluvium sediment layers from Merapi volcanic ash which is relatively soft. The Yogyakarta earthquake on May 27th, 2006 (Ml 5.9 RS / Mw 6.3) showed that this kind of geological condition experienced the most severe damage, reaching four to five times more than that of areas with hard rock geological structure.

Peta Kerusakan Daerah Trimulyo, Jetis, Bantul (www.unosat.org)

In the Special Province of Yogyakarta (DIY), records show that 175,687 houses collapsed totally or were heavily damaged, 101,082 houses were moderately damaged, and 151,919 houses experienced light damage. The number of deaths recorded was 5,716 people, while 18,702 people were injured.

Approximately 70% of both light and heavily damaged houses, were unreinforced brick masonry houses or brick masonry with reinforced concrete (Bappenas, 2006). This type of house - brick masonry with reinforced concrete - is very common in the community, so it was prioritized in the post-earthquake rehabilitation and reconstruction projects and a standard reference has been made for earthquake-resistant houses.

introduction

Table 1. The number of researched houses in the Village of Trimulyo

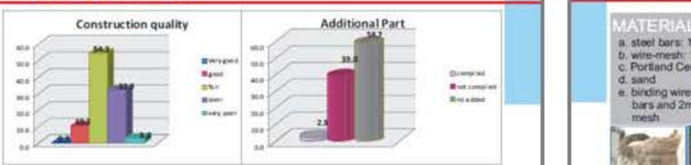
No.	Subvillage Name	House code	Researched Houses	Total Houses
1	Bembem	4B-37…4B-86	25	320
2	Blawong I	4C-1…4c-25	25	380
3	Blawong II	4C-26…4C-48	23	410
4	Bulu	5B-34…5B-94	26	416
5	Cembing	5B-22…5B-33	24	310
6	Denokan	6B-10…5B80	22	250
7	Karangsemut	5B-11…5B-68	23	205
8	Kembang Songo	4B-26…4B-36	24	585
9	Ponggok I	4B-1…4B-25	25	340
10	Ponggok II	3B-1…3B-30	30	475
11	Puton	6B-1…6B-9, 5B-21	23	360
12	Sindet	5B-1…5B-55	30	226
		Total Number	300	4277

This manual was based on research in the Village of Trimulyo, Jetis Bantul resulting from the community experience in the Yogyakarta post-earthquake rehabilitation and reconstruction programs. A survey was carried out on 300 houses involved in rehabilitation programs and earthquake post-reconstructions that were assisted by various funding agencies and through community self-help. Results from the observation found a lack in adherence to provisions in the *Earthquake-Resistant Houses Standards* reference document (a key requirement).

The findings showed:
House extensions that did not follow references (39%); wall width larger than 9 m² (7.3%); poor quality brick masonry (28%); beam and column steel bar diameter less than or equal to 8 mm (17%); poor quality concrete (40%); poor quality house construction (35%); and a lack of various other elements, including absence of bracings between the gable frames, bad beam to column joints, too thin concrete cover, porous concrete, and also roof frames not anchored to ring beam.

(Posyanis UGM, 2006)

introduction



(SNS, 2009)

Based on the results of the observation, house retrofitting reconstruction and rehabilitation programs were held for the community through the following activities:

1. training for community capacity building to provide knowledge about earthquake safe techniques for brick masonry and retrofitting for masons and community members (240 participants in two training programs).
2. application of retrofitting techniques learned through training, by retrofitting twelve sample houses
3. dissemination of the retrofitting methods through the manual.

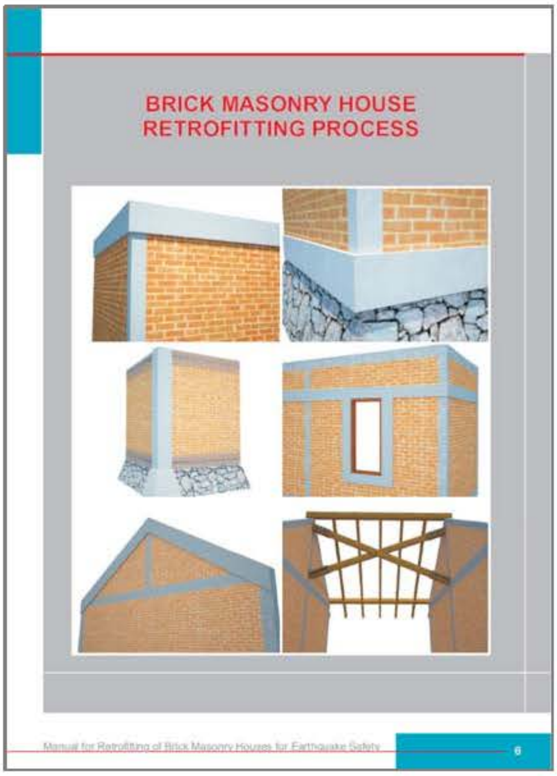
The purpose of this manual is to introduce one of the methods for retrofitting brick masonry houses (with reinforced concrete) using wire-mesh and steel bars to meet the requirements of seismic-safe building standards. This guide is intended primarily for foremen and masons in the construction of brick masonry houses. This manual was developed as a result of discussions, training activities, and practical field work with the masons and construction workers in Trimulyo Village, Jetis, Bantul District, together with SNS International Disaster Prevention Support Center and UGM POSYANIS, with funding by the Japan Platform.

materials & equipment

MATERIALS

a. steel bars: 10 mm diameter
b. wire-mesh: 1 inch width, 1 mm diameter
c. Portland Cement
d. sand
e. binding wire: 3mm diameter to bind steel bars and 2mm diameter to bind wire-mesh
f. timber: 50mm x 70mm, length 4 m
g. water
h. U-plates
i. bolts: 10 mm diameter, length 20 mm

a. tape measure
b. bar cutter
c. bar bender
d. forceps
e. saw
f. wire-mesh cutter
g. hand-held drill
h. concrete drill bits
i. wood drill bits
j. shovel & trowel
k. hammer
l. bucket
m. measuring line
n. nails
o. pencil
p. electricity enhancer



BRICK MASONRY HOUSE RETROFITTING PROCESS

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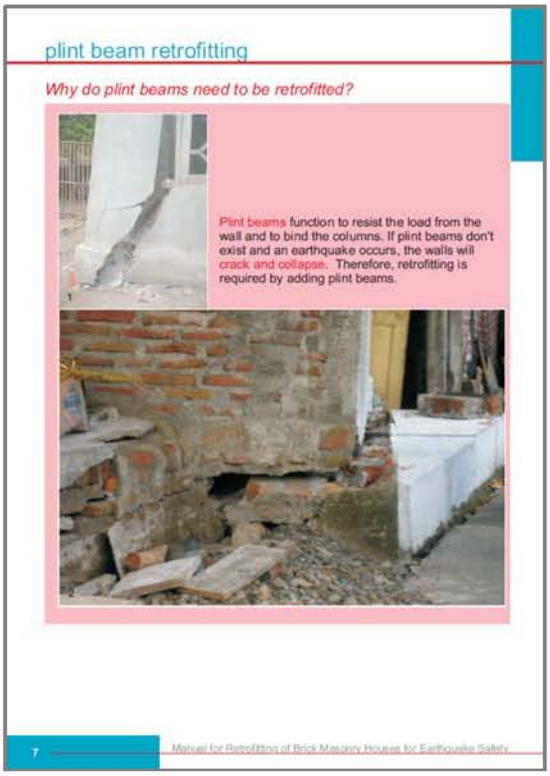

plint beam retrofitting

Why do plint beams need to be retrofitted?

Plint beams function to resist the load from the wall and to bind the columns. If plint beams don't exist and an earthquake occurs, the walls will crack and collapse. Therefore, retrofitting is required by adding plint beams.

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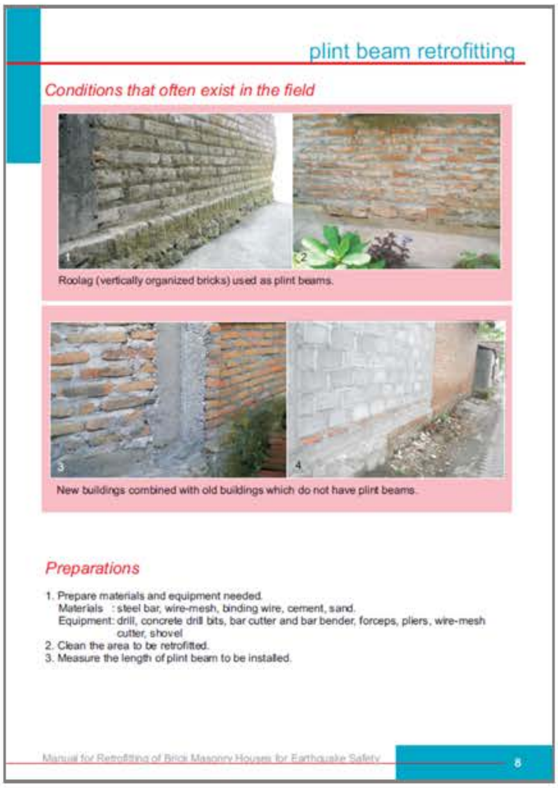

plint beam retrofitting

Conditions that often exist in the field

Roolag (vertically organized bricks) used as plint beams.

New buildings combined with old buildings which do not have plint beams.

Preparations

1. Prepare materials and equipment needed.
   Materials : steel bar, wire-mesh, binding wire, cement, sand.
   Equipment: drill, concrete drill bits, bar cutter and bar bender, forceps, pliers, wire-mesh cutter, shovel
2. Clean the area to be retrofitted.
3. Measure the length of plint beam to be installed.

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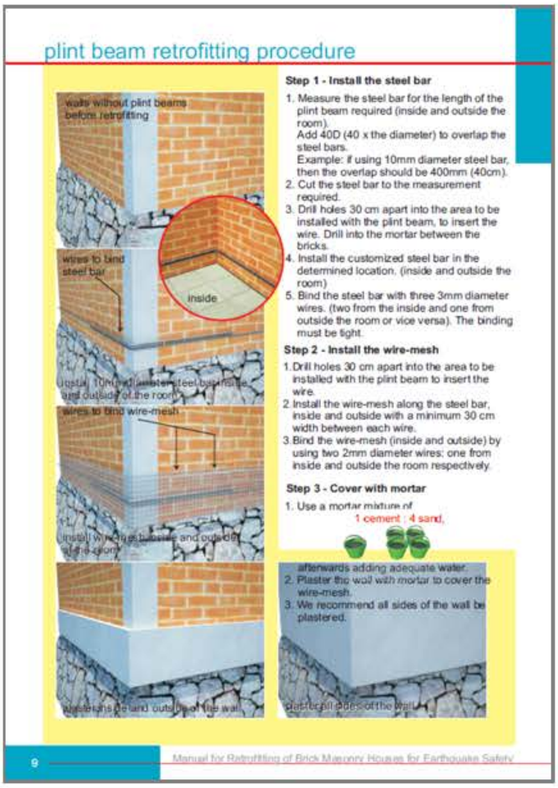

plint beam retrofitting procedure

Step 1 - Install the steel bar

1. Measure the steel bar for the length of the plint beam required (inside and outside the room).
   Add 40D (40 x the diameter) to overlap the steel bars.
   Example: if using 10mm diameter steel bar, then the overlap should be 400mm (40cm).
2. Cut the steel bar to the measurement required.
3. Drill holes 30 cm apart into the area to be installed with the plint beam, to insert the wire. Drill into the mortar between the bricks.
4. Install the customized steel bar in the determined location. (inside and outside the room)
5. Bind the steel bar with three 3mm diameter wires. (two from the inside and one from outside the room or vice versa). The binding must be tight.

Step 2 - Install the wire-mesh

1. Drill holes 30 cm apart into the area to be installed with the plint beam to insert the wire.
2. Install the wire-mesh along the steel bar, inside and outside with a minimum 30 cm width between each wire.
3. Bind the wire-mesh (inside and outside) by using two 2mm diameter wires; one from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of 1 cement : 4 sand, afterwards adding adequate water.
2. Plaster the wall with mortar to cover the wire-mesh.
3. We recommend all sides of the wall be plastered.

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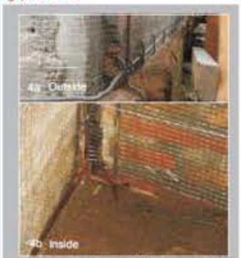
plint beam retrofitting process

Examples of plint beam retrofitting process

Wall without plint beams.

Cut the steel bar according to the required size.

Cut the wire-mesh to a 30cm width, with length to suit the required size.



Install the steel bar and the wire-mesh. If there is an overlap of the steel bar at the corner of the room, add 40D length and bend it to follow the plint beam direction.

Plaster all walls with a mixture of 1 cement: 4 sand.

around plint beam retrofitting

How can retrofit plint beams be fitted to meet door frames?

In an emergency, if the floor has been laid in the room, to install the new steel bar around the building, we need to dig out the area along the inside wall and under the door frame to install the steel bar.

around plint beam retrofitting

COST ESTIMATION
1 m FOR PLINT BEAM RETROFITTING, WIDTH 45 cm
(Unit Price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

1 m Steel bar P10 and Wire-mesh 1" width 45 cm

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
1.05	m	Steel bar	4,173.91	4,382.61		
1.05	m	Wire-mesh 1" width 45 cm	8,500.00	8,925.00		
0.073	kg	Binding wire	25,000.00	1,818.18		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
		Sum of material and labor (IDR)		15,125.79	5,512.50	20,638.29

1 m Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.113	bag	Cement (40 kg)	41,000.00	4,612.50		
0.009	m³	Sand	70,000.00	661.50		
0.09	person/day	Mason	35,000.00		3,150.00	
0.18	person/day	Mason's assistant	25,000.00		4,500.00	
		Sum of material and labor (IDR)		5,274.00	7,650.00	12,924.00

	Material Cost	Labor Cost	Total Cost
Cost Estimation per m (IDR)	20,399.79	13,162.50	33,562.29

wall retrofitting

Why do walls need to be retrofitted?

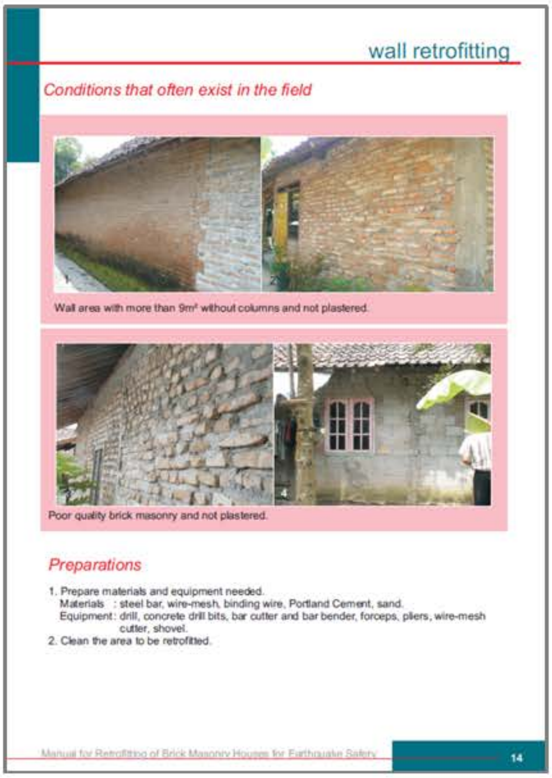
If the wall width is more than 9m² it will crack easily when exposed to shocks.

If the condition of the brick masonry is poor, it will collapse easily when exposed to shocks.

There are two conditions that require wall retrofitting

a. If the wall frame is more than 9 m²
 the retrofitting method used is to add a column or beam to divide the wall into 2 sections of the same area.

b. If walls have bad quality brick masonry or mortar, or walls are not straight
 the retrofitting method used is to install the wire-mesh on the face of all walls and plaster it with 2 cm thickness of cement mortar.



wall retrofitting

Conditions that often exist in the field

Wall area with more than 9m² without columns and not plastered.

Poor quality brick masonry and not plastered.

Preparations

1. Prepare materials and equipment needed.
   Materials : steel bar, wire-mesh, binding wire, Portland Cement, sand.
   Equipment: drill, concrete drill bits, bar cutter and bar bender, forceps, pliers, wire-mesh cutter, shovel.
2. Clean the area to be retrofitted.

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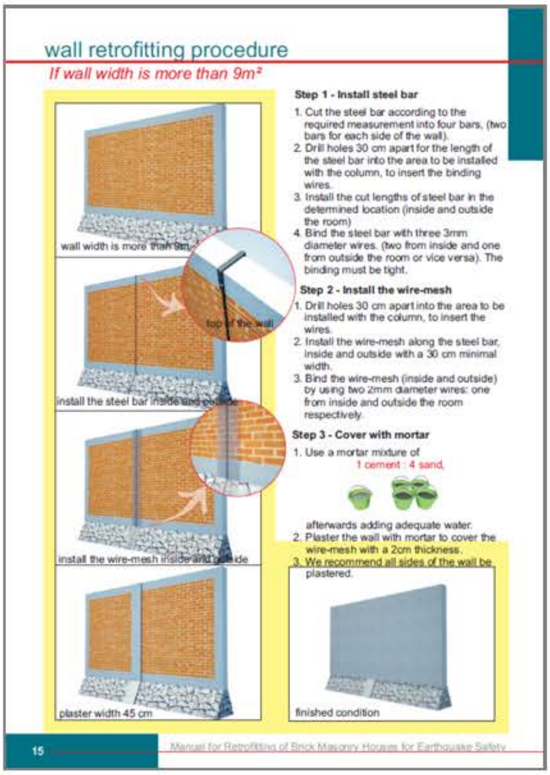

wall retrofitting procedure

If wall width is more than 9m²

Step 1 - Install steel bar

1. Cut the steel bar according to the required measurement into four bars, (two bars for each side of the wall).
2. Drill holes 30 cm apart for the length of the steel bar into the area to be installed with the column, to insert the binding wires.
3. Install the cut lengths of steel bar in the determined location (inside and outside the room)
4. Bind the steel bar with three 3mm diameter wires. (two from inside and one from outside the room or vice versa). The binding must be tight.

Step 2 - Install the wire-mesh

1. Drill holes 30 cm apart into the area to be installed with the column, to insert the wires.
2. Install the wire-mesh along the steel bar, inside and outside with a 30 cm minimal width.
3. Bind the wire-mesh (inside and outside) by using two 2mm diameter wires: one from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of
   1 cement : 4 sand,
   afterwards adding adequate water.
2. Plaster the wall with mortar to cover the wire-mesh with a 2cm thickness.
3. We recommend all sides of the wall be plastered.

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wall retrofitting process

Example of wall retrofitting process by adding columns

Bend the steel bar for the overlap above the ring beam then cut wire-mesh to a 45 cm width.

Drill the area to be installed with the steel bar and wire-mesh.

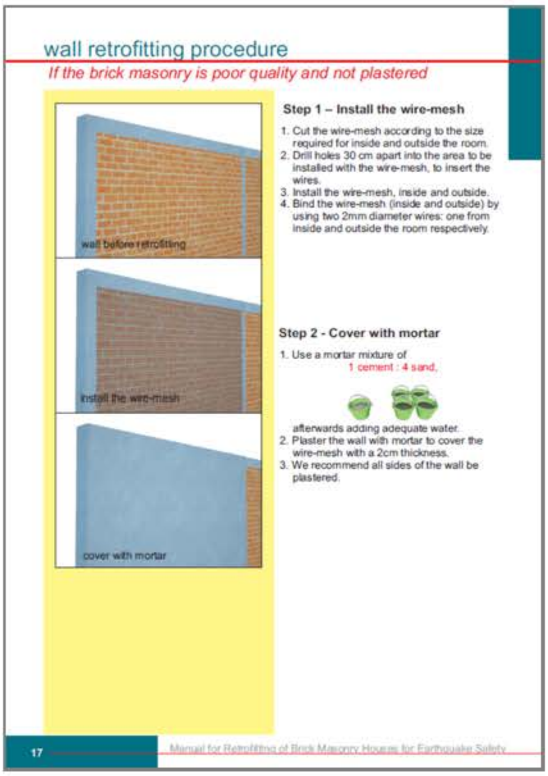
Install the steel bar, the under part is bent at 40D length and planted at a minimum 40cm depth under the ground surface, while the top part overlaps the ring beam.

Install the wire-mesh on the inside and outside of the wall.

Cover the steel bar and wire-mesh planted under the ground surface with a concrete mixture of 1 cement : 2 sand : 3 gravel, or use a mortar mixture of 1 cement : 4 sand.

Plaster the wall with a mixture of 1 Portland Cement: 4 sand.

Manual for Retrofitting of Brick Masonry Houses for Earthquake Safety 16



wall retrofitting procedure

If the brick masonry is poor quality and not plastered

Step 1 – Install the wire-mesh

1. Cut the wire-mesh according to the size required for inside and outside the room.
2. Drill holes 30 cm apart into the area to be installed with the wire-mesh, to insert the wires.
3. Install the wire-mesh, inside and outside.
4. Bind the wire-mesh (inside and outside) by using two 2mm diameter wires: one from inside and outside the room respectively.

Step 2 - Cover with mortar

1. Use a mortar mixture of
   1 cement : 4 sand,
   afterwards adding adequate water.
2. Plaster the wall with mortar to cover the wire-mesh with a 2cm thickness.
3. We recommend all sides of the wall be plastered.

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wall retrofitting process

Examples wall retrofitting process if quality of brick masonry is poor


Poor quality of brick masonry wall


Measure the wire-mesh required


After drilling the holes for binding wires, mark the plaster then install the wire-mesh on the wall that has been plastered. The marks will ease application of the final plaster layer. Try to place the wire-mesh between the two plaster layers.


The distance between the holes for the binding wire must be 30cm apart.


Plaster using a mortar mixture of 1 cement : 4 sand.

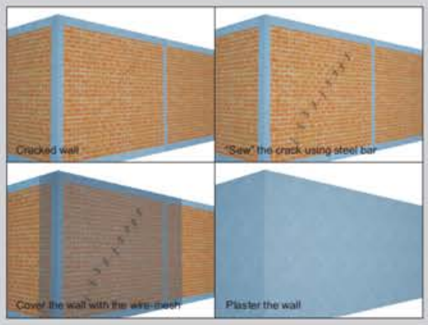

We recommend the entire wall be plastered.

around wall retrofitting

How can brick masonry that was damaged during an earthquake but hasn't collapsed yet be retrofitted?

1. First, check the width of the crack.
   a. If the crack width is more than 1 cm, it is better to make a new wall.
   b. If the crack width is less than 1 cm, then first "sew" the crack using 6mm diameter steel bar.
2. For point 1b, first "sew" the crack by drilling the area along the crack's side to insert the pre- customized steel bar, then insert grouting into the crack slit (eg. Sika grout). Next, cover the entire wall with wire-mesh and plaster it.

Note:
Even if the condition of a wall built before the earthquake is upright and straight (not askew or curved), it's better to consult with a construction expert to check for any wall damage to ensure building safety.



around wall retrofitting

How can the corners of non-anchored walls be prevented from cracking, due to an earthquake?

At the corner of the meeting between two walls, install 90 cm width wire-mesh and bend at the middle, then install on both sides of the wall in the same way that wire-mesh is set into the wall.

COST ESTIMATION
1 m² FOR WALL RETROFITTING
(Unit price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

Wire-mesh 1" lebar 45 cm

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
1.1	m²	Wiremesh 1" width 90 cm	18,900.00	20,790.00		
0.068	kg	Binding wire	25,000.00	1,704.55		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
		Sum of material and labor (IDR)		22,494.55	5,512.50	28,007.05

1 m² Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.25	bag	Cement (40 kg)	41,000.00	10,250.00		
0.021	m³	Sand	70,000.00	1,470.00		
0.2	person/day	Mason	35,000.00		7,000.00	
0.4	person/day	Mason's assistant	25,000.00		10,000.00	
		Sum of material and labor (IDR)		11,720.00	17,000.00	28,720.00
				Material Cost	Labor Cost	Total Cost
		Cost Estimation per m² (IDR)		**34,214.55**	**22,512.50**	**56,727.05**

column retrofitting

Why must walls have columns?

Walls without columns collapse easily when earthquakes occur.
No columns or columns that are too small will weaken a building.

column retrofitting

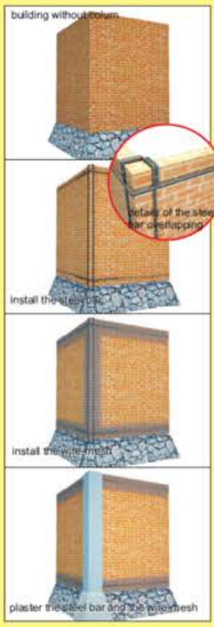
Conditions that often exist in the field

No columns in the building.

Preparations

1. Prepare materials and equipment needed.
   Materials : steel bar, wire-mesh, binding wire, cement, sand.
   Equipment : drill, concrete drill bits, bar cutter and bar bender, forceps, pliers, wire-mesh cutter, shovel.
2. Clean the area to be retrofitted.
3. Measure the height of the future column to the depth of the foundation, and add length for overlap on the ring beam.

column retrofitting procedure



Step 1 - Install the steel bar

1. Cut the steel bar according to the required measurement into four bars (two bars for each side of the wall)
2. Drill holes 30cm apart into the wall to be installed with steel bar, to insert the binding wires. Drill into the mortar between the bricks.
3. Install the cut lengths of steel bar in the determined location (inside and outside the room)
4. Bind the steel bar with three 3mm diameter wires. (two from inside and one from outside the room or vice versa). The binding must be tight.

Step 2 - Install the wire-mesh

1. Drill holes 30cm apart into the area to be installed with wire-mesh, to insert the wires.
2. Install the wire-mesh along the steel bar, inside and outside with a minimum 45 cm width.
3. Bind the wire-mesh (inside and outside) by using two 2mm diameter wires: 1 from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of
   1 cement : 4 sand,

   afterwards adding adequate water.
2. Plaster the wall with mortar to cover the wire-mesh with a 2cm thickness.
3. We recommend the entire wall be plastered.

column retrofitting process

Example of the column retrofitting process

First, measure the steel bar and the wire-mesh needed. The retrofitting location must be cleaned.

Drill holes 30 cm apart into the wall using a concrete drill bit, to insert the binding wires.

Please note:
Drill into the mortar between the bricks.
Avoid drilling holes in the bricks.

After drilling the wall, install the steel bar and bind with three 3mm diameter wires, then install the wire-mesh and bind it with two 2mm diameter wires.

After both the steel bar and the wire-mesh are installed inside and outside of the room, plaster the wall with a cement : sand = 1 : 4 mortar mixture.

5. The finished condition of the retrofitted wall

around column retrofitting

How can steel bars and wire-mesh for column retrofitting be installed in walls under gable frames with no practical columns?

1. Retrofitting is carried out by adding columns using the appropriate column retrofiting procedures.
However, in this case, use four steel bars - two steel bars for the inside and two for the outside of the wall. Measure the steel bars along the required height of the column, add the length of the bar that will be planted into the foundation and bend it 40 x diameter (for bottom part of steel bar) then add 30 cm to the top part of the bar as the overlap to bind the wood roof frame. (See Figure 2)

Binding wire length is:
(wall thickness x 2) + 10 cm = 30 cm untill 50 cm

2. If there is a steel bar connection, use steel bar of 40 x diameter length for the overlap. Bind both steel bars inside and outside with three 3mm diameter wires: two wires from inside and one wire from outside (or vice versa) with 30 cm distance between each bind. To bind the wire-mesh, use two 2mm diameter wires and bind from both the outside and inside of the wall.
3. Drill the holes for binding wire into the mortar between the bricks as it is stronger than drilling into the bricks; this will also deter rust. Avoid drilling holes into the brick.

around column retrofitting

How can cracks around the column at the joining of old walls and new walls of additional rooms be fixed?

Sometimes, room additions were not planned from building conception, so steel bars were not prepared for the joining of the new walls.
The recommended procedure is to retrofit the wall using wire-mesh and steel bars. On the outside wall, use steel bar and 90 cm width wire-mesh. On the inside of the room, in the corner column, install the steel bar and wire-mesh at the bevel position so it unites the cracks.In both room corners, use 90 cm width wire-mesh at the bevel position with 45 cm at each side to form a double L.

COST ESTIMATION
1 m FOR COLUMN RETROFITTING, WIDTH 45 cm
(unit Price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

1 m Steel bar P10 and Wire-mesh 1" width 45 cm

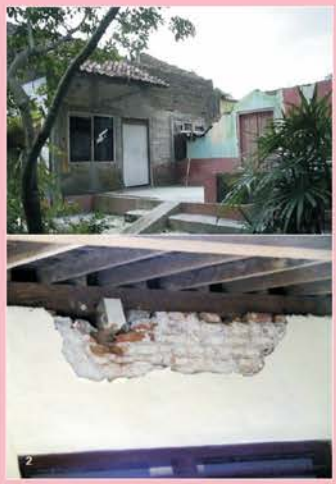
Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
2.1	m	Steel bar	4,173.91	8,765.22		
1.05	m	Wiremesh 1" width 45 cm	8,500.00	8,925.00		
0.073	kg	Binding wire	25,000.00	1,818.18		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
			Sum of material and labor (IDR)	19,508.40	5,512.50	25,020.90

1 m Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.113	bag	Cement (40 kg)	41,000.00	4,612.50		
0.009	m^3	Sand	70,000.00	661.50		
0.09	person/day	Mason	35,000.00		3,150.00	
0.18	person/day	Mason's assistant	25,000.00		4,500.00	
			Sum of material and labor (IDR)	5,274.00	7,650.00	12,924.00
				Material Cost	Labor Cost	Total Cost
			Cost Estimation per m (IDR)	**24,782.40**	**13,162.50**	**37,944.90**

ring beam retrofitting

Why must walls have ring beams?



Ring beams function to tie the walls of a building together so the building framework becomes one rigid unity.
No ring beams will cause a wall to collapse easily during an earthquake.

ring beam retrofitting

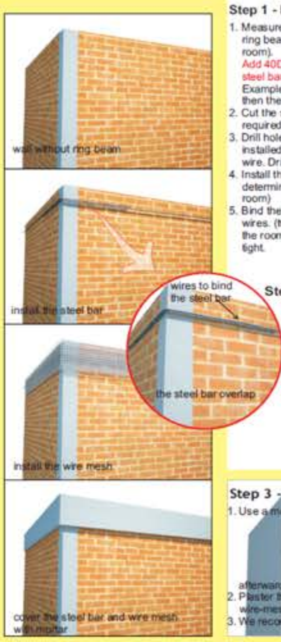
Conditions that often exist in the field

No ring beams in the building

Preparations

1. Prepare materials and equipment required.
   Materials : steel bar, wire-mesh, binding wire, cement, sand.
   Equipment: drill, concrete drill bits, bar cutter and bar bender, forceps, pliers, wire-mesh cutter, shovel, trowel.
2. Clean the area to be retrofitted.
3. Measure the length of the ring beam to be installed.

ring beam retrofitting procedure



Step 1 - Install the steel bar

1. Measure the steel bar for the length of the ring beam required (inside and outside the room).
   Add 40D (40 x the diameter) to overlap the steel bars.
   Example: if using 10mm diameter steel bar, then the overlap should be 400mm (40cm).
2. Cut the steel bar to the measurement required.
3. Drill holes 30 cm apart into the area to be installed with the ring beam, to insert the wire. Drill into the mortar between the bricks.
4. Install the customized steel bar in the determined location. (inside and outside the room)
5. Bind the steel bar with three 3mm diameter wires. (two from inside and one from outside the room or vice versa). The binding must be tight.

Step 2 - Install the wire-mesh

1. Drill holes 30 cm apart into the area to be installed with the ring beam, to insert the wire.
2. Install the wire-mesh along the steel bar, inside and outside with a minimum 30 cm width.
3. Bind the wire-mesh (inside and outside) using two 2mm diameter wires: one from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of
   1 cement : 4 sand,

   afterwards adding adequate water.
2. Plaster the wall with mortar to cover the wire-mesh.
3. We recommend the entire wall be plastered.

ring beam retrofitting process

Example of the process of ring beam retrofitting

Before the steel bar and the wire-mesh are installed, first measure to the required length/size, then cut accordingly.

Drill holes 30 cm apart into the wall, then install the steel bar on both sides (inside and out) by binding with three 3mm diameter wires. Afterwards, install the wire-mesh on both sides (inside and out) and bind with two 2mm diameter wires.

After the steel bar and the wire-mesh are installed tightly (tied to both sides), plaster the wall with a cement : sand = 1 : 4 mortar mixture. After the wall is plastered, cover with cement paste.

around ring beam retrofitting

COST ESTIMATION
1 m FOR RING BEAM RETROFITTING, WIDTH 45 cm
(unit Price per by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

1 m Steel bar P10 and Wire-mesh 1" width 45 cm

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
1.05	m	Steel bar	4,173.91	4,382.61		
1.05	m	Wire-mesh 1" width 45 cm	8,500.00	8,925.00		
0.073	kg	Binding wire	25,000.00	1,818.18		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
		Sum of material and labor (IDR)		15,125.79	5,512.50	20,638.29

1 m Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.113	bag	Cement (40 kg)	41,000.00	4,612.50		
0.009	m^3	Sand	70,000.00	661.50		
0.09	person/day	Mason	35,000.00		3,150.00	
0.18	person/day	Mason's assistant	25,000.00		4,500.00	
		Sum of material and labor (IDR)		5,274.00	7,650.00	12,924.00

1 m Scaffolding

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.142	person/day	Carpenter	35,000.00		4,961.25	
0.014	person/day	Head Carpenter	45,000.00		637.88	
0.047	person/day	Carpenter's assistant	25,000.00		1,181.25	
0.027	person/day	Mason's assistant	25,000.00		675.00	
		Sum of material and labor (IDR)		0.00	6,780.38	6,780.38

	Material Cost	Labor Cost	Total Cost
Cost Estimation per m (IDR)	**20,399.79**	**19,942.88**	**40,342.67**

opening retrofitting

Why must openings such as windows and doors be retrofitted?

Earthquake damage often causes cracks at the corner of openings, so retrofitting around the opening is needed.

opening retrofitting

Conditions that often exist in the field

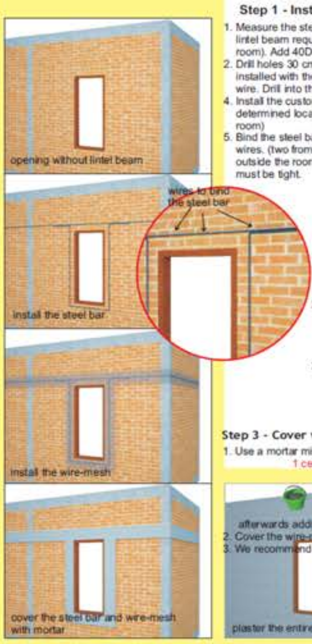
No lintel beam above the opening.

The lintel beam above the opening does not span the length from one column to the other.

Preparations

1. Prepare materials and equipment required.
   Materials : steel bar, wire-mesh, binding wire, cement, sand.
   Equipment: drill, concrete drill bits, bar cutter and bender, forceps, pliers, wire-mesh cutter, shovel, trowel.
2. Clean the area to be retrofitted of moss and other dirt.

opening retrofitting procedure



Step 1 - Install the steel bar

1. Measure the steel bar for the length of the lintel beam required (inside and outside the room). Add 40D bar length.
2. Drill holes 30 cm apart into the area to be installed with the lintel beam, to insert the wire. Drill into the mortar between the bricks.
4. Install the customized steel bar in the determined location. (inside and outside the room)
5. Bind the steel bar with three 3mm diameter wires. (two from the inside and one from outside the room or vice versa). The binding must be tight.

Step 2- Install the wire-mesh

1. Drill holes 30 cm apart into the wall beside the opening, to insert the wires.
2. Install the wire-mesh to surround the inside and outside of the opening with a minimum 30 cm width.
3. Bind the wire-mesh (inside and outside) by using two 2mm diameter wires: one from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of 1 cement : 4 sand, afterwards adding adequate water.
2. Cover the wire-mesh with mortar
3. We recommend the entire wall be plastered.

opening retrofitting process

Example of the opening retrofitting process

Drill into the mortar for the binding wire holes. Avoid drilling holes into the bricks. Before installing the wire-mesh, the wall should be cemented with a 1 cm thickness and wire-mesh should then be placed in the middle of the plaster.

Install the steel bar and the wire-mesh both inside and outside of the wall.

After drilling, install the steel bar and the wire-mesh, then bind with the wire (for the steel bar use three 3mm diameter binding wires; for the wire-mesh use two 2mm diameter binding wires.).

After both the steel bar and the wire-mesh are installed tightly to both sides (inside and out), plaster with a cement : sand = 1 : 4 mortar mixture.

Attention:
Housing health regulations must be adhered to. There must be ventilation above the lintel beams.

around opening retrofitting

How can a steel bar be installed in round openings?

1. Cut the steel bar along the round of the opening with the ace position the width of the wire-mesh (ideally 45 cm, or a minimum 30 cm) approximately 22.5 cm or a minimum15 cm from the bank of the door frame. Add the length 40 x diameter to the steel bar on both sides.
2. Bend the steel bar to form a U-shape to surround the opening.
3. Install on both sides of the wall and bind with wire (see figure 1).
4. Install the steel bar for the lintel together with the steel bar around the opening so they join, then bind together (see figure 2).

How can wire-mesh be bound to round openings?

1. Cut the D 2mm wire to a 35 cm length and fold in the middle so it becomes 17.5 cm. Next, take two pieces and join together from two directions - on the inside and the outside of the wall using one binding wire each (will need two workers). Then, bind tightly using pliers. Before binding, place a size 5 or 7 cm nail at both tips of the wire to hold more than one wire so the wire-mesh won't easily break (see figure 3).
2. Install the wire-mesh overlap so it joins in a horizontal and vertical direction meeting (see figure 5).

around opening retrofitting

Is there another way to create lintel beams?

1. Place the steel bar above the door/window. It is best to put the bar along and attach to all the walls of the house. Use one or two 10 diameter mm steel bars cut according to the length of the wall around. For each overlap use 40 x the steel bar diameter length which must then be placed at the corner of the wall (see figure 3). Bind with wire and fill the space around the wire with mortar. Then, spread the wire-mesh horizontally around. At the meeting, the wire-mesh sheets must overlap one another.
2. If using two steel bars, before installing wire-mesh, a U-shaped 6 mm diameter ring bar with neatly bent tips to form a 135° angle should be installed at a 30cm distance. Install these ring bars alternating from the inside and the outside (in a U-shaped formation) (see figure 2). The length of the 6 mm diameter ring bars must be 20 cm + (2 x thickness of the wall) + (2x5) cm (see figure 1).

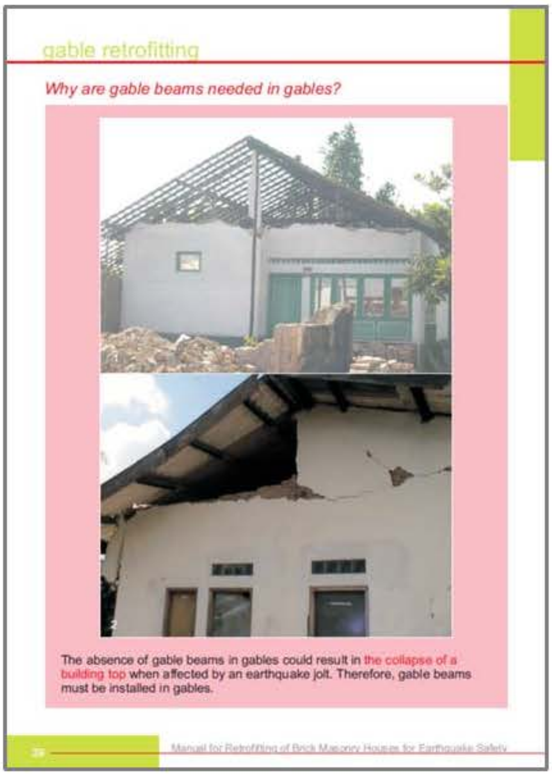
COST ESTIMATION
1 m FOR LINTEL BEAM AND OPENING RETROFITTING, WIDTH 45 cm
(Unit price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

1 m Steel bar P10 and Wire-mesh 1" width 45 cm

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
1.050	m	Steel bar	4,173.91	4,382.61		
1.050	m	Wire-mesh 1" width 45 cm	8,500.00	8,925.00		
0.073	kg	Binding wire	25,000.00	1,818.18		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
			Sum of material and labor (IDR)	15,125.79	5,512.50	20,638.29

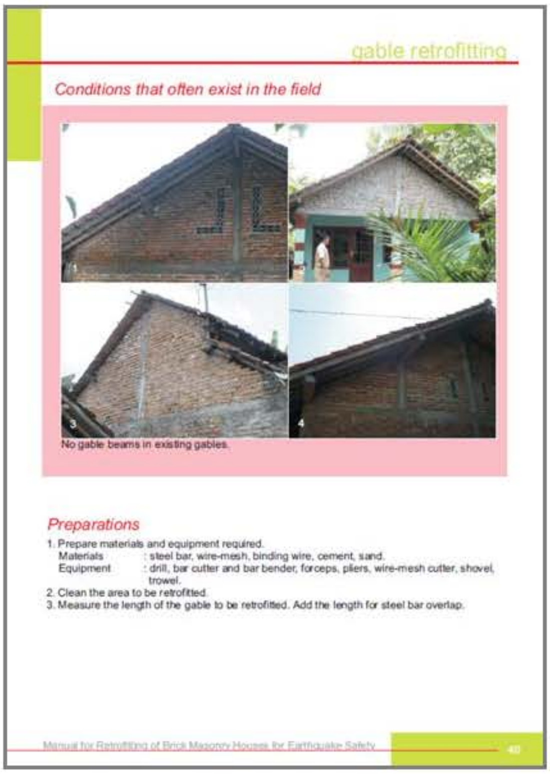
1 m Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.113	bag	Cement (40 kg)	41,000.00	4,612.50		
0.009	m³	Sand	70,000.00	661.50		
0.09	person/day	Mason	35,000.00		3,150.00	
0.18	person/day	Mason's assistant	25,000.00		4,500.00	
			Sum of material and labor (IDR)	5,274.00	7,650.00	12,924.00
				Material Cost	Labor Cost	Total Cost
			Cost Estimation per m (IDR)	20,399.79	13,162.50	33,562.29



Why are gable beams needed in gables?

The absence of gable beams in gables could result in the collapse of a building top when affected by an earthquake jolt. Therefore, gable beams must be installed in gables.

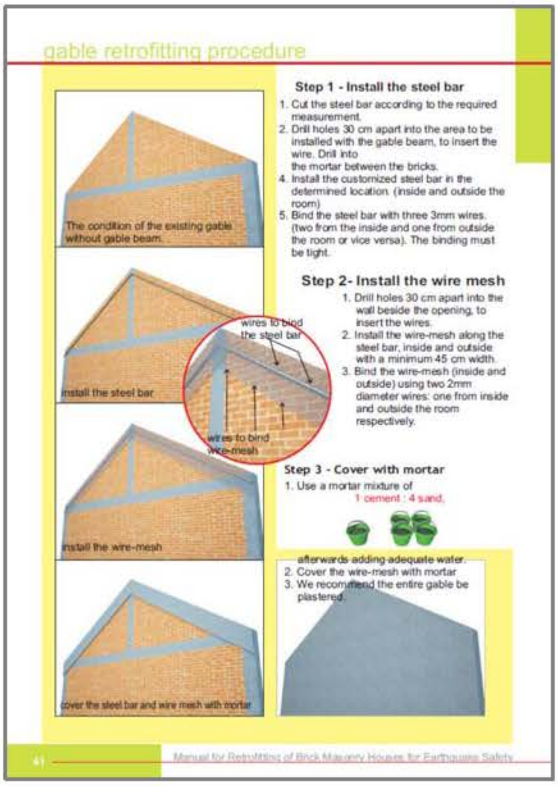


Conditions that often exist in the field

No gable beams in existing gables.

Preparations

1. Prepare materials and equipment required.
   Materials : steel bar, wire-mesh, binding wire, cement, sand.
   Equipment : drill, bar cutter and bar bender, forceps, pliers, wire-mesh cutter, shovel, trowel.
2. Clean the area to be retrofitted.
3. Measure the length of the gable to be retrofitted. Add the length for steel bar overlap.



Step 1 - Install the steel bar

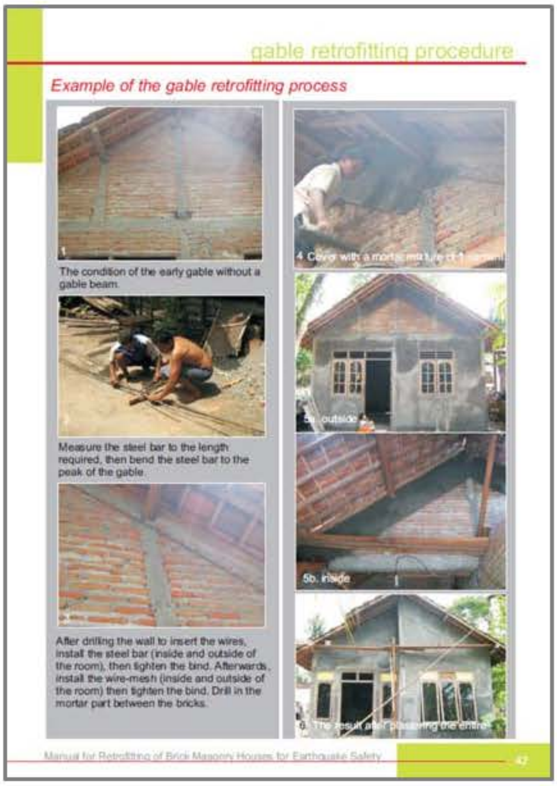
1. Cut the steel bar according to the required measurement.
2. Drill holes 30 cm apart into the area to be installed with the gable beam, to insert the wire. Drill into the mortar between the bricks.
4. Install the customized steel bar in the determined location. (inside and outside the room)
5. Bind the steel bar with three 3mm wires. (two from the inside and one from outside the room or vice versa). The binding must be tight.

Step 2- Install the wire mesh

1. Drill holes 30 cm apart into the wall beside the opening, to insert the wires.
2. Install the wire-mesh along the steel bar, inside and outside with a minimum 45 cm width.
3. Bind the wire-mesh (inside and outside) using two 2mm diameter wires: one from inside and outside the room respectively.

Step 3 - Cover with mortar

1. Use a mortar mixture of 1 cement : 4 sand, afterwards adding adequate water.
2. Cover the wire-mesh with mortar
3. We recommend the entire gable be plastered.



Example of the gable retrofitting process

The condition of the early gable without a gable beam.

Measure the steel bar to the length required, then bend the steel bar to the peak of the gable.

After drilling the wall to insert the wires, install the steel bar (inside and outside of the room), then tighten the bind. Afterwards, install the wire-mesh (inside and outside of the room) then tighten the bind. Drill in the mortar part between the bricks.

around gable retrofitting

What are the details for installing the steel bars at the bottom of the gable beam and the meeting at the corner of the wall?

The steel bar must be bent in an upright direction with the wall (do not stop only at the gable side) in order to achieve better resistance. The wire-mesh installation and plastering must follow, covering the steel bar.

around gable retrofitting

How should the steel bar and wire-mesh be installed to the height of the gable?

1. Erect bamboo/wood scaffolding to the height of the ring beam. Ascertain the scaffolding will be able to resist the approximate weight of at least three adults (approx. 250 kg) or more.
2. Attach a thread from the ace of the left-hand ring beam approximately 15 cm to the side of the gable's ace, then pull to the gable's peak. Nail the thread approximately 15 cm under the roof top. Pull down to the side of the ace of the right ring beam so it is symmetrical with the beginning of the thread.
3. Measure the steel bar to the length of the thread and add a bend at the bank with 40x steel bar diameter length at the right and left sides.
4. Install the steel bar and bend following the thread mark. Attach to both sides of the gable inside out. Bind the steel bar and wire-mesh every 30 cm.

COST ESTIMATION
1 m RETROFITTING FOR GABLE BEAM, WIDTH 45 cm
(Unit Price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

1 m Steel bar P10 and Wire-mesh 1" lebar 45 cm

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
1.05	m	Steel bar	4,173.91	4,382.61		
1.05	m	Wire-mesh 1" width 45 cm	8,500.00	8,925.00		
0.073	kg	Binding wire	25,000.00	1,818.18		
0.075	person/day	Mason	35,000.00		2,625.00	
0.023	person/day	Head Mason	45,000.00		1,012.50	
0.075	person/day	Mason's assistant	25,000.00		1,875.00	
			Sum of material and labor (IDR)	15,125.79	5,512.50	20,638.29

1 m Mortar 1 Cement : 4 Sand

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.113	bag	Cement (40 kg)	41,000.00	4,612.50		
0.009	m^3	Sand	70,000.00	661.50		
0.09	person/day	Mason	35,000.00		3,150.00	
0.18	person/day	Mason's assistant	25,000.00		4,500.00	
			Sum of material and labor (IDR)	5,274.00	7,650.00	12,924.00

1 m Scaffolding

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
0.142	person/day	Mason	35,000.00		4,961.25	
0.014	person/day	Head Mason	45,000.00		637.88	
0.047	person/day	Labor	25,000.00		1,181.25	
0.027	person/day	Labor for scaffolding	25,000.00		675.00	
			Sum of material and labor (IDR)	0.00	6,780.38	6,780.38
				Material Cost	Labor Cost	Total Cost
			Cost Estimation per m (IDR)	**20,399.79**	**19,942.88**	**40,342.67**

roof bracing retrofitting

Why should a roof frame have bracing?

Gable frames without bracing can easily collapse if an earthquake occurs.

The bracing functions as a fastener between two gables/gable frames so during an earthquake they will move together in one direction.

roof bracing retrofitting

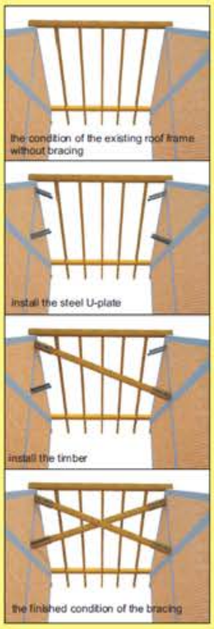
The condition that often exist on the field

No bracing in the gable frames

Preparations

1. Prepare materials and equipment required.
   a. Timber: 50mm x 70mm, length 4m
   b. U-plates: 17 cm width steel with 4 bolt holes
   c. Bolts: 10 mm diameter; 20cm length
   d. Binding wires
   e. Drill
   f. Concrete drill bits
   g. Wood drill bits
   h. Saw
   i. Hammer
   j. Tape measure
2. Measure the diagonal distance between gables

procedure for making bracing



Step 1 –Cut the timber

1. Cut the timber according to the measurement - 2 lengths in total.
2. Cut the timber 40 cm - 4 lengths in total.
3. Mark the timber according to the holes in the U-plate then drill them.
4. Tie the marked timber using the wires (temporarily only), then drill them together so the holes that have been made do not shift.

Step 2- Install the steel U-plate

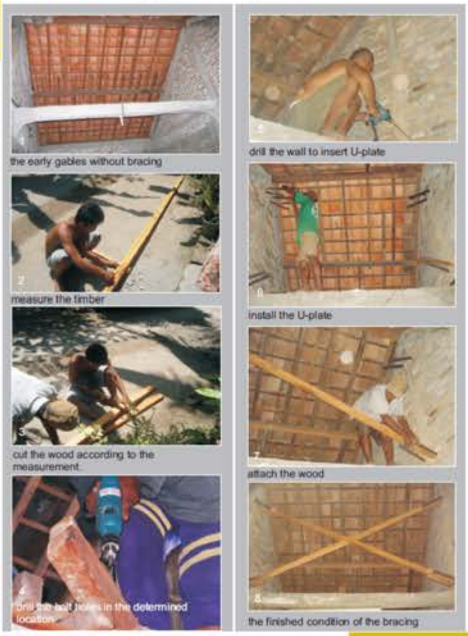
1. Drill the upper and lower centers of each gable.
2. Install the steel U-plate in the askew position in a diagonal direction as illustrated in the picture.

Step 3 – Install the timber

1. Attach the timber to the steel U-plate that has previously been installed.
2. Install the bolt between the wood and the steel U plate then tighten up.

process of making bracing

Example of the bracing installation process

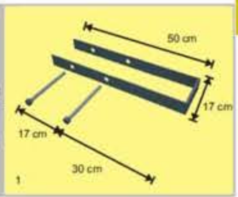


1 the early gables without bracing
2 measure the timber
3 cut the wood according to the measurement
4 drill the bolt holes in the determined location
5 drill the wall to insert U-plate
6 install the U-plate
7 attach the wood
8 the finished condition of the bracing

around making of bracing

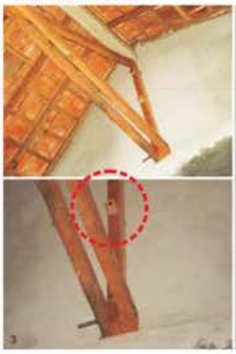
Could the U-plate and the bolt for the bracing be bought in a building materials shop? What size should be used?

U-plates that are available in building materials shops are generally used for making wood gable frames for the roof frame. The U-plate needed for this retrofitting is 50 cm in length and has a gap width of 17 cm. It must be pre-ordered from a building materials shop. The plate material is the same as the U-plate material available in the market for roof frames - usually with a plate width of 5 cm and 4.5 mm thickness. The diameter of the bolt holes is 10 mm with a distance of 17 cm between holes. There must be 2 bolts. (See the picture)



1

How can bracing be made for houses that are close to or abut other houses?


2
3

The bracing can still be installed but with a different method.

1. Install timber length vertically exactly under the corner of the gable, using a10mm diameter dynabolt that is half the length of the bricks. The timber can be drilled beforehand. (If using a dynabolt, the strength is only in the adhesiveness of the bolt). Alternatively, fisher plastic nuts and bolts that don't corrode or Sika grout can be used, because dynabolts rust easily.
2. Afterwards, lay the bracing on the vertical timber length and reinforce with the bolts.

around making of bracing

Is there a different way to install U-plates on gable frames?

The U-plates can be installed overlapping in either the upper or lower positions with a distance of 5-7 cm. For packing, two or three 5/7 timber pieces can be inserted in various positions between the beam and U-plates, depending on the flexibility of the wood.


1 2 3 4

COST ESTIMATION
1 PAIR OF BRACINGS
(Unit Price by 30 April 2009) Exchange Rate US$ 1 = IDR 10,800.00

Quantity	Unit	Item	Unit Price	Material Cost	Labor Cost	Total Cost
20	m	Timber 5/7 coconut wood	6,000.00	120,000.00		
4	set	U-Plate and 2 bolts -10 mm	33,000.00	132,000.00		
1	person/day	Carpenter	35,000.00		35,000.00	
0.1	person/day	Head Carpenter	45,000.00		4,500.00	
0.5	person/day	Carpenter's assistant	25,000.00		12,500.00	
			Cost Estimation per pair (IDR)	252,000.00	52,000.00	304,000.00

1. finished plint beam retrofitting
2. finished wall retrofitting (outside)
3. finished wall retrofitting (inside)
4. finished column retrofitting
5. finished ring beam retrofitting

1. finished lintel beam retrofitting (outside)
2. finished lintel beam retrofitting (inside)
3. finished gable retrofitting
4. finished bracing retrofitting
5. finished bracing retrofitting

about SNS International Disaster Prevention Support Center

In recent years, massive earthquakes have occurred around the world almost every year, and some of these earthquakes have claimed tens of thousands of lives. In particular, these earthquakes have caused tremendous damage to Asia and the surrounding areas. For example, earthquakes in Turkey (1999), India (2001), Iran (2003), Indonesia (2004, 2006), and Pakistan (2005) inflicted horrendous damage beyond all imagination.

For example, Bam Earthquake (6.3 magnitude), which occurred on December 26, 2003 in the southeast of Iran, claimed more than forty thousand lives. Furthermore, approximately 13 years before the Bam Earthquake, the 1990 Rudbar Earthquake that affected areas along the Caspian Sea killed approximately twenty thousand people. In fact, over a period of around forty years from 1962 to 2003, the people in Iran experienced five large earthquakes which claimed thousands of lives.

According to research carried out by the Earthquake Research Institute of Tokyo University in 1991 which focused on causes of earthquake damage in Iran, one of the main factors in earthquake damage between 1962 and 1990 was the collapse of fragile and non-engineered buildings. Similarly, fragile and non-engineered buildings were also identified by the Building Research Institute of Japan as a main cause in the massive damage from the Bam earthquake. So, in every earthquake in Iran, the same factor has led to the loss of so many lives.

Japan is another earthquake-prone country well-known throughout the world. The Great Hansin-Awaji Earthquake of 1995 directly hit Kobe metropolitan area and its surrounds, killing more than six thousand people. Based on our experience of the Great Hansin-Awaji Earthquake and others, Japan has accumulated techniques, policies, and knowledge for earthquake prevention, such as earthquake-safe construction techniques for construction suitable to the regional characteristics of Japan.

We are quite sure that the techniques and knowledge accumulated will be very useful for future earthquake prevention in Asia and its surrounding areas, providing they are transferred in a way that will take into account the social and cultural differences of each region. Thus, by developing disaster-prevention measures suited to the respective regional characteristics, we are also confident that we can mitigate some future disasters.

The mission of SNS International Disaster Prevention Support Center is to support the people of Iran, and other Asian regions, in developing their own culture for disaster mitigation. To achieve this mission, an analysis of the causes of damage from certain natural disasters such as earthquakes in these areas was done, and based on this, various activities for disaster mitigation were held.

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Architectural Mobile Clinic Project

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PANDUAN PELAKSANAAN
RUMAH YANG LEBIH AMAN TERHADAP GEMPA

Mengapa dan Bagaimana Seharusnya Lebih Aman Terhadap Gempa?

Rumah Dinding Pasangan Bata dengan Bingkai Beton Bertulang

Untuk Tukang

Edisi Ketiga 2010

JAPAN PLATFORM

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CATATAN:

Pendapat yang tercantum dalam buku ini adalah merupakan milik penulis dan tidak mencerminkan seluruh SNS International Disaster Prevention Support Center atau Universitas Gajah Mada

Penunjukan nama dan penampilan materi dalam publikasi ini tidak menyiratkan ekspresi pendapat apapun pada SNS International Disaster Prevention Support Center, Universitas Gajah Mada, mengenai status hukum setiap negara atau wilayah, kota atau daerah, atau yang berwenang, atau mengenai penetapan batas-batasnya.

Daftar isi

Pendahuluan

Dalam kurun waktu lima tahun terakhir, daerah pantai barat Pulau Sumatera telah mengalami beberapa kali gempa kuat. Dari gempa Aceh 26 Desember 2004 (9.3 Mw) hingga terakhir gempa Sumatera Barat 30 september 2009 lalu dengan magnitude 7,6 SR (Mw). Menurut BMKG, Episenter di kedalaman 71 km pada koordinat 0.84° LS dan 99.65° BT, berada 57 km lepas pantai barat laut dari Kota Pariaman.

Dampak dari gempa Sumatera Barat menyebabkan kerusakan di 13 kabupaten. Yaitu, Kab. Padang Pariaman, Kota Pariaman, Kota Padang, Kab. Pasaman Barat, Kab. Agam, Kab. Pesisir Selatan, Kota Bukit Tinggi, Kota Solok, Kota Padang Panjang, Kab. Solok, Kab. Pasaman, Kab. Tanah Datar and Kab. Kepulauan Mentawai.

Tercatat lebih dari 1.100 orang meninggal dunia dan sedikitnya 3.000 terluka (BNPB, 2009), serta 279.432 bangunan rusak. Jumlah rumah tinggal yang mengalami kerusakan mencapai 114.797 kategori rusak berat, 67.198 rusak sedang dan 67.839 rusak ringan (Pusat Studi Bencana Universitas Andalas, 2010). Mayoritas rumah tersebut adalah rumah pasangan bata baik tanpa perkuatan (*unconfined brick masonry*) maupun dengan bingkai beton bertulang (*confined brick masonry*). Berdasarkan hal tersebut sangat diperlukan program pengurangan dampak/ kerugian akibat gempa di masa mendatang. Salah satu diantaranya adalah dengan cara membangun rumah tinggal pasangan bata dengan bingkai beton bertulang yang lebih aman terhadap gempa.

Panduan ini dibuat berdasarkan analisis kerusakan rumah tinggal dan survei kebiasaan tukang bangunan dalam membangun rumah tinggal pasangan bata disertai *cheking* pelaksanaan lapangan di Nagari Pakandangan Kec. Enam Lingkung Kab. Padang Pariaman. Wawancara dilakukan terhadap 110 tukang bangunan sebelum program rehabilitasi dan rekonstruksi rumah pasca gempa Sumatera Barat 2009 dilaksanakan. Dari wawancara tersebut diperoleh beberapa kebiasaan baik (*best practise*) dan kurang (*bad practise*) dalam membangun rumah pasangan bata dengan mengacu pada buku saku (*key requirement)* versi kerjasama Pemerintah Prop. Sumatera Barat, Dept. PU dan JICA (2009).

Berdasarkan hasil survei tersebut maka diadakan kegiatan sebagai berikut :

1. pelatihan peningkatan kapasitas bagi tukang bangunan, untuk menyebarkan pemahaman tentang rumah pasangan bata yang lebih aman terhadap gempa. Pelatihan dilakukan dalam 5 kali paket pelatihan, masing-masing paket terdiri dari sekali pelatihan bersifat teori dan sekali bersifat simulasi, diikuti oleh 110 tukang bangunan.
2. pengetahuan dari pelatihan dipraktikan untuk pelaksanaan di lapangan pada rumah yang sedang membangun pra Program Rehab/Rekons Sumatera Barat (5 rumah).
3. pendokumentasian dan penyebarluasan hasil praktek pelaksanaan di lapangan melalui buku panduan ini.

Panduan ini bersifat melengkapi dari Buku Saku Persyaratan Pokok Rumah yang Lebih Aman terhadap Gempa. Didalamnya berisi tentang panduan proses cara melaksanakan mendirikan rumah tinggal pasangan bata yang lebih aman terhadap gempa disesuaikan dengan kebiasaan tukang setempat. Panduan ini terutama ditujukan untuk mandor dan tukang bangunan karena mereka adalah pelaksana lapangan dalam mewujudkan rumah yang lebih aman terhadap gempa. Panduan ini dikembangkan dari hasil wawancara para tukang setempat, aktivitas pelatihan, diskusi dan praktik lapangan para tukang bangunan dari Nagari Pakandangan, Enam Lingkung, Padang Pariaman, Sumatera Barat yang diorganisasi oleh SNS dari Jepang dan didanai oleh Japan Platform.

1. Bahan Bangunan

1. Batu pondasi

- Batu kali / gunung yang keras
- Batu dipecah lebih dahulu (baik)
- Umumnya dipakai batu kali (lokal)

Jatuhkan batu dari ketinggian 1 m ke atas batu lainnya. Batu yang baik harus tetap utuh.

2. Bata Merah

Ukuran bata merah setempat 10 cm x 21 cm x 5 cm

Buruk

Baik

3. Kayu

Kayu yang digunakan harus berkualitas baik, yaitu :
- keras, kering, berwarna gelap, tidak ada cacat kayu, lurus.

Catatan kebiasaan setempat :
Umumnya digunakan kayu kelapa. Proses pengeringannya sbb: setelah kayu dipotong sesuai ukuran, satu bulan didiamkan dengan cara ditaruh berdiri di tempat teduh, kemudian direndam di kolam air selama satu bulan, selanjutnya digunakan. Kayu tersebut mudah dikerjakan dan dapat tahan sampai lebih dari 50 tahun.

4. Mortar

Perbandingan campuran volume mortar sebaiknya : 1 semen : 4 pasir bersih + air secukupnya.
Sebaiknya mortar digunakan tidak lebih dari 45 menit setelah pengadukan.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 2

1. Bahan Bangunan

Mortar

Dari survei yang dilakukan terhadap 110 responden tukang di Kec. Enam Lingkung, sebanyak 90 % tukang telah terbiasa memakai komposisi campuran mortar 1:3, dan hanya 7 % tukang memakai 1:4.
Untuk komposisi campuran beton sebanyak 57 % tukang terbiasa memakai 1:1:2, dan hanya 20 % tukang memakai 1:2:3 (lihat Grafik disamping).

Sumber : SNS International, 2010

5. Beton untuk Beton Bertulang

1 zak semen tipe I berat 50 kg dibutuhkan maksimum 0,5 x 50 = 25 liter air bersih

Semen Type I (50 kg)

Air bersih ember bekas cat 20 L

Adukan beton encer (Buruk)

Adukan beton plastis (Baik)

Praktek pengujian adukan beton terinspirasi dari poster yang disusun Teddy Boen

Kerikil diayak dengan ayakan kawat ¾ inch (20 mm).

3 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

1. Bahan Bangunan

Proses Pembuatan Adukan Beton

1. Tuang 2 bagian pasir kemudian tuang 1 bagian semen di tempat pengadukan.
2. Aduk 2 bagian pasir dan 1 bagian semen hingga merata.
3. Sebar mendatar adukan semen dan pasir.
4. Tuang 3 bagian kerikil ke dalam adukan semen dan pasir.
5. Tuang 0,5 bagian air sedikit demi sedikit.
6. Aduk seluruh bahan material tersebut hingga diperoleh adukan yang plastis (pulen).
7. Cek dengan pengujian sederhana.

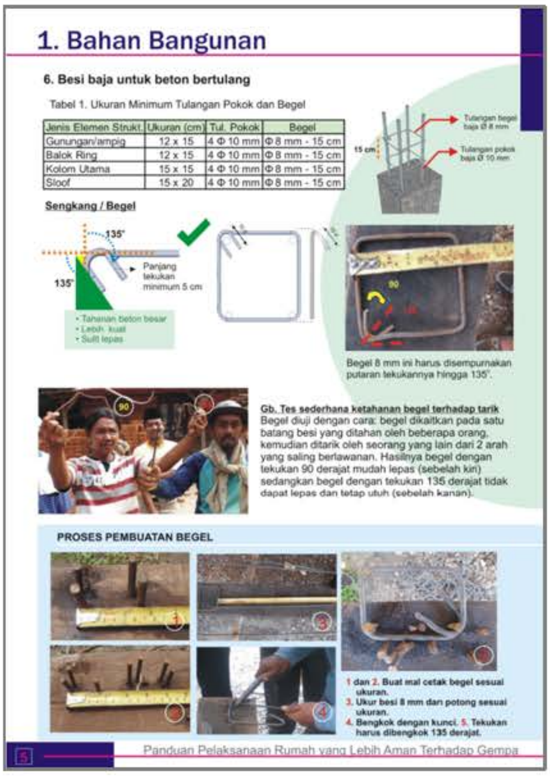
Ingat : setiap 1 zak semen 50 kg digunakan maksimum 25 lt air.

Doc. SNS International (2010)

Cetakan/bekisting balok gantung baru dapat dilepas setelah 14 hari.

Aspek Keselamatan Tukang / Pekerja

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 4



1. Bahan Bangunan

6. Besi baja untuk beton bertulang

Tabel 1. Ukuran Minimum Tulangan Pokok dan Begel

Jenis Elemen Strukt.	Ukuran (cm)	Tul. Pokok	Begel
Gunungan/ampig	12 x 15	4 Φ 10 mm	Φ 8 mm - 15 cm
Balok Ring	12 x 15	4 Φ 10 mm	Φ 8 mm - 15 cm
Kolom Utama	15 x 15	4 Φ 10 mm	Φ 8 mm - 15 cm
Sloof	15 x 20	4 Φ 10 mm	Φ 8 mm - 15 cm

Sengkang / Begel

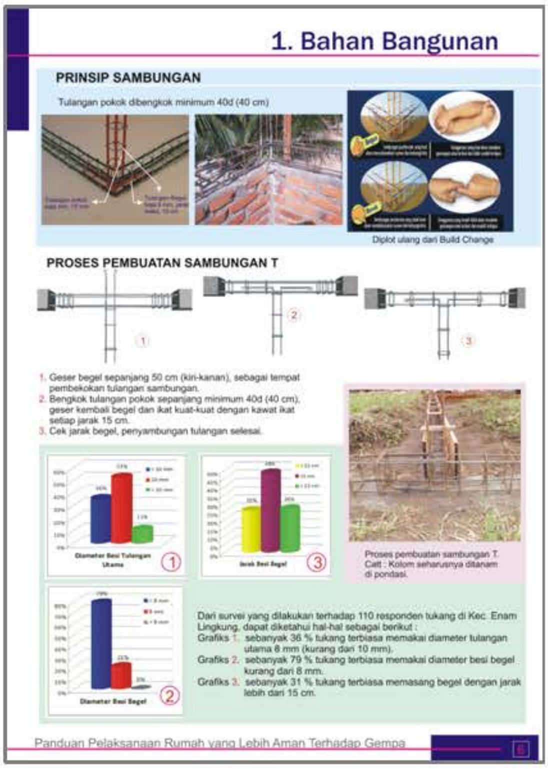
Begel 8 mm ini harus disempurnakan putaran tekukannya hingga 135°.

Gb. Tes sederhana ketahanan begel terhadap tarik
Begel diuji dengan cara: begel dikaitkan pada satu batang besi yang ditahan oleh beberapa orang, kemudian ditarik oleh seorang yang lain dari 2 arah yang saling berlawanan. Hasilnya begel dengan tekukan 90 derajat mudah lepas (sebelah kiri) sedangkan begel dengan tekukan 135 derajat tidak dapat lepas dan tetap utuh (sebelah kanan).

PROSES PEMBUATAN BEGEL

1 dan 2. Buat mal cetak begel sesuai ukuran.
3. Ukur besi 8 mm dan potong sesuai ukuran.
4. Bengkok dengan kunci. 5. Tekukan harus dibengkok 135 derajat.

5 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa



1. Bahan Bangunan

PRINSIP SAMBUNGAN

Tulangan pokok dibengkok minimum 40d (40 cm)

Diplot ulang dari Build Change

PROSES PEMBUATAN SAMBUNGAN T

1. Geser begel sepanjang 50 cm (kiri-kanan), sebagai tempat pembekokan tulangan sambungan.
2. Bengkok tulangan pokok sepanjang minimum 40d (40 cm), geser kembali begel dan ikat kuat-kuat dengan kawat ikat setiap jarak 15 cm.
3. Cek jarak begel, penyambungan tulangan selesai.

Proses pembuatan sambungan T.
Catt : Kolom seharusnya ditanam di pondasi.

Diameter Besi Tulangan Utama (1)
Jarak Besi Begel (3)
Diameter Besi Begel (2)

Dari survei yang dilakukan terhadap 110 responden tukang di Kec. Enam Lingkung, dapat diketahui hal-hal sebagai berikut :
Grafiks 1. sebanyak 36 % tukang terbiasa memakai diameter tulangan utama 8 mm (kurang dari 10 mm).
Grafiks 2. sebanyak 79 % tukang terbiasa memakai diameter besi begel kurang dari 8 mm.
Grafiks 3. sebanyak 31 % tukang terbiasa memasang begel dengan jarak lebih dari 15 cm.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 6

2. Pondasi

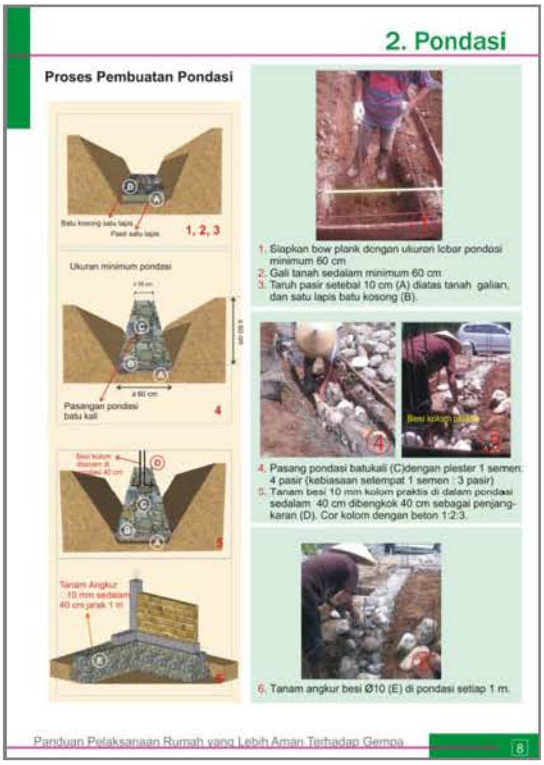
Kerusakan Bagian Pondasi Akibat Gempa

Secara umum bangunan ini rusak karena pondasi dibuat tidak memenuhi syarat dari yang seharusnya yaitu bahan bukan batu kali/gunung yang keras, ukuran pondasi tidak memadai, dan kondisi tanah kurang baik (seperti : sawah, rawa, tanah bergerak/tebing).

tanah bergerak/labil membahayakan bangunan rumah jika terjadi goncangan gempa.

Dari survei yang dilakukan terhadap 110 responden tukang di Kec. Enam Lingkung, dapat diketahui bahwa: Sebanyak 53 % tukang telah terbiasa membuat pondasi dengan ukuran sesuai persyaratan dan 47 % tukang belum sesuai persyaratan.
Sebanyak 81% tukang terbiasa memakai pasir satu lapis dibawah pasangan pondasi dan hanya 19 % membuat pondasi tanpa lapisan pasir dibawahnya.

7 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa



2. Pondasi

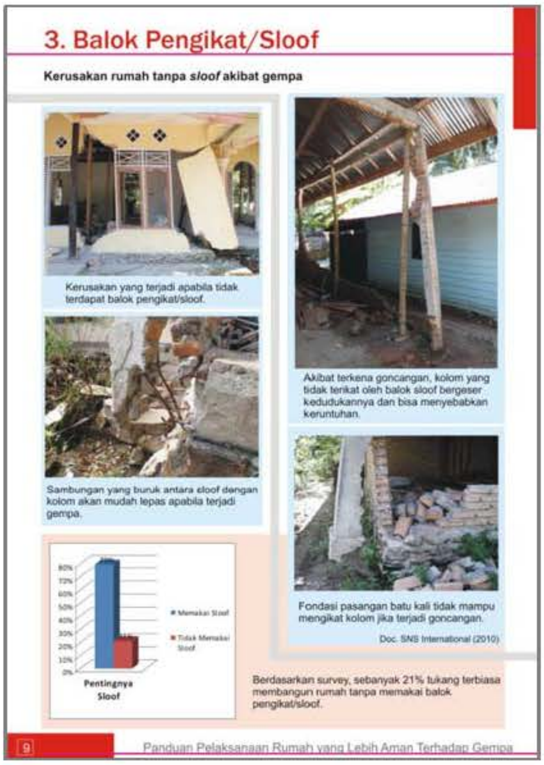
Proses Pembuatan Pondasi

1. Siapkan bow plank dengan ukuran lebar pondasi minimum 60 cm
2. Gali tanah sedalam minimum 60 cm
3. Taruh pasir setebal 10 cm (A) diatas tanah galian, dan satu lapis batu kosong (B).

4. Pasang pondasi batukali (C)dengan plester 1 semen: 4 pasir (kebiasaan setempat 1 semen : 3 pasir)
5. Tanam besi 10 mm kolom praktis di dalam pondasi sedalam 40 cm dibengkok 40 cm sebagai penjangkaran (D). Cor kolom dengan beton 1:2:3.

6. Tanam angkur besi Ø10 (E) di pondasi setiap 1 m.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 8



3. Balok Pengikat/Sloof

Kerusakan rumah tanpa *sloof* akibat gempa

Kerusakan yang terjadi apabila tidak terdapat balok pengikat/sloof.

Akibat terkena goncangan, kolom yang tidak terikat oleh balok sloof bergeser kedudukannya dan bisa menyebabkan keruntuhan.

Sambungan yang buruk antara sloof dengan kolom akan mudah lepas apabila terjadi gempa.

Fondasi pasangan batu kali tidak mampu mengikat kolom jika terjadi goncangan.

Doc. SNS International (2010)

Berdasarkan survey, sebanyak 21% tukang terbiasa membangun rumah tanpa memakai balok pengikat/sloof.

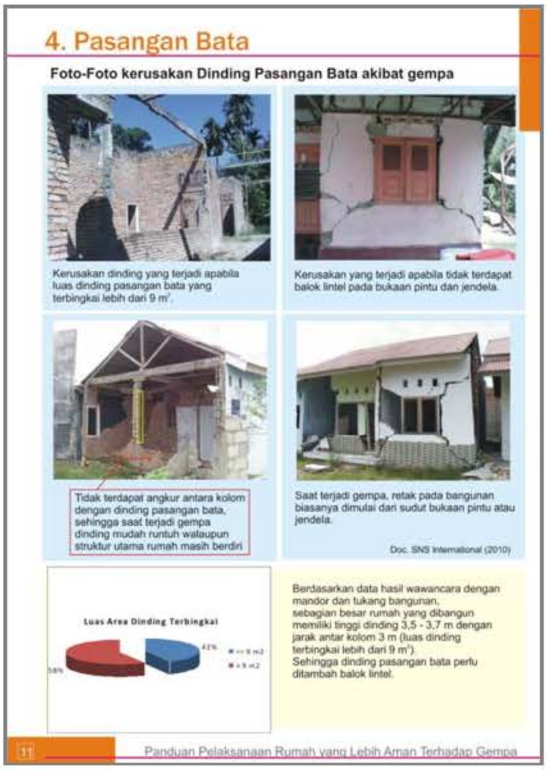
9 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

3. Balok Pengikat/Sloof

Proses Pembuatan Balok Pengikat/Sloof

1. Rangkai begel diameter 8 mm dengan jarak tiap begel15 cm. Pada ujung tulangan yang akan dijadikan sambungan, sisakan tulangan pokok sepanjang 40 cm.
2. Pada sambungan sudut, ujung tulangan pokok dibengkokan sepanjang 40 cm. Kemudian ikat kedua rangkaian tulangan dengan kawat ikat besi beton.
3. Buat bekisting dari papan kayu dengan lebar bagian dalam 15 cm dan tinggi 20 cm. Bakisting harus kuat dan kokoh saat (pengecoran) dan tutup rongga bekisting dengan kertas semen. Untuk menjaga tebal selimut beton 2 cm, buat beton tahu (miring) setebal 2 cm atau sisipkan kerikil dengan ukuran ± 2 cm.
4. Lakukan pengecoran dengan campuran beton yang telah dipersiapkan. Padatkan beton dengan cara dirojok dan diketok-ketok bagian samping bekisting. Setelah 3 hari bekisting sloof bisa dibuka.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 10



4. Pasangan Bata

Foto-Foto kerusakan Dinding Pasangan Bata akibat gempa

Kerusakan dinding yang terjadi apabila luas dinding pasangan bata yang terbingkai lebih dari 9 m².

Kerusakan yang terjadi apabila tidak terdapat balok lintel pada bukaan pintu dan jendela.

Tidak terdapat angkur antara kolom dengan dinding pasangan bata, sehingga saat terjadi gempa dinding mudah runtuh walaupun struktur utama rumah masih berdiri

Saat terjadi gempa, retak pada bangunan biasanya dimulai dari sudut bukaan pintu atau jendela.

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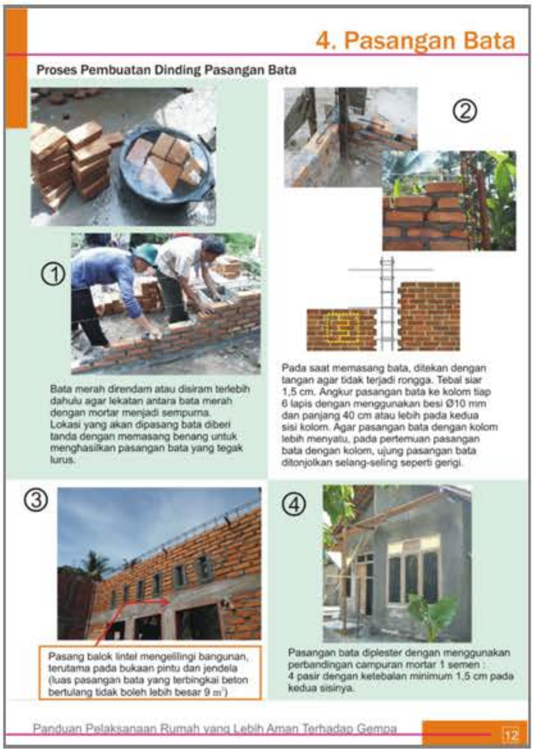
Berdasarkan data hasil wawancara dengan mandor dan tukang bangunan, sebagian besar rumah yang dibangun memiliki tinggi dinding 3,5 - 3,7 m dengan jarak antar kolom 3 m (luas dinding terbingkai lebih dari 9 m²).
Sehingga dinding pasangan bata perlu ditambah balok lintel.

11 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa



4. Pasangan Bata

Proses Pembuatan Dinding Pasangan Bata

① Bata merah direndam atau disiram terlebih dahulu agar lekatan antara bata merah dengan mortar menjadi sempurna. Lokasi yang akan dipasang bata diberi tanda dengan memasang benang untuk menghasilkan pasangan bata yang tegak lurus.

② Pada saat memasang bata, ditekan dengan tangan agar tidak terjadi rongga. Tebal siar 1,5 cm. Angkur pasangan bata ke kolom tiap 6 lapis dengan menggunakan besi Ø10 mm dan panjang 40 cm atau lebih pada kedua sisi kolom. Agar pasangan bata dengan kolom lebih menyatu, pada pertemuan pasangan bata dengan kolom, ujung pasangan bata ditonjolkan selang-seling seperti gerigi.

③ Pasang balok lintel mengelilingi bangunan, terutama pada bukaan pintu dan jendela (luas pasangan bata yang terbingkai beton bertulang tidak boleh lebih besar 9 m²)

④ Pasangan bata diplester dengan menggunakan perbandingan campuran mortar 1 semen : 4 pasir dengan ketebalan minimum 1,5 cm pada kedua sisinya.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 12

5. Kolom dan Balok Keliling/Ring

- **Foto-Foto Kerusakan Rumah Tinggal Tanpa Kolom dan Balok Keliling/Ring akibat Gempa**

Rumah tanpa kolom dan balok keliling/ring akan mudah rusak atau bahkan runtuh jika terkena goncangan gempa

Dinding pasangan bata mudah runtuh apabila tidak dibingkai oleh kolom dan balok keliling beton bertulang

Ukuran diameter tulangan yang tidak memenuhi syarat menyebabkan kerusakan

Sambungan yang lemah mengakibatkan dinding pasangan bata retak dan bisa berakibat keruntuhan

Sambungan besi tulangan antara kolom dan balok keliling/ring yang buruk akan mudah lepas

Kerusakan pada dinding tembokan tanpa balok ring

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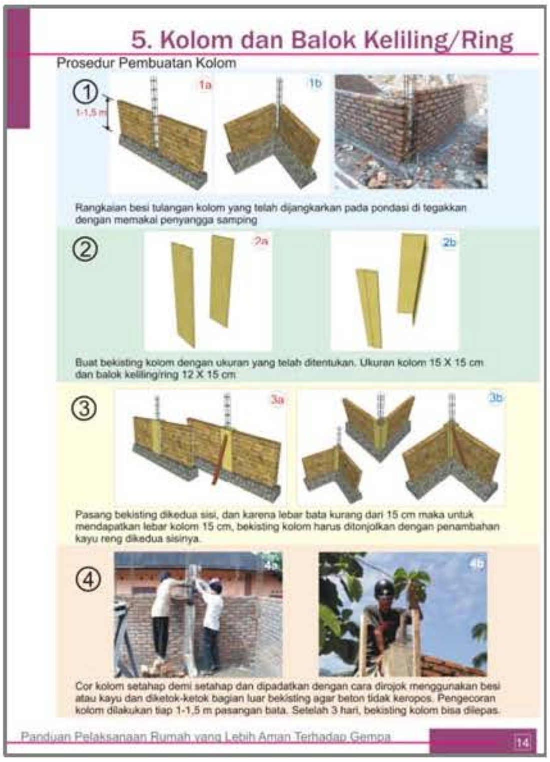
13 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa



5. Kolom dan Balok Keliling/Ring

Prosedur Pembuatan Kolom

① 1-1,5 m 1a 1b

Rangkaian besi tulangan kolom yang telah dijangkarkan pada pondasi di tegakkan dengan memakai penyangga samping

② 2a 2b

Buat bekisting kolom dengan ukuran yang telah ditentukan. Ukuran kolom 15 X 15 cm dan balok keliling/ring 12 X 15 cm

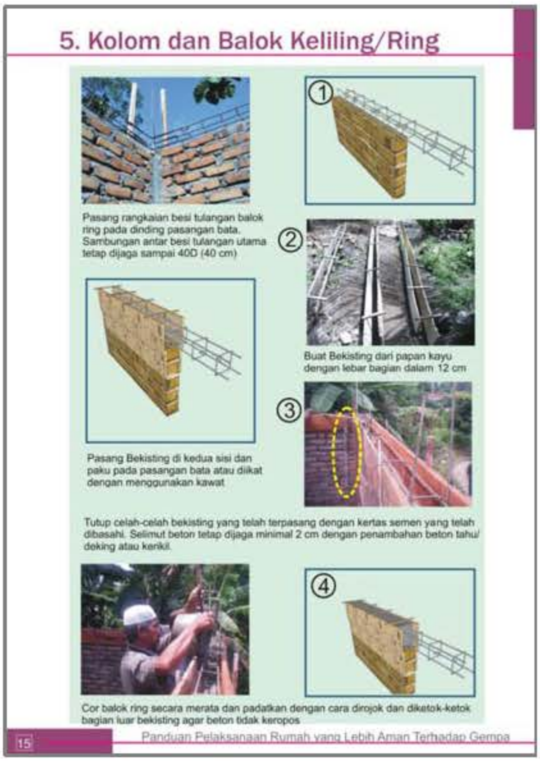
③ 3a 3b

Pasang bekisting dikedua sisi, dan karena lebar bata kurang dari 15 cm maka untuk mendapatkan lebar kolom 15 cm, bekisting kolom harus ditonjolkan dengan penambahan kayu reng dikedua sisinya.

④ 4a 4b

Cor kolom setahap demi setahap dan dipadatkan dengan cara dirojok menggunakan besi atau kayu dan diketok-ketok bagian luar bekisting agar beton tidak keropos. Pengecoran kolom dilakukan tiap 1-1,5 m pasangan bata. Setelah 3 hari, bekisting kolom bisa dilepas.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 14



5. Kolom dan Balok Keliling/Ring

①

Pasang rangkaian besi tulangan balok ring pada dinding pasangan bata. Sambungan antar besi tulangan utama tetap dijaga sampai 40D (40 cm)

②

Buat Bekisting dari papan kayu dengan lebar bagian dalam 12 cm

Pasang Bekisting di kedua sisi dan paku pada pasangan bata atau diikat dengan menggunakan kawat

③

Tutup celah-celah bekisting yang telah terpasang dengan kertas semen yang telah dibasahi. Selimut beton tetap dijaga minimal 2 cm dengan penambahan beton tahu/ deking atau kerikil.

④

Cor balok ring secara merata dan padatkan dengan cara dirojok dan diketok-ketok bagian luar bekisting agar beton tidak keropos

15 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

5. Kolom dan Balok Keliling/Ring

① ②

Bengkok rangkaian besi yang telah dilebihkan ujungnya sepanjang 40 cm terlebih dahulu sebelum dipasang.

Pasang rangkaian besi tulangan yang telah dibengkok diatas pasangan bata

③ ④

Geser besi tulangan begel ke samping untuk memudahkan penempatan sambungan besi tulangan utama, kemudian bengkok besi tulangan kolom ke arah besi tulangan balok

Geser kembali besi tulangan begel ketempat semula dengan jarak antar begel 15 cm, kemudian ikat dengan kawat bendrat

Cara lain seperti yang disajikan pada halaman 21 buku ini:
√ Pembengkokan besi tulangan utama bisa juga dikerjakan diatas (pada lokasi pemasangan balok keliling/ring) dengan memakai 2 kunci besi
√ Dengan penambahan 4 batang besi tulangan Ø10 mm yang sudah dibengkok L, dengan panjang masing-masing sisi bengkokan 40 cm dimasukan dalam sambungan besi tulangan balok dan kolom telah terpasang.

! Yang perlu diingat:
Panjang sambungan (bengkokan) 40D (jika menggunakan besi tulangan utama Ø10 mm, panjang bengkokan 40 cm)

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 16

6. Gunung-Gunung/Ampig/Singok

Foto-foto kerusakan dinding ampig tanpa bingkai beton bertulang akibat Gempa

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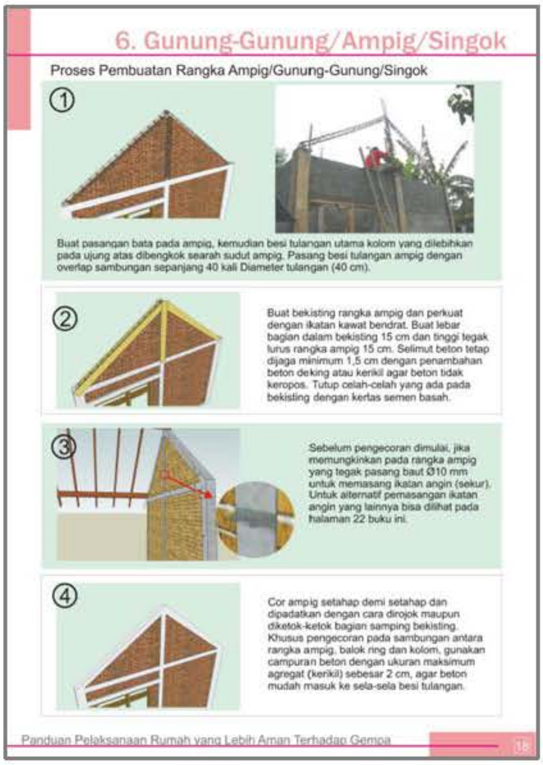
Kerusakan ampig terjadi karena pasangan bata tidak terbingkai oleh beton bertulang. Kondisi ini akan sangat membahayakan penghuni rumah apabila gempa terjadi.

17 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa



6. Gunung-Gunung/Ampig/Singok

Proses Pembuatan Rangka Ampig/Gunung-Gunung/Singok

① Buat pasangan bata pada ampig, kemudian besi tulangan utama kolom yang dilebihkan pada ujung atas dibengkok searah sudut ampig. Pasang besi tulangan ampig dengan overlap sambungan sepanjang 40 kali Diameter tulangan (40 cm).

② Buat bekisting rangka ampig dan perkuat dengan ikatan kawat bendrat. Buat lebar bagian dalam bekisting 15 cm dan tinggi tegak lurus rangka ampig 15 cm. Selimut beton tetap dijaga minimum 1,5 cm dengan penambahan beton deking atau kerikil agar beton tidak keropos. Tutup celah-celah yang ada pada bekisting dengan kertas semen basah.

③ Sebelum pengecoran dimulai, jika memungkinkan pada rangka ampig yang tegak pasang baut Ø10 mm untuk memasang ikatan angin (sekur). Untuk alternatif pemasangan ikatan angin yang lainnya bisa dilihat pada halaman 22 buku ini.

④ Cor ampig setahap demi setahap dan dipadatkan dengan cara dirojok maupun diketok-ketok bagian samping bekisting. Khusus pengecoran pada sambungan antara rangka ampig, balok ring dan kolom, gunakan campuran beton dengan ukuran maksimum agregat (kerikil) sebesar 2 cm, agar beton mudah masuk ke sela-sela besi tulangan.

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 18

7. Ikatan Angin

Kerusakan rangka atap rumah pasangan bata akibat gempa

Kuda-kuda kayu atap tanpa ikatan angin mudah rusak saat terjadi gempa. Ikatan angin berfungsi sebagai pengikat antara dua gunungan/kuda-kuda agar pada saat terjadi gempa dapat bergerak searah (bersama-sama).

Pasangan bata dan struktur beton mengalami kerusakan parah, tetapi rangka atap tetap utuh dan tetap menyatu.

Dinding dan struktur roboh, tetapi rangka atap tetap utuh dan menyatu.

Hasil pengamatan rangka atap rumah pasangan bata akibat gempa Sumatera Barat 2009 di Padang Pariaman menunjukkan rangka atap masih dalam kondisi baik. Umumnya atap rumah menggunakan bahan ringan (seng) dan penyambungan rangka atap kayu menyatu dan cukup ikatan antar kuda-kuda dan gording.

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Kondisi atap secara umum di Sumatera Barat

Dari hasil survey, 97 % tukang sudah terbiasa memakai ikatan angin.

Atap ringan (seng), ikatan angin dipasang lurus horizontal atau silang. Sambungan kayu hanya dipaku, dan balok latai disatukan dengan balok kayu lain memakai sistem kotak/diagonal (grid).

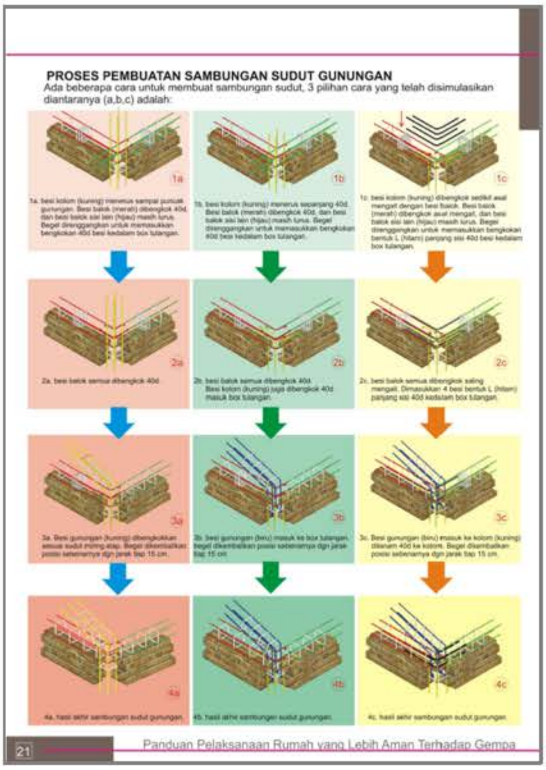
19 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

7. Ikatan Angin

Proses Pemasangan Ikatan Angin

Plat U

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 20



PROSES PEMBUATAN SAMBUNGAN SUDUT GUNUNGAN

Ada beberapa cara untuk membuat sambungan sudut, 3 pilihan cara yang telah disimulasikan diantaranya (a,b,c) adalah:

21 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

8. Perkiraan Anggaran Biaya Rumah

1 **PERKIRAAN ANGGARAN BIAYA 1 M3 PEKERJAAN PONDASI BATUKALI RUMAH SEDERHANA**
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1 1 m³ Pasangan Batu Kali 1 Semen : 4 Pasir

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
3,300	zak	Semen PC (50) kg	52.000,00	171.600,00		
0,520	m³	Pasir pasang	75.000,00	39.000,00		
1,200	m³	Batu kali	80.000,00	96.000,00		
0,120	oranghr	Tukang batu	70.000,00		8.400,00	
0,180	oranghr	Kep. Tukang batu	85.000,00		15.300,00	
3,600	oranghr	Pekerja	50.000,00		180.000,00	
			Jumlah Bahan dan Upah	306.600,00	203.700,00	510.300,00

2 1 m³ Urug Pasir Bawah Pondasi

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
1,200	m³	Pasir urug	65.000,00	78.000,00		
0,300	oranghr	Pekerja gali	50.000,00		15.000,00	
0,010	oranghr	Mandor	85.000,00		850,00	
			Jumlah Bahan dan Upah	78.000,00	15.850,00	93.850,00

3 1 m³ Gali dan Angkut Tanah Biasa

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,980	oranghr	Pekerja gali	85.000,00		83.300,00	
0,025	oranghr	Mandor	50.000,00		1.250,00	
			Jumlah Bahan dan Upah	0,00	84.550,00	84.550,00

4 1 m³ Urug Tanah Kembali

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,380	oranghr	Pekerja gali	85.000,00		32.300,00	
0,055	oranghr	Mandor	50.000,00		2.750,00	
			Jumlah Bahan dan Upah	0,00	35.050,00	35.050,00
				Bea Bahan	Bea Upah	Bea Total
Perkiraan Anggaran Biaya per m³ Pondasi batukali 1 : 4 (Rp)				384.600,00	339.150,00	723.750,00

2 **PERKIRAAN ANGGARAN BIAYA 1 M2 PASANGAN BATA MERAH RUMAH SEDERHANA**
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1 1 m² Pasangan Bata Merah 1 Semen : 3 Pasir

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,480	zak	Semen PC (50) kg	52.000,00	24.960,00		
0,049	m³	Pasir pasang	75.000,00	3.675,00		
72,000	bh	Bata merah	500,00	36.000,00		
0,225	oranghr	Tukang batu	70.000,00		15.750,00	
0,022	oranghr	Kep. Tukang batu	85.000,00		1.870,00	
0,600	oranghr	Pekerja	50.000,00		30.000,00	
			Jumlah Bahan dan Upah	64.635,00	47.620,00	112.255,00

2 1 m² Plesteran 1 Semen : 3 Pasir

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,170	zak	Semen PC (50) kg	52.000,00	8.840,00		
0,026	m³	Pasir pasang	75.000,00	1.950,00		
0,200	oranghr	Tukang batu	70.000,00		14.000,00	
0,020	oranghr	Kep. Tukang batu	85.000,00		1.700,00	
0,400	oranghr	Pekerja	50.000,00		20.000,00	
			Jumlah Bahan dan Upah	10.790,00	35.700,00	46.490,00

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 22

8. Perkiraan Anggaran Biaya Rumah

3 **PERKIRAAN ANGGARAN BIAYA 1 M2 PEKERJAAN ATAP RUMAH SEDERHANA**
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1 1 m³ Kuda-Kuda Kayu

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
1,100	m³	Balok kayu 6/12 kruing	2.100.000,00	2.310.000,00		
15,000	kg	Besi strip	17.000,00	255.000,00		
5,800	kg	Baut/paku	15.000,00	87.000,00		
8,000	oranghr	Tukang kayu	70.000,00		560.000,00	
2,000	oranghr	Kep. Tukang kayu	85.000,00		170.000,00	
4,000	oranghr	Pekerja	50.000,00		200.000,00	
			Jumlah Bahan dan Upah	2.652.000,00	930.000,00	3.582.000,00

2 1 m³ Gording/nok kayu

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
1,100	m³	Balok kayu 6/12 kruing	2.100.000,00	2.310.000,00		
3,000	kg	Baut/paku	15.000,00	45.000,00		
5,000	oranghr	Tukang kayu	70.000,00		350.000,00	
2,000	oranghr	Kep. Tukang kayu	85.000,00		170.000,00	
2,000	oranghr	Pekerja	50.000,00		100.000,00	
			Jumlah Bahan dan Upah	2.355.000,00	620.000,00	2.975.000,00

3 1 m² Pekerjaan Usuk/Kaso Kruing atau Setara

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,0090	m³	Usuk kayu 5/7 cm kruing	2.100.000,00	18.900,00		
0,0040	m³	Reng 3/4 cm jati	5.900.000,00	23.600,00		
0,200	kg	Baut/paku	15.000,00	3.000,00		
0,100	oranghr	Tukang kayu	70.000,00		7.000,00	
0,010	oranghr	Kep. Tukang kayu	85.000,00		850,00	
0,150	oranghr	Pekerja	50.000,00		7.500,00	
			Jumlah Bahan dan Upah	45.500,00	15.350,00	60.850,00

4a 1 m² Atap Seng Gelombang

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,2500	lbr	Seng gelombang 180	52.000,00	13.000,00		
0,100	kg	Baut/paku	15.000,00	1.500,00		
0,080	oranghr	Tukang kayu	70.000,00		5.600,00	
0,008	oranghr	Kep. Tukang kayu	85.000,00		680,00	
0,150	oranghr	Pekerja	50.000,00		7.500,00	
			Jumlah Bahan dan Upah	14.500,00	13.780,00	28.280,00

4b 1 m² Atap Genting

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
25,0000	bh	Genteng abadi	1.400,00	35.000,00		
0,100	oranghr	Tukang kayu	70.000,00		7.000,00	
0,010	oranghr	Kep. Tukang kayu	85.000,00		850,00	
0,160	oranghr	Pekerja	50.000,00		8.000,00	
			Jumlah Bahan dan Upah	35.000,00	15.850,00	50.850,00

5 1 m Pasang Bubungan Atap

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
3,5000	bh	Bubungan genteng	1.800,00	6.300,00		
0,1000	m³	Pasir pasang	75.000,00	7.500,00		
0,200	zak	Semen PC	52.000,00	10.400,00		
0,250	oranghr	Tukang batu	70.000,00		17.500,00	
0,025	oranghr	Kep. Tukang batu	85.000,00		2.125,00	
0,600	oranghr	Pekerja	50.000,00		30.000,00	
			Jumlah Bahan dan Upah	24.200,00	49.625,00	73.825,00
				Bea Bahan	Bea Upah	Bea Total
Perkiraan Anggaran Biaya per m² Atap Seng (Rp)				284.716,00	206.780,00	491.496,00
Perkiraan Anggaran Biaya per m² Atap Genting (Rp)				305.216,00	208.850,00	514.066,00

23 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

8. Perkiraan Anggaran Biaya Rumah

4 PERKIRAAN ANGGARAN BIAYA 1 M' PEMBUATAN BALOK SLOOF UKURAN 15 X 20 CM
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1.) 1 m' Bekisting Sloof

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,00072	m³	Papan 2X20x200	3.000.000,00	2.160,00		
0,00051	m³	Kayu 4x6x400	1.000.000,00	510,00		
0,012	kg	Paku	15.750,00	189,00		
0,0015	oranghr	Kep. Tukang	80.000,00		120,00	
0,015	oranghr	Tukang Kayu	70.000,00		1.050,00	
0,006	oranghr	Pekerja	60.000,00		360,00	
			Jumlah Bahan dan Upah	2.859,00	1.530,00	4.389,00

2.) 1 m' Mengerjakan/Memasang Besi Tulangan

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,67	bt	Besi Ø10 mm x 12 m	43.000,00	28.810,00		
0,43	bt	Besi Ø8 mm x 12 m	36.000,00	15.480,00		
0,106	kg	Kawat	15.000,00	1.585,98		
0,005	oranghr	Kep. Tukang	80.000,00		394,73	
0,049	oranghr	Tukang Besi	70.000,00		3.453,91	
0,049	oranghr	Pekerja	60.000,00		2.960,50	
			Jumlah Bahan dan Upah	45.875,98	6.809,14	52.685,12

3.) 1 m' Cor Beton Bertulang 1:2:3

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,0246	m³	Batu Pecah	77.777,78	1.913,33		
0,0162	m³	Pasir	85.714,29	1.388,57		
0,255	zak	semen (50 kg)	52.000,00	13.260,00		
0,003	oranghr	Kep. Tukang	80.000,00		240,00	
0,03	oranghr	Tukang Batu	70.000,00		2.100,00	
0,18	oranghr	Pekerja	60.000,00		10.800,00	
			Jumlah Bahan dan Upah	16.561,90	13.140,00	29.701,90
			Perkiraan Anggaran Biaya per m1	65.296,88	21.479,14	86.776,03

5 PERKIRAAN ANGGARAN BIAYA 1 M' PEMBUATAN KOLOM UKURAN 15 X 15 CM
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1.) 1 m' Bekisting Kolom

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,00054	m³	Papan 2X20x200	3.000.000,00	1.620,00		
0,003825	m³	Kayu 4x6x400	1.000.000,00	382,50		
0,009	kg	Paku	15.750,00	141,75		
0,001125	oranghr	Kep. Tukang	80.000,00		90,00	
0,01125	oranghr	Tukang Kayu	70.000,00		787,50	
0,0045	oranghr	Pekerja	60.000,00		270,00	
			Jumlah Bahan dan Upah	2.144,25	1.147,50	3.291,75

2.) 1 m' Mengerjakan/Memasang Besi Tulangan

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,67	bt	Besi Ø10 mm x 12 m	43.000,00	28.810,00		
0,372	bt	Besi Ø8 mm x 12 m	36.000,00	13.392,00		
0,102	kg	Kawat	15.000,00	1.523,34		
0,005	oranghr	Kep. Tukang	80.000,00		379,14	
0,047	oranghr	Tukang Besi	70.000,00		3.317,50	
0,047	oranghr	Pekerja	60.000,00		2.843,57	
			Jumlah Bahan dan Upah	43.725,34	6.540,21	50.265,55

3.) 1 m' Cor Beton Bertulang 1:2:3

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,01845	m³	Batu Pecah	77.777,78	1.435,00		
0,01215	m³	Pasir	85.714,29	1.041,43		
0,19125	zak	semen (50 kg)	52.000,00	9.945,00		
0,00225	oranghr	Kep. Tukang	80.000,00		180,00	
0,0225	oranghr	Tukang Batu	70.000,00		1.575,00	
0,135	oranghr	Pekerja	60.000,00		8.100,00	
			Jumlah Bahan dan Upah	12.421,43	9.855,00	22.276,43
			Perkiraan Anggaran Biaya per m1	58.291,02	17.542,71	75.833,72

Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa 24

8. Perkiraan Anggaran Biaya Rumah

6 PERKIRAAN ANGGARAN BIAYA 1 M' PEMBUATAN BALOK RING UKURAN 12 X 15 CM
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

1.) 1 m' Bekisting Balok Ring

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,000432	m³	Papan 2X20x200	3.000.000,00	1.296,00		
0,000306	m³	Kayu 4x6x400	1.000.000,00	306,00		
0,0072	kg	Paku	15.750,00	113,40		
0,0009	oranghr	Kep. Tukang	80.000,00		72,00	
0,009	oranghr	Tukang Kayu	70.000,00		630,00	
0,0036	oranghr	Pekerja	60.000,00		216,00	
			Jumlah Bahan dan Upah	1.715,40	918,00	2.633,40

2.) 1 m' Mengerjakan/Memasang Besi Tulangan

Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,67	bt	Besi Ø10 mm x 12 m	43.000,00	28.810,00		
0,372	bt	Besi Ø8 mm x 12 m	36.000,00	13.392,00		
0,102	kg	Kawat	15.000,00	1.523,34		
0,005	oranghr	Kep. Tukang	80.000,00		379,14	
0,047	oranghr	Tukang Besi	70.000,00		3.317,50	
0,047	oranghr	Pekerja	60.000,00		2.843,57	
			Jumlah Bahan dan Upah	43.725,34	6.540,21	50.265,55

3.) 1 m' Cor Beton Bertulang 1:2:3

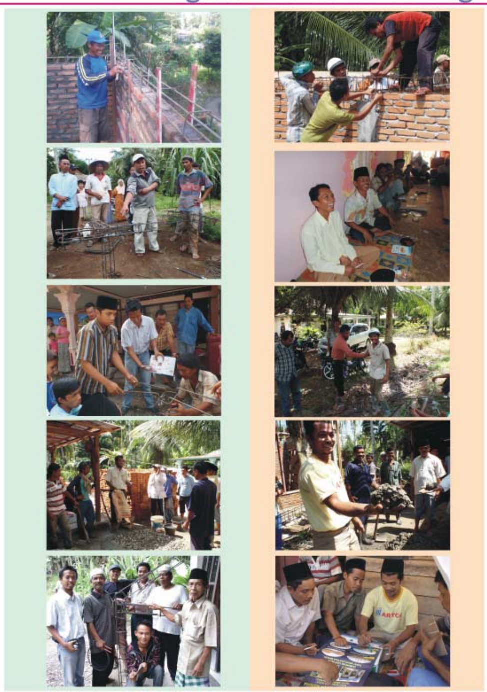
Kebutuhan	Satuan	Item Biaya	Harga Satuan	Bea Bahan	Bea Upah	Bea Total
0,01476	m³	Batu Pecah	77.777,78	1.148,00		
0,00972	m³	Pasir	85.714,29	833,14		
0,153	zak	semen (50 kg)	52.000,00	7.956,00		
0,0018	oranghr	Kep. Tukang	80.000,00		144,00	
0,018	oranghr	Tukang Batu	70.000,00		1.260,00	
0,108	oranghr	Pekerja	60.000,00		6.480,00	
			Jumlah Bahan dan Upah	9.937,14	7.884,00	17.821,14
			Perkiraan Anggaran Biaya per m1	55.377,88	15.342,21	**70.720,09**

PERKIRAAN ANGGARAN BIAYA RUMAH SEDERHANA TYPE 36 (6 m X 6 m, LUAS 36 m²)
(Harga Satuan per 20 Maret 2010, lokasi di Kec. Enam Lingkung, Padang Pariaman)

No	Jenis Pekerjaan	Volume	Sat	Bobot (%)	Harga Satuan (Rp) Bahan	Harga Satuan (Rp) Upah	Harga Satuan (Rp) Total	Harga Total (Rp) Bahan	Harga Total (Rp) Upah	Harga Total (Rp) Total
1	2	3	4	5	6	7	8 = (6 + 7)	9 = (3 x 6)	10 = (3 x 7)	11 = (3 x 8)
1	Pembersihan Lokasi	45,0	m²	0,50	0,00	6.000,00	6.000,00	0,00	270.000,00	270.000,00
2	Pengukuran dan bouplank	36,0	m¹	0,38	3.100,00	2.600,00	5.700,00	111.600,00	93.600,00	205.200,00
3	Galian tanah pondasi	15,2	m³	2,38	0,00	84.550,00	84.550,00	0,00	1.285.160,00	1.285.160,00
4	Urug tanah kembali	5,4	m³	0,84	0,00	84.550,00	84.550,00	0,00	456.570,00	456.570,00
5	Urugan pasir	1,7	m³	0,29	78.000,00	15.850,00	93.850,00	129.480,00	26.311,00	155.791,00
6	Pekerjaan Pondasi batu kosong	3,3	m³	0,80	96.000,00	35.050,00	131.050,00	317.760,00	116.015,50	433.775,50
7	Pekerjaan Pondasi batu kali 1:4	8,2	m³	7,77	306.600,00	203.700,00	510.300,00	2.526.384,00	1.678.488,00	4.204.872,00
8	Pekerjaan Struktur Beton :			18,45						
	a. Sloof	36,0	m¹	5,77	65.296,88	21.479,14	86.776,02	2.350.687,85	773.249,04	3.123.936,89
	b. Kolom	41,0	m¹	5,75	58.291,02	17.542,71	75.833,72	2.389.931,76	719.250,96	3.109.182,72
	c. Balok ring	36,0	m¹	4,71	55.377,88	15.342,21	70.720,09	1.993.603,68	552.319,56	2.545.923,24
	d. Balok ampig	17,0	m¹	2,22	55.377,88	15.342,21	70.720,09	941.423,96	260.817,57	1.202.241,53
9	Pekerjaan Atap :			13,48						
	a. Rangka Kuda-kuda	0,5	m³	3,56	2.652.000,00	930.000,00	3.582.000,00	1.432.080,00	502.200,00	1.934.280,00
	b. Gording/Usuk/reng	54,0	m²	6,07	45.500,00	15.350,00	60.850,00	2.457.000,00	828.900,00	3.285.900,00
	c. Atap seng gelombang	54,0	m²	2,82	14.500,00	13.780,00	28.280,00	783.000,00	744.120,00	1.527.120,00
	d. Bubungan atap	7,4	m²	1,01	24.200,00	49.625,00	73.825,00	179.080,00	367.225,00	546.305,00
10	Pek. Pasangan Bata 1:4	99,0	m²	20,54	64.635,00	47.620,00	112.255,00	6.398.865,00	4.714.380,00	11.113.245,00
11	Pek. Plesteran 1:4	180,0	m²	15,47	10.790,00	35.700,00	46.490,00	1.942.200,00	6.426.000,00	8.368.200,00
11	Pek. Pintu/Jendela	1,8	m³	12,18	2.652.000,00	930.000,00	3.582.000,00	4.879.680,00	1.711.200,00	6.590.880,00
12	Pekerjaan lantai ubin	36,0	m²	6,92	68.000,00	36.000,00	104.000,00	2.448.000,00	1.296.000,00	3.744.000,00
	Jumlah			100				**31.280.776,25**	**22.821.806,63**	**54.102.582,89**

25 Panduan Pelaksanaan Rumah yang Lebih Aman Terhadap Gempa

Kegiatan Pelatihan Tukang



Tentang SNS International Disaster Prevention Support Center

Dewasa ini, beberapa gempa besar terjadi di dunia hampir setiap tahun dan beberapa di antaranya merenggut puluhan ribu jiwa. Khususnya, gempa-gempa ini menyebabkan kerugian yang amat besar di Asia dan beberapa wilayah sekeliling Asia. Sebagai contoh, gempa Turki (1999), Iran (2003), Indonesia (2004, 2006, 2009), dan Pakistan (2005) mengakibatkan kerusakan amat parah melampui apa yang kita bayangkan.

Sebagai contoh, di Iran, gempa Bam (6,3 *Mw*) terjadi pada 26 Desember 2003 di Iran bagian tenggara merenggut lebih dari 40.000 jiwa. Terlebih, kira-kira 13 tahun sebelum gempa Bam, gempa Rudbar (kawasan sepanjang Laut Kaspia) terjadi pada 1990 membunuh hampir 20.000 jiwa. Maka, selama sekitar 40 tahun antara 1962 hingga 2003, warga Iran harus mengalami lima kali gempa besar dan mengakibatkan korban ribuan jiwa.

Menurut penelitian mengenai kerusakan akibat gempa di Iran oleh Earthquake Research Institute of Tokyo University pada 1991, satu dari beberapa penyebab kerusakan gempa di Iran antara 1962 hingga 1990 adalah runtuhnya bangunan *non-engineered* akibat konstruksi bangunan yang tidak kuat. Hasil yang kurang lebih sama dilaporkan oleh Building Research Institute of Japan. Maka, di Iran, penyebab yang sama di setiap gempa telah merenggut begitu banyak jiwa.

Sebagai tambahan, Jepang adalah negara yang terkenal paling rawan gempa di muka bumi dan gempa besar Hansin-Awaji pada tahun 1995 mengguncang kota metropolitan Kobe dan daerah sekitar Kobe dan telah membunuh lebih dari 6.000 jiwa. Namun, warga Jepang telah mengumpulkan beberapa teknik, peraturan, dan pengetahuan untuk pencegahan bencana gempa seperti teknik-teknik konstruksi yang aman terhadap gempa bagi karakteristik daerah di Jepang berdasarkan pengalaman gempa besar Hansin-Awaji dan yang lainnya.

Kami cukup yakin bahwa kumpulan teknik dan ilmu pengetahuan ini akan berhasil untuk pencegahan bencana gempa di masa datang di Asia dan daerah lain di sekitarnya. Jika teknik dan ilmu pengetahuan ini disebarkan pada daerah tanpa memandang perbedaan sosial dan budaya, maka, kami yakin bahwa kita dapat melakukan mitigasi bencana di masa datang dengan membangun langkah-langkah pencegahan bencana yang sesuai dengan karakter daerah mereka.

Misi SNS Internatioanal Disaster Prevention Support Center adalah untuk mendukung warga di Iran dan kawasan lain di Asia untuk membangun budaya mereka sendiri dalam mitigasi bencana. Untuk menjalankan misi ini, kami telah menganalisis penyebab-penyebab kerusakan beberapa bencana alam seperti gempa di daerah-daerah tersebut dan memeliki beberapa kegiatan untuk mitigasi bencana berdasarkan analisis tersebut.

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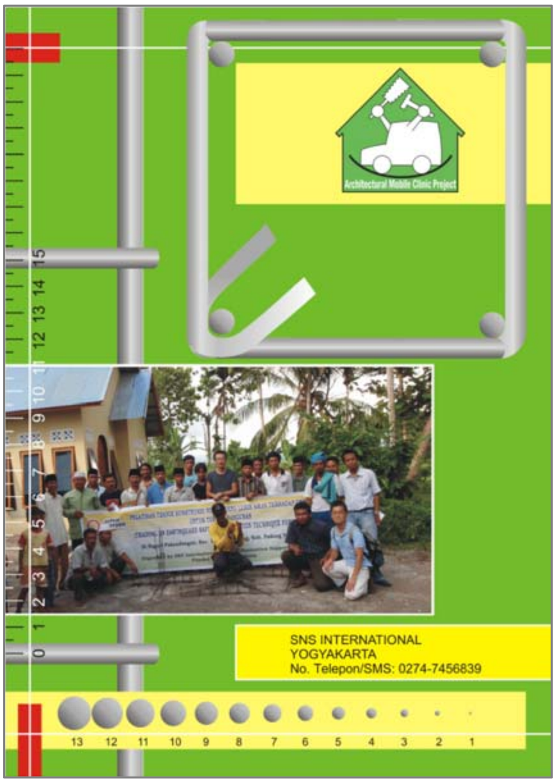

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Hiroshi IMAI