Technical Information

for Disaster Mitigation of Masonry Structures

Architectural Institute of Japan

Managing Committee on Box-Shaped Wall Structures

Scientific Sub-Committee on Seismic Performance of Masonry Constructions in Foreign Countries

March, 2017

Preface

A great loss of human beings has been caused by collapse of masonry houses by devastating earthquakes in foreign counties, in particular, in developing countries. Looking back at the last 10 years, we can remember Central Java Earthquake of 2006, Ica Earthquake of 2007, Peru, Off Padan Earthquake of 2009, Indonesia, and Haiti Earthquake of 2010. Furthermore, in rising countries such as China and Nepal, collapse of masonry houses has been the main reason why a number of human losses are caused during earthquakes. It was reported that most of those destructed masonry houses were constructed without engineering consideration, so-called non-engineered construction. From the experience of the earthquake disasters in the world in the last 10 years, the earthquake disaster mitigation of vulnerable unreinforced masonry houses is still now the urgent subject to be solved internationally. In the present state mentioned above, international organizations (NGO et al.) have been involved in safer housing projects in developing countries, at the same time, guidelines of construction technologies and seismic diagnosis have been published by international organizations. Technical support and capacity buildings to Japan are still largely expected by developing countries threatening to large earthquakes. The scope of the present technical handbook is to give efficient technical information for disaster mitigation of masonry structures, mainly, of masonry ordinary houses. The information described in this handbook will be useful to people concerned to construction of masonry houses in developing countries in seismic regions.

The present technical information was published by the Managing Committee on Box-Shaped Wall Structure, Architectural Institute of Japan. Here, the managing Committee on Box-Shaped wall Structure is composed of 4 sub-committees. It was edited on the basis of the activities of one of sub-committees, Scientific Sub-Committee on Seismic Performance of Masonry Construction in Foreign Countries.

March, 2017

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Architectural Institute of Japan

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	*: 2012-2014	**: 2013-2014	***: 2011-2013
	****: 2012-2013		

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Contents

Chapter 1 Introduction

1.1 Background and Purposes

Most of human losses in the recent devastating earthquakes in the world have been caused by Tsunami or collapse of non-engineered masonry buildings due to strong ground motions in developing countries. In particular, collapse of ordinary masonry houses constructed in the traditional manner without any or little knowledge of seismic design has caused great disasters in earthquake-prone countries. Construction materials of those houses are not only natural ones such as stones and adobe but also man-made ones such as bricks and concrete blocks, being got easily and at low cost in each area. Such vulnerable constructions of non-engineered houses are widely spread in earthquake-prone developing countries even today. In order to mitigate those earthquake disasters, this technical information handbook is published to disseminate basic knowledge of seismic evaluation, design of new constructions as well as retrofitting of existing constructions.

The contents of this technical information handbook are as follows. Following Chapter 1, earthquake damage to masonry structures by the recent events were reviewed in Chapter 2 to show the characteristics of the damage to masonry buildings, indicating vulnerability in out-of plane response and necessity for seismic intervention. Seismic intensity scales were also compared in Chapter 2. For mitigation of the disaster, it goes without saying that not only development of the appropriate affordable techniques but also dissemination of the knowledge and techniques are essential requirements. Chapter 3 describes various practical approaches to disseminate technologies with development of capacity building of human sources in developing countries. On the other hand, seismic structural strengthening and retrofitting technologies were summarized in Chapter 4, where effectiveness of those technologies was evaluated in engineering manner. This chapter must give useful information for choosing technologies in practical cases. To ensure seismic safety of masonry constructions, both newly constructions and existing constructions should be dealt with. Chapter 5 outlines seismic designing methods of masonry buildings in guidelines/codes published in both Japan and foreign countries. Furthermore, Chapter 6 also reviews seismic evaluation methods of existing masonry buildings in Japan and foreign countries. Finally, Chapter 7 introduces activities of the international association for guidelines to reduce earthquake disasters caused by collapse of non-engineered masonry constructions. At the end, appendix provides the overviewing of housing material worldwide.

1.2 Edition

A number of scientific committees are organized in Architectural Institute of Japan. The present handbook was edited on the basis of the 4-years activities of Scientific Sub-committee on Seismic Performance of Masonry Constructions in Foreign Countries under Structural

Scientific Committee.

Chapter 2 Recent Earthquake Damage to Masonry Structures

2.1 Introduction

Earthquake damage to masonry structures is still severe over the world. The most severe disasters have been caused particularly in developing countries because of low qualities of material, design, and construction, such as the Mw (: moment magnitude) 7.0 earthquake that struck Haiti on 12 January 2010 [2.1], the Ms (: surface wave magnitude) 8.0 Wenchuan, China earthquake on 12 May 2008 [2.2-2.3], the Mw 6.6 Bam, Iran earthquake on 26 December 2003[2.4], etc. The inventory survey on earthquake-damaged structures including masonry systems after the Bam earthquake is introduced to show the vulnerability of masonry, in particular adobe, in this chapter. Additionally, damage to masonry structures in developing countries is likely to happen even by lower ground motions, compared to disasters in developed countries. This chapter also exemplifies the 2013 Aceh, Indonesia earthquake with the magnitude of 6.1. Damage to masonry structures is investigated to clarify their lower seismic performance, major factors to cause heavier damage, and future actions to prevent such damage through findings from the post-earthquake on-site investigation.

Damage to masonry structures is also common interests even in developed countries. Historical heritages, substandard buildings, and nonstructural components also suffered moderate to heavy damage due to e.g. the 2011 Christchurch, New Zealand earthquake [2.5] and the 2009 L'Aquila, Italy earthquake [2.6]. Heavy damage to nonstructural components sometimes prevented buildings from immediate occupancies even though structural damage of buildings were relatively minor [2.7]. Similar problems were pointed out for reinforced concrete nonstructural components in Japan particularly after the 2011 Tohoku earthquake [2.8]. Future studies seem to be needed not only to improve the seismic performance but also reducing damage to masonry structures.

2.2 Importance of Construction Material and Quality

—from the 2003 Bam, Iran Earthquake

This section summarizes the findings from inventory survey which was carried out after the 2003 Bam, Iran earthquake [2.4]. The investigation results indicated that the most important key factors included application of reliable materials and appropriate construction techniques to masonry construction:

2.2.1 Summary of Survey

The Bam, Iran earthquake, which struck Bam city on Dec. 26, 2003, as shown in Figure 2.1, destroyed many buildings and houses and killed more than 26,000 people, almost 20% of the population in Bam city. An inventory survey of the buildings around the Bam seismological observatory (Governor's Building) operated by the BHRC (: Building and Housing Research Center) was carried out in order to investigate the building characteristics and the damage levels. This investigation was conducted in the abutting area within one block along the main street in N-S, E-W, and NW-SE directions from the center point of Governor's Building, as shown in Figure 2.2.

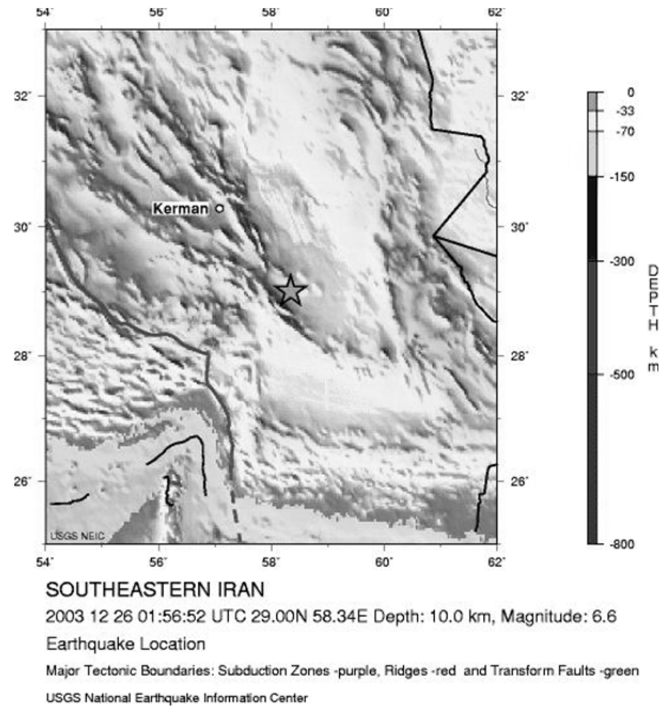


Figure 2.1 Epicenter of the 2003 Bam, Iran Earthquake by U.S. Geological Survey [2.9]

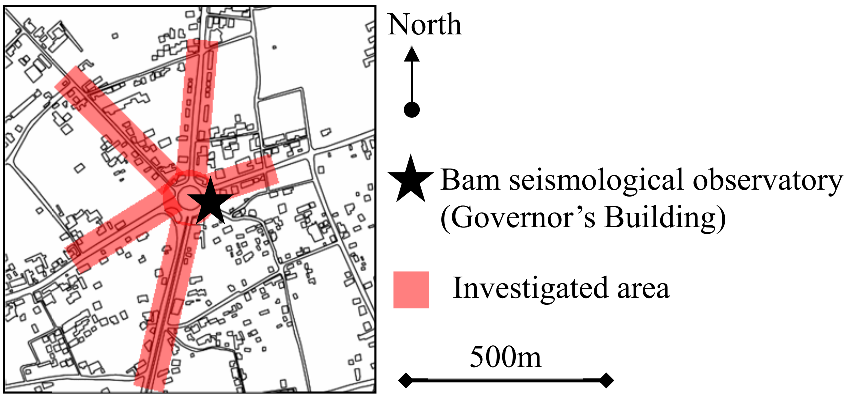


Figure 2.2 Investigated Area

Data regarding to building name, structural system, age, number of stories, usage, and damage level of 94 buildings in the investigated area were collected. The structural systems were categorized as follows:

Adobe	: adobe (sun-dried brick) masonry (Photo 2.1(a)),
SM	: simple masonry (Photo 2.1(b)),
S-frame+SM	: steel moment resisting frame with simple masonry wall (Photo 2.1(c)),

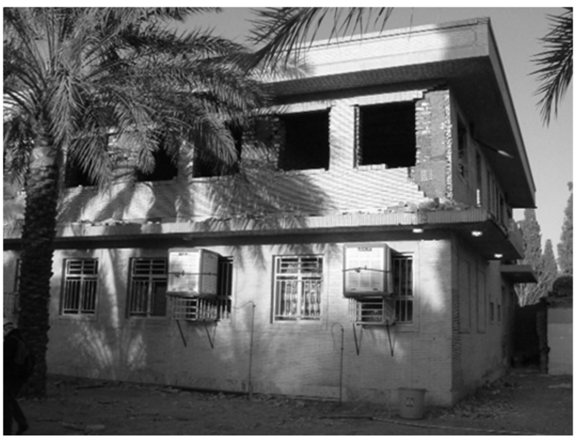
S-brace+SM : steel braced frame with simple masonry wall (Photo 2.1(d)),
RC-tie+SM : simple masonry wall confined with reinforced concrete tie (Photo 2.1(e)),
RC-frame+SM : reinforced concrete resisting frame with simple masonry wall,
S : steel moment resisting frame (Photo 2.1(f)).

(a) Adobe

(b) Simple Masonry (SM)

(c) Steel frame with SM (S-frame+SM)

(d) Steel braced frame with SM (S-brace+SM)



(e) SM confined with RC tie (RC-tie+SM)

(f) Steel moment resisting frame (S)

Photo 2.1 Typical Structural Systems in Investigated Area

Figure 2.3 shows the distribution of the structural systems in the investigated area. Adobe, SM, S-frame+SM, and S-brace+SM buildings occupied approximately 90% of all 94 buildings (: 23, 24, 27, 13, 1, 1, 1, and 4 for Adobe, SM, S-frame+SM, S-brace+SM, RC-tie+SM, RC-frame+SM, S, and unknown buildings, respectively) in this area. The ratios of S-frame+SM and S-brace+SM buildings were as large as those of Adobe and SM buildings, because the investigated area was located in the central part of the city.

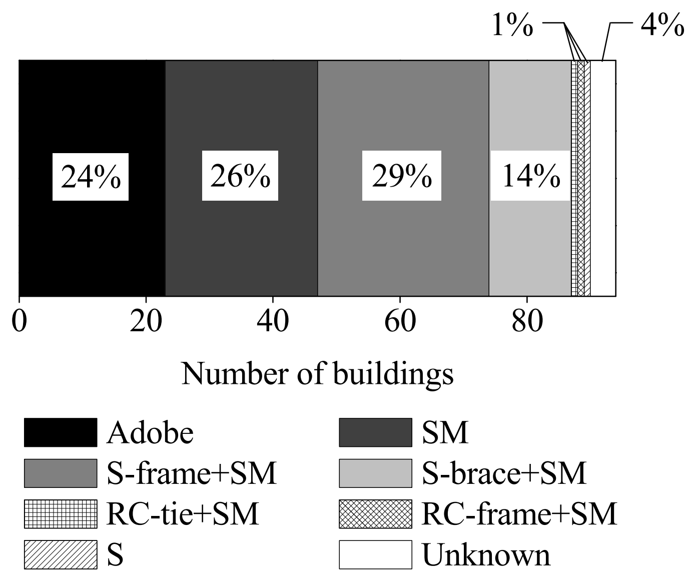


Figure 2.3 Distribution of structural systems

In order to have a framework for evaluating the damage grade of the buildings, the European Macroseismic Scale 1998 (EMS-98, refer to Appendix.1) classification of masonry buildings, as shown in Table 2.1 [2.10], was used for the investigation. EMS-98 is widely used for evaluating conditions of earthquake-damaged buildings in the world. In this classification, the building damage is categorized into 5 grades.

Table 2.1 Damage Grade According to EMS-98 [2.10]

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse.

2.2.2 Comparisons of Damage

Figure 2.4 shows the damage grade distribution for each structural system, where a building without damage is classified into 0. All Adobe buildings were classified into Grade 4 and Grade 5. Sum of the ratios of Grade 4 and Grade 5 in SM buildings exceeded 30%, which was much smaller than Adobe buildings. The damage ratios of S-frame+SM and S-brace+SM buildings were expected to be much less than that of SM buildings, however, there were no significant differences among them. This was caused by brittle fracture of poor welded connections in a few S-frame+SM and S-brace+SM buildings. On the other hand, the damages of RC-tie+SM and RC-frame+SM buildings were quite slightly damaged because connections in these buildings were constructed monolithically. These results, however, were derived from the only one case in each system. The damage level of one S building, which was the gymnasium structure, was Grade 1.

The survey results above clearly indicated the importance of usage of engineered materials; nevertheless, low quality of construction caused severe damage to buildings in spite of application of engineered materials. These seemed to be common key issues to improve the seismic performance of building in other developing countries as well as in Bam, Iran.

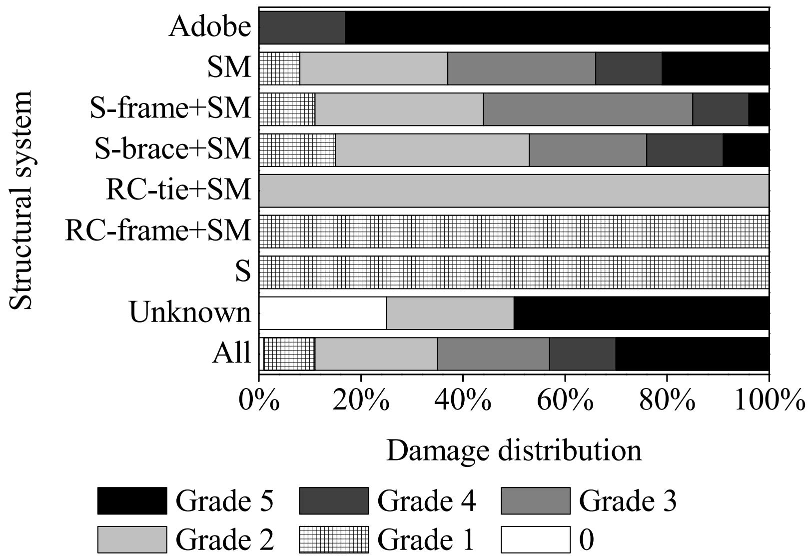


Figure 2.4 Damage Distribution of Each Structural System

2.3 Out-of-Plane Vulnerability of Masonry

—from the 2013 Aceh, Indonesia Earthquake

This section introduces seismic vulnerability of masonry structures in developing countries focusing on the 2013 Aceh, Indonesia earthquake. Out-of-plane failure seemed to be one of the most important key issue to upgrade the seismic performance of masonry construction:

2.3.1 Summary of Survey

Aceh province which is located in the northwestern region of Sumatra island, Indonesia is close to a major earthquake fault line. After the greatest earthquake at 9.1 on the Richter scale (M_L), which caused a huge tsunami on December 26, 2004, a lot of aftershocks have happened such as the 2009 West Sumatra earthquake.

A destructive earthquake with the magnitude 6.1 M_L occurred in the central area of Aceh province about 181 km southeast from the provincial capital of Banda Aceh, as shown in Figure 2.5. According to U.S Geological Survey [2.9], the epicenter of earthquake, which occurred at 14:37 (local time in Indonesia) on July 2, 2013, was located at 4.698^{o}N, 96.687^{o}E with a depth of 10 km, as shown in Figure 2.6.

Completely collapsed houses were observed at several villages such as Serempah and Ratawali close to the epicenter, while Takengon, the capital of Aceh Tengah district about 20 km southeast from the epicenter, did not suffered serious damage, as shown in Photo 2.2.

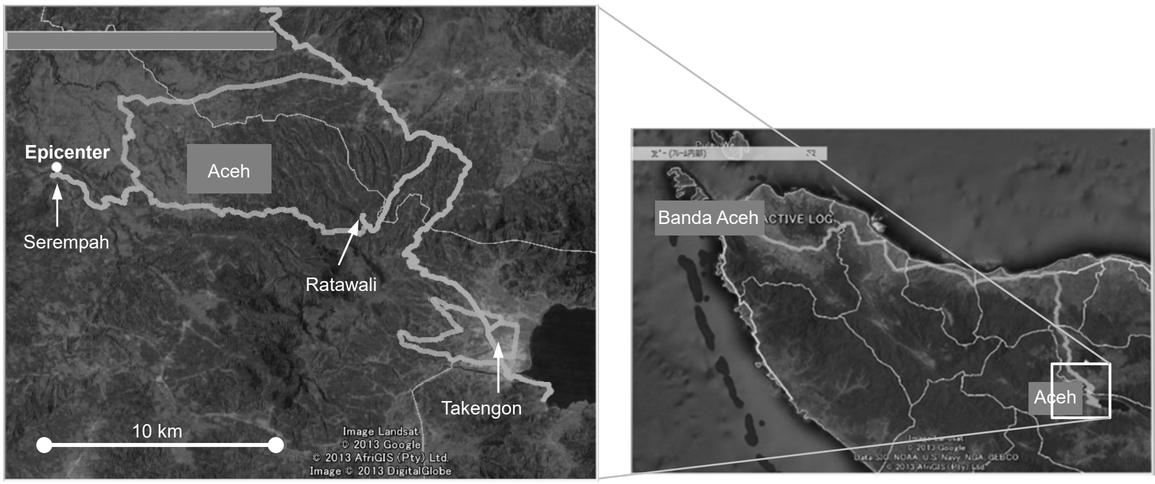


Figure 2.5 Survey Route Map (Google Earth)

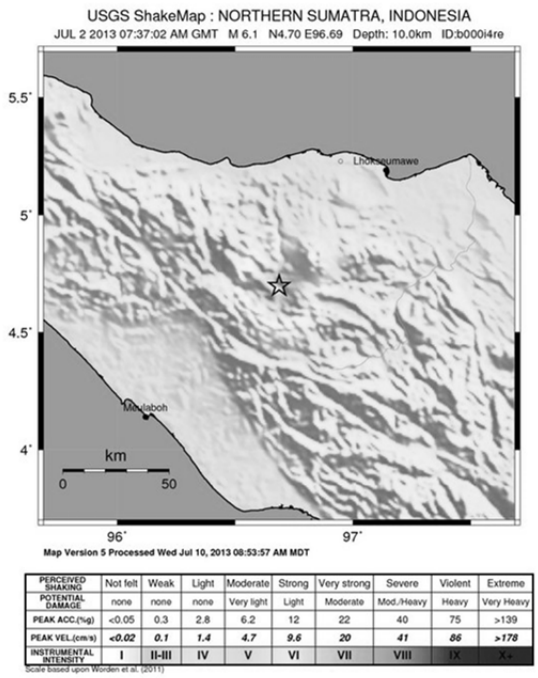


Figure 2.6 Shake Map of the 2013 Aceh Earthquake [2.10]

Photo 2.2 Post-Earthquake Conditions at Investigated Areas (Left: Ratawali, Right: Takengon)

2.3.2 Typical Constructions and Damage

Building/housing structural systems can be roughly classified into four types, as shown in Photo 2.3:

RC	: reinforced concrete,
CM	: confined masonry,
T	: timber,
T+M	: timber with masonry spandrel walls.

The last three types were typical structures at villages in the mountain range close to the epicenter.

(a) Reinforced Concrete (RC)

(b) Confined Masonry (CM)

(c) Timber (T)

(d) Timber with Masonry Spandrel Walls (T+M)

Photo 2.3 Typical Constructions Observed in Earthquake-Damaged Areas

Photo 2.3(a) shows an example of typical RC buildings whose major damage was observed to non-structural masonry walls as well as structural columns. Severe damage to non-structural walls prevented RC buildings from immediate occupancy, as shown in Photo 2.4.

Photo 2.4 Damage to Nonstructural Walls in RC Buildings Preventing Immediate Occupancy

CM houses consist of brick walls with slender RC tie columns/beams, which are provided along the perimeters of masonry walls, and a wooden/aluminum roof truss with tiles/zinc plates or an RC roof slab, as shown in Photo 2.3(b). This type of construction suffered moderate to heavy damage such as: complete collapse, collapse of confining elements, out-of-plane failure of walls, etc., as shown in Photo 2.5. Photos 2.3(c) and 2.3(d) show T and T+M houses, respectively. Both systems consist of wooden walls and a roof made with tiles/zinc plates, while the latter has brick spandrel walls under wooden walls. Although damage to these systems was generally lighter, some of them leaned due to ground settlement or damage to masonry spandrel walls, as shown in Photo 2.6.

(a) Complete Collapse

(b) Collapse of Confining Elements

(c) Out-of-Plane Failure of Gable Wall

(d) Out-of-Plane Failure of Walls

(e) Leaning of wall

(f) Shear Crack on Wall

(g) Separation

Photo 2.5 Typical Damage to Confined Masonry

(a) Timber House Damaged Due to Ground Settlement

(b) T+M Type House Leaning with Failure of Spandrel Walls

Photo 2.6 Damage to Timber Constructions

2.3.3 Findings from Inventory Survey

An inventory survey was conducted at Ratawali village 11 km far from the epicenter. Sixty-four samples of affected structures were inspected for the survey. Figure 2.7 compares the number of samples among four construction types. CM and T types covered 45% of total samples, respectively. On the other hand, only one RC and five T+M samples were obtained at the village.

Damage to CM structures was classified into five grades based on European Macroseismic Scale 1998 (EMS-98, refer to Appendix.1), as show in Table 2.1. Figure 2.8 shows the distribution of damage grades for CM structures which are exemplified in Photo 2.5. Most of CM structures suffered severe damage: Grades 5 and 4 for 62% and 24% of the total, respectively. Photos 2.5(c) to 2.5(g) summarize typical damage to masonry walls. Figure 2.9 shows the ratio of such observed wall damage: out-of-plane failure, leaning, shear cracking, and separation between wall and boundary elements. Out-of-plane failure and leaning of walls were clearly caused by out-of-plane direction loads and generally lead higher damage grades of 5 to 3. On the other hand, walls with shear/separation cracks were judged as smaller grades of 2 to 1, which might be caused by in-plane direction loads. Only two samples were obtained for the latter case according to the investigation results. Moreover, complete collapses with damage grade of 5 also seemed to be related to out-of-plane failure of walls, while it is impossible to exactly identify particular causes of collapses. Therefore, upgrading the out-of-plane performance of masonry walls is essential to effectively reduce severe damage to masonry structures.

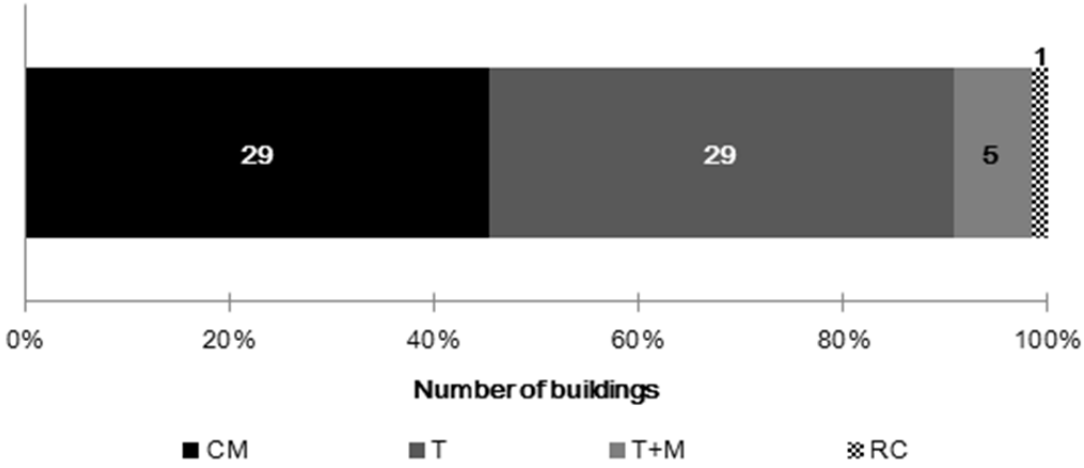


Figure 2.7 Structural Systems at the Investigated Area

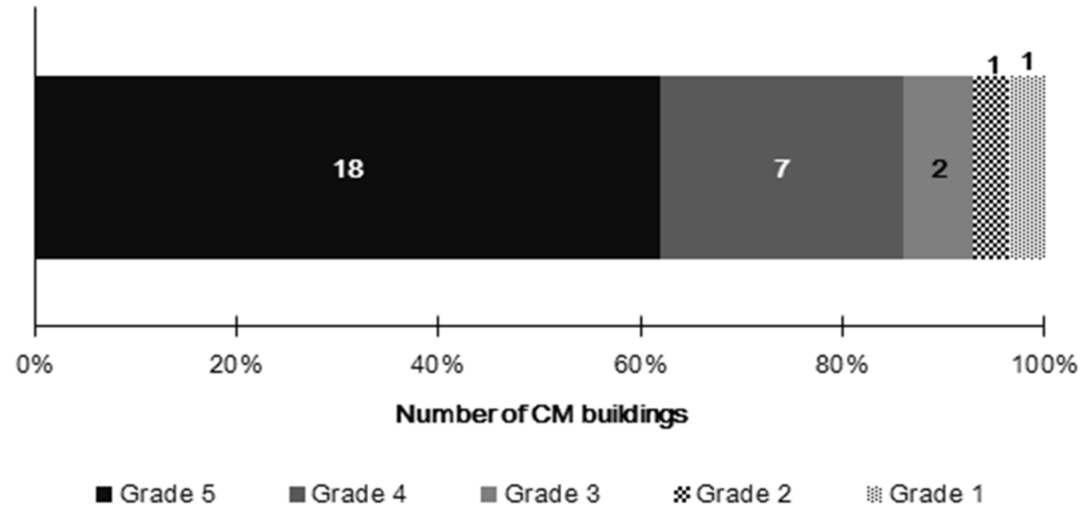
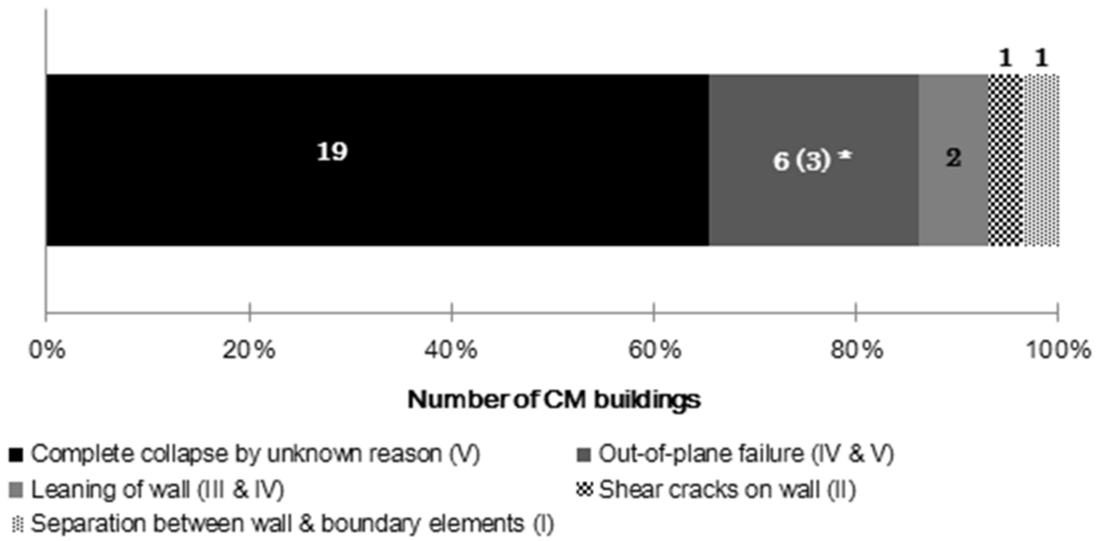


Figure 2.8 Distribution of Damage Grades for CM Construction



where * indicates number of out-of-plane failure of gable walls and parentheses in the legend give the damage grades.

Figure 2.9 Distribution of Wall Damage Patterns for CM Construction

2.4 Concluding Remarks

Two examples of the post-earthquake on-site investigations were introduced in this chapter. The first case from the 2003 Bam, Iran earthquake particularly indicated two key factors: construction materials and qualities to prevent masonry buildings from severe damage. Improving these factors are strongly recommended to reduce earthquake disasters of masonry structures in developing countries. The second case from the 2013 Aceh, Indonesia earthquake verified that severe damage to masonry structures attributed to out-of-plane failure. Strengthening the out-of-plane performance seems to be effective to rationally reduce earthquake damage to masonry structures, which possibly is realized by not only strengthening masonry walls in the out-of-plane direction but also upgrading structural integrity, lateral stiffness, and in-plane resistance of overall structures.

Appendix.1 Damage Classification in European Macroseismic Scale (EMS-98 [2.10])

A.1.1 EMS-98 as Scale of Seismic Intensity

Some scales of seismic intensity are used in different parts of the world. For example, one is Modified Mercalli Intensity scale (MMI) used in United States, another is Medvedev-Sponheuer-Karnik scale (MSK-64) in the former communist bloc including Russia, and another is JMA seismic intensity scale in Japan. The indexes have been developed in each region, there is no global standard.

The European Macroseismic Scale (EMS-98) is one of the basis for evaluation of seismic
22 intensity, largely improving the MSK-64. After editing the test version EMS-92, the final version was issued in 1998 and is used in. The latest edition was issued in 1998, and is used in European countries and also in a number of countries outside Europe. It comes with a detailed manual, which includes guidelines, illustrations, and application examples.

A.1.2 Damage Classifications of EMS-98

EMS-98 defines a seismic intensity at a specific place using combination of vulnerability and damage classification of building. There are 12 divisions of intensities defined from 6 vulnerability classes and 5 grade damage classifications (shown in Table.2.2 and 2.3). For example, VIII Heavily damaging is referred as: Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.

The damage of buildings is classified into 5 grades: G1-G5, as shown in Table.2.1 and Table.2.4. The seismic deformation performance depends on the building types. The classification methods are indicates separately into 2 types of masonry and RC. It is widely applied for grasping damage distribution and quick inspections to mitigate secondary damage. During a large earthquake, most of vulnerable buildings like adobe often suffer serious damage as G5.

The 25 classification examples about every kind of building structures are given with some comments in EMS-98. In the case of partial story-collapse, the determination can be difficult. When the ground floor has collapsed, mostly the grade is G5. However, one of upper stories has collapsed, it can be G4 because of a potential for retrofitting or moving to a different location. In recent years, satellite images have also been used to damage detection [2.11], [2.12].

Table.2.2. Differentiation of structures into vulnerability classes [2.10]

	Type of Structure	Vulnerability Class A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	O					
	adobe (earth brick)	O	—				
	simple stone	----	O				
	massive stone		—	O	----		
	unreinforced, with manufactured stone units	----	O	----			
	unreinforced, with RC floors		—	O	----		
	reinforced or confined			----	O	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	----	—	O	----		
	frame with moderate level of ERD		----	—	O	—	
	frame with high level of ERD			----	—	O	—
	walls without ERD		----	O	—		
	walls with moderate level of ERD			----	O	—	
	walls with high level of ERD				----	O	—
STEEL	steel structures			----	—	O	—
WOOD	timber structures		----	—	O	—	

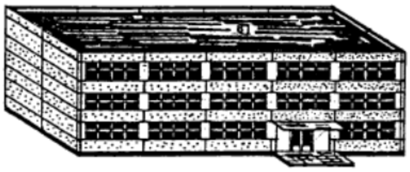
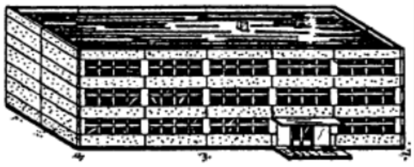
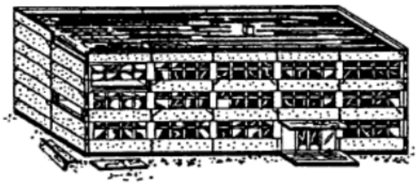
O most likely vulnerability class; — probable range;
----range of less probable, exceptional cases

Table.2.3. Short form of the EMS-98. [2.10]

EMS intensity	Definition	Description of typical observed effects (abstracted)
I	Not felt	Not felt.
II	Scarcely felt	Felt only by very few individual people at rest in houses.
III	Weak	Felt indoors by a few people. People at rest feel a swaying or light trembling.
IV	Largely observed	Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.
V	Strong	Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut.
VI	Slightly damaging	Many people are frightened and run outdoors. Some objects fall. Many houses suffer slight non-structural damage like hair-line cracks and fall of small pieces of plaster.
VII	Damaging	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well built ordinary buildings suffer moderate damage: small cracks in walls, fall of plaster, parts of chimneys fall down; older buildings may show large cracks in walls and failure of fill-in walls.
VIII	Heavily damaging	Many people find it difficult to stand. Many houses have large cracks in walls. A few well built ordinary buildings show serious failure of walls, while weak older structures may collapse.
IX	Destructive	General panic. Many weak constructions collapse. Even well built ordinary buildings show very heavy damage: serious failure of walls and partial structural failure.
X	Very destructive	Many ordinary well built buildings collapse.
XI	Devastating	Most ordinary well built buildings collapse, even some with good earthquake resistant design are destroyed.
XII	Completely devastating	Almost all buildings are destroyed.

Table.2.4. Classification of damage of RC buildings. [2.10]

Classification of Masonry buildings is shown in Table .2.1.

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

A.1.3 Case Example of Damage Evaluation According to EMS-98

(a)

(a) Masonry building
Damage is found at only penthouse part (not visible in photo), main building is almost not damaged.
Concrete shear wall exists in central part. Damage grade is G2.

(b)

(b) Masonry building
If shear cracks extends to the structure frame, be G4. In the case of damage of finish only, it can be determined as G3 damage.

(c)

(c) Adobe building
Identified as G5 damage due to the near total collapse.

Photo.2.7 Damage evaluation of buildings suffered from Peru, Pisco earthquake 2007

Appendix.2 The Japan Meteorological Agency (JMA) Seismic Intensity Scale

The new JMA Seismic Intensity Scale has been calculated from observed strong ground motions since 1996 and it is classified into 10 grades (0, 1, 2, 3, 4, 5 lower, 5 upper, 6 lower, 6 upper, 7). Tables 2.5 explaining the JMA Seismic Intensity Scale show the phenomena and damage [2.13-14].

The JMA Seismic Intensity Scale is calculated by the Fourier transform of acceleration time history records, applied a band pass filters [2.15-16]. If the earthquake acceleration records are steady sine wave, the relation between the maximum acceleration and the JMA Seismic Intensity Scale can be defined. The relation is shown in Figure 2.10. Shabestari and Yamazaki compared the JMA Seismic Intensity Scale (I_{JMA}) with a Modified Mercalli Intensity (MMI) using earthquake record in California. Figure 2.11 shows the relation between the MMI and the JMA Seismic Intensity Scale [2.15]

Table.2.5 Summary of Tables explaining the JMA Seismic Intensity Scale [2.14]

JMA Seismic Intensity Scale	
0	Imperceptible to people, but recorded by seismometers.
1	Felt slightly by some people keeping quiet in buildings.
2	Felt by many people keeping quiet in buildings.
3	Felt by most people in buildings.
4	Most people are startled. Hanging objects such as lamps swing significantly. Unstable ornaments may fall.
5-	Many people are frightened and feel the need to hold onto something stable. Dishes in cupboards and items on bookshelves. Unsecured furniture may move, and unstable furniture may topple over.
5+	Many people find it difficult to walk without holding onto something stable. Dishes in cupboards and items on bookshelves are more likely to fall. Unsecured furniture may topple over. Unreinforced concrete-block walls may collapse.
6-	It is difficult to remain standing. Many unsecured furniture moves and may topple over. Doors may become wedged shut. In wooden houses with low earthquake resistance, tiles may fall and building nay lean or collapse.
6+	It is impossible to remain standing or move without crawling. People may be thrown through the air. Most unsecured furniture moves, and is more likely to topple over. Wooden houses with low earthquake resistance are more likely to lean or collapse. Large cracks may from, and large landslides and massif collapses.
7	Wooden houses with low earthquake resistance are even more likely to lean or collapse. Wooden houses with high earthquake resistance may lean in some cases. Reinforced- concrete buildings with low earthquake resistance are more likely to collapse.

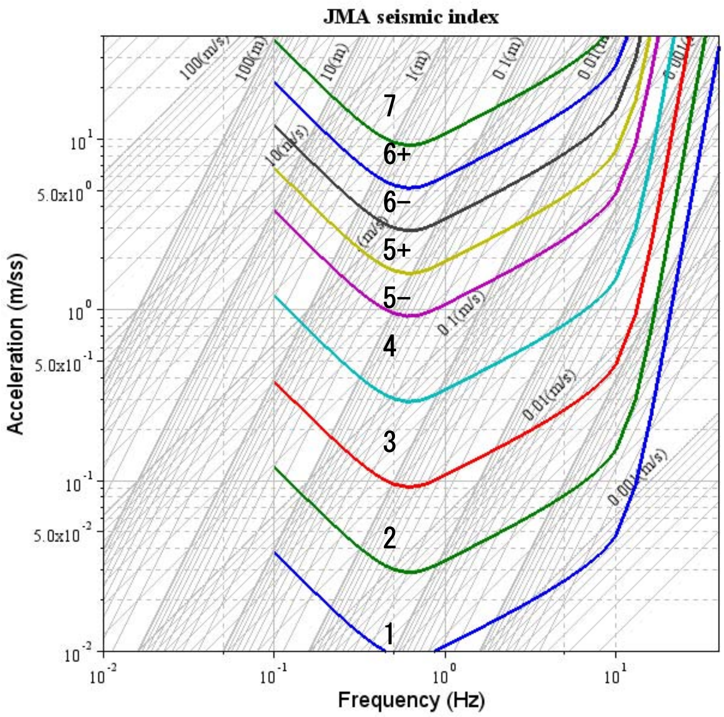


Figure 2.10 The relation between the maximum acceleration and the JMA Seismic Intensity Scale

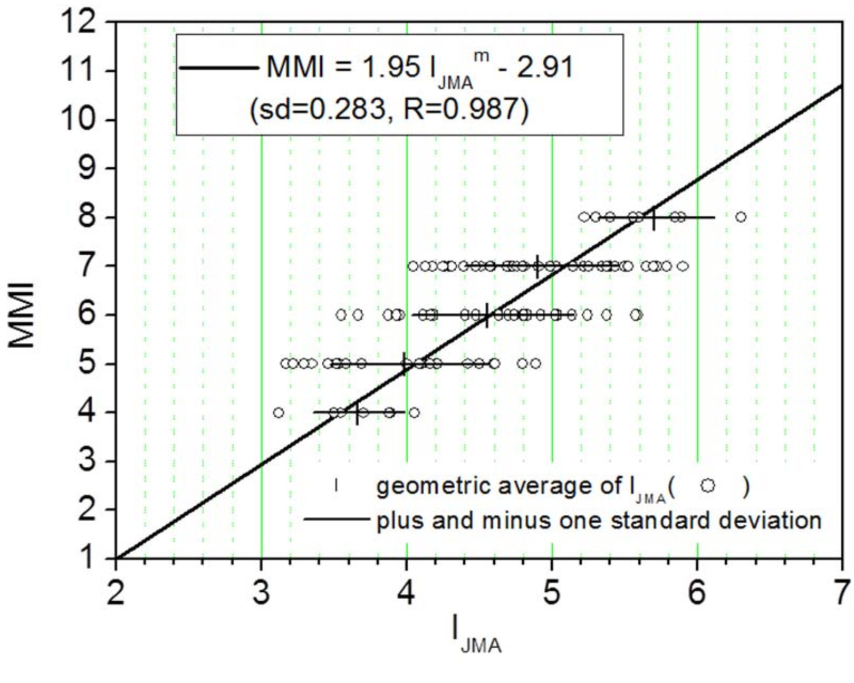


Figure 2.11 The linear relation between the MMI and the I_{JMA}. The bars represent the geometric average of I_{JMA} for a given MMI unit. Horizontal lines show the range of mean plus

or minus one standard deviation for each MMI rank. Open circles denote the I_{JMA} values. [2.15]

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Chapter 3 Dissemination of Technology and Development of Capacity

3.1 Introduction

Dissemination of technologies on non-engineered houses is a very tough task, as that of engineered ones usually does not work effective, therefore specific kinds of activities appropriate to non-engineered houses have to be designed. Under this situation, various organizations like international organization, donors, NGOs, and researchers have been trying various ways. First this report clarifies difference of dissemination activities between engineered and non-engineered houses. Then five groups in two categories of approaches are explained. Typical examples of each group are introduced in this chapter as well in attached Example sheets.

3.2 Stakeholders in construction of houses <Engineered houses>

Engineered houses are constructed by housing supply sectors with investment of users. The housing supply sectors comprise architects, engineers, manufactures of materials, and construction workers. Another important stakeholder group is governmental organizations such as central government and implementing agencies of building administration such as municipalities. Both of the housing supply sectors and the governments have technical knowledge, which works as a common platform for communication. Most of dissemination and capacity development activities are conducted on this platform. Relations among them can be illustrated in Figure 3.1.

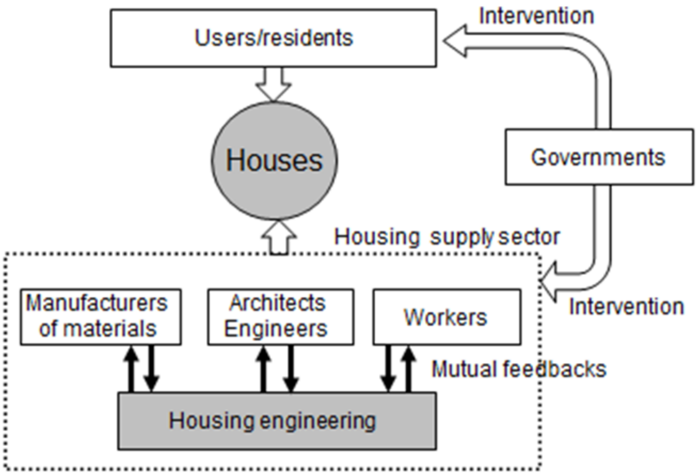

Fig. 3.1 Stakeholders and the relation <engineered houses>

3.3 Stakeholders in construction of houses <Non-engineered houses>

On the other hand, situation in case of non-engineered houses is much different. (See Figure 3.2) Most of stakeholders in housing supply sectors of non-engineered houses reside in a same community or the neighboring ones. Construction materials such as bricks, lumbers are manufactured by local manufactures usually without quality control. Workers also reside in the same area. It is usual that a foreman in the same community organizes a construction team by employing people in neighborhood (often little experience of construction works). In case of traditional houses in remote areas such as sun-dried brick (adobe) houses, most of works are usually conducted by family members including adobe manufacturing, collecting materials like woods and roofing materials under conditions that occupational/professional service of construction works is not available in such areas because of small size of local markets. Another aspect of this situation is economic one. People construct those types of houses are usually low income and could not afford to pay for contractors nor engineers.

In most of countries, professional engineering service is available for large-scale buildings and houses for rich people. This implies that there exists a gap between those services and non-engineered houses, which can be illustrated in Figure 3.2. Many governments usually do not find out an effective way to intervene. In some cases, NGOs support those people usually in a component of comprehensive types of projects like community development/empowerment.

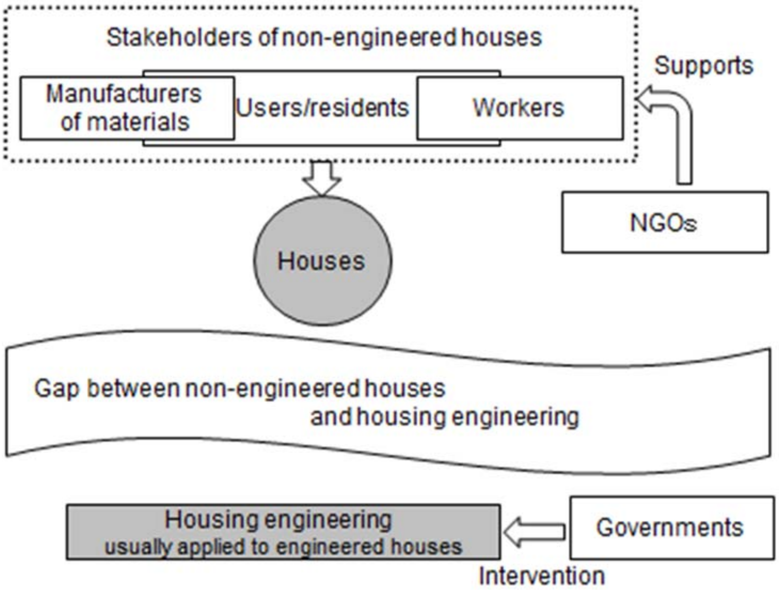

Fig. 3.2 Stakeholders and the relation <non-engineered houses>

Table 3.1 Comparison of engineered and non-engineered construction

Aspects/items	Conventional/non-engineered	Engineered
Materials	Available in the area No control	Usually controlled in size, quality, etc.
Construction workers	Non/semi-skilled workers	Skilled workers
Technical intervention	No/little intervention	Intervention in design, construction procedures, etc.
Users/residents	Low/middle income people	Middle/high income people

Table 3.1 shows comparison of non-engineered houses and engineered ones in key aspects. It should be learned that seismic technologies for non-engineered houses should be 1) simple enough for non/semi-skilled workers to understand and employ in limited availability of tools and facilities at construction sites, 2) affordable enough for low/middle income users who should pay additional costs. Concerning dissemination and capacity development, it is quite critical that workers are non/semi-skilled and that there is no/little intervention of engineer group. This means there exists no platform on which the case of engineered houses relies much for communication.

3.4 Possible channels for dissemination and capacity development

Various approaches conducted by donors and NGOs could be categorized applying the relation of the stakeholder in Figure 3.2. The categorization is shown in the below table which has five groups in two categories. Each of the groups is described with examples in the following sections.

Categories	Groups
Direct	Approaches to users/residents: Figure 3.3
	Approaches to workers : Figure 3.3
Indirect	Approaches through engineer community: Figure 3.4
	Approaches through governments: Figure 3.5
	Approaches through NGOs: Figure 3.6

3.4.1 Direct approaches to users/residents, manufactures and workers (See Figure 3.3)

Distribution of leaflets and posters, seminars, workshops, and training programs to users/residents, manufactures and workers could be categorized into this group. This group could have direct effects and response from participants (final users to employ the technologies). On the other hand, diffusion from the participants to other people (trickle-down effects) is limited because they are the final users. Therefore there need other strategies for scaling up effects of dissemination and capacity development. In the context, ToT approach (Training of Trainers. Trained trainers are expected to give trainings to more trainees in the next steps.) are widely adopted. It must be noted that contents of training, textbooks and other materials should be easy and user-friendly for people without technical knowledge.

(1) Approaches to users/residents

Distribution of leaflets or seminars for users to recognize significance and effects of seismic technologies are usual activities for this approach. Recognition of risks by usual people is rather tough job in case of earthquake disasters because of long returning periods. For easy understanding of risks and effects, demonstration or experiencing types of activities are introduced in cases such as Example No. 1 of attached examples of this chapter. Activities for housing facilitators (young engineers or students employed in community-based type projects to facilitate people and community to construct houses) could be also categorized into this group. (See Example No. 2)

(2) Approaches to workers

Workers are the people who actually apply seismic technologies in their construction works. Therefore, in addition to lectures in classrooms, practical ways such as training to learn constructing skills are often introduced as well. (See Example No. 3 and No. 4)

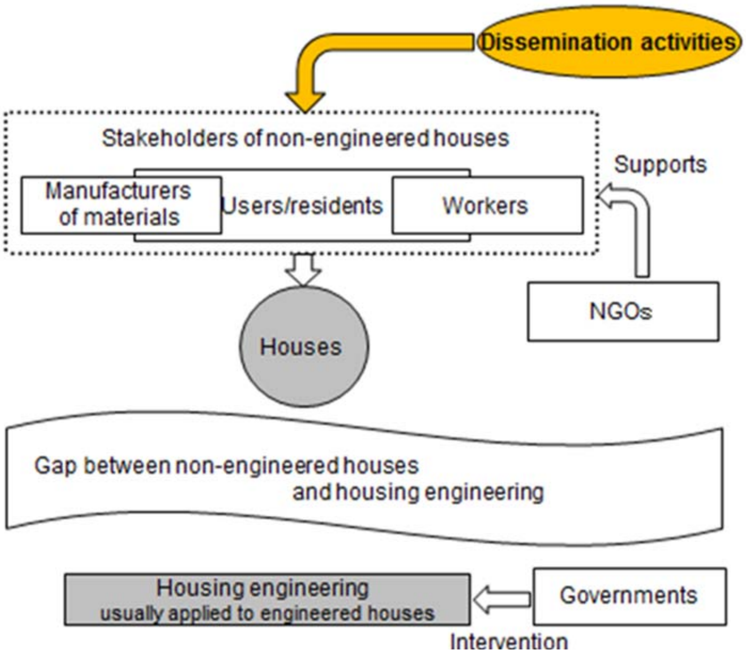

Fig. 3.3 Direct approaches to users/residents, manufactures and workers

3.4.2 Indirect approaches through engineer communities, governments and NGOs

(1) Approaches through engineer communities (See Figure 3.4)

It is usual that few engineers or researchers are involved in non-engineered houses because engineers hardly get fees for their technical service and researchers seldom obtain good academic achievement or praise for beneficial knowledge from their students. Under these circumstances, dissemination activities for engineer community to recognize the significance of non-engineered houses in disaster mitigation in their own country are essential as a first step. Engineers in each of the countries must be a key stakeholder because they could contribute far more than ones from outside of the country. Publications such as the guideline for Earthquake Resistant Non-engineered Construction and Tutorials by World Housing Encyclopedia (WHE) explained in Chapter 5 and “the Guidelines for Earthquake Resistant Non-Engineered Construction” introduced in Chapter 7 could be categorized in this group. It is recommended to show how to overcome the gap between engineering and non-engineered houses shown in Figure 3.4 because most of people in engineer community have little knowledge and experience on this issue.

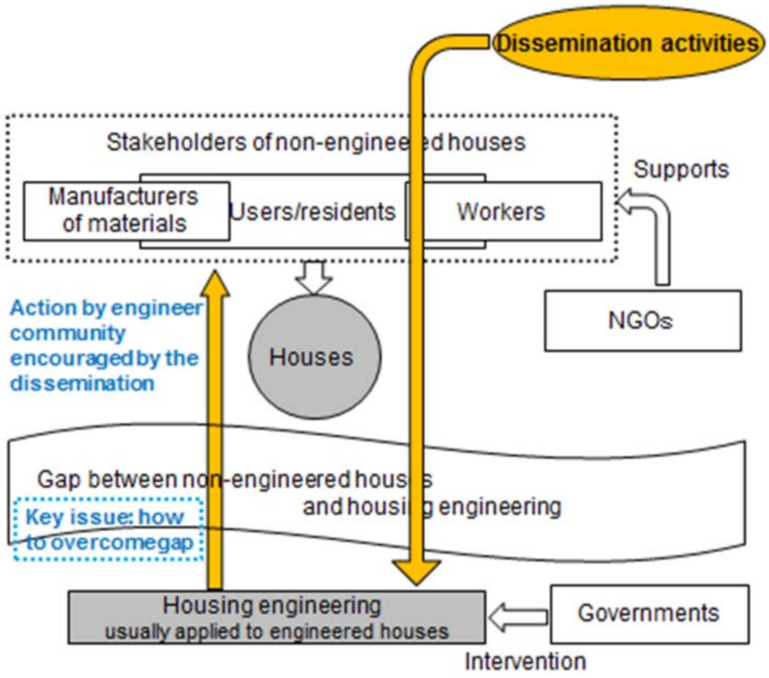

Fig. 3.4 Approaches through engineer communities

(2) Approaches through governments (See Figure 3.5)

Governments are major actors in case of engineered structures in a way like development of technical guidelines/codes and implementation of building permits. In case of non-engineered houses construction, they are also expected to play an important role even though the circumstances are much different and far difficult. They could have several options of activities such as activities to users, workers, engineer community and NGOs. Similar to the case of the approach through engineer communities described in the previous section, it is recommended to show how to overcome the gap between engineering and non-engineered houses. An example in El Salvador (See Example No. 5) takes an approach to follow similar way to engineered houses. In the project, expert team from Japan and Mexico supported El Salvador experts and government to develop official technical guidelines on non-engineered houses. An Indonesian case (See Example No. 6) also took a similar approach. The Indonesian project was implemented in reconstruction procedures from the earthquake disaster by Central Java Earthquake in 2006. It was featured by creation and adoption of very simple guideline applied only to one story houses. In implementation stage, administrative supports for local governments to enforce the guideline was also provides. United Nations Center for Regional Development (UNCRD) conducted a project to provide comprehensive support to governments in accordance with local necessity of each county. (See Example No. 7)

It should be noted that effects of this approach depend on policies of decision makers such as presidents, ministers, governors, mayors and so on. In case decision makers are supportive to poor people, bigger contribution would be achieved by this approach. Sustainability needs to be considered for cases of changes of policies by replacement of policy makers by election or others.

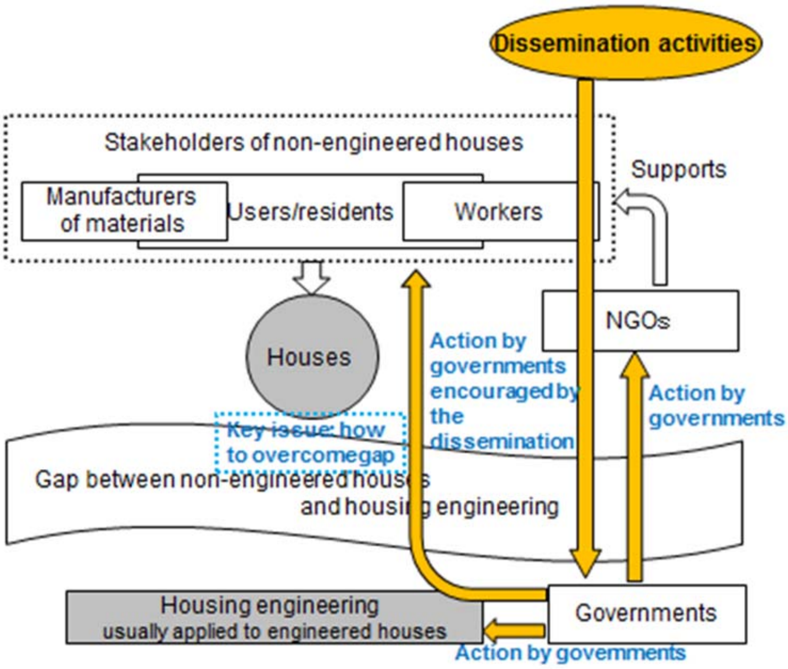

Fig. 3.5 Approaches through governments

(3) Approaches through NGOs (See Figure 3.6)

Most of NGOs conduct grass-root type projects and close relation with people and communities, which allow them free from the difficulties to overcome the gap. Considering this aspects, they are one of appropriate stakeholders for dissemination activities on non-engineered houses. On the other hand, they have problems of scaling up just like direct

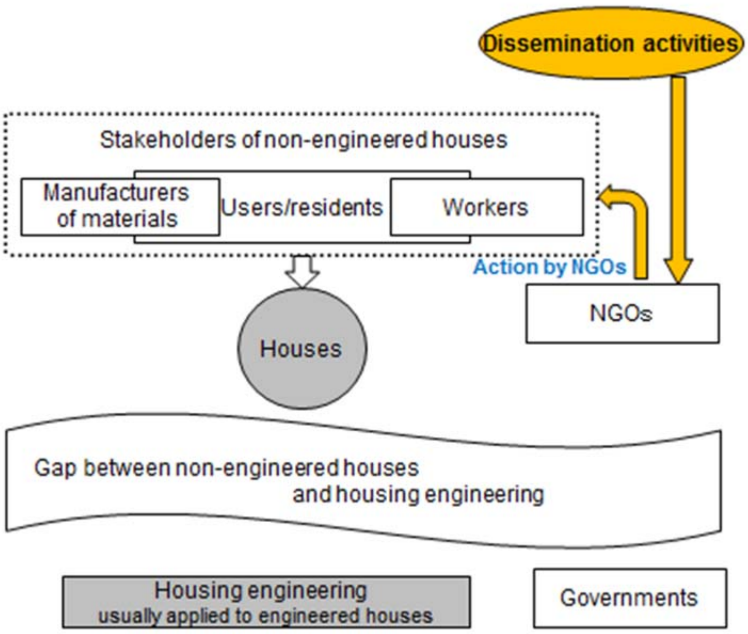

Fig. 3.6 Approaches through NGOs

approach stated in 3.4.1. Example No. 8 is an example of this approach even though dissemination is indirect (from the donor (JICA) to NGOs through participants (the trainees in the JICA project))and unplanned.

3.5 Conclusions

Dissemination and capacity development activities on non-engineered houses are far more difficult than engineered houses because stakeholders directly involved in construction (users/residents, workers and manufacturers of materials) have neither technical knowledge, nor common platform of communication. Furthermore this issue has difficulties which are common with “poverty reduction”, a common goal of international donor community, as most of users are in low income groups and they are not able to afford to invest enough for safety. In spite of the difficulties, several relevant organizations and the donor community have been conducting various projects as mentioned in previous sections. There is no common single solution on this issue. It is necessary to draw lessons from the experiences and to create effective strategies which are appropriate to social, economic and political situation of each county.

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Attached Example sheets

No. 1 Demonstration and explanation of simple shaking table test in Banda Aceh

No. 2 Lectures for housing facilitators in Banda Aceh

No. 3 Dissemination on Construction Technology for Low-Cost and Seismic Resistant Houses in Peru

No. 4 Architectural Mobile Clinic by SNS

No. 5 The enhancement of the construction technology and dissemination system of the earthquake-resistant "vivienda social"

No. 6 Development of simple technical guideline for one story houses and its enforcement in Central Java, Indonesia

No. 7 Housing Earthquake Safety Initiative (HESI) by UNCRD

No. 8 Diffusion of technologies through NGOs in Peru

Example sheets for dissemination of seismic designs

No. 1

Project title	Demonstration and explanation of simple shaking table test (A component of Multi Donor Fund Community-based Settlement Reconstruction and Rehabilitation Project (MDF-CSRRP))	Author	Tatsuo Narafu
		Affiliation, contact address	Japan International Cooperation Agency (JICA) Narafu.Tatsuo@jica.go.jp
Implementer	The World Bank/Building Research Institute (BRI)/National Society for Earthquake Technology (NSET), Nepal	Targeted group	people and communities
Country/Region	Aceh, Indonesia	Duration	2006
Structural types	Confined brick masonry	Reference	http://www.nset.org.np/nset2012/index.php/photogallery/type-picture/galcategoryid-34NA
Type of activities	☐publication	■seminars/workshops	☐trainings ☐others( )

<Background information>
Aceh, Indonesia is one of the most heavily damaged areas by the Indian Ocean Earthquake and Tsunami 2004 and many international organization, donors, and NGOs participated in reconstruction from the disaster. This activity is a component of a multi donor fund project managed by the Word Bank.

<Outline of activities>
Demonstration to show people and communities how large is the difference between resilient and vulnerable houses. Two scaled model houses (1/10) were prepared. One is constructed with proper construction works and another with poor ones.

Both were shaken on a simple shaking table actuated by springs.
As shaking motion became stronger and stronger, one with poor construction works was getting damaged while one with good construction works suffered little. Along with the demonstration experts explained causes and reasons of vulnerability at each of stages in a easy way for dwellers.
The audience could simply understand the difference between the two models and significance of seismic resilience of houses by the demonstrate and explanation.

<Impacts and evaluation>
The audience looked much attracted in the demonstration, understand the message organizers would like to convey, and convinced significance of seismic resilience of

<reference>

Detail of 1/10 scaled model house of confined brick masonry houses

Model houses and an experts surrounded by audience

The model house with poor construction works was getting damaged while shaking motion became stronger

The audience is much attracted and many tool photos

The final stage of the demonstration. The model house with poor construction works totally collapsed.

Example sheets for dissemination of seismic designs

No. 2

Project title	Lectures for housing facilitators (A component of Multi Donor Fund Community-based Settlement Reconstruction and Rehabilitation Project (MDF-CSRRP))	Author	Tatsuo Narafu
		Affiliation, contact address	Japan International Cooperation Agency (JICA) Narafu.Tatsuo@jica.go.jp
Implementer	The World Bank/Building Research Institute (BRI)	Targeted group	housing facilitators who support people and communities
Country/Region	Aceh, Indonesia	Duration	2006
Structural types	Confined brick masonry	Reference	NA
Type of activities	□publication ■seminars/workshops	□trainings	□others ( )

<Background information>

Aceh, Indonesia is one of the most heavy damaged areas by the Indian Ocean Earthquake and Tsunami 2004 and many international organization, donors, and NGOs participated in reconstruction from the disaster. This activity is a component of a multi donor fund project managed by the Word Bank.

<Outline of activities>

In reconstruction from the disaster, the World Bank took community-based approach and encourage people and community to reconstruct their houses by themselves with support both in technical and social by the Bank.

Recovery from damages in people and family has various aspects like job/income opportunity, physical and mental health, education, shelter and living environment, etc. In order to support recovery of people and family, the bank employed young experts and students for consultation of each of people.

Those people are called "facilitators". Housing facilitators are one of those facilitators to help people and community to reconstruct houses and community facilities like foot paths, etc. with their expertise. Most of them are young architects, engineers or students of the expertise.

The housing facilitators work in close relation with people representing their interests. In addition they have certain level of technical knowledge. Therefore they could be good media to people in receiving technical information from experts, translating into easy expression and delivering to people.

The Bank and BRI organized lectures for the housing facilitators. As most of them were young and did not have enough practical knowledge, lectures allotted much time for knowledge on actual materials and tools and practice on site.

<Impacts and evaluation>

The facilitators were highly motivated to support affected people to recover from tragic natural disaster enthusiastic to learn knowledge new for them. They played essential role in this community-based project.

A lecture in a classroom

Lecture on a simple test on quality of aggregates

Samples for lectures, various kinds of aggregate

Exercise of simplified concrete slump test with a PET bottle

Project title	Dissemination on Construction Technology for Low-Cost and Seismic Resistant Houses	Author	Tatsuo Narafu
		Affiliation, contact address	Japan International Cooperation Agency (JICA) Narafu.Tatsuo@jica.go.jp
Implementer	JICA/CIDAP(Peruvian NGO)	Targeted group	Workers (dwellers)
Country/Region	Peru	Duration	2004-2010
Structural types	Adobe	Reference	NA
Type of activities	☐publication ☐seminars/workshops	■trainings	☐others ( )

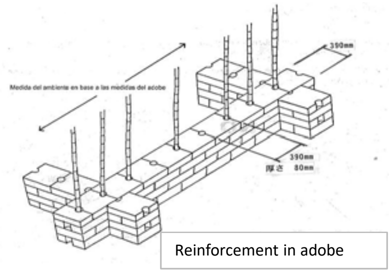
<Background information>

Adobe is one of the most vulnerable types of housing (re: photo), which is constructed usually by residents by themselves.
Several methods for reinforcing are proposed
This project employed a method proposed by Peruvian researchers using canes in both vertical and horizontal direction and wood beams on top of adobe walls. (re: illustration)

Adobe houses destroyed by Pisco EQ 2007

<Outline of activities>

Dissemination of the seismic design and construction skills for workers (residents in this case) by training through construction actual houses.
The project was implemented by a Peruvian NGO (CIDAP) in cooperation with municipalities.
The training was composed of 1)lectures (technical workshops) on design and construction works on each stage of total construction procedures (re: photo) and 2)construction work to build actual houses under guidance of engineers from the NGO (re: photo).
Total number of houses constructed in the project is 12 and participants in each of houses are around 20.



Reinforcement in adobe

<Impacts and evaluation>

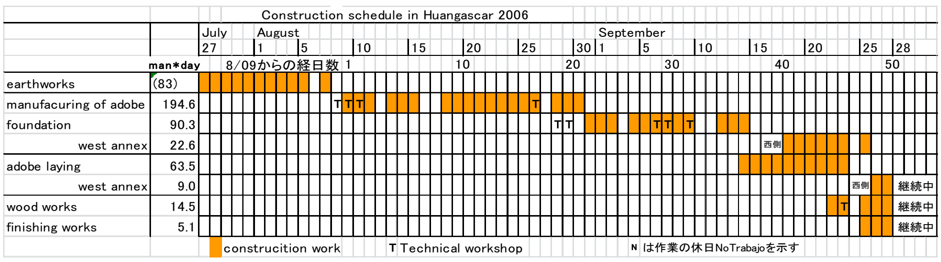
According to results of questionnaires to participants most of them think they could learn the seismic design and willing to apply it to their own houses.
The design was proved to be resilient enough by Pisco EQ 2007, where the houses by the project suffered little whereas most of neighboring houses were heavily damaged.
The design was employed by international NGOs in community development projects for improving living environment and around 10 houses were constructed.
A mayor of one of the project sites applied the design to small municipal buildings such as community health care centers, consulting office and so on and around 10 buildings were completed.

Technical workshops

<reference>
Tatsuo Narafu et al. "LESSONS ON DISSEMINATION OF TECHNOLOGIES OF SEISMIC NON-ENGINEERED HOUSES -A CASE STUDY OF A TRAINING PROGRAM IN PERU-", XIth International Conference on the Study and Conservation of Earthen Architectural Heritage, Terra 2012, Lima, Peru

Constructing works

Schedule of training



Example sheets for dissemination of seismic designs

No. 4

Project title	Architectural Mobile Clinic by SNS	Author	Hiroshi IMAI (SNS/NIED)
		Affiliation, contact address	National Research Institute for Earth Science and Disaster Prevention (NIED), imai@bosai.co.jp
Implementer	SNS International Disaster Prevention Support Center Japan, Fund by Japan Platform	Targeted group	Masons and Communities
Country/Region	Yogyakarta, Padang Pariaman, Indonesia	Duration	2007-2010
Structural types	Confined brick masonry,	Reference	
Type of activities	■publication ■seminars/workshops	■trainings	□others ( )

<Background information>

The central Java Earthquake was occurred in Yogyakarta province on May 27 2006, there were 175,687 houses that totally collapsed and heavy damaged. The number of deaths was 5716 people. And Padang Earthquake on Sep 30 2009 had caused around 110,000 houses totally collapsed and heavy damaged, and more than 1,100 people was killed. The large number of casualties caused non-engineered construction. it should be given the first priority.

Training for masons in Padang pariaman

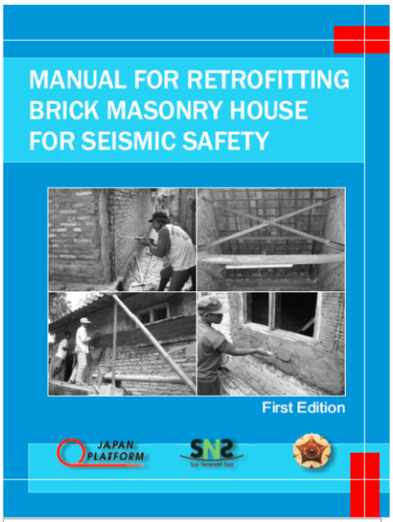
<Outline of activities>

SNS International Disaster Prevention Support Center Japan conducted "Architectural Mobile Clinic Project"
Based on the results of the observation, we held reconstruction housing and rehabilitation programs retrofitting for the community the following activities.
1. Training for mason and worker to provide technical advise safer construction of masonry house.
2. Seminar for people to provide basic knowledge for as safer house as rise awareness.
3. Publishing manual for safer house and retrofitting method for non-engineered house.
These manuals were intended primarily for the mason for construction of brick masonry houses. This manual was developed from the training activities, discussions and practices with the masons and construction workers with the UGM POSYANIS, organized by SNS International and funded by the Japan Platform.

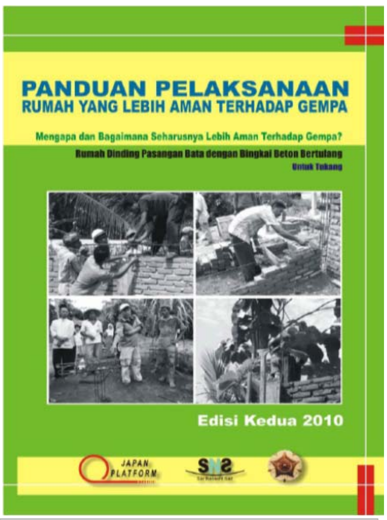
Seminar for people in Padang pariaman

<Impacts and evaluation>

We conducted survey questionnaire about each workshop. According to answer from participants, They needed very basic knowledge to build safer construction for lack of knowledge and practical training. Therefore, these our activities had highly impacts.



Publication : Retrofitting manual, Yogyakarta, 2007



Publication : Safer construction, Padang Pariaman, 2010

Publication : Safer construction, Padang Pariaman, 2010

Example sheets for dissemination of seismic designs

No. 5

Project title	The enhancement of the construction technology and dissemination system of the earthquake-resistant "vivienda social"	Author	Naomi Honda
		Affiliation, contact address	Building Research Institute honda@kenken.go.jp
Implementer	JICA/Vice Ministry of Housing and Urban Development of El Salvador*1	Targeted group	Official, Builder, Designer
Country/Region	El Salvador	Duration	2009-2012
Structural types	Improved Adobe, Concrete Block, Soil Cement, Block Panel	Reference	
Type of activities	■publication □seminars/workshops	□trainings	■others (development of official guidelines)

<Background information>

Two earthquakes of 2001 seriously damaged many buildings in El Salvador, especially low-cost houses.
Experiment and study on earthquake-resistant low-cost houses were carried out from 2003 to 2008 supported by JICA.
Based on the above-mentioned project, a new JICA's project started from 2009 for the purpose of drafting 3 technical standards and 1 technical manual on low-cost houses.

Adobe houses destroyed by EQ 2001

<Outline of activities>

The subjects of this project are 4 methods of construction, which are, or expected to be widely used in the future.
The project was implemented by Vice Ministry of Housing and Urban Development in cooperation with 2 universities and 2 institutions related to housing construction.
They conducted necessary research and drafted 3 technical standards (Improved Adobe Concrete Block, Soil Cement) and 1 technical manual (Block Panel)*2. These drafts are characterized by the following.
1) They are intended for small houses under 50 m2 of area.
2) Structural calculation isn't necessary and only structural specification is stipulated for many engineers and officials to use them easily.
In addition, aiming for a dissemination of earthquake-resistant houses, they conducted some workshops for local officials responsible for authorizing home buildings and developed brochures for the public.

Structural test

<Impacts and evaluation>

The technical manual of Block Panel was published officially by Vice Ministry of Housing and Urban Development in October 2010.
The technical standard of Concrete Block and Soil Cement was reported in a daily government newspaper of El Salvador in March 2014 through procedures of Public Comment. It will be in force from September 2014.
The technical standard of Improved Adobe is in the process of formalization as of June 2014.

These results can be expected to be applied to actual construction in El Salvador. Moreover, they can be expected to extend through Central and South America.

21

DIARIO OFICIAL.- San Salvador, 11 de Marzo de 2014. MINISTERIO DE OBRAS PÚBLICAS, TRANSPORTE Y DE VIVIENDA Y DESARROLLO URBANO

RAMO DE OBRAS PÚBLICAS, TRANSPORTE Y DE VIVIENDA Y DESARROLLO URBANO

Government newspaper of the technical standard

notation

*1: In El Salvador, every ministry has several "vice ministries". For example, Ministry of Public Works, Transport, Housing and Urban Development has three Vice Ministries and Vice Ministry of Housing and Urban Development is one of them.

*2: Block Panel was developed in Cuba and adopted by a few organizations in El Salvador, therefore it was considered that Block Panel didn't need general standards.

Workshop for local officials

Workshop about Adobe in Honduras

Brochures for the public

Example sheets for dissemination of seismic designs

No. 6

Project title	Development of simple technical guideline for one story houses and its enforcement (A components of "Technical Cooperation Project for Reconstruction from Central Java Earthquake")	Author	Tatsuo Narafu
		Affiliation, contact address	Japan International Cooperation Agency (JICA) Narafu.Tatsuo@jica.go.jp
Implementer	Japan International Cooperation Agency (JICA)	Targeted group	Provincial government
Country/Region	Special Province of Yogyakarta, Indonesia	Duration	2006-2007
Structural types	Confined brick masonry	Reference	NA
Type of activities	□publication □seminars/workshops	□trainings	■others (technical cooperation for local government)

<Background information>

Central Java earthquake 2006 (M:6.3 UNOSAT) caused heavy damage of 5,715 dead, about 50,000 injured and more than 100,000 houses collapsed. In order to reconstruct from the disaster Indonesian government decided to offer subsidy for people to reconstruct own houses. The government tool this opportunity to make houses resilient against future earthquake by following building permit procedures in complying a technical guideline. At that moment legal scheme of building permit did exist and a technical guideline for seismic design. However the guideline is too complicated for small one story houses and most of those houses were constructed without building permit. Therefore JICA expert team supported to local Government of Special Province of Yogyakarta to develop a simple technical guideline for one story houses and its

<Outline of activities>

Development of a simple technical guideline applicable only for small one story houses, "Key Requirements", which consists of 12 items of requirement, far simple than the original one.

Leaflets and posters on Key Requirements were prepared and distributes. A series of seminars for people were also organized.

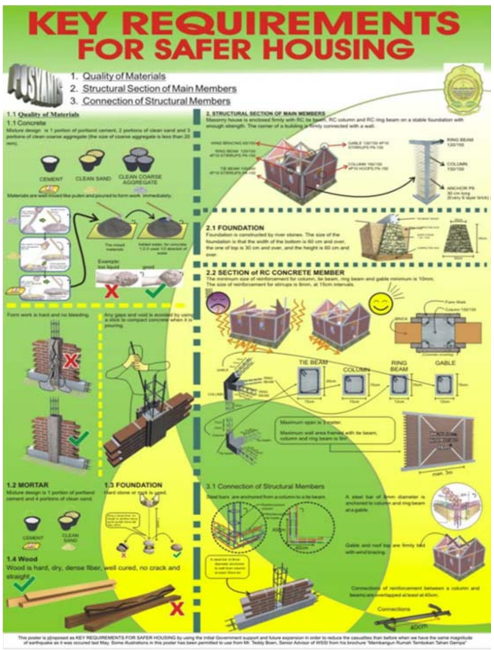
Another important pillar of activities is establishment and capacity development of implementation body. For the purpose series of seminar and training of governmental officials of the Province were organized to develop capacity to manage the procedures from acceptance of application of building permits, processing in relevant sections, examination application documents and issuing permits. Since usual people are not familiar with official procedures to prepare documents and submit, consulting offices were set up for convenience of applicants where people could have any kinds advice.

A seminar to disseminate the simple technical guideline "Key Requirements" to people

<Impacts and evaluation>

Reconstruction of houses is quite urgent as those are basic infrastructure for living of affected people. Total reconstruction procedures were almost satisfactory to meet the needs with tentative flexible management that in case application were to be submitted for sure later construction was allowed to start and subsidy would be received. The capacity of the local government to help people to prepare application documents and processing them was not developed enough in spice of various activities.

A consulting office for people to help to prepare documents and apply for building permits



A seminar for capacity development of government officials in charge of building permits

A poster of the simple technical guideline "Key Requirements"

No. 7

Project title	Housing Earthquake Safety Initiative (HESI) by United Nations Centre for Regional Development (UNCRD)	Author	Shoichi Ando, Jishnu Subedi, Hayato Nakamura (2007-2010, UNCRD Hyogo)
		Affiliation, contact address	National Graduate Institute for Policy Studies (GRIPS), ando@grips.ac.jp
Implementer	Disaster Management Planning Hyogo Office, United Nations Centre for Regional Development, NSET-Nepal, CISMID-UNI-Peru, ITB-Indonesia	Targeted group	government officers and communities
Country/Region	Nepal (Kathmandu), Peru (Lima), Indonesia	Duration	2007-2010
Structural types	Confined brick masonry, RC and others	Reference	http://www.uncrd.or.jp/index.php?menu=229
Type of activities	■publication ■seminars/workshops	■trainings	■others (Policy recommendation)

<Background information>

The collapse of buildings causes major tragedies in the earthquake related disasters. In order to achieve resilient social infrastructures with earthquake resistant buildings, cooperation of engineers and governments is essential. Though many earthquake prone countries now have building codes, there is serious challenge for effective implementation of the building code and retrofitting policy because of lack of awareness , lack of institutional mechanism.

HESI Conference in Peru, 2007 at UNI-FIC CISMID (Japan-Peru Seismic DM Center)

<Outline of activities>

United Nations Centre for Regional Development (UNCRD) Disaster Management Planning Hyogo Office launched the Housing Earthquake Safety Initiative (HESI) Jan. 2007-2010, and conducted various activities throughout the three target countries.

UNCRD provides an international information exchange platform to share policies.

The project aims to improve the safety of houses and protect them from earthquake through effective implementation of building code and retrofitting policy. Although building code is a large part of building safety, it is important and key element.

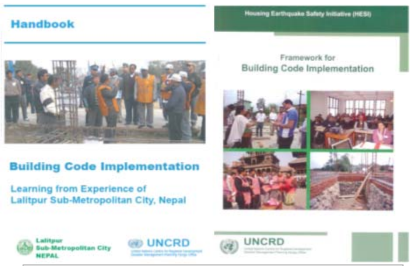
The activities included perception and implementation gap analysis of target countries, raising awareness and capacity development among stakeholders, developing policy recommendation, guidelines and dissemination on improving building safety regulations.

Field Visit with Seismic experts and policy makers at the HESI event in Nepal, 2007

<Impacts and evaluation>

Under this initiative, UNCRD provides an international information exchange platform to share policy experiences as well as the cases of school safety (SESI) project. There are several effective tools to reduce or prevent life and property losses during an earthquake.

It is verified that effective building code implementation requires not only the capable national institutions for strict enforcement but also means to engage community people.



Publications of HESI project, officers/ engineers training guideline for Nepal (upper), Building code implementation Indonesian guideline (lower) in 2007-09

<reference>

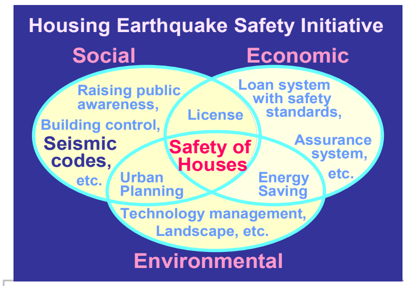
HESI and SESI publications: http://www.uncrd.or.jp/index.php?menu=229

HESI int'l sympo 2008: http://www.uncrd.or.jp/content/documents/From%20Code%20to%20Practice.pdf

HESI Handbook Nepal 2008: http://www.uncrd.or.jp/index.php?page=view&type=400&nr=156&menu=229

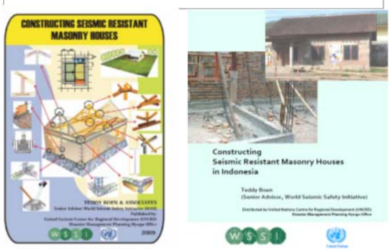
HESI Peru WS 2007: http://www.uncrd.or.jp/index.php?page=view&type=400&nr=176&menu=229

HESI Indonesia Guide 2009: http://www.uncrd.or.jp/index.php?page=view&type=400&nr=155&menu=229



Concept and related fields of "Housing Earthquake Safety" including building codes

Awareness event on "Earthquake Day" of Nepal on 16 January, 2008 (NSET & UNCRD)



Example sheets for dissemination of seismic designs

No. 8

Project title	Diffusion of technologies through NGOs	Author	Tatsuo Narafu
		Affiliation, contact address	Japan International Cooperation Agency (JICA) Narafu.Tatsuo@jica.go.jp
Implementer	JICA (indirect)/Caritas CRS(International NGO)	Targeted group	NGOs
Country/Region	Peru	Duration	2008-2010
Structural types	Adobe	Reference	NA
Type of activities	☐publication ☐seminars/workshops	☐trainings	■others (diffusion through participants of training)

<Background information>

JICA conducted a project "Dissemination on Construction Technology for Low-Cost and Seismic Resistant Houses" in 2004-2010 constructing 12 model houses in 8 municipalities. (re: Example sheet No.3) Huangascar, Yauyo Province, Lima State, happened to be a project site of a rural area development projects consisting of agricultural productivity improvement, construction of irrigation facilities, community governance, and housing improvement by Caritas and CRS(both are international NGOs).

A seismic adobe house being constructed in the rural area development project by the NGOs

<Outline of activities>

Former participants of JICA project proposed NGOS to adopt the seismic adobe houses they learned in the project and NGOs accepted it.

Around 15 houses of the seismic adobe houses were reported to construct by the rural area development project.

Former participants of the JICA dissemination project proposed to apply the seismic design to houses by the NGO project

<Impacts and evaluation>

This is a good practice of dissemination projects that the technologies were applied to houses out side of the dissemination project although dissemination was indirect (via participants of the training course) and unplanned (JICA did not plan to disseminate to NGOs as it did not know Huangascar would be a project site of NGOs).

This case shows high possibility of dissemination of technologies for low income groups through NGOs as target groups of NGOs are often low income group. The possibility should be further explored in more direct or planned manner.

A staff of Caritas presenting the seismic adobe houses constructed in their project at Terra 2012, an international conference at Lima, Peru

<reference>

Tatsuo Narafu et al. "LESSONS ON DISSEMINATION OF TECHNOLOGIES OF SEISMIC NON-ENGINEERED HOUSES -A CASE STUDY OF A TRAINING PROGRAM IN PERU-", XIth International Conference on the Study and Conservation of Earthen Architectural Heritage, Terra 2012, Lima, Peru

A completed seismic adobe house in Huangascar, Yauyo Province, Lima State

A house owner of a seismic adobe house with construction colleagues of Urbano Tejada Schmidt, a leader of CIDAP, and Casimiro Bautista Satelo, an engineer

Chapter 4 Classification and Effects of Strengthening and Retrofitting Techniques

4.1 Introduction

There is a high stock of existing buildings including historical and cultural monuments around world constructed with unreinforced masonry (URM). In recent earthquakes, it has been proved that many of URM structures such as ordinary houses, schools and so forth, are highly vulnerable and as a result there is a serious need for proposing appropriate seismic retrofitting techniques for them.

In this chapter, the existing URM retrofit strategies and techniques are introduced. And the effects of the retrofitting techniques of URM are also compared. In addition, a research information collecting system for retrofitting of URM is proposed.

4.2 Retrofit Strategies of Masonry

From a general rehabilitation point of view, the concept of preservation of masonry buildings can be categorized as the following actions [4.1]:

a) Stabilization
b) Repair
c) Strengthening
d) Seismic retrofit

Stabilization is generally applied to historical monuments which are partially collapsed during the time and mainly deals with improvement in masonry materials subjected to gradual quality decay or failures caused by past earthquakes or human-made damages. In the other words, stabilizing saves the structural integrity of the existing buildings.

Repair deals with recovering of the initial mechanical or strength properties of the materials or structural components of URM structure. The purpose of repair is not to correct the deteriorations of structure and in this sense it is different from stabilization.

Since it is not clear if the initial structural performance of a URM structure meets the seismic requirements, there is a need to provide additional strength to building. Strengthening is aimed to respond to a more demanding level of structural safety.

Due to the earthquake-induced nature of the inertia lateral forces, sometimes strengthening is not the proper response and some other modifications in structural behavior are needed. In the other words, seismic retrofit process may not necessarily contribute to the strengthening of URM structure. Even sometimes partial weakening (or adding ductility) of the structure may provide an adequate seismic performance. Therefore, seismic retrofitting can be a better solution to respond the seismic demands of a URM building than only strengthening.

Also, the seismic retrofit policies of URM structures may be categorized as partial and global retrofitting which includes the following features [4.2]:

a) Improving structural connections

b) Increasing the rigidity of floor slabs

c) Increasing the strength/deformability of load bearing walls

As a global retrofit plan, all seismic acceptance criteria - including both partial and global behavior - should be fulfilled.

The most important factor that should be considered in the retrofit design of a URM structure, - whether a global or partial method - is the expected failure modes. Due to the complex seismic response of the components of a URM building and different study requirements, the failure causes of the structure should be prioritized. As it was mentioned before, in-plane and out-of-plan failure mechanisms of the load bearing walls play a key role in the URM collapse. Therefore, retrofitting of URM walls is the most important part of a global retrofit plan.

4.3 Retrofit Techniques of URM

There are various methods of URM retrofitting in different categories, and some of them are under research process [4.3, 4.4, 4.5, 4.6, 4.7]. Application of these methods to URM structures is expected to increase the strength and/or ductility of the structure.

Figure 4.1(a) and (b) show schematic diagrams for the retrofitting techniques of URM structure, which are expected as the actions of c) Strengthening or d) Seismic retrofit in the section 4.2. A summary of the URM retrofitting methods with a brief review on the related literature comes below. The sign of "I" or "O" surrounded by the square in Figure 4.1(b) shows that the experiments for investigating the in-plane or out-of-plane mechanical characteristics of masonry walls were conducted in the related literature, respectively.

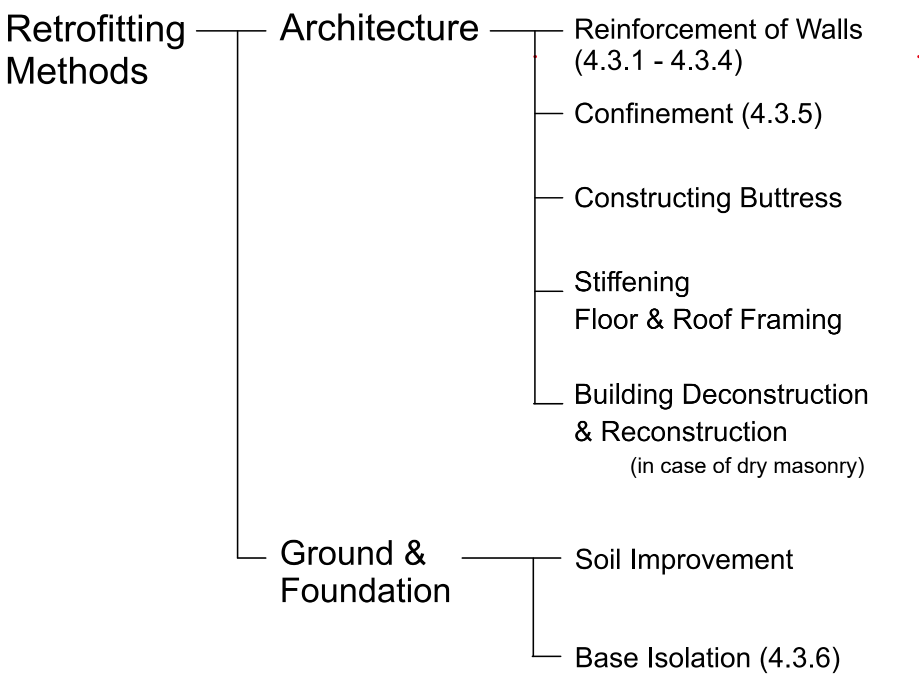


Figure 4.1(a) Schematic Diagram for the Retrofitting Techniques of URM Structure

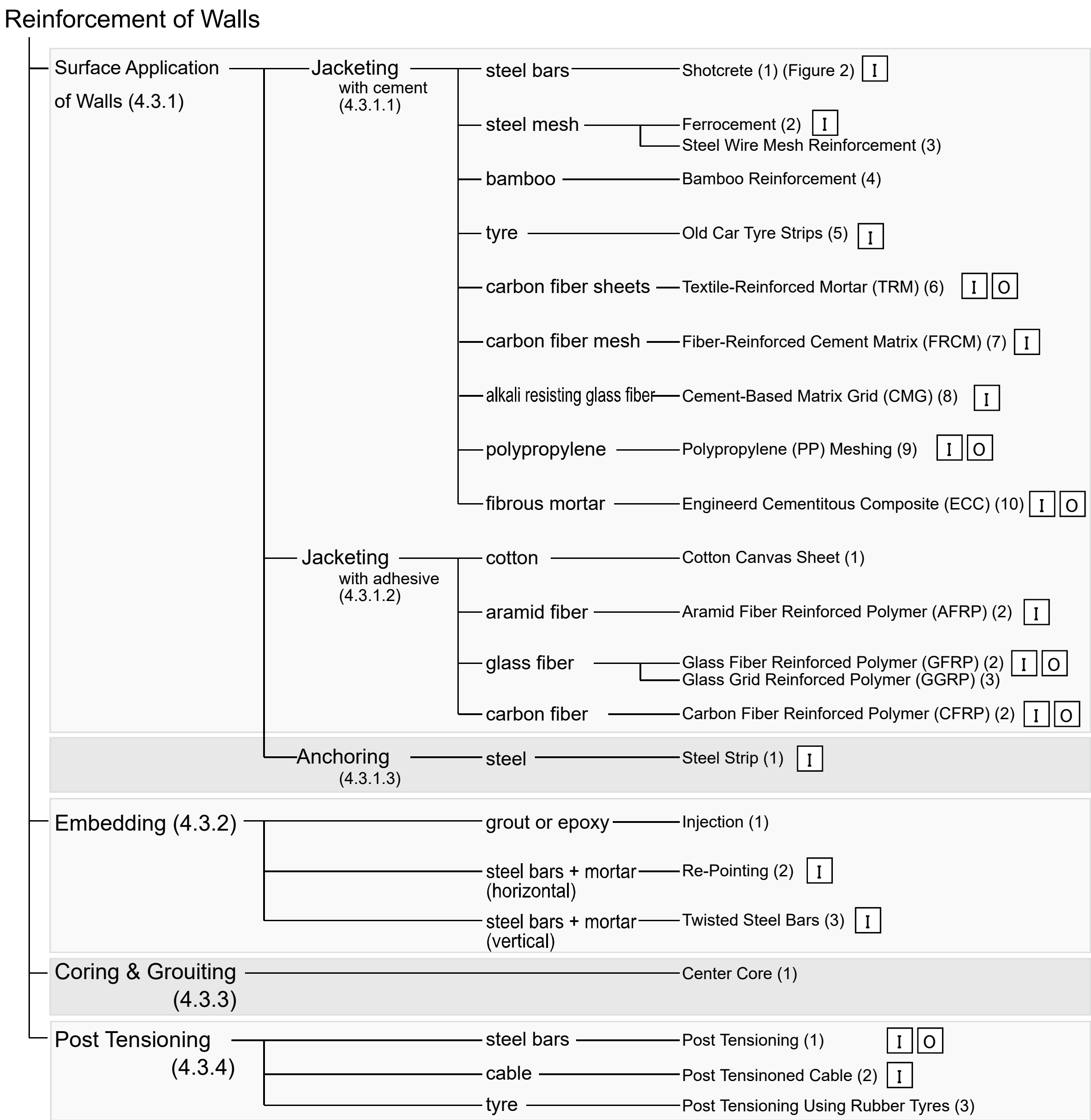


Figure 4.1(b) Schematic Diagram for the Reinforcing Techniques of URM Walls

4.3.1 Surface Application

Surface application is a common strategy for URM, which has largely developed through practical application experiences. Since in this approach, retrofitting covers the surface of masonry walls, it is not suitable for historical structures with architectural values. Recent methods in this category are introduced below.

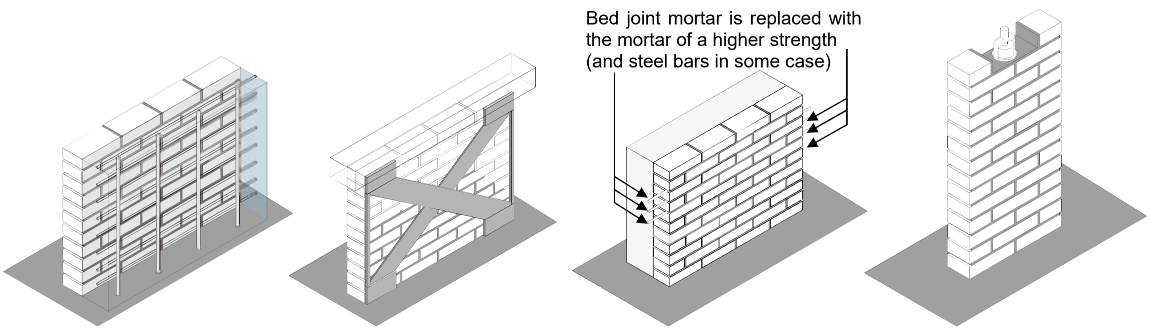
4.3.1.1 Jacketing (Reinforcements + Cementitious Materials)

(1) Shotcrete

Shotcrete is a covering method of masonry walls with sprayed concrete reinforced by the mesh of steel bars as shown in Figure 4.2(a). This technique consists of:

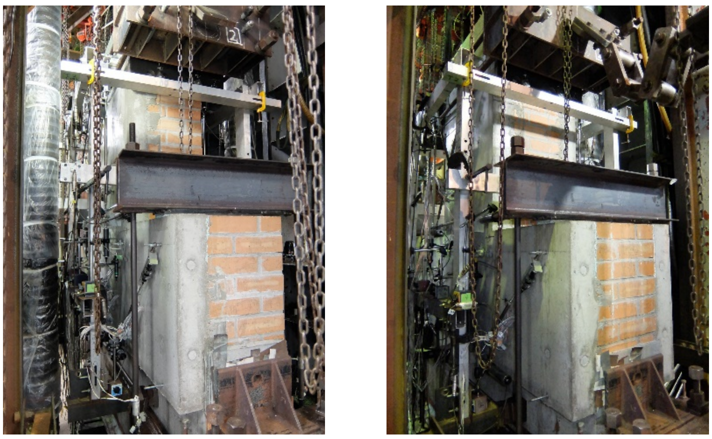
- Shrinkage control by reinforcing bars
- Shear dowels
- A cleaned surface, watered and grinded
- Sprayed wall surface [4.4]

Several experiments have shown that the application of shotcrete increases the lateral strength of the specimens by a factor of approximately 3.6 and using it on both sides of the wall (generally 20 mm thick layers) makes the wall more ductile. This type of retrofitting improves the energy dissipation by a factor of 4.2. Also the stiffness of the retrofitted specimens is approximately 3 times the stiffness of the unretrofitted one [4.8]. Moreover, shotcrete increases the flexural strength of URM walls [4.9]. The reinforcing method of placing a reinforced concrete panel on the surface of a URM wall, not spraying, as shown in Figure 4.3 is also often used.



(a) Shotcrete (4.3.1.1(1)) | (b) Steel Strip (4.3.1.3(1)) | (c) Re-Pointing (4.3.2(2)) | (d) Post Tensioning (4.3.4(1))

Figure 4.2 Outline of Retrofitting Techniques for URM Structure



Left: One Side

Right: Both Sides

Figure 4.3 Reinforcing Method of Placing Reinforced Concrete Panel

(2) Ferrocement

The ferrocement overlay rehabilitation is the fixing of a galvanized iron mesh to a wall via nails or other connectors and covering it with a rich mix of cement-sand mortar with the ratio of 1:3 [4.10]. Some experimental works showed that this method increases the strength of the wall slightly. It was shown that the ferrocement surface coating added little flexural strength over rocking because the tensile strength of the steel hardware cloth was very small. Also, the effectiveness of ferrocement overlay as indicated with the product of strength times ductility, was roughly equal to one of the non-rehabilitated specimens [4.11]. However, this type of retrofitting technique showed remarkable effect for the brick house stacked in the stretcher bond manner on the shaking table test conducted by NIED Japan in 2014.

(3) Steel Wire Mesh Reinforcement

Steel wire mesh reinforcement consists of two horizontal and vertical strips. Vertical strips are applied at the intersection of walls, the centre of long walls and at free ends. The horizontal strips applied at the top of the walls connect all of the vertical strips. These strips are covered with a cement cover to protect them from corrosion. Retrofitted houses in Peru with this method showed no damage during the 2001 and 2007 earthquakes (south Peru, Magnitude=8.4 Richter). Even retrofitted walls without covering mortar showed an appropriate seismic behavior [4.5].

(4) Bamboo Reinforcement

The retrofitting system in this technique consists of buttresses, a ring beam, vertical and horizontal bamboo used as internal reinforcement. Experiments have shown a significant increase like 400% in ultimate displacement [4.12]. However, due to various environmental conditions of earthquake-prone regions of world, this material is not generally available.

(5) Old Car Tyre Strips

In this method, old tyres are cut into strips and placed in the canals opened in the masonry wall. And strips are covered by high quality or plastering mortar. The experiments for investigating the in-plane mechanical characteristics of masonry walls were conducted in the related literature [4.13].

(6) Textile Reinforced Mortar (TRM)

Textile Reinforced Mortar (TRM) layers are made of carbon fiber textile meshes roving in two orthogonal directions with a mortar containing polymeric additives [4.14]. TRM jacketing improves both the strength and ductility of the URM wall and it is a strongly recommended retrofitting method for unreinforced masonry walls subjected to in-plane loading (improvement by a factor of 5-6.5) [4.4]. A comparative experimental study showed that TRM jackets are at least 65–70% and 15–30% as effective as fiber reinforced polymers (FRP) jackets for shear strength and deformation capacity with identical fiber configurations [4.15].

(7) Fiber-Reinforced Cement Matrix (FRCM)

This strengthening system consists of a composite material made out of carbon fibers embedded within a fiber-reinforced cement mortar. Diagonal-compression tests for investigating the in-plane mechanical characteristics of masonry walls were conducted in the related literature [4.16].

(8) Cement-Based Matrix-Grid (CMG)

This system consists of an alkali resistant (AR) glass coated grid, SRG 45 (structural reinforcing grid), and a polymer modified AR-glass fiber reinforced mortar. Experiments showed that applying various arrangements of the CMG system improves the strength and ductility of a URM wall significantly. It improves the shear strength by a factor of 1.7 or 2.0. However it does not affect the initial stiffness of the wall [4.17].

(9) Polypropylene (PP) Meshing

This method uses polypropylene bands in a mesh form embedded in a cement layer cover. This method extremely improves the shear behavior and deformability of URM wall. Moreover, the retrofitted walls exhibit a 60% residual strength after peak strength, which is sustained even for larger deformations. However, since PP-bands have a relatively low stiffness compared to the masonry walls, they do not contribute to increase the wall peak strength. [4.18]. PP bands are cheap and therefore this retrofitting method is simple and suitable for developing countries as it was used in Nepal, Pakistan and Kathmandu [4.5]. In addition, this meshing is also fixed around the masonry wall directly and used without a cement layer cover in some cases. In such a case, the method can be categorized into Anchoring of Section 4.3.1.3.

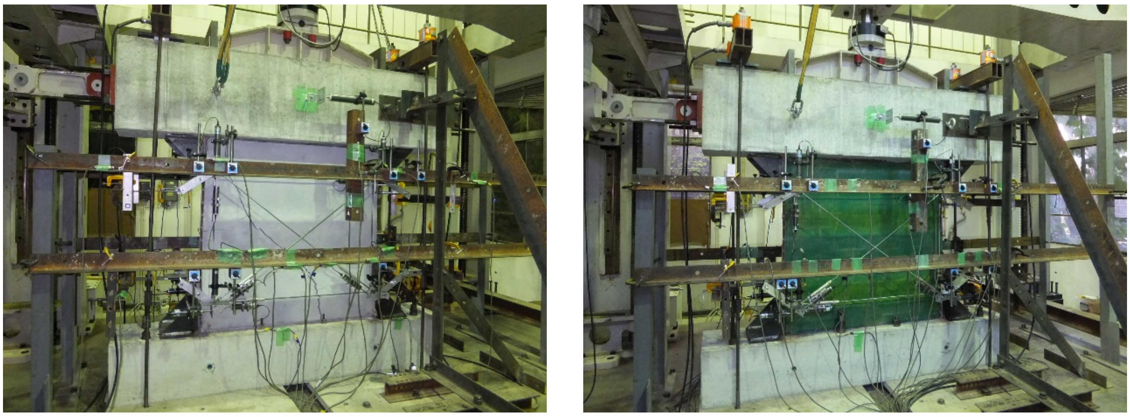


Figure 4.4 Reinforcement with (a) ECC (Left) or (b) AFRP Sheet (Right)

(10) Engineered Cementitious Composite (ECC)

ECC with multiple fine cracks is a cement-based composite material with a strain-hardening tensile behavior and an excellent capability to control the width of crack [4.19, 4.20]. This composite material has shown a high strain capacity and can absorb and dissipate high amounts of energy [4.21].

Lin et al. [4.22] conducted some in-plane and out-of-plane tests on the ECC retrofitted masonry specimens and examined a two story URM building shotcreted with ECC in New

Zealand. As a result of out-of-plane tests in the literature, an increase in maximum load of 1.6 times the strength of the bare wall was observed when ECC retrofitting was applied on the compression surface and an increase of 13.2 times when it was applied on the tension side.

Figure 4.4(a) shows the horizontal loading test status of a brick wall applied with 20mm thick ECC to both sides. The loading test was conducted at Kyushu University, Japan in 2013.

4.3.1.2 Jacketing (Reinforcements + Adhesives)

(1) Cotton Canvas Sheet

In this method, the canvas strips were adhered to the wall in the three directions (horizontal, vertical, and diagonal). Shake table tests were conducted on three pairs of strengthened and non-strengthened masonry walls in the related literature [4.23].

(2) Fiber Reinforced Polymer (FRP)

Fiber Reinforced Polymers (FRP) composites are made of fibers in a polymeric matrix. FRP materials are lightweight and non-corrosive. They exhibit high tensile strength and impact resistance, and are available in several forms like mesh strips, reinforcing bars, and prestressing tendons [4.24]. Applying FRP to a URM wall increases both the in-plane and out-of-plane characteristics of the wall [4.25].

Some studies showed that FRP overlays improve the shear resistance of the wall by a factor of 1.3 to 2.9. Ultimate drift of the retrofitted specimen was about 1.2 times of the one for unretrofitted specimen and the extent of this improvement depends on fiber characteristics and applying position and direction.

Under static cyclic loading test, application of FRP improved the lateral resistance by a factor of 1.7 to 5.9. However, as it reported in several experimental research works available in literature, debonding occurred at lateral load levels ranging from 50% to 80% of the ultimate load resistance [4.26]. Debonding of FRP highly limits the performance of this method.

Glass fiber reinforced polymer (GFRP) strips have been used for retrofitting of concrete members for many years with great success. Easy application and good ductility of this method have made it suitable for URM structures.

Some experiments showed that the application of GFRP strips in a horizontal configuration improves both in-plane and out-of-plane flexural and shear behavior. However, using only vertical strips can improve the in-plane performance [4.27].

Carbon fiber reinforced polymer (CFRP) is a kind of FRP which is made of high strength fibers (carbon) embedded in a polymeric resin matrix. The fibers resist tension while the resin transfers the loads among the fibers [4.28]. Experiments showed that on average, the maximum lateral force resisted by the CFRP reinforced wall specimens was 1,500% greater than the capacity of unreinforced reference specimens [4.29].

Aramid fiber reinforced polymer (AFRP) is characterized by light weight and high tensile strength. AFRP have been successfully used for retrofitting of concrete members. Figure 4.4(b) shows the horizontal loading test status of a brick wall applied with AFRP sheet to both sides of them. The loading test was conducted at Kyushu University, Japan in 2013.

(3) Glass Grid Reinforced Polymers (GGRP)

GGRP system consists of a glass unidirectional reinforcement grid and polyurea resin to create a composite laminate. GGRP has many desirable properties such as rapid cure and insensitivity to humidity along with good physical properties, including a high degree of hardness, flexibility, and tensile strength. Studies showed that using the GGRP system increases in-plane and out-of-plane strengths and the stiffness of URM walls. It increases the lateral strength of the URM wall by a factor of 5 [4.30].

4.3.1.3 Anchoring of Reinforcements

(1) Steel Strip

In this method steel strips in different arrangements are applied to the surface of URM wall as shown in Figure 4.2(b). Numerous experiments proved that by using steel strips the compressive strength of the wall was increased from 12 to 26 percent and the shear strength was increased from 30 to 87 percent, as well as a considerable increase in the elastic limit of the wall [4.31].

Application of steel strips is effective in increasing in-plane strength, ductility, and energy dissipation capacity of the wall too [4.32].

Figure 4.5 shows the diagonal compression test status of a brick prism applied with steel plates to both sides of them. The compression test was conducted at Kyushu University, Japan in 2015.

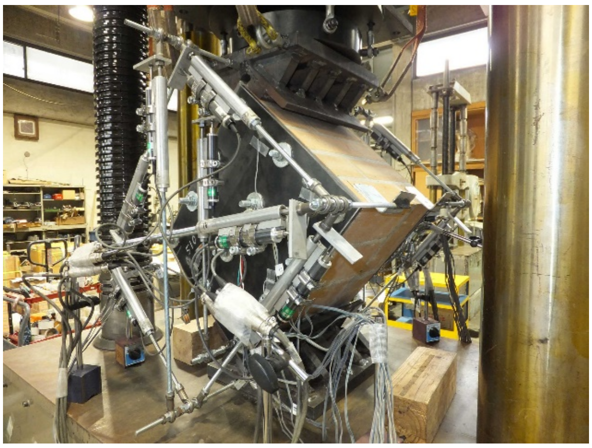


Figure 4.5 Reinforcement with Steel Plate

4.3.2 Embedding Reinforcements to Wall

(1) Injection

In this method grout or epoxy injection is used to fill voids or cracks. Since this method does not affect the surface of the wall, it is popular for historical buildings with special architectural features. This technique is very useful for the purposes of improving compressive and shear strength of URM walls by restoring the initial stiffness of it. However, in cases where injection is applied to some parts of a building and the strength of the building increases partially, it is necessary to prove that other parts or the whole building do not become dangerous [4.9].

(2) Re-Pointing

If the bricks of a wall are in good quality but the mortar is weak, this method can be used. The mortar is replaced with the mortar of a higher strength as shown in Figure 4.2(c). Some studies showed that minimal amount of material is required in this technique. However, no noticeable improvement was observed in the dynamic behavior of the retrofitted specimens in the studies [4.12].

(3) Twisted Steel Bars

In this method, 30 mm deep and 10-14 mm wide slots were cut into the masonry from the surface, and an approximately 10 mm thick bead of grout was injected into the back of the slot. The twisted steel reinforcing bars were inserted into the slots by pushing them, and then the slots were filled with grout as shown in Figure 4.6. Diagonal-compression tests for investigating the in-plane mechanical characteristics of masonry walls were conducted in the related literature [4.33].

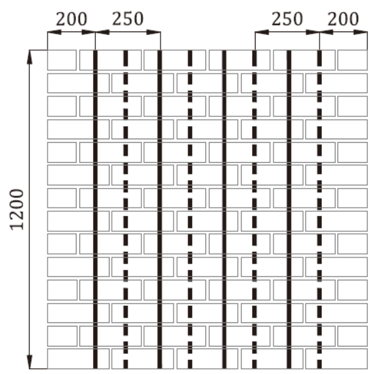


Figure 4.6 Twisted Steel Bars (4.3.2(3)) [4.33]

4.3.3 Coring and Grouting

(1) Center Core

The center core system consists of a reinforced, filled core placed in the center of an existing URM wall. Reinforcing bars are anchored to the roof and foundation. The filler material itself consists of a binder material (e.g. epoxy, cement, and polyester) and a filler material (e.g. sand). However, improvement in shear resistance in the case of using epoxy and polyester with sand is more than cement grout while the energy dissipation during loading is limited [4.9]. Retrofitted structures resist both in-plane and out-of-plane loadings, and in a static cyclic test, its ultimate load resistance may be doubled [4.12].

Experiments showed that the ductility and out-of-plane behavior of the wall retrofitted with this technique was improved [4.34].

4.3.4 Post Tensioning to Wall

(1) Post Tensioning

In this method, a low level pre-compression was applied using a single mechanically restrained tendon inserted into a cavity at the centre of the walls as shown in Figure 4.2(d). The flexural testing for investigating the out-of-plane mechanical characteristics of masonry walls was conducted in the related literature [4.35].

In other study, vertical and diagonal rebars were placed on the outside of the walls between the concrete floor and ceiling slabs of the masonry test house. And post-tension was applied to the rebars. Horizontal loading tests to the ceiling slab for investigating the in-plane mechanical characteristics of masonry walls were conducted in the study [4.36].

(2) Post Tensioned Cables

In this method, cables consist of prestressed strands of high-tension steel protected from corrosion by grouted steel tubes. The diagonal cables are applied like a bracing system of a steel structure, and are anchored at the foundation and roof. Special mats are made for the anchoring cables at the roof and foundation [4.37].

Adding cables as a tensile element to walls makes them ductile and able to dissipate higher seismic energy. Experiments showed that this method can improve the lateral strength of URM wall by a factor of 2 [4.38].

(3) Post-Tensioning Using Rubber Tyres

In this method, released compressive force from the stretched rubber produces the post tensioning effect on URM walls. Scrap rubber tyres assembled by wooden and metal connectors are used. Experiments showed that this technique improves the ductility of walls and prevents its sudden collapse caused by an earthquake. However, the efficiency of this method depends on the direction of reinforcement. Using horizontal and vertical reinforcements causes increase in failure acceleration by 70% and 40%, respectively. And application of them in both directions causes 110-120% increase in failure acceleration [4.39].

4.3.5 Confinement

In this method, tie columns confine the URM wall at corners, intersections, and the border of openings. In some countries like China and Iran, this method applies to new masonry construction as the confined masonry structure [4.40]. However, because of the minor effects of using columns alone for the confinement of walls, it is necessary to apply a horizontal element like a beam to the system. This method improves the ductility and energy dissipation of a masonry structure. Also it improves the structural integrity of URM considerably. The intensity of this improvement depends on the relative rigidity between the masonry and the surrounding frame and also material properties [4.9, 4.12].

4.3.6 Base Isolation

In this method, URM building is isolated from ground excitation by using isolators. Sometimes because of the structural weakness of a superstructure or its historical value, it is impossible to retrofit it by other methods and base isolation can be considered as a proper solution. However, the process of a base isolation technique can be very difficult.

At first, loads carried by a superstructure must be transmitted gradually to the temporary supports. Then by casting needle-beams under masonry walls and installing some under the beams, loads can be transmitted to the foundation or base [4.41].

There are some base isolators that are being used nowadays, but applying these systems to URM structures is unreasonable especially in developing countries. Among the base isolators, friction seismic isolation (FSI) is the most suitable method for masonry structures. In the FSI technique there is no need for any spring or complicated device [4.42].

4.4 Comparison of the Retrofit Techniques Effects

In this research, investigations on the effects of some proposed retrofit techniques were conducted using the results of 8 diagonal compression tests [4.16, 4.17, 4.22, 4.33, 4.43, 4.44, 4.45, 4.46], 12 in-plane loading tests [4.8, 4.11, 4.13, 4.15, 4.18, 4.28, 4.31, 4.32, 4.36, 4.38, 4.47, 4.48] and 6 out-of-plane loading tests [4.29, 4.35, 4.44, 4.47, 4.49, 4.50] for masonry walls. Two indices of R_S and R_D were used for comparing the reinforcement effects derived from those 26 experimental results.

Strength increasing ratio, R_S is calculated from the following equation (4.1).

$$R_S = \frac{F_r}{F_{ur}} \qquad (4.1)$$

where F_r is the maximum strength (Table 4.1) of the reinforced specimen and F_{ur} is the maximum strength of the unreinforced specimen.

In case of cyclic loading test, if the maximum strengths exist in two (plus and minus) directions [4.15], average of absolute value of the maximum strength in each direction is applied to equation (4.1).

Deformation capacity increasing ratio, R_D is calculated from the following equation (4.2).

$$R_D = \frac{D_r}{D_{ur}} \qquad (4.2)$$

where D_r is the drift angle (Table 4.1 & Figure 4.7) of the reinforced specimen at that point in time when the strength becomes to 80% of the maximum after the strength reaches the maximum, and D_{ur} is the drift angle of the unreinforced specimen at the above point in time.

If the strength does not decrease to 80% of the maximum, the maximum drift angle given in the loading test is applied to equation (4.2).

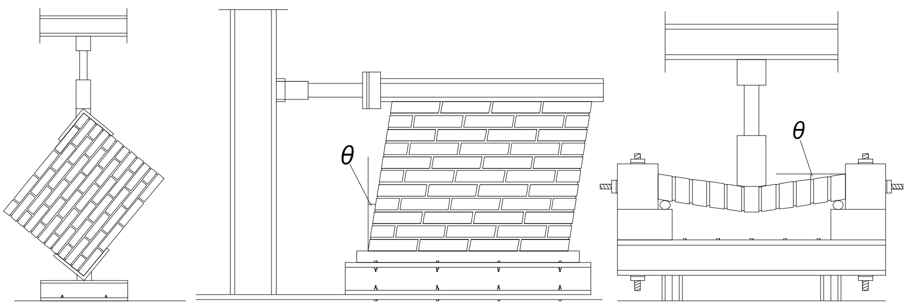
R_S and R_D derived from the above mentioned 26 experimental results are shown in Figure 4.8-4.10. Each line in the figures has connected the maximum and the minimum of the experimental results in references, and shows the range of the value of R_S or R_D expected by the reinforcement. In cases where the experimental results are shown by the graph in references, both of R_S and R_D can be calculated, but only R_S can be calculated in cases where only the maximum strengths are shown in references. About the asterisk (*) of PP Meshing, the meshing embedded in a cement layer cover was used in the in-plane loading test.

Generally, in-plane strength of URM wall is larger than out-of-plane strength of it. Therefore, the phenomenon, in which only R_S or R_D derived from out-of-plane loading tests are extremely large, is expected. However, as shown in Figure 4.8-4.10, the value of R_S or R_D is more greatly affected by the kind of the reinforcing method than the kind of loading test.

Moreover, the significant difference of R_S or R_D was observed by the difference of reinforcing material, even if the same fixing method of reinforcement was applied.

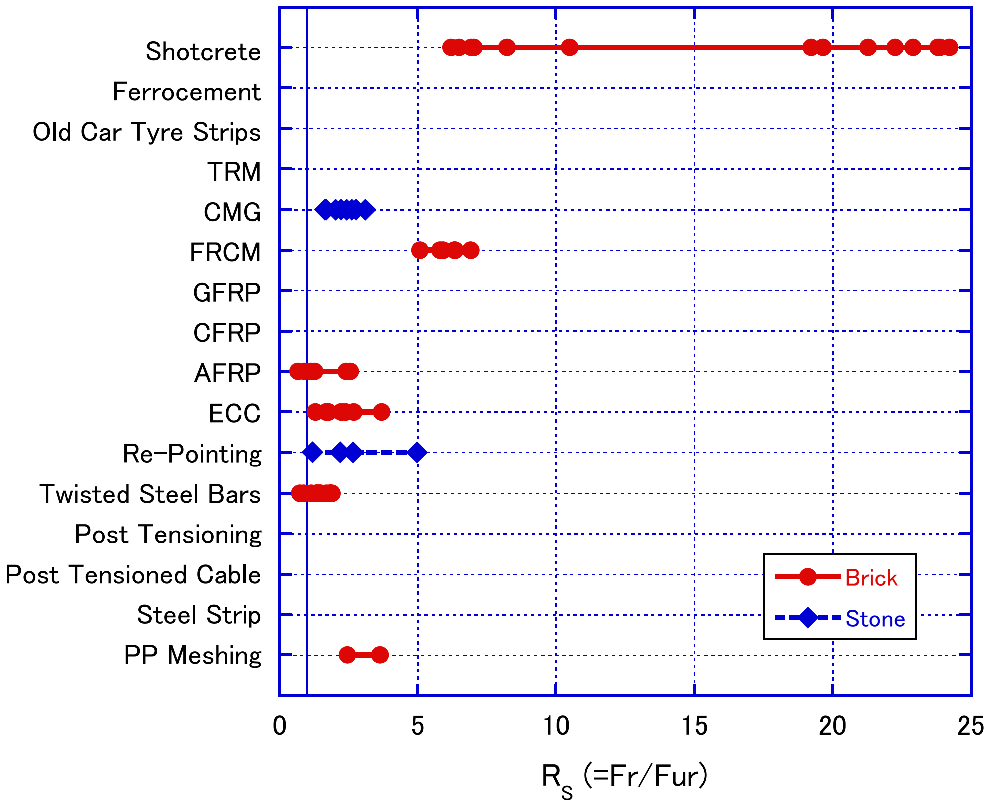
Table 4.1 Definition of Maximum Strength and Drift Angle

		Maximum Strength (N/mm^2)	Drift Angle θ (rad.)
Diagonal Compression Test			$\dfrac{\left(\text{Displacement in Diagonal Direction}\right)}{\left(\text{Length in Diagonal Direction}\right)}$
In-plane Horizontal Loading Test	Monotonic	$\dfrac{\left(\text{Maximum Load in Bed Joint Direction}\right)}{\left(\text{Sectional Area in Bed Joint Direction}\right)}$	$\dfrac{\left(\text{Displacement in Horizontal Direction}\right)}{\left(\text{Height of Loading Point}\right)}$
	Cyclic		
Out-of-plane Horizontal Loading Test	Monotonic		$\dfrac{\left(\text{Out of plane Displacement}\right)}{\left(\text{Half of Wall Height}\right)}$
	Cyclic		

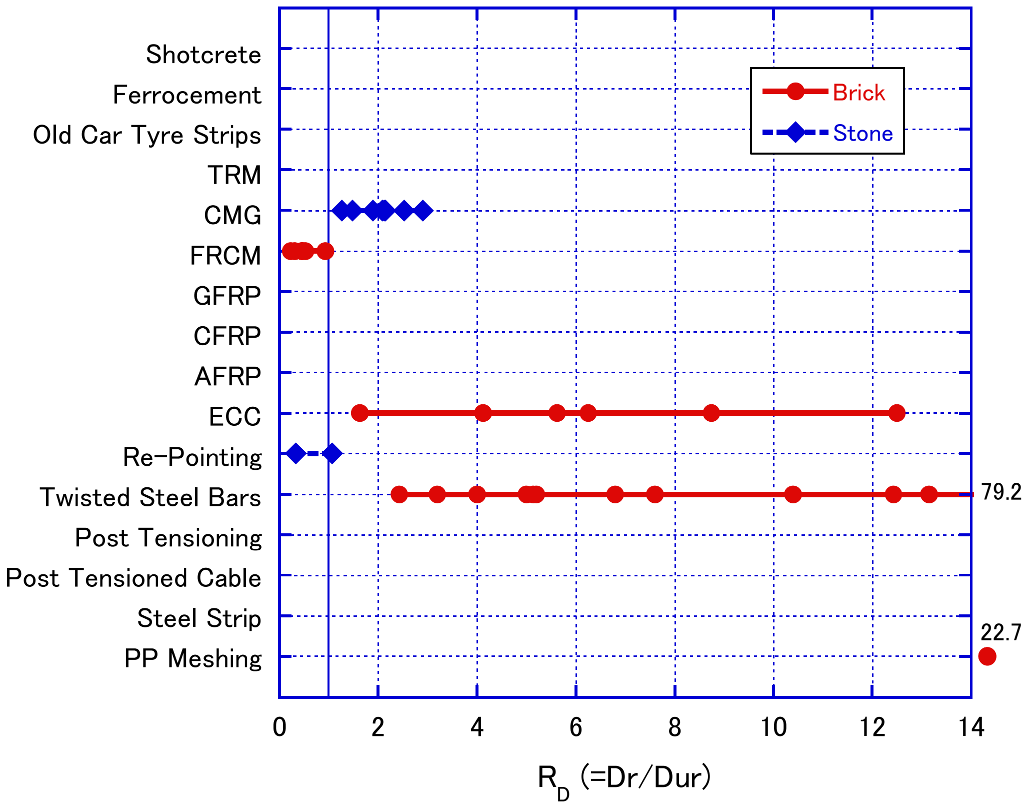


(a)Diagonal Compression Test (b)In-Plane Loading/Cyclic Test (c)Out-of-Plane Loading/Cyclic Test

Figure 4.7 Kinds of Loading Tests and Drift Angle θ

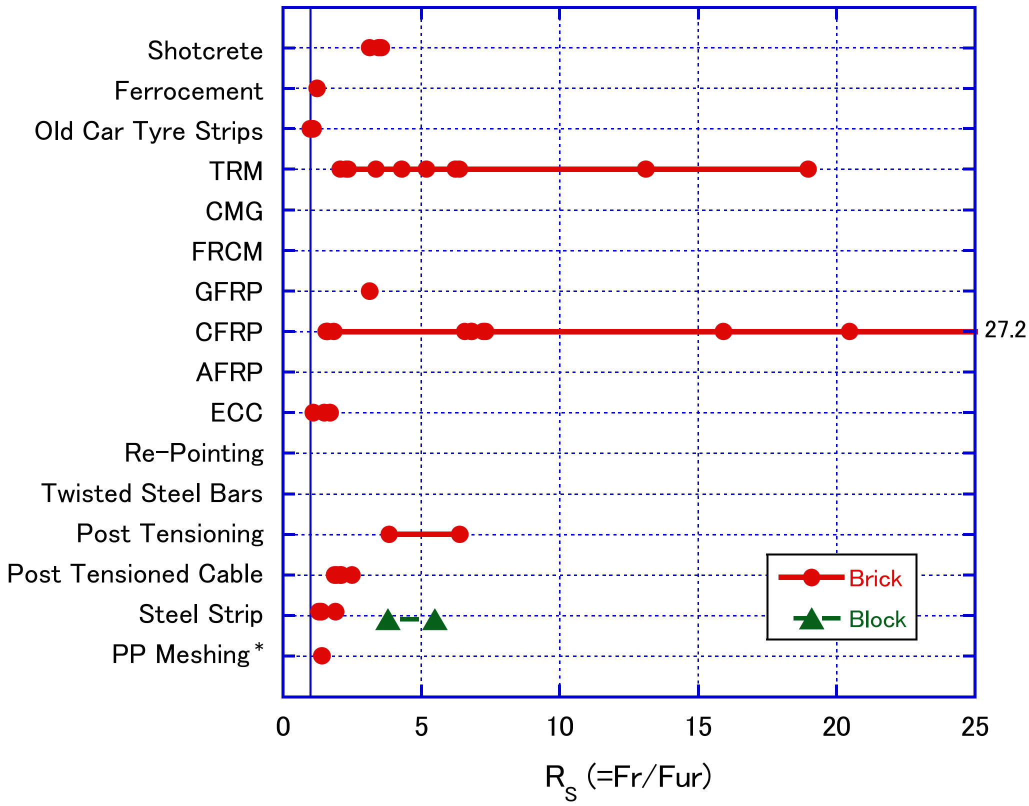


(a) Strength Increasing Ratio, R_S

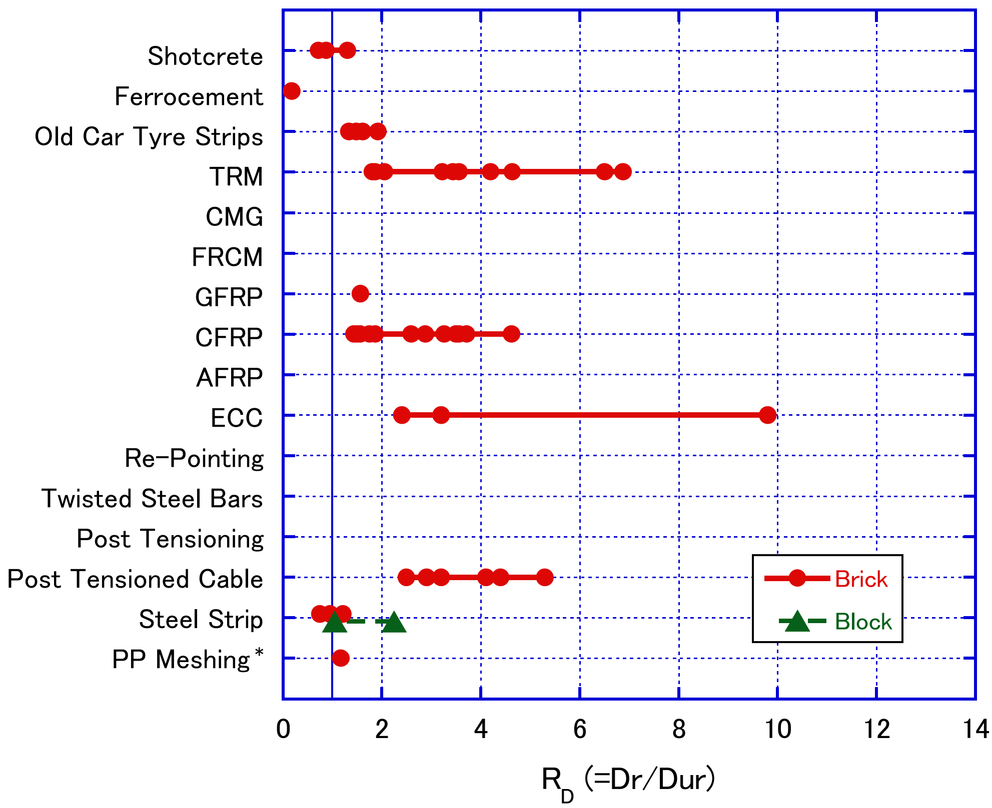


(b) Deformation Capacity Increasing Ratio, R_D

Figure 4.8 R_S and R_D Derived from the Diagonal Compression Tests

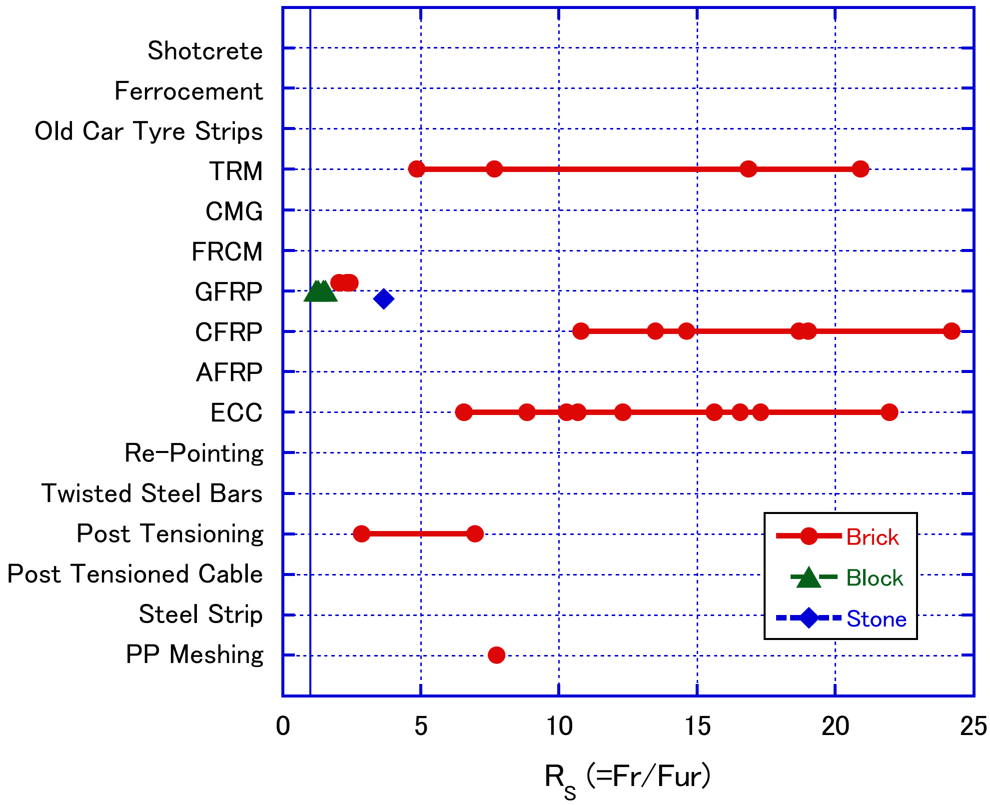


(a) Strength Increasing Ratio, R_S

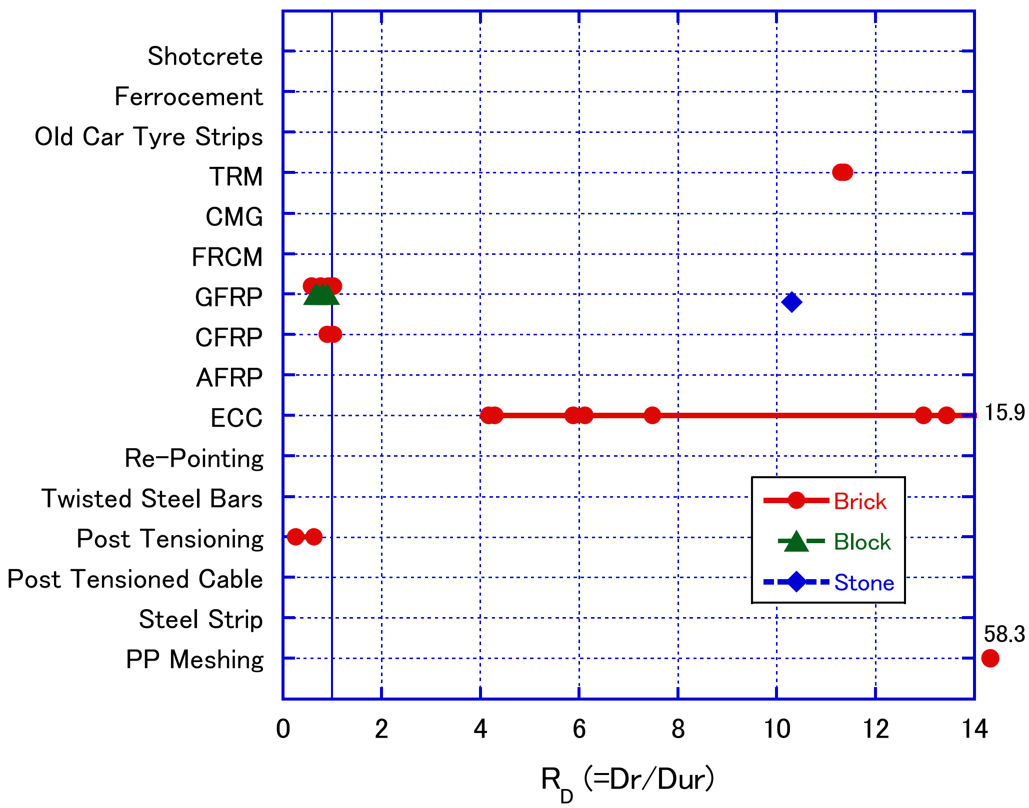


(b) Deformation Capacity Increasing Ratio, R_D

Figure 4.9 R_S and R_D Derived from the In-plane Loading Tests



(a) Strength Increasing Ratio, R_S



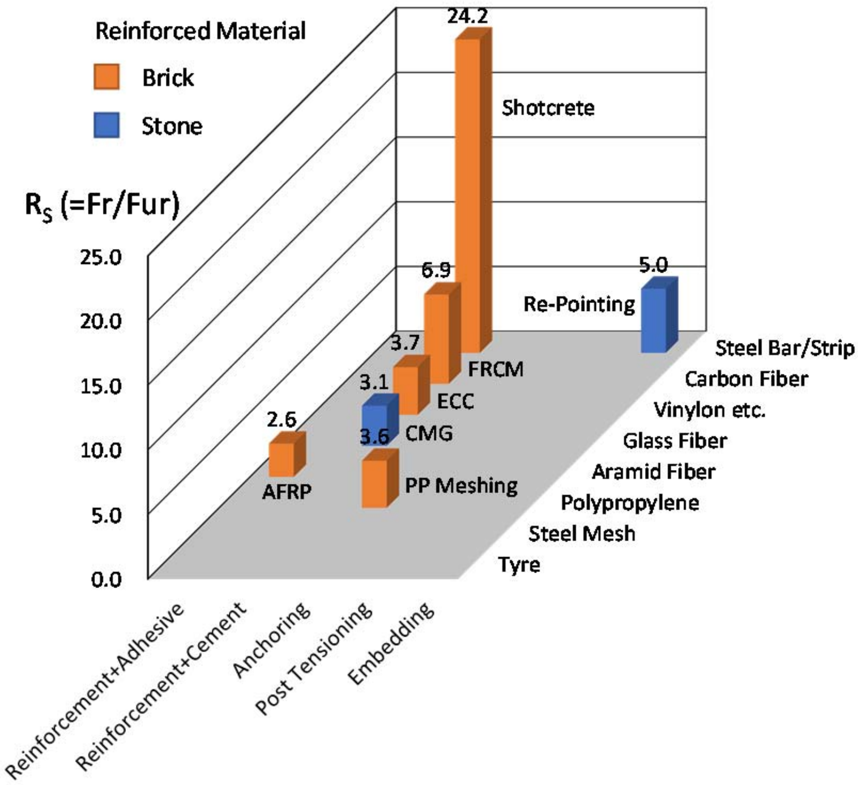
(b) Deformation Capacity Increasing Ratio, R_D

Figure 4.10 R_S and R_D Derived from the Out-of-plane Loading Tests

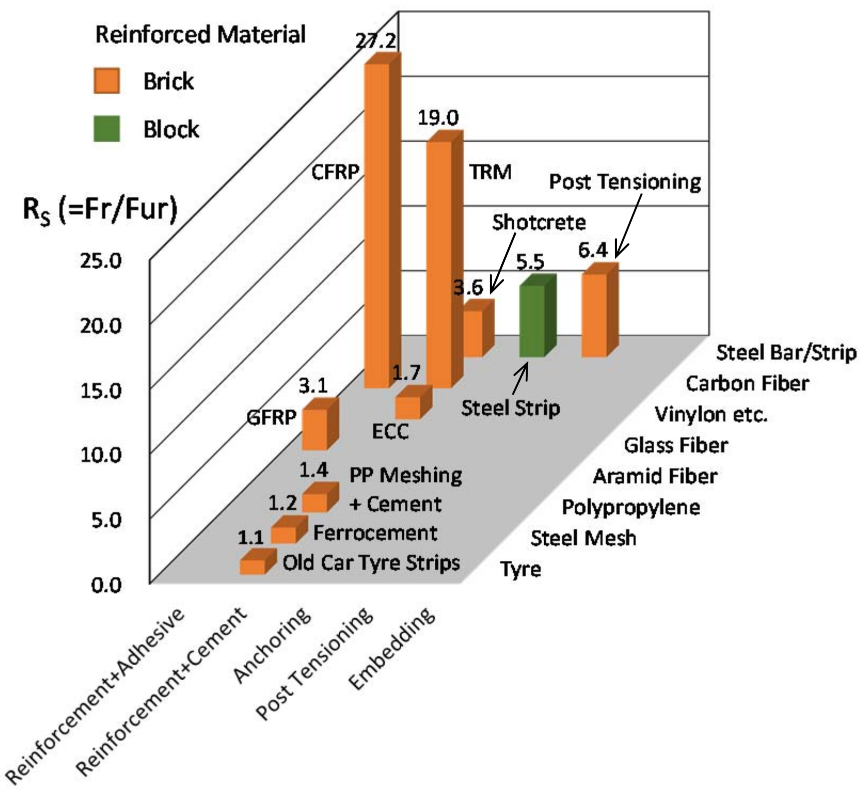
About the retrofitting techniques in Figure 4.1(b), the result of having arranged the reinforcing material on the vertical axis and having arranged the reinforcing method on the horizontal axis is shown in Table 4.2. Moreover, Figure 4.11 shows the matrix of Table 4.2 on the level surface (x-y plane) and the value of R_S on it (in the direction of z) for every kind of loading test. In this figure, the maximum of R_S is shown in the vertical axis among the results of the specimens reinforced with the material and method shown in the matrix of level 2 axes. The rows and columns of the matrix are changed to large order of R_S in order to make the degree of effects easy to understand, and to make a target easy to check in cases where the same technique is improved. About the specimens reinforced by PP Meshing, before the maximum load was measured, load once decreased during the loading in the diagonal compression test and the out-of-plane loading test. Such figures are useful for understanding the range and order of the reinforcement effect approximately, and for motivating the researchers and engineers in the world to develop the reinforcing method with a higher effect.

Table 4.2 Matrix of Retrofitting Techniques for URM Structure

Methods / Materials			Surface Applications 1. with Cement	Surface Applications 2. with Adhesive	3. Embedding	4. Anchoring / 5. Post Tensioning
A. Organic Materials			(Reinforcement)+(Cement)	(Reinforcement)+(Adhesive)		
A. Organic Materials		Bamboo	Bamboo reinforcement			
A. Organic Materials		Cotton		Cotton Canvas Sheets		
B. Inorganic Materials		Steel Bar/Strip	Shotcrete		(Reinforcement)+(Cement/Adheseve) Re-Pointing Twisted Steel Bars	Steel Strip Post Tensioning Post Tensioning Post Tensioned Cable
B. Inorganic Materials		Steel Mesh	Ferrocement			
C. High Polymer Materials		Tyre	Old Car Tyre Strips			Post Tensioning Using Rubber Tyres
C. High Polymer Materials	Polymer Fiber	Vinylon etc.	ECC			
C. High Polymer Materials	Polymer Fiber	Polypropylene	PP Meshing (FRP)+(Cement)	(FRP)+(Adhesive)		PP Meshing
C. High Polymer Materials	Polymer Fiber	Glass Fiber	CMG	GFRP GGRP Hybrid Textile		
C. High Polymer Materials	Polymer Fiber	Aramid Fiber		AFRP	Re-Pointing	
C. High Polymer Materials	Polymer Fiber	Carbon Fiber	TRM FRCM	CFRP		

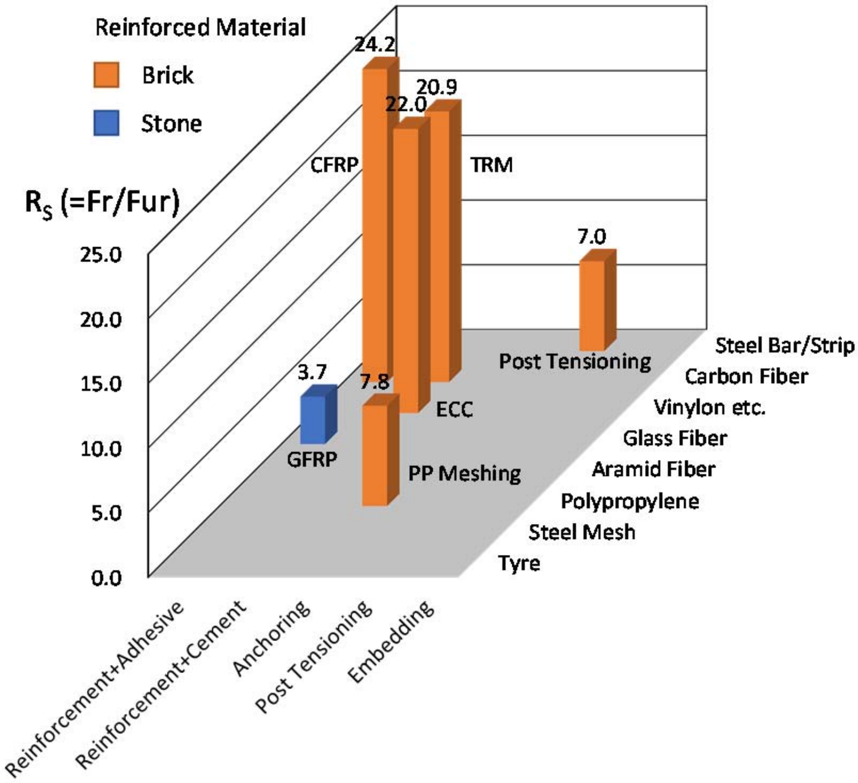


(a) Results of the Diagonal Compression Tests



(b) Results of the In-plane Loading Tests

Figure 4.11 The maximum of R_S about Each Retrofitting Techniques



(c) Results of the Out-of-plane Loading Tests

Figure 4.11 The maximum of R_S about Each Retrofitting Techniques (Continued)

4.5 Gathering and Sharing of Research Information

A list of the data extracted from each literature in this research is shown in Table 4.3. It is desirable that each technique of these data is assembled into the technical examples for users such as ones in the appendix to this chapter. The category of each technique is shown in each sheet of the appendix using the signs (A-C and 1-5) shown in Table 4.2. As the experimental

Table 4.3 List of the Data Extracted from Literature

Information of Experiment	Retrofitting Method
	Kind of Loading Test
Information of Specimen	Name of Specimen
	Size of Specimen
	Specifications of Strengthening
Result of Experiment	Load or Strength
	Displacement or Strain
	R_S (=Fr/Fur)
	R_D (=Dr/Dur)
Information of Literature	Title of Literature
	First Author

data about R_S, R_D, etc. around the world is accumulated like a database, it is expected that the database can be more useful as data for examining the retrofitting method to be used. And disclosing effect comparisons of retrofitting techniques such as Figure 4.11 will advance collection of newer and more reliable technical information. In order to improve the safety of URM structures for earthquake, such a collecting and sharing system of research information about retrofitting of URM should be constructed and utilized.

4.6 Conclusion

In this chapter, the existing URM retrofit strategies and techniques were introduced. And the effects of the retrofitting techniques of URM were also compared. In addition, the importance of constructing and utilizing a collecting and sharing system of research information about retrofitting of URM was described.

As a result of this chapter, figures comparing the effects of the retrofitting techniques were shown. They are useful for understanding the range and order of the reinforcement effect approximately. And disclosing effect comparisons of retrofitting techniques like the figures will advance collection of newer and more reliable technical information. Also, it is desirable that each technique of these data is assembled into the technical examples for users such as ones in the appendix to this chapter.

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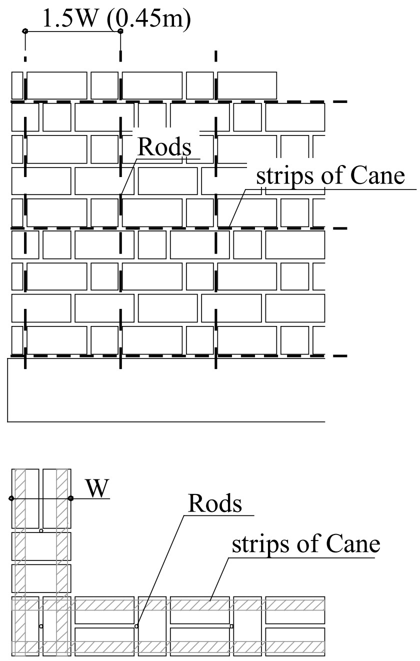
No. 1 Category: A3	Name Cane-reinforced adobe building by Pontificia Universidad Católica del Perú (PUCP)		
Experts' name	PUCP, J. Vargas, M. Blondet	Country	Peru
Method	Superstructure	Wall reinforcement / Buttress /Horizontal stiffened / Core adding/ Unit repair	
	Understructure	Ground improvement / Base isolation	
Material	Applied to	Brick / Stone / Hollow block / Adobe /	
	Using	Cane	
Reference	Marcial Blondet, Julio Vargas, Nicola Tarque y José Velásquez :LA TIERRA ARMADA: 35 AÑOS DE INVESTIGACIÓN EN LA PUCP		

Based on some static trials, the most efficient reinforcement was achieved by placing the entire vertical rods inside the walls spaced 1.5 times the thickness of the walls, and tried to strips of crushed cane placed in four rows of mortar (Figure 1, Diagram).

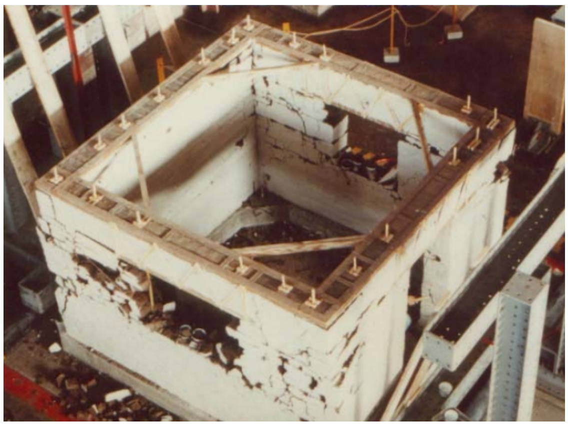
The modules one was unreinforced and the other one reinforced (rod placed horizontally every 0.45m and crushed cane in four courses and upper beam slab of wood) were tested using the vibrating table. Unreinforced building collapse after the separation of the walls at the corner (Figure 2. Left). Reinforced one maintains integrity even with repeated severe earthquakes (Figure 2. Right).

Figure 1. Appearance of reinforcement



Diagram

Unreinforced building



Reinforced building

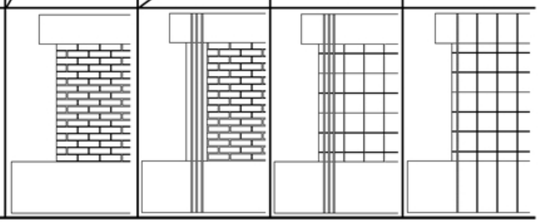
Figure 2. Breakdown pattern

No. 2 Category: C1	Name Seismic retrofit of unreinforced clay brick masonry wall using polymer-cement mortar		
Experts' name	K. Kikuchi, M. Kuroki	Country	Japan
Method	Superstructure	Wall reinforcement / Buttress /Horizontal stiffened / Core adding/ Unit repair	
	Understructure	Ground improvement / Base isolation	
Material	Applied to	Brick / Stone / Hollow block / Adobe /	
	Using	Polymer-cement mortar (PCM), steel bars	
Reference	K. Kikuchi, M. Kuroki, M. Toyodome, C. Escobar, Y. Nakano : SEISMIC RETROFIT OF UNREINFORCED CLAY BRICK MASONRY WALL USING POLYMER-CEMENT MORTAR		

The study is to investigate the seismic performance of unreinforced masonry (URM) wall retrofitted with reinforced polymer-cement mortar (PCM). Four unreinforced clay brick masonry wall specimens with 100 mm in wall thickness were constructed first, then three of them were retrofitted with PCM applied on one of their surfaces forming a thickness of 40 mm, in which different vertical and horizontal steel bars had been arranged. The specimens were tested under cycle reversal loading method. Test results demonstrate that the application of reinforced PCM wall provides higher lateral load carrying capacity to URM wall, and also different failure modes were observed in three retrofit wall specimens.

Figure 1 Construction of reinforced PCM wall

Table 1 List of test specimens

Specimen		No.1	No.2	No.3	No.4
Details of Reinforced PCM walls	wall thickness (mm)		40	40	40
	Flexural reinforcing bars		3-D13 (#4)	3-D13 (#4)	1-D10 (#3)
	Vertical steel bars			D6 (#2) @200 (Not anchored)	D6 (#2) @200 (Anchored)
	Horizontal steel bars			D6 (#2) @200	D6 (#2) @200
Elevation					

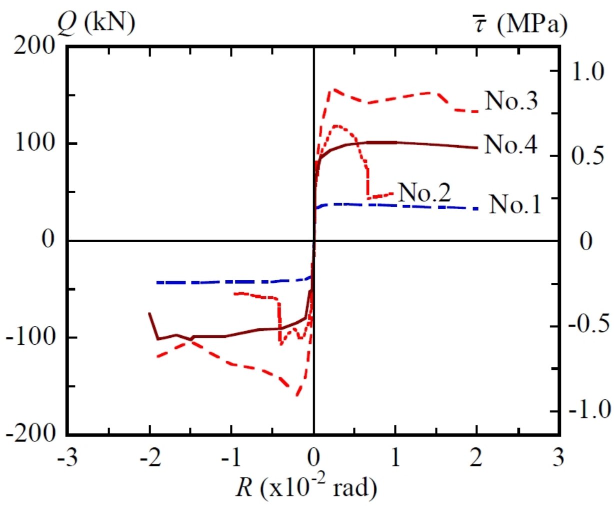


Figure 2 *Q-R* envelop curves for all test specimens

Table 2 Increasing ratio of strength and deformation capacity
$R_S=F_{RM}/F_{URM}$, $R_D=D_{RM}/D_{URM}$

		F: Strength	D: Deformation Capacity (0.8F)
1	URM	35 kN *	0.03×10^{-2} rad *
No.2	RM	112 kN	0.48×10^{-2} Rad
	Ratio	$R_S = 3.2$	$R_D = 16.0$
No.3	RM	158 kN	1.50×10^{-2} Rad **
	Ratio	$R_S = 4.5$	$R_D = 50.0$
No.4	RM	102 kN	1.99×10^{-2} Rad **
	Ratio	$R_S = 2.9$	$R_D = 66.3$

* The value at flexural cracking is used for URM.
** The maximum deformation in a positive direction is used for calculation of average value because the value at 0.8F is larger than final loading.

Chapter 5 Seismic Structural Designing Methods of Masonry Buildings

5.1 Introduction

Most of the loss of life in past earthquakes has occurred due to the collapse of buildings, constructed in traditional materials like stone, brick and adobe, which were not particularly engineered to be earthquake resistant. In view of the continued use of such buildings in most countries of the world, it is essential to introduce earthquake resistance features in their design and construction.

Some countries have technical knowledge and construction standard for masonry structures, such as AIJ Standard [5.1] [5.2] in Japan, International Building Code (IBC) [5.3] [5.4] in the United States, and Eurocode [5.5] ~ [5.10] in EU. And another example is that World Housing Encyclopedia has published some tutorials for masonry structures [5.11] [5.12].

Each text has different contents because they have been defined by their own countries background. For the reasons, the aim of this chapter is to introduce the contents of these texts and give a reference page on website.

5.2 Commentary on AIJ Standard for Structural Design of Unreinforced Masonry Structures (1989 Edition)

5.2.1 Articles 1 and 2. Classification of unreinforced masonry structures

Masonry structures presented in this Standard are unreinforced masonry structures for which steel reinforcing bar is not provided in masonry structural elements. The masonry structures are composed of masonry units such as clay bricks, natural stones and concrete blocks which are laid and jointed each other by using joint mortar, and these are designated as clay masonry, stone masonry and concrete block masonry, according to the adopted masonry units. In addition, those masonries are classified into two classes, Class 1 and Class 2, depending on the compressive strengths of the adopted masonry units. Unreinforced masonry structures composed of the masonry units with compressive strengths of not less than 6.0MPa are classified as Class 1, and those of not less than 10.0MPa are as Class 2. As described later, the scale of structures and wall thickness are decided depending on this classification. As for concrete block masonry structures, both of the hollow concrete blocks and solid concrete blocks may be used, but only solid concrete block units shall be used for Class 2 masonry structures.

5.2.2 Articles 3 through 6, and 10 through 12. Brief description of structures

Unreinforced masonry structures are included in box type wall structures, and the first layer of the lowermost masonry walls is laid on the cast-in-place reinforced concrete (RC) footing beams which are connected each other. On the top of the masonry walls of each story, cast-in-place RC collar beams are provided continuously. Accordingly, all the top and bottom of the masonry walls of unreinforced masonry structures are reinforced with cast-in-place RC beams or girders. When RC cast-in-place floor slabs are provided, however, RC collar beams need not be provided, in one-story buildings. All the floor slabs including roof-floor slabs shall be constructed with cast-in-place RC slabs or rigidly assembled precast RC slabs, except for lowermost floor slabs and roof-floor slabs. When soil condition in construction site is not firm, it is recommended that the lowermost floor slabs be constructed with RC floor slabs. In the present Standard, requirements for geometries of buildings such as maximum total height and story height, arrangement and thickness of bearing walls, and total width of openings of the bearing walls are specified.

Because masonry walls of unreinforced masonry structures are not expected to resist higher tensile and shear stresses, these walls shall be designed very carefully against earthquake loading. Considering the obtained data of earthquake damages in the past, the followings are important subjects in designing unreinforced masonry structures:

(1) This system is not suitable for large scale buildings with wide floor areas.

(2) The building shall have well balanced shape in elevation, and the bearing walls shall be arranged in good balance in plan so as to distribute stress uniformly to bearing walls.

(3) Bearing walls shall be designed so as to make the tensile and shear stresses in walls as small as possible. For instance, it is recommended to select the appropriate combination of height and horizontal length of the bearing walls, and total width of openings of the bearing walls.

(4) During an earthquake, cracking and failures are expected not only at wall-edges and wall-to-wall connections, but also out-of-plane turnover at high gables. Therefore, wall-edges and wall-to-wall connections shall be designed to be rigid and firm, and high gables should be reinforced with collar beams and/or RC roof-slabs to prevent turnover.

(5) In order to prevent buildings from differential settlement, footing beams with high strength and rigidity should be provided.

5.2.3 Article 3. Maximum height of masonry structures

Total height of Class 1 buildings is limited up to 6 meters. When the thickness of bearing wall is more than 1.2 times or more as large as the minimum required thickness specified in Article 5, however, buildings with height up to 9 meters may be constructed. In case of Class 2 buildings, total height is limited up to 9 meters. When buildings with light roof trusses and RC roof slabs, the height of roof and eaves up to 9 and 6 meters may be permitted for Class 1 masonry, and 13 and 9 meters for Class 2 masonry (for Class 1 masonry with wall thickness of 1.2 times as much as minimum requirement). The story height of masonries of all classes is limited up to 3 meters.

5.2.4 Article 4. Arrangement of walls

Bearing walls of masonry buildings are required to resist in-plane shear forces due to earthquakes as well as gravity loads. The walls shall be provided as in good balance as possible all over the building plan. When the eccentricity between center of gravity and center of rigidity is large in distance, torsional displacement around the center of rigidity is expected during an earthquake, and walls located far from the center of rigidity may be subjected to unexpected larger stresses (see Figure 5.1). On the other hand, when a building have small eccentricity, but distance between two adjacent walls is large, in-plane lateral shear forces in floor slabs are not expected to transfer smoothly to all the walls. For this reason, minimum requirement for divided floor area is specified in this Article, where definition of the "divided floor area" is a floor area enclosed by the central lines of the horizontal cross-section of surrounding walls (see Figure 5.2). This requirement is introduced to distribute bearing walls uniformly all over the building. Maximum values for divided floor area are specified for the classes of buildings, and are given in Table 3 in Article 4. The maximum length of walls between adjacent parallel walls is limited up to 10 meters (this wall length includes widths of openings), where "adjacent parallel walls" are defined as two bearing walls parallel to each other which are connected perpendicularly to the bearing wall under consideration. If the wall-length between adjacent parallel walls is large, the out-of-plane flexural resistance and the torsional resistance of the wall are expected to be small. This requirement is for providing the wall higher resistance against out-of-plane flexure and torsion during an earthquake.

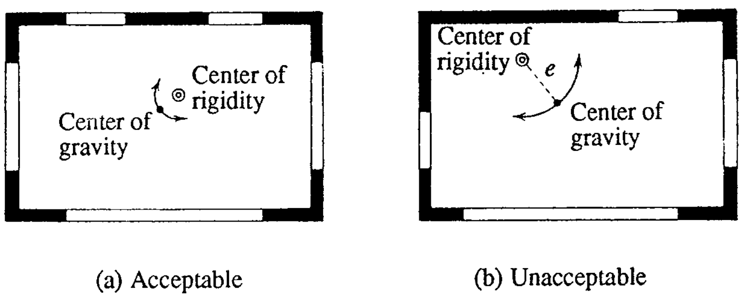


Figure 5.1. Arrangement of walls relating to danger of torsional vibration

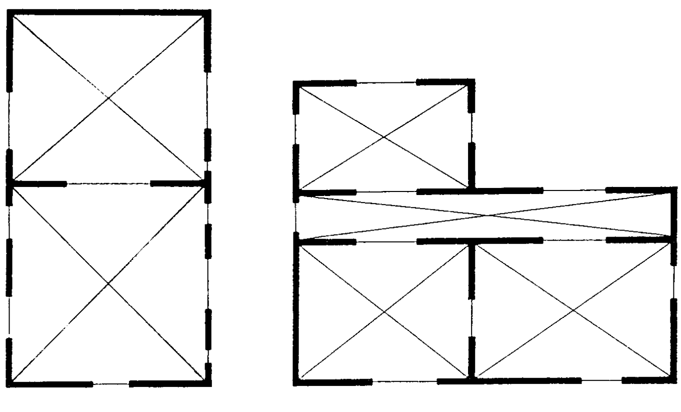


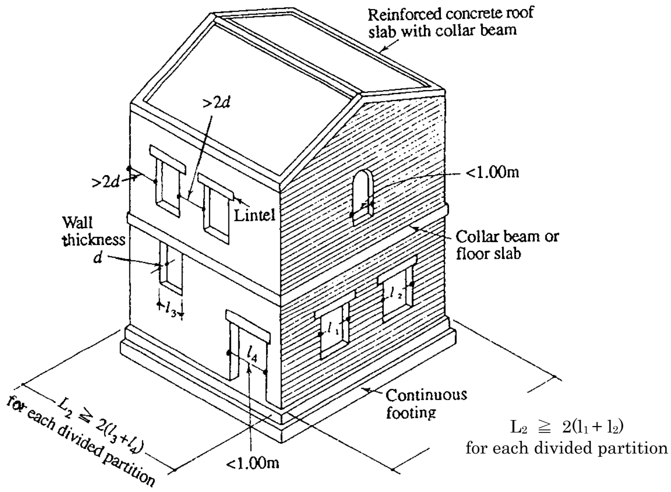
Figure 5.2. Divided floor areas

5.2.5 Article 5. Thickness of walls

Thickness of bearing walls shall not be less than 20 cm, and the required minimum thickness of the wall is depending on the type of walls such as exterior or partition walls, number of story, location of wall along the stories and length of each wall. Specified values of wall thickness are given in Table 4 in Article 5. In case of a wall with longer length or supporting more stories, required thickness will be larger. For example, bearing walls of more than two-story building and more than 5 meters long shall be designed to be 40 cm or thicker.

5.2.6 Article 6. Openings of walls

Masonry buildings with larger amount of bearing walls are more seismic resistant than those with less wall amount. The total width of openings of bearing walls is limited. Figure 5.3 shows this limitation by an illustrative example.



Total length of walls ≧ 2 times of total width of openings

Figure 5.3. Limitation of total width of openings

5.2.7 Article 7. Reinforcement for upper part of openings

Masonry walls located at the upper part of openings are required to be supported by RC lintels. In case of an opening less than 1 meter wide, masonry arch members may be adopted to support the wall above the opening. In this case, however, it is recommended that the distance between the edge of opening and extreme edge of the wall (“e“ in Figure 5.4) shall not be less than the specified lengths which are twice of wall thickness and 60 cm, because collapse of the arch is expected if the distance (e) is small.

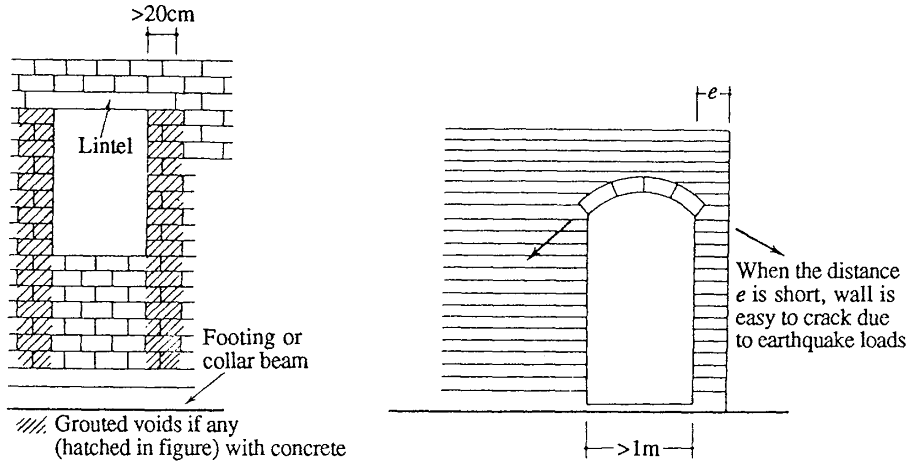


Figure 5.4. Reinforcement of upper part of openings

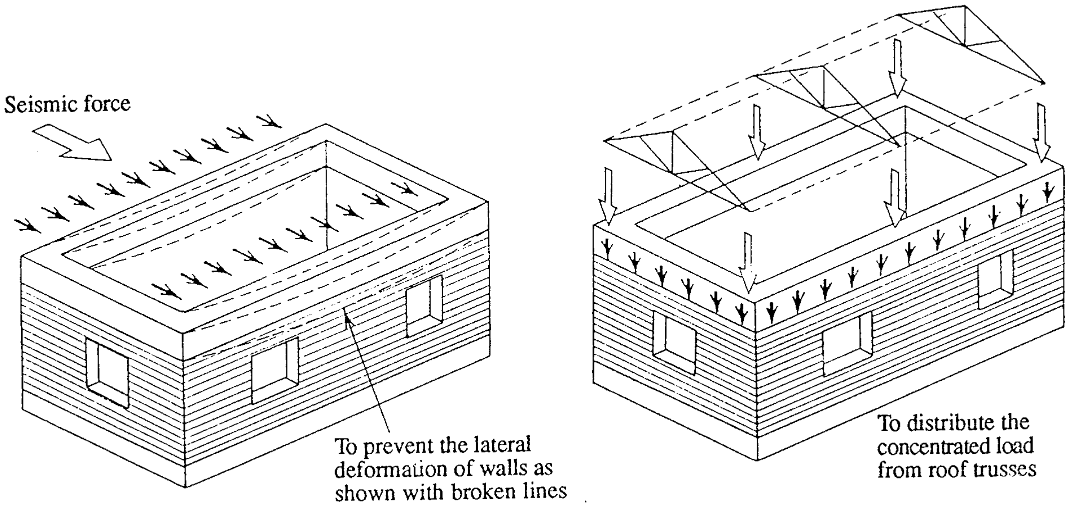
5.2.8 Article 11. Collar beams

Structural role of collar beams is to connect the top of bearing walls each other. It is recommended that the bearing walls are arranged in good balance in plan in both longitudinal and transverse directions. Accordingly, the collar beams are also provided so as to divide the building plan orderly in both of the longitudinal and transverse directions. When there is no bearing wall below the level of the collar-beams, collar beams connect the top of bearing walls each other. In such a case, the collar beam shall be designed as an ordinary RC beam. Collar beams shall be provided along the wall-lines which determine divided floor area described in Article 4.

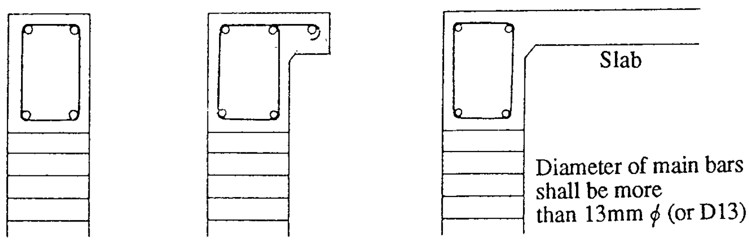
The depth of the collar beam shall not be less than 1.5 times as much as the wall-thickness, nor less than 30 cm. In one-story building without RC roof-floor slab, effective width of the collar beams shall be equal to or more than 1/20 of the distance between center lines of adjacent parallel walls. This requirement is to prevent the walls from turnover in out-of-plane direction. The effective width required for collar beams is presented in Figure 1 in Article 4. The role of the collar beams of one-story building and an example of reinforcing details are illustrated in Figure 5.5.

5.2.9 Article 13. Masonry garden walls and fences

Masonry units of masonry garden walls and fences are required to be connected each other by using metal pieces, or masonry fences shall be reinforced with steel reinforcing bars in both horizontal and vertical directions, because turnover in out-of-plane direction is expected during an earthquake. Accordingly, unreinforced masonry fences are not permitted to be constructed.



(a) Function of collar beams of one-story building without roof slabs



(b) Details of collar beam section

Figure 5.5. Collar beams in one-story building

5.2.10 Article 14. Construction works

Construction works of unreinforced masonry structures shall conform to the requirements of JASS7 (Specification for Masonry Work) and Guide for Reinforcement of Concrete and Masonry Wall Structures by AIJ. In addition, several items to be emphasized in masonry works are stated in this Article, concerning laying up masonry units, joint mortar bedding and bond patterns, etc.

5.3 International Building Code (IBC)

The IBC is a model building code developed by the International Code Council (ICC). It has been adopted throughout most of the United States. IBC consists of 35 Chapters and Chapter 21 gives provisions of Masonry design and construction.

5.3.1 Section 2101: General

Chapter 21 provides comprehensive and practical requirements for masonry construction, based on the latest state of technical knowledge. The provisions address

Section 2102: Definitions and notations
Section 2103: Masonry construction materials
Section 2104: Construction
Section 2105: Quality assurance
Section 2106: Seismic design
Section 2107: Allowable stress design
Section 2108: Strength design of masonry
Section 2109: Empirical design of masonry

The provisions are intended to result in safe and durable masonry.

The design methods listed in the provisions can be categorized into two general design approaches for masonry. The first approach, engineered design, encompasses working stress, prestressed masonry and strength design. The second approach, prescriptive design, includes the empirical design method. Prescriptive design is not needed engineering analysis but permitted only under limited conditions.

5.3.2 Section 2103: Masonry construction materials

Proper selection of materials is essential to produce masonry with adequate strength and durability. This section includes test procedures and criteria for establishing and verifying quality, and requires conformance to ASTM International (ASTM) standards. The standards include requirements for materials, manufacture, physical properties, strength, absorption, minimum dimensions and permissible variation, inspection, testing and rejection. This section addresses

2103.1 Concrete masonry units
2103.2 Clay or shale masonry units
2103.3 AAC (Autoclaved aerated concrete) masonry
2103.4 Stone masonry units (marble, limestone, granite, sandstone, slate)
2103.9 Mortar

5.3.3 Section 2104: Construction

This section establishes the requirements, based on accepted practice and referenced standards, regulating materials and construction methods used in engineered and empirically designed masonry construction. This section addresses

2104.1 Masonry construction

2104.1.1 Tolerances

2104.1.2 Placing mortar and units

2104.1.3 Installation of wall ties

2104.1.4 Chases and recesses

2104.1.5 Lintels

2104.1.6 Support of wood

2104.2 Corbeled masonry

2104.3 Cold weather construction

2104.4 Hot weather construction

5.3.4 Section 2105: Quality Assurance

This section requires to comply with the inspection and testing requirements of Chapter 17, which references the quality assurance provisions in the MSJC (the Masonry Standards Joint Committee) Code [5.13] and Specification.

The quality assurance provisions emphasize verification of masonry compressive strengths. This is accomplished by comparing conservatively estimated strengths (based on unit strength and mortar type) or tested prism strengths to the specified compressive strength of the masonry. For example, the compressive strength of clay masonry shall be determined based on the strength of the units and the type of mortar as below.

Table 5.1. Compressive strength of clay masonry (Table 2105.2.2.1.1)

Net area compressive strength of clay masonry units (MPa)		Net area compressive strength of clay masonry (MPa)
Type M or S mortar*	Type N mortar*	
11.71	14.47	6.89
23.08	28.59	10.34
34.11	42.72	13.78
45.47	56.84	17.23
56.84	70.97	20.67
68.21	-	24.12
79.24	-	27.56

*type of mortar is defined by ASTM Specification C-270

5.3.5 Section 2106: Seismic design

This section requires the use of the MSJC Code for specific seismic design criteria. Requirements established for various seismic risk categories are cumulative from lower to higher categories. These prescriptive and design-oriented provisions have been established to improve the performance of masonry structures during seismic events by providing additional structural strength, ductility and stability against the dynamic effects of earthquake ground motion.

More information on seismic design is contained in the commentaries to ASCE 7-10 [5.14] and the 2009 National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA P-750) [5.15].

5.3.6 Section 2107: Allowable stress design

This section, Allowable stress design method refers to Chapter 8 of the MSJC Code.

For allowable stress design, linear elastic materials following Hooke's Law are assumed, that is, deformations (strains) are linearly proportional to the loads (stresses). All materials are assumed to be homogeneous and isotropic, and sections that are plane before bending remain plane after bending. The allowable stresses are fractions of the specified compressive strength, resulting in conservative factors of safety.

5.3.7 Section 2108: Strength design of masonry

This section, Strength design method refers to Chapter 9 of the MSJC Code.

Strength design methodology, in which internal forces resulting from application of factored loads must not exceed design strength (nominal member strength reduced by a strength reduction factor φ).

Materials are assumed to be homogenous, isotropic, and exhibit nonlinear behavior. Under loads that exceed service levels, nonlinear material behavior, cracking, and reinforcing bar slip invalidate the assumption regarding the linearity of the stress-strain relation for masonry, grout, and reinforcing steel. If nonlinear behavior is modeled, however, nominal strength can be accurately predicted.

Additionally, masonry designed by this method must be inspected during construction in accordance with the special inspection provisions.

5.3.8 Section 2109: Empirical design of masonry

Empirical provisions are design rules developed by experience rather than engineering analysis. This method is based on several premises; gravity loads are reasonably centered on bearing walls; effects of reinforcement are neglected; walls are laid in running bond and buildings have limited height, seismic risk and wind loading. There is a checklist for use of this method on Appendix A of the MSJC Code (Table 5.2).

COMMENTARY

Table CC-A.1.1 — Checklist for use of Appendix A – Empirical Design of Masonry

1.	Risk Category IV structures are not permitted to be designed using Appendix A.
2.	Partitions are not permitted to be designed using Appendix A.
3.	Use of empirical design is limited based on Seismic Design Category, as described in the following table. (see table below) [1] Lap splices are required to be designed and detailed in accordance with the requirements of Chapters 8 or 9.
4.	Use of empirical design is limited based on wind speed at the project site, as described in Code A.1.2.3 and Code Table A.1.1.
5.	If wind uplift on roofs result in net tension, empirical design is not permitted (A.8.3.1).
6.	Loads used in the design of masonry must be listed on the design drawings (1.2.2b).
7.	Details of anchorage to structural frames must be included in the design drawings (1.2.2e).
8.	The design is required to include provisions for volume change (1.2.2h). The design drawings are required to include the locations and sizing of expansion, control, and isolation joints.
9.	If walls are connected to structural frames, the connections and walls are required to be designed to resist the interconnecting forces and to accommodate deflections (4.4). This provision requires a lateral load and uplift analysis for exterior walls that receive wind load and are supported by or are supporting a frame or roofing system.
10.	Masonry not laid in running bond (for example, stack bond masonry) is required to have horizontal reinforcement (4.5).
11.	A project quality assurance plan is required (3.1) with minimum requirements given in Table 3.1.1.
12.	The resultant of gravity loads must be determined and assured to be located within certain limitations for walls and piers (A.1.2.1).
13.	Ensure compliance of the design with prescriptive floor, roof, and wall-to-structural framing anchorage requirements, as well as other anchorage requirements (A.8.3 and A.8.4).
14.	Type N mortar is not permitted for foundation walls (A.6.3.1(g)).
15.	Design shear wall lengths, spacings, and orientations to meet the requirements of Code A.3.1.

Seismic Design Category	Participating Walls	Non-Participating Walls, except partition walls
A	Allowed by Appendix A	Allowed by Appendix A
B	Not Allowed	Allowed by Appendix A
C	Not Allowed	With prescriptive reinforcing per 7.4.3.1[1]
D, E, and F	Not Allowed	Not Allowed

[1] Lap splices are required to be designed and detailed in accordance with the requirements of Chapters 8 or 9.

Table 5.2. Checklist for use of Empirical design method

5.3.8.1 Section 2109.3: Adobe construction

Requirements for adobe construction are a combination of empirical provisions and rudimentary engineering. Since there are no ASTM standards for adobe materials, test methods have been included in the code. Design is based on gross cross-sectional dimensions.

Adobe is classified as below,

Unstabilized adobe: It does not contain stabilizers and is generally not durable.

Stabilized adobe: It is manufactured with stabilizers to increase its durability and decrease its water absorption.

Both types of adobe must meet the following requirements.

2109.3.1.1: Compressive strength

Average compressive strength, based on five specimens tested must be at least 2.07 MPa and no individual unit is permitted to have less than 1.72 MPa.

2109.3.1.2: Modulus of rupture

Average modulus of rupture, based on five specimens tested must be at least 0.35 MPa and no individual unit is permitted to have less than 0.24 MPa.

2109.3.1.3: Moisture content requirements

Adobe units shall have a moisture content not exceeding 4 percent by weight.

2109.3.1.4: Shrinkage cracks

Adobe units shall not contain more than three shrinkage cracks and any single shrinkage crack shall not exceed 76 mm in length or 3.2 mm in width.

2109.3.3: Allowable stress

The allowable compressive stress based on gross cross-sectional area of adobe shall not exceed 0.21MPa.

2109.3.4.1: Number of stories

Adobe construction shall be limited to buildings not exceeding one story, except that two story construction is allowed when designed by a registered design professional.

2109.3.4.2.2: Mortar joints

Adobe units shall be laid with full head and bed joints and in full running bond.

2109.3.4.4: Wall thickness

The minimum thickness of exterior walls in one-story buildings shall be 254 mm. The walls shall be laterally supported at intervals not exceeding 7315 mm. The minimum thickness of interior load-bearing walls shall be 203 mm. In no case shall the unsupported height of any wall constructed of adobe units exceed 10 times the thickness of such wall.

2109.3.4.7.2: Wood tie beams

Wood tie beams shall have a minimum depth of 152 mm and a minimum width of 254 mm. Wood tie beams is constructed above adobe masonry walls to distribute loads from floors and roofs.

5.4 Eurocode

5.4.1 Generals

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN 1990, Eurocode: Basis of structural design.

EN 1991, Eurocode 1: Actions on structures.

EN 1992, Eurocode 2: Design of concrete structures.

EN 1993, Eurocode 3: Design of steel structures.

EN 1994, Eurocode 4: Design of composite steel and concrete structures.

EN 1995, Eurocode 5: Design of timber structures.

EN 1996, Eurocode 6: Design of masonry structures.

EN 1997, Eurocode 7: Geotechnical design.

EN 1998, Eurocode 8: Design of structures for earthquake resistance.

EN 1999, Eurocode 9: Design of aluminium structures.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

Each part of the Eurocode has a National Annex (NA) which provides the Nationally Determined Parameters (NDPs) to be used in the application of Eurocode in a particular country. Typically the National Annex will state values and classes applicable to that country and only a symbol is given in the Eurocode. This method makes different countries be possible to use Eurocode without any inconsistencies.

5.4.2 Eurocode 6: Design of masonry structures.

Scope of Eurocode 6 is follows:

1. Eurocode 6 applies to the design buildings and civil engineering works, or parts thereof, in unreinforced, reinforced, prestressed and confined masonry.
2. Eurocode 6 deals only with the requirements for resistance, serviceability and durability of structures. Other requirements, for example, concerning thermal or sound insulation, are not considered.
3. Execution is covered to the extent that is necessary to indicate the quality of the construction materials and products that should be used and the standard of workmanship on site needed to comply with the assumptions made in the design rules.
4. Eurocode 6 does not cover the special requirements of seismic design. Provisions related to such requirements are given in Eurocode 8 which complements, and is consistent with Eurocode 6.

5. Numerical values of the actions on buildings and civil engineering works to be taken into account in the design are not given in Eurocode 6. They are provided in Eurocode 1.

Eurocode 6 comprises the following parts.
① Part 1-1: General rules for reinforced and unreinforced masonry structure.
② Part 1-2: Structural fire design
③ Part 2: Design considerations, selection of materials and execution of masonry.
④ Part 3: Simplified calculation methods for unreinforced masonry structures.

5.4.2.1 Part 1-1: General rules for reinforced and unreinforced masonry structures.

Part 1-1 describes the principles and requirement for safety, serviceability and durability of masonry structures. The following subjects are dealt with in Part 1-1:
Section 1: General;
Section 2: Basis of design;
Section 3: Materials;
Section 4: Durability;
Section 5: Structural analysis;
Section 6: Ultimate Limit State;
Section 7: Serviceability Limit State;
Section 8: Detailing;
Section 9: Execution;

This is based on the limit state concept used in conjunction with a partial factor method.
General rules require that:

$Ed \leqq Rd$

Where

Ed = design values of the effect of actions
Rd = design value of the resistance

The partial factor method, the design value for a material property is obtained by dividing its characteristic value by the relevant partial factor for materials as follows:

$Rd = Rk / \gamma_M$

Where

Rd= design value of resistance
Rk = characteristic value of the resistance
γ_M = partial factor for a material property

Partial factor for materials
・Two levels of attestation of conformity are recognized.
・manufacture : Category Ⅰ and Ⅱ

・execution control : 1 and 2

For plain masonry, if the ultimate limit state is satisfied, no checks for serviceability limit states are required. This assumes compliance with the limiting dimensions and rations specified in Eurocode 6.

5.4.2.2 Part 1-2: Structural fire design.

This part deals with the design of masonry structures for the accidental situation of fire exposure and identifies differences from, or supplements to, normal temperature design. Only passive methods of fire protection are considered and active methods are not covered. It addresses the need to avoid premature collapse of the structure and to limit the spread of fire.

5.4.2.3 Part 2: Design consideration, selection of materials and execution of masonry.

This part gives the basic rules for the selection and execution of masonry to enable it to comply with the design assumptions of the other parts of Eurocode 6. It includes guidance on factors affecting performance and durability, storage and use of materials, site erection and protection, and the assessment of the appearance of masonry.

5.4.2.4 Part 3: Simplified calculation methods for unreinforced masonry structures.

This part contains simplified calculation methods for unreinforced masonry structures. These methods are based on the principles contained in Part 1 and should not be confused with simple rules developed on the basis of experience. In general, these methods are more conservative than design based on Part 1.

If you need more details you should refer http://www.eurocode6.org/ .

5.4.3 Eurocode 8: Design of structures for earthquake resistance.

Scope of Eurocode 8 is to apply to the design and construction of buildings and civil engineering works in seismic regions. Its purpose is to ensure that in the event of earthquakes:

- human lives are protected
- damage is limited
- structures important for civil protection remain operational.

Section 9 of Eurocode 8 is Specific rules for masonry buildings. This section applies to the design of buildings of unreinforced, confined and reinforced masonry in seismic regions and is an additional rules of Eurocode 6(Eurocode 8 does not consider out of plane deformation of the walls while in the framework of Eurocode 6 in-plane and out-of plane action effects are simultaneously considered.).

5.5 The World Housing Encyclopedia (WHE), Tutorials

The WHE is a project of the Earthquake Engineering Research Institute and the

International Association for Earthquake Engineering. Volunteer earthquake engineers and housing experts from around the world participate in the web-based project by developing reports on housing construction practices and prepare tutorials on various construction technologies such as adobe building, stone masonry and confined masonry. These tutorials explain about their characteristics and methods how to reinforce them. The WHE is also a partner of the World Banks Safer Homes Stronger Communities project. All information provided by the volunteers is peer-reviewed. Visit www.world-housing.net for more information.

I. Earthquake-Resistant Construction of Adobe Buildings: A Tutorial

Adobe mud sun dried blocks are one of the oldest materials and the use of this material is very common in some of the world's most hazard-prone regions. Traditional adobe construction responds very poorly to earthquake ground shaking because its heavy weight, low strength and brittleness. Additionally, skilled technicians (engineers and architects) are generally not involved (non-engineered construction). As a result, considerable damage and loss of life has occurred repeatedly.

To mitigate this damage, this tutorial gives the following contents.

・Introduction
・Earthquake performance
・Improved earthquake performance of new adobe construction
・Seismic reinforcing system for new and existing adobe construction
・Seismic protection of historic adobe buildings
・conclusions
・references

This tutorial gives typical earthquake damage patterns include vertical cracking and separation of walls at the corners, diagonal cracking in the walls, and out-of-plane wall collapse.

As a result, the key factors of the seismic performance are

・Adequate soil properties and construction quality
・Wall construction
・Robust layout
・Use of improved building technologies with seismic reinforcement

II. Improving the Seismic Performance of Stone Masonry Buildings : A Tutorial

Durable and locally available stone has been used as a construction material since ancient times. Stone houses, palaces, temples, and important community and cultural buildings can be found all over the world. But traditional stone masonry dwellings have proven to be extremely vulnerable to earthquake shaking, thus leading to unacceptably high human and economic losses, even in moderate earthquake.

This document explains the underlying causes for the poor seismic performance of stone masonry buildings and offers techniques for improving it for both new and existing buildings. The contents are as follows;

・Introduction
・Seismic deficiencies and damage patterns
・Stone masonry construction with improved earthquake performance
・Retrofitting a stone masonry building
・Conclusions
・References
・Glossary

The proposed techniques have been proven in field applications, are relatively simple, and can be applied in areas with limited artisan skills and tools.

The authors of this document believe that there are two main challenges related to improving the seismic performance of stone masonry buildings; technical challenges and challenges related to the technology transfer.

5.6 Concluding Remarks

Some countries and regions have technical knowledge and construction standard for masonry structures. Though each has different contents because of the differences of their background, critical issues are almost same. For the reasons, these are useful for the countries which there are no standards and regulations in order to build appropriate earthquake resistant masonry houses.

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Chapter 6 Seismic Evaluation Methods of Existing Masonry Buildings

6.1 Introduction

In this chapter, the guidelines for seismic diagnosis of existing masonry buildings, employed or proposed in both Japan and the other countries, were reviewed to understand the present state of available methodologies to disaster mitigation of masonry houses in developing countries. In addition, a simplified seismic diagnosis method proposed recently for existing masonry houses in a developing country was introduced. To discuss the present state and subject of the seismic diagnosis methods, the present document summarizes the methods of seismic diagnosis described in those guidelines and the recently proposed method. As seismic evaluation methods of existing RC structures can be referred to existing masonry structures, furthermore, sometimes they were applied to practical projects, the present document also describes guidelines of existing RC structures.

6.2 Seismic Diagnosis Guidelines Utilized/Proposed in Japan

6.2.1 Guideline proposed by Hokkaido Building Engineering Association

Hokkaido Building Engineering Association proposed Guidelines for Seismic Evaluation of Existing Brick Masonry Buildings[6.1]. This guideline describes the methods mainly to perform seismic diagnosis of a number of historical brick masonry buildings that still remain and are utilized as schools, shops and warehouses in Hokkaido. At present, this guideline is one of the most practical ones applicable to diagnosis of existing masonry buildings of which story is three or less than three with regular plan and elevation. The concept of the method is on the basis of quantity of walls and brick strength as ;1) Evaluation can be done for in-plane and for out-of-plane of walls, respectively. 2) Diagnosis for in-plane of brick walls is based on shear stress evaluation in horizontal section in reference to the Japan guideline of seismic evaluation of existing RC buildings published by JBDPA[6.2]. 3) Seismic load for safety evaluation for out-of-plane of walls is 1.0, shear coefficient.

This guideline is composed of the following articles as ;

1. Limitation of application
2. Principle of seismic diagnosis
3. Survey of buildings and tests
4. Requirement condition for seismic baring wall
5. Strength of wall
6. Evaluation of out-of-plane baring capacity
7. Judgment of seismic safety

Appendix. Example of application to brick masonry school

In article 3, the following surveys/tests are required prior to evaluation. 1)Condition of joints, 2)Cracks and deterioration, 3)Compressive strength of walls (joints and brick, prism) 4)Compressive strength and neutrality depth of RC beams 5)Irregular settlement and tilting

6)Dimensions and shape of building necessary for seismic evaluation.

In article 4, the structural condition of brick walls is defined to account for seismic baring wall for evaluation as ; 1)Thickness should be more than 1/20 of height and 200mm. 2) Walls with straight joints cannot be accounted as baring wall. 3)Horizontal length of walls between openings should be more than 600mm.

In article 5, strength of walls should be evaluated from the tests shown in article 3 or given as upper limit strength as ; 1) Compressive strength 4.5N/mm^2, 2)Shear strength 0.45N/mm^2, 3) Tensile strength 0.45N/mm^2.

In article 6, safety evaluation method of out-of-plane behaviors of walls is described. Hence, the following equations must be satisfied as ;

For $\sigma_c \geq \sigma_b$

$$\sigma_c + \sigma_b \leq \text{ Compressive strength of wall} \tag{6-1}$$

For $\sigma_c < \sigma_b$

$$\sigma_b - \sigma_c \leq \text{Tensile strength of wall} \tag{6-2}$$

Here, σ_c : Vertical load N/ Sectional area A,

σ_b : Moment M / Section coefficient Z

Induced moment depends on boundary condition as ;

$M = \kappa WH/8$: both upper and lower boundary are hinge

$M = \kappa WH/12$: both upper and lower boundary are fix

Here,

W : Weight of wall

H : Effective length of span for out-of-plane resistance

κ : $Z \cdot K \cdot A_i$

Z, A_i are defined in Japan building Code

A_i : Coefficient representing seismic shear force distribution

Z :Earthquake regional coefficient

K : Seismic horizontal force coefficient in out-of-plane. $K = 1.0$ is required.

Article 7 composes a total of eight items.

1) Seismic evaluation of in-plane earthquake resistance is described. As mentioned, this article was proposed in reference to Japan Standard for Seismic Evaluation of Existing RC buildings. This standard for RC building is summarized in 6.4.1. This evaluation method is outlined as;

For safety, the following equations must be satisfied for safety ;

$$I_S \geq I_{S0} \tag{6-3}$$

$$q \geq 1.0 \tag{6-4}$$

Here, I_S : Seismic index of structure

I_{S0} : Seismic demand index of structure

(≥ 0.6 , for school buildings ≥ 0.7)

q : q index

When a wall is safe against the seismic load in out-of-plane direction

$$I_S = I_{S1}$$

I_{S1} : calculated by Eq.(6-5)

$$q = q_1$$

q_1 : calculated by Eq.(6-6)

When there is a wall being not safe against the seismic load in out-of-plane direction,

$$I_S = \min(I_{S1}, I_{S2})$$

I_{S1} :calculated from Eq.(6-5)

$$I_{S2} = I_{S0} \times K_{\min}$$

$$q = \min(q_1, q_2)$$

q_1 : evaluated from Eq.(6-6)

$$q_2 = K_{\min}$$

$K_{\min}$ denotes the minimum seismic force calculated from safety limit by out-of-plane force $K_{\min} < 1.0$.

2)Evaluation of seismic index of structure

In article 7, seismic index of structure I_{s1} is evaluated from the following equation as ;

$$I_{s1} = Q_u \cdot F \cdot T \cdot S_D \Big/ \sum (W \cdot A_i \cdot Z \cdot R_t) \qquad (6\text{-}5)$$

Here, Q_u : Ultimate lateral strength

F : Ductility index

T : Time index

S_D : Irregularity index

R_t : Vibration characteristics coefficient

W : Weight of structure for seismic calculation

3) Evaluation of q index

$$q_1 = Q_u \cdot T \cdot S_D \Big/ (\sum W \cdot A_i \cdot Z \cdot R_t \cdot S_t) \qquad (6\text{-}6)$$

Here, S_t : structural characteristic coefficient to represent ductility (Ds-value defined in JBC)

$S_t = 0.55$ is recommended.

4) Evaluation of ultimate lateral strength Q_u

$$Q_u = \alpha \cdot A_w \cdot \tau_w \qquad (6\text{-}7)$$

Here, A_w : sectional area of wall in horizontal direction

τ_w : shear strength of wall per unit sectional area

α : Reduction factor to account for openings

5) Evaluation of Ductility index F

$F = 0.6$ is recommended for brick masonry structure

6) Evaluation of Time index T

$$T = (T_1 + T_2 + \cdots\cdots + T_n) / N$$

Time index is given in the Standard for Seismic Evaluation (JBDPA) (See6.4)

7) Evaluation of structural characteristic coefficient S_t

$$S_t = 0.55$$

8) Irregularity index S_D

Irregularity index S_D denotes Index to account for the shape complexity and eccentricity, and irregular distribution of layer stiffness along the height. The procedure to calculate S_D is given in Table 5 of the Guideline[6-1].

6.2.2 AIJ Guideline for Seismic Performance Evaluation of Existing Partially Grouted Concrete Masonry Buildings

The Managing Committee on Box-shaped Wall Structures of the Architectural Institute of Japan (AIJ) established a subcommittee during 2009-2012 to collect, organize, and investigate information related to the seismic performance evaluation of existing unreinforced masonry and reinforced masonry buildings. Following this, another subcommittee was established in 2013 and creation of a guideline for seismic performance evaluation of existing masonry buildings is being carried out focusing on a partially grouted concrete masonry building called "Reinforced hollow unit concrete masonry building".

The partially grouted concrete masonry building is composed of concrete masonry walls, reinforced concrete (R/C) collar beams, R/C floor slabs, and R/C footing beams as shown in Figure 6.1. Usually, only the hollow portions of the masonry body that have reinforcing bars are filled with concrete or mortar. Buildings of this system were constructed widely in Japan in 1960s and 1970s, and have been used for more than 30 years passing through a drastic revision of seismic regulations in 1981.

The tentative contents of the guideline are as follows.

Chapter 1: General

Chapter 2: Principle of Seismic Performance Evaluation

Chapter 3: Structural Features of Load Bearing Wall

Chapter 4: Inspection on Current Building Condition

Chapter 5: Seismic Performance Evaluation Based on Lateral Load-carrying Capacity Calculation

Chapter 6: Seismic Performance Evaluation Based on Seismic Screening Method

Chapter 7: Seismic Performance Evaluation Based on Equivalent Linearization Method

Appendix: Application Example of Seismic Performance Evaluation

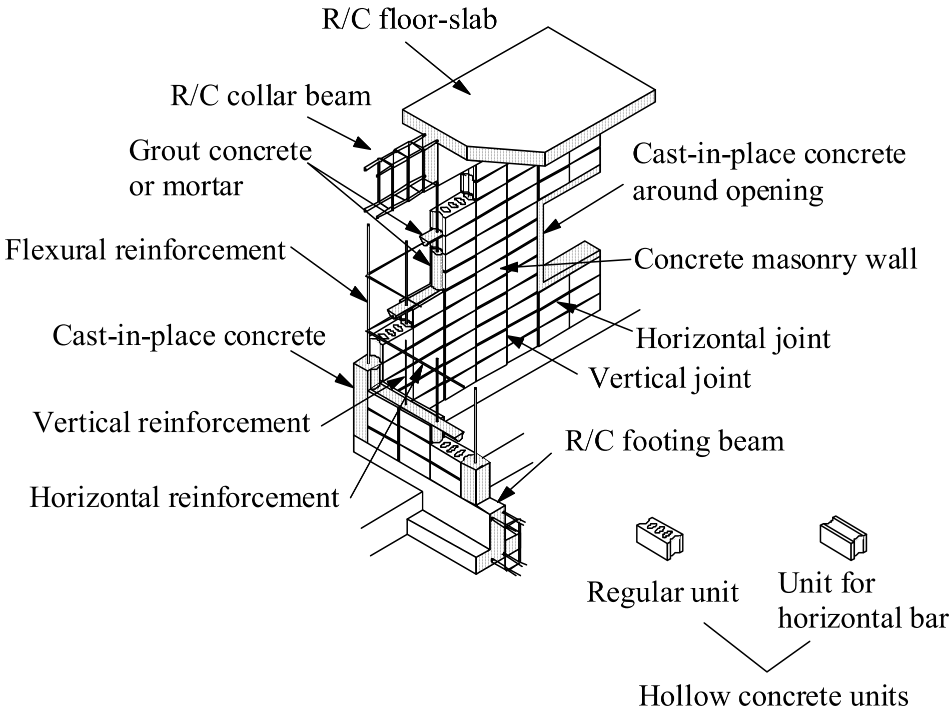

Figure.6.1 Example of partially grouted masonry building [6.2]

As shown above, three types of evaluation methods will be included in the guideline. The first method described in Chapter 5 is based on the lateral load-carrying capacity calculation that is widely used in the earthquake resistant design of new buildings with medium rise. A correction factor for the required lateral load-carrying capacity is introduced in order to consider the deterioration due to aging and the difference in specific requirements between former and current standards. The second method described in Chapter 6 is based on the seismic screening standard for existing R/C buildings [6.3]. The last method described in Chapter 7 is based on the equivalent linearization method that can evaluate the response to different seismic actions.

6.3 Seismic diagnosis guidelines utilized/proposed in foreign countries

6.3.1 Italian codes (CIRCOLARE 2 febbraio 2009, n. 617)

The title of the document is translated into “code No 617 of February second of 2009”. The code is not only for historical masonry structures but also about modern buildings such as RC and steel structures. The chapters related to historical masonry structures are mainly Chapter 8 and 11. In this summary, Chapter 7 is also mentioned briefly as it also includes discussions on masonry structures. Since the complete translation has been presented, only relevant/significant parts are discussed.

(1)Picked up Chapters

C7.8, C8.7.1 and C11.10 are summarised. They are regarding construction of masonry. Chapter 7 is about seismic actions. Chapter 8 is about existing buildings. Chapter 11 is about materials.

In Chapter 7, as a chapter of seismic actions, masonry construction is discussed. The use of nonlinear static analysis is recommended for the verification of limit state (Damage limit state and Ultimate limit state) (See Figure. 6.2). Damage limit state (SLD) is satisfied when the displacement of the control point of interest (e.g. top of the structural element) is lower than 0.003h (h=height of the structural element). Ultimate limit state (SLU) is satisfied when reduction of the capacity is not more than 20% of its maximum capacity (See Figure. 6.2).

In Chapter 8, existing buildings are discussed. For instance, verification of local mechanisms (C8.7.1.6) is discussed. For verification, it is proposed to use limit equilibrium analysis. Under this analysis it is considered that the structure is composed of rigid bodies. Verification is made on each rigid body (e.g. façade and part of the wall). It is carried out under three hypothesises. Firstly, masonry is not resistant in tension. Secondly, slipping between blocks does not occur. Thirdly, it is considered that compressive strength of masonry is infinite. The analysis method is called kinematic limit analysis. Applying the principle of virtual work to the regarding mechanism, it is possible to verify seismic safety in terms of seismic coefficient (a*0) (linear kinematic analysis) or of ultimate displacement (d*u) (nonlinear kinematic analysis) (See Figure.6.3).

In Chapter 11, materials are discussed. As for masonry, it is discussed in C11.10. The methods of experiments and determination of the mechanical parameters are discussed. For instance, characteristic compressive strength under vertical loads is defined. In this document, characteristic strength is defined as the value of the strength which is exceeded by 95% of all the measured values. The value of the characteristic strength f_{bk} is obtained by using the following equation.

$$f_{bk} = f_{bm}(1 - 1.64\delta) \tag{6-8}$$

where:

f_{bm} = mean strength of the individual elements f_{bi};

$\delta = s/f_{bm}$= coefficient of variation;

s = estimated standard deviation;

$$s = \sqrt{\frac{\sum^{n}(f_{bm} - f_{bi})^2}{n-1}} \tag{6-9}$$

(n = number of tested elements: n has to be larger than 30.)

The value of f_{bk} is not acceptable for δ> 0.2

(2) Discussions

For historical masonry buildings, use of nonlinear static analysis and limit kinematic analysis is suggested in the code. In practice, the latter (limit kinematic analysis) is principally used since it is more simple than nonlinear static analysis. Nonlinear dynamic analysis (NDA) is hardly used in practice although this method is more advanced than the above-mentioned ones due to its complicity and extreme computational effort.

(3)Other chapters

Chapter 1 is introduction. Chapter 2 is safety and performance demands. Chapter 3 is actions of earthquakes, winds and snows. Chapter 4 is about normal-use buildings (civil and industrial buildings). Chapter 5 is about bridges. Chapter 6 is about soil conditions. Chapter 9 is about static testing. Chapter 10 is about preparation of legislative reports of structural projects. Chapter 12 is reference. At the end of the code, there are appendices.

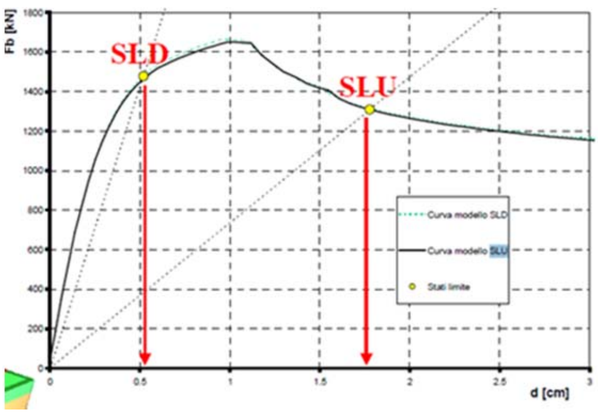

Fig.6.2.Example of capacity curve provided by non-linear static analysis [6.4]

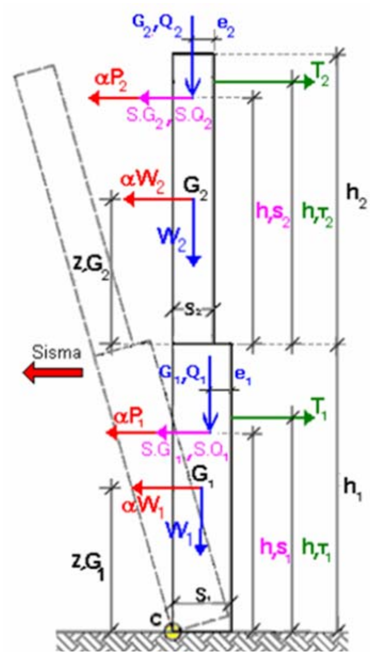

Fig.6.3 Example of linear kinematic analysis [6.4]

6.3.2 ISO 13822 Annex Heritage Structures

ISO 13822 Annex was recently published as an annex of evaluation of existing structures (ISO 13822) for structural diagnosis of heritage structures. This standard was based on recommendation for the Analysis, Conservation and Structural Restoration of Architectural Heritage, ISCARSAH ICOMOS[6.5]. When masonry houses have historical cultural values, this guideline should be referred. The chapters of this guideline are ;

1. Introduction

2. Fundamentals
3. Terms and definitions
4. General framework of assessment
5. Data for assessment
6. Structural analysis
7. Verification
8. Assessment based on satisfactory performance
9. Structural intervention
10. Report contents

The contents of this standard is rather conceptual with no description of practical evaluation methodologies. Among chapters, Chapter 6 , 7 and 8 can be referred when they perform seismic evaluation of existing buildings that have historical values. In Chapter 6, calibration and validation of models are described. In addition, model uncertainties are dealt with in this Chapter.

6.3.3 NIKER Project [6.6]

(1) Introduction of the project

The title is abbreviation of **N**ew **I**ntegrated **K**nowledge based approaches to the protection of cultural heritage from **E**arthquake-induced **R**isk (See Figure 6.4). This NIKER project is a European project that started in 2010 and finished recently for protection of cultural heritages against earthquakes, funded by European Commission. A total of 18 institutes and universities from European and the surrounding countries participated in this international project.

The project aims at developing and verifying innovative materials and technologies for systemic improvement of state (SLD) is satisfied when the displacement of the control point of interest (e.g. top of the structural element) is lower than 0.003h (h=height of the structural element). Ultimate limit state (SLU) is satisfied when reduction of the capacity is not more than 20% of its maximum capacity (See Figure 6.2).

- Creation of a database with new relational structure with the task of orienting and assisting the development of materials and techniques for intervention (main achievement at 12 months)
- Experimental testing, numerical simulation, parametric modelling and derivation of design methods for vertical and horizontal structural elements and connections (obtained at 24 months) and for the overall seismic behaviour of buildings (obtained at 30 months)
- Development of knowledge-based assessment procedures and final validation of the entire methodology on real case-studies. Guidelines for end-users (final project milestone, at 36 months)

(2)WPs (Workpakages)

Shown in Figure 6.4, WP1 and WP2 are related to administrative businesses. WP3 provide the State of Art discussions from research which each participant has carried out in their own institute. The achievement of this WP is realised as the NIKER Catalogue. This presents earthquake-induced failure mechanisms, construction typologies and materials, interventions and assessment techniques. This aims at knowledge-based optimisation of interventions and definition of main design parameters and requirements for materials and intervention techniques**.** WP4, 5 and 6 focus on practice of experiments on structural elements (vertical, horizontal elements and connections respectively), WP7 carries out experiments on structural systems: e.g. vault and wall, one- and multiple-storey box structures. WP8 studies reliability of numerical studies. Experiments carried out during WP4, 5, 6 and 7 are taken advantage of in this workpackage. Thus, comparison between experimental and numerical studies is carried out. In WP9, long-term monitoring is carried out on 16 case studies. Also in workpackage, numerical study is carried out, referring to the monitoring carried out. WP10 summarizes the final achievement of the project. Guideline for the end-users is presented. This is for the direct end-users of the developed technologies and tools (designers, architects, engineers, construction companies, bodies responsible of building maintenance, etc.), with practical information on design of interventions, execution of techniques, assessment

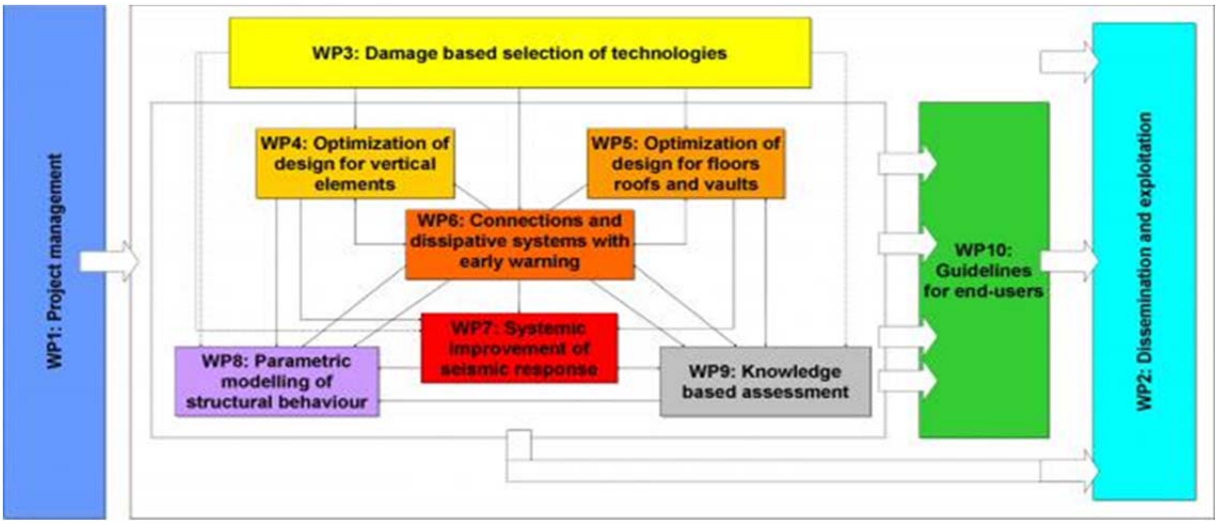

Fig.6.4 Outlines of NIKER Project [6.6]

(3) Comments

NIKER focuses mostly on masonry structures. Apart from the WP4 (experiments on timber floors and roof trusses), the discussions and/or research are made on masonry. The author who had been involved in this project felt that the project has an aspect that participants expect funding to carry out research of their interest rather than preparing a new guideline by working together. Besides, three years was not sufficient to provide comprehensive results. As a matter of fact, WP8 group showed great advance after NIKER project was over. The guideline (WP10) is satisfactory good for those end users but it would have been done better in many ways. For instance it was written only by one institute. However, it would have been written (or at least revised) by various institutes/participants.

6.3.4 Guideline for evaluation and mitigation of seismic risk to cultural heritages, Italy

The Ministry for Cultural Heritages and Activities, Italy, published the Guidelines for evaluation and mitigation of seismic risk to cultural heritage (2007)[6.4]. In Chapter 3.1, Italian Code of existing structures including cultural heritages, on the other hand, this guideline deals with only cultural heritages.

This Italian guideline for cultural heritages composes of 7 chapters and 3 appendixes. The chapters are listed as;

1. GUIDELINE OBJECTIVES
2. SAFETY AND CONSERVATION REQUIREMENTS
3. SEISMIC ACTION
4. KNOWLEDGE OF THE BUILDING
5. STRUCTURAL MODELS FOR THE EVALUATION OF SEISMC SAFETY
6. SEISMIC IMPROVEMENTS CRITELIA AND STRENGTHENING INTERVENTIONS
7. SUMMARY OF THE SEISMIC SAFETY EVALUATION PROCESS AND INTERVENTION DESIGN FOR SEISMIC IMPEOVEMENTS

Appendix A Program for monitoring the state of conservation of listed architectural heritage

Appendix B Structural analysis of historic masonry structures

Appendix C Model for the evaluation of the seismic vulnerability of churches

In Chapter 5, three levels of seismic evaluation are defined as ;

(1) Quantitative analysis and evaluation with simplified mechanical models (LV1)

Seismic evaluation level, LV1, is evaluated for qualitative analysis and evaluation with simplified models. Seismic index I_S is defined as ;

$$I_S = \frac{a_{SLU}}{\gamma_1 \cdot S \cdot a_g} \qquad (6\text{-}10)$$

Where, a_{SLU} is the ground velocity which brings about the ultimate limit state, γ_1 is the coefficient of importance, S is the factor which takes into account the stratigraphic profile of the terrain beneath the foundation and any eventual morphological effects ; a_g is the reference peak ground acceleration of the site. A safety index with a value superior to 1 indicates that the building is able to sustain the seismic action, if the $I_S < 1$, the safety of the building is inferior to what is desired.

In this guideline, evaluation methods are described for two types of heritage structures, 1) Buildings, villas and other structures with bearing walls and horizontal diaphragms, 2) Religious buildings, and other structures with large halls, without intermediate diaphragms, and 3) Towers, bell towers, and other tall and slender structures. . For the first structural type 1), the following evaluation procedure is described as .

In Eq.(6-10), a_{SLU} is given as ;

$$a_{SLU} = \frac{q \cdot F_{SLU}}{e^* \cdot M \cdot C(T)} \tag{6-11}$$

Here,

F_{SLU} : shear resistance of the building

q : coefficient of structure. $q = 3$ for buildings of regular height, $q = 2.25$ in other cases.

M : total of seismic mass

e^* : fraction of participating mass according to the means of collapse.

$C(T)$: normalizing spectrum obtained by the ratio between the range of elastic response and PGA which takes site characteristics

Shear resistance F_{SLU} is given by ;

$$F_{SLU} = \frac{\mu_{Xi} \xi_{Xi} A_{Xi} \tau_{Xi}}{\beta_{Xi}} \tag{6-12}$$

Here,

A_{Xi} : area resistant to shearing of the walls on the same floor

ξ_{Xi} : coefficient of in-plane irregularity of the same floor

$$\beta_{Xi} = 1 + 2\frac{e_{yi}}{d_{yi}} \leq 1.25 \tag{6-13}$$

e_{yi} : eccentricity

d_{yi} : distance between the barycentre of the rigidity and the walls in direction X

μ_{xi} is a coefficient that considers the homogeneity of the rigidity and resistance of masonry piers

τ_{di} is the value of the calculation of the shear resistance of the walls of the masonry piers of floor i as ;

$$\tau_{di} = \tau_{0d}\sqrt{1+\frac{\sigma_{0i}}{1.5\tau_{0d}}} \qquad (6\text{-}14)$$

τ_{0d}: the value of the calculation of shear resistance of the masonry by considering the confidence factor F_C

σ_{0i}: the average vertical tension

The fraction of the mass which participates in the dynamic motions is given by ;

$$e^* = \frac{\left(\sum m_i \cdot \phi_i\right)^2}{M\sum m_i \cdot \phi_i^2} \qquad (6\text{-}15)$$

m_i: the mass on the same floor

ϕ_i: the lateral displacement of the same floor

When the means of collapse cannot be defined, it is possible to refer to two collapse mechanisms as;

For collapse of the same floor k (when a floor is weaker than the others),

$$e^* = \frac{N+1-k}{N} \qquad (6\text{-}16)$$

N: the number of floors

For uniform collapse,

$$e^* = 0.75 + 0.25N^{-0.75} \qquad (6\text{-}17)$$

For the structural types of 2) and 3), the evaluation methods are also described, respectively.

(2) Evaluation of individual macro elements (LV2, Local collapse mechanism)

Seismic evaluation level 2, LV2, is defined as evaluation of individual macro elements considering local collapse mechanism. This level is applied when restoration interventions are designed which involve single parts of a construction. The evaluation of seismic safety in the field of planned interventions on single elements can be performed by referring to local models which use specific autonomous structural components of the building (macro model). In Appendix C, local collapse mechanisms are summarized to evaluate seismic vulnerability of religious buildings (See Fig.6.5).

(3) Global evaluation of seismic response of the building, LV3.

This level of evaluation considers the seismic safety of the entire construction, whenever

the ground acceleration brings the construction to the ultimate limit state whether as a whole or significant individual elements (macro elements).
Simplified models for estimating the ground acceleration which corresponds to limit state, LV1, are described in this guideline.

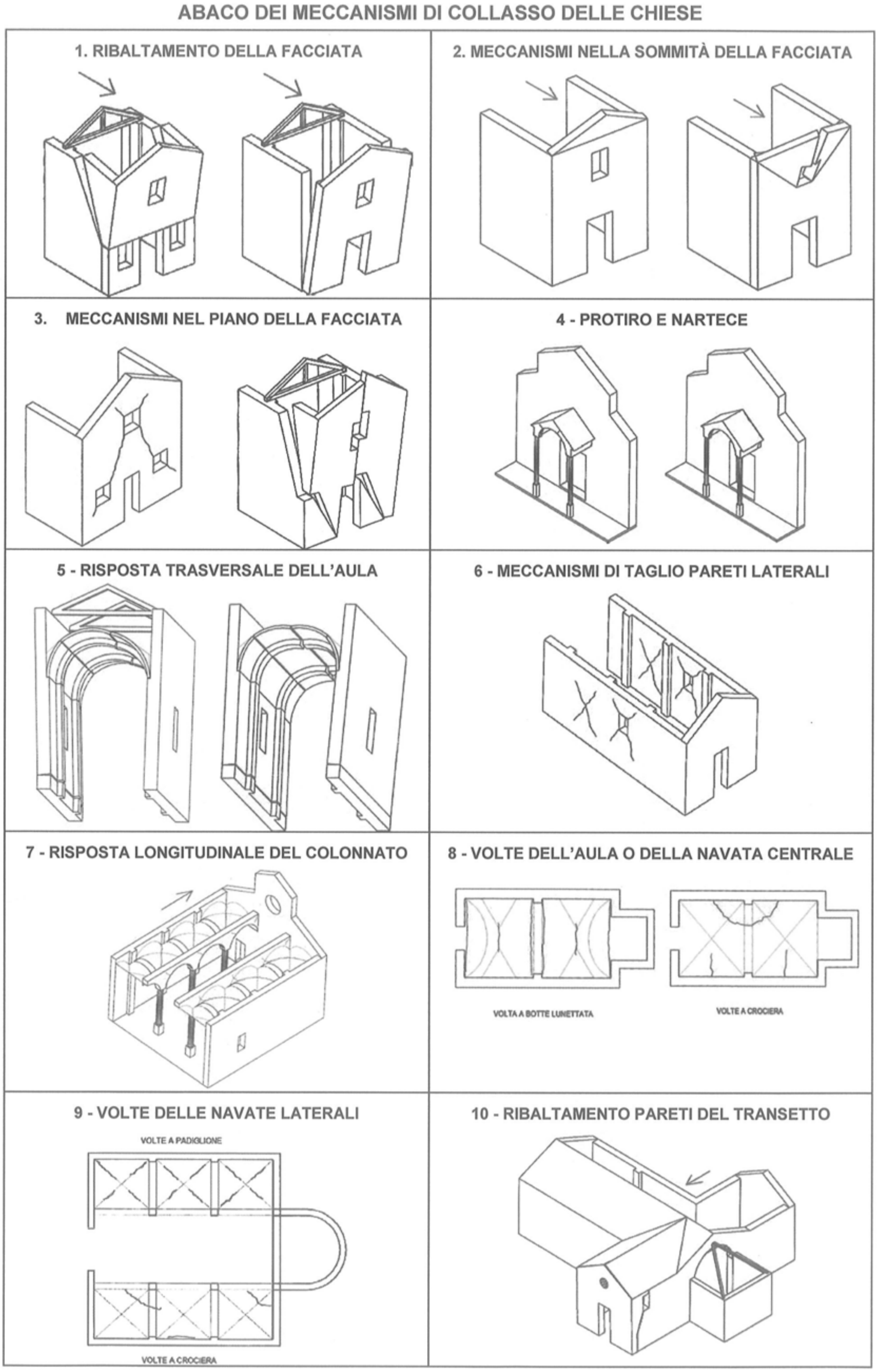

Figure.6.5 Local collapse mechanisms in churches (1/3)[6.4]

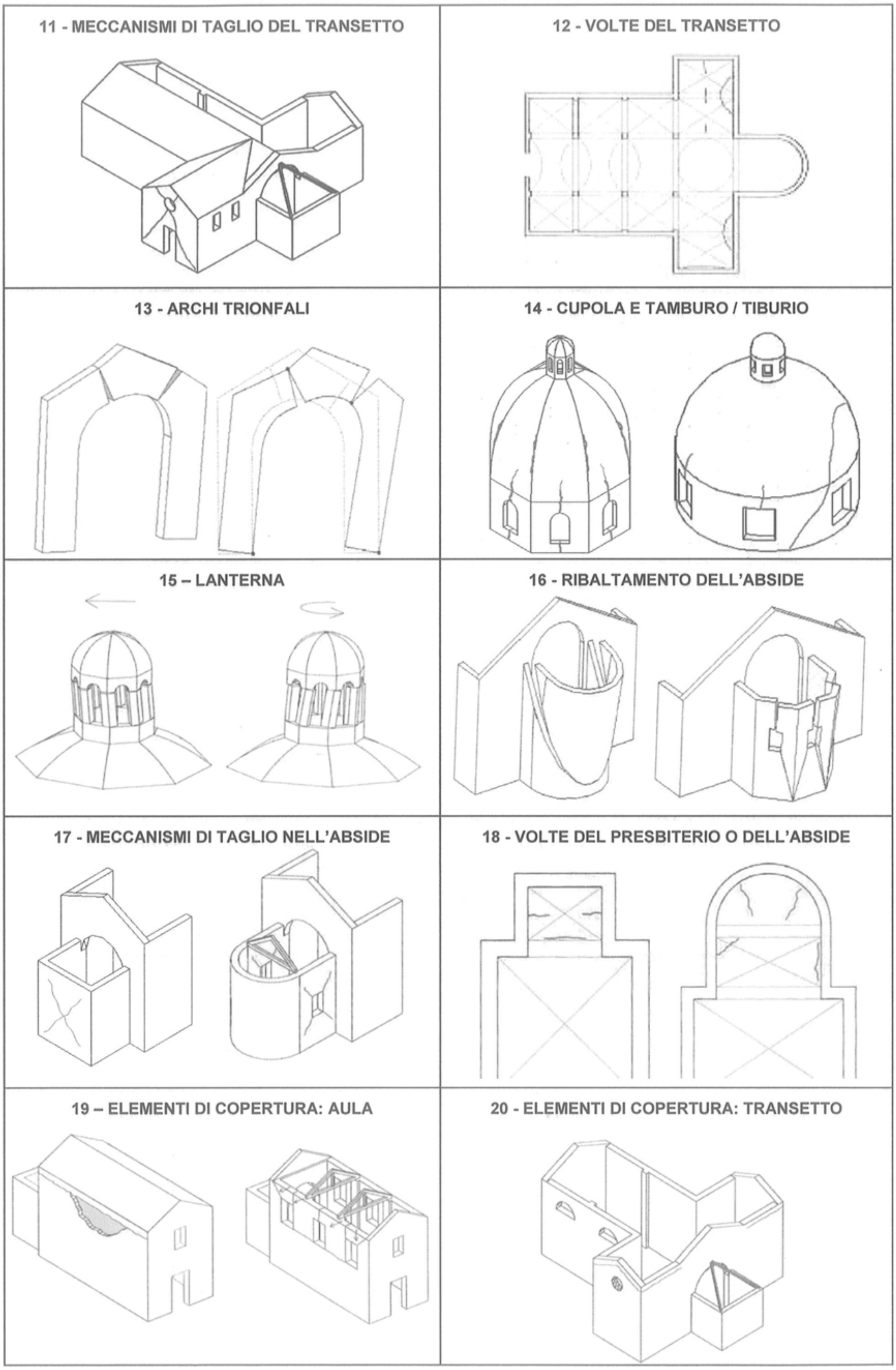

Figure.6.5 Local collapse mechanisms in churches (2/3)[6.4]

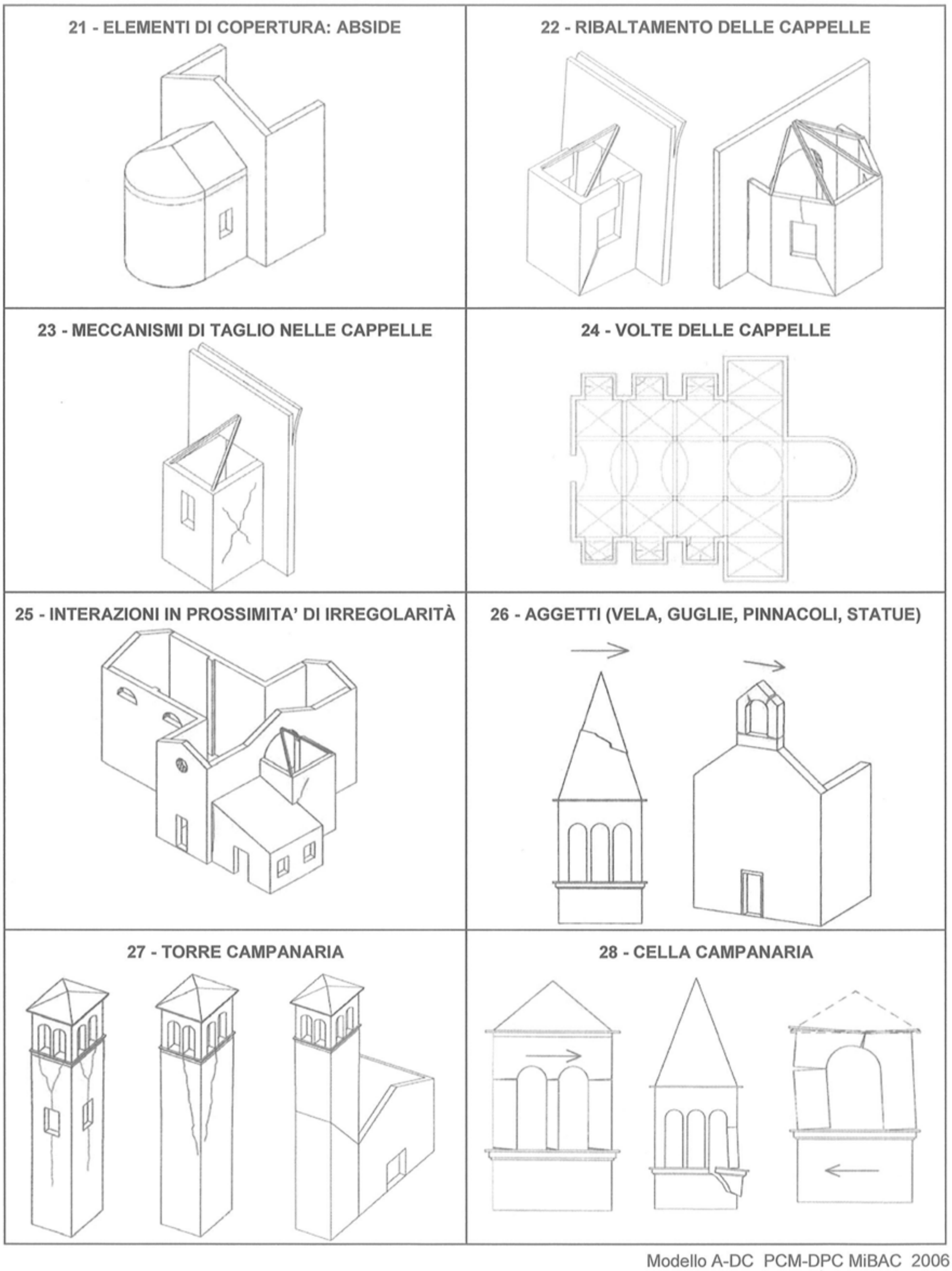

Figure.6.5 Local collapse mechanisms in churches (3/3)[6.4]

6.4 Seismic evaluation methods of RC building for reference to existing masonry buildings

6.4.1 Japan Standard for Seismic Evaluation of Existing RC buildings[6-2]

The Standard for Seismic Evaluation (JBDPA), designed primarily for pre-damaged existing RC buildings in Japan, defines the following structural seismic capacity index *Is* at each story level in each principal direction of a building.

$$Is = Eo \times S_D \times T \tag{6-18}$$

where,

Eo : basic structural seismic capacity index, calculated by the product of Strength Index (*C*), Ductility Index (*F*), and Story Index (ϕ) at each story and each direction when a story or a building reaches the ultimate limit state due to lateral force ($Eo = \phi \times C \times F$)

C : index of story lateral strength expressed in terms of story shear coefficient

F : index of story ductility, calculated from the ultimate deformation capacity normalized by the story drift of 1/250 when a typical-sized column is assumed to fail in shear. *F* is dependent on the failure mode of a structural member and its sectional properties such as bar arrangement, member's geometric size etc. *F* is assumed to be in the range of 1.27 to 3.2 for ductile columns, 1.0 for brittle columns and 0.8 for extremely brittle short columns.

ϕ : index of story shear distribution during earthquake, estimated by the inverse of design story shear coefficient distribution normalized by the base shear coefficient. $\phi = (n+1)/(n+i)$ is basically employed for the *i*-th story of an *n* story building

S_D : reduction factor to modify *Eo* index due to stiffness discontinuity along stories, eccentric distribution of stiffness in plan, irregularity and/or complexity of structural configuration, basically ranging from 0.4 to 1.0

T : reduction factor to allow for time-dependent deterioration grade, ranging from 0.5 to 1.0

A required seismic capacity index *Iso*, which is compared with *Is*-index to identify structural safety against an earthquake, is defined as follows.

$$Iso = Es \times Z \times G \times U \tag{6-19}$$

where,

Es : basic structural seismic capacity index required for the building concerned. Considering past structural damage due to severe earthquakes in Japan, the standard value of *Es* is set 0.6.

Z : factor allowing for the seismicity

G : factor allowing for the soil condition

U : usage factor or importance factor of a building

Typical I_{so} index is 0.6 considering E_s = 0.6 and other factors of 1.0. It should be noted that C_T x S_D defined in Eq.(7-20) is required to equal or exceed 0.3 Z x G x U in the Standard to avoid fatal damage and/or unfavorable residual deformation due to a large response of structures during major earthquakes.

$$C_T \times S_D = \phi \times C \times S_D \qquad (6\text{-}20)$$

Seismic rehabilitation of existing buildings is basically carried out in the following procedure.

(1) Seismic evaluation of the structure concerned (I_s and $C_T \times S_D$)

(2) Determination of required seismic capacity (I_{so})

(3) Comparison of I_s with I_{so} and of C_T x S_D with 0.3 Z x G x U

  * If $I_s < I_{so}$ or $C_T \times S_D < 0.3\ Z \times G \times U$ and therefore rehabilitation is required, the following actions (4) through (6) are needed.

(4) Selection of rehabilitation scheme(s)

(5) Design of connection details

(6) Reevaluation of the rehabilitated building to ensure the capacity of redesigned building equals or exceeds the required criteria

6.4.2 American Standard for Seismic Evaluation of Existing RC Buildings

The Standard (ASCE, 2003)[6.6] provides a three-tiered process for seismic evaluation of existing buildings in any level of seismicity. Buildings are evaluated to either the Life Safety or Immediate Occupancy Performance Level.

Scope:

This standard provides a process for seismic evaluation of existing buildings. It is intended to serve as a nationally applicable tool for design professionals, code officials, and building owners looking to seismically evaluate existing buildings. This standard may be used on a voluntary basis or may be required by the authority having jurisdiction. A major portion is dedicated to instructing the evaluating design professional on how to determine if a building is adequately designed and constructed to resist seismic forces. All aspects of building performance are considered and defined in terms of structural, nonstructural, and foundation/ geologic hazard issues. Lifelines such as water, electrical, natural gas supply, and waste disposal lines beyond the perimeter of the building, which may be necessary for buildings to be occupied, are not considered in this document.

The evaluation procedures include a consideration of ground shaking and to a limited extend other seismic hazard such as liquefaction, slope failure, surface fault rupture, and effects of neighboring structures. Other phenomena such as tsunami, lateral spreading and local topological effects are not considered.

Basic Requirements:

The evaluation process consists of the followings three ties, as shown in Figure 6.6: Screening Phase (Tier 1), Evaluating Phase (Tier 2), and Detailed Evaluation Phase (Tier 3). As indicated in Figure 6.6, the design professional may choose to (1) report deficiencies and recommend mitigation or (2) conduct further evaluation, after any tier of the evaluation process.

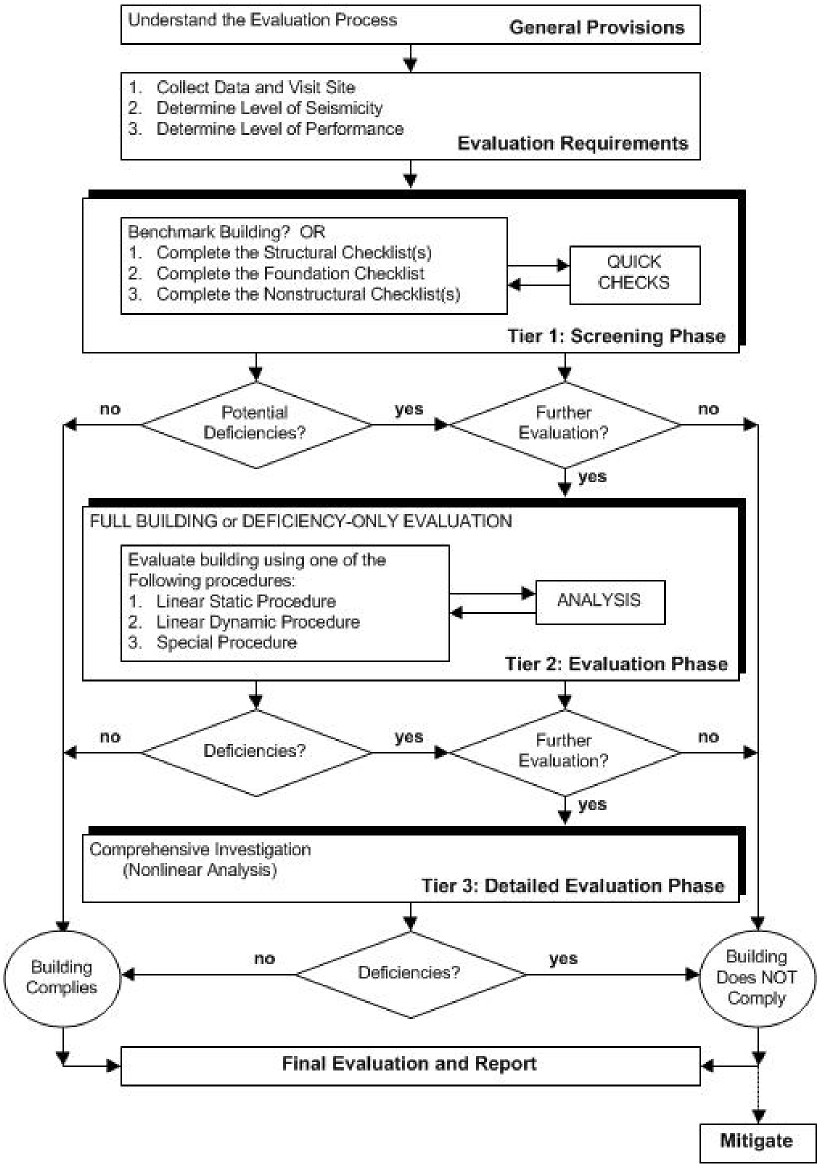

Fig.6.6 Flowchart of seismic evaluation of existing RC buildings [6.3]

Tier 1- Screening Phase :

The screening phase, Tier 1, consists of three sets of checklists that allow rapid evaluation of the structural, nonstructural, and foundation/geologic hazard elements of the building and site conditions. It shall be completed for all building evaluations conducted in accordance with this standard. The purpose of a Tier 1 Evaluation is to screen out buildings

that comply with the provisions of this standard or quickly identify potential definiteness. In some cases, “Quick Checks” may be required during a Tier 1 Evaluation; however, the level of analysis necessary is minimal. If deficiencies are identified for a building using the checklists, the design professional may proceed to Tier 2 and conduct a more detailed evaluation of the building or conclude the evaluation and state that potential deficiencies were identified. In some cases, a Tier 2 or Tier 3
Evaluation may be required, even if no deficiencies are noted in Tier 1.

Tier 2- Evaluation Phase:

For Tier 2, a complete analysis of the building that addresses all of the deficiencies identified in Tier 1 shall be performed. Analysis in Tier 2 is limited to simplified linear analysis methods. If deficiencies are identified during a Tier 2 Evaluation, the design professional may choose to either conclude the evaluation and report the deficiencies or proceed to Tier 3 and conduct a detailed seismic evaluation.

Tier 3- Detailed Evaluation Phase:

References that describe methods for conducting a Tier 3 Detailed Evaluation are provided in Section 7.5 commentary of this standard. Recent research has shown that certain types of complex structures can be shown to be adequate using nonlinear analysis procedures even though other common procedures do not. While these procedures are complex and expensive to carry out, they often result in construction savings equal to many times their cost. The use of Tier 3 procedures must be limited to appropriate cases.

6.5 Simplified methodology developed for developing countries

Imai et al (2013) developed practical tools for vulnerability and safety evaluation of concrete hollow brock (CHB) houses in the Philippines[6.8]. The outline of this method is summarized as ;

The National Research Institute for Earth Science and Disaster Prevention (NIED) with the Philippine Institute of Volcanology and Seismology (PHIVOLCS) is currently implementing a Program on “Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines”. Part of this project is the “Development of Practical Tools for Vulnerability and Safety Evaluation of Houses in the Philippines”. The project developed the following two tools:

1) Tool 1: 12-point Questionnaire: How Safe is My House? Self-check for earthquake safety (See Figure 6.7)
2) Tool 2: Software to evaluate safety and vulnerability of houses (See Figure 6.8)

Target users for Tool 1 are the house owners with CHB/masonry and wooden houses having one to two floors. They can answer the 12-point questionnaire using a paper copy/hardcopy or 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. It has visuals and user-friendly interface so that any user with the assistance of engineers can use this Tool. Target users are also house owners with CHB masonry structure having one to two floors and using a personal computer. The outputs are scoring of the house, vulnerable part of the house, and suggestions on how to strengthen the house.

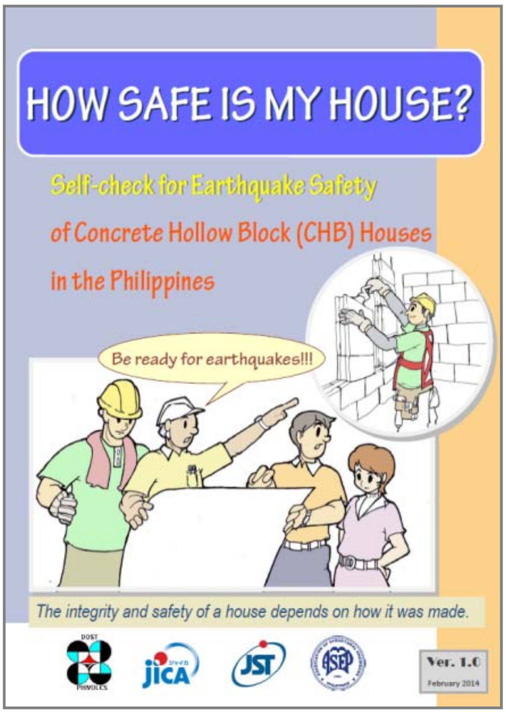

Figure.6.7 Cover sheet of questionnaire[6.8]

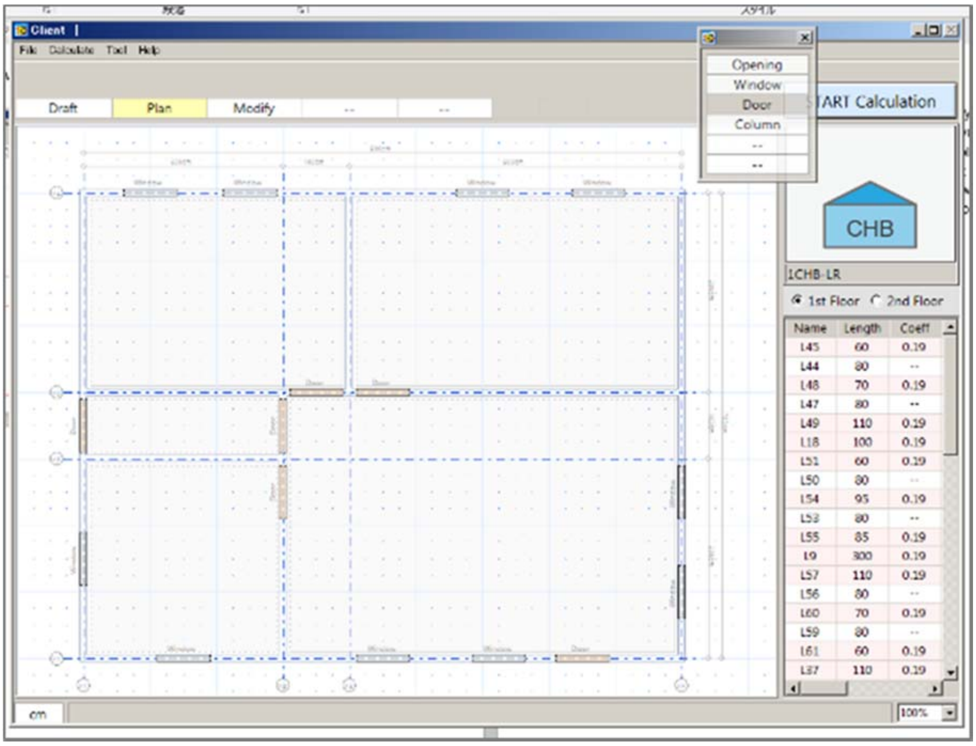

Fig.6.8 Software to evaluate seismic safety [6.8]

6.6 Discussions and concluding remarks

Guidelines for seismic evaluation of existing masonry buildings, employed or proposed in both Japan and foreign countries were reviewed. In addition, those for reinforced concrete block buildings and reinforced concrete buildings, published in Japan, were introduced.

For existing masonry structures, several seismic evaluation methods were proposed and employed in practical diagnoses, however, the subject at the present is to verify those evaluation methods. Comparison of the earthquake damage to masonry buildings and the evaluation should be needed to verify those methods. A simplified method for owners was introduced to conduct seismic safety judgment of the Philippines's CHB houses. Such simplified methods would be practically useful for mitigation of earthquake disasters in developing countries. This implies necessity for further study to develop simplified methods available to brick or stone masonry houses.

Acknowledgements

The author would like to express gratitude to Prof. Minamide, and Prof. Adachi, Hokkai Gakuen University, and Prof. Mizoguchi, Muroran Institute of Technology, for their giving us information on the guideline of Hokkaido Building Engineering Association.

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[6.2] AIJ Guideline for Seismic Performance Evaluation of Existing Partially Grouted Concrete Masonry Buildings

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[6.6] NIKER, http://www.niker.eu.

[6.7] ASCE, *ASCE Standard for Seismic Evaluation of Existing Buildings (ASCE/SEI 31-03),* American Society of Civil Engineers,2003

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IV,pp973-974,2014)

Chapter 7 Current and Future Assignment for Measures to Reduce Earthquake Disaster : Revised Guidelines for Earthquake Resistant Non-Engineered Construction

7.1 Introduction

A large majority of houses and buildings in the world can be classified as non-engineered construction. Most of the loss of lives in past earthquakes have occurred during the collapse of these houses and buildings. Because of the continued use of such construction in the world, the International Association for Earthquake Engineering (IAEE) published the “Guidelines for Earthquake Resistant Non-Engineered Construction” in 1986 (see Fig.7.1). More than twenty years have passed since the 1986 edition and also the guidelines are still used in many parts in the world, the revision of the guidelines will be helpful to minimize the damage and loss of lives caused by earthquakes. The final draft with a number of pictures (see Figs. 7.2-7.9) can be downloaded at the web site of IISEE (http://iisee.kenken.go.jp) and it is going to published by UNESCO.

7.2 Non-Engineered Construction

Many buildings are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and/or engineers. Some types of the non-engineered construction are (1) un-reinforced masonry (stone, brick or concrete block masonry) (see Figs.7.3 and 7.5), (2) confined masonry (see Fig.7.4), (3) wooden construction (see Fig.7.6), (4) earthen construction (adobe or tapial, i.e. rammed earth) (see Fig.7.7), etc.

In un-reinforced construction, masonry walls consist of fired bricks, solid concrete blocks, hollow concrete or mortar blocks, etc. The main weaknesses in un-reinforced masonry construction are a) heavy and stiff buildings, attracting large seismic inertia forces, b) very low tensile and shear strength, particularly with poor mortars, c) brittle behaviour in tension as well as compression, d) weak connections between walls, etc. Therefore, use of mud or very lean mortars is unsuitable.

Confined masonry consists of masonry wall of clay brick or concrete block units and horizontal and vertical reinforced concrete members that confine the masonry wall panels at four sides. Vertical members are called “tie-columns”, and though they resemble columns in reinforced concrete (RC) frame construction, they are of much smaller cross-section. Horizontal elements, called “tie-beams”, resemble beams in RC frame construction, but also of much smaller section. It must be understood that the confining elements are not beams and columns in the way these are used in RC frames. Rather they function as horizontal and vertical ties or bands for resisting tensile stresses.

Wood has a high strength per unit weight and is very suitable for earthquake resistant structure. However, heavy cladding walls impose high lateral loads on a wooden frame beyond its structural capacity. Although seismically suitable, use of timber is declining in building construction even where it used to be the prevalent material on account of vanishing forests due to population pressure. The situation in many countries of the world has in fact become rather alarming on account of the ecological imbalance. Hence use of timber must be restricted in building construction for seismic strengthening weaker construction such as adobe and masonry. Wooden construction is suitable in those areas where wood is still abundantly available as a renewable resource.

In earthen construction, walls are the basic structural elements and can be classified as a) hand-formed by layers, b) adobe or blocks, c) tapial or pise (rammed earth), and d) wood or cane mesh frameworks with mud. This material has clear advantage of costs, aesthetics, acoustics, heat insulation and low energy consumption, but it has some disadvantages such as being weak under earthquake forces and water action. However, technology developed to date has allowed some reduction of its disadvantages. Earthen construction is, in general, spontaneous and a great difficulty is experienced in the dissemination of knowledge about its adequate use. The recommendations are applicable to earthen construction in general, but they are especially oriented to popular housing, aiming to enhance the quality of spontaneous, informal construction which cause the greatest loss of life and damage during seismic events. Therefore, not included are solutions involving the use of stabilizers (cement, lime, asphalt, etc.) to improve the strength or durability. But to enhance the dynamic behaviour of the structure economically, minimum use of the expensive materials (concrete, steel, wood, etc.) is indicated.

7.3IAEE Guidelines in 1986

The "Guidelines for Earthquake Resistant Non-Engineered Construction" was published by the International Association for Earthquake Engineering (IAEE) in 1986 (see Fig.7.1). It is a revised and amplified version of "Basic Concepts of Seismic Codes, Vol.1, Part II, Non-Engineered Construction", published also by IAEE in 1980. The revision resulted from the work of an ad-hoc Committee, integrated by Anand S. Arya, Chairman (India), Teddy Boen (Indonesia), Yuji Ishiyama (Japan), A. I. Martemianov (USSR), Roberto Meli (Mexico), Charles Scawthorn (USA), Julio N. Vargas (Peru) and Ye Yaoxian (China).

The guidelines start with the presentation of the basic concepts that determine the performance of constructions when subjected to high intensity earthquakes, as well as with the sensitivity of that performance to the basic geometrical and mechanical properties of the systems affected. This information is later applied to the formulation of simplified design rules and to the presentation of practical construction procedures, both intended to prevent system collapse and to control the level of damage produced by seismic excitations. Emphasis is placed on basic principles and simple solutions that can be applied to different types of structural systems, representative of those ordinarily used in low-cost housing construction in different regions and countries in the world.

The guidelines consist of nine chapters, i.e. 1) The Problem, Objective and Scope, 2) Structural Performance during Earthquakes, 3) General Concept of Earthquake Resistant

Design, 4) Buildings in Fired-Brick and Other Masonry Units, 5) Stone Buildings, 6) Wooden Buildings, 7) Earthen Buildings, 8) Non-Engineered Reinforced Concrete Buildings, 9) Repair, Restoration and Strengthening of Buildings, and Appendices.

7.4 Revision of the Guidelines

Three members of the committee for the 1986 edition, i.e. Anand S. Arya, Teddy Boen and Yuji Ishiyama met in Tokyo, Japan during "The International Symposium on Earthquake Safe Housing", which was held in 2008. Since more than twenty years had passed after the publication and also the guidelines are still used in many parts in the world, they discussed the possible revision of the guidelines and agreed to make a working group in IAEE including the original members who are willing to participate in it and some new members who are also willing to join it. But on the whole, the above three members have revised the Guidelines with the help of a few international experts. Since there is no special fund allocated to the working group in IAEE, the revision is mainly done through e-mail communications. The activities on the revision have been supported in parts by UNESCO and the International Institute of Seismology and Earthquake Engineering (IISEE), JAPAN. The three members met in Delhi, India in April, 2010 and in Singapore in March 2011. The final draft for the IAEE Guidelines can be downloaded at the website of IISEE (http://iisee.kenken.go.jp).

Since the principles included in the Guidelines still apply until now, this revised edition essentially retains the Guidelines in the original form except for some minor editorial changes and modifications. Some building damage photographs from recent earthquakes have been included for illustration (see Figs.2, 3, 5, 6 and 7) so that the concept of the guidelines will be easily understood. A major addition is Confined Masonry in Chapter 4 (see Fig.7.4) and Appendices in Chapter 10 giving a table for assessment of seismic safety of a masonry building, and examples of posters on brick and wooden buildings (see Figs.7. 8 and 7.9).

As to the confined masonry, the finished appearance looks similar to the ordinary RC frame construction with masonry infills, but they are very different. The differences are related to the construction sequence, as well as to the manner in which these structures resist gravity and lateral loads. In RC frames, columns and beams are constructed, then the masonry wall units infill the frames. In confined masonry, usually masonry walls are constructed and then the tie-columns and tie-beams are constructed. In RC frames, the RC columns and beams carry the vertical gravity as well as the lateral loads from earthquakes or wind storms unaided by the masonry infills. In the case of confined masonry buildings, the wall panels are the main load carrying elements (both vertical and horizontal) aided by the confining elements (tie-columns and tie-beams) for resisting tensile forces.

7.5Concluding Remarks

The revision of the Guidelines for Earthquake Resistant Non-Engineered Construction is almost completed. The latest version can be downloaded at the website of IISEE. And it is going to be published by UNESCO. If you have any comments on the Guidelines, please contact to: Anand S. Arya (India): asarun3155@gmail.com, Teddy Boen (Indonesia): tedboen@cbn.net.id, or Yuji Ishiyama (Japan): to-yuji@nifty.com.

Acknowledgement

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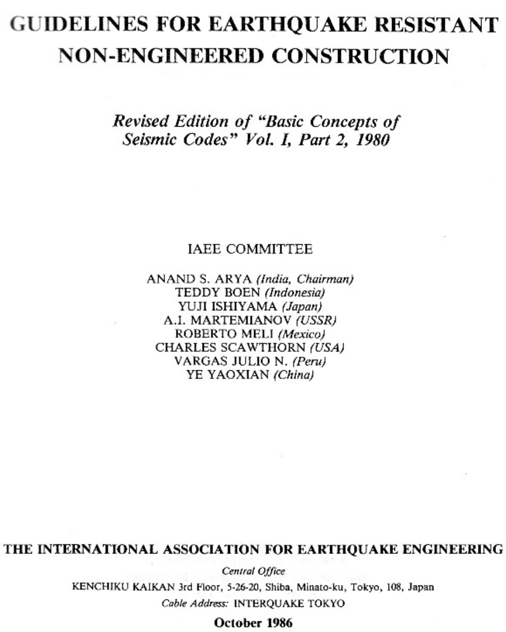

GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION

Revised Edition of "Basic Concepts of Seismic Codes" Vol. I, Part 2, 1980

IAEE COMMITTEE

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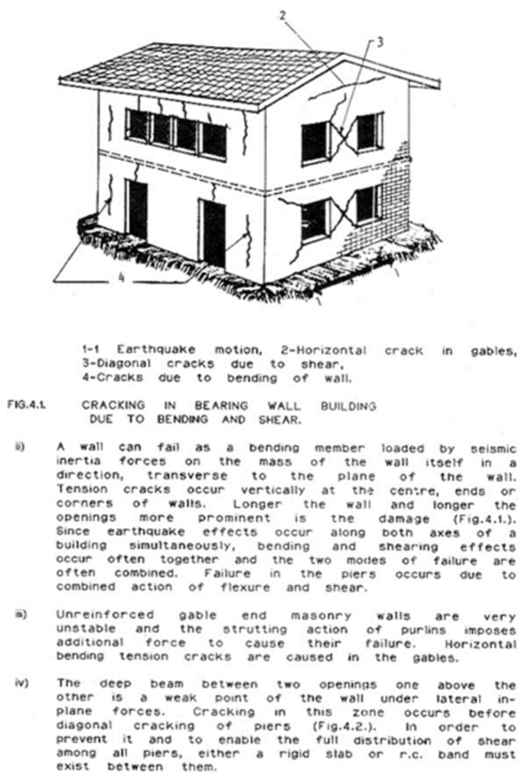
October 1986

Fig.7.1 (a) Title page of IAEE Guidelines for Earthquake Resistant Non-Engineered Construction (1986)



1-1 Earthquake motion, 2-Horizontal crack in gables, 3-Diagonal cracks due to shear, 4-Cracks due to bending of wall.

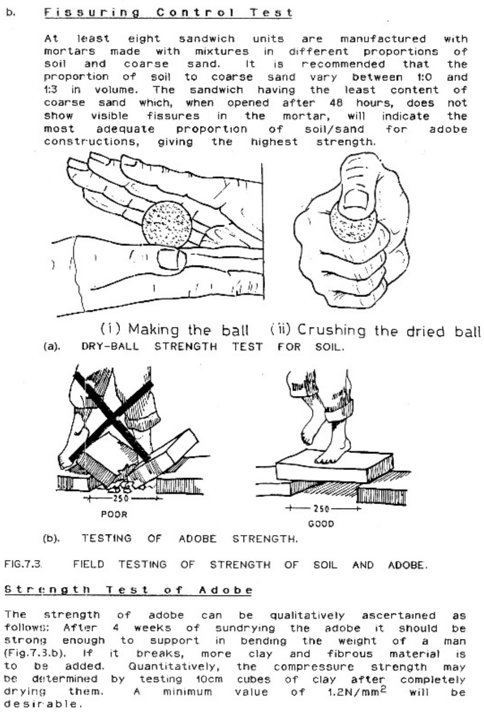
FIG.4.1. CRACKING IN BEARING WALL BUILDING DUE TO BENDING AND SHEAR.

ii) A wall can fail as a bending member loaded by seismic inertia forces on the mass of the wall itself in a direction, transverse to the plane of the wall. Tension cracks occur vertically at the centre, ends or corners of walls. Longer the wall and longer the openings more prominent is the damage (Fig.4.1.). Since earthquake effects occur along both axes of a building simultaneously, bending and shearing effects occur often together and the two modes of failure are often combined. Failure in the piers occurs due to combined action of flexure and shear.

iii) Unreinforced gable end masonry walls are very unstable and the strutting action of purlins imposes additional force to cause their failure. Horizontal bending tension cracks are caused in the gables.

iv) The deep beam between two openings one above the other is a weak point of the wall under lateral in-plane forces. Cracking in this zone occurs before diagonal cracking of piers (Fig.4.2.). In order to prevent it and to enable the full distribution of shear among all piers, either a rigid slab or r.c. band must exist between them.

Fig.7.1 (b) Easy to read with illustrations (1986 IAEE Guidelines)



b. Fissuring Control Test

At least eight sandwich units are manufactured with mortars made with mixtures in different proportions of soil and coarse sand. It is recommended that the proportion of soil to coarse sand vary between 1:0 and 1:3 in volume. The sandwich having the least content of coarse sand which, when opened after 48 hours, does not show visible fissures in the mortar, will indicate the most adequate proportion of soil/sand for adobe constructions, giving the highest strength.

(a). DRY-BALL STRENGTH TEST FOR SOIL.

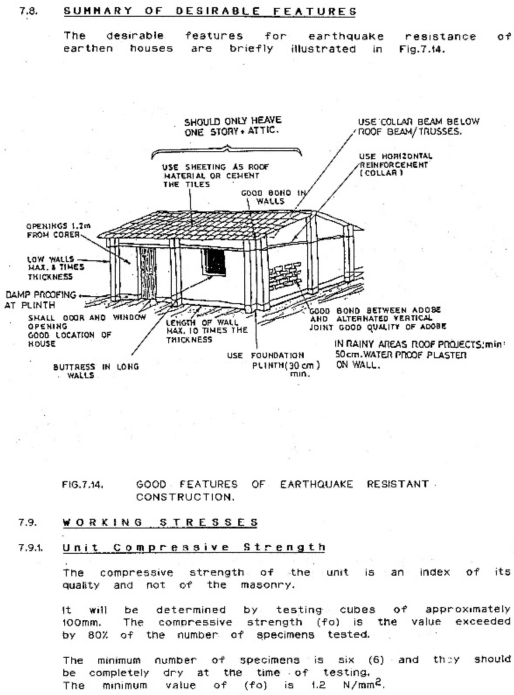
(b). TESTING OF ADOBE STRENGTH.

FIG.7.3. FIELD TESTING OF STRENGTH OF SOIL AND ADOBE.

Strength Test of Adobe

The strength of adobe can be qualitatively ascertained as follows: After 4 weeks of sundrying the adobe it should be strong enough to support in bending the weight of a man (Fig.7.3.b). If it breaks, more clay and fibrous material is to be added. Quantitatively, the compressure strength may be determined by testing 10cm cubes of clay after completely drying them. A minimum value of $1.2 N/mm^2$ will be desirable.

Fig.7.1 (c) Applicable at construction site (1986 IAEE Guidelines)



7.8. SUMMARY OF DESIRABLE FEATURES

The desirable features for earthquake resistance of earthen houses are briefly illustrated in Fig.7.14.

FIG.7.14. GOOD FEATURES OF EARTHQUAKE RESISTANT CONSTRUCTION.

7.9. WORKING STRESSES

7.9.1. Unit Compressive Strength

The compressive strength of the unit is an index of its quality and not of the masonry.

It will be determined by testing cubes of approximately 100mm. The compressive strength (fo) is the value exceeded by 80% of the number of specimens tested.

The minimum number of specimens is six (6) and they should be completely dry at the time of testing.
The minimum value of (fo) is $1.2 N/mm^2$.

Fig.7.1 (d) Desirable features of earthen construction (1986 IAEE Guidelines)

Fig.7.2 (a) Damage caused by tsunami 1992 Flores Earthquake, Indonesia

Fig.7.2 (b) Damage caused by tsunami 2004 Ache Earthquake, Indonesia

Fig.7.3 (a) Out-of-plane failure of brick masonry wall, 1994 Liwa Earthquake, Indonesia

Fig.7.3 (b) Out-of-plane failure of brick masonry wall, 2006 Central Java Earthquake, Indonesia

Fig.7.4 (a) Construction of confined masonry, Single story house, Ache, Indonesia

Fig.7.4 (b) Construction of confined masonry, Two storey house under construction Java, Indonesia

Fig.7.5 (a) Damage to stone masonry
: Un-reinforced stone masonry
2005 Northern Pakistan Earthquake

Fig.7.5 (b) Damage to stone masonry
: Damage to the stone masonry wall
2005 Northern Pakistan Earthquake

Fig..7.6 (a) Damage to wooden houses
Damage concentrated to the first storey
1995 Kobe Earthquake, Japan

Fig.7.6 (b) Damage to wooden houses
Detail of the damaged wooden house
1995 Kobe Earthquake, Japan

Fig.7.7 (a) Damage to earthen buildings: Damaged adobe 2007 Pisco Earthquake, Peru

Fig.7.7 (b) Damage to earthen buildings: Damaged tapial, 1990 Rioja Earthquake, Peru

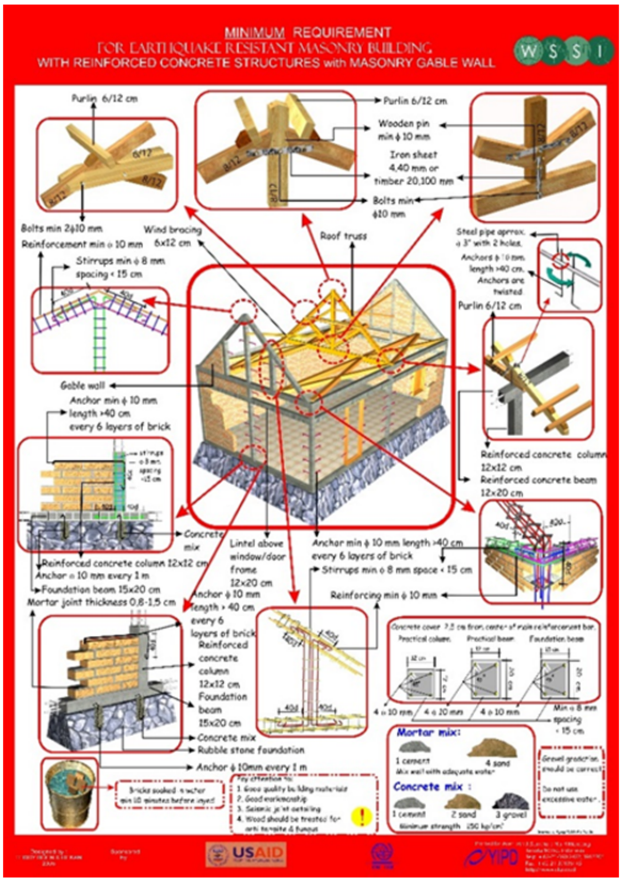


Fig.7.8 Poster for half brick confined masonry

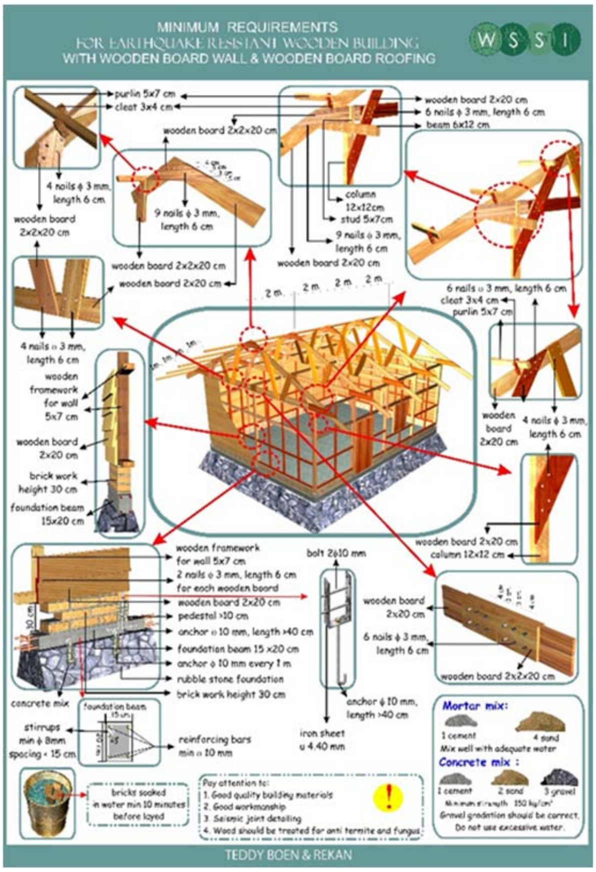


Fig.7.9 Poster for wooden construction

Appendix Housing materials worldwide; understanding through statistics

1 Introduction

Housing as a building type has a number of units however each unit's scale is relatively small. Easily available materials or techniques around the area is used for its construction in common. Therefore, the housing specifications are of great variety by region and are difficult to be recorded. So, the statistics about housing specifications worldwide have not been prepared. Even if there are domestic statistics, it is difficult to grasp the housing specifications across the countries for the differences of those contents. In order to examine the sustainable and proper strengthening of the housing which has regional character, it is necessary to understand the local construction method.

In this paper, we try to organize the housing specifications by statistical data. It is also trial to position of our object, the housing that require strengthening, among the housings in the world.

2 Existing statistics

The factor which affect housing specifications are divided geological elements (soil, vegetation, meteorological phenomenon, etc.) and social elements (economy, industrial structure, institution, etc.). Geological elements can been seen in conventional housings and these distribution has already organized such as maps. It is also known that the industrial structure affect the housing material or structure however, these distribution have not been organized.

2.1 Number of housing and its material

Statistic about housing has been summarized by UN statistics division since 1971. It has revised 7 times (2011, 2001, 1995, 1983, 1975-77, 1972-74) and is available on website [App.1]. Latest data is in 2011 and has shown in 12 tables [App.2].

One table is about housing number, and it covers 77 countries data. From this data, the ratio between the housing units and the population is 4.4 person per units in average. Compare to the world population in 2011, that is about 70 hundred millions [App.3], the number of housing units in the world can be estimated about 16 hundred millions. In developing countries, population of the units may higher than 4.4, the estimated number, 16 hundred millions, will be the number at most.

The other table shows the construction material of outer walls by 36 countries (3.6 hundred million units) [Figure App.1]. Material of outer wall dose not directly mean the structural character, however, the part is needed higher performance. Brick, adobe, and concrete are major materials and its share is 85%. Brick and adobe occupy 62% and these are assumed masonry buildings. Because the concrete contains reinforced concrete wall and concrete block masonry wall, a part of the concrete (23%) will be masonry. So at least, 62% of housing units are estimated as masonry.

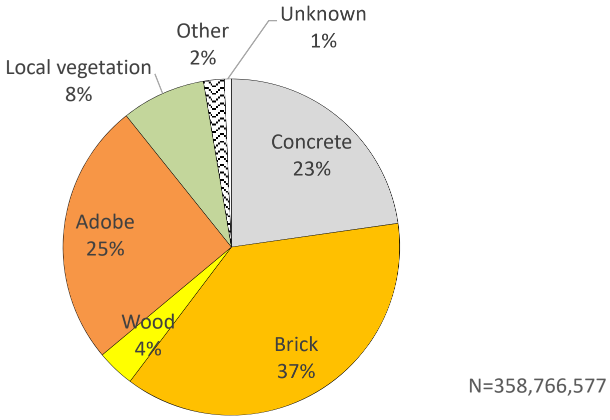


Figure App.1 Construction material of outer wall

Drawing by [App.1]

This UN statistic is not contain Japanese information about materials, however, Japanese domestic statistic covers the material of structure. By Japanese Housing and Land Survey [App.4], housing specifications are divided as wood structure 58%, steel - reinforced concrete structure 34%, and steel structure 8%. According to contents of UN statistic, it is translated to wood 58%, concrete 34%, and other 8%, respectively. In addition to Japan, obtained domestic data of Philippine [App.5], Zambia [App.6], and Nepal [App.7] are also translated to UN contents. Then it is illustrated on maps [Figure App.2].

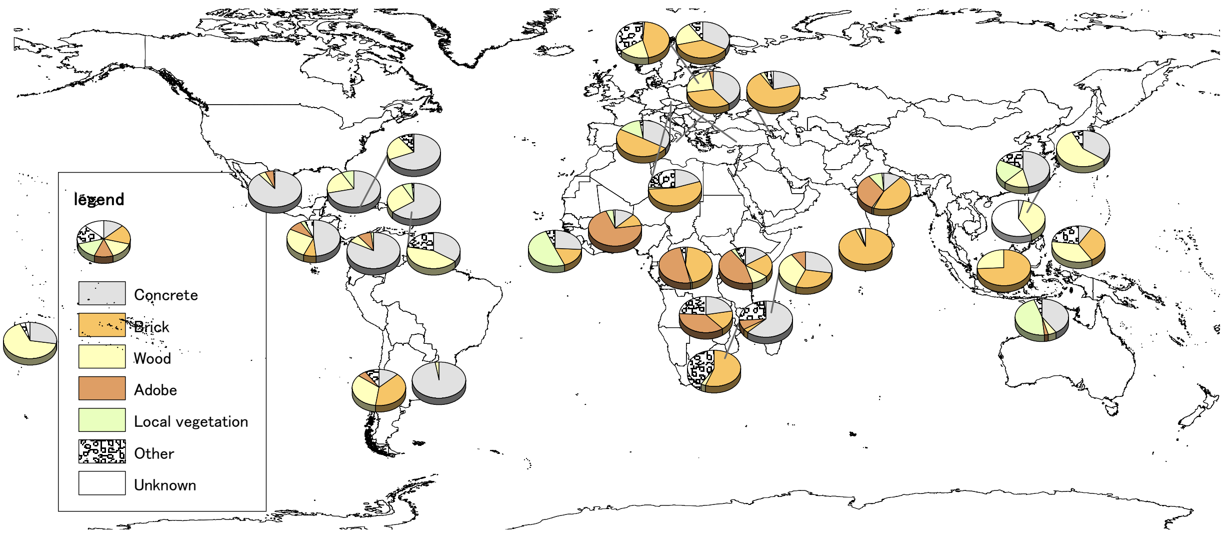


Figure App.2 Construction material of outer wall

Drawing by [App.1（except the country whose data is only Other/Unknown）] and domestic data[App.4-7]

2.2 Modern material

Modern material cement and steel can improve structural performance. Once the industry developed, it becomes workable alternative for the locally existing housing construction.

2.2.1 Cement

Statistics about cement production and consumption are summarized by CEMBUREAU [App.7, 8].

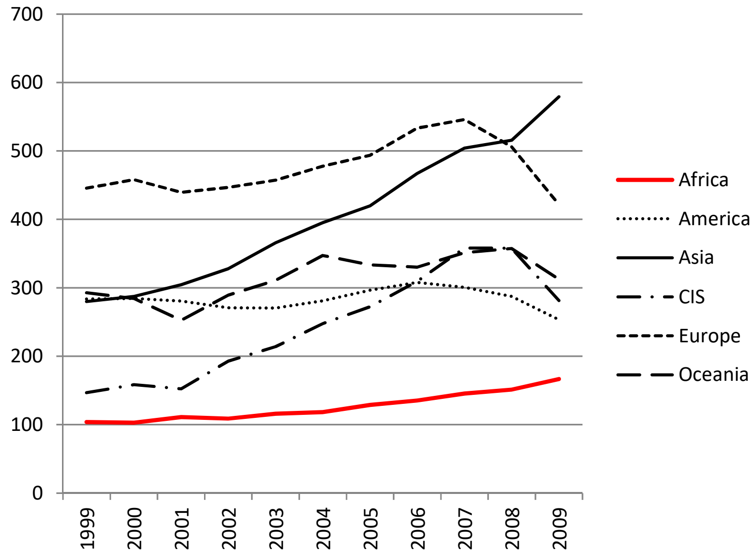


Figure App.3 Transition of cement consumption per capita（kg）

Drawing by [App.8]

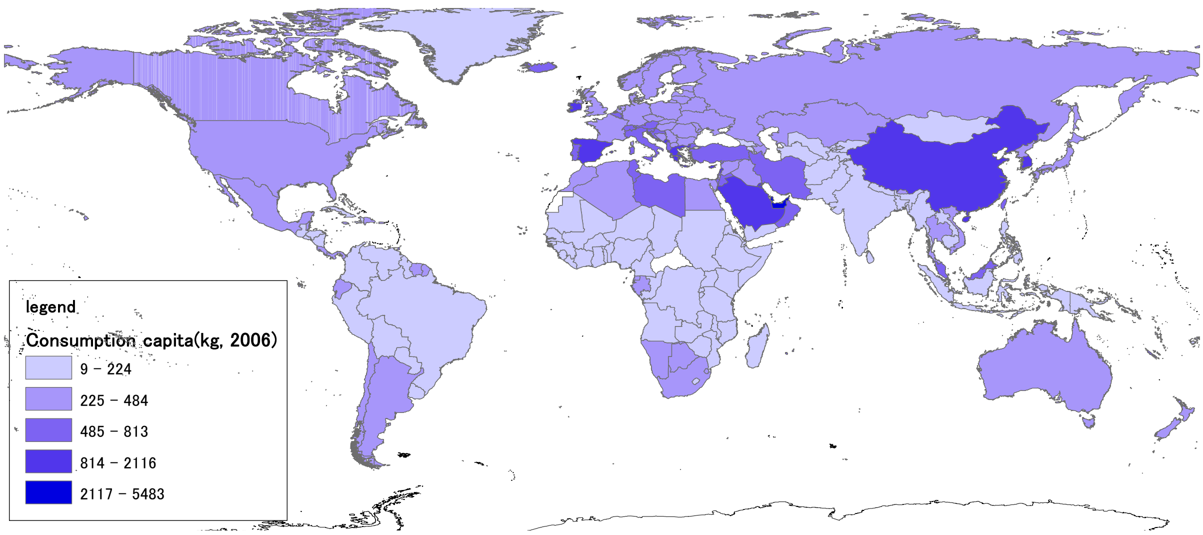


Figure App.4 Cement consumption per capita in 2006（kg）

Drawing by [App.9]

In developed countries, the demand of cement is stagnation. On the other hand, it is growing in developing countries. When the world economy met the depression in 2008, developed countries met depression. However, Asia and African countries have kept growing (Figure App.3, 4).

Recently developing countries meet urbanization which leads infrastructure development with large demand of cement. Cement production need constant production by the character of the industry. So, once the production and delivery route is consolidated, it will be easy to use for the building material as well as housing.

2.2.2 Steel

Statistics about steel production and used amount are summarized by World Steel Association [App.9,10].

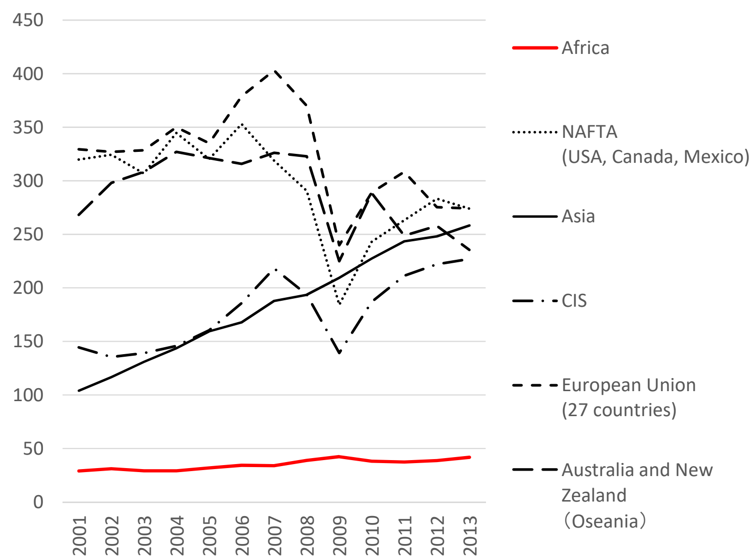


Figure App.5 Transition of used amount steel per capita（kg）

Drawing by [App.10]

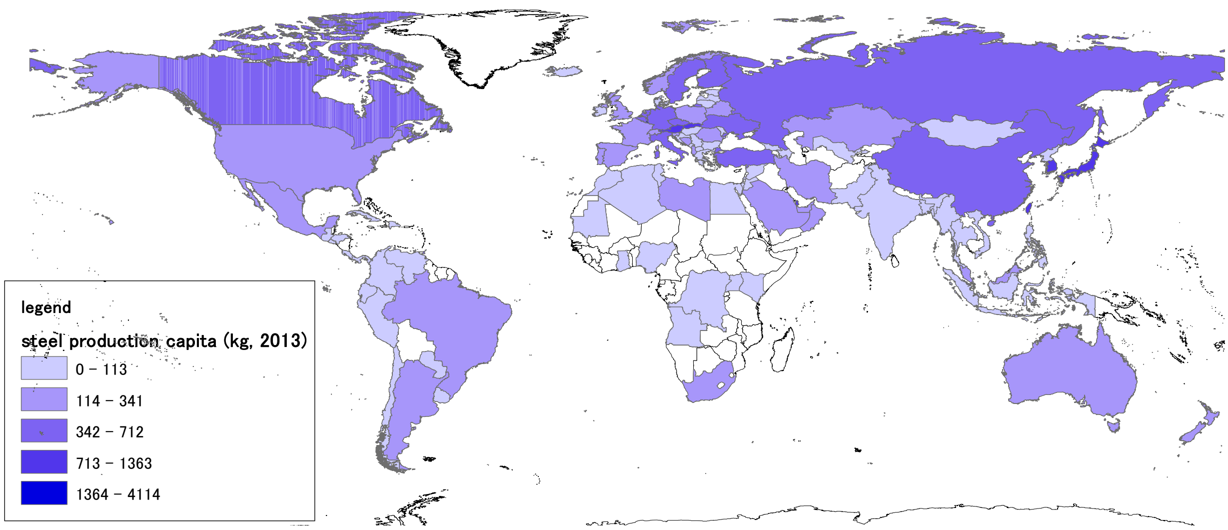


Figure App.6 Steel production per capita in 2013（kg）

Drawing by [App.11]

In developed countries, the demand of steel is stagnation, same as cement. Asia region keeps growing, however, growth of African region is still small amount (Figure App.5, 6).

Cement can be delivered by raw material. Steel is delivered by variously fabricated (rebar, sheet, shape steel). It means that the steel's value of commodity is higher than cement. In addition, production facility of steel is more advanced than cement. So production facility of steel is not widely distributed. Then, there is a differences the usability of those materials for housing.

3. Conclusion

The followings are understood about number of housing and those materials.

- Average population per a housing is 4.4 by the data containing 77 countries. The number of housing are estimated 16 hundred millions at most.
- 85% of construction material of outer walls is brick, adobe, and concrete by the data containing 36 countries. At least, the share of masonry housing unites is estimated 65%.
- Cement consumption is stagnation in developed countries, and growing in Asian and African countries.
- Steel used amount is stagnation in developed countries, and growing in Asian besides still small amount in African.
- Cement and steel are both modern material, however, the usability for the housing materials are different by value of commodity, the production facility, the situation of distribution, and the situation of the delivery.

The statistics about housing specifications covers limited countries, however, these information helps as a general and perspective understanding. To complement particular situation by domestic statistics, it will lead to figure out the actual condition of housing specifications worldwide.

References

[App.1] UN Statistic division: Compendium of Human Settlements Statistics / Compendium of Housing Statistics http://unstats.un.org/unsd/demographic/scaoncerns/housing/default.htm

[App.2] It shown the number of living quarters, the number of occupied housing by type, urban/rural location, number of rooms, equipment or facility (water, toilet, bathing, kitchen, fuel) , construction material of outer walls.

[App.3] UN: World Urbanization Prospects, the 2011 Revision, http://esa.un.org/unpd/wup/

[App.4] the Ministry of Internal Affairs and Communications : 2013Housing and Land Survey, http://www.e-stat.go.jp/SG1/estat/NewList.do?tid=000001063455

[App.5] The National Statistics Office: The 2010 Census of Population and Housing,

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