Annex 3

Country Report

Indonesia

Country Report WFEO-UNESCO
Guideline for low rise wall type structures

INDONESIA

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1 Introduction

Indonesia is an archipelagic island country in Southeast Asia, lying between the Indian Ocean and the Pacific Ocean (Fig. 1). It stretches almost 4000 kilometers from east to west with a total area of 1,904,569 square kilometers. The major islands are Sumatra, Java, Kalimantan (Indonesia's part of Borneo), Bali, Sulawesi and Irian Jaya (also called West Papua), as shown in Fig. 2. The total population is 242,968,342 (2010 est.) [1]. The capital city of Indonesia is Jakarta where is located in Java Island.

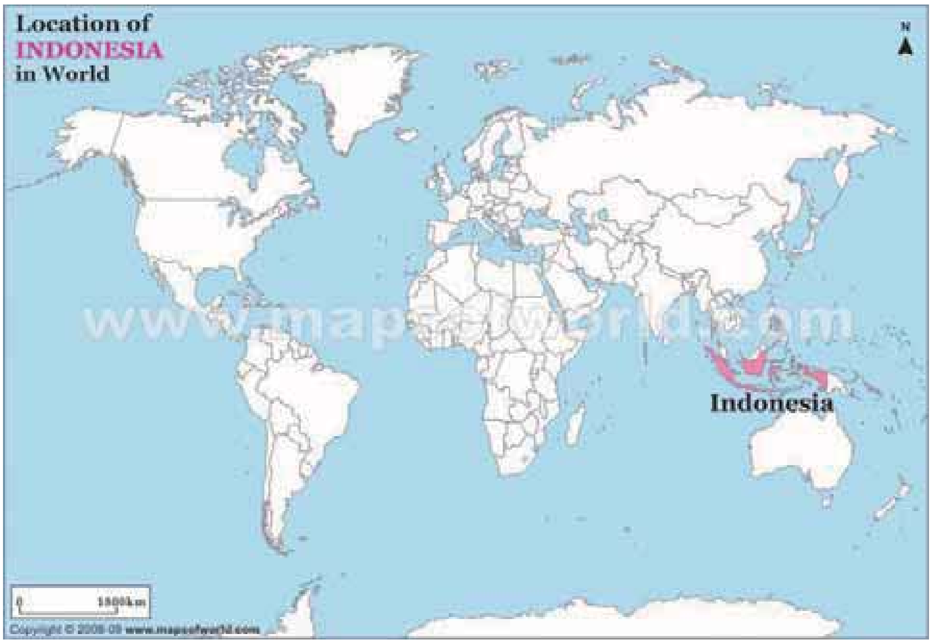

Figure 1 Location of Indonesia.

(Source: http://www.mapsofworld.com/indonesia/indonesia-location-map.html)

Figure 2 Detailed map of Indonesia.

(Source: http://www.indonesiamatters.com/86/idonesian-provinces-map)

2 Seismic sources and earthquake damage in Indonesia

Indonesia is situated within a zone of intense seismic activity known as the Pacific Ring of Fire where the Indo-Australian Plate is being subducted beneath the Eurasian Plate. The subduction creates regular earthquakes as reported by Indonesian Meteorological and Geophysical Agency in Fig. 3. About 30% of the great earthquakes in the world have been occurred on Indonesia area within last decades. Several of these earthquakes were followed by tsunami.

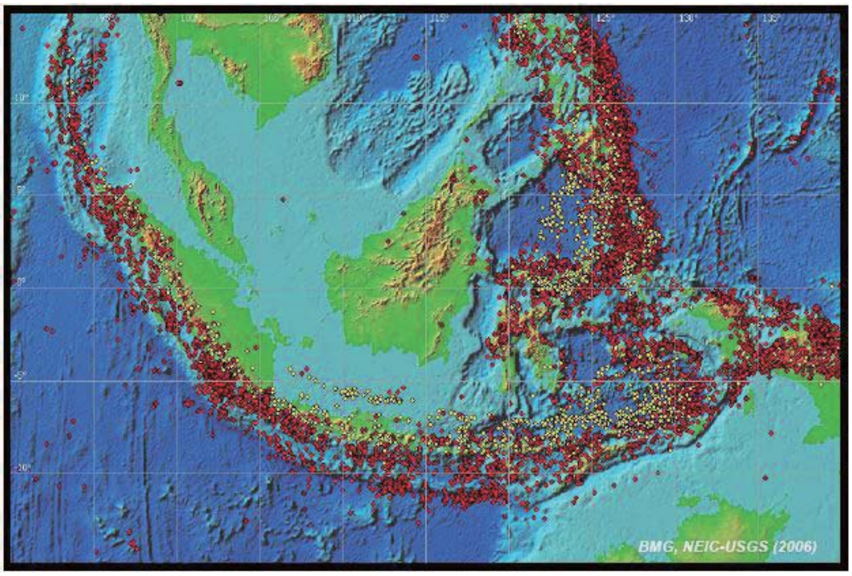

Figure 3 Epicenter map of Indonesia's Earthquakes
(http://dianwida.files.wordpress.com/2009/09/map-gempa.jpg?w=460&h=307)

Figure 4 Damage to R/C buildings and roads due to the Sep. 30, 2009 earthquake.

Due to strong ground motion, large numbers of infrastructures, including residences, roads, bridges, water supply systems, telecommunication facilities have been damaged. Field observation after earthquake showed that most of RC frames structures with brick and hollow concrete block masonry walls have been flattened as shown in Fig.4. These photographs were taken after Sumatran September, 30 2009 earthquake. Many people were trapped under the rubbles. Table 1 shows the recent destructive earthquakes and damage occurred in Indonesia [2-4]. In case of residences and houses, most damage was observed to unconfined masonry and timber frame structures.

Table 1 Recent earthquakes and damage in Indonesia

No	Earthquake name	Magnitude (M_L)	Deaths/ Lost	Injured	Damaged Building			Damaged Houses		
					Severe	Moderate	Light	Severe	Moderate	Light
1	Tsunami Aceh earthquake, December 26, 2004	8.9	220,240	na	3,017	616	1,435	85,804	142,489	na
2	Nias earthquake, March 28, 2005	8.6	915	75,499	1,451		77	13,480	39,722	
3	Yogyakarta earthquake, May 27, 2006	6.3	5,737	38,423	127,879	182,392	261,219			
4	West Sumatra-Bukitting gearthquake, March 6, 2007	6.4				2,543		12,948	12,801	17,970
5	Bengkulu and Mentawai earthquake, September 12 and 13, 2007	8.4 and 7.9			2			88,487	10505	49,433
6	Tasikmalaya earthquake, September 2, 2009	7.3			8,585		9,111	900		512
7	West Sumatra-Padang earthquake, September 30, 2009	7.6	>1000	>2000	3,927	2,236	1,767	119,005	73,733	78,802
8	West Sumatra-Mentawai earthquake, October 26, 2009	7.2	546	412	14			522		204

3 Regulations for building design

3.1 Seismic design regulations

Indonesia has been published a seismic design code called SNI 03-1726-2002 i.e. Procedures for Earthquake Resistance Design for Houses and Buildings [5]. This code is intended to govern the seismic design of building, however, the code are not applied to buildings in the following cases.

a) Buildings with unusual structural systems or those still require any proofs of eligibility.
b) Buildings with a base isolation system.
c) Construction except for buildings/houses, such as bridges, tunnels, docking ports, offshore platforms and other facilities.

The code uses the following documents as references.

1. SNI 03-1726-1989 "Procedures for Earthquake Resistance Design for Houses and Buildings", Ministry of Public Works.
2. National Earthquake Hazard Reduction Program (NEHERP) Recommended Provisions for Seismic Regulation for new Buildings and Structures, 1997 Edition, Part 1- Provisions, Part 2 – Commentary; FEMA 302, Feb. 1998.
3. Uniform Building Code (UBC), 1997 Edition, Volume 2, Structural Engineering Design Provisions, International Conference of Building Official, April 1997.

In order to ensure the building's structure stable during strong ground motion, the earthquake loading have to be applied following the guidelines in the code. The earthquake plan is set considering a return period for 500 years and the possibility is limited to 10% over building life time of 50 years.

3.2 Seismic design of regular structure

The building's structures must be designated in regular form, i.e. they meet the following requirements [5].

1. Buildings are no more than 10 stories or 40 meters.
2. Buildings have a rectangular plan with no bulges or small bulges having the length of projection in each direction less than 25% of each dimension of floor plan.
3. Buildings do not have reentrant corner or have reentrant corner having the length less than 15% of the largest plan dimension.
4. Buildings have lateral force resisting system that is perpendicular and parallel to each orthogonal axis of the building.

5. Buildings have a horizontally regular shape without large set-backs. Each floor area is equal to or larger than 75% of the largest floor area underneath. However, penthouses having two stories or less are not considered as set-backs.
6. Buildings have uniform lateral stiffness. Difference of lateral stiffness is less than 30% between stories.
7. Buildings have a uniform distribution of mass along the height, which means that each floor mass is no more than 150% of the floor mass above/below the concerned floor. Roofs and penthouses do not need to comply with this provision.
8. Buildings have continuous vertical lateral force resisting system.

When the requirements mentioned above are satisfied, a static equivalent analysis may be conducted to determine the effect of earthquake loading to building's structure. Main parameters for the analysis are given as follows.

Base shear, V by equivalent static earthquake loads is calculated by using Eq. 1.

$$V = \frac{C_1.I.}{R}.W_t \qquad (1)$$

where,

C_1 = Spectral response.

I = Important factor.

W_t = Total of vertical dead load and reduced vertical live load.

R = Reduction factor.

Seismic coefficient (C_1) is determined based on seismic zone (Fig. 5; zone 6 is the highest), natural period, and soil types, as shown in Fig. 6. Fundamental natural vibration period of a structure, T in each major axis direction can be determined by the Reyleigh's formula in Eq. 2.

$$T = 6.3\sqrt{\frac{\sum_{i=1}^{n} W_i d_i^2}{g\sum_{i=1}^{n} F_i d_i}} \qquad (2)$$

where, d_i = Horizontal displacement of concerned story.

Soil is classified into stiff, medium or soft type according to soil properties as shown in table 2 calculated using Eq.3 to Eq.5.

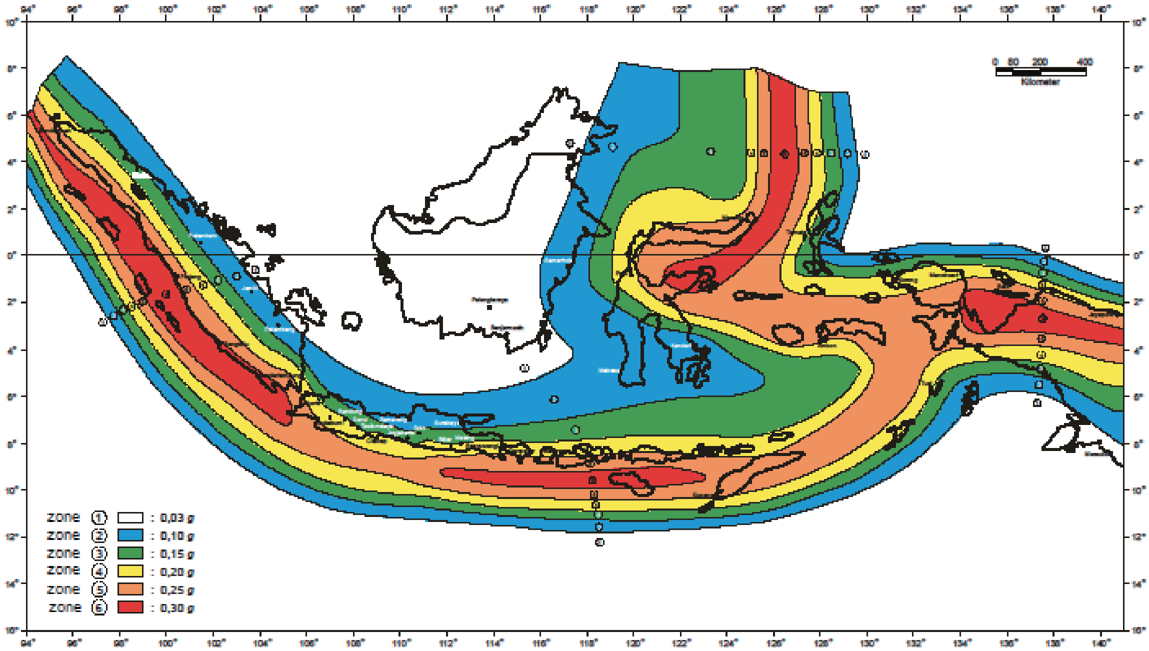

Figure 5 Seismic zones in Indonesia with assumed peak accelerations.

Table 2 Soil types

Soil description	**Weight average soil properties for top 30m of soil profile**		
	Shear wave velocity, V_s (m/sec)	**SPT, N**	**Undrained shear strength, S_u (kPa)**
Stiff soil	≧350	≧50	≧100
Medium soil	175 to 350	15 to 50	50 to 100
Soft soil	<175	<15	<50
	It also includes any soil profile with more than 3 m thick of soft soil with *PI* > 20, W_n > 40%, and *Su* < 25 kPa		

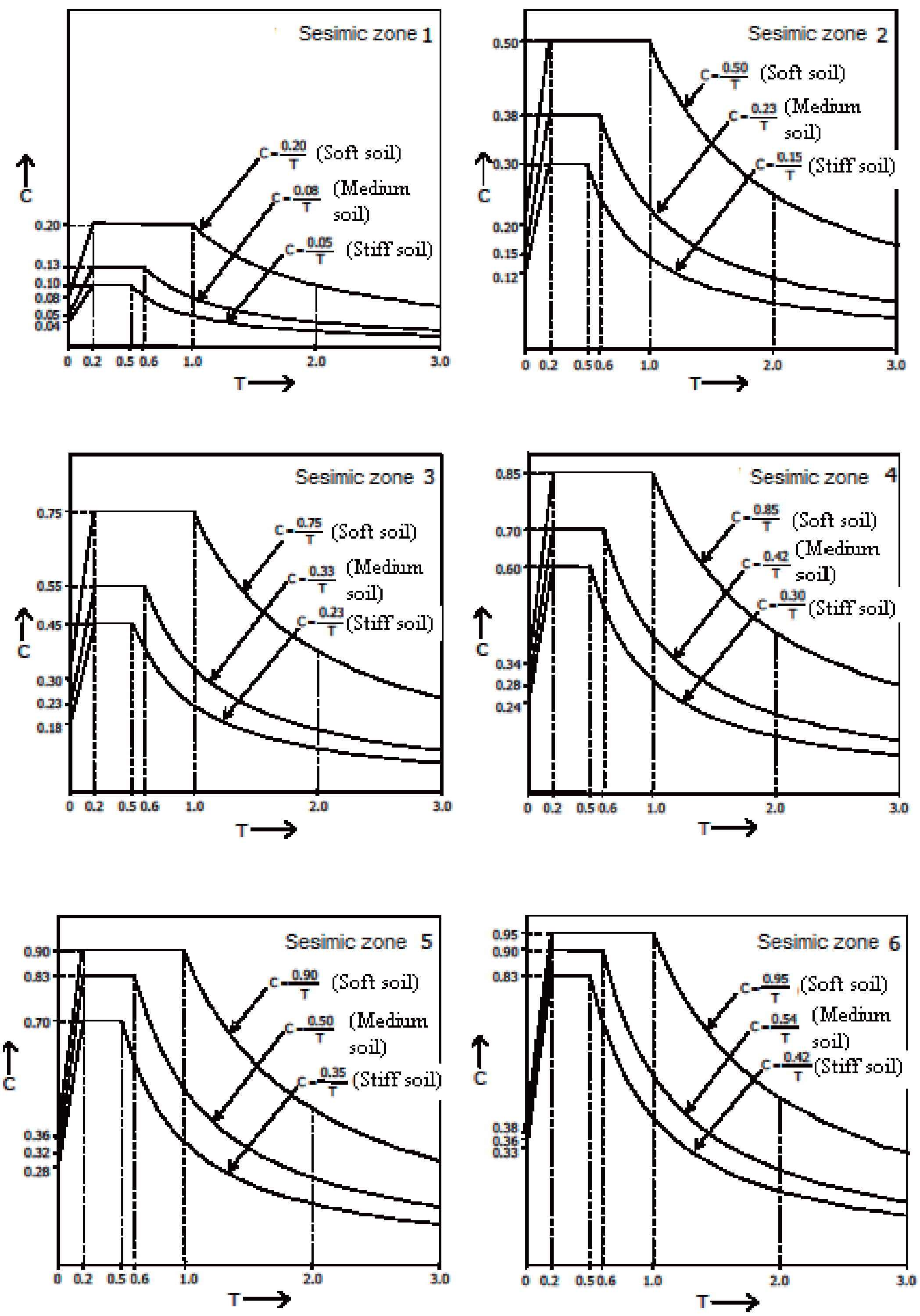

Figure 6 Spectral responses under earthquakes for each seismic zone.

$$\bar{V}_s = \frac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} t_i / v_i} \tag{3}$$

$$\bar{N} = \frac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} t_i / N_i} \tag{4}$$

$$\bar{S}_{su} = \frac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} t_i / S_{ui}} \tag{5}$$

where, t_i = thickness of *i*th-layer, V_{si} = shear wave velocity on *i*th-layer, N_i = standard penetration test result of *i*th-layer, S_{ui} = undrained shear strength of *i*th-layer, m = layer number, PI = plasticity index of clay, w_n = water content, and S_u = shear strength of concerned layer.

Importance factor, I is obtained by using Eq.6 which depends on building categories as shown in table 3.

$$I = I_1 \,.\, I_2 \tag{6}$$

where, I_1 is modification factor on return period due to the probability of seismic exceedance. I_2 is modification factor on return period due to the building life time. I1, I2 and I are given in accordance with Table 3.

Reduction factor, R is defined by Eq.7,

$$1.6 \le R = \mu . f_1 \le R_m \tag{7}$$

where, ductility factor of a building, μ is determined by Eq.8 or governed in Table 4 based on the performance level.

$$1.0 \le \mu = \frac{\delta_m}{\delta_y} \le \mu_m \tag{8}$$

where,

f_1 = over strength factor (its value is fixed at 1.6)

δ_m = maximum deformation.

δ_y = deformation at initial yielding.

μ_m = ultimate ductility.

Table 3 Importance factor for various building categories.

Type of Building	Importance Factor		
	I_1	I_2	I
Occupancy Structures (Buildings for residence, shop and office. etc)	1.0	1.0	1.0
Special structures (monuments, museum, etc)	1.0	1.6	1.6
Essential facilities that should remain functional after an earthquake, such as hospitals, food storages, emergency relief administrations, electric stations, water suppliers, and radio/television facilities	1.4	1.0	1.4
Distribution facilities for gas or petroleum products in urban areas	1.6	1.0	1.6
Structures for supporting/containing dangerous substances (such as acids, toxic substances, etc.)	1.6	1.0	1.6
Other structures	1.5	1.0	1.5

Table 4 Ductility and reduction factor based on performance of building

Performance of building	μ	R
Elastic	1.0	1.6
Partial ductile	1.5 2.0 2.5 3.0 3.5 4.0	2.4 3.2 4.0 4.8 5.6 6.4
Ductile	5.3	8.5

Ultimate ductility (μ_m), maximum reduction factor (R_m), and overstrength factor (f_1), of a building are determined depending on structural systems, as shown in Table 5.

Table 5 Ultimate ductility (μ_m), maximum reduction factor (R_m), and overstrength factor (f_1).

Structural system	System description	μ_m	R_m	f_1
Bearing wall system	1. RC Shear wall	2.7	4.5	2.8
	2. Light steel-frame Bearing wall with tension-bracing	1.8	2.8	2.2
	3. Bracing frame, where bracing carries gravity load			
	a. Steel	2.8	4.4	2.2
	b. RC (not for seismic zone of 5 & 6)	1.8	2.8	2.2
Building Frame System	1. Eccentric steel bracing frame (RBE)	4.3	7.0	2.8
	2. RC Shear wall	3.3	5.5	2.8
	3. Ordinary bracing frame			
	a. Steel	3.6	5.6	2.2
	b. RC (not for seismic zone of 5 & 6)	3.6	5.6	2.2
	4. Special concentrically braced frame			
	a. Steel	4.1	6.4	2.2
	5. Ductile RC shear wall	4.0	6.5	2.8
	6. Full ductile cantilever shear wall	3.6	6.0	2.8
	7. Partial ductile cantilever shear walls	3.3	5.5	2.8
Moment-Resisting Frame System	1. Special Moment Resisting Frame (SMRF)			
	a. Steel	5.2	8.5	2.8
	b. RC	5.2	8.5	2.8
	2 Concrete Intermediate Moment Resisting Frame (IMRF)	3.3	5.5	2.8
	3. Ordinary Moment Resisting Frame (OMRF)			
	a. Steel	2.7	4.5	2.8
	b. RC	2.1	3.5	2.8
	4. Special Truss Moment Frame (STMF) of Steel	4.0	6.5	2.8
Dual system	1. Shear wall			
	a. RC with SMRF	5.2	8.5	2.8
	b. RC with OMRF of steel	2.6	4,2	2.8
	c. RC with IMRF	4.0	6.5	2.8
	2. EBF of Steel			
	a. with SMRF	5.2	8.5	2.8
	b. with OMRF	2.6	4.2	2.8
	3.Ordinary braced frame			
	a. Steel with steel SMRF	4.0	6.5	2.8
	b. Steel with steel OMRF	2.6	4.2	2.8
	c. RC with SRPMK (zone 5 & 6 excluded)	4.0	6.5	2.8
	d. RC with concrete SMRF (zone 5 & 6 excluded)	2.6	4.2	2.8
	4. Special concentrically braced frames			
	a. Steel with SRPMK	4.6	7.5	2.8
	b. Steel with SRPMB	2.6	4.2	2.8
Cantilever Column building System	Cantilever column structure	1.4	2.2	2.0
Shear Wall – Frame Interaction system	Concrete (zone 3, 4, 5 & 6 excluded)	3.4	5.5	2.8
Single sub-system	1. Open steel frame	5.2	8.5	2.8
	2. Open RC frame	5.2	8.5	2.8
	3.Open reinforced concrete frame with pres-tress	3.3	5.5	2.8
	4. Full ductile framed concrete	4.0	6.5	2.8
	5. Partial ductile framed concrete	3.3	5.5	2.8

Equivalent static earthquake loads, *Fi* captured on floor levels are determined by Eq.9.

$$F_i = \frac{W_i . Z_i .}{\sum_1^n W_i \, Z_i} . V \qquad (9)$$

If ratio of building height to length of floor plan in each direction is equal to/more than 3 (H/L ≧ 3), 10% of Base shear (0.1 V) must be applied to the top of floor, whereas 90% of that is distributed on the other floors calculated based on Eq.10.

$$F_i = \frac{W_i . Z_i .}{\sum_1^{n-1} W_i \, Z_i} . 0.9 . V \qquad (10)$$

where,

W_i = Weight of concerned story.

Z_i = Height of concerned story.

n = Total number of story.

3.3 Structural regulations for low rise buildings and houses

In Indonesia, there are different types of low rise building: reinforced concrete (RC) frame with brick masonry and unreinforced/reinforced hollow concrete block masonry. All types are called as confined masonry.

3.3.1 One story building

Most one story buildings are confined masonry buildings, in particular RC frames with brick masonry. According to the building standard law, one story confined masonry buildings should meet the following requirements [6].

1. Compressive strength of concrete must be at least 175 kg/cm2 with a mixture of cement: sand: aggregate: water = 1: 2: 3: 0.5.
2. Sand and aggregate must be clean without mud.
3. Casting of frame must be done continuously.
4. Tension strength of bar must be at least 2400 kg/cm2.
5. For bearing walls with no beam and column, wall area must be no more than 16 m2. Otherwise, lintel beams of 15 cm x 20 cm and columns of 15 cm x 15 cm must be constructed.
6. Minimum diameter of longitudinal/shear reinforcement for lintel beams and columns is 10 mm/6 mm. Spacing of shear reinforcement is at least 150 cm. Requirements for details of reinforcements are shown in Fig. 7.

7. Minimum diameter of longitudinal/shear reinforcement for foot beams is 12 mm/8 mm, as shown in Fig. 8.
8. Anchor of minimum diameter of 10 mm and length more than 40 cm must be placed at every 6 layer of brick for connecting between column and wall as shown in Figure 9.

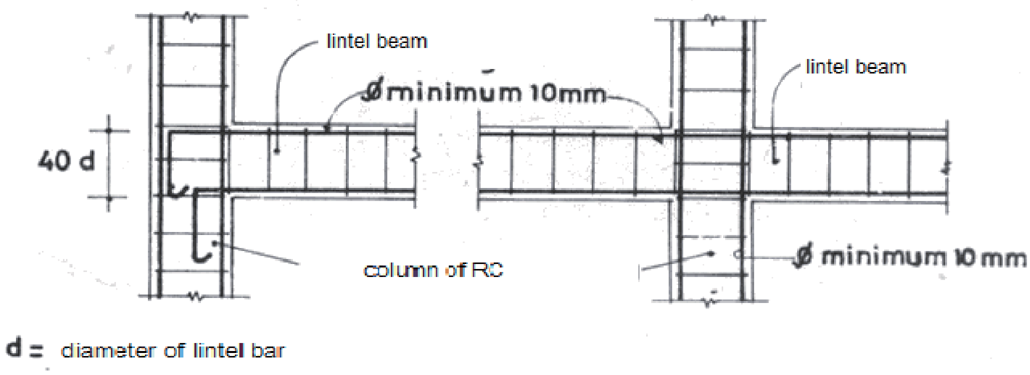

Figure 7 Details of lintel beam and column.

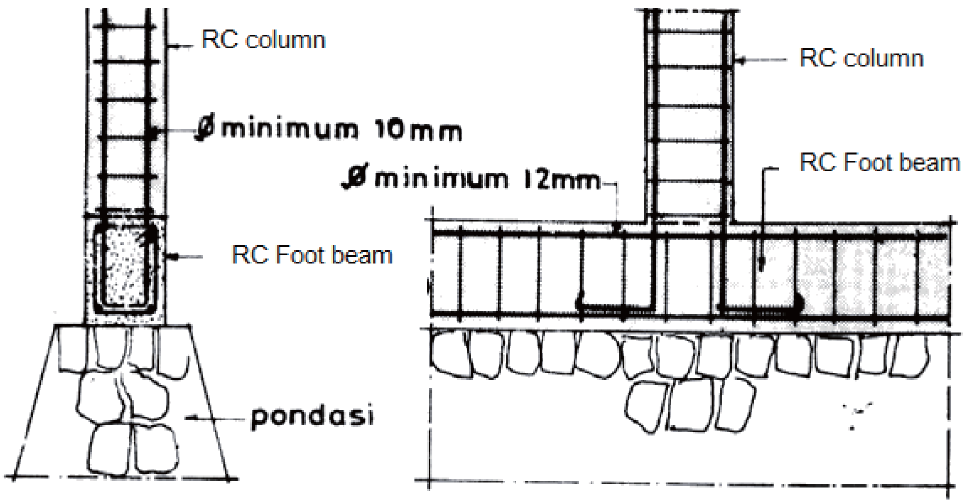

Figure 8 Details of foot beam and column.

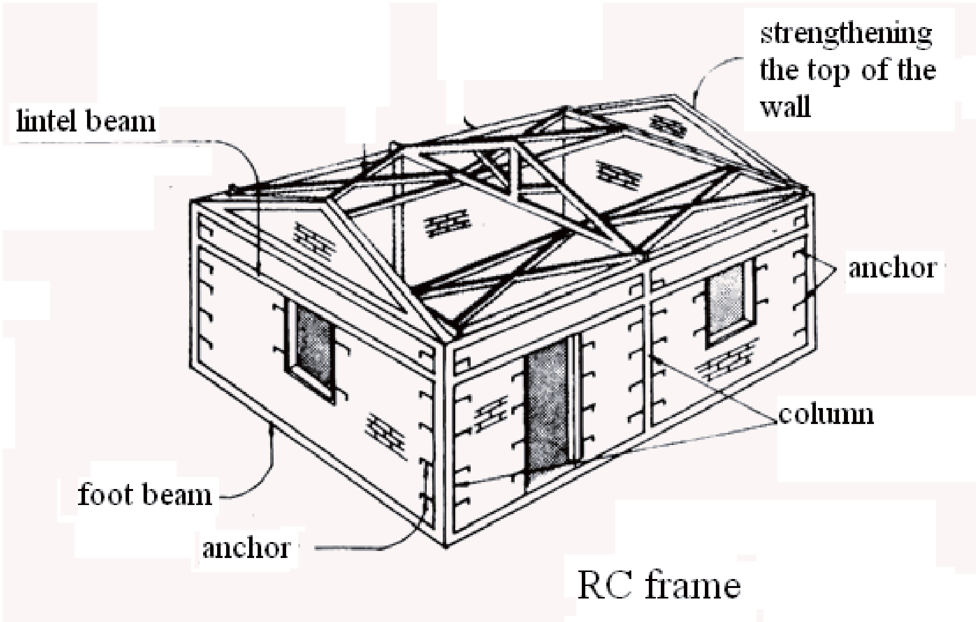

Figure 9 RC frame structure with masonry wall panel

3.3.2 Multi story building

Most multi story buildings are confined masonry buildings, in particular RC frames with brick masonry. The standard law for multi story building involves the following requirements [6].

1. Minimum compressive strength of concrete is 175 kg/cm2 and minimum reinforcement strength is 2400 kg/cm2.
2. Diameter of shear reinforcement for beams and columns is at least 8 mm. Amount of reinforcements in beams and columns must be calculated based on existing Indonesian standard (RC building design standard of Indonesia [7]).
3. Column and beam must contain at least 4 steel bars.
4. Top reinforcement of slabs must be embedded in beam at least 40 times the diameter, as shown in Fig. 10.
5. Requirements for details of reinforcements at a roof/floor beam-exterior column joint are shown in Fig. 11/Fig. 12.
6. Requirements for details of reinforcements at a floor beam-interior column joint are shown in Fig. 13.
7. Requirements for details of reinforcements around foundations are shown in Fig. 14.

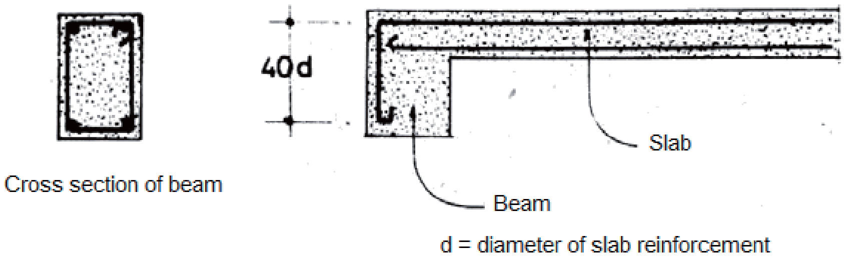

Figure 10 Details of beam-slab connection.

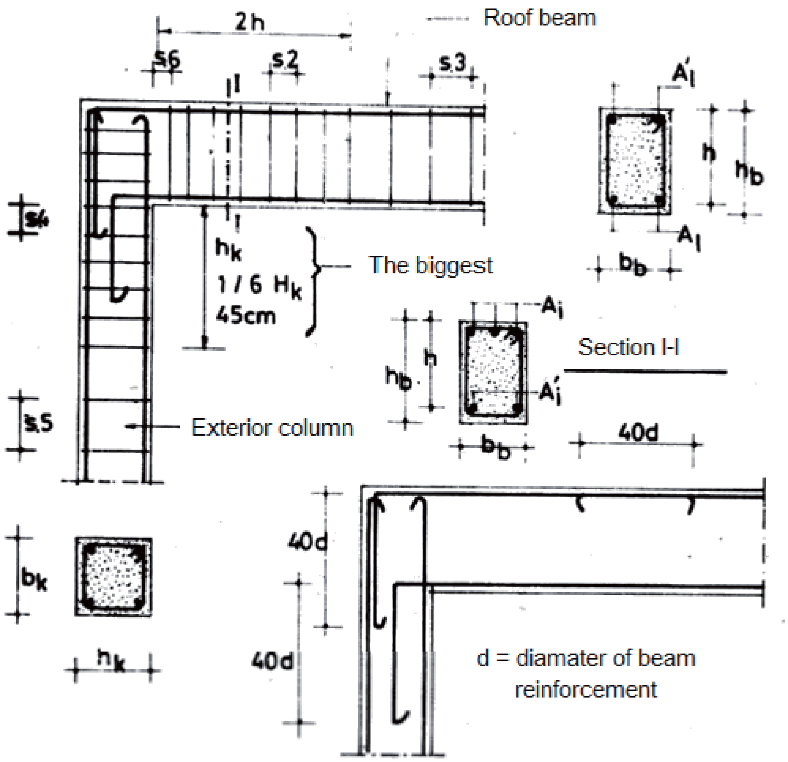

Figure 11 Details of roof beam-exterior column joint.

where,

s2 maximum $= \frac{h}{4}$, 16 d, 15 cm — the smallest

d=diameter of reinforcemen of beam

s3 maximum $= \frac{h}{2}$, 15cm — the smallest

s4 maximum = 10cm

s5 maximum $= \frac{b_k}{2}$, 20cm — the smallest

s6 maximum = 7,5cm

diameter of shear reinforcement of beam and column; minimum 9 mm

$A_l \text{ min.} = A_l' \text{ min} = \frac{14\, b_b\, h}{\sigma_{au}}$

$A_i \text{ min.} = \frac{14\, b_b\, h}{\sigma_{au}}$

$A_i' \text{ min.} = \frac{14\, b_b\, h}{\sigma_{au}}$, $= 0{,}5\, A_i$ — The biggest

(σ_{au} = yielding stress in kg/cm2

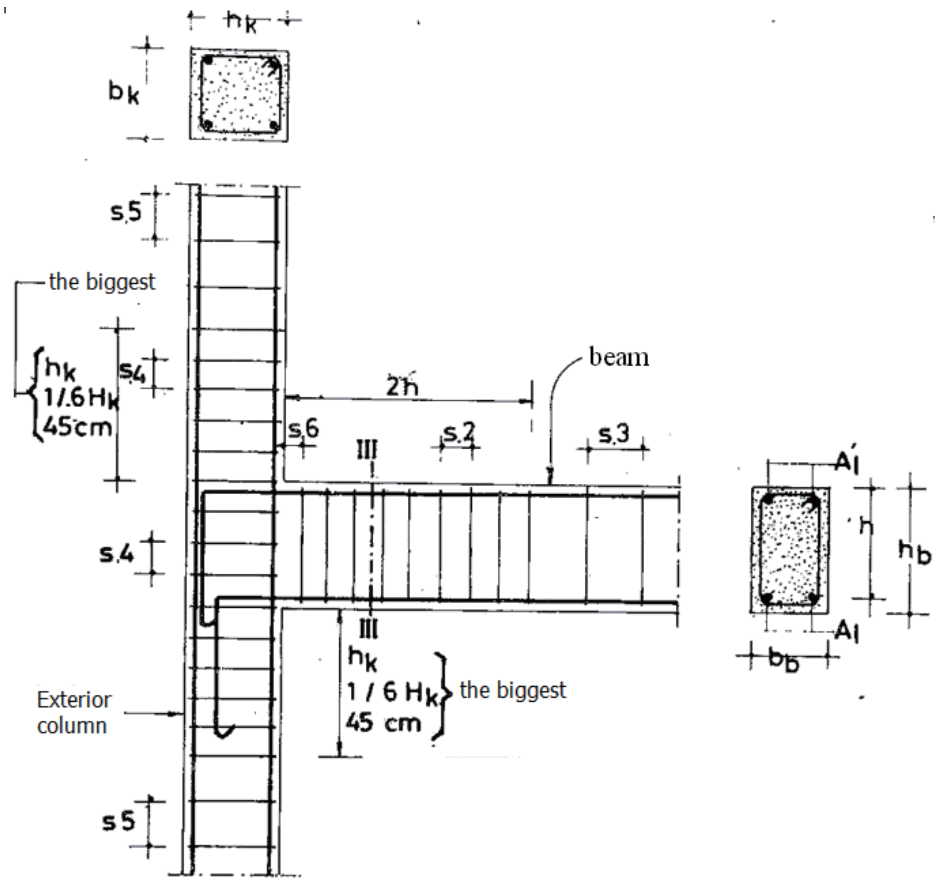

Figure 12 Details of floor beam-exterior column joint.

where,

$$s_2 \text{ maximum} = \left.\begin{array}{l} \frac{h}{4} \\ 16\,d \\ 15\text{ cm} \end{array}\right\} \text{the smallest}$$

d=diameter of reinforcement of beam

$$s_3 \text{ maximum} = \left.\begin{array}{l} \frac{h}{2} \\ 15\text{cm} \end{array}\right\} \text{the smallest}$$

$$s_4 \text{ maximum} = 10\text{cm}$$

$$s_5 \text{ maximum} = \left.\begin{array}{l} \frac{bk}{2} \\ 20\text{cm} \end{array}\right\} \text{the smallest}$$

$$s_6 \text{ maximum} = 7{,}5\text{cm}$$

minimum diameter of shear reinforcement is 9mm

$$A_l \text{ minimum} = A'_l \text{ minimum} = \frac{14\, b_b h}{\sigma_{au}}$$

$$A_i \text{ minimum} = \frac{14\, b_b h}{\sigma_{au}}$$

$$A'_i \text{ minimum} = \left.\begin{array}{l} \frac{14\, b_b h}{\sigma_{au}} \\ 0{,}5\, A_i \end{array}\right\} \text{the biggest}$$

(σ_{au} = yielding stress of reinforcement - kg/cm^2).

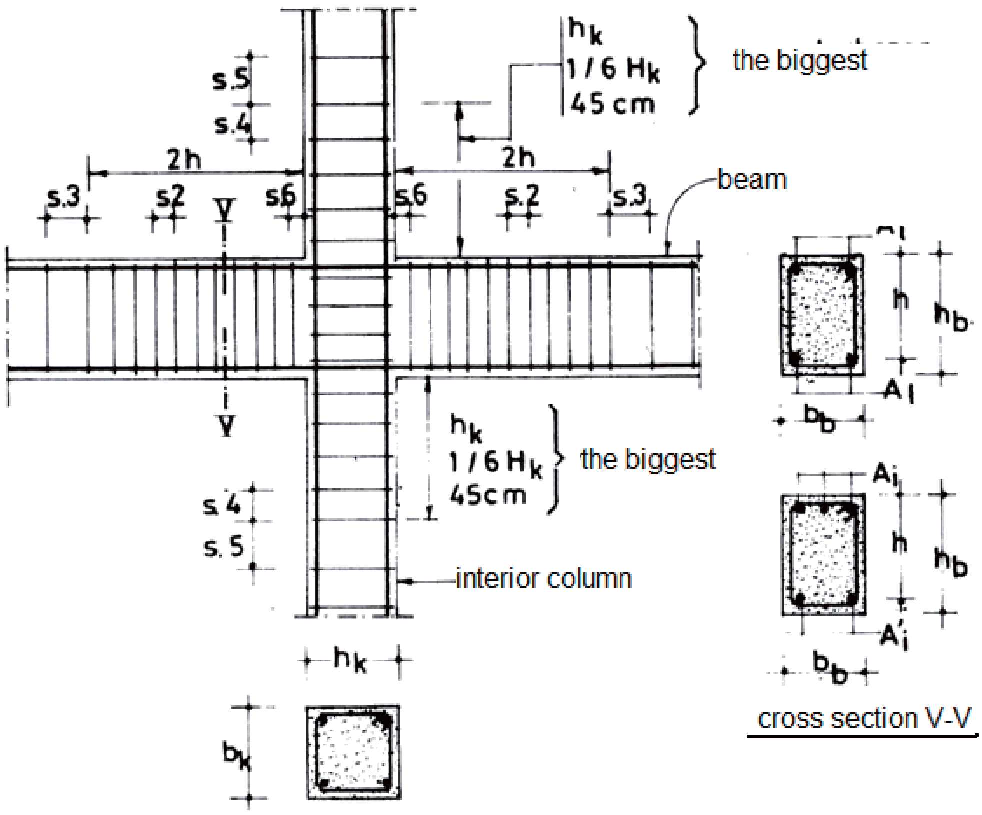

Figure 13 Details of floor beam-interior column joint.

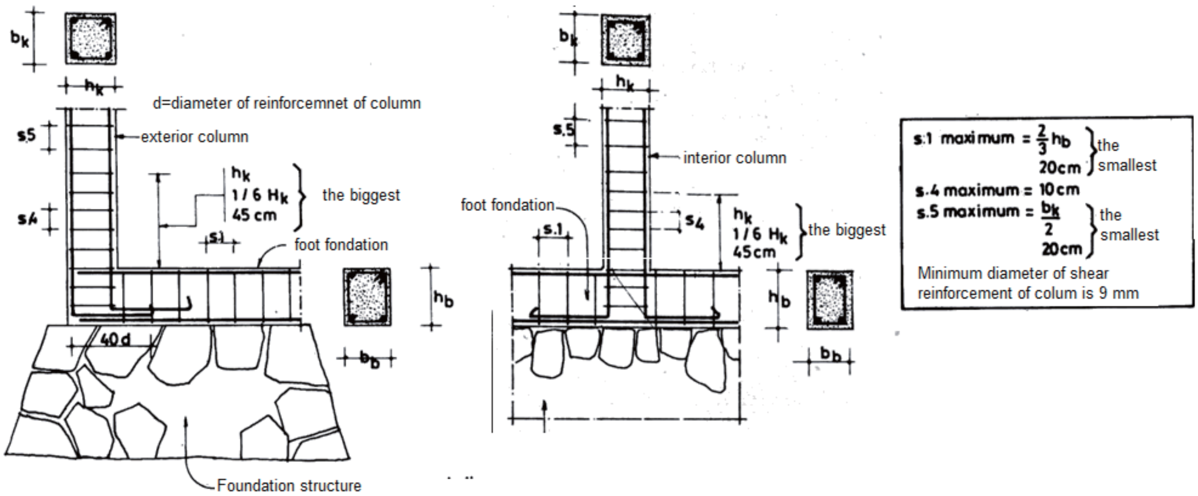

Figure 14 Details of column bottom and foundation.

3.3.3 Residence/housing

In Indonesia, houses are built using timber, confined masonry (includes confined brick masonry and reinforced hollow concrete masonry), and unconfined brick masonry. However, unconfined brick masonry does not have any regulations (is not recommended).

3.3.3.1 Timber structure

Timber structures are wood frame structures which with notch joint using at least 4 bolts with diameter of 10 mm at a joint. In Indonesia, several timber structures infilled with different types of wall are built: timber structure with wood panels, timber structure with brick walls, and their hybrid.

3.3.3.2 Confined masonry structure

a. Single-story house

1. Unreinforced brick wall

1. For walls with no beam and column, wall area must be no more than 12 m2.
2. Compressive strength of brick is at least 30 kg/cm2.
3. Compressive strength of mortar used for joint material and finishing is at least 30 kg/cm2 with a mixture of cement : sand = 1 : 6.
4. Thickness of wall finishing is at least 1 cm.
5. Anchor of minimum diameter of 10 mm and length more than 40 cm must be placed at every 6 layer of brick.

2. Unreinforced hollow concrete wall

1. Mixture for hollow concrete blocks must be cement : sand = 1 : 10.
2. Compressive strength of hollow concrete blocks is at least 15kg/cm2

b. Two-story house

1. Unreinforced brick wall

1. Compressive strength of concrete is not less than175 kg/cm2 and tension strength of bar is not less than 2400 kg/cm2
2. Minimum diameter of beam and column hoop is 8 mm. Reinforcement area and hoop spacing of beam, column and slab must be calculated based on existing Indonesian standard (RC building design standard of Indonesia) [9].
3. Anchor of minimum diameter of 10 mm and length more than 40 cm must be placed at every 6 layer of brick

2. Reinforced hollow concrete block wall

1. Thickness of wall is at least 15 cm.
2. Height of wall is no more than 20 times the thickness.
3. Length of wall is no more than 50 times the thickness.
4. Horizontal distance between two openings in panel is no less than 30% of the average height of openings.
5. Diameter of bars is 10 mm which are arranged at least one bar at every 80 cm of spacing in vertical and horizontal directions.
6. At the corner or at connection between walls, diameter of reinforcement is at least 12 mm.

4. Reference

1. http://www.infoplease.com/ipa/A0107634.html
2. Master Plan for The Rehabilitation and Reconstruction of Region and Communities of The Province of Nanggroe Aceh and The Island Nias, Province of North Sumatra Rehabilitation and Reconstruction Master Plan, (www.undp.org/cpr/disred/documents/tsunami/indonesia/report/masterplan_0405_English.pdf)
3. National Disaster Management Coordinating Board of Indonesia (BAKORNAS): http://bakornaspb.go.id/website (in Indonesian).
4. Maidiawati and Yasushi Sanada, 2008. “*Investigation and Analysis of Building Damaged during the September 2007 Sumatra, Indonesia earthquakes*”, Journal of Asian Architecture and Building Engineering, November 2008, 378.
5. Ministry of Public Works, SNI 03-1726-2002 ”*Procedures for Earthquake Resistance Design for Houses and Buildings*,” (in Indonesiaan)
6. Ministry of Public Works, “*Technical Requirement for Low Rise Building and Houses*”, 2006, (in Indonesian)
7. Indonesian standards on procedures for calculation of reinforced concrete buildings (SNI-03-2847-2002) (in Indonesian)

Annex 4

Country Report

Japan

Country Report WFEO-UNESCO

Guidelines for low rise wall type structures

JAPAN

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CONTENTS

1 Introduction

1.1 General information[i]

1) Official name：Japan
2) Area:377,944 km^2
3) Population:127,692,000
4) Density: 342/km^2
5) Capital city: Tokyo[ii]
   -Coordinates: *WGS84* 35° 41′ 22″ N, 139° 41′ 31″ E
   -Area: 2,188 km^2
   - Population: 12,828,000

Figure 1. Location of Japan
(Google Map)

1.2 Geography[iii]

Japan is an island country forming an arc in the Pacific Ocean to the east of the Asian continent. The land comprises four large islands named (in decreasing order of size) Honshu, Hokkaido, Kyushu, and Shikoku, together with many smaller islands. The Pacific Ocean lies to the east while the Sea of Japan and the East China Sea separate Japan from the Asian continent.

In terms of latitude, Japan coincides approximately with the Mediterranean Sea and with the city of Los Angeles in North America. Paris and London have latitudes somewhat to the north of the northern tip of Hokkaido.

Japan's total land area is about 378,000 square kilometers which is thus approximately the same size as Germany, Finland, Vietnam, or Malaysia. It is only

1/25 the size of the United States and is smaller than the state of California.

About three-fourths of Japan's land surface is mountainous. As it is situated along the circum-Pacific volcanic belt, Japan has several volcanic regions—usually considered to number seven —from the far north to the far south. Of the total number of volcanoes, approximately 80 are active. Japan has almost 1/10 of the world's approximately 840 active volcanoes, even though it has only about l/400 of the world's land area

1.3 Seismic sources for Japan

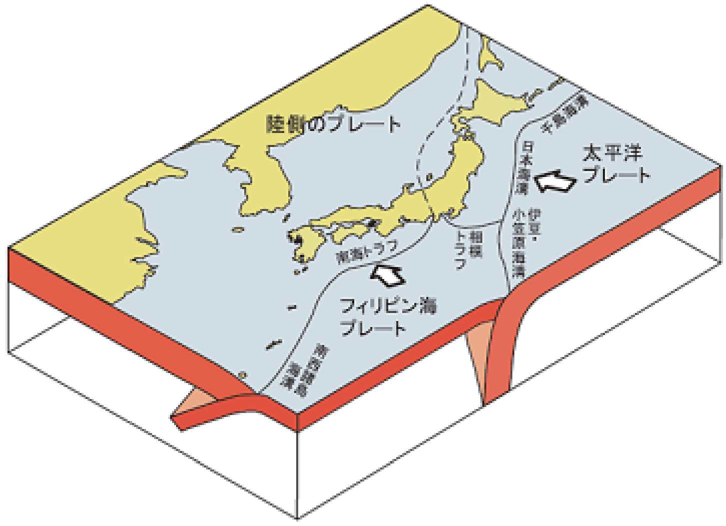
Japan is located in the boundaries of oceanic plate (Pacific plate and Philippine Sea plate) and landward plate.

The Pacific Plate is subducting beneath the landward plate and Philippine Sea plate in Kuril Trench, Japan Trench and Izu-Bonin Trench. Also Philippine Sea plate is subducting beneath the landward plate in Nansei Trench, Nankai Trough, Suruga Trough and Sagami Trough (Figure 2). In addition, Japan is located in the Pacific Ring of Fire and 108 active volcanoes, which account for 7.0 percent of the world, are distributed

Because located on the complex crustal structure, Japan is one of the earthquake-prone countries in the world, and has been often hit by an earthquake that caused heavy damage (Figure 3).

Every year there are approximately 1,000 earthquakes which are strong enough to be felt. In January 1995, the Great Hanshin-Awaji Earthquake killed approximately 6,000 people, injured over 40,000, and left 200,000 homeless.

図2－3－1 日本列島とその周辺のプレート



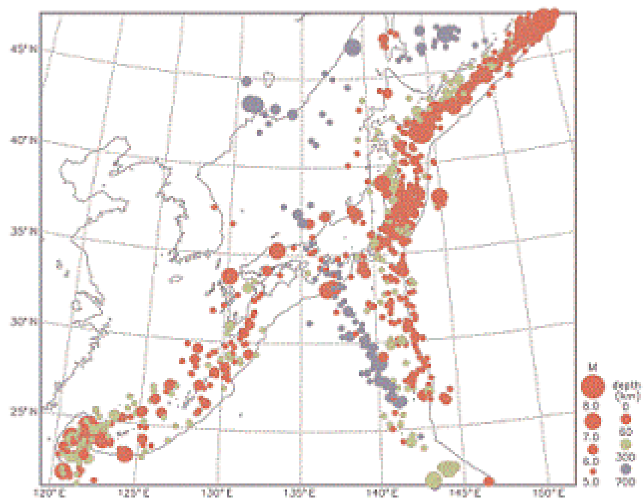
（注）図中の矢印は，陸側のプレートに対する各プレートの相対運動を示す。
日本海東縁部（図中の点線）に沿って，プレート境界があるとする説が出されている。

資料：地震調査研究推進本部地震調査委員会編
「日本の地震活動－被害地震から見た地域別の特徴－＜追補版＞」

Figure 2.　Plate around Japan

(White paper 2009, Cabinet office of Japan)

図2－3－2 日本付近の地震活動



（注）1999年～2008年に発生したマグニチュード5以上の地震で，
気象庁において震源を決定したもの。

Figure 3. Earthquake around Japan (More than M5, 1999-2008)

(White paper 2009, Cabinet office of Japan)

1.4 History of building regulations

In Japan, the first construction Law was established in 1919, with its enforcement order and enforcement regulation, which defined the technical criteria about the masonry buildings, as shown followings.

- Masonry Unit shall be placed with cement mortar
- The thickness of masonry walls on each floor shall be not less than the thickness of each wall immediately above
- Thickness of masonry walls shall be more than 30cm etc
- The length of masonry walls shall not exceed 10.8m
- Slenderness ratio between the length and thickness shall be more than 1/12

In 1923, The Great Kanto Earthquake (M7.9) hit the Tokyo metropolitan area, which caused 100 thousand deaths. In the wake of this catastrophe, this code was amended, for example, maximum height of masonry changed from 20m to 13m. In consequence, masonry construction with bricks had decreased and Reinforced Concrete Buildings had taken main role of the building construction. This tendency has continued until now, thus in Japan there are not many buildings with masonry, except historical construction.

In 1948, The Fukui Earthquake (M7.1) occurred, which caused 3,769 deaths. After that, new construction code has established, which is the current code called "Building Standards Law". In this code, allowable stresses method has been adopted and standard shear coefficient defined as 0.2. (Previously it was 0.1)

In 1968, The Tokachi earthquake struck and caused many shear failure in columns. Therefore, the Building Standard Act has amended in 1971, with the introduction of the hooping rule etc.

In 1978, the enforcement order was amended drastically, called "Shin-Taishin Design method" (Revised Seismic Design Method), which adopted Ultimate Strength, Stiffness Ratio, Eccentricity Ratio, Deformation and more.

1.5 Current situation of building regulations

The Great Hanshin-Awaji Earthquake (M7.3) occurred on January 17,1995, which caused over 6,400 deaths and apx.640 thousands damaged houses. After this disaster, construction code was amended in 2000 to secure the structure of the buildings, and also this amendment includes the introduction of Inspection system of third party, rationalize of regulations and Performance-based system.

In 2005, the building code scandal has occurred and many buildings were found that they did not have enough earthquake resistance. This scandal was recognized as social problem, and led to the tightening of regulations with amendment of related law in 2007

Figure 4 : The Great Hanshin-Awaji Earthquake
(Photo: Kobe City Local Government)

2 Guidelines for low rise wall type structures

2.1 Basic Information of Japanese Building Standard Act

2.1.1 Purpose of Building Standard Act

Basically all buildings shall comply with Building Standard Act and related laws, regulations and other related codes, whose objective is to establish minimum standards regarding the site, structure, facilities, and use of buildings in order to protect life, health, and property of the nation, and thereby to contribute to promoting public welfare.

2.1.2 Outline of Building Standard Act

As for technical standards for buildings, the Law prescribes "building code" and "zoning code”. (Figure 5)

The “building code” is technical standards for all buildings in order to ensure building safety with regards to structural strength, fire prevention devices, sanitation, dwelling environment (such as air ventilation, day-lighting etc), equipment etc. As for structural strength, technical criteria and calculation methods are defined. After the amendment of the construction code in 2000, Japanese law system has changed from Specification-based system to Performance-based system, which allows diverse construction if it can ensure the structural safety.

The "zoning code" is technical standards to ensure rational and safe utilization of land and to improve environment. Such utilization is required by towns and cities where buildings are concentrated.

As for "building code", structural strength, fire prevention devices, sanitation, are defined.

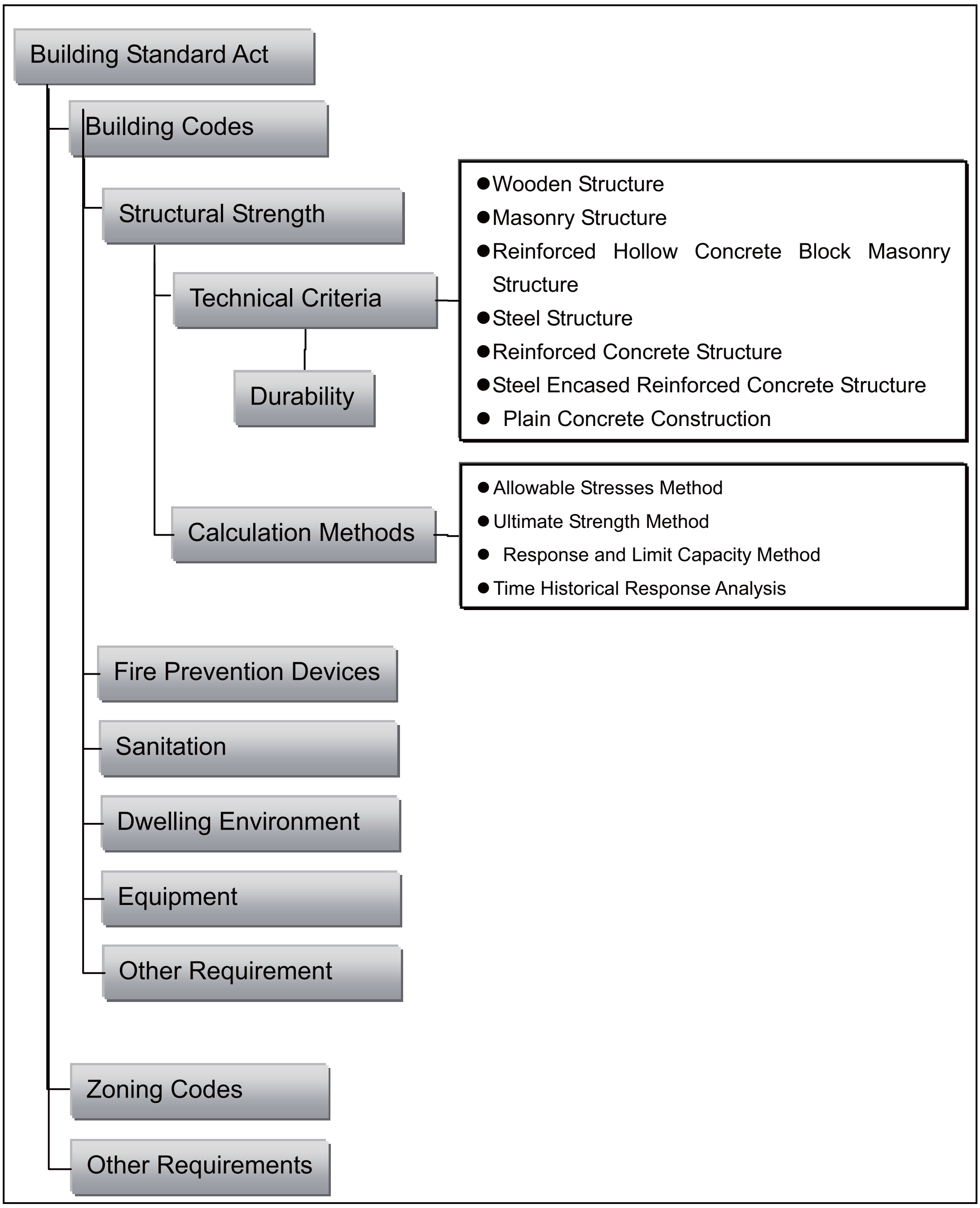


Figure 5 Framework of Japanese Building Standard Act

2.1.3 Other related laws and guidelines

In addition to the Building Standard Act, other related law defined Technical Criteria and other regulation, (Urban Planning Law, The Fire Defense Law, Act on Architects and Building Engineers etc)

On the other hands, some institutions like AIJ (Architectural Institute of Japan) have formulated guidelines. Although these guidelines do not have legal binding force, they are widely used because basically aim in the facilitation of the construction.

In case of Masonry, AIJ has published “AIJ Standards for Structural Design of Masonry Structures” which includes masonry, reinforced concrete block and hollow concrete block. Also, “AIJ Standards for Structural Calculation of Reinforced Concrete Structures” is one of the most famous guidelines for RC buildings.

2.2Structural Calculation

2.2.1 Calculation methods

Depending on the type of construction, basically four different methods can be used to perform the structural design:

- Allowable Stresses Method
- Ultimate Strength Method
- Response and Limit Capacity Method
- Time Historical Response Analysis
- In some cases (ex. small construction), Structural Calculation is not necessary.

2.2.2 Loads and external forces

Loads and external forces acting on a building shall be those mentioned to the following items. Value, or its calculation methods, of these loads are defined in the ENFORCEMENT ORDER.

- Permanent load
- Imposed load
- Snow load
- Wind load
- Seismic force

2.3 Seismic force

The seismic story shear coefficient shall be calculated by the following formula.

$$C_i = Z \cdot R_t \cdot A_i \cdot C_0 \quad ^{*1}$$

2.3.1 Seismic story shear (C_i)

C_i in the formula above means the seismic story shear coefficient of the aboveground part of a building at a given height.

2.3.2 Zone Coefficient (Z)

Z in the formula above means a value to be specified within a range between 1.0 and 0.7 according to the extent of earthquake damage, seismic activity and other seismic characteristics based on the record of earthquake in the region concerned.

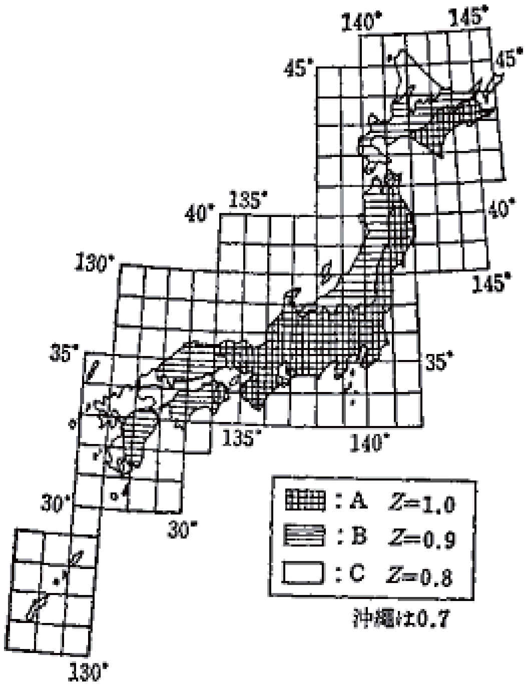


Figure 6. Zone Coefficient

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2.3.3 Vibration Characteristics Coefficient *(R_t)*

R_t in the formula above means a value representing vibration characteristics of building to be obtained by the calculation method according to the natural periods in the elastic range of building and kinds of ground.

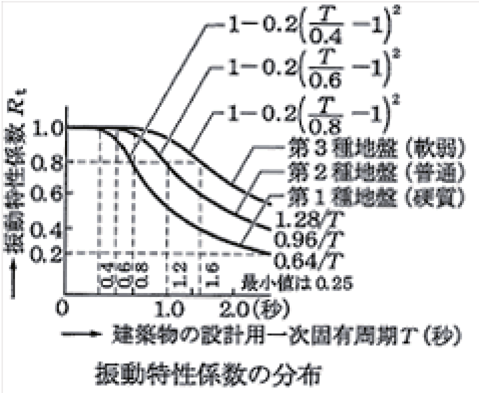


Figure 7.　Vibration Characteristics Coefficient

2.3.4 Vertical Distribution of Seismic Story Share Coefficients (A_i)

A_i in the formula above means a value representing a vertical distribution of seismic story shear coefficients according to the vibration characteristics of buildings to be obtained by the following formula.

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i \right) \frac{2T}{1 + 3T}$$

Where,

$T = h(0.02 + 0.01\alpha)$

Where,

h : height of the building

α : Ratio of the height of the stories against h, whose beams and columns are mainly constructed with steel or wood

α_i :Sum of permanent load and imposed load of mentioned story

2.3.5 Standard shear coefficient (C_0)

C_0 in the formula above means the standard shear coefficient, which shall be 0.2 of more. In calculating a required value of horizontal load-carrying capacity, the standard shear coefficient shall be 1.0 or more.

2.4 Allowable Unit Stress and Material Strength

2.4.1 Allowable Unit Stress

To calculate in Allowable Stresses Method, Allowable Unit Stress is needed, which is provided in ENFORCEMENT ORDER with each materials- Timber, Steel, Concrete, Welding, High Strength Bolting and Ground and Foundation Piles. The values of allowable Unit Stress of other materials such as Masonry Block Unit etc are specified by Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Table 1 Allowable Unit Stress (Concrete)

<table>
<tr><td colspan="4">Allowable unit stress for sustained forces (unit: Newton/sq. mm)</td></tr>
<tr><td>Compression</td><td>Tension</td><td>Shear</td><td>Bond</td></tr>
<tr><td>$\frac{F}{3}$</td><td colspan="2">$\frac{F}{30}$
(If the MLIT has specified a different value for concrete whose value of F exceeds 21, that specified value)</td><td>0.7
(0.6 when using light weight aggregate)</td></tr>
<tr><td colspan="4">Allowable unit stress for temporary forces (unit: Newton/sq mm)</td></tr>
<tr><td colspan="4">2 times the values of allowable unit stress for compression, tension, shear or bond for sustained forces, respectively.(If the MLIT has specified different tension and shear values for concrete whose F exceeds 21, that specified value)</td></tr>
<tr><td colspan="4">F: Standard Concrete Strength (compressive strength to be used in designing, Newton/sq. mm)
➢ Minimum requirement (by ENFORCEMENT ORDER) :12N/mm^2
➢ AIJ Guideline
<table><tr><td>Level</td><td>Durability</td><td>Newton/sq. mm</td></tr><tr><td>Normal</td><td>30 years</td><td>18</td></tr><tr><td>Standard</td><td>65 years</td><td>24</td></tr><tr><td>Long Term</td><td>100 years</td><td>30</td></tr></table></td></tr>
</table>

Table 2 Allowable Unit Stress (Masonry)

<table>
<tr><td colspan="4">Allowable unit stress (unit: Newton/sq. mm)</td></tr>
<tr><td colspan="2">(for sustained forces)</td><td colspan="2">(for temporary forces)</td></tr>
<tr><td>Compression</td><td>Shear*</td><td>Compression</td><td>Shear*</td></tr>
<tr><td>$\frac{F}{3}$</td><td>$\frac{\sqrt{0.1F}}{3}$</td><td>$\frac{2}{3}F$</td><td>$\frac{\sqrt{0.1F}}{2}$</td></tr>
</table>

F:Standard Concrete Strength

- ENFORCEMENT ORDER

  Less than the average value of the compressive strength test at the age of 28 days

- AIJ Guideline

Class	Height of buildings	Newton/sq. mm
1	6m	60
2	9m	100

Table 3 Allowable Unit Stress (Hollow Concrete Block **)**

- It's not specified in ENFORCEMENT ORDER
- AIJ guideline

In AIJ guideline, 3 types of blocks are defined as their quality.

Maximum value	Story	Height	Eave Height	Compression
Class A	2	8.2m	7m	4 N/mm^2
Class B	3	12.2m	11m	6 N/mm^2
Class C	3	12.2m	11m	8 N/mm^2

2.4.2 Material Strength

To calculate in Ultimate Strength Method or Response and Limit Capacity Method, Material Strength is needed, which is provided in ENFORCEMENT ORDER with each material. But using Ultimate Strength Method or Response and Limit Capacity Method, which is usually for the buildings over 31 meters height, for masonry is not popular in Japan, the Material Strength of masonry and Hollow Concrete Block are not specified in ENFORCEMENT ORDER.

Table 4 Material Strength (Concrete)

Material Strength (unit: Newton/sq. mm)		
Tension	Shear	Bond
$\frac{F}{10}$ (If the MLIT has specified a different value for concrete whose value of F exceeds 21, that specified value)		2.1 (1.8 when using light weight aggregate)

F: Standard Concrete Strength (compressive strength to be used in designing, Newton/sq. mm)

2.5 Technical criteria for low rise wall type structures

In Japan, low rise constructions are built using three different modalities: Masonry, Reinforced Hollow Concrete Block Masonry, and Concrete Walls.

In addition to this section, there are other technical requirements which theoretically don't have concern with structural issue, for instance technical requirements for fireproof performance which, in some cases, may decide the structural factor such as thickness of walls.

2.5.1 Masonry

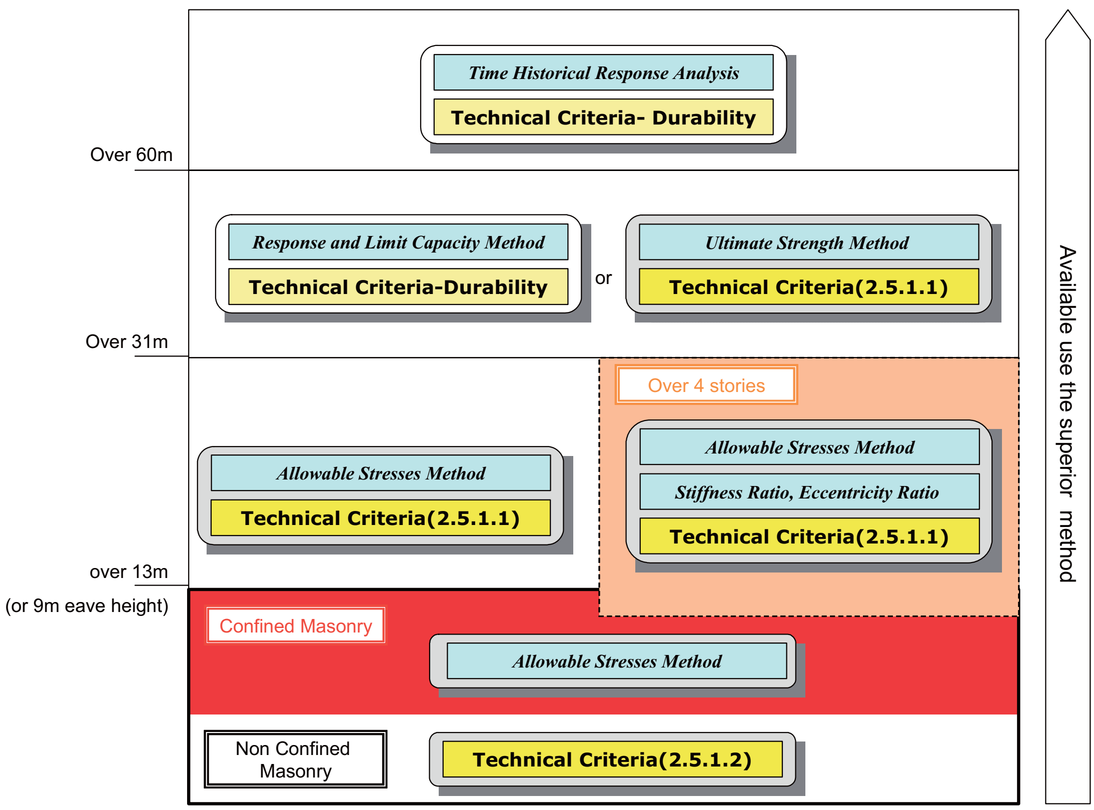


Figure 8 Category of calculation for Masonry Construction

2.5.1.1 Buildings over 13m, or whose eave height is over 9m

a) Bearing walls shall be provided with steel bars of 12mm or more in diameter vertically at the end and the corner, and shall be provided with steel bars of 9 mm or more in diameter vertically and horizontally at intervals of up to 80 cm.

b) Bearing walls shall be so constructed as to permit the transmission of existing stress between the said bearing walls and other parts by fixing hook-shaped ends of vertical reinforcing bars into the foundation or foundation beams and into the wall girders or roof slabs at a depth of at least 40 times the diameter of the said vertical reinforcing bars.

c) Horizontal reinforcing bars shall be as described in each of the following items,
   - The end shall be hooked-shaped.
   - The length of lapped joints shall be 25 times or more of the bar diameter
   - When the end of bearing walls of reinforced masonry structure contacts other bearing walls or columns constituting elements necessary for structural resistance, the ends of horizontal reinforcing bars shall be developed to them and the length of developed part shall be 25 times or more of the bar diameter, except in cases where the ends of horizontal reinforcing bars are welded.

d) Masonry unit shall be placed so that mortar may spread evenly over the entire face of the joint, and hollow parts with steel bars and those contacting vertical joints shall be filled with mortar or concrete。

e) The vertical reinforcing bars of bearing walls, gates or fences of masonry structure shall not be spliced in the hollow part of masonry unit, except in case of connection by welding or other joining methods with strength equal or superior to that of welding.

f) When the masonry buildings are reinforced by steel frame, masonry walls shall be connected firmly to the upright framing of steel by bolts, cramps or other metal fasteners.

g) When the masonry buildings are reinforced by reinforced concrete, masonry walls shall be connected firmly to the bearing walls or upright framing of reinforced concrete by shear key, steel bars or other similar method.

2.5.1.2 Buildings under 13m and its eave height is under 9m

This section shall apply only those masonry buildings that are not reinforced with steel bars, steel frames or steel reinforced concrete and which have not been confirmed to be safe from the viewpoint of structural strength through structural calculation with allowable stress method. .

a) Length and depth of the wall

The length of masonry walls shall not exceeded 10m. If the walls are connected with two adjacent walls, the mentioned length can be the central distance between those walls.

The thickness of the wall shall be the followings,

Length of the walls	Less than 5 m	More than 5m
More than Two-Story Buildings	30cm	40cm
One-Story Buildings	20cm	30cm

Also, the thickness of masonry walls on each floor shall be not less than 1/15 of the height of the said walls on the said floor, and shall be not less than the thickness of each wall immediately above.

In case of masonry partition walls, the thickness may be less than the mentioned value, in range less than 20cm.

b) Wall Girders

Masonry buildings shall be provided with wall girders (Ring Beam) of steel or reinforced concrete structure, at the top of the said walls on each floor.

c) Openings

The total width of openings in each wall between adjacent walls on each floor shall not exceed 1/2 of the length of that wall, total width of openings on each floor shall not exceed 1/3 of the total length of the walls on that floor, and the vertical distance from an opening to another opening directly above shall be 60cm or more.

Also, the horizontal distance between openings in masonry walls on each floor, or between an opening and the center line of each adjacent wall shall be twice or more of the thickness of the masonry walls concerned, (except in case where the peripheries of said opening are reinforced with steel frame or reinforced concrete. And reinforced concrete lintels shall be placed at the top of openings wider than 1m.

d) Channels Cut in Wall

If masonry walls are to be provided with vertical channels continuing for a distance of 3/4 or more of the height of the said walls on each floor, the depth of such vertical channels shall not exceed 1/3 of the thickness of the said walls, and if horizontal channels are to be made, the depth of such horizontal channels shall not exceed 1/3 of the thickness of the said walls and the length shall not exceed 3 m.

e) Execution of Masonry Structure

Masonry unit shall be placed so that mortar may spread evenly over the entire face of the joint and shall be placed without any straight joints.

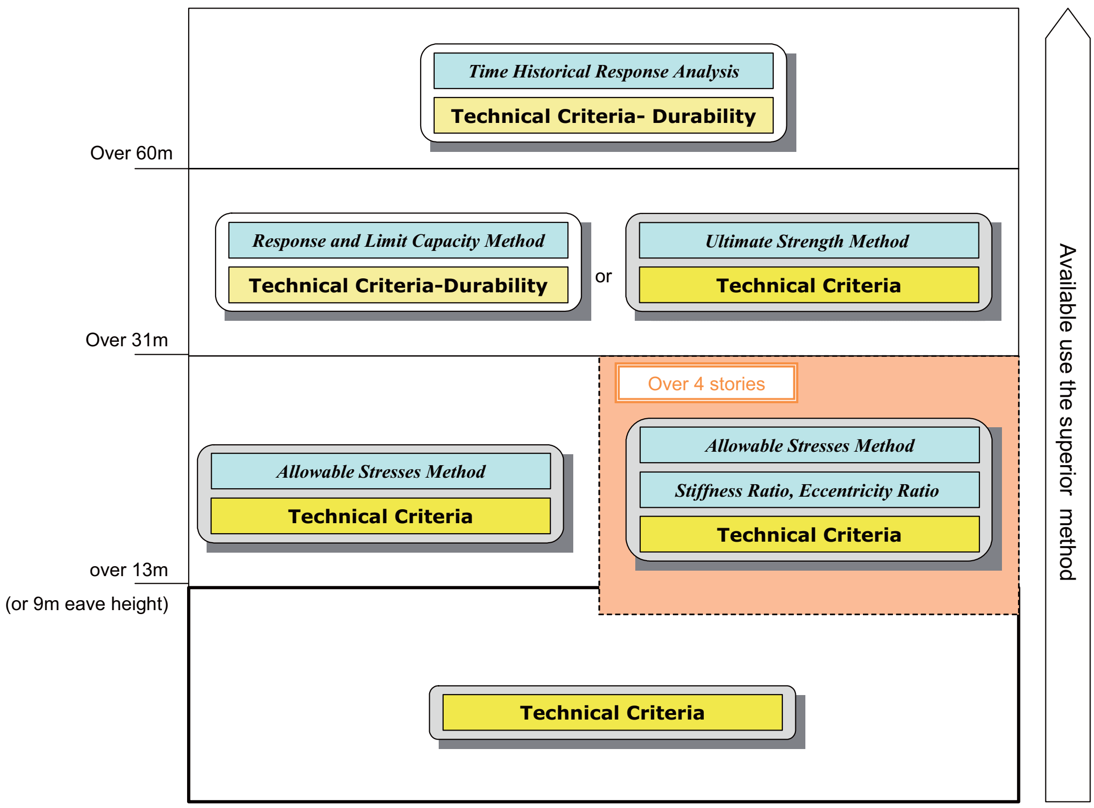
Mortar shall be cement mortar, with the following mixture

- Cement : Sand = 1 : 3
- Cement : Lime : Sand = 1 : 2 : 5

f) Stories

According to the Building Standard Act, there is no regulation of the limit of the stories for masonry buildings, but AIJ guideline only cover up to three stories masonry buildings.

2.5.2 Reinforced Hollow Concrete Block Masonry

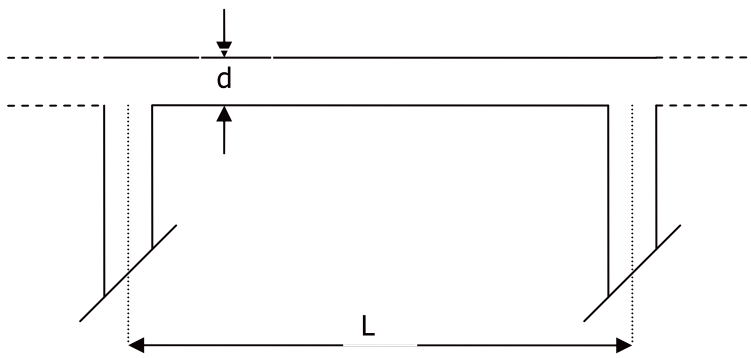


a) Length and depth of the wall

The total length of bearing walls of reinforced hollow concrete block masonry structure in each of the span and longitudinal directions on each floor shall be not less than 15 cm per 1 sq m of floor area of the said floor.

The thickness of bearing walls (=d) should be the followings.

- More than 15 cm, and
- More than 1/50 of L (="distance between supporting points receiving horizontal force on the bearing wall")



Also, the horizontally projected area of the part surrounded by the center lines of bearing walls of reinforced hollow concrete block masonry structure on each floor shall be 60 sq m or less.

b) Wall Girders

At the top of bearing walls of reinforced hollow concrete block masonry structure on each floor, wall girders (Ring beam) of reinforced concrete structure shall be placed.

In this case, the effective width of wall girders shall be 20 cm or more and 1/20 or more of the distance between supporting points receiving horizontal force on the bearing wall.

c) Reinforcement of Bearing wall

Bearing walls shall be,

- Provided with steel bars of 12mm or more in diameter vertically at the end and the corner
- Provided with steel bars of 9 mm or more in diameter vertically and horizontally at intervals of up to 80 cm.

- So constructed as to permit the transmission of existing stress between the said bearing walls and other parts by fixing hook-shaped ends of vertical reinforcing bars into the foundation or foundation beams and into the wall girders or roof slabs at a depth of at least 40 times the diameter of the said vertical reinforcing bars.

Horizontal reinforcing bars shall be as described in each of the following items,

- The end shall be hooked-shaped.
- The length of lapped joints shall be 25 times or more of the bar diameter
- When the end of bearing walls of reinforced masonry structure contacts other bearing walls or columns constituting elements necessary for structural resistance, the ends of horizontal reinforcing bars shall be developed to them and the length of developed part shall be 25 times or more of the bar diameter, except in cases where the ends of horizontal reinforcing bars are welded.

d) Openings

According to the Building Standard Act, there is no regulation of the limit of the openings if the criteria shown in a). However AIJ guideline recommends considering the Eccentricity ratio of each story, and the continuity of the bearing walls between upstairs and downstairs.

e) Masonry Joints and Hollow Parts Execution of Hollow Concrete Block Masonry

Concrete blocks shall be placed so that mortar may spread evenly over the entire face of the joint, and hollow parts with steel bars and those contacting vertical joints shall be filled with mortar or concrete.

f) Joint of vertical reinforcing bars

The vertical reinforcing bars of bearing walls, gates or fences of masonry structure shall not be spliced in the hollow part of masonry unit, except in case of connection by welding or other joining methods with strength equal or superior to that of welding.

g) Curtain Walls

Curtain walls of reinforced hollow concrete block masonry structure shall be firmly connected by steel bars, to elements necessary for structural resistance of construction other than wooden structure and masonry structure (excluding reinforced hollow concrete block masonry structure).

h) Stories

According to the Building Standard Act, there is no regulation of the limit of the stories for Reinforced Hollow Concrete Blocks Masonry buildings, but AIJ guideline covers says, "because this construction method is appropriate for houses within 3 stories, AIJ guideline covers only these constructions."

2.5.3 Reinforced Masonry (RM)

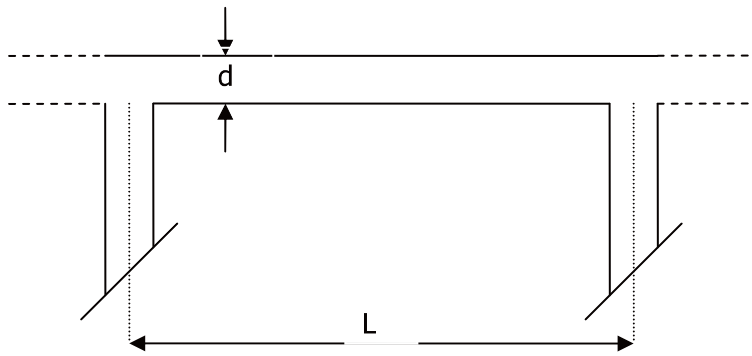
In the Building Standard Act Enforcement Order, technical criteria has been decided by each type of building construction- wood, masonry, reinforced hollow concrete block masonry, steel, reinforced concrete and non-reinforced concrete. For any other special structures, such as membrane structures, wooden-panelized structures etc., Minister of Land, Infrastructure, Transport and Tourism will establish as a Public Notice.

In 2003, the technical criteria of "Reinforced-Concrete Masonry Structure" have been established as a Minister's Public Notice. In case of Reinforced- Concrete Masonry Structure Building, the following criteria shall be obeyed, additionally to the criteria of Reinforced Concrete Structure.

a) Length and depth of the wall

Length (L) and depth (d) of bearing wall shall be the followings.

- "L" shall be more than 590mm.
- "L" shall be more than the length in which 3 vertical reinforcing bars can be placed.(2 for both sides and 1 between these bars).
- "d" shall be more than 190mm.
- "d" shall be more than L/22



Also, the arrangement of baring walls shall be well-balanced, and the horizontally projected area of the part surrounded by the center lines of bearing walls shall be 60 sq m or less.

b) Reinforcement of Baring wall
Total area of the baring wall of each floor shall be following

$$\sum Aw \geq Z \cdot W \cdot Ai \cdot \beta$$

Where,

Aw: Total area of the baring wall (mm)
Z: 2.3.2
W: Permanent load + Imposed load
Ai: 2.3.4
β : $\sqrt{18/F}$, where F= Standard Strength of RM

Also, reinforcing bar of bearing walls shall be the followings.

- Vertical reinforcing bar ratio shall be more than 0.2%
- Interval of vertical bar shall be less than 400mm, as well as less than the width of masonry units.
- Diameter of vertical bar shall be the following.
  - Within the 3 floor from the top floor – 12mm
  - Other, including basement floor – 15mm
- Horizontal reinforcing bar ratio shall be the followings.
  - Within the 3 floor from the top floor – more than 0.2%
  - Other, including basement floor – more than 0.25%
- Interval of horizontal bar shall be the followings, and less than the height of masonry unit.
  - Within the 3 floor from the top floor – less than 300mm.
  - Other, including basement floor – less than 200mm.

:

c) Hollow Parts Execution of RM
- Hollow parts of the RM unit shall be within 50-70%.
- Hollow part shall be completely filled with concrete, with at maximum 2 reinforcing-bars.

d) Stories and heights
- Maximum stories : 3, except basement floor,

- Maximum eave height: 12m
- Maximum KAIDAKA : 3.5m
- If the building is confirmed by following structural calculation methods to be safe, maximum stories shall be 5, and maximum eave height shall be 20m.
  - Story drift angle shall not be greater than 1/2000
  - Confirmed by Response and Limit Capacity Method
  - $\Sigma 2Aw \geqq ZWAi\beta$,

3 Outline of construction practices

3.1 Type of constructions

There is no clear definition of “Low Rise Buildings”, but according to the regulation of Tokyo Metropolitan Government, it means “building which has 7m or more of the eave height, or which has more than 3 stories except basement floor”.

Low-rise buildings in Japan are typically constructed by wood, especially for houses. In some cases, Low-rise buildings are constructed with Reinforced Concrete, Concrete Block, but Masonry Construction with Concrete Block or Masonry is rare as described in Table 5.

Table 5. Building Starts 2009, by total floor area

	Total	W	RC+S	RC	S	Concrete Block	Other*
Rate by structure	100.0	43.1	2.6	20.6	33.2	0.07	0.4
Houses	63.4	93.6	18.2	56.2**	32.6	61.5	37.2
Other Buildings	36.6	6.4	81.8	43.8	67.4	38.5	62.8

*Including masonry, brick, plain concrete, plain concrete block, and so on.

**Basically mid-to-high-rise housings

3.2 Conformation of Construction of Buildings

3.2.1 Engineered constructions.

Japanese Building Standard covers all constructions. Regardless of the scale, structural features and use etc., all constructions shall be obeyed this law.

According this law, local government shall establish the District Construction Surveyor called "Kenchiku-Shuji", who should confirm and inspect all buildings**. Nowadays in Japan, this building conformity inspection system has completely established.

**exception of the Building Regulation Conformity Inspection system, in case of masonry and reinforced concrete (satisfy all the following conditions)

-area: outside of City Planning Area and Quasi-city Planning Area

-scale: one-story building

-size: less than 100m2 (in case of house, less than 200m2)

3.2.2 Non-Engineered constructions.

Basically, "Non-Engineered buildings" don't exist in Japan because of the following reasons.

- All buildings have to be confirmed by authority of building officials for its constructions except those mentioned 3.2.1.
- Even in case of the buildings mentioned in 3.2.1, it's very rare that the owners themselves, who don't have engineering knowledge, construct their own buildings. Generally contractors who have enough experience, knowledge and technique to construct the safe buildings do that.
- Almost all building materials to the market in Japan have been industry-standardized, like JIS-Japan Industrial Standards, which meet the technical required level by Building Standard Act. For instance, most of the Concrete Block on the market meets "JIS A-5406- Concrete Block for Buildings", with sufficient strength for safe buildings.

In case of cultural properties, Building Standard Act is not mandatory. So, theoretically it's possible to construct (or basically restore) without any technical regulations. But even in this case, usually special committee consisting of intellectuals and scholars consider the project from the object of engineering consideration, and decide material selection, structural calculations, etc.. Therefore, these constructions also categorized as "engineered buildings".

4 Earthquake damage of low rise constructions

According to the Japanese Building Standard Act, low rise construction almost always shall be regulated only by technical criteria. (In the light of height, story, use and structural feature, structural calculation is often unnecessary.). But in fact, these low rise buildings have suffered severe damage from past major earthquakes.

In the "miyagi-oki earthquake" (M7.4) that occurred in the year 1978, 16 people are killed, 10,119 people are injured, 4,385 houses are completely or partially destroyed and 86,010 houses are damaged. In this earthquake, Dr. Toshio SHIGA, emeritus professor of Tohoku University, researched the damage of RC-constructions, which revealed the proportional relation between the damage of RC-constructions and quantity of walls, including secondary wall, and columns (Figure 10. Shiga-map). The result of this research is reflected in the Revision of the Building Standard Act implemented in 1980, in which stipulation of quantity of walls is incorporated.

Figure 9
1978 Miyagi earthquake
(Photo: Tohoku University)

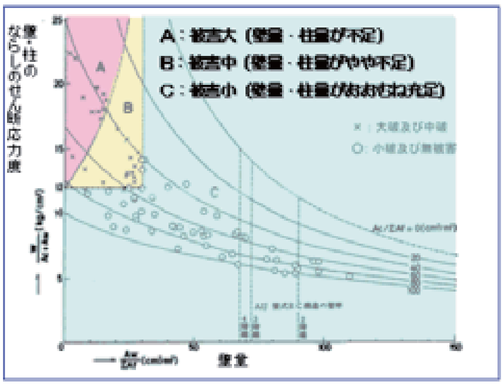


Figure 10
Shiga-Map (Toshio-Shiga)

The great Hanshin Earthquake occurred in 1995 (M7.3) killed 6,434 people. 249,180 houses were completely or partially destroyed and in total 390,506 houses are damaged[iv]. As learning from this catastrophe, Building Standard Act was revised in 2000, complementing the stipulation of well-balance of walls, etc.

Figure 11
The Great Hanshin-Awaji Earthquake
(Photo: Kobe City Local Government)

Figure 12
The Great Hanshin-Awaji Earthquake
(Photo: Kobe City Local Government)

5 Current research outputs

5.1Current research in AIJ

Table 6 shows the number of published paper of AIJ with the subject "masonry". As described in 3.1, historically wooden construction has widely spread in Japan, and in the modernized process, RC and Steel construction have taken place on it. For this reason, there are few masonry constructions and less research on it.

Table 6 Number of published paper of AIJ (Architectural Institute of Japan)

	2010	2009	2008
Number of thesis*	2179	2698	2746
With the subject "Masonry"**	7 (0.3%)	8 (0.3%)	11 (0.4%)

*Count from the database "CiNii" (Scholarly and Academic Information Navigator, National Institute of Information)

**Count the thesis that match the keyword "Masonry" from CInII

5.2. Research on RM[v]

From 1984 to 1988, the coordinated earthquake research program had carried out by BRI-Building Research Institute of Japan and NSE-National Science Federation of the U.S., under the auspices of the "U.S.-Japan Cooperative Program in Natural Resources (UJNR) on Wind and Seismic Effect."

Within this program, "Reinforced Masonry (RM) Structure" was addressed. Contents of this study was various, such as material study, member study and construction experiments including five story full scale prototype test on RM building.

As a result of this test, comprehensive design guidelines for "Medium Rise RM Structure" were developed in 1991. Also this achievement has reflected to the Minister's Public Notice No.463, 2003, whose resume was described in 2.5.3. This Public Notice has ease the construction of Middle rise RM building (upper 5 stories), without special process that was formerly necessary.

Figure 13
RM-Guideline
(Published by Japan Association for Building Research Promotion)

5.3 restoration of cultural property

As for cultural property of masonry buildings, some researched have done, but basically the purpose of these researches is "restoration", and considering each situations, structural calculation, material selection etc. have done for the requisite structural ability. (These studies have not necessarily for universal issue, but individual issue,)

Table 7: Recent Restoration projects of Masonry constructions

Building Name	Building information	Construction (Restoration)	Location
Mitsubishi-Ichigokan (Mitsubishi Estate Co.,Ltd,)	Brick masonry-3-1, 6,212 m2	1894 (2010)	Tokyo
The red-brick building of the Central Government Building No.6	Brick masonry-3 9,426 m2	1895 (1994)	Tokyo
Yokohama Red Brick Warehouse	Brick masonry-3 x 2 16,330 m2	1907 (2002)	Yokohama

Figure 14

The red-brick building of the Central Government Building No.6

(Photo: Ministry of Land, Infrastructure, Transport and Tourism)

REFERENCES

[i] Ministry of Internal Affairs and Communications, Statistics Bureau, 2008 (2,3,4)
[ii] Tokyo Metropolitan Government, 2008
[iii] "Web Japan" -http://web-japan.org/ (sponsored by the Japanese Ministry of Foreign Affairs)
[iv] "The Great Hanshin-Awaji Earthquake" (Fire and Disaster Management Agency, May 19th,2006)
[v] Japan Association for Building Research Promotion - http://www.kksk.or.jp/

Annex 5

Country Report

Mexico

Country Report WFEO-UNESCO
Guidelines for low rise wall type structures

MEXICO

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CONTENTS

1 Introduction.

1.1 General information

Official name： Estados Unidos Mexicanos
Area: 1,978,800 km^2
Population: 112,322,757
Density: 56.8 inhabitant/km^2
Capital city: Distrito Federal

Figure 1. Location of Estados Unidos Mexicanos

1.2 Geography

Mexico is bordered by the United States to the north and Belize and Guatemala to the southeast. Mexico is about one-fifth the size of the United States. Baja California in the west is an 800-mile (1,287-km) peninsula that forms the Gulf of California. In the east are the Gulf of Mexico and the Bay of Campeche, which is formed by Mexico's other peninsula, the Yucatán. The center of Mexico is a great, high plateau, open to the north, with mountain chains on the east and west and with ocean-front lowlands beyond.

The geography of Mexico ranges from deserts to mountains to tropical beaches. Much of northern Mexico is desert. The Chihuahua Desert is covers the center and eastern part of Mexico. The Sonora Desert extends from the center of Mexico to the Pacific Coast. Mexico City is arguable the largest metropolis in the world with a population of over 17 million

people in the greater Mexico City area. Mexico City is the capital of Mexico and plays an important role in the political and economic development of the country.
Surrounding Mexico City are a series of mountain ranges, raising the elevation of Mexico City to over seven thousand feet above sea level. Mexico's mountain ranges include the Sierra Madre Occidental in the east, the Sierra Madre Oriental in the west, and the Sierra Volcanica Transversal which lies to the south of Mexico City. One of the more famous mountain peaks in Mexico is Popocatepetl, which means “Smoking Mountain” in the Aztec language of Nahuatl.
Mexico’s coast is lined with tropical beaches both along the Pacific Ocean and along the Caribbean Sea.

1.3 Seismic activity in Mexico

Mexico is located in one of the most seismically active areas in the world. Just during the 20th century, three M≥8 earthquakes and 68 earthquakes with magnitudes between 7 and 8 occurred. In general, most destructive earthquakes occur along the south coasts of the Pacific Ocean, with depths smaller than 50 km, as the result of subduction mechanisms. Less often, deeper earthquakes are produced by normal fracture of the oceanic plates. In the northwest, earthquakes are due to slip faults that are part of the San Andreas Fault System. For seismic design purposes (CFE, 1994), the country is divided into four hazard zones (Fig. 2). Zone D corresponds to the highest and Zone A to the lowest seismic hazard. Over 25% of the people live in zones C and D (high and severe seismic hazard), and more than 60% live in the moderate seismic hazard zone.

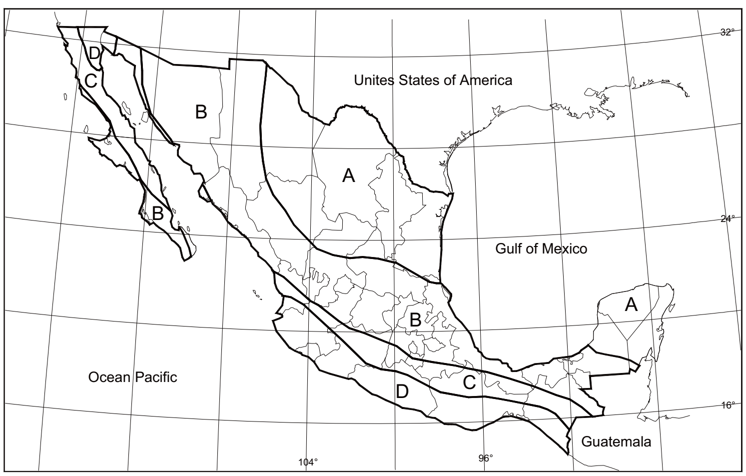

Figure 2. Seismic Zones of Mexico (from CFE, 1994)

Situated atop three of the large tectonic plates that constitute the earth's surface, Mexico is one of the most seismologically active regions on earth. The motion of these plates causes earthquakes and volcanic activity.
Most of the Mexican landmass rests on the westward moving North American plate. The Pacific Ocean floor off southern Mexico, however, is being carried northeast by the underlying motion of the Cocos plate. Ocean floor material is relatively dense; when it strikes the lighter granite of the Mexican landmass, the ocean floor is forced under the landmass, creating the deep Middle American trench that lies off Mexico's southern coast. The westward moving land atop the North American plate is slowed and crumpled where it meets the Cocos plate, creating the mountain ranges of southern Mexico. The subduction of the Cocos plate accounts for the frequency of earthquakes near Mexico's southern coast. As the rocks constituting the ocean floor are forced down, they melt, and the molten material is forced up through weaknesses in the surface rock, creating the volcanoes in the Cordillera Neovolcánica across central Mexico.

Areas off Mexico's coastline on the Gulf of California, including the Baja California Peninsula, are riding northwestward on the Pacific plate. Rather than one plate subducting, the Pacific and North American plates grind past each other, creating a slip fault that is the southern extension of the San Andreas fault in California.
Mexico has a long history of destructive earthquakes and volcanic eruptions. In September 1985, an earthquake measuring 8.1 on the Richter scale and centered in the subduction zone off Acapulco killed more than 4,000 people in Mexico City, more than 300 kilometers away. Volcán de Colima, south of Guadalajara, erupted in 1994, and El Chichón, in southern Mexico, underwent a violent eruption in 1983. Paricutín in northwest Mexico began as puffs of smoke in a cornfield in 1943; a decade later the volcano was 2,700 meters high. Although dormant for decades, Popocatépetl and Ixtaccíhuatl ("smoking warrior" and "white lady," respectively, in Náhuatl) occasionally send out puffs of smoke clearly visible in Mexico City, a reminder to the capital's inhabitants that volcanic activity is near. Popocatépetl showed renewed activity in 1995 and 1996, forcing the evacuation of several nearby villages and causing concern by seismologists and government officials about the effect that a large-scale eruption might have on the heavily populated region nearby.

1.4 History of building regulations

Seismic design codes in Mexico are more than 60 years old. At several moments of their history, Mexican codes have contributed with new ideas and methods, some of which have later been adopted in codes elsewhere (Fukuta, 1991). Some examples: in 1942, the importance factors; in 1957, the linear distribution of seismic forces with height, the dynamical method of analysis, the first limits to lateral displacement of structures, and higher seismic coefficients for soft-soil sites (in fact, the first compulsory seismic microzoning); in 1976, new strength-reduction factors. In the following paragraphs, a brief description of the evolution of Mexican building codes and seismic design practice will be presented, along with some comments on the codes' enforcement and compliance. In the final part, we will discuss some of the most important innovations, regarding seismic design, contained in the latest version of the Mexico City Building Code, issued in early 2004.

The evolution on Mexico City Building Code

In Mexico, building codes are to be issued by each of the more of 2400 municipalities. Regarding requirements for structural design, local building codes, when available, usually refer to technical standards typically issued by other parties, and most often to the Technical Norms of the Mexico City Building Code (MCBC). Several attempts to implement a National Model Code for structural design have insofar failed. However, the Mexico City Building Code is, in fact, used as a model code because it is the most widely recognized technical document for structural design in the country.
The first MCBC was issued in 1942; since 1966, contains a complete set of regulations for structural design. In 1976, the code adopted a coherent format for all materials and structural systems, based on limit states design philosophy. Only the general criteria have remained in the main body of the code and the specific requirements have been separated in a set of Technical Norms (Criteria and Loading, Seismic Design, Wind Design, Foundation Design, Concrete Structures, Steel Structures, Masonry Structures and Timber Structures). The design philosophy and the specific values for intensity of loads and load factors are the same for all structural materials. Strength reduction factors have been developed independently for each material and mode of failure.
Great importance is given to the seismic design, which is performed with the same procedure for all materials; only reduction factors to account for non-linear behavior, as well as detailing requirements for ductility, are associated to specific structural systems. As in most present international regulations, structures are required to not exceed lateral drifts that could cause non structural damage under moderate, frequent earthquakes, and are allowed to undergo significant post-elastic displacements under severe, rare events. For this last condition, forces determined for elastic behavior are significantly reduced according to the ductility that could be developed by each particular structural system, for

which detailed requirements are defined in order to guarantee the highest possible level of ductility.
The MCBC has been updated approximately every ten years, the process being coordinated by a technical committee integrated by academics and practitioners, aimed directly at updating the code, and especially the requirements for seismic design; the city government has sponsored a significant amount of research. In February 2004 a new version of the Code and of its technical norms has been issued.

Code enforcement and compilance

It can be safely stated that a significant wealth of knowledge on seismic design has been gathered in the country in the last 50 years, and especially after the 1985 Mexico earthquake, and that this knowledge has led to the development of updated and refined seismic codes and standards. Nevertheless, it must be admitted that the available knowledge has not thoroughly reached the common design and construction professional (Meli and Alcocer, 2004). It is also apparent that the design codes are often incorrectly understood or misinterpreted, and are often not complied with by lay practitioners. The lack of building code compliance shall not be regarded merely as a legal issue to be addressed only through enforcement actions. One significant reason for the lack of compliance with construction codes is that requirements are not understood and correctly applied by all designers and contractors. There is a vast difference between the level of expertise and quality of practice of a relatively small group of well-informed specialists and academics, and that of most professionals and construction workers. This is true in Mexico City itself, but is especially evident when the large disparity of knowledge and of consciousness about seismic problems along the country is considered. It could be concluded that to attain a reasonable safety level, it is essential to have consistency between the regulations, the level of expertise of most design and construction professionals, and local materials and construction systems. Given that the level of expertise and quality of practice of design and construction professionals in the country is quite diverse, one way to reach this goal is to implement codes with procedures and requirements of different levels of complexity. The most complex and comprehensive rules should be aimed at large, important structures; simple yet conservative approaches would be followed for most common structures limited to certain size, geometry and complexity. As it will be seen later, this is the case of the new version of the Mexico City building code, which includes two design procedures with different levels of complexity.
For the case of common structures designed through simple approaches, it would be wise to implement a series of safety checks or limits based on critical features of the structure to avoid undesirable performance. Such limits can best be related to geometric rules that are used to establish member dimensions and basic percentages of reinforcement. One successful example of a simplified method, allowed for several decades in the MCBC, is aimed at verifying the seismic safety of low-rise walled buildings with a regular and symmetric structural layout. After few calculations, the required wall area in the two principal plan directions can be readily determined. No similar procedures are available for other kinds of structures.
Considering that the critical point for the success of a code is not the quality of the code itself, but rather its correct understanding and application, commentaries, figures and design aids that facilitate its correct use have been produced and intense dissemination programs have been implemented by professional associations and colleges; nevertheless, misunderstanding of code requirements is common, thus showing a need for more efficient mechanisms to promote and assure code compliance.
All enforcement mechanisms developed and put into practice by building authorities in different parts of the country have had their drawbacks and limitations. The most obvious one is that local offices, generally at the municipal or county level, typically do not have a technical group with proper qualifications and enough size to thoroughly review structural designs, grant building permits, and inspect the general quality of construction of all buildings. This situation is particularly prevalent in small municipalities, where local budgets are commonly too scarce to support this very necessary group. Furthermore,

specialized technical boards in public offices have substantially diminished in recent years. To overcome this problem, responsibilities for inspection and quality assurance have been assigned to private professionals certified for these purposes; the mechanism has partially benefited building quality, but its implementation must be greatly improved.

For structures of high importance the participation of highly qualified professionals in the design and construction processes has been fostered through the development of a registry of specialists, strictly rated by their peers. Furthermore, a “liability statement on structural safety” must be issued by one of these qualified specialists, who must participate during the whole process (preliminary studies, design and construction. In Mexico City, such “liability statement” is mandatory for critical facilities, as well as for large buildings, and should be issued prior to occupancy and every three years or after an intense earthquake.

Non-engineered construction is common in Mexico. As a consequence, a large percentage of the building stock (and in some parts of the country, the vast majority) is built without construction permits, without compliance with codes, and without the participation of qualified professionals. Although this phenomenon is prevalent in rural zones, it has also become characteristic of large urban areas, mainly in poor neighborhoods. As an example, it has been estimated that from the 700,000 housing units built in Mexico every year, at least 300,000 fall in this category.

Because in this type of construction builders are not aware of, or disregard the importance of design codes and regulations, mere code enforcement cannot be considered a viable solution. Increase in construction quality should come from improvements in the skills of builders, and in the strength and durability of construction materials. Nonetheless, this is the most difficult group of the construction industry to reach using common technology-transfer mechanisms. First, quality improvement of non-engineered construction becomes more complicated because this construction practice evolves with little or no influence of specialists and organized boards. In this evolution, cultural and economic aspects play a very significant role, and in some cases, act as an obstacle to improvement. Second, an important drawback is that structural safety is not usually a primary concern of those living in non-engineered buildings, and that is difficult to “sell” to a population with serious unmet needs in their everyday lives.

The most significant success case for the improvement of the structural safety of non-engineered construction in Mexico has been de development and dissemination of confined-masonry construction.

Walls confined with vertical and horizontal reinforced concrete elements, bond beams and tie-columns around the perimeter, were adopted in Mexico City in the 1940’s to control the wall cracking caused by large differential settlements in the soft soil of the central portion of the city. Several years later, after examining its excellent seismic performance, this system became popular, even outside the soft soil area of the city, and in other zones of high seismic hazard. It must be pointed out that confined masonry has evolved essentially through an informal process based on experience, and that it has been incorporated in formal construction through code requirements and design procedures that are mostly rationalizations of the established practice, even after been validated by structural mechanics principles and experimental evidence. In non-engineered construction, the system is of general use in seismic prone urban areas of the country, and is slowly but steadily disseminating also in rural areas. The lesson that could be extracted from this case is that structural solutions akin to the local practice, but with superior performance based on their improved layout, materials and structural features must be promoted and disseminate to potential beneficiaries of this program, case studies of success attained in similar areas and conditions.

1.5 Current situation of building regulations

General remarks

As previously mentioned the most widely known seismic regulations in México are those of Mexico City (MCBC). These provisions are generally adopted for other parts of the country, with due considerations to the differences in seismic hazard and soil conditions.

The MCBC is constituted by general provisions included in the main body of the Code, and by Complementary Technical Norms for specific materials.

Scope

Explicit concepts

The Norm defines minimum requirements; the designer, in agreement with the owner, may choose more conservative requirements to reduce economic losses.

Performance Objectives

The purpose of the Norm is to obtain an adequate safety to ensure than, for the maximum probable earthquake, there will be no major structural failures nor loss of life, although there could be damages that impair serviceability and demand major repairs.

Seismic zoning and site characteristics

Seismic Zoning (Quality of Data)

As mentioned, the Norm is intended for Mexico City. The version of 1995 had three zones (I, II and III). The proposed Norm of 2003 has six Zones because Zone III is further divided into four subzones (I, II, III_a, III_b, III_c and III_d) as shown in next figure:

The Zones are essentially defined by the type of site conditions, which have been extensively studied.

Levels of Seismic Intensity

For Group B buildings only one level of seismic intensity is assigned to each particular seismic zone or subzone. These levels are incremented by 50% for Group A buildings and are also different for the simplified method of analysis. However, these modifications are not associated to specific seismic intensities.

Site Classification

As mentioned, the area is divided into six different zones and subzones according to site characteristics:

Zone I: Hard Ground

Zone II: Transition

Zone III: Soft Soil (divided into four subzones)

Peak Ground Accelerations

Horizontal peak ground accelerations a_0 (as related to gravity) are defined for each zone or subzone:

Zone	a_0
I	0.04
II	0.08
III_a	0.10
III_b	0.11
III_c	0.10
III_d	0.10

Parameters for structural classification

Occupancy and Importance

There are two Groups, with corresponding Importance Factors:

Group A: Are those structures whose failure may cause a high number of deaths, high economic or cultural losses, hazard due to their toxic or explosive contents. Also includes those which must remain serviceable after an urban emergency. Importance Factor I = 1.5

Group B: All structures not included in Group A. Importance Factor I = 1.0

Structural Type

No specific chapter or article of the Norm explicitly defines the structural types. However several structural types are mentioned in relation with the definition of the Reduction Factor Q used in the Design Spectra. These are:

Frame systems (steel, concrete, steel-concrete composites).

Flat slab systems (concrete, steel),

Wall systems (masonry, concrete, steel, steel-concrete composites).

Braced frame systems (steel, concentric and eccentric).

Prefabricated concrete systems.
Dual systems, combination of the above systems with minimum strength for the frames.
Structural Regularity: Plan and Vertical
A Regular structure must satisfy eleven requirements (for plan and vertical regularity); otherwise it will be Irregular:

- Essentially symmetric plan. Orthogonal resisting components.
- Slenderness ratio less than 2.5.
- With to length ratio less than 2.5
- No plan reentrant corners.
- Stiff and strong diaphragms.
- Diaphragms without openings.
- Uniform floor weights along weight (no more than 10% increase over inferior floor).
- Uniform floor dimensions along height.
- All columns restricted in both horizontal directions at each floor.
- No more than 50% reduction on strength and stiffness among adjacent floors.
- Eccentricity less than 10% of plan dimensions in floor (both directions).

Additionally, an Irregular structure is defined as Severely Irregular if:

- Presents more than 100% reduction on strength and stiffness among adjacent floors.
- Contains eccentricities larger than 20% of plan dimensions in any floor.

For an Irregular structure, the Reduction Factor Q will be multiplied by 0.9 if one irregularity is present, by 0.8 if there are two irregularities and by 0.7 for Severe Irregularities (keeping $Q \geq 1$).
Structural Redundancy
If any column, wall or braced frame contributes with more than 35% of the total strength, its strength will be 80% of the corresponding nominal value estimated with the Norms.
Ductility of elements and components
The MCBC contains specific requirements to achieve either high or moderate ductility on the structural members and components for each structural material. The Reduction Factor Q is larger for structures designed with high ductility elements.

Seismic actions
Elastic Response Spectra (Horizontal and Vertical)
An elastic response spectrum is defined only for the Mode Superposition methods. The horizontal acceleration response spectra, a, is given by:
$a = a_o + (c - a)(T/T_a)$ for $T < T_a$
$a = c$ for $T_a \leq T \leq T_b$
$a = q\,c$ for $T > T_b$
where $q = (T_b / T)^r$ and the values of c, a_o, T_a, T_b and r for each Zone are given in the following Table:

Zone	c	a_o	T_a	T_b	r
I	0.16	0.04	0.20	1.35	1.0
II	0.32	0.08	0.20	1.35	1.33
III_a	0.40	0.10	0.53	1.8	2
III_b	0.45	0.11	0.85	3.0	2
III_c	0.40	0.10	1.25	4.2	2
III_d	0.30	0.10	0.85	4.2	2

Design Spectra
A Reduction Factor Q’ is used for calculation of lateral seismic forces with Static and Mode Superposition Methods, where:
$Q' = Q$ for T unknown or $T \geq T_a$
$Q' = 1 + (T / T_a)(Q - 1)$ for $T < T_a$

Where Q can take values of 1, 1.5, 2, 3 and 4 according to Structural Types, structural materials and ductility of elements and components. The following Table summarizes the requirements for different Q values:

Q	Requirements
4	a. Frame or Dual structural types of steel, concrete or steel-concrete composites with frames able to resist 50% of acting seismic force. b. Dual structural types with masonry walls if the structure without them is able to resist 80% of total lateral forces. c. Minimum lateral strength on any story is within 35% of the total average. d. If steel braced frames are present, they must be eccentrically braced. e. Elements and components designed for high ductility.
3	a. Previous (Q=4) conditions b, d and e are satisfied but either conditions a or c are not (in any story) b. Concentric steel braced frames designed for high ductility.
2	a. Frame, wall or dual structural types of steel, concrete, steel-concrete composites or masonry not satisfying any of the requirements for previous (Q= 3 or 4) conditions. b. Prefabricated concrete buildings. c. Some types of timber or steel buildings according to their specific norms.
1.5	a. Wall structural types with hollow masonry walls. b. Timber frame buildings.
1	Buildings with other structural materials and without technical justification for higher values.

Simplified Analysis and Design Procedures.
A Simplified Analysis Method can be applied to buildings satisfying the following requirements:

- At each plant, at least 75% of vertical loads are supported by nearly symmetrically distributed walls (masonry, concrete, steel plate, concrete-steel composite or braced timber walls) integrated by horizontal diaphragms (slabs) with enough stiffness and strength.
- Plan length to width ratio is less than 2.
- Height is less than 13m and its ratio to minimum horizontal dimension is less than 1.5.

Horizontal displacements, torsion and overturning moments are not considered. It is only necessary to check that, at each story and for each horizontal direction, the shear strength is at least equal to the seismic demand calculated with the Static Method Procedures but using the Seismic Coefficients given in the following Table for type B buildings (or 1.5 times those values for Type A buildings):

Zone	Concrete or solid masonry walls			Hollow masonry walls		
	Construction high H (m)			Construction high H (m)		
	H < 4	4<H<7	7<H<13	H < 4	4<H<7	7<H<13
I	0.07	0.08	0.08	0.10	0.11	0.11
II or III	0.13	0.16	0.19	0.15	0.19	0.23

Static Method Procedures.
This method can be applied to regular buildings no more than 30m high or irregular buildings no more than 20m high in Zones II and III, or for buildings no more than 40m high for regular and no more than 30m high for irregular in Zone I.
Initially, the total base shear force V_o as a ratio of the total structural weight W_o is calculated as:
$V_o / W_o = c / Q' \geq a_o$
V_o is distributed as forces F_i on each floor of weight W_i and height h_i :
$F_i = V_o [W_i h_i / \Sigma_k W_k h_k]$
The fundamental period T is then calculated by Rayleigh's Method.
If $T \leq T_b$ then $V_o / W_o = (a/Q')$ and F_i is recalculated with the above equation.
If $T > T_b$ then the forces F_i at each level are:
$F_i = W_i (k_1 h_i + k_2 h_i^2) (a/Q')$ where $a \geq a_o$
and $k_1 = [1 – 0.5 r (1-q)] [W_o / \Sigma_k W_k h_k]$
$k_2 = 0.75 r (1–q) [W_o / \Sigma_k W_k h_k^2]$
$q = (T_b / T)^r$

Safety verifications
Building Separation
The Code specifies minimum separations from site boundaries of 50mm or the corresponding inelastic horizontal displacements increased by 0,001, 0.003 or 0.006 times the height for Zones I, II or III. For the Simplified Method of Analysis the increments are 0.007, 0.009 and 0.012. When significant, base rotations must be considered.
From adjacent buildings or independent bodies of one building, their total separation will be the added values of both bodies or half of it if they have similar structural systems and the same height in all levels.
Requirements for Horizontal Diaphragms
Apart from the fact than the diaphragms of Regular Structures must satisfy certain requirements, there are no specific design requirements for them other than the statement that they should have enough strength and stiffness to resist and transmit the seismic forces to the resistant systems.
Requirements for Foundations
Apart from a minor reference that both the structure and its foundation must satisfy all ultimate and serviceability limits, foundation requirements are not included in the "Complementary Technical Norms for Earthquake Resistant Design" but in the MCBC.
Stiffness and damping properties of foundations are specified for evaluation of soil-structure interaction effects.

Small residential buildings
No specific recommendations are given for small residential buildings but the provisions for Simplified Analysis are applicable to many of these buildings.

2 Outline of construction practices

2.1 Housing is built through one of the following three processes:

Informal construction. The lack of land stocks adequate for housing projects, and the large deficit (of more than 700,000 houses yearly) have forced the development of this construction sector. Official statistics indicate that more than 70% of the total dwellings belong to this category. Such process typically involves the invasion of private or public grounds not adequate for housing, and the construction of houses without land titles, building permits and the participation of engineers or architects. It is also characterized by the participation of family members in the construction and procurement phases and by the use of weak materials and deficient structural systems (such as adobe and plain masonry). It is commonly found in rural and in poor urban areas. In Mexico City, for example, 61% of the housing stock has been informally constructed (FICA, 2000).

Housing financed through Government programs. The Federal Government operates three large programs aimed at financing the construction of low-income housing (FICA, 2001). One program deals with mortgages to workers from the private sector (*Infonavit*). In this program, over 60% of the financial resources come from the 5% tax applied to the salaries of more than 12 million workers, which amounts for one-third of the demand; the remainder 40% is collected via mortgage liquidation, payments, and capital interests. This program is responsible for over two thirds of the formal construction of housing in the country. The second program, *Fovi*, was originally intended to direct resources from the banking and financial systems to housing construction. Since 1994, *Fovi* deals primarily with "No Bank Banks", and is responsible for about 20% of the formal housing. *Fovissste* is the third program and is focused on loans to employees of the Federal Government. Over 6% of the total formal housing is its responsibility. Government loans mostly applied to purchase new or existing housing, build in a plot owned by the worker, to improve the house, and to pay the debts related to the previous items. Engineers and architects are involved in the design and construction processes. For comparison, the balance of mortgages in the country is of the order of 8% of the gross national product, whereas in Spain and the US such balance is 23 and 59%, respectively.

Private construction. In this category, architects and/or civil engineers are hired for design and construction. Housing of middle-to-upper class people belongs to this category. Construction is typically financed through personal savings and commercial mortgages. Because of the quality of materials, design and construction process, this category is the least vulnerable to earthquakes.

2.2 Type of construction in Mexico

The Federal Government, State governments and academic institutions to identify the prevalent housing types have carried out several efforts. However, they have been mostly directed to catalog the architectural features, as well as their relationship with the climate, with little, or almost no information on the characteristics of the structural system. Within the scope of the project reported herein, housing types have been grossly grouped according to the kind of building materials used in the vertical structural system (i.e. walls, columns), and in the horizontal structural system (floors, roofs).

It is recognized that this classification is far too broad if quantitative vulnerability assessments are to be made. Indeed, the nature of a building material by itself is not commonly enough to conclude about a vulnerability rating of a particular housing type. For instance, buildings built with bricks with sufficient number and well-detailed confinement elements would have a quite low vulnerability rating. On the contrary, plain masonry brick walls would be assigned a high vulnerability rating. In short, the broad classification presented here does not consider any type of reinforcement and quality of construction.

Seven groups have been identified according to their material in the vertical structural system: 1) adobe construction; 2) plain masonry walled houses; 3) confined and reinforced masonry; 4) structural concrete walled houses; 5) structural concrete frame buildings; 6) wooden structures; and, 7) others.

In adobe houses, walls are made of adobe blocks joined by mud mortar; roofs comprise wood trusses that support clay tiles. Generally, walls are not tied together nor are confined. A typical adobe building has one or two rooms; distributed in a rectangular plan with average dimensions of 4 x 8 m. Heights are of the order of 3 m. Most adobe dwellings are 30 to 50 years old, although in the central districts of old villages, much older houses can be found. According to the national censuses (e.g. INEGI, 1990 & 2000), adobe construction is rapidly disappearing.

Walls in plain masonry houses are made of artificial stones, i.e. clay or concrete bricks and blocks, or of natural stones. Similarly to adobe construction, walls lack of any reinforcement to improve their tensile strength or wall confinement. Reinforced concrete slabs, wooden slabs, bearing earth layers for temperature isolation, and wooden trusses supporting clay tiles, are the three types of roofs most widely found. Houses of 2.4-m high are standard. The usual floor plain is around 16 to 45 m², with three rooms.

Both adobe and plain masonry dwellings are representative of the informal construction process explained before. They are found in rural areas, as well as in urban areas, which could have been defined in the past as rural because of the number of inhabitants. Both systems belong to the highest rating of vulnerable houses. The lowest-income population of the country inhabits these housing types.

Confined masonry has become the most popular and cost-effective construction system for dwellings. Walls, either made of hand-made or industrialized masonry units, are confined by slim and lightly reinforced concrete tie-columns, TCs, and bond-beams, BBs. TCs and BBs are intended to confine the wall in plane, and to avoid the disengagement of masonry after inclined cracking. Also, these elements act as connectors, tying together the transverse walls and the walls with floors and roofs. Although not explicitly considered in the design process, tie columns contribute to enhance the wall lateral strength. In recent times, in order to improve wall lateral strength and deformability, particularly in buildings 4-to-6 stories high for which story shears are highest, horizontal reinforcement or welded wire meshes anchored to the wall have been used. Depending upon the soil compressibility, strip footings, mat foundations or mat foundations with concrete piles are used.

Reinforced masonry is a much less favored system. Failures in past earthquakes, attributed to substandard construction practice and errors, have prompted designers and constructors to stay away from this system. Nevertheless, in some housing projects, hollow concrete masonry units have been internally reinforced with horizontal and vertical mild steel bars. Cavities are often filled with joint mortar or, if properly performed, with special grouts or mortars.

In the past decades, reinforced concrete walls have been used to improve the earthquake resistance capacity of 4-to-6 story high buildings. Because of the speed of construction and cost, concrete is now being used to build the whole structure. Tunnel forms or steel formwork are used. Typically walls are 100-mm thick, and reinforced with minimal amounts (e.g. 0.0025). Walls are often reinforced with steel welded wire meshes. One-to-two story houses, supported on a 150-to-200-mm thick slab foundation are standard. Recently, cellular concrete has been used in areas where thermal isolation is necessary. This is the case of the northern part of the country where temperature variations between day and night are high.

When properly designed and constructed, confined and reinforced masonry, as well as concrete walled houses have a low-to-very low vulnerability rating.

In large urban areas, and for middle-class people, medium-rise reinforced concrete frames infilled with masonry walls are common. Structures have 5 to 15 stories. Pre-1950's constructions featured stiff brick infills covered with thick finishings that considerably augmented the lateral strength and stiffness, as well as the energy dissipation capacity, of the slender, inadequately detailed columns, beams and joints. Nevertheless, the satisfactory performance of this version led to conclude, erroneously, that by keeping the same dimensions and the detailing of frames, but replacing the stiff infills by lighter, more flexible ones, the response would be similar. The 1985 Mexico City, earthquakes, in particular, provided evidence on the contrary. The vulnerability rating of infilled frames is quite broad, since it strongly depends upon the relative strength and stiffness of infills to frame, as well as on the detailing of frames.

Wooden houses are mostly built in regions of high humidity and temperature, particularly along the coast. In this category, *bahareque* (or rammed earth) and cane walls are included. Thatched roofs and single-room houses are typical. Houses are most often built directly over the ground, without any foundation system; the soil is leveled and slightly compacted before construction. In general, vulnerability rating is medium-to-low, depending upon material deterioration.

There are other housing types in the country, but their quantities are too small to be of significance if compared to the above-mentioned categories. Among them, shabby houses made of timber frames wrapped with cardboard sheets are the most representative. These homes are regularly found over sloped terrain, like the slopes along the creeks. Inhabitants are in extreme poverty. For this people, the only choice for a dwelling is to invade private or public propriety and to self-construct their home. Evidently, they lack of public services (water supply, drainage, electric power). The floor of the house is of dirt.

3 Earthquake damage of low rise constructions

3.1 History

It is fair to say that, at the national level, the quality of materials and construction practices are quite heterogeneous, both in the urban and rural context. Common deficiencies found in damaged homes are low-strength masonry units, low-strength mortars, and lack of inspection and control of the construction process itself, rendering, among others, to insufficient foundations, inadequate or non-existing confinement or reinforcement, and lack of continuity.

Earthquake reconnaissance studies have pointed out that damage has been exacerbated because of poor or lack of maintenance and preservation. Dampen walls and roofs, either because of leaks or deficient waterproofing, are especially vulnerable to earthquake attack. Prevalent damage observed in housing can be classified as follows (Tena, 1997): 1. Inclined cracking in walls with or without confinement elements, TCs and BBs, with masonry and concrete spalling. 2. Inclined cracking of plain masonry window piers. 3. Short inclined cracks starting at re-entrant corners of openings. 4. Inclined cracking in TCs or BBs. 5. Cracks and spalling in concrete elements not designed for durability. 6. Tilting of houses because of liquefaction of underlying sandy soil deposits. 7. Structural concrete elements poorly detailed to attain ductile behavior; i.e. insufficient anchorage and low confinement. 8. Damage of walls because of pounding to adjacent structures. 9. Concentration of damage in few elements due to flexible floor and roof diaphragms, especially in wooden and thatched horizontal structural systems. 10. Vertical cracking at corners of plain masonry walls credited to out-of-plane wall deformations and low-strength masonry. In the extreme case, walls fail, the floors and the roof detach from the walls and then collapse. 11. Inadequate structural layouts to resist earthquakes commonly characterized by: a) asymmetric in-plan distribution of walls leading to large torsional vibrations; b) reduced wall area to resist the seismic-induced loads, particularly parallel to the front of the house; and, c) irregular distribution of stiffness over the height of the building, giving rise to flexible stories (commonly at the ground level), often with inadequately detailed and unconfined elements. 12. Substandard construction practices in reinforced masonry walls, specifically, lack of placement of some reinforcing bars, inadequate anchorage or bars and, more often, incomplete filling of grout in hollow blocks.

3.2 Housing Distribution Patterns

In order to implement efficient and effective seismic vulnerability reduction programs, it is essential to understand the social condition of the inhabitants, as well as the physical (engineering) vulnerability of the house. With the aid of Geographical Information Systems, and using the data from the national censuses, a series of maps, at a national scale, which correlate seismic hazard, the type of housing and an indigence index have been produced. According to preliminary results of the 2000 General Census of Population and Housing (INEGI, 2000), there are 21.9 million houses in Mexico; 71.2 % are in urban areas (INEGI, 2000). With regards to the construction materials used in walls, 79% are built with brick, block, stone or concrete (so called, durable materials), and almost 10% is made of adobe. Regarding the roofing materials, 64% have concrete or masonry slabs, either with or without earthen layers, and 19% are of metal or asbestos sheets supported on wooden rafters. It is important to mention that data from the general censuses cannot be used to assess the actual seismic vulnerability of the house, because no information about reinforcing schemes is inquired. Just the material used is recorded. Nevertheless, censuses' information is useful to understand housing trends.

In Figure 3, the percentage of houses, per state, made of walls built with durable materials and with concrete or masonry roofing slabs is shown. The seismic hazard map of Figure 2 is superimposed. It is evident that inside seismic regions C and D, there are several states in which the percentage of this kind of houses is quite low; actually, in the southernmost states, masonry houses with asbestos or metal sheet roofs and adobe houses are prevalent.

In Table 3, the percentage of houses for all combinations of roof (or floor) and wall materials at a national level is presented. It is evident that the first five combinations are those for houses with durable materials in walls and that the second four correspond to dwellings with adobe walls. However, for the latter, the distribution of predominant materials is quite uniform.

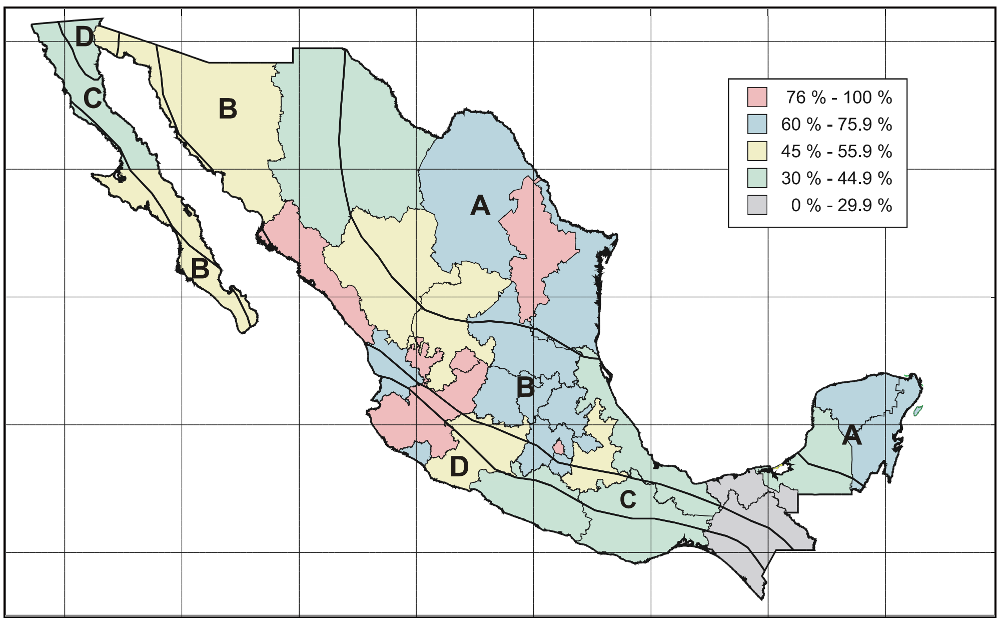

Figure 3. Percentage of houses, per state, made of walls built with durable materials and with concrete or masonry roofs

Table 3. Predominant construction materials in walls and roofs, in percentage (INEGI, 2000)

Predominant material in walls	Predominant material in roofs				
	Metal/asbestos sheets	Thatched	Concrete or masonry slabs	Cardboard sheets	Clay tiles
Brick, block, stone, concrete	11.4	1.9	61.3	2.1	2.0
Adobe	3.1	1.0	2.4	0.7	2.8
Wood	2.9	1.5	0.05	1.9	0.3
Cardboard sheets	0.1	0.02	0	0.6	0
Bahareque	0.5	0.4	0	0.3	0.1

Aimed at understanding the relationship between the housing types and the socioeconomic level of the population, the map of Figure 4 portrays the indigence index superimposed on the amount of adobe houses in each state; again, the seismic hazard zones are also displayed. The indigence index was devised by the National Council of Population to measure the quality of life in communities (CONAPO, 1995).
This index takes into account, among several factors, the literacy rate, and the percentage of houses with public services (running water, drainage, electricity). From the graph, it is clear that inside the seismic regions C and D, several states with high and very high indigence indices have large amounts of adobe houses. This is an indication that for a vulnerability reduction programs to be effective, they must be part of broader programs that encompass other improvements in the quality of life. Indeed, for inhabitants in extreme poverty, is not enough to enhance the earthquake resistance characteristics of their houses; it is necessary to improve or supply water, drainage, electricity, schools, etc. and, particularly, means for a sustained development.

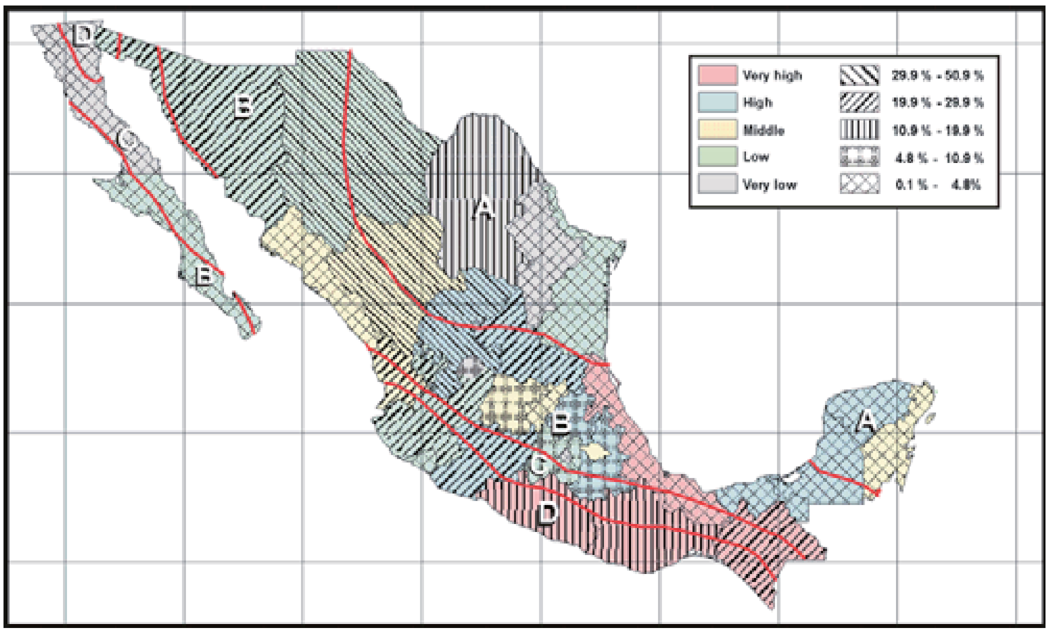

Figure 4. Percentage of adobe house density (number of houses divided by number of inhabitants), per state, compared to the indigence index

4 Current research output

4.1 Rehabilitation and Reconstruction Efforts

In the aftermath of earthquakes, Federal and State authorities are prompted to reconstruct the areas damaged. Typically, the Federal Government covers about two thirds of the cost, supplying technical guidance and financial support. The beneficiaries themselves through a temporary employment program that lasts few months after the event commonly carry out rehabilitation efforts. Several techniques have been used in the past, for adobe construction as well as for masonry houses. In general, these techniques are aimed at increasing the tensile strength of the walls, as well as at improving the integrity of the house by inter-connecting the walls and the walls and floors or roofs (FICA, 1999). Perhaps the prevalent rehabilitation technique is wall jacketing with welded wire meshes, or chicken-wire meshes, covered with cement or lime mortar. Meshes are typically anchored to the wall by wire ties through the walls, and more recently, by steel staples (used for barbed wires) driven into the wall. Mortars can be applied in a single layer, after the mesh is directly anchored to the wall, or in two layers; the first one before the mesh is anchored, and the second one to cover the mesh (Fig. 5). To improve the integrity of the dwelling, TCs and BBs are commonly built at wall edges and at wall intersections.

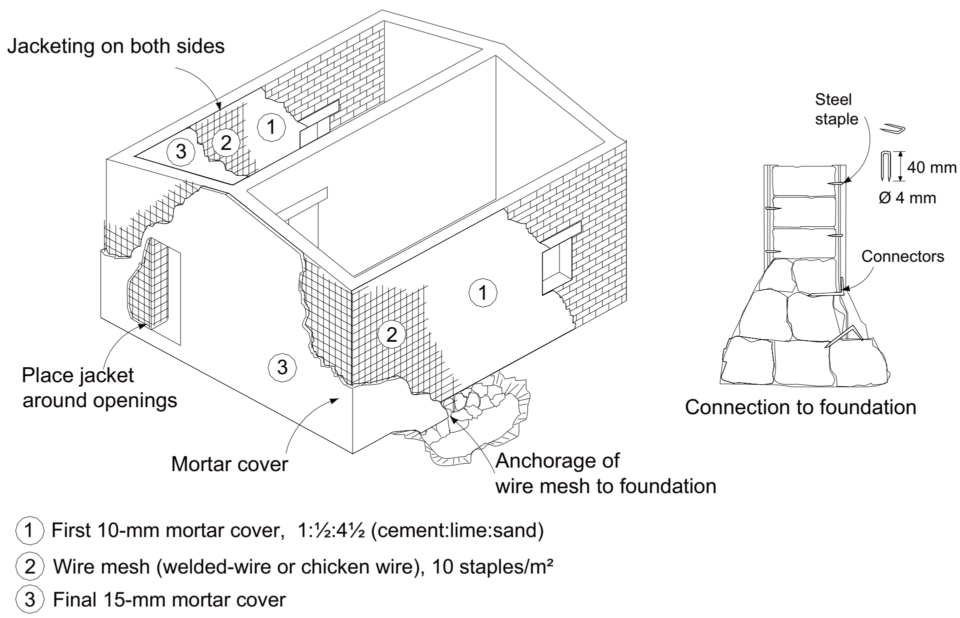

Figure 5. Rehabilitation of adobe houses with wall jacketing

In recent earthquakes, the Ministry of Social Development has carried out reconstruction programs based on single-story houses made of reinforced concrete frames infilled with masonry walls. Such prototypes are grossly over designed, especially because wall participation to lateral strength and stiffness is disregarded. This is attributed to the Ministry's negligence to incorporate local construction practices and materials in programs designed in the capital city to solve all kinds of reconstruction efforts. Evidently, the cost is excessive.

REFERENCES

Comisión Federal de Electricidad (CFE, 1994), "Manual de Obras Civiles. Diseño por Sismo," *(in Spanish),* Mexico, D.F.

Consejo Nacional de Población (CONAPO, 1995), "Indicadores Sociodemográficos," *(in Spanish)*, México, D.F.

Departamento del Distrito Federal (DDF, 1995), "Normas Técnicas Complementarias para Diseño y Construcción de Estructuras de Mampostería," *(in Spanish),* Mexico, D.F., February, 16 pp.

Flores, L.E., M.A. Pacheco and C. Reyes (2001) "Algunos estudios sobre el comportamiento y rehabilitación de la vivienda rural de adobe," *(in Spanish),* CENAPRED, IEG/03/01, Mexico, D.F., March, 123 pp.

Fundación ICA (FICA 1999), "Edificaciones de mampostería para vivienda," *(in Spanish),* Mexico, D.F., 316 pp.

Fundación ICA (FICA 2000), "Experiencias de autoconstrucción de vivienda en México," *(in Spanish),* Cuadernos FICA, Mexico, D.F., 56 pp.

Fundación ICA (FICA 2001), "Financiamiento de la vivienda en México," *(in Spanish),* Cuadernos FICA, Mexico, D.F., 38 pp.

INEGI (1990). XI General Census of Population and Housing. www.inegi.gob.mx

INEGI (2000). XII General Census of Populatino and Housing. www.inegi.gob.mx
Tena, A. (compiler) (1997), “El macrosismo de Manzanillo del 9 de octubre de 1995,” *(in Spanish),* Mexican Society of Earthquake Engineering, 343 pp.
Ordaz M. and Meli R. (2004), “Seismic Design and Codes in Mexico”, 13th World Conference on Earthquake Engineering. Vancouver, B.C., Canada August 1-6
Fukuta, T. (1991). “Seismic design in Mexico City”, *Building Research Institute*, Ministry of Construction, Japan.
Meli, R. and S. Alcocer (2004), “Implementation of Structural Earthquake Mitigation Programs in Developing Countries”, *Natural Hazards Review, ASCE,* Volume 5 Issue 1, 29-39.