World Housing Encyclopedia

an Encyclopedia of Housing Construction in Seismically Active Areas of the World

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Combined and Confined Masonry Construction

Report #	160
Report Date	01-09-2010
Country	MEXICO
Housing Type	Confined Masonry Building
Housing Sub-Type	Confined Masonry Building : Clay brick masonry, with concrete tie-columns and beams
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Summary

It is defined as combined and confined masonry structures those where the bearing/seismic walls are made by alternating courses of lightweight concrete blocks (inexpensive in Mexico) with courses of fired clay bricks (more expensive) and they are confined with cast-in place reinforced-concrete tie-beams and tie-columns (Figure 1). The impact of confining elements in

masonry walls includes: a) enhancing their stability and integrity for in-plane and out-of-plane earthquake loads, b) enhancing their strength (resistance) under lateral earthquake loads and, c) reducing their brittleness under earthquake loads and hence improving their earthquake performance. Although combined masonry construction has historical background in Mexico and worldwide (i.e., Tena-Colunga et al. 2009), combined and confined masonry became popular in recent times by the initiative of the inhabitants of the central Mexican states of Puebla, Tlaxcala and Oaxaca. This modern version of combined and confined masonry has been used since the early 1990s. Different arrangements to combine and alternate brick courses with block courses have been used (Juárez-Angeles 2009, Salinas-Vallejo 2009), but the one that it is most commonly used is the one depicted in Figure 1, where three courses of clay bricks alternate with a course of concrete blocks. Usually, this type of construction is being used for housing in rural and urban regions of Mexico, but it has also being used for warehouses and apartment buildings up to three stories high. The most common floor systems used with combined and confined masonry are: a) cast-in-place reinforced-concrete slabs 10 to 12 cm thick and, b) precast beams with concrete block infill and concrete topping (cast-in-place) and, c) cast-in-place waffle flat slab with polystyrene infill. Because of the poor quality of the concrete blocks produced in the central regions of Mexico, combined and confined masonry walls have similar behavior but lower shear strength and ductility compared to traditional confined masonry walls made of fired clay bricks only (Tena-Colunga et al. 2009). Nevertheless, these structures have had good performances during moderate and strong earthquakes, such as the M=6.5 June 15, 1999 Tehuacán earthquake and the M=7.6 January 21, 2003 Tecomán earthquake.

1. General Information

Buildings of this construction type can be found in most parts of Central Mexico, in particular in the states of Puebla, Tlaxcala, Estado de México, Hidalgo, Querétaro, Morelos, Oaxaca, Colima and is starting to be used in Mexico City as well (Figure 2). The earthquake hazard in this region of Mexico is high. This type of housing construction is commonly found in rural, sub-urban and urban areas. This construction type has been in practice for less than 25 years.

Currently, this type of construction is being built. The number of applications of this building typology is growing very fast nationwide. Usually, this type of construction is primarily being used for housing (both for low-income and middle-income), but it is also being used for warehouses and apartment buildings up to three stories high. Among the reasons for their increasing popularity are: a) the significant cost savings and construction time when compared to the traditional confined masonry construction using only fired clay bricks, as the concrete blocks are cheaper than clay bricks and less mortar is needed to bond this type of walls and, b) the aesthetic appearance of combined masonry walls because of the appealing contrast in colors of the layers of bricks and blocks. In fact, for this type of masonry walls, house owners frequently do not use painted mortar/lime or stucco finishing for facades. This type of construction has become so popular that after the Tecomán earthquake, the combined and confined masonry was a popular construction types chosen by residents who needed to reconstruct their houses after demolishing because of severe damage (Reyes et al. 2006).

Figure 1. Most common configuration of combined and confined masonry:

Figure 2. States in Central Mexico where combined and confined masonry

3 courses of bricks alternate with 1 course of concrete blocks.

is used (colored in gray).

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. This is particularly common in rural areas When separated from adjacent buildings, the typical distance from a neighboring building is several meters.

2.2 Building Configuration

The typical plan layout is rectangular or nearly-rectangular (trapezoid, etc). It is common to have one-story and two-story structures for housing. The façade walls always have openings for doors and windows, ranging for 30% to 50% of the total area of the wall. Perimeter perpendicular walls to the façade sometimes have openings, but most commonly they do not have openings; therefore, the highest wall density of these houses is commonly in the direction perpendicular to the façade.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). The main use of buildings of this type is single family house, but commercial usage has also been detected (stores, warehouses and apartment buildings, for example, Figures 3 and 4). In a typical building of this type, there are no elevators and no fire-protected exit staircases.

2.4 Modification to Building

Extensions to houses (additional rooms built after the initial construction) are common practice in rural and suburban areas of Mexico, particularly when the family grows, for example, extra rooms needed for a married son/daughter with children. Depending on the land availability, these additional rooms are built on the ground level (preferred, primarily in rural areas) or in upper stories (primarily in suburban areas).

Figure 3. Combined and confined masonry warehouse: 3 courses of bricks alternate with 3 courses of concrete blocks.

Figure 4. Three-story combined and confined masonry apartment building: 3 courses of bricks alternate with 2 courses of concrete blocks.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐

Masonry	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☑
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
		36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate	☐

Timber	Load-bearing timber frame		levels	
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

This construction type is defined as Combined and Confined Masonry, where the walls are made by alternating courses of concrete blocks with courses of fired clay bricks, confined by reinforced-concrete tie-beams and tie-columns.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Vertical loads on the building are resisted by the combined and confined masonry wall system.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is confined masonry wall system. Lateral loads on the building are resisted by the combined and confined masonry wall system, mostly with rigid and semi-rigid diaphragms made with cast-in-place RC floor systems. Different arrangements to combine and alternate brick courses with block courses have been used (Figure 1 and Figures 3 to 9), as briefly illustrated here and explained in detail elsewhere (Juárez-Angeles 2009, Salinas-Vallejo 2009). The most commonly used combination pattern is the one depicted in Figures 1 and 9, where three courses of clay bricks alternate with a course of concrete blocks. The characteristics, dimensions, reinforcement and spacing of the RC confining elements (tie-beams and tie-columns) are identical of the Mexican practice for traditional confined masonry structures made with fired-clay bricks or concrete blocks (for example, NTCM-2004 2004).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 6 and 14 meters, and widths between 8 and 20 meters. The building has 1 to 3 storey(s). The typical span of the roofing/flooring system is between 3 to 6 meters. The typical storey height in such buildings is from 2.20 to 2.40 meters. The typical structural wall density is up to 10 %. Usually, higher structural wall density is in the direction perpendicular to the façade.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☑	☑
	Waffle slabs (cast-in-place)	☑	☑
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐

	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

The most common floor systems used with combined and confined masonry are: a) cast-in-place reinforced-concrete slabs 10 to 12 cm thick and, b) precast beams with concrete block infill and concrete topping (cast-in-situ) and, c) cast-in-place waffle flat slab with polystyrene infill. These floor systems can be classified as rigid or semi-rigid diaphragms for the typical spans of the floor systems used in this type of construction, according to recent analytical studies (Tena-Colunga and Cortés 2009, Cortés 2009). However, for single story construction, sometimes metal, asbestos or industrialized cardboard corrugated sheets are used as roof system (Figure 9), usually anchored directly in the walls using nails or screws. Metal corrugated sheets are also used as roof systems in warehouses (Figure 3). Then, for such conditions, these structures should be considered as having no diaphragm or a very flexible diaphragm.

3.6 Foundation

Type	**Description**	**Most appropriate type**
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☑
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Depending on the availability of materials and the soil conditions, rubble stone strip footing, reinforced-concrete strip footing or a reinforced-concrete slab are used.

Figure 5. Combined and confined masonry fence: 2 courses of bricks alternate with 3 courses of concrete blocks.

Figure 6. Combined and confined masonry store: 2 courses of bricks alternate with 1 course of concrete blocks.

Figure 7. Combined and confined masonry store: 2 courses of bricks alternate with 2 courses of concrete blocks.

Figure 8. Combined and confined masonry house: 1 course of bricks alternate with 1 course of concrete blocks.

Figure 9. One-story combined and confined masonry house: 3 courses of bricks alternate with 1 course of concrete blocks.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). For residential use, each building has 1 housing unit in it. For apartment buildings, each structure consists of 5 to 10 housing units. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

Usually, a single family occupies a housing unit. Nevertheless, poor people may have large families (the original parents and the families of their married sons/daughters with children) sheltered in a housing unit.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

For poor people, the members of the family usually have either low-income formal job (less than $300.00 U.S. per month) and/or are in the informal economy (self-employed in low-income commercial or manufacturing activities). Therefore, the family needs many of them to work in order to afford living. In such families, it is common that at least one of their relatives has experience as a bricklayer.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐

4:1	☑
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

For poor people, the ratio of the Housing Unit Price to their Annual Income is between 3:1 to 4:1. Their typical source of financing for the purchase of a house is almost nonexistent. Poor people usually start buying building materials with their own very small personal savings and/or a loan from a relative, and then start building their home by their own means. In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

In each housing unit, there is at least 1 bath-and-toilet for poor people, but middle class people have at least 2 bath-and-toilets and may have up to 4 bath-and-toilets. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership , individual ownership , ownership by a group or pool of persons and others.

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☑
Ownership by a group or pool of persons	☑
Long-term lease	☐
other (explain below)	☑

Ownership with debt, usually to a relative.

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☑	☐	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☑	☐	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☐	☑
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☐	☑
Additional Comments	The building is often regular with regards to its plan and somewhat irregular in elevation because of the location of windows openings. At each storey level, the height-to-thickness ratio (h/t) of shear walls is adequate for confined masonry construction (h/t less than 20). Up to date, there is no reliable information about the quality of maintenance for buildings of this type; however, there are no visible signs of deterioration of building materials, particularly in the weaker material, the concrete blocks. This is an important aspect to highlight, as for this type of construction, house owners frequently do not use painted mortar/lime or stucco finishing for facades and therefore building materials (bricks and blocks) are directly exposed to weathering effects (rain, temperature, etc).			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	These walls are made with non-industrial fired clay bricks and lightweight concrete blocks with no quality control and therefore, they do not fulfill the Mexican standards for structural use. The mortar mix used by the people has volumetric proportions:1:2:6 (cement:lime:sand), clearly a mix that is out of what it is recommended in the Mexican and other international masonry codes for seismic zones. Limited shear strength and deformation capacity (ductility). Cannot develop a ductile flexural failure mode. It is a common poor construction practice to build window openings without tie-column (unconfined), which results in lower shear strength, deformation capacity, and walls integrity. Another common deficiency is to leave slender ending walls (H/L>4) known as mochetas in Mexico without tie-columns at the free end. Typically, tie-columns and tie-beams have stirrups spaced every 20 cm. Therefore, after the initial cracking of the walls, shear cracks propagate through the tie-columns reducing considerably the stability of the wall (besides its strength, stiffness and deformation capacity). To prevent these effects closer stirrups should be used at the ends of tie-columns and tie-beams.	High wall density and a reasonably good confinement practice according to Mexican standards (tie-columns separated up to 4 m and tie-beams placed at top and bottom of the walls or separated up to 3m). Good quality of workmanship. These structures have had good performances during moderate and strong earthquakes, such as the M=6.5 June 15, 1999 Tehuacán earthquake and the M=7.6 January 21, 2003 Tecomán earthquake.	To date, no information is available.
Roof and Floors	Some single story houses and warehouses have industrialized light corrugated sheets as roof system, then performing similar to structures with no diaphragm that are very vulnerable to out-of-plane failures of the walls, specially if orthogonal walls are not well tied together.	Most structures have rigid, cast-in-place reinforced concrete diaphragms, that are rigid and strong.	To date, no information is available

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *E: LOW VULNERABILITY (i.e., very good seismic performance)*, the lower bound (i.e., the worst possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is *F: VERY LOW VULNERABILITY (i.e., excellent seismic performance)*.

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☐	☐	☑	☐	☐	☑

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1999	Tehuacán Earthquake	M=6.5	IX (MMI)
2003	Tecomán Earthquake	M=7.6	VIII (MMI)

No damage was observed/reported for one and two stories combined and confined masonry houses at small towns in Puebla (Cholula) and Tlaxcala states during the moderate June 15, 1999 Tehuacán earthquake (Tena-Colunga et al. 2009). This earthquake was particularly damaging for unreinforced masonry churches (known in Mexican Architecture as Colonial Churches), primarily built from centuries XVII to XIX. Many of these churches experienced partial or total collapses. In Cholula, the main two churches experienced heavy partial collapses, whereas nearby combined and confined masonry houses did not crack. In small towns and villages in Tlaxcala, Colonial Churches experienced extensive shear cracking of the walls of front towers whereas nearby combined confined masonry houses remained undamaged.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	The combined and confined masonry construction currently used in Mexico for non-engineered construction is composed of non-industrial fired clay bricks and lightweight concrete blocks with no quality control. Typical dimensions of masonry units (length, width, thickness) are the following: a) for fired-clay bricks: 23 cm x 12 cm x 6.5 cm, b) for solid concrete blocks: 38 cm x 12 cm x 18.5 cm.	Experimental testing of masonry units following the Mexican Masonry Code (NTCM-2004, 2004) allowed to assess index properties for bricks and blocks (Tena-Colunga et al. 2009, Juárez-Ángeles 2009, Salinas-Vallejo 2009). The following values were obtained for bricks: Volumetric weight 1.57 ton/m3, Absorption 18.3%, Initial rate of absorption 59.3 gr/minute, Saturation coefficient 0.94, Mean modulus of rupture fr=8.8 kg/cm2 (0.86MPa), Mean compressive strength fp=103.6 kg/cm2 (10.1 MPa), Design compressive strength fp*= 55.3 kg/cm2 (5.4 MPa). The following values were obtained for concrete blocks: Volumetric weight 1.08 ton/m3, Absorption 26.5%, Initial rate of absorption 32.7 gr/minute, Saturation coefficient 0.94, Mean modulus of rupture fr=9.8 kg/cm2 (0.96MPa), Mean compressive strength fp=43.3 kg/cm2 (4.2 MPa), Design compressive strength fp*= 24.7 kg/cm2 (2.4 MPa).	The mortar bed joint ranges from 1 cm (3/8) to 1.5 cm (5/8) in thickness. Head joints are filled with mortar and they are usually 1 cm (3/8) thick. The mortar mix used by the people has the following volumetric proportions: 1:2:6 (cement:lime:sand). It is worth noting that this volumetric proportioning, used for non-engineered construction in Mexico, does not satisfy the minimum volumetric requirements proposed by NTCM-2004, but it is used as it is an inexpensive mortar and workability is good. However, it is also worth noting that this mortar mix has better volumetric proportioning than mortar type O (1:2:9) allowed by masonry codes of the United States for non-seismic regions (Tena-Colunga et al. 2009). The following properties were obtained from the experimental testing of non-engineered mortar (Tena-Colunga et al. 2009, Salinas-Vallejo 2009): Volumetric weight 1.51 ton/m3, Mean compressive strength fj=79.5 kg/cm2 (7.8 MPa), Design compressive strength fj*= 43.8 kg/cm2 (4.3 MPa). It is worth noting that non-engineered mortar would satisfy NTCM-2004 minimum design strength requirement for structural use of having fj*>= 40 kg/cm2 (3.9 MPa), despite the fact that this mortar mix does not satisfy the minimum volumetric proportions established by NTCM-2004.	Sets of masonry prisms and wallets (small square masonry subassemblies) were constructed to define the compressive strength, Young's modulus, design shear strength and shear modulus for the combined masonry, following the general guidelines and requirements provided by NTCM-2004, as described elsewhere (Tena-Colunga et al. 2009, Salinas-Vallejo 2009). For practical purposes, the weighted properties obtained from the axial compression prism tests were fm*=15.7 kg/cm2 (1.5 MPa) and Em=15,572 kg/cm2 (1,527 MPa) or Em=991.8fm*. From the diagonal compression wallet tests, differences were obtained for shear strength indices values depending on the small wallet arrangement (Tena-Colunga et al. 2009). However, for practical purposes, the design shear strength vm* varied from 1.2 to 1.6 kg/cm2 (0.12 to 0.16 MPa) and the average shear modulus varied from 3,157 to 4,257 kg/cm2 (310 to 417 MPa). Confining reinforced-concrete tie-beams and tie-columns are usually built using the Mexican practice, which is the one outlined in detail in NTCM-2004 (2004). Therefore, the minimum dimension of the tie-beam or the tie-column is equal to the wall thickness and the design compressive strength for the concrete is f´c=150 kg/cm2 (14.7 MPa). Longitudinal reinforcement is composed of Grade 60 steel (fy= 60 ksi = 4,200 kg/cm2 = 412 MPa), corrugated, number 3 (3/8 in diameter) bars; a minimum of 4 longitudinal bars are typically placed in tie-beams and tie-columns. Transverse reinforcement is usually provided by Grade 31 steel (fy=31.25 ksi = 2,200 kg/cm2 = 216 MPa), non-corrugated, number 2 (1/4 in diameter) bars composing stirrups spaced 20 cm along the length of the tie-column or tie-beam.
Foundation		For cast-in-place reinforced-concrete strip footings or a reinforced concrete slab, the design compressive strength for the concrete (f´c) usually varies from 150 to 200 kg/cm2 (14.7 to 19.6 MPa). Corrugated grade 60 steel bars (fy= 60 ksi = 4,200 kg/cm2 = 412 MPa) are used for reinforcement.		Rubble stone strip footings are used when rocks are readily available in-situ; therefore, their quality and strength has an important range of variation. However, the mortar mix used to joint the stones is exactly the same one used in the walls, this is, it has the following volumetric proportions: 1:2:6 (cement:lime:sand). Mortar head and bed joints are highly irregular as they depend on the shapes of the rocks, but their average thickness may range from 1.5 cm to 2 cm (5/8 to 3/4 inches).
Frames (beams & columns)				
	Cast-in-place reinforced concrete slabs are the most commonly used floor systems and thy are usually	For precast beams with concrete block infill and concrete topping (cast-in-situ) floor systems, commonly known as 'vigueta y bovedilla' in Mexico, the design compressive strength for the prestressed concrete inverted		

Roof and floor(s)	10 to 12 cm thick depending on the clear span and the aspect ratio for the plan of the building. The design compressive strength for the concrete (f´c) usually is 200 kg/cm2 (19.6 MPa) for rural construction and 250 kg/cm2 (24.5 MPa) for sub-urban and urban construction. Corrugated grade 60 steel bars (fy= 60 ksi = 4,200 kg/cm2 = 412 MPa) are used for reinforcement.	T beams is f´c= 350 kg/cm2 (34.3 MPa), for the hollow concrete blocks is f*p=100 kg/cm2 (9.8 MPa) and for the cast-in-situ concrete topping is f´c= 200 kg/cm2 (19.6 MPa). Usually, for typical clear spans in these slabs and aspect ratios for the plan of the building (length/width ≤ 2), a concrete topping 3 cm in thickness with a welded wire mesh 66-1010 (3.5 mm in diameter, 0.61 cm2/m reinforcement area) is required for design under gravitational loading, according to design manuals of fabricants (Cortés 2009). The required depth for the prestressed inverted T beam is 10 cm and usually has 3 strands, one at the top 3 mm in diameter and two at the bottom (flange) 5 mm in diameter. As the hollow concrete block has 13 cm in depth, the total depth (thickness) for this floor system is typically 16 cm.		For cast-in-place waffle flat slab with polystyrene infill, the design compressive strength for the concrete (f´c) usually varies from 200 to 250 kg/cm2 (19.6 to 24.5 MPa). Corrugated grade 60 steel bars (fy= 60 ksi = 4,200 kg/cm2 = 412 MPa) are used for reinforcement. The polystyrene infill typically has the following dimensions: 40 cm x 40 cm x h´, where h´ is the total depth of the slab less the thickness of the compression concrete topping (flange thickness). The compression concrete topping varies from 3 cm to 5 cm in thickness depending on the clear span. The total depth (thickness) for this floor system varies from 13 cm to 20 cm depending on the clear span and the aspect ratio for the plan of the building (Cortés 2009).

6.2 Builder

Among low-income class the houses are built by the homeowner or a relative of the homeowner. For middle-income people, usually the builder is hired by the owner. Depending on the budget, the building team can be composed of: a) a team of independent bricklayers or, b) an engineer/architect that directs a team of bricklayers.

6.3 Construction Process, Problems and Phasing

Combined and confined masonry is typically built by a team of bricklayers. Sometimes they are supervised the most experienced bricklayer called 'maestro' (master) who is the one responsible for taking charge of construction decisions. In some other cases, an architect/engineer are in charge for the design of the structure and being responsible for the construction process. Conventional manual tools are used by bricklayers to build these structures. The construction of this type of housing takes place in a single phase. Typically, the building is originally not designed for its final constructed size. Depending on the budget of the owner, the construction of this type of housing takes place in a single phase (good budget) or incrementally over time (limited budget). Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

Combined and confined masonry houses are mostly designed empirically by extrapolating the Mexican construction practice for confined masonry houses made with fired-clay bricks or concrete blocks. Low-income people usually hire a 'maestro' (master bricklayer) to help them 'design' their home and to built it (if the master bricklayer is not a relative or a friend of the family). Middle-income people usually hire an architect or an engineer to design their home to suit their needs (basically an architectural design) and then to take charge of the construction process. If an architect is in charge, it is likely that no structural calculations would be done. If an engineer is in charge, most likely he would do a quick calculation of wall density using the simplified method for seismic analysis of Mexican building codes and would assume that the shear strength of combined and confined masonry is the smallest one of the two involved material, which in Mexico would be the concrete blocks.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country. The current building code is NTCM-2004 (2004). This construction type is not addressed by the codes/standards of the country yet. However, since combined and confined masonry structures are basically sister structures of traditional confined masonry structures made with fired-clay bricks only or with concrete blocks only, most of the procedures and recommendations available in NTCM-2004 (2004) can be used as reference for improving the design of combined and confined masonry. In absence of experimental data to assess design properties for combined and confined masonry (for example, fm*, vm*), one may conservatively assume that these properties would be the same of the weakest of the two materials (in Mexico, concrete blocks), granted that the masonry units (bricks and blocks) and the mortar used fulfill all the requirements set in NTCM-2004.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

In rural and suburban zones, building permits are not required to build this housing type. However, in urban zones, particularly in important cities (for example, Mexico City, Querétaro or Puebla), building permits are required to build this housing type. Perhaps that is one of the reasons that combined and confined masonry has not yet extended in important cities such as Puebla or Querétaro, but in smaller cities, towns and villages of those states. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s). Usually, little or no maintenance is done on the façade (exterior walls).

6.8 Construction Economics

Rural construction cost: 120-150 $US/m2, suburban construction cost: 180-250 $US/m2. This estimated cost includes all that is required in the construction process (plumbing, electricity, finishing, etc.). Labor cost is similar to traditional confined masonry construction made with only fired clay bricks.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Earthquake insurance is available as supplement of other insurance (fire, robbery), but people living in these houses usually do not have money to pay for it. As a matter of fact, Mexican household usually do not buy insurance for their home, even if they have the money for that. The reason is that insurance companies (national and international) do not have a good reputation in Mexico.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used

Deficient confinement of windows and door openings and/or 'mochetas'	Adding the corresponding tie-columns
Low lateral shear strength of existing walls	Wall jacketing: adding a welded-wire mesh to the walls to improve their lateral shear strength and deformation capacity

NTCM-2004 (2004) has general provisions for the rehabilitation of masonry structures and for the correct confinement of masonry structures, including the placement and detailing of tie-columns and tie-beams. Besides, it has recommendations for the seismic design of confined masonry walls strengthened with a welded wire mesh and mortar.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
The addition of tie-columns to properly confine windows and door openings and 'mochetas' (very slender walls [h/L>4] with an unconfined or free end) has been successfully conducted in traditional confined masonry structures made with fired clay bricks only or concrete blocks only. In fact, the addition of tie-beams and tie-columns has also been done in very old, former unreinforced masonry structures in Mexico.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
This practice has been done both as a mitigation effort on an undamaged building and as repair following an existing damage due to soil settlements or the action of an earthquake. The use of a wall jacketing by using a welded-wire mesh anchored to the walls through nails and covered with mortar has been used for decades in Mexico to repair cracked confined masonry walls due to soil settlements or the action of an earthquake. This technique has been proved to be very effective for confined masonry structures during experimental tests as it increases both their shear strength and their deformation or ductility capacity (Ruiz and Alcocer 1998). This is one of the reasons that wall jacketing is now included in NTCM-2004 (2004) as an option for original design as well.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
The inspection level is similar to the one for a new construction.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Usually, for a retrofit or a strengthening, an engineer is involved. However, for low-income people, the master bricklayer ('maestro') and his team are the only ones involved.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Some confined masonry houses made with fired clay bricks were retrofitted using additional tie-columns or wall jacketing in Mexico City previous to the 1985 Michoacán earthquake. None of them were reported/observed to experience any damage as a consequence of the Ms 8.1, September 19, Michoacán earthquake.

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