World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Combined and Confined Masonry Construction

Report#	160
Last Updated	
Country	Mexico
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Important

Association for Earthquake Engineering, the Engineering Information Foundation, John A, Martin & Associates, Inc. or the participant’s organizations.

General Information

Building Type:	Combined and Confined Masonry Construction
Country:	Mexico
Author(s):	Arturo Tena-Colunga Artemio Juarez-Angeles Victor Hugo Salinas-Vallejo
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in most parts of Central Mexico, in particular in the states of Puebla, Tlaxcala, Estado de Mexico, Hidalgo, Queretaro, 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.
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 (Juarez-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-inplace) 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 ma
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwellingMixed residential/commercial
Typical number of stories:	1-3
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	The main function of this building typology is mixed use (both commercial and residential use). The main use of buildings of thi

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	The typical plan layout is rectangular or nearly-rectangular (trapezoid, etc). It is common to have one-story and two story structures for housing.
Typical plan length (meters)	6-14
Typical plan width (meters)	8-20
Typical story height (meters)	2.2 - 2.4
Type of Structural System	Masonry: Confined Masonry: Clay brick masonry with concrete posts/tie columns and beams
	Vertical loads on the building are resisted by the

Additional comments on structural system	combined and 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 (Ju#rez-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).
Gravity load-bearing & lateral load-resisting systems	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 tiecolumns.
Typical wall densities in direction 1	5-10%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	The typical structural wall density is up to 10 %. Usually, higher structural wall density is in the direction perpendicular to the facade.
Wall Openings	The facade 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 facade 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 facade.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	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).
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footingShallow Foundation: Reinforced concrete strip footing
Additional comments on foundation	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.
Type of Floor System	Other floor system
Additional comments on floor system	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) castin- 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 Cortes 2009, Cortes 2009).
Type of Roof System	Roof system, other
Additional comments on roof system	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.
Additional comments section 2	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.

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

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

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	The combined and confined masonry construction currently used in Mexico for nonengineered construction is composed of nonindustrial fired clay bricks and lightweight concrete blocks with no quality control. Typical dimensions of masonry units (length, width, thickness) are the following: a) for firedclay bricks: 23 cm x 12 cm x 6.5 cm, b) for solid concrete blocks: 38 cm x 12 cm x 18.5 cm.	Characteristic Strength: 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, JuarezAngeles 2009, Salinas-Vallejo 2009). The following values w ere 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). Mix Proportions: 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. Comments: 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 tiecolumns 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), noncorrugated, number 2 (1/4 in diameter) bars composing stirrups spaced 20 cm along the length of the tie-column or tie-beam.
Foundations		Characteristic Strength: 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. Comments: 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).
Floors	Cast-in-place reinforced concrete slabs are the most commonly used floor systems and thy are usually 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 suburban and urban construction. Corrugated grade 60 steel bars (fy= 60 ksi = 4,200 kg/cm2 = 412 MPa) are used for reinforcement.	Characteristic Strength: 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 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 (Cortes 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. Comments: 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 (Cort#s 2009).
Roof		
Other		

Design Process

Who is involved with the design process?	ArchitectOther
Roles of those involved in the design process	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.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	OwnerBuilderOther
Roles of those involved in the building process	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.
Expertise of those involved in building process	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.
Construction process 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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	No
	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

Applicable codes or standards	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.
Process for building code enforcement	

Building Permits and Development Control Rules

Are building permits required?	No
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and 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, Queretaro 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 Queretaro, but in smaller cities, towns and villages of those states.

Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	Usually, little or no maintenance is done on the facade (exterior walls).

Construction Economics

Unit construction cost	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.
Labor requirements	
Additional comments section 3	

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

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

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

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

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

Socio-Economic Issues

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. For residential use, each building has 1 housing unit in it. For apartment buildings, each structure consists of 5 to 10 housing units.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	5-10
Additional comments on number of inhabitants	
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	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.

Typical Source of Financing	Owner financedPersonal savings
Additional comments on financing	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.
Type of Ownership	RentOwn outrightUnits owned individually (condominium)Owned by group or poolOther
Additional comments on ownership	Ownership with debt, usually to a relative.
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	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.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1999	Tehuacan Earthquake
2003	Tecoman Earthquake

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	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 Tehuac#n 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.
Additional comments on earthquake damage patterns	

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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	TRUE

	foundation.	
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	TRUE
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.	TRUE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing	TRUE

	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.	N/A
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	N/A

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	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).
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	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) know n as mochetas in Mexico without tie-columns at the free end. Typically, tie-columns and tiebeams 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.
Earthquake-resilient features in walls	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 Tehuac#n earthquake and the M=7.6 January 21, 2003 Tecom#n earthquake.
Seismic deficiency in frames	
Earthquake-resilient features in frame	
	Some single story houses and warehouses have

Seismic deficiency in roof and floors	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.
Earthquake resilient features in roof and floors	Most structures have rigid, cast-in- place reinforced concrete diaphragms, that are rigid and strong.
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class			|-			-|

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	**Seismic Strengthening**
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

Additional comments on seismic strengthening provisions	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.
	The addition of tie-columns to properly confine

Has seismic strengthening described in the above table been performed?	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 a repair following earthquake damages?	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.
Was the construction inspected in the same manner as new construction?	The inspection level is similar to the one for a new construction.
Who performed the construction: 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 has been 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 Michoacan earthquake. None of them were reported/observed to experience any damage as a consequence of the Ms 8.1, September 19, Michoac#n earthquake.
Additional comments section 6	

References

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