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
Reinforced-concrete frame with lightly reinforced-masonry infill

Report #	164
Report Date	14-10-2012
Country	BELIZE
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
Author(s)	Laura Redmond, Reginald DesRoches
Reviewer(s)	Emrah Erduran

Summary

This type of home is a reinforced concrete frame building with brick infill on the second story. The infill may be lightly reinforced and the first story is either left open to prevent flooding in hurricanes, or later, when the individual has more money the bottom story is often infilled with

masonry (which is not tied into the frame). This construction practice may make these structures vulnerable to seismic events as the building is effectively a large mass placed on top of a very flexible soft story. Additional vulnerabilities may stem from settlement of the wood pile foundations as the soil conditions are variable and generally no formal geotechnical surveys are done in Belize.

1. General Information

Buildings of this construction type can be found in and around the larger cities of Belize like Belize City, Belmopan, and Corozal. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 100 years.

Currently, this type of construction is being built. The main use of this construction typology is for residential purpose, but often in the downtown areas, the bottom story is infilled with masonry and the first story is used for commercial activity.

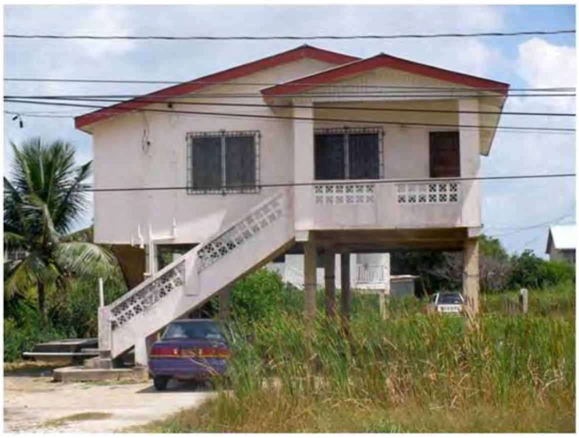

Figure 1: Typical concrete stilt frame home.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. The typical distance from a neighboring building varies depending on whether it is built in the busy downtown areas or outside the city center. Downtown, houses can be as close as 1 meter, away from the city center, typical separation distance is 10 meters When separated from adjacent buildings, the typical distance from a neighboring building is 1-10 meters.

2.2 Building Configuration

Buildings are regular in plan, but very often have an open first story, which could produce a soft-story mechanism. There are typically one to two windows on each face of the building with a single front door.

2.3 Functional Planning

The main function of this building typology is single-family house. Downtown, it can be a mixed-use property with commercial stores in the first level. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Typically, there is a single door on the second level with stairs leading down. If the first story is infilled, there is typically a door on the first level as well.

2.4 Modification to Building

The modification which is most typical is to infill the first story with masonry. Many buildings are constructed over a long period of time, leaving rebar exposed to weather. Sometimes additional stories are added when the foundations may not have been designed for that additional amount of load.

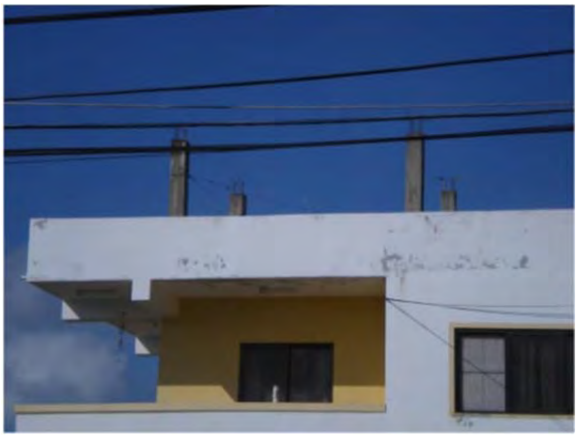

Figure 2: House with unfinished story.

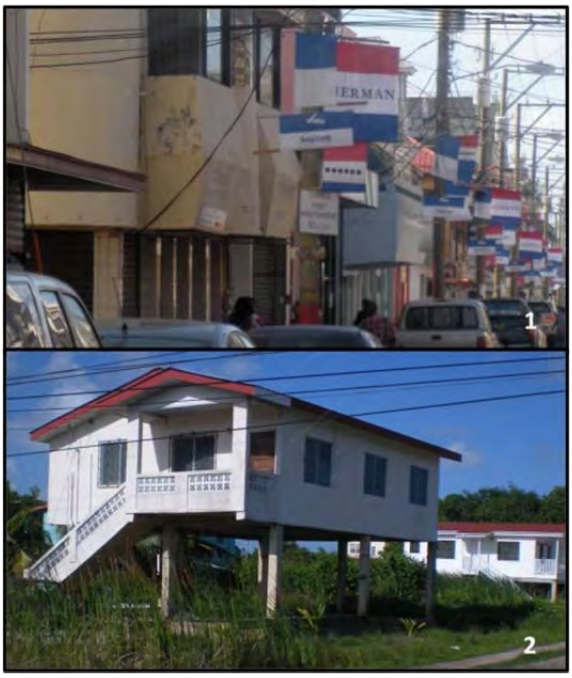

Figure 3: Typical spacing between residences in (1) urban areas, (2) rural areas.

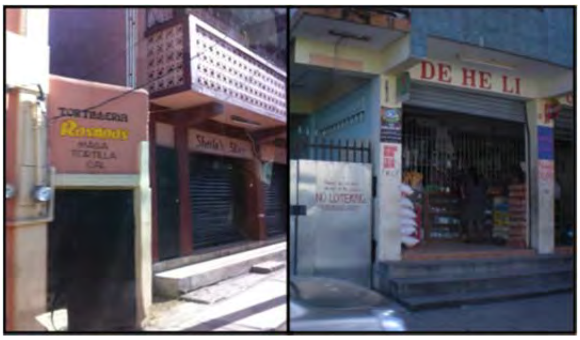

Figure 4: Commercial space in first level of downtown residences.

Figure 5: Typical building with (1) stilt construction and (2) later an infill wall being added at ground level.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	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)	☐
	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	☐

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	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	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate 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)	☐

Most residential structures are built by contractors based on experience, rather than being designed. If an engineer or architect is hired to build the house, it is designed for gravity and wind loads, but no earthquake effects, and usually the infill walls have light reinforcing.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. The vertical load-resisting system is either designed as only reinforced concrete frame, or as a shared action between a lightly reinforced infill wall and the frame. If it is the latter, the wall typically has both vertical and horizontal rebar and is tied into the frame. Beams and slabs carry the floor loads to the columns and walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. The lateral load-resisting system is only designed to take wind pressure loads, not seismic ones. The infill walls are usually reinforced to withstand wind pressures. Walls are designed separately from the framing system and the frame is designed to take the entire lateral load, assuming no interaction between the frame and the wall, even though they are often tied together with rebar.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 15 meters, and widths between 10 and 15 meters. The building has 2 to 3 storey(s). The typical span of the roofing/flooring system is 5 meters. The typical storey height in such buildings is 3-4 meters. The typical structural wall density is up to 10 %. This value is uncertain as we were unable to go inside any of the traditional houses.

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	☑	☑

Roofs are typically either a reinforced flat slab (~40% of residences) or a metal sheeting roof on timber trusses (or just rafters) and purlins (~60% of residences).

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	☐

The foundation consists of wood files. Typically they have wood piles with concrete caps that attach to slab beams at the foundation. Since no soil testing is done in Belize, they are typically driven in until they do not move. Often, more than one tree trunk must be driven into the same location because the soil is so soft in some areas.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is 5-10. The number of inhabitants in a building during the day or business hours is 5-15 (upper limit based on commercial space in the first floor). The number of inhabitants during the evening and night is 5-12 (upper limit if extended family is living in same household).

4.2 Patterns of Occupancy

Typically residences in urban areas are occupied by the nuclear family and sometimes have businesses in the first story. Residences in rural areas typically do not have any commercial space in the building and the building will be occupied by both the nuclear and extended family.

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)	☐

Depends very much on the location of the building and how many people live in the house. The higher-income families live in the cities and do not share the home with extended family. Lower-income families live in rural areas and will share the home with extended family.

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)	☐

In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

4.4 Ownership

The type of ownership or occupancy is ownership with debt (mortgage or other) and individual ownership.

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)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	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		☐	☑	☐

Additional comments:

1) Lateral Load Path: Not designed for EQ forces.
2) Building Configuration: regular in plan but not in elevation (soft story).
3) Roof Construction: roofs not designed for EQ, about 50% have adequate tie-downs for hurricanes.

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Pile Foundation	Soils are variable and no testing is conducted. Houses often have visible settlement.	N/A	Houses sunk several feet into the ground
Concrete Frame System	Not designed for earthquake forces. Often small 10-14" and lightly reinforced. If masonry walls have reinforcement connecting through the frame this additional stiffness is not accounted for. Soft story mechanisms are likely because the bottom level is often left open.	N/A	None observed
Infill Walls	The infill walls may be unreinforced, which may fall out during a seismic event. If the walls are reinforced, they connect through the frame and this additional lateral stiffness is not accounted for.	Most of the walls have light reinforcement to prevent them from falling out during a seismic event	Cracking of the infill wall in small seismic event
Roof	Most roofs are not designed for earthquakes and do not have out-of-plane bracing, additionally only about 50% of roofs have adequate tie-downs.	N/A	No earthquake damage observed, but many roofs taken off during hurricanes

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY *(i.e., poor seismic performance),* the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY *(i.e., very poor seismic performance),* and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY *(i.e., moderate 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
1976	(15.32°N, 89.10°W)	7.5	
1977	(16.70°N, 86.61°W)	6.1	
1980	(15.89°N, 88.52°W)	6.7	
1997	(16.16°N, 87.92°W)	6.1	
1999	(15.78°N, 88.33°W)	6.7	
2009	(16.73°N ,86.22°W)	7.3	

Most past earthquakes have not shown significant damage to the concrete-type housing. This is primarily because the past earthquakes have been far off the coast of Belize in the Caribbean Sea.

Figure 6: Damages observed after the 2009 earthquake: wood stilt buildings toppled, or sunk several feet into the ground.

Figure 7: Highly variable soil conditions, these houses have been abandoned after sinking several feet.

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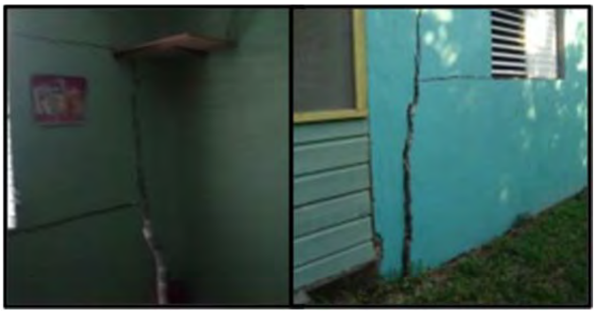

Figure 8: Cracking of masonry after the 2009 earthquake.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	CMU block	Blocks have 1800psi compressive strength.	6-8" Block Production Facility follows ASTM	If reinforced they are grouted every 12" with a no. 5 bar, and most have horizontal rebar tying into the concrete columns.
Foundation	Timber piles	Unknown	N/A	Entire tree trunks are used as piles
Frames (beams & columns)	Reinforced concrete	They are 3500psi and up, depending on job specifications.	Mix proportions vary by project, and most have a 0.4 to 0.6 water to cement ratio.	Cement is Type I imported from Mexico. The limestone, sand and other aggregate is obtained from local quarries.
Roof and floor(s)	The roof is either a flat reinforced slab or corrugated metal roofing with timber trusses. The floors are reinforced concrete solid slabs.	If concrete is used its compression strength is 3500 psi and up, depending on job specifications.	unknown	Only about 50% of roofs have adequate tie downs.

6.2 Builder

In formally constructed residences the house is built by a contractor who is hired by the homeowner. Informal construction is typically built by the owner or the community.

6.3 Construction Process, Problems and Phasing

In formally constructed residences, the house is designed and plans are drawn by either a technician, an architect or an engineer and sent for approval by the Central Building Authority. Once they have a building permit, construction is conducted in a single phase by either the engineering company, or a contractor the owner has hired to build the house. Informal construction does not undergo any formal design process and often plans are not even drawn. The construction may be conducted in phases if the individual does not have enough money to complete it in a single phase, often leaving the rebar exposed to weather for several years. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. Although typically constructed in one phase lasting approximately 5 months, informal construction can occur over several years.

6.4 Design and Construction Expertise

Most residential homes are not "designed" and are drawn up by technicians with high school or technical college degrees who have experience in construction. Details are generally determined based on experience and similarly sized projects. Construction workers and contractors typically have no formal training. Larger projects require the stamp of an engineer, who must have a 4 year degree and be licensed.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. The Central Building Authority (CBA) is a new governing body established in 2008, it is comprised of a 12 person board and 4 inspectors. Their primary purpose is to make recommendations to the local building authorities within each city. Currently the CBA recommends using the IBC design code, but the CUBiC, British Standards, and UBC are also commonly used. The year the first code/standard addressing this type of construction issued was 1986. The Caribbean Uniform Building Code, (CUBiC) was the first national code ever recognized. The most recent code/standard addressing this construction type issued was 2008. The most current recommendation of the Central Building Authority is to use the IBC standard.

In order to get a permit to build, the CBA recommendations specify that a building 1-2 stories tall and less than 1,000 sq. ft. can be constructed by a technician or "design" process; buildings that are 1,000-3,000 sq. ft. must have the stamp of either an architect or engineer, and buildings greater than 3,000 sq. ft. must have the stamp of both an engineer and an architect. However, no calculations must be submitted, just the final drawings with the appropriate stamps needed for approval. Inspections are conducted before occupancy and for a change of use. CBA also recommends routine inspection of commercial structures every four years. However, the CBA has no direct control over the municipal inspectors, who can choose to follow the CBA recommendations or not. However, the CBA does supersede the municipal authorities if a dispute arises. For example, if a resident feels that the local authority did not do a good job of reviewing their permit requests, or that their neighbor is building something that should not have been approved, but the municipal authority approved, he can petition the CBA. The CBA can then overrule the decision of the local authority, if it is found to be incorrect.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

Again, because the CBA has limited power, houses are often built informally without authorization. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s). The CBA recommends routine inspection of commercial structures every four years, but the local district authorities can choose rather or not to enforce this requirement. Residential construction is maintained by the owner.

6.8 Construction Economics

A house typically takes 5 months to construct. The completed house costs up to an estimated $200/m2.

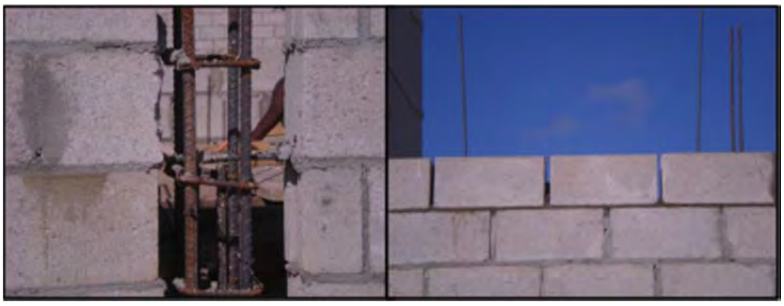

Figure 9: Concrete frame and masonry construction. (Note the CMU is used as formwork for the columns. Walls often have horizontal rebar as shown in the left picture.)

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Insurance is now available against floods, hurricanes and earthquakes.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction:

Seismic Deficiency	Description of Seismic Strengthening provisions used
Soft story on open first level	Additions of shear walls at first story
Lack of continuity and lateral stability of roof	Applying roof ties to timber and corrugated metal roofing
Unreinforced infill likely to fall out in a seismic event	Use fiber reinforced polymer to confine masonry into wall, or place reinforcement in the wall by drilling through beams above and fully grout.

Strengthening of New Construction:

Seismic Deficiency	Description of Seismic Strengthening provisions used
Large settlements in soft soils	Conduct soil testing to determine locations of soft clay and the depth needed to drill to bedrock
Soft story on open first level	Additions of shear walls and columns at first story

Currently there are no companies with soil testing equipment or capabilities, but this is certainly needed.

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?

Retrofit practices have been started by a few companies in Belize, who have rebar scanners and insert reinforcement where it is not found to strengthen the structure. Some retrofit with respect to hurricanes has also been started using roof ties for timber roofs and corrugated metal roofing. Limited retrofit has begun using FRP wraps on commercial structures.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?

The work was done as a mitigation effort on an undamaged building.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

The construction retrofits are inspected in the same manner as new construction.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

An engineer or contractor performed the construction of the seismic retrofit measure.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

There has been no documented case of performance of these retrofits in subsequent seismic events.

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Authors

1. Laura Redmond
   Civil Engineering, Georgia Institute of Technology
   Mason Building, 790 Atlantic Drive, Atlanta GA 30332, USA
   Email: laura.mae.redmond@gmail.com

2. Reginald DesRoches
   Civil Engineering, Georgia Institute of Technology
   Mason Building, 790 Atlantic Drive, Atlanta GA 30332, USA

Reviewer

1. Emrah Erduran
   Dr.
   NORSAR, Program 3: Earthquakes and the Environment
   Kjeller 2027, NORWAY
   Email: emrah@norsar.no