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
Timber stilt homes

Report #	165
Report Date	22-09-2012
Country	BELIZE
Housing Type	Timber Building
Housing Sub-Type	Timber Building : Post and beam frame (no special connections)
Authors	Laura Redmond, Reginald DesRoches
Reviewer	Sugeng Wijanto

Summary

This type of home is a wood frame building built on stilts. The first story is left open to prevent flooding in hurricanes. 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 come from settlement effects of the stilts, which are attached to concrete footings, 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 the suburbs surrounding Belize City and Belmopan, as well as rural communities throughout the country. This type of housing construction is commonly found in both rural and sub-urban areas. This construction type has been in practice for less than 100 years. Currently, this type of construction is being built.

Figure 1: Typical timber stilt home

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

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

2.3 Functional Planning

The main function of this building typology is single-family house. Extended family will live in the house as well if the family is poor. In a typical building of this type, there are no elevators and no fire-protected exit staircases. There is typically a single front door with a staircase leading from the second story entrance to the ground.

2.4 Modification to Building

There are no typical structural modifications to the original building plan.

Figure 2: Typical wooden stilt home with a shed added underneath

Figure 3: Close up of wood stilts

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	☐
	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	☐

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

3.2 Gravity Load-Resisting System

The vertical load-resisting system is timber frame. Loads are transferred to the frame through a plywood floor.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame. The lateral load-resisting system is not formally designed. As built, the siding and the plywood walls take the pressure loading from wind, but these structures have been shown to perform poorly in hurricanes.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 5 and 10 meters, and widths between 5 and 10 meters. The building is 2 storey high. The typical span of the roofing/flooring system is 2-5 meters. The typical storey height in such buildings is 3-4 meters. The typical structural wall density is up to 1 %.

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 typical flooring system is plywood panels nailed into wood joists. The corrugated metal sheeting used for roofing is rarely tied down appropriately for hurricanes and there has been severe damage to the roofs in the past.

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	☑

Typically, the buildings have shallow concrete footings that are made of plain concrete and a timber post is attached with a bracket.

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 people in the house typically depends on the income of the family. If they are poor, which tends to be the majority rural community, the extended family will also occupy the house.

4.2 Patterns of Occupancy

In the rural communities occupancy does not vary much, with only the men gone throughout the day as most make their living by farming their own land. In suburban areas the entire family may be gone for the day, at jobs or school in the city.

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)	☐

The higher-income families live in the suburbs and do not share the home with extended family members. Lower-income families live in rural areas and will share the home with extended family members.

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	See below.	☐	☑	☐

Additional comments:

1) Lateral Load Path: The lateral load system is designed for wind loads but do not have seismic connections. The buildings are not designed for earthquake forces.
2) Building Configuration: The houses are regular in plan but not in elevation (soft story).
3) Roof Construction: Roofs are not designed for earthquakes and about 50% have adequate tie-downs for hurricanes.
4) Quality of Workmanship: Often inexperienced laborers build their own homes, and no special connections are used.

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Footing Foundation	Soils are variable and no testing is conducted. Houses often have visible settlement. Footing has no reinforcement.	N/A	Houses sunk several feet into the ground.
Wood frame system	They are not designed for earthquake forces, and no special connections are used. Soft story mechanisms are likely because the bottom level is often left open.	N/A	None observed.
Wood post stilts	Simple connections are used for both the footing-column and the second story-column connections, and are not likely to have much lateral capacity.	N/A	Houses have fallen off their timber post stilts during a past earthquake.
Roof	Most roofs are not designed for earthquakes and do not have out-of-plane bracings, Additionally, only about 50% of roofs have adequate tie-downs.	N/A	No earthquake damage observed, but many roofs have been 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 B: MEDIUM-HIGH VULNERABILITY *(i.e., poor 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	

The past earthquakes listed here are only those over magnitude 6.0. The effects of the earthquakes are often less intense in Belize because the earthquake epicenters have been fairly shallow and far off the coast in the Caribbean Sea.

Figure 4: Wooden stilt houses may be poorly maintained, but still occupied

Figure 5: Stilt houses fell off their timber posts during the 2009 earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/ dimensions	Comments
Walls	The walls are made of plywood or press board with wood siding.			Building data is unknown and in poor families the materials may be reclaimed.
Foundation	The foundations are timber posts attached to un-reinforced concrete footings.			
Frames (beams & columns)	The frames and columns are timber posts and beams.			
Roof and floor(s)	The roof is constructed of corrugated metal sheeting placed on timber trusses, often without tie downs. The floor is a plywood sheeting nailed into timber joists attached to the beams.			

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 to the Central Building Authority (CBA) for approval. 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. However, most of the timber homes in the area are informally constructed. 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.

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. Engineers and architects are typically not involved in the construction process of this type of housing.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Currently the CBA recommends using the IBC design code, but the Caribbean Uniform Building Code (CUBiC), the British Standards, and the former UBC are also commonly used. The year the first code/standard addressing this type of construction issued was 1986. The first building code in place was the CUBiC. The most recent code/standard addressing this construction type issued was 2008. The Central Building Authority now recommends the use of the IBC.

The Central Building Authority 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. It is up to the local authorities to enforce their recommendations.

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 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 contractor; buildings that are 1,000-3,000 sq. ft. must have the stamp of either an architect or an engineer, and buildings greater than 3,000 sq. ft. must have the stamp of both an engineer and an architect. However, there is no requirement for calculations to be submitted, just the final drawings with the appropriate stamps needed for approval. Inspections are conducted before occupancy starts and in case of 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. The CBA does supersede the municipal authorities, in case that a resident or his neighbor feels that the local authority did not do a good job of reviewing their permit requests, or in case that their neighbor is building something that the municipal authority approved, but he feels that it should not have been he can ask the CBA to reevaluate it.

Buildings of this type are rarely reported to the Central Building Authority, and are usually built informally.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder. 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

Construction typically takes less than five months.

Figure 6: Construction of a timber stilt home

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 available. In Belize, 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 and columns at first story
Lack of continuity and lateral stability of roof	Applying roof ties to timber and corrugated metal roofing
Poor connection between the timber posts and the second story	Special connection detailing for timber should be used

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

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?

This work has been done on undamaged buildings.

8.3 Construction and Performance of Seismic Strengthening

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

The construction retrofits were 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 is no documented case of performance of these retrofits in subsequent seismic events.

References

1. Personal communication (interview)
   Carlton N. Young
   Young's Engineering Consultancy Limited. 828 Coney Drive, PO Box 2665 Belize City, Belize

2. Personal communication (interview)
   Dwayne A.W. Thurton
   Anthony Thurton and Associates Limited. P.O. Box 777 1 ½ Mls Western Highway Belize City, Belize

3. Personal communication (interview)
   C. Phillip Waight
   Central Building Authority. 23 Cor. Baymen Ave & 5th St. P.O. Box 2589 Belize City, Belize

4. Earthquake in Belize, Monkey River Hardest Hit, Images of the Damage
   Belize News Post
   http://belizenewspost.com/2009/06/02/belize-news/earthquake-in-belize-monkey-river-hardest-hit-images-of-the-damage/

Author(s)

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(s)

1. Sugeng Wijanto
   Senior Lecturer
   Civil Engineering Dept., Trisakti University
   Jakarta Barat 11440, INDONESIA
   Email: s.wijanto1@xtra.co.nz