World Housing Encyclopedia

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

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HOUSING REPORT
Typical Single-Story Residential Construction Practices in Trinidad and Tobago

Report #	156
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Country	TRINIDAD AND TOBAGO
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in lime/cement mortar
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Summary

Typical single-story residential construction in Trinidad and Tobago comprises 100 mm thick unreinforced clay tile or concrete block masonry (URM) load-bearing walls supporting the roof. The roofing is a 20 to 30 degree gable or hipped shape and is of approximately 0.2 to 0.5

kN/m2 in weight. It comprises galvanized steel sheets supported by timber laths or cold-formed steel Z-purlins, in turn supported by timber or structural steel rafters. The rafters are nailed or bolted to the top of the walls, without blocking between the rafters. The flexible roof cannot act as a diaphragm. The soil class ranges from IBC classes B to E. Given the significant seismic hazard for Trinidad and Tobago, (i.e. rock PGA in the range of 0.2g to 0.6g for 10% exceedance probability in 50 years), this form of residential construction is quite vulnerable.

1. General Information

Buildings of this construction type can be found in throughout Trinidad and Tobago. This type of housing construction is commonly found in rural, sub-urban and urban areas.

This form of construction is to be found in about 70% of all of the residential construction (i.e. isolated houses, apartment buildings, condominiums, townhouses).

This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This type of construction has become prevalent because it is the least costly.

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. On sloping land it is common practice to cut or fill and use retaining walls When separated from adjacent buildings, the typical distance from a neighboring building is 5.0 meters.

2.2 Building Configuration

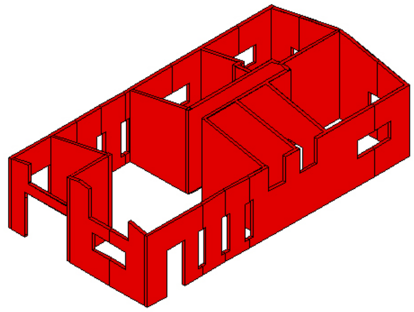
A typical residential structure is rectangular and 8.6 m wide x 11.0 m long, in plan. The floor height is typically 2.4 m. The walls on the perimeter of the roof support the roof, though sometimes an interior wall can be used as well. The same type of URM wall is used for the internal partitions and are connected to other walls by 'toothing'. A typical structural wall is part of the bedroom so is about 3.7 m long. It usually has one window opening 1.8 m x 1.2 m so the percentage of openings is about 25%. Door openings are mostly to be found in the internal partition walls which are not load-bearing. A typical door opening is 1.0 m x 2.0 m.

2.3 Functional Planning

The main function of this building typology is single-family house. By "single-family" is meant the extended family of, in many instances, grandparents, aunts, uncles, or their children. In a typical building of this type, there are no elevators and no fire-protected exit staircases. The means of escape in case of a fire is principally via a central corridor that typically connects the front to the rear of the house.

2.4 Modification to Building

The most common type of modification is to add along one or both sides of the house for additional bedrooms, expansion of the kitchen or living room, or for a carport.



Example layout of a single-story URM house in Trinidad and Tobago

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	☐
		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)	☐

It is not "brick" that is used, but rather either clay tiles, which have horizontal cells, or concrete hollow blocks, which have vertical cells.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is un-reinforced masonry walls. The load-bearing walls are under combined axial load and out-of-plane bending. Since they are supported at the base on a simple mortar bed, and given the simple connection to the roof rafters at the top, the walls are 'pinned' at their base and at the top of the walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is un-reinforced masonry walls. Under lateral load the walls cannot be considered as flanged in -plan since the vertical connections between walls at their corners are inadequate for structural integrity. Given the low roof weight and wall weight, and their squat aspect ratio, the walls will act as shear walls resisting in-plane sliding loads at the base joint and out-of-plane toppling loads. There is a RC beam at the top of the walls that act as a "ring beam" enabling a degree of interaction among orthogonal walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 7 and 14 meters, and widths between 6 and 10 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 9.0 meters. The house is typically rectangular in plan. The typical storey height in such buildings is 2.4 meters. The typical structural wall density is up to 3 %. There is limited scope for variation since the amount of structural wall area is determined by the roof support requirements.

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 floor is a 100mm thick slab-on-grade and the reinforcement is steel fabric of 142 mm2/m. The roofing is comprised of galvanized steel sheets supported by timber laths or cold-formed steel Z-purlins, in turn supported by timber or structural steel beams or rafters.

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	☐

It consists of cast in-place reinforced concrete piers. Wall footings are used when the soil is firm. They are typically 0.6m wide and 0.3m deep with 3 No. 12mm high tensile steel longitudinal rebars, and 10mm mild steel transverse rebar at 250mm center-to-center spacing. Cast-in-place piers are used when the soil is soft. The tie-beams are typically 0.3m wide and 0.4m deep with 3 No. 12mm high tensile steel longitudinal rebars top and bottom, and 10mm mild steel transverse rebar at 200mm center-to-center spacing. The piles are typically spaced 3.0m apart along wall lines and are 300mm in diameter and 4.0m deep with 4 No. 16mm high tensile steel longitudinal rebar, and 10mm mild steel transverse rebar at 200mm center-to-center spacing. For both types of foundation, the concrete typically has a 28-day compressive strength of 21 MPa (3000 psi). The regions between the tie beams are comprised of slab-on-grade concrete construction as described previously for the case of shallow foundations.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). A typical household comprises of the "extended" family in which case, in addition to the parents and children, there are also grandparents, aunts, uncles, some of their children, and friends. In many instances there is only one parent. The number of inhabitants in a building during the day or business hours is less than 5. During the day it is common for retired or unemployed persons to be home. The number of inhabitants during the evening and night is 5-10. It is common for visitors to periodically live in the house, and may stay at a number of houses over time. This is due to their inability to afford rent.

4.2 Patterns of Occupancy

The retirees or unemployed usually come and go. The former assist with obtaining supplies, and the latter seek work or odd jobs.

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 type of residential structure described herein is used by all income levels since it has become a standard of housing construction.

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), 1 toilet(s) only and 1 bathroom(s) induding toilet(s).

4.4 Ownership

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

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		
		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 quality of the materials and workmanship relative to standards' requirements are not measurable since no standards exist for this type of housing construction.			

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Roof	No chord continuity	None	Not tested historically under strong ground motion
Load-bearing Walls	Unreinforced, slender, low bearing stress	None	Not tested historically under strong ground motion

Foundation	None	Capacity to demand probably high	Not tested historically under strong ground motion

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *A: HIGH VULNERABILITY (i.e., very 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
1766		7.9	
1825			VIII (MMI)
1910			VIII (MMI)
1954		>6.5	VIII (MMI)
1968		5.1	VI(MMI)
1982		5.4	
1983		5.8	
1988		6.2	
1996		6.0	V(MMI)
1997		5.9	

The durations for the earthquakes were short (<6 sec). Damage was mainly as repairable horizontal or diagonal cracking to piers. In south Tobago in the 1997 event there was considerable liquefaction failure. There were about 3 events of magnitude > 5.5 from 1997 to the present of (MMI) V to VI. Data is available from the Seismic Research Center of The University of the West Indies.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
			The clay tile units are 100	Sometimes at wall intersections, when the concrete blocks are used, rebar is

Walls	100 mm thick clay tile (ASTM C34) or concrete hollow vertical cell block (ASTM C129)	The 100 mm thick clay tile 28-day compressive strength is typically 2.5 MPa (individual unit). The 100 mm concrete block 28-day compressive strength is typically 3.0 MPa (individual unit).	mm thick by 300 mm long by 200 mm high. The concrete block units are 100 mm thick by 400 mm long by 200 mm high. All mortar mixes are typically of 1 part cement to 3 parts sand. Lime is typically not used.	placed vertically in the cells and grouted with a wet mix. This is ineffective since the dimensions of the cell are too small relative to the rebar for adequate compaction (i.e. 10mm and 25mm respectively), and the grout w/c is too high.
Foundation	Reinforced concrete	The foundation concrete typically has a 28-day compressive strength of about 21 MPa (3000 psi). Longitudinal rebar is typically deformed and of yield strength of 410 MPa. Transverse rebar is typically smooth and of yield strength of 250 MPa.	Concrete mixes for foundation elements are typically 1 part cement to 3 parts fine to 3 parts coarse aggregate. The w/c is not measured during construction but probably varies from 0.60 to 0.70.	
Frames (beams & columns)				
Roof and floor(s)	The roofing system is considered a 'deck' system since a truss is not typically used. It is a system of sheeting, secondary and main beams.	The sheeting is typically corrugated or patterned galvanized steel sheet of 26 g thickness. It is supported on treated timber beams (100mm wide by 50mm deep), or 100mm cold-formed steel Z-section purlins. In the former case, the timber beams span 1.2m, and the Z-purlins span 3.0m. The main beams or ?rafters? are typically 200 mm deep if of timber, but of 100mm deep mild steel I-section if of steel beams.	The floor is a 100mm thick concrete slab-on-grade reinforced with steel fabric 142 mm2/m. The concrete typically has a 28-day compressive strength of about 21 MPa (3000 psi).	

6.2 Builder

The builder typically lives in this type of construction.

6.3 Construction Process, Problems and Phasing

The typical construction process is: 1. Prepare the site. 2. Install the foundation. 3. Install the floor slab. 4. Build the external walls on the floor slab. 5. Install the roof. 6. Build the internal partition walls. 7. Install the electrical and plumbing items. 8. Plaster all walls. 9. Paint the walls. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

The design is 'deemed-to-satisfy' based on custom, and the construction is by uncertified apprentices of certified builders, but under their supervision. Certified architects or engineers have no role with respect to typical residential single-story construction in Trinidad and Tobago.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

6.6 Building Permits and Development Control Rules

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

6.8 Construction Economics

Typical construction cost is TT$2,800/m2 including contractor markup and excluding the cost of the land (1TT$=US$6.36). The current labor to material cost is about 75%.

Photo of URM clay tile house

Photo of concrete block house

Formwork for RC ring beam

Rebar cage for RC ring beam

Timber roof beam to wall plate connection

Stem wall of foundation for load-bearing walls

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. Strengthening is not officially recognized. Though stated as available, the coverage is usually lumped with other natural disaster coverage so is nominal and typically insufficient.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls have insufficient ductility and strength in both the in-plane and out-of-plane directions	None used

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls have insufficient ductility and strength in both the in-plane and out-of-plane directions	None used

None exists as a code, but the University of the West Indies developed recommendations based on wall testing and the use of ferrocement overlays. This is available over the internet.

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 strengthening procedure described has not been utilized.

8.3 Construction and Performance of Seismic Strengthening

Reference(s)

1. The Hysteretic Behaviour of Ferrocement-Retrofitted Clay Tile Walls
   Richard P. Clarke and Anil K. Sharma
   American Concrete Institute Structures Journal 2004 Vol 101 No. 3 pp 387-394

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