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
Rammed earth house with pitched roof (Nyumba yo dinda OR Nyumba ya mdindo)

Report #	45
Report Date	05-06-2002
Country	MALAWI
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Rammed earth/Pise construction
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Summary

This type of construction is used for residences only. The building technique consists of in-situ ramming of moist soil in a carefully aligned/placed mold. The mold dimensions are between (250 - 300 mm) wide X (400 - 450 mm) long X (200 - 300 mm) height. The plan of the house

is rectangular. The roof is either grass thatch or iron sheets supported on timber poles. This type is found in all three regions of Malawi. The strength of the wall is low and depends on the compacting effort applied. The expected seismic performance is poor. There are no vertical or horizontal reinforcements.

1. General Information

Buildings of this construction type can be found in The house type is found in all three regions of Malawi. This house type represents about 35% of total housing stock in Malawi. This type of housing construction is commonly found in rural areas. This construction type has been in practice for less than 100 years.

Currently, this type of construction is being built. .

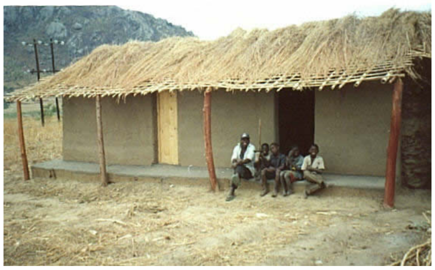

Figure 1: Typical "nyumba yo dinda" house

Figure 2:Typical Building

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 2-3 meters.

2.2 Building Configuration

Rectangular shape. Generally three openings are provided, i.e. one door and two windows. The door is in front and so are the windows. The door is about 1.7 m high X 0.6 m wide. The windows are 0.3 m wide X 0.6 m high. The window and door areas are about 5% of the overall wall surface area.

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. None.

2.4 Modification to Building

Re-roofing and wall smearing i.e. smearing with specially prepared mud mortar.

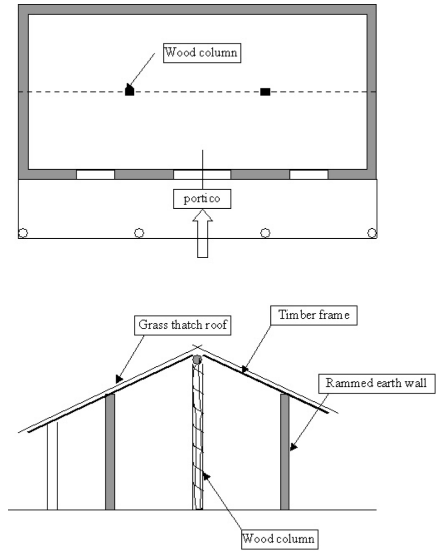

Figure 3: Plan and transverse section of a typical building

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	☐
		17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
			Designed for seismic effects,	

Structural concrete	Moment resisting frame	19	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). The roof is directly supported by the rammed earth wall which in turn rests directly on the ground.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. The wall is made by use of a mould which is placed where the wall will be located. Moist soil is placed in it and rammed using a tamping wooden piece in at least three layers. The process is repeated until the proper height is reached. The wall height is about 2.5 m with a thickness of between 0.20 m and

0.30.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 6 and 6 meters, and widths between 4 and 4 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: This is only indicative size because the size varies depending on the requirements of the owner. Typical Story Height: The length to width ratio is never less than 2. The typical storey height in such buildings is 2.1 meters. The typical structural wall density is more than 20 %. About 30%.

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	☑	☑

Rammed earth with plaster/smear finishing. Floor is considered to be a flexible diaphragm.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☐

	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☑
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Figure 4: Critical structural details

Figure 5: An illustration of key seismic features and/or deficiencies

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is less than 5. or 5-10.

4.2 Patterns of Occupancy

Generally one family occupies one housing unit.

4.3 Economic Level of Inhabitants

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

50% very poor and 50% poor. It is difficult to estimate the ratio of house price/annual income.

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 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Bathrooms and toilets are externally provided by a small shelter and a pit latrine. .

4.4 Ownership

The type of ownership or occupancy is outright ownership 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		
		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				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Very poor lateral resistance; lintels provided are very weak; soil structure is brittle and prone to crumbling.	Built in situ.	
Frame (columns, beams)			
Roof and floors	No ties between roof and wall; weak joining of roof members; and floor is made up of rammed earth.	Wide bearing area at roof support.	

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 *A: HIGH VULNERABILITY (i.e., very 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
1957	Champira	5	MMI IIIV
1966	Mwanza	5.3	
1967	Thambani in Mwanza	5.4	
1989	Salima	6	MMI VIII

In 1973 another earthquake hit Livingstonia with magnitude of 5.1 on the Richter scale. The 1989 Salima earthquake was the worst in Malawi. 9 persons lost their lives whilst over 50,000 people were left homeless. Geologists forecast more intense earthquakes in Malawi. Rammed earth buildings were the worst affected.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rammed earth.	N/A		
Foundation				
Frames (beams & columns)	Timber			
Roof and floor(s)				

6.2 Builder

Yes.

6.3 Construction Process, Problems and Phasing

The house is built by a special master builder who learns the job as an assistant. He learns the job as he helps with bringing the soil (as assistant). A pit is dug and water is poured in it overnight. The soil is only expected to be moist i.e. the soil must not retain the water. The tools used are a hoe, two buckets, a mould, a tamping wooden piece, and a scraper for removing soil from the mould. FOUNDATION: There is no foundation. The lines of the walls are marked on leveled ground, pegs are placed where necessary. WALL CONSTRUCTION: The wall is made of rammed earth. A site of the soil pit is identified with trials to make sure that the soil does not have a lot of clay content. Soil is dug and water poured in it to soak it over night. The moisture of the soil is critical so that remixing is done from time to time. The soil is then moved to the mould which is already placed in the proper place on the construction site. The soil is rammed in layers in the mould. It is necessary to ensure that a proper compacting effort has been achieved before removing the mould. ROOFING: The roof is made up of grass thatch placed on timber poles made into a grid/mesh to retain the grass. The poles are supported on a timber pole beam which is itself supported on two king posts which are supported by timber pole beams spanning across the longitudinal walls. The two beams are placed at 1/4 points from the ends. Once the grass thatch has been placed, small sized timber poles are split and placed above grass and tied to poles below grass so that grass does not move out of place. This is done at 1/3 points all round. OPENINGS: The openings are few. Timber lintels are provided although not strong. 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

Generally good level of expertise based on this practice. No role so far.

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 not authorized as per development control rules. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

Difficult to estimate because of communal nature of working. The builder, assistant, and others for drawing water from borehole, etc.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Weak lintels	Reinforcing with wood lintels
No ties between roof and wall	Inserting of ties
Weak joining of roof members	Wood transverse connections

Weak lintels Reinforcing with wood lintels. No ties between roof and wall Inserting of ties. Weak joining of roof members Wood transverse connections.

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?

No.

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

Repair following earthquake damage.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

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

The owner - no architects or engineers are involved.

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

N/A.

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