World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT
Unreinforced masonry houses made of fired clay bricks

Report#	205
Last Updated	
Country	Malawi
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Reviewers	

Important

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General Information

Building Type:	Unreinforced masonry houses made of fired clay bricks
Country:	Malawi
Author(s):	Viviana Novelli Panos Kloukinas Ignasio Ngoma Innocent Kafodya John Macdonald Katsu Goda
Last Updated:	
Regions Where Found:	Buildings of this type are the most commonly used in Malawi for both formal and informal settlements. According to the 2008 Census, this building type represents 38.5% of all houses in the country. However, since Malawi is experiencing rapid economic and social changes, including population growth with a high annual rate of about 3%, the percentage mentioned above for this house type has increased considerably.
Summary:	Houses made of unreinforced masonry in Malawi are low-rise constructions (typically one-storey and rarely two-storey). A typical storey height is between 2.0m and 2.5m. The plan of the houses has a rectangular shape, and the footprint changes according to the needs and economic resources of the household. A typical footprint is 8mx6m. Houses with greater footprint than typical are generally constructed with better materials and better structural detailing than smaller ones. Bearing walls are single or double skin with a thickness ranging from 100mm to 280mm. The wall thickness varies depending on the size of bricks which are produced locally, with no standard procedure and quality control; the sizes of locally made bricks differ from those of the standardized bricks (220x110x55 or 215x102.5x55 mm). Timber wall plates, to support a roof structure, are used only occasionally on the top of the longest external walls of the houses. The most common mortar adopted for these houses is mud. However, cement is becoming popular, although this material is still considered expensive for the country. Irregular configurations of openings in the wall creates an uneven distribution of load

	path on spandrels and piers. Lintels on the top of the openings are often not in place. When lintels are implanted, these are made of bamboo/timber planks, masonry bricks, or concrete beams. Concrete lintel bands are used in new houses with masonry bricks and cement mortar. Most houses have pitched or sloped roofs, therefore houses have gables. The gable height is between 0.5m and 1.5m. Gable walls are rarely connected to the roofs, and gable bands are not used to prevent overturning of the gables during an earthquake. Two main roof systems that are adopted for this building type are: light timber truss supporting thatch and timber truss supporting corrugated light metal sheets. These roof systems are classified as light weight structure with a flexible behavior, as they are made of light timber planks and are completely disconnected from t
Length of time practiced:	76-100 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	1
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Houses of this type have a wide variety in geometry, structural features, mechanical properties, and deficiencies. Although they

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	Buildings of this construction type have rectangular shapes in plan, with internal walls distributed parallel or orthogonal to the external walls. Re-entrant corners are not considered as irregularity in plan that causes torsion under seismic events, since the observed re-entrant corners are not significantly deeper respect to the plan dimensions in both directions.
Typical plan length (meters)	8
Typical plan width	6

(meters)	0
Typical story height (meters)	2.00-2.50m
Type of Structural System	Masonry: Unreinforced Masonry Walls: Brick masonry in mud/lime mortarMasonry: Unreinforced Masonry Walls: Brick masonry in lime/cement mortar
Additional comments on structural system	External load-bearing walls can be single- or double-skin made of clay bricks with mud or cement mortar. The walls have the function to carry 1) gravity loads: self-weight and light roof, and 2) lateral loads from earthquakes and wind. Past post-earthquake assessments in Malawi and pictures of houses collapsed after Karonga Earthquake in 2009 in section 5.2, have underlined that double-skin walls are generally connected; therefore, houses are highly likely to collapse due to the overturning of at least two adjacent walls. Out-of-plane failure modes of a single wall generally occur in slender single-skin walls subjected to earthquakes.Internal load-bearing walls are mostly single-skin made of clay bricks with mud or cement mortar. The walls have the function to carry 1) gravity loads: self-weight, and 2) lateral loads from earthquakes, if these are connected to the adjacent external walls. Light roof does not sit on internal walls; therefore, the roof weight is only distributed on external walls.
Gravity load-bearing & lateral load-resisting systems	Two building types are applicable to the houses in Malawi 1) unreinforced masonry walls with mud mortar and 2) unreinforced masonry walls with cement mortar. Construction quality can vary significantly within the same type. If built properly (e.g. good connections and good quality materials), buildings with mud mortar can be more resistant than the ones with cement mortar. It is important that both types are considered together in relation to the structural quality detailing of the houses.
Typical wall densities in direction 1	4-5%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	No additional comments.
	Openings are mainly distributed on the longest external walls of the houses. The shortest external walls with gables do not always have openings, indeed only big houses have openings on external walls. Openings are evenly spaced and

Wall Openings	symmetrically distributed. On occasion, they are in a central position or are distributed on only one side of the external walls. The sizes of typical door are width of 800 mm and height of 1800 mm. Windows have different sizes; therefore, dimensions of piers/spandrels can vary within the same wall. Spandrel height can also be very different in the same wall, since openings are not always positioned at the same height. In some cases, spandrels are particularly small (only 300mm). For a typical external wall of 8m, the number of openings is 4 and the percentage of openings with respect to the area of the wall is around 4-5 %.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	New constructions often have a portico made of columns with unreinforced brick masonry or reinforced concrete. Irregularities are observed in the type of materials adopted in the external walls to increase the height of the houses, and to fix damaged walls. Presence of chimneys is also an element of vulnerability, which can be identified in larger houses with better construction detailing and good materials.
Type of Foundation	Shallow Foundation: Wall or column embedded in soil, without footingShallow Foundation: No foundation
Additional comments on foundation	- Houses with fired bricks and mud mortar with a size plan smaller than the typical one (8 m x 6 m) do not have foundations. The walls are built directly on the ground where pegs are placed as anchorages. Houses with larger floor footage have the plinth filled with compacted soil. The plinth walls are usually built directly on the ground. The plinth height of about 300 mm is constructed to prevent damage to the superstructure walls due to water ingress. - Houses with fired bricks and cement mortar often have plinth walls with 1) concrete strip footing with a depth of 230 mm or 2) plinth beams or slab. The inside of the plinth is filled with either compacted soil or crushed or screed surface finish. The plinth height of about 500 mm is constructed to prevent damage to the superstructure walls due to water ingress.
Type of Floor System	No elevated or suspended floor system (single-story building)
	Houses of this class are generally single-storey

Additional comments on floor system	buildings, and the ground level of this type is made with earth or concrete. In case houses have two storeys, the ground level is made of earth or concrete while the first upper floor is a flexible system made of timber beams.
Type of Roof System	Wooden structure with light roof coveringBamboo, straw, or thatch roof
Additional comments on roof system	Two main roof types for unreinforced masonry brick houses in Malawi are light timber truss-supporting thatch and timber truss-supporting corrugated light metal sheets. Traditionally, roofs were only made of thatching, but corrugated light metal sheets have become the most used roof system in Malawi. The timber truss, made of rafters of 150 mm x 50 mm running orthogonal to the longest external walls, sits directly on the external walls. The lack of pad stones under the purlins/rafters causes severe vertical cracks in the walls indicating an inappropriate distribution of the weight of the roof system. Wall plates are rarely adopted under rafters, and the use of timber ring beams to tie bearing walls is not part of the construction methods adopted for this type of buildings. Both roof types are light horizontal systems, and they are not considered fully rigid along the entire plane and therefore do not act as rigid diaphragms. Furthermore, the roofs are not connected to the bearing walls, therefore they are not providing any restraints against lateral movements of the walls due to winds or earthquakes.
Additional comments section 2	
Infill wall material	No additional comments.

Figure 9. Typical structural detailing

Figure 10. Internal walls are

of a wall connection.

orthogonal and parallel to the external facades.

Figure 11. Typical example of house with a re-entrant corner located on the longest external facade.

Figure 12. Unreinforced Masonry Walls: house with brick masonry and mud mortar.

Figure 13. Unreinforced Masonry Walls: house with brick masonry and cement mortar.

Figure 14. House in clay bricks and mud mortar with a lack of connections between walls. The front facade is completely detached from the side facade due to a weak mortar and presence of fragile bricks. Constructional materials are low quality.

Figure 15. House in clay bricks and mud mortar with a lack of connections between walls and the roof made of a timber system supporting metallic corrugated sheets. Constructional materials are medium quality.

Figure 16. House in clay bricks and mud mortar built with constructional materials of good quality. Walls and roof are properly connected.

Figure 17a. openings: regular distribution of the windows/doors.

Figure 17b. openings: windows are in a central position.

Figure 17c. openings: on the shortest facade windows/doors are distributed on the left side and on the longest facade windows/doors are distributed on the right side.

Figure 18. Presence of chimney. This is a seismic vulnerability element occasionally observed in big houses constructed with good quality construction.

Figure 19. House with a small portico on the front facade, made of columns in bricks.

Figure 20. Use of unburnt bricks for the extension of a wall made of burnt bricks.

Figure 21. Platform of about 30 cm constructed under the house with bricks and mud mortar.

Figure 22. Platform of about 30 cm constructed under the house with bricks and cement mortar.

Figure 23. Shallow trench in the soil to embed the plinth wall.

Figure 24. Double skin plinth wall to support a single skin masonry, to be filled with compacted soil.

Figure 25. Triple skin plinth wall to support a double skin masonry, filled with crushed brick and finished with cement/sand screed.

Figure 26. Typical roof made of light timber truss supporting thatch.

Figure 27. Typical roof made of light timber truss supporting

Figure 28. Internal view of a roof made of light timber truss

corrugated metallic corrugated sheets.

supporting corrugated metallic corrugated sheets. Timber truss does not sit on the internal walls.

Figure 29. Timber structure of the roof sits directly on the walls. The use of ring-beams at the top of the walls is not part of the construction techniques.

Figure 30. Example of wall plate, adopted underneath the rafters. Poor detailing is underlined by the presence of cracks and lack of maintenance is detected by loss of plaster.

Figure 31. The lack of padstones underneath the purlins/rafters causes severe vertical cracks on the walls indicating an inappropriate distribution of the weight roof system.

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Fired bricks made of clay and mud or cement/sand mortar	Recommended cement/sand mortar mixture ratios are between 1:4 to 1:6 (1:3 for special occasions and foundations), but in practice people use even less cement than 1:8. Mortar mixtures rarely contain any lime, it is only cement and sand. Brick sizes (in mm): 190x90x50, 200x100x60 and 220x110x60Bricks are solid and commonly laid on dry mortar. Due to these reasons, bonding between bricks and mortar is very weak. Ordinary clay bricks made locally have low compressive strengths between 1 to 6MPa. Accordingly, the masonry units have even lower compressive strengths between 0.5 and 3 MPa and are even weaker in tension (tensile strengths generally <0.1MPa) and shear (shear strengths generally <0.2MPa).
Foundations	Plinth walls:1) with/without strip footing 2) with plinth beams or slab	- Houses with fired bricks and mud mortar with a size plan smaller than the typical one (8 m x 6 m) do not have foundations. The walls are built directly on the ground where pegs are placed as anchorages. Houses with larger floor footage have the plinth filled with compacted soil. The plinth walls are usually built directly on the ground. The plinth height of about 300 mm is constructed to prevent damage to the superstructure walls due to water ingress.- Houses with fired bricks and cement mortar often have

		plinth walls with 1) concrete strip footing with a depth of 230 mm or 2) plinth beams or slab. The inside of the plinth is filled with either compacted soil or crushed or screed surface finish. The plinth height of about 500 mm is constructed to prevent damage to the superstructure walls due to water ingress.
Floors	Timber beams, if houses are two-story buildings	Single-storey buildings: ground level is made of earth or concrete. Two-storey buildings: ground level is made of earth or concrete and first floor is a flexible system made of timber beams.
Roof	Pitched or sloped roofs made of timber truss supporting 1) thatch or 2) metal corrugated sheet	Flexible light timber truss, with rafters of 150 mm x 50 mm, sits on wall plates running along the top external walls in the longest direction of the houses. Poor detailing is emphasized by lack of connection between walls/gable and roof, lack of ring beams to tie walls together, and lack of pad stones to ensure adequate load distribution of the roof.
Other	Connected to the external walls	Made of bricks. They play an important role to prevent overturning of the walls under seismic loading.

Design Process

Who is involved with the design process?	None of the above
Roles of those involved in the design process	A formal design process is not in place. Houses are made by owners/builders using local materials and local construction techniques without proper engineering design. The masons role is to build and

	advise the owner.
Expertise of those involved in the design process	Not applicable.

Construction Process

Who typically builds this construction type?	OwnerMasonBuilderOther
Roles of those involved in the building process	Houses are made by owners/builders using local materials and local construction techniques without any engineering design. The masons role is to build and advise the owner.
Expertise of those involved in building process	During constructions, there are no interventions by qualified architects and engineers and the building process is not based on licensing or accountability checks. Very little expertise is available and therefore the quality of the houses is generally very poor. Owners/masons involved in the building process do not have any technical knowledge on how houses should be built to be resistant against earthquakes. Their knowledge is based on local experience.
Construction process and phasing	Construction materials are purchased by owners.The houses are built according to the following order -Papering the ground level, where walls will sit-Walls are built using traditional techniques and local materials -Roof is made in place and sits on the wallsTools typically used during the construction: measuring tape, hoes, builders level, strings, trowels, water drums, timber for pegs, and mortar holding points.
Construction issues	Problems related to seismic vulnerability are not taken into account during construction.

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Standard: MS 791-1:2013 'The structural use of masonry - Part 1: Unreinforced masonry walling'. This standard is specifically for the design of masonry constructions, but this is not generally followed in practice.After the Karonga earthquake in 2009, SAFER HOUSE CONSTRUCTION GUIDELINES have been produced by the Department of Housing and Urban Development within the Ministry of

	Lands, Housing, and Urban Development to provide practical advice to those involved with the construction of houses.
Process for building code enforcement	Not applicable.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	Formal or traditional authority provides land allocation for all construction types in formal and informal settlements, and new constructions are registered at the local city council or district commission authority. However, in the informal settlements, since there is not a proper urban planning, and houses are built without or with minimum engineering intervention from an architect or structural engineer in the design and construction process, there is a very little control on the land use and the type of constructions in these settlements (Malawi News Agency, 2016; Food Agriculture and Natural Resources Policy Network, 2006; and Kishindo, 2004).

Building Maintenance and Condition

Typical problems associated with this type of construction	Brick production has contributed to environmental problems including deforestation, decreased soil productivity, lowered ground water levels, and particularly air pollution. Deforestation and high CO_2 emissions.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on	Houses are often deteriorated due to weathering and externals/internal walls are often damaged by severe cracks indicating partial failures of the houses. Most of the cracks are located under the rafters of the timber roof, underling an inadequate distribution of the load, although roofs are of light weight and flexible. Cracks are also visible on gables, failing for overturning since they are

maintenance and building condition	completely disconnected from the roofs. Lack of proper intersection between internal and external walls can be identified by the presence of vertical cracks located on external walls. Severe damage is also caused by settlements. Spoiling and crashing of the masonry bricks are also commonly observed. Interventions to prevent further damage are generally not adopted, and new houses or houses well-kept represent only a minority in the country.

Construction Economics

Unit construction cost	Reference year for the following cost: 2018. Since Malawi is experiencing rapid economic and social changes, including population growth, as reported in section 1.3, the costs in this section may change rapidly in the future.The unit rate range per m2 is: K 11,000.00 to K 15,000.00 (US$ 15.00 to US$ 20.00). The costs are based on unit cost of materials and prevailing labour rates as prescribed by the Ministry of Labour.
Labor requirements	Labour requirements-Required time to complete a house depends on the availability of the construction materials and the financial resources of the householder.-One mason with one helper lays 75 bricks per hour. (i.e. 600 bricks per day)-A mason with one helper takes 6 weeks to build a typical house (8 m x 6 m).
Additional comments section 3	No additional comments.

Figure 32. Typical local brick with mud mortar

Figure 33. Typical local brick with cement mortar

Figure 34. Example of buttresses well connected to the front walls of the house made in masonry brick and cement mortar.

Figure 35. Example of buttresses completely disconnected from the front walls of the house made in masonry brick and mud mortar.

Figure 36. House deteriorated due to weathering, severe cracks and low maintenance. Some bricks are completely deteriorated or crushed.

Figure 37. Vertical crack underneath the timber planks supporting the corrugated metallic sheets of the roof.

Figure 38. Typical cracks indicating

Figure 39. Gable walls completely

the overturning of the gable due to the purlins in the roof pushing against the wall.

detached from the roof structure.

Figure 40. Low maintenance of the house. Mortar is partially lost due to the loss of the plaster that has accelerated the process of degradation of the constructional materials.

Figure 41. Vertical crack running along the gable wall due to the weak connection between the external facade and internal facade.

Socio-Economic Issues

Patterns of occupancy	Dwelling houses.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	<5
Additional comments on number of inhabitants	Mostly women and children live in these houses. During working hours, men are at work, or live abroad.
Economic level of inhabitants	Low-income class (poor)Middle-income class
	Reference year for the following cost: 2018. Since Malawi is experiencing rapid economic and social changes, including population growth, as reported in section 1.3, the costs in this section may change rapidly in the future. Economic level of inhabitants-

Additional comments on economic level of inhabitants	Most inhabitants are in informal settlements with income of less than US$ 1 per day-People who are engaged in formal sector mostly get wages/salaries in range US$ 33 to US$ 250 per month-A bag of cement is US$ 10.The minimum salaries are set by the Ministry of Labour for urban and rural areas. Companies generally pay employers according to the minimum wages.
Typical Source of Financing	Owner financedPersonal savingsInformal network: friends or relativesSmall lending institutions/microfinance institutionsCommercial banks/mortgages
Additional comments on financing	The vast majority of the dwellings are owner funded. According to a UN-Habitat report, less than 20% of the population has access to bank loans and mortgages and more than 55% have no formal or informal borrowing sources.
Type of Ownership	RentOwn outright
Additional comments on ownership	According to the 2008 Census the ownership ratio is 87% nationwide, but it drops to 50% in urban areas. Information related to the rural area is not available.
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	Not applicable.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	Not applicable.
Additional comments section 4	Not applicable.

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter

2018	25 km from Nsanje, Southern Region, Malawi
2009	22.2 km from Karonga, Northern Region, Malawi
2009	2.2 km from Karonga, Northern Region, Malawi
2009	26 km from Karonga, Northern Region, Malawi
1999	47 km from Chala, Rukwa, Tanzania
1989	11 km from Salima, Malawi
1989	km from Nkhata Bay, Northern Region, Malawi
1985	36 km from Usevia, Katavi, Tanzania
1976	36 km from Chama, Eastern, Zambia

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	The damage record from past earthquakes is limited. Information related to the damage patterns on this type of constructions is available from the 1989 Salima earthquake (Gupta and Malomo, 1995, Chapola and Gondwe, 2016) and the 2009 Karonga earthquake (United Nations Resident Coordinator, 2009, United States Geological Survey, 2009). During these earthquakes, many of the houses had severe vertical cracks along the side edge of the walls, underlining a lack of connection between facades that visibly collapsed for overturning. Out of plane failure mode was a very common mechanism for these buildings when they were constructed with slender single skin bearing walls. Lack of connections between walls and roof was also the cause of out of plane failure mode of gables. In these constructions, use of gable plates was not part of the construction practice, therefore gables were not restrained and purlins in the roofs were free to push against gable walls causing an arch crack pattern, commonly observed for these house types. In-plane failure modes were common for this type of houses. These failure modes were identified based on the observed crack patterns: 1) X-shape cracks on piers and spandrels, or 2) diagonal cracks involving the failure mode of entire walls. Corner failure modes were also observed for houses with double-skin walls, showing a better capacity and a

	stronger connection between walls than houses with single skin walls. Typically, houses with a corner failure mode had also a partial/total collapse of roofs.
Additional comments on earthquake damage patterns	No additional comments.

Structural and Architectural Features for Seismic Resistance

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

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	N/A
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	N/A
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.	FALSE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s)	FALSE

	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.	FALSE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	FALSE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few	FALSE

	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).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	These houses are simple rectangular shape constructions. Irregularity in plan or elevation is not a factor affecting the seismic performance, since the houses in question are of single storey. The main seismic vulnerability issues are: 1) poor structural detailing in the connections between (gable) walls and roofs. This causes out of plane failures, the mechanisms to which masonry bearing walls and gables with lack of detailing are mostly vulnerable. 2) Low mechanical properties of local materials. This causes an unpredictable response of the constructions, decreases the capacity of the houses and generates brittle seismic failures. 3) Lack of maintenance. This degrades the seismic capacity and increases the existing structural weakness in buildings. There are also other minor structural vulnerabilities observed for this type of houses, one of those are the re-entrant corners of the longest external walls in bigger houses. However, since the re-corners are never deeper than 1 m, they do not need to be considered as an element of irregularity that significantly impacts the seismic vulnerability. Porticoes are also a common irregularity for these constructions. These are rarely connected to the houses, and in many cases, they are composed by single columns disposed in front the main entrance of the houses to support thatch or corrugated metal sheets extended from the roofs. As these porticoes are generally disconnected from the houses, they do not impact on the building performance. However, they need to be considered as hazard elements, since they can collapse in case of an earthquake. Additional floors are rarely constructed. Occasionally, wall heights are increased using materials with different mechanical properties from the ones used in the initial construction.

Vertical irregularities

typically found in this construction type	Re-entrant corner
Horizontal irregularities typically found in this construction type	No irregularities
Seismic deficiency in walls	Walls are made of clay masonry bricks produced locally. Mechanical properties of the local materials are much lower than the standardized ones. Intersecting external walls are generally connected, however they are often built with slender single-skin walls, which decrease the capacity of the building. The walls perform better when they are double skin and built with cement mortar. However, informal houses are mostly built with very weak mud mortar. Walls are disconnected from the roof in most of the houses and there are no elements (i.e. ring beams) tying walls together. Wall plates are occasionally used to support rafters.
Earthquake-resilient features in walls	Connections between external walls are generally good. However, since the deficiencies, (i.e. slenderness of the walls and low mechanical properties of the materials) increase the vulnerability, low seismic performance is expected for these houses.
Seismic deficiency in frames	Not applicable.
Earthquake-resilient features in frame	Not applicable.
Seismic deficiency in roof and floors	The main issue is related to the lack of connection between roof and walls.
Earthquake resilient features in roof and floors	Roofs are flexible systems, consisting of detached timber posts which are rarely connected to the houses. Therefore, if a roof collapses under a lateral load, it might cause injuries, but not necessarily deaths.However, the lack of connections of the roofs to the walls results in inadequate load transfers from the roof to the walls, and high risk for the houses to fail in out of plane.
Seismic deficiency in foundation	Deeper foundations are required.
Earthquake-resilient features in foundation	Not applicable.

Seismic Vulnerability Rating

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

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

Figure 42. Karonga earthquake (2009). Out of plane failure mode due to lack of connections between slender single skin bearing walls made of clay bricks and mud mortar.

Figure 43. Karonga earthquake (2009). Collapse of the gable underlined by an arch crack pattern. The failure is caused by the improper connection between the gable and roof.

Figure 44. Karonga earthquake (2009). In plane failure modes of the spandrels on the top of the openings, and collapse of the roof. House has single skin walls made of clay brick of medium quality and cement mortar. The crack pattern is not visible, since

Figure 45. Karonga earthquake (2009). Corner failure mode. Collapse of the right corner of the house with double skin of clay brick of medium quality and mud mortar.

Figure 46. Karonga earthquake (2009). This type of failure involves the failure of three facades, well connected, which fail because the front facade completely collapsed in overturning and part of the side facades slid. The roof completely collapsed due

Figure 47. High seismic vulnerability of informal houses is given by a poor connection between walls

Figure 48. High seismic vulnerability of informal houses is given by a poor connection between walls and roof.

Figure 49. High seismic vulnerability of informal houses is given by poor quality of the mechanical properties of the bricks produced locally. Bricks have different size from the standards ones, and they differ considerably in terms of strength.

Figure 50. High seismic vulnerability of informal houses is given by low maintenance, and existing damage due to structural deficiencies.

Figure 51. Presence of small re-corners do not affect substantially the seismic vulnerability of the informal houses.

Figure 52. Columns of portico do

Figure 53. Columns of portico are

not impact on the seismic vulnerability of the informal houses, as they are built as a single degree of freedom detached from the main structures.

made of reinforced concrete to support canopy extended from the roof structure.

Figure 54. Columns of portico are made of bricks to support canopy extended from the roof structure

Figure 55. Seismic vulnerability - Class A: house with single skin walls made of local bricks and mud mortar. Roof is a flexible system made of timber purlins and rafters supporting corrugated metallic sheets, very damaged by weathering and deformed by la

Figure 56. Seismic vulnerability - Class B: house with single skin walls made of local bricks and mud mortar. Roof is a flexible system made of timber purlins and rafters supporting thatch. The roof sits directly on the walls. No restating elements are in

Figure 57. Seismic vulnerability - Class B: house with single skin walls made of local bricks and mud mortar. Roof is a flexible system made of timber purlins and rafters supporting corrugated metallic sheets. The roof sits directly on the walls, partiall

Figure 58. Seismic vulnerability - Class B: informal house with double skin walls made of local bricks and mud mortar. Roof is a flexible system made of timber purlins and rafters supporting corrugated metallic sheets. Rafters/purlins are nailed to wall p

Figure 59. Seismic vulnerability - Class C: house with double skin walls made of local bricks and mud mortar. Roof is a flexible system made of timber purlins and rafters supporting corrugated metallic sheets. Rafters/purlins are nailed to wall plates fix

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
overtuning of walls	build buttressesuse of standardised materialensure good intersections between walls
lack of connection of the walls at the top level	timber ring beam at the top wall
wall slenderness, poor mechanical proprieties	Walls should be two skin layers and built with standardised bricks
inadequate distribution of the load	lintels on the top of the openingPadstone to support raftersRegular opening
improve connections between walls	quoinsuse of standardised materialImprove detailing in the connections

Additional comments on seismic strengthening provisions	For buildings of this type, no strengthening interventions are in place. Therefore, the listed interventions above are proposed strategies to improve the building deficiencies.

Has seismic

strengthening described in the above table been performed?	Not applicable.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Not applicable.
Was the construction inspected in the same manner as new construction?	Not applicable.
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Not applicable.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Not applicable.
Additional comments section 6	Not applicable.

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