World Housing Encyclopedia

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

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HOUSING REPORT
Vivienda de Bahareque

Report #	141
Report Date	10-08-2007
Country	EL SALVADOR
Housing Type	Timber Building
Housing Sub-Type	Timber Building : Walls with bamboo/reed mesh and post (Wattle and Daub)
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Summary

The bahareque construction type refers to a mixed timber, bamboo and mud wall construction technique which was the most frequently used method for simple houses in El Salvador before the 1965 earthquake (Levin, 1940; Yoshimura and Kuroki, 2001). According to statistics of the Vice-ministry of Housing and Urban Development in the year 1971 bahareque buildings had a share of 33.1 % of all buildings in El Salvador, while in 1994 the percentage of

bahareque declined to about 11 % (JSCE, 2001b) and in 2004 to about 5 % (9 % in rural areas; according to Dowling, 2004). The term 'bahareque' (also 'bajareque') has no precise equivalent in English, however in some Latin American countries this construction type is known as 'quincha' (engl.: wattle and daub). In order to prevent confusion it should be noted, that in El Salvador the term 'bahareque' is used for all types of this mixed construction type regardless the material of the horizontal elements (struts).

Bahareque buildings are characterized by high flexibility and elasticity when carefully constructed and well-maintained, and thus originally display good performance against dynamic earthquake loads. However, bahareque buildings in most cases show high vulnerability during earthquakes. This is caused by poor workmanship (carelessness and cost-cutting measures during construction), lack of maintenance (resulting in a rapid deterioration of building materials), and structural deficiencies such as a heavy roofing made out of tiles. Bahareque structures are primarily of residential use and only one story. The structural walls are mostly composed of vertical timber elements and horizontal struts which are either made of timber slats, cane/reed (carrizo), bamboo (vara de castilla, caña brava or caña de bambú) or tree limb (ramas). These members are generally 2- to 3-inches thick and are fastened at regularly spaced intervals from the base to ceiling height at the vertical elements (with nails, wires or vegetal fibers). This creates basketwork type skeleton which is then packed with mud and clay filler combined with chopped straws (or sometimes with whole canes), and covered with a plaster finish in some cases. In rural areas, the walls are often left plane, without any lime plaster and whitewash, or paint, which gives them a wavy surface with an unfinished character. It should be noted that bahareque houses in rural areas are quite different from those in urban areas both in terms of their esthetical appearance as well as their structural capacity (cf. Figures 1 and 2).

1. General Information

Buildings of this construction type can be found in many places throughout the country. However, the percentage of these buildings is higher in rural areas than urban areas. This type of housing construction is commonly found in both rural and urban areas.

Even though the basic construction technique is the same, there are differences between bahareque buildings found in urban and rural areas. Those found in urban areas are more stable and have more substantial construction, complete with (adobe-based or lime-based) plaster, and whitewash or paint (Figure 4), while those in rural regions appear to be temporary shacks reflecting a lower income level (Figure 3).

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. However, only in rural areas. In urban areas it is not used anymore and the remaining bahareque dwellings from earlier days are oftentimes abandoned and derelict.

Figure 1. Typical bahareque building for rural areas.

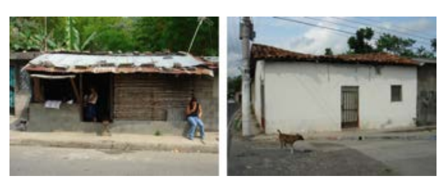

Figure 3. Typical bahareque buildings in rural areas.

[Click to enlarge figures]

Figure 2. Typical bahareque building for urban areas.

Figure 4. Typical bahareque buildings in urban areas.

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 variable, from cm to meters.

2.2 Building Configuration

The typical shape of the building plan for this housing type is rectangular. Figures 5 to 9 illustrate the plans, cross-sections and views of typical bahareque houses as can be found in rural areas. These representations are buildings from Guatemala since comparable information is hard to find for El Salvador. However, the structural details of bahareque buildings in El Salvador and Guatemala are comparable. The doors are usually located at the center of the wall, the windows at both sides of the door. For those walls without a door, the windows are located close to the corners. The window and door area is around 12% of the overall wall surface area. The average dimensions of doors are: width 1.00 m and height 2.10 m. The average dimensions of windows are: width 1.0 m and height 0.80 m.

2.3 Functional Planning

The main function of this building typology is single-family house. In rural areas, general use is residential. In urban areas, bahareque houses can also accommodate retail trade or handicraft businesses. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Generally, these buildings have two doors, one at the front and one on the building?s back side entering the backyard.

2.4 Modification to Building

In some cases, outer walls of bahareque buildings are supplemented by masonry walls added inside the structure (Figure 10). The most frequent modification of bahareque buildings is replacing the heavy clay roof tiles with metal sheeting such as corrugated iron or aluminum plates.

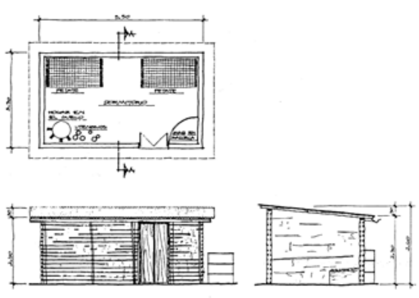

Figure 5. Plan shape, cross-section and view of a typical residential bahareque building in a rural area (here: San Antonio Palop

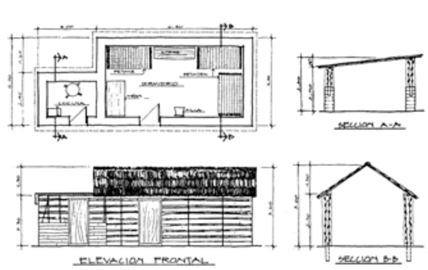

Figure 6. Plan shape, cross-sections and view of a typical bahareque building with an annex of adobe walls in a rural area (here: San Antonio Palop

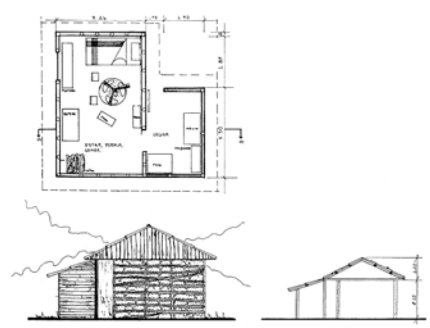

Figure 7. Plan shape, cross-section and view of a typical bahareque building with a wooden annex in a rural area (here: Soloma/Guatemala; taken from Marroquin and G

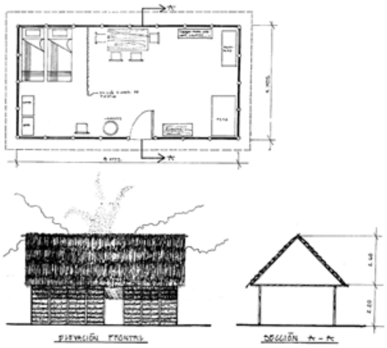

Figure 8. Plan shape, cross-section and view of a typical bahareque building in a rural area (here: Purulh

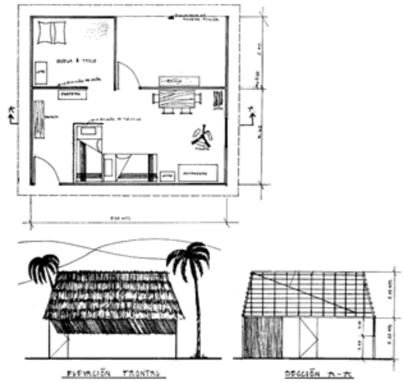

Figure 9. Plan shape, cross-section and view of a typical bahareque building in a rural area (here: Purulh

Figure 10. Modification of a bahareque house by an additional wall at the inside made of masonry bricks (Santa Tecla).

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	☐
	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	☐

Structural concrete		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 timber frame. Gravity loads from the roof construction itself (dead loads) or from live loads such as wind impact are directly transferred from the roof construction to the corner columns (wooden posts) which take the entire gravity load and transfer it to the ground (or foundation). In urban areas, most of the bahareque houses have a base (pedestal) forming the foundation made out of clay bricks, field stones or even concrete. The base can reach up to one meter above the ground with the bahareque walls resting on it (Figure 14). The bahareque shacks found in rural areas often possess no foundation or only a strip footing comprised of field stones or bricks. Since the indigenous method of roof covering with palm fronds is mainly replaced by heavy clay tiles of burnt adobe the largest gravity loads result from the weight roof construction.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame. The lateral load-resisting system of bahareque houses principally consists of a flexible mixed wall construction made out of vertical timber elements and horizontal struts which are fastened at regularly spaced intervals at the columns (Figure 11). Even though these wall constructions are packed with mud and clay filler combined with chopped straws (or sometimes with whole canes), they show elasticity and are characterized by a very low self weight (Figure 12). In most cases, sufficient bracing of the walls, e.g. by diagonal trusses (Figure 13), is not provided resulting in a lack of adequate wall strength in both the in-plane and out-of-plane directions (Yoshimura and Kuroki, 2001). In addition, lateral resistance is reduced by the failure to set the vertical structural elements (wooden corner columns) deeply and firmly into the ground (Levin, 1940). The gabled roof generally consists of a light wood frame construction which is not able to support any lateral loading. At best, a tight connection of the roof construction with the walls can only be assumed at the corner columns.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 8 and 10 meters, and widths between 4 and 8 meters. The building has 0 to 1 storey(s). The typical span of the roofing/flooring system is 4-8 meters. Story heights vary between 1.8m and 3.0m. The typical storey height in such buildings is 2.4 meters. The typical structural wall density is up to 5 %. .

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 made of earthen materials or cast plaster (screed). The roof is considered a flexible diaphragm. Details of a typical roof construction are given in Figure 15.

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	☐

In rural areas, bahareque houses generally possess no foundation or only a strip footing of field stones or bricks. Here, the vertical timber elements are simply set firmly into the ground at the corners which in many reported cases is not sufficient. In urban areas, foundations are built as bases (pedestals) consisting of field stones, day bricks or concrete into which the vertical posts are inserted (Figure 14).

Figure 11. Detailing and fastening of the horizontal struts at the vertical timber elements. [Click to enlarge figures]

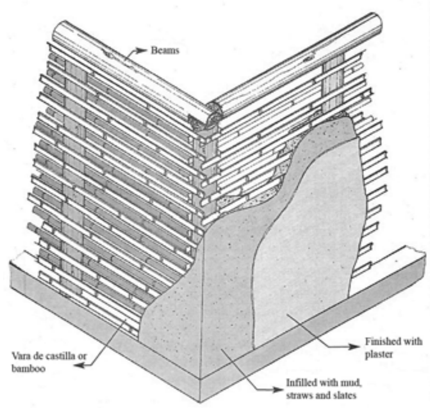

Figure 12. Detailing of a bahareque wall (after Carazas-Aedo and Rivero-Olmos, 2002)

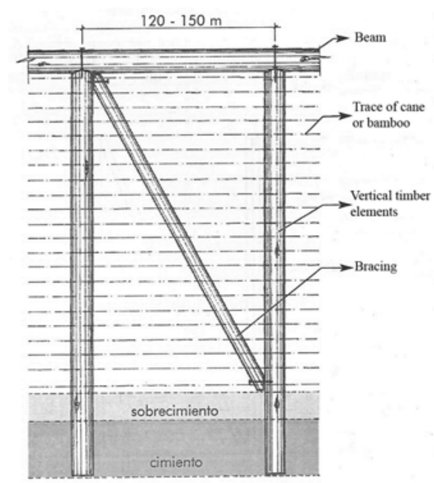

Figure 13. Elevation view of a bahareque wall (after Carazas-Aedo and Rivero-Olmos, 2002).

Figure 14. Bahareque building in an urban area with a pedestal made of clay bricks.

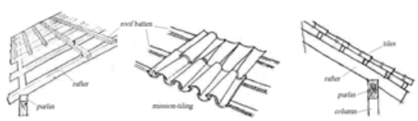

Figure 15. Detailing of the wooden roof construction of bahareque houses (taken from Moisa-Perez and Medrano-Lizama, 1993).

Figure 16. Low adherence of plaster due to weathering effects and missing connection to the wall materials

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). Due to the small plan dimensions and thus small living area, generally only one family occupies these buildings. 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 5-10.

4.2 Patterns of Occupancy

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 housing unit price to annual income for very poor is US$ 2000 / 4300, and for poor, it is US$ 5000 / 7200.

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 no bathroom(s) including toilet(s).

However, in many cases (especially in rural areas), bahareque buildings have no internal latrines or bathrooms. The latrines are usually placed inside a small shack, which is located in the backyard. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or	Most appropriate type

occupancy?	
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	- insufficient bracing reducing wall strength - faulty tieing of horizontal members to the columns reducing wall strength - deterioration of wall materials due to effects of climate and vermins	- flexibility, elasticity - low dead loads	- in-plane and out-of-plane failure
Frame (wooden corner columns)	- insufficient number of posts - insufficient foundation depth - lack of preservative treatment of timber leading to deterioration due to vermins (insects) - decay/rot of buried partion of column bases due to missing foundation and/or lack of preservative treatment	- flexibility, elasticity	- anchorage/embedding failure of wooden posts - diagonal shear cracking
Roof	- no diaphragm effect - no tight connection to the walls - high dead loads in case of heavy roof tiles (inverted pendulum) - material deterioration of wooden (or metal) trusses due to climatic effects	- low dead loads in case of palm fronds or corrugated iron sheeting	- total and partial collapse of roof construction
Other	- low adherence of plaster due to weathering effects and missing connection to the walls (Figure 16)		- spalling of plaster

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate 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 D: MEDIUM-LOW VULNERABILITY (i.e., good 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
1917	June 8, West of San Salvador	Ms 6.7	N.A.
1919	April 28, San Salvador	Ms 5.9	N.A.
1936	Dec. 20, San Vicente	Ms 6.1	VII-VIII (SIEBERG)
1951	May 6-7,Jucuapa, Chinameca, and Santiago de Maria	Ms 5.9, Ms 6.0, Ms 5.5	I(MSK) < VIII
1965	May 3, San Salvador (d = 10 km)	Ms 5.9	VIII (MMI)
1982	June 19, Pacific Ocean	Mw 7.3	VII (MMI)
1986	Oct 10, South of San Salvador	Mw 5.7 (Ms 5.4)	VIII (MMI)
2001	Jan 13,Pacific Ocean (100 km southwest of San Miguel)	Mw 7.7 (Ms 7.8)	VII-VIII (MMI)
2001	Feb 13,San Juan Tepezontes	Mw 6.6 (Ms 6.5)	VII (MMI)

The bahareque construction type is not covered by the vulnerability table of the European Macroseismic Scale EMS-1998 (Grünthal (ed.) et al., 1998). This building type has proven to perform better under lateral earthquake shaking than adobe structures. Additionally, its reported flexibility/elasticity as well as some favorable features such as the lightweight wall (and roof) construction may justify the classification into vulnerability class C. However, it should be stated, that this strongly depends on the quality of materials, workmanship, and the state of maintenance. Most of the bahareque buildings which can be found nowadays are older and show weathering effects and have to be classified into vulnerability class A.

1917: The use of bahareque construction techniques in the urban areas of San Salvador is forbidden by legislative decree, following the June 8 earthquake (Moisa-Perez and Medrano-Lizama, 1993).

1936, December 20 (local: December 19, 20:41 h) earthquake: According to Levin (1940), the intensity of the earthquake near the city San Vicente ?certainly exceeded grade VII of the Sieberg scale, and probably reached grade VIII.? Uncertainties in the intensity assignment arise from the fact that most of the damage was concentrated on traditional building types, such as adobe or bahareque, which are not mentioned in the intensity scales, and due to the considerable number of buildings already damaged by foreshocks from the preceding morning. The isoseismal map of the earthquake was drawn largely with the following as a basis: Isoseismal zone VIII: poorly constructed or weak bahareque houses collapsed, plaster fell from the walls of well-constructed bahareque houses, some heavy tile roofs either collapsed or were considerably deformed. Isoseismal zone VII: good bahareque houses were unaffected except for falling plaster and deformation of tile roofs; some old or poorly constructed bahareque houses collapsed. Beyond isoseismal zone VI there was no visible damage to structures.

1951, May 6?7 (UTC: 23:03 h, 23:08 h on May 6 and 20:22 h on May 7): A series of three destructive earthquakes (Ms 5.9, Ms 6.0, Ms 5.5) destroyed the cities of Jucuapa and Chinameca with about 400 fatalities (Bommer et al., 2002) as well as the city of Santiago de Maria. The size of the affected area was very small, ?a few adobe and bahareque houses did withstand the shocks, but all of these had been built within two or three years prior to the earthquake? (Ambraseys et al., 2001).

1965, May 3 (UTC: 10:01 h): Rosenblueth and Prince (1966) report that ?at 4h 01 m 35s (local time) on the 3rd of may, 1965, the capital city of the Republic of El Salvador was shaken by an earthquake that caused severe damages and a death toll of 127 people (..). Its epicenter was located near the city in a distance of 10 km and a superficial focus of about 8 km. The Richter magnitude was computed as 6.? Regarding the damages to bahareque buildings, the authors stated that ?the larger death toll was caused by the collapse of bahareque dwellings. However, the behavior of this type of constructions was satisfactory, generally; bahareque structures collapsed when three factors were present all together: the wood was rotten, the foundation soil was loose sand and it was located close by the area of maximum intensity.?

1986, October 10 (UTC: 17:49 h): Based on Harlow et al. (1993) the earthquake ?killed an estimated 1,500 people, injured 7,000 to 10,000 others, and left more than 100,000 people homeless (Olsen, 1987). The earthquake occurred on a shallow fault beneath the city of San Salvador at 11:49 a.m. local time and was assigned a surface-wave magnitude (Ms) of 5.4 by the U.S. National Earthquake Information Center.? Whilst Anderson (1987) stated ?that new bahareque construction holds up well, on the average, under earthquake ground shaking. But failure of this building system during the earthquake, as well as failure of adobe construction, was extensive in the southern sector of San Salvador. This included the neighborhoods of Santa Anita, Modelo, and San Jacinto (near the Presidential Palace). Based on experiences in past Central American earthquakes, collapse of bahareque dwellings is often due to failure of the structural timber caused by rot or damage by insects.? Figure 17 illustrates some damages to bahareque dwellings cause by the 1986 event.

2001, January 13 (17: 33 UTC) earthquake: The epicenter was located 100 km southwest of the city San Miguel in the subduction zone offshore from El Salvador. The depth of the mainshock was 39 km (NEIS). According to the Seismological Center of Central America (CASC) the maximum ground shaking intensity in the coastal area of El Salvador (near the epicenter) was I(MMI) = VIII, in most cities of El Salvador I(MMI)=VII (Sawada et al., 2001; Yoshimura and Kuroki, 2001). Bommer et al. (2002) suggest that ?MM intensities throughout the southern half of the country were between VI and VII with local pockets of higher intensity between VII and VIII.? Examples of damaged bahareque houses within different villages of the region Usulután are given in Figure 18.

2001, February 13 (14:22 UTC) earthquake: It is reported that this event, with an epicenter close to the town of San Juan Tepezontes, caused maximum shaking intensities of VII-VIII (MMI) in the area from Lake Ilopango in the west to San Vicente in the east, and VI in San Salvador. However, a more recent study revealed that the maximum intensities did not exceed VII (Bommer et al., 2002). Figure 19 illustrates some damaged bahareque houses located in the city of San Vicente.

* based on information taken from: Ambraseys et al. (2001), Bommer et al. (2002), Lopez et al. (2004), Lopez et al. (2006), SNET (2004), Yoshimura and Kuroki (2001).

Figure 17.Damaged bahareque dwellings after the San Salvador earthquake on October 10, 1986 (left: San Jacinto neighborhood; right: after Kuroiwa, 1987). [Click to enlarge figures].

Figure 18. Structural damage to bahareque dwellings caused by the earthquake on January 13, 2001.

Figure 19. Structural damage to bahareque dwellings in the city of San Vicente caused by the earthquake on February 13, 2001.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Building materials for the walls include timber slats, cane/reed, bamboo or wooden limbs with mud and clay filler.	There is no information on strengths of materials used in this construction.	Likewise, no information is available on the mix proportions of materials and on dimensions of walls.	
Foundation	The foundations are typically mud, fieldstones and concrete.			
Frames (beams & columns)	The frame (wooden corner columns) are made of (crudely) trimmed timber.			
Roof and floor(s)	The roofs are wooden bars with clay tiles or (corrugated) iron. The floors are of earthen materials or cast-in-place plaster (screed).			

6.2 Builder

Generally, the building is occupied by the builder himself.

6.3 Construction Process, Problems and Phasing

Since this construction type is officially forbidden in San Salvador, information on the construction process is hard to obtain. 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

During the design and construction no external expertise is involved. In most cases the builder erects the building for his own. Neither architects nor engineers are involved in the design or construction of these buildings.

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.

This housing type is no longer built in urban areas. In rural areas, it is built without supervision by authorities. Building permits are not required to build this housing type.

6.7 Building Maintenance

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

6.8 Construction Economics

This building typically cost US$15 per square meter. This housing typically takes 75 man days to build.

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
Heavy roof	Substitution of heavy roof tiles by (corrugated) iron sheeting
Weak roof construction	Tight connection to the walls; replace rotten wood elements
Deterioration of wooden elements due to climatic effects and vermin	Apply wood preservative (e.g. petrol)
Rotten column bases (wooden posts)	Apply wood preservative against moisture, vermins, and rodents (e.g. lime mortar)
Insufficient wall strength	Add (diagonal) bracing, additional horizontal struts (at the walls both inside and outside), additional tieing of

	horizontal members to the vertical posts, replace infill material with mud reinforced with organic fibers (e.g. hay)
Spalling of plaster	Use of lime-based plaster (also to protect the walls from humidity) and use of plaster reinforcement or lathing (e.g. barbed wire, wire netting)

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Heavy roof	Use of (corrugated) iron sheeting
Weak roof construction	Tight connections to the walls
Deterioration of wooden elements due to climate and vermin	Apply wood preservative (e.g. petrol)
Rotten column bases (wooden posts)	Rotten column bases (wooden posts)
Insufficient wall strength	Use of sawed lumber as vertical posts set firmly every 3 or 4 ft. into the ground (foundation) at the corners and at wall-panel points - Additional (diagonal) bracing - Additional or stronger horizontal struts of which the uppermost may serve as a beam at which the roof construction can be connected - Tieing of horizontal members to the vertical posts
Spalling of plaster	Use of lime-based plaster (also to protect the walls from humidity) and use of plaster reinforcement or lathing (e.g. barbed wire, wire netting)

A very detailed overview of strengthening and retrofitting measures for bahareque dwellings is given by Irula et al. (2002).

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?

Sporadically, seismic strengthening measures are applied especially to existing structures.

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

No ongoing mitigation efforts on new or existing structures could be observed.

8.3 Construction and Performance of Seismic Strengthening

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