13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2646

THE SEISMIC PERFORMANCE OF BAHAREQUE DWELLINGS IN EL SALVADOR

Manuel LÓPEZ[1], Julian BOMMER[2] and Patricia MÉNDEZ[3]

SUMMARY

Throughout the history of El Salvador, construction practices have been influenced by earthquakes happening in that region. One of the most successful attempts, developed by the Salvadorian indigenous population, was *bahareque*. In fact, a primitive type of *bahareque* was already used in El Salvador before the Spanish invasion. This first *bahareque* consisted of small tree branches bonded with clay, where wooden frames covered by palm fronds constituted the roof. This type of construction possesses structural unity as well as great elasticity and is seismically resistant to a remarkable degree. However, some foreigner features, added during the colonial period, reduced its seismic performance. Since *bahareque* is an ancient and traditional technique which has been developed and improved during generations, it must be considered as a cultural patrimony of El Salvador; therefore, it must be preserved and its seismic performance enhanced to offer a cheap, secure and native housing solution to the people with the most need.

In this paper the *bahareque* building system is explained and its advantages and disadvantages are studied. Performance of the *bahareque* affected by recent earthquakes in El Salvador is discussed. In addition, possible methods to enhance the seismic resistance of the system are presented.

INTRODUCTION

The term *bahareque* has no precise equivalent in English. It refers to a type of frame construction; the material of which consists of crudely trimmed wooden poles 15 cm or so in diameter and tree branches graduating in diameter from 1.5 cm to approximately 7.5 cm. The poles are set firmly in the ground at wall corners, at intermediate panel points, if the wall is long, and wherever needed to frame doors and windows. Upon these upright members are fastened the 5 and 7.5 cm branches as horizontal members at regularly spaced intervals from base to ceiling height. Upon these, in turn, are woven branches of smaller diameter, both vertically and horizontally. This results in a sort of basketwork skeleton, upon which mud is plastered both inside and out, thereby forming walls the thickness of which approaches the diameter of the upright members.

[1] PhD student, ROSE School, Pavia, Italy. Email: manuel.lopez@unipv.it
[2] Reader in EQ Hazard Assessment, Imperial College London, UK. Email: j.bommer@imperial.ac.uk
[3] Depto de Mecánica Estructural, Universidad Centroamericana "José Simeón Cañas", San Salvador, El Salvador. Email: pdhasbun@ing.uca.edu.sv

BACKGROUND

Seismic hazard in El Salvador.

El Salvador lies near the western edge of the Caribbean plate on the Pacific coast of Central America. A few tens of kilometers offshore from El Salvador, the Cocos plate is subducted below the Caribbean plate in the Middle America trench, producing Benioff-Wadati zones down to about 200 km (Dewey & Suarez [1]). Large events are triggered by the plate convergence, taking place at a rate of 7-9 cm/year, but no earthquake in this zone during the last century has reached magnitudes M_W 8.0. The most recent earthquake of this type occurred on 13 January 2001, with a magnitude M_W 7.7, causing damage to thousands of traditionally built houses and triggering hundreds of landslides, which were the main causes of fatalities.

A second source of seismicity affecting El Salvador is a zone of upper-crustal earthquakes that coincide with the Quaternary volcanoes that extend across the country from west to east forming part of a volcanic chain extending throughout the isthmus from Guatemala to Panama. Due to their shallow foci and their coincidence with the main population centers, these earthquakes have been responsible for far more destruction in El Salvador, as in neighboring Nicaragua, than the larger earthquakes in the subduction zone. During the 20th century, such shallow focus earthquakes caused destruction on at least seven occasions, sometimes occurring in clusters of two of three similar events separated by periods of minutes or hours. San Salvador, the capital city, has been badly hit by this type of earthquakes on 8 June 1917 (M_S 6.7); on 28 April 1919 (M_S 5.9); on 3 May 1965 (M_S 5.9), which caused about 120 deaths; and 10 October 1986 (M_S 5.4), which left 1500 dead and 100,000 homeless. The most recent event of these shallow focus, moderate magnitude earthquakes was on 13 February 2001, M_W 6.6, which caused 315 deaths, affecting the area around the San Vicente volcano. This area was also hit by an event on 20 December 1936, M_S 6.1, killing more than a 100.

Major earthquakes also occurred on the Motagua and Chixoy-Polochic faults that traverse Guatemala and mark the boundary between the Caribbean and North American plates, but they are distant enough not to produce damaging motions in El Salvador. The M_S 7.5 Guatemala earthquake of 4 February 1976 caused shaking that did not exceed MM intensity of V within El Salvador (Espinoza [2]).

Earthquakes are also produced by areas of tectonic extension in Honduras, including the Honduras Depression and a small area at the junction of Honduras, El Salvador and Guatemala (Sutch Osiesky [3]; White [4]). The largest earthquake during the 20th century in this zone was that of 29 December 1915 (M_S 6.4), for which Ambraseys and Adams [5] relate press reports alleging two deaths in San Salvador due the collapse of walls, although the effects in El Salvador were clearly not overly important.

Figures 1 and 2 are presented to illustrate the effect of both subduction and upper-crustal earthquakes. One readily notices that in the central valley and the southwest area of the country the seismic hazard is higher; coincidentally, at least three-quarters of the population of El Salvador currently live in that region.

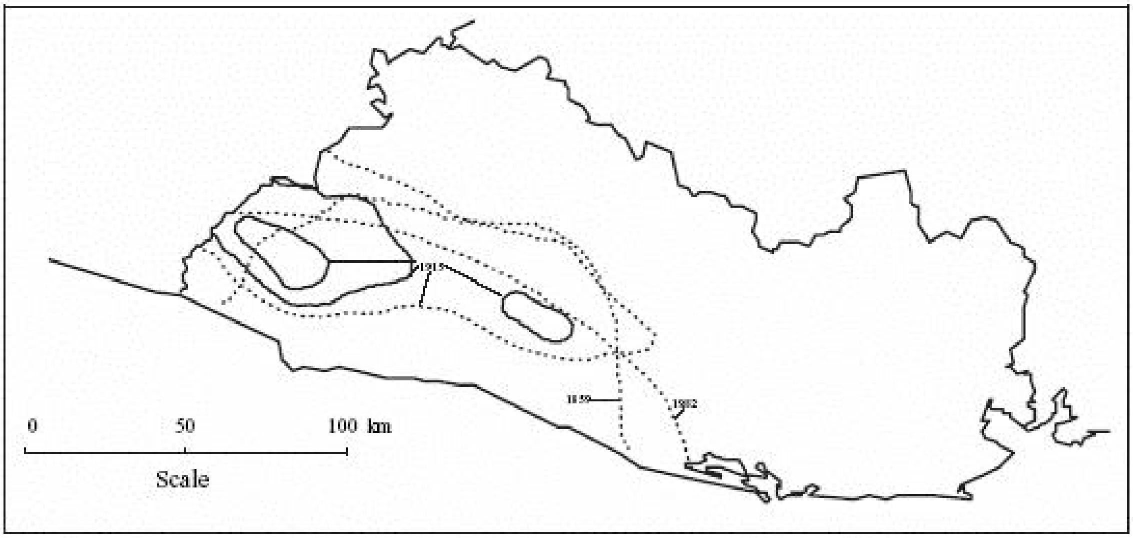


Figure 1. Isoseismal of MM intensity VII (dotted), VIII (solid) and IX (solid) in El Salvador from subduction earthquakes (Bommer *et al*. [6]).

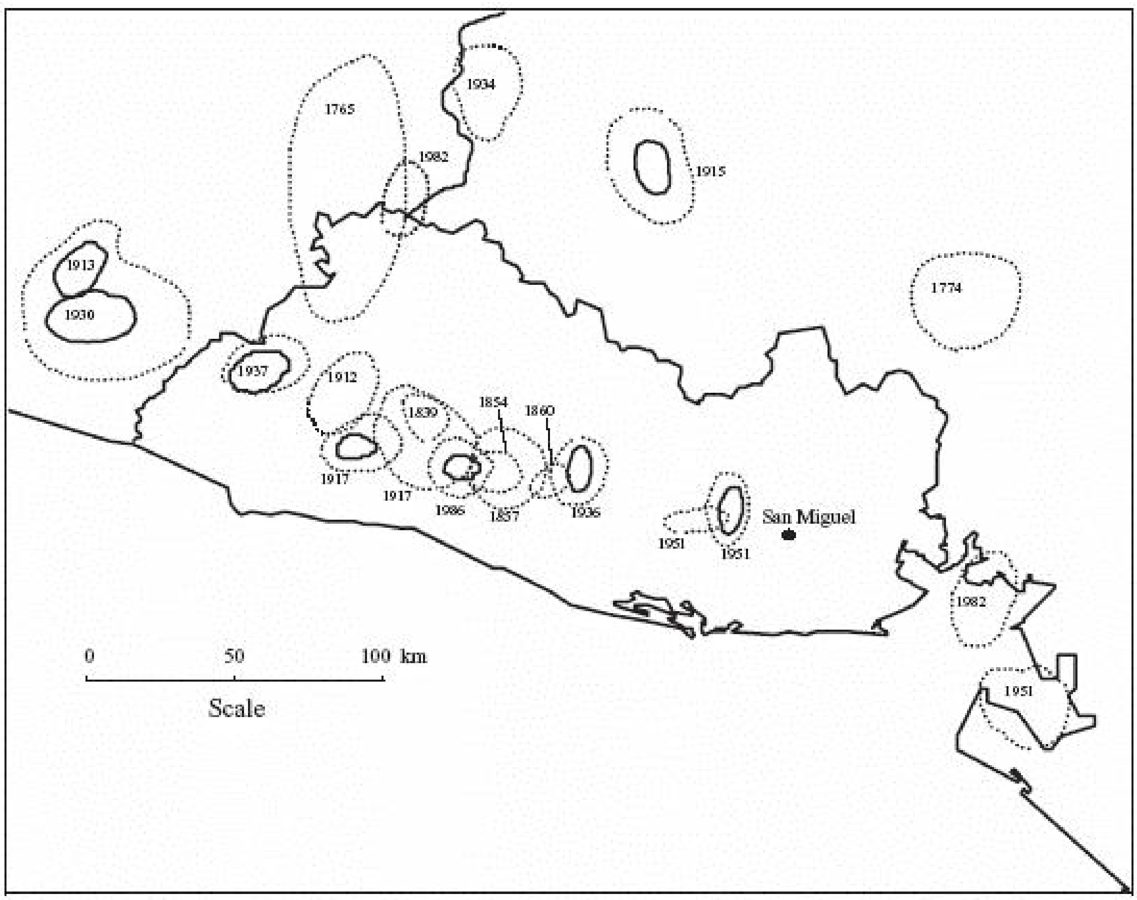


Figure 2. Isoseismal of MM intensities VII and VIII in El Salvador from upper-crustal earthquakes (Bommer *et al*. [6]).

Construction system for dwellings in El Salvador

In El Salvador the construction system for most dwellings are *adobe*, *bahareque,* reinforced brick masonry (*mixto*), wood frames covered by thin metal sheets (*lámina*), and wood frames cover by palm fronds (*ranchos*). There are some other building practices, less used, such as concrete and soil-cement block masonry, steel frames covered by precast walls, reinforced concrete houses and apartment buildings (Bommer *et al*. [7]).

The main characteristic of the *adobe* system is that lateral and vertical loads are supported by walls which are composed of bricks and mortar, made of pumitic ash, with high stiffness and mass but very low strength and cohesion. Roofs of *adobe* houses may be of metal sheets and/or clay tiles supported by wooden trusses, or thatched roofs supported on wooden timber purlins. Load transfer between the roof and walls is often not effective. *Bahareque* consists of timber vertical elements and horizontal timber, cane or bamboo elements, with mud infill and finished with plaster. The seismic resistance of *bahareque* depends primarily on the condition of the timber and cane elements, having relatively low vulnerability when carefully maintained. *Bahareque* is a more expensive building system than *adobe*. However, roofs are similar to those for *adobe* and show the same problems.

After the 1873 and 1917 earthquakes in San Salvador (Harlow *et al*. [8]), however, another conversion in building practice took place. This time, a structural system composed of wood or metal frames (covered by thin metal sheets) named *lámina* was used to rebuild the city. This system had the important benefit of possessing low mass, thus allowing, for the first time in El Salvador, the construction of buildings with more than one story. The oldest buildings that can currently be found in San Salvador date from the beginning of the twentieth century and make use of this particular structural system.

Another type of construction system introduced in the last century was mixto. *Mixto* is composed of fired clay bricks with mortar and slender elements of concrete with thin steel reinforcement, of the same thickness as the wall, which are not properly reinforced concrete and are known as *nervios* (nerves or tendons). This system, in which the load is borne by the masonry walls, has relatively good seismic resistance but is considerably more expensive than the previously described systems.

One system that has always been present in the Salvadorian countryside, even before the Spanish conquest, is wooden frames covered by palm fronds, which has excellent seismic resistance but this building practice is rapidly disappearing due to the scarcity of materials and the lack of security that such dwellings provide. In common with most other countries in the world, the general population aspires to housing that reflects a higher level of prosperity and despite the almost complete seismic safety of these *ranchos*, they are viewed as the lowest level of formal (as opposed to shanty dwellings) housing and they are therefore not a preferred option.

In general, *mixto* is, by far, the housing construction method most used in El Salvador with *adobe* and *bahareque* systems in the second and the third positions, respectively (Table 1). However, there is a decreasing tendency in the usage of the last two building types, more marked in the *bahareque* case, figure 3. Such trend has increased more after the 2001 earthquakes. For instance, from the total pre-earthquake housing stock of 1,383,145, 20% were affected, i.e. 276,594. From the latter, 32,332 houses were *bahareque* dwellings of which 24,871 units were destroyed and 7,461 houses were damaged, Dowling [9].

Table 1. Pre-earthquake housing units, in El Salvador, depending on type of construction according to Dowling [9].

Type of Dwelling	Number of Units		
	Urban	Rural	Total
Total	860,082	523,063	1,383,145
Mixto or concrete	685,464	178,476	863,940
Bahareque	27,625	45,633	73,258
Adobe	118,622	241,347	359,969
Timber	5,924	30,933	36,857
Lámina	17,116	11,740	28,856
Other	5,331	14,934	20,265

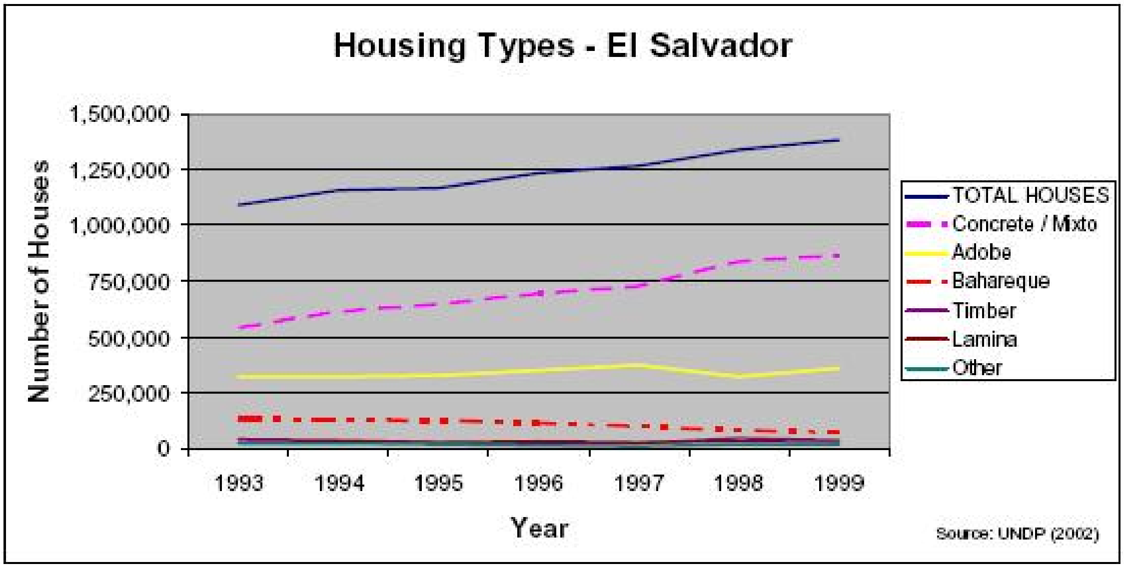


Figure 3. Number of houses by housing material, El Salvador 1993-1999 (Dowling [9])

BAHAREQUE IN EL SALVADOR

Construction system

Before the Spanish invasion of Central America, *bahareque* was already widely used. The first type of *bahareque* consisted of small tree branches bonded with clay. Later, the building process changed and became more developed. For instance, some *bahareque* dwellings were constructed by using a foundation of stones or clay into which vertical wooden posts were inserted. Horizontal rods were attached to the vertical posts and both structural member formed the skeleton of the dwelling. The body of the house was created using bamboo elements with mud infill and covered by plaster (Figure 4). Wood frames covered by palm fronds constituted the roof (Figure 5), an excellent feature from a seismic resistance point of view.

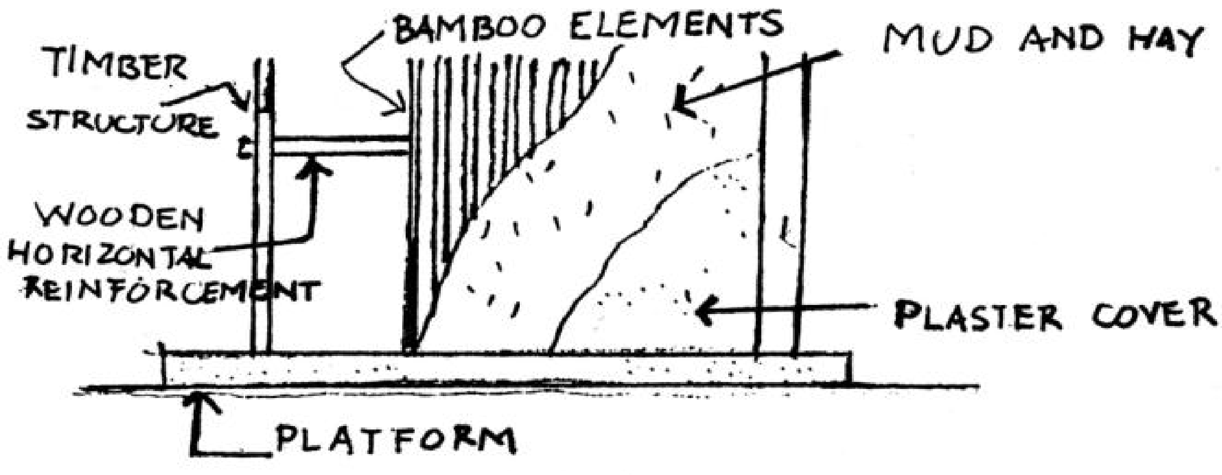


Figure 4. Main components of the *bahareque* indigenous dwellings (Moisa y Medrano [10]).

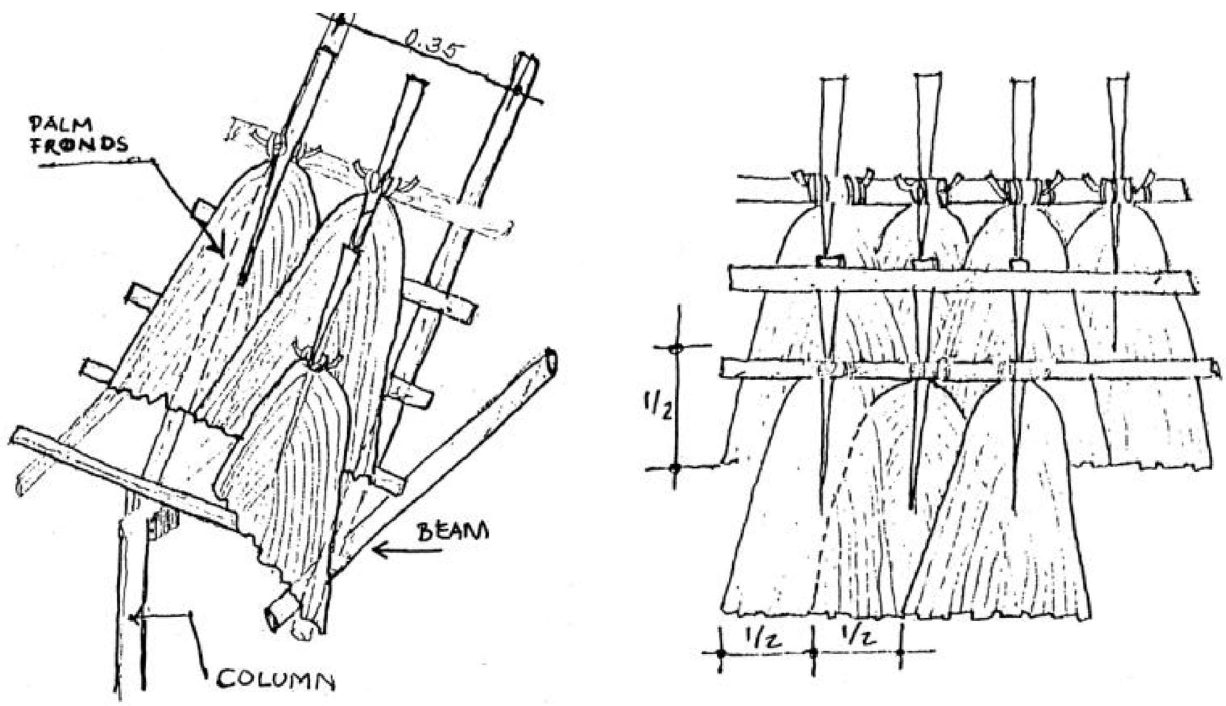


Figure 5. Roof details of the *bahareque* indigenous dwellings, (Moisa y Medrano [10]).

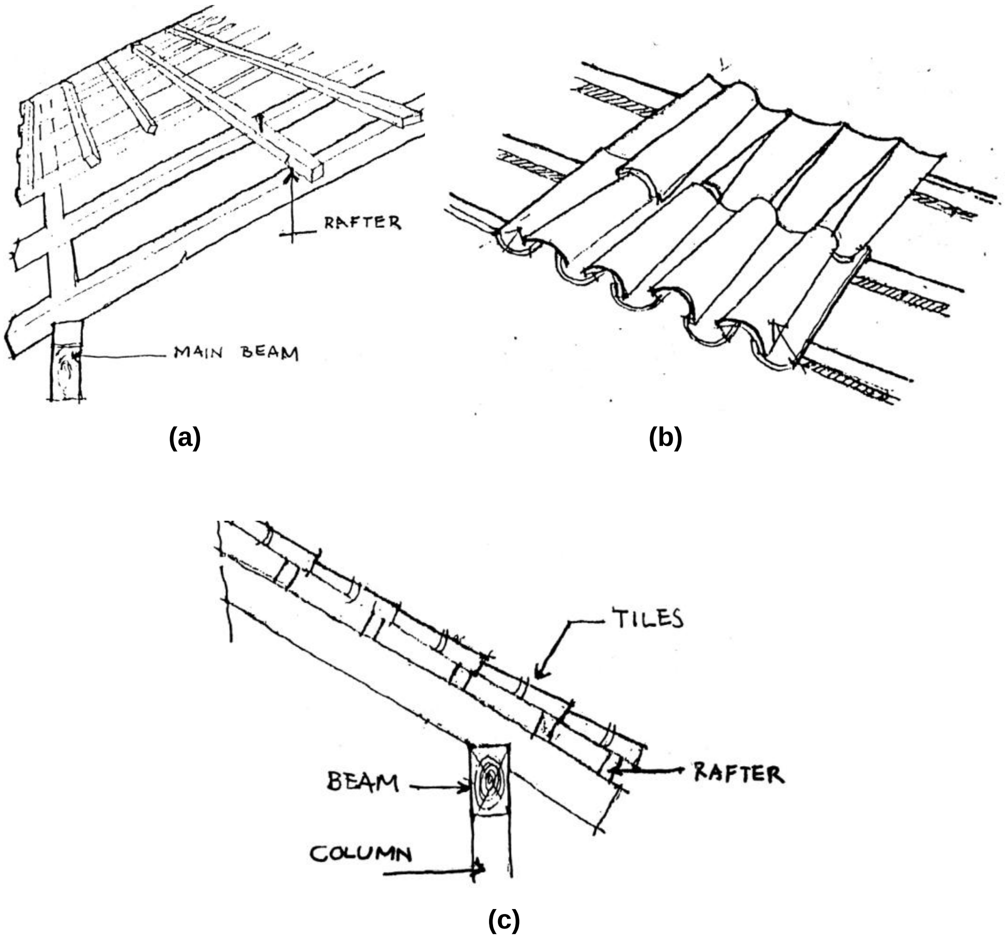


Figure 6. (a) Wooden grid where tiles are placed, top left. (b) position of tiles on the grid, top right. (c) lateral detail of tile position on the grid, bottom (Moisa y Medrano [10]).

During the colonial period, *bahareque* continued being used; however, it was enforced, by the *conquistadores*, that the roofs of the dwellings were made of wooden frames and clay tiles (Figure 6). This shift reduced considerably the seismic performance of *bahareque* since roofs became heavy and badly integrated with walls. Nevertheless, *bahareque* substituted *adobe* both in rural and urban areas, due to its seismic resistance, during the XVIII and XIX centuries. It has been reported that *bahereque* was officially banned from urban areas after the 8 June 1917 San Salvador earthquake (Moisa & Medrano [10]). However, it seems that this regulation, if it ever existed, never came into enforced effect because Rosenblueth & Prince [11], reporting the 3 May 1965 San Salvador earthquake, mentioned that "*the majority of the low- class dwellings and a great number of the middle-class housing are made, partially or totally of bahareque*".

Presently, *bahareque* has some variants (Figure 7). The framework can be made of wooden studs, wooden braces or wooden grid with bamboo strips or barbed wire to provide better infill adhesion. Mud, mud with pebbles or stones, and mud with tile pieces may constitute the *bahareque* infill. To cover the wall a plaster made of lime or mud is employed. In any case the roof is made of wooden frames and clay tiles.

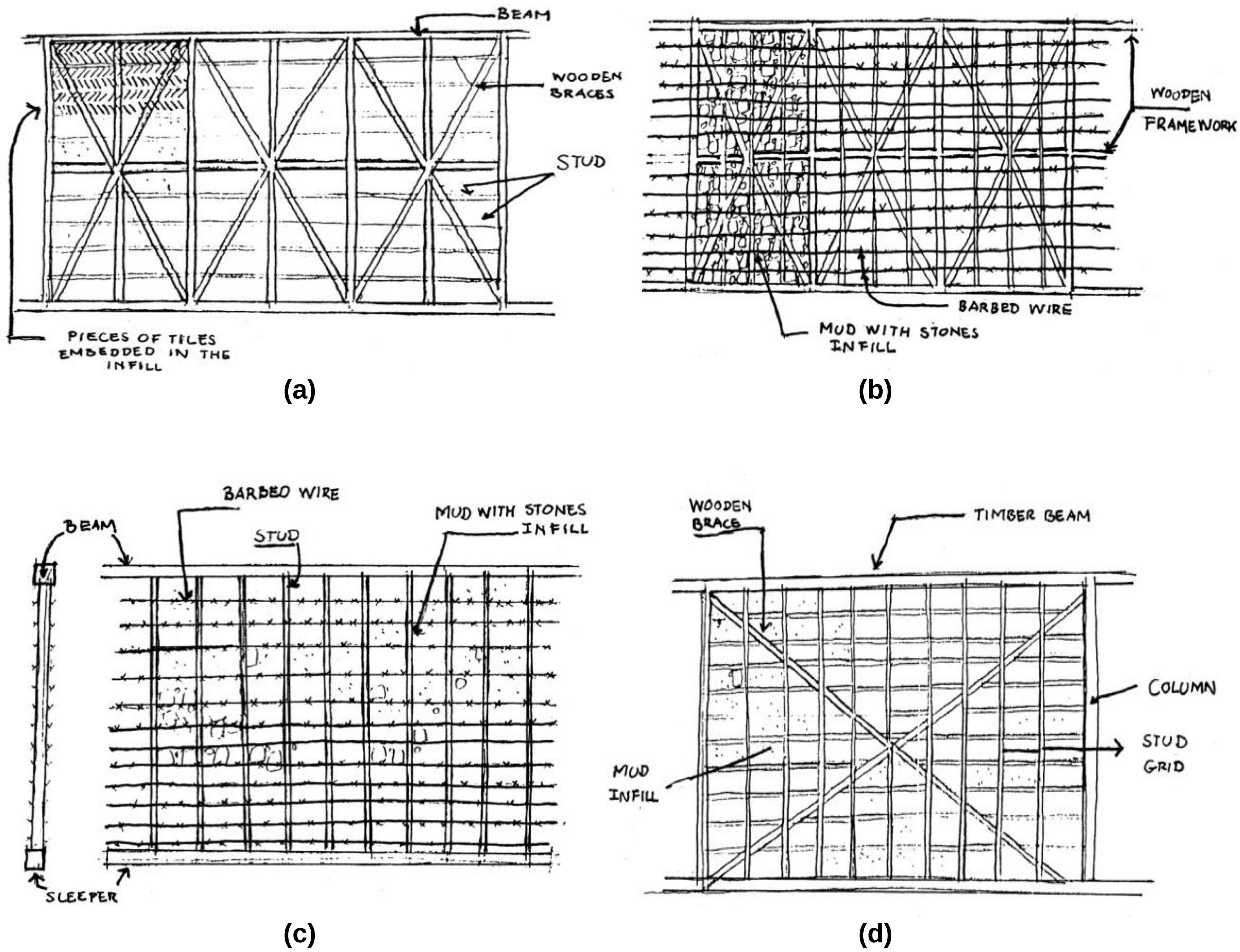


Figure 7. (a) Framework using wooden braces and studs, mud employed as infill and cover, top left. (b) Framework of wood reinforced with barbed wire, pebbles and mud uses as infill, mud cover, top right. (c) Framework made of studs reinforced with barbed wire, infill of mud and stones, mud cover, bottom left. (d) Framework made of wooden columns and stud grids, infilled and covered by mud (Moisa y Medrano [10]).

EARTHQUAKE RESISTANCE OF BAHAREQUE

Earthquake damage to *bahareque*

The central valley of El Salvador has been always subjected to earthquakes. The early Indians, centuries before the Spanish colonization, had compared the earth vibrations to the swinging of their hammocks and appropriately gave the valley a name whose Latinized equivalent is “El Valle de las Hamacas” (Levin [12]). A summary of the most important events that have taken place in the last one hundred years, and their effects on *bahareque* constructions, follows.

On 8 June 1917 an earthquake occurred west of the capital, San Salvador, which was assigned a magnitude M_S 6.7 by Ambraseys and Adams [5] and M_S 6.5 by White and Harlow [13], causing destruction in Armenia, Ateos, Quezaltepeque and other towns. The earthquake was followed by an eruption of the San Salvador volcano, which resulted in lava flows to the north (Bommer *et al*. [7]). Dwellings constructed with adobe were completely damaged. A number of *bahareque* dwellings were totally destroyed, as well; however, there were many of *bahareque* buildings which did not collapse and some others could withstand the event with minor damage [14].

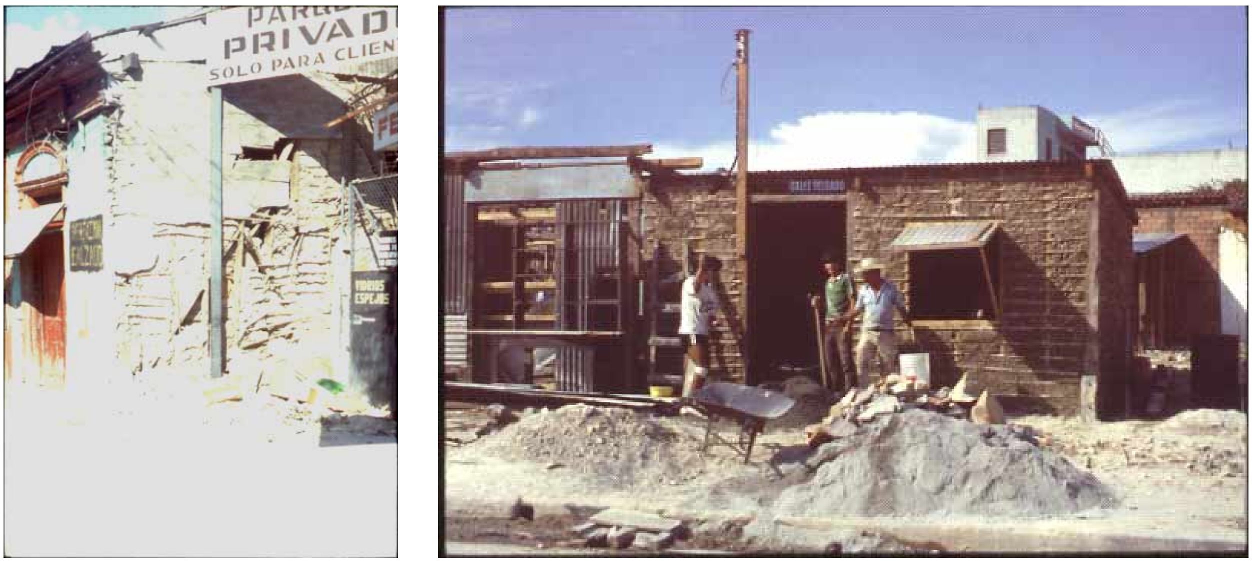
On 19 December 1936 an earthquake of M_S 6.1 caused very heavy damage to the town of San Vicente (Bommer *et al*. [7]), 40 km east of San Salvador. Levin [12] conducted a detailed reconnaissance of the affected area. He reported that most of the adobe houses suffered collapse or deformation of two walls and the cracking of the other two; poorly constructed or weak *bahareque* houses collapsed; but, well-constructed *bahareque* houses in general were unaffected except for falling plaster and deformation of the tile roof. Furthermore, Levin states that *bahareque* construction, if well built, is seismically resistant to a remarkable degree. In addition, the causes of its failure are not inherent to *bahareque* and can be attributed to one or more of three remediable factors: (1) lack of structural unity, due to faulty tying of horizontal members to the upright members, especially at corners; (2) failure to set the uprights deeply and firmly into the ground; and (3) excessive weight of a tile roof.

In May 1951, three earthquakes that occurred over two days caused extensive damage to villages in a small area of eastern El Salvador (Ambraseys *et al*. [15]). The most affected towns were San Buenaventura, Nueva Guadalupe, Jucuapa and Chinameca. At the time of the earthquake sequence, Chinameca and Jucuapa were respectively the fifteenth and nineteenth largest towns in El Salvador. The second census of population, carried out at 1950, denotes that the rural population, in the municipalities in Jucuapa and Chinameca, was 56% and 63% of the totals respectively. The first national housing census, which was performed at the same time as that of the population census, indicates that in Chinameca and Nueva Guadalupe 47% and 60% respectively of the houses were built from *bahareque*. In addition, in both previously mentioned towns, the most widely used roofing material was clay tiles, accounting for more than 97% of the housing. Ambraseys *et al*. [15] state that very few buildings in the most heavily affected area survived. The few *adobe* and *bahareque* houses that did withstand the shocks had been built within two or three years prior to the earthquake. Additionally, these authors further expressed that *adobe* and *bahareque* deteriorate very rapidly due to the climatic effects and the action of insects and their vulnerability is very much a function of their age.

On 3 May 1965, San Salvador was hit by an earthquake (M_s 5.9) which caused 127 deaths. The epicenter was located about 10 km east of the city and its focal depth was believed to be around 8 km. Rosenblueth & Prince [11] made an extensive survey of the effects of this event on different building systems. Regarding *bahareque* they reported that it is frequent that after 10 or 15 years, the wood in this type of constructions is already damaged by insects and parasites to such an extent that it powdered even with a gentle touch. Dwellings that possessed cured wood did not show this behavior but the percentage of *bahareque* housing using this treated wood was very low. It is stated that the majority of the low-class dwellings and an appreciable quantity of the middle-class housing were built totally or partially using *bahareque*. They were puzzled by the low percentage of *bahareque* housing that was damaged by the earthquake that had taken place earlier in the century. They reasoned that might have happened because those dwellings were recently built, just prior to the 1919 event, because these dwellings were built just after the 1917 earthquake and areas with unstable subsoil conditions had not yet been used. In summary these researchers stated that *bahareque* system performed badly when the following three factors were present: decayed timber, loose sand present as the subsoil, and high intensities due to near source effects.

An earthquake on 19 June 1982, M_W 7.3, offshore from western El Salvador, did cause widespread damage in the southwest of the country, mainly in *adobe* and *bahareque* houses, and triggered many landslides. The failure of *baharaque* was due to the construction age, low quantities of timber used in the construction of the dwellings and that the wood was damage by insects or decayed (Alvarez [16]).

Another earthquake severely damage San Salvador on 10 October 1986. This M_W 5.7 event left more than 1500 dead and 10,000 injured (Durkin [17]). As in previous earthquakes affecting the capital city, this one had a very superficial focal depth (approx. 8 km) and was located just below the metropolis. It is reported that the new *bahareque* construction held up well, on the average, under the ground shaking (Anderson [18]). However, failure of this building system was extensive in the southern sector of San Salvador. Again, it is stated that the failure of this system was often due to failure to structural timber caused by rot or damage by insects. Figure 8a shows a typical bahareque failure where the bamboo was in very bad shape. Once this reinforcement fails the mud-filled wooden lattice breaks down. It is interesting to note that as in the aftermath of some other past events, dwellings are rebuilt by using the same building practice (Figure 8b).



(a) (b)

Figure 8. (a) *Bahareque* house damage in the 1986 San Salvador earthquake, (b) *Bahareque* house rebuilt following the 1986 earthquake in San Salvador.

The first two seismic events affecting El Salvador in the new millennium were on 13 January and 13 February 2001. The first one was a subduction earthquake with a magnitude M_W 7.7. The death toll was reported as 844 (Bommer *et al*. [7]). The second earthquake was an upper-crustal event, and took place along the volcanic chain, with a magnitude M_W 6.6; the number of casualties was 315. In both events the overwhelming majority of the damaged houses were *adobe* and *bahareque*, with the former being the most susceptible type of housing. The damage to *bahareque* ranged from plaster falling (Figure 9a), to complete collapse (Figure 9b). Again, it has to be pointed out that the condition of the structural wood in *bahareque* and the weight of the roof were important factors in the seismic behavior of *bahareque* dwellings [19].

(a) **(b)**

Figure 9. (a) Superficial damage to *bahareque* in Santiago de Maria caused by the 13 January 2001 earthquake, (b) Collapse of *bahareque* dwelling in San Agustín due to the 13 January 2001 earthquake.

Figure 10. Damage to *bahareque* in San Vicente caused by the 13 February 2001 earthquake

Following the 2001 earthquakes in El Salvador, it has been observed that there is an almost generalized resistance to re-building dwellings in either *adobe* or *bahareque*, since both systems were seen to perform poorly, which has led to mistrust in these systems. The preference for re-building has been the *mixto* system, wherever funds have been available, but this form of construction has been beyond the reach of most of those made homeless by the two earthquakes. Large numbers of those made homeless by the earthquakes have chosen to re-build using *lámina*, corrugated zinc sheeting over a simple wooden frame, despite the intolerable heat generated in such dwellings in El Salvador's tropical climate. This situation is exacerbated by professionals who have made sweeping recommendations regarding *adobe* and *bahareque*: Salazar & Seo [20] suggest that "*an attempt should be made to propose simple guidelines to improve their performance during earthquakes*". However, they then go on to state that "*it would be desirable to prohibit these types of constructions*", a simplistic and unrealistic attitude reminiscent of the various proposals made to ban the use of *taquezal* in Nicaragua following the 1972 Managua earthquake (EERI [21]).

There are, in fact, a number of initiatives to promote more earthquake-resistant *adobe* construction in El Salvador (e.g. Equipo Maíz [22], Dowling [23]) but no parallel program for *bahareque*. Even the 1994 seismic design code of El Salvador includes an annex of guidelines for adobe construction but does not mention *bahareque* building practice at all (López *et al.* [24]). Following the 1936 earthquake in San Vicente, Levin [12] made a similar observation that many were concerned with promoting improvements to the construction of adobe but little attention was given to promoting the construction of safer *bahareque*. In part this lack of attention to *bahareque* may reflect the fact that it is an inherently more resistant system than *adobe*, but the suggestion that the use of *bahareque* be outlawed is to dismiss the wisdom accumulated over many generations by the population of El Salvador in developing a system that is well adapted to providing earthquake resistance in addition to being suitable for the climatic conditions. To group *adobe* and *bahareque* together is perhaps the first mistake: although both systems sustained considerable damage in the 2001 earthquakes, well maintained *bahareque* consistently performed much better than any *adobe* construction. The fact that the drawbacks that *bahareque* presents are easily corrected, and that once they are rectified this type of construction becomes almost ideal from the point of view of resistance to earthquake-induced stresses, would be expected to generate interest in research in developing a more seismically-resistant and durable *bahareque*. There are other factors that favor work on improving *adobe* construction, including the fact that it is a cheaper system than *bahareque*, but some of the improvements that have been proposed for *adobe* are not cheap. It is difficult not to conclude that cultural attitudes are playing a negative role here, with the wisdom and adaptability of the affected population being undervalued and ignored. The fact is that *bahareque* is the result of the local population, affected again and again by destructive earthquakes, gradually improving *adobe* construction, and arguably they have been more successful than the many imported ideas regarding strengthening and reinforcement of *adobe,* although the value of the latter is not to be dismissed either.

Seismic strengthening of bahareque

Bahareque, a traditional construction system in El Salvador, is a practice that has lasted centuries without substantial changes. It is cheap, easy to build and does not need highly trained workmanship. This type of construction, if firmly rooted in the ground and adequately tied together, possesses structural unity as well as great elasticity, and is seismically resistant to a remarkable degree. Nevertheless, *bahareque* has failed to win the complete confidence of the people because, while the proportion of damage suffered by it has been low, the actual number of *bahareque* buildings ruined has sometimes been considerable, as in 2001 earthquakes. The failure of *bahareque* to provide adequate resistance and protection duirng earthquakes in El Salvador has been caused by a number of technical factors related both to the construction of these dwellings and to lack of maintenance. Some corrective measures to avoid the damage in that constructive system and prolong its useful life are the following:

- The timber to be used must be treated to protect it from insect and mouse attacks. Pig soap (*jabón de cuche*) or petrol can be used for this purpose.

- Provide maintenance to the damaged areas; it is desirable that this process is carried out in the dry season.

- The foundation timber, which must be firmly grounded in the soil, should be treated with lime mortar to protect it against moisture and insects.

- The soil that is used must contain sand and clay. Sand will give strength and clay will work as bonding agent.

- The foundation beam, made of stones or blocks bonded by mortar, must have at least a height of 0.30 m above the ground, on top of which the wooden frame must be placed. The foundation beam is needed to protect the timber from the ground moisture.

- The spacing of the bamboo or wooden grid must be less than 0.15 m.

- The infill paste should contained vegetable fibers to increase the strength.

- The usage of barbed wire on the *bahareque* grid gives more adherence to the infill paste.

- It is ideal that the plaster cover be made of lime to protect the walls from humidity and to provide a neat finish.

The only problem still to be solved concerns the roof. The tiled roof, so characteristic of Spanish architecture, is a major shortcoming for the seismic performance of *bahareque* dwellings. An ideal roof material would be palm fronds below which some kind of plastic fabric can be placed to work as a waterproof material. However, it will be unlikely that people in cities, at least, would give up the tiles for palm fronds for aesthetic and other reasons. Another solution would be to use fiber-cement sheets as roof cover; although it is not the optimum answer, these sheets have much lower weight that their tile counterparts.

ACKNOWLEDGMENTS

The authors wish to express gratitude to Israel Vladimir Escobar, Edgar Peña, Alfredo Gavidia y Mauricio Valencia who helped by sending information to write this paper. We are also very grateful to Dominic Dowling for providing information from the forthcoming EERI publications on earthquake-resistant adobe in El Salvador.

REFERENCES

1. Dewey JW, Suárez G. “Seismostectonics of Middle America.” Slemmons DB, et al., Editors. Neotectonics of North America. Geological Society of America Decade Map, Vol. 1, GSA, 1991, p. 309-321.
2. Espinoza AF. “The Guatemala earthquake of February 4, 1976: a preliminary report.” US Geological Survey Professional Paper, 1002.
3. Sutch Osiesky, P. “Estimated intensities and probable tectonic sources of historic (pre-1898) Honduran earthquakes.” Bulletin of the Seismological Society of America 1981; 71: 865-881.
4. White RA. “Tectonic implications of upper-crustal seismicity in Central America.” Slemmons DB et al., Editors. Neotectonics of North America. Geological Society of America Decade Map, Vol. 1, GSA, 1991, p. 323-338.
5. Ambraseys NN, Adams RD. “The seismicity of Central America: A descriptive catalogue 1898-1995.” London: Imperial College Press, 2001.
6. Bommer JJ, McQueen C, Salazar W, Scott S, Woo G. “A case study of the spatial distribution of seismic hazard (El Salvador).”Natural Hazards 1998; 18:145-166.
7. Bommer JJ, Benito MB, Ciudad-Real M, Lemoine A, López-Menjivar MA, Madariaga R, Mankelow J, Méndez de Hasbun P, Murphy W, Nieto-Lovo M, Rodríguez-Pineda CE, Rosa H. “The El Salvador earthquakes of January and February 2001: context, characteristics and implications for the seismic risk.” Soil Dynamics and Earthquake Engineering 2002; 22: 389-418.
8. Harlow DH, White RA, Rymer MJ, Alvarez SG. “The San Salvador earthquake of 10 October 1986 and its historical context.” Bulletin of the Seismological Society of America 1993; 83: 1143-1154.

9. Dowling DM. “Lessons learned over time: Adobe housing reconstruction after the 2001 El Salvador earthquakes” (In Press). Learning from earthquakes series, Earthquake Engineering Research Institute 2004: V.
10. Moisa-Perez LC, Medrano-Lizama CC. “Sistemas constructivos tradicionales en la arquitectura de El Salvador (Thesis).” Universidad Albert Einstein, El Salvador, 1993.
11. Rosenblueth E, Prince J. “El temblor de San Salvador, 3 de Mayo de 1965; Ingeniería Sísmica.” Ingeniería 1966; México DF: UNAM; 36: 31-58.
12. Levin SB. “The Salvador earthquakes of December, 1936”. Bulletin of the Seismological Society of America 1940; 30: 377-407.
13. White RA, Harlow DH. “Destructive upper-crustal earthquakes of Central America since 1900.” Bulletin of the Seismological Society of America 1993; 83:1115-1142.
14. Barba Jacob P. “El terremoto de San Salvador.” San Salvador: Dirección de Publicaciones e Impresos, 1997.
15. Ambraseys NN, Bommer JJ, Buforn E, Udías A. “The earthquake sequence of May 1951 at Jucuapa, El Salvador.” Journal of Seismology 2001; 5: 23-29.
16. Alvarez S de J. “Informe técnico sobre aspectos sismológicos del terremoto en El Salvador, 19 de Junio de 1982”. San Salvador, El Salvador: Centro de Investigaciones Geotécnicas, Ministerio de Obras Públicas; 1982.
17. Durkin ME. “The San Salvador earthquake of October 10, 1986-Architecture and Urban Planning.” Earthquake Spectra 1987; 3(3): 609-620.
18. Anderson RW. “The San Salvador earthquake of October 10, 1986-Review of Building Damage.” Earthquake Spectra 1987; 3(3): 497-541.
19. López-Menjivar MA, Andrade-Cruz RA, Escobar-Flores CA, Flores-Alvarado AV, Nieto-Lovo MA. “Reporte de los eventos sísmicos ocurridos el primer trimestre de 2001 en El Salvador”. Escuela de Ingeniería Civil, Universidad de El Salvador; 2001.
20. Salazar, W. & K. Eeo. “Earthquake disasters of 13 January and 13 February 2001, El Salvador”, Seismological Research Letters 2003; 74(4), 420-439.
21. EERI. Proceedings of the Conference on the Managua, Nicaragua, earthquake of December 23, 1972. San Francisco, 29-30 November, 2 volumes, Earthquake Engineering Research Institute. 1973.
22. Equipo Maíz. “La casa de adobe sismorresistente”, Equipo Maíz 2001., San Salvador, El Salvador, 91 pp
23. Dowling DM. “Adobe housing in El Salvador: Earthquake performance and seismic improvement”. Rose WI, Bommer JJ, López DL, Carr MJ & Major JJ, Editors. Natural Hazards in El Salvador. Geological Society of America, 2004, p. 281-300.
24. López MA, Bommer JJ, Pinho R. “Seismic hazard assessments, seismic design codes, and earthquake engineering in El Salvador.”Rose WI, Bommer JJ, López DL, Carr MJ & Major JJ, Editors. Natural Hazards in El Salvador. Geological Society of America, 2004, p. 301-320.