A REVIEW OF THE SEISMIC BEHAVIOR OF EARTHEN HOUSING IN NICARAGUA

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ABSTRACT : Earthen construction is typical in the rural areas of Nicaragua. Two types are identified: The Taquezal and the Adobe which seem promissing for low cost massive housing. However, their vulnerability to earthquakes and other environmental risk had limited their use.

The paper describes efforts to make earthen construction safer, appropriate for energy conservation and suitable for using alternate forms of energy.

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Introduction

Earthen construction is typical of low cost rural housing in Nicaragua. There are two types: Taquezal widely used in the Central and Northern part and along the Pacific Coast; and adobe used in the Northen and Central regions. Both types are vulnerable to earthquakes and other environmental risks and had suffered serious damages and even collapse under seismic loads.

Until recently, nobody seems concerned with their safety and the only regulation which appears in the Building Code prohibited their use. However, this type of housing is widespread in the rural and semiurbans areas where people have identified themselves with them.

An analysis of the economic situation of construction materials and the construction patterns shows,that earthen houses will be difficult to erradicate from the construction habits of the Nicaraguan rural people. This, and the fact that earthen houses are suitable for energy saving, have good thermical and accoustical insulation properties, makes them a very attractive low cost housing solution, if properly protected against seismic events.

This paper will review the typical earthen construction in Nicaragua, the progress made to make them safer since the 1972 earthquakes and the experimental work being done to take advantages of their design for energy saving and as receptors of alternate forms of energy.

A brief review of the existing taquezal and adobe construction follows.

Taquezal Construction

Earthen construction is the Nicaraguan answer to low cost rural housing. Their construction patterns although very diversified have changed very little, in spite of earthquakes, volcanic eruptions and other events.

Nicaragua, the largest country in Central America, has an extension of 130.000 Km.2 and about 2.6 millions inhabitants. It is bounded by the Atlantic and Pacific Ocean at the East and West respectively and by the Republics of Honduras and Costa Rica at the North and South respectively. Most of its inhabitants are Spaniard and Indian descents and were precisely the Spaniards who introduced earthen construction to the country.

Fig. 1 and Table 1 show the distribution of Earthen housing in Nicaragua. The major concentration exists in the Northen part, but the construction along the Pacific Coast, a high seismic risk zone, is also considerable. From the earthen houses listed in Table 1, it is seen that taquezal is most popular than adobe construction, in the urban and rural areas.

FIG. I TAQUEZAL AND ADOBE HOUSING IN NICARAGUA.

TABLE 1. EARTHEN HOUSING IN NICARAGUA

MAJOR CITIES	ADOBE WALLS				TAQUEZAL WALLS			
	URBAN AREA		RURAL AREA		URBAN AREAS		RURAL AREAS	
	UNITS	%	UNITS	%	UNITS	%	UNITS	%
EL PAIS	11,616	100	8308	100	15825	100	13949	100
CHINANDEGA	283	2.44	526	6.33	751	4.75	1478	10.60
LEON	2103	18.10	371	4.47	1750	11.06	1182	8.47
MANAGUA	2449	21.10	324	3.90	7677	48.51	314	2.25
MASAYA	911	7.84	60	0.72	695	4.39	61	0.44
GRANADA	1616	13.91	83	100	963	6.09	52	0.37
CARAZO	133	1.14	25	0.30	101	0.64	75	0.54
RIVAS	307	2.64	80	0.96	120	0.76	62	0.44
CHONTALES	337	2.90	430	5.18	168	1.06	396	2.84
BOACO	550	4.73	2167	26.08	243	1.54	540	3.87
MATAGALPA	814	7.01	2106	25.35	879	5.55	2080	14.91
JINOTEGA	216	1.86	339	4.08	355	2.44	521	3.74
ESTELI	175	1.51	492	5.92	675	4.27	2138	15.33
MADRIZ	313	2.69	353	4.25	879	5.55	2294	16.44
NUEVA SEGOVIA	1367	11.77	905	10.89	559	3.53	2513	18.02
RIO SAN JUAN	5	0.04	13	0.16	8	0.05	18	0.13
ZELAYA	37	0.32	34	0.41	2	0.01	225	1.61

SOURCE : NATIONAL HOUSING SURVEY, 1971.

NOTE: Earthen Housing in Managua was practically destroyed by the 1972 Earthquake. Therefore, the data presented may not be representative.

The taquezal construction is characterized by a system of earthen walls, shaped by a wood frame and sometimes reinforced by small stones,pieces of clay tiles, straw and wood. It has no resistence to shear loads and vibrations.

As an illustration and to describe the taquezal system, a typical house located in Northen Nicaragua is shown in Fig. 2.

The site where the house is located is flat, but high and dry; it receives 600 cm. of rain annually.

The house appears to have been built in one stage although, it is possible that the wood bedrooms and the store room may have been built as an addition after the rest of the house was finished and occupied for a time.

The transfer load mechanism is provided by a wood framework composed of wood posts and wood tie beams. The wood posts, four on each eave side, are buried in the ground up to about a yard and tied to the crown beams at the top. The framing is appropriated to transfers vertical loads, fairly well; however, it has no ability to take lateral loads, as is the case of the earthen walls of the taquezal system.

Walls and Foundations

Foundations are a vital part of earthen construction. Those corresponding to the house considered,are obtained by filling ditches connecting the columns by rocks (Fig. 3c). Although this is not a usual practice in earthen houses, rock foundations are a good low cost footing solution as they absorb surface waters, thus protecting the earthen walls against damage and even collapse. The construction of a poor cement concrete beam on top of this base will strengthned the wall. Other improved solutions known as "minifaldas" consist in extending the beam foundation up to 2 - 3 ft. height.

The main feature of a taquezal wall is a double face framework or mold designed to be filled by a mud like mix. The frame is obtained by buring in the ground additional poles 2 - 3 ft. apart and tying or nailing horizontal "lath" sticks or wattle to both sides of these posts.

The wattle can be sticks, bamboo, caña brava and others. Sticks of 1" x 2" of sawn lumber are a common type used.

The mud filling is obtained by mixing a clayey soil with water and adding stones or pieces of clay tiles and sometimes straw or cow manures. The practice of mixing straw, small branches, dry corn leaves and similar materials is harmful as it diminished the compressive strength of the dried earthen mix. Furthermore the organic material rotten or decomposes easily and dries out, loosing volume and propiciating further cracks.

A better earthen mix should be one of stabilized soil using the appropriate stabilizer with the local soil, to meet the minimum allowable stresses. It follows that, this type of construction will be attractive when the

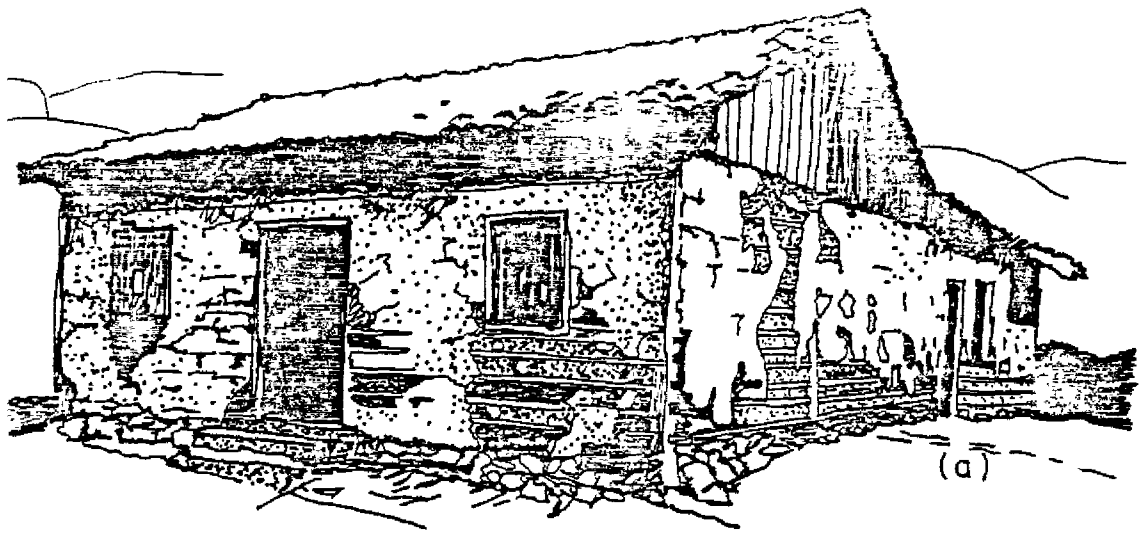
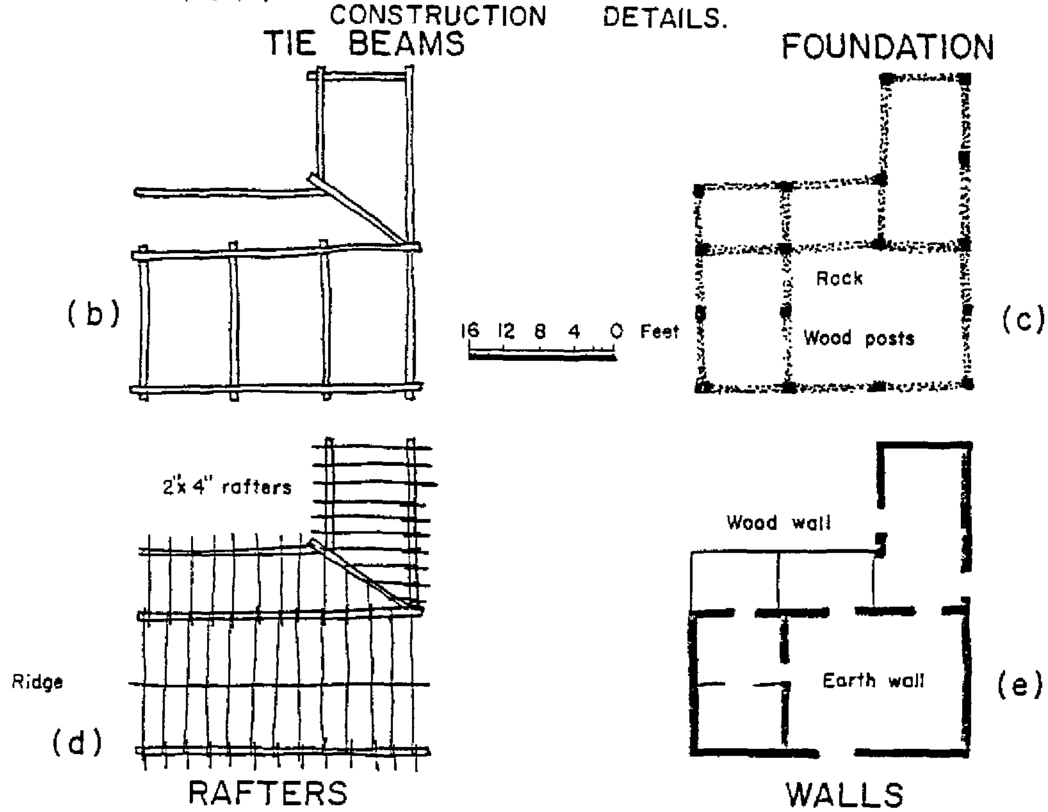


FIG. 2 (a,b,c,d,e) TAQUEZAL HOUSE AND PLAN VIEW OF CONSTRUCTION DETAILS.



appropriate soil and stabilizer are in location, or nearby. Otherwise, transportatio cost could be a decisive factor. Climate, humidity and local soil conditions are important factors to be considered.

After the filling has dried, the wall is finished with a mud plaster and painted with a mixture of spend carbide and water. Other paints used are limewater solutions. A common problme in earthen houses is the spalling off of the finish. This can be corrected with a soil-cement mix using a percentage of cement higher than that used in the walls.

Roofing

The roof framework, was constructed by assembling rafters and tie beams to the wall framework Fig. 3(b and d). The 2" x 4" rafters about 2 feet on center, are laid with the slope of the roof and the 1" x 2. purlins, on which clay "teja" tiles are laid, are nailed across the rafters, at 6" spacing.

Hand made teja tiles are about 12" long, they provide a roofing attractive and economical. However, as a heavy roof cover it increases the danger during earthquakes, specially if they are not fixed properly.

The conventional way to laid teja tiles is in rows, overlaping one another like the scales of a fish. The last row at the top is fixed to the ridge by a mortar. Figs. (3a, b) show two typical roof-details used in Nicaragua. Fig. 3(a) indicates a load bearing ridge, while Fig. (3b) shows a non-load bearing ridge rafter, where the resulting thrust will require a tie beam.

The floor of this house is packed earth. New improved floor solutions have been worked out and will be presented later.

The urban areas use more sophisticated taquezal construction, filling the double wood frame with a mix of soil, water, cement and lime and adding large stones, pieces of clay tiles and the like as filling. It was the popular type of construction in Managua, before the 1931 and 1972 earthquakes.

Both earthquakes demostrated the dangerous behavior of this construction. Most of the taquezal building collapsed burying thousands of people under the rubble. The failure was mainly caused by a weak and a rotten wood framework or a badly deteriorated by termites. Housing in Managua went from taquezal to reinforced concrete, wood, reinforced or confined masonry. Secondary cities and small towns have conventional taquezal houses of one and two stories. However, this type of construction could be improved by increasing the strength properties of the earthen mix and by establishin methods of design and construction for seismic safety.

A serious objection to the taquezal system is the heavy weight of the walls which generates high seismic forces. As a result, the walls will deform beyond the permissible limit loosing its capacility of resistence.

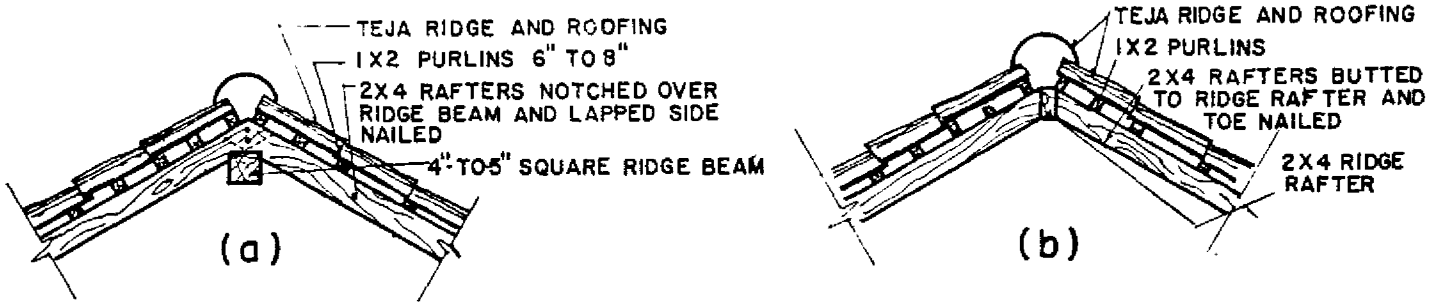


FIG. 3 (a,b) ROOF DETAILS FOUND IN EARTHEN HOUSES

As a first solution approach, one may considered the possibility of having the taquezal wall works as a shear wall. This requires an integrated wall, which is not the case under the actual methods of construction.

However, by designing a filling with different sizes of stones to minimize voids and to keep contact which each other, a network stress transmission can be created, establishing a good force resistant system.

A filling of the residual voids with soil cement mix would set the basic supporting system. To integrate the framework to this system, such that the hybrid structure behave mononilitically, the wood studs, of the frameword can be coated with a glue-cement mix, that will give a good bond with the filling. The coating will also protect the wood against termites, fire and humidity.

Another alterantive would consist in designing the framework to resist the lateral forces. In general, taquezal framework have behaved satisfactorily under seismic loads. Failures have occurred when the base of the columns have rotten or deteriorated by termites or other insects. The behavior of the frames will improve considerably if a treated column base, is fixed to a concrete foundation.

Another objection to traditional taquezal construction, has been the use of heavy weight roofs, since they generate lateral forces that can not be transmitted to the framework due to the lack of adequate connection. By designing good connections between the roof system and the framework an integral behavior of the structure can be achieved.

Adobe Housing

To review existing adobe construction, consider the house shown in Fig. 6 (a,b). The supporting frame is a 9 wood posts of 6 sq. inc. sections tied at the botton by a 6" x 4" concrete grade beam built directly over the ground. This beam is reinforced with two strands of barbed wire stretched between the columns.

A better foundation is found in some adobe houses, where trenches connecting the columns have been dug and filled with large river rocks. The grade beam is then pour on top of this base.

As before, the wood posts are embedded up to 1 yd. in the ground. To complete the wall framing, the columns are fixed to a wood beam at the top. The roof frame is then build, placing the teja tiles, sometimes before the construction of the walls.

The adobe walls are built using adobe bricks of about 3" x 5" x 10" giving a wall thickness of 5 inches. The bricks are laid within the wood frames with thick mortar joints of about 1 inch until the height of doors and windows is reaches. A second concrete beam reinforced by barbed wire to withstand stress concentrations is placed at the height of doors and windows. The wall is completed withthe last row placed under the tie beam. If any gap is left, it is filled out with a mortar.

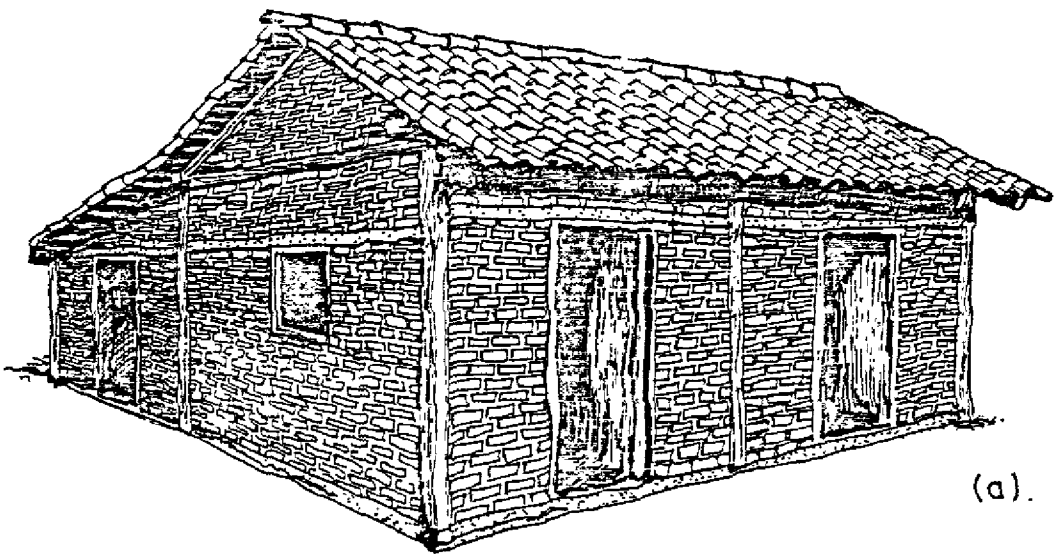
Other details of the house are similar to the previously described. A combination of taquezal and adobe walls is also used in the rural areas of Nicaragua.

The taquezal and adobe housing shown, are inadequate to resist lateral loads such as those from earthquakes or winds being taquezal the most critical.

In order to improve the performance of earthen construction during a seismic event, work is being carried out on various aspects of earthen materials and their technology for construction.

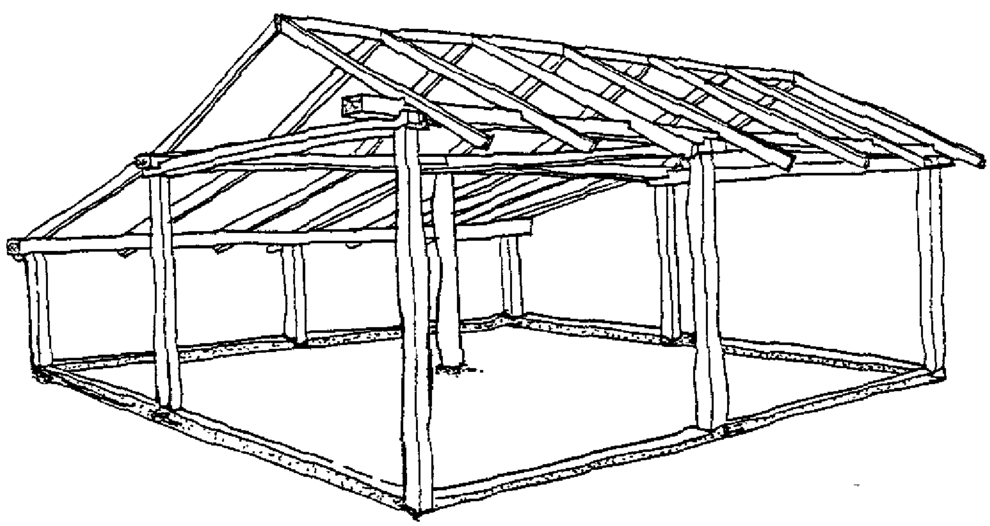
Materials: Adobe

This material, generally understood as a mix of soil and water subjected to a natural process of drying, has been in use for several centuries around the world. Although the behavior of adobe is complex, technical specifications can be established for its rational use in construction. Adobe in Nicaragua is characterized for its row material disponibility, low cost, easy fabrication and construction, good thermical and accoustical properties and a resistance to termites and fire. It sounds like an ideal material, however, it has serious disadvantages such as poor behavior under weathering conditions, low compressive strength and noticeable cracking due to high soil contraction.



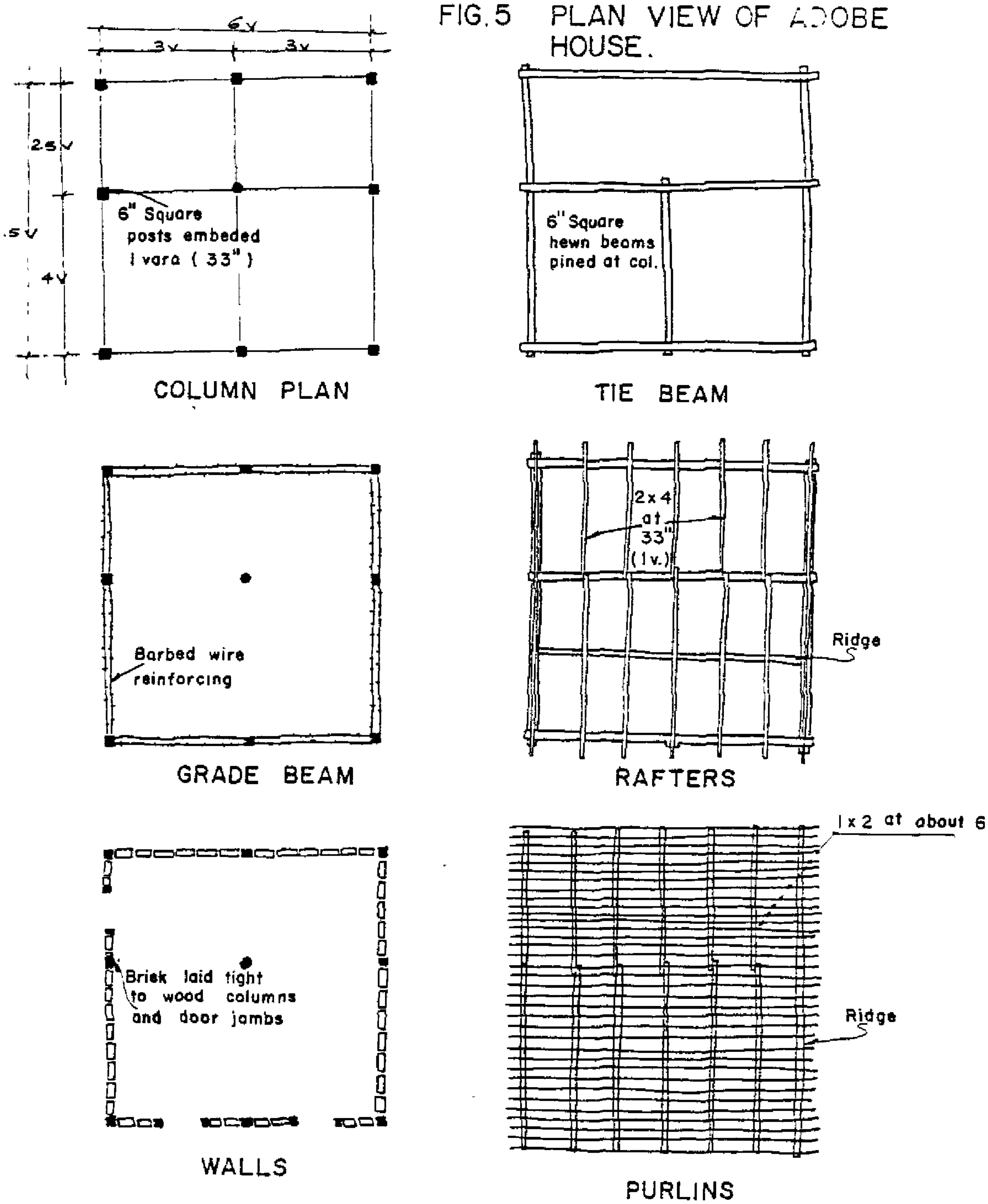
(a).

FIG. 4. (a, b) ADOBE MASONRY HOUSE AND FRAMING SYSTEM.



(b)

FIG. 5 PLAN VIEW OF ADOBE HOUSE.



The conventional process of making adobe, consists in selecting the appropriate soil, mix it with water and let the mix sits for a day. The mix is then poured into wood molds, where it will dry in the natural environment. for about three weeks. However, the 24 hours sitting of the mix is not necessary as it have been proven elsewhere that during this time, no organic decomposition can take place.

In some places, straw, grass and others are added to the mix, but this is not a good practice as it diminished the resistant properties of adobe. Furthermore, the inclusion of organic materials will increase the tendency of adobe to crack.

A first study, intended to optimize the stabilization of adobe in Nicaragua, was carried out by using clayey soils and stabilizers which can be found or produced locally, such as Portland Cement, Puzzolana, Lime and others. The results can be described briefly as following:

a) The combination of Lime & Puzzolana as a stabilizer is a good economical solution for the appropriate soil, if puzzolana natural deposits are nearby. Otherwise, the costs my be prohibited since the cost of obtaining the required fine puzzolana, must be included. Natural puzzolanas of volcanic origin are found in Nicaragua in the form of pumice.

   The workable time for adobe stabilized with lime and puzzolana may be extended up to 2 1/2 hours.

b) For the samples of soils studied and considering several factors, such as weathering performance, cost, impermeability and mechanical properties, it was concluded that a 5% of cement as stabilizer and the combination of 15% lime and 15% of puzzolana were the optimum for such soils.

c) Weathering test were carried in stabilized and non-stabilized soils. A cube of 2" x 2" x 2" of non-stabilized soil lasted only 4 minutes in static water, while one stabilized with 5% of cement may be desintegrated in 3 years.

d) For the soils considered the compressive strength of stabilized adobe using lime and puzzolana showed higher values.

e) Tests for measuring the tensile strength were also performed on stabilized and non-stabilized adobe samples of 2" x 2" x 2". The tests indicated results about 8% of the corresponding compressive strength.

The above work was mainly oriented toward the chemical properties of the stabilization process.

As a first study in Nicaragua is invaluable, but due to the severe limitations at that time, the results obtained should be examined very carefully.

Further work is needed along these lines. Since extensive work on the stabilization of soils, has been done elsewhere, it was decided to use soils stabilization to Nicaraguan soils.

Adobe Stabilized with Cement

To further the previous work and to enhance the practical applications for construction, a program for stabilized adobe with cement, oriented toward housing was carried thoroughly.

The objective of the program is to technify the use of adobe, its physical-mechanical properties, the methods of fabrication and construction for low cost housing, safe and adequate for the different regions of the country.

The program started with the study of the physical properties of soils in the vecinity of prospective housing projects. Samples from the Departments of Managua, Rivas, Nueva Segovia, Leon, Chontales and others were obtained, keeping in mind that the best soils for the stabilization of adobe bricks with cement, are those with a 75% of sandy material and a 10 - 15% of clay. Table 2 lists the physical properties of the soils.

Bricks can be fabricated by hand or by machine. The first type is the traditional one, using wooden modls. The fabrication by machine implies the use of the CINVA-RAM.

As one of the objectives of the program, is the study of adobe masonry construction, a series of static tests to determine the mechanical properties of small assemblazes was carried out.

Compressive Strength Tests for Adobe Bricks

The size of bricks considered is 30 x 15 x 10 cms., with the following properties; fine texture, weight of 5.5 Kgs., compressive strength of 60 Kg/cm2, and 31% of absorption in 24 hours.

The ultimate compressive strength was obtained by testing the units after 28 days of fabrication and have them submitted to a process of 7 days of curing.

Several mix proportions of soil-cement varying from 8:1, 17:1 were tried. However, the ration 10:1, was the optimum with regard cost and structural behavior.

The results show that the mechanical properties of bricks fabricated by machine, are higher than those made by hand.

TABLE 2.- PHYSICAL PROPERTIES OF STUDIED SOILS

LOCATION PROJECT	BORING No.	DEPTH Mts.	LIQUID L. (5)	PLASTIC L. (%)	PLASTICITY INDEX (%)	MAX. UNIT WEIGHT (Kg/m^3)	OPTIMUM MOISTURE CONTENT (%)	CLASSIFICATION	
								U.S.C.S.	H.R.B.
José I. Gómez, Managua.	1	1.0	47	40	7	--	--	M.L.	A-5
José I. Gómez, Managua.	2	1.5	37	33	4	--	--	S.M.	A-2-4
Ingenio Benjamin Zeledón, Rivas.	1	--	--	--	-	1300	36.2	O.H.	A-7-5
" "	2	--	--	--	-	1284	28	O.L.	A-6
" "	3	--	N.P.	N.P.	N.P.	1670	19.2	S.M.	A-2-4
Nueva Segovia, Totogalpa (yellow)	1	--	27	15	12	--	--	S.C.	A-2-6
" (red)	2	--	28	13	15	--	--	G.C.	A-2-6
San Juan del Río Coco.	1	--	28	18	10	--	--	S.C.	A-2-4
Sto. Tomás, Chontales.	1	--	45	14	31	--	--	O.L.	A-7-5

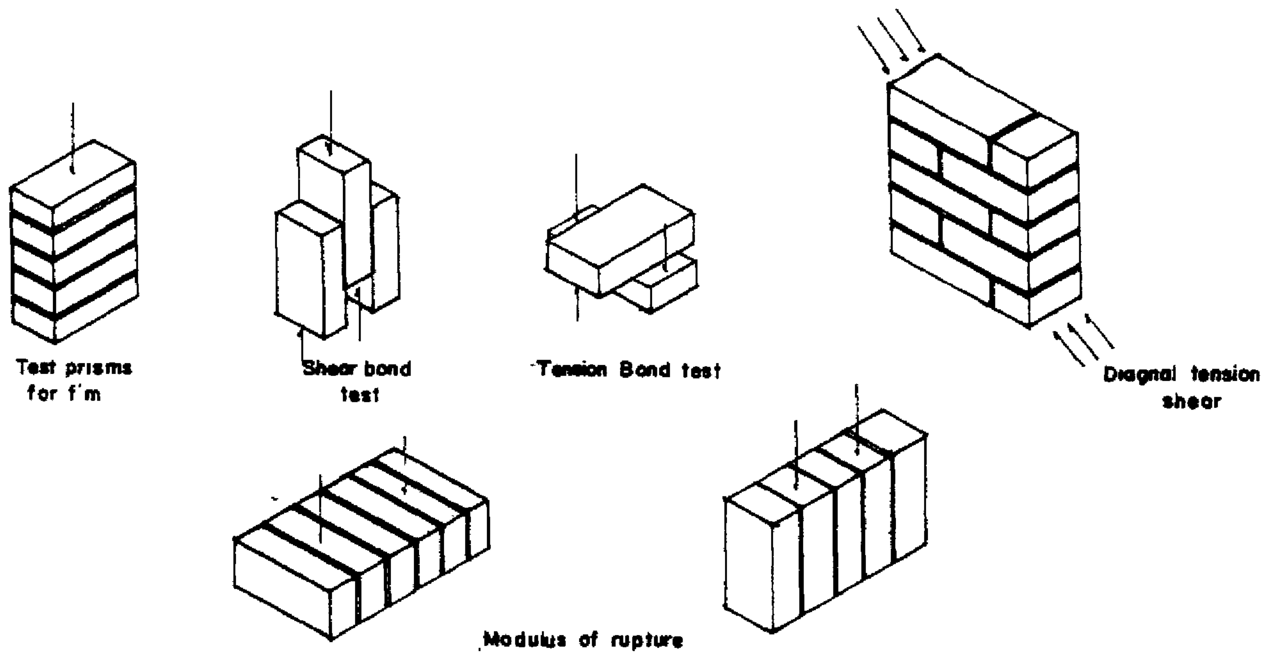


FIG-6 LABORATORY SPECIMENS IN MECHANICAL PROPERTIES TESTING

The average compressive strength for hand made bricks was 29 Kg/cm2. while the machine made was 60 Kg/cm2.

Tables 3 and 4 show the results of the compressive strength tests in hand and machine made adobe bricks stabilized with cement.

Flexure Tests

As it can be seen in Fig. 6, the arrangement used for the flexure tests, would give bending stresses normal to the joint. The maximum span length considered was 18" and the soil-cement mortar joint used a 10:1 mix proportion. The average bending stress, was found to be of 2.95 Kg/cm2.

Bonding Tests

The tests to develop the maximum bonding stresses were designed, considering the texture and thickness of the units, the flowing and mix proportion of the mortar and the absortion of the assemblage. The tests were carried on machine made adobe bricks and the assemblages used can be seen in Fig.6

TABLE 3.- BRICKS COMPRESSION STRENGHT

Hand made

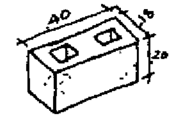
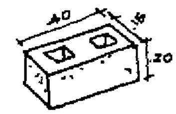
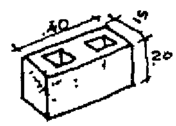
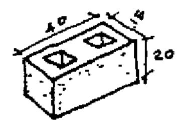
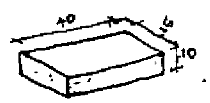
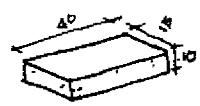
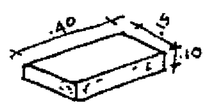
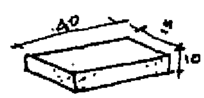
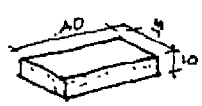
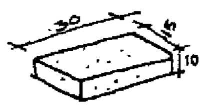
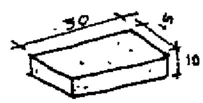
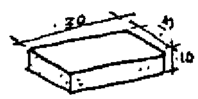
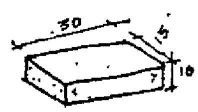
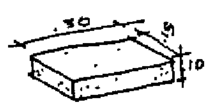
SOIL CEMENT PROPORTION	GEOMETRY IN CMS.	COMPRESSION STRESS Kg/cm^2	NOTATIONS
8:1		8.0	Soil from Rivas (A-6)
8:1		23.01	Soil from Rivas (A-7-5)
10:1		15.06	Soil from Rivas (A-6)
14:1		3.75	Soil from Rivas (A-6)
17:1		30.7	Soil from Rivas (A-2-4)
10:1		30.41	Soil from Ocotal (A-2-6)
17:1		20.42	Soil from Ocotal (A-2-6)
10:1		32.88	Soil from Totogalpa (A-2-6)
12:1		28.8	Totogalpa
12:1		28.6	San Juan del Río Coco (A-2-4)
12:1		27.3	San Juan del Río Coco

TABLE 4.- <u>BRICKS COMPRESSION STRENGHT</u>

Machine manufactured

SOIL:CEMENT PROPORTION	GEOMETRY IN CMS.	COMPRESSION STRENGHT Kg/cm^2	NOTATIONS
10:1		55.46	Soil from Dolores, Rivas (A-2-4)
12:1		56.84	Soil from Dolores, Rivas (A-2-4)
10:1		17.67	Soil from Chinandega, Paredones (A-7-5)
13:1		61.19	Soil from José Isaías Gómez (A-2-4)
10:1		76.7	Soil from San Pedro de Lóvago, Chontales

(a) PRISMS COMPRESSION STRENGTH

ADOBE BRICK STABILIZED WITH CEMENT	f_e Kg/cm^2	PROPORTION OF MORTAR	f_b Kg/cm^2	f'm Kg/cm^2	$f'm/f_e$
José I.Gómez	61	1:10	16	19.26	0.31
" "	61	1:10	16	25.4	0.41
" "	61	1:10	16	23.3	0.38

(b) SHEAR BONDING TESTS

SOIL CEMENT BRICK	MORTAR	f_b Kg/cm^2	STRESS Kg/cm^2
José I. Gómez	8:1	16	1.47
" "	10:1	16	2.06

(c) TENSION BONDING

SOIL CEMENT BRICK	MORTAR	f_b Kg/cm^2	STRESS Kg/cm^2
José I. Gómez	8:1	16	3.31
Sn. Pedro de Lóvago (Chontales)	10:1	16	1.01

(d) DIAGONAL TENSION SHEAR

SOIL CEMENT BRICK	MORTAR	h/l	f'm Kg/cm^2	V_c Kg/cm^2	$\sqrt{f'm}$
José I. Gómez	1:10	1.0	19.26	2.69	0.61
" "	1:10	0.67	19.26	2.97	0.67

TABLE 5

A summary of the results of the experimental program, follows:

a) The average compressive stress of machine and man made adobe bricks stabilized with cement were respectively, 60 Kg/cm2. and 20 Kg/cm2.

b) The average f'm found, using a mortar joint of 10:1 proportion and machine made bricks was 22.65 Kg/cm2.

c) The average shear bond stresses found, without considering confined normal stresses was 2 Kg/cm2, while the average tension bond stress obtained was 1.5 Kg/cm2.

d) The diagonal tension mode of failure was verified, by cracks crossing the brick and mortar simultaneously. The average diagonal tension shear stress was found to be 2,8 Kg/cm2.

e) The average bending stress normal to the joint was 2.95 Kg/cm2.

To complement the above experimental study, dinamic tests should be performed.

Adobe Construction for Cooling Passive Solar System

An experimental work is underway using adobe construction for cooling passive solar systems, in tropical areas.

A 2.8 mt. x 3.5 mt. model was built, using poured in place cement stabilized adobe bricks of 7.2" x 11" x 32". The structural system and roofing details are shown in Fig. 7.

Wind valves were localized at the botton and top of the walls facing wind currents. The combination of earthen material thermal insulation properties, convenction currentes inside the model and the inverted roof system, force the inside temperature to be lower than outside.

The results seems promissing for cooling low cost housing.

Seismic Zoning for Adobe Housing

To improve the safety of adobe construction against seismic events, a study was carried out to find the maximum dimension values to be used in adobe housing according to the seismic zones established by the Nicaraguan Building Code. The results appear in the form of recommended values, shown in Fig. 8.

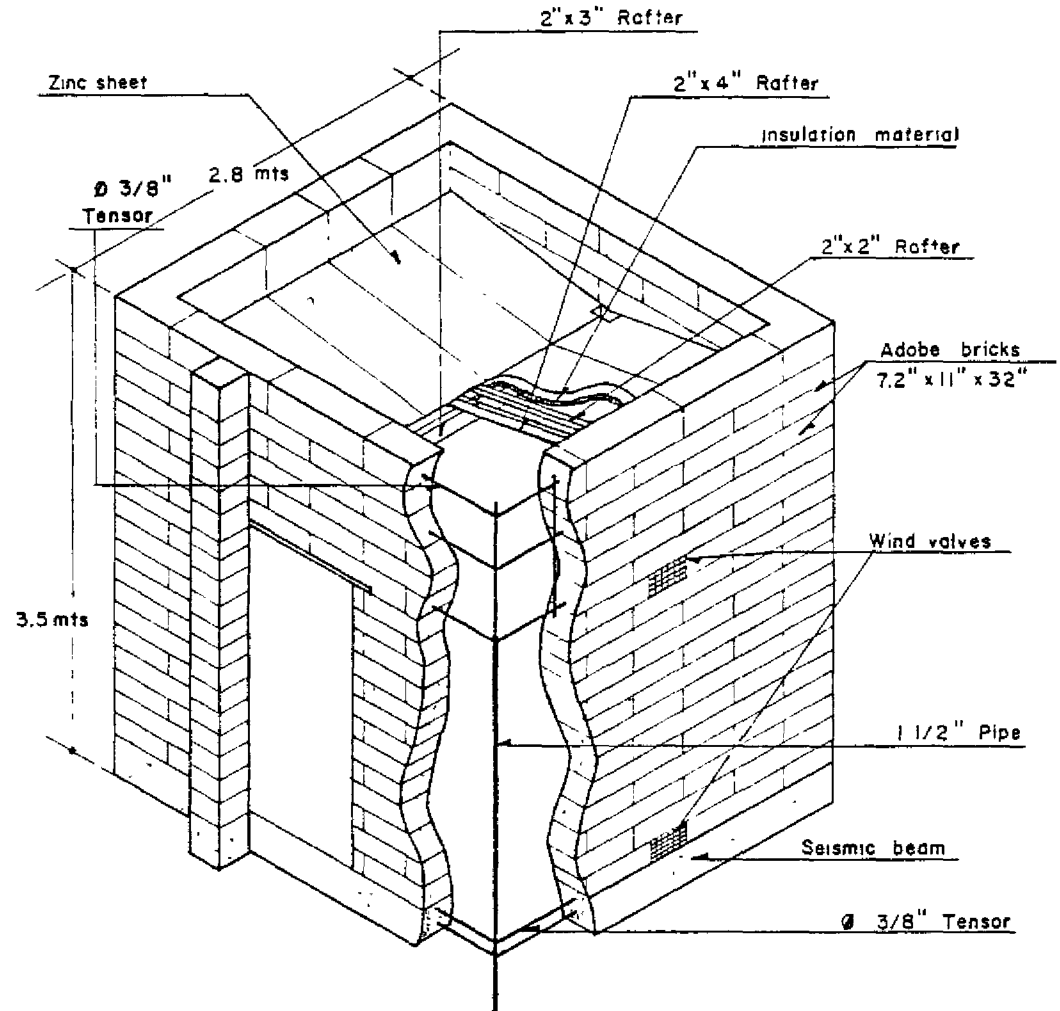


FIG. 7.
ADOBE CONSTRUCTION IN A COOLING PASSIVE SOLAR EXPERIMENTAL MODEL.

Maximum values of l and h for stabilized adobe housing

Seismic zone	Wall thickness	Max. length	Max height
Zone 1 Zelaya northen Jinotega	t= 0 15 t= 0 20 t= 0 30	6.21m (5 45m) 7 18 m. 8.79m.	4.78 m (296m) 5 51 m. (3 95m) 6.75m. (5.92m)
Zone 2 Central region	t= 0 15 t= 0.20 t= 0.30	4 46 m. 5.15 m 6 31 m.	3.43m (296m) 3.95 m 4 84 m
Zone 3 Chinandega, Rivas and others	t= 0.15 t= 0 20 t= 0 30	3 20m. 3 70 m. 4.53	2.46 m 2.84 m 3 48 m
Zone 4 Leon, Jinotepe and Granada	t= 0.15 t= 0.20 t= 0.30	2 91 m 3.36 m 4 12 m.	2.24 m. 2 58 m 3.16 m
Zone 5 Masaya and others areas of the pacific	t= 0.15 t= 0 20 t= 0 30	2.83 m 3.26 m 4.00 m	2.17 m. 2.51 m 3.07 m
Zone 6 Managua	t= 0 15 t= 0 20 t= 0.30	2.48 m 2.86 m. 3.51 m	1.91 m 2.20 m. 2 69 m.

Effects of wind on l and h for the Atlantic coast and for the central region are shown in parenthesis

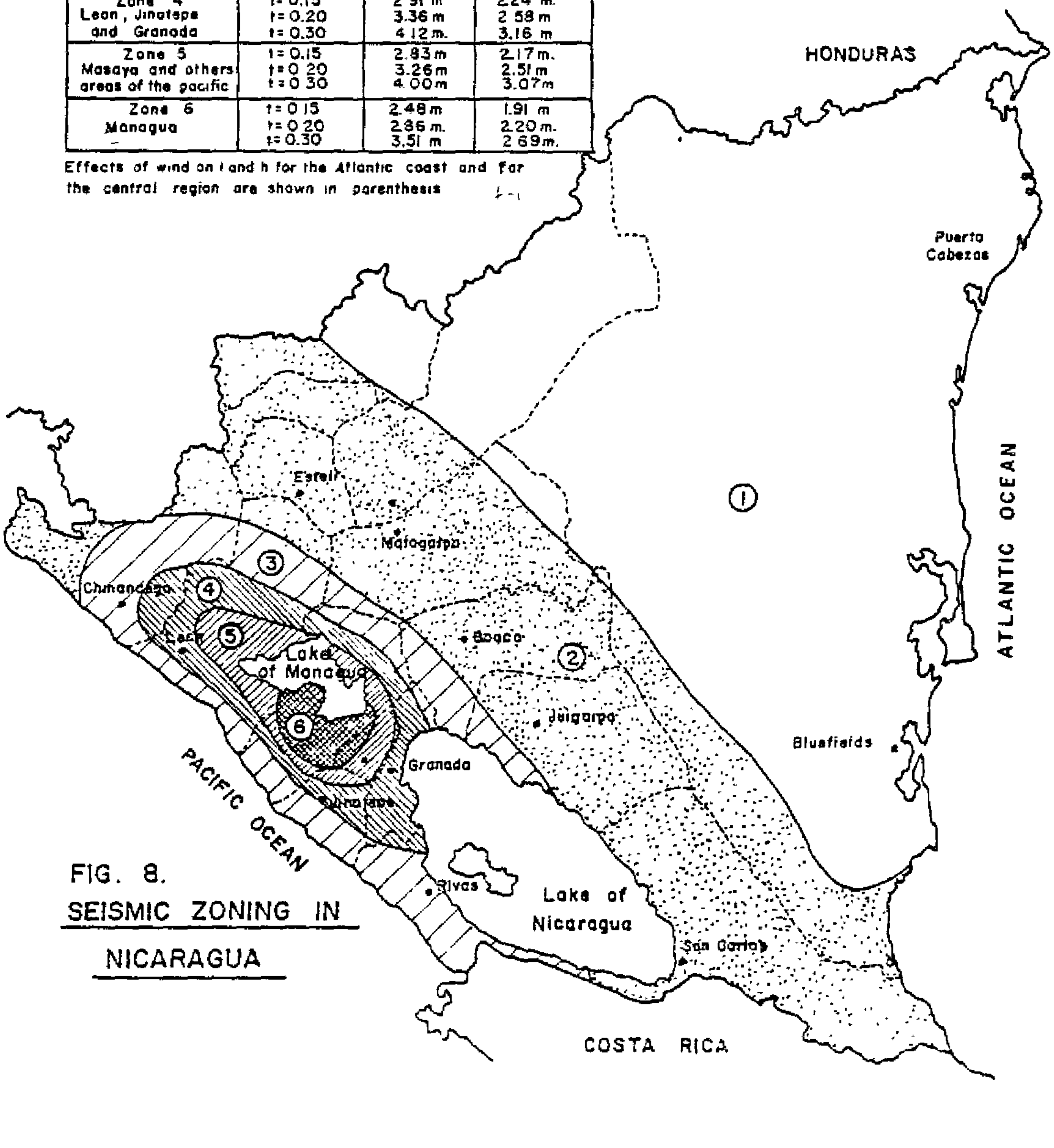


FIG. 8.
SEISMIC ZONING IN NICARAGUA

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