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Earthquake Injuries Related to Housing in a Guatemalan Village

Aseismic construction techniques may diminish the toll of deaths and serious injuries.

Roger I. Glass, Juan J. Urrutia, Simon Sibony, Harry Smith, Bertha Garcia, Luis Rizzo

In the last decade, three major and many lesser earthquakes along the Pacific Coast of Central and South America have claimed approximately 100,000 lives and left an even greater number injured. Since the majority of these deaths and injuries are caused by the collapse of man-made structures, many changes in construction have been advocated to diminish the health consequences of earthquakes. Even in the simplest environment, the application of the principles of aseismic construction in fact might reduce the loss of property and life substantially.

The earthquake of 4 February 1976 devastated a large area of Guatemala leaving 22,778 dead and 76,504 injured (*1*) (Fig. 1). In the aftermath of this disaster, an opportunity arose for us to study the patterns of death and serious injury in the village of Santa Maria Cauque and to relate them to the different types of construction employed in the town. In particular, we wanted to determine which types of building materials and which designs of houses currently in use were most effective in preventing major trauma. We also thought that this might help to substantiate the health consequences of aseismic building practices.

For 15 years, Santa Maria Cauque has been the focus of many longitudinal epidemiological studies of the Institute of Nutrition for Central America and Panama (INCAP) (*2*). The village, located in the highlands 30 miles west of Guatemala City, had a population of 1577 Indians of Maya-Cakchiquel extraction for whom Spanish is a second language. The villagers farm and raise chickens and for the most part live in one-room shelters made of adobe brick or cornstalk, roofed with thatch, tile, or corrugated tin. The health center with its physician and team of nurses and aides is accepted by the Indian community and was available for the collection of the data in this article.

The earthquake, which registered as 7.5 on the Richter scale, occurred at 3:05 in the morning, when all the villagers were asleep. It lasted 39 seconds, and this prevented anyone from leaving his home or seeking safer refuge under furni-

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ture, in corners, or near door jambs. When it was over, all of the buildings of the town were destroyed except those four made of reinforced concrete—the health clinic, the town hall, the school, and a single home. Seventy-eight people, or 5 percent of the population, were killed and many more were injured. The clinic began functioning immediately, and additional supplies arrived within 5 days. Within 2 weeks, clinic personnel undertook epidemiologic surveillance of infectious diseases and investigated individual responses to the earthquake and desires regarding future housing.

In this article we begin by examining the age, sex, and birth order trends of earthquake-related deaths and serious injury in the village of Santa Maria Cauque. As in other natural disasters, the risk of serious or fatal injury was found to be greatest to the young and the elderly. We then present a "best house–worst house" prediction model, which we developed by surveying all the households in the village and relating the type of construction materials and design with the extent of injury of the occupants ("between house" survey). The "worst houses" proved to be the old structures made of adobe brick and crowded with more than seven people. The "best houses" were the nonadobe structures. The type of roof, size and number of rooms, and the number of doors and windows did not seem to matter. In the second of the two surveys we made, representatives of each of 58 households in which there was a death or a serious injury were interviewed to determine why some individuals sleeping under the same roof survived unharmed whereas others were seriously or fatally injured ("within-house" survey). In both surveys we tried to ask questions relevant to current low-cost building practices in order to discover which of the practices might be altered to diminish the risk of future injury in this region of continuing earthquake activity.

Table 1. Birth order of children dying from earthquake-related injury. The families included at least three children.

Birth order	Deaths (%)*	Survivors (%)*
First	6 (20)	24 (80)
Penultimate	14 (47)	16 (53)
Last	8 (27)	22 (73)

*Departure from linear $\chi_1^2 = 5.08$ ($P < .05$).

Survey of Death and Serious Injury

Within 48 hours of the earthquake, certificates of death for 78 villagers had been registered at the town hall. An abbreviated census taken of the entire town 2 weeks later confirmed this total. Age- and sex-specific death rates were calculated based on detailed census data from January 1976 (Fig. 2). The age-specific mortality rates were high for the young and the old, but low for those of middle age. Further inspection of the data suggested that infants under 1 year of age had lower mortality rates than their older siblings. This led us to examine the mortality of children as related to their birth order as it had been recorded in the census (Table 1). The risk of death to the youngest child (the last born) was lower than to his next older sibling. The risk of death ($P < .05$), was greatest to the penultimate child, and this risk decreased thereafter with increasing age, with the risk to the oldest child (the first born) being the least. It later became clear that the youngest child usually slept with the mother and was thus somewhat protected. In traditional societies the risk of malnutrition, infectious diseases, and childhood death is greatest to the penultimate child and it seems that the risk of death from earthquake-related trauma may be greatest to him as well.

The seriously injured were defined as those patients whose injuries required hospitalization or outpatient care with an extended follow-up of more than 2 weeks and included major fractures (30), severe contusion (4), and open wounds (4). These data were recorded in the health clinic and represent a selection of the most serious cases cared for by the medical staff. Notable among these injuries

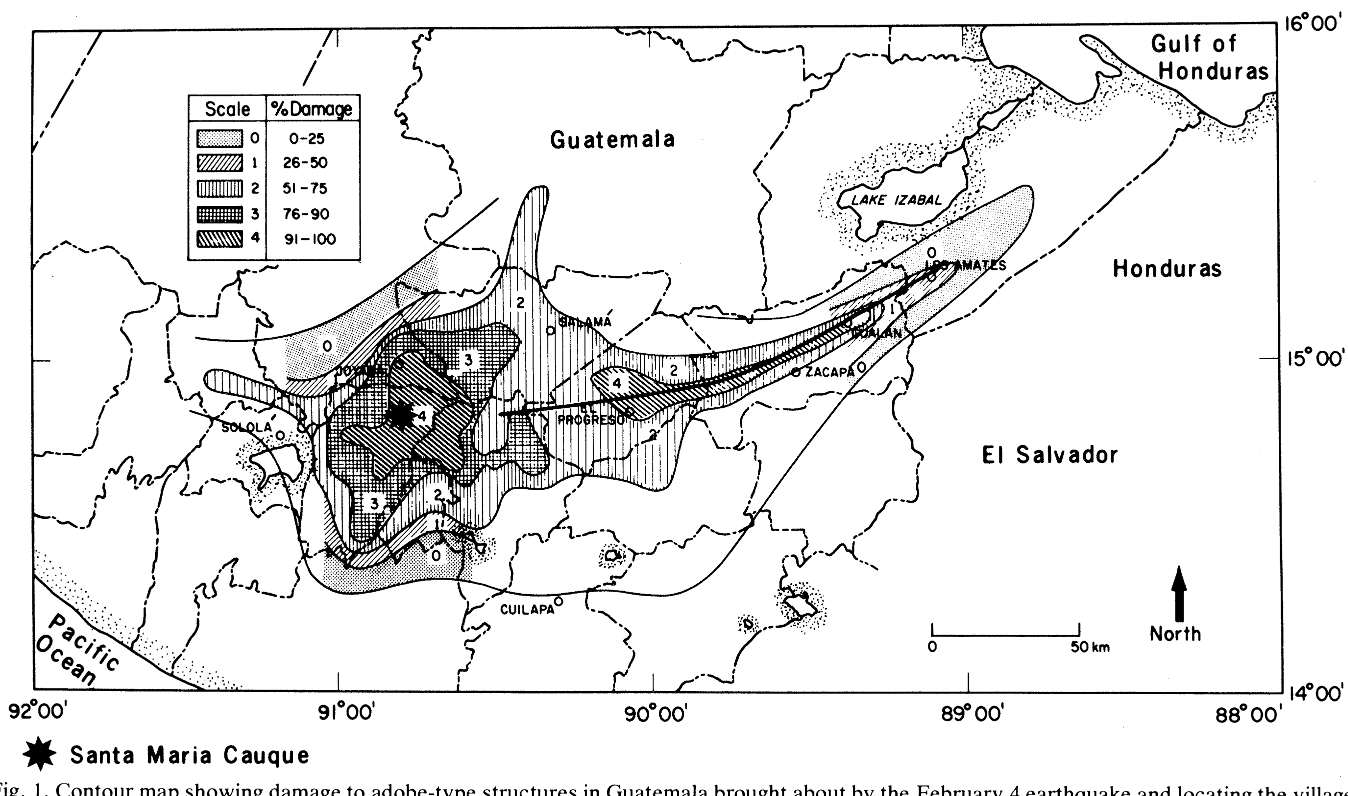

Fig. 1. Contour map showing damage to adobe-type structures in Guatemala brought about by the February 4 earthquake and locating the village of Santa Maria Cauque. [Courtesy of A. F. Espinosa (8)]

were five fractures of the pelvis and two fractures of the spine with cord injury. The age-specific rates of serious injuries increased continuously with age (Fig. 2). Few persons below 20 years of age were seriously injured, and the risk of injury was consistently greater to women than to men for almost all age groups. This pattern is similar to the distribution of hip fractures in the United States, which occur preferentially in elderly and postmenopausal women because of their weakened osteoporotic bones.

The patterns of death and serious injury observed in the study indicate that the risk of earthquake-related trauma is greatest to the young and the elderly; hardy adults survive. This same trend was observed in two other Guatemalan villages surveyed after this earthquake and in the Managua earthquake of 1972 (Fig. 3). It is also similar to the pattern of death noted by Sommer in the East Bengal cyclone of 1970 (3). The physical stamina associated with adults may be the most important factor in surviving life-threatening natural disaster.

Table 2. Distribution and relative risk of major injury (serious or fatal) by type and age of house and family size.

Item	Major injury: Present	Major injury: Absent	Relative risk of major injury*	P	χ_1^2
Type of house					
Adobe	60	161		< .001	
Nonadobe	0	36			
Age of house†					
Old (8+ years)	45	100	1.6	< .07	3.21
New (0 to 7 years)	15	61			
Family size†					
Large (7+ persons)	35	37	2.9	< .001	24.9
Small (1 to 6 persons)	25	124			

*Ratio of rate per subgroup 1 to rate per subgroup 2. †Adobe houses only (N = 221).

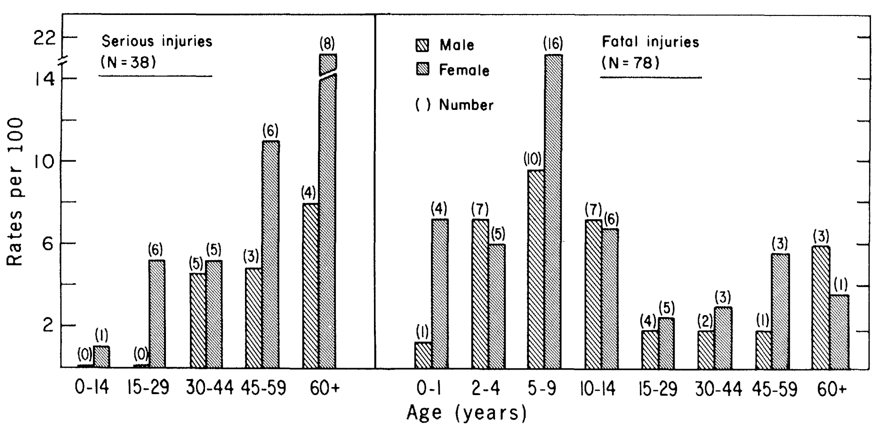

Fig. 2. Age-specific rates for earthquake-related trauma.

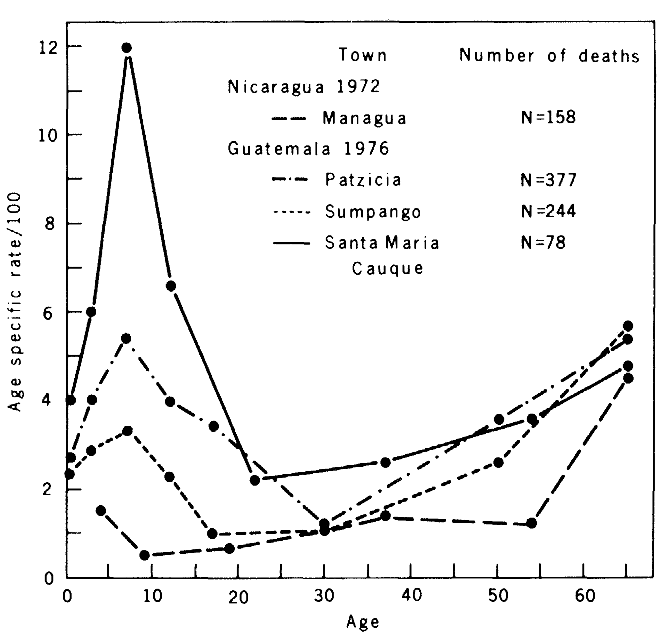

Fig. 3. A comparison of age-specific mortality rates in four Central American towns from two different earthquakes.

Housing Factors Related to Trauma: The "Between House" Survey

Why did the collapse of some houses result in greater physical injury than the collapse of others? A team of five nurses and health workers queried 259 of the 277 heads of household to determine the number of people at home on the night of the earthquake and the type of construction of the destroyed house. The topics of the questionnaire included the size of the house, the type of walls and roof, the number of rooms, doors, windows, and the age of the house or the year of its last major renovation. In addition, a coded index of social class derived in 1974 that was available for 198 of the 258 families was added to the data (4). These data were then assigned, on the basis of the presence or absence of a major (serious or fatal) injury, to two groups.

All of the deaths and serious injuries occurred in adobe homes (Table 2). The heavy adobe blocks, held together by a weak mud mortar, separated easily under the force of the earth tremors. While all but one of the nonadobe houses in the town also collapsed, none of these caused major trauma. The principal nonadobe house was made with lightweight cornstalk walls supported on a wooden frame, a structure that is theoretically aseismic. While the walls did collapse, the frame and the roof either remained intact or only partially collapsed.

Since 85 percent of the houses in the town were made of adobe, we analyzed all other variables bearing on the adobe houses alone (N = 221) (5). The age of the adobe was the only other variable found to be even marginally significant (P < .10), with adobe homes more than 7 years old having a 1.6-fold increase in the relative risk of major injury compared to newer adobe homes. This effect of age of adobe may or may not be a chance association. Age tends to dry out the bricks and make them brittle. Methods of adding oil to the adobe have been suggested but never applied in this area. Alternatively, adobe made long ago might have contained different mixtures of sand and clay. Too much sand would make the adobe more brittle with age and more dangerous. Since no analysis of the bricks was performed, we are unable to argue for either of these hypotheses.

Other housing variables were investigated, namely, number of rooms, size of house, number of doorways and windows, and type of roof. None of these was significantly correlated with the extent of injury. Engineers believe that large rooms are structurally more hazardous than small rooms because the walls have less reinforcement from corners or cross braces. We constructed an index of room size (square meters per room) to test this hypothesis and found that in adobe houses, where room size varied from 4 to 64 meters square, room size was not associated with the extent of injury. The socioeconomic index was found to be uncorrelated with severity of injury. However, it was found to be correlated with the size of the house, confirming it as a valid indicator of socioeconomic status.

The ability of a small house either to withstand a quake or to fall slowly without injuring its occupants has been studied by different groups of engineers and has led to several concepts in aseismic design (6). Houses with a rigid frame and light walls, such as the wood-frame and cornstalk houses in this study, withstand a quake well because the frames remain erect even though the lightweight walls may collapse. Adobe houses in this village were made without internal reinforcements, solid frames, or support cables, all of which have been advocated to make adobe walls aseismic. While it is generally believed that long, narrow rooms gain stability when subdivided into smaller rooms, our reinforcement index (square meters per room) was unable to substantiate this belief. Likewise, neither the number of doors in the house nor the number of windows, both of which should weaken the adobe wall in the face of an earthquake wave, was found to be correlated with the mortality experience in this community. These observations suggest that old adobe is overwhelmingly unstable in an earthquake of this magnitude and that neither wall reinforcements, doors, windows, nor room size or roof type significantly altered this result. The risk of major injury (relative odds, 2.9 to 1) was greater to a household with a large family because more potential victims were present. Nonetheless, this risk was greater than the increase to be expected because more people were available to be injured. Individuals in families with more than seven people had twice the risk of suffering a major injury as members of smaller families (Table 3). This is consistent with our initial observation that those people making up the large families, the children and the elderly, have the highest rates of earthquake trauma. Adults might survive the trauma of a 60-pound adobe brick falling 6 feet; the children and the elderly did not. Examination of the joint effect of family size and age of adobe demonstrated these to be independent variables.

Table 3. Trauma rates and family size.

Family size (No.)	Serious injury or death in families*			
	Present		Absent	
	No.	Percent	No.	Percent
2 to 6	34	6	594	94
7+	71	11	577	89

*$P < .001$; $\chi_1^2 = 12.25$.

Table 4. Protective effects of reinforced structures. In calculating the χ^2, we have ignored the nonindependence between the fates of different individuals in the same house, and the appropriate P value may therefore be slightly less extreme than those indicated. N.S., not significant.

Sleeping area	Protection	Fate: Survival	Fate: Death	P^* (χ_1^2)
In corners	Yes	95	17	N.S.
	No	197	41	(.11)
Near door	Yes	122	34	N.S.
	No	142	24	(2.46)

The "Within House" Survey

In the households where there was a death or serious injury, what factors influenced the different fates of individuals living under the same roof? Fifty-eight heads of households in which there were major injuries were interviewed by three nurses selected for their sensitivity and experience in relating to the community. By means of the interview the nurses attempted to establish (i) the floor plan of the houses at the time of the quake; (ii) the places where everyone was sleeping; (iii) the direction in which the walls fell; (iv) the reason why some were saved and others injured; and, if possible, (v) the cause of death or injury. Because of the emotional nature of the material required, six houses were chosen to determine whether the study method was valid. The interviewers found that the community members talked freely about what had occurred and that the interview did not uncomfortably infringe upon the privacy of the villagers. The information gathered was recorded on a questionnaire that contained a previously drawn floor plan of the house with ample space to record the diversity of responses and was tabulated by hand in response to the different hypotheses in question.

Age and birth order. The low mortality rates for children less than 1 year of age and the protected position of the youngest child in the family was consistent with the hypothesis that the youngest child slept with the mother and shared her fate, while the penultimate child slept apart from the mother. The survey revealed this to be the case. In families of three children or more, 29 of 30 youngest children and only 11 of 30 penultimate children were sleeping with their mothers ($P < .005$). In all families, the youngest child generally shared the fate of his mother, with both surviving (28) or dying (5), versus the mother dying alone (1) or the child dying alone (1) ($P < .005$, Fisher's test).

In ten homes, there occurred a death of a child sleeping in the same bed with two or more of his siblings and no adult. Again the risk was greatest (80 percent) to the youngest child in bed (who was never the youngest child in the family), followed by that to the middle child (45 percent), and then to the oldest (20 percent) ($P < .05$). With the exception of the youngest child, death in children was a function of age alone, with the risk of death from trauma greater to the smaller children than to their older siblings.

Structural considerations. Doorjambs and corners are generally considered to be the most structurally reinforced areas in the home and should confer some measure of protection in periods of tremor. This was not true in these adobe homes. We found no significant difference in mortality rates between people who slept in corners and people who slept along unsupported walls of adobe structures, nor between people who slept next to the door and those who slept at a distance from the door (Table 4).

Material causing trauma. Eighty-two percent of the families of people who suffered major injuries attributed the trauma to adobe blocks alone. Nine percent claimed that injury was related to the beams supporting the roof, and 9 percent felt that it was related to a combination of both adobe blocks and beams. Roofing materials were not mentioned, a finding that was consistent with the previous survey.

Possible interventions. Two speculative interventions that might diminish earthquake mortality were tested and found to be of little consequence. (i) If a fault is known to be active, will any wall in the house be more or less likely to collapse and inflict injury? Although 68 percent of the walls lying in an east-west direction in Santa Maria Cauque did fall predominantly to the north ($N = 170$, $P < .0001$) toward Chimaltenango, the local epicenter, we observed no difference in mortality rates between villagers sleeping in beds located against these walls and those in beds against walls located perpendicular to these. Moreover, the intricate pattern of lesser faults as shown on the geological maps of Guatemala and the inability to predict the exact site of the epicenter make an accurate determination of future quakes quite difficult to predict. (ii) Could an organized rescue system have altered the mortality experience in the community? Six people who died in the quake remained communicative until dawn, 3 hours after the initial event. The darkness of night and the distance between houses delayed their early rescue. At best an early and completely effective rescue effort might have saved only 7 percent of those who died.

Discussion

Earthquakes have periodically been a major determinant of mortality and injury along the Pacific Coast of Central and South America. This well-delineated area coincides with the interface of major tectonic plates whose activity will continue to menace the individuals living in this area. The extent to which future earthquakes will continue to cause death will depend on our developing techniques for building low-cost aseismic housing (*7*) and upon our ability to encourage changes in construction among peoples of widely different cultures and beliefs.

The experience of Santa Maria Cauque teaches us several lessons. First, all of the deaths and serious injuries were associated with housing. In every case, the collapse of an adobe structure was involved, and either the adobe or the beams that it supported were identified as the instruments of trauma. No other factors related to the earthquake, such as landslides, epidemics, exposure to cold, or loss of food supplies, accounted for a single death in this community at the time of the earthquake or in the following 8-week period of the study. The inability of adobe homes to withstand earthquake forces has been recognized in previous earthquakes in Central and South America. In fact, the Mercalli scale of earthquake intensity is based in part on the degree of damage that occurs in buildings of different integrity of construction. For example, in Fig. 1, the line delineating an area with greater than 50 percent damage to adobe structures roughly coincides with the border between zones with Mercalli readings of 6 and 7 (*8*). The relation between death and injury in earthquakes of different intensity and in areas with different building styles must become a focus for further study if trauma related to earthquakes is to be minimized (*9*).

Second, the observation that nonadobe houses caused no major injury indicates that alternative and relatively safe forms of housing already exist in this community and are within the construction abilities of these people. It is interesting to note that adobe is a relatively new construction material in the village. In 1924, there was no adobe in Santa Marie Cauque, and all of the houses were built of cornstalk, mud-covered slats (or *bajareque*) and similar materials attached to a simple wood frame. Elders in the community recall that in the earthquake of 1918 there were no deaths and few injuries from these houses, even though every structure in the village was destroyed. In 1925, the first adobe house was introduced, modeled after the houses built by the Spaniards in Guatemala City. It was recognized that the Spanish city dwellers had suffered many deaths in the earthquake of 1918 from adobe brick, but to the Indians, an adobe home represented the status and prestige associated with the Spanish culture. Adobe bricks were cheap and easy to make, offered protection to the occupants from extremes of temperature, and were more permanent and finished than cornstalk or *bajareque*, which had to be changed periodically. By 1963, 50 percent of all the houses in Santa Maria Cauque were made of adobe, and by 1971, this had increased to 85 percent. In just 40 years the risk of earthquake-related trauma to the village had gone from minimal to maximum. One wonders what impact a housing code prohibiting the construction of adobe houses promulgated following the 1918 disaster might have had on the heavy death toll from the recent quake.

The earthquake has greatly altered peoples' housing preferences and permitted the introduction of nontraditional building ideas (*10*). In 1971 a study of housing preference indicated adobe to be the preferred type of home construction. Two weeks after the earthquake, a repeat poll of housing preference in Santa Maria Cauque revealed that only 1 percent of the people surveyed wanted to live in an adobe structure, the rest preferring cornstalk, wooden boards, or concrete block. The international relief effort introduced wooden lean-tos with tin roofs into the village. Within 2 months, the village was rebuilt in imported, and hence expensive, aseismic style. In some ways, this might be compared to vaccinating a population after the major epidemic had passed.

Following the recent earthquakes in Peru, Nicaragua, and Chile, architects and engineers directed their attention toward the development of low-cost aseismic housing built of materials used traditionally in this area of the world. Adobe was identified as a material that fared poorly under the stress of an earthquake. Changes in the geometry, mass distribution, and stiffness properties of the adobe walls were suggested to counteract the lateral forces of an earthquake. Methods of reinforcing adobe structures with wooden wall frames, internal cables, cross supports along freestanding walls, smaller door and window openings, all have been recommended as well as the use of adobe to a maximum height of 1 meter. Houses designed with light walls, such as cornstalk walls, reinforced with a rigid frame, are more resilient and earthquake-proof than unreinforced load-bearing wall structures such as adobe. Other suggestions for building new aseismic homes from traditional materials and altering standing structures abound. They remain to be disseminated, and their value in preventing mortality remains to be tested. The present study was able to show that adobe construction without these innovations was quite traumatic; that new adobe was a better building material perhaps because of increased moisture or different mixtures of sand and clay and that minor structural supports (smaller rooms, reinforced corners, doors, for instance) in fact provided no measurable protection in an adobe home.

Improved earthquake prediction and the early warning offered by preliminary tremors have been helpful in decreasing earthquake mortality (*11*). The reported evacuation of a number of Chinese cities based on correct seismic prediction has been credited with saving many lives. Other unpredicted quakes in China have left many dead, underscoring the imperfect science of prediction. Preliminary tremors before the Managua earthquake of 1972 probably saved many people who chose to camp for months in tents outside their homes (*12*). Similar tremors prior to the Guatemala earthquake of 1918 led rich families to build wooden shacks (*tembleros*) in their courtyards in which they would sleep and seek protection when the tremors increased (*13*). Such preliminary tremors provide great motivation to begin preventive relief work by reinforcing homes, removing high objects and heavy overhangs, or moving to more aseismic alternate shelters. Neither prediction nor premonitory tremor occurred in Guatemala. The first wave of the earthquake was the strongest and most damaging.

If earthquake injury is to be diminished in the future, efforts will have to be directed toward the prevention of trauma caused by man-made structures. The major health consequences of earthquakes in Latin America consist not of the epidemics or famines that are overpopularized and relatively unimportant, but of the trauma that occurs within moments of the major quake. Good rapid epidemiological diagnosis of community problems elsewhere after a natural disaster would be useful in confirming this finding and in redirecting relief toward the more useful and more enduring development of aseismic housing. Also useful would be the recognition of the concept of prevention of earthquake-related mortality by government officials and by planners in public health and in urban and rural development. The enactment and enforcement of improved building codes and the education of the population in simple techniques of aseismic construction will have to become a first priority. Included in any code should be severe limitations on the use of adobe in this area as a housing material. This must be accompanied by further research in aseismic engineering, earthquake prediction, community education, and the epidemiology of disaster injury and its prevention.

References and Notes

1. Official estimates of deaths and injuries as recorded in the *Diario de Centro America (Guatemala City, Guatemala)* (24 February 1976), p. 6.
2. A complete review of the work of INCAP in Santa Maria Cauque will be forthcoming [L. J. Mata, *The Children of Cauque* (MIT Press, Cambridge, Mass., in press)].
3. For age-specific mortality rates from Nicaragua, see *Encuesta sobre algunos efectos demograficos y de salud del terremoto de Managua* (Ministerio de Salud Publica, Managua, Nicaragua, 1974); from Guatemala, see C. V. de Goyet and E. Jeanée, *Soc. Occup. Med.* **4**, 212 (1976); and from East Bengal, see A. Sommer and W. H. Mosley, *Lancet* **1972-I**, 1029 (1972).
4. This index developed by L. J. Mata is based on 12 indicators of material possession and levels of education of the family.
5. For a discussion of the properties of adobe brick and the construction of an adobe home, see E. H. Boudreau, *Making the Adobe Brick* (Fifth Street Press, Berkeley, Calif., 1971), pp. 13–21; *Earth for Homes* (Department of Housing and Urban Development, Washington, D.C., June 1970); L. W. Neubauer, *Metodos de construccion con adobe* (Univ. of California Press, Davis; distributed by AID, 1974).
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11. The controversy over the ability to predict earthquakes is discussed in F. Press, *Sci. Am.* **232** (No. 5), 14 (1975); G. F. White, Ed., *Natural Hazards* (Oxford Univ. Press, Oxford, 1974), pp. 274–283; W. Sullivan, *New York Times Magazine* (25 April 1975), pp. 37–58; D. Shapley, *Science* **193**, 656 (1976).
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14. We thank B. Mejia, N. Solomons, J. Faigenblum, P. Dardon, O. de Maldonado, E. de Tobar, C. Monzon, I. Perez, E. de Juarez, G. Linares (INCAP), K. Deuschle, G. Keusch, T. C. Chalmers (Mt. Sinai Medical Center, New York), B. Stoll, and R. Peto.

NEWS AND COMMENT

Auburn Dam: Earthquake Hazards Imperil $1-Billion Project

Since the collapse of the Teton Dam in Idaho in June 1976, the Bureau of Reclamation, builder of the Teton project, has been undergoing a time of trial. Its competence and credibility have been called into question, and two of its high officials have resigned under pressure. Furthermore, the bureau's troubles are by no means over yet. Now, its huge $1-billion Auburn Dam and reservoir project in California, on which more than $150 million already have been spent, may have to be abandoned because of earthquake hazards and a questionable choice of dam site and design.

The Auburn Dam would be built adjacent to the city of Auburn on the North Fork of the American River in the western foothills of the northern Sierra Nevada Mountains. Nearly 700 feet high and 4150 feet long, this thin arch, double curvature structure (curving gently from bottom to top as well as from side to side) would be the largest concrete dam of its kind in the world.

If the dam should suddenly collapse as the result of an earthquake—possibly one induced by the immense water pressures from the deep Auburn reservoir itself—the disaster that would ensue would be probably the greatest ever caused by the failure of a man-made structure. A 100-foot high wall of water would rush down the American River, washing out the bureau's Folsom Dam some 15 miles away, then descend rapidly upon metropolitan Sacramento, only 30 miles to the southeast of Auburn.

The lives of 750,000 persons would be imperiled, the California state capital would be wiped out, three military air bases would be destroyed, and several hundred thousand acres of rich farmland would be flooded. The potential economic losses are incalculable but would certainly run into the tens of billions of dollars.

Nobody can say what the probabilities are of such a disaster occurring if the dam is built as now designed. But state and federal officials have deemed them to be sufficiently great to delay awarding the main construction contract—thus far the only major construction work done has been for foundation preparation—pending further risk evaluation. In fact, Congress, which by and large has protested President Jimmy Carter's water projects "hit list," has itself concurred in the White House decision that the project should not go forward until it can be declared safe.

The Bureau of Reclamation is a 75-year-old agency which Westerners have properly esteemed for its role in helping bring prosperity to many formerly dusty cow towns and crossroads that would never have amounted to anything without development of life-giving water resources. But, since the Teton disaster,