Review of Non-Engineered Houses in Latin America with Reference to Building Practices and Self-Construction Projects
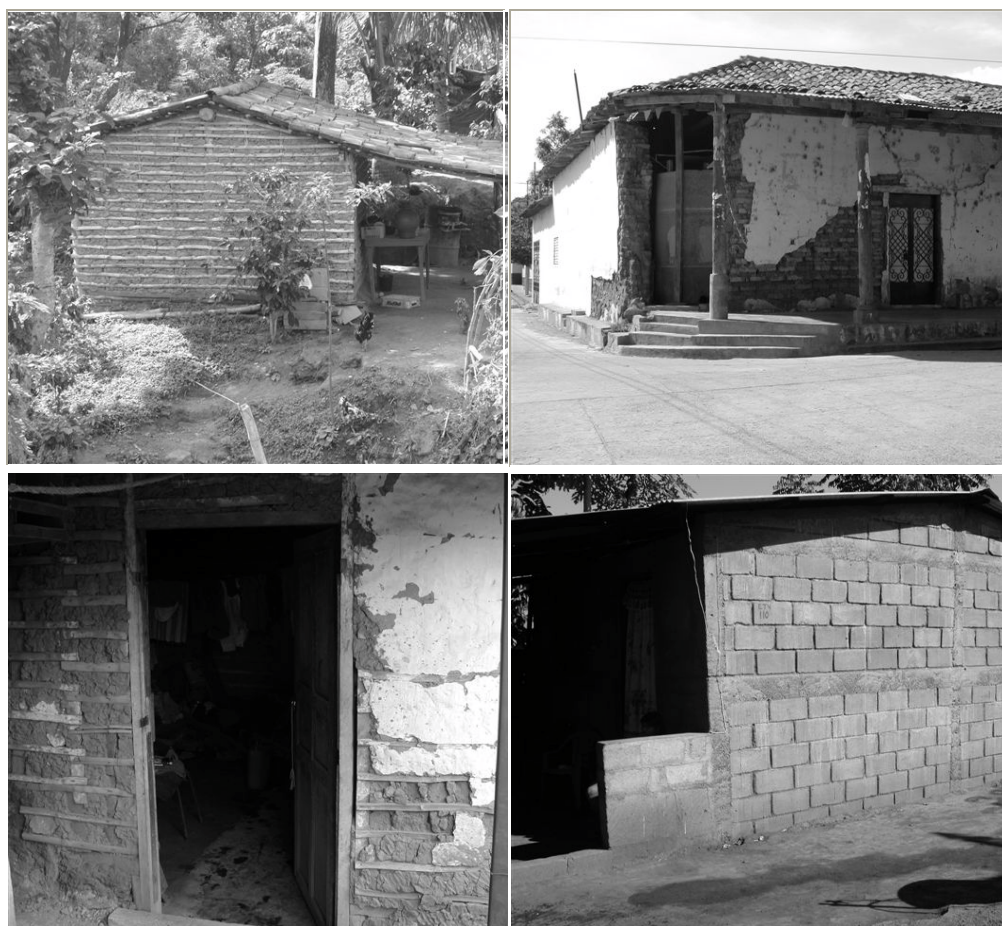
Aikaterini Papanikolaou, Fabio Taucer

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Summary

This report presents a review on non-engineered buildings, that at present make up a substantial part of the Latin American residential fabric. Within the different self-construction practices, earth-based construction techniques constitute the focal point of the report, as adobe housing units are traditionally prevalent in the region. Special consideration is given to the identification of the factors contributing to the high levels of seismic risk associated to non-engineered buildings as evidenced by the devastating effects following past and more recent earthquakes. The seismic performance of Latin American non-engineered housing units is documented through case studies from field reports of previous seismic events. The current housing and post-disaster reconstruction policies currently in effect in Latin American countries are also presented, as major components that determine the seismic risk associated to self-constructed dwellings. Finally, the report provides a detailed review on a thorough selection of the manuals produced to date that support self- and assisted-construction housing projects of earth-based, concrete masonry and reinforced concrete housing units.

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Recommendations

This manual should serve primarily as an information source for those institutions involved in the implementation of cooperation projects in the field of infrastructure reconstruction and earthquake risk mitigation programs in Latin America.

The authors encourage practitioners, engineers, researchers and decision makers involved in the construction of houses of less developed areas in Latin America through self-construction and mutual-help projects of non-engineered structures, to make use of, and disseminate as much as possible, this report.

Finally, the authors would like to underline that the information presented in the report has been extracted from an extensive and careful review of many bibliographical sources, ranging from material published on textbooks, journals, manuals and conference proceedings, to information extracted from the internet, where all the references prompting to web pages can be considered to be valid at least up to the publication date of the report. Moreover, special care was taken in order to ensure that all the information sources were called for in this work.

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Acknowledgements

Foreword

The area of Latin America and the Caribbean has historically been affected by natural catastrophes, producing a large number of casualties and economic disruption. However, as we enter the XXI century, the technological advances of science that should have had contributed to reduce the vulnerability of the population against natural disasters have not given the expected results. While most advanced societies have been able to put into practice the most recent technological developments to the service of reducing natural risk, their vulnerability still remains high, due to the economic implications owing to infrastructure damage, even at low levels of human fatalities. For societies with lower levels of economic development that have not benefited from the new technologies developed to reduce risk against natural hazards, the vulnerability is centred on the infrastructure damage related to both basic services and housing units, and on the resulting human casualties.

The present report focuses on the vulnerability and risk reduction of the earthquake hazard, responsible in the region for more than half of the total number of human fatalities due to natural hazards. Indeed, most of the life losses are the result of the collapse of the dwellings that house a large part of the population in the poor rural areas of Latin America and the Caribbean. These dwellings, that have not entered the cycle of formal construction and have not been the product of modern earthquake resistant-design concepts, are known as non-engineered buildings and are the main subject of the present report.

In this context, the European Commission, through the Joint Research Centre and in support to the Sustainable Rural Development, Infrastructure and Environment Unit of the Latin America Directorate of AIDCO, has prepared a comprehensive report on the earthquake vulnerability of the Latin American and Caribbean countries in the field of non-engineered structures. In particular, the report focuses in the region of Central America, where the Delegation of the European Commission in Managua is implementing a 25 million Euro cooperation project for the construction of more than 6,000 homes in El Salvador following the damages caused by the earthquakes of January and February of 2001.

The present report aims at providing a comprehensive review on the existing vulnerability of non-engineered structures and on the proposals relevant to the reduction of risk associated to earthquake hazard, a subject that has seldom been covered by the traditional channels of scientific research in the area of earthquake engineering. The report is divided into five chapters: the first chapter describes the seismic risk associated to non-engineered buildings; the second chapter reviews the housing and post-disaster reconstruction policies, using as example two case studies in El Salvador and Colombia; the third chapter describes in detail the techniques used for earth-based construction, with particular emphasis on adobe constructions; the fourth chapter examines the seismic performance of non-engineered housing units, of both adobe and informal reinforced concrete buildings, supported by the reports of four case studies following destructive earthquakes in Mexico, El Salvador, India and Iran; lastly, the fifth chapter provides a detailed review on the manuals produced to date for self-construction of earth-based, concrete masonry and reinforced concrete dwellings, in particular for the area of Latin America. All chapters are accompanied by a synopsis and the report is closed with a set of conclusions and recommendations.

The report should serve as a source of information to support the implementation and assessment of cooperation projects in the area of seismic risk reduction and infrastructure reconstruction following earthquake disasters. Moreover, the contents of the report should also serve as reference for engineers, and the scientific community in general, that work in the field of self-construction of non-engineered structures with improved earthquake resistance.

CHAPTER 1

Seismic Risk Associated to Non-Engineered Buildings

1.1   Introduction

The scope of this chapter is to present the various different factors that contribute to the high seismic risk of non-engineered housing units in Latin American countries. In order to provide a thorough insight to the issue, the three major components that constitute the problem are separately discussed. These are: the seismic hazard in the region, the building sample under exposure (i.e. the non-engineered structures) and the vulnerability of this sample with regards to seismic events.   Additional to this information, the basic principles of seismic risk assessment modelling are briefly presented.   The chapter concludes with a synoptic presentation of the factors contributing to the high level of seismic risk associated to non-engineered buildings in Latin American countries.

1.2   Seismic Risk - Definitions

The terminology found in the literature related to the subject of natural hazards is often contradictory. The concepts of *disaster, hazard, vulnerability* and *risk* are frequently confused with one another and with the extreme event itself (Gravley, 2001). For the purposes of this report, the aforementioned terms are clarified hereafter, both in their generic form and in conjunction with their identification as *seismic*, were applicable.

Disaster

Based on the definition used in the UNDP[1]/UNDRO[2] Disaster Management Manual (1994), a *disaster* is *"the occurrence of a sudden, or major misfortune which disrupts the basic fabric and normal functioning of a society (or community); an event, or series of events, which gives rise to casualties and/or damage, or loss of property, infrastructure, essential services, or means of livelihood, on a scale which is beyond the normal capacity of the affected communities to cope with unaided"*.

Hazard

A generally accepted definition of *hazard* (applicable to engineering purposes) would be (slightly paraphrasing Coburn et al., 1994): *"the probability of occurrence, within a specified period of time and a given area, of a particular, potentially damaging phenomenon of a given severity/intensity. The resulting damages should account for significant losses in terms of human lives and/or elements of the natural or built environment"*. Viewed within this context, a **seismic hazard** can be defined as "*the probability of occurrence, within a specified time interval and a given area, of an earthquake of a given magnitude that may produce adverse effects on human activities*".

Vulnerability

Vulnerability, according to Coburn et al. (1994), can be perceived as *"the extent to which a community, structure, service, or geographic area is likely to be damaged, or disrupted, by the impact of a particular disaster hazard, on account of their nature, construction, and proximity to hazardous terrain, or a disaster-prone area"*.   Under the scope of engineering mandates, vulnerability is a mathematical function defined as the degree of loss to a given element at risk, or set of such elements, expected to result from the impact of a disaster hazard of a given magnitude. It is specific to a particular type of structure, and may be expressed on a scale of 0 (no damage) to 1 (total damage).

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[1] *United Nations Development Programme.*
[2] *United Nations Disaster Relief Organization.*

The term *risk* refers to the *"expected losses from a given hazard to a given element at risk, over a specified future time period"*[3]. According to the way in which the element at risk is defined, the risk may be measured in terms of expected economic loss, or in terms of numbers of lives lost, or the extent of physical damage to property. Generally, risk is understood as a function of hazard and vulnerability[4]:

$$\left[R_{ij} \right] = \left[H_j \right] \times \left[V_{ij} \right]$$

(1-1)

where, for an *Element at Risk "i"* (e.g. an individual building) in a given unit of time:

$\left[R_{ij} \right]$ is the *Risk*, i.e. the probability (or average rate) of loss to element i, due to a hazard of severity j;

$\left[H_j \right]$ is the *Hazard, i.e.* the probability (or average rate) of experiencing a hazardous event of severity j;

$\left[V_{ij} \right]$ is the *Vulnerability,* i.e. the level of loss that would be caused to the *Element at Risk "i"*, as a result of experiencing a hazard of severity j.

By summing the risk from all levels of hazard, ($j_{min} \leq j \leq j_{max}$), the *Total Risk* to any individual element can be derived. It should be noted that loss is the specific loss, perceived as a proportion of the total value of the element "i".

The same plurality of definitions for risk is also observed for the concept of **seismic risk**. In an authoritative attempt to provide all interested parties with a commonly accepted definition of seismic risk, the Earthquake Engineering Research Institute published a glossary of standard terms for use in this subject (see: EERI Committee on Seismic Risk, 1984). According to the latter, *"seismic risk is the probability that social or economic consequences of earthquakes will be equal to, or exceed specified values at a site, at several sites, or in an area, during a specified exposure time"*.

Three essential components are involved in the determination of seismic risk, each of which should be separately quantified (Fig. 1-1): The seismic hazard occurrence probability, the elements at risk[5] (or else, exposure items) and the vulnerability of these elements. Therefore, in order to determine the seismic risk associated to non-engineered structures in Latin American countries, there are three essential questions to be answered:

- What is the seismic hazard occurrence probability in the region?
- What are the characteristics of the indigenous non-engineered structures?
- What is the vulnerability of these structures with regards to expected seismic events?

The following parts of this chapter elaborate on the aforementioned issues. Prior to the discussion pertinent to the seismic hazard estimation in Latin American countries, an overview of the occurring natural disasters in the region is given.

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[3] *This (official) definition of terms for risk assessment in natural disasters was established in an international convention agreed by an expert meeting organized by the Office of United Nations Disaster Relief Co-ordinator (UNDRO) in 1979.*

[4] *Several authors state that the right hand side of this equation should incorporate the alleviating effect of any Disaster Reduction measures undertaken, i.e.: Risk = (Hazard x Vulnerability) - Disaster Reduction. It can be argued, though, that the existing estimated vulnerability of the element(s), used for the calculation of risk in equation (1), should already encompass the effect of all the Disaster Reduction measures that **have been** undertaken.*

[5] *Generally, the identification of the exposure sample necessitates the compilation of an inventory of people, or buildings, or other infrastructure elements, which would be affected by the seismic hazard, if it occurred, and, where required, estimating their economic value. For instance, the HAZUS99 methodology categorizes the structures' inventory in: the general building stock, the essential facilities (medical care facilities, emergency response facilities and schools), the transportation lifeline systems (transportation lifelines, including highways, railways, light rail, bus systems, ports and harbours, ferry systems and airports), and the lifeline systems (potable water, electric power, wastewater, communications, and liquid fuels, such as oil and gas). The HAZUS99 methodology is a risk estimation procedure/software developed by the Federal Emergency Management Agency (FEMA, 1999), for the US. (see: http://www.app1.fema.gov/hazus/hazus4a.htm).*

the text in Spanish is as follows

Generally, earthquakes, floods and hurricanes are responsible for 90% of the economic costs from natural hazards worldwide. Countries tend to be impacted by the same types of natural hazard events: earthquakes usually occur in well-defined seismic zones; windstorms usually travel along identified hurricane paths; and floods usually occur in river and coastal areas. Different countries are impacted by different phenomena, while it is not uncommon for some countries to be exposed to more than one natural hazard. The disaster distribution, by type, in the LAC region, for the period of 1970 – 1999, is shown in Fig. 1-3. Selected natural disasters (excluding seismic events) that occurred in the region during approximately the same time period are listed in Table 1-1, along with the corresponding reported fatalities.

* Famine, insect infestation, wave/surge and extreme temperature.
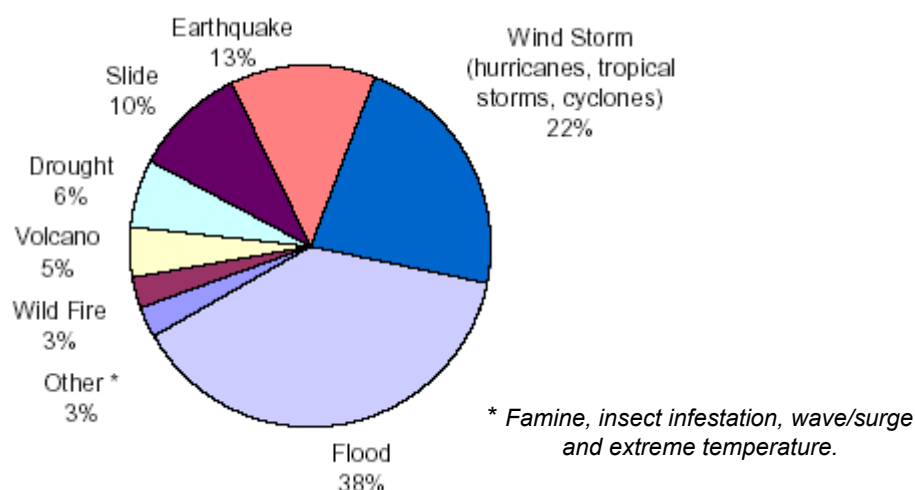
Fig. 1-3 The disaster distribution, by type, in the LAC region. [source: Charvériat (2000), based on data provided by CRED - Centre on the Epidemiology of Disasters]

Table 1-1 Selected natural disasters in Latin America and the Caribbean, excluding seismic events, for the period: 1974-1999. (sources: PAHO/WHO, 1994; USAID/OFDA, 1993; UN/DHA; SINAPROC, 1992; ECLAC/IDB, 2000; CRED, 2000)

Year	Country	Type of disaster	No of deaths reported
1974	Honduras	Hurricane (Fifi)	8,000
1979	Dominican Republic	Hurricanes (David & Frederick)	1,400
1980	Haiti	Hurricane (Allen)	220
1982	Mexico	Volcanic Eruption	1,770
1983	Peru	Flood	364
1985	Colombia	Volcanic Eruption	23,000
1987	Ecuador	Tsunami	1,000
1988	Brazil	Flood	355
1988	Jamaica	Hurricane (Gilbert)	45
1988	Mexico	Hurricane (Gilbert)	225
1988	Nicaragua	Hurricane (Joan)	116
1989	Antigua, Guadeloupe, Montserrat, Puerto Rico, St. Kitts and Nevis, U.S. Virgin Islands	Hurricane (Hugo)	56
1992	Nicaragua	Tsunami	116
1993	Honduras	Tropical Storm (Gert)	103
1994	Haiti	Tropical Storm (Gordon)	
1997-8	Andean countries[†]	El Niño	600
1998	Central American countries	Hurricane (Mitch)	9,124
1998	Dominican Republic	Hurricane (Georges)	288
1998	Peru	Flood	340
1999	Venezuela	Floods / Debris flows	≈ 30,000

[†] *Bolivia, Colombia, Ecuador, Peru and Venezuela*

Country-wise, Bolivia, along with Colombia and El Salvador, is particularly struck by floods and droughts due to the El Niño phenomenon. The two most recent disaster events in Bolivia are the February 2002 floods in La Paz and the May 1999 earthquakes near Tarija, which measured 6.3 on the Richter scale.

Colombia is primarily affected by earthquakes and tsunamis; it is also exposed to floods and volcanoes, with consequent mud slides. In 1906, an earthquake of magnitude 8.9 Mw hit off the Pacific Coast of Colombia and was felt in the entire country and surroundings. The most important recent event in Colombia was the 1999 earthquake in Quindio, known as the "*Eje Cafetero*" disaster because the shocks affected a key coffee producing area.

The most important hazard events in El Salvador are earthquakes and volcanic eruptions, with resulting landslides likely and tsunamis possible. Earthquakes have struck San Salvador 13 times over the past 400 years, almost destroying the city in 1854, 1873, 1917 and 1986. The largest recent events in El Salvador were the earthquakes of January and February 2001, with Richter magnitudes of 7.6 and 6.6, respectively.

The Dominican Republic usually faces hurricane and earthquake hazards. The latest major earthquake in the Dominican Republic occurred in 1946 with a magnitude of 8.1 on the Richter scale. The most important recent event was Hurricane Georges in 1998, which ranked 3 out of 5 on the Saffir Simpson hurricane scale, while hurricane David in 1979 ranked a full 5.

Based on the information reported in the EM-DAT database[6]; depicting the World Bank Development Indicators, Nicaragua appears to be the Central American country hardest hit by disasters in the last 30 years. In terms of occurrence and occurrence per km^2, Nicaragua is in the middle range (with 26 disasters reported within this time period), but has the highest ratio of fatalities as a share of the total population, as well as a very high ratio of cumulative losses/GDP (338%). By comparison, Costa Rica, which experienced 33 disasters - a high number given its small size - has a fatalities per population ratio 36 times lower, and a loss/GDP ratio 25 times lower.

Compared with other Central American countries, Mexico, despite the highest number of disasters, enjoys much lower ratios in terms of occurrence per km^2, fatalities/population and losses per GDP. Belize and Panama have the best record in the sub region, with a low number of disasters, fatalities and losses, both in absolute and relative terms. The performance of Honduras and Guatemala is similar to that of Nicaragua, but with a lower loss/GDP ratio.

In the South America sub-region, Brazil has by far the highest occurrence of disasters, with 3.4 disasters per year on average, followed by Colombia and Peru with more than 2 disasters a year. By contrast, Uruguay experienced a disaster every four to five years. Despite a low rate of occurrence given its size, Venezuela has a high ratio of fatalities per population, exceeded only by Peru. The rest of the region has a rather low ratio of fatalities/population. In terms of the relative magnitude of damages, Ecuador has a surprising 42% of losses as a share of its 1998 GDP, due to the magnitude of declared losses after the 1987 earthquake and the 1998 El Niño. Only three other countries have a percentage of damages to GDP greater than 10%, Bolivia, Colombia and Peru, while the rest of the countries, including countries experiencing many disasters such as Brazil and Chile, have a fairly low percentage, between 0.1 and 6.3%.

As stated by Charvériat (2000), these country indicators clearly corroborate the positive correlation between poverty incidence and vulnerability to disasters and the negative correlation between country size and economic vulnerability to disasters. Based on the views of Clarke et al. (2000), the principal causes of vulnerability in the region include: rapid and uncontrolled urbanization, the persistence of widespread urban and rural poverty, the degradation of the region's environment resulting from the mismanagement of natural

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[6] *The EM-DAT database was developed by the Centre for the Epidemiological Study of Disasters (CRED) of the Catholic University of Louvain in Belgium. In this database, natural disasters are defined as natural hazards, which have caused 10 or more fatalities, affected 100 or more people or resulted in a call for international assistance, or the declaration of a state of emergency. The database includes the following types of natural hazards: drought, earthquakes, extreme temperature, famine (natural), flood, insect infestation, slides, volcano, wave/surge, wildfire, windstorms and epidemics. For 1970-99, EM-DAT covers 972 disaster cases for Latin America and the Caribbean. The discussion presented herein, concerning Central and South American country indicators relative to disaster consequences, is reproduced from the Inter-American Development Bank publication "Natural Disasters in Latin America and the Caribbean: An Overview of Risk", prepared by Charvériat (2000).*

resources, inefficient public policies, and lagging and misguided investments in infrastructure. Development and disaster-related policies have largely focused on emergency response, leaving a serious underinvestment in natural hazards mitigation.

1.3.2 Earthquake fatalities

Despite the fact that earthquakes account for only 13% of the total natural disasters in the LAC region, as shown in Fig. 1-3, seismic events were the deadliest type of disasters causing 53% of the total fatalities within the time period between 1970 and 1999 (Fig. 1-4)[7]. This is due to the fact that (particularly in this part of the world) the average death/earthquake occurrence ratio was 950, whereas for floods and windstorms the ratio was around 100. Given their higher rate of occurrence, floods and windstorms end up ranking second and third, as the cause of disaster-related fatalities with 21% and 11% of total fatalities respectively. Though rare, catastrophic volcano eruptions caused 10% of total fatalities, due to a fatality/occurrence ratio of nearly 500.
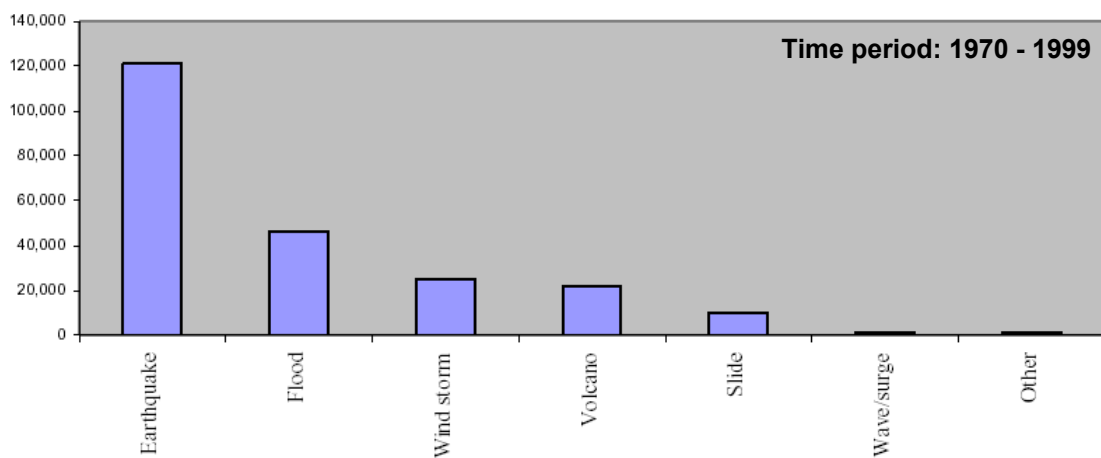
Fig. 1-4   Cumulative fatalities by type of natural disaster in Latin America and the Caribbean. (source: Charvériat, 2000)

Casualties in earthquakes arise mostly from structural collapses. It is estimated that the percentage of earthquake-induced life losses, which are attributed to building failures, ranges between 75 and 90% of the total number of earthquake fatalities. Fig. 1-5 shows the causal distribution of earthquake fatalities for each half of this century[8].
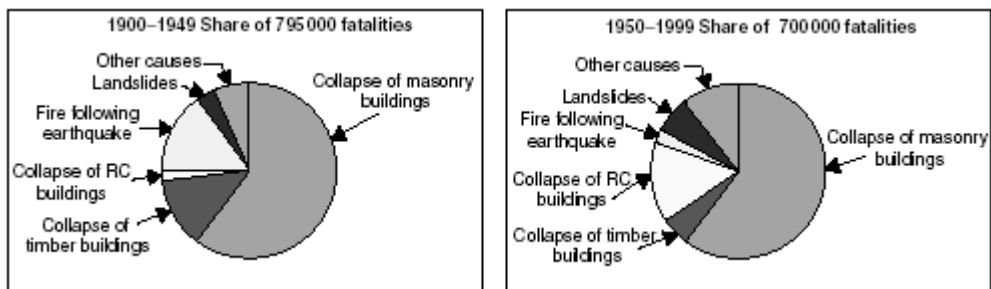
Fig. 1-5   Breakdown of earthquake fatalities, by cause, for each half of this century. (source: Coburn and Spence, 2002)

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[7] *Catastrophic earthquakes account for 60% of worldwide casualties associated with natural disasters (Shedlock and Tanner).*
[8] *Lethality per collapsed building, for a given class of buildings, can be estimated by the combination of factors representing the population per building, occupancy at the time of the earthquake, occupants trapped by collapse, mortality at collapse and post-collapse mortality (Erdik and Aydınoğlu, 2003).*

In an effort to discern statistical relationships between earthquake mortality and critical earthquake destructiveness parameters, Gutiérrez et al. (2004) studied a worldwide parametric data set of destructive historical earthquake events. In this work, mortality was obtained by dividing the reported number of fatalities by the total population contained in the affected area. Earthquake mortality was assumed to be correlated in a causal, but complex (non-linear) fashion to certain parameters, the selection of which was restricted by their availability. These parameters were divided into demographic (e.g. maximum, mean and total population) and physical. The latter category included the following parameters: the intrinsic properties of earthquake events (depth and magnitude), the distance from the epicentre and the radius of circle encompassing the affected area, the time of earthquake occurrence, the type of dominant hazard in the area (average and maximum), geomorphologic and soil characteristics (such as the maximum and minimum slope and the soil texture), the GDP of the affected country and the reported injuries and fatalities. Information on type and quality of housing was unavailable on a worldwide scale and, hence, this parameter was not included in their analysis. The study concluded that the highest mortalities are correlated with poorly developed, rural and semi-rural areas, whereas highly developed urban centres are the least vulnerable.

The statistics recording death due to earthquakes identify a wide range of collateral earthquake-induced causes of death. These include deaths from: fires following earthquakes[9], tsunamis generated by off-shore events, rock-falls, landslides and other hazards triggered by earthquakes. Secondary causes of death, officially attributed to the occurrence of an earthquake, range from medical conditions induced by the shock of experiencing the ground motion, to accidents occurring during the disturbance, epidemic among the homeless and shootings during looting and social unrest. Any or all of these may be included in published death tolls from any particular earthquake. It is clear from reports, however, that in most large-scale earthquake disasters, the principal cause of death is the collapse of buildings (Coburn and Spence, 2002). The role of the building type, the time of earthquake occurrence and the population density to the resulting death toll, following a seismic event, is described in the following section.

(a)   Life losses as a function of the housing type

The data shown in Fig. 1-5 demonstrates that, by far, the greatest proportion of fatalities result from the collapse of masonry buildings. These are primarily weak masonry buildings (adobe, rubble stone or rammed earth), unreinforced fired brick or concrete block masonry that can collapse even at low intensities of ground shaking and will definitely collapse very rapidly at high intensities[10]. Lighter forms of construction, especially woodframe, or *bahareque*, have proved to be much less dangerous. Some indicative figures are given hereafter:

- Kuroiwa et al. (1973) report that during the 1970 earthquake in Peru more than 90% of the damaged buildings consisted of adobe buildings; their collapse resulted into 40,000 deaths.
- After the 1976 earthquake in Guatemala, a survey showed that in one village with a population of 1,577, all of those killed (78) and severely injured had been in adobe buildings, whereas all residents of woodframe buildings survived.
- In the 1992 earthquake in Erzincan, Turkey, there was extensive structural damage throughout the region, especially in the city where mid-rise, unreinforced masonry buildings incorporating a "soft" first floor design (large store windows for commercial use) and one storey adobe structures were most vulnerable to collapse. Out of a total of 526

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[9] *Historically, the greatest risk comes from fire, although in recent decades, post-earthquake fires causing mass casualties have been uncommon. However, in the aftermath of the earthquake that hit Kobe, Japan, in 1995, over 150 fires occurred. Some 500 deaths were attributed to fires, and approximately 6,900 structures were damaged. Fire-fighting efforts were hindered because streets were blocked by collapsed buildings and debris, and the water system was severely damaged.*

[10] *In earthquakes affecting higher quality building stock, e.g. Japan and the United States, more fatalities are caused by the failure of non-structural elements or by earthquake-induced accidents than by the collapse of buildings, mainly because low proportions of buildings suffer complete collapse. Examples of failure of non-structural elements are pieces being dislodged from the exterior of buildings, the collapse of freestanding walls, or the overturning of building contents and equipment.*

people who died in the city, 87% were indoors at the time of the earthquake; of these, 92% died due to collapse of structures, such as the ones described above (Angus et al., 1997).

- In the earthquake affecting the villages of Aiquile and Totora in Bolivia in 1998, 90% of deaths resulted from the collapse of adobe housing.
- In the 2001 earthquakes in El Salvador, more than 200,000 adobe buildings were severely damaged or collapsed, 1,100 people died under the rubble of these buildings, and over 1,000,000 people were made homeless (EERI, 2001). That same year, the earthquake in the south of Peru caused the death of 81 people, the destruction of almost 25,000 adobe houses and the damage of another 36,000 houses, with the result that more than 220,000 people were left without shelter (USAID, 2001).

Buildings of the Low Strength Masonry type (or else LSM, in which earthen structures are included) are very common in seismic areas around the world and still today make up a very large portion of the world's existing building stock. For example, the Andean countries of South America - Argentina, Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela - have a combined population of about 140 million; approximately 25% (35 million people) of this population currently live in adobe housing. Many millions of people throughout the developing world are in the same condition and much of the increasing populations in developing countries will continue to be housed in this type of structure for the foreseeable future.

The aforementioned projection is based on the macroeconomic shocks that have plagued the Latin America and Caribbean region over the last twenty years, as it is evident that low quality housing is directly related to low income. Giving ground to figures, about 33% of the population in LAC lives in moderate poverty, while 16% lives in extreme poverty (Londoño and Székely, 1997)[11]. Poverty is not evenly distributed in the region, not even within the same country. Some countries like Nicaragua and El Salvador have 70% of their population living in poverty, while Argentina, Chile and Venezuela have only an estimated 20% of the population living in poverty (Attanasio and Székely, 1999). Large countries such as Brazil and Mexico have on their soil respectively 46% and 13% of the total poor population in Latin America and the Caribbean (Londoño and Székely, 1997).

(b)   Life losses related to the time of earthquake occurrence

Night occurrence was particularly lethal in the earthquakes of Guatemala (1976) and Bolivia (1998), where most damage occurred in adobe houses. In urban areas with well-constructed housing but seismically vulnerable public buildings, earthquakes occurring during the day result in higher death rates. This was the case in the 1997 earthquake that struck the towns of Cumaná and Cariaco, Venezuela. In Cumaná an office building collapsed, and in Cariaco two schools collapsed, accounting for most of the dead and injured. Nevertheless, to date there is no evidence of strong correlation between the time of earthquake occurrence (i.e. type of human activity) and the resulting fatalities. This conclusion was also confirmed by Gutiérrez et al. (2004).

(c)   Life losses related to the population density

The total number of deaths and injuries is likely to be much higher in densely populated areas. As demonstrated in Fig. 1-6, this condition holds true for most of the Central American countries. Furthermore, the highest population density in these countries is located in the vicinity of active or dormant volcanoes, as well as in the areas of contact between the tectonic plates that produce frequent and strong earthquakes. An explanation exists for these demographics: people have always chosen to settle in high-risk zones, since these are generally the areas with the most benign climate and the best agricultural lands. Moreover, a relatively large percentage of the population, especially in urban areas, is living in highly vulnerable zones due to a dearth of sufficiently detailed maps revealing such vulnerabilities. Unfortunately, the same dearth extends to regulations and other legal measures that could be duly implemented (SG-SICA, 2002).

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[11] *Usually, "absolute" income poverty is considered in terms of $/day (i.e. independent of the national poverty line of each country). The Human Development Report for the year 2003 (realized within the framework of the United Nations' Development Programme) provides data on the existing population below income poverty line; the latter is set to 1$/day (extreme poverty) and 2$/day (moderate poverty) [see: http://www.undp.org/hdr2003/indicator/pdf/hdr03_table_3.pdf].*

Fig. 1-6 Average number of people per square kilometre.
(source: http://www.overpopulation.com/faq/Basic_Information/population_density/maps/latin_america.html)

1.4   Seismic hazard in Latin America

1.4.1 Assessment principles

The assessment of seismic hazard consists of the following basic steps:
- Definition of the nature and locations of earthquake sources;
- Magnitude-frequency relationships for the sources;
- Attenuation of ground motion with distance from source (including path-related effects);
- Determination of ground motions at the site (site response and topographical influence), having the required probability of exceedance.

Seismic risk and hazard statements are essentially forecasts of future situations, and thus, inherently uncertain. The uncertainties that arise during assessments of this type are partly due to the fact that the processes involved in forecasting likely future seismic activity are not (yet) fully understood, and partly due to the scarcity and varying quality/reliability of available relevant data.

Seismic hazard assessments of reasonable credibility involve considerable knowledge of both the historical seismicity[12], and the geology of the area under consideration. Where available, other geophysical or seismological knowledge, such as crustal strain studies, may also be helpful, particularly in evaluating regional seismic activity patterns. In this context, seismic hazard maps constitute a very useful tool used for seismic risk assessment, as they depict the levels of chosen ground motions that likely will, or will not, be exceeded in a specified exposure time period.

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[12] *Seismicity is defined as the frequency of occurrence of earthquakes per unit area in a given region.*

1.4.2 Seismic activity in Central and South America

Intense seismic activity in the region is attributed to its geological morphology. The Andes, Caribbean, and Central American mountains, which are the main landforms of the region, are seated where major tectonic plates interact (Figs 1.7a & b). Generally, 90% of all earthquakes occur along the plate boundaries. Almost all of the known major earthquakes in the Americas have occurred along the western edges of these three plates, where they are overriding, or sliding past the Pacific, Cocos, Nazca, and associated smaller plates (Fig. 1-8). Tectonic movement, though, is not the only reason for which earthquakes occur in this part of the world. The mountains of the Caribbean and of Central and South America are geologically young, with a great number of volcanoes[13] (Fig. 1-9); their activity also induces seismic events.
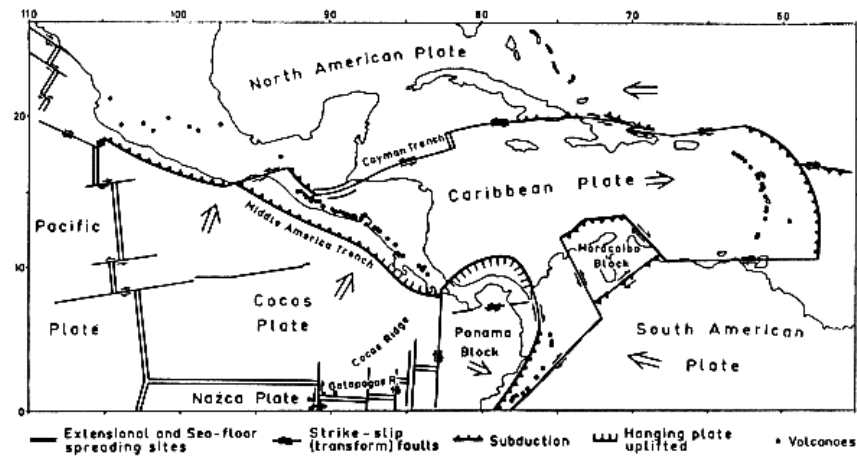
(a)

(b)

Fig. 1-7   (a) Tectonics of Central America and the Caribbean; (b) The major tectonic plates of the Americas are named in white letters. [sources: (a) Weyl, 1980; (b) http://seismo.ethz.ch/gshap/paigh/shedams_1.gif]

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[13] *In Ecuador, for example, the central plateau is surrounded by more than two dozen volcanoes.*
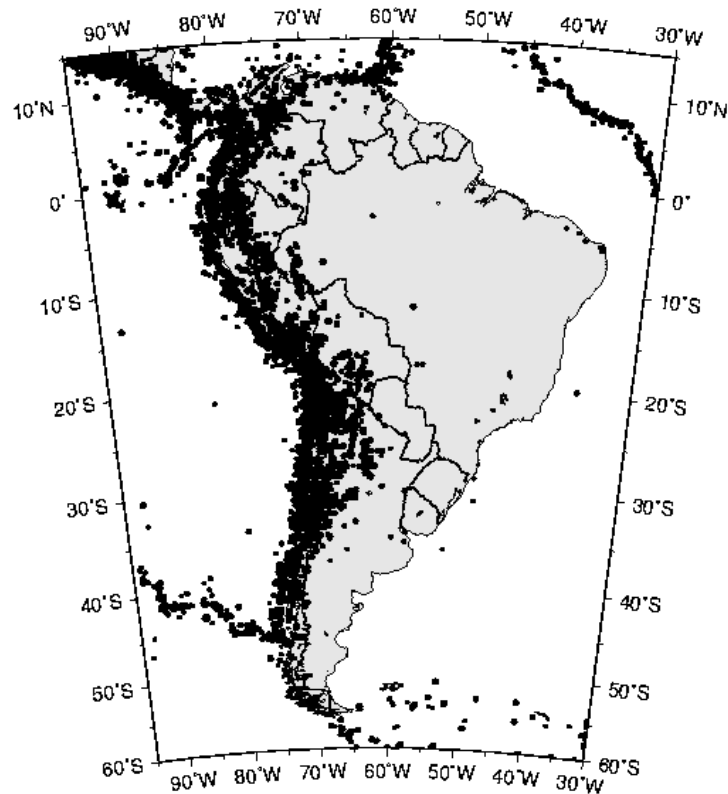
Fig. 1-8 Plot of earthquakes with M ≥ 4.6 that occurred during the years 1900 through 1994.[14] (source: http://seismo.ethz.ch/gshap/paigh/shedams_5.gif)

Fig. 1-9 Major volcanoes in Central and South America and the Caribbean.
(source: Ewert et al., 1997)

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[14] *M stands for the moment magnitude of the earthquake and is generally a more preferred magnitude measure, because it is directly related to the seismic moment.*

Table 1-2 summarizes the major earthquake events in the Latin America region since 1960 and presents the corresponding data, including number of killed and affected people, earthquake magnitude and economic losses.

In El Salvador, and in the last century alone, there were eleven earthquakes that caused significant damage (Fig. 1-10). The relatively recent earthquake of 13 January 2001 was the second largest in terms of magnitude, taking second place only to the earthquake of 1915. This earthquake bears more similarity to the 1976 Guatemalan earthquake, both in terms of magnitude and induced damages.

Table 1-2 Major earthquake events in the Latin America. (main source: ECLAC/IDB 2000)

Year	Country	Killed	Affected[†]	Magnitude (Richter scale)	Total Damages[‡]
1960	Chile	5,700	no data	8.5	no data
1970	Peru	66,794	3,216,240	7.8	2,225
1972	Nicaragua	10,000	720,000	8.5	2,968
1976	Guatemala	23,000	4,993,000	7.5	2,147
1985	Chile	180	1,482,275	6.3	2,272
1985	Mexico	8,776	130,204	8.1	6,216
1986	El Salvador	1,000	770,000	5.5	2,231
1987	Colombia	1000	no data	7.0	7,168
1987	Ecuador	4,000	227,000	6.1 & 6.8	1,352
1991	Costa Rica & Panama	73	no data	7.5	~ 2,300
1999	Colombia	1,186	1,205,933	5.8	1,580
2001	El Salvador	827	1,160,316	7.6	970.5
2001	El Salvador	255	83,435*	6.6	

[†] *According to ECLAC (1999), affected people are defined as those requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance; individuals are also considered affected when there is the appearance of a significant number of cases of an infectious disease introduced in a region or a population that is usually free from that disease.*

[‡] *Direct and indirect damages in millions of $, as per 1998, except of the 2001 El Salvador earthquakes, which are expressed in 2001 economic terms.*

* *Source: ECLAC (2001), based on figures from the National Emergency Committee (COEN, 2001). The population considered by COEN to have been affected, with or without loss of dwelling.*
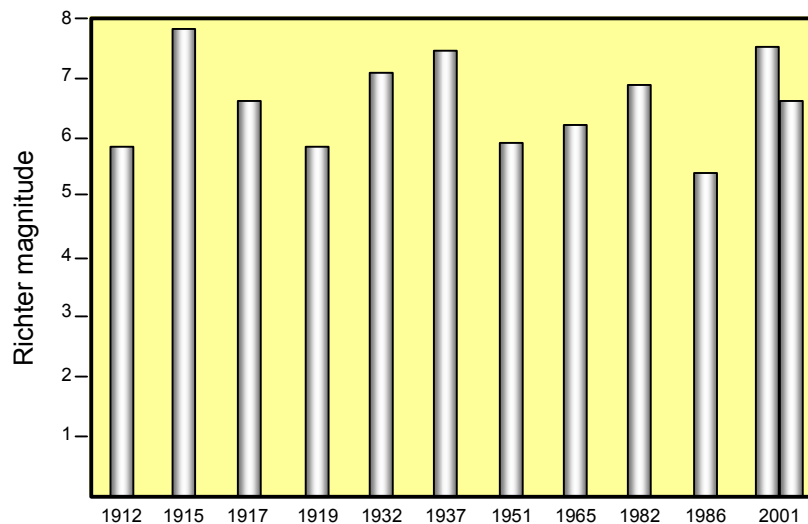
Fig. 1-10 Richter magnitudes of earthquakes occurring in El Salvador during the 20th century. (source: partially based on data provided by the National Earthquake Information Center, Earthquake Search Results 1900-1999, United States Geological Survey)

1.4.3 Seismic hazard maps

Hazard assessment programs in the region of Latin America commonly specify a 10% chance of exceedance (90% chance on non-exceedance) of some ground motion parameter for an exposure time of 50 years, corresponding to a return period of 475 years. Commonly mapped ground motions are maximum intensity, peak ground acceleration (PGA), peak ground velocity (PGV) and several spectral accelerations (SA).

Each ground motion mapped corresponds to a portion of the bandwidth of energy radiated from an earthquake. PGA is the most commonly mapped ground motion parameter because current building codes that include seismic provisions specify the horizontal force a building should be able to withstand during an earthquake in proportion to the inertial mass of the structure. PGA and 0.2s SA correspond to short-period energy that will have the greatest effect on short-period structures (one- to two-story buildings, which are the most common in the region). Longer-period SA maps (1.0s, 2.0s, etc.) depict the level of shaking that will have the greatest effect on longer-period structures (10+ story buildings, bridges, etc.).

The seismic hazard map of South America is shown in Fig. 1-11a and depicts peak ground accelerations (PGA) with a 10% chance of exceedance in 50 years. The site classification (soil conditions) is rock, for the whole region. The return period for all countries is 475 years, except for Mexico where it is 500 years. This seismic hazard map of the Americas is the result of decades of work and the contributions of hundreds of scientists and technical personnel, as well as universities and public and private agencies and organizations, throughout the Americas[15].

Fig. 1-11b illustrates the seismic hazard map of Central America and the Caribbean, and is consistent with Fig. 1-11a in terms of peak ground acceleration, probability of exceedance and return period. This map was made as part of the UN project GSHAP (Global Seismic Hazard Assessment Project). It becomes clear that the seismic hazard (as defined previously) is high (and in most cases very high) for the Central America and western South America regions.

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[15] *Various researchers have published probabilistic seismic hazard maps of countries, or regions of South America. The* Centro Regional de Sismología para America del Sur *(CERESIS) was established in 1971 to coordinate and increase the observation, recording, analysis, and interpretation of seismicity in South America. CERESIS published the first regional seismicity catalogues and hazard maps in 1981 and also cooperated with the Pan-American Institute of Geography and History (PAIGH) to produce a seismic hazard map of the region (Tanner and Shepherd, 1997). In 1995, researchers from four European-Mediterranean (EUME) and five Andean Pact (JUNAC) countries formed the Pilot Project for the Regional Earthquake Monitoring and Seismic Hazard Assessment (PILOTO). Among the many achievements of this group is an Andean region seismic hazard map. A complete summary of the PILOTO seismic hazard map may be found in Dimatè et al. (1999). The seismic hazard map of South America (Fig. 1-11a) is a combination of the maps produced under the auspices of PAIGH and PILOTO.*
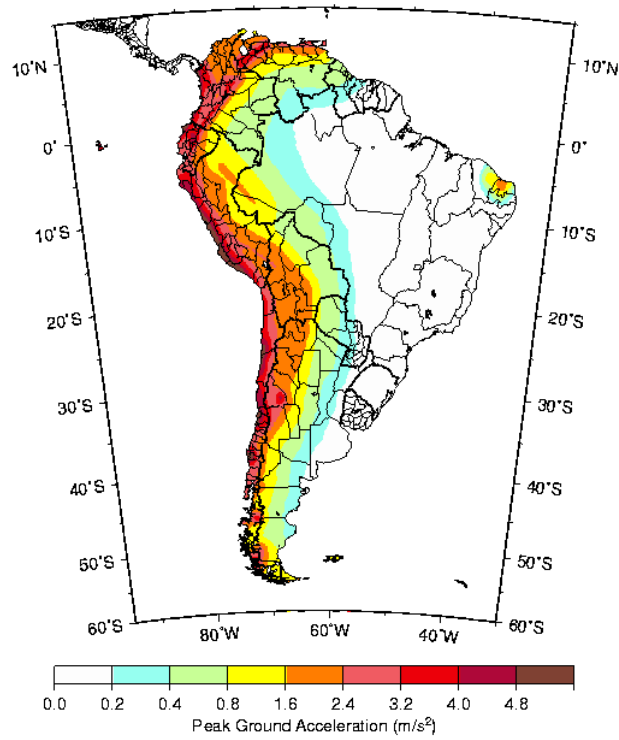
(a)
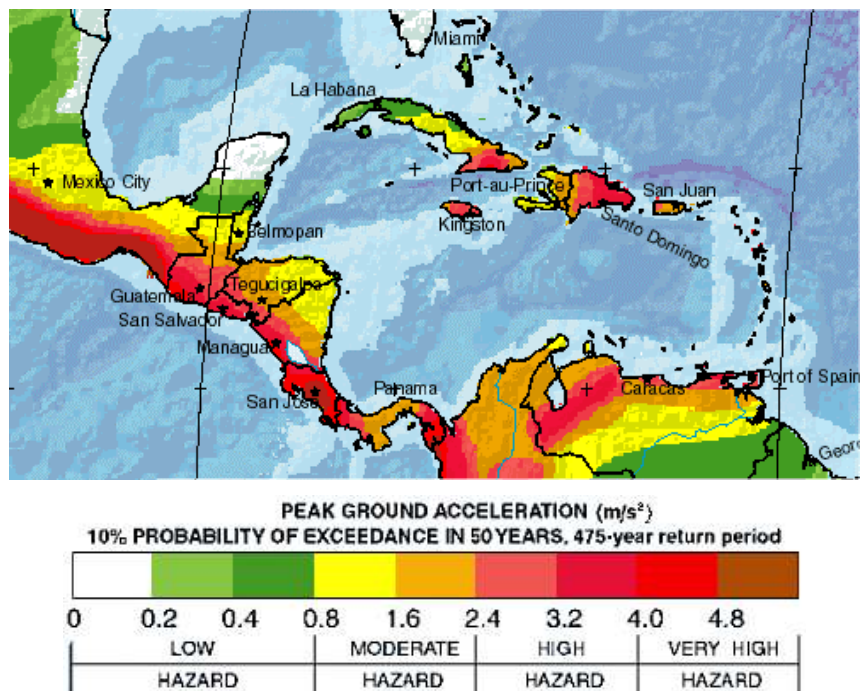
(b)

Fig. 1-11 Seismic Hazard in: (a) South America; (b) Central America and Caribbean.
[sources: (a) the "Seismic Hazard Map of the Western Hemisphere", by Shedlock and Tanner
http://www.seismo.ethz.ch/gshap/paigh/amerstext.html;
(b) http://geology.about.com/library/bl/maps/blcentralamerica.htm]

1.5 Non-engineered buildings

1.5.1 Traditional and contemporary structures

According to Arya (1994), "non-engineered buildings" are defined as those that are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design. These vernacular dwellings are proportioned based on experience (rules of thumb passing from one generation to the other) and they are mostly made out of wood, clay, concrete blocks, sun-dried clay bricks (adobe – see Fig. 1-12a), field (or rubble) stone and brick, as well as combinations of these locally available materials. Cement, lime, or clay-mud are generally used for mortar compositions.

Additional to these traditional structures, non-engineered reinforced concrete (RC) frame buildings are also part of the bulk of buildings built today in an informal way, by semi-skilled professional builders (Fig. 1-12b). The quality of concrete and the placement of reinforcement are usually considered to be low. Most non-engineered reinforced concrete buildings consist of moment resisting frames with unreinforced infill walls made of hollow clay bricks or hollow concrete blocks. They are usually two- to five-storeys high and square in plan, although additions/alternations result in more irregular layouts. Weak or soft stories are common, while shear walls are rarely used. Floors are typically reinforced concrete slabs. The larger dimension of the column cross section is usually oriented in the same direction through the whole building, while the short dimension of the cross section matches the wall thickness. This results in the weak direction coinciding with the strong beam – weak column condition.

(a)   (b)

Fig. 1-12 (a) Traditional adobe dwelling in Argentina; (b) Non-engineered reinforced concrete frame building in Venezuela. [sources: (a) EERI, 2003; (b) EERI, 2002]

In the rapidly growing urban areas of the developing countries it is quite common that the owners themselves construct their dwellings. In the best cases, the construction takes place under the guidance of a head-mason, or a carpenter who, nevertheless, lacks comprehensive knowledge on earthquake-resistant principles. Occasionally, these local and often self-taught builders may adopt improved construction practices derived from the observed behaviour of such buildings during past earthquakes. Ought to both the inherent weakness of the materials used (mostly in the case of traditional buildings), and to fundamental construction flaws, these structures are extremely prone to collapse due to floods, cyclones and earthquakes.

Non-engineered buildings usually do not go through the building permit process and are prevalent in rural areas and in the periphery of large urban centres. In particular, some characteristics of the rural communities in Latin American countries that contribute to the vulnerability of non-engineered houses include (Lizarralde, 2000[16]):

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[16] *Although Lizarralde's work refers to Colombia, it can be safely postulated that most Latin American rural areas share many common characteristics.*

- Lack of proper access roads to the rural areas;
- Lack of a wide coverage of public services;
- Lack of education (including high levels of illiteracy);
- Poverty;
- Lack of political influence and social isolation in some cases;
- Difficulties in receiving information, and little access to knowledge;
- Settlements are located in high risk areas, usually on slopes and in proximity to water resources (therefore prone to floods);
- Lack of building codes and construction supervision.

1.5.2 Dwellings in slums and shantytowns

(a)   Where

Latin America and the Caribbean (LAC) is the most urbanized region in the developing world: 75%, or 391 million of its population, live in cities and towns.   In seven countries the proportion of the urban population is more than 90% of the country's population (UN-Habitat, 2003a). The urban population in the region, as a whole, is projected to reach 84% of its total population by 2030.   Being the result of province-to-city migration, an unprecedented spontaneous urban growth has taken place during the past 50 years, manifesting itself in the form of peri-urban shantytowns. This phenomenon is considered as the most important and dynamic adoption of urban space, not only for the Latin American region, but also for the entire planet (de Bustillos et al., 2003). It is estimated that in 2001 one-third of the total Latin American urban population was living in precarious settlements, described by the general terms "slums" also known in the region (among other names), as *tugurios*, *asentamientos irregulars*, *ranchos* or *favelas* (UN-Habitat, 2003a). The distribution of slums in the region is illustrated in Fig. 1-13, whereas figures regarding urban and slum population as percentages of the total, are listed in Table 1-3.
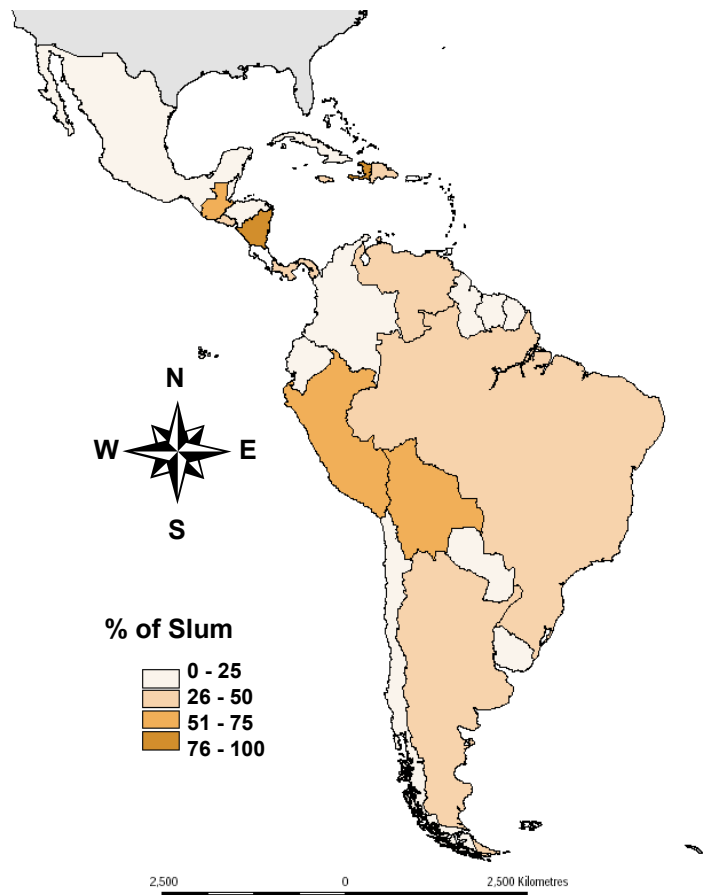
Fig. 1-13 Prevalence of slums in LAC region, per country. (source: UN-Habitat, 2003a)

Table 1-3 Slum incidence in LAC region. (source: UN-Habitat, 2003a)

	Total Population	Urban Population		Slum Population	
	(in thousands)	(in thousands)	(in % of the total population)	(in % of the total population)	(in thousands)
Latin America and the Caribbean	526,657	399,385	75.8	127,567	31.9
Central America	37,112	19,275	51.93	8,177	42.42
Caribbean	41,675	27,461	65.89	5,89	21.46
South America	347,485	277,795	79.94	98,803	35.56

(b)   Why

Overcrowding and poverty (wages down to the level of basic subsistence), combined with the inability of the formal sector (public, or private) to provide adequate and affordable housing (e.g. lack of efficient financing schemes, weak administration, corruption, etc.) has forced the housing production in the peripheries of municipal centres to be undertaken informally. Whether through land invasion or (more usually) through illegal lot sales, self-built housing has become the prime means of access for would-be homeowners to enter the land and housing markets (Gilbert and Ward, 1985). Buildings erected by incoming or migrant segments of the population are usually constructed without specific permission and are not regulated by any building control procedures. Public authorities are hard pressed enough to provide basic water and drainage services to serve the new population, much less to attend to how they house themselves.

(c)   What

Slums, generally, describe old residential buildings, which have deteriorated and lack essential services (but - in most cases - do not lack security, in terms of tenure). Shanties, on the other hand, refer to spontaneous settlements, which have developed in the outskirts of a city. The term *slum* has, however, come to include all the types of informal settlements that are quickly becoming the most visual expression of urban poverty (UN-Habitat, 2002a). The quality of dwellings in such settlements varies from the simplest shack, to permanent structures, while access to water, electricity, sanitation and other basic services and infrastructure tends to be limited, if non-existent. Such settlements are referred to by a wide range of names and include a variety of tenure arrangements.

As Gough and Kellet (2001) report (focusing on the contemporary Colombian informal settlements), most households start by building a shack of temporary materials. The walls are usually of *esterilla* (split bamboo), which is sometimes covered with plastic sheets to keep out the rain, with a roof of second-hand clay tiles, or *cartón* (bitumised cardboard) (Gough, 1996). In other cases, timber poles, boards' cladding, recycled metal sheets and other found materials are used for building the temporary shacks (Kellett, 1995). The aim of all households living in these temporary structures is to consolidate their dwelling in the future (i.e. to make it more permanent, through a process of gradual improvement). Almost all self-help builders nowadays aim to have a brick (or block) house, with an asbestos-cement roof, metal doors and windows with bars (for security reasons).

There are many possible routes from the typically small, temporary, one-room, un-serviced dwellings, to large, permanent, multi-room, fully serviced dwellings. Many houses are slowly, but steadily consolidated in an incremental way with rooms gradually being added and facilities upgraded, as income allows (Fig. 1-14). Other houses remain unchanged, receiving little more than basic maintenance and remain at this stage for long periods; when the opportunity arrives they are expanded as quickly as possible.

The various stages of the consolidation process for the self-built houses are characterized, according to Gough and Kellet (2001), as follows: temporary (non-permanent materials and form), hybrid (a dwelling which includes some permanent construction, combined with temporary elements), developing (a dwelling mainly in permanent, but unfinished materials) and completing (a dwelling with living room, kitchen and at least two bedrooms with wall finishes in some rooms). Because of the continuous and incremental nature of most construction, it is rare to find dwellings, which are regarded by their owners as "*casas terminadas*" (completed houses).

(a)

(b)

(c)

Fig. 1-14 (a) A small bamboo house (*ranchito*) in Pereira, Colombia, around which the family have started to build brick walls (1987); (b) Six months later the brick walls have reached window height; (c) Ten years later, two floors have been built: the family lives on the first floor and rents out the ground floor. (source: Gough and Kellet, 2001)

1.6 The vulnerability of non-engineered structures

1.6.1 Theoretical background on vulnerability assessment for buildings

This seismic risk component reflects the degree of damages (or losses, more generally) to buildings, or people, or any other element at risk, should they experience a certain level of seismic hazard. The vulnerability representation of exposed systems is facilitated through their sub-division into classes, according to the characteristics that most influence their response (Rossetto and Elnashai, 2003). Buildings may be classified into distinct types, whose performance in earthquakes is likely to be similar both in nature, and in degree. There exists a basic set of characteristics, which determine the damageability of buildings:

(a)   The form of construction

The type of load-bearing structure (e.g. load-bearing masonry, reinforced concrete frame, etc.) is the most important factor affecting earthquake damage. Coburn and Spence (2002) provide a classification of the construction types found in many seismic areas of the world (Table 1-4), a similar detailed categorization of load-bearing systems is given in the EERI World Encyclopaedia Reports (Table 1-5). The vulnerability of these construction types, on average, can be expected to decrease from the top to the bottom of both lists. For instance, non-engineered structures are more vulnerable than engineered ones, and rubble stone and earthen structures are more vulnerable than timber ones, within the category of non-engineered structures.

In the European Macroseismic Scale (EMS[17]), six classes of decreasing vulnerability are proposed (A-F), of which the first three represent the strength of a "typical" adobe house, a brick building and a reinforced concrete (RC) structure. Classes D and E are intended to represent approximately linear decreases in vulnerability as a result of improved level of earthquake resistant design (ERD), and also provide for well-built timber, reinforced or confined masonry and steel structures, which are well-known to be resistant to earthquake shaking. Finally, class F is intended to represent the vulnerability of a structure with a high level of earthquake resistant design. The classification of structures (buildings) used in the European Macroseismic Scale, along with the corresponding vulnerability classes is given in Table 1-6.

It is evident that high seismic vulnerability is assigned to buildings without earthquake-resistant design. Such buildings include both engineered and non-engineered construction. Engineered buildings of this type are typically the case in regions of low seismicity, where earthquake design regulations are non-existent, or are present only in a recommendatory manner[18]. Nevertheless, engineered structures with modern structural systems, but not specifically designed against lateral seismic loads, can still provide a certain level of earthquake resistance, which can be comparable to the level incorporated in engineered buildings with ERD (EMS-98).

On the other hand, well built, non-engineered wooden, or masonry structures can behave in a fashion comparable to buildings with ERD. This may also apply to buildings to which special strengthening measures have been applied (retrofitting). In such cases, even field stone structures with good strengthening measures, or carefully detailed adobe ones, can behave well above their normal vulnerability class.

Vulnerability factors, related to the construction form, include: non-symmetrical, or irregular plans, height-wise stiffness differentials, unidirectional orientation of the lateral force resisting system (in RC frame systems), combination of different construction systems within the same structure (e.g. incremental construction of a self-built house, over time), excessive wall openings (in masonry structures), heavy roofs and inadequate roof-to-walls connections (in masonry structures), inadequate foundations' design (depth, dimensions, etc.), design faults (e.g. vertical load-bearing elements not aligned from one floor to the next).

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[17] *The European Macroseismic Scale is a modification of the Modified Mercalli scale and it is currently more used in Europe.*

[18] *In this case, consideration of seismic input in the design of engineered buildings depends upon the individual initiative of the designers, the prevalent construction practices in the region/country and the availability of funds. In case clients require(d) design against earthquakes in a country that does not (did not) have regulation to govern the design of strength of structures, it is (was) a common practice for the engineer to use the code of the country in which he/she was trained. Under such conditions, there is no consistency in the design of structures (ADPC, 2003).*

Table 1-4 Classification of construction types, found in many earthquake-prone areas of the world. (source: Coburn and Spence, 2002)

Construction type classification		Main structural classification		Building type		Other vulnerability parameters
Non-engineered buildings	Masonry Type **A** – Weak masonry	**AR**	Rubble stone	**AR1**	Rubble stone masonry in mud or lime mortar	Roof type (heavy/lightweight), craftwork quality, age, condition, structural deterioration
		AE	Earthen	**AE1**	Rammed earth construction, earth, cob, *pisé*, or solid soil	
				AE2	Composite earth with timber, or fibre, wattle and daub, earth and bamboo	
		AA	Adobe (earth brick)	**AA1**	Adobe (sun-dried earth brick in mud mortar)	
	Masonry Type **B** – Load-bearing unit block masonry	**BB**	Unreinforced brick	**BB1**	Unreinforced fired brick masonry in mud mortar	Roof type (heavy/lightweight), number of storeys, plan shape and room sizes, mortar strength, masonry bond, construction quality
				BB2	Brick masonry with horizontal reinforcement	
		BC	Concrete block	**BC1**	Concrete block	
		BD	Dressed stone masonry	**BD1**	Stone masonry, squared and cut, dimensioned stone, monumental	
	Building Type **C**	**CC**	Reinforced concrete (RC) frame, cast *in situ*	**CC1**	Reinforced concrete frame, *in situ*	Column and beam sizes, spans, structural form, regularity
	Frame structures	**CT**	Timber frame	**CT1**	Timber frame with heavy infill masonry (e.g. *Bagdadi*)	Roof type (heavy/lightweight), number of storeys, age, jointing quality, connection to foundations
				CT2	Timber frame with timber cladding, lightweight structure	
Engineered buildings	Building Type **D** – Engineered buildings	**DB**	Reinforced unit masonry	**DB1**	Reinforced brick masonry	Design for earthquake resistance
		DC	*In situ* RC frame	**DC1**	*In situ* RC frame with non-structural cladding	Conformity to earthquake design code (date of construction and code revision at that time)
				DC2	*In situ* RC frame with infill masonry	
				DC3	*In situ* RC frame with shear wall	
		DP	Precast RC structures	**DP1**	Precast RC frame with infill masonry	Design quality, structural detailing Quality of construction
				DP2	Precast RC frame with concrete shear walls	
				DP3	Precast large-panel structure	
		DH	Hybrid, or composite steel/ RC structures	**DH1**	Composite steel frame with *in situ* RC casing	
		DS	Steel frame structures	**DS1**	Light steel frame (portal frame, steel truss, low rise)	
				DS2	Steel frame, moment resistant	
				DS3	Steel frame with infill masonry	
				DS4	Steel frame, braced	
				DS5	Steel frame with RC shear wall, or core	

Table 1-5 Categorization of load-bearing systems, following the format of the EERI World Encyclopaedia Reports.

Material	Type of Load-Bearing Structure	#	Subtypes
Masonry	Stone masonry	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)
		2	Massive stone masonry (in lime or cement mortar)
	Earthen walls	3	Mud walls
		4	Mud walls with horizontal wood elements
		5	Adobe block or brick walls
		6	Rammed earth/*Pisé* construction
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)
		12	Reinforced in cement mortar (various floor/roof systems)
		13	Large concrete block walls with concrete floors and roofs
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)
		15	Designed with seismic features (various ages)
		16	Frame with unreinforced masonry infill walls
		17	Flat slab structure
		18	Precast frame structure
		19	Frame with concrete shear walls-dual system
		20	Precast pre-stressed frame with shear walls
	Shear wall structure	21	Walls cast in-situ
		22	Precast wall panel structure
Steel	Moment resisting frame	23	With brick masonry partitions
		24	With cast in-situ concrete walls
		25	With lightweight partitions
	Braced frame	26	Concentric
		27	Eccentric
Timber	Load-bearing timber frame	28	Thatch
		29	Post and beam frame
		30	Walls with bamboo/reed mesh and post (wattle and daub)
		31	Wooden frame (with or without infill)
		32	Stud wall frame with plywood/gypsum board sheathing
		33	Wooden panel or log construction
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers
	Other	35	

Table 1-6 Classification of structures (buildings) into vulnerability classes, according to the European Macroseismic Scale (EMS-98).

Type of structure		Vulnerability Class					
		A	B	C	D	E	F
MASONRY	Rubble stone, fieldstone	O					
	Adobe (earth brick)	O———					
	Simple stone	|·····O·····					
	Massive stone			O·····|			
	Unreinforced with manufactured stone units	|·····O———					
	Unreinforced with RC floors			O·····|			
	Reinforced, or confined			·····O———			
REINFORCED CONCRETE (RC)	Frame without earthquake-resistant design (ERD)	|·····O·····|					
	Frame with moderate level of ERD		|·····O———				
	Frame with high level of ERD			|·····O———			
	Walls without ERD		|·····O———				
	Walls with moderate level of ERD			|·····O———			
	Walls with high level of ERD				|·····O———		
STEEL	Steel structures				|·····O———		
WOOD	Timber structures			|·····O———			

O most likely vulnerability class; —— probable range; ········ range of less probable exceptional cases.

(b)   Age & History

The age of a building is directly related to its condition. For engineered structures, the age is indicative of the building practices and/or codes, which were in effect during its construction period; this information is very useful in estimating the structure's vulnerability. For non-engineered structures, however, the building practices remain generally unchanged in the course of time and thus, the age of a building can only give information in regard to the level of its decay. Additional factors that may also have an important effect on a building's proneness to structural failure due to earthquakes include previous earthquake-induced damage, maintenance, rehabilitation and/or strengthening measures undertaken (or not), change of use, storey additions, etc.

(c)   Quality of construction

Earthquake-induced damage is likely to be more extensive and/or severe if the quality of building materials is low (e.g. poor proportioning of earth mixture in adobe bricks), if the workmanship is insufficient (e.g. due to untrained self-help builders), or if there is a deliberate neglect of conforming to good practice (e.g. for cost-cutting reasons).

(d)   Soil & Position of structure

The soil type (and stratification) in combination with local geo-morphological characteristics (e.g. slope effects) play an important role in determining a structure's vulnerability due to strong ground motion. For instance, a building located on soft soil or over liquefiable sand stratum is likely to be more vulnerable than that located on firmer foundation soil strata. An additional consideration is the structures' arrangement over the built area. For instance, adjoining buildings could be damaged due to "pounding effects", or access may be severed due to rubble blockage in the narrow alleys around the buildings, resulting into additional life losses.

1.6.2 Damage states

In most of the developments made for earthquake loss scenarios, the seismic vulnerability of buildings has been expressed as the probable distribution of damage (for a specific type/group of buildings) following a certain level of seismic hazard. This is achieved through relating a measure of the expected structural damage to a ground motion parameter that is representative of the damage potential of the earthquake (such as intensity, or peak ground acceleration). The format used for the definition of the probable distribution of damage depends on the method of defining the earthquake hazard parameter.

The level of damage can either be quantified in financial terms, through the use of "the repair cost ratio" (RCR – the cost of the repair and reinstatement of the building to the cost of its total replacement), or it can be expressed in a more qualitatively way, through the use of a damage scale, comprised of discrete and descriptive damage classes. These structural damage states, are associated to broad descriptors, such as "light", "moderate", "severe", "partial collapse", and can be elaborated with more detailed descriptions, which may use quantitative measures, such as crack widths. A commonly used set of damage states is the six-point scale defined in the European Macroseismic Scale, presented in Appendix A. Coburn and Spence (2002) provide a more elaborate definition of the EMS damage states, for masonry and concrete frame buildings (Table 1-7).

Table 1-7 Damage states for masonry and concrete frame buildings. (source: Coburn and Spence, 2002)

	Damage level	Definition for load-bearing masonry	Definition for RC-framed buildings
D0	Undamaged	No visible damage	No visible damage
D1	Slight Damage	Hairline cracks	Infill panels damaged
D2	Moderate Damage	Cracks 5-20 mm	Cracks < 10 mm in structure
D3	Heavy Damage	Cracks > 20 mm, or wall material dislodged	Heavy damage to structural members, loss of concrete
D4	Partial destruction	Complete collapse of individual wall, or individual roof support	Complete collapse of individual structural member, or major deflection to frame
D5	Collapse	More than one wall collapsed, or more than half of roof	Failure of structural members to allow fall of roof, or slab

Using the information given in the International MSK Intensity scale (Medvedev et al., 1964), Arya (2000) provides the likely percentages of buildings (both engineered and non-engineered) to experience certain levels/types of damage, for the intensities VII, VIII and IX (see: Table 1-8). These percentages are grouped into four general categories: Most (about 75%), Many (about 50%), Few (about 15%) and Single (about 5%), whereas the description of damage grades is: Total (G5), Destruction (G4), Heavy (G3), Moderate (G2) and Minor (G1). This tabular presentation provides a crude qualitative estimation of the seismic vulnerability of buildings.

Table 1-8 Seismic intensity and maximum damage to buildings. (source: Arya, 2000)

Building Type	Intensity		
	VII	VIII	IX
Type A: Mud and Adobe houses, random-stone constructions	Most have large deep cracks; Few suffer partial collapse	Most suffer partial collapse; Few suffer complete collapse	Most suffer complete collapse
Type B: Ordinary brick buildings, buildings of large blocks and prefabricated type, poor half timbered houses	Many have small cracks in walls	Most have large and deep cracks; Few suffer partially collapse	Many partially collapse; Few completely collapse; Few have minor cracks
Type C: Reinforced buildings, well built wooden buildings	Many have fine plaster cracks	Most have small cracks in walls; Few may have large deep cracks	Many have large and deep cracks; Few partially collapse;

From Table 1-8, it is clear that the non-engineered traditional buildings, particularly the ones consisting of fieldstone or adobe walls, are liable to heavy damage, destruction and total collapse, even at moderate MSK Intensities VII and VIII. Such intensities are likely to occur in the epicentral areas of 6.0 to 6.5 Magnitude shallow focus earthquakes. In the higher Intensity of IX, which will be likely in 6.6 to 7.2 Magnitudes, Type A buildings will rarely survive and even Type B buildings consisting of unreinforced ordinary brick walls, concrete block constructions, and better quality stone structures will be destroyed on a large scale, and only the buildings of Type C, namely reinforced buildings and well built wooden buildings will have a chance to survive.

1.6.3 Vulnerability functions

Vulnerability functions (or fragility curves) relate the probability of exceedance of multiple damage states (as the latter have been previously determined) to a parameter of ground motion severity and can, therefore, be regarded as a graphical representation of seismic risk. In the case of building populations, their use yields a prediction of the proportion of the exposed stock in each damage state after an earthquake that causes a certain spatial distribution of ground motion severity (Rossetto and Elnashai, 2003). There are two approaches commonly followed in vulnerability estimation[19]:

- The analytical (predicted vulnerability): Either through detailed time-history analysis or through simplified methods, dynamic analyses of single structures and building types are carried out and the seismic performance to a given ground shaking intensity is computed, thus providing insight to the corresponding damage.

- The empirical (observed vulnerability): This "experience data" approach is based on the fact that certain classes of constructed facilities tend to share common characteristics and to experience similar types of damage in earthquakes. Based on post-earthquake surveys, data on damage for various building classes are collected and related to estimated, or measured, ground motion.

The former approach is suitable for use primarily with engineered structures and facilities, where a reasonable estimate of earthquake resistance may be made, but for which only a limited amount of damage data is available (although information of this kind is progressively augmenting in volume). The latter method is more suitable for non-engineered structures built with low-strength materials, such as sun-dried mud bricks or unreinforced masonry, whose earthquake resistance is more difficult to calculate, but for which substantial statistical damage data may be available (Coburn and Spence, 2002).

In Fig. 1-15, MSK intensity-based vulnerability curves are given for different building types, representing structural damage as an "average loss ratio", which is identical to the aforementioned "repair cost ratio". From Fig. 1-15, it becomes clear that:

- The average loss ratio increases (in a non-linear way) for all building types, as the earthquake intensity increases;

- The weaker the building (e.g. adobe, or unreinforced masonry, or – for the same building type – the taller the building is), the higher the average loss ratio is for any intensity level; and

- The existence of earthquake resisting features (like "ring beams" crowning the walls at the roof level) induces lower average loss ratios, for any building type and for the same seismic intensity level.

Arya (2000) states that when the average loss ratio reaches 60% or higher, the building approaches partial collapse, at about 75% total collapse is experienced, at about 50% heavy damage has occurred, whereas at about 30% the damage is moderate. Therefore, Arya concludes that, for saving lives, the seismic strengthening should aim to the reduction of the expected average loss ratio to well below 50%. It should be noted, though, that setting desired vulnerability goals expressed in financial terms (represented by repair cost ratios) might be misleading, as there are many different repairing and strengthening methods which are also dependent on the type of the building. Furthermore, construction costs vary significantly from place to place, and through time. It is generally accepted that even for

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[19] *Rossetto and Elnashai (2003) classify the existing vulnerability curves into four generic groups, adding to the empirical and analytical ones the judgmental, which derives from expert opinions and the hybrid, which incorporates combinations of the other three approaches.*

moderate damage levels, the repairing and/or strengthening cost of vernacular buildings is almost invariably greater than their full replacement.

A   =   Buildings in Field Stone, Rural Buildings, Unburnt Brick Houses, Clay House (1 to 1 ½ storey)
B   =   Ordinary Brick Buildings, Buildings in Large Blocks, Half Timbered Buildings in Natural Dressed Stone (1 to 1 ½ storeys)
C1 =   Buildings in strengthened masonry in cement (1 to 2 storeys)
C2 =   Reinforced Concrete and Steel Buildings, Ell Built Wooden Buildings.
A- =   A-Type, But Taller (2 or more storeys)
A+ =   A-Type, with Earthquake Resistance Features
B- =   B-Type, But Tallar (2 or more storeys)
B+ =   B-Type with Earthquake Resistance Features

Fig. 1-15 Vulnerability functions based on the MSK seismic intensity scale. (source: Arya, 2000)

 Going back to the use of the sequential damage states' system, a different type of vulnerability curves has been developed, in order to relate damage distributions for a specific building type (as a percentage of damaged buildings, per damage state), to a parameterless scale of seismic intensity. This parameterless scale of seismic intensity (PSI, or ψ) has been devised in an effort to cancel the subjectivity and the lack of continuity that are associated to the seismic intensity scales of the MSK, or the EMS type[20]. Examples of PSI-based vulnerability curves are given in Fig. 1-16, for various building types, as per Coburn and Spence (2002).
 From the aforementioned curves it can be postulated that rubble stone, or adobe masonry buildings are more vulnerable than non-engineered reinforced concrete or reinforced masonry ones, as for the same parameterless intensity value, a higher percentage of the former building type is likely to reach or to exceed a certain damage level. This becomes clear in Fig. 1-17 that illustrates the damage type thresholds between slight and no damage (D0-D1), and total and partial collapse (D4-D5), for different types of buildings.

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[20] *The PSI scale is based on the proportion of brick masonry buildings damaged at, or above, level D3 (i.e. Heavy damage, see Table 1-7). It is assumed that this proportion is normally distributed with respect to the ground motion scale. The ψ parameter is defined so that 50% of the sample is damaged at level D3, or above, when $\psi=10$, and the standard deviation is 2.5. Now, the ratios of the proportions of buildings reaching, or exceeding each damage level D0 to D5, over the proportion of damaged building (of the same type) at and above damage level D3 (i.e. the relative performance of the sample) have been found (observed) to be fairly constant, regardless the assigned seismic intensity. This relative performance of the each building sample is dependent on the building type.*
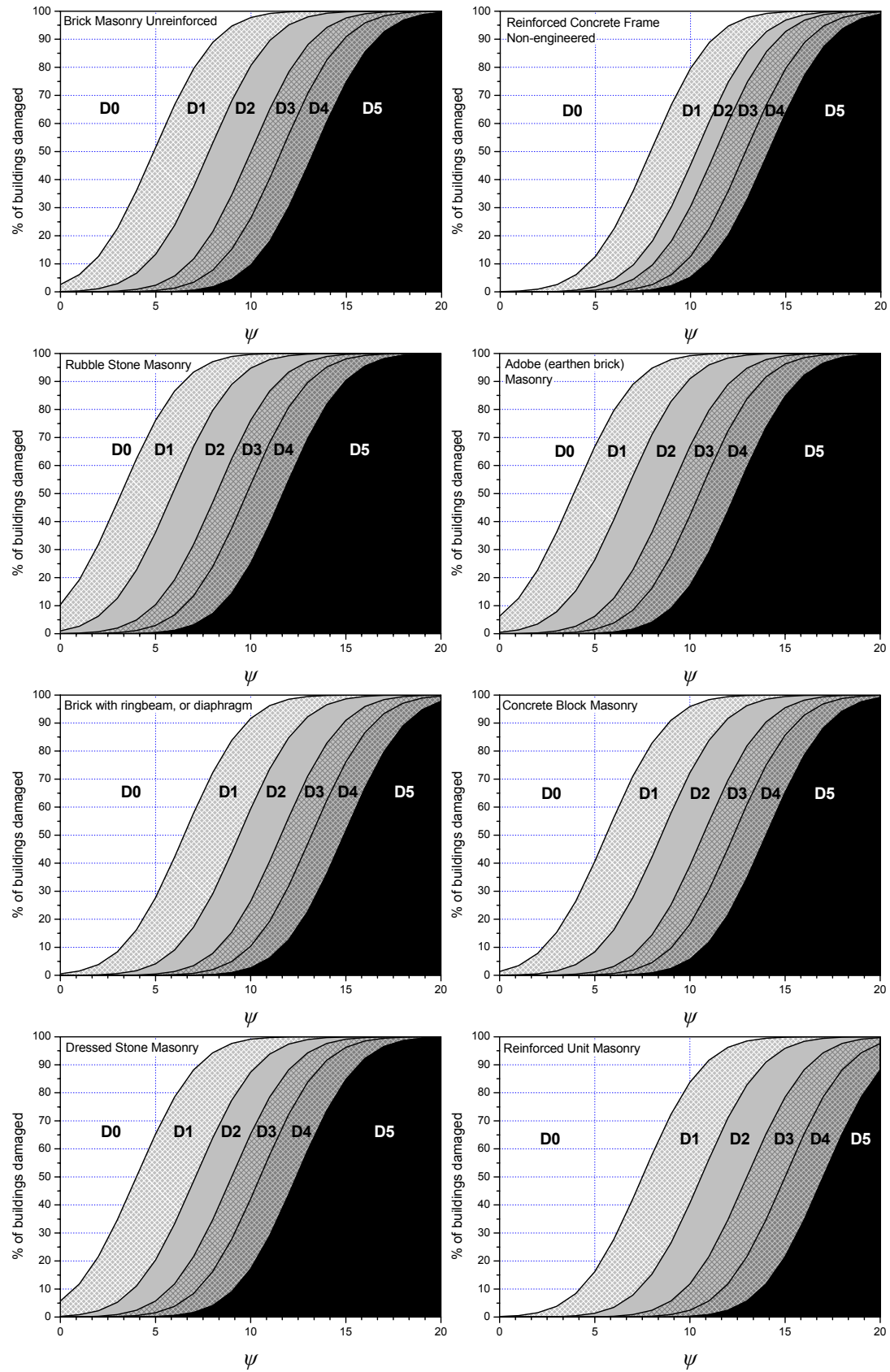
Fig. 1-16 PSI-based vulnerability curves for various building types.
(source: Coburn and Spence, 2002)
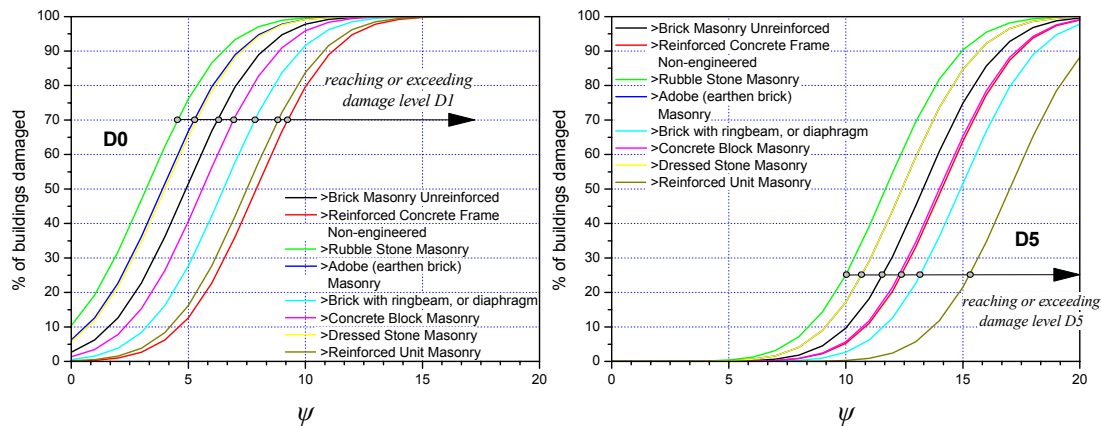
Fig. 1-17   Comparison of damage type thresholds between (a) Slight and no damage (D0-D1); (b) Total and partial collapse (D4-D5).

1.6.4 Vulnerability of slums

It would be more than ironic to argument on the vulnerability of the structures that comprise the world's shantytowns, let alone on their seismic resistance. By definition[21], a slum dwelling is one that lacks one or more of the following conditions: access to improved water and sanitation facilities, sufficient-living area (not overcrowded), structural quality/durability of dwellings and security of tenure; in this sense slum dwellings are per se vulnerable.

Taking into consideration the component of structural quality/durability, defined by the UN-Habitat Expert Group Meeting on urban indicators (UN-Habitat, 2002b – see Table 1-9), one can easily conclude that disaster-resistance, generally, and earthquake-resistance, more specifically, are not amongst the characteristics that render an urban permanent shelter an acceptable habitational solution. Although compliance to the building codes is one of the characteristics listed in Table 1-9, more attention is drawn on the protection that the structure is able to provide to its dwellers against heavy climatic conditions, rather than on its performance during the occurrence of a natural disaster. In other words, in many developing countries, disaster-resistance lies as a "step further" in the process of providing safe public housing.

Table 1-9 Characteristics comprising acceptable structural quality/durability of dwellings.
    (source: UN-Habitat, 2002b)

A house is considered as "durable" if it is built on a non-hazardous location and has a structure permanent and adequate enough to protect its inhabitants from the extremes of climatic conditions such as rain, heat, cold, and humidity:

- Permanency of structure;
- Permanent building material for the walls, roof and floor;
- Compliance to building codes;
- The dwelling is not in a dilapidated state;
- The dwelling is not in need of major repair;
- Location of house (hazardous);
- The dwelling is not located on, or near toxic waste;
- The dwelling is not located in a flood plain;
- The dwelling is not located on a steep slope; and
- The dwelling is not located in a dangerous right of way (rail, highway, airport, power lines).

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[21] *See: UN-Habitat (2002b) "Defining Secure Tenure, Slums and Global Sample of Cities", UN-HABITAT, Expert Group Meeting on urban indicators, Nairobi, Kenya, 2002.*

1.7   Synopsis

In this chapter the various different factors that contribute to the high seismic risk of non-engineered housing units in Latin American countries were presented and analysed. More specifically, the three major components that constitute the problem were separately discussed: the seismic hazard in the region, the building sample under exposure (i.e. the non-engineered structures) and its vulnerability with respect to seismic events. The analysis clearly indicates that the level of seismic hazard in the region is very high. Furthermore, the existence of a considerably precarious building stock, combined with continuing informal construction activities and vulnerability characteristics of social nature, such as poverty and lack of risk awareness, constitute a life threatening scenario in view of future earthquake occurrences, for both rural and urban Latin American settlements.

CHAPTER 2

Housing and Post-Disaster Reconstruction Policies

2.1   Introduction

This chapter discusses past and current housing and post-earthquake Latin American reconstruction policies and comments on their suitability as earthquake risk reduction measures. More specifically, the different types of public policy response towards low-income housing markets are presented and the existing models for post-earthquake housing recovery processes are outlined. The various actors involved in the sector of popular housing are described and the issue of self-help housing projects is analysed. A better insight to such projects is provided through the description of two typical case studies regarding participative construction initiatives that took place in El Salvador and Colombia. Following the discussion on the shortcomings associated to post-disaster reconstruction policies, the chapter concludes with a series of recommendations targeting on the reduction of vulnerability through the implementation of successful housing, reconstruction and rehabilitation projects.

2.2   Types of vulnerability associated to the built environment

There are different types of human activities that result into different types of vulnerabilities that may be of physical, environmental, economic, and/or social nature. The physical vulnerability, which depends on the actual location of settlements and the condition of the associated infrastructure, has been dealt with in the previous chapter. The environmental vulnerability is related to the way in which the environment is exploited, weakening its elements or ecosystems and making them more vulnerable. The economic vulnerability is generated by the lack of appropriate economic resources and by the inappropriate use of available means for improvement.

   Finally, the social vulnerability can be well divided into educational, cultural, organisational, institutional and political. This type of vulnerability comes from weaknesses of social and/or political systems and processes, such as inadequate social behaviour, beliefs, organisational structures, bureaucracy, etc. The following part of this chapter offers information on the typical forms of housing and post-disaster reconstruction policies in Latin American countries. It is evident that these policies reflect a country's vulnerability status in organisational, institutional and political terms.

2.3   The housing sector

According to Jones and Ward (1994), two broad types of public policy response towards low-income housing markets have been put into practice during the past thirty years in developing countries. First, "urban projects" were conducted, which relied upon the active support of the public sector intervention in low-income housing. This approach found its outlet in new "sites-and-service" type of programs and in the upgrading of existing settlements. Generally, the aim was for the government to work collaboratively with the so-called "self-help" settlements, in order to provide basic services and land titles, leaving much of the dwelling construction in the hands of the households themselves (and this is what the term "self-help" stands for). This projects-based approach of sponsored direct government intervention was widely espoused during the 1980s and continues today (Payne, 1984; UN-HABITAT, 1996).

   The second housing policy involved a less direct form of intervention, in which the aim was: (a) to build up the capacity of the housing market, to work more effectively, and (b) to strengthen the local urban management administrative capacity, making housing and urban development more sustainable and replicable (Jones and Ward 1994; UN-HABITAT, 1996). This meant reducing subsidies, registering property ownership, recovering service installation

and consumption costs etc. – for rich and poor alike. Since 1990, this "urban management" approach exists in parallel with direct intervention supports at the local level of municipalities.

Notable progress has been achieved in many of the Latin American countries during the past two decades in policy formulation, addressing the escalating demand for permanent shelter. The principal aim of many governmental authorities in the region is to reorganize the housing system in such way that access of the low-income population to a viable habitational solution is facilitated. This is meant to be achieved primarily by means of ample participation of the civil society. The principal lines of action towards the aforementioned goal include:

▪ Institutional modernization of the housing sector (e.g. measures against perplexing and time-consuming bureaucratic procedures);

▪ Inter-institutional coordination;

▪ Modernization of the normative frame (e.g. revision and update of the legal aspects regarding real estate property, apartments' tenancy, design and construction of new buildings, strengthening / rehabilitation of existing ones, etc.);

▪ Implementation of innovating mechanisms for financing access to popular housing (e.g. efficient loans' / mortgages' supply system);

▪ Optimization of land use and of basic infrastructure facilities (i.e. rational use of the existing natural resources, balanced urban growth, sustainable development, etc.);

▪ Decentralization (i.e. fortification of the managerial capacity of the municipal governments to plan, execute and evaluate independently their own housing projects).

As far as slums are concerned, they are now viewed in a more positive way by public decision-makers than in the past. They are increasingly seen as places of opportunity, rather than places of despair[1]. National approaches to slums have generally shifted from negative policies such as forced eviction, benign neglect and involuntary resettlement, to more positive policies such as self-help and in situ upgrading, enabling rights-based policies (UN-Habitat, 2003b).

Despite the progress realized in many institutional mechanisms, which focus on urban planning and on supplying affordable housing to domestic country-to-city migrants, several countries in the region still do not have explicit and/or coherent policies on the provision of permanent shelters. It is often assumed that, compared to the ever growing urban housing deficit, there are no significant rural shelter problems, and that rural inhabitants will, one way or the other, manage to provide their own shelter without assistance from the government, or from any other formal institutions (UN-Habitat, 1995). Additionally, the issue of rural housing has received little attention by the academia, resulting into limited published data, which could be consulted by policy-makers for guidance.

The reasons why rural housing has been assigned with a low value of development priority include: (a) the politically more organized pressure from the urban populace; (b) the absence of land ownership in rural areas, which restricts all official housing programs to be implemented only within the context of agrarian reforms; (c) the geographical dispersal of rural communities within the same country, which often induces higher costs per housing unit, due to higher distances between the building sites and the materials' procurement areas; and (d) the lack of information relevant to the existing needs for permanent rural shelters (in terms of financing, building materials, availability of professional help, etc.), as a result of inadequate means of communication (including roads, railways, public transport and telecommunication services).

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[1] *According to the UN-Habitat publication "Guide to Monitoring Target 11: Improving the lives of 100 million slum dwellers", slums can be divided into two broad classes:*

- *Slums of hope: i.e. "progressing" settlements, which are characterized by new, normally self-built structures, usually illegal (e.g. squatters) that are in, or have recently been through, a process of development, consolidation and improvement; and*

- *Slums of despair: i.e. "declining" neighbourhoods, in which environmental conditions and domestic services are undergoing a process of degeneration.*

2.4   Reconstructing the built fabric after a disaster

It can be argued that, according to a generally accepted perception, reconstruction actions account for measures taken to re-establish a community after a period of rehabilitation, subsequent to a disaster. These actions would include construction of permanent housing, full restoration of services, and complete resumption of the pre-disaster state. During the rehabilitation period, operations and decisions are taken, with a view to restoring the stricken community to its former living conditions, while encouraging and facilitating the necessary adjustments to the changes caused by the disaster.

The strategies followed in order to house survivors after a disaster can be grouped in two main approaches. In the first one, several industrialized solutions for emergency, temporary and even permanent shelters have been manufactured to meet the needs of reconstruction[2]. In the second one, housing is associated with a process and is considered as an integral part of a complex permanent reconstruction program. According to this approach, ambitious plans of community reconstruction, victims' participation, self-help construction and holistic measures of development have been proposed and implemented. Comerio (1998) distinguishes four alternative models of the post-earthquake housing recovery process:

1. The redevelopment model: complete redevelopment of the devastated area, provided by the national government;

2. The capital infusion model: infusion of the outside aid, targeted to low-income housing, provided by the national government, international aid and NGOs;

3. The limited intervention model: assumes private insurance will cover some losses, property prices will adjust, and government will assist only the poorest;

4. The market model: complete reliance on market forces to adjust, adapt and reconstruct after the disaster.

For the first three models, the course of actions may be summarized as follows:

1. Assessment of communities and beneficiaries (selection criteria[3]);

2. Assessment of housing models and designs;

3. Bidding process;

4. Project allocation;

5. Organization with the communities;

6. Execution and overview of the job.

The recent trends in policy-making, regarding post-disaster reconstruction projects, align with the principles of sustainable development. The latter should be seen as an integrative and holistic concept, striving for harmony and balance between the three spheres seen as integral to development: the biophysical environment, society and culture, and the economy. In this sense, sustainable construction is one of the integral processes of sustainable development aiming to restore and maintain harmony between the natural and the built environment, and create settlements that affirm human dignity and encourage economic equity (du Plessis, 2002). Nevertheless, sustainability, as a concept, has only recently been introduced to developing countries and is not yet a priority[4].

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[2] *Living in these units might be acceptable for short periods, in good weather conditions and urban areas, but cannot fulfil people's need for a long time and will consequently add social problems. In the long term, people start to add some part to the shelter either to compensate for the shortage of space, or protect themselves against bad weather. Overall evaluation showed that the temporary settlements not only creates social and economic problems, but also prolongs the reconstruction period (Ghafory-Ashtiany, 1999).*

[3] *The process for the selection and assessment of the communities and families to be benefited by any post-disaster reconstruction program is a very difficult task to perform, due to the large number of families and sectors suffering from the consequences of the disaster.*

[4] *This is not surprising, as large projects, which were initiated not only to face a disaster-induced housing deficit, but also to improve the housing conditions of the urban poor, were not motivated by improvements in the overall sustainability of the city, but rather by the need to improve the economic indicators of employment generation through construction activities to meet the targets set by political agendas.*

2.5   Institutions

As previously noted, there are many actors in the sector of popular housing. In housing projects that are either part of a country's customary planning, or part of a post-disaster reconstruction phase, a multitude of governmental organizations (GOs, see Table 2-1 for Central America), non-governmental organizations (NGOs) and private companies are involved. In order to give an insight of the number and nature of such actors, an extensive list is provided, for the case of El Salvador, in Appendix B.

Table 2-1 Housing and Human Development Ministries in Central America. (source: Patiño, 2000)

Country	Sectoral Governing Body	Legal Framework	Specialized Financing Institution	Responsibility of Planning & Land Ordnance	Main programs
Guatemala	Ministry of Infrastructure, Communications & Housing (MICV)	Framework law of Housing and Human Settlements (1996), Law of Regularization, Consolidation & Legalization of Human Settlements (1996)	Guatemalan Fund for Housing & Insured Mortgage Fund	MICV & the Municipalities	FOGUAVI has the Social & Private programs
Honduras	Secretariat of Public Works, Transportation, & Housing	The Sector is currently in the process of legal and institutional organization	National Fund for Construction & Housing, Social Housing Fund	National Board of Land Management & Human Settlements	Programs of: Urban Housing Improvement, Legalization of Rural Housing
El Salvador	Vice-Ministry of Housing and Urban Development - VMVDU	There is no Framework law. The VMVDU is assigned to the Ministry of Public Works	Social Fund of Housing (formal sector) & National Fund of Popular Housing (informal sector)	VMVDU, Municipalities, Freedom & Progress Institute, National Registry Centre	Program of Human Settlements
Nicaragua	Nicaraguan Institute of Urban and Rural Housing	The Sector is in the process of legal and institutional organization	Social Fund of Housing and Nicaraguan Fund of Housing (BAVINIC is in technical closing)	INVUR, Nicaraguan Institute of Territorial Studies and Municipalities	National Program of Housing, Improvement of Neighbourhoods, Emergency Housing, Self-construction
Costa Rica	Ministry of Housing & Human Settlements	MIVAH does not have a Framework law. There is a Law of the Housing Financial System	Housing Mortgage Bank (Law of the Housing Financial System)	National Institute of Housing and Urban Planning, National Registry and Municipalities	Family Housing
Panama	Ministry of Housing	Law of the Ministry of Housing (1973) Law 22 of 1991 that establishes the National Housing Policy and Law 61 (1996) creating the Urban Development Program	National Mortgage Bank (Mortgage Fund & Fund of Guarantee created in July 1996 for financing social housing)	Ministry of Housing & Local Governments	Program for Prompt Response to Social Housing, Housing Improvements (loan for materials), Regularization of Spontaneous Settlements

Furthermore, all the countries in the Central American region have been creating joint coordination networks for the comprehensive management of disaster risk. These centres play an important role in prevention, mitigation and emergency management, as well as in many aspects of post-disaster reconstruction activities, including housing. A listing of such cooperative entities, for the Latin American region, is given in Appendix C.

2.6   Self-help housing projects

According to Arrigone (▆▆▆), self-help can be defined - in the broadest sense - as a process whereby individuals, or groups, uplift the quality of their life by using their own resources. In a narrower sense, self-help housing can be defined as the system by which low-income persons or families, work individually or in groups, providing their labour on a voluntary basis, generally without remuneration, to build, extend or improve their houses.

Through self-help housing projects (the Spanish terms being: *autoconstrucción* and *autoproducción*), the exploitation of locally available resources is necessitated, the latter including building materials, traditional technologies, craftsmanship skills, professional expertise, informal small entrepreneurship, people's savings and community organization. Project participants may receive assistance, whether financial, technical, administrative, or in the form of building materials / tools, by governmental and/or non-governmental organizations, church foundations, private companies, etc. There are several different forms of self-help housing projects, the most common of which are listed and explained in Table 2-2. The classification of self-help housing projects by scale is given in Table 2-3, as reported by (Rodríguez and Åstrand, ▆▆▆).

Table 2-2   Different forms of self-help housing projects. (source: Arrigone, 1994)

Type	Description	Example
Spontaneous unaided self-help	Persons, or households, work individually to satisfy their own needs without any external assistance.	The construction and upgrading of dwellings in most of the squatter settlements and rural areas around the world, carried out spontaneously by people without any financial and technical support, are typical of this form of self-help.
Spontaneous unaided mutual help[5]	A group of persons, or families, work together helping each other to satisfy their needs without external assistance.	Families in rural areas in developing countries often help each other to build, extend, or repair houses, small community buildings (such as schools and community halls), services (such as water supply) and fencing.
Aided self-help	Persons, or households, work individually to satisfy their own needs and receive some assistance, either financial, or technical, or in the form of building materials, community organization, or other. The assistance may be provided by private, semi-private or public organizations, or a combination thereof.	Many aided self-help housing projects have been implemented in developing countries since the late 1950s, some massively in urban areas. International and national development financing organizations, GOs and NGOs were involved in supporting the planning and implementation of this form of self-help. Notable examples in Latin America could be mentioned in Chile, Colombia, El Salvador.
Aided mutual help	A group of persons, or families, work together, helping each other to satisfy their own needs and receive some assistance, either in the form of financial, or technical services, building materials, community organization, or other. Private, semi-private, or public organizations, or a combination thereof may provide the assistance.	This alternative has been used in low-income housing projects to provide new dwellings to project participants; it falls under the same World Bank approach of progressive development[6]. The upgrading of services (sewerage, water, storm water drainage, roads and pedestrian ways) in squatter settlements is also an activity in which this form of self-help has frequently been used. The upgrading of squatter settlements in the main urban areas of Brazil such as Rio de Janeiro and Sao Paulo is worth mentioning (Arrigone, 1987a; Arrigone, 1987b; and Arrigone, 1991).

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[5] *Commonly referred to in Spanish as "*Ayuda Mutua*".*

[6] *A method of housing construction, or upgrading, achieved through staged development, in which the infrastructure and sometimes parts of the house are built by a contractor, and the rest of the dwelling is completed by the family; or through self-help, which can be organized in the following ways (Keare and Parris, 1982): (a) mutual help, in which families work together in groups; (b) self-help construction, in which a family hires a contractor to build its house; (c) self-help construction, in which a family hires and supervises individual labourers; and (d) self-help construction, in which a family uses its own labour to build or extend its house.*

Table 2-3 Classification of self-help housing projects according to scale.

Scale	Description
Large	National programmes, such as those implemented in Algeria and Cuba. These programmes typically involve great efforts in planning, coordination and training, requiring political commitment at national level and long term economic possibilities. Normally, the goal is to build tens of thousands of housing units per year.
Inter-mediate	Self-help housing programmes carried out by regional, or local authorities, such as municipalities; they might also be implemented in collaboration with NGOs. Normally, the goal is to build several thousand of housing units per year.
Small	These programmes are often run by NGOs working with housing, or development in general. Sometimes, these projects can also be carried out by Community Based Organizations (CBOs), cooperatives, or private companies. The size of these projects is often 50-500 units.

Important aspects of self-help housing include: cost of construction, technical quality, construction time, social and economical development and gender awareness. Organized self-help housing is often selected as a way of reducing the cost of construction through participation of the households. Generally, construction costs are lower in organized self-help housing projects than in contractor built dwellings of similar quality (Rodríguez and Åstrand, 1996).

Fig. 2-1   Belém, an area of "self help housing" built on the Amazon River in Iquitos, Peru (1987). (source: http://uts.cc.utexas.edu/~gwk/courses/grg319/slides/popslides/fig23pop.html)

Fig. 2-2   Future homeowners work on their house in El Salvador.[7] (source: basin news / June 2002 / No. 23 : http://www.skat-foundation.org/resources/downloads/pdf/as/basinnews_23.pdf)

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[7] *This housing project was implemented by Habitat for Humanity International (HFHI), within the framework of a multinational disaster response effort undertaken in Honduras, Nicaragua, El Salvador, Guatemala and the Dominican Republic, after the 1998 occurrence of Hurricanes Mitch and Georges. Habitat for Humanity International (HFHI) is a non-profit, ecumenical Christian housing ministry that pursues the elimination of homelessness and poverty housing from the world. As of July 2000, 18 months after the inception of the Special Programme, nearly 5,000 homes had been built in Honduras, Nicaragua, El Salvador, Guatemala and the Dominican Republic.*

In the following sections, two case studies of two relatively recent post-earthquake housing reconstruction projects are discussed, namely in El Salvador and in Colombia, addressing the sheltering needs that arose from the earthquakes of 2001 and 1999, respectively.

2.6.1 Case Study: El Salvador

In the framework of the reconstruction process in El Salvador, following the 2001 earthquakes, there were (and still are) many methods for co-operation, which make use of the resources and expertise of NGOs, government, private companies and beneficiaries, in an attempt to rehabilitate the country's building stock. These different types of co-operation range from very intensive supervision, to a basic delivery of materials, and also from minor integration of beneficiaries, up to the point in which they are almost fully responsible for a reconstruction site (Rademaker, 2002).

The majority of projects focused on the reconstruction of El Salvador are still being executed using the mutual assistance type of co-operation between the assisting organization and the beneficiaries. Outside this concept, there are either projects being executed without any participation of the beneficiaries at all, or projects in which the beneficiaries execute the construction nearly without any assistance. Rademaker (2002) reports the realization of two distinct types of reconstruction projects based on the housing type that is provided[8]: (a) Concrete-block houses, and (b) Adobe houses[9].

For the production of concrete-block houses, several organizational schemes were applied. In the first weeks following the earthquakes, building materials were donated to the people in need by Churches, city councils and other organizations[10]. The donors usually left the actual construction of the houses for the beneficiaries to execute, although they were sometimes involved in helping to organize the construction. There was virtually no provision for training the locals in the basics of construction practices, or for providing technical support or supervision. The quality of the resulting housing units is, therefore, directly dependent on individual skills.

Following this somewhat hasty response to spontaneous reconstruction activities on behalf of several organizations, the government made a rather extensive use of private companies in a more organized way. This approach aimed at the construction of a high number of houses in large-scale sites and the subsequent relocation of the affected population to their new dwellings. The private companies were sponsored by government subsidies and, typically, used a number of construction workers accompanied by a paid assistant; an engineer, or experienced construction worker, was also employed to supervise them. In rare cases, private companies were hired by NGOs to carry out the construction of houses provisioned in the project. The quality of the resulting housing units, in this case, is dependent on the financial resources, the level of professional expertise and the time spent by the private companies.

Finally, within the context of self-help housing projects, a number of beneficiaries worked together with a schooled construction worker, in order to build concrete-block houses. This construction worker was supervised by the assisting organization in charge of the self-help project and, in some cases, an engineer had supervision over a number of these so-called "*maestros de obras*". The quality of the constructed houses depends on the size (and former experience) of the organization, the size of the project (e.g. number of beneficiaries working with an experienced construction worker and number of construction workers per supervisor and per engineer) and the degree to which the beneficiaries were involved in the construction project.

Adobe housing projects are generally cheaper than the concrete-block ones, reserving a higher degree of participation for the beneficiaries; they are also usually located in rural areas

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[8] *His observations were made during field studies in El Salvador between October 2001 and May 2002, while his research was assisted by FUNDASAL* (Fundación Salvadoreña de Desarrollo y Vivienda Mínima).

[9] *Rademaker notes a lack of projects addressing the construction of* bahareque *(wattle and daub) houses. Note, that the description of both adobe (sun-dried mud brick) and* bahareque *structures is given in detail in Chapter 3.*

[10] *Some families could buy their own materials (no assisting organization was involved, whatsoever). These cases, though, were not very common, as (relatively) rich people, that could afford to buy building materials, were more likely to hire professionals for the construction of their dwellings.*

where traditional building techniques are still prevalent, and they are carried out by organizations that are more idealistically motivated (e.g. organizations that foster sustainable construction methods, preservation of cultural aspects, etc.).

Adobe construction initiatives in El Salvador were carried out either without any input from assisting organizations, or within self-help projects. In all cases, the available knowledge of the locals, deriving from centuries of experience in building with earth, was put into practice. Nevertheless, experience alone has been proven inadequate to address structural problems related to the earthquake resistance of adobe houses, even more so in cases where technical support has not been available.

Focusing on the cases in which technical assistance was available, Rademaker (2002) marks that, through the most intensive form of cooperative construction process, the people were trained on how to build an adobe house by actively participating in an example-project[11]; then, the same people were used as supervisors in following, wider construction projects. From the assisting organization an engineer usually visited the projects at various times. In other cases, experienced adobe construction workers worked with the beneficiaries, while explanations were given during the construction.

Other housing solutions have been sought, though, apart from concrete-block and adobe constructions. For instance, about 30% of the houses built as part of a housing project undertaken by the Salvadoran Foundation of Development and Low-cost Housing (FUNDASAL) and co-financed by KfW[12] were steel structures, suitable for dismantling. This is mainly in view of the fact that land tenure was dubious for a considerable part of the plots. Yet, the standard house in this project did consist of hollow block walls and concrete tile roofing[13]. An alternative type of housing, consisting of prefabricated units, was also provided by governmental organizations through the financial support offered by the government of Japan. The latter gave approximately $2.1 million to the GOs for the procurement of materials to construct 10,000 units of prefabricated housing and about $345,000 to the Japanese Red Cross for emergency shelter.

As a general conclusion, it is evident that there is a plethora of post-earthquake reconstruction policies in El Salvador. Each NGO/project has implemented a different way of offering help to the earthquake victims, resulting into a considerably wide range of "finished products" (i.e. permanent dwellings), in terms of structural performance (earthquake resistance being a key feature) and durability. It seems that the prime interest of many involved in the reconstruction phase was the maximization of the "beneficiaries/budget" ratio, possibly in the expense of quality. Under the light of this estimation, an inspection of the newly constructed dwellings is considered to be necessary.

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[11] *One such hands-on training project began as an initiative by two second-year Civil Engineering students at Imperial College, London, under the supervision of Dr Julian Bommer. The primary objective of this project was to disseminate knowledge regarding simple, effective techniques, which were aiming at the improvement of the seismic resistance of adobe buildings, through a participatory process of the local community. The construction of the adobe building (that would serve as a day-care station) took place in the village of Condadillo. See: "Improved Adobe in El Salvador", a powerpoint presentation to the EERI conference in Oakland, CA., 2002, by D. Dowling, in: www.world-housing.net/Tutorials/AdobeTutorial/Reference_7.pdf, and the expedition description of the students' group from the Imperial College to El Salvador, in: http://www.cv.ic.ac.uk/el_salvador/index.html.*

[12] *KfW is a German banking group that provides (among other services) support to reconstruction initiatives in developing countries, through financial aid and banking expertise (see: http://www.kfw.de/EN/Inhalt.jsp).*

[13] *In the framework of this particular project, up to 2,000 low-cost houses and their related basic infrastructure services were to be reconstructed in four communities, located in the eastern part of the Department of La Paz, one of the country's, most affected areas by the earthquake. A Project Implementing Unit (PIU) was created that was in charge of all essential preparatory and implementation activities in the project area. The beneficiaries were selected by the respective local authorities on the basis of detailed surveys conducted within the framework of the project, following a set of criteria mutually agreed upon by FUNDASAL and KfW. Community workers of the PIU mobilized the beneficiaries and supervised them during the construction phase. About seven families at a time were organized into one construction team responsible for constructing the houses, on a self-help basis, with the support of a skilled brick layer (see: "EL SALVADOR: Post-earthquake Reconstruction of Housing", in . GITEC News Letter, December 2001, http://www.gitec-consult.de/New/Pdf/46.pdf).*

2.6.2 Case Study: Colombia

Lizarralde (2000) gives a thorough insight to the reconstruction processes that followed the 1999 earthquake in Colombia[14]. After the disaster, the State responded by providing a 1.7 billion pesos fund called FOREC (*Fondo para la reconstrucción del eje cafetero*), lead by the Presidency. The fund was created from resources of the National Budget, donations and financing of the World Bank. The Colombian government opted for an institutional structure that involved the participation of the private sector. The affected area was divided in 32 zones, or regions, and reliable NGOs (all non-profit institutions with the most effective management infrastructures) were selected to administrate each zone. Each NGO received the responsibility of one town or a section of a big city. The Coffee Growers' Federation (CGF) was selected to manage the resources of the rural areas.

The reconstruction program of the Coffee Growers' Organisations allowed people to repair or build houses with any of the different choices available in the market. The affected families could receive financial aid, information and technical assistance offered by the program through any of the three possible options: (i) prefabricated houses promoted by the CGF[15], (ii) houses from other NGOs' programs, or (iii) houses of layout and construction method of individual preference. For the construction phase, people could choose between building themselves or hiring labour. Whatever the option used, the house had to be earthquake-resistant in order to be eligible for funding. For this purpose, twenty-three specialized engineers were selected with the task to insure the earthquake-resistance of the units.

The technologies, among which the beneficiaries could choose, ranged from houses in *guadua*[16] to traditional masonry and reinforced concrete structures. Especially for the cases of self-help projects, the CGF supported the rural community with education and technical assistance. For instance, the Federation developed in joint venture with the German Government a program for the construction of 300 self-help houses, following the traditional *guadua* building technique. The institutions of the venture provided the resources and the community provided the labour force.

To reinforce the self-help programs, the CGF published an educational guide (manual) for the construction of earthquake-resistant one- and two-storey houses. The guide, illustrated with multiple colour drawings and schemes, provided not only technical instructions but also general knowledge in a basic language appropriate for communities with little education. The guide described processes and recommendations for concrete and masonry construction (Fig. 2-3). As a complement to the same program, a second guide was provided to the community. The latter described processes and recommendations for construction of one-storey houses using traditional technologies, adopting *guadua* as the main structural material. Also in this case, colourful easy-to-read graphics were used to reach most of the population[17]. The actual construction was supervised by a selected group of specialists in order to guarantee the earthquake-resistance of the structures and finishing.

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[14] *The January 1999 earthquake in Colombia left 1,170 dead, 150,000 homeless and destroyed almost 40,000 houses, with 1.66 billion US dollars in direct damages. The rural reconstruction program, developed by the Coffee Growers' Federation (CGF), was based on helping the community to cope with the situation, through an efficient institutional model. An ambitious housing agenda was developed, aiming at providing with permanent shelter to more than 10,000 peasant families, within a period of 10 months.*

[15] *Comprised of prefabricated modular systems. However, other "mixed" systems were used, including modular steel timber structures with brick masonry or bahareque divisions.*

[16] *A traditional form of construction that involves the use of a type of endemic bamboo (guadua angustifolia, or "giant American bamboo", as it is known today). Support poles, tie beams, roof trusses, rafters and struts are made out of this bamboo. The whole structure is held in place either by tightly bound liana or by nails. The siding for housing is typically fashioned from green bamboo culms, split longitudinally with an axe at several points on each node and flattened in unfinished, board-like planks, about twenty to twenty-five centimetres wide. These are fastened to the frame with galvanized wire, or nails (Parsons, 1991). When the hollow inter-nodal sections of a beam are filled with cement at appropriate points, resistance to compression is substantially enhanced, which extends the range of design options (Hidalgo, 1974).*

[17] *More on manuals targeting self-help projects can be found in Chapter 5.*

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Fig. 2-3 A page from the construction manual developed for a self-help construction project in Colombia. (source: Federación Nacional de Cafeteros de Colombia. "*De los corazones sismo resistentes del Quindío para Colombia: Guía practica de construcciones sismo resistentes para viviendas de uno y dos pisos*", Quindio, 1999)

2.7 Shortcomings

Despite considerable progress has been achieved in developing countries in the past two decades in policy formulation, there is a widening gap between the latter and the implementation process. As a result, the status of low-income housing delivery is far beyond being satisfactory. The main shortcomings and/or constraints for this situation include: lack of effective implementation strategies, inadequate supply of affordable land and infrastructure, poor safeguard of property tenure, inadequacy of housing finance systems, poor utilisation of local building materials and technologies, lack of support to small-scale construction activities, inappropriate standards and legislation, inadequate participation of communities in shelter development process and support to self-help (Erguden, 2001).

Being more specific about these shortcomings, let us refer to the difficulties that were faced during the USAID housing reconstruction activities in El Salvador (see: USAID, 2002). The mission had planned to complete 7,135 houses by July 31, 2002 under Phase I of the housing reconstruction program (see Appendix B). However, only 3,903 houses or 55% of the number planned, were actually completed on that date. In general, the shortfall was due to coordination and planning problems at the outset of the program, inflexible payment procedures that caused liquidity problems for some contractors, and weaknesses in the supervision of the contractors employed by the grantees (a group of GO and NGOs). As a result, houses were not being delivered to the beneficiaries as quickly as planned.

The shortcomings associated to the post-disaster reconstruction policies originate from the more general policy-making area of risk management strategies. One consistent drawback in the risk mitigation processes of developing countries has been the lack of planning and financial protection against disasters. Traditionally, developing countries have relied on emergency transfers from their limited government budgets, reallocation of existing loans, and donations from international agencies to fund their disaster losses. This use of resources for reconstruction financing places an increasing strain on the ability of the countries to fund longer-term economic and social development programs (Freeman et al., 2003).

Financial problems, though, are not the only obstacles in the risk reduction processes, undertaken by the majority of developing countries. In technical terms, the expertise and methodologies are readily available within the scientific and technical communities to generate appropriate standards of design and construction for disaster-resistant structures and critical facilities. In many developing countries, nevertheless, people with the right training, skills and motivation are in short supply. At the same time, professional structures may be weak, so that nationally recognized standards of professional qualification and conduct are lacking. The problem is not so much that codes are inadequate, since most of

the countries have adopted building codes requiring disaster-resistant design and construction, but that they are not enforced effectively.

2.8   Recommendations

The most important recommendation for successful housing, reconstruction and rehabilitation projects is that they should proceed in ways that reduce the future vulnerability associated to the earthquake hazard (therefore, risk) and promote development objectives. These risk reduction actions should aim for the minimization of all types of vulnerability components, which are related to the built environment. Therefore, the recommendations may separately address the issues of physical, environmental, economic, and social vulnerability. Nevertheless, the fact that the aforementioned components are strongly interrelated has to be taken into consideration.

Finally, it should be noted that in this section, the recommendations proposed do not address the multi-factorial problems of rapid urbanization and uncontrolled construction of unofficial, precarious dwellings.

2.8.1 Physical vulnerability

Countries should generally invest in disaster prevention and mitigation measures, in order to avoid the need of rebuilding their housing stock after a disaster occurs. Land-use planning, building codes and proper construction standards should be developed prior a disaster occurrence. If not carried out before, reconstruction after a disaster should provide the opportunity to implement proper risk reduction measures for the future[18].

The design and construction of hazard-resistant structures constitute some of the most cost-effective means of reducing risks. The existence of an integral system of building codes, construction standards, planning controls and building by-laws is essential to protect the built environment from unnecessary loss, or damage from natural hazards. This system should be:

▪ Realistic, given the economic, environmental or technological constraints of each country;
▪ Consistent to the current building practice and technology;
▪ Regularly updated in the light of developments in current knowledge;
▪ Fully understood and accepted by the professional interests that relate to the legislation; and
▪ Enforced, to avoid the legislative system being ignored, or falling into disrepute.

Within this context, the following issues should be addressed, through effective legislative and executive forms:

1. Site selection: It is imperative to designate/locate an adequate site for reconstruction. During the process, factors such as local geology and seismicity, specific geotechnical characteristics and existing site effects should be taken into consideration. The relocation of a village or a town, which generally inflicts adverse socio-economic and cultural aspects, should be done if the existing site poses great danger to the reconstruction (e.g. if a landslide is probable in the vicinity, or if the site is close to a fault line).

2. Seismic-resistant design: All new structures should be designed against earthquake, according to the expected earthquake hazard of the region. The construction materials to

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[18] *It is less costly to incorporate structural mitigation components into new structures, than it is to retrofit existing ones. Ideally, mitigation measures are undertaken during reconstruction to avoid recreating prior vulnerable conditions. One good example is the reconstruction and mitigation program undertaken in Peru by the NGO Caritas. In consultation with the affected communities, this NGO promoted the use of local earthquake-resistant materials for housing reconstruction. To directly assist the most needy households, Caritas used a work-for-materials program in which locals received materials in exchange for participation in community projects. An earthquake the following year proved the success of the project: most houses built during the Caritas project withstood the earthquake measuring 6.2 on the Richter scale (Schilderman, 1993).*

be used should be of high quality, reasonably accessible and not excessively costly[19]. The environmental compatibility of construction materials and processes should also be considered. More on this issue is presented in Chapters 4 and 5.

3. Construction process: The construction work of the designed dwelling should be done either by certified construction companies or by trained people under the direct supervision of certified engineers. Quality control and supervision of all construction stages are the key-elements to successful (re)construction. For participatory housing (re)construction projects (i.e. with the participation of the house owners), one should not allow untrained and/or unsupervised people to build their own dwellings.

2.8.2 Environmental vulnerability

This issue is closely related to environmental sustainability issues, which are often disregarded when housing (re)construction projects are being conceived and implemented in developing countries. Many policy-makers justify this omission, as the top priority objective is to house the maximum number of people in the minimum possible time.

Ideally, though, a number of technologies for production of new building materials that are cost-effective and eco-friendly[20] should be explored in developing countries, as the availability of conventional construction materials is expected to fall considerably short of their demand (both globally and in the countries under question), despite initial improved productivity. Furthermore, large-scale, centralized production leads to large transportation distances of raw materials and end products, high marketing costs and other add-ons. Contrary to this macro-production system, local micro-production facilitates distribution of wealth and power, leading to a balanced growth (du Plessis, 2002).

However, most of the technologies aiming at cost-efficiency and eco-compatibility are still in the experimental or demonstration stage, thus requiring the "luxury" of time for their development. Nevertheless, there exist some traditional technologies, which incorporate environmental requirements. Examples of these technologies include earth-based construction, the use of timber from sustainable managed sources and the use of other organic products such as straw and bamboo. It is indisputable, though, that the aforementioned building techniques went into general disfavour due to the poor behaviour of traditional dwellings against seismic or severe meteorological events (e.g. Hurricane Mitch). Additional to this reason, traditional materials/methods are associated to poverty, while industrialized ones represent for the local population a more "modern" and "noble" status of living (see Chapter 3).

2.8.3 Economic vulnerability

Low-cost residential construction and housing reconstruction projects should be strongly related to the opportunities for economic recovery in the community. Combined with the creation of local employment opportunities and with the regional construction market, housing projects may enhance both the psychological and the material well-being of the survivors. Examples of successful reconstruction and rehabilitation programs that simultaneously addressed both the need to provide income support and the need to reconstruct are:

- The workfare community reconstruction projects, following the floods in Gujarat, India, which provided both needed work and income protection for poor families, as well as necessary reconstruction activities (Bhatt, 2001);
- The workfare projects following the 1985 earthquake in Mexico City, which created more than 175,000 jobs for the victims of the event (Kreimer and Echeverria, 1998).

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[19] *For example, if high quality constitutive materials for concrete (sand, gravel, water and cement) cannot be obtained or if they are expensive, the use of a concrete frame structure should be avoided and the structure should be designed using steel or prefabricated members.*

[20] *For instance, the utilization of industrial and agricultural waste, or renewable materials, such as sugar cane, bamboo, etc.*

2.8.4 Social/Political vulnerability

Summing up the various recommended policies and institutional frameworks, as well as the suggested extent of people's participation in the public housing and post-disaster reconstruction projects, the following points are noted (largely based on the ideas stated by Freeman et al., 2003):

- Governments should analyze the risk associated to earthquake events. Techniques for evaluating the seismic risk exist and most countries have the necessary data to assess seismic hazard exposure and vulnerability. What is lacking is the time and resources to integrate the available information, thus limiting the ability of governments to plan for disasters instead of only responding to them. The evaluation should be done at the national, regional, and municipal levels, addressing all essential infrastructure and buildings (priority should be given to schools and hospitals).

- A clear inventory of obligations, for which the government is responsible, should be created. There should generally be a role-casting plan dividing the tasks and the consequent responsibilities between the different actors that are expected to take part in the relief and post-disaster reconstruction phase. For instance, if the government is responsible for a risk, this should be made clear and the obligation should be budgeted, prior to the hazard occurrence. This means that the financing of the losses should be decided whether it is to be realized through reserve funds, calamity funds, contingent credits, insurance or through external credits.

- It is evident that there exists an international consensus that solutions based on popular participation are necessary to improve housing conditions for low-income households. Nevertheless, the issue of the way and the extent to which people should participate to reconstruction projects is still open to debate.

- Taking advantage of the population's awareness of the effects of disasters, the reconstruction stage should provide an opportunity for the implementation of educational and technical assistance programs, which could mitigate the effect of future natural hazards. This is also an opportunity to correct previous technological, or structural deficiencies, common to residential construction, and to educate the community about the importance of maintenance and the correct reinforcement of structures. The build-up of self-respect and self-confidence of the residents, as well as the encouragement towards gender equality are some of the additional benefits of such popular educational projects.

- Population awareness, however, is not always a fact. Most of the communities are not fully aware of the physical vulnerability that is associated to their built environment with respect to earthquake occurrence. Even if they are aware of the existing seismic risk, they are either not confident about the positive impact of appropriate seismic strengthening measures, or convinced that undertaking such measures is not a top priority. It is evident, therefore, that public awareness projects should be carried out. The most appropriate way to sensitize people is by demonstration projects, as the example described in Appendix D.

- In order to gain the fastest economic and social reconstruction, permanent residential programs must be implemented as soon as possible after the disaster. As many authors argue, several social negative consequences and undesirable effects in the built environment can be the result of delaying the permanent reconstruction process by allowing programs of temporary shelter. Different in their very nature, urban and rural low-cost housing reconstruction projects should be considered in their own distinct ways. Affected communities with traditional cultural roots are usually sceptical to external projects of intervention. Therefore the reconstruction approach for traditional poor communities must not only meet technical and physical needs but also must involve a cultural perspective (which, on the other hand, should never be in expense of safety)[21].

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[21] *Examples of "good practice" rural housing projects are given in Appendix D. These are reproductions from Skat Consulting publications.*

2.9 Synopsis

In this chapter, elaborate information on past, current and post-earthquake housing policies in Latin American countries is presented and linked to the existent seismic risk level in the region. The urgent need of undertaking seismic risk mitigation measures is emphasized. The focal point of these measures is the reconstruction process, which should lead to the alleviation of both the qualitative and the quantitative deficiency of the existing building stock. Reconstruction policies should aim for the minimization of all types of vulnerability components, which are related to the built environment, while promoting development objectives and sustainability perspectives.

CHAPTER 3

Earth-based construction

3.1   Introduction

The scope of this chapter is to briefly present the earth-based construction practices, which are still found in different parts of the world. Following some epigrammatic historical data, the social acceptance of earthen buildings is argued. In the next part of the chapter, various aspects of earth, as a building material, are described, such as its composition, its stabilizing agents and the associated testing methods. A short description of the different types of earthen buildings follows, focusing on the building practice of the adobe type, typically present in Latin American countries. Finally, the main points of the chapter are summarized in the synopsis.

3.2   Historical background

Ten thousand years after man devised means of constructing permanent sheltering, earth probably remains world's commonest building material. Today, one third of mankind is still dwelling in earth structures, while in developing countries this figure represents more than one half of the local population (Minke, 2000a & Houben and Guillaud, 1994).

Some of the most magnificent monuments, part of the global cultural heritage, continue to be enduring proofs of earth being used for construction purposes throughout many millennia. In Europe, one of the oldest settlements is situated in Thessaly, Greece (Argissa, Nea-Nicodemia, Sesklo), where primitive dwellings dating from the 6th millennium B.C. were of woven wood and clay: these dwellings subsequently evolved into groups of square structures built from sun-dried brick (adobe). The use of the latter in combination with tuff, gypsum, schist, marble and wood can be also traced in the magnificent Minoan palaces of Knossos and Phaistos (Crete, 1700 B.C. – see Fig. 3-1a). Clay was sun-dried for adobe bricks (average dimensions of 460-610x350-400x100-130 mm) using straw or seaweed as binder, while the roofs were covered with *"lepidha"*, a bluish-black impermeable clay, for weather proofing (Graham, 1987).

As one continues to garner information from archaeological findings, a planet-wise mosaic of diverse earthen structures can be clearly seen. In the African continent, homes constructed from woven reeds and branches covered with clay, or filled with clods of earth were used in settlements found at the Merimd and Fayum sites in the Nile Delta (Egypt, 5th millennium B.C.), while the remains of mud brick walls as part of fortification formations, can still be seen in the desert (Fig. 3-1b). In the Middle East, the oldest dwellings of Jericho (8th millennium B.C.) were round, with stone-bedded foundations and walls consisting of earth bricks, in the form of hand-shaped loaves. In China, the use of earth brick in-fills for timber frame buildings is alleged to date from the Han dynasty (300 B.C. to 300 A.C.) and in the American continent the appearance of sun-baked earth bricks is connected to the building practices of the pre-Colombian civilizations that flourished in Central America.

(a)   (b)

Fig. 3-1 (a) The palace of Knossos in Crete; (b) Egyptian Mud Brick Wall at Medinet Habu.

3.3   Global distribution of earthen housing

Evidence of earth building can be found all around the world. Through trial and error, the traditional societies managed to develop several earth-based building techniques, properly adjusted to the local soil type and climate conditions and to their cultural and economical backgrounds. There exists a certain (denser) distribution pattern of earthen housing (Fig. 3-2), which, nevertheless, does not coincide with places of specific climate, seismic, and/or socioeconomic characteristics. Overview of Fig. 3-3 (global moderate to very high seismic hazard distribution) and Fig. 3-4 (global rainfall distribution) supports this conclusion.

Yet, there are cases where the population sheltered in earthen buildings are the inhabitants of countries often struck by natural disasters, such as earthquakes and floods (e.g. most of the countries in Central and South America – see Figs.3-2 to 3-4). Only in this part of the world, between 1972 and 1999, extreme geological events killed 65,503 people and affected 4.4 million others (OFDA/CRED). As described in Chapter 1, the poor seismic performance of traditional, inadequately maintained, self-built earthen constructions bears a substantial share of the death toll.
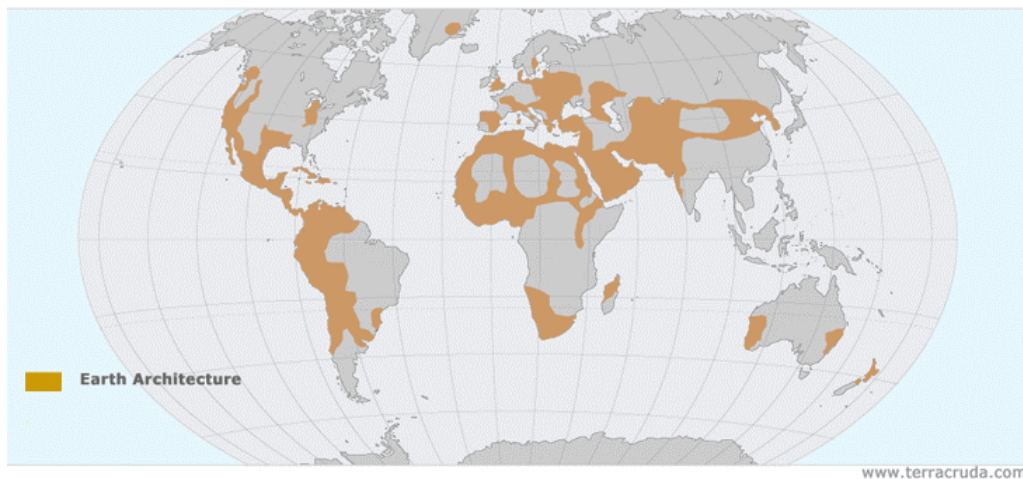
Fig. 3-2 Map of global earth building distribution.
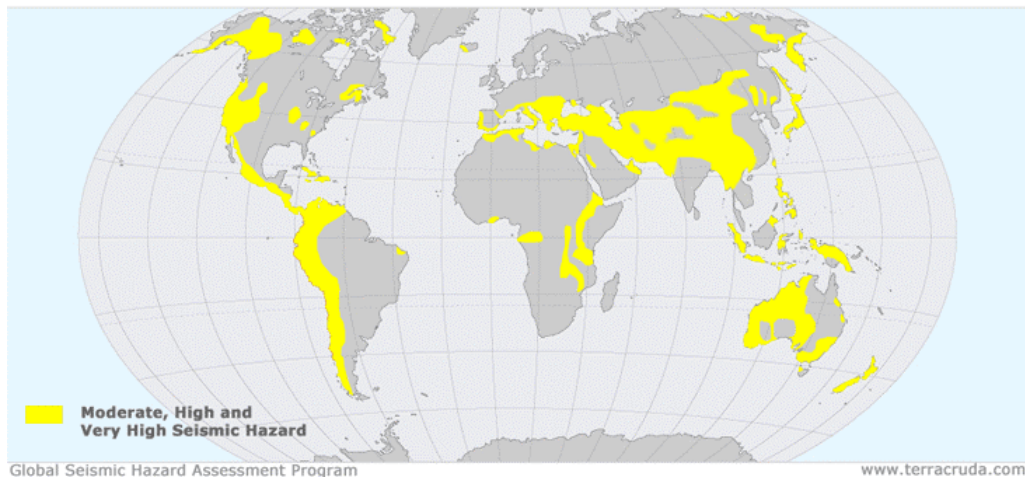
Fig. 3-3 Map of global moderate to very high seismic hazard distribution.
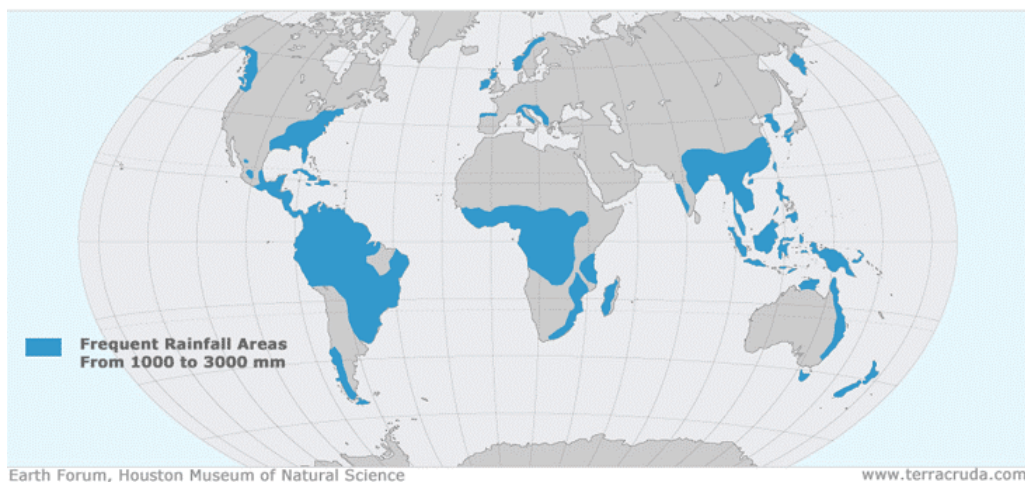
Fig. 3-4 Map of global rainfall distribution (with densities varying from 1000 to 3000 mm/year).

3.4   Social acceptance of earth buildings

Earth has a split social image: poverty and wealth, with adobe seen either as a material of last resort, or as a "chic" material to be used in expensive, custom-designed homes (McHenry,)). It is quite ironic that ought to the heavy labour cost in developed countries, on one hand, and to the abundance of working force in developing countries, on the other, earth-based construction practice has often been referred to as the housing of choice for the idle rich and the idle poor, respectively.

While it is due to the well-established (and ecologically-wise correct) trend for sustainable, "green" building technologies, that earth-based construction alternatives are fostered and encouraged in developed countries, these reasons are somewhat of a luxury in the developing ones[1]. Earth constitutes the prime building material in impoverished parts of the world mainly because the immense shelter requirements in developing countries can only be met through the use of local materials and through self-help construction processes. In this case, the use of building materials such as brick, concrete, steel, and other industrialized production techniques is deterred, not only due to the associated high cost and lack of resources, but also to the temporality of housing deriving from questionable legal status of land ownership.

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[1] *The principal reason for promoting the use of earth-based materials in developed countries is their excellent sustainability characteristics. These include low carbon emissions, efficient use of finite resources, minimising pollution and waste, use of benign (non-toxic) materials and local sourcing.*

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During the last decades, an increasing mistrust in traditional earth building has been noted, originating from the people most affected by the severe consequences that the natural disasters had on their self-built houses. For instance, after the devastating earthquake of 4 February, 1976 in Guatemala, that caused the death of some 24,000 people and destroyed more than 250,000 houses, clay construction was thought of as unsafe and the national government was considering a ban on adobe, a construction technology widely used in this country (Rhyner). Following the need to provide a cost-efficient, and yet disaster-resistant, vernacular housing to the low-income social part of developing countries, much scientific effort has gone into giving earth building the technical and social credibility that it deserves.

Additional to the mistrust in clay construction, oblivion of traditional earth building techniques, in combination with scarcity of skilful manpower, act against the adoption of this type of dwellings as an appropriate type of sustainable habitation in developing countries. Adobe dwellings are rapidly disappearing and being replaced by a new type of rural housing (when possible - mostly through sporadic housing projects), using new materials and building methods, such as concrete blocks, fired bricks, concrete slabs, galvanized sheets, etc. This is ought to the fact that earthen dwellings are, for the majority of people in developing countries, synonymous to poverty, and thus entail a stigma of social inferiority. This perception is quite difficult to change. The local people seem to prefer the use of new industrial materials and methods, in the sake of "modernity", or "status", even if this will shoulder them with onerous economic burden (e.g. heavy loans)[2].

3.5   Earth as a building material

3.5.1 Composition

Earth (or else loam) used for the manufacturing of adobe bricks is a mixture of clay (particles of diameter less than 0.002 mm), silt (particles of diameter greater than 0.002 mm and less than 0.06 mm) and sand (particles of diameter greater than 0.06 mm and less than 2 mm), and sometimes it contains larger aggregates like gravel and stones. Clay acts like a binder for all larger particles in the loam, as cement does in concrete. Silt, sand and aggregates act as the fillers in the loam (Minke, 2000a).

According to Vargas et al. (1984), clay is the most important component of the soil. In particular, clay particles control the cohesive bonding and plastic properties of soil, and the way it responds to moisture; therefore, clay content controls the shrinkage and swelling behaviour of earthen structural components, as well as their strength (Walker, 1995)[3].

Sand particles provide the granular skeleton of the material and although they lack cohesion, their inter-grain contact provides the material with high frictional strength. Sand particles contribute to the limitation of shrinkage and swell. Silt particles (as well as gravel in small proportions) also contribute to frictional strength and can act as pore filler for sandier soils.

Soil dug from a depth of less than 400 mm usually contains plant matter and humus (the product of rotting plants). Earth, as a building material, should be free of any organic constituents. The following table lists compositions of soils that are suitable for adobe brick fabrication (Hohn and Kratzer, 2003). The ternary diagram in Fig. 3-5 is based on the percentage ranges given in Table 3-1.

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[2] *As an example, the transportation cost of these "modern" materials is very high, and sometimes it equals the cost of the material itself (Cheikhrouhou, 2000). Moreover, as Lützen and Rambøll (2000) state, low-cost housing, in order to be sustainable, it must include economic, ecological, technological, socio-cultural and organizational issues. The antithesis between the scope of the aforementioned holistic sustainability approach and the use of new industrial materials is obvious; these materials are not compatible with the environment (either natural or built) and have poor thermal insulation performance.*

[3] *Unlike sands and gravels, clays are unstable and are very sensitive to variations in humidity. They are greatly attracted to water and as their moisture content rises, the films of absorbed water become thicker and the total apparent volume of the clay increases. Conversely, during the shrinkage, which occurs as they dry out, cracks can appear in the clay mass, reducing its strength. When next exposed to moisture, these cracks form channels through which water can penetrate the material.*

Table 3-1 Soil compositions suitable for adobe bricks. (source: Hohn and Kratzer, 2003)

Soil (Textural Name)	Sand (%)	Clay (%)	Silt (%)
Loamy sand	70 - 85	0 – 15	0 – 30
Sandy loam	50 – 70	15 – 20	0 – 30
Sandy clay loam	50 – 70	20 – 30	0 – 30
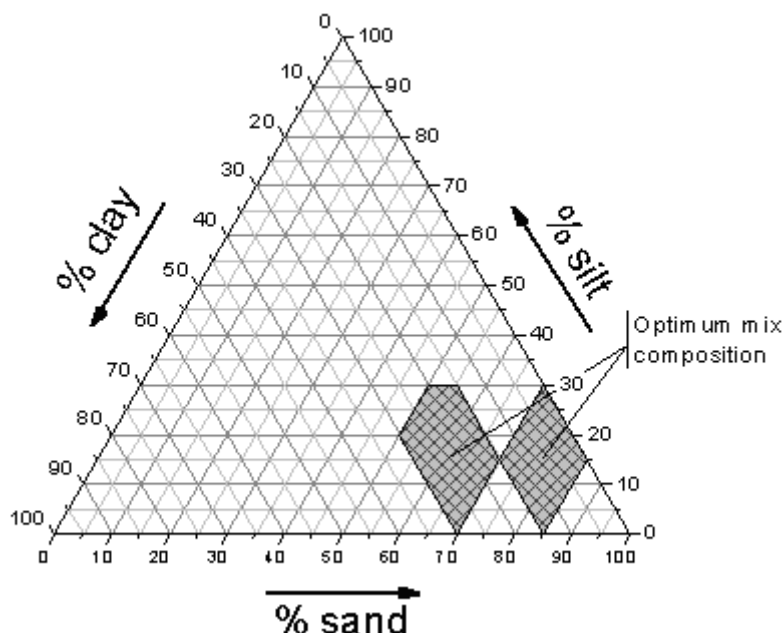
Fig. 3-5 Optimum soil mix composition for adobe making.

3.5.2 Soil stabilization

Soil stabilization is the mechanical, physical, or chemical treatment of a soil designed to increase or maintain its stability, or otherwise to improve the engineering properties of the soil, enabling it to serve as a better construction material (UN-HABITAT, 1992). In other words (and slightly paraphrasing Sparkes and Smith, 1945) the main purpose of stabilization is to maintain the moisture content and the mechanical properties of the soil at a satisfactory level, so that it will retain its original (compacted) state indefinitely under stress and weather conditions.

Different engineering uses of soil pose different requirements in strength and other properties. The most common soil quality improvements through stabilization include the reduction of the shrinkage/swelling effect (directly related to waterproofing), and the increase in density, strength and durability. In the selection of an additive, the factors that must be considered are the type of soil to be stabilized, the type of soil quality improvement desired, the methods of mixing and curing of the materials, the cost and the potential health hazard (e.g. toxicity) of different stabilizers. A detailed, up-to-date compilation of available information on soil stabilization methods and findings is reported by Burroughs (2001)[4]. There are three broad types of stabilization:

▪ Mechanical stabilization is the general term for stabilization by compacting the soil, also known as production of compressed earth blocks (CEB). This process leads to the decrease of the soil's porosity and permeability, and increase of its density and compressive strength.

▪ Physical stabilization refers to the addition of particulate material to the soil, for example clay and sand. For instance, in El Salvador, a local, very fine, white, pozzolanic soil, called

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[4] *Although Burroughs's work refers to rammed earth structures, the principles of soil stabilization apply to most earth-based types of construction.*

"tierra blanca" (literally white earth), is added in the soil/sand mix. The reported mix composition by Dowling (2■■■ is 2:2:1 for sand:*tierra blanca*:soil. According to Bommer et al. (1998), th■ volcanic originating soil can be classified as a silty sand and exhibits marked heterogeneity.

- Chemical stabilization involves the addition of chemicals to the soil, particularly cement, lime, asphalt and industrial by-products. In civil engineering applications of stabilized earth, over 90% involves the aforementioned materials or combinations of these (USACE, ■■■).

(a)   Stabilization against shrinkage

Typical soil, without additives, will shrink between 3% and 12% in the case of wet mixtures, and between 0.4% and 2% for drier mixtures (such as soil used for rammed earth, or compressed adobe blocks). Generally, stabilization against shrinkage is achieved through the addition of sand, or larger aggregates to the earthen mixture (this procedure is also called "thinning"). In this way, the relative clay content, and therefore the shrinkage, is reduced. Another measure is the addition of fibres, such as straw, animal or human hair, fibres from coconuts, sisal, *agave* or bamboo, needles from trees and cut straw. In this case, shrinkage is reduced due to fact that some of the water is absorbed by the fibres and, hence, the binding force of the mixture is raised. Especially for straw, studies by Vargas et ■■ 986) have shown that a 2% straw by weight of dry soil is essential for controlling cracks due to drying shrinkage.

Straw is the most commonly used additive for mud mixtures. The perception that straw addition increases the compressive strength is erroneous. Both compressive strength and density are reduced, as can be seen in Fig. 3-6, whereas loss of workability is also noted.
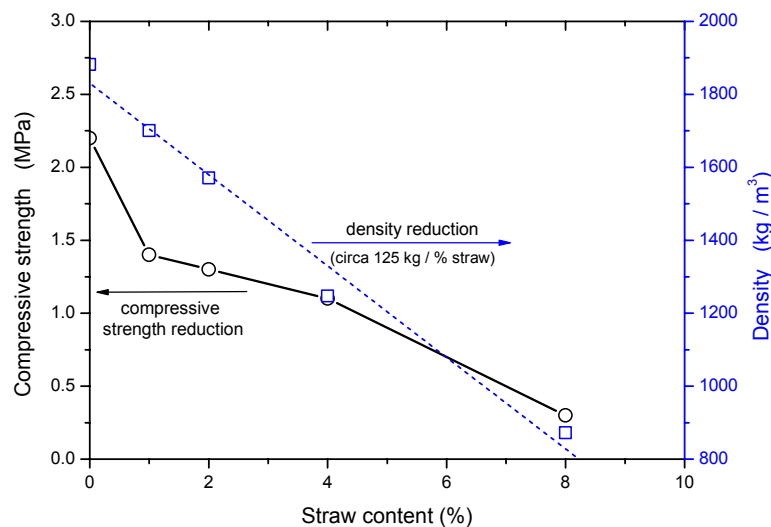
Fig. 3-6   Reduction of the compressive strength of earth mixture, by adding cut straw (50 mm in length). (source: an investigation conducted at the FEB, referenced by Minke, 2000a)

Islam and Watanabe (20■■ carried out an experimental program in order to investigate the influence of straw content and length (10 – 30 mm), on the compressive strength, elastic modulus, failure strain and ductility (ratio of failure strain to yield strain) of adobe mixes. It was concluded that: (1) straw content less or equal to 1% (by weight) was not effective to improve ductility, (2) for higher straw contents (1.5 – 3.0%) both failure strain and ductility were increased, (3) for the same straw content, longer straw was found to improve ductile behaviour, (4) elastic modulus and compressive strength were reduced in respect to straw content and length.

(b)   Stabilization against water erosion

The addition of stabilizers is necessary should the earthen building components be directly exposed to rain, either in their in-service state, or prior to the construction process (unsheltered storage). Different types of additives have been reported: Mineral stabilizers,

such as cement, lime and bitumen emulsion; animal products, such as blood, urine, manure[5], gelatin, bee wax and animal glue[6]; combinations of mineral and animal products (e.g. lime + manure, or lime + whey[7]); plant products, such as starch, locust bean tree solution and oil or latex-containing plant juices (e.g. from the rubber plant *"Euphorbia lacter"*, from sisal, *agave*, bananas and prickley-pear cactus); artificial chemical stabilizers, such as synthetic resins, paraffins, synthetic waxes and latex (however, these products, are not indigenous, they are expensive, prone to UV degradation and act as a vapour barrier).

It should be noted that the control of drying shrinkage cracking and permeability is of great importance, should the erosion of mud bricks and stuccos be minimized; material damage due to rain impact initiates around areas of weakness, which in turn are located in the vicinity of shrinkage cracks (Heredia et al. 1988). Burroughs (2001) describes two stabilization methods that reduce water erosion (and thus reduce swell and shrinkage of soils). The first method involves the filling of all the voids, pores and cracks (and micro-cracks) with a material that is unaffected by water; asphalt is probably the best example of a stabilizing agent that acts in this way, but is highly toxic. The second method is to dispense in the soil a material that expands upon contact with water, thus preventing the infiltration of pores (UN-HABITAT, 1992). Bentonite is a typical example of a material used in this way, but is not a locally available material.

In the aforementioned publication of Heredia et al. (1988) a series of recommendations were proposed, as a measure to enhance durability of adobe structures. These recommendations were the result of an extensive experimentation on stabilization of soil mixtures for mud stuccos. It was proven that the use of a cactus solution was the optimum one:

1. Preparation of the cactus solution by soaking pieces of cactus until the soft part dissolves completely, leaving only the skin as a residue. The product is characterized by a gluey consistency, green colour and strong smell. Over-ageing should be avoided, as it changes the colour to blackish, lowers the consistency of the fluid and reduces the effectiveness (optimum ageing period: 14-25 days, in ambient temperature of 15 to 20 °C). The cactus solution should be used instead of water in mixing the mud stucco.
2. Removal of any loose dust from the adobe wall surface and application of the cactus solution, in order to provide a good bond and to seal the pores before application of the stucco. The drying of this primary coat might require a few days (e.g. a week)[8].
3. Application of the stucco in two layers: a bottom layer about 12 mm in thickness and a top layer approximately 3 mm in thickness. The stucco for the bottom layer should be made of soil, straw and coarse sand in amounts that should be determined to maintain a balance between adequate workability and resistance to cracking on drying (different soils require different "mix designs"). The top layer should contain smaller pieces of straw and no coarse sand. In this way, the top layer covers the micro cracks of the bottom one and provides a surface that is more suitable for stone polishing.
4. Grinding of the stucco surface, after the latter has dried out, with a rough-textured granite stone. Following this, the wall surface has to be moistened with the cactus solution and polished with a smooth-textured basaltic stone, in order to render the surface totally impervious to water.
5. A final hand of the cactus solution should be applied on the polished wall surface.

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[5] *Many traditional societies employ cow-dung and other animal excreta in wet or flocculent form in order to increase the cohesion between soil particles. The cow-dung surrounds the soil particles and glues them together on drying, maintaining their stability, as long as excessive moisture is not present. The presence of fibres in the cow-dung also reduces crack formation. Adversely though, addition of this kind of manure to soil mixtures reduces their compressive strength (Ngowi, 1997).*

[6] *Protein gelatine obtained by boiling skins and hoofs of cattle and horses.*

[7] *The watery part of milk produced when raw milk sours and coagulates.*

[8] *In stabilized earth brick construction there is much larger room for errors. Variables such as consistency of the mix, amount of moisture in the soil prior to mixing, as well as others, create inconsistencies in stabilized earth brick construction.*

Fig. 3-7 Family plastering an adobe house.
(source: http://www.nmculturenet.org/features/hfae/adobe/gallery/muddin.html)

(c)   Asphalt stabilization

The mechanisms involved in the stabilization of soils and aggregates with asphalt differ greatly from those involved in cement and lime stabilization. The basic mechanism involved in the asphalt stabilization of fine-grained soils is a waterproofing phenomenon. Asphalt stabilization can improve durability characteristics, since the soil particles or aggregates are coated with water-repelling asphalt film. Drawbacks to the method are the unfavourable reaction to the smell and colour of the additive, the material's toxicity and the difficulty to clean the equipment used.

(d)   Lime stabilization

Lime is the oldest soil-stabilizing agent known. It is inexpensive, but care must be taken to protect workers from breathing in lime dust (in case of quicklime use). In the field, the most appropriate manner in preparing the soil-lime is by mixing the dry soil with lime. After thoroughly mixing the material, the water is added. The dominant reaction in soil stabilization with lime is of pozzolanic type, if the material to be stabilized contains clay particles (or pozzolanic materials) that react with lime[9]. Lime is unlikely to successfully stabilize organic soils, or those soils that are deficient in clay (e.g. less than 10%, according to Dumbleton, 1962). A measure of the soil suitability regarding lime stabilization is given by Thompson (1966); according to his characterization, a soil is identified as "reactive" if it reacts with lime to produce a substantial strength increase (> 0.345 MPa, following a 28-day curing at 22.8 ºC), whereas it is identified as "non-reactive" if the displayed pozzolanic activity is limited (< 0.345 MPa strength increase)[10].

Treatment with either quicklime or hydrated lime is very beneficial (for clay-rich soils in particular), as both strength and workability are improved[11]. The addition of 2-3 % of quicklime to a soil quickly reduces plasticity by hydration (dries the soil) and breaks up the lumps (UN-HABITAT, 1992). The usual quicklime addition for soil stabilization ranges between 6 and 12% and is similar to the amounts required for cement stabilization. Lime-treated soils exhibit reduced shrinkage potential (lime is more effective for reducing the linear shrinkage than cement) and increased compressive strength. As an example of the relationship between unconfined compressive strength and lime content, the results of an investigation conducted by Akpokodje (1985) on Australian arid zone soils are given in Fig. 3-8a. The soils included a sandy loam (59% sand, 28% silt and 13% clay), a silty loam (15% sand, 75% silt and 10% clay) and a clay loam (36% sand, 27% silt and 37% clay). For both the clay loam and the sandy one, a lime content of 2% resulted in a 7-day compressive strength of about 0.7 MPa, but increasing the percentage to 4% resulted in nearly doubling the compressive strength (Fig. 3-8a). It is worth noting that further increases in lime content lead into no significant increase in compressive strength.

Lime-stabilized materials are usually assessed at 7 and 28 days. However, high lime contents will not necessarily promote high early strengths. Figure 3-8b shows the variation of

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[9] *Reactions of pozzolanic type: reactions between lime, water, and various sources of soil silica and alumina to form cementitious materials.*

[10] *This criterion is the same for any chemical used for soil stabilization, according to ASTM Standard D 4609 (Standard Guide for Evaluating the Effectiveness of Chemicals for Soil Stabilization).*

[11] *There are arguments supporting the use of hydrated lime over quicklime.*

compressive strength as a function of lime content and time. It is made clear that, although early strength gains (7-days' strength) are likely to be small, the long term ones (28 days, and more) can be significant.

(a)   (b)
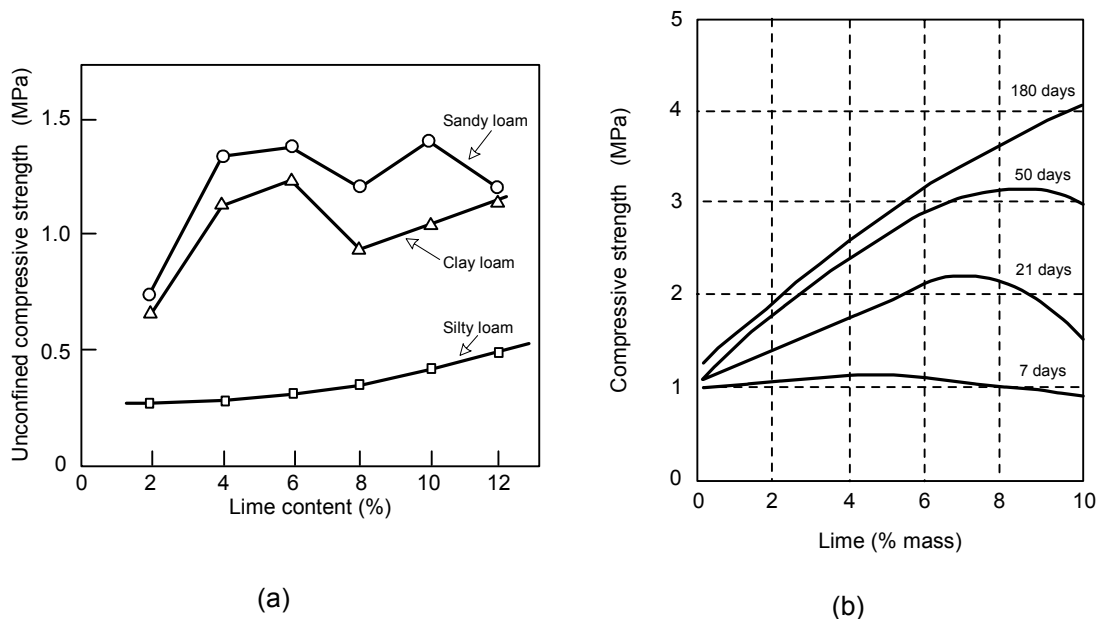
Fig. 3-8   (a) Relationship between unconfined compressive strength and lime content; (b) Compressive strength variation with lime content and time. [sources: (a) Akpokodje, 1985; (b) Ausroads, ▨]

(e)   Cement stabilization

Nearly all soils can be stabilized with cement and have significant improvement in their properties. However, cement stabilization works best on sandy soils, as the mixing is facilitated by their granular structure[12]. Cement stabilization resembles lime stabilization in many ways, except that with cement, pozzolan material is inherently present and need not be derived from the soil itself. Cement stabilization requires sufficient water for hydration of the cement and the silty-clay particles, as well as for adequate mixture workability.

Cement-stabilized soils usually exhibit some shrinkage on curing and drying in a magnitude that depends on several factors, including cement content, soil type, water content, degree of compaction and curing conditions. Nevertheless, careful curing might result in the decrease of the swell/shrinkage effect. For example, for the sandy loam tested by Akpokodje (1985), a quantity of 6% of cement reduced the natural soil swell from 2% to 0.1%, and the swell of a clay loam from 6% to 0.7%. The shrinkage of these soils for the same cement content was reduced from 1% to 0.2% and from 6% to 2%, respectively.

Generally, the compressive strength is dependent on the amount of the cement used. Compared to lime, it can be said that (as a rule of thumb) the ratio of the strength increase of cement-stabilized soil to lime-stabilized soil, per % of stabilizer, is about 2:1. In the UN-HABITAT recommendations (1992) an addition of 6% cement is prescribed, although some soils may require only 3% and others may need as much as 12%. Walker (1995) states that at greater than 10%, cement content, stabilization becomes uneconomical, whereas at less than 5% cement content, the stabilized blocks are rendered too friable for easy handling. Akpokodje (1985) extended his previously mentioned investigation on soil stabilization (soil types: clay loam, sandy loam and silty loam), experimenting with cement. He concluded that the compressive strength increases as a linear function of cement content between 0 and 12% (Fig. 3-9).

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[12] *The mechanism of cement stabilization differs between soil types. In non-cohesive soils, the particle sizes are smaller than the cement grains and can, therefore, be coated by the latter. Once cement is hydrated, it bonds soil particles at points of contact, resulting in an increase of the mixture's strength. The better the gradation of the soil, the higher is the number of contact points and, thus, the higher is the strength. On the contrary, in cohesive soils, many particles are finer than cement grains. In this case, the cement hydration products bond with clay particle concentrations, forming a stabilized structure.*

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In an attempt to quantify the increase of the compressive strength of cement-stabilized soil, in terms of cement content in the mix, data from five experimental investigations is compiled in Table 3-2. Based on results from work conducted by Akpokodje (1985), Bryan (1988), Croft (1968), Ngowi (1997) and Walker (1995), information is extracted in the form of unconfined compressive strength per % of cement addition (Table 3-2[13]). It should be noted that for the results provided by Walker (1995), the compressive strength increase per % addition of cement stated in Table 3-2 accounts for the mean value corresponding to soils with up to 40% of clay content (Fig. 3-10). Excluding the value obtained for Croft (1968), it can be postulated that, the compressive strength increase expected, after the addition of 1% of cement (by dry soil weight) is 0.35 MPa. It is evident, though that, given the material's inherent variability, any suggestion of the kind is likely to be approximate, therefore, physical testing should be conducted at all times.

Table 3-2 Compressive strength increase per % addition of cement, according to various experimental investigations.

Researcher(s)	Compressive strength increase per % addition of cement (MPa / 1%)	Cement percentage range (% soil's dry weight)	Curing time (days)
Akpokodje (1985)	0.28	2.0 – 6.0	7
Bryan ( )	0.32	5.0 – 10.0	28
Croft ( )	0.64	5.0 – 10.0	7
Ngowi (1997)	0.47	5.0 – 15.0	Not indicated
Walker ( )	0.33	5.0 – 10.0	Not indicated
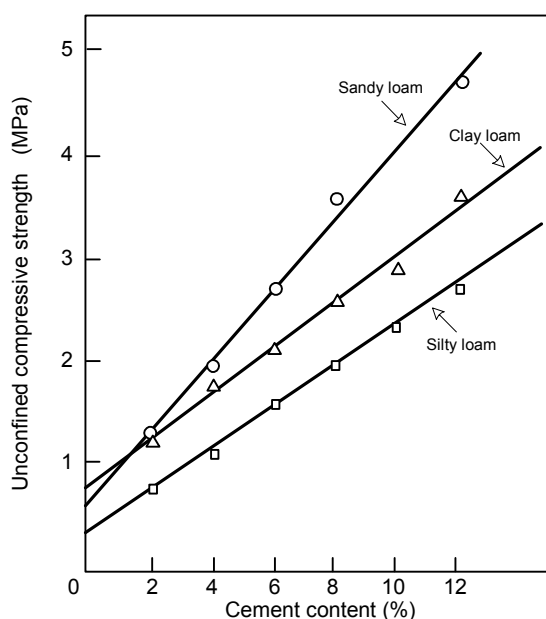
Fig. 3-9 Relationship between unconfined compressive strength and cement content.
(source: Akpokodje (1985)

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[13] *Data corresponding to Akpokodje's, Bryan's and Croft's investigations was extracted from Burroughs's doctoral thesis (in the absence of the originals) and, therefore, the exact test conditions remain unknown. Ngowi performed compressive strength tests on manually compressed adobe bricks (maximum exerted pressure: 2 MPa), following the procedure described in BS 5921:1985. Walker also used manually compressed adobe bricks (maximum exerted pressure in the range of 2 – 4 MPa), which were tested both in saturated (immersed in water for 24 hours prior to testing) and in dry condition. The value referenced in Table 3-2 was derived from the characteristic saturated compressive strength values, reported by Walker. Further calculations revealed that the value of compressive strength increase per % addition of cement, remains constant should average saturated compressive strengths be used, but varies considerably in the case of mean compressive strengths (both dry and saturated).*
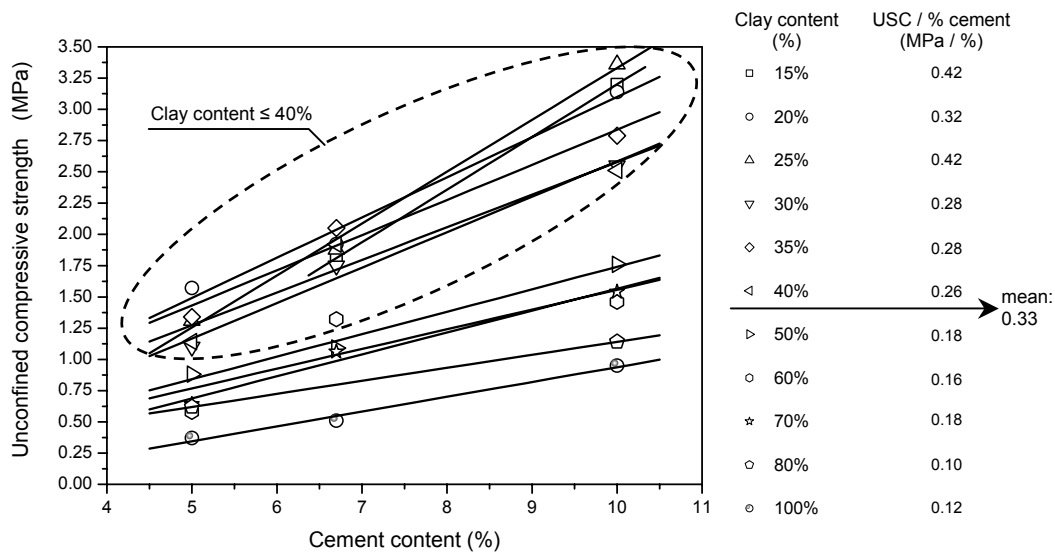
Fig. 3-10 Unconfined compressive strength versus cement content, based on data provided by Walker (1995). Linear regression results are also noted.

Cement is still a relatively expensive building material in developing countries, despite the fact that between 1990 and 2000 cement production has grown 55% in these countries and only 3% in developed ones (Vanderley, 2003). Additionally, it is a highly energy consumptive building material, in regard to its production process; the latter has also a major environmental impact. According to Humphreys and Mahasenan (2002) the cement industry is responsible for about 3% of the global anthropogenic greenhouse gas emission, and for 5% of global anthropogenic CO_2. This information has to be taken into account when decision-making policies regarding housing projects in developing countries are drawn. The housing deficit of these countries is enormous: in 19 Latin America and Caribbean countries there is a need to construct 17 million new houses (Mac Donald and Simioni, 1999[14]). Answering these social demands can only be in the path of sustainable development. A very effective way of reducing CO_2 emissions involved in cement production process is mixing clinker with supplementary materials (blending), such as fly ash, blast furnace slag and silica fume.

Especially for the case of earth-based construction, several cement replacement materials have been investigated as soil stabilizers. These include fly ash (e.g. Kaniraj and Havanagi, 1999), cement kiln dust (Miller and Azad, 2000), rice-husk ash (Basha and Hashim, 2003) and others. The question lies in the availability of these industrial/agricultural by-products in developing countries. For the case of fly ash, though, volcanic ashes (like the aforementioned *tierra blanca*) can be successfully used instead.

(f)   Stabilization using alternative materials

Innovative solutions have been proposed and developed, aiming to the use of reclaimed material, such as paper (or paper mill) waste. Paper adobe (also called "fidobe", short for "fibrous adobe") is a mixture of soil, chipped paper or cardboard and water, which hardens into a durable block that has a considerably higher insulating properties than plain adobe. Being lighter in weight, it is also easier to work with. Other approaches include lime-soil stabilization combined with industrial waste (Kamon and Nontananandh, 1991) and burned olive waste-soil stabilization (Atom and Al-Sharif, 1998).

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[14] *One should also take into account the fact that, although some part of this deficit must have been covered by construction projects that have been undertaken since 1999, the recent natural disasters that hit some of these countries (e.g. El Niño, El Salvador 2001 earthquakes) must have kept the number of new dwellings needed to the same (if not even higher) levels.*

3.5.3 Simple field tests

When building with earth, it is important to have a thorough grasp of the following three fundamental soil properties:

- The texture or particle size distribution of the soil, i.e. the quantity of stones, gravels, sands, silts and clays present, expressed in percentage terms;
- The plasticity of the soil or the ease with which it can be shaped;
- The compressibility of the soil, or the extent to which voids, and therefore its porosity, can be reduced to a minimum.

The following tests are not very accurate but they are simple and can be done in situ in a relatively short time. They are of qualitative value only, and their interpretation gives an insight to the suitability of the soil sample for building purposes.

(a)   Estimation of soil suitability

- *Smell test (Minke, 2000a)*: Pure loam is odourless, but smells musty if it contains deteriorating humus or organic matter.

- *Nibble test (Minke, 2000a)*: A pinch of soil is lightly nibbled. Sandy soil produces a disagreeable sensation, as opposed to silty soil, which gives a sensation that is not so objectionable. Clayey soil gives a sticky, smooth or floury sensation.

- *Wash test (Minke, 2000a)*: A humid soil sample is rubbed between the hands. If the grains can be clearly felt, it indicates sandy or gravelly soil, while if the sample is sticky but the hands can be rubbed clean when dry, it is indicative of silty soil. If the sample is sticky, making it necessary to use water to clean the hands, it indicates a clayey soil.

- *Cutting test (Minke, 2000a)*: A humid sample of the earth is formed into a ball and cut with a knife. If the cut surface is shiny, it means that the mixture has high clay content; if it is dull, it indicates a high content of silt.

- *Sedimentation test (Minke, 2000a & CRATerre, 1979)*: The mixture is stirred with a lot of water in a transparent cylindrical glass jar or bottle, of at least 1/2 litre capacity (approx. 1/4 soil and 3/4 water). The top is then sealed, the content is well shaken and is left to stand for at least 30 min. The largest particles first settle at the bottom, the finest on the top (Fig. 3-11). From this stratification one can distinguish successive strata at sudden changes of grain-size distribution, but cannot estimate accurately the proportion of the constituents (the strata may not coincide with the actual defined limits between clay and silt, and between silt and sand).
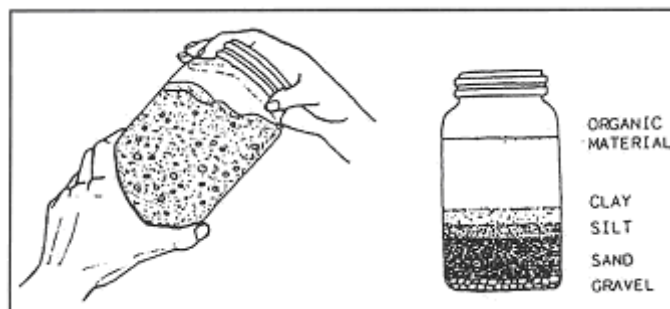
Fig. 3-11 Sedimentation test. (source: CRATerre, 1979)

- *Ball dropping test (Minke, 2000a)*: The mixture to be tested has to be as dry as possible, yet wet enough to be formed into a ball of 40 mm diameter. When this ball is dropped from a height of 1.5 m on to a flat surface, different results can occur (Fig. 3-12). If the ball flattens only a little bit and shows hardly any, or no cracks (Fig. 3-12a & b), it has a high binding force, which is ought to the very high clay content. In this case the mixture should be thinned by adding sand. On the contrary, if the ball breaks apart in small pieces (Fig. 3-12d), it has a very low clay content and the soil, where the sample comes from, cannot be used as a building material. In the case of the ball shown in Fig. 3-12c, the mixture has relatively poor binding force, but usually can be use for mud bricks (adobes).
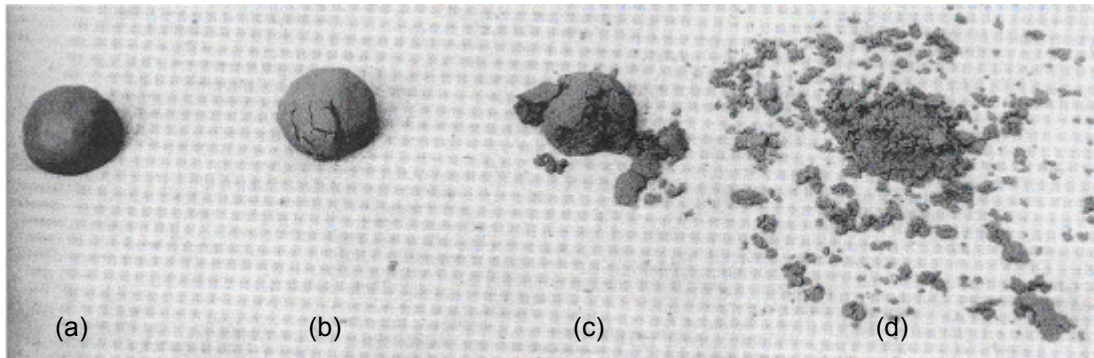
Fig. 3-12 Loam balls after the dropping test. (source: Minke, 2000a)

- *Consistency test (Minke, 2000a)*: Moist earth is formed into a ball of 20-30 mm in diameter. This ball is rolled into a thin thread of 3 mm diameter. If the thread breaks or develops large cracks before it reaches a 3 mm diameter, the mixture is slowly moistened until the thread breaks after reaching a diameter of 3 mm. This mixture is then formed into a ball. If this is not possible, then the sand content is too high, and the clay content too low. If the ball can be crushed between the thumb and the forefinger (needing a lot of force), the clay content is high and should be thinned by adding sand. If the ball crumbles very easily, then the loam contains little clay.

- *Dry Strength Test (IAEE, 1986)*: Five or six small balls of soil of approximately 20 mm in diameter are made. Once they are dry (after 48 hours), each ball is crushed between the forefinger and the thumb (Fig. 3-13). If they are strong enough that none of them breaks, the soil has enough clay to be used in adobe construction, provided that some control over the mortar micro-fissures caused by the drying process is exercised. If some of the balls break, the soil is not considered to be adequate, because it does not have enough clay and should be discarded.

Fig. 3-13 Dry strength test of soil, as per IAEE, 1986.

- *"Cigar" test (CRATerre-EAG, 1995)*: This test enables one to observe the cohesion of the soil and above all, the quantity and quality of the clays present. All gravel is firstly removed from the sample, which is then moistened and well kneaded until a smooth paste is obtained. The sample is left to stand for 30 min (or more, if possible) to allow it to become very smooth. Consequently, the loam is rolled between the hands into a cigar shape of 30 mm in diameter. The "cigar" is placed across the palm of the hand and pushed gently forward with the other hand, until a piece breaks-off (Fig. 3-14). The length of the piece that breaks-off is measured, the procedure is repeated for several times, and an average value of the measured lengths is obtained. If this length is less than 50 mm, the soil contains too much sand, or if it is found to be more than 150 mm, then the soil contains too much clay. Values between 50 and 150 mm indicate that the soil has good cohesion.

Fig. 3-14 "Cigar" test, as per CRATerre-EAG, 1995.

- *"Biscuit" test (CRATerre-EAG, 1995)*: As in the "cigar" test, a gravel-free soil sample is moistened and well kneaded until a smooth paste is obtained. The lump is moulded into flat biscuit-shaped discs approximately 30 mm in diameter and 10 mm thick, which are left to dry. If the biscuit is cracked or if there is a clear gap between the dried sample and the sides of the mould, the soil contains too much clay. Also, if the "biscuit" is very hard to break (i.e. if it breaks with an audible crack), then the soil has a high clay content. On the contrary, if the disc is brittle, but breaks fairly easily and can be crumbled between the thumb and forefinger, the soil is classified as a good, sandy-clayey one.

Fig. 3-15 "Biscuit" test, as per CRATerre-EAG, 1995.

(b)   Estimation of brick and mortar adequacy

- *Microcracking control test (Vargas et al. 1984 & IAEE, 1986)*: This test consists in making two or more sandwiches (adobe bricks joined with mortar) using existing adobe bricks and mortar made of the soil under study. After 48 hours drying in the shade, the sandwiches are carefully opened and the mortar is examined. If the mortar does not show visible cracking, then it is adequate for adobe construction. Otherwise, the use of coarse sand (0.5 to 5 mm approx.) is necessary as an additive to control microcracking. In the latter case, at least eight sandwich units are manufactured with mortars made with mixtures in different proportions of soil and coarse sand, in order to determine the most adequate soil-coarse sand proportion. It is recommended that the proportions of soil to coarse sand vary between 1:0 and 1:3 in volume. The sandwich having the least content of coarse sand which, when opened after 48 hours, does not show visible fissures in the mortar, will indicate the most adequate proportion of soil/sand for adobe constructions, giving the highest strength.

- *Mortar joint bond strength test (Minke, 2000a)*: Two burnt bricks are joined by a 20 mm thick mortar, the upper brick skewed at 90° to the lower. After the mortar is dry, the upper brick is laid on brick supports at both ends, while the lower is loaded with a sand-filled container (Fig. 3-16). When the mortar breaks, the weight of the lower brick and the sand-filled container divided by the mortar area gives the adhesive strength. This holds true when rupture occurs at the joint (i.e. at the mortar-brick interface). If the failure occurs within the mortar layer, then the calculated strength represents the mortar's direct tensile strength, which is less than that of the joint.
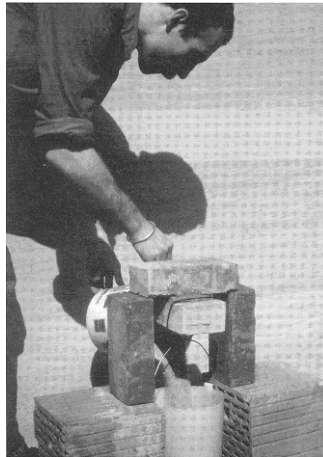
Fig. 3-16 Field test to derive the bond strength of mud mortar.

- *Qualitative strength test of adobe bricks (IAEE, 1986)*: The strength of an adobe brick can be qualitatively ascertained a follows: after 4 weeks of sun drying the adobe, it should be strong enough to support in bending the weight of a man (Fig. 3-17). If it breaks, more clay and fibrous material is to be added. Quantitatively, the compressive strength may be determined by testing 100 mm cubes of clay after completely drying them. A minimum value of 1.2 MPa is desirable.
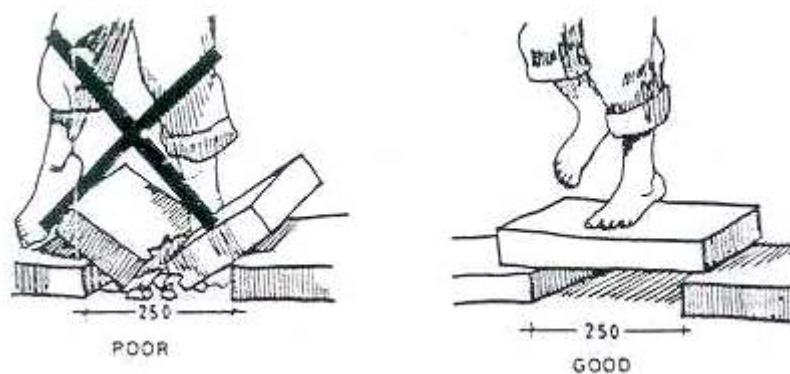
Fig. 3-17 Simple field test for the determination of adobe brick strength. (source: IAEE, 1986)

3.5.4   Laboratory tests

More elaborate tests than the ones described above have been developed (e.g. by CRATerre-EAG, 2   ), and their realization requires a properly equipped laboratory, manned by experienced personnel. These tests provide with accurate, quantitative results. The testing procedures developed by CRATerre-EAG, for the case of CEB, are given in Table 3-3. According to the author's knowledge there are no tests developed exclusively for the case of non-pressed or untreated earth blocks, but this fact should not deprive the proposed CEB tests of their general applicability (except of the optimum water content test).

A brief description of the scope of the "Raw material identification tests" and of the "Manufacturing test" as described in Table 3-3, is given hereafter, followed by a more elaborate presentation of the reported methodologies regarding the "Finished product tests". Two more tests, additional to the ones proposed by CRATerre-EAG, are also described.

Table 3-3 Laboratory tests for the determination of material and product properties for compressed earth blocks. (source: CRATerre-EAG, 2000)

Raw material identification tests	Manufacturing tests	Finished product tests
▪ Water content	▪ Optimum water content	▪ Dry compressive strength
▪ Particle size distribution: Wet sieving		▪ Wet compressive strength
▪ Particle size distribution: Sedimentation		▪ Dry tensile strength
▪ Consistency limits		▪ Abrasive strength
▪ Methylene blue test		▪ Capillary absorption
▪ Organic matter		▪ Dimension, Mass, Apparent density

- *Water content*: This test aims at the identification of the water content of a soil sample.

- *Particle size distribution – Wet sieving*: This test aims at identification of the percentage mass of the various elements of a soil, the sizes of which are greater than 0.08 mm.

- *Particle size distribution – Sedimentation*: Sedimentation analysis is a test which complements particle size distribution analysis realized by sieving. It is applied to the fine elements of less than 0.1 mm, for which it is not possible to use sieves.

- *Consistency limits*: The consistency of a soil is expressed by physical constants, known as the Atterberg limits. These constants mark the thresholds between: (i) the passage of a soil from a liquid state to a plastic state (liquid limit – LL), and (ii) the passage of a soil from the plastic state to a solid state (plastic limit – PL). These limits indicate the water content of a soil at the state of transition in question, expressed as a percentage of the mass of the dry material. The difference between liquid and plastic limit, called the plasticity index, defines the range of the plastic zone and is a characteristic value for the soil under investigation.

- *Methylene blue test*: This test measures the capacity of the fines in a soil to absorb methylene blue, and is suitable for studying clays, or clay fractions of a soil, since – depending on their mineralogical composition – these may have very different specific areas.

- *Organic matter*: This test allows the organic matter content of a soil sample to be identified.

- *Optimum water content*: This test enables one to determine the capacity of a soil to be compacted, as a result of a variable compacting force applied directly using a given CEB production press.

- *Dry compressive strength*: It should be noted that there is not yet a universally recognized test standard to assess the compressive and the tensile strength of earthen unfired blocks. The American Society of Testing and Materials has issued the following three standards for the assessment of compressive strength of cement stabilized soil:

▪ ASTM - D1632-96 Standard Practice for Making and Curing SOIL-Cement Compression and Flexure Test Specimens in the Laboratory.

▪ ASTM - D1634-00 Standard Test Method for Compressive Strength of SOIL-Cement Using Portions of Beams Broken in Flexure (Modified Cube Method).

▪ ASTM - D1633-00 Standard Test Method for Compressive Strength of Moulded SOIL-Cement Cylinders.

According to the latter, a 101.6 mm diameter and 116.4 mm high (height to diameter ratio: 1.15) cylindrical specimen is loaded at an axial strain rate of 1mm/min, using a Universal Testing Machine. Alternatively, a 71.1 mm diameter and 142.2 mm high (height to diameter ratio: 2) cylindrical specimen can be used. The load to failure is recorded and the unconfined compressive strength (UCS, in MPa) is computed as follows:

$$UCS = \frac{P_u}{A} \qquad (3\text{-}1)$$

where P_u is the maximum load recorded (in N), and A is the specimen's cross sectional area (in mm^2).

The new section R614 "Earthen Wall Structures" of the International Residential Code, specifies the strength requirements for adobe units and mortar. For the determination of dry compressive strength, no standard-size blocks are required. Unconfined compression testing is performed on 5 specimens in the position in which the earthen units are supposed to be used; the specimens are dried at a temperature of 29ºC (± 9º) and in an atmosphere of relative humidity of not more than 50%. The average dry compressive strength should be in the order of 2 MPa (actual specified value: 2068 kPa), and no individual unit may have a strength value of less than 1.7 MPa (the same requirements apply for the New Mexico Adobe and Rammed Earth Building Code).

A different method for the assessment of the dry compressive strength of unfired earth bricks is proposed by CRATerre-EAG. The test consists in subjecting a sample to simple compression until failure, the sample being made up of two half-blocks[15] of homogenous structure, one placed on top of the other and stuck together using a mortar made of earth (of thickness less or equal than 10 mm), or alternatively of sand cement, in the case of stabilized CEBs. The half-blocks are derived from a single unit[16] after performing a tensile strength test, or alternatively, by using a mallet in the way shown in Fig. 3-18a.

The sample (Fig. 3-18c) is crushed in the direction in which they are laid, by the effect of a constant displacement, or a constantly increasing load provided by a press[17]. To avoid problems relating to uneven contact points, both faces of the specimen are faced with a cement paste, sheets of cardboard or plywood. The average compressive strength of the blocks is the arithmetic average of the compressive strengths of at least three tests, carried out from specimens of the same lot. The dry compressive strength is calculated by eq.(3-1)[18].

| (a) | (b) | (c) |
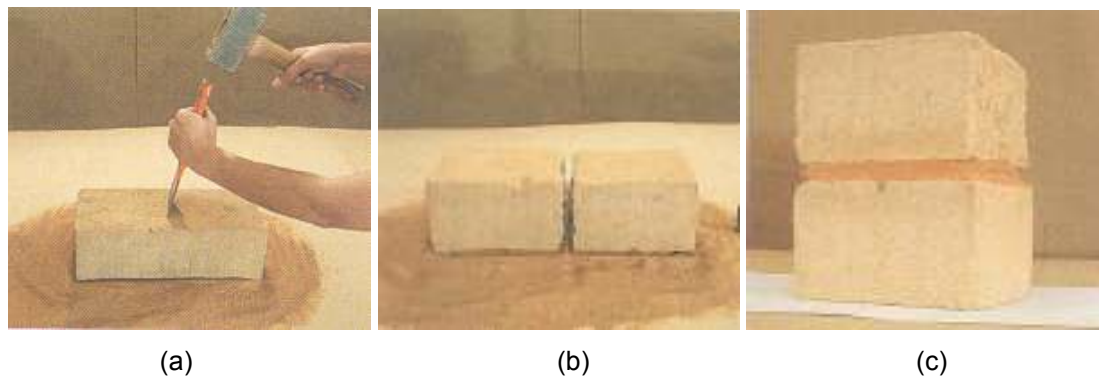
Fig. 3-18   (a) Breaking up a single brick into two pieces; (b) The two half-blocks; (c) Sample to be tested in unconfined compression.

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[15] *Standard half-block measuring approximately: 147 x 140 x 100 mm. Minimum height for each block: 60 mm.*

[16] *The brick has to be oven-dried first at 40ºC, until a constant mass is obtained (the mass of the block is constant when the difference in mass does not exceed 0.1% between 2 weightings at a 24 h interval). Specimens are to be tested after allowing them to rest for 2 h.*

[17] *The block should not fail in the first 15 sec. The load increase should be within the range of 0.15 and 0.25 MPa/sec, or the displacement rate should be kept steady at 0.02 mm/sec.*

[18]
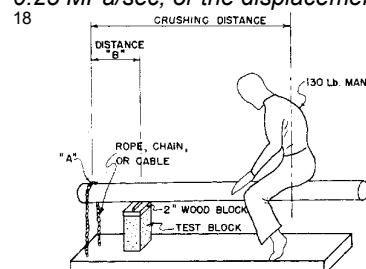
An in-situ simplified method of assessing the dry compressive strength of adobe bricks, as proposed by the U.S. Peace Corps. Alternatively, if a press is used, a pressure gage can be attached to it and provide with a value of the maximum pressure that can be applied to the brick.

(http://mng-unix1.marasconewton.com/peacecorps/Documents/R0034/r0034e/r0034e04.htm)

- *Wet compressive strength*: It is evident that the mechanical characteristics (tensile and compressive strength) of wet blocks are inferior compared to dry blocks. Reduction in compressive strength with saturation can be attributed to the development of pore water pressures and the liquefaction of unstabilized clay particles in the block matrix (Walker, 1995). It is therefore useful to test them in wet state, in order to obtain a lower bound of their carrying capacity.

The International Residential Code, specifies that the specimens should be under water for not less than 8 h, or longer, as required until fully saturated. Unconfined compression testing is performed on 5 saturated specimens. The average wet compressive strength should be in the order of 2 MPa (actual specified value: 2068 kPa) and no individual specimen may have a strength value of less than 1.7 MPa.

The method proposed by CRATerre-EAG is adapted from the operational method for dry compressive strength test. The half-blocks should be placed under water for two hours, ensuring that there is at least 50 mm of water above the upper faces of the blocks.

It should be noted that the majority of published laboratory results refer to stabilized adobe units (mostly with cement). One should also bear in mind that the available data is strongly dependent on specific soil constituents, compaction pressures, curing procedures, etc., and it cannot be reliably used for generalizations. Based on the results derived from Walker's (1995) extensive experimental program, the ratio between dry and saturated (wet) compressive strength (for cement stabilized soil, with clay content up to 40%, and cement content in the range of 5 to 10%) can be estimated to be (circa) 1.6 MPa. Minke (2000a) reports similar results, with the wet compressive strength of unstabilized soil being equal to zero (Fig. 3-19).
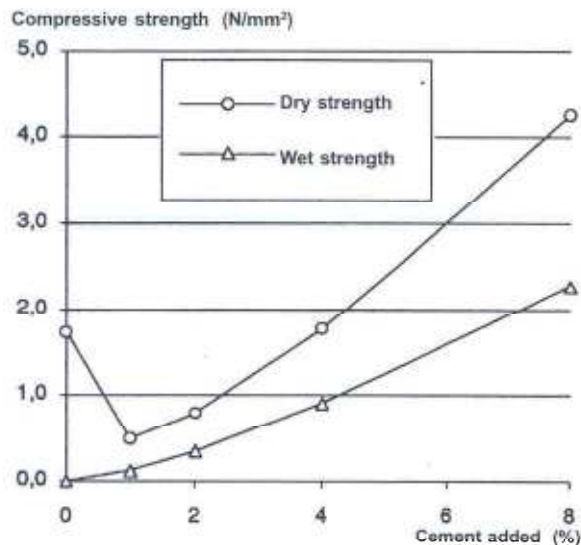
Fig. 3-19 Dry versus wet compressive strength of handmade adobes with varying contents of cement. (source: Minke, 2000a)

- *Dry tensile strength*: The CRATerre test derives from the splitting tensile test (Brazilian test). It involves subjecting the block to a compressive force along two rods, located on each side of the block, which results in an average tensile stress along a vertical face passing between these two rods (see Fig. 3-20). The rods are made of rigid plastic or hard wood. Drying of the specimens and loading rate follow the procedures described in the dry compressive strength procedure. The same operation is repeated for each of the two half-blocks, which derive from the loading of the whole block (Figs.3-20b & c).
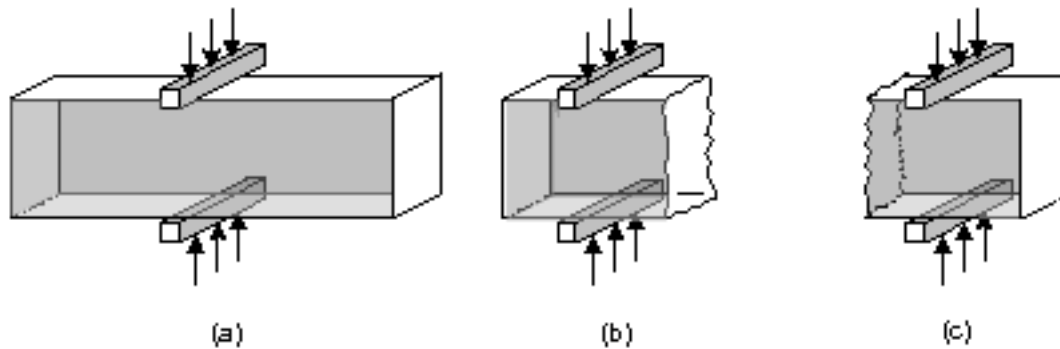
Fig. 3-20   (a) Splitting test on the whole block; (b) & (c) Splitting test on each of the two half-blocks.

The average tensile strength of the blocks is the arithmetic average of the tensile strengths of at least three tests, carried out from specimens of the same lot.   The tensile (splitting) strength of the blocks is expressed by eq.(3-2), as a modification of the formula corresponding to the Brazilian test on cylindrical specimens.

$$f_{b,dry}^t = 0.9 \left(2P_u / \pi \ell h \right) \tag{3-2}$$

where $f_{b,dry}^t$ is the calculated tensile splitting strength of the blocks (in MPa), P_u is the maximum load recorded (in N), ℓ is the specimen's length (in mm) and h is the specimen's height (in mm).

The New Mexico State Adobe Building Code (1991) - Section 2413, requires the conduct of a three-point bending test (Fig. 3-21), as an indirect way to assess the dry tensile strength of adobe blocks through the estimation of the Modulus of Rupture (MOR).   Each unit should average 0.35 MPa in MOR, when tested according to the following procedure: a standard 101.6x 254x355.6 mm cured unit is laid over (cylindrical) supports spaced at 50 mm from each end and extending across the full width of the unit.   A cylinder 50 mm in diameter is laid midway, between and parallel to the supports.   Load is applied to the cylinder at a rate of 0.037 N/sec until rupture occurs.   The MOR (in MPa) is taken from eq.(3-3).

$$MOR = 1.5 \times \left(P_u \ \ell / bh^2 \right) \tag{3-3}$$

where b is the specimen's width (all dimensions in mm).
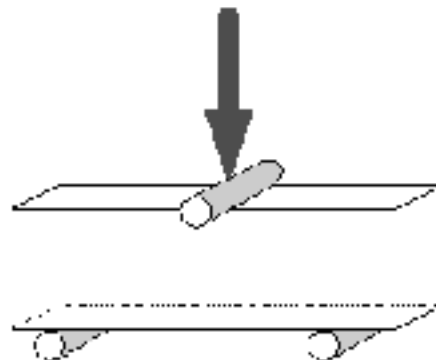
Fig. 3-21 Three-point bending test lay-out.

The block flexural strength was closely correlated in Walker's (1995) publication with cement and clay content; values for MOR exhibited similar trends to compressive strength behaviour and in all cases ranged between 3.5 and 16.5% of the characteristic (dry) compressive strength values.

- *Abrasive strength*: This test is performed in order to estimate the block's resistance to mechanical erosion. The block is subjecting to brushing with a metal brush at a constant pressure over a given number of cycles. The abrasive strength is proportional to the abrasion coefficient, which is expressed as the ratio of the surface subjected to brushing (using the one that actually is to be exposed in a real structure) to the quantity of material removed by brushing.

- *Capillary absorption*: This test assesses the water absorption rate of a block, in a capillary absorption situation, after a partial immersion of 10 min (the depth of the water should be kept constant throughout the test at 5 mm). The block is weighed both oven-dried and after the immersion and the water absorption coefficient (C_b) is calculated (in g/cm^2), according to eq.(3-4).

$$C_b = 31.62 \times (m_h - m_d)/S \qquad (3\text{-}4)$$

where m_h is the mass of the brick (in grams) after the 10 min immersion, m_d is the oven-dry mass of the brick (in grams), and S is the surface of area of the submerged face (in cm^2).

- *Dimension, Mass, Apparent Density*: This is not actually a test, but rather a "quality control" procedure, performed in order to determine the physical characteristics of a block lot. Especially for handmade (i.e. hand-pressed) adobes, there exists a strong possibility for the blocks to "slump" and/or shrink on removal from the mould. The latter may also warp due to repeated use. It is therefore essential to monitor the actual blocks' dimensions, as well as their "orthogonality". Mass is determined by weighing, after drying the blocks in an oven (as per previously described). Finally, the apparent density is a readily available measure of the extent of compaction of the blocks.

- *Spray test*: Durability is tested by spraying the blocks with water according to a standard procedure and making observations for any erosion, or pitting. This test -described in USAID, 1981- assesses the block's resistance against hard and driving rain and can give satisfactory results even when laboratory equipment is not available[19]. The supplies needed include: a spray nozzle that can produce a hard spray all over a block (a 100 mm in diameter shower head is usually used), some wire mesh covered with fly screen, to place the blocks on, a water supply that delivers a fairly constant pressure for two or more hours (the water pressure usually used is about 1.35 bar) and an accurate gage for measuring the water pressure (mounted in the pipe supplying water to the spray nozzles, at a point near the nozzles).

The bricks are placed on the wire mesh, attached on wooden blocks, so that they are suspended a few centimetres off the ground, with their largest face square to the spray nozzles. The distance between the block arrangement and the nozzles should be about 200 mm. Two hours after continuous spraying, the blocks are removed and examined closely. The depth of pitting, or surface erosion is measured and notes are kept regarding the time required for any block to completely fall apart or get washed away by the spray. In Fig. 3-22, the set-up of a test similar to the afore-described one is given simulating the effect of rain on stucco panels.

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[19] *Should laboratory equipment be available, the following standards are pertinent: ASTM - D559-03 Standard Test Methods for Wetting and Drying Compacted SOIL-Cement Mixtures, and ASTM - D560-03 Standard Test Methods for Freezing and Thawing Compacted SOIL-Cement Mixtures.*
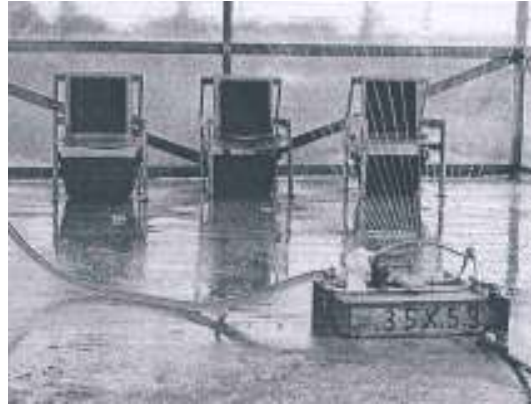
Fig. 3-22 Simulated rain test on stucco panels. (source: Heredia et al., 1988)

- *Linear shrinkage test*: This test (described in: Webb and Lockwood, 19==;==Webb, 1988; ==z== and Mukerji, 1988) is pe==r==med in order to estimate the proportion of the clay fraction in a soil from its linear shrinkage value and by implication, the stabiliser type and amount. The test's procedure is as follows:

1. A quantity of about 1.5 to 2.0 kg of the representative soil sample, which has passed through the 6 mm sieve, is moistened. The soil has to be wet enough to form a paste, which when tapped brings water to the surface. The moistened soil sample should be able to retain its shape, without staining the hands when squeezed between them, and should not break into several smaller lumps when dropped from a height of one metre;
2. A wooden mould with internal dimensions 600x40x40 mm, open at the top, with formica lined walling, is lightly smeared (internal surfaces) with a suitable lubricant. This is done to prevent the soil adhering to the internal surfaces of the mould, which would interfere with the movement while shrinking;
3. The mould is filled with the soil in three equal layers, while tapping and lightly pressing it in all four corners using a wooden spatula. This is done to eliminate any trapped air pockets from the soil; the top of the final layer is smoothened using the spatula, so that the soil exactly fills the mould box. This ensures that any soil that would have extended over is removed;
4. The filled box is then left with its contents in the sun for a period of 5 to 7 days, or in a shaded area for 7 to 10 days; during this period, the mould and its contents should not be rewet, e.g. by rain or addition of more water;
5. At the end of the drying period the soil should have dried out and shrunk either as: a single piece, several pieces with cracks across the width, or hogged up and out of the mould in a crescent shape.
6. The linear shrinkage is then calculated by determining the shrinkage gap by deducting the length of the dry soil sample from that of the mould cavity box. The shrinkage is expressed as a percentage of the original mould cavity length, or simply in millimetres.

$$L_s = \left(\frac{L_w - L_d}{L_w} \right) \times 100 \quad (\%) \qquad (3\text{-}5)$$

where L_s is the linear shrinkage (%), L_w is the length of the wet soil prism (in mm), and L_d is the length of the dry soil prism (in mm).

Shrinkage and severe cracking across the width of a soil is an indication of high sand content soils of low clay and silt. Shrinkage with hogging up and out is an indication of a high clay content soil.

In the Table 3-4 the typical requirements for dry and wet compressive strength values, as well as for spray and linear shrinkage test values, are listed, according to most American codes addressing earth-based construction issues.

Table 3-4 Typical required values for various tests (American codes).

Tests	Rainfall per year		
	< 0.5 m	between 0.5 & 1.3 m	> 1.3 m
Spray Test	Pitting is less than 13 mm deep.	Pitting is less than 6.5 mm deep.	No pitting of surface; a light roughening is allowable.
Dry Compressive Strength	Minimum of 1.7 MPa for adobe and rammed earth. Minimum of 2.1 MPa for pressed blocks.	Minimum of 1.7 MPa for adobe and rammed earth. Minimum of 2.1 MPa for pressed blocks.	Minimum of 1.8 MPa for adobe and rammed earth. Minimum of 2.1 MPa for pressed blocks.
Wet Compressive Strength	Minimum of 0.7 MPa for adobe and rammed earth with good surface coatings, 1.2 MPa without surface coatings. Minimum of 1.0 MPa for pressed blocks.	Minimum of 0.85 MPa for adobe and rammed earth. Minimum of 1.1 MPa for pressed blocks.	Beat soils will meet requirements for dry compressive strength. Can be somewhat less.
Linear shrinkage (length change)	Maximum of 0.8 mm for 305 mm block.	Maximum of 0.8 mm for 305 mm block.	Maximum of 0.8 mm for 305 mm block.

3.6   Types of earthen buildings

3.6.1 General

There are generally twelve broad earth construction categories. Their suitability is strongly dependant on the type of soil used and its hydration state. The distribution of different earth building techniques in the Americas is illustrated in Fig. 3-23, while the total existing combinations are arrayed in Table 3-5. Both illustrations are reproduced from the textbook "Earth Construction – A Comprehensive Guide", by Houben and Guillaud, 1994. A short description of each of the different earth-based construction methods follows, placing particular emphasis on adobe building constructions.
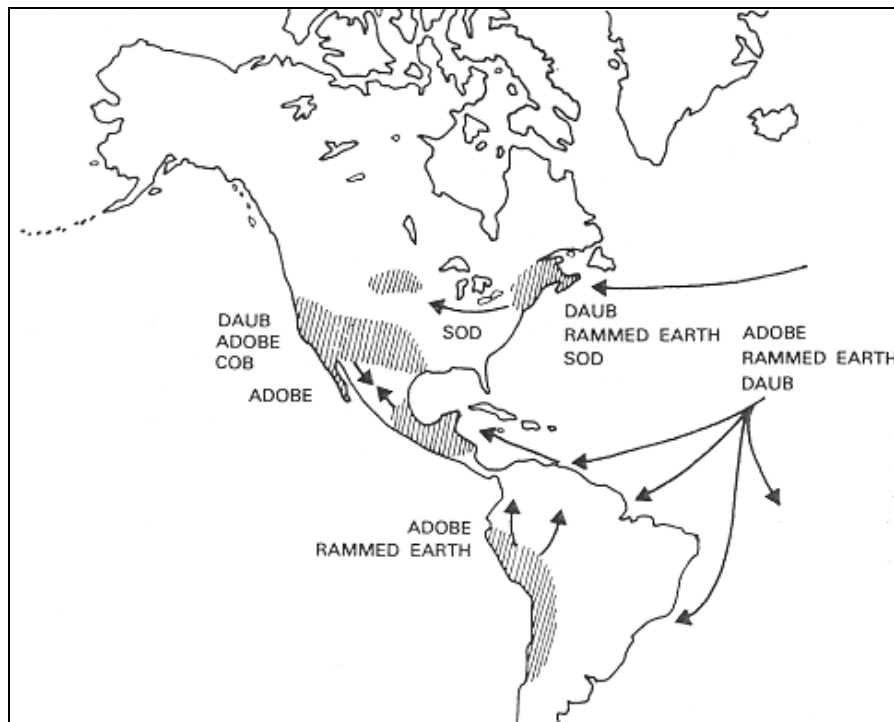
Fig. 3-23 Distribution of different earth building techniques in the Americas.
(source: Houben and Guillaud, 1994)

Table 3-5 Earth building techniques, according to the hydration state of the existing soil.

(source: Houben and Guillaud, 1994)

	Soil hydration state											
	Concretion		Dry		Humid		Plastic		Soft		Liquid	
	Rocky	Crumbly	Solid aggregation	Friable aggregation	Dry soil	Moist soil	Solid paste	Semi-solid paste	Semi-soft paste	Soft paste	Mud	Slurry
Organic	4			2		4						
Gravelly	1		3						7		10	
Sandy						5		9		8		
Silty							6					11
Clayey										12		

1	2	3	4	5	6	7	8	9	10	11	12
Dugout	**Earth sheltered space**	**Fill-in**	**Cut blocks**	**Compressed earth**	**Direct shaping**	**Stacked earth**	**Moulded earth**	**Extruded earth**	**Poured earth**	**Straw Clay**	**Daubed earth**
Dwelling dug directly out of a layer of the earth's crust	A structure built in a material other than earth, is encased and covered by earth	Upgraded soil is used to fill hollow materials used as a framework	Blocks of earth are cut directly from the ground	Blocks or massive walls are formed by compressing soil in moulds of formwork	Thin walls are built by direct manual shaping of plastic soil	Thick walls are built up by pilling up pasty balls of earth on top of one another	Pasty soil is moulded by hand or in moulds of various shapes	A soil paste is extruded by a machine and building elements are made from it	Liquid soil poured into formwork or moulds serves as a kind of concrete	A slurry consisting of clayey soil binds shreds of straw fibre to produce a fibrous material	Clayey soil mixed with fibres is applied in a thin layer to fill in a support

Notation

Rocky concretion: Monolithic agglomerations of coarse material; compact and heavy soil which is difficult to cut.

Crumbly concretion: Agglomerations of crumbly or decomposed material, including peat and sod, which is easy to cut.

Solid aggregation: Perfectly dry soil in large, solid lumps.

Friable aggregation: Absolutely dry soil in powder form.

Dry soil: Soil characterized by a naturally low humidity (4 to 10%); it is dry rather than moist to the touch.

Moist soil: Soil unmistakably moist to the touch (8 to 18%), but cannot be shaped because of its lack of plasticity.

Solid paste: An earth ball (moisture content 15 to 30%), which flattens only slightly when dropped from a height of one metre is formed by powerful kneading with the fingers.

Semi-solid paste: Only slight finger pressure is sufficient to form an earth ball (moisture content 15 to 30%) which flattens slightly but does not disintegrate when dropped from a height of one metre.

Semi-soft paste: With this very homogenous material it is very easy to shape an earth ball that is neither markedly sticky nor soiling (moisture content 15 to 30%) that flattens markedly without disintegrating when dropped from a height of one meter.

Soft paste: This kind of soil is so adhesive and soiling (moisture content 20 to 35%) that it is extremely difficult, if not impossible, to make balls from it.

Mud: This kind of soil is saturated with water and forms a viscous, more or less liquid mass.

Slurry: This consists of a suspension of clayey earth in water and constitutes a highly liquid fluid binder.

3.6.2 Examples of earth-based construction methods

(a) Dugout

In the Aegean island of Santorini, the slope and hardness of the ground, coupled with the need for material saving, led to the creation of vaulted caves dug into the top layer of the volcanic ash that were used as dwellings (Fig. 3-24), stables, wineries, etc. Besides the ease of construction, a major advantage of these excavated dwellings is their remarkable seismic and thermal performance (Stasinopoulos, 2002).

Fig. 3-24 Cave houses in Santorini.
(source: Wojtowicz, 1997: Personal photographic archive, available online at: http://www.slawcio.com/caves.html)

(b) Earth sheltered space

There are two basic types of earth-sheltered housing—underground and "bermed" (or banked with earth). Certain characteristics such as the location and soil-types of the construction site, the regional climate, and the design preferences are central to which type of earth-sheltered housing is the most appropriate one. Underground housing means an entire structure built below grade or completely underground. A bermed structure may be above grade, or partially below grade, with outside earth surrounding one or more walls (see Fig. 3-25). Both types usually have earth-covered roofs, and some of the roofs may have a vegetation cover to reduce erosion (source: http://www.eere.energy.gov/erec/factsheets/earth.pdf).

Fig. 3-25 Earth-sheltered house. (source: http://www.paulinehurren.com.au/earth.html)

(c) Fill-in

Apart from the variety of existing hollow blocks that can be filled with earth, more innovative ideas have been proposed, such as the use of loam-filled hoses, synthetic bags, and disregarded car tires. In the first technique (developed by Gernot Minke in 1992, in Kassel, Germany), elastic cotton hoses are filled with a mineral loam mixture; they are then hand-smoothed, so that the loam oozes and forms a thin mud cover over the fabric. When staked, these mud coverings adhere together (Minke, 2000a)[20]. The second technique (Building

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[20] *A similar technique to this one is called SuperAdobe and involves the use of continuous sandbag tubing commonly used in the fabrication of sand bags for flood control, military trenches, retaining walls, and similar tasks. Structures are constructed by laying out coils of the tubing, which is filled with a*

Research Institute, University of Kassel, Germany, 1978) involves the construction of walls, which are formed by two layers of jute[21] fabric. Thin wooden posts are hammered into the ground and the fabric is fixed to these from the inside. The space between is filled with soil (Fig. 3-26). The last technique makes the use of discarded car tires in-filled with soil dug out from the foundation of the structure under construction.

Fig. 3-26 Germany, Kassel School of Architecture. (source: Minke)

(d)   Cut blocks

"Soddies" are small houses with walls built of stacked layers of uniformly cut turf (sod). The individual "bricks" of sod are held together by the thick network of roots that made preparing fields for planting so very difficult. Sod is cut with special plows, or by hand, with an axe and/or shovel. Roofs are made from timber, rough or planed, and covered with more sod. If timber is not available, roofs are built up with twigs, branches, bushes and straw. The building in Fig. 3-27 is at Ash Hollow, Nebraska, and was reconstructed in 1967 (from: http://websteader.com/wbstdsd1.htm).

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cement stabilized earth or sand mix as the coil is laid down. Each coil is locked to those below it by coils of barbed wire. Coils with a greater amount of cement are used as foundation and structures are typically built partly below grade so that the volume of soil excavated can provide sufficient material for the construction. Structures are built-up in the manner of coiled pottery; domed and barrel vault shapes are predominant. Smaller scale details are formed by using smaller lengths of tubing down to the size of small block-like bags, which are stacked in a brick fashion. The completed structures are covered in a thick coating of adobe plaster inside and out supported by metal or plastic mesh. This is critical not only for appearance but because the material of the bags can deteriorate rapidly when exposed to UV light.

*   SuperAdobe offers great reduction in construction time and labour overhead compared to other earthen construction techniques. This is because the sandbag tubing is simply filled with loose earth material as the coils are laid in place, eliminating steps like brick fabrication and mortaring and the lifting of any heavy components. Low skill requirement and the fact that soil composition is not as critical an issue as it is with most other earthen building techniques are additional advantages of this building system. However, it is not without some significant limitations. Curved forms are critical to structural integrity with this technique. Long straight walls are unstable with this kind of structure and so designs tend to be limited to domes, cylinders, and barrel vaults. Multi-storey structures may only be possible with separate internal mezzanine structures, except in the possible case of very small cylinders and domes or walls of great thickness relative to the supported deck area. Windows and doors are typically limited to arched or round shapes, because of the inability to integrate lintels into the structure. The structure has to coil over such openings. Aging of the sandbag material is a critical issue, because it is normally designed to deteriorate or be biodegradable and failure of this material can lead to critical structural failure. Finally, while the structures can provide their own monolithic roof forms, adobe does not weather well and the structures may require additional protection in the form of elastomeric coatings in all but the driest climate conditions (Hunting, 2003).*

[21] *Jute is an extremely versatile vegetable fibre known for its strength and durability. Jute fibres are long, varying from 1.5 to 3.5 metres, totally biodegradable and of good quality. Jute fabric (fibres woven into burlap) is extremely durable and has very little stretch, thus making it ideal for many different forms, from bags to carpets and clothing.*

(a)   (b)

Fig. 3-27 (a) A "soddie" house; (b) Wall detail.

(e)   Compressed (or Rammed) earth

Rammed earth construction (also referred to as *tapial* in Latin America, or else, *pisé de terre*, in France) is conducted by erecting wooden or metal forms for the walls and filling them with a moist cement stabilized earth mix which is compacted by pounding with hand tools (with conical or flat heads) or with a mechanical compactor. Metal rebar is often added to further increase ductility. Different kinds of earth or mineral compounds are sometimes added to each earth layer (of thicknesses ranging between 100 and 150 mm) for the sake of decoration. The finished walls are massive and monolithic (Fig. 3-28), offering high strength, high thermal mass and higher insulation value than block/brick construction. High load bearing strength allows for multi-storey structures, usually based on floor decks supported by massive wood beams. The same types of roof systems employed with adobe can be used but metal or shingle roofing with a wide overhang is more typical. No surface finishing is required except for aesthetic effect. A beeswax finish is typical for the interiors as it allows the attractive wall texture to remain visible.

   Rammed earth is one of the most labour-intensive earthen construction processes of all because of the combination of heavy form erection, wall pounding, and mixing/moving large volumes of earth.

Fig. 3-28 Rammed earth house in Otorohonga, New Zealand.
(source: http://www.hahaha.com.au/rammed.earth/kiwi.htm)

(f)   Direct shaping

The plastic earth is potter-like shaped. This technique is used a lot in Africa, for houses and granaries (Fig. 3-29). The most beautiful examples are found in Cameroon.

Fig. 3-29 Nigeria, Joss. Shaping a granary. (source: CRATerre-EAG)

(g)   Stacked earth

Plastic soil is formed in balls, which are freshly stacked on each other. This technique is mainly used in Africa, India and in Saudi Arabia, but the most beautiful examples are encountered in Yemen. The contemporary name of stacked earth is cob[22] (or *wichert*); a name derived from the British Isles. In the U.S., cut sod bricks are called *"terrones"*. This technology is the predecessor to adobe and has its equivalents in all the regions where adobe is common. Unlike adobe and straw bale construction, cob does not use bricks, or blocks. Instead, wall surfaces can be sculpted into smooth, sinuous forms. A cob home may have sloping walls, arches and lots of wall niches.

Construction begins with a foundation system akin to adobe, but often much higher off the ground (Fig. 3-30), particularly where damp climate makes ground seepage a critical issue. Courses of damp cobs are stacked along wall lines with one to a couple of layers completed within a day. Modern cob construction may top the walls with a concrete bond beam, use a wooden bond beam, or a separate roof frame supported on a post and beam system (Hunting, 2003).

Fig. 3-30 Cob house in Mayne Island, Canada. (source: http://www.cobworks.com/maynegallery.htm)

(h)   Moulded earth

This building technique involves the use of clay bricks (adobe) formed in moulds and (traditionally) dried in the sun. Adobe[23] is one of the oldest and most common building materials known to man. These unbaked bricks consist of sand, sometimes gravel, clay, water and often straw or grass mixed together by hand, formed in wooden molds and dried by the sun. When machinery is not available, earth is manually tamped in the mould; else, mechanical compression is used (manual, or motorized presses), in order to accommodate large production outputs of compressed earth blocks. The advantages and disadvantages associated with adobe construction are listed in Table 3-6.

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[22] *In Old English, "cob" was a root word, which meant lump, or rounded mass.*

[23] *The word adobe comes from the ancient Arabic building tradition called* "al-tob". *The Spanish, because of their contact with the Moors of North Africa, knew the process and called it adobe. According to Houben and Guillaud (1994), the accurate Arabic word is* "ottob", *which in turn is related to* "thobe", *the Egyptian word for sun-dried brick. In Latin America, alternative terms for adobe are* "mampuesto", *or* "chan" *(local Guatemalan term).*

Table 3-6 Advantages and disadvantages in building with adobe.

Advantages	Disadvantages
▪ Low cost: The only costs implemented are the ones corresponding to the labour required for preparation and placement. ▪ Material availability: Earth is a local material, contributing to sustainable development. ▪ Requirement of low skill and technology level (simplicity of dwelling's lay-out and of constructional technique): Earth is ideal for self-help construction. ▪ Improved thermal and acoustic insulation properties. ▪ Good fire resistance: According to the German Building Standards, earth, even with a high straw content, is not combustible, if its density is higher than 1700 kg/m^3. For light earth/fibre mixes fire resistance can be enhanced with the use of earth or lime renders and plasters. ▪ Healthy indoor environment: As a result of earth's combination of high thermal mass, hygroscopicity (the ability to absorb and release moisture), and permeability/breathability (Hunting, 2003). ▪ Environmentally friendly construction type: Adobe is a renewable, non-toxic resource that can be readily recycled; its use contributes to the elimination of hazardous emissions involved in the construction process. ▪ Form versatility of architectural items.	▪ Lack of uniformly accepted criteria; as a result of this an accurate evaluation of the finished product cannot be achieved. ▪ Earth is not an industrial/standardized building material: Depending on the site where the earth is dug out from, it has different amounts and types of clay, silt, sand and aggregates. Due to the diversity of its characteristics, the mix design of the earth-based building materials needs to be appropriately adjusted. ▪ Traditional adobe buildings are prone to partial or total collapse due to medium and high earthquake intensities; they are also prone to destruction due to heavy rainfall, flood, or hurricanes. ▪ Structural integrity depends largely on construction details. ▪ Design limitations - e.g. on size of openings for windows and doors. ▪ The construction period is weather-dependent. ▪ Adobe structural members shrink significantly when drying out: Due to evaporation of the water used to prepare the mixture (which is required to activate the clay's bonding ability and to achieve workability), shrinkage cracks occur. The linear shrinkage ratio is usually between 3% and 12% for wet mixtures used for the brick fabrication and the preparation of mortar. Limitation of drying shrinkage can be achieved through the reduction of clay and water content, optimization of grain size distribution and the use of additives (Minke, 2000a). ▪ Fast deterioration of load-bearing capacity is observed when the structure is insufficiently maintained.

Today some commercially available adobe-like bricks are fired (kiln-dried). These are similar in size to unbaked bricks, but have a different texture, color, and strength. Similarly, some adobe bricks have been stabilized (as described in a previous part of this report), containing cement, asphalt and/or bituminous materials, but these also differ from traditional adobe in their appearance and strength. More information on adobe is provided in a following, separate part of this report. The mechanically compressed earth blocks are briefly described hereafter.

The mechanically compressed earth blocks are basically similar to the adobe ones; the main difference is in the method of block fabrication. Instead of a wet mud being loaded into moulds and air dried, this type of block uses a drier mix of earth with a stabilizer, such as cement, which is loaded by bin into a molding machine. The hand-operated press machine is commonly referred to as a "Cinva ram" (Fig. 3-31). There are several different types of presses. *Manual presses* carry out only the (static) compression and ejection of the blocks, and can be mechanical, hydraulic or both, in operation. *Motorized presses* enable higher production rates (e.g. greater than 800 blocks per day). Certain motorized presses may exert dynamic compaction. *Light mobile production units* (which are transportable) and *fixed*
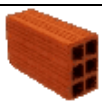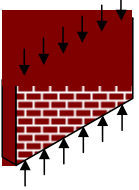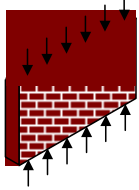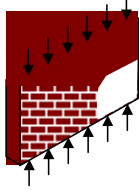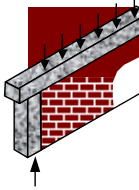
production units (which are difficult to transport) are motorized, and sometimes automated. In addition to the compression and ejection of the blocks, they also carry out raw material preparation and/or removal of the products.

(a)   (b)

Fig. 3-31 (a) A "Cinva ram" press; (b) This house was built using compressed earth bricks in Ivory coast, within 10 days, by trainees, who were part of a local development program. [sources: (a) http://www.northcoast.com/~tms/adobe.html; (b) http://www.earth-auroville.com]

The compression process reduces the volume of earth and rearranges clay particles to form a more stable material matrix. Compressed earth blocks are denser (and hence, more durable) than adobe bricks, and offer a higher geometric uniformity. A comparative listing of appearance, performance and structural use of different building blocks is given in Table 3-7.

Table 3-7 Comparison of different building blocks. (source: Terre-EAG, 1995)

	Characteristics	Unit	CEB	Fired Bricks	Adobes	Concrete Blocks
	Shape & Size (ℓ x w x h)	(mm - average)	(295 x 140 x 90)	(220 x 105 x 65)	(400 x 200 x 100)	(400 x 200 x 150)
Appearance	Surface		smooth	rough to smooth	irregular	rough
	Visual aspect		medium to good	good to excellent	poor	average
Performances	Wet compressive strength	MPa	1 - 4	0.5 - 6	0 - 5	0.7 - 5
	Reversible thermal dilation	%	0.02 – 0.2	0 – 0.02	-	0.02 – 0.05
	Thermal insulation	$W/m^2\,^{\circ}C$	0.81 – 1.04	0.7 – 1.3	0.4 – 0.8	1.0 – 1.7
	Density	kg / m^3	1700 - 2200	1400 - 2400	1200 - 1700	1700 - 2200
	Durability	-	low to very good	low to excellent	poor	low to very good
	Use in masonry	-	Load-bearing / without render	Load-bearing / without render	Load-bearing / with render	Load-bearing / with render

(i)   Extruded earth

A very clayey soil (large aggregates having been removed) is fed into a machine in the state of semi-solid paste and is extruded through it in different shapes. The blocks are often hollow (in order to reduce weight and increase thermal insulation) and are cut to the desired length, once these are on the delivery belt (Fig. 3-32); this technique was developed in the 20<th century. Several companies in Germany and one in Switzerland are producing large extruded lightweight panels from earth, usually mixed with cut straw, or sawdust, or lightweight aggregates, like perlite. Their density varies from 800 to 1000 kg/m^3 and they are used for non-load-bearing interior walls, or for the interior layer of exterior walls (Minke, __b).

Fig. 3-32 Extruded earth profiles production line. (source: unknown)

(j)   Poured earth

The technical name for poured earth is formwork cob. Like rammed earth, poured earth walls are erected between formwork (as in Fig. 3-33) using a sandy material with coarse to fine granular particles. The external walls (usually 300 mm thick) are load-bearing and can be engineered to 2-3 stories. The material usually contains 5-8% by volume of white cement at a ratio of about 20:1. Sufficient water is added to allow the mix to flow into the wall forms, which are left in position for about 12 hours. The ultimate finish can be natural - from the formwork- or sand blasted (source: http://www.startingpoint.com.au/sppages/repe.htm).

Fig. 3-33 Walls of poured earth in casting process, using the FORMBLOCK patented formwork system. (source: http://www.formblock.com.au/what_is_formblock.htm)

(k)   Straw clay

This earthen construction practice can be also considered as one of the five methods of building with straw (straw bale construction style). Straw bales come in all shapes and sizes, from small two-string to larger three-string bales and massive conical or round bales. The medium sized rectangular three-string bales are preferred for building construction. Three-string bales are better structurally, have higher R-value, and are often more compact. A typical medium-sized, three-wire bale may be 0.58 x 0.40 x 1.06 m and may weigh from 37 to 42 kg. The smaller two-wire bales, which are easier to handle, are roughly 0.46x0.35x0.91 m and weigh 25 to 30 kg. If the current trend continues, it may not be long before "construction-grade" bales begin to appear (U.S. Department of Energy, Energy Efficiency and Renewable Energy, April 1995). Straw can be used for building purposes as follows:

1. *In-fill or non-structural bale* - This building system, useful for construction of large structures, depends on a pole or post-and-beam building design. Post-and-beam construction employs a skeleton of vertical posts and horizontal beams (heavy wooden, steel, or concrete post and beam systems) to support the roof. The straw-bale walls are non-loadbearing; the integrity of a wall unit is achieved by piercing the bales with rebar, or bamboo, and attaching them to a pole or column. A recent innovation uses bales with holes cut in them as forms for casting a reinforcing concrete frame, much like a giant version of insulated concrete forms.

2. *Structural bale* - The building process is akin to adobe construction, starting with the same type of foundation and using large bales of straw as "bricks" (Fig. 3-34). Automatic straw balers create tight building blocks that are stacked up to one- and one-half stories. The "straw bricks" are "nailed" in place using long metal pins (often threaded rod), tension cables or special gripping plates. The walls are then covered on both sides with a mesh lathe, which is attached by wire pins on the bales, while the surfaces are plastered using a soil/straw mixture. As a load bearing wall system the bales must be topped with a bond beam of heavy lumber, steel or concrete.

3. *Straw-clay building* - A batter of clay and water stirred into the loose straw produces a straw-reinforced clay mud. In the past, this mixture was packed into a double-sided wood form between the posts and beams of a timber-frame building. Today, a lightweight wooden ladder like frame replaces the old heavy timber frame. European heavy timber structures using this method are still standing after more than 200 years. This method has passed the most stringent European fire codes.

4. *Mortar bale* - Structural mortar, made of portland cement and sand, is applied between the straw bales. When dry, its lattice structure remains intact if the straw bales should ever fail. This method, developed in Canada, passes Canadian building codes. Bales are stuccoed on the exterior and plastered on the interior to protect them and provide an attractive finish. The mortared joints, stucco and plaster also add to the structural integrity of the wall system.

5. *Pressed straw panels* - Straw is compacted under certain temperatures. The resulting panels are 100 percent straw that can be used to build pre-fabricated structures, not only walls, but also roofs and floors.

The low skill requirement, coupled to a high insulation value and fast construction, are key attractions for this technology. It has enjoyed a very wide range of climate conditions for its use, proving effective insulation in every climate, from desert, to humid, to cold winter regions. It is a less time consuming form of construction, due to the large size of the bales; however, they are not of insignificant weight and limit to a great extent the geometry of the structure. Labour overhead is in general lower than in adobe construction; however, this may not be the case if extra effort must be spent on building a post and beam frame (Hunting, 2003).

Fig. 3-34 Straw-bale house under construction.
(source: The Straw Bale Building Association http://strawbalebuildingassociation.org.uk/g10.html)

(I)   Daubed earth

This type of construction is widely known as "wattle and daub" in Europe and Australia (also referred to in some areas as "rab and dab"), whereas in Latin America it bears the name *"bahareque"*, or *"quincha"*. It is the predecessor to the lathe and plaster interior wall systems predominantly used in western European construction between the 17th and the 19th century, up to the introduction of drywall products (Hunting, 2003).

Typically, the technique consists in the in-fill of panels in timber framed structures (such as the one in Fig. 3-35a), comprising of vertical staves of timber (e.g. oak) or bamboo (Fig. 3-35b & c), interwoven with fine flexible branches or twigs (Fig. 3-33d), usually of hazel, of about one metre length and one centimetre diameter, and daubed with (by firmly pressing in) a mixture of mud, dung (daub) and chopped straw. These panels can be both single and double-layer grids. The resulting structural system is very light and flexible, as it is basically a timber frame structure with flexible joints and earth in-fill. The walls have neither insulation value nor thermal mass and systematic maintenance is needed, in order to compensate for the effect of weathering on the wooden or cane elements.

In Peru, *quincha* consists of wooden frames in-filled with interwoven cane and coated with a mixture of mud (*barro*) and plaster, gesso or a VAX of sand combined with concrete on both sides. In the past, two-storey houses were usually built with an adobe first storey and a lighter second storey made out of *quincha*; the walls were finished with elaborate stucco friezes and adornments. This type of construction can still be appreciated today in churches and old houses in some cities of the Peruvian coast, such as Trujillo and Lima (Blondet et al., ?).

Within the scope of the research program "Peru Project" (financed by the International Development Research Council - IDRC, Ottawa, Canada), *"estera"*, a crushed and woven cane mat stretched across and nailed to a wooden frame, was used for the construction of wall panels (Annual report, Technical University of Nova Scotia, School of Architecture, 1988, http://www.idrc.ca/library/document/051904/). This process was repeated on both sides of the panel (dimensions: 2.4 m high x 0.8 m wide); placed side-by-side and nailed together. The whole room was tied together by the use of a collar beam. The roof system consisted of a round cane (*caña brava*) placed over wood joists spaced at 0.8 m modules. A light corrugated roof made from jute[24] was used to cover the joists.

In El Salvador, houses of *bahareque* are usually topped with a tin roof (*lámina*). There are practically no foundations for the *bahareque* walls: a perimetric trench 100-150 mm in depth is excavated, in which the walls are fitted; the latter are further stabilized by the pilling of soil on both sides of their bases. *Bahareque* buildings are prone to physical decay due to the action of parasites (endemic bamboo insects) that find a favourable habitat in the crevices of the *bahareque* walls and roofs, causing infection to humans through the *"Mal de Chagas"* disease[25].

Prefabricated wall elements, based on the "wattle and daub" system, were developed by CEPED in Camari, Brazil (as reported by Minke, 2001); the panels were in-filled in-situ.

(a)

(b)

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[24] *A mixture of jute fibres and concrete, placed in a mould, shaped and dried.*
[25] *After several years of an asymptomatic period, 27% of those infected develop cardiac symptoms which may lead to sudden death, 6% develop digestive damage mainly* megaviscera*, and 3% present peripheral nervous involvement (from: http://www.who.int/ctd/chagas/disease.htm).*

(c)   (d)

Fig. 3-35   (a) A wattle and daub building in Cayman Islands; (b) Traditional wattle and daub
system, Venezuela; (c) *Quincha* building tutorial in Panama; and (d) Panel to be
in-filled with earth. [sources: (a) http://www.cayman500.ky/img/ACF14E6.pdf); (b) Minke, 2001; (c)
photo by Barkema, D. in http://www.thepanamanews.com/pn/v_09/issue_13/community_01.html; and
(d) http://www.northcoast.com/~tms/papercrete.html]

3.7   Adobe Construction

3.7.1 General

Adobe construction has been practiced in Latin America since the colonial times and it is still
being used in rural and suburban areas following the same traditional building processes. In
most urban areas, though, this building technique is no longer permitted. For instance, the
San Salvador Metropolitan building and planning agency (OPAMSS) and the Vice Secretary
of Housing (*Vice-Ministerio de Vivienda*) have prohibited the construction of adobe housing,
owing to its poor seismic performance. However, as many cities in Latin America have
experienced very high rates of growth during the last century, urban areas often contain
adobe constructions that were built in the past on ground, which, until recently, was
considered as rural (this is particularly true in Argentinean cities)[26].

3.7.2 Building configuration

Buildings of this type usually serve as single-family dwellings (with the number of inhabitants
varying between 5 and 10), featuring heights of one-storey (2.5 to 3.0 m high) and rectangular
or square plans (roughly 6 to 30 m in length and 5 to 15 m in width). Wall-to-wall span varies
between 3 and 6 m. In some cases, the houses also include a commercial space. It should
be noted, though, that the reported data on the characteristics of adobe dwellings appears to

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[26] *Information on the typical adobe construction practices of Latin American countries has been drawn
from the following World Housing Encyclopaedia Reports:*

- *"World Housing Encyclopaedia Report, Country: El Salvador, Housing Type: Vivienda de Adobe
(Adobe house)", Contributors: Manuel A. Lopez, Julian Bommer and Gilda Benavidez, Last
Modified: 11/8/2003";*

- *"World Housing Encyclopaedia Report, Country: Argentina, Housing Type: Traditional adobe house
without seismic features", Contributors: Virginia I. Rodriguez, María I. Yacante and Sergio Reiloba,
Last Modified: 17/6/2003";*

- *"World Housing Encyclopaedia Report, Country: Argentina, Housing Type: Traditional adobe house
with reinforcement", Contributors: Virginia I. Rodriguez, María I. Yacante and Sergio Reiloba, Last
Modified: 17/6/2003";*

- *"World Housing Encyclopaedia Report, Country: Argentina, Housing Type: Adobe house",
Contributors: Cesar Loaiza, Marcial Blondet and Gianfranco Ottazzi, Last Modified: 17/6/2003".*

be contradictory, even within the same country. For instance, according to Carazas (2001), despite the existing law in Peru, people continue to build two-storey adobe dwellings (to minimise the total construction costs with respect to the building area).

3.7.3 The role of engineers and local artisans

Generally, neither engineers, nor architects have a role in the design or construction of this housing type, as this is typically an informal construction. Even if professionals were to be involved in any of the construction phases, there is a lack of knowledge in the seismic design of adobe structures. Moreover, although there exists a high level of expertise in traditional construction practices within the village artisans, they tend to be scarce in number, and the rest of the "official" work force is usually not trained. In general, adobe dwellings are built by their future occupants; however, there are examples of new houses built by professional construction companies and NGO's under the supervision of either engineers or local site intendants (*maestros de obras*).

3.7.4 Building permits and development control rules

There are no consistent policies adopted between the different Latin American countries with respect to the official authorization required for the construction for this type of vernacular housing. In El Salvador, for example, building permits are required, despite the fact that the construction procedure is most of times purely informal. In Peru, the approval from the municipal authorities (equivalent to a building permit) is required only in urban areas, whereas in rural areas the construction of adobe houses is usually disregarded by the local administrations. In Argentina, on the other hand, building permits are required as a function of the adobe building to be constructed. In the case of traditional houses built with no seismic features, these permits are not required; whereas, should the house be reinforced (following certain structural measures to improve its seismic behaviour), building permits and approval of the house plans are required, the construction procedure is subject to specific regulations and the construction is controlled by the corresponding state authorities.

Generally, it can be postulated that there are no development control rules, according to which further construction (modifications to the original plan) can be authorized. The owner modifies the house according to his own needs, generally without any professional input. A typical pattern of modification of these structures is the erection of additional parts. In the coastal region of Peru, for example, it is common that owners build an additional floor with *quincha*.

3.7.5 Building materials and construction processes

(a) Adobe bricks

As described in section 3.5, the thick, malleable mud used for adobe brick making consists of sand and clay, mixed with water to a plastic consistency. Commonly, straw or grass, is included as a binder. Although they do not help to reinforce the bricks, or give them added long-term strength, straw and grass do help the bricks shrink more uniformly while they dry. More important for durability, is the inherent clay-to-sand ratio found in the soil. The prepared mud is placed in wooden or metal forms (of a single, or multiple compartments), tamped and leveled by hand or machines.

Interesting production practices can be traced in traditional adobe making techniques. For example, in Sri Lanka the mud is pilled-up into a dome shape and covered with banana leaves or jute bags for a period of three to four days, in order to limit the loss of heat that is generated during the hydration, hydrolysis and microbial action, that tempers the mud. This process results into a highly adhesive soil mortar, suitable for all types of building work (Nandadeva, 1990). A similar "curing" procedure – called *mauken*, in German – is referenced by Minke (2000a), while the wet loam mixture is allowed to stand for a period of 12 to 48 hours. Through this procedure, also known in Peru as "sleeping" of the mud, a better integration and distribution of water with the clay particles is achieved, thus enhancing the cohesive properties of adobe.

When the bricks are stripped off the moulds, they are left to dry on a level surface covered with straw, sawdust, sand or grass to avoid any sticking (Fig. 3-36). After several days of drying, the adobe bricks are ready for air curing. This process consists of standing the bricks on the narrow edge for a period of four weeks or longer. Placing the bricks on the narrow edge minimizes the brick's exposure to the sun, slows down the drying process, and prevents cracking (Chayet et al., 1990). The drying period varies from country to country: from two weeks in Peru, to four weeks in El Salvador.

(a)   (b)

Fig. 3-36   (a) Arrayed adobe bricks, left to dry in the sun (Ecuador); (b) Releasing adobe brick off the (metal) mould. (source: Minke, 2000a)

Adobe bricks are of various sizes (from 200x110x50 mm to 600x300x100 mm) and weights (from 2 kg to 30 kg). The most common size of adobe blocks and their approximate weights are listed in Table 3-8 (Hohn and Kratzer, 2003).

Table 3-8   Typical dimensions and weights of rectangular adobe bricks.

Width (mm)	Length (mm)	Height (mm)	Weight (kg)
200	400	100	14
255	400	100	18
230	460	100	18
300	460	100	24
305	400	130	27
260	520	130	28
305	460	130	30

(b)   Mortar

Typically, most adobe walls are composed of adobe bricks laid with mud mortar. Such mortar exhibits the same properties as the bricks: relatively weak and susceptible to the same rate of hygroscopic swelling and shrinking (i.e. due to moisture absorption), thermal expansion and contraction, and deterioration. Consequently, no other material has been as successful in bonding adobe bricks. Today, cement and lime mortars are commonly used with stabilized adobe bricks (cement added to the mix), but cement mortars are incompatible with unstabilized adobe because the two have different thermal expansion and contraction rates. Cement mortars thereby accelerate the deterioration of adobe bricks since the mortars are stronger than the adobe.

(c)   Wall coatings

Adobe surfaces are extremely fragile and need frequent maintenance. To protect the exterior and interior surfaces of new adobe walls, surface coatings such as mud plaster, lime plaster, whitewash and stucco are used. Such coatings applied to the exterior of adobe construction provide retarded surface deterioration by offering a renewable surface to the adobe wall. Usually it is the owner who maintains the house, but given the lack of economic resources, there is little or no maintenance, and over time the construction deteriorates.

Mud Plaster: Mud plaster has long been used as a surface coating. Like adobe, mud plaster is composed of clay, sand, water, and straw or grass, and therefore exhibits compatible properties to those of the original adobe. The mud plaster naturally bonds to adobe, as both of them are made of the same materials. Although applying mud plaster requires little skill, it is a time-consuming and laborious process. Once in place, the mud plaster is smoothened to a "polished" texture by hand, deerskins, sheepskins and small, slightly rounded stones.

▪ *Whitewash*: Consisting of ground gypsum rock, water and clay, whitewash acts as a sealer, which can be either brushed on the adobe wall or applied with large pieces of coarse fabric, such as burlap. In principle, whitewash is generally considered inexpensive and easy to apply.

▪ *Lime Plaster*: Lime plaster, widely used in the XIX century as both an exterior and interior coating, is much harder than mud plaster. It is, however, less flexible and cracks easily. It consists of lime, sand, and water and is applied in heavy coats with trowels or brushes. To make the lime plaster adhere to adobe, walls are often scored diagonally with hatchets, making grooves about 25–35 mm deep. The grooves are filled with a mixture of lime mortar and small chips of stone or broken roof tiles. The wall is then covered heavily with the lime plaster.

▪ *Cement Stucco*: Cement stucco consists of cement, sand, and water and is applied with a trowel to form 1 to 3 coats over a wire mesh nailed to the adobe surface. This coating, however, does not create a bond with unfired or unstabilized adobe and relies on the wire mesh and nails to hold to the adobe bricks. Since a firm connection of the nails within the adobe is difficult to achieve, a firm surface cannot be guaranteed. Even when very long nails are used, moisture within the adobe may cause the nails and the wire to rust, thus loosing contact with the adobe.

▪ *Other Traditional Surface Coatings*: These have included items such as paints (oil base, resin, or emulsion), portland cement washes, coatings of plant extracts and even coatings of fresh animal blood (mainly for adobe floors). Some of these coatings are inexpensive and easy to apply, provide temporary surface protection and may be available to the adobe owner.

3.7.6 Structural features

(a) Foundations

Adobe building foundations vary significantly due to the difference in local building practices and availability of materials. Many foundations are large and well constructed (e.g. isolated, or strip footings), but others are almost nonexistent. The materials most often used are bricks, reinforced concrete, fieldstones, cavity walls (double) in-filled with rubble stone, tile fragments or seashells. Adobe buildings are rarely constructed over basements or crawlspaces. In Latin America, as a rule of thumb, foundation depths vary between 0.50 and 0.80 m, whereas the widths are generally equal, or slightly bigger than the widths of the supported walls.

(b) Walls

Traditionally, adobe walls tend to be massive (0.8 to 1.0 m), in order to serve as load-bearing elements, and seldom exceed two stories in height. Often, buttresses brace exterior walls for added stability. For example, the lower part of Tibetan buildings is heavily buttressed, or alternatively, the walls may be battered approximately 3 to 6 degrees on the outside, thereby providing more resistance to earthquakes. The thickness of the walls has, unfortunately, been diminished in contemporary adobe dwellings, aiming to the maximization of the net living area. The maximum wall height per construction day is often kept to 1m, in order to avoid crushing of the lower brick layers due to the wall's own weight before the mortar is consolidated. In Peru and in some parts of the Southwest US, it is common to place a long wooden timber atop the last courses of adobe bricks. This timber (tie beam) provides a long horizontal bearing plate for the roof thereby distributing the weight of the roof along the wall.

(c)   Floors

Historically, flooring materials were placed directly on the ground with little or no sub-flooring preparation. Flooring materials in adobe buildings have varied from earth to adobe brick, fired brick, tile or flagstone (called *lajas*), to conventional wooden floors.

(d)   Roofs

In Latin America, adobe roofs of the "colonial" style (mostly featured in the XVII to mid XIX century, but still providing the guidelines for contemporary roof configurations) tend to be flat with low parapet walls. They consist of logs, supporting wooden lathing or layers of twigs covered with packed adobe earth, clay tiles, plastic or metal sheathing. When lumber is available in large quantities (and provided that there is sufficient labour force), the roof is supported on an external independent system comprised of wooden poles. The wood may be aspen, mesquite, cedar, poplar, or any other type available. Roughly dressed logs (called *vigas*) or square-shaped timbers, are spaced on close centres (0.7 m or less) resting either on the horizontal wooden member, which tops the adobe wall, or on decorated cantilevered blocks (corbels), set into the adobe wall. Traditionally, these *vigas* often project through the wall façades. Wooden poles about 50 mm in diameter (called *latias*) are then laid across the top of the *vigas*. Hand-split planks (called *cedros*, if obtained from cedar and *savinos*, if obtained from cypress) or *"saguaro"* (cactus) ribs are used instead of poles, when available; in some areas, these elements are laid in a herringbone pattern. Next, cedar twigs, plant fibres or fabric are placed on top of poles or planks. These serve as a lathing on which 150 mm, or more, of adobe earth is compacted. If planks are used, twigs are not necessary. A coating of adobe mud is then applied overall. The flat roofs are sloped somewhat toward drains of hollowed logs (called *canales* or *gargola*s), tile or sheet metal that project through the parapet walls. Gable and hipped roofs are also popular in adobe buildings.

The roof system can be considered in the analysis of these structures as a flexible diaphragm. The following roofing systems are not applicable to Latin American adobe houses: masonry (e.g. vaults, or composite masonry and concrete joists), structural concrete (e.g. solid – either cast in place, or precast – slabs, cast in place waffle or flat slabs, precast joist system, precast hollow core slabs, precast beams with concrete topping, post-tensioned slabs), steel (composite steel deck with concrete slab).

3.7.7 Building codes and standards for adobe and compressed earth block construction

Codes regarding earth construction (non-engineered construction, in general) and more importantly, code enforcement are non-existent in many rural areas worldwide. As Arya (2000) states, the Codes and Guidelines developed through the standard making bodies remain *recommendatory documents* of good engineering practices, and their implementation depends upon the decision of the Heads of Agencies, Departments, Organisations, Institutions owning the buildings and structures in the public and private sectors. The majority of private individuals remain uninformed. The following list (in alphabetical order) summarizes the existing documentation (formal, or semi- formal

Argentina: Adobe housing is addressed by the 1951 Building Code of the Province of San Juan, the Earthquake-proof Norms Concar 70, the Argentinean Earthquake-proof Norms 80 and the 1990 INPRES CIRSOC Norms.

ASTM: A fairly recent document has been developed by Subcommittee E06.71 and issued (02-07-2003): *"WK573 Guide for Earthen Construction"*. This standard provides guidance for earthen construction that addresses both technical requirements and considerations for sustainable development. Earthen construction includes adobe, rammed earth and other earth technologies used as structural wall systems. [Keywords: adobe; alternative agricultural products; alternative building materials; bio-based products; energy; efficiency; indoor environmental quality (IEQ); sustainability; sustainable development; thermal mass; traditional construction].

Australia: A publication in 1952 by G. F. Middleton, entitled *"Bulletin 5: Earth-Wall Construction"*, described a code of practice for earth construction and was regularly republished. This publication has been accepted in Australia as the standard reference in earth building, detailing soil selection, construction methods and testing procedures. In addition, the National Building Technology Centre brought out a revised edition in 1987. In 1995, A.W. Page from the Department of Civil Engineering and Surveying, University of Newcastle, published *"Unreinforced Masonry Structures – An Australian Overview"*. Following the failure of the joint Australia/New Zealand committee to write a joint standard, Peter Walker of Bath University has written an Australian Handbook to be published by Standards Australia.

El Salvador: RESESCO (1997), *"Reglamento Para La Seguridad Estructural de las Construcciones: Folleto Complementario Adobe (Regulations for the Structural Safety of Construction: Complementary Brochure Adobe)"*, Asociación Salvadoreña de Ingenieros y Arquitectos, Ministerio de Obras Publicas, El Salvador, 36 p.

France: During the period of reconstruction after World War II, three documents of an official nature were published:

"REEF DTC 2001 Béton de terre et béton de terre stabilisé, 1945"

"REEF DTC 2101 Constructions en béton de terre, 1945"

"REEF DTC 2102 Béton de terre stabilise aux liants hydrauliques, 1945".

A special set of specifications was prepared for the *Village Terre de l'Isle d' Abeau*. This official document served as a reference document for insurers, the site manager, architect, contractors and the inspecting body: *"Recommendations pour la conception des bâtiments du Village Terre-Plan Construction, 1982"*.

The following document presents a series of standards ratified as African Regional Standards which should from now onwards enable authorities responsible for building projects to accept proposals made for the use of compressed earth blocks from contractors and builders: *"Compressed Earth Blocks: Standards"*, by Houben H. and Boubekeur S., CRATerre-EAG, 1998, ISBN 2-906901-19-9 142 pp CRATerre.

Germany: The DIN norms for building with earth were published from 1944 to 1956 (*"DIN 18951-18957: Normen zum Lehmbau"*). Several books and technical notes on building with earth have become reference documents in their field. In 1998, the German supreme state building authority established a new technical regulation of earth construction: *"Earth Construction Rules – Terms, Building Materials, Construction Units"* (*"Lehmbau-Regeln" – Begriffee, Baustoffe, Bauteile"*, in German only). The German earth construction association, Dachverband Lehm e.V., produced this agreed document, which covers all forms of earth construction. This document is the current state-of-practice in building with clay and earth in Germany. Based upon a detailed definition of earthen building materials, it details the constitution, use and assessment of different materials, the construction and execution of earthen structures as well as earth and clay-based plasters and dry-lining methods. The final chapter covers material and building-element characteristics and properties.

India: Specifications on stabilized earth blocks were published by the Indian Standards Institute in 1960 *"IS 1725 - Specification for soil-cement blocks used in general building construction"*, and more recently, guidelines were published (1993) on *"IS: 13827-1993 - Improving Earthquake Resistance of Earthen Buildings"*, both by the Bureau of Indian Standards in New Delhi. The guidelines covered in the latter standard deal with the design and construction aspects for improving earthquake resistance of earthen houses, without the use of stabilizers such as lime, cement, asphalt, etc. The provisions of this standard are applicable for seismic zones III, IV and V. No special provisions are considered necessary in Zones I and II. However, considering inherently weak against water and earthquake, earthen buildings should preferably be avoided in flood prone, high rainfall areas and in seismic zones IV and V. Guidelines for Block or Adobe Construction, Rammed earth construction, Seismic strengthening of bearing wall buildings, Internal bracing in earthen houses and earthen constructions with wood or cane structures have been elaborated in this standard.

International Organisations: The International Union of Test and Research Laboratories for Materials and Construction (RILEM) and the International Council for Building Research Studies and Documentation (CIB) established in 1987 the technical commission *RILEM/CIB: TC 153-W90 "Compressed Earth Block Technology"* on earth construction, aiming to the compilation of recommendations and technical specifications regarding earth construction. Additionally, the RILEM Technical committee *TC 164-EBM "Mechanics of Earth"*, which ran between 1994-2000, has not yet published its findings.

Ivory Coast: Published in 1980 the *"Recommendations for design and construction of low-cost buildings in soil cement"* by LBTP (the Building and Public Works Laboratory) in Abidjan.

Morocco: Numerous technical documents have been published by the Ministry of the Interior and the Public Research and Testing Laboratory (LPEE) and are currently being updated by the Technical Building Control Department.

New Zealand: The New Zealand Standards for earth buildings are new publications, first issued in 1998. These specific codes are an adjunct to the existing National building standards for the country. The codes were written in three (3) parts:

"NZS 4297 – Engineering Design of Earth Buildings". This document is a reference dictionary for the following two publications. It contains the definition of terms, formulas, notations, limits and parameters necessary to use and interpret the relevant codes.

"NZS 4298 – Materials and Workmanship for Earth Buildings". This publication contains the codes relating to earth materials. It also helps to define performance criteria in earth buildings such as wind load and seismic resistance.

"NZS 4299 – Earth Buildings not requiring Specific Design". This document provides detailed requirements related to structural issues, such as footings, walls, diaphragms, bond beams, lintels, wall openings and control joints.

Prior to these Standards, the Ministry of Works and Development issued in 1975 the following document: *"Building in Earth: A Preliminary Guide"*, Wellington, MoWD, 8.

Peru: The official state building code for adobe structures is: *"Norma Adobe -Código E-080"*, 1997, Reglamento Nacional de Construcciones, Cámara Peruana de la Construcción, 16th edition.

South Africa: The South African Board of Standards, or SABS, controls new construction and alternative building techniques in South Africa. Various publications have been produced on earth construction. However, no means exist to apply or enforce codes effectively in rural areas. They do however require qualification of new building methods if those methods are to be used in urban environments. In the rural environments, many alternative building methods are used without formal SABS approval. The Dept. of Agricultural Technical Services wrote the *"Farm-Made Bricks and Blocks for Buildings"* publication in 1973.

Switzerland: There are three Swiss codes of practice for earth construction. These cover earth building techniques and methods, properties of earth, examples of construction, working methods and techniques and Swiss examples of earth constructions.

"The Swiss Society of Engineers and Architects (SIA) - Document D 0111"

"The Swiss Society of Engineers and Architects (SIA) - Document D 0112"

"The Swiss Society of Engineers and Architects (SIA) - Document D 077".

Turkey: In Turkey, adobe constructions are well described both by standards and earthquake code: *"Cement treated adobe bricks"*, (TS537 – in Turkish), Turkish Standards Institute, Oct. 1971, *"Adobe blocks and production methods"* (TS2514 – in Turkish), Turkish Standards Institute, Feb. 1977, Adobe construction part of *"Code for the buildings which will be built in disaster areas – Earthquake Code"* (in Turkish), Ministry of Reconstruction and Resettlement, Earthquake Research Institute, Jul. 1975, *"Adobe buildings and construction methods"* (TS2515 – in Turkish), Turkish Standards Institute, Feb. 1977.

<u>United Nations</u>: Three codes of practice have been published by the United Nations:

"58/II/H/4 - Manual on stabilised soil construction for housing", Fitzmaurice, R., 1958;

"64.IV.6 - Soil-cement: Its use in building", 1964, and

"Earth Construction Technology", United Nations Centre For Human Settlements, Nairobi, 1992.

<u>United States</u>: The National Bureau of Standards published several relevant documents in the 1940's, whereas various Uniform Building Code (UBC) Standards were published nationally in the 1970's by the U.S. Department of Interior Building and Indian Affairs, such as the:

Recommended standards of the International Conference of Building officials, 1973: *"Methods for sampling and testing Unburned Clay Masonry Units"* and the *"Uniform Building Section 2403 - Unburned Clay Masonry"*, 1973.

These standards were modified for the different states of Texas, New Mexico, Arizona, Utah, California and Colorado. Regulations regarding building with adobe appear in the Uniform Building Code (UBC) under *"unfired clay masonry"* and in the Southern and Standard Building Codes under *"adobe"*:

"Uniform Building Code Standards – Section 24-15, 2403: Unburned Clay Masonry Units and Standards".

Typically in the U.S. when a builder attempts to build with earth blocks, he or she must provide copies of the codes already developed by other States in order to obtain approval. Most building inspectors will "adapt" UBC code from another State for a newly introduced material, such as adobe or compressed earth blocks. In seismic areas, only the California codes are applicable, and again, were designed for traditional adobe construction.

New Mexico – *"New Mexico Adobe and Rammed Earth Building-Code"*: (1991 New Mexico Building Code: CID-GCB-NMBC-91-1): http://www.earthbuilding.com/nm-adobe-code.html. Regulation and Licensing Department, Construction Industries Division, General Construction Bureau, 725 St. Michaels Drive, P.O. Box 25101, Santa Fe, New Mexico 87504.

California – *"San Diego County, California – Adobe Policy"* (Policy Number: TB-2405-1 / Effective Date: 12/7/81): http://www.earthbuilding.com/san-diego-adobe-code.html.

Colorado – *"Regulation: City of Boulder, Colorado: Adobe Code - Chapter 97: Earthen Masonry Units"*: (http://www.naturalbuilder.com/Boulder%20adobe%20Code.html).

<u>Europe</u>: The Centre for the Development of Enterprise (CDE) has published a number of European Guides/Standards on compressed earth blocks within the context of its mission, which is to provide technical and commercial assistance to small and medium-sized enterprises in ACP (Africa, Caribbean, Pacific) countries. These documents have been prepared in collaboration with the Geomaterials Laboratory of the Department of Civil Engineering and Building [*Laboratoire Géomatériaux* (LGM) / *Département Génie Civil et Bâtiment* (DGCB], as part of the National Engineering Institute for Public Works of Lyon [*École nationale des travaux publics de l'État* (ENTPE)], with CRATerre-EAG (the International Centre for Earth Construction – School of Architecture of Grenoble) and with the support of ARSO (the African Regional Organization for Standardization). The following documents have been especially prepared, so that together they form a coherent ensemble, enabling all the main stages of compressed earth block production, design and construction to be thoroughly understood.

"Compressed Earth Blocks: Production Equipment", CDE Guide, "Technologies series" N°5, CRATerre – EAG: Houben H., Rigassi V., Garnier P., CDE, Brussels, Belgium, 1996, ISBN 2-906901-13-X (Distributed by CDE and CRATerre-EAG).

"Compressed Earth Blocks: Standards", CDE Guide, "Technologies series" N°11, CRATerre – EAG: Houben H., CDE: Boubekeur S., CRATerre – EAG, Brussels / Villefontaine, Belgium / France, 1998, ISBN 2-906901-19-9 (Distributed by CDE and CRATerre-EAG).

"Compressed Earth Blocks: Volume I - Manual of production", CRATerre – EAG: Rigassi V., Aus der Arbeit von GATE, Friedrich Vieweg & Sohn, Braunschweig/Weisbaden, Germany, 1995, ISBN 3-528-02079-2 (CRATerre-EAG/BASIN).

"Compressed Earth Blocks: Volume II - Manual of design and construction", CRATerre – EAG: Guillaud H., Joffroy Th., Odul P., Aus der Arbeit von GATE, Friedrich Vieweg & Sohn, Braunschweig/Weisbaden, Germany, 1995, ISBN 3-528-02079-6(CRATerre-EAG/BASIN).

"Compressed Earth Blocks: Testing procedures", CDE Guide, "Technologies series" N°16, CRATerre – EAG: Rigassi V., CDE: Boubekeur S., CDE, Brussels, Belgium, 2000, ISBN 2-906901-28-8 (Distributed by CDE, ENTPE and CRATerre-EAG).

"The basics of compressed earth blocks", CRATerre – EAG: d'Ornano S., Aus der Arbeit von GATE, GTZ, Eschborn, Germany, 1991(Distributed by CRATerre-EAG/BASIN).

"Earth construction: a comprehensive guide", CRATerre – EAG: Houben H. and Guillaud H., IT Publications, London, United Kingdom, 1994, ISBN 1-85339193-X (Distributed by CRATerre-EAG).

"Modernité de l'architecture de terre en Afrique. Réalisations des années 80", CRATerre – EAG: Guillaud H., CRATerre-EAG, Grenoble, France, 1990, ISBN 2-906901-04-0 (Distributed by CRATerre-EAG).

3.8 Synopsis

In this chapter the earth-based construction practices, which are still encountered in different parts of the world were briefly presented, with special consideration to adobe construction in Latin American countries. Despite the fact that a considerable amount of scientific work has been carried out in the field of earth-based construction, which is also reflected in the existing building codes and standards listed in this chapter, the literature survey reveals a growing feeling in the local population of mistrust in this traditional building method and a general adverse social perception, closely related to the poverty profile that adobe as a building material entails. Low cost, material abundance and sustainability of the built environment, being the principal advantages of earthen structures, might just not be enough to preserve and even promote adobe construction in developing countries. Unless measures are undertaken in order to alleviate the fundamental disadvantage of these buildings, being their high vulnerability against natural disasters, earth will be abandoned as a housing solution in developing countries.

CHAPTER 4

Seismic performance of non-engineered housing units

4.1   Introduction

This chapter comprises an overview of the existing knowledge on the seismic performance of non-engineered adobe and reinforced concrete frame structures. Based on the experience gained from past earthquakes, typical damage patterns and related structural defects of both construction types are presented. Especially for the case of adobe dwellings, a classification of the earthquake-induced damages and a discussion on the systemization and dissemination of scientific knowledge regarding their seismic performance are also provided. The chapter focuses next on the experimental investigations carried out by the academia addressing: (i) the seismic performance assessment of adobe buildings; and (ii) the evaluation of several strengthening measures. Following, a visualization of the effects of strong ground motions on non-engineered buildings is given by means of an extensive collection of photographs compiled from three case studies: (i) The October 1995 Manzanillo, Mexico earthquake; (ii) The January 2001 Gujarat, India earthquake; and (iii) The January 2001, El Salvador earthquake. A summary of the issues discussed in this chapter and pertinent conclusions are given in the synopsis section.

4.2   Adobe buildings

4.2.1 Typical earthquake-induced damages

Typical adobe construction, corresponding to traditional practices, is very similar to that of unreinforced masonry. Unreinforced masonry (URM) buildings consist of structural systems where there is no confinement or steel reinforcement within the masonry walls. It should be noted though, that the definition of an unreinforced masonry building varies from country to country. Some countries classify unreinforced infill walls within a reinforced frame as URM, while others classify unreinforced exterior veneers on to a wood frame as URMs. According to the authors' perception, URM buildings should be considered those which have bearing walls of unreinforced masonry; only in this perspective adobe construction can be regarded as a subdivision of the URM structural system[1].

(a)   Damage patterns

Damage to adobe structures due to seismic loading is usually severe. Even a low intensity earthquake is enough to produce cracks and to weaken the structure, thus reducing its resistance to the seismically induced stresses and ultimately leading to its complete destruction. Due to the heavy mass of the debris, rescue work of buried people is difficult and time-consuming, especially when fallen debris blocks the streets.

As with unreinforced masonry, damage to adobe structures takes the form of separation of walls from roof (and floor, where present) diaphragms, and of in-plane shear cracking combined with out of plane failure. Due to the absence of reinforcement, such combined failures often lead to the collapse of walls and parapets. Out-of-plane overturning of cantilever adobe walls is also quite common. Generally, the seismic performance of non-engineered URM dwellings - omitting the earthquake's characteristics, such as the magnitude and the distance to the fault - is a function of wall thickness and height (slenderness ratio), internal subdivisions (spans), openings (dimensions and arrangement), roof mass and its ability of providing a rigid diaphragm action, nature of the continuity with adjacent dwellings, and site effects (soil suitability).

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[1] *According to EC6, "unreinforced masonry" is the one that "is not containing enough reinforcement so as to be considered as reinforced masonry"; the latter is defined as the "masonry in which bars or mesh are embedded in mortar, or concrete so that all the materials acts together in resisting action effects".*

Tolles et al. (1996) provide an illustration of the failure typology observed in historic adobe buildings, as shown in Fig. 4-1, whereas Coburn (1986) represents the progress of damage in weak masonry structural systems as in Fig. 4-2. Another schematic summary of the most common failures is reproduced in Fig. 4-3, based on the CENAPRED (*El Centro Nacional de Prevención de Desastres*) publication "Reinforcement Methods for Self-construction of Rural Housing", presented at the First National Conference on Actions for Risk Prevention (*Primera Jornada Nacional De Simulacros Para La Prevención De Riesgos*, México, 2000) [2].
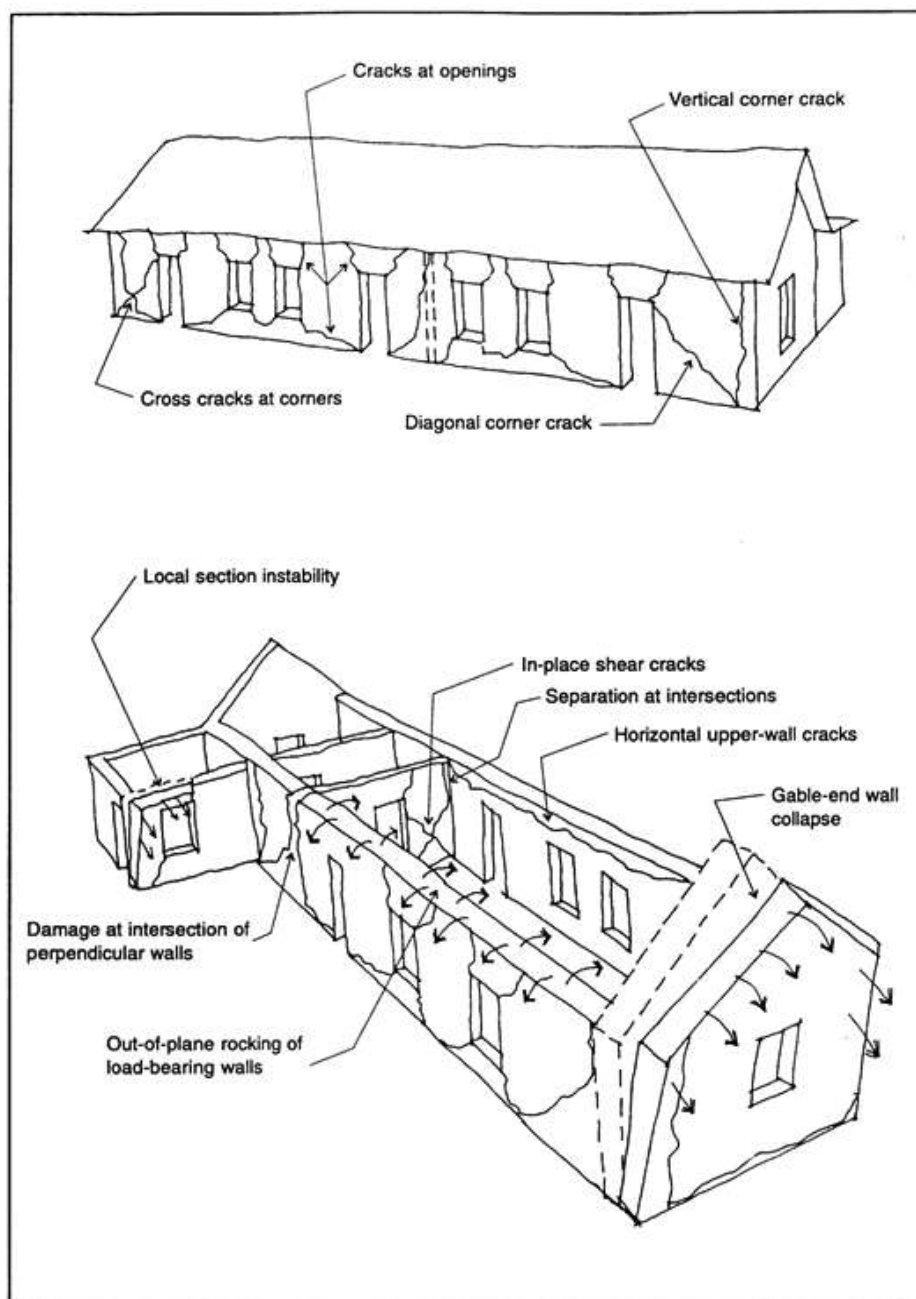
Fig. 4-1 Failure typology in historic adobe buildings. (source: Tolles et al., 1996)

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[2] *This document is available on-line at: http://www.world-housing.net/Tutorials/AdobeTutorial/Reference_3.pdf (Spanish version of the figure). The English version of the figure can be found in the document "Earthquake-Resistant Construction of Adobe Buildings: A Tutorial, available at: "http://www.world-housing.net/Tutorials/AdobeTutorial/Adobe%20Tutorial.pdf.*
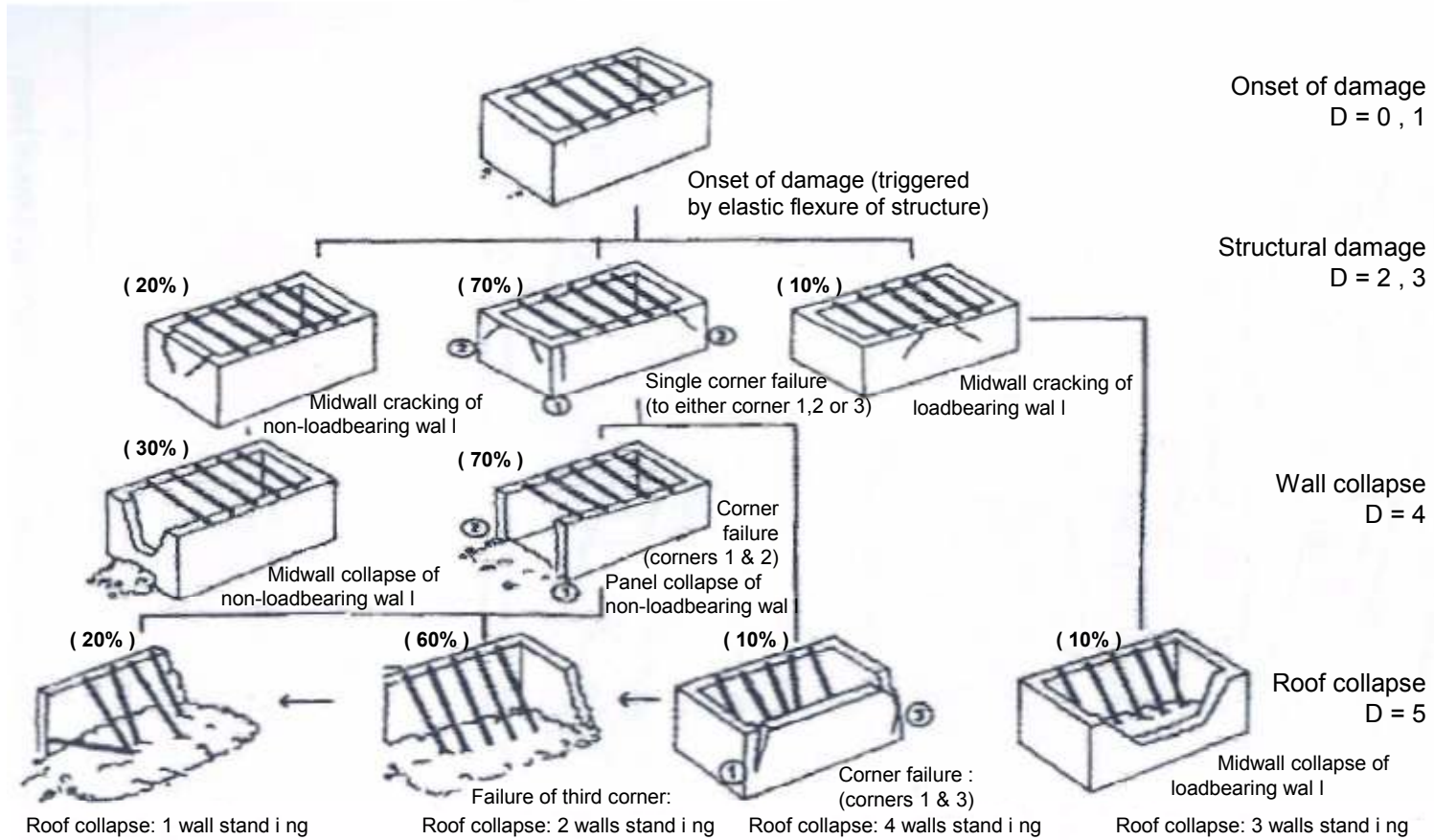
Fig. 4-2 Damage progress in weak masonry structural systems. (source: Coburn, 1986[3])

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[3] *Although this figure refers to stone structures, it is also representative for adobe ones. The only difference is that stone masonry tends to crumble more than adobe construction, which usually breaks into larger pieces (Tolles and Krawinkler, 1990).*
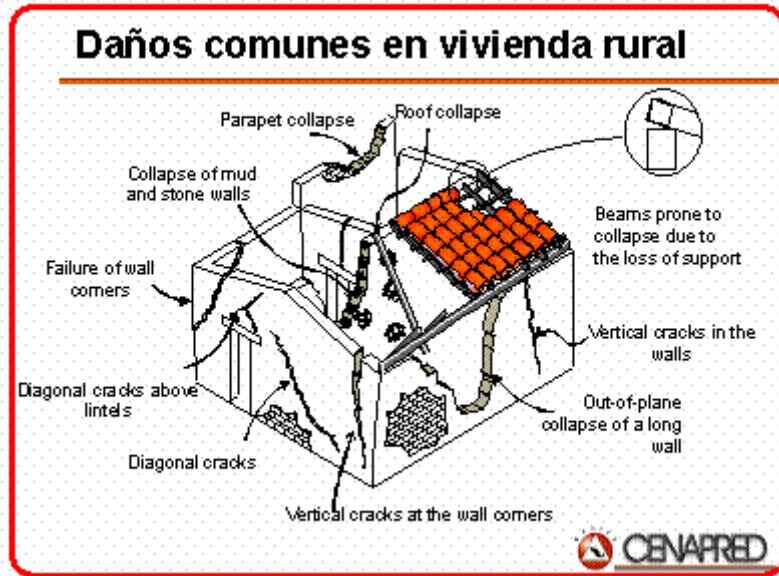
Fig. 4-3 Common earthquake-induced damages in adobe rural dwellings.
(source: CENAPRED, 2000)

A very comprehensive listing (and visualization, see Fig. 4-4a & 4-4b) of typical damages and types of collapses in earthen buildings is given in IAEE Manual "Guidelines for Earthquake resistant non-engineered construction" (Chapter 7). According to this publication, the experience gained from previous earthquakes has shown that earthen buildings may be cracked at MSK Intensity VI, wide cracks and even partial collapse may occur at MSK VII and collapses are widespread under MSK VIII. Such intensities are likely to occur in the epicentral areas of 6.0 to 6.5 Magnitude shallow focus earthquakes. Damage is always much more severe in two storey buildings than in one-storey ones (see Fig. 4-4c).

(a)

(b)

(c)
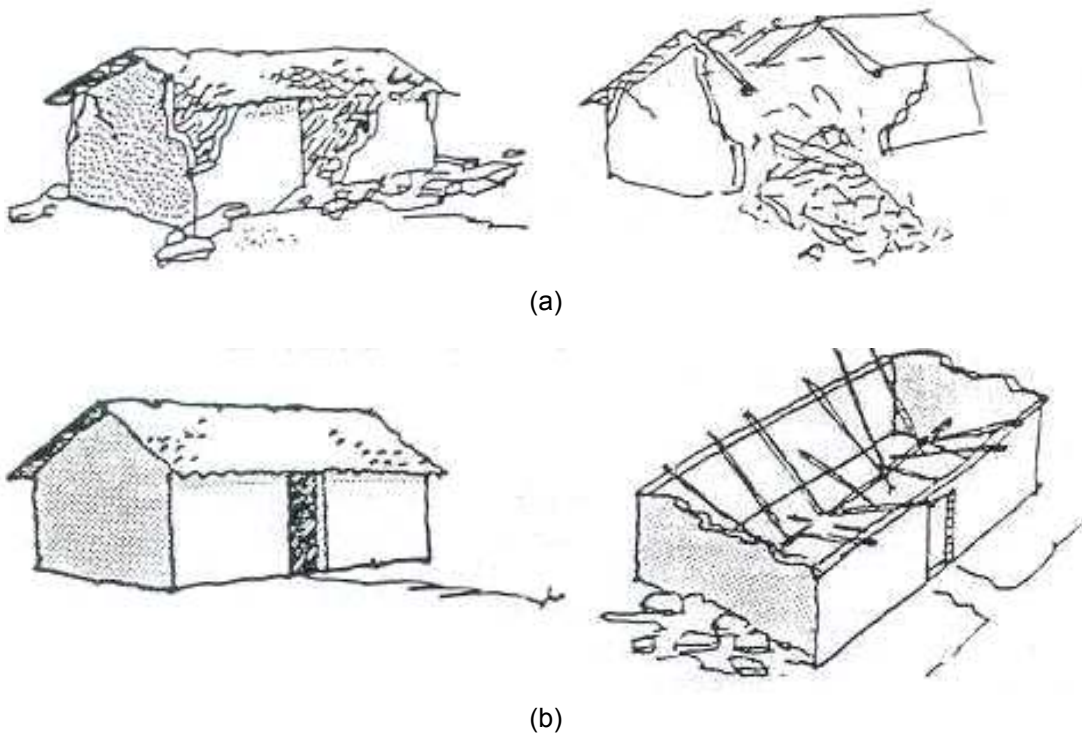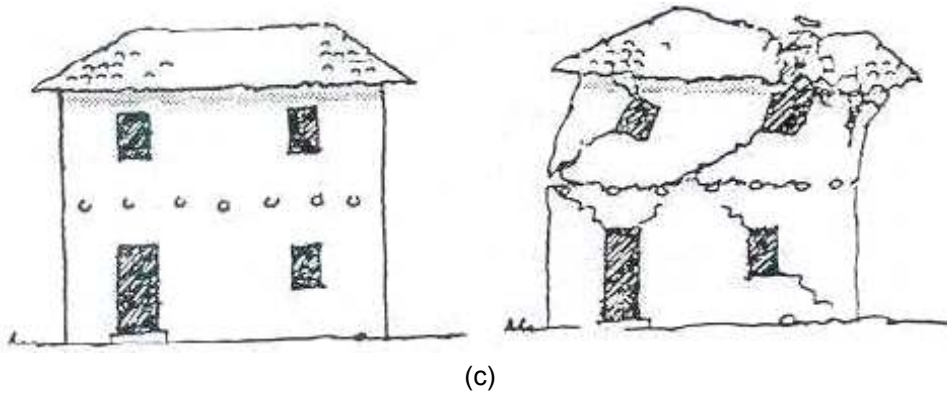
Fig. 4-4 (a) Corner failure and out-of-plane collapse of walls; (b) Effect of gables' collapse; and, (c) Two-storey house damage/collapse. (source: IAEE, 1986)

Tolles and Krawinkler (1990) describe the seismic behaviour of Low-Strength Masonry (LSM), a subdivision of which the adobe masonry structures can also be regarded as. Forces parallel to the plane of the walls (in-plane forces) cause diagonal cracking in the short-end walls, while forces perpendicular to the plane of the walls (out-of-plane forces) cause flexural stresses. The authors attribute the damages most often observed (both shear and flexural cracking) to the low tensile strength of LSM materials.

The walls typically fall outward allowing the heavy tile or earthen roofs (up to 450 mm thick) to collapse, easily killing the occupants trapped inside. The failure of building corners results from a combination of flexural and tensile stresses. Once the corners have failed, the adjacent walls are more likely to partially collapse and/or overturn (Coburn, 1986). Vera et al. (2000) report that the main damages in Mexican adobe buildings are vertical cracks in the intersections of perpendicular walls. Once the walls are separated, and if the roof does not serve as a rigid diaphragm, pieces of adobe assemblies work independently and tend to overturn due to inertial forces acting perpendicularly to their plane.

Blondet et al. (2002) report that newer adobe structures in Peru are especially vulnerable against earthquakes, as the walls are built narrower (than traditionally practiced) due to the high cost of land; thus, they do not have the resisting area necessary to provide the required lateral strength. This disadvantageous condition was clearly manifested during the most recent earthquakes in Peru (the 1996 earthquake in Nasca and the 2001 one in Moquegua), where thousands of adobe dwellings collapsed.

(a)   (b)
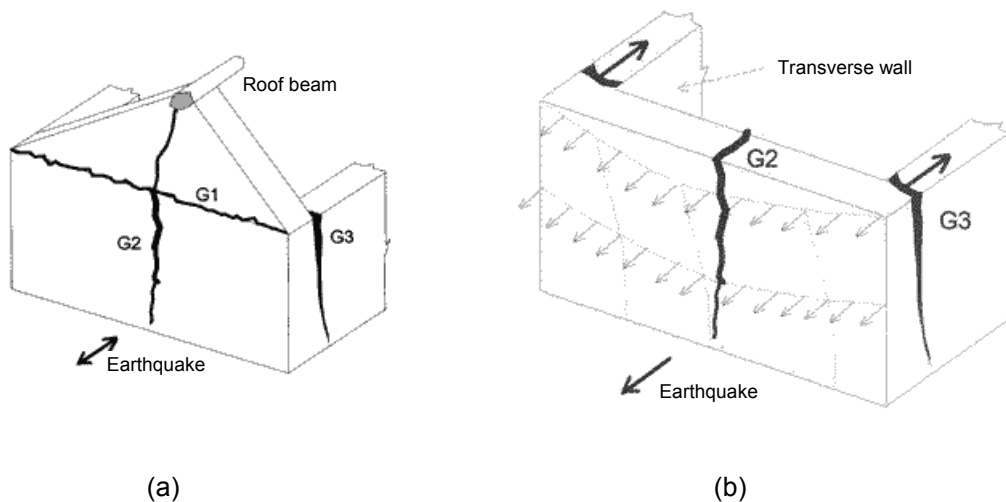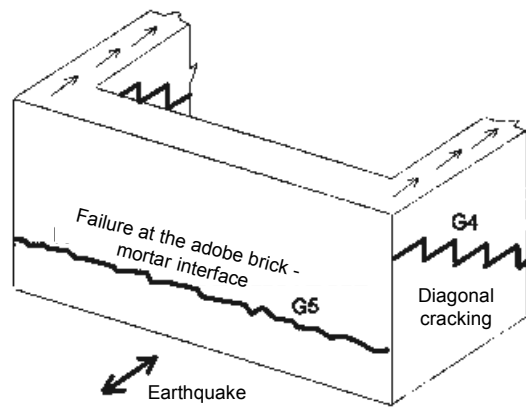
(c)

Fig. 4-5 Schematic indication of the most common structural failures found in self-built adobe houses. (source: Zegarra et al., 1997)

Zegarra et al. (1997) describe the formation mechanism of the principal cracks in adobe dwellings that undergo seismic loading. Initially, cracks G1 and G2 appear on gable walls, which are perpendicular to the ground motion direction (Fig. 4-5a). The G1 crack is formed at the base of the triangular gable wall, which finally collapses due to the overturning forces induced by the roof beam (typically constructed out of a tree trunk). Crack G2 occurs due to: (i) the absence of a tie-beam, placed at the top of the walls that restrains substantial lateral displacements, and (ii) the generally large distance between transverse (buttress) walls. Crack G3 is the result of a poor transfer mechanism for earthquake-induced tensile forces between perpendicular walls (ought to defective construction techniques, e.g. lack of tie-beams or confinement columns) (Fig. 4-5b). The vertical splitting of the corners can be extremely dangerous, as it eliminates the transversal wall supports and turns them into cantilevers that overturn outward as the ground motion continues. Both G2 and G3 cracks propagate along the entire building's height, being wider at the top of the walls, where displacements are larger.

Shear failure of walls under in-plane seismic loading is an additional type of failure often observed; it is characterized by diagonal cracking, usually of an "escalating" profile, as the crack propagates along the vertical and horizontal mortar-adobe bricks joints, that lie at the wall's diagonal, due to weak adhesion of the materials at the interface (Fig. 4-5c). Usually shear failure follows the creation of cracks G1 and G2. It is possible for an additional longitudinal crack to develop (G5 – Fig. 4-5c) at the footing/wall interface (should a footing exist), due to out-of-plane seismic loading of the walls.

(b)   Damage classification

Vargas (1998) classifies the damages in adobe buildings, as follows:

Light damage:
- Cracks in non-structural elements (secondary walls, ornaments, etc.);
- Erosion, or loosening of plasters and stuccoes;
- Faults in the roof-covering;
- Slight cracks in floors;
- Window frames out of joint.

Moderate damage:
- Small cracks in structural elements, corners, window and door angles, connecting points between lintels and walls, connecting points between roof (beams) and walls;
- Superficial erosion of walls;
- Loosening of secondary elements in the roof system;
- Walls slightly out of plumb;
- Large cracks in floors;
- Displacement of doors and window frames.

Severe damage:	▪ Cracks in structural elements;
	▪ Partial detachment of walls and roofs;
	▪ Walls severely out of plumb;
	▪ Differential settlement of foundations;
	▪ Severe erosion of walls.

A more systematic classification of the damages in rammed-earth, adobe and bahareque buildings, is given by the Colombian Association of Earthquake Engineering (Asociación Colombiana de Ingeniería Sísmica – AIS) and is given below:

No damage:	Cracks having width of less than 0.4 mm, almost imperceptibles on the walls' surface.
Light damage:	Easily perceptible cracks during visual inspection, having widths of more than 0.4 mm and less than 2 mm.
Moderate damage:	Diagonal cracks and partial loss of the render. The cracks' width ranges from 2 to 4 mm.
Heavy damage:	Diagonal cracks of widths greater than 4 mm, and extensive loss of the render.
Severe damage:	Loss of the structural integrity in the form of local crushing of the wall, visible deformation, partial collapse or appreciable inclination of the wall.

In the following photos severe damages of rammed earth and bahareque dwellings are illustrated.

Fig. 4-6 Severely damaged rammed earth ("*tapial*") and *bahareque* dwellings. (source: AIS, 2002)

4.2.2 Defects in self-built adobe houses

The pathology of earthen buildings affected by earthquakes shows that the material damage and the fatal consequences are often the result of ignorance, careless and/or defective construction, lack of supervision at all stages of production of the material, deficient design and lack of maintenance. The following listing summarizes the most common defects present in self-built adobe dwellings:

A. Construction

   A1. Foundation

         The foundation is non-existent.

      A1.2 The foundation is not deep enough.

      A1.3 The foundation is poorly built.

      A1.4 There is a lack of proper drainage around the foundation.

      A1.5 The foundation lies on inappropriate soil (e.g. differential settlements and consequent wall cracking may be caused due to foundations built on soft spots such as loose soil, backfilled trenches and differentially weathered rock; the same effect is caused by foundations built on hard spots, such as stubs of previous walls).

A1.6 The footing of the walls may be undermined by animals and roots; animals can remove soil and cause foundations to subside; roots affect a radius up to 2.5 times the height of the vegetation and their growth can cause the foundation to heave; in clayey soils the roots of trees remove pore water and consolidate the ground.

A1.7 A surcharge of a mound on one side of the wall, accompanied by a moisture gradient across the wall thickness, may result in the development of a shear zone, which, depending upon internal friction, can lead to the collapse of the wall.

A2. Walls

A2.1 Walls are too high and too long.

A2.2 Walls' aspect ratio (height over thickness) is too large.

A2.3 The brick-laying techniques are improper. As a result, the following can be observed:
- poor overlapping of bricks;
- incomplete fill between the horizontal and vertical joints between adobe blocks;
- missing bricks;
- poor geometrical quality of the walls (e.g. undulations and sagging);
- poor interlocking at the intersections of walls;
- failure during construction of the wall to insert the wooden plugs for fastening frames, partitions and ornaments;
- settlement of the lower adobe layers (building rate in the vertical direction is too rapid);
- shrinkage cracks running horizontally between 'lifts' (the inferior layer is too dry before placing the upper one, or the interface between the 'lifts' is not rough enough).

A2.4 The dimensions of adobe bricks are inappropriate (especially in regard to thickness).

A2.5 The adobe bricks are insufficiently dried (use of very fresh – "green" – bricks).

A2.6 Points of weakness are formed on the walls by "putlog" holes for scaffolding or ornamental detailing; the collapse of walls often coincides with a major horizontal line of weakness formed by a row of joist holes. Additional points of weakness are often formed due to rotting or moth-eaten wood joists, door/window frames and internal cane reinforcement that soften the soil after they decay. Wood elements act as a reservoir of higher moisture content, failing to bond with adjacent adobe bricks, due to their different material properties (such as expansion coefficients).

A3. Openings (doors, windows)

A3.1 The number and/or the area of the openings is excessive.

A3.2 Openings are close to the corners of the house (leading to corner failure).

A3.3 The lintels are insufficiently embedded in the walls (leading to shearing-off of the lintel from the wall).

A3.4 The frame jambs are not sufficiently strong (leading to buckling).

A3.5 The openings are too close together (resulting into too slender an intermediate pier frame, leading to buckling).

A4. Roof

A4.1 The roofing system is too heavy (e.g. thick earthen roofs).

A4.2 The roof supports are inadequate.

A4.3 The elements of the pediment or gable are poorly joined to the rest of the structure.

A4.4 The eaves of the roof are not large enough to protect the walls from rain.

A5. Assembly
   A5.1 A "wall anchoring system" is lacking (e.g. a tie or ring beam).
   A5.2 The distance between columns, wall intersections and other load-bearing members is too big.
   A5.3 The structure is more than one storey high.

B. Materials

   B1. Adobe
      B1.1 Inappropriate soil is used (e.g. large cavities may be created in the walls by the decay of organic inclusions, reducing the soil's binding potential and introducing a weak area in the wall).
      B1.2 The proportion of the stabilizing material is erroneous.
      B1.3 Excessive mixing water is used or the building takes place during the rainy season without adequate protection.

C. Other (maintenance, usage)

      C1 When repair patches are used, consisting of materials of different origin or mechanical/physical behaviour, spalling-off of wall portions is highly probable; if the repair material is weaker than the original one used for the wall formation, it decays out, or if it is stronger (or more durable) it can induce decay and cracking elsewhere.
      C2 The lack of maintenance of the externally applied wall coatings renders the walls prone to humidity ingression.
      C3 Subsequent changes in the structure are usually made in the expense of safety (e.g. addition of new construction of greater rigidity of the initial building).

A sketch summarizing the typical construction mistakes, which are held responsible for the partial or total collapse of earthen structures, is provided by IAEE (1986) (Fig. 4-7a) and lies in very good agreement with Minke (2001) (Fig. 4-7b).
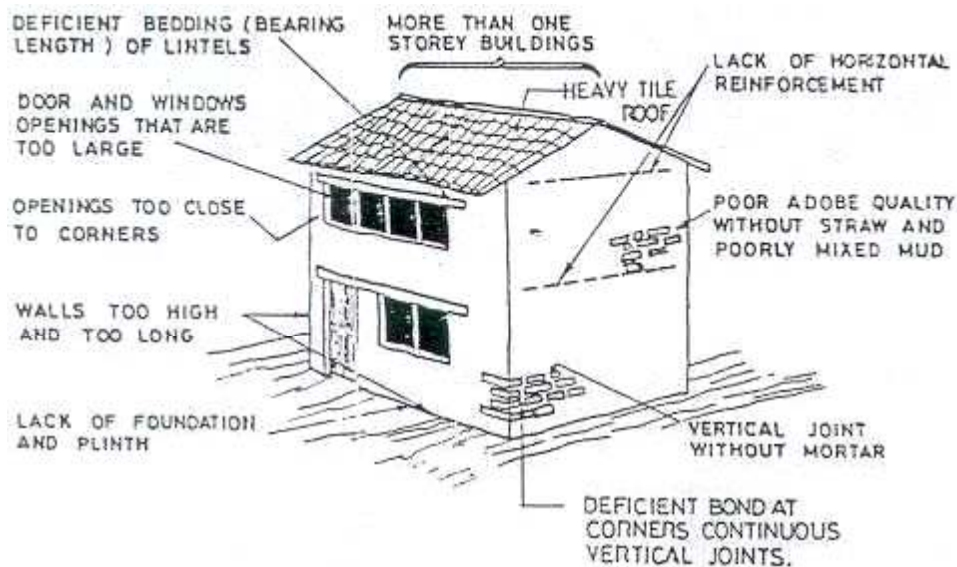
(a)
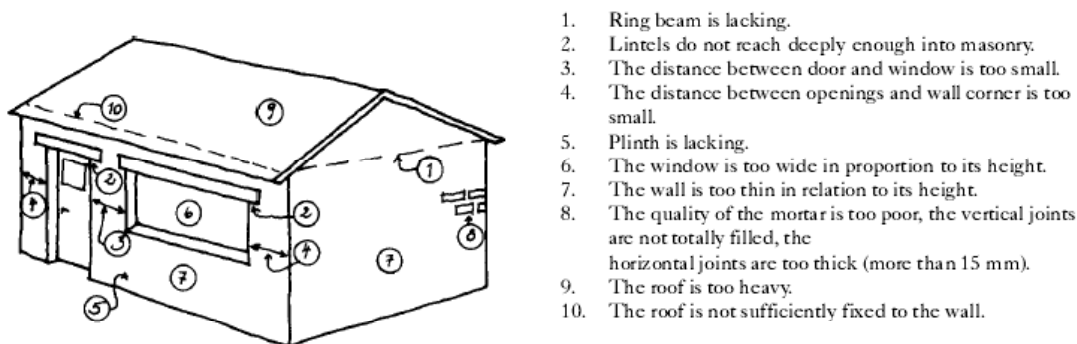
1. Ring beam is lacking.
2. Lintels do not reach deeply enough into masonry.
3. The distance between door and window is too small.
4. The distance between openings and wall corner is too small.
5. Plinth is lacking.
6. The window is too wide in proportion to its height.
7. The wall is too thin in relation to its height.
8. The quality of the mortar is too poor, the vertical joints are not totally filled, the horizontal joints are too thick (more than 15 mm).
9. The roof is too heavy.
10. The roof is not sufficiently fixed to the wall.

(b)

Fig. 4-7 Graphical indication of the most common deficiencies found in self-built adobe houses: (a) IAEE Manual "Guidelines for Earthquake resistant non-engineered construction", 1986; (b) Minke G. "Construction manual for earthquake resistant houses built of earth", 2001.

4.2.3 Efforts towards the systemization of scientific knowledge on the seismic performance of earthen buildings

To the knowledge of the authors there has been only one Workshop focusing on the seismic behaviour of earthen buildings, namely the *International Workshop on Earthen Buildings in Seismic Areas*. This Workshop was convened in May 1981, in Albuquerque at the University of New Mexico and was jointly hosted by the Engineering College of the University and INTERTECT (a Dallas-based consulting firm). The organization of the Workshop was financially supported through the National Science Foundation, the Office of Foreign Disaster Assistance (Agency for International Development) and the non-governmental organization "Appropriate Technology International".

The emphasis of the workshop was on non-engineered adobe houses in seismic areas, although information about related forms of earthen and unreinforced masonry structures was also presented and discussed.

The workshop aimed at achieving the following objectives:

1. To develop a clear statement of the problems associated with earthen low-rise buildings in seismic areas.

2. To define the existing (i.e. up to early '80s) state-of-the-art in regard to earthen building materials, design and construction methods in seismic regions.

3. To identify and categorize existing national and international research findings in related areas and seek to establish their applicability to the seismic design and construction of earthen buildings.

4. To identify appropriate channels for technology transfer across international boundaries and to explore social and economic barriers to such transfer.

5. To identify opportunities for cooperative international research.

6. To identify and describe the gaps in the present body of knowledge and define research needs.

After the 1981 event, no other conference specifically addressing the seismic performance of earthen structures was organized. Pertinent publications (mainly of descriptive character, discussing the consequences of past earthquakes to earthen structures) may be found in the "TERRA 2000" and "TERRA 2003" conferences and in the International Conference and Fair "Modern Earth Building".

The former were the 8th and 9th International Conferences, respectively[4], focusing on the study and conservation of earthen architecture, which brought together experts from around

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[4] *The first TERRA conference was organized nearly 30 years ago.*

the world to discuss new ideas and developments in the conservation of earthen architecture. The latter was organized by *Die Wille gGmbH - Redaktion Moderner Lehmbau* in 2002 and 2003 in conjunction to fairs, offering the opportunity to enterprises from Germany and other countries to exhibit earth building products and projects. The aim of these conferences was to discuss recent and future developments on earth building, exchange information and enhance dissemination methods of earth building techniques. During the 2003 event a special session was dedicated to earthquake resistant earth-based constructions.

In the light of the 2004 Bam earthquake in Iraq[5], resulting into a devastating death-toll and extensive damage to one of the world's most famous historical earthen monuments, the citadel of *Arg-e-Bam*[6], more attention is expected to be paid by the academia to the issue of earthen structures in seismic prone areas in the immediate future[7].

(a)   (b)

Fig. 4-8   The citadel in Bam: (a) before and (b) after the earthquake of December 2003. (source: Schroeder, 2004, "Building with Earth in Iran", available in: http://www.dachverband-lehm.de/pdf/DVL_terra2003_bam_gb.pdf)

4.2.4 Experimental investigations and improvement measures

Davis (2002) in an ECEE keynote paper gives a very apposite discussion on the discrepancy between the current engineering practices (as well as the responsibility that arises from them) and the existing stock of structurally vulnerable non-engineered structures. He remarks that it remains something of a paradox that the failures of non-engineered buildings, held responsible for the majority of human losses due to earthquakes, attract the least attention from the engineering profession. According to the Davis's experience, there are two explanations that can account for the aforementioned contradiction. The first aligns with the perception that by definition, "a non-engineered building is outside the engineer's scope, or mandate", while the second highlights the luck of adequate funding to support the necessary research, or implementation, of improved structural measures for such low-cost structures.

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[5] *On Friday, 26 December, 2004 at 5:26 A.M. local time a magnitude 6.6 (shallow – 10 km of depth) earthquake stroke the south-eastern Iranian city of Bam, resulting into at least 30,000 fatalities, 30,000 injuries and severe damage or destruction of 85% of the building stock and infrastructure in the affected area (see; Preliminary Earthquake Report U.S. Geological Survey, National Earthquake Information Center, available at: http://earthquake.usgs.gov/recenteqsww/Quakes/uscvad.htm).*

[6] *The historical citadel of Arg-e-Bam is more than 2000 year old, comprising the largest mud-brick complex in the world. This historical monument is located on an igneous hill, on the verge of the Silk Road and has an area of some 240,000 m[2]. There is no information about the exact date of the construction, but according to Persian history it goes back to more than 2000 years ago; it has been repaired many times, and was residential till 150 years ago.*

[7] *The irony: The Terra 2003 Conference took place from 29 November to 2 December, 2003 in Yazd, approximately 400 km from Bam. The Iranian Cultural Heritage Organization (ICHO) hosted the congress supported by a series of national and international organisations such as UNESCO, ICOMOS, ICCROM, as well as several Iranian universities. One of the three excursions organized by the ICHO included a round-trip to Bam, and a photo of the old town of Bam and the citadel can be seen on the cover of the conference proceedings (Fig. 4-8a). It was also announced at the Terra 2003 that a Centre for the Research and Documentation of Adobe Architecture would be established in Yazd supported by the Iranian government. Furthermore, it was suggested that the 10th International Conference on the Study and Conservation of Earthen Architecture, the Terra 2006, should again take place in Yazd. (Schroeder, 2004).*

Isolated exceptions to such negative attitudes include important work realised in Peru, United States[8], Mexico[9] and India[10]. In the following paragraphs, only the experimental work conducted in Peru and United States is presented, being relatively more recent and/or more extensive than the others:

(a)   Research conducted at the Pontifical Catholic University of Peru

The following presentation of the research undertaken at the Pontifical Catholic University of Peru is mainly based on the document: "*Adobe in Peru: Tradition, Research and Future*", by Blondet M., Torrealva D. and Villa García G[11].

The first research project developed at the Catholic University of Peru (PUCP) in 1972 consisted of the experimental study of several alternatives for structural reinforcement of adobe houses, made with materials available in rural regions. A 4x4 meter reinforced concrete tilting platform was built to test these specimens. Modules were successively built on top of the platform. Testing consisted of slowly tilting the platform and measuring the tilt angle at collapse. The lateral component of the weight of the module was then used as a parameter to quantify the maximum seismic force for each module (Figs. 4.9a & b, Corazao and Blondet, 1974)[12].

| (a) | (b) |
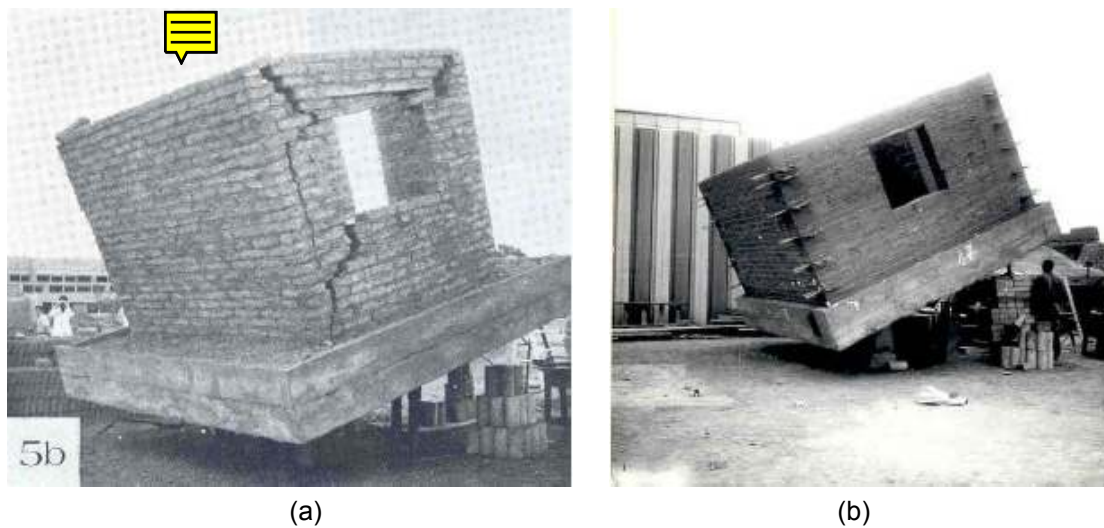
Fig. 4-9   Tilt-table tests on adobe structures: (a) Module without reinforcement; (b) Module reinforced with cane. (source: Corazao and Blondet, 1974)

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[8] *Not included herein: Tests on large-scale adobe models fitted with wood bond beams and various types of wire mesh attached to wall surfaces that were conducted at the University of California, Berkeley (Scawthorn and Becker 1986).*

[9] *The first shaking-table tests were performed at the National University of Mexico during the 1970s (Meli, Hernandez, and Padilla 1980). Nine model adobe buildings, 1:2.5 in scale, were tested. The specimens were tested by applying uniaxial, horizontal earthquake motions perpendicular to the long axis of the models. The primary failure mode was the out-of-plane bending of the long walls. There was no roofing system or roof diaphragm and the roof loads were simulated by placing steel beams across the two long walls. The buildings were modified to include a concrete bond beam, horizontal steel rods, and welded wire mesh applied to the exterior adobe surface.*

[10] *One key-centre for research on the strengthening of non-engineered construction is the Central Building Research Institute, and the Department for Earthquake Engineering at the University of Roorkee in the State of Uttar Pradesh, India, led by the Professor A.S. Arya.*

[11] *This document was submitted as a paper to: "Modern Earth Building 2002" – International Conference and Fair, 19 - 21 April, Berlin (available at: www.world-housing.net/Tutorials/AdobeTutorial/Reference_2.pdf).*

[12] *A series of structures with four meeting walls 2.6 m x 2.6 m x 2.4 m high (with no roof) and with a variable number of openings and different reinforcement elements were tested on this platform, whose inclination could simulate horizontal static accelerations, which were 23 to 42% of the acceleration of gravity (Vargas, 1983).*

The main conclusion of this investigation was that vertical reinforcement, combined with the placement of horizontal crushed cane at every fourth row of adobe blocks, notably increased the seismic strength of the housing modules. This was also verified through monotonic lateral load tests of full-scale walls. The cane reinforcement almost doubled the maximum horizontal load capacity and, most importantly, increased by almost six times the lateral deformation of the reinforced walls, with respect to the unreinforced walls. The cane reinforcement thus provided both strength and ductility to the adobe masonry, which is weak and fragile by nature.

In 1979, the PUCP and the National Autonomous University of Mexico (UNAM) developed a cooperative research project on adobe masonry[13]. Specimens were tested in axial compression and diagonal compression. Differences in the order of 500% were found in the maximum resistance in diagonal compression for masonry specimens made out of blocks of different materials, but of similar resistance in axial compression (Vargas et al, 19   This result led to an investigation funded by USAID, in which the influence of the properties of the soil and the use of natural additives on the seismic strength of adobe walls was studied. Samples of soil were gathered from six zones in Peru, to correlate their physical, chemical, and mineralogical characteristics with the strength of the adobe masonry built with each soil. Axial compression, indirect tension, diagonal compression (Fig. 4-10a) and full-scale shear tests (Fig. 4-10b) were performed. In addition, field tests were developed to determine the most adequate quality of soil to manufacture adobe blocks and to determine adequate composition of the mortar to build the adobe walls.
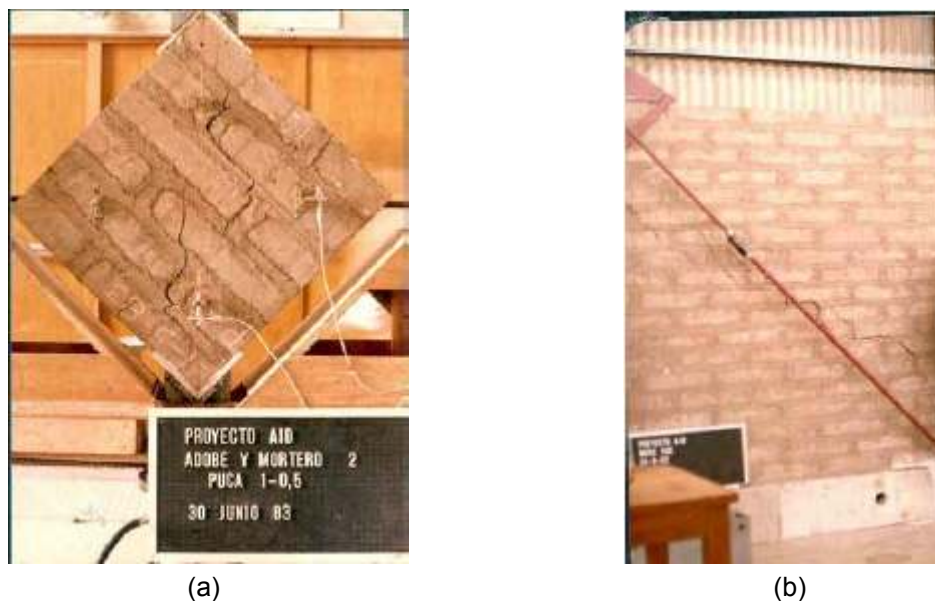
Fig. 4-10 (a) Diagonal compression test; (b) Full-scale wall test.

The main conclusions of the investigation initiated in 1979 were that clay is the most important component of soil, providing the dry strength of the blocks (also see Chapter 2). However, a high content of clay increases drying shrinkage, which causes cracking in the walls. It was determined that micro-cracking due to drying shrinkage can be controlled with the addition of straw or thick sand to the mortar. It was also concluded that the traditional process of "sleeping" or soaking the clay for 24 hours before using it is highly beneficial, since it activates the clay's bonding properties when it is in contact with water (Vargas et al, 1984). More a   tically, the conclusions drawn from this experimental investigation are:

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[13] *The Earthquake Resisting Structures Laboratory of the PUCP, inaugurated in 1979, was created with the assistance of the Peruvian and Dutch governments. The laboratory has a seismic simulator, consisting of a 4.4 m x 4.4 m platform designed to move in one horizontal direction, with displacements of up to 150 mm, velocities of up to 500 mm/s and accelerations up to 1.2 g, carrying test specimens weighing up to 16 tons. This facility greatly enhanced the experimental testing capabilities of the researchers of the PUCP.*

- Compressive tests of adobe cubes containing large amounts of straw exhibit linear behaviour up to failure, which occurred at unusually high strain values (10%). Note that this conclusion comes in contradiction to the findings of Islam and Watanabe (2001), where linear behaviour was observed up to "yielding" strains less than 2%; failure strains were generally less than 5% (see Chapter 3);
- The shear strength of adobe walls depends primarily on micro-cracking of the mortar, due to restrained drying shrinkage. The latter does not affect compressive strength to the same extent;
- Volumetric drying shrinkage depends largely on the plasticity of the clay and amount of coarse material present in the soil;
- The most efficient way to control drying shrinkage is to introduce large amounts of straw in the mix (2-3% by weight).
- The diagonal compressive strength of adobe walls improves with the addition of straw in the mortar.
- If the height of a cantilever adobe wall is larger than the limiting value $h_{max} = f_r / 2\tau$ (where f_r the modulus of rupture of the wall and τ its unit weight), then the wall is likely to crack and collapse due to out-of-plane flexure.

In 1992, the PUCP obtained support from the International Development Research Centre of Canada (IDRC) to verify the efficiency of the recommendations for improved adobe constructions, through dynamic testing of full-scale adobe modules. Eight modules were built and tested, with variations in the constructive technique, the cane reinforcing system and the configuration of wall openings. Each module was tested in several phases to represent a series of seismic events of increasing intensity. The instrumentation consisted of displacement and acceleration transducers to measure the seismic excitation and the corresponding structural response.

The main conclusions obtained were that improvements in the construction technique (the quality of materials and labour) by itself increased the resistance and stiffness of the uncracked walls, but had negligible influence after the occurrence of significant cracking. The horizontal and vertical cane reinforcement (Fig. 4-11a), combined with a solid collar beam can prevent the separation of the walls in the corners due to strong earth motion, and thus, can maintain the structure's integrity after the walls fail (Fig. 4-11b, Otazzi et al,).

(a)   (b)

Fig. 4-11 (a) Cane reinforcement; (b) Reinforced module after a seismic test.

The PUCP published a booklet in order to disseminate to the Peruvian coastal population the methodology of cane-reinforced adobe. Featuring detailed illustrations (Fig. 4-12a) and simple language, the booklet explained the constructive details of reinforced adobe dwellings. A video was also produced, with footage of the seismic simulation tests, to complement the information in the pamphlet. In addition, communal premises were built in two marginal urban regions of Lima and in four rural communities of Piura, a coastal city located 1,000 km north of Lima (Fig. 4-12b, Villa García et al, 1990). These constructions were built with the participation of the people residing in these communities, who were trained in the use of this new technology. Good receptivity among the settlers towards the adobe reinforcement system was observed.
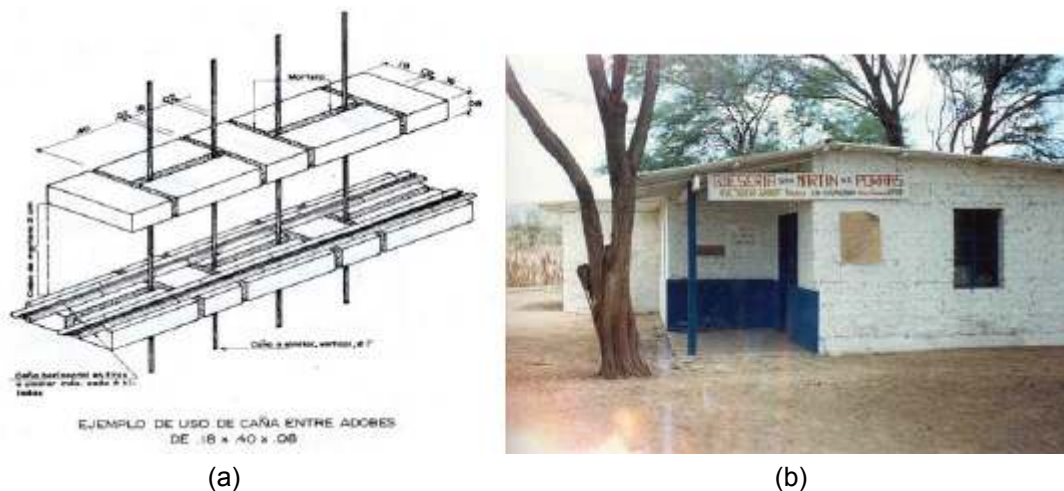
Fig. 4-12 (a) Sketch from the dissemination booklet; (b) Reinforced adobe cheese factory.

Later visits to communities where prototypes were built using the technology of adobe reinforced with cane revealed that even though the improved technology was accepted by the population, it was not assimilated as their own tradition (they would not make use of it spontaneously). This was probably exacerbated by the added expense of reinforcement materials and the extra effort required for the construction of the walls.

A project was then initiated for the sale of adobe dwellings through bank loans (Zegarra et al.,), as another attempt to disseminate the new technology among middle class urban dwellers. This project took place in the urban zone of the city of Piura, and was funded by the IDRC. Sixteen dwellings, 50 m^2 each, with a simple but well-completed finish, were built and sold. The cost per dwelling was approximately US $ 5,000, financed through a ten-year loan. After the publicity campaign to let the population know of this project and to bring about the settlers' participation, it was clear that demand was much higher than supply, showing that the solution was attractive to middle class settlers. The houses were finished before the El Niño phenomenon of 1998 and they suffered little damage from the heavy rains. This shows that, with adequate protection, reinforced adobe dwellings are capable of resisting torrential rains (Figs. 4.13a & b).

Fig. 4-13 (a) Cane reinforcement; (b) Finished dwellings after El Niño.

During the first twenty years, adobe research in the PUCP was focused in new adobe dwellings with better seismic behaviour. The development of a retrofitting method addressing the improvement of the behaviour of thousands of existing adobe dwellings, built without any reinforcement, was yet to be addressed. Through an agreement with the Centro Regional de Sismología para América del Sur (CERESIS), an experimental project was funded by the Deutsche Gesalischft für Technische Zusammenarbeit (GTZ), to develop simple techniques to reinforce existing adobe dwellings. This effort was officially designated as an IDNDR (International Decade for Natural Disaster Reduction) demonstration project.

The main objective of the aforementioned project was to evaluate and establish simple, low-cost procedures for reconditioning existing adobe houses, taking into account: (1) the

type of soil on which they were built, and (2) the size, the shape and the construction characteristics. The reconditioning aimed at the structural upgrading of adobe structures (one that can be realized by the owners – i.e. unskilled workers), so that the occupants would have sufficient time to evacuate their houses, before they collapse.

The project's distinct goals were (Zegarra and Giesecke, ☰):

- To establish a methodology to characterize types of existing adobe housing (determination of prevalent shapes and sizes).
- To establish a simple procedure to evaluate the seismic safety of an existing adobe house and to determine whether there is a need for its reconditioning.
- To develop simple reconditioning procedures that make use of local materials and can be adopted without professional help.
- To carry out static and dynamic tests on the PUCP shaking table, in order to evaluate the most important reconditioning procedure(s).
- To disseminate the developed technology, using well-illustrated manuals and videos, as well as field demonstrations[14].

Different reinforcement materials were tested, like wooden boards, ½-inch ropes, chicken wire mesh and steel welded meshes. Seismic simulation tests were performed on "U"-shaped walls, with and without reinforcement (Fig. 4-14a). The most efficient type of reinforcement, in terms of delaying the collapse of the structure, consisted of a welded mesh (1 mm wires spaced at ¾ inches), nailed with metallic bottle caps against the adobe (Fig. 4-14b, also see Chapter 5). The mesh was placed in horizontal and vertical strips simulating beams and columns, and was covered with mortar made with cement and sand. The strengthening method has been adopted by other Latin American countries, such as in Ecuador (see: Aguiar Falconí, ☰).

(a)   (b)

Fig. 4-14 (a) U Walls with and without mesh; (b) Wall wire mesh reinforcement.

The fundamental objective of the solutions proposed by the PUCP research team was to help the most economically depressed sector of society in obtaining safe and adequate housing. Blondet et al. (2002) state that the active participation of external agents is needed to disseminate the improved technology and to reduce the cost that burdens the dwellers. They also report, however, that it has been very difficult to convince the population to adopt these techniques and to use them on their own accord. Rural communities of Peru are extremely poor, and they cannot afford any increase in the cost of their dwellings; they also have very strong traditions and tend to reject suggestions from outsiders, even considering the improved seismic safety of the new proposals. Yet another important and recurring problem is the fact that the use of local materials, such as cane, to build thousands of houses in a short time is impossible because of the lack of large quantities of this material.

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[14] *An interesting point made by the authors is that: "after each important earthquake, a series of brochures and manuals are prepared and distributed, with an assortment of recommendations to improve the seismic resistance of adobe constructions, many of them with contradictory appreciations and, generally, without the benefit of laboratory or field tests to guarantee proper performance."*

(b)   Research conducted at the John A. Blume Earthquake Engineering Center, Department of Civil Engineering, Stanford University

This research program was conducted by E. Leroy Tolles, within the framework of his PhD dissertation and under the guidance of Professor Helmut Krawinkler.   The objectives of Tolles's study were to:

1. Explore the possibilities and limitations of reduced-scale model testing of adobe construction;

2. Evaluate the problems of dynamic similitude and material simulation in small-scale models;

3. Study the dynamic response characteristics of simple adobe house configurations; and

4. Assess the relative effectiveness of several simple improvement techniques.

To fulfil these objectives, two series of tests were performed: a material testing program and a series of dynamic tests on six reduced-scale (1:5) models of adobe houses (a typical specimen is shown in Fig. 4-15). The goals of the tests on materials were to investigate the effects of scaling time and size on the properties of adobe bricks and assemblies. The goals of the dynamic tests on the adobe mock-ups were to study the elastic and post-elastic dynamic behaviour of these buildings through shaking table tests. Each model was tested to collapse. The improvement techniques investigated were:

1. Using a light-weight roof;

2. Anchoring the roof beams to the supporting walls; and

3. Adding a bond beam.
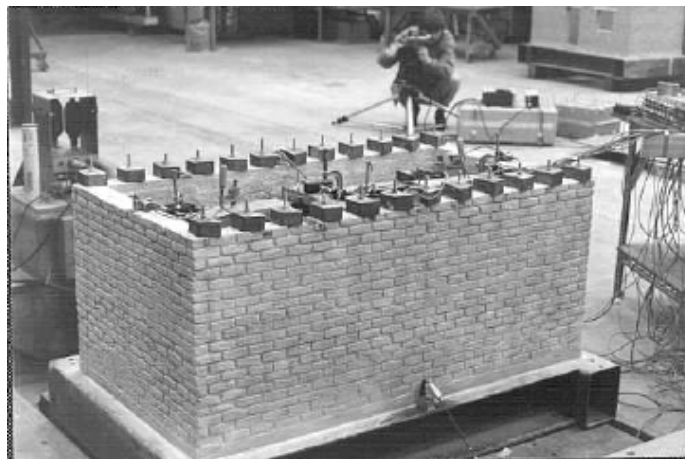
Fig. 4-15   One of the model adobe houses tested by Tolles. The roof is simulated through the addition of weights on the long walls. (source: Tolles and Krawinkler, 1990)

The schematics of every specimen used in the experimental program are given in Fig. 4-16. The shaking table tests (see Fig. 4-17 for the set-up configuration) provided basic information on the extent of damage and the types of failure that occur in adobe buildings during major seismic events. Wall overturning was the most often observed mode of failure. A lighter roof delayed initial structural damage but had negligible effect on the model's resistance to collapse. Both anchored roof beams and bond beams tied the walls together, helped prevent wall overturning, and increased the model's resistance to collapse. Figure 4-5 provides a summary of damages induced to the model houses through simulated shocks of increasing intensity.

The most important conclusions regarding the seismic behaviour of low-strength masonry (LSM) buildings (adobe in this study) are summarized below (as given in the last chapter of Tolles's dissertation):

1. Significant cracking of LSM buildings is unavoidable during severe seismic events.

2. Linear-elastic modelling techniques cannot predict the collapse load of an adobe building; they can be used to determine areas of maximum stress and locations where cracking is correlated with the collapse load. Substantial changes occur in the dynamic behaviour of

a building as damage develops. The mechanisms that lead to collapse may be very different from those that cause first cracking.

3. The dynamic, post-elastic behaviour of LSM buildings must be understood in order to design proper details that help prevent collapse. Two elements of elastic design methods that are misleading for post-elastic design are: (1) the emphasis on the strength of the building, and (2) the use of static forces to approximate the effect of dynamic inertial forces.

   In post-elastic design, strength is only a secondary issue. Even when the walls of an LSM building are badly cracked and have lost most of their strength, the building may not collapse. If the details of the building's construction hold the broken pieces together, the risk of structural collapse can be significantly reduced. Three important aspects of post-elastic seismic response of LSM buildings are stated hereafter:

   ▪ The response is dynamic. Applying a horizontal load at the top of a damaged wall is very different from shaking the wall at the base;

   ▪ Maintaining structural continuity is critical. Minimal ties added in critical locations can significantly reduce the risk of structural collapse; and

   ▪ Improvement techniques should effectively reduce the large deflections that can lead to structural collapse. A bond beam can reduce large, out-of-plane deflections of the walls. Anchors along the length of a bond beam can reduce the in-plane displacements of broken pieces of a wall.

4. Construction details that provide structural continuity can greatly improve the post-elastic behaviour of LSM buildings. The construction details must assist a building in maintaining structural continuity during the large post-elastic deformations that occur during severe seismic events. It is most important that the connections have the capability of accommodating large deformations while still maintaining their integrity.
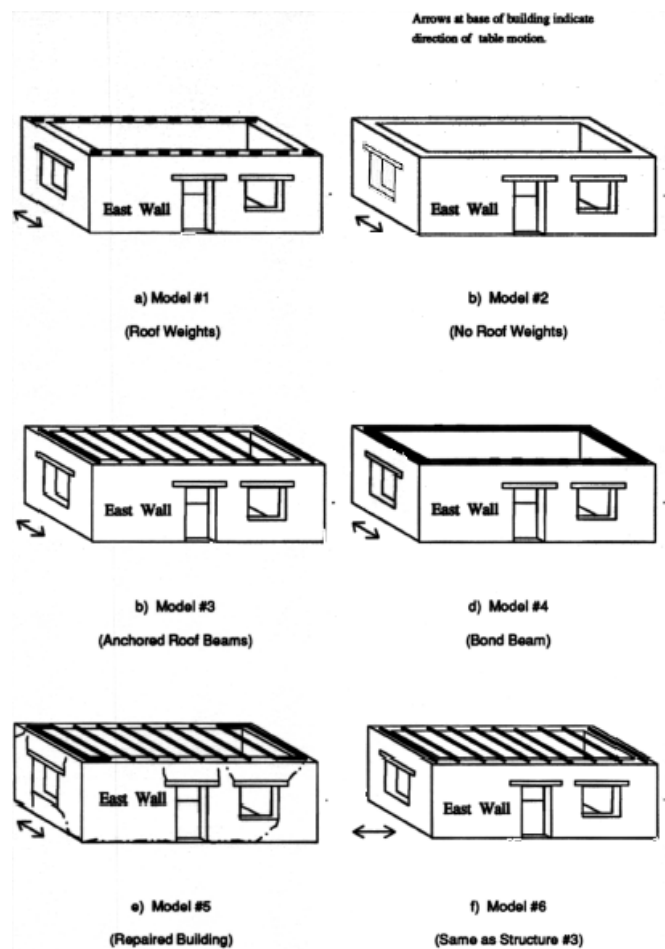
Fig. 4-16 The six reduced-scale (1:5) models of adobe houses used in the experimental program conducted by Tolles. (source: Tolles and Krawinkler, 1990)

Fig. 4-17 Specimen mounted on the seismic table.

The most important conclusions regarding the effect of the improvement techniques to the seismic behaviour of LSM (adobe) buildings are listed below:

1. It is most important to use structural collapse as the criterion for evaluating a suggested improvement or repair technique. Structural collapse is the most critical aspect of the seismic behaviour of LSM buildings. Therefore, it is essential to understand the effects of an improvement technique on structural performance as a building approaches collapse.

2. One of the most important aspects of an improvement technique is preventing overturning of the walls, which is one of the principal modes of failure in LSM buildings. Both bond beams and anchored roof beams are effective in reducing the risk of wall overturning. Roof or bond beams must be securely attached to the walls.

3. Bond beams were the best single improvement technique tested in this program. If properly anchored to the walls, a bond beam helps prevent wall overturning and can reduce in-plane degradation of the walls. A bond beam should be anchored to the building along its entire length.

4. Securely anchored roof beams improve the out-of-plane behaviour of the walls. During strong seismic events, the stability of two parallel walls is significantly improved by coupling the tops of the walls with anchored roof beams. The coupling allows the two walls to transfer loads between walls and forces one of the walls to fall inward.

5. The behaviour of in-plane walls can be improved by tying the top of the wall together with a continuous plate anchored to the top of the wall. A continuous plate that is anchored along the length of the top of walls helps to "confine" the wall. The relative displacements of the broken sections of the wall are reduced by this "confinement", which reduces cyclic degradation of the walls.

6. Pre-existing damage may have little effect on the collapse level of a building if the building is properly detailed. When a building is designed or repaired such that overturning of the walls is prevented, pre-existing structural cracks do not necessarily affect the collapse level of the building. If it is properly tied together, an LSM building will be able to withstand seismic forces that are much more severe than those that caused initial damage. Cracks will develop well before the stability of the building has been threatened.

Synoptically, in this study it is concluded that life-threatening collapse of adobe buildings can be considerably delayed by adding simple, but well-designed details that tie the walls together at the roof level. However, the author states that there is no simple means of preventing extensive damage in adobe buildings during severe earthquakes. The design of these details and the extent to which they improve structural performance can only be assessed through analytical or experimental means that are capable of predicting dynamic response to the stage of incipient collapse. According to the author, the most effective means of achieving this goal is shaking table tests on reduced-scale models.

Table 4-1 Summary of damage to models. (source: Tolles and Krawinkler, 1990)

Table 4-1 (cont'd) Summary of Damage to models. (source: Tolles and Krawinkler, 1990)

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Table 4-1 (cont'd) Summary of Damage to models. (source: Tolles and Krawinkler, 1990)

Model #5 (Repaired Model)

Building Damage | Damage Index

0.10
a) Damage after Test #4 (EPGA = 0.23 g)

0.15
b) Damage after Test #5 (EPGA = 0.26 g)

0.25
c) Damage after Test #6 (EPGA = 0.32 g)

0.45
d) Damage after Test #7 (EPGA = 0.42 g)

0.60
e) Damage after Test #8 (EPGA = 0.49)

Model #6 (Anchored Roof Beams)

Building Damage | Damage Index

0.00
a) Damage after Test #4 (EPGA = 0.23 g)

0.08
b) Damage after Test #5 (EPGA = 0.28 g)

0.15
c) Damage after Test #6 (EPGA = 0.32 g)

0.60
d) Damage after Test #7 (EPGA = 0.42 g)

1.00
e) Damage after Test #8 (EPGA = 0.49)

(c)   Research conducted within the framework of the Getty Seismic Adobe Project

The Getty Seismic Adobe Project (GSAP) was initiated by the Getty Conservation Institute in November 1990 for the purpose of developing technical procedures for improving the seismic performance of historic adobe structures with minimal impact (i.e. minimal intervention and reversibility of strengthening measures) on the historic fabric of these buildings. The program focused on the Spanish colonial missions and historic adobes in seismic areas of the South-western region of the United States, with expected applications to historic adobes in other seismic regions, particularly Central and South America.

Within the framework of the GSAP project, a series of shaking-table tests was conducted in order to study the seismic performance of adobe wall assemblies. Six small-scale (1:5) and two large-scale (1:2) models were investigated: three of the small-scale models had rectangular plans with no roof or floor systems and the remaining three models were more complete, featuring the typical *tapanco*-style adobe buildings, which are characterized by gable-end walls, an attic floor, and roof framing; the large-scale models (also of the *tapanco*-style) were tested in order to investigate the possible effects of gravity loading on the effectiveness of retrofit measures and the patterns of damage.

The retrofit systems tested in GSAP involved horizontal and vertical straps, crossties, vertical centre-core rods and improvements in the anchoring of the roof to the walls (bond beams). A brief description of these systems is provided hereafter:

- The vertical and horizontal straps were made of a 3 mm wide, flexible, woven nylon strap typically used for a bootlace. The straps always formed a loop either around the entire building or around an individual wall and they were passed through small holes in the wall; the two ends were then knotted together.
- Crossties were made of 1.5 mm diameter nylon cords and were inserted through small holes in the wall to reduce the differential displacement across cracks and to provide a through-wall connection.
- The centre-core elements were comprised of 3 mm diameter steel rods. The rods were drilled directly into the adobe after flattening each end into a V-shaped form and they were left in place either as-is or they were anchored with an epoxy grout. All centre-core rods were located entirely within the adobe wall and were not connected to the concrete base. When used in conjunction with wood bond beams, the rods were anchored to the bond beam with an epoxy resin.
- The wood bond beams were 38 mm wide and 10 mm thick, anchored to the walls with 3 mm diameter and 89 mm long coarse-threaded screws. The holes for the screws were predrilled before placement.

The following main conclusions were drawn from the GSAP project:

- Each method proved to be successful in reducing the tendency of the model buildings to collapse.
- Vertical straps were most effective for reducing the risk of out-of-plane wall collapse, but had little or no effect on the initiation and early development of crack damage. In general, the strapping system controlled the relative displacement of cracked sections of walls.
- Overturning of walls can be prevented if wall anchorage to the roof and/or floor system is ensured.
- Vertical centre-core rods installed in the adobe walls were found to be particularly effective in delaying and limiting the damage to both in-plane and out-of-plane walls. Epoxy grout surrounding the rods provided effective shear transfer between the adobe and the steel rods.
- The performance of small- and large-scale model buildings was very similar in many ways. The general development of cracks, the failure modes and effects of the retrofit measures on building behaviour were alike. For the most part, the behaviour of the small-scale models was an acceptable predictor of large-scale model performance.

(d)   Research conducted at UC Berkeley

A reinforcement technique was explored by testing a full-scale adobe wall with a mesh fabric (burlap) lining between rows of bricks, and thus sandwiching the mortar horizontal joints. The researchers claim that the impact of this extra constructional step bears minimal time and labour penalties[15].

Taking into consideration that the target population in the regions of interest would have difficulty finding entire sheets of burlap sufficient for constructing a house, two methods of layering burlap in the mortar were tested through diagonal compression tests: 1) a continuous, uncut horizontal layer and 2) a layer of overlapping pieces cut to lengths from 100 to 130 mm and to a width that matches the depth of the wall unit (100 mm, see Fig. 4-18a). The third wall unit was a control specimen containing no burlap (Fig. 4-18b)[16].

(a)   (b)

Fig. 4-18   (a) Burlap pieces cut from coffee bags; (b) Control specimen in the process of drying. (source: http://www.engineering4theworld.org/adobe.html)

The control specimen was capable of withstanding a lateral force of 12 kN, equivalent to a maximum shear stress of 0.14 MPa. The specimen failed in a sudden and brittle manner, along a single line, showing little post cracking deformability (toughness). The burlap-fortified specimens, on the other hand, showed more than 225% increase in ultimate strength and much greater toughness over the control specimen (Fig. 4-19).

More precisely, the specimen with the burlap pieces had an ultimate load capacity of 26.7 kN and the maximum shear strength that was developed was of 0.32 MPa. Multiple small cracks were observed, demonstrating that the burlap layers served to deter crack propagation in a single area, thus dissipating energy within the entire specimen. Initially, the failure was observed along one of the mortar joints, but eventually the cracking propagated through the bricks, indicating that the burlap layers were of higher strength than the bricks.

The specimen made with continuous burlap strips showed an ultimate load capacity of 30.2 kN, corresponding to a maximum shear strength of 0.36 MPa. After the onset of failure (first crack appeared along a single mortar joint), the specimen exhibited a far more distributed crack pattern that the other two specimens, which was attributed to the toughening effect of the interlayer friction from the continuous burlap strip.

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[15] *See Pescovitz (2003) in the electronic version of the newsletter "Berkeley Engineering", Volume 3, Issue 5, June/July 2003 (http://www.coe.berkeley.edu/labnotes/0603/ostertag.html). This investigation is being conducted under the supervision of Claudia P. Ostertag, Associate Professor, Civil and Environmental Engineering Department, University of California, Berkeley.*

[16] *The description of these tests is available at: http://www.engineering4theworld.org/adobe.html, an on-line report by Meyer et al.; the photos presented here are also from the aforementioned web site. Ho et al. (2001) also present a very pertinent work.*
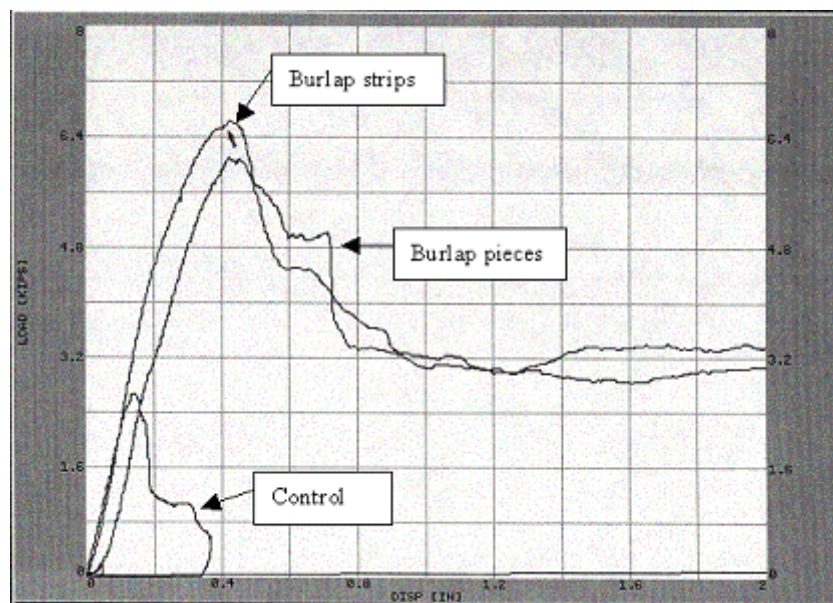
Fig. 4-19 Diagonal compression tests: load [kip] vs. displacement [in] graph, for all specimens. (source: http://www.engineering4theworld.org/adobe.html)

4.3 Informal reinforced concrete buildings

People in the rapidly growing informal settlements spreading around urban Latin American areas have abandoned traditional building materials, such as adobe and wood, and have turned to more "modern", "noble" and/or "safe" ones (according to their perception), such as concrete and steel. There exists a multitude of reasons for this revulsion of the public feeling towards the use of indigenous materials and building practices, the most important of which are discussed in this section.

As already stated in Chapter 3, earth-based and wooden houses have been associated by the population to poverty and inferior social status, on one hand, and to the high risk of homelessness and mortality on the other. Additionally, and especially on the periphery of urban centres, there is a scarcity of natural materials, such as sufficient quantities of soil, wood and bamboo. It should be noted that this scarcity is becoming increasingly prominent even in rural areas, due to the depletion of natural resources and the lack of environmental policies that support sustainability. Another factor that encourages the construction of reinforced concrete structures is the shortage of building lots, especially legally owned ones. This shortage, in combination with overpopulation, has resulted into the need for multi-storey residential buildings, which cannot be erected through traditional construction methods. Finally, it should be underlined that the cement industry in Latin American countries is steadily growing due to rise of per-capita incomes, more stable political structures, greater urban and industrial expansion and a steady increase in cross-continental trade.

The afore-described situation leads most of the self-builders to construct houses consisting of reinforced concrete structural elements, without any professional input (i.e. neither during the design phase, nor the construction one). The whole endeavour is usually based on observation from other nearby building sites, or (in the best of cases) on labour experience gained by the owners during their occupation as construction builders[17].Typical buildings of this type are two to three stories high, having two or three bays in the longitudinal direction (spaced at 3 to 4 m) and four or five bays in the transverse direction (4 to 5 m apart). The main load bearing system consists of reinforced concrete frames (columns and beams lacking moment-resisting capacity) with masonry infill walls of hollow clay bricks, or concrete blocks. The roof structure varies significantly from place to place; the main configurations

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[17] *This urban housing construction type is abundant in the Andean states of Venezuela. In some cities, like Mérida, this construction accounts for 40 per cent of the total building stock (EERI World Housing Encyclopaedia Report, on "Urban non-engineered popular housing on flat terrain" of Venezuela, available at: www.eeri.org/lfe/pdf/venezuela_urban_non_engineering_popular.pdf).*

include lightweight sheets (e.g. zinc), supported on slender I-shaped steel beams, or a reinforce concrete slab, which is used as a terrace, with one meter high masonry parapet that serves as a guardrail along the perimeter.

It is important to stress the fact that the seismic resistance of non-engineered reinforced concrete frame buildings is expected to be markedly inferior to the resistance of non-seismically detailed engineered ones. In addition to the absence of a lateral-load resistance mechanism, common to both construction types (non-engineered and non-seismically engineered), the non-engineered buildings incorporate a combination of quality-related deficiencies, which significantly contributes to the formation of a failure mechanism that may lead to complete collapse; these quality-related deficiencies are mostly ought to the lack of appropriate construction skills and to a low construction budget.

4.3.1 Typical earthquake-induced damages and related construction defects

It is generally very difficult to identify a reinforced concrete frame structure as being non-engineered, after its completion. If the structure is not distinctively irregular, or if it is undamaged, it is very hard to ascertain whether any professional engineering input was involved either during its design phase and/or its construction period. The most important causes for structural failure during earthquakes, apart from defects related to the building's general configuration, usually lie within the RC members and underneath the external covering (e.g. deficient reinforcement detailing, poor concrete compaction, inadequate wall-to-column connections, etc.). These structural defects and the associated failure types are presented hereafter in more detail.

Beam-to-column joints are typically the weakest link in the lateral-load resistance mechanism of this type of RC frame buildings, since the moment transfer capability and the shear resistance of such connections under reverse cyclic loading is severely limited; this is primarily due to lack of adequate detailing of both the longitudinal and the transverse steel reinforcement bars. Commonly encountered detailing mistakes include:

- Widely spaced stirrups, resulting into unconfined plastic hinge zones and insufficient shear capacity (e.g. stirrup spacing larger than the depth of the element's section – see Fig. 4-20);
- Small stirrup diameters (6 mm, or less);
- Use of inappropriate steel (e.g. cold formed steel of low ductility, or smooth rebars);
- Inserts in structural elements and/or joints, such as drain pipes and other service lines, resulting into weakened sections;
- Splices with inadequate development length, or located in the hinge region (e.g. at the bottom of columns in successive stories);
- Light or non-existent transverse reinforcement in joints;
- Inadequate tie anchorage (90° angle of anchorage, instead of 135°, as recommended in seismic codes) of longitudinal bars and stirrups.

Failures resulting from the aforementioned structural defects include diagonal cracking of columns and/or of beam-column joints and concrete crushing at column bases and/or buckling of the longitudinal reinforcement in the vicinity of supports. Other failure types, which are also attributed to poor detailing of connections between structural members, include: roofs sliding off of supports, collapse of gable frames and out-of-plane collapse of infill walls.

"Strong-beam/weak-column" systems might result in single- or multiple-storey collapses, following severe storey-wide column damages. This type of failure induces very high level of casualties, especially if total ("pancake-type") collapse occurs. This collapse pattern was common for many non-engineered multi-storey RC apartment buildings in Turkey, following the 1999 Kocaeli earthquake[18]. The collapse of a single storey, usually observed in the

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[18] *The 7.4 magnitude Kocaeli earthquake caused more than 17,000 confirmed deaths, whereas another 20,000 people were declared missing and presumed dead. High collapse rates and associated casualties in the affected areas were attributed to poor construction practices and lack of engineering supervision, or code enforcement (non-engineered structures). Most of these buildings had five floors (this number ranging from 3 to 7), with an average of ten residential units per building and five residents per unit. Built with non-ductile reinforced concrete frames and hollow clay tile infill walls, these structures suffered catastrophic levels of damage and caused large numbers of life losses.*

ground floor of buildings, is attributed to the development of a "soft-storey" mechanism, and takes place in stories of relative lower strength and stiffness that experience most of the displacement demand imposed by the earthquake. These soft stories experience large, uncontrolled deformations that result in partial or total collapse. Soft stories are usually developed in the presence of large openings, such as windows, pedestrian corridors, garages and open fronts used as windows for commercial purposes (Fig. 4-21). These openings are usually located asymmetrically through the plan of the building, causing further problems related to torsion.

The "short-column" type of damage in non-engineered reinforced concrete structures is evidenced in the form of diagonal column cracking (see Fig. 4-22). The presence of mid-height masonry infill walls, above or below window openings, decreases the effective length of columns, increasing their stiffness and thus attracting high shear forces that in most cases exceed the shear capacity of the member, even when the transverse reinforcement has been carefully detailed.

Fig. 4-20 Close-up view of the rubble from a damaged multi-storey building in Ahmedabad (namely the Manasi complex), after the Gujarat (western India) earthquake of 26 January, 2001; the photo shows the reinforcement arrangement and the quality of concrete used in the columns.[19] (source: Karkee and Itagaki,

Fig. 4-21 Collapse of a building with an open front (a pedestrian corridor), following the 1999 earthquake in Central Taiwan (also known as the 921 Chi-Chi earthquake)[20]. (source: Tsai et al.,

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[19] *The authors note that a significant portion of the damaged houses - resulting into a high number of casualties - seem to have been non-engineered structures. Although Karkee and Itagaki do not clarify whether or not the Manasi complex was non-engineered, this photo successfully illustrates a common structural deficiency for both non-engineered and low-quality engineered RC structures. More information on the Gujarat earthquake and its consequences to the local non-engineered built fabric are given in a following part of this chapter.*

[20] *On 21 September, 1999 a magnitude $M_L = 7.3$ earthquake struck the central region of Taiwan. Following the 921 Chi-Chi earthquake, two after-shocks of $M_L = 6.8$ occurred about 30 and 127 hours*

Fig. 4-22 (a) A Colombian self-built RC structure, featuring "short" columns; (b) Close-up of a short column (adjacent to two mid-height infill walls) that failed in shear. (source: Taucer, 1999)

As mentioned in Chapter 2, the incremental consolidation of the initial "core" house that takes place as the household's income improves is a common construction-related phenomenon in informal settlements. The structural changes to the structure, such as the addition of an extra floor, are also carried out without any professional guidance, resulting into serious construction mistakes; these include:

- Lack of vertical continuity of columns (i.e. the new columns are supported on beams of the lower storey - see Fig. 4-23, or they just rest on the concrete slab), resulting into excessive stress concentrations on the supporting elements (large bending moments induced on the supporting beams, or punching shear on the slab);
- In the case that columns are erected in continuity with the existing ones, the lap splices are usually not sufficient to provide adequate transfer of stresses;
- Indirect beam supports (beams resting on beams), introducing torsion to the supporting beam;
- Eccentric beam supports (the beam centerline does not coincide to the column axis), introducing additional moment to the column;
- Irregular floor plans, inducing torsion effects and uneven distribution of the building's structural mass;
- Canopies that serve as first storey terraces, supported on slender columns at one end and on beams running into the main structural frame at the other, often fail in a "soft-storey" mode.

The vulnerability associated to these structural defects is greatly aggravated when the existing "core" house has suffered severe damage, due to previous earthquakes. Similar exacerbating effects are introduced when the owners undertake structural rehabilitation and strengthening works without the supervision of an engineer. In this case, some structural deficiencies that result from poor workmanship and lack of knowledge include: discontinuity of the additional reinforcement (e.g. the additional longitudinal reinforcement used for a column's jacket may not anchored to the foundation and/or to the successive columns by means of sufficiently long development lengths or bends – see Fig. 4-24a), inadequate concrete cover (Fig. 4-24b) and asymmetrically distributed structural mass and/or stiffness. A common mistake is found when the section of a member (especially in columns) is increased without providing adequate detailing for an effective transfer of stresses to the original structure, with the result that the now stiffer element attracts higher forces that are not corresponded with an equal increase in strength and ductility.

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after the main shock. The 921 Chi-Chi earthquake caused collapses or damages of various degrees to approximately 9,000 buildings. A large percentage of buildings that collapsed were un-reinforced clay block masonry houses and non-engineered one-to-three stories reinforced concrete frame structures, with brick infill partitions and exterior walls. Although the authors do not specifically identify the building shown in Fig. 21 as a non-engineered one, this photo successfully illustrates the "soft-storey" type of failure, which is common in many non-engineered RC structures.

Fig. 4-23 Lack of vertical continuity of columns in a Colombian self-built RC structure. (source: Tauce⬚⬚99)

| (a) | (b) |

Fig. 4-24   Non-engineered retrofitting interventions after the 1999 Kocaeli earthquake: (a) Additional external reinforcement around a column to be jacketed: the longitudinal reinforcement is not properly anchored into the joint; (b) Insufficient concrete cover on a recently retrofitted column. (source: Caicedo et al., ⬚)

Additional failures account for differential settlement of the foundations owing to the poor quality of the soil and/or to the absence of a bottom tie-beam connecting individual footings. Other failures observed are related to the pounding effects resulting from inadequate spacing between adjacent buildings and to non-structural damages, such as dislocated roof tiles and wall cracking owing to insufficient anchorage length of lintels.

Finally, poor workmanship may result into the formation of: cold joints between lifts; cavities due to insufficient compaction that lead to pull-out of reinforcing bars (weak steel-concrete bond); reduced member sections due to problems in placing the formwork and extended shrinkage cracking due to deficient curing.

4.4 Effects of earthquakes on non-engineered buildings: case studies

4.4.1 The October 1995 Manzanillo, Mexico earthquake

A magnitude Ms 7.6 earthquake struck Manzanillo, Mexico, coastal town about 550 km west of Mexico City, on 9 October, 1995 at 09:37 local time. Approximately 40 people were killed and another 100 injured. Two major buildings collapsed in the Manzanillo area, and damage was widespread among many buildings of the affected area. The shaking was felt strongly in Mexico City and as far away as Dallas, Texas and Oklahoma City, Oklahoma.

The old Manzanillo downtown area is composed of low-rise commercial, administrative and residential buildings, most of which are of non-engineered unreinforced masonry construction. Lightly reinforced concrete framing elements (horizontal *dalas* and vertical *castillos*) of the same thickness as the single-wythe brick, or block walls are used in many of these structures. A few one-storey commercial buildings used light steel frames as part of the structural system.

Most of the damage occurred in non-engineered masonry constructions. The damage observed after the earthquake indicated that the use of concrete columns and beams can greatly enhance the performance of these buildings. Among the non-engineered buildings of vernacular unreinforced masonry construction, those with short storey heights (about 2.5 m) performed better than those with higher storeys. The use of mid-storey concrete beams (*dalas*) was associated with better performance, apparently limiting out-of-plane failures. Shear failures in concrete column boundary elements (*castillos*) were frequently observed; however, buildings with these elements generally performed better than those without them.

In the non-engineered low-rise masonry buildings, diagonal cracks between openings were common in both brick and block walls. Shear failure of the vertical lightly reinforced concrete members was common through many buildings. In the collapse of a two-storey police station, insufficient continuity of the framing elements appeared to have caused the damage. Complete collapses occurred in many of the simple masonry buildings that did not make use of supplementary horizontal and vertical concrete elements (Fig. 4-25). Much of these constructions were built with clay tile roofs; the tiles were often shaken loose[21].

Fig. 4-25   This two-story home in Manzanillo collapsed due to a heavy roof and inadequate walls. (source: EERI, 1995)

4.4.2 The January 2001, El Salvador earthquake

El Salvador was struck by two devastating earthquakes within a month. The first earthquake of 13 January, 2001 centered off El Salvador's Southern coast and with a magnitude of 7.7, damaged and destroyed nearly 108,000 houses and killed at least 944 people, including hundreds of residents buried by a landslide in Las Colinas mountainside in the city of Nueva San Salvador (Santa Tecla). The second earthquake took place on February 13 and with a magnitude 6.6, hit several central provinces, killing at least 322 people and destroying more

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[21] *The data presented here is extracted from the "EERI SPECIAL EARTHQUAKE REPORT - DECEMBER 1995". This report was compiled from information submitted by Julio Ramirez of Purdue University and Raymond Pugliesi of Degenkolb Engineers.*

than 34,500 houses; although of smaller magnitude, this earthquake created substantial levels of damage.

In the rural area of El Salvador, the dwelling construction types mostly used are adobe, *bahareque*, reinforced concrete block masonry, reinforced brick masonry (*mixto*), wood frames covered by thin metal sheets (*lámina*), and wood frames covered by palm fronds (*ranchos*). A brief description of these construction types (except adobe and *bahareque*) follows.

Reinforced masonry construction is popular in El Salvador. The use of concrete blocks is more extended than the use of clay bricks, as the latter are not widely available in the market. Fig. 4-26 shows a typical reinforced masonry building under construction. In 1994, the Ministry of Public Works published the "Guidelines for the Design and Construction of Masonry". This document establishes the minimum requirements for the design, construction and supervision of the construction of these structures. In general, it was observed that modern buildings, presumably built under this regulation, did not suffer much damage.

Fig. 4-26 Reinforced masonry house with concrete blocks under construction.
(source: JSCE, 2001)

Mixto is composed of fired clay bricks with mortar and lightly reinforced slender concrete elements of the same thickness as the wall known as *nervios* (nerves or tendons). This system, in which the load-bearing system is provided by the masonry walls, has relatively good seismic resistance, but is considerably more expensive than both adobe and *bahareque*.

Lámina is the name given to buildings of timber or metal frames covered by thin metal sheets, usually founded on 0.5 m high block walls. *Lámina* has good seismic resistance due to its low weight. Finally, wood frames covered by palm fronds have excellent seismic response characteristics, but this building system is rapidly disappearing due to the scarcity of materials.

Other rural building practices, which are less widely used, include concrete and soil-cement block masonry using soil-cement blocks and steel frames infilled with precast walls. The total country's built fabric (i.e. both urban and rural) is illustrated in Fig. 4-27.
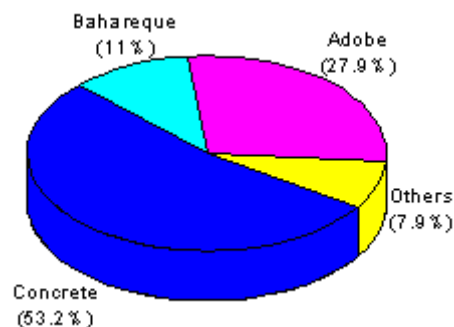
Fig. 4-27 Distribution of dwellings in El Salvador (1994). (source: the figure is based on data provided by the Vice-ministry of Housing and Urban Development)

The earthquakes of January and February of 2001, left a toll in El Salvador of an estimated 335,749 housing units that were either destroyed or suffered minor to major damage, depending upon their structural characteristics and the type of soil of the affected areas [based on estimations of the National Emergency Committee (COEN), see Table 4-2]. This number corresponded roughly to 20% of the existing housing stock of the country.

Table 4-2 Summary of dwellings affected by the 2001 earthquakes in El Salvador. [source: COEN (2001), as reported by OPS ( )]

Housing units	Earthquake		Total
	13/01/2001	13/02/2001	
Damaged	169,792	15,706	185,498
Destroyed	108,261	41,302	149,563
Buried due to landslides	688	0	688
Total sum of affected housing units	278,741	57,008	**335,749**

According to information provided by the Vice Ministry for Housing and Urban Development (*Viceministerio de Vivienda y Desarrollo Urbano* - VMVDU), the housing shortage in El Salvador in 1999 amounted to 555,604 units, of which 507,227 (91%) corresponded to a qualitative deficit, that is, housing that needed improvements, and 44,377 (9%) corresponded to a quantitative deficit. The loss of more than 150,000 housing units and the deterioration of about 185,000 are added to the total accrued housing shortage.

A house is considered deficient if it lacks all the services of electricity, water and sanitation supply, or if it has some of its structural components (ceiling, floor and walls) constructed with materials of low quality. As deficient construction materials (according to the VMVDU), are considered: (i) straw, palm and wooden remainders for the roof, (ii) earth for the floor, and (iii) *bahareque*, adobe, wood, straw, palm and wooden remainders for the walls. According to the 1999 Multiple Purpose Home Survey (*Encuesta de Hogares de Propósitos Múltiples* - EHPM), 43% of the houses were built with deficient materials (see Table 4-3). The majority of these houses are situated in rural areas, as demonstrated by the same table.

A comparison of the data contained in the Multiple Purpose Home Survey for 1999, prepared by the Ministry of Commerce's Department of Statistics and Census (*Dirección General de Estadística y Censos* - DIGESTYC), against figures representing the percentages of the various types of construction materials used in home building in various regions, demonstrates that the houses affected by the earthquake were located in zones in which the predominant building materials include adobe and *bahareque* (see Table 4-4 and Fig. 4-28). The combined percentages of damaged adobe and *bahareque* walls exceed 50% of the total affected walls (see Fig. 4-29, based on the data of Table 4-4).

Similarly, by comparing the data from the Multiple Purpose Home Survey for 1999 against the poverty indices for the various regions of the country, (see Table 4-5 and Fig. 4-30), the greatest damage was evidenced in the Departments with the highest poverty levels. The damage patterns clearly revealed the social vulnerability of poor people forced to live in susceptible locations and vulnerable houses. Small towns such as San Agustín, where 80% of the houses were made from adobe, were particularly hard hit. The same pattern was visible in small hamlets and villages, where adobe was even more dominant and where the quality of construction was generally poor. Even in San Salvador, where damage to engineered structures was very limited, extensive damage was observed in shanty dwellings such as in the José Cecilio del Valle area adjacent to the exclusive Escalón neighbourhood, due to the high intensity of the shaking and to the instability of sloping terrain.

As previously mentioned, the overwhelming majority of the damaged houses were of adobe and *bahareque*, with the former being the most susceptible one. Timber frames and reinforced masonry houses performed significantly better and it was not uncommon to visit locations where most adobe houses were in a state of at least partial collapse, whereas reinforced masonry houses were practically unscathed[22].

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[22] *The following information is compiled from reports on the 2001 El Salvador earthquakes, and namely from: Bommer et al. (2002), JSCE (2001) and EERI (2001).*

Figure 4-31a shows a typical adobe dwelling, damaged by the 2001 earthquakes. Load transfer between the roof and the walls, or between adjacent walls, is often not effective in these structures that exhibit low strength associated to high mass and stiffness. Although there are techniques to reinforce adobe structures during the construction phase in order to improve their seismic performance (see section 4.2.4), these are not put into practice in El Salvador.

Figure 4-31b shows a typical *bahareque* structure that suffered a limited amount of damage. This construction system has proven to perform better than adobe structures during earthquakes, since its seismic resistance depends primarily on the condition of the timber and cane elements, having low vulnerability when carefully maintained (the tropical climate and insects rapidly deteriorate these building materials). Generally, *bahareque* is a more expensive building system than adobe, and according to discussions with Salvadoran engineers (JSCE, 2001) this system is almost not used for new constructions anymore.

Table 4-3 Houses built with deficient materials. (source: EHPM, 1999)

Department	% of houses having at least one deficient material	Urban (% of the total)	Rural (% of the total)
San Vicente	76.01	28.95	47.06
Cabañas	72.34	18.69	53.65
Morazán	72.01	17.03	54.98
Ahuachapán	71.25	15.00	56.26
Usulután	68.55	22.38	46.16
Chalatenango	62.12	17.26	44.86
Cuscatlán	60.29	14.24	46.06
Sonsonate	59.37	19.33	40.05
Santa Ana	58.43	20.81	37.63
La Unión	57.74	11.33	46.41
San Miguel	48.16	14.49	33.67
La Libertad	35.85	10.41	25.44
La Paz	34.60	22.03	45.94
San Salvador	14.20	10.75	3.45
Total	43.00		

Table 4-4 Typology of the walls of the affected housing units by Department (all figures given in percentages). [source: ECLAC (2001) on the basis of figures provided by the National Emergency Committee (COEN) and the Multiple Purpose Home Survey for 1999, from the Ministry of Commerce's Department of Statistics and Census (DIGESTYC)]

Department	Houses affected	*Bahareque* walls	Adobe walls	Concrete walls	Other walls
San Vicente	69	17	50	25	6
Cabañas	2	16	51	25	6
Morazán	≈ 0	20	45	17	17
Ahuachapán	16	14	37	29	19
Usulután	74	19	35	34	11
Chalatenango	≈ 0	5	69	22	2
Cuscatlán	22	14	45	35	4
Sonsonate	30	11	24	46	17
Santa Ana	7	8	41	43	6
La Unión	4	16	40	34	8

Table 4-4 (cont'd) Typology of the walls of the affected housing units by Department (all figures given in percentages). [source: ECLAC (2001) on the basis of figures provided by the National Emergency Committee (COEN) and the Multiple Purpose Home Survey for 1999, from the Ministry of Commerce's Department of Statistics and Census (DIGESTYC)]

Department	Houses affected	*Bahareque* walls	Adobe walls	Concrete walls	Other walls
San Miguel	13	16	22	51	8
La Libertad	24	13	20	58	7
La Paz	64	12	45	33	8
San Salvador	3	7	5	80	6

EFFECTS OF THE JANUARY 13, 2001 EARTHQUAKE IN EL SALVADOR

PERCENTAGE OF HOUSING UNITS AFFECTED, BY DEPARTMENT

(GRAPH WITH THE DISTRIBUTION OF HOUSING UNITS ACCORDING TO BUILDING MATERIALS)

Type of material
- Concrete
- *Bahareque* & adobe
- Other materials

% affected houses
- 0.1 - 6.7 %
- 6.7 - 15.8 %
- 15.8 - 30.1 %
- 30.1 - 74.2 %

Fuente: Información del COEN al 2 de febrero de 2001
Encuesta de Hogares de Propósitos Múltiples 1999. DIGESTYC

Source: Information from the National Emergency Committee (COEN)
as of February 2, 2001
Multiple Purpose Home Survey 1999,
Ministry of Commerce's Department of Statistics and Census (DIGESTYC)

Fig. 4-28 Percentage of housing units affected, by Department, according to building materials.
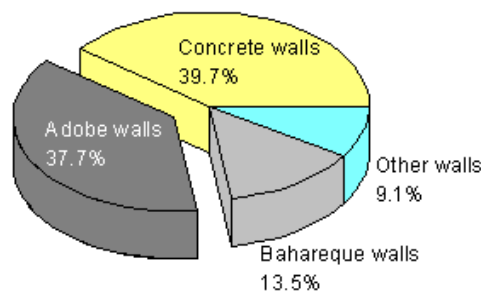
Fig. 4-29 Total percentages of the damaged walls, as per Table 4-4.

Table 4-5 Housing by Department, according to poverty indices. [source: ECLAC (2001) on the basis of figures provided by the National Emergency Committee (COEN) and the Multiple Purpose Home Survey for 1999, from the Ministry of Commerce's Department of Statistics and Census (DIGESTYC)]

Department	Houses affected	Relative poverty	Extreme poverty	No poverty
San Vicente	69	29	31	40
Cabañas	2	24	40	36
Morazán	0	31	28	41
Ahuachapán	16	24	36	40
Usulután	74	30	25	45
Chalatenango	0	27	29	44
Cuscatlán	22	25	14	61
Sonsonate	30	30	19	51
Santa Ana	7	27	18	55
La Unión	4	27	24	49
San Miguel	13	27	18	55
La Libertad	24	20	13	67
La Paz	64	29	21	50
San Salvador	3	21	7	72

EFFECTS OF THE JANUARY 13, 2001 EARTHQUAKE IN EL SALVADOR
PERCENTAGE OF HOUSING UNITS AFFECTED, BY DEPARTMENT
(GRAPH WITH THE DISTRIBUTION OF HOUSING UNITS ACCORDING TO POVERTY)

Poverty level
a
Households over the poverty line
Households under the poverty line

% affected houses
0.1 - 6.7 %
6.7 - 15.8 %
15.8 - 30.1 %
30.1 - 74.2 %

30   0   30   60 Kilometers

Fuente: información del COEN al 2 de febrero de 2001
Encuensta de Hogares de Propósitos Multiples 1999. DIGESTYC

Fig. 4-30 Percentage of housing units affected, by Department, according to poverty level.

(a)   (b)

Fig. 4-31   (a) Typical adobe house damaged by the earthquake; (b) *Bahareque* structure, which suffered mud cover spalling. (source: JSCE, 2001)

A compilation of photos found in the literature, relevant to the 2001 El Salvador earthquakes, is given hereafter.

(a)   (b)

Fig. 4-32   (a) Collapsed adobe house in San Agustín, of which only the door remains standing after the 13 January earthquake; behind are houses of *mixto* and *lámina*, which have survived the earthquake (source: Bommer et al., 2002); (b) Damaged adobe house in Santiago de María. (source: photo by Julian Bommer – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-33   (a) Collapsed adobe house in Canto La Concordia, near Jiquilisco [source: Salvadorean Programme for Research on Development and Environment (PRISMA)]; (b) Near-collapse of an older adobe structure in Santa Tecla. (source: photo by Conrad Paulson and Larry Hultengren – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

<center>(a)</center>

<center>(b)</center>

Fig. 4-34 (a) Older adobe structure in Santa Tecla. Note the loss of roof tiles and damage at the corner of the structure (source: photo by Conrad Paulson and Larry Hultengren – annotated picture from EERI special newsletter report on the El Salvador earthquakes of January 13th and February 13th, 2001); (b) View of a *bahareque* (made from timber vertical members, bamboo horizontal, infilled with mud and covered with stucco) house in Apastepeque. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

<center>(a)</center>

<center>(b)</center>

Fig. 4-35 (a) View of a destroyed adobe house in Candelaria (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001); (b) A typical *bahareque* house in Santa Tecla. (source: annotated photo by Seo and Salazar a, 2001)

<center>(a)</center>

<center>(b)</center>

Fig. 4-36 (a) *Bahareque* wall in detail. The frame was made of vertical elements in wood and horizontal elements in bamboo; (b) Damage of adobe houses in Santiago de María, Usulután. (source: annotated photos by Seo and Salazar a, 2001)

(a)

(b)

Fig. 4-37 (a) *Bahareque* houses in Santiago de María: these performed much better than adobe houses from the earthquake engineering point of view; (b) A typical adobe structure: wooden columns and beams prevented the total collapse of the building. (source: annotated photo by Seo and Salazar ▆▆▆ a, 2001)

(a)

(b)

Fig. 4-38 (a) A typical *bahareque* structure: the roof triangle was made of wood (source: annotated photo Seo and Salazar ▆▆▆ rra, 2001); (b) Destruction of an adobe dwelling in Candelaria. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)

(b)

Fig. 4-39 (a) Destruction of an adobe portal in Cojutepeque; (b) A severely damaged adobe school in Cojutepeque where some students were killed. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-40   (a) Shear failure in *mixto* walls in Cojutepeque; (b) Damaged adobe house in Cojutepeque. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-41   (a) Severely damaged adobe house in Cojutepeque; (b) Damage to an adobe structure in Cojutepeque. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-42   (a) Destruction of an adobe house with some concrete elements in Cojutepeque (source: P3); (b) Total collapse of adobe houses in El Carmen county. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-43 (a) Total destruction of adobe and *bahareque* dwellings in Guadalupe; (b) Damage to *mixto* construction in San Vicente. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and February 13, 2001)

(a)   (b)

Fig. 4-44 (a) Damage to a *bahareque* construction in San Vicente; (b) Moderate damage to an adobe construction. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-45 (a) Damaged *bahareque* house in San Vicente; (b) Adobe construction in total ruins. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-46   (a) *Mixto* construction in the town of Santa Cruz Analquito still standing, but surrounding a destroyed adobe construction; (b) House of *mixto* construction in Santa Cruz Analquito still standing next to an adobe house turned into rubble. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-47   (a) Adobe house with columns still standing in Verapaz; (b) *Mixto* house in Verapaz still standing next to an adobe house in total ruins. (source: photo by Manuel López Menjívar, University of El Salvador – annotated picture from EERI special newsletter report on the El Salvador earthquakes of 13 January and 13 February, 2001)

(a)   (b)

Fig. 4-48   (a) Inner view of a *bahareque* house where a tree trunk was used as a column; (b) Inner view of the same house showing a brick wall with no reinforcement. (source: annotated photo by Seo and Salazar [a, 2001])

4.4.3 The January 2001 Gujarat, India earthquake

On 26 January, 2001 at 08:46 local time, a magnitude 7.7 (M_w) earthquake occurred in the seismically active area of the Kutch (or else Kachchh) District of the Gujarat State of India, about 600 km northwest of Bombay (Mumbai). It is estimated that the earthquake caused nearly 20,000 deaths, 150,000 injuries and affected 15,700,000 people in the State of Gujarat. In the Kutch District, about 258,000 houses (90% of the housing stock) was damaged or destroyed, whereas in the entire Gujarat State, about 839,000 houses (approximately 24% of the housing stock) was also either damaged, or destroyed. Most of these buildings were non-engineered, unreinforced stone masonry buildings (only 10% of the structures in Kutch are engineered constructions; however, most of them do not comply with Indian code requirements).

Generally, urban masonry in this geographical area consists of burned brick, cut stone and cement mortar, while rural practice uses random rubble masonry (RRM), unburned bricks and mud mortar (see Fig. 4-49). These buildings have various roof types including reinforced concrete slab, wood and tiles. Approximately 90% of houses in rural areas were of RRM type.
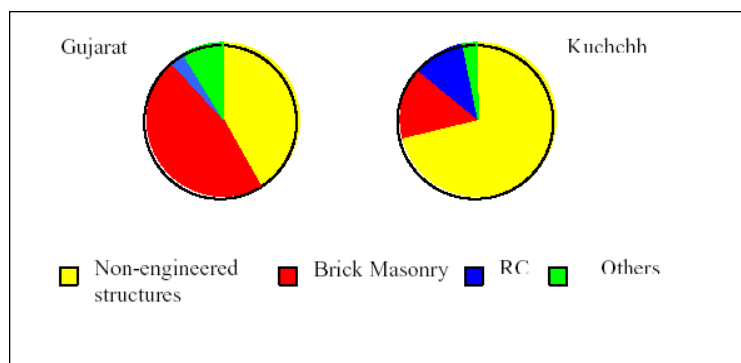
Fig. 4-49 Distribution of buildings by materials (Gujarat state and Kuchch district).
(source: IITB and EDM/NIED, 2001)

The damage to houses indicates that more than 187,000 *pucca* houses (generally constructed using durable materials such as cement, concrete and brick) collapsed and about 500,000 were severely damaged, whereas about 183,000 *kachchha* houses (constructions with adobe or other less durable materials) were completely destroyed (IITB and EDM/NIED, 2001).

In the epicentral region, almost all non-engineered structures and a large proportion of poorly constructed engineered ones suffered major damage or collapsed. It is interesting to note that several properly constructed engineered and non-engineered structures in the epicentral region escaped with only minor damage. This clearly demonstrates the importance of proper construction practice for seismic safety of buildings. Fig. 4-50 shows a masonry building with earthquake-resistant features (lintel bands) in Ratnal that escaped with minor damage while all adjoining non-engineered structures suffered total collapse.

Fig. 4-50 Residential building constructed using brick masonry with lintel band survived at Ratnal. (source: IITB and EDM/NIED, 2001)

The most extensive damage was observed to adobe and other constructions using local materials in rural areas. The damage to these buildings was also the largest contributor to the large number of fatalities. Non-engineered cut-stone and brick masonry buildings that were over 50 years old were also severely damaged in large numbers, leading to the death or injury of their occupants (the destruction of entire neighbourhoods was observed in Anjar, Bhachau and Bhuj). The masonry buildings under 20 years old suffered relatively less damage, underlying the importance of maintenance in seismic resistance of masonry buildings (IITB and EDM/NIED, 2001).

According to the "Interdisciplinary Observations on the January 2001 Bhuj, Gujarat Earthquake", a report sponsored by the World Seismic Safety Initiative (WSSI) and the Earthquakes and Megacities Initiative (EMI), the following factors were identified as weaknesses of non-engineered masonry constructions in Gujarat that led to their damage and collapse and the subsequent loss of lives:

- Most of the old buildings in the non-formal sector are constructed of poor quality materials that are not properly maintained. The deterioration of these materials, particularly mud mortar, contributed to many collapses in Anjar, Bhachau and Bhuj.
- In many non-engineered buildings there is a lack of integrity between the walls, the roofs and the foundations. The connections between these elements are inadequate to prevent the buildings from coming apart. Proper connections and detailing that respect the traditional type of construction must be developed to improve the structural integrity of the non-engineered masonry buildings in Gujarat.
- Insufficient repair and maintenance of buildings damaged by floods and cyclones in the past also contributed to the losses incurred during the earthquake. The collapse of some buildings in the District of Surendranagar could be attributed to foundation damage caused by flooding in previous years.
- In some instances, the heavy weight of the roof exacerbated the damage that was incurred in non-engineered masonry buildings. Because these heavy roofs are necessary for protection against the cyclones that frequently occur in the region, it is impractical to eliminate them. Instead, builders must be made aware of the danger they pose and be given proper instructions as on how to best construct the walls to provide adequate seismic restraint to these roofs.
- Stone parapets and architectural facades of many buildings that were inadequately reinforced or anchored were severely damaged. While damage to these elements does not cause buildings to collapse or become uninhabitable, the rubble does pose a threat to life when falling into the street or sidewalks.
- The narrow lanes that characterize many of the older neighbourhoods pose a significant threat to life-safety, particularly when debris falls off the buildings. In addition, narrow lanes make difficult the organisation of the rescue operations.

Masonry buildings were not the only non-engineered structures that suffered heavy damage or even complete collapse. In the last 10 to 15 years, two- to three-storey reinforced concrete frame structures have become a common construction feature of domestic buildings in Kutch. The frames are infilled with brick masonry and the roof is either made of a flat concrete slab or of pitched timber elements to keep the interior of the building cool in the summer. These buildings often have an open first floor (without infill walls), the space being used as parking lots or commercial stores, resulting in weaker ground floors causing soft storey failures.

In many cases where the owner had employed an architect or local structural engineer to design the building, no seismic design provisions were followed. The "non-structural" infill wall panels acted many times as a first line of resistance, compensating for the inherent weaknesses of the reinforced concrete elements. The following photographs illustrate some of the most common causes that led to the collapse of the non-engineered (or inappropriately engineered) reinforced concrete frame structures in the Bhuj area following the 2001 earthquake.

Fig. 4-51 Typical soft storey and torsion collapse in Bhuj. (source: Gujarat Relief Engineering Advice Team - GREAT, 2001)

Fig. 4-52 Heavy compressive stresses and large deformations caused total destruction of the column head; heavily bent longitudinal reinforcement is shown. The large spacing of stirrups did not provide effective confinement of the concrete core. (source: Gujarat Relief Engineering Advice Team - GREAT, 2001)

Fig. 4-53 Separation between the ground beam and the column junction caused by crushing of the concrete (city of Sukhpur). The damage worsened by the presence of a plastic pipe within the column. (source: Gujarat Relief Engineering Advice Team - GREAT, 2001)

4.5 Conclusions

The bibliographical survey revealed that a substantial amount of knowledge exists on the seismic performance of adobe buildings through: (i) on-site post-earthquake reconnaissance visits lead by experts to record and identify damage typologies and structural defects; and (ii) experimental investigations conducted to assess the seismic performance of such structures. From the current state of research it is evident that adequate structural safety (i.e. at least avoidance of partial or total collapse) of non-engineered adobe buildings can be ensured by adopting appropriate design and construction details, involving relatively small additional costs. These general constructional features are:

- *Simplicity and symmetry in plan and elevation.*
- *Enclosed space*: The construction should be compact, with small rooms and properly bonded walls forming a box-like enclosure.
- *Openings in walls*: Door and window openings should be small and centrally located.
- *Height*: Restriction of height for load bearing wall buildings is necessary to ensure better seismic safety. For instance, the Peruvian adobe code (see Chapter 3 for reference) allows the construction of only one-storey adobe houses. According to the Indian Standards the maximum suggested height for adobe buildings is restricted to one storey, plus attic. Table 4-6 provides recommendations regarding maximum wall heights, as a function of the building type.
- *Roofs*: The type of roof plays an important role in the seismic behaviour of buildings and generally it should be as light as possible. All elements of a roof should be adequately bonded together in order for the roofing system to act as a single rigid diaphragm holding all the walls together.
- *Walls*: The slenderness ratio of the walls (i.e. height over width) should be kept as low as possible. Brick laying techniques should ensure verticality and proper overlapping, especially at the walls' intersections. A bond beam running along the perimeter of the walls seems to be the most efficient way to maintain the structural integrity of the assembly during strong ground shaking. Gable tops of walls, constituting the most unstable part of a building, should either be completely avoided, or covered by lighter material, like sheeting, boarding, etc.
- *Foundations*: The entire foundation should be on the same type of soil and should provide for adequate protection against humidity ingress to the upper structure.
- *Materials*: The soil must be free of foreign matter; the mud must be mixed as thoroughly and uniformly as possible; the blocks must be left to dry in the shade and they must be cleaned prior to their use; wetting of the blocks prior to mortar applications will prevent water absorption; joint must be uniform and the verticality of walls should be checked[23].

As far as non-engineered reinforced concrete frame buildings are concerned, it should be noted that experimental investigations for the assessment of the seismic performance of non-seismically detailed RC structures (being the closest engineered analogue to the non-engineered ones) are notably scarce. Suggestions relevant to the improvement of the dynamic behaviour of non-engineered RC frame buildings should therefore aim at avoiding those construction practices that result into structural collapse, as discussed earlier in this chapter. General recommendations, such as the pursuance of symmetrical distribution (both in plan and in elevation) of mass and stiffness, would greatly enhance the seismic performance of non-engineered structures.

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[23] *In more technical terms, the Peruvian code on adobe structures, based on the work carried out at the PUCP, specifies the minimum allowable compressive strength of adobe blocks equal to 1.2 MPa (desirable range: 1.5 – 2.0 MPa); dictates that 1% straw addition (by weight) is mandatory for drying shrinkage prevention (straw length should be in the order of 50 mm) and suggests that a lower threshold of shear strength of adobe masonry can be taken equal to 0.025 MPa (although values greater than 0.05 MPa have been recorded).*

Table 4-6 Suggested maximum building heights for non-engineered buildings in moderate and severe seismic zones (according to Indian Standards, Arya 1994).

Building type	Suggested maximum height
Adobe house	1 storey, or 1 storey + attic
Field stone (random rubble) masonry in clay mud mortar	1 storey, or 1 storey + attic
Dressed stone masonry in cement mortar	2 storeys, or 2 storeys + attic
Brick masonry in mud with critical sections in cement mortar	2 storeys, or 2 storeys + attic
Brick or cement block masonry in good cement mortar	3 storeys, or 3 storeys + attic
Reinforced masonry	5 storeys, or as per design by a qualified engineer
Wood frame	2 storeys, or 2 storeys + attic

4.6   Synopsis

An overview of the existing knowledge on the seismic performance of non-engineered adobe and reinforced concrete frame structures was presented in this chapter. Focal issues in this part of the report were: the identification of typical damage patterns and related structural defects of both construction types; the classification of earthquake-induced damages, by degree of severity, for adobe dwellings; a summary on conferences held in order to systemize and disseminate the scientific knowledge regarding the seismic performance of earth-based buildings; and experimental programs carried out by the academia to assess the structural response of adobe houses exposed to earthquake loads and to explore the effectiveness of several strengthening measures. Finally, three case studies were presented and supported by a series of photographs, concerning the effects of past earthquakes on non-engineered buildings. The mechanisms that lead to the catastrophic failures that resulted in large life losses have been explored and well documented, especially for the case of adobe dwellings. The main conclusion drawn from this chapter is that the knowledge necessary for the prevention of the structural collapse of non-engineered structures during moderate to strong earthquakes is already existent. The challenge lies in the implementation of effective means for disseminating this knowledge to the population at risk.

CHAPTER 5

Manuals on self-construction

5.1   Introduction

In this chapter, a review of the existing manuals on self-construction practices is presented. These documents have been developed by various institutes, governmental/non-governmental organizations, private companies and/or academia, in order to disseminate the existing knowledge on safe construction methods to untrained people who participate in self-construction housing projects in developing countries. The manuals, listed and presented hereafter, are mainly addressed to Latin American self-builders and deal with both traditional construction systems, such as adobe and *bahareque*, and more "modern" ones, such as confined masonry and reinforced concrete frame structures.

Prior to the presentation of the manuals, information is given on the available means of information transfer in self-construction housing projects and on the features that render a self-construction manual an efficient educational tool. The manuals, which are listed, are commented on the basis of the aforementioned features and on their contents. Effort was made in order to successfully summarize the construction processes described in adobe, *bahareque* and reinforced concrete manuals. The listing of other manuals, such as those referring to masonry buildings or for which the available information is limited, was decided for the sake of completeness.

Furthermore, selected technical documents are presented, despite the fact that their layout does not conform to the characteristics of a publication that provides step-by-step instructions to self-builders. They may be considered as compilations of guidelines of good construction practice, or as summaries of the outcomes of experimental projects in the field of improved traditional construction methods. Nevertheless, the information included in these technical documents is presented in a simple, popularized manner and can be readily used by people with fair knowledge of structural design and/or construction practices, in order to further disseminate this information to the less knowledgeable part of the population.

5.2   Means of information transfer in self-construction housing projects

By definition, the success of a self-construction housing project largely depends on the competency of its basic actors, meaning the beneficiaries themselves who are actively involved in the building process. Under this scope, safe, traditional and innovative building technologies should be disseminated to untrained and unskilled (or semi-skilled) people through appropriate channels of information transfer. Whatever the chosen media, the educational and training tools for self-builders should be effective, comprehensible and fully adapted to the needs and requirements of the target users. They should stimulate an active attitude and promote an effective acquisition of knowledge[1].

Figure 5-1 (Aysan et al., 1995) shows the relative impact of different conceptual types of teaching/training in terms of the effectiveness concerning the knowledge acquisition and retention. It becomes clear from this figure that only through a "hands-on" learning procedure,

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[1] *Also see: HYPERTEXT ON MANUALS DESIGN FOR SELF-HELP BUILDING IN DEVELOPING COUNTRIES, at: http://www.forumhabitat.polito.it/manuali/welcom_g.htm. This is part of the project: "TRAINING MANUALS FOR SELF-HELP BUILDING IN DEVELOPING COUNTRIES", conducted by the "Forum: Habitat in Developing Countries". The latter is an Internet resource aiming at providing information to researchers and professionals working for the improvement of the built environment in developing countries, and at facilitating communication among them. The Forum is a research project of the* Dipartimento Interateneo Territorio *and the Library* Territorio Ambiente *(specialized in planning in developing countries) of the* Politecnico di Torino*, Italy, in partnership with the School of Specialization "Technology, Architecture and Town in Developing Countries". The aforementioned project aims at cataloguing and discussing techniques and communication tools (e.g., manuals, videos, games, etc) for self-help building programmes all around the world.*

a high degree of skill and knowledge may be attained. The results are even more pronounced when such as procedure becomes repetitive.
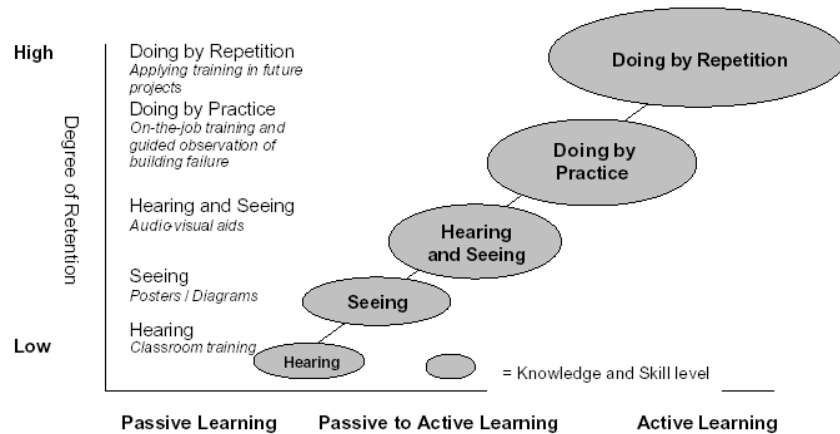
Fig. 5-1 Relative impact of different conceptual types of teaching/training.
(source: Aysan et al., 1995)

Although generally most commonly used, printed materials (in the form of self-construction manuals) are not the only available media for training self-builders. The choice of the most adequate form of communication is dependent on the existing limits and objectives of the work. According to the Forum "Habitat in Developing Countries", when choosing a media, the following points should be considered:

- What is the object of the message?
- How the message can be locally conveyed?
- What are the available alternatives and which of them are compatible with the characteristics of the users?

Examples of dissemination techniques, besides manuals, are given below:

- *Prototypes & mock-ups*: In the case of large-scale housing projects, one or more full-scale model houses (prototypes) are constructed under the guidance and supervision of engineers and/or skilled builders. The future self-builders are trained by participating to the construction phase. After the completion of the prototype(s) these "experienced" builders pass-on their knowledge to the rest of the community. In some cases, simple mock-ups are also used to better visualize the principles of the construction method to be used (Fig. 5-2).

Fig. 5-2   A mock-up of wall to roof connection. [source: Mincks et al. (2001) "*Reforzar y conectar para proteger - Un manual de capacitación para la construcción de casas resistentes a desastres*", published by NAHB and HUD[2]]

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[2] *Available from ToolBase Services, at:*
http://www.toolbase.org/tertiaryT.asp?DocumentID=3074&CategoryID=1624#contact.

▪ *Videos*: This disseminating technique started as an initiative of the UNCHS/HABITAT (United Nations Centre for Human Settlements), in 1979, through the organization of the competition "Habitat Film Script". The scope was for the participants to submit a video that presented a project, based on self-construction and community participation. Since then, many NGOs and professional associations have produced such educational videos[3].

▪ *Cartoons*: This means of communication is very appealing, due to its entertaining character. The risk is to distract the reader from the technical contents of the illustrations. In Fig. 5-3, part of a four-page cartoon-like document published by CERESIS (Centro Regional de Sismología para América del Sur) is shown (the whole document is found in Appendix E), whereas Fig. 5-4 presents one of the best cartoons used for the purposes of a self-construction manual. This is a fairly recent manual ("*La casa de adobe sismorresistente*", 2001), published by two Salvadoran organizations (*Equipo Maíz* and *UNES* Unión Ecológica Salvadoreña - Salvadoran Ecological Union).

Fig. 5-3   Part of the four-pages publication of CERESIS, communicating the need for the reinforcement of adobe houses, based on the recommendations made by the Pontifical Catholic University of Peru. (source: http://www.banmat.org.pe/Terremoto.htm)

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Fig. 5-4 The contents page of the manual "*La casa de adobe sismorresistente*", published in 2001 by the Salvadoran organizations *Equipo Maíz* and *UNES* Unión Ecológica Salvadoreña - Salvadoran Ecological Union·

▪ *Posters*: The most synoptic and (probably) most illustrative way of passing-on printed self-construction guidelines is provided in the form of posters, known as *"Cartillas de autoconstrucción"*. Examples of such posters are the ones produced by SENA (*Cartillas de Autoconstrucción*. 1984, 1990) and by the Brazilian ONG "Tiba" (a 12-drawings' poster showing the fundamental steps to make self-constructed building elements). These illustrations are usually placarded in areas of heavy traffic, such as bus, or train stations.

▪ *Internet*: The information society is currently making possible the dissemination of educational material (of almost any kind) through the use of the World Wide Web[4]. This has also been the case for the free Internet guided courses provided by SENA (Fig. 5-5), the Colombian National Service of Learning (*Servicio Nacional de Aprendizaje*[5]).

Among the "virtual courses" provided, the most interesting one (which is directly related to the construction of private houses), relates to the construction of one- and two-storey earthquake resistant houses according to the Colombian Normative. This course is entitled: "*Construcción de casas sismo-resistentes de 1 y 2 pisos*" and is available on line at: http://www.senamed.edu.co/cursos%20virtuales/construccion/PPALconstruccion.htm.

Other affiliated web sites also host the course in agreement with SENA (e.g. http://www.arquitectuba.com.ar/sismoresistentes.asp: this is the site of ArquitectUBA Online, which is one of the most highly rated portals for Latin American professionals in the construction field).

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[4] *There is a multitude of publications that can be ordered through electronic libraries and other institutes (see Appendix E).*
[5] *SENA is a national public entity with legal status, with its own patrimony and administrative autonomy, ascribed to the Labour and Social Security Ministry of Colombia. It offers and executes integral vocational training for the integration of people to productive activities that contribute to the economic, social and technical development of the country. Visit: http://www.sena.edu.co. In the following figure the "Map of vocational training" is given for Latin America and the Caribbean, displaying national public entities, such as SENA, devoted to public teaching/training (source: http://www.ilo.org/public/english/region/ampro/cinterfor/ifp/index.htm).*

Fig. 5-5   The site of the virtual course "*Construcción de casas sismo-resistentes de 1 y 2 pisos*" provided by the Colombian National Service of Learning – SENA.

The course is addressed to people who already have some knowledge in construction, like engineers, architects, certified construction workers or instructors in the field of self-construction. Apart from basic knowledge of construction practices, the users of the tutorials are expected to have computer skills (such as being able to work with word processors, spreadsheets and programs to navigate in internet). The course includes a series of tutorials in digital format and offers the possibility of personal consultation and support through discussion forums and e-mail-based tutorship. The estimated time for the completion of the course is a trimester and a certificate is provided by SENA provided that an evaluation procedure is undertaken. The latter is done through questionnaires that the students fill-in and submit on-line to the person responsible for the e-course.

It is important to note the limitations of this training method that expects from users to possess some previous experience in construction, to have basic computer skills and have access to an internet connection, all prerequisites that may be hard to find in rural, poor areas.

5.2.1 What is a self-construction manual?

This section discusses the general aspects related to manuals designed for providing technical knowledge to self-help builders during participatory housing projects. These aspects include the definition of the manuals' purpose, the characteristics of the target group (users), contents and appearance among others. Suggestions for the compilation of a successful manual, which may be used as an effective medium of instruction, are proposed.

(a)   The manual's purpose

To constitute an educational tool (most often informal) that can be used by the unskilled/untrained part of the population involved in housing projects (representing the target group). The technical knowledge, disseminated through a manual of this kind, should be

sufficient to capacitate the target group to build safe, permanent dwellings with the support and control of qualified personnel.

(b)   Characteristics of the target group

The characteristics of the users vary through both time and place and should be defined following a socio-economic and cultural survey of the community the manual is addressed to. First of all, the level of risk awareness of the target group has to be identified. It is very common for people to be unaware, or misinformed of the existing dangers that their immediate habitat poses (e.g. liquefiable soil or inappropriate soil for the production of earthen bricks). Therefore, before starting with the training process, a detailed and clear identification of the existing risks should be presented, in order to justify the actions concerned with the proposed construction methods.

Secondly, in order to promote and implement a construction technology without having the risk of rejection or incognizance of the provided solution/material, it is necessary to have a thorough knowledge of the traditional building forms and techniques that a certain society is accustomed to.

Furthermore, as the manual must be, above all, easily understood, the literacy level of the users should be determined prior to selecting the text, the graphics and the general layout. Figures 5-6a and 5-6b illustrate the illiteracy rates worldwide and in selected countries of the Latin America and Caribbean region, respectively. As it can be seen, although the region's mean value of illiteracy rate is around 12%, there exists a great variation from country to country, ranging between 40 and 3%. Finally, as the physical capabilities between different genders and ages have a wide range of variation, the demographic map of the target community should be taken into account.
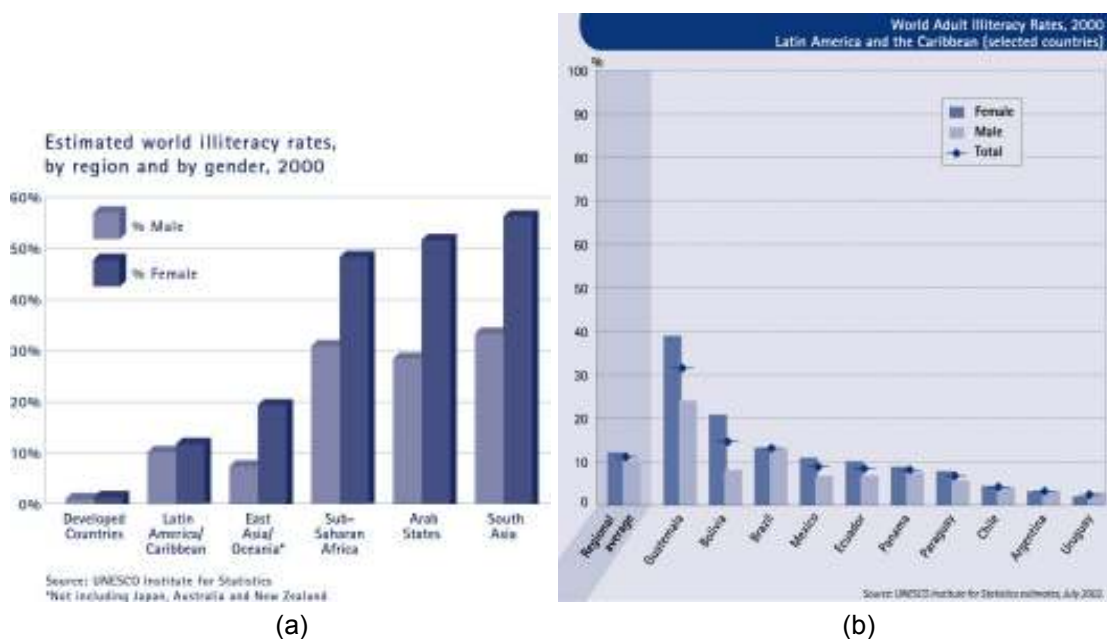
Fig. 5-6   Gender breakdown of illiteracy rates by: (a) World regions; and (b) Selected countries in Latin America and the Caribbean.

(c)   Contents

The type and amount of information included in a self-construction manual depends not only on the kind of building system proposed and promoted, but also on the level of relative pre-existing knowledge, among the users. As previously noted, should a lack of risk awareness be detected, it is important that a basic description of the hazards the community is prone to (in this case, earthquakes), as well as of their consequent effects, are included in the manual. Especially for the case of earthquake occurrence, it is imperative that the target group acquires a fundamental, crude knowledge of the way strong earth motion acts on their houses (see Fig. 5-7).

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¿ QUE SON LOS TERREMOTOS ?

(a)

SENA
Programa de Reconstrucción

(b)

(c)
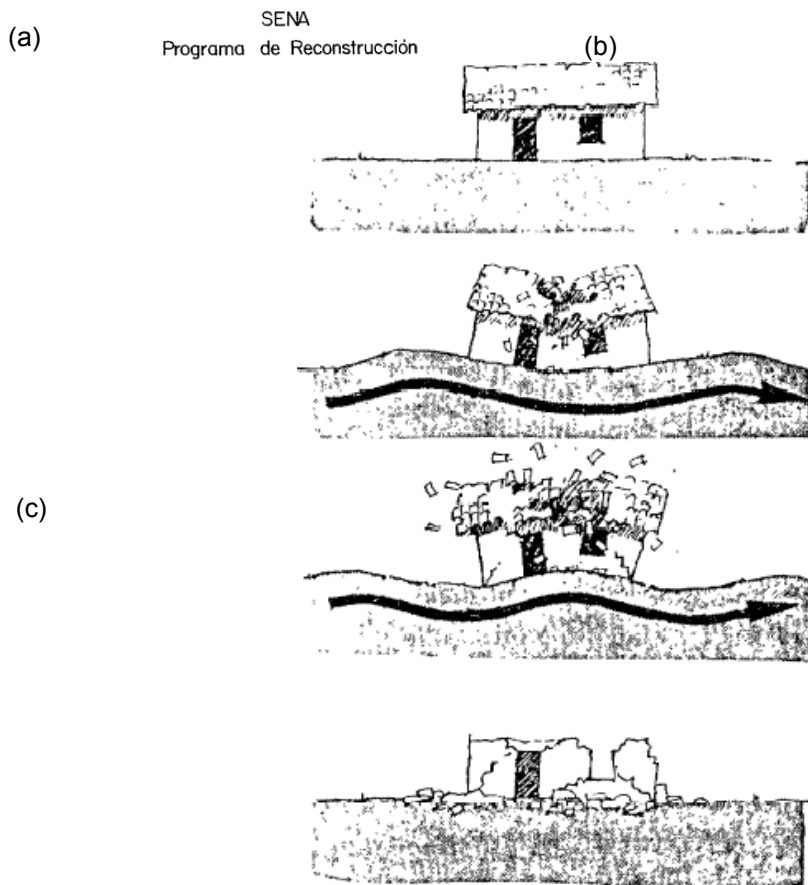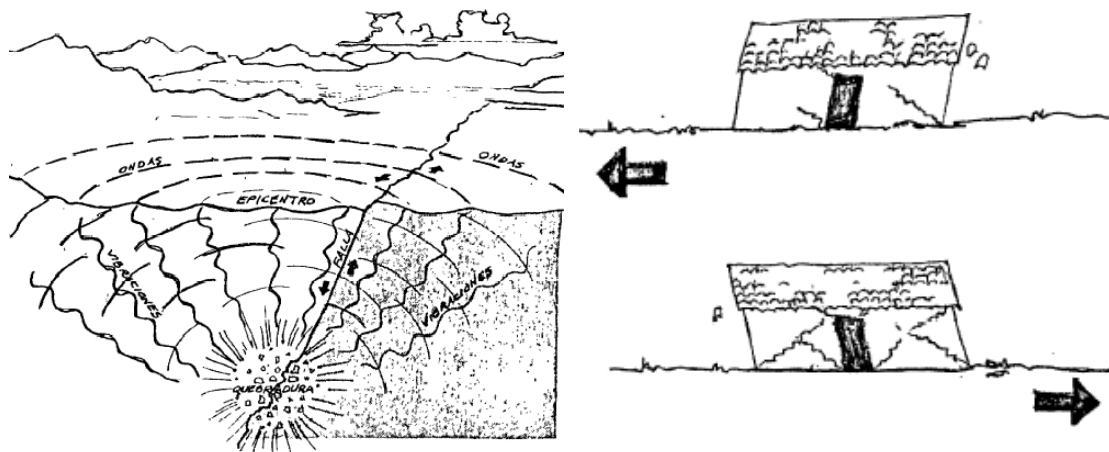
Fig. 5-7 Graphical explanation of: (a) Earthquake generation; (b) & (c) Earthquakes' effects on houses. (source: "*Construcciones sismo-resistentes: Manual para instructores*", *SENA - Servicio Nacional de Aprendizaje*, Colombia 1983)

The introductory part of several manuals contains recommendations relative to the location of the house, such as the ones given in Fig. 5-8, and information about the expected cost per housing unit. It is very important for people to be convinced, in the initial stages of the self-construction project, that building safer dwellings does not entail excessive additional costs.

Evite construir en zonas bajas

Evite zonas altas sin protección del viento

Evite terreno suelto o relleno

Evite construir en barrancas

Evite pendientes donde hay peligro de derrumbes

Evite construir cerca del mar o de un río
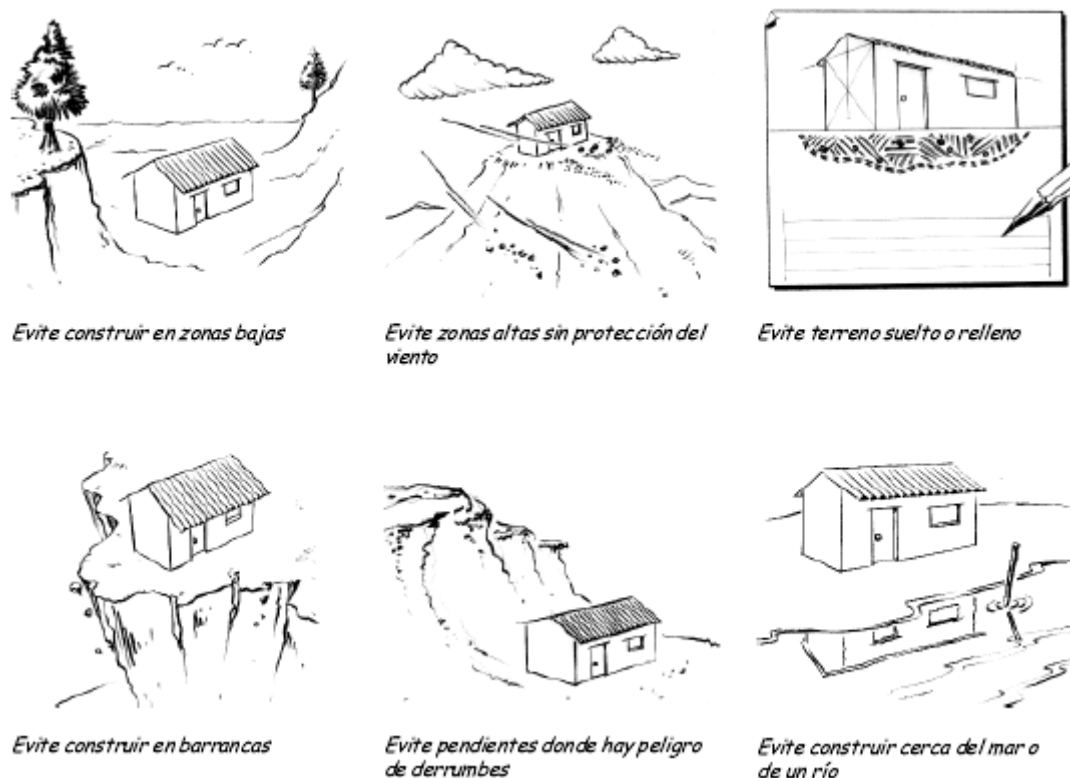
Fig. 5-8   Annotated sketches indicating the "Don't"s in selecting a building site. (source: Mincks et al., 2001, "*Reforzar y conectar para proteger - Un manual de capacitación para la construcción de casas resistentes a desastres*", published by NAHB and HUD)

After having dealt with the selection of the building site, most manuals introduce the participants to the principles of safe (i.e. earthquake-resistant) structural configuration, in terms of geometry (dimensions and general layout) and uniformity (consistency of the materials used and stiffness distribution). It is important for the self-builders to understand that regularity and symmetry, both in plan and in elevation, constitute the most decisive factors of seismic performance of their houses.

Additionally, as it is very common for most families to follow an incremental construction process (adding new parts to the "core" house, when their income improves, see Chapter 1), it is important to emphasize the vertical continuity of columns or load-bearing walls from the foundations up to the roof, with no interruptions or changes in the materials used. The manuals should also stress the importance of limiting the size and number of openings. Such points are successfully illustrated in Fig. 5-9.

The following parts of the manuals introduce the participants to the construction materials and the structural units (should there be any) used in the building process. For instance, in projects for the construction of adobe houses, practical means of assessing the soil properties (Fig. 5-10) and proper ways of producing adobe blocks (Fig. 5-11) are presented. In case concrete is used, mix proportions and right mixing methods are provided, the mix composition depending on the type of structural member to be cast. Regarding this point, it is essential to provide the most comprehensible and practical methodologies and measuring units. Relative volume quantities are generally used, as shown in Fig. 5-12. It is important to adopt local measuring units and to depict materials as they are available on the market (for instance, the quantities of cement are best denoted by the number of cement bags). A presentation of the necessary tools is often included, in conjunction with the building materials used in the construction (Fig. 5-13).
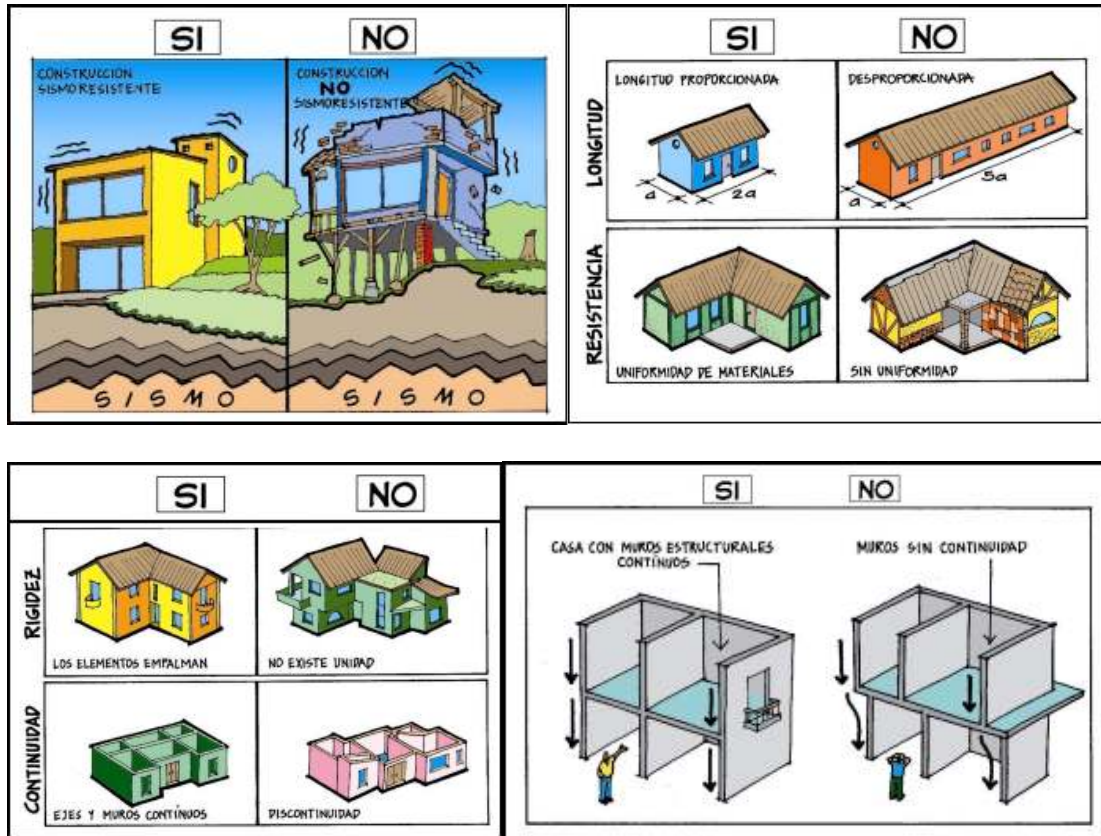
Fig. 5-9 Illustrations of "wrong" and "correct" structural configurations. (source: "*Manual de Construcción, Evaluación y Rehabilitación sismo resistente de viviendas de mampostería*", *La Red de Estudios Sociales en prevención de desastres en América Latina, Asociación Colombiana de Ingeniería Sísmica – AIS*, 2001)
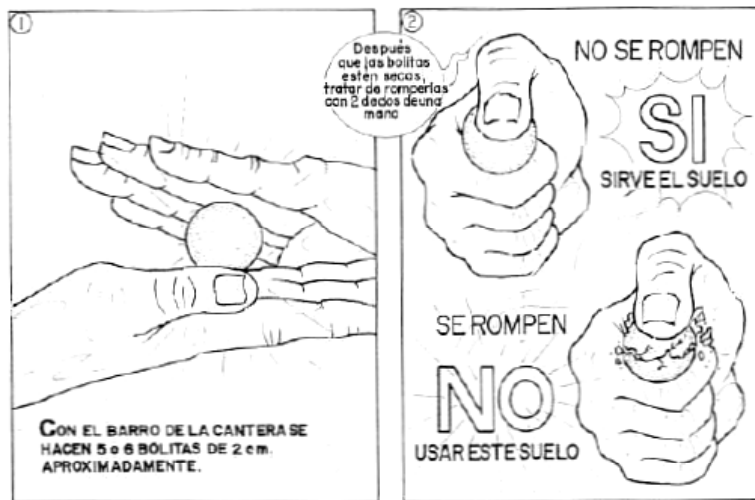
Fig. 5-10 Practical method of assessing the suitability of the soil composition for the construction of adobe blocks. (source: "*Nuevas Casas Resistentes De Adobe*", *Pontificia Universidad Católica del Perú – PUCP* and *Centro Internacional de Investigación Para el Desarrollo - CIID*, Lima, Perú)

En el piso que hemos elegido ponemos la adobera previamente
mojada y rociada con arena fina por dentro
para que el barro no se pegue.

Para que los adobes no se rajen por el calor del sol...

* Formamos una bola de barro
y la tiramos con fuerza!

* Se cubren con paja o plástico.

* Luego apisonamos
con el pie para compactar
el barro.

* Después de 5 días
raspamos los adobes
y los ponemos de costado.

* Y emparejamos con una
regla de madera.

* Luego retiramos la adobera
con cuidado para que el adobe
recién hecho no se deforme.

* Para guardarlos los apilamos
de esta manera unos 20 días.

Fig. 5-11   The recommended method of producing adobe blocks in step-by-step drawings.
(source: "*Terremoto?... ¡Mi casa si resiste! - Manual de construcción para viviendas sismo resistentes en adobe*", CTAR/COPASA, GTZ, PUCP, SENCICO, 2nd Edition, Arequipa, Perú, 2002)

Dosificación del Concreto

Elementos	Cemento	Arena lavada	Grava
Bases	1 parte	2 partes	2 ½ partes
Columnas y Vigas	1 parte	2 partes	2 partes
Pisos	1 parte	2 partes	3 partes
Dinteles	1 parte	2 partes	3 partes

Fig. 5-12   Concrete mix compositions, according to the type of the structural member. The materials' quantities are given in "parts", where a "part" is considered to be a reference volume, consistently used for every measurement throughout the project (such as a bucket, a jar or a box). (source: "*Manual de Construcción, Evaluación y Rehabilitación sismo resistente de viviendas de mampostería*", *La Red de Estudios Sociales en prevención de desastres en América Latina* (2001), *Asociación Colombiana de Ingeniería Sísmica – AIS*)
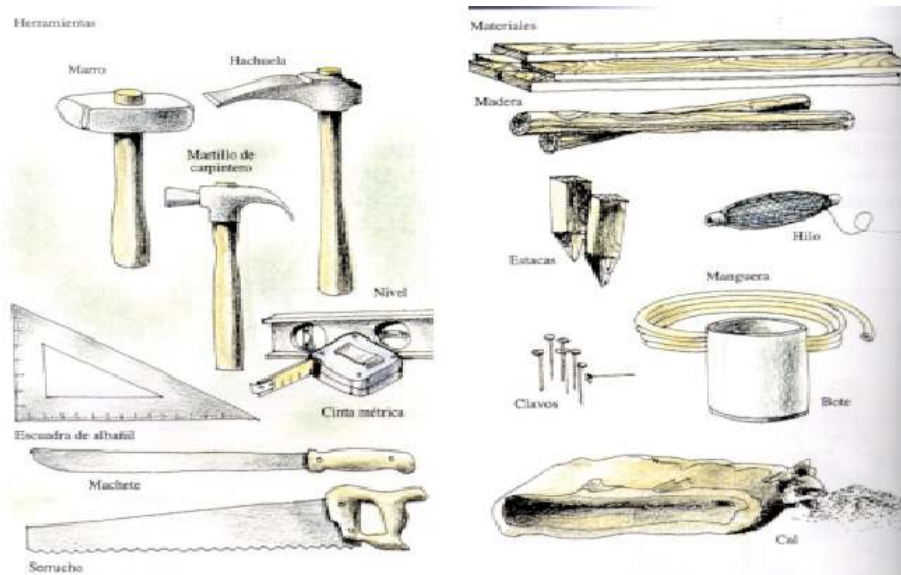
Fig. 5-13 Tools needed for the preliminary works preceding the construction of foundations.
(source: José de Jesús Saldaña Guerra, "*MANOS A LA OBRA / MANUAL DE AUTOCOSTRUCCIÓN*",
Instituto Mexicano del Cemento y del Concreto - IMCYC, México, 1999)

Many self-construction manuals dedicate an important part to the initial works, which are basic for the erection of a house, such as cleaning and alignment of the land, and marking of the excavation lines and the position of the walls. After having dealt with these issues, the construction phases are thoroughly explained, from the foundation level to the top of the house. According to the length of the manual, other instructions might be included, such as how to adjust doors and windows, build the stairs, set-up of hydraulic and electrical facilities and how to proceed with the final finishes of the walls and the roof, emphasizing the need for protection, durability and future maintenance of the finished house.

It is important to note that users may be intimidated by long manuals. Therefore, the information has to be given in the most compact way possible. The bibliographical survey, realized within the framework of the INFRAID project, revealed the existence of self-construction manuals as bulky as 464 pages long (see: José de Jesús Saldaña Guerra, "*Manos a la obra / Manual de autoconstrucción*", *IMCYC* INSTITUTO MEXICANO DEL CEMENTO Y DEL CONCRETO, México, 1999) and as "telegraphic" as 25 pages long (see: Morales Morales, et al., "*Manual para la construcción de viviendas de adobe*", 2nd Edition, eds.: Campos Siguenza A. and Vásquez Huamaní O, CISMID-FIC-UNI, Lima, Perú, 1993).

(d)   Appearance

It is evident that the manual's layout strongly influences the way its users respond to it. In this sense, text and graphics have to be carefully selected during the designing phase of the manual.

- *Text*: In order for a manual to be as practical as possible, the text should be restricted to the most essential information (usually annotating a figure). The language used should conform to the local language and idiom, the vocabulary should be colloquial and the sentences short. The use of technical terms should be generally avoided; if not possible, they should be explained in the text or in a glossary annexed to the manual.

  The text flow should be organized in a in a hierarchical order, following the steps of the building process. It is advisable to arrange the text in short paragraphs, adequately spaced, so that the reader can easily access the specific information he/she is seeking, without getting confused. The selected format of the text, such as the fonts used (font type, size and colour) plays an important role to the communicability of the written message. According to the Forum "Habitat in Developing Countries", handwritten fonts, which are somehow less technical and may be more attractive, can nevertheless, be more difficult to read, especially by people with low-literacy levels.

- *Graphics*: For an engineer to be able to design a self-construction manual, he/she has to detach himself/herself from their professional perspective and try to look upon the housing unit and its construction process from the point of view of an untrained person. Under this perspective, architectural drawings (plan, prospects and sections), as well as standard graphic conventions, are very unlikely to be understood and, therefore, they should either be avoided or explained through a preliminary training. In any other case, the self-builders may subconsciously interrelate the construction of a safe, seismic-resistant house, to complex and "high-tech" procedures.

  From an educational point of view, it is very efficient to transfer information in a "Do" and "Don't" type of figures, such as those shown in Figs. 5-9 and 5-10. In this way, the project participants can easily identify the construction flaws of past practices. Photographs and three-dimensional figures greatly enhance the understanding of height and depth, providing that artistic features (shading, colour, etc.) do not work in expense of the technical ones. Finally, if safety instructions are not explicitly given in the text, the figures must implicitly urge the users to apply safety measures, when necessary (see Fig. 5-14).

Fig. 5-14 Overhead ceiling plastering. Notice the use of goggles. (source: José de Jesús Saldaña Guerra, "*MANOS A LA OBRA / MANUAL DE AUTOCOSTRUCCIÓN*", *Instituto Mexicano del Cemento y del Concreto - IMCYC*, México, 1999)

Concluding this part of the chapter, it should be emphasized that a manual alone cannot constitute a self-standing educational tool for enabling untrained people to build their own houses. The information included in the manual has to be communicated through personal tutoring and guidance.

5.3   Manuals for earth-based dwellings

5.3.1 Adobe construction

(a)   Self-construction manuals

In this section, several self-construction manuals concerning adobe dwellings are listed following a chronological order, according to the date of their publication. The manuals on which information was available are briefly commented in regard to both their contents and their communication style.

- Ministerio de Vivienda y Construcción (1976) "Construyendo con adobe", INIAVI Instituto de Investigación para la Acción en Vivienda, Lima, Perú.

- Caritas de Guatemala (1976) "Manual para la construcción de viviendas con adobe".
  The production of this manual was part of a project financed by UN following the devastating effects of the earthquake in Peru, in 1970. The purpose of the project was to

investigate the reasons that lead to the collapse of thousands of adobe dwellings. According to the findings of the project, it was the lack of knowledge of basic construction principles and the deficient workmanship that comprised the most important causes of structural failure. The manual published within the framework of this project aimed at improving the observed deficiencies through the dissemination of appropriate building techniques for adobe dwellings. According to Kurt Rhyner[6], this manual has been used as the main reference literature for many non-governmental organizations that were in charge of collaborative housing projects in various countries, such as El Salvador, Honduras, Nicaragua, Cuba, Ecuador and Dominican Republic.

- SENA Servicio Nacional de Aprendizaje and INTERTECT – Especialistas internacionales en reconstrucción (1983) "Construcciones sismo-resistentes: Manual para instructores - Sección 10: Cómo reparar una casa de adobe", Popayán, Colombia.
  [Available online at: http://www.crid.or.cr/crid/CD_Asentamientos_Humanos/pdf/spa/doc7685/doc7685.htm]

This manual was created within the framework of the self-construction project, undertaken by SENA, after the 1983 earthquake in Popayán. Its purpose was to serve as an educational tool for the "construction and social promotion instructors" (*instructores de construcción y promoción social*), whose task was to teach to the local population how to construct safer houses and to repair the damaged ones.

The manual consists of ten thematic parts, namely: (1) What are earthquakes?; (2) In what way does an earthquake affect a house?; (3) Principles of seismic-resistant construction; (4) How to construct a masonry house (confined by reinforced concrete elements); (5) Typical damages (of masonry houses); (6) How to inspect and evaluate a house damaged by an earthquake; (7) Questionnaire for the damage evaluation; (8) How to repair a masonry house; (9) How to repair an adobe house; and (10) How to repair typical damages.

In communicating the available information, more emphasis was given to the visualization of the instructions than to the text itself, as can be seen in Fig. 5-15. In the introductory note of the manual it is stressed that the learning process should consist of several instructing sessions and that any construction work should take place with the supervision of a technically qualified person.

For adobe structures, the recommended steps for their rehabilitation are presented in a series of briefly annotated figures (ten pages):
- First, the house is inspected (according to the procedure described in a previous part of the manual), the damage is identified (as structural, or non-structural) and the damaged areas to be repaired are marked.
- Then, the roof is disassembled (tiles, canes and timber beams/rafters) and the gables are demolished, along with the top parts of the walls.
- Adobe bricks adjacent to the marked damaged areas are removed (the ones that are cracked or distorted are rejected) and these spots are reconstructed.
- A wooden collar beam is placed at the top of the walls and is braced by diagonal wooden elements at the corners.
- Steel wire mesh jacketing is applied on top (horizontally) and on each side (vertically) of every corner, encasing the collar beam and the walls (the mesh is pinned on the walls with nails or rivets) and the walls are plastered.
- The gables (previously formed by adobe bricks) are replaced by wooden trusses and foils of lamina are placed on a simple roof supporting system.

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[6] *See: http://www.ecosur.org/eng/archivo/adobe_baja_verapaz.php.*

COLOQUE MALLA

ASEGURE LA MALLA AL MURO CON GRAPAS O CLAVOS Y REPELLE.
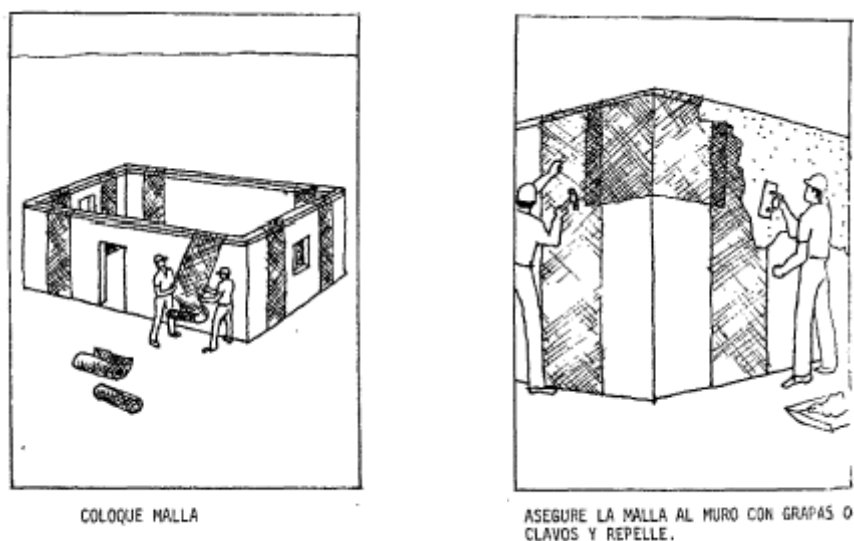
Fig. 5-15 Application of the steel wire mesh.

■ PUCP Pontificia Universidad Católica del Perú /CIID Centro Internacional de Investigación Para el Desarrollo "Nuevas Casas Resistentes De Adobe", ■■■a, Perú.
[Available online at: http://www.world-housing.net/Tutorials/AdobeTutorial/Reference_13.pdf]

The date of publication of this manual is unknown, but it is safe to assume that it was on this document that many later ones were based upon. This material was prepared from the Pontifical Catholic University of Peru and the International Research Centre by Development. The construction system that is described is the bamboo reinforced adobe masonry. Step-by-step well-illustrated instructions, accompanied by short explanatory text, are provided for the assessment of the soil suitability (for both the adobes' fabrication and the mortar mixing), for the right proportioning of the earthen mixture and for the fabrication of the moulds and adobe bricks.

The construction of the foundations and the footings is then presented, the latter formed with no-fines concrete. The walls' reinforcement is both vertical and horizontal. Detailed figures are provided for the proper erection of the walls (in these guidelines, the encasement of the vertical reinforcement is not achieved by adobe bricks of special configuration, i.e. grooved ones). The horizontal reinforcement is applied every fourth course of adobe bricks. At the top level of the walls, a collar beam is constructed with the use of timber beams placed at the inner and outer side of the walls, interconnected by transversal wooden sticks, while the space between them is filled with mortar.

One of the two walls, parallel to the largest dimension of the house, is built higher than the other, forming a continuous gable for the single-pitched roof, which is formed by canes nailed on timber beams. The canes are plastered with straw-reinforced earthen mortar and flat tiles are put in place (using cement mortar to hold them together). The walls are then reinforced using steel wire and held in place by small plates, which in turn are nailed on the walls in every third brick course (see Fig. 5-16). It should be noted that the evolution of this external reinforcement system lead to the use of readily available electric-welded steel wire mesh. Finally, the walls are plastered. The manual concludes with brief instructions on the finishing of the floors (installations and levelling) and with two alternative house plans.
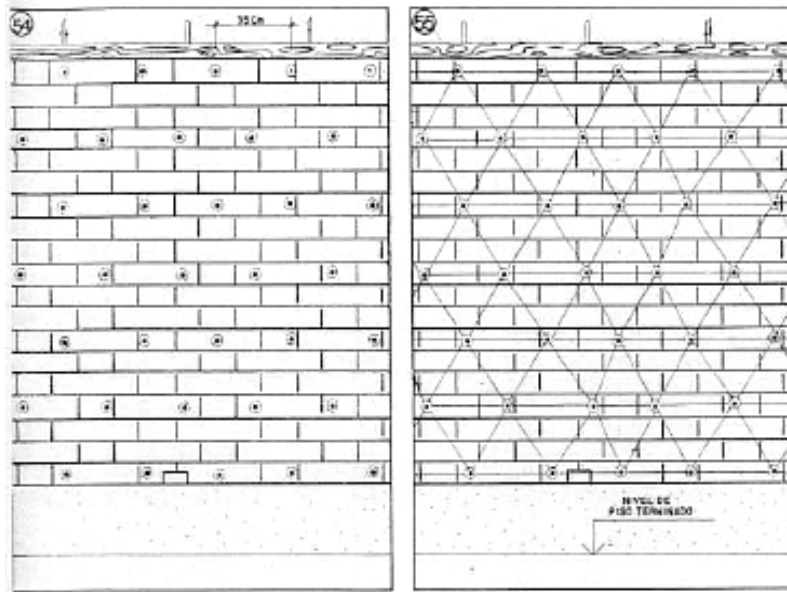
Fig. 5-16 Application of the steel wire on the walls following a rhomboid pattern.

Oshiro Higa, F. (1990) "El Adobe estabilizado - Construcción de una vivienda económica en adobe estabilizado", Serie: Técnicas Constructivas, Manual de Apoyo No.2, 30 p., PREDES Centro de Estudios y Prevención de Desastres (ed.), Lima, Perú.

[Available online at:
http://www.crid.or.cr/crid/CD_Asentamientos_Humanos/pdf/spa/doc158/doc158-contenido.pdf]

This manual is part of a publications' series, entitled "Construction Techniques", published by the Peruvian Centre of Studies & Prevention of Disasters (PREDES). It is addressed to builders/masons, as well as to architects and engineers, but it is not strictly considered by its publishers as a "recipe-type" manual. The proposed innovation in this manual is to use cement-stabilized earth for both the adobe blocks and the mortar (see Chapter 2). The construction method is applicable to one storey houses, with the key structural elements being: (1) adequately deep foundations (according to the soil type), (2) wall pilasters, (3) a wooden collar beam connecting the roof to the walls; and (4) a properly constructed wooden roof (see Fig. 5-17).

(a)

(b)

(c)   (d)
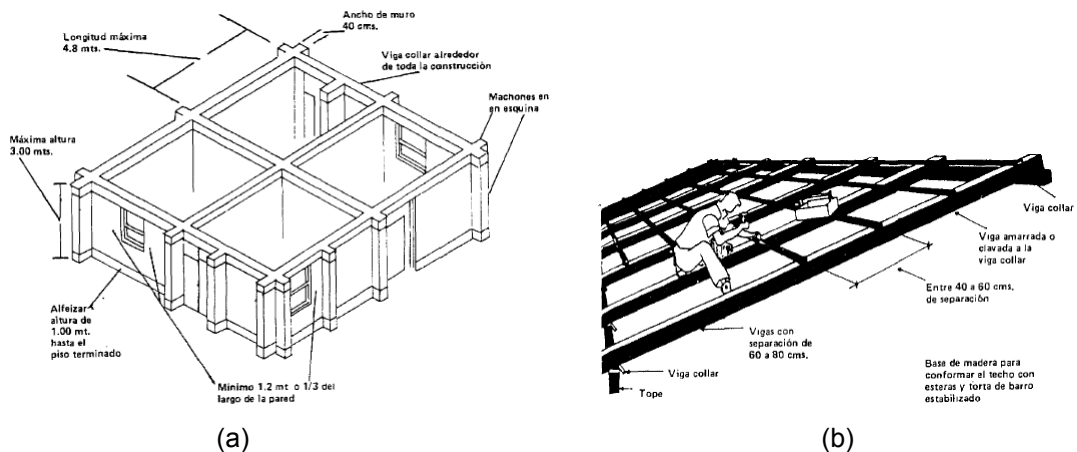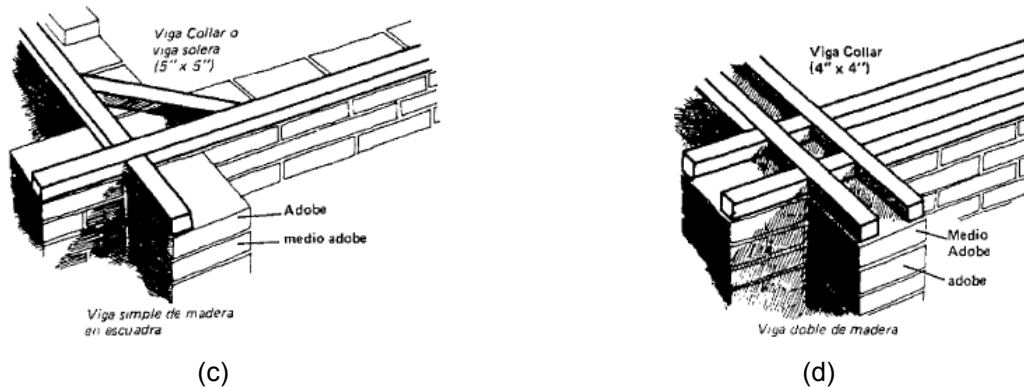
Fig. 5-17   Graphics from the manual "*El Adobe estabilizado - Construcción de una vivienda económica en adobe estabilizado*", illustrating: (a) the general plan layout; (b) the roof; and (c) & (d) alternative construction methods for the collar beam.

Recommendations are given for the making of the adobe blocks (including mix proportions) and for the construction of the walls (such as leveling, course laying types, etc.). A very interesting feature is the reporting of the most common mistakes in adobe construction, given in combination with the corresponding recommended practices. Finally, the manual cannot be characterized as a "step-by-step" set of recommendations, while prior knowledge in construction is rather a prerequisite.

- Morales Morales, R.; Torres Cabrejos, R.; Rengifo, A.L. and Irala Candiotti, C. (1993) "Manual para la construcción de viviendas de adobe", p. 25, 2nd Edition, Campos Siguenza, A. and Vásquez Huamaní, O. (eds.: CISMID Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres and FIC-UNI Facultad de Ingeniería Civil del Universidad Nacional de Ingeniería), L Perú.

[Available online at: http://cidbimena.desastres.hn/pdf/spa/doc12966/doc12966-contenido.pdf]

This manual summarizes the results of the research conducted by the Civil engineering Department of the National Engineering University of Peru, aiming at the improvement of traditional adobe construction techniques. This research was supported by the Ministry of Housing, through the National Institute of Research and Normalization for the Housing Sector (*Instituto Nacional de Investigación y Normalización de la Vivienda – ININVI*), the International Agency for Development (*Agencia Internacional de Desarrollo – AID*) and the Japanese Government, through the Building Research Institute – BRI.

During the years 1970-1978 an extensive experimental project on the seismic performance assessment of single-storey adobe buildings was carried out at FIC-UNI, setting-up the bases of recommendations, which through the 1985 and the 1993 publications, were meant to be disseminated to a large part of the population.

The manual starts by listing the principal causes of the most common failures observed in adobe structures. Terms like "flexure" and "tension", used to explain the different failure mechanisms, may not be well understood by self-builders. Yet, other figures that are more explanatory indicate all the major structural deficiencies of adobe houses.

Recommendations related to the selection process of the most suitable soil for the fabrication of adobe blocks (practical field tests, as well as earth stabilization methods, e.g. with asphalt, cement or lime), as well as an elaborate description of the proper way to fabricate adobe blocks is then presented (dimensions, mixture proportions, molding, curing, storing and quality control).

The manual tangles next with general construction aspects, such as the selection and the preparation of the proper building site. Recommendations for the construction of the foundations and footings are given next, while it is suggested that a small trench is also dug underneath the roof's edge in order to collect rainwater. With respect to the construction of walls and as far as dimensioning is concerned (compare with the relevant recommendations of IAEE's Committee on Non-engineered buildings, presented in a

following section of this chapter), the manual recommends the following: $\ell \leq 10t$; $h \leq min(8t, 3m)$; the width of an opening should not exceed 1.20 m; the sum of the widths of the openings of a wall should not exceed one third of the total wall's length; the distance between an outside corner and the opening should be no less than $min(3t, 0.90m)$; the bearing length (embedment) of lintels on each side of an opening should not be less than 0.4 m, where ℓ is the length of the wall between two consecutive walls at right angles to it, t is the wall's thickness and h is the wall's height.

The reinforcement of the walls is presented in a following section of the manual. The use of horizontal and/or vertical cane (mature and dry) reinforcement is recommended. The horizontal reinforcement should be placed at (maximum) every fourth course of adobe bricks; these reinforced courses should coincide with the upper and lower bands of openings, which should be further reinforced with lintels. The vertical reinforcement runs along the height of the wall in grooves formed by the alignment of adobe bricks of special geometry (having semicircular indentations at opposite ends). Provision should be taken at the construction phase of the foundation, so that the vertical canes are embedded in it. The canes should also be tied to the collar beam. For the construction of the latter, many alternatives are provided (using natural timber, sawn or semi-processed wood, reinforced concrete, see Fig. 5-18).

For the proper erection of walls, the manual illustrates how the adobe bricks should be laid at corners and at T-sections (mid-length intersections of walls), according to whether the blocks are rectangular or square (which are preferred, according to the authors of the manual). Both horizontal and vertical joints (formed by straw-reinforced earth mortar) should not exceed 20 mm in thickness, whereas the vertical joints should not be continuous. The construction of pilasters at walls' intersections is strongly advised.

Single or double-pitched roofs are recommended, having slopes between 15 and 30 per cent and overhanging from the walls for at least half a metre. The roof system consists of canes nailed on rafters, which in turn are supported on the bottom of the collar beam and at the top of the roof beam (for a double-pitched roof). The canes are covered by straw-reinforced earth mortar (covered with tiles or asphalt-stabilized in case of humid areas). Plastering alternatives are listed next, and the manual concludes with a figure summarizing basic recommendations (this figure can be easily compared to the one provided at the beginning of the manual, depicting the most common structural flaws).

TRONCOS DE 4" DE DIAMETRO

MADERA RUSTICA SEMILABRADA

SECCION 8"x 4"

MADERA ASERRADA

MADERA RUSTICA SEMILABRADA CON DIAGONALES COMO REFUERZO DE ESQUINAS

CONCRETO ARMADO
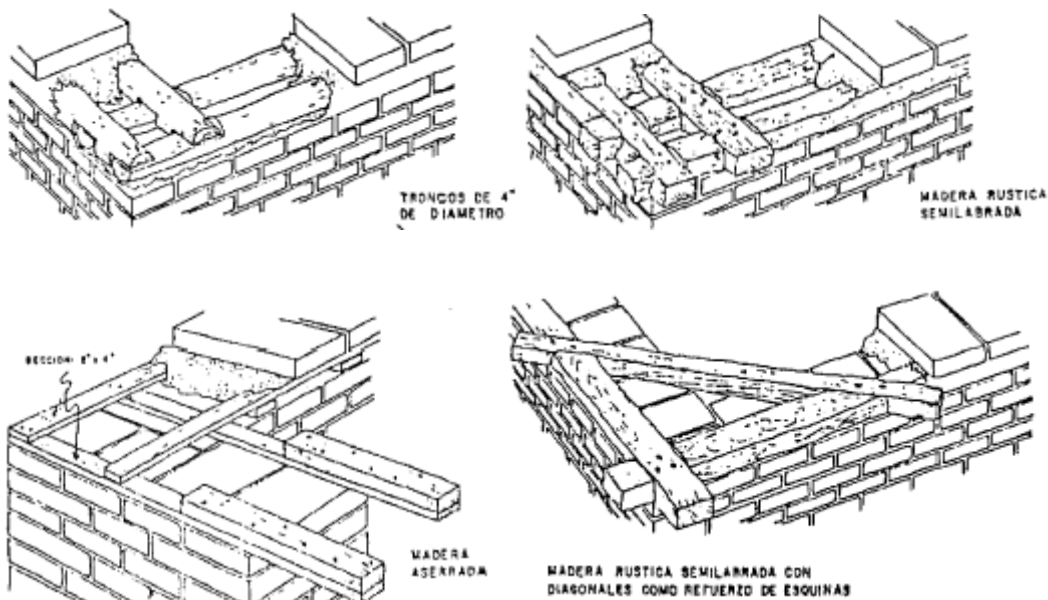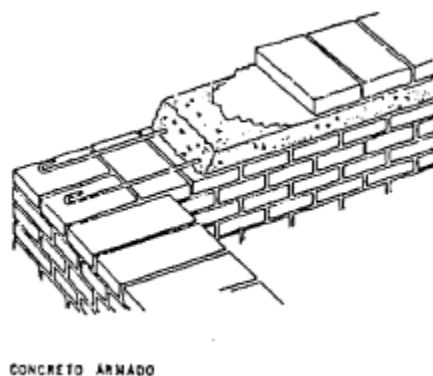
Fig. 5-18 Configuration alternatives for the construction of the collar beam.

- Castillo, A.; Chaparro, L.; Hidalgo, B. and Dunia Vela, T.S.U. (1994) "Así se construyen las viviendas en los Arangues", Línea de investigación: "La vivienda en la arquitectura Venezolana desde sus orígenes, en función de planteamientos de tecnología alternativa", p. 80, Ediciones Nuestro Taller, CINVIV Centro de Investigación de la Vivienda, FAULA Facultad de Arquitectura de la Universidad de los Andes, Mérida, Venezuela.

This manual was created by the Venezuelan Centre for housing research (CINVIV) and the Faculty of Architecture of the University of the Andes, in Mérida, Venezuela, under the auspices of the Foundation of Popular Housing (*FVP Fundación de la Vivienda Popular*), and addresses the educational purposes of a collaborative housing project in the rural area of Arangues. Emphasis was placed in transferring the information through images and drawings, while the text was limited to the commentaries of figures describing the step-by-step processes needed for each construction phase.

The construction system that is described in the manual corresponds to adobe. A brief introduction about practical field tests to assess the properties of the available soil and the preparation of the moulds to produce the adobe bricks is given. An interesting feature of the manual is the apportionment of the different construction steps to the different actors of the self-construction project (i.e. the responsibility of different construction works may be appointed to either qualified technicians, families, or the whole community, depending on the degree of difficulty of the task and expertise needed).

The instructions that present the different phases for constructing an adobe house start by presenting a list of necessary tools and a description on the manufacturing process of adobe blocks (both simple and pressed). The construction of the foundations and footings is then presented (one figure per page – generally big and not very detailed), followed by the wall erection process and the roof configuration (reeds on wooden beams, covered by straw-reinforced earth mortar). Instructions for the electrical and plumbing installations are given, along with a guide on how to build an exterior latrine. Finally, plans of a typical house are provided, as well as three cardboard pages with ready-to-cut peaces for putting together a maquette of the proposed house.

- DIB/SAHB (1995) "Manual para autoconstructores Lak'a Uta", Servicio de Asentamientos Sostenibles en Bolivia / Danish International Human Settlement Service – DIB.

This manual was produced within the scopes of the "Lak'a Uta" project[7], carried out in Bolivia. This self-construction project was implemented in Lahuachaca, a small village

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[7] *In the local* Aymara *language* "Lak'a Uta" *means "Houses of Earth". The* Lak'a Uta *concept is innovative due to the use of a parabola shaped self-supporting vault made of earth blocks (adobes). DIB is deeply involved in Latin America through the* Lak'a Uta *project in Bolivia. A relevant interesting publication of DIB is: "Building with Earth - the Nubian Arch and the Parabola House", elaborating on the*

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located on the *Altiplano* (a 4,000 meter high plateau), and aimed at creating low-cost, comfortable, health-conscious housing with minimal impact on the environment by making the best of use of natural resources. The project was characterized by the regeneration of indigenous techniques, such as the use of sun-dried adobe bricks and plaster containing donkey excreta and cactus broth, which have been produced in the Andes for thousands of years. Additional features of the project were the training of local population without technical knowledge in do-it-yourself construction techniques and the financing of low-income households using micro-credit schemes.

▪ SENCICO Servicio Nacional de Normalización, Capacitación e Investigación para la Industria de la Construcción [8] (1997) "Manual de autoconstrucción: Adobe", Lima, Perú[9].

▪ Hadzich, M. (1999) "Vivienda antisísmica de adobe: Manual de construcción", Serie: La casa ecológica, n. 1, PUCP, Lima, ISBN: 9972-42-155-4[10]

This manual is comprised of step-by-step instructions for the construction of a seismic-resistant adobe house reinforced by bamboo stems. The construction method corresponds to the one developed by the Pontifical Catholic University of Peru (PUCP) and accounts for a 78 m^2 dwelling with two rooms, which can be extended to four rooms.

▪ Cavada Diez, M. et al. (2001) "La casa de adobe sismorresistente", Equipo Maíz and UNES Unión Ecológica Salvadoreña (eds.), p. 84, San Salvador, El Salvador. [Available online at: http://www.unes.org.sv/unes/La%20Casa%20de%20Adobe%20Sismoresistente.zip]

This manual was compiled after the 2001 earthquakes in El Salvador, after an initiative undertaken by the non-governmental Organization *Equipo Maíz* and the Salvadoran Ecological Union – UNES. In the introduction, it is stated that those who want to build their houses following the recommendations given in this manual should consult with an experienced builder. It is thus assumed that the manual was not *per se* published within the framework of a specific housing project, although it may be used for self-construction purposes. It is interesting to note that prior to discussing construction issues, the authors of the manual express some positions of political nature, such as:

- The occurrence of disasters is not the main cause for the high number of human life losses, but rather, the deficiencies that characterize man-made structures. By adopting proper construction methods a drastic reduction of death tolls may be achieved

- The reconstruction process should be a turning point for the country, enabling the population to fight poverty, social injustice and all those factors that contribute to physical, social and economic vulnerability. Temporary shelters made with scrap materials (laminas and plastic parts) should not be considered as housing solutions and reconstruction should provide new job opportunities for the unemployed.

The text continues with the argument that people should build with adobe (following specific construction instructions), despite many concerns expressed against this construction system (it is even expressed that the cement companies, for their own financial profit, promote cement-based construction methods).

The advantages and disadvantages of building with adobe blocks are presented and it is emphasized that much research has been focused on the improvement of traditional earth-based construction techniques (the CRATerre institute is referenced), in order to restore people's faith in adobe.

The actual construction recommendations are presented from page 25 onwards, starting with the structural deficiencies observed in many adobe houses, remonstrated by structural features of good practice. Next, the construction of adobe bricks (as well as of the cement-stabilized type) is described (in the most complete and step-by-step way), giving special attention to the selection of the appropriate soil type and mix proportions.

In the next part of the manual, the construction method is (also very elaborately) described, accounting for the bamboo-reinforced (both vertically and horizontally) adobe masonry system, with pilasters and collar beam (apparently following the suggestions made by the Pontifical Catholic University of Peru – see Fig. 5-19). The manual concludes with brief instructions for the roof construction and plastering of the walls.

(a)

(b)

(c)

(d)
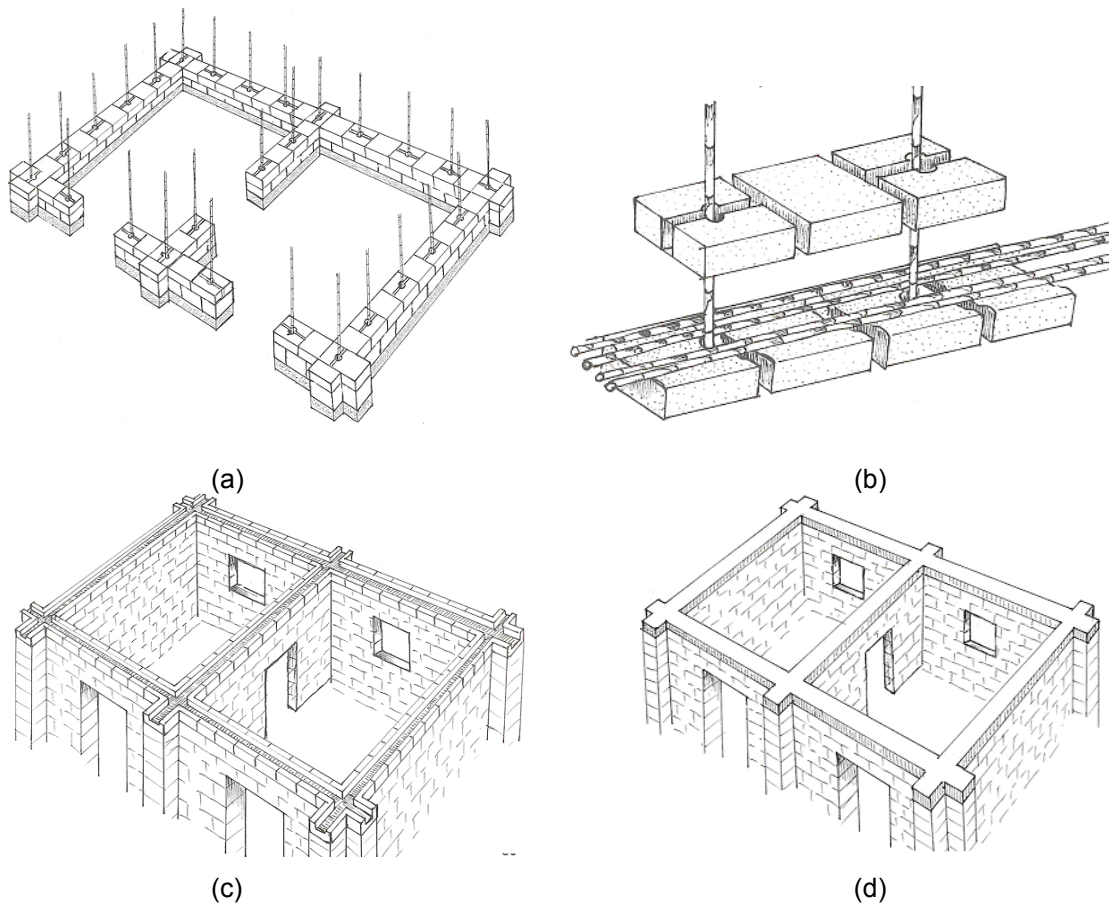
Fig. 5-19 Graphics from the manual "*La casa de adobe sismorresistente*", illustrating: (a) the layout of foundation, footing and first course of adobe bricks; (b) the vertical and horizontal reinforcement; and (c) & (d) the collar beam.

■ GTZ Gesellschaft für Technische Zusammenarbeit, PUCP Pontificia Universidad Católica del Perú –and SENSICO Servicio Nacional de Normalización, Capacitación e Investigación para la Industria de la Construcción (2002) "Terremoto?...Ì Mi casa si resiste! – Manual de construcción para viviendas sismo resistentes en adobe", p. 49, 2nd Edition.

[Available online at: http://www.world-housing.net/Tutorials/AdobeTutorial/Reference_5.pdf]

This is a publication within the CTAR/COPASA project, following the earthquake of 23 June, 2001 in Peru and aims at capacitating local artisans/masons (of the Arequipa district) to reconstruct the damaged and destroyed houses in collaboration with the beneficiaries and under the supervision of the project's technical team. The manual incorporates most of the features that render a publication of this type a very successful educational tool. As far as the format is concerned, the manual is very user-friendly, with many easy-to-understand graphics (elegantly designed and adequately spaced), the text is limited to explanatory captions adjacent to the provided figures, the vocabulary is colloquial and the total length of the manual (49 pocket-size pages) does not intimidate the user.

The described construction system is an improvement of the traditional Peruvian adobe houses, the proposed seismic-resistant features being the result of extensive research conducted by the Pontifical Catholic University of Peru, in the field of seismic performance and strengthening of adobe structures. This fact is referenced at the beginning of the manual, fortifying the participants' confidence in the proposed interventions, which are the reinforcement of the walls (and their intersections) with electric-welded steel wire mesh and the use of a reinforced concrete collar beam.

The manual follows a step-by-step instruction procedure, beginning with the most common flaws/mistakes in constructing an adobe house (from its placement, to the bad quality of adobe blocks) and concludes with the construction of windows, doors, floors and terraces (giving special consideration to the presence of humidity barriers). Additionally, exact material quantities are provided for the construction of a 36 m^2 dwelling, allowing the users to estimate the cost of their house prior to its construction.

The course of actions is as follows: the lot is cleaned and leveled; the foundation is constructed using no-fines concrete (special consideration is given to the adequate depth of the excavation and the careful compaction of the concrete); the footing is cast, using no-fines concrete but of smaller aggregates; the adobe blocks are manufactured (following instructions concerning practical ways of assessing the soil's properties – the earth mixtures contains cactus juice, straws and is left to cure for three days before use, as described in Chapter 2); the walls are erected, giving special attention to: moistening the footing, to limit the water absorption when mixing the soil mortar, keeping the verticality of the walls, ensuring sufficient overlapping between the brick courses (especially at the corners), totally filling the joints with mortar and embedding the steel mesh connectors at specified locations; the steel wire mesh is put into place; the concrete collar beam is cast (a special feature of which are the "shear keys" formed as "sockets" at the top level of walls' intersections); the (single-pitched) roof is constructed (clay tiles on wooden structure); doors and windows are fixed; the walls are plastered; the floors and porches are formed. Selected graphics from the manual are shown in Fig. 5-20.
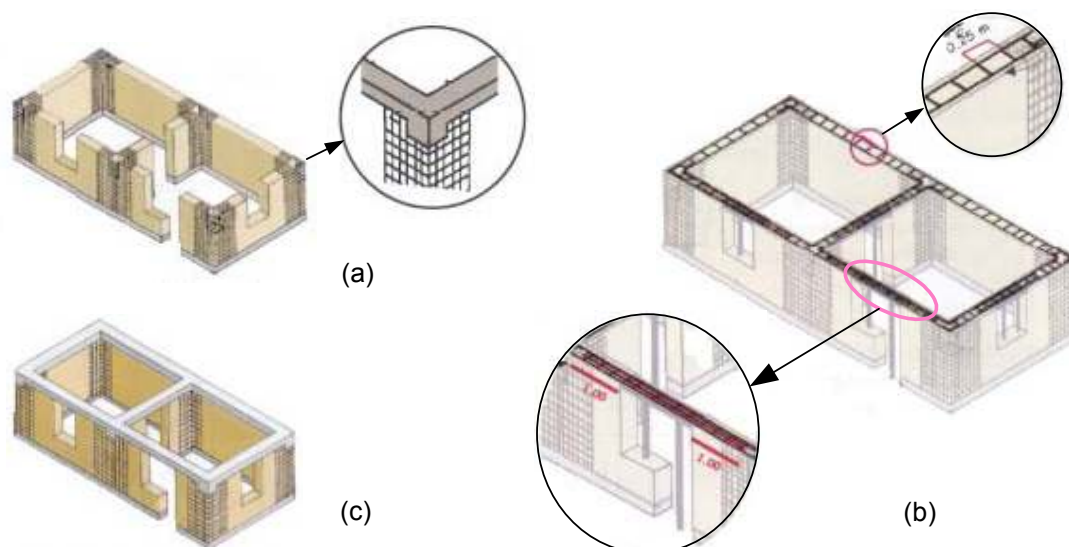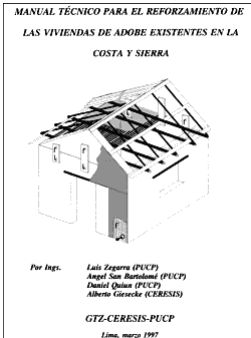
Fig. 5-20 (a) Reinforcement with the steel wire mesh and corner detail; (b) reinforcement arrangement of the collar beam and details for stirrups (not closed) and openings (two additional rods, extending for 1 m on both sides of the opening); and (c) casting of the collar beam (the "sockets" at the top level of the walls' intersections can be clearly seen).

▪ PREDES Centro de Estudios y Prevención de Desastres (2002) "Construyendo casas de adobe más resistentes", Guía de orientación para la Autoconstrucción de Viviendas, p. 40, Lima, Perú.

(b) Technical Documents (addressing improved seismic performance and/or rehabilitation)

▪ Zegarra, L. (PUCP Pontificia Universidad Católica del Peru); San Bartolomé, A. (PUCP); Quiun, D. (PUCP) and Giesecke A. (CERESIS Centro Regional de Sismología para América del Sur) (1997) "Manual técnico para el reforzamiento de las viviendas de adobe existents en la Costa y sierra", financed by GTZ Gesellschaft fur Technische Zusammenarbeit, Lima, Peru.
[available at:
http://sipan.inictel.gob.pe/ceresis/proyect/madobe/manual.htm]

This manual summarizes the findings of the research project that was carried out by the professors (Zegarra, San Bartolomé and Quiun) of the Engineering Department of the Pontifical Catholic University of Peru in collaboration with the South American Regional Seismological Centre (CERESIS) and the German Association for Technical Co-operation (GTZ).

The manual is not specifically addressed to a certain group of people (professionals, self-builders, etc.), but most likely it will not be used as an educational tool of self-construction housing projects, since in its present form, its layout does not conform with the characteristics of a self-construction manual as presented at the beginning of this chapter (for instance, figures are scarce).

The purpose of this research was to develop a simple reinforcing system of adobe houses that would delay their complete collapse (i.e. inhibit the formation of vertical cracks in the corner of the walls) during an earthquake and provide enough time to the occupants to evacuate. Many alternatives were experimentally investigated and the most efficient one proved to be the reinforcement with a welded wire mesh made of 1 mm galvanized wires spaced at 20 mm and placed in strips: vertically, at the corners of all interior perpendicular walls, simulating columns; and horizontally, surrounding the upper perimeter, simulating a crown beam of the wall; the mesh is then covered with a cement–sand mortar.

The manual starts with the description of the damage types/sequences in un-reinforced adobe houses (see Chapter 4) and continues with the listing of the conditions under which a damaged house cannot be readily reinforced with the proposed system. These conditions account for damages that must be restored prior to the application of the steel wire mesh; these are damaged lower parts of the walls (e.g. erosion due to humidity), damaged roofs (e.g. moth-eaten, rotten timber beams) and cracks with a width greater than 3 mm. For the first case, the roof must be disassembled, while for the second case the walls' bases must be rebuilt and protected against water/humidity ingression with the construction of a narrow pedestal. For the case of a damaged roof, this must be taken apart and reconstructed, while a reinforced concrete collar beam should be placed on top of the walls (vertical strips of the steel wire mesh are necessary only at the corners of intersecting walls). Should large cracks be present on the walls, these have to widened, cleaned, dampened and filled with mortar.

The materials needed for the proposed reinforcement method and their use are presented next, along with the necessary tools. It is interesting to note the use of (most probably aluminium) bottle taps from refreshment drinks as anchoring plates (washers) for the steel wire mesh (the taps are nailed in the walls). A step-by-step description of the strengthening procedure is then provided, beginning with recommendations for the calculation of the materials' quantities. The work's sequence is as follows:

The existing gypsum, or mud plastering is removed and the areas of the walls to be reinforced are thoroughly cleaned;

The zones to be reinforced are marked with chalk and 30 mm square holes are opened every 0.5 m along the centreline of the vertical mesh strips (starting 250 mm lower from the top of the walls);

Small steel connectors (each connector consisting of a single steer wire 200 mm in length, longer than the thickness of the wall) are placed into each hole, the interiors of which are moistened and filled with a 1:4 cement:sand mortar mixture;

The vertical mesh strips are fastened to the adobe wall with taps and nails (in a 250 by 250 mm grid arrangement), and the horizontal strips are fixed. The strips should be placed on each side of the walls, except in cases of detached houses (unless all the owners agree). The average width of the mesh strips is 450 mm, depending on the type of the wall intersections (Fig. 5-21a);

The ends of the connectors 90° are bended and nailed on the adobe wall;

The reinforced areas are moistened and plastered with cement-sand mortar, applied in two layers.

For the cases of gable-end walls (higher than 4 m), the authors propose the confinement of the critical area on both sides of the wall-pediment interface with wooden planks embedded in the adobe walls and interconnected with steel wire connectors (see Fig. 5-21b)

(a)

(b)
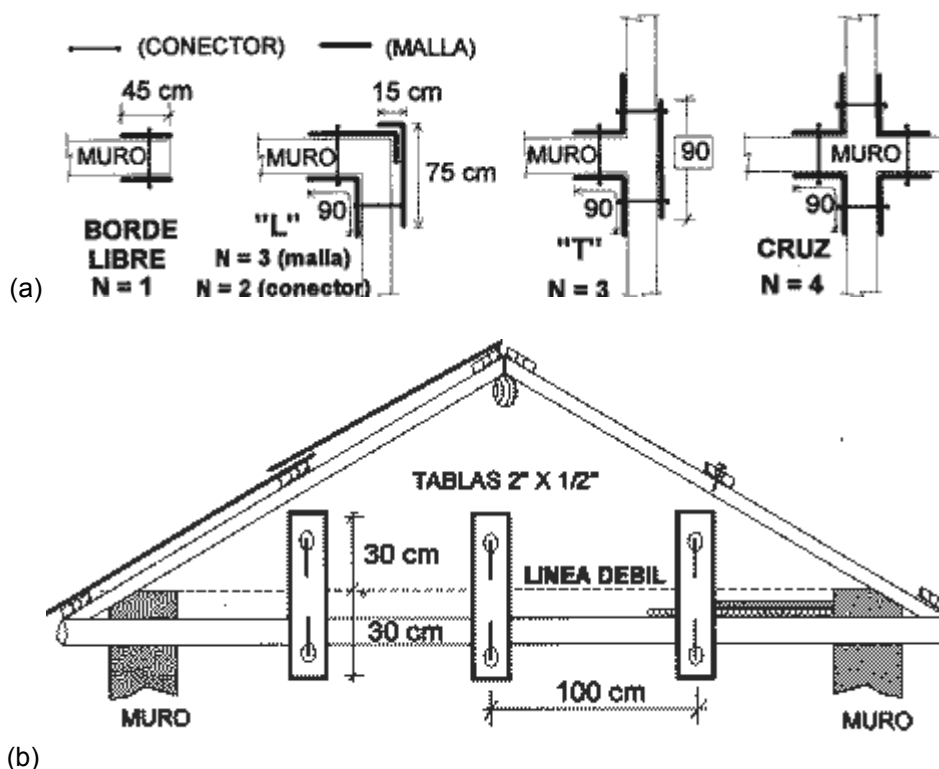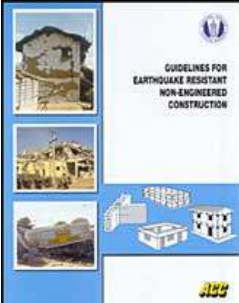
Fig. 5-21 Proposed strengthening measures according to Zegarra et al. (1997): (a) Different arrangements of vertical steel wire mesh strips, according to the type of the wall intersections in plan; (b) Strengthening of the area adjacent to the wall-pediment interface.

▪ Revenue & Forests Department of India (1998) "Earthquake-Resistant Construction and Seismic Strengthening of non-engineered buildings in rural areas of Maharashtra: Manual", Maharashtra Emergency Earthquake Rehabilitation Programme, p. 146, Mumbai, India.

The manual provides background material on the causes of earthquakes, local seismicity and basic information about seismic design and traditional construction practices in the Maharashtra State region of India. Guidelines for the seismic design of new houses are given, including general rules for construction of reinforced cement concrete (RCC) bands in masonry buildings. Strengthening provisions for undamaged houses are also discussed. Recommendations for the repair of damaged stone, burnt brick and adobe masonry wall buildings are given. Basic patterns of damage to foundations and roof structures are also described[11].

▪ IAEE INTERNATIONAL ASSOCIATION FOR EARTHQUAKE ENGINEERING (2001) "Guidelines for Earthquake Resistant Non-Engineered Construction - Chapter 7: Earthen Buildings".

[Available online at: http://www.nicee.org/Manuals/iaee/Ch7.htm]

This is a new printing of an original manual entitled "Guidelines for Earthquake Resistant Non-Engineered Construction", developed and published in 1986 by the International

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[11] *Abstract taken from the QUAKELINE database. This database is developed and maintained by the Multidisciplinary Center for Earthquake Engineering Research (MCEER), SUNY at Buffalo.*

Association for Earthquake Engineering (IAEE[12]) as a revised and amplified version of the document: "Basic Concepts of Seismic Codes, Vol.1, Part I, Non- Engineered Construction" that was first published by IAEE in 1980. The 1986 source document was republished in 2001 with permission from IAEE and funding from the Associated Cement Companies (ACC).

The manual discusses the means by which a variety of traditional non-engineered building constructions that are common in many parts of the world, and particularly in economically disadvantaged countries, can be designed and built, so that the risk of damage resulting from the earthquake hazard is significantly reduced. The topics discussed are: structural performance during earthquakes (with emphasis on masonry structures), general concepts of earthquake resistant design of fired-brick, stone, wooden, earthen and non-engineered reinforced concrete buildings, as well as repair, restoration and strengthening techniques.

In the preface of the 1986 edition it was stated "The material included in the book should be found useful to people at various levels concerned with earthquake disaster mitigation through the construction of safe housing for and by the masses". The manual was not meant to be used as a self-construction educational tool within the framework of participatory housing projects, although it contains a large number of explanatory figures (as the one shown in Fig. 5-22). It could be considered as a compilation of guidelines of good practice for most earth-based construction types that can be consulted by people that are well acquainted with design methodologies and construction practices (such as engineers, architects and skilled builders). The information is given in a compact but very comprehensible way.

For the case of earthen dwellings, the typical damages and collapse patterns, the different classifications of earth-based construction practices and the properties of earth as a building material (also providing field tests for assessing the strength of both soil and adobe blocks) are described. Recommendations concerning the seismic-resistant features of walls, foundations, roofs, collar beams, pilasters/buttresses, vertical reinforcement in the walls and diagonal bracing are provided, along with guidelines for plastering and painting. Finally, a graphical summary of the desirable structural features that provide resistance against earthquake is provided (see Chapter 4).
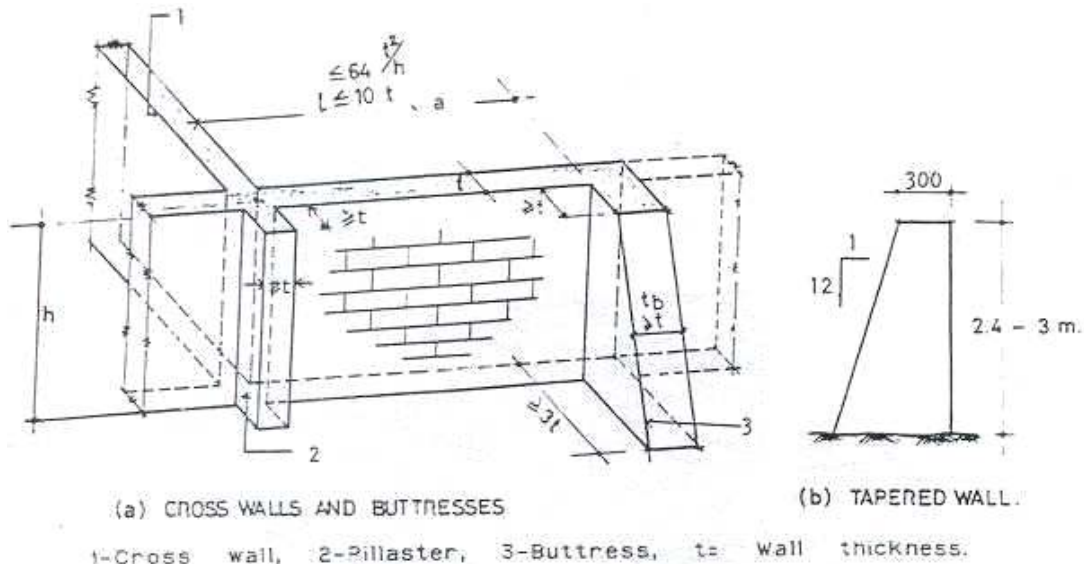
Fig. 5-22 A very useful figure showing the recommended relative wall dimensions.

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[12] *The objective of IAEE is to promote international cooperation among scientists, engineers and other professionals in the broad field of earthquake engineering, through the interchange of knowledge, ideas and the results of research and practical experience.*

Concerning the design of walls, the manual gives the following set of recommendations, as a function of the following seismic zones defined according to the expected MSK intensities:

Zone A: Risk of Widespread Collapse and Destruction (MSK IX or greater);
Zone B: Risk of Collapse and Heavy Damage (MSK VIII likely);
Zone C: Risk of Damage (MSK VII likely);
Zone D: Risk of Minor Damage (MSK VI maximum).

a. The height of an adobe building should be restricted to one storey, plus an attic, in seismic zones A and B, and to two storeys in zone C.

b. $\ell \leq min\left(64\left(\dfrac{t^2}{h} \right) ,\ 10t \right);$

c. When a longer wall is required, the walls should be strengthened by intermediate vertical buttresses;

d. $h \leq 8t$;

e. The width of an opening should not be greater than 1.20 m;

f. The distance between an outside corner and an opening should not be less than 1.20 m;

g. The sum of the widths of openings in a wall should not exceed one-third of the total wall length in seismic zone A and 40% in zones B and C;

h. The bearing length (embedment) of lintels on each side of an opening should not be less than 0.5 m;

i. Hand-formed walls should preferably be made tapering upwards, keeping the minimum thickness at 0.3 m at the top and increasing towards the bottom with a batter of 1:12;

j. Providing outside pilasters at all corners and junctions of walls will substantially increase the seismic stability of the building.

Notation: ℓ is the length of a wall between two consecutive walls at right angles to it, t is the wall's thickness and h is the wall's height.

- Minke, G. (2001) "Construction Manual for Earthquake Resistant Houses Build of Earth", GATE - BASIN BUILDING ADVISORY SERVICE AND INFORMATION NETWORK at GTZ GESELLSCHAFT FUR TECHNISCHE ZUSAMMENARBEIT GmbH, p. 51, Kassel, Germany.
  [Available online at:
  www.gtz.de/basin/publications/books/ManualMinke.pdf]

This manual is mainly comprised of the results of research conducted at the Building Research Laboratory of the University of Kassel, Germany, on low-cost, single-storey houses built of earth and found in rural areas of earthquake-prone zones of Latin America. After referring to some fundamental factors that affect the seismic performance of houses, such as their shape and their location in regard to the slope of the terrain, the typical failures of adobe structures attributed to common design mistakes are presented. Following, a presentation of the various existing techniques of building with earth is given. The wall types considered are of: rammed earth, adobe, wattle and daub, and textile elements filled with earth.

The manual briefly describes each of the aforementioned systems, accompanied by many explanatory graphics and photos. Interesting variations/alternatives of these earth-based construction systems, which were put into practice in past housing projects (e.g.

reinforced rammed earth and adobe walls with vertical bamboo rods, concrete frame structure with adobe wall infills, etc.), are also mentioned. The manual concludes with construction recommendations concerning critical joints and elements, such as the joints between foundation, plinth and wall, ring beams, gables, roofs, domes and openings.

The manual, in its present state, cannot address the educational requirements of self-construction projects, but it may be used as a very good, compact, introductory text by anyone who is interested in current earth-based construction practices and fairly knowledgeable on structural design and construction issues.

▪ Núñez de Hércules; Rosa Delmy et al. (2001) "Sistemas sismo resistente de construcción de vivienda utilizando la tierra", FUNDASAL Fundación Salvadoreña de Desarrollo y Vivienda Mínima, San Salvador, El Salvador.

▪ Blondet, M. (PUCP Pontificia Universidad Católica del Peru); Villa Garcia, G.M. (PUCP) and Brzev, S. (British Columbia Institute of Technology) (2003) "Earthquake-Resistant Construction of Adobe Buildings: A Tutorial", Greene, M. (ed.).

[Available online at: http://www.world-housing.net/Tutorials/AdobeTutorial/Adobe%20Tutorial.pdf]

This most up-to-date tutorial is published as a contribution to the EERI/IAEE World Housing Encyclopaedia, Earthquake Engineering Research Institute, Oakland, California. As stated in the Word Housing Encyclopaedia site of the EERI, the purpose of these tutorials is to outline the key factors affecting seismic performance and to offer recommendations for improved earthquake-resistant construction practices for new buildings and for strengthening existing buildings at risk. The tutorials contain links to the relevant publications and web sites as well as video clips. The first online tutorial currently available on the site is related to adobe construction, both in English and in Spanish language.

Like the manual issued by the Committee on Non-Engineered structures of the IAEE (as mentioned earlier in this chapter), this tutorial is a compilation of guidelines of good practice and it cannot be used for educating/capacitating self-builders. Nevertheless, it is exclusively focused on adobe structures and more specifically on the improved earthquake performance of new adobe structures that can be ensured if certain structural features are incorporated in adobe dwellings.

The latter are based on the latest achievements in the field of earthquake-resistant adobe structures, within which the ones of the Pontifical Catholic University of Peru deserve special attention in this publication (the authors of the tutorial are actually pioneers in the field). Apart from the improved earthquake performance of new adobe structures, the seismic strengthening of existing adobe buildings and the seismic protection of historic adobe buildings are additional subjects that are tangled in this tutorial.

The tutorial begins with a brief introduction on adobe construction, followed by the description of the typical patterns of earthquake damage (relevant illustrations, which can be found in some EERI/IAEE World Housing Encyclopedia reports - www.world-housing.net - are also provided).

Addressing the improved earthquake performance of new adobe structures, three key factors are recognized as critical: (1) Adobe block composition and quality of construction; (2) Robust layout; and (3) Improved building technologies including seismic reinforcement. Regarding the first factor, recommendations are given for the practical determination of the soil's suitability and for the proper manufacturing of adobe blocks. Regarding the second, the dwelling should be: squat, single-storey, with small openings and a regular, compact plan with frequent cross-walls. The improved building technologies in seismic areas that include the use of reinforcement, account for the

results of the extensive work done in PUCP and recent application projects, as the one described by Dowling, 2002 (see "Improved Adobe in El Salvador", a project presentation available at:
www.world-housing.net/Tutorials/AdobeTutorial/Reference_7.pdf).

These technologies recommend the use of horizontal and vertical reinforcement (bamboo, reeds, cane, vines, rope, timber, chicken wire, barbed wire or steel bars), buttresses and pilasters, and a ring beam (recommended to be combined with the use of truss-like timber ties between the lintels and the ring beam).

The section of the manual that describes the seismic strengthening of existing adobe buildings is based on the findings of Zegarra et al., 1997 (i.e. reinforcement with welded mesh externally applied on the walls and covered with cement-sand mortar). When addressing the seismic protection of historic adobe buildings, the tutorial summarizes the retrofitting recommendations that were suggested by the Getty Conservation Institute as part of the Getty Seismic Adobe Project (GSAP), which aimed at developing technical procedures for preventing the structural instability of historic adobe buildings during earthquakes with minimal intervention to their original fabric.

5.3.2 *Bahareque* construction

▪ FOSOVI Fondo Social de la Vivienda (1992) "Cómo hacer nuestra casa de bahareque", p. 35, United Nations Development Programme (PNUD Programa de las Naciones Unidas para el Desarrollo) and United Nations Conference for the Human Establishments (CNUAH - Hábitat Conferencia de las Naciones Unidas sobre los Asentamientos Humanos), Proyecto HON91-021: "Apoyo a la Estrategia Nacional de Vivienda y Asentamientos Humanos", Tegucigalpa, Honduras.

[Available online at:
http://www.fporideh.org.hn/seccion2/Doc/1035.zip]

This is a pocket-size 35 page long manual developed within the framework of the United Nations Development Programme, under the auspices of the Social Housing Fund of Honduras. This publication was based on a manual developed for Ecuador in 1986, and it is accompanied by two more manuals, one for adobe and another one for timber structures (which are not published on the web). The scope of the manual is to disseminate the existing knowledge on "appropriate housing technologies", considered by officials of the residential sector in Honduras as a promising housing solution.

The manual consists of a series of sketches (one page long each) where the house itself is drawn as an animated object that instructs the self-builders on the appropriate way of how to construct a house of this type. There is no reference made in the text to earthquakes or seismic-resistant structural features.

The manual starts by providing information related to the selection and preparation of the appropriate building site. Instructions are then given for marking the foundations and carrying out the excavations. The foundations are constructed by placing big stones at the bottom of the trench, followed by smaller ones on the top and finished with cement grout. A footing is also constructed (serving as a barrier against humidity) using cement-stabilized earth and stones smaller than those used in the trench. Flexible steel rods (connectors) are fixed to the footing prior to its casting, so that a running wooden base beam can be clamped on the footing.

The basic frame is then set up by placing timber poles and connecting them at the top with wooden beams. Diagonal bracing is used between two consecutive poles and wooden lintels are placed at the top of the doors and at the top and bottom of the window openings. The diagonal bracing of the walls is complemented by an auxiliary wooden mesh, which holds the woven bamboo stems in place. The formed panels are then filled and covered with soil mortar, starting from the lowest level and patching no more than 0.6 m at a time. Alternatives to the construction of the panels are also provided, based on local practices from Honduras. A selection of different types of roofs is proposed. Finally, the walls are plastered in two layers, the first one being of cement-stabilized earth mortar and the second one of a thinner mix (several "recipes" are given). The manual recommends the construction of a small trench to collect the rainwater.

▪ Oshiro, H.F. (1990) "Como reforzar y proteger una casa de esteras", Serie: Técnicas Constructivas, Manual de Apoyo No.1, 30 p., PREDES Centro de Estudios y Prevención de Desastres (ed.), Lima, Perú.

▪ Guevara, A. and Romero, G. (1993) "La casa de quincha mejorada – Cómo construirla", p. 66, PREDES Centro de Estudios y Prevención de Desastres (ed.), Lima, Perú.

This is a self-construction guide that describes, step-by-step, the construction of an improved version of the Peruvian wattle and daub (*bahareque*) house.

▪ Pontificia Universidad Católica del Perú and Technical University of Nova Scotia, Canada (1996) "Diseño y Construcción en Quincha", Proyecto Construcciones en Quincha, p. 40.

(financed by: Centro Internacional de Investigaciones para el Desarrollo del Canadá)

This manual was developed by the Pontifical Catholic University of Peru and the Technical University of Nova Scotia, Canada, within the framework of the project entitled "*Construcciones en Quincha*" and it is addressed to a wide variety of users, regardless their construction skills. The information is provided in a very comprehensible, complete and artistically appealing way, with many drawings and photographs taken from construction sites in Villa El Salvador.

The example described in this manual corresponds to a single-storey communal, multi-purpose building. After a short introduction, the manual briefly describes the construction system: the foundation consists of cane reinforced concrete and a 150 mm wide concrete footing cast on top of it (with a minimum height of 200 mm). The walls are formed from wooden prefabricated panels (0.8 m x 2, or 2.40 m); these panels are completed by weaving canes in a mat-type way and by filling in the formed "pockets" with earth mortar. The final width of the walls is 150 mm. Both "conventional" and "seismic-resistant" panels are connected in order to form the walls (Fig. 5-23a). The double-pitched roof (with a low inclination of 3.75%) is composed of timber runners resting on top of the walls, on one end, and on the main roof beam, on the other, supporting canes covered by cement mortar 20 mm thick. The construction system is summarized in Fig. 5-23b.

In the remaining parts of the manual, every construction step is elaborately described and explained with very detailed sketches and plans. Namely, materials and preliminary works, foundations, panels' design (giving special consideration to symmetry and regularity), panels' assembling, collar and main roof beams and rafters (the roof beams are advised to be dimensioned by a professional), matting, structural details (connections), doors and windows, plastering and finishing, and installations.

One of the most interesting guidelines given in the manual (being a research result of the work done in PUCP) allows the determination of the number of "conventional" and "seismic-resistant" panels needed in each direction (North-South & East-West), depending on the area covered by the *bahareque* building. According to this recommendation, the number of "conventional" panels should be equal to area/6 and the "seismic-resistant" ones should be half as much (area/12), located at the corners of the building and at wall intersections.

(a)   (b)
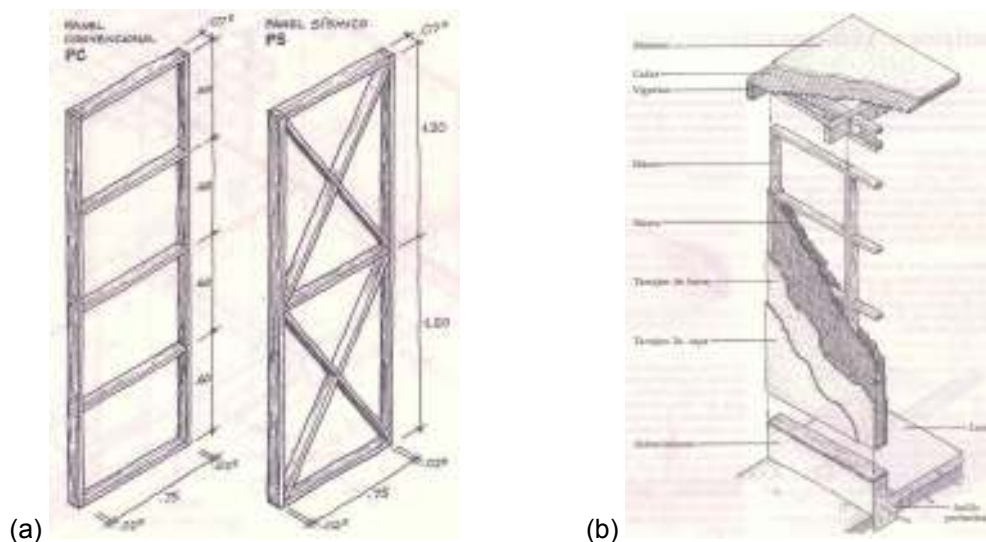
Fig. 5-23   (a) "Conventional" and "seismic-resistant" type of panels; and (b) Graphical summary of the *quincha* (Peruvian *bahareque*) construction system.

PREDES Centro de Estudios y Prevención de Desastres (1997) "Como construir casas con quincha mejorada", p. 35, 2nd edition, Lima, Perú.

This is a self-construction guide that describes an improved version of the Peruvian wattle and daub (*bahareque*) construction method. Drawings of a typical module are included. This is probably a more recent publication of the one referenced above.

La Red de Estudios Sociales en prevención de desastres en América Latina (2001) "Manual de construcción sismo resistente de viviendas en bahareque encementado", p. 70, AIS Asociación Colombiana de Ingeniería Sísmica.
[Available online at: http://www.desenredando.org/public/libros/2001/csrvbe/guadua_lared.pdf]

This construction manual presents the seismic-resistant structural requirements related to the simplified design and construction of single- and two-storey "cemented" *bahareque* houses (i.e. houses made of cement in-filled bamboo walls). The manual has been elaborated by the Colombian Association of Seismic Engineering - AIS[7], with the financial

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[7] *The Colombian Association of Seismic Engineering (AIS) is a non-profit legal entity, with the mission to: promote the study and improvement of methodologies and techniques relative to Seismic*

support of the Fund for the Reconstruction and Social Development of the Coffee Sector - FOREC and the CORONA organization[8]. Its purpose was to promote the diffusion and application of the proposed structural system in the Latin American and Caribbean countries, and in particular in El Salvador, in the hope that this will facilitate the reconstruction process following the destructive earthquakes of 2001. The target group is comprised of professionals in the field of construction, as well as of people with no particular expertise.

The manual has been designed and written in a language that is easy to understand and incorporates a multitude of detailed coloured drawings. The different chapters of the manual cover the issues of earthquake-resistant construction (general plan of the house, regularity, vertical continuity, symmetry, etc.), general requirements for earthquake-resistant design (e.g. construction joints between detached houses, to avoid the "pounding" during an earthquake), foundations, installations, walls (bearing and non-bearing), diaphragms, columns, roofs and joints. Also included, are a glossary and a brief bibliography. Since the complete description of the sequence of works escapes the purposes of this report, only the basic features of the construction system are given hereafter. The bearing framework is made either of large bamboo stems, or by a combination of sawn timber and bamboo elements in-filled with panels made of reeds' matting, timber boards, or a combination of other materials. A steel wire mesh is then fixed on the panels and the "wall' is covered with cement mortar. The main skeleton is formed by nailing, or screwing a top and a bottom bamboo stem (or timber beam) to vertical elements of the same material and, occasionally, by reinforcing the frame with additional diagonal members.
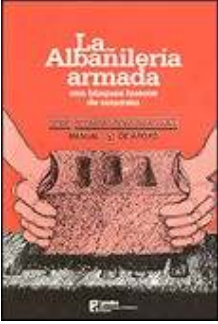
- PREDES Centro de Estudios y Prevención de Desastres (2002), "Construyendo con quincha mejorada", p. 35, Lima, Perú.

  This orientation guide for the self-construction of houses (as it is referred to by the publisher) was developed by the technical team of PREDES in order to offer assistance to the rural communities of Castilla, Arequipa, which were affected by the June 23, 2001 earthquake.

- FUNDASAL (2002) "Capacitación Bahareque Mejorado", Centro de Investigación, Capacitación y Producción de Materiales, Fundación Salvadoreña de Desarrollo y Vivienda Mínima, Ciudad Delgado, San Salvador, El Salvador.

5.4   Manuals for reinforced concrete block masonry dwellings

▪ Oshiro Higa, F. (1990) "La albañilería armada – Con bloques huecos de concreto", Serie: Técnicas Constructivas, Manual de Apoyo No.3, p. 30, PREDES Centro de Estudios y Prevención de Desastres (ed.), Lima, Perú.

▪ Moas, M. (1993) "Manual para la construcción de viviendas de un piso con bloques de concreto", San José, Costa Rica.

[Available online at:
http://www.crid.or.cr/crid/CD_Asentamientos_Humanos/pdf/spa/doc3365/doc3365.htm]

The manual was commissioned by the *Comisión Nacional de Emergenicas* following the earthquakes of Cóbano (1990), Piedras Negras (1990) and Limón (1991) in Costa Rica. The purpose of the manual was to serve as basis for implementing a practical training course directed to masons and constructors to improve constructions techniques and the use of adequate materials for the construction of one storey houses.

The manual is divided in three chapters and is accompanied by four appendices. The first chapter describes the process for mixing concrete and the minimum dimensions required for the steel reinforcement and the concrete blocks; a limited number of figures is contained in this chapter. The second chapter is very brief and explains in one paragraph the principles of earthquake resistant constructions. The third chapter describes the actual construction process, from the preparation of the foundations to the construction of the walls, crown beams, windows and roof gable, all supported by a good number of figures. The appendices contain recommendations for the construction in sloping terrain, the use of special blocks (beam-blocks) for the construction of horizontal beams, the construction of confined masonry with cast-in-situ reinforced concrete columns (masonry blocks used as formwork) and the minimum requirements set by the construction code in Costa Rica for the strength properties of the hollow concrete blocks. The manual also contains some pictures showing the failures observed when inappropriate reinforcing techniques are used.

In general, the manual contains a considerable amount of written text and detailed tri-dimensional figures (Fig 5-24a) that makes its use appropriate only for literate people with good skills in geometry and construction. No formulas are presented, other than the use of minimum dimensions.

The value of the manual lies in the good information relating to the detailing shown for the placement of the steel reinforcement in both vertical and horizontal directions, as well as at corner and 'T' joints. It is interesting to note that no reference is made to the construction of the roof or of a rigid diaphragm that ties together the walls. However, in the drawings is shown the use of buttresses (*mochetas*) positioned normal to the wall spaced at every 2.5 to 3 meters and formed by two blocks tied with steel reinforcement hooks (Fig. 5-24b).

The only drawback of the manual may lay in the complexity of the arrangement of the steel reinforcement, that although necessary for ensuring an appropriate seismic response, it may limit its use in the field of self-construction. In fact, to achieve a good design according to the recommendations of the manual, the authors feel that skilled workmanship, appropriate guidance and construction control will be necessary through

the whole construction process.

| (a) | (b) |
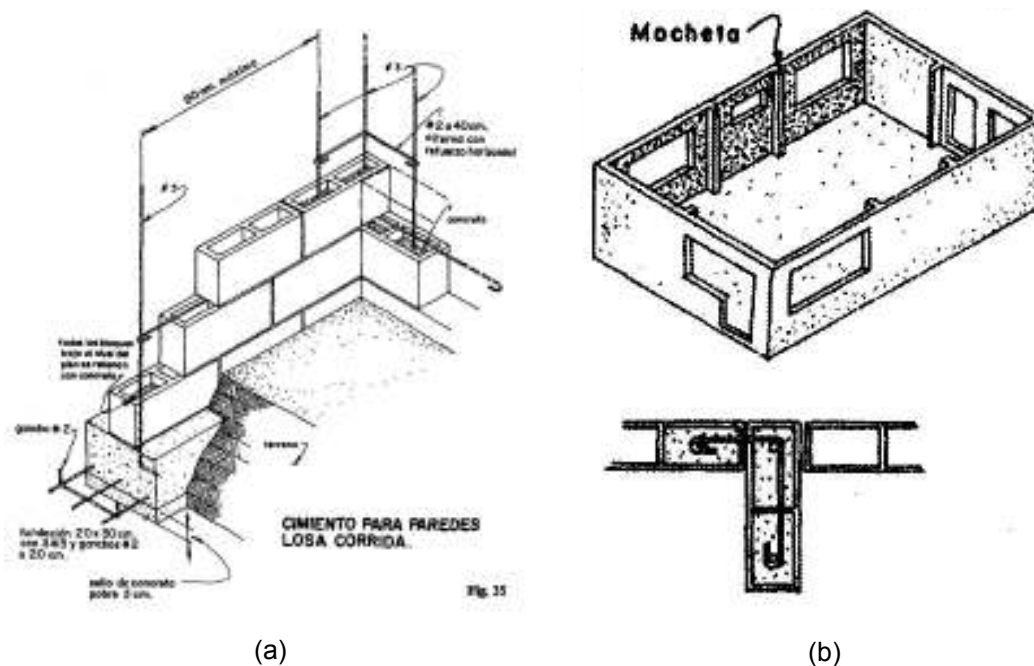
Fig. 5-24 Extract from "*Manual para la construcción de viviendas de un piso con bloques de concreto*": (a) Foundation detail for continuous walls (Fig. 35, p. 28); (b) Buttress detail (*mocheta integral*) (Fig. 15, p. 14).

SENA ₛₑᵣᵥᵢᶜᵢₒ ₙₐᶜᵢₒₙₐₗ ᵈₑ ₐₚᵣₑₙᵈᵢ�zₐⱼₑ, "Construcciones menores sismo resistentes: Manual técnico de capacitación", Bogotá, Colombia.

[Available online at: http://www.crid.or.cr/crid/CD_Asentamientos_Humanos/pdf/spa/doc3370/doc3370.htm]

This manual was developed by the *Servicio Nacional de Aprendizaje* (SENA, National learning service, Colombia) with the aim of promoting proper construction of minor masonry buildings according to the minimum requirements established by the *Código Colombiano de Construcciones Sismo-Resistentes* (CCCSR, Colombian code for earthquake resistant constructions) to guarantee the protection of the built environment and its occupants. The manual was intended to give a direct contribution to professionals, construction technicians and master builders that participate in both the design and the construction process.

As from 7 June, 1984, the National government of Colombia requires that all popular housing is built conforming to the requirements of the CCCSR-84 for one and two storey structures. In this context, the manual is directed to construction trainers with the mission of transferring technical knowledge to the beneficiaries that participate in self-managed construction projects.

The manual is divided in two parts, the first part relates to the generalities of earthquake resistance, while the second part describes the technical aspects of the construction process. In the first part, a thorough description of the concepts of earthquake resistant design, the origin of earthquakes, the seismic risk and the failures observed in building structures is presented (a very good figure describing the different modes of failure – twelve in total – is contained in the manual). In the second part, the

planning of the project in terms of cost, amount of material and time is presented, followed by the construction of foundations and drainage, the construction of walls and structural confinement elements, and the construction of the roof, floor and finishing.

The type of construction technique described in the manual corresponds to that of confined masonry. Clear and simple drawings are used to explain the construction procedure, placing emphasis in the reinforcement details at joints (Fig. 5-25).

1 La armadura estará integrada por al menos 4 barras longitudinales de 3/8" y estribos de 1/4", colocados a 20 cms como máximo entre sí.

Figure el hierro de acuerdo con el detalle estructural; la armadura tendrá una resistencia mínima de 2.400 kg/cm2.

Varilla Ø 3/8"

Fleje Ø 1/4"

.20   20   20   20

E Ø 1/4"   Ø 3/8"

15

Varilla Ø 3/8"

Fleje Ø 1/4"
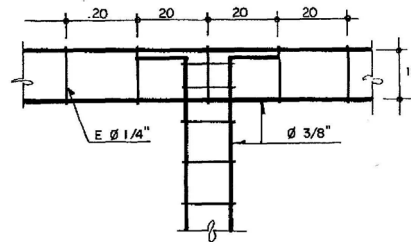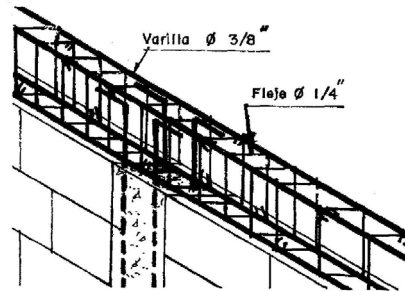
En todos los cruces de muros las barras deben formar ángulos rectos, traslapando una longitud igual a 40 veces el diámetro de la varilla como mínimo.

Alambre #18
Para amarres

.30
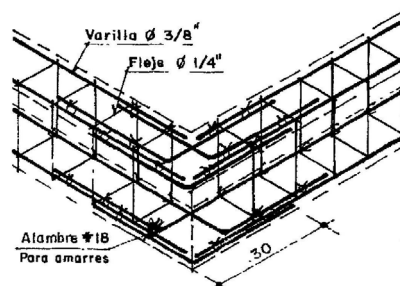
3 Los estribos serán de hierro de 1/4" y deben figurarse cumpliendo las exigencias previstas para columnas.

Fig. 5-25 Extract from "*Construcciones menores sismo resistentes: Manual técnico de capacitación*": Steel reinforcement details of connections (p. 84).

In general, the content of the manual is such that it can be intended to be used by both specialized technicians and professionals, especially through the information contained in the first part, as well as by trainees that are new to the construction sector, by means of the self explanatory drawings of the second part. In spite of the simplicity of the drawings and figures, the use of the manual needs the guidance of skilled workers, especially for the distribution and placement of the reinforcement elements in the structure.

■ MANUAL DE CONSTRUCCIÓN, EVALUACIÓN Y REHABILITACIÓN SISMO RESISTENTE DE VIVIENDAS DE MAMPOSTERÍA
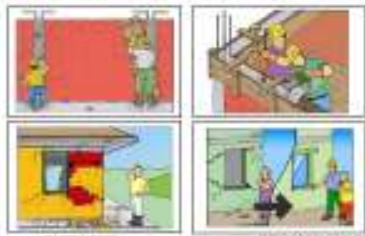
La Red de Estudios Sociales en prevención de desastres en América Latina (2001) "Manual de Construcción, Evaluación y Rehabilitación sismo resistente de viviendas de mampostería", AIS Asociación Colombiana de Ingeniería Sísmica.

[Available online at: http://www.desenredando.org/public/libros/2001/cersrvm/mamposteria_lared.pdf]

The manual was developed by the *Asociación Colombiana de Ingeniería Sísmica* (AIS, Colombian association of earthquake engineering) with the support of *La Red de Estudios Sociales en Prevención de Desastres en América Latina* (LA RED, Social studies network for disaster prevention in Latin America), the *Fondo para la Reconstrucción y Desarrollo Social del Eje Cafetero* (FOREC, Reconstruction and social development fund of the coffee 'axis') and the *Dirección para la Prevención y Atención de Emergencias de Bogotá* (DPAE, Directorate for emergency assistance and prevention of

Bogotá). One thousand copies of the manual were distributed for its dissemination and implementation in Latin America and the Caribbean, especially in El Salvador, in the aftermath of the earthquakes of January and February of 2001.

The manual is based on the design provisions for one and two storey structures contained in the new Norms for Earthquake Resistant Design and Construction NSR-98, published in Colombia and based on the provisions of the CCCSR-84 first issued in 1984.

The manual consists of 173 pages and is divided into four chapters. The first chapter illustrates the provisions contained in Title E of NSR-98 (for the construction of single homes in projects with less than 15 houses with a total construction area no larger than 3000 m^2) and is divided into seven sections, namely: earthquakes and earthquake resistance, earthquake resistance principles, building location, structural configuration, materials, foundations and walls. The second chapter contains information on how to evaluate the seismic vulnerability of existent one- and two-storey houses, with the aim of identifying the vulnerable elements that need to be retrofitted in order to enhance the safety of the structure and improve its seismic response. The third chapter presents a methodology to evaluate the damage of houses affected by earthquakes, to estimate how to improve their seismic resistance and behaviour. The fourth chapter presents how to reinforce, repair or reconstruct vulnerable structures that have been affected by earthquakes. The manual was directed to professionals and to non-experts in the field of seismic rehabilitation.

The four chapters of the manual are described with clear and colorful figures that explain all the comments given in the text. The comments themselves are concise and explain with sufficient detail the issues presented. There is also a good number of dimensions and formulas that are intended for the use of professionals or skilled technicians. Some of the figures were already present in the SENA Manual, however, the present manual goes further in the use of improved figures and sketches and in covering the area of vulnerability and damage assessment as well as retrofitting and repair measures.

As with the SENA manual, the LA RED manual is concerned with the construction of confined masonry houses, and is supported by improved and very well sketched figures, such as those shown on Fig. 5-26 and Fig. 5-27. In particular, Fig. 5-27a shows a closer spacing of stirrups in the vicinity of the node, a detail not commonly found in construction manuals that ensure the formation stable plastic hinges that enhance the energy dissipation capacity of the structure. In addition, the construction of the floor slab is also discussed (for two-storey constructions), and details on how to install the electrical and sanitary services is discussed. The last two chapters (that describe damage assessment and repair techniques) are not commonly found in most manuals, and as such, the information contained is very valuable.

(a)   (b)

Fig. 5-26   Extract from "*Manual de Construcción, Evaluación y Rehabilitación sismo resistente de viviendas de mampostería*": (a) Distribution of column and beam confinement elements (p. 1-30); (b) Construction procedure of confinement elements (p. 1-30).

(a)   (b)
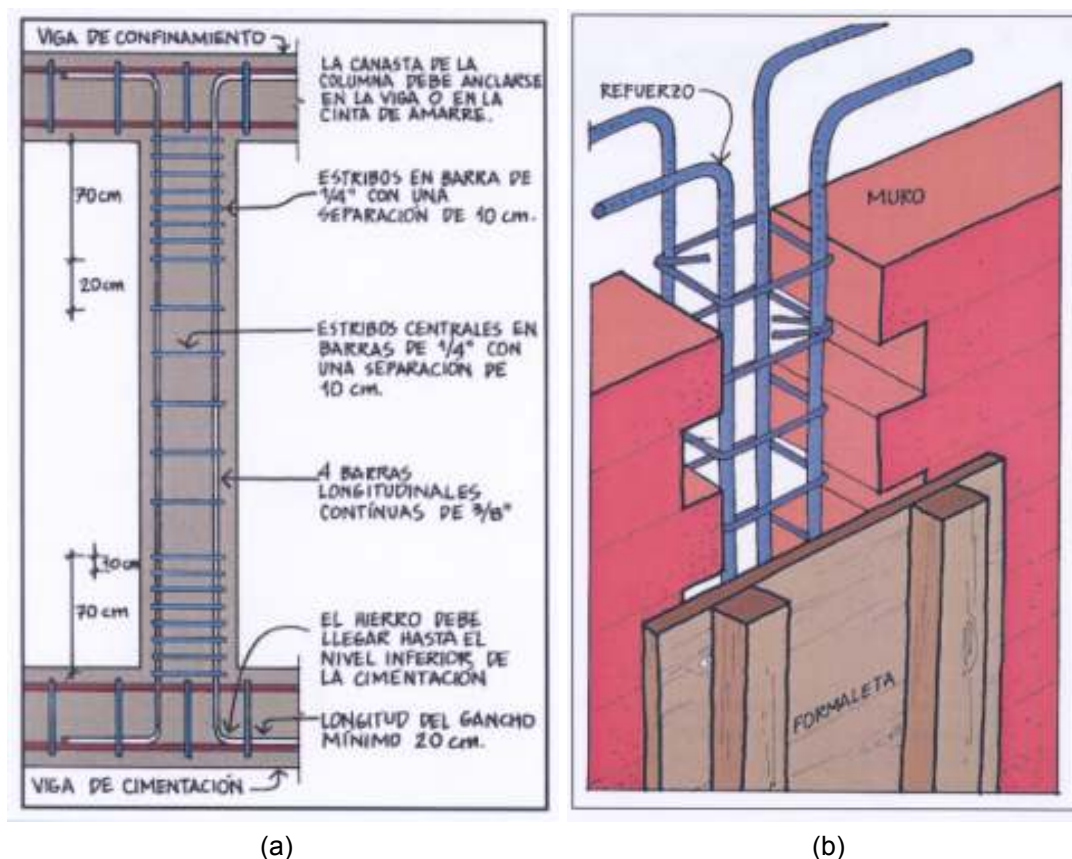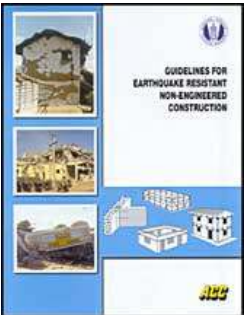
Fig. 5-27 Extract from "*Manual de Construcción, Evaluación y Rehabilitación sismo resistente de viviendas de mampostería*": (a) Steel reinforcement detail of confinement column (p. 1-32); (b) Detail of formwork and placement of steel reinforcement (p. 1-35).

In general, the authors feel that the use of the manual will mostly benefit skilled workers and technicians, with the support of professionals for the execution of large scale projects and for damage assessment, repair and strengthening measures. Nevertheless, the clarity and simplicity of the figures is such that they can be used as an effective tool to train unskilled workers and to guide them through the construction process.

5.5   Manuals for reinforced concrete dwellings

▪ IAEE ɪɴᴛᴇʀɴᴀᴛɪᴏɴᴀʟ Aꜱꜱᴏᴄɪᴀᴛɪᴏɴ ꜰᴏʀ Eᴀʀᴛʜꞯᴜᴀᴋᴇ Eɴɢɪɴᴇᴇʀɪɴɢ (2001) "Guidelines for Earthquake Resistant Non-Engineered Construction - Chapter 8. Non-Engineered Reinforced Concrete Buildings".

[Available online at: http://www.nicee.org/Manuals/iaee/Ch8.htm]

This document, and its preceding editions (see relevant notes in previous part of this chapter), was among the first (if not the first) to deal with the issue of non-engineered reinforced concrete buildings found in semi-urban and rural areas of various countries. First, the identification of typical failure patterns, attributed to respective structural deficiencies, is provided.   According to the IAEE Committee for non-engineered structures, the most common types of damages are:

(1) Roofs sliding off of supports, due to inadequate beam-wall, or beam-column connections;

(2) Out-of-plane collapse of infill walls, due to inadequate connections between the framework and the walls;

(3) Column crushing at supports, due to the lack of effective confinement (lack of stirrups);

(4) Diagonal column cracking, due to short column effect and/or to insufficient transverse reinforcement;

(5) Diagonal cracking of beam-column joints, due to inadequate detailing of the junction;

(6) Pulling-out of reinforcing bars, due to improper anchorage length and/or poor compaction of concrete;

(7) Collapse of gable frames, due to inadequate joint configuration;

(8) Differential settlement of the foundations, due to soil failure (improper selection of the building site, in terms of soil suitability);

Next in the manual, some guidelines of good practice are given, addressing the production of good quality concrete. Within this scope, the recommendations are focused on: mix proportioning (the method of measuring materials being consistent with simple procedures applicable to self-construction practices), mixing procedure, formwork quality, casting, compacting, curing and forming of construction joints. Information relevant to the configuration of the reinforcement include recommendations on the placing of rebars, addressing minimum cover, tying of longitudinal bars and stirrups with transverse bars and binding wire, minimum overlap lengths and configuration of bar and stirrup ends. It is interesting to note that the recommendations related to steel reinforcement do not exclude the use of smooth mild-steel bars.

Following the aforementioned recommendations, the critical sections in RC frames are indicated (corresponding to the likely locations for the formation of plastic hinges, i.e. the ends of beams up to a length of about twice their depth, the ends of columns equal to approximately one-sixth of the clear height of the columns between floors and the beam-column joints). This section, along with the following ones, is related with more technical issues, such as the detailing of linear members and beam-column joints. However, although these issues are presented in a relatively simple way, they cannot be used by untrained builders without the supervision of an engineer. The recommended details of connections in earthquake resistant frames are given in a series of figures, such as the one shown in Fig. 5-28 (which can be directly compared with the one given in the presentation of the next manual). For Fig. 5-28, the following conventions apply:

$$S_2 \leq min\left(\frac{h}{4} \ , \ 16d\right); \quad S_3 \leq \frac{h}{2}; \quad S_4 = 75 \ mm \ - \ 100 \ mm; \quad S_5 \leq min\left(\frac{b_k}{2} \ , \ 200\right);$$

$S_6 = 50 \ mm$, where d is the bar diameter of the beam reinforcement.

l_0: overlap length to develop full tensile strength, $\approx 55d$, including bends and hooks;

l_d: anchorage length to develop full tensile strength, $\approx 55d$, including bends and hooks;

Stirrup diameter in beams and columns: minimum = 6 mm, preferable = 8 mm.
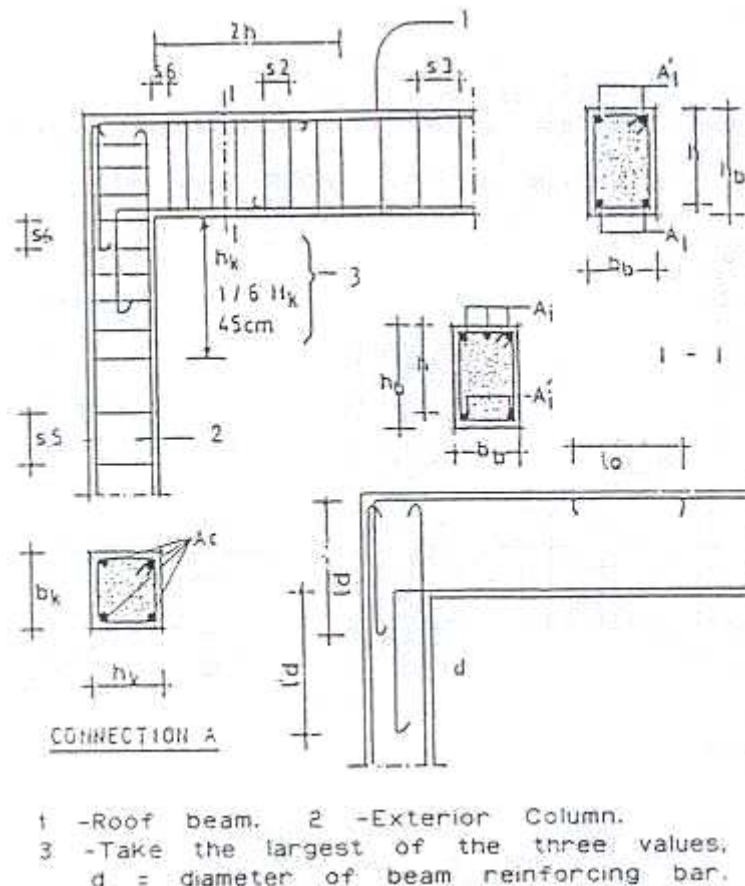
Fig. 5-28 Extract from the manual "Guidelines for Earthquake Resistant Non-Engineered Construction - Chapter 8. Non-Engineered Reinforced Concrete Buildings": Connection between roof beam and exterior column.

- GREAT GUJARAT RELIEF ENGINEERING ADVICE TEAM (2001) "Repair and strengthening guide for earthquake damaged low-rise domestic buildings in Gujarat, India", Dinesh Bhudia Patel; Devraj Bhanderi Patel and Khimji Pindoria (authors), p. 91, GREAT Publication: June 2001.

  [Available online at:
  http://www.arup.com/geotechnics/HTML/Articles/FINAL-GUIDE07SEPT2001.pdf]

This Guide was prepared by a group of British engineers (with knowledge of local conditions), after the 26 January, 2001 earthquake in Kutch, Gujarat, India that had a devastating effect on the area, with many buildings damaged and large loss of human lives. The main scope of the guide was to provide instructions to the owners/occupiers and local builders who wished to carry out proper repairs to the damaged buildings and/or strengthening works, in order to enhance the seismic resistance of the structures. The target group also includes engineers and architects, local authorities, relief agencies and any other parties interested in repairing and/or retrofitting the damaged building stock of Kutch.

The types of structures considered in this document are low-rise (two-storey, plus roof), non-engineered masonry buildings (rubble and cut stone) and reinforced concrete frame systems. Although the document concentrates on providing repair and strengthening instructions for non-engineered existing structures, some guidance is also

provided for the design and construction of new cut-stone or block work masonry buildings no higher than two stories; a relevant note is included for reinforced concrete buildings of the same height. Furthermore, in the introductory part of this Guide, some earthquake-related issues are explained in simple terms, such as: why earthquakes happen in India, which regions are seismically active, how buildings respond to an earthquake, and how to safely carry out good repair and strengthening techniques to earthquake damaged buildings.

The authors of this document explicitly state that this guide is intended to provide general assistance and guidance in the repair process, but it is not supposed to substitute the relevant Indian standards related to earthquake design and construction. Additionally, the owner of the building is totally responsible for determining the need for repair and its extent and whether it is practical and safe to carry out the repair works within a given budget. The guide also advises that the building owner should in all cases seek professional advice from a qualified structural engineer before carrying out any repairs.

As far as non-engineered reinforced concrete buildings are concerned, the manual (based on the contents/recommendations found in the IAEE guidelines, which were presented in a previous section) first describes the main structural deficiencies present in typical structures of this type found in the region. Taking into consideration that this sort of identification of flaws in structural configurations is very rare in literature, the contribution of the authors in the field of non-engineered buildings is very important. More specifically, the following structural deficiencies are identified and partly visualized through photographs:

(1) Inadequate building and soft storey configurations (e.g. large spans, absence of moment resisting concrete frames, addition of another floor to an older RC building featuring deficient connections of columns to the original concrete frame and alteration of the structural mass);

(2) Window openings in infill panels (e.g. large openings, placed too close to the corner columns of the building, lintels placed over the openings but not extending over the length of the wall);

(3) Deficient design/construction of columns and beam-column joints [e.g. drain pipes and other services placed inside columns, excessive stirrup spacing (typically 200-300 mm), small stirrup diameters (6 mm), absence of anchorage (hooks) at the ends of stirrups and longitudinal bars];

(4) Roof failures (mainly non-structural damage to pitched roofs as a consequence of tile dislocation);

(5) Canopy structures (first storey terraces supported by slender columns at one end and beams running into the main structural frame at the other end).

(6) Foundations without a bottom tie-beam.

The presence of non-structural infill walls was also commented: these infill panels, mainly made out of cut-stone masonry or concrete blocks, behaved as shear walls, preventing in many cases complete collapse of the structure, despite the fact that they were not designed for this purpose. The most prominent structural deficiencies, found in non-engineered reinforced concrete structures, are better explained through the description of the failure patterns of a three-storey reinforced concrete frame structure which was severely damaged in Kundanpur (near Kera).

Before advancing with the rehabilitation and strengthening measures of non-engineered buildings, the manual clarifies the nature of repair and retrofit actions and provides a brief set of comments on the cost that seismic protection entails to building owners. The assessment of the damages incurred by a building before taking any repair and/or strengthening measures, is also synoptically described.

Focusing on the repair and strengthening of reinforced concrete frame buildings with masonry or block-work infill wall panels, a set of recommendations accompanied by a brief descriptive text are given in graphical form (Fig. 5-29). The repair measures address the main structural members, more precisely the beam-column joints, both external (T - sections) and internal ($+$ - sections), as well as the construction of shear walls (either built of concrete blocks or of cut stone). Two examples are given on the safe sequence of works to repair two T-type beam-column joints: the connection of a single-storey internal column to the beam and the connection of a beam to a corner column extending from the ground to the first floor. Additionally, detailing guidelines are provided for both column

and beam elements, following the Indian code. Finally, jacketing procedures are described for beams and columns.

It should be noted that, as the authors emphasize in the introductory part of this manual, the repair/retrofitting actions proposed and described in this document should not (and most probably cannot) be executed by untrained builders. In this sense, the manual serves as a very good summary of some of the most common repair and retrofitting measures, which can be used by professionals (engineers trained in seismic-resistant design).

In the guidance notes for new buildings, the authors state in a very compact form, their recommendations of good practice, referring to: the location of the building, the required materials for the infill walls and their construction, the general structural form and the configuration of the building, the foundations, the openings, peripheral ties (gable bands, lintels, etc.), slabs, beams and columns, roofs and miscellaneous features. It is interesting to note that the use of rubble stone and adobe infill walls is not recommended and that it is proposed for the walls to be built prior to the casting of the columns, so that the former serve as shutters for the latter, in order to obtain a strong wall-column bond.
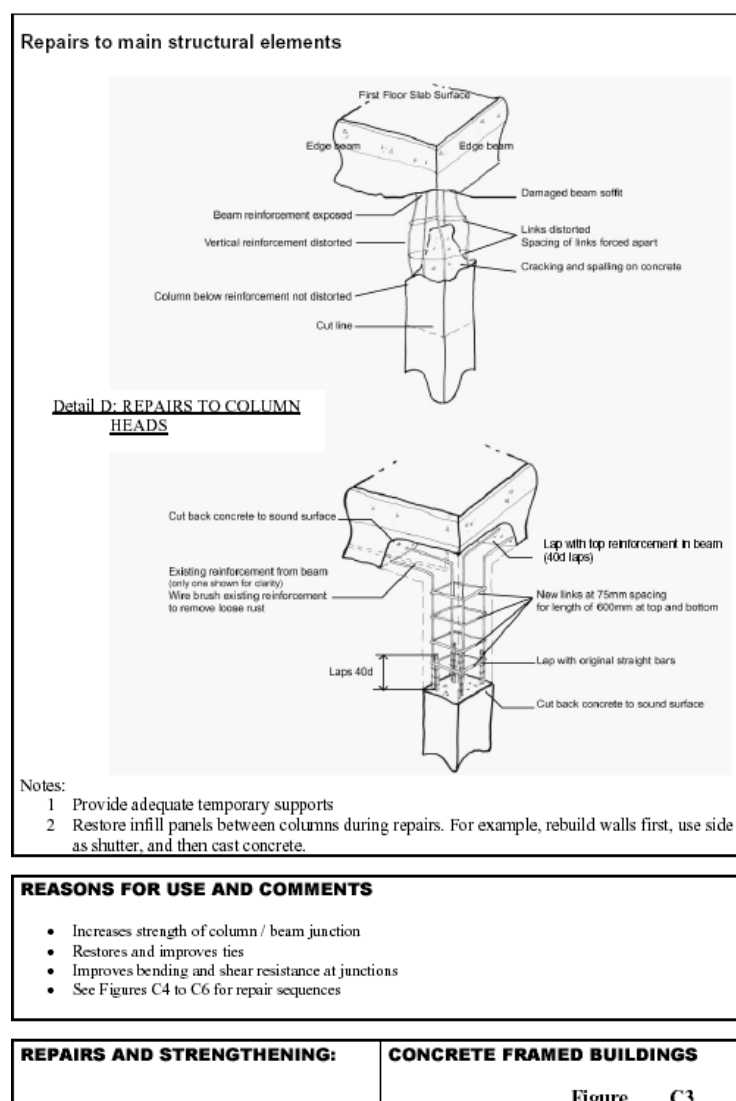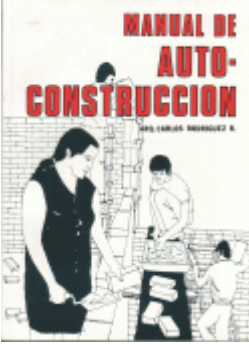
Fig. 5-29 Extract from the manual "Repair and strengthening guide for earthquake damaged low-rise domestic buildings in Gujarat, India": Connection between roof beam and exterior column.

5.6   Other manuals

- UNAYAN (1977) "Manual de auto-construção", Calcuta, India.

- Ministero de la Construccion, Depto. Editorial del Centro de Informacion de la Construccion, Cuba (1981) "Manual de Autoconstrucción".

- Ministerio de la Construcción (1981) "Manual de Autoconstrucción", Depto. Editorial del Centro de Información de la Construcción, Habana, Cuba.

- Nisnovich, J. (1986) "Manual de autoconstrucción para la vivienda popular", CEUR/Centro de Estudios Urbanos y Regionales. Club del Hornero, Buenos Aires, Argentina.

- "Manual de soluciones simples para la vivienda precaria/Operación Invierno", Santiago, Chile.

- Chiaparra, M.G. (1992) "Manual de Derecho de Cooperativas de Vivienda", Centro de Formación Cooperativa, Montevideo, Uruguay.

- Cementos Apasco, Federación de Colegios de Arquitectos de la Republica Mexicana, Colegio de Arquitectos de La Ciudad de México, A.C. (1996) "Mi Casa: Manual de Autoconstrucción", México. Educational comic about building and house construction.

- Rodríguez, C. (1997) "Manual de autoconstrucción", p. 200, México, ARBOL, ISBN: 9684611676 351.

  This manual seems to be a very elaborate one (200 pages long), dealing with all the aspects of the construction of a private house, including hydraulic, electrical and sanitary installations, terraces, etc[9].

- Rodríguez, C. (1997) "Manual de Autoconstrucción y Mejoramiento de la Vivienda", UNAM Universidad Nacional Autónoma de México and CEMEX, México.

  This manual was jointly developed by the Engineering faculty of the National Autonomous University of Mexico and the cement and ready-mix concrete company CEMEX. Previous editions of this manual demonstrated the great demand for technical assistance in printed form, concerned with self-construction techniques for private houses.
       This work was the result of the cooperation of specialists from many fields, such as engineers, architects, experts in mass communication means, sociologists, publishers, human resources experts, construction foremen, carpenters and plumbers. The scientific auspice was provided from the Engineering faculty of the UNAM, CEMEX offered economic support and the Centre of Cement and Concrete Technology (CTTC)

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[9] *The description given by www.editorialpax.com/temas/T_HABITA.HTM is not clear though about the construction method that is being instructed through the pages of this manual.*
[10] *The description was based on the one from:*
http://www.arquinauta.com/cemex/noticia.php?id_not=12, and on web-published news releases.

participated in providing technical assistance. It is interesting to note that 20,000 copies of a revised version of this manual (2003) were disseminated all over the country through the network of distributors of Construrama materials. The first publication of this material dates back to 1980[10].

- Van Lengen, J. (1998) "Manual del arquitecto descalzo: Cómo construir casas y otros edificios", p. 548, México, ARBOL, ISBN: 9684612222.

  This is another lengthy manual, which is addressed to constructors, foremen, bricklayers, craftsmen (such as carpenters and plumbers), authorities of small municipalities that seek assistance on how to develop their communities and their built environment, and to people who want to construct their own house or to indicate to the contractor how they want the construction of their house to proceed.

Among other subjects, the manual elaborates on design issues, material properties, weather-related construction matters, hydraulic, electrical and sanitary installations, etc[11].

- José de Jesús Saldaña Guerra (1999) "MANOS A LA OBRA / MANUAL DE AUTOCONSTRUCCIÓN, MCYC Instituto Mexicano del Cemento y del Concreto, p. 243, México.

  [Available online at: http://mail.imcyc.com/manosalaobra/manos.htm]

  The Mexican Cement and Concrete Institute has published this very extensive and elaborate manual that, through 18 well illustrated chapters, provides to the self-builder all the necessary instructions to build a reinforced masonry house, starting from the general scheduling of the works and concluding with the flooring and plastering procedures.

- Barrionuevo, R. "Precasas Industrializadas y Autoconstrucción", IAVI Instituto Argentino de la Vivienda and CORVI La Corporación de la Vivienda de [5].

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[11] *The description was taken from: www.editorialpax.com/temas/T_HABITA.HTM.*

5.7   Synopsis

In this chapter, a review of the existing manuals on self-construction practices was presented. The review revealed the existence of a broad spectrum of these documents, especially for the case of adobe construction. More precisely, the publication of self-construction manuals for adobe structures seems to have preceded the one for *bahareque* dwellings. On the contrary, manuals that tangle the issue of self-constructed reinforced concrete structures are relatively scarce. There exist many differences between the various manuals concerning both their contents (i.e. guidelines and recommendations) and the way in which these are given (e.g. graphical inputs, length and complexity of the text). For instance, some manuals recommend technical assistance, while others not. Moreover, the issue of seismic resistance of self-constructed houses is not addressed in every manual.

There is a number of critical questions to be answered, regarding the way the existing manuals reach their target groups, the manner in which the recommendations included in these manuals are put into practice and the measures taken for this knowledge to be maintained and passed-on by the participants in self-construction housing projects. These questions can only be answered through visits in the countries under investigation and discussions conducted with the locals. The scope of any organization contributing to earthquake risk mitigation actions in developing countries, by means of popular housing and education, should not be the production of yet another manual, but its meaningful impact to the end-users.

Conclusions

A comprehensive review on the vulnerability and risk reduction against earthquake hazard of non-engineered constructions has been presented, with emphasis on the area of Latin America and the Caribbean. A list of research institutions and organisations, as well as of experts working in the field has been presented and should serve as a valuable reference tool for civil engineers, scientists and policy makers.

For completeness, a summary of the synopses presented at the end of every chapter is given in the following:

- The level of seismic hazard in the LAC region is very high. The existence of a considerably precarious building stock, combined with continuing informal construction activities and vulnerability characteristics of social nature, such as poverty and lack of risk awareness, constitute a life threatening scenario in view of future earthquake occurrences, for both rural and urban Latin American settlements.

- There is an urgent need of undertaking seismic risk mitigation measures. The focal point of these measures should be the reconstruction process in the post-disaster period, which in turn should lead to the alleviation of both the qualitative and the quantitative deficiency of the existing building stock. Construction policies, along with rehabilitation ones, should aim at the minimization of all types of vulnerability components, which are related to the built environment, while promoting a feasible and realistic compromise between development objectives and sustainability perspectives.

- Despite the fact that a considerable amount of scientific work has been carried out in the field of earth-based construction, the literature survey revealed a growing feeling of mistrust in the local population and a general adverse social perception closely related to the poverty profile that adobe as a building material entails. Low cost, material abundance and sustainability of the built environment might just not be enough to preserve and even promote adobe construction in developing countries. Unless measures are undertaken in order to alleviate the fundamental disadvantage of these buildings, being their high vulnerability against natural disasters, earth will be abandoned as a housing solution in developing countries.

- An overview of the existing knowledge on the seismic performance of non-engineered adobe and reinforced concrete frame structures was presented, focusing on the classification of earthquake-induced damages and on the identification of typical damage patterns and related structural defects. A summary on the experimental programs carried out to assess the seismic structural response of adobe houses, the effectiveness of several strengthening measures and the dissemination efforts through conferences was also presented. Three case studies were discussed, concerning the effects of past earthquakes on non-engineered buildings and the mechanisms that lead to the catastrophic failures that resulted in large life losses, especially for the case of adobe dwellings. The literature survey revealed that the knowledge necessary for the prevention of the structural collapse of non-engineered structures during moderate to strong earthquakes is already existent; the challenge lies in the implementation of effective means for disseminating this knowledge to the population at risk.

- A review of the existing manuals on self-construction practices was presented, revealing the existence of a broad spectrum of documents, especially for the case of adobe construction; the number of manuals for self-constructed reinforced concrete houses was rather scarce. The compilation of manuals showed that many differences exist between both their contents and the way in which these were given. For instance, some manuals recommend technical assistance, while others not, and the issue of seismic resistance of self-constructed houses was not addressed in every manual. There is a number of critical questions to be answered, regarding the way the existing manuals reach their target groups, the manner in which the recommendations included in these manuals are put into practice and the measures taken for this knowledge to be maintained and passed-on by the participants in self-construction housing projects. These questions can only be answered through visits in the countries under investigation and discussions conducted with the locals. A multi-factorial problem of such dimensions cannot be treated with universally applicable "recipes". The scope of any organization contributing to earthquake

risk mitigation actions in developing countries, by means of popular housing and educational programs, should be the meaningful impact of manuals to the end-users; this impact should be monitored through a number of follow-up evaluation visits at the self-construction sites.

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X

Y

Z

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APPENDIX A

MACROSEISMIC INTENSITY SCALE

Definitions of intensity degrees

Arrangement of the scale:

a) Effects on humans
b) Effects on objects and on nature
c) Damage to buildings

Introductory remark:

The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s) also, when these effects are not mentioned explicitly.

Intensity I: Not felt

a) Not felt, even under the most favourable circumstances.
b) No effect.
c) No damage.

Intensity II: Scarcely felt

a) The tremor is felt only at isolated instances (<1%) of individuals at rest and in a specially receptive position indoors.
b) No effect.
c) No damage.

Intensity III: Weak

a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.
b) Hanging objects swing slightly.
c) No damage.

Intensity IV: Largely observed

a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.
b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
c) No damage.

Intensity V: Strong

a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
c) Damage of grade 1 to a few buildings of vulnerability class A and B.

Intensity VI: Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.

c) Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1.

Intensity VII: Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
   Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
   A few buildings of vulnerability class C sustain damage of grade 2.
   A few buildings of vulnerability class D sustain damage of grade 1.

Intensity VIII: Heavily damaging

a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.
   Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.
   Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.
   A few buildings of vulnerability class D sustain damage of grade 2.

Intensity IX: Destructive

a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
c) Many buildings of vulnerability class A sustain damage of grade 5.
   Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
   Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
   Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
   A few buildings of vulnerability class E sustain damage of grade 2.

Intensity X: Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5.
   Many buildings of vulnerability class B sustain damage of grade 5.
   Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
   Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
   Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
   A few buildings of vulnerability class F sustain damage of grade 2.

Intensity XI: Devastating
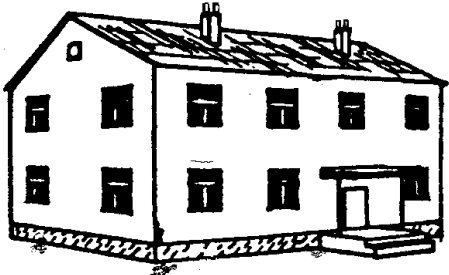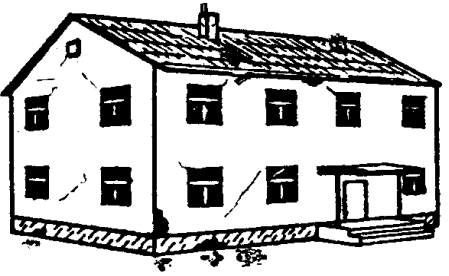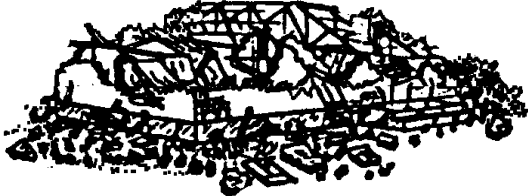
c) Most buildings of vulnerability class B sustain damage of grade 5.
   Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
   Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
   Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
   Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

Intensity XII: Completely devastating

c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

Classification of damage

Note: the way in which a building deforms under earthquake loading depends on the building type. As a broad categorisation one can group together types of masonry buildings as well as buildings of reinforced concrete.

Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage **(no structural damage, slight non-structural damage)** ▪ Hair-line cracks in very few walls. ▪ Fall of small pieces of plaster only. ▪ Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** ▪ Cracks in many walls. ▪ Fall of fairly large pieces of plaster. ▪ Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage **(moderate structural damage, heavy non-structural damage)** ▪ Large and extensive cracks in most walls. ▪ Roof tiles detach. Chimneys fracture at the roofline; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage **(heavy structural damage, very heavy non-structural damage)** ▪ Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction **(very heavy structural damage)** ▪ Total or near total collapse.

Classification of damage to buildings of reinforced concrete	
	Grade 1: Negligible to slight damage **(no structural damage, slight non-structural damage)** - Fine cracks in plaster over frame members or in walls at the base. - Fine cracks in partitions and infills.
	Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** - Cracks in columns and beams of frames and in structural walls. - Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	Grade 3: Substantial to heavy damage **(moderate structural damage, heavy non-structural damage)** - Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. - Large cracks in partition and infill walls, failure of individual infill panels.
	Grade 4: Very heavy damage **(heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	Grade 5: Destruction **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.
Definitions of quantity	
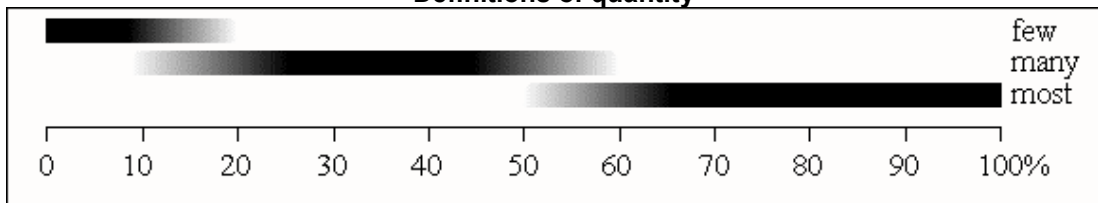
Grades 1 to 5 are often denominated as "D1" to "D5", respectively, whereas D0 stands for Undamaged structures.

APPENDIX B

Table B-1 Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
VMVDU - *Viceministerio de Vivienda y Desarrollo Urbano* (Vice-Ministry of Housing and Urban Development)	Ministry	The Vice-Ministry of Housing and Development is addressing the current problems in regard to Salvadoran Urban and Housing Development. Its mission is to promote norms, coordinate and facilitate the development and alignment of urban and territorial issues and to enable the population's access to housing. Post-earthquake reconstruction projects led by the Vice-Ministry: 1. Housing reconstruction project The objective was to provide a housing solution to the families affected by the earthquakes of 2001. The Government of El Salvador provided the Local Governments financial resources to remove rubble and debris, with the purpose of preparing the land for the construction, initially of the temporary houses and later of the permanent ones. 2. Temporary housing project This project (handled through FISDL) provided the Local Governments with construction materials and tools. The latter were given to the affected families, in order to proceed to the immediate construction of temporary shelters that would house them until the construction of the permanent houses. 3. Population reallocation project This project aimed at reallocating 50,000 families that had lost their houses due to the earthquakes, from their former highly vulnerable living areas, to new ones. $3,500 dollars of subsidies were given per family; of these, $2,000 were allocated for the reconstruction of new houses, while $1,500 for purchasing a lot. 4. Reconstruction project of permanent houses This project was addressed to the families that legally owned houses that were totally destroyed, but which could be reconstructed in their original lot. The beneficiaries of the project were the poorest families. Households with an income of up to two minimum wages received a subsidy of up to $ 2,000, and households with an income between two and four minimum wages received up to $1,000. 5. Rehabilitation of damaged houses This project was designed to support the families in the process of repairing their houses; the project granted $500 to each family. 6. Credit issuance mechanism for reconstruction This project opened lines of credit with favourable conditions for the population, so that they could repair or reconstruct their houses. The maximum amounts that were granted were of $7,000 for reconstruction and $3,000 for repair. The project was directed to families who had legal land ownership titles and who were able to cope with the terms of credit issuance.	http://www.vmvdu.gob.sv/default_english.htm

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
VMVDU - *Viceministerio de Vivienda y Desarrollo Urbano* (Vice-Ministry of Housing and Urban Development)	Ministry	7. Technical assistance project This project had two fundamental objectives: first, to create the capacity of the Salvadoran society to actively participate in the process of national reconstruction (with respect to the housing sector); and second, to support the local governments so that they could assume an important role in the process of community reallocation. 8. The PROARES project *Programa de la Unión Europea de Apoyo a la Reconstrucción de El Salvador (PROARES) para viviendas, infraestructura básica, social y comunal* - European Union program in support to the reconstruction of El Salvador, for housing and social, communal, basic infrastructure. This project is an initiative of the European Union (managed by the FISDL), encompassing the efforts of many other national institutions. This program started in March 2000 and will remain active until March 2005. The investment amounts to 32 million Euros, 25 million financed by the European Union and 7 million by the Government of El Salvador. The objectives are to: (a) contribute to the reconstruction process, following the 2001 earthquakes; (b) support the implementation of disasters' prevention measures; and (c) restore the social/housing indices that existed before the earthquakes in the Departments of Cuscatlán, La Paz and San Vicente, favouring local development and reducing the environmental vulnerability to natural catastrophes. The expected results are: a) the construction of permanent houses for low-income victims; b) the reconstruction of basic infrastructure facilities, such as the provision of potable water and sewage systems; c) the reconstruction of social infrastructure buildings, such as primary schools and health-centres; and d) the reconstruction of communal infrastructure.	http://www.vmvdu.gob.sv/default_english.htm

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
FONAVIPO - *Fondo Nacional de Vivienda Popular* (National Popular Housing Fund)	GO	The mission of these funds is to provide the low-income population with general financing opportunities, in order to improve their housing conditions. They are all actively involved in the reconstruction process, following the 2001 earthquakes.	http://www.fonavipo.gob.sv/#
FSV - *Fondo Social para la Vivienda*	GO		http://www.fsv.gob.sv/
FISDL – *Fondo de Inversión Social para el Desarrollo Local de El Salvador* (Social Investment Fund for Local Development)	GO		http://www.fisdl.gob.sv/fis_static/paginas/english.htm
ISDEM – *Instituto Salvadoreño de Desarrollo Municipal* (Salvadoran Institute for Municipal Development)	GO	This is an independent institution, specialized in giving technical, administrative, financial and legal assistance to municipalities, in the field of administration and planning. Its aim is to promote the creation of favourable conditions for economic progress and social welfare.	http://www.isdem.gob.sv/

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
COEN - *Comité de Emergencia Nacional* (National Emergency Committee)	GO	The mission of this Committee is to provide a constant and permanent process of prevention, mitigation and handling of the Emergencies and Disasters at a national level, based on the organization and the participation of the population.	http://www.gobernacion.gob.sv/Web-coen/front%20coen.htm
COMURES - *Corporación de Municipalidades de la República de El Salvador (*Corporation of Municipalities of the Republic of El Salvador)	Municipality Administra-tion	The Corporation of Municipalities of the Republic of El Salvador is an association of private and public utilities that groups the 262 municipal governments of the country.	http://www.comures.org.sv/comures/
FUSAI – *Fundación Salvadoreña de Apoyo Integral* (Salvadoran Foundation for Integral Support)	NGO	FUSAI is a non-profit association, created in 1993 assuming the continuity of the operations of the Salvadoran Association of Integral Support (ASAI), which was founded in 1988, with the support of the United Nations, and dissolved in 1995. Its mission is to promote and to implement integral solutions in order to diminish the deficit of housing and services in the vulnerable low-income communities of the country. Following, a list is given of selected recent housing projects: **Project** — **Resources** — **Duration** Reconstruction of the infrastructure damaged by the January 2001 earthquake — FUNDESO[†] — 2001- In-situ reconstruction of 116 dwellings in San Pedro, Nonualco — GTZ[‡] — 2001-2002 In-situ reconstruction of 536 dwellings in San Vicente — FONAVIPO — 2002- In-situ reconstruction of 536 dwellings in Ciudad Arce — CARE — 2002- Education / Qualification of the population, in order to participate in the Projects of Reconstruction for the 47 affected Municipalities after the earthquakes of January and February 2001 — RTI[*] — 2002-	http://www.fusai.org.sv/ Information on the **Hábitat** programme in: http://www.fusai.org.sv/habitat.html

[†] FUNDESO: *Fundación de Desarrollo Sostenible* (Foundation of Sustainable Development, NGO): http://www.fundeso.org/html/web/2003/112750.html.

[‡] GTZ (Gesellschaft für Technische Zusammenarbeit) - GATE (German Appropriate Technology Exchange) is a NGO specializing in environmental resource protection and dissemination of appropriate technologies for developing countries: http://www5.gtz.de/gate/.

[*] RTI International is a trade name of Research Triangle Institute. It is an independent organization dedicated to conducting innovative, multidisciplinary research that improves the human living conditions. With funding from the U.S. Agency for International Development (USAID), RTI worked with more than 40 municipal governments in El Salvador to plan, finance, and implement basic municipal services programs: http://www.rti.org/index.cfm.

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
CARE - Cooperative for Assistance and Relief Everywhere	NGO	CARE is one of the world's largest private international humanitarian organizations, committed to helping families in poor communities to improve their lives and achieve lasting victories over poverty. Responding to the 2001 earthquakes, CARE focused its aid on rural communities, located in the Departments of Usulután, San Vicente, La Paz and Cuscatlán, where the damage and need was the greatest. In these areas, CARE also delivered aid through a network of local partner organizations and community associations. Through financing from the U.S. Agency for International Development, USAID, of a total of $14,995,735, two major housing reconstruction projects have been undertaken by CARE, aiming at the construction of seismic-resistant, permanent houses. During phase I of the project (23/03/01 – 28/02/03), 1,009 units were built, while during phase II (13/06/02 – 31/01/04) 2,900 more units were completed. The collaborating counterparts of this project include: FUNDAMUNI[1], FUNDESA[2], REDES[3], ILP[4], VMVDU, FUSAI, *Visión Mundial* (a Christian organization http://www.visionmundial.org/), and COMURES.	http://www.care.org/
CHF International - The Cooperative Housing Foundation	NGO	CHF International helps people throughout the world improve their lives through development of community, habitat, and finance. Historically focused on housing, CHF now addresses concerns in the areas of environment, infrastructure, income-generation, civil society, health, and emergency management. Beginning in 1952, CHF helped families build affordable housing in rural America and in low-income urban neighbourhoods, primarily by organizing local housing cooperatives. In the 1960s, the U.S. Agency for International Development (USAID) asked CHF to apply its models of cooperative housing, micro-lending, self-help construction, and community organizational development in Central America. Within the framework of post-earthquake response projects, addressing the need for temporary and permanent shelter, CHF constructed 11,246 temporary housing units and is in the process of providing 5,000 permanent ones. The financing of these projects comes from USAID and the construction is realized in coordination with local governments, FISDL, COEN, ILP, national and international NGOs and private companies.	www.chfhq.org

[1] FUNDAMUNI (*Fundación de Apoyo a Municipios de El Salvador* - Foundation for the support to the Municipalities of El Salvador): This foundation is dedicated to foster, promote and facilitate processes of local development, with the participation of the population, mainly in rural and poor municipalities of the country.

[2] FUNDESA (*Fundación para el Desarrollo* – Foundation for the Development): This foundation aims at supporting sustainable development of rural communities, by enhancing the local organizational, economic, political and social capacities (see: http://www.fundesa.org.sv/fundesa/).

[3] REDES (*Asociación de Reconstrucción y Desarrollo de El Salvador*): This is a private non-profit institution, founded in 1989 to assist the process of repatriation of displaced population and refugees (see: http://www.alpimed.org.sv/redes.asp).

[4] ILP (*Instituto Libertad y Progreso* – The Institute for Liberty and Progress): The institute's main goal is (through the project: "*Programa El Salvador, País de Propietarios*") to facilitate and assure resources for the legalization of property and to speed up the registry inscription, benefiting low income persons living in marginal zones, slums, illegal lots, etc., nationwide and (through the project: "*Programa de Seguridad Jurídica Rural*" - PROSEGUIR), to give individual judicial security to each beneficiary from the Program, through the partition of lots that currently are owned collectively (see: http://www.vmvdu.gob.sv/web_personal/ILP.htm).

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
FUNDASAL - *Fundación Salvadoreña de Desarrollo y Vivienda Mínima* (Salvadoran Foundation of Development and Basic Housing)	NGO	The mission of this organization is to promote sustainable social development, through the improvement of housing conditions and support to the productive activities of the socially excluded rural and urban population. Recent projects: (a) Rehabilitation of precarious settlements (in Las Palmas, Los Manantiales and Las Mercedes, with the financial contribution of the German government); (b) Setting up new settlements (in El Sauce) and (c) Production of educative material (e.g. 8 videos related to natural phenomena and disasters, images on the effects caused by earthquakes, systems of construction with alternative materials and vulnerability assessment of the poor communities and families of the country).	http://www.fundasal.org.sv/
UNES - *Unión Ecológica Salvadoreña* (Salvadoran Ecological Union)	NGO	This organization has constructed an earthquake-resistant model adobe house. According to AFSC (American Friends Service Committee); this model house was the only one left standing when the 2001 El Salvador earthquakes occurred (see: http://www.afsc.org/emap/help/peru706.htm).	http://www.unes.org.sv/unes/index.html
AFSC - American Friends Service Committee	NGO	The American Friends Service Committee (AFSC) is a Quaker organization that includes people of various faiths who are committed to social justice, peace, and humanitarian service. AFSC is exploring ways to support the efforts of the Salvadoran Ecological Association (UNES) to promote the construction of environmentally friendly adobe houses, both in El Salvador and in other Central American countries.	http://www.afsc.org/
Fundación Habitat	NGO	The Habitat Foundation is a private non-profit organization, primarily aiming to promote the integral improvement of the person, the family and the communities of limited economic resources of El Salvador, especially through the provision of housing solutions and answers to environmental problems, both in urban zones, as well as in the rural ones.	www.fundhabitat.org.sv
SACDEL - *Sistema de Asesoría y Capacitación para el Desarrollo Local* (Consultancy and Qualification System for the Local Development	NGO	A private non-profit organization created with the basic function to promote participative democracy and sustainable human development. Interesting project: "Local Economic Development", action "Cooperative of production of construction equipments from local resources (municipalities of Santa Elena and Verapaz)".	http://www.sacdel.org.sv/
Asociación Equipo Maíz (Corn Team Association)	NGO	This is a community development organization, devoted to popular education, through the production of fun, easy-to-read publications on issues including fair trade, gender, the environment, and disaster prevention. This group partnered with the National University and other NGOs in disseminating the know-how regarding the construction of low-cost, self-built, earthquake-resistant adobe houses.	-

Table B-1 (cont'd) Actors in the Salvadoran sector of popular housing.

Name	Type of institution/ organization	Short Description	Web Site
OXFAM - America	NGO	Oxfam America is part of a 12-member confederation of development organizations, Oxfam International. Oxfam International organizations fund development projects in more than 100 countries, collaborating on strategic, long-term efforts to help build strong local organizations that can promote self-sufficiency. Among other actions, Oxfam International affiliates provide rapid humanitarian assistance in emergencies. In incidences of war, natural disaster, and other crises, Oxfam funnels funds, contribute expertise, and influence key actors to relieve suffering and help communities get back on the road to a healthy, sustainable future. The participation of this organization to post-earthquake relief/rehabilitation processes in El Salvador was immediate and extensive. (see: http://www.oxfamamerica.org/emergency/art733.html)	www.oxfamamerica.org www.oxfam.org
EHC - The Earthquake Hazard Centre	Network	An information network and dissemination centre for earthquake-resistant construction in Developing Countries.	http://www.ehc.arch.vuw.ac.nz/
ASIA - *Asociación Salvadoreña de Ingenieros y Arquitectos* (Salvadoran Association of Engineers and Architects)	Professional Association	Specialists well acquainted with practice for safety evaluation and retrofitting procedures for engineered and non-engineered construction.	http://www.asia.org.sv/
CASALCO - *Cámera Salvadoreña de la Industria de Construcción* (Salvadoran Chamber of Construction Industry)			www.casalco.org.sv/
Federación Salvadoreña de Ingenieros, Arquitectos y Ramas Afines			-

APPENDIX C

Table C-1 Joint coordination networks for the comprehensive management of disaster risk and housing deficit.

Name	Short Description	Web Site
CEPREDENAC - Coordination Centre for the Prevention of Natural Disasters in Central America	CEPREDENAC was established in 1988 as a coordination centre for strengthening the capacity of the region, as a whole, to reduce the vulnerability of the population to the effects of disastrous phenomena. The Centre promotes and coordinates the international cooperation, the exchange of information, experience, technical and technological advice in matters of prevention in order to reduce the natural disasters, and thus contribute to the improvement in decision making about planning and management that will benefit the Central American area. Ongoing programmes relevant to the strengthening of structures and seismic protection are (see: http://www.cepredenac.org/11_engl/program.htm): (i) FEMID: "Strengthening of Local Structures for Disaster Mitigation" (*Fortalecimiento de Estructuras Locales Para la Mitigación de Desastres*) - a regional Program which has received technical and financial support from Germany, through the German Cooperation Agency (GTZ) and the European Commission Humanitarian Office (ECHO); (ii) RELSAT: "Strengthening Local Structures and Early Alert Systems" (*Reforzamiento de Estructuras Locales y Sistemas de Alerta Temprana*) - supported by the Swedish International Development Agency (SIDA). Its main focus is institutional development of CEPREDENAC and its affiliated institutions; (iii) RESIS: "Reduction of Natural Disasters in Central America, Earthquake Preparedness and Hazard Mitigation" (*Mitigación del Riesgo Sísmico y Preparativos para Terremotos*) - supported by the Norwegian Agency for Technical Cooperation (NORAD). The objective is to strengthen seismological institutions and national projects, including seismic micro-zonation and risk analysis.	http://www.cepredenac.org/11_engl/11_index.htm
La Red de Estudios Sociales en prevencion de desastres en America Latina (The Network of Social Studies in prevention of disasters in Latin America)	The NETWORK was created in 1992 in Port Lemon, Costa Rica by a multi-disciplinary group of 16 specialists in disaster-related subjects and belonging to governmental, nongovernmental, academic and international institutions from 7 countries (Brazil, Canada, Colombia, Costa Rica, Ecuador, Mexico and Peru). Initially conceived as a mechanism to facilitate the comparative investigation on the disasters from a social perspective, nowadays the NETWORK has become the space of encounter of hundreds of people and institutions involved in the management of the risks and the disasters that affect the different countries from Latin America and the Caribbean, as well as other countries in the world.	http://www.desenredando.org/

Table C-1 (cont'd) Joint coordination networks for the comprehensive management of disaster risk and housing deficit.

Name	Short Description	Web Site
CEPRODE - *Centro de Protección para Desastres* (Disaster Protection Centre)	CEPRODE is a non-profit Association of public utility and of social interest, founded in 1991. It bases its activity in principles of human promotion and social solidarity, qualification and social investigation and conservation of natural resources in communities of high risk. CEPRODE's work is related to research in thematic areas of natural disasters, environment and natural resources preservation, education in risk management, and others. All the projects incorporate communitarian organization, disaster awareness of the population in risk and environmental education.	http://www.ceprode.org.sv
CRID - *Centro Regional de Información sobre Desastres, America Latina y el Caribe* (The Regional Disaster Information Centre)	The Regional Disaster Information Centre is an initiative sponsored by six organizations that decided to join efforts to ensure the compilation and dissemination of disaster-related information in Latin America and the Caribbean.	http://www.crid.or.cr/crid/ing/index_ing.html
EIRD - *Estrategia Internacional Para la Reducción de Desastres* (International Strategy for Disaster Reduction - ISDR)	The UN has ISDR as a global framework for action with a view to enabling all societies to become resilient to the effects of natural hazards and related technological and environmental disasters, in order to reduce human, economic and social losses. It is based on a conceptual shift from the sheer protection against hazards to the management of risk through the integration of disaster reduction into sustainable development. The implementation of the Strategy is premised on the establishment of partnerships between governments, non-governmental organizations, UN agencies, the scientific community, the media as well as other relevant stakeholders in the disaster reduction community. The four goals of the ISDR are to increase public awareness about disaster reduction, to obtain commitment from public authorities, to stimulate inter-disciplinary and inter-sectoral partnerships, and the improvement of the scientific knowledge of the causes of natural disasters and the consequences of natural hazards.	http://www.eird.org
WSSI - WORLD SEISMIC SAFETY INITIATIVE	WSSI, an undertaking of the International Association of Earthquake Engineering (IAEE), was founded to advance and spread earthquake engineering knowledge worldwide. Its goals are to: a) enhance the distribution of earthquake engineering information and knowledge so that engineers can design and construct earthquake-resilient structures; b) improve earthquake engineering practices for all types of construction by incorporating experience and research findings into recommended practices and codes in earthquake-prone countries; and c) advance engineering knowledge through problem-focused research. WSSI sponsors projects that will: a) transfer technology; b) develop professional engineering practice; and c) address crucial research questions that constitute gaps in our knowledge of structures respond to earthquakes and how they can be built to withstand them.	http://www.wssi.org

Table C-1 (cont'd) Joint coordination networks for the comprehensive management of disaster risk and housing deficit.

Name	Short Description	Web Site
EMI - Earthquakes and Megacities Initiative	EMI is an international scientific, non-governmental organization dedicated to the acceleration of earthquake preparedness, mitigation, and recovery of large urban areas (i.e., Megacities). EMI is a catalyst for scientific and technical knowledge to the end-users. EMI focuses its efforts on developing capacity in Megacities of the developing world where the effects of earthquakes could be devastating to the people, their economy, their culture, and their environment (see: http://www-mega/downloads/3cdPgmDefinition-Vs2.pdf).	http://www-megacities.physik.uni-karlsruhe.de/
MINURVI - *Entidad de coordinación y de cooperación intergubernamental de los países de América Latina y del Caribe, en el área del desarrollo sustentable de los asentamientos humanos*	This is the coordinating and intergovernmental cooperation entity of the Latin American and Caribbean countries, in the area of sustainable development of human settlements. It is composed by the Ministers of State and the other governmental authorities under whose competence are found, in the respective countries, the affairs linked to the sustainable development of human settlements. Each country-member must designate the governmental authorities, which will represent them in the MINURVI meetings. The objectives are to: 1. Represent the Latin American and Caribbean interests as regards to the themes of sustainable development of human settlements; 2. Contribute and follow up the implementation of the agreements, directions, and strategies related to the Habitat Agenda, with the Agenda 21, as regards to, and specially the Regional Action Plan on Human settlements for Latin America and the Caribbean and the Regional Action Plan on Human Settlements in the Caribbean.; 3. Promote the exchange and discussion of the experiences amongst the member countries in the field of housing and development; 4. Promote and implement work programs common to the countries of the regions and sub-regions.	-
FUNDEMUCA - *Fundación para el Desarrollo Local y el Fortalecimiento Municipale Institucional de Centroamérica y el Caribe*	The Foundation for the Local Development and the Municipal and Institutional Fortification of Central America and the Caribbean.	-
Fundeso - *Fundación para el Desarrollo Sostenible* (Foundation for Sustainable Development)	This is a non-profit private foundation (NGO) that promotes programs of integral and sustainable development in developing countries, and in Latin America especially. The principles of Fundeso are the recognition and promotion of human dignity, the support of self-development and of self-sufficiency of the populations with which it works.	http://www.fundeso.org/html/web/2003/112750.html

Table C-1 (cont'd) Joint coordination networks for the comprehensive management of disaster risk and housing deficit.

Name	Short Description	Web Site
CCVAH - *Consejo Centroamericano de Vivienda y Asentamientos Humanos* (The Central American Council for Housing and Human Settlements)	The Central American Council of Housing and Human Settlements was created on 3 June, 1992, at a meeting of the Senior authorities Sector held in Managua, Nicaragua. It gathers the ministries and regulatory institutions of the seven countries of the region. Between 1995 and 1996, the CCVAH led in the region the preparatory process of Habitat II, which it led, among other things, to the formulation of the Regional Plan of Action in Human Settlements 1996- 2000. Three elements constitute the Institutional Mandate of the CCVAH: ▪ Consolidate the management of the Housing and Human Settlements Sector at the regional level, promote the integration of policies and strategies, and facilitate the development of human resources, share experiences, and institutional strengthening. ▪ Bring into line, in the Central American region, the growth of human settlements with social and economic policies, and urban planning with environmental protection. ▪ Promote the international cooperation in technical and financial aspects related to the Sector.	http://www.sgsica.org/instituciones/inst_reg/ccvah.php also see: http://www.sgsica.org/instituciones/index.php
FEMICA - *La Federación de Municipios del Istmo Centroamericano* (The Federation of Central American Isthmus Municipalities)	FEMICA is a non-profit organization, created in September 1991, representing the one hundred thousand eighty-five municipalities of Central America. Its mission is to consolidate local democracy, by strengthening the relations of the municipalities with the local civil society, in order to promote the decentralization processes and respond to the problems of local governance. FEMICA is part of the International Union of Local Authorities (IULA).	http://www.femica.org/
FCOC - *Federación Centroamericana de Organizaciones Comunales* (Central American Federation of Community Organizations)	Member of the federations of community grassroots organizations, FCOC is the Central American chapter of the Continental Front of Community Organizations, based in Managua in February 1987. Since then, it has been promoting a process of approximation, exchange, and coordination among regional community organizations. It integrates 12 national organizations, from Belize to Panama. This federation has been actively involved in the impetus to the Central American Alliance for the Participatory Management of Human Settlements. Some of its national associates develop housing programs at the community level. Their objectives are: ▪ To improve the quality of life of the inhabitants, to search for a better life for the Central Americans within the heart of the communities. ▪ To work for the integral development through the leading participation of citizens. ▪ To fight against poverty, underdevelopment and inequality, in the context of the search for a lasting peace in the Region, as part and as an expression of the desired integration.	http://agora.ya.com/fcocca/fcoc/fcoc.htm

Table C-1 (cont'd) Joint coordination networks for the comprehensive management of disaster risk and housing deficit.

Name	Short Description	Web Site
FORHUM (The Superior School of Habitat and Local Development)	FORHUM is a network of non-governmental organizations and university centres related to habitat management, which is structuring a regional Program for human resources education, with emphasis on local risk management and human mobility, based on the experience developed for nearly nine years in the Andean Region. The educative program is designed and executed by four institutions of the Andean region of Latin America: the CEHAP[1] of the National University of Colombia, CITY of Ecuador, CERES[2] of Bolivia and CIDAP[3] of Peru.	http://www.cidap.org.pe/forhum.htm
ACENVI - *Asociación Centroamericana para la Vivienda* (The Central American Association for Housing)	This Association gathers public and private institutions working in the field of housing financing. It has a Regional Directory that coordinates with the National Executive Secretariats and the General Secretariat. In the last period it has been committed to the promotion of regional mechanisms that make possible to improve the acquisition of internal and external financial resources for the construction of houses.	www.fonavipo.gob.sv/acenvi.htm

[1] CEHAP: *La Escuela del Hábitat* - The School of Habitat (formerly known as Training centre for the Popular Habitat) is assigned to the Faculty of Architecture of the National University of Colombia (http://www.unalmed.edu.co/tmp/maestria_habitat.html#_Toc17781905).

[2] CERES: *Centro de Estudios de la Realidad Económica y Social* - Training centre of the Economic and Social Reality (http://www.ceresbolivia.org/).

[3] CIDAP: *Centro de Investigación, Documentación y Asesoría Poblacional* – Research, Documentation and Consultancy Centre for the Population (http://www.cidap.org.pe).

APPENDIX D

Demonstration project

The following information has been extracted from the report of the "Field Shake Test Program", carried out by the Ahmedabad Study Action Group (A.S.A.G.)[1], as part of a broader rehabilitation scheme addressing the affected population of the Marathwada region of Maharashtra State, in Western India, following the Latur earthquake of 1993.

A.S.A.G. aimed at enhancing peoples' ability to ensure their own long-term safety against future earthquakes, following an approach of "learning while doing". During the first three and a half years after the earthquake, A.S.A.G. successfully demonstrated appropriate alternatives for seismically safe new constructions, as well as the proper repair and retrofitting techniques for improving the seismic resistance of existing houses.

Within the framework of the aforementioned actions, A.S.A.G. also took up a programme of awareness and confidence build-up in earthquake hazard reduction measures. This required the development of effective means of communication. As a result, posters, brochures, booklets, manuals, video films, etc. were developed and used through meetings, group discussions, display of videos, posters, models, etc. that took place in the villages, in bus terminals and in village fairs. A.S.A.G. also organized a large number of training programmes for local masons, but it was difficult to convince house owners about the effectiveness of the proposed earthquake-resistant measures.

Realizing that it was imperative for the trained masons to have confidence in the technologies that they were promoting and subsequently implementing, A.S.A.G. proceeded to the initiation of the Field Shake Test Program. The primary objectives of this project were:

- To build peoples' confidence in earthquake-resistant building technologies, including the retrofitting of existing houses.
- To impress upon the people the consequences of living in seismically unsafe houses.
- To make a video film for a larger audience in different parts of the state and the country.
- To enhance the understanding of the performance of simple structures, with and without earthquake resisting features under the impact of an earthquake.
- To evolve a setup that can be used by others for future exploration in this field.

The tests consisted of simultaneously subjecting two half-scale structures of the same type, one strengthened and one traditionally built, to a sequence of gradually increasing horizontal shocks and monitoring their comparative performance. The specimens were mounted on a platform, which was undergoing a series of horizontal shocks, produced by a tractor, dashing against the platform. The intensities of the shocks were varied approximately by varying the speed of the tractor at the time of impact.

Typically, in each test one of the structures was of a type commonly built by the people, and the other was its improved version, or a better alternative. Each pair's long sides were perpendicular to the direction of the platform movement (i.e. North-South direction). The pairs of specimens involved in the tests are given in the following Table, followed by photos of the third test.

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[1] See: "*FIELD SHAKE TEST PROGRAM - A SURE WAY OF CONFIDENCE BUILDING IN QUAKE RESISTANT BUILDING TECHNOLOGY*", August 1999, Ahmedabad Study Action Group, Kashmira Chambers, 5th Floor, Behind Popular House, Navarangpura, Ahmedabad, GUJARAT 380009, INDIA. Test Report Prepared by Rajendra Desai & K.S. Jagadish, funded by BILANCE, Netherlands (www.antenna.nl/bilance).

Table D-1 Pairs of specimens involved in the "Field Shake Test Program", carried out by the Ahmedabad Study Action Group (A.S.A.G.).

Test #	Traditional Structure	Improved Structure
1	**Walls**: 300 mm thick & 1150 mm high, of UCRM[2] Masonry. **Roof**: "Malwad" roof, without posts, with 300 mm thick mud layer and traditional timber understructure, consisting of 100mm x 50mm main beams, cross beams and planks, resting directly on the walls.	**Walls**: 300 mm thick & 1150 mm high, of UCRM in mud mortar, retrofitted with 37.5 mm thick reinforced micro-concrete band under the roof level, and reinforced concrete bond elements (one every 0.25 m[2] of wall surface). **Roof**: "Malwad" roof, with timber joists resting on and tied down to the band with a 3 mm wire, at a spacing of 300 mm. In-plane diagonal ties of 2-3 mm wires under the roof plane. The mud layer is 100 mm thick.
2	**Wall**: 175 mm BBMM[3] with cement plaster on inside & outside faces. **Roof**: CGI[4] sheet placed directly on walls and one purlin, and weighed down with boulders.	**Wall**: 220 mm UCRM with roof level reinforced micro-concrete band & mid-height reinforced micro-concrete corner bracket. **Roof**: CGI sheet anchored to 50 mm round timber wall plate, with J-Hooks. Wall top diaphragm made of timber planks, a timber strut and diagonal 2-3 mm wire ties, pre-tensioned by twisting.
3	**Wall**: 115mm BBCM[5] with mud plaster on inside & outside faces **Roof**: CGI sheet placed directly on walls and one purlin, and weighed down with boulders.	**Wall**: 115 mm BBMM with roof level reinforced micro-concrete band & mid-height reinforced micro-concrete corner bracket. **Roof**: CGI sheet anchored to 50mm round timber wall plate with J-Hooks. Wall top diaphragm made of timber planks, a timber strut and diagonal 2-3 mm wire ties, pre-tensioned by twisting.
4	**Wall**: 150 mm Adobe (sun dried mud block) masonry in mud mortar with mud plaster on all faces. **Roof**: CGI sheets placed directly on wall and a wood purlin, and weighed down with boulders.	**Wall**: 150 mm special adobe (with "V" shaped groove along its long side) in mud mortar, plastered with mud on all faces with lintel level bamboo band and mid-height level chicken wire mesh, plus vertical 2 mm wire reinforcement on all faces. **Roof**: CGI sheets anchored to wall plates with "J" hooks. Wall top diaphragm made of timber planks, a timber strut and diagonal 2-3 mm wire ties, pre-tensioned by twisting. Wall top diaphragm anchored to walls with 2 mm wire reinforcement.

(source: http://thinkcycle.media.mit.edu/thinkcycle/main/development_by_design_2001/enhancing_earthquake_resistance_through_upgraded_vernacular_building_systems___facilitating_evolution_of_its_delivery_system/field_shaketable_test.pdf)

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[2] *Uncoursed Rubble Masonry in Mud Mortar.*
[3] *Burnt Brick In Mud Mortar.*
[4] *Corrugated Galvanized Iron.*
[5] *Burnt Brick in Cement Mortar.*

(a)

(b)

Fig. D-1   (a) Conventional building on the left, shortly before total collapse; (b) Improved building on the left, conventional building on the right at collapse. (source: http://www.ehc.arch.vuw.ac.nz/newsletters/oct99/page4.htm)

APPENDIX E

Libraries & Information Services

INSTITUTO MEXICANO DEL CEMENTO Y DEL CONCRETO, A.C.

BIBLIOTECA - IMCYC (http://www.imcyc.com/)
Search parameters: Tema: AUTOCONSTRUCCION Subtema: GENERAL
Display of some of the results:

- ANALISIS GENERAL DEL DESARROLLO DE PROYECTOS DE EMERGENCIA POR AUTOCONSTRUCCION
- ASPECTOS CUALITATIVOS DE LA AUTOCONSTRUCCION
- AUTOCONSTRUCCION
- AUTOCONSTRUCCION EN FILIPINAS CON LA COLABORACION GUBERNAMENTAL
- AUTOCONSTRUCCION ESPONTANEA: SOLUCION O PROBLEMA?
- AUTOCONSTRUCCION UTILIZANDO TECNOLOGIAS SOCIALMENTE APROPIADAS, EN CHILE
- AUTOCONSTRUCCION VERTICAL
- AUTOCONSTRUCCION. YAREA GIGANTESCA DE LA CONSTRUCTORA PUEBLO
- CARACTER ECONOMICO-SOCIAL DE LA AUTOCONSTRUCCION EN AMERICA LATINA
- COMPONENTES CONSTRUCTIVOS DE LA PRODUCCION INFORMAL DE VIVIENDAS CASO DE MARACAIBO, VENEZUELA
- CONCRETO PARA VIVIENDAS DE MUY BAJO COSTO EN PAISES EN DESARROLLO
- CONSIDERACIONES A IDEALIZACIONES DEL CALCULO ESTRUCTURAL ANTISISMICO DE VIVIENDAS DE BAJO COSTO
- CURSO SOBRE TECNICAS CONSTRUCTIVAS INDUSTRIALIZADAS PARA VIVIENDAS DE BAJO COSTO EN AMERICA LATINA
- EL CONCRETO EN LA AUTOCONSTRUCCION Y REHABILITACION DE LA VIVIENDA
- EL SIGNIFICADO POTENCIAL DE LA AUTOCONSTRUCCION PLANIFICADA
- EXPERIENCIAS DE AUTOCONSTRUCCION DE VIVIENDA EN MEXICO
- EXPERIENCIAS EN LA AUTOCONSTRUCCION DENTRO DEL PROGRAMA APOYO TECNICO A LA COMUNIDAD DE LA E.S.I.A. ZACATENCO
- FERROCEMENT, PREFABRICATION, SELF-HELP FOR LOW COST HOUSING
- FORMALIZACION DEL SECTOR INFORMAL DE VIVIENDA EN AMERICA LATINA
- HORMIGON: UN PUNTO DE VISTA COMO MATERIAL PARA VIVIENDA DE BAJO COSTO
- INDUSTRIA RURAL DE AUTOCONSTRUCCION
- INVESTIGACIONES EN AUTOCONSTRUCCION
- L AUTOCOSTRUZIONE NEL MEZZOGIORNO
- L INFORMAZIONE TECNICA PER L AUTOCOSTRUZIONE
- LA APLICACION DEL FERROCEMENTO A LA CONSTRUCCION DE VIVIENDA DE BAJO COSTO
- LA AUTOCONSTRUCCION COMO ALTERNATIVA DE VIVIENDA
- LA CONSTRUCCION DE LA VIVIENDA DE BAJO COSTO EN BRASIL
- LA CONSTRUCCION EN MADERA: SU INDUSTRIALIZACION
- LA PRODUCCIONDE MATERIALES DE CONSTRUCCION LOCALES A BASE DE MATERIALES VEGETALES
- LA TECNOLOGIA DE LA VIVIENDA TAMBIE COMO PROCESO SOCIAL
- LA TIERRA UN MATERIAL A INVESTIGAR
- LA TIERRA
- LA VIVIENDA AUTOSUFICIENTE
- LA VIVIENDA INFORMAL. LA MAS AVANZADA TECNOLOGIA EN AMERICA LATINA: POLITICAS PARA FACILITAR LA CONSTRUCCION DE ALOJAMIENTOS
- LA VIVIENDA RURAL, MUCHOS MITOS Y UNA META
- LAS CONSTRUCCIONES CON TIERRA, HOY UNA VISION DESDE LATINOAMERICA
- LAS CONSTRUCCIONES DE TIERRA OBJETO DE RESTAURACION
- LOW COST CONSTRUCTION RESISTANT TO EARTHQUAKES AND HURRICANTES
- LOW-COST HOMES ARE AGAIN ALL BRICK
- LOW-COST HOUSING WITH WOOD IN LATIN AMERICA

- MANOS A LA OBRA. EMPLEOS IMPORTANTES PARA QUE USTED CONSTRUYA O REFORME SU CASA
- MANUAL DE AUTOCONSTRUCCION
- MANUAL DE AUTOCONSTRUCCION Y MEJORAMIENTO DE LA VIVIENDA
- MANUAL DE CONSTRUCCION DE VIVIENDA POPULAR
- MATERIALES DE RESIDUOS SOLIDOS APLICABLES A SISTEMAS CONSTRUCTIVOS PARA LA VIVIENDA DE BAJO COSTO
- MATERIALES, TECNOLOGIAS Y PROTOTIPOS DE VIVIENDA DE MUY BAJO COSTO
- NEW BUILDING MATERIALS FOR ULTRA LOW-COST HOUSING IN DEVELOPING COUNTRIES
- PILOT HOUSING PROJECT IN CENTRAL AMERICA
- PROCESO DE CONSTRUCCION PARA VIVIENDAS DE BAJO COSTO BASADO EN TECNICAS DE CAPAS DE MORTERO ARMADO
- RECOMENDACIONES PARA AUTOCONSTRUCCION
- SISTEMAS CONSTRUCTIVOS EN COLOMBIA, CUBA Y VENEZUELA
- SISTEMAS CONSTRUCTIVOS MAS UTILIZADOS EN EL PERU: MEJORAS PROPUESTAS
- SISTEMAS INDUSTRALIZADOS PARA CONSTRUCCION DE VIVIENDAS EN GUATEMALA
- SITUACION ACTUAL Y LINEAMIENTOS TECNOLOGICOS PARA LA VIVIENDA DE BAJOCOSTO EN EL ECUADOR
- SITUACION DE ALOJAMIENTO EN BRASIL Y UTILIZACION DE SISTEMAS DE AUTO-AYUDA Y AYUDA MUTUA EN LA PRODUCCION DEL AMBIENTE CONSTRUIDO
- TECNOLOGIA MEJORADA PARA LA CONSTRUCCION DE MUROS DE ADOBE
- TECNOLOGIE APPROPRIATE: AUTOCOSTRUZIONE E INDUSTRIA EDILIZIA
- UNA PROPUESTA ESQUEMATICA PARA EL ANALISIS DE LA AUTOCONSTRUCCION EN LATINOAMERICA COMO FENOMENO MASIVO Y PLURAL
- UTILIZACION DE MATERIALES AUTOCTONOS EN LA CONSTRUCCION DE VIVIENDAS EN ZONAS TROPICALES EN AMERICA LATINA
- VENTA MODULADA DE MATERIALES A LA POBLACION PARA LA AUTOCONSTRUCCION
- VIVIENDA DE CONCRETO DE MUY BAJO COSTO
- VIVIENDA DE MUY BAJO COSTO
- VIVIENDA EN ADOBE
- VIVIENDA POR AUTOCONSTRUCCION
- VIVIENDA RURAL Y URBANA DE BAJO COSTO
- VIVIENDA SIN COSTO

Other documents can be ordered from:
La Fundación HABITAT COLOMBIA: http://www.fundacionhabitatcolombia.org

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