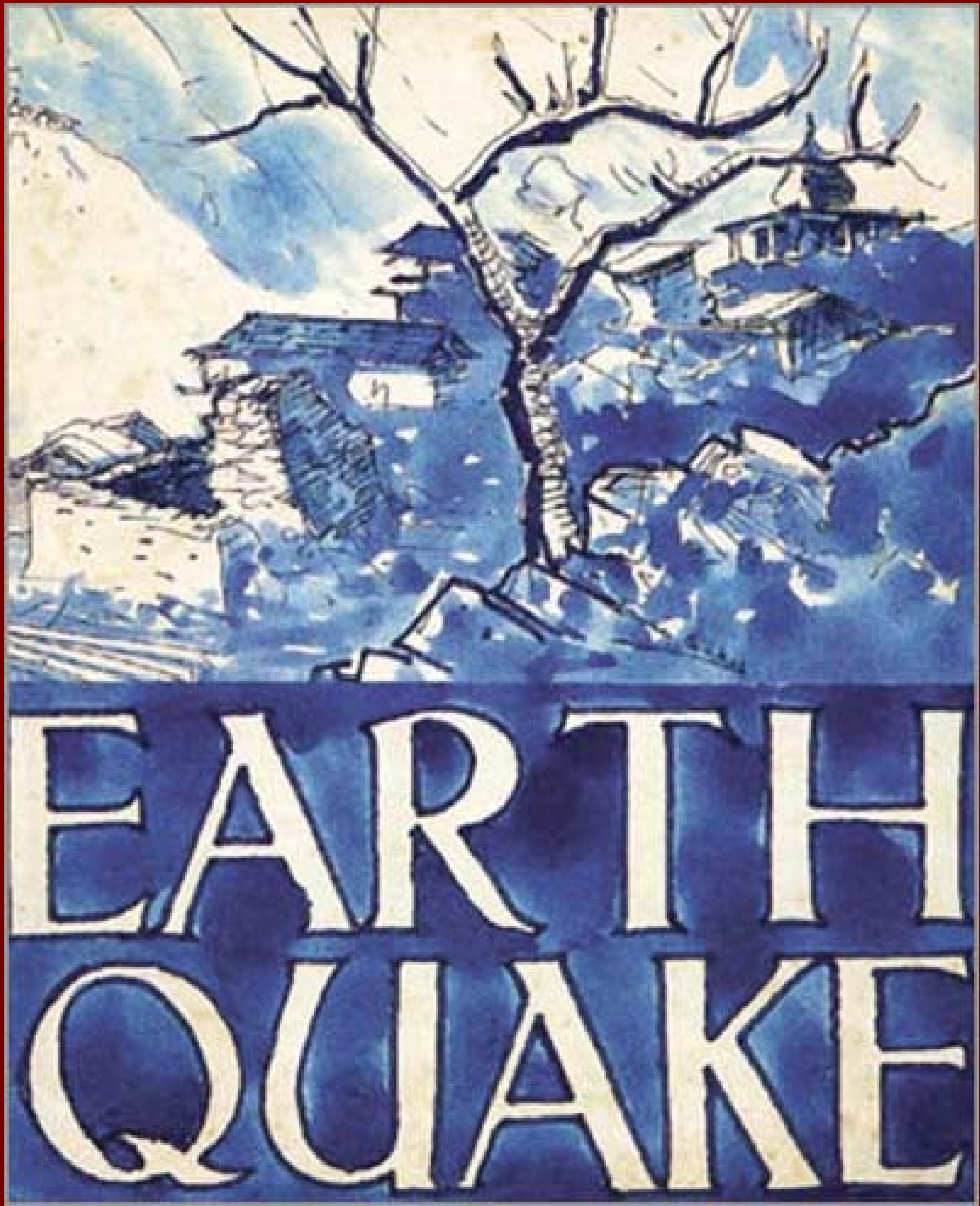
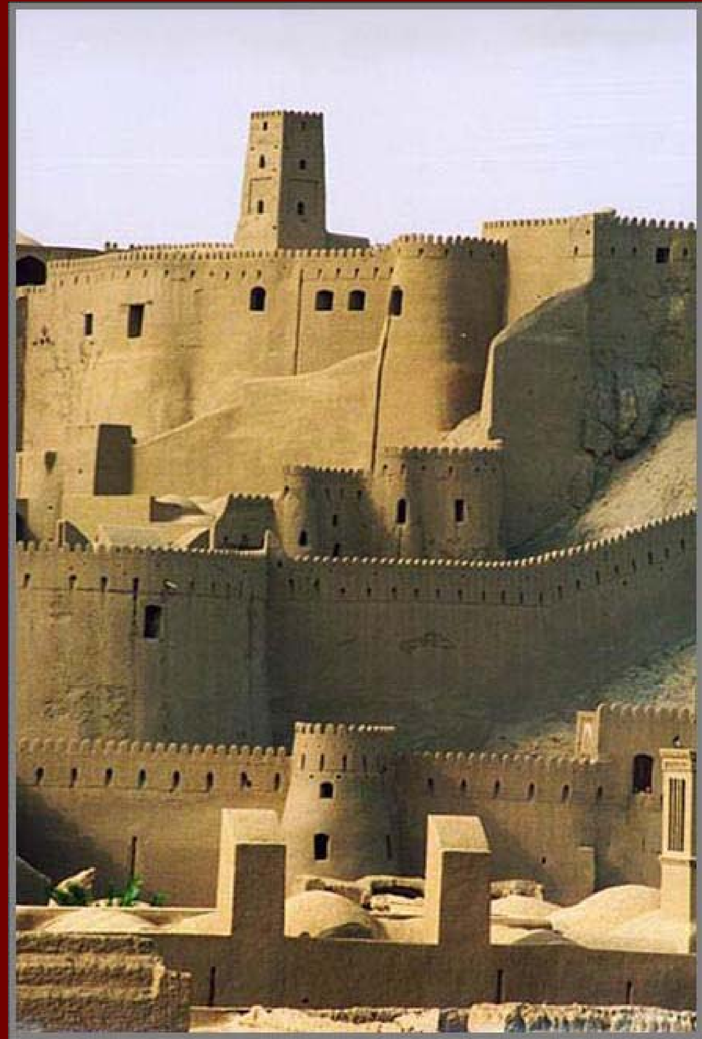
Earth construction





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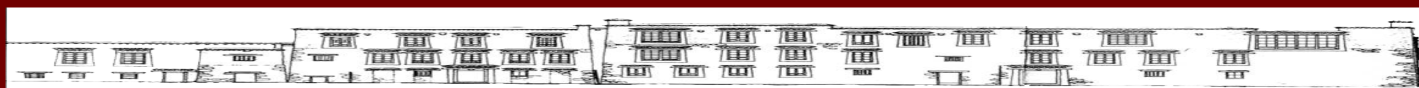
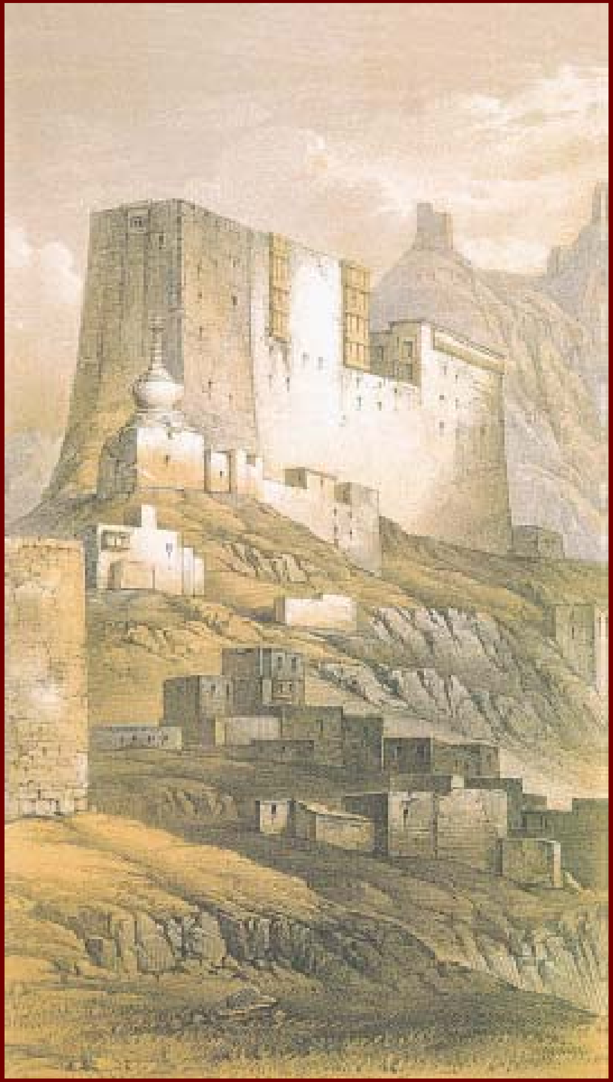


Earth construction

Earth as a building material has lost its credibility chiefly because most modern houses with earth walls cannot withstand earthquakes, and because earth is viewed a building material for the poor.

In this context, it is worth mentioning that a census conducted by the Salvadoran government after the earthquake of January 13, 2001 (measuring 7.6 on the Richter scale), states that adobes houses were not worse affected than other types of construction.

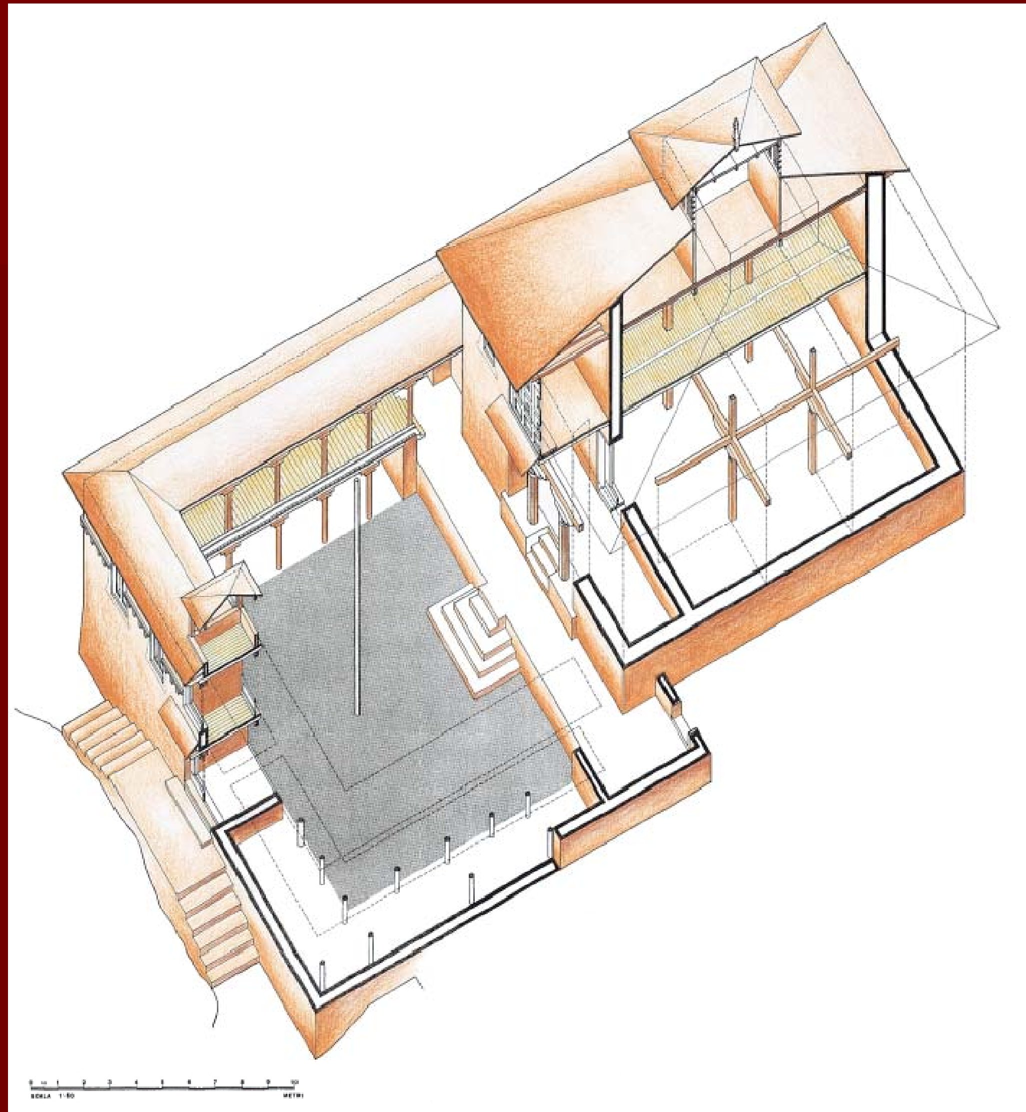
On the other hand, many historical earthbuildings have withstood several strong earthquakes in recent centuries, for example the condominiums of the Hakas in China and many solid rammed earth fincas in Argentina. But also houses with lightweight roofs and flexible wattle-and-daub walls can withstand earthquake shocks because of their ductility (flexibility).



The quality of an earthquake-resistant structure can be expressed in the formula: structural quality = resistance x ductility

This means that the lower the resistance of a given structure, the higher its flexibility must be, while the higher its flexibility, the lower the required resistance.

It is not earth as a building material which is responsible for structural failures, but instead the structural system of a given building and the layout of its openings, as discussed in the following sections.



Condominiums of the Hakas in China

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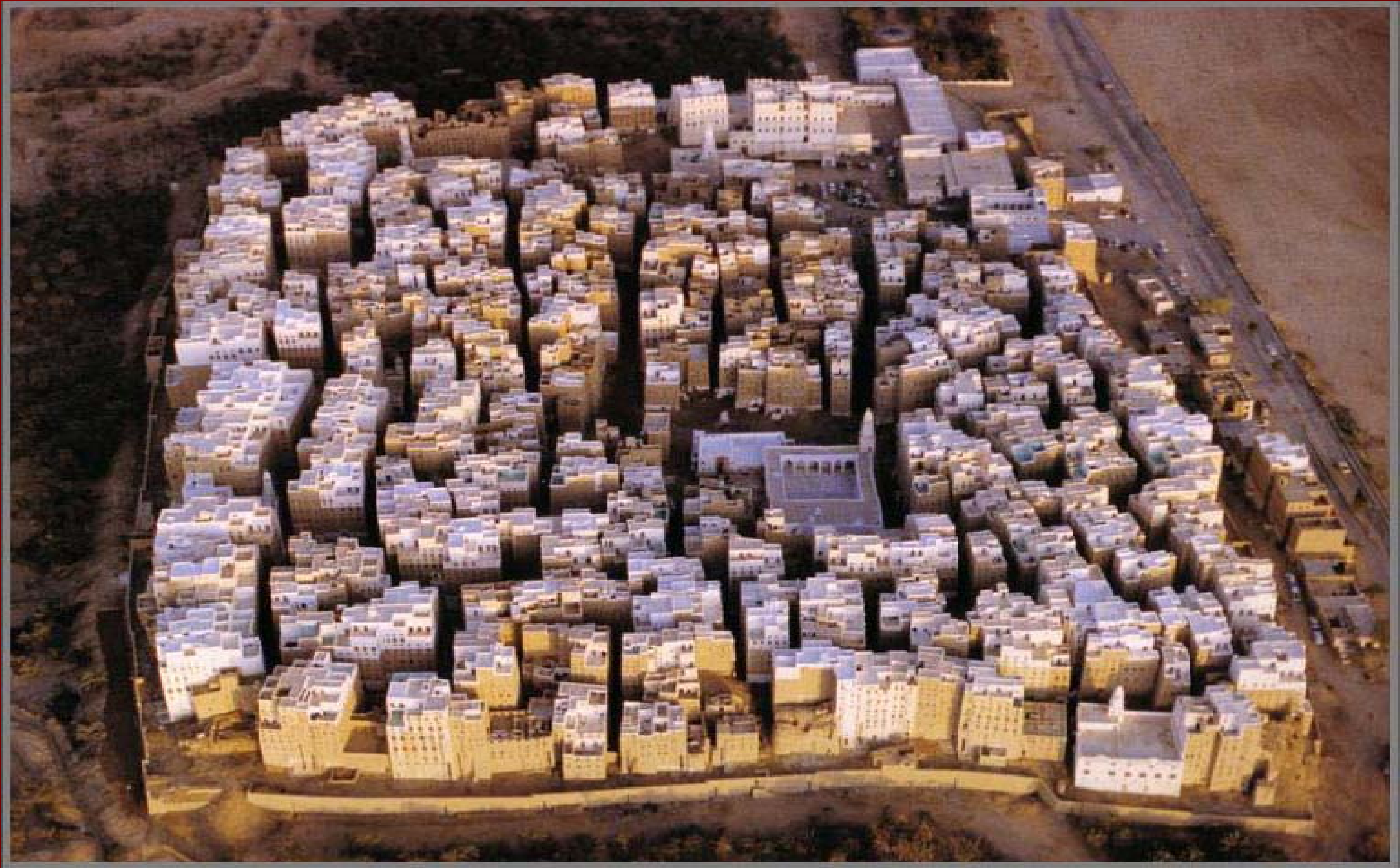

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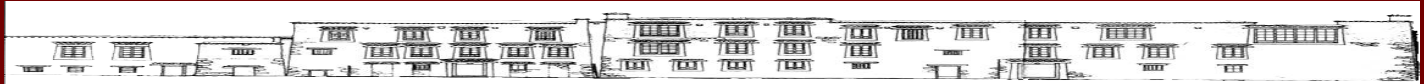


Structural measures

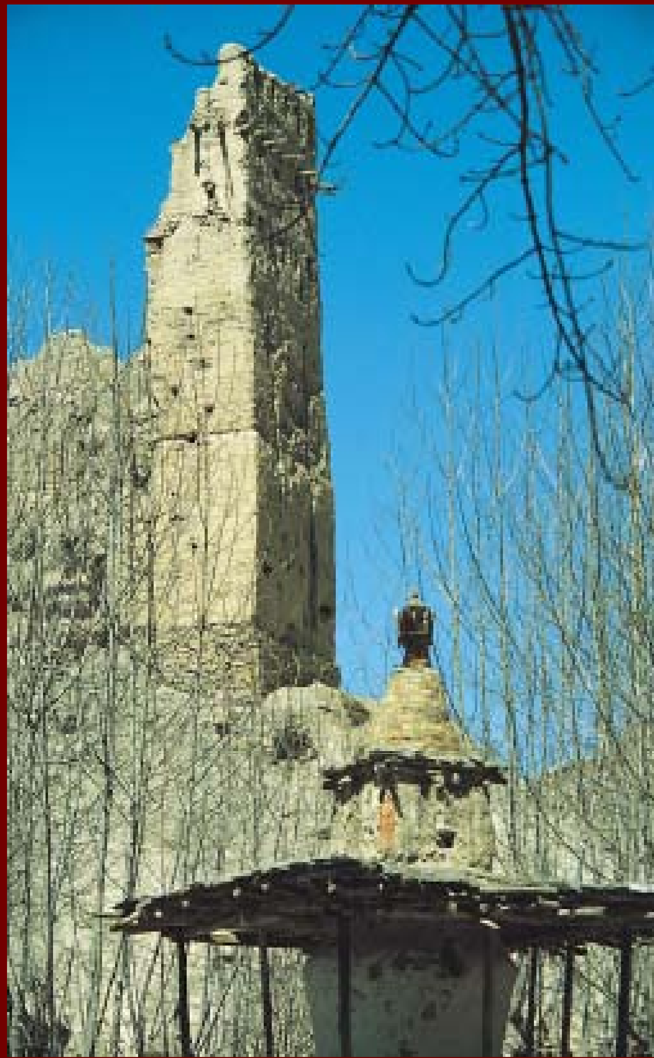
When designing for earthquake-prone zones, it should be considered that the seismic forces acting on a building are proportional to its mass, and that deflection increases significantly with height.

When designing two-storeyed buildings, therefore, it is advisable that the ground floor be built solid, while the upper floor is kept light, preferably with a flexible framed structure.

Heavy roofs with slabs, slates and tiles should be avoided in principle.

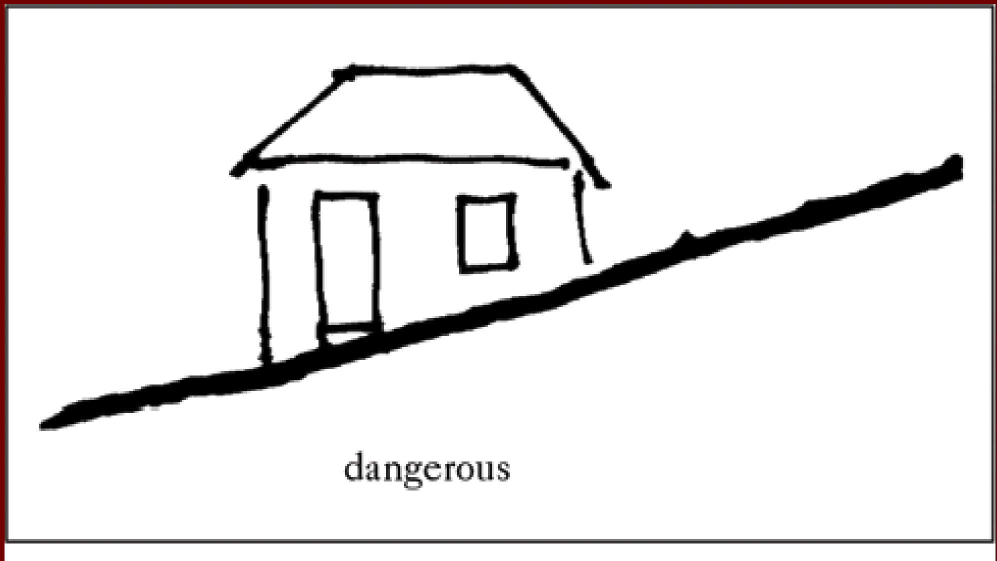
Walls usually fall outwards because they lack a closed ring beam, sufficient bending and shear strength, and because door and window openings weaken the wall structure.

Under seismic influences, forces are concentrated into the corners of these openings, creating cracks.

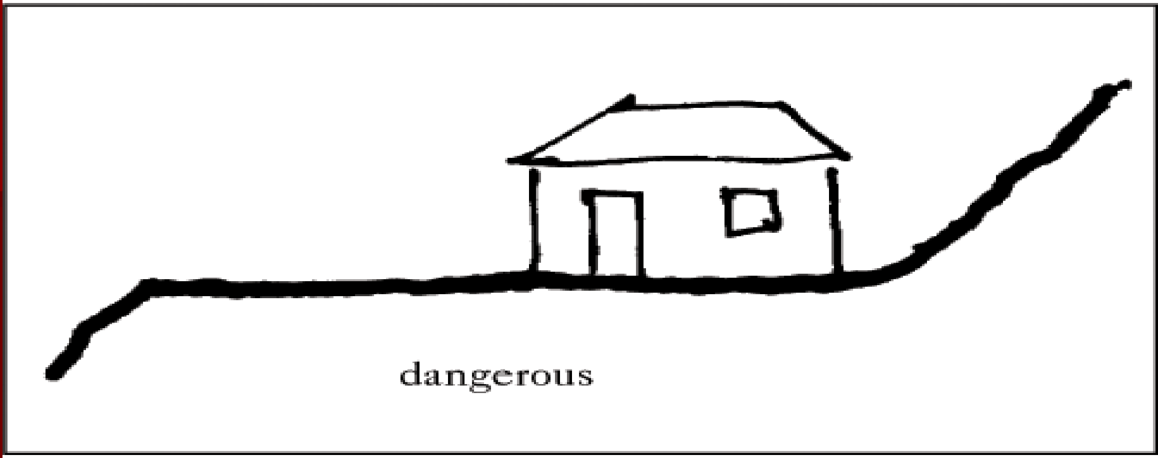


In order to reduce the danger of collapse, the following points should be kept in mind:

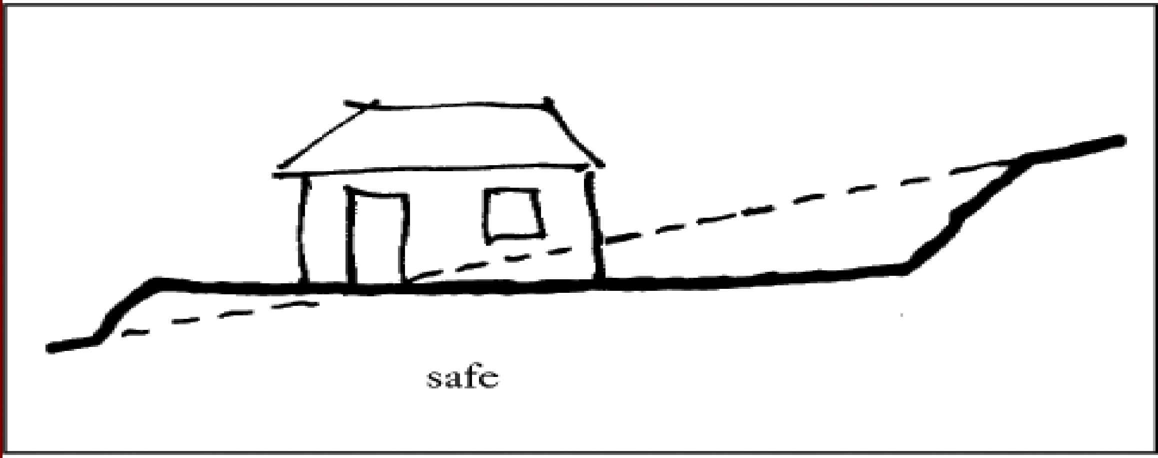
1. Houses should not be located on inclined sites
2. The building's resonant frequency should not match the frequency of the earth movement during earthquakes.
   This means that heavy houses with solid construction should not rest on hard rock bases, but instead on sandy or silty soils.
   Light houses, however, perform better on hard rock than on soft soil.



Correct building position

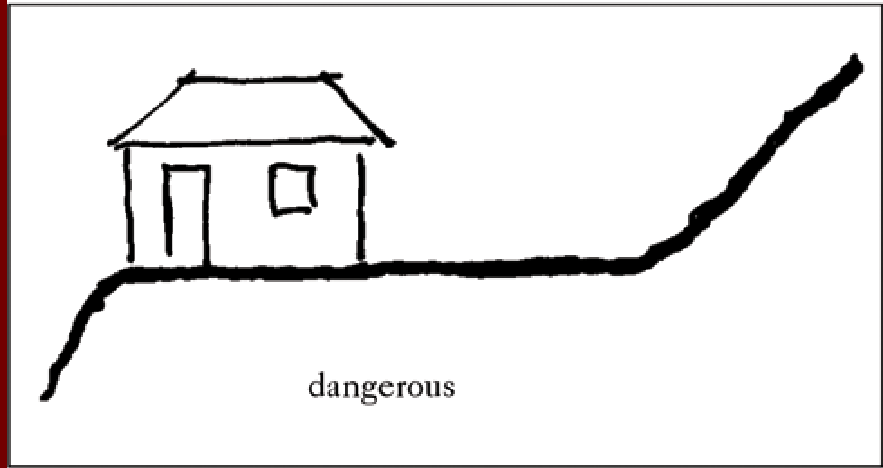


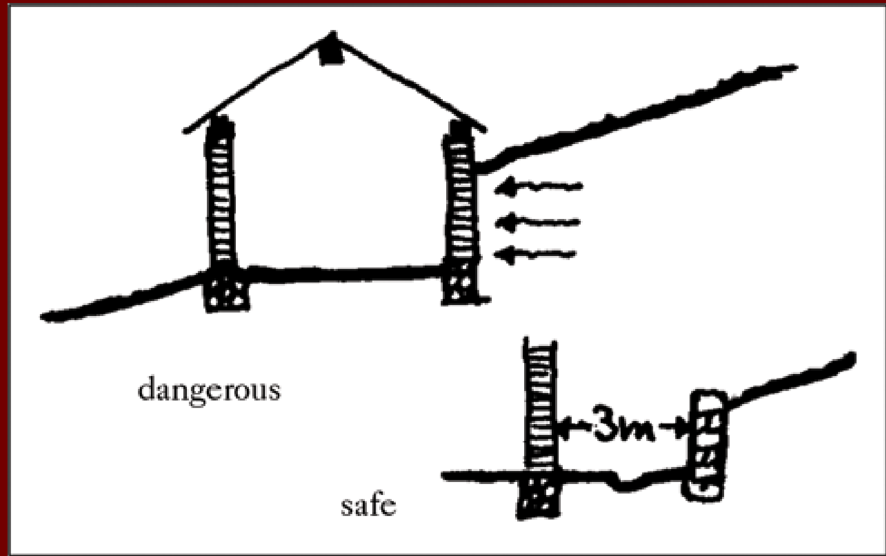
2-4



2-5

2-1 to 2-5 Location of a house on the slope



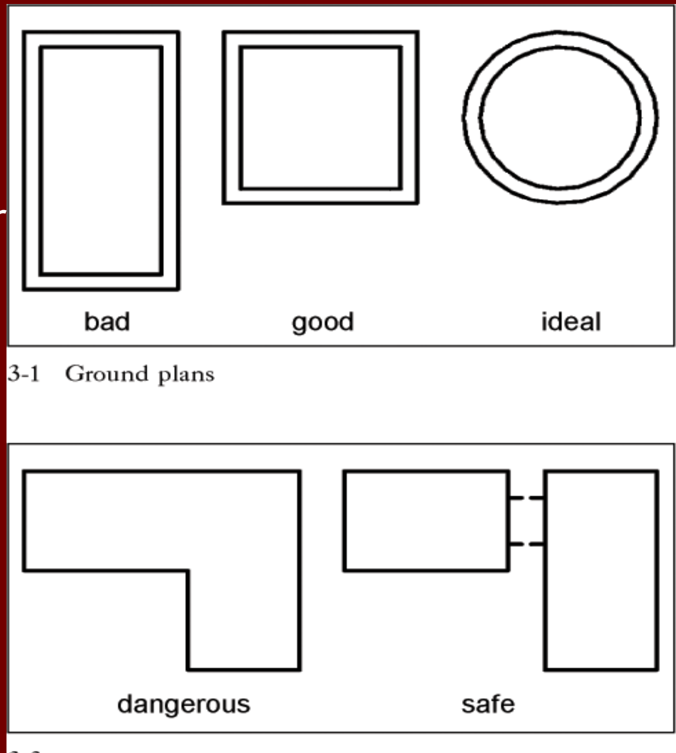


House of Gyegu destroyed by earthquake

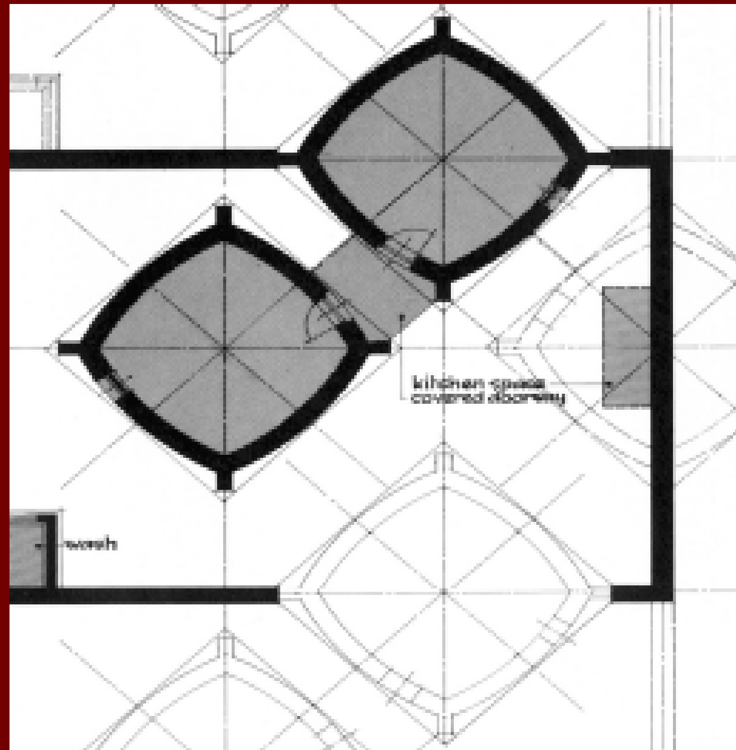
Correct plan shapes

3. The different parts of a house should not have foundations on different levels, nor have differing heights. If they do, then they should be structurally separated. Since sections of different heights display differing
resonant frequencies, they should be allowed to oscillate independently.

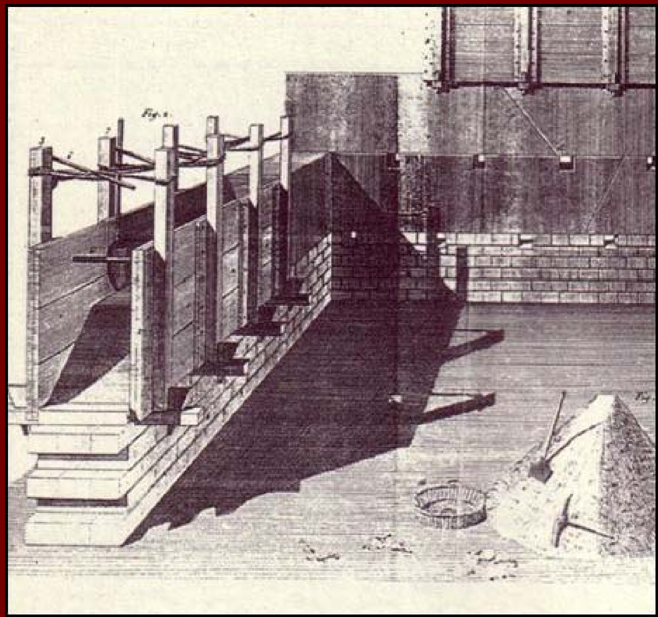
4. Plans should be as compact as possible, and should be symmetrical.
Circular plans give better rigidity than rectangular ones

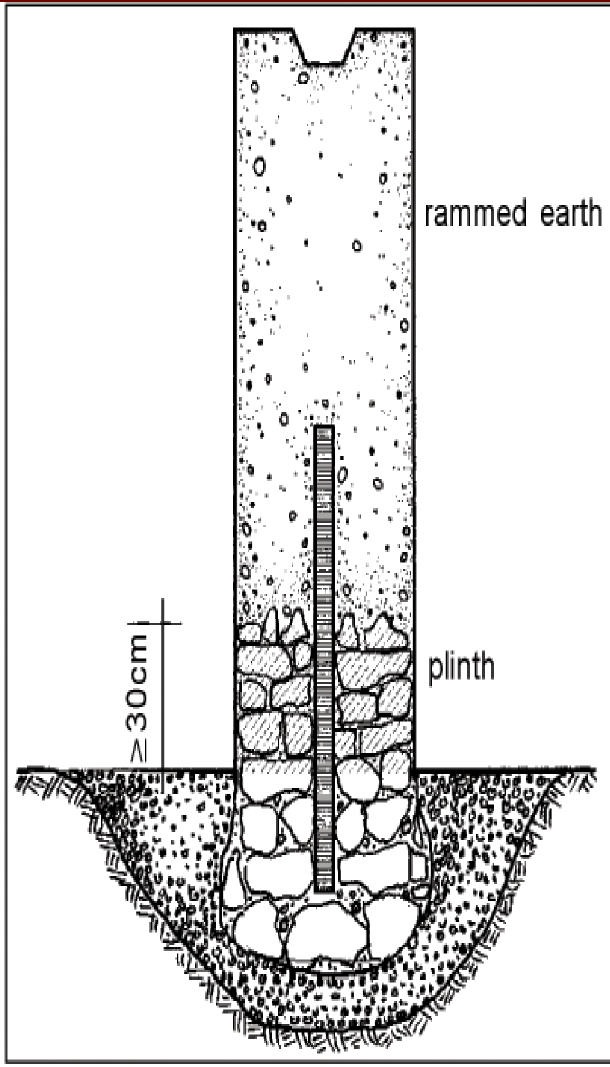


3-1 Ground plans



5. Foundations have to act like stiff ring anchors, and should therefore be reinforced.
6. Foundations, walls and roofs should be well fixed to each other, the joints being able to withstand the shear forces produced.

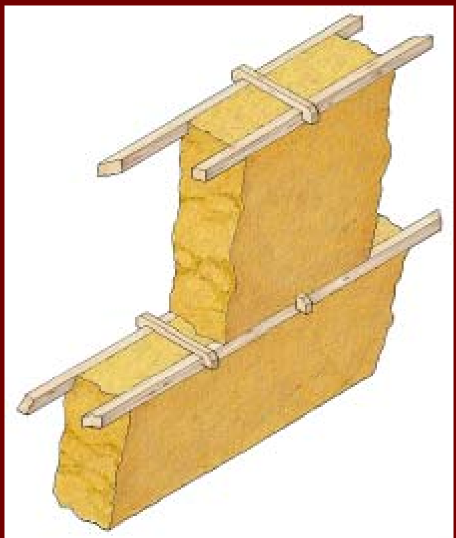


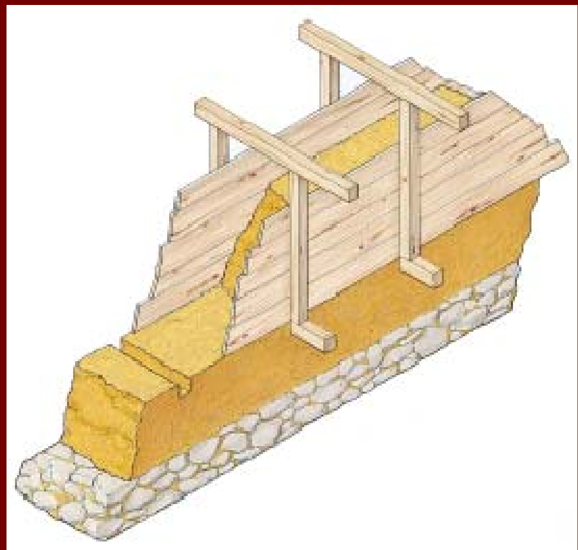


-3 Floating foundation

7. Walls must be stable against bending and shear forces. Masonry work must have fully filled joints and strong mortar.
8. Load-bearing masonry walls should have minimum thicknesses of 30 cm; their heights should not exceed eight times their thicknesses
9. Masonry walls should be stiffened with piers at a minimum every 4 m (with minimum sections of 30 x 30 cm), or with posts that are structurally fixed in the foundation (i.e. able to take movement)
10. Wall corners, joints between walls and across walls, as well as door openings have to be stiffened by vertical posts of either timber or reinforced concrete, which are structurally fixed in the foundation, or by

buttresses, so that horizontal forces do not open these elements





11. Walls have to be finished on top by a ring beam, which has to be adequately fixed to the walls.
12. Extra lintels above doors and windows should be avoided, and should be formed by ring beams
13. Roofs should be as light as possible.
14. The horizontal thrusts of vaults and domes should be sufficiently contained by ring beams, buttresses or ties.
15. Openings destabilise walls and should be carefully proportioned

There are two basic approaches to earthquake resistance designing.

The first and most commonly used method is to construct walls, roofs and their joints stiffly enough so that they cannot break or be deformed under seismic loads.

The second approach is to endow the structure with sufficient ductility so that the kinetic energy of any seismic impact will be dissipated via deformation. This is the more intelligent solution, especially as it entails fewer structural problems and materials.

If, for example, a vertical wall with a framed structure stabilised by tensile diagonals is impacted horizontally from the right there will be a concentration of stress on both ends of the tie leading from lower left to upper right.

Weakness, then, will occur first at these joints, possibly leading to wall failure.

An elastically framed structure without diagonals, on the other hand – provided the corners are able to take some moment and that no structural element is overloaded – usually allows deformation to occur without leading to wall collapse.

In the second case, obviously, the infill of the frame must also be somewhat flexible.

There are three different general principles for designing earthquake-resistant structures:

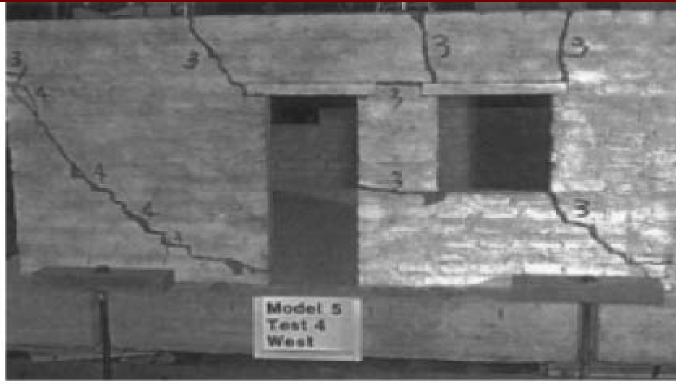
1. Walls and roof are well interconnected and rigid enough that no deformation occurs during earthquakes.
2. Walls are flexible (ductile) enough so that the kinetic energy of the earthquake is absorbed by deformation. In this case it is necessary to install a ring beam strong enough to take bending forces; the joints between wall and ring beam, and ring beam and roof must be strong enough.
3. The walls are designed as mentioned under 2, but the roof is fixed to columns that are separated from the wall, so that both structural systems can move independently, since they have different frequencies during an earthquake.

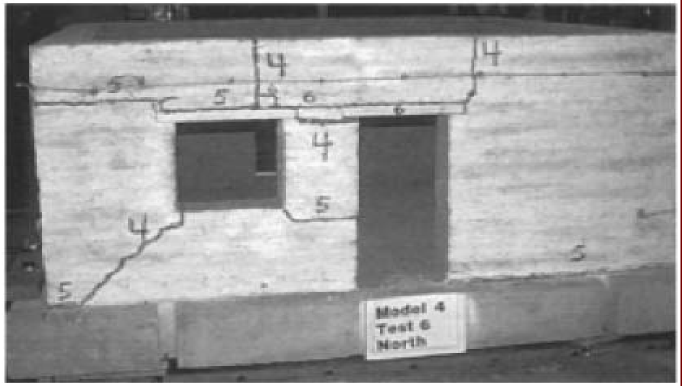
Three research projects undertaken by the Building Research Laboratory, University of Kassel, Germany, analysing earthquake damage to single-story rural houses in Guatemala, Argentina and Chile, concluded that the same errors in structural design consistently led to collapse.

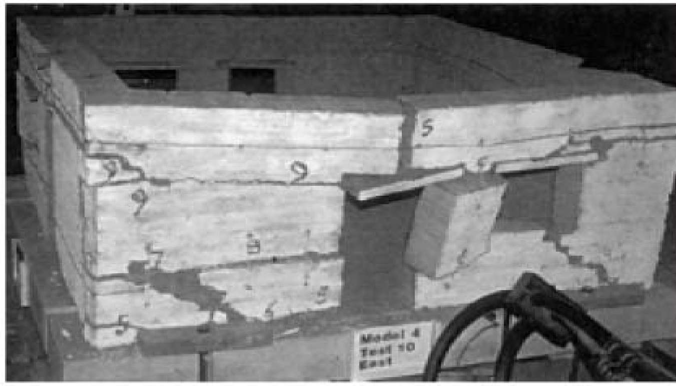
At the BRL, a simple test was developed within the context of a doctoral thesis

to show the influence of wall shape on resistance to seismic shocks.

A weight of 40 kg at the end of a 5.5-m-long pendulum was allowed to fall against a model





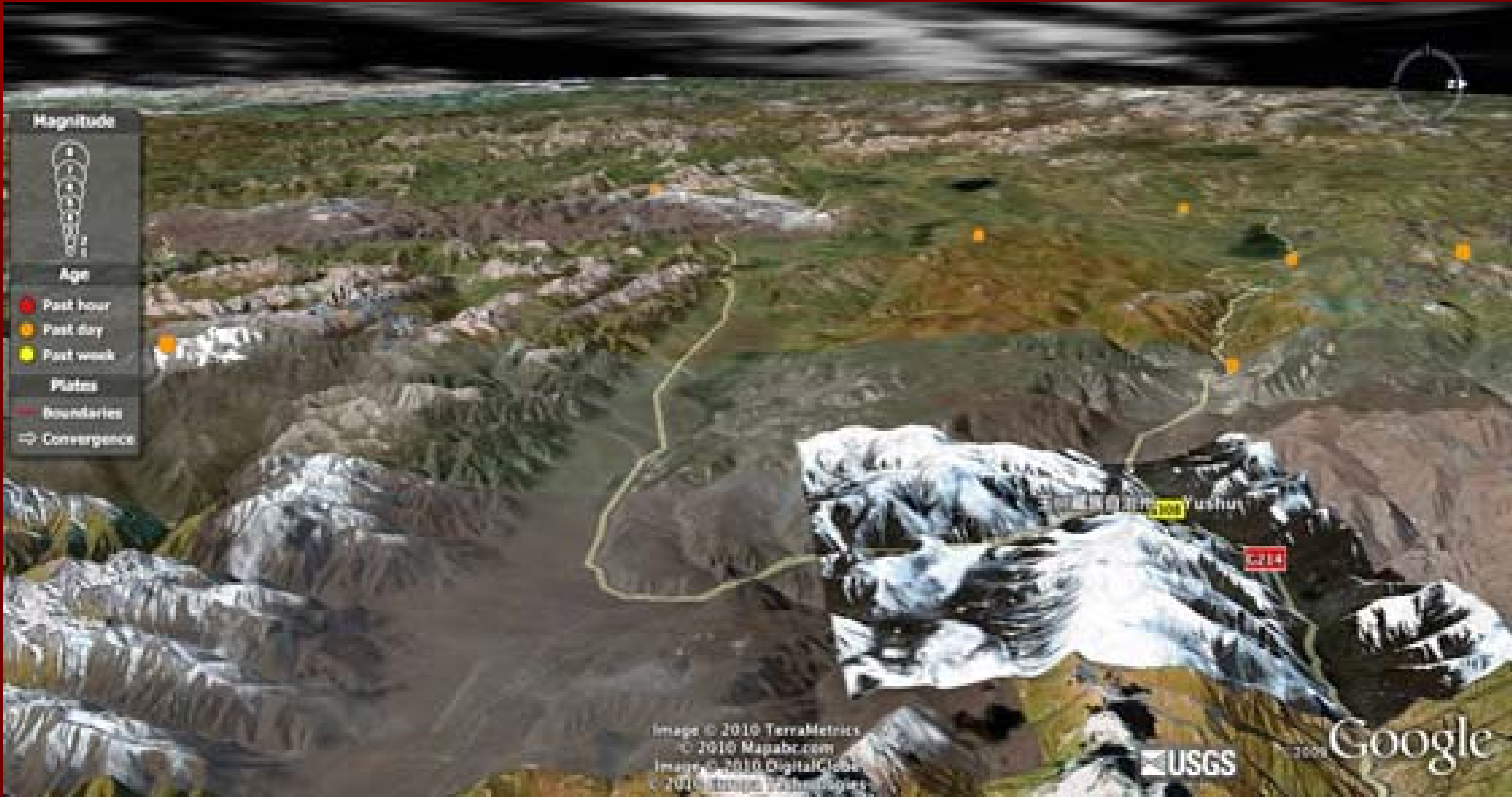


-1 to 4-3 Typical failures caused by seismic movements (Tolles et al. 2000)

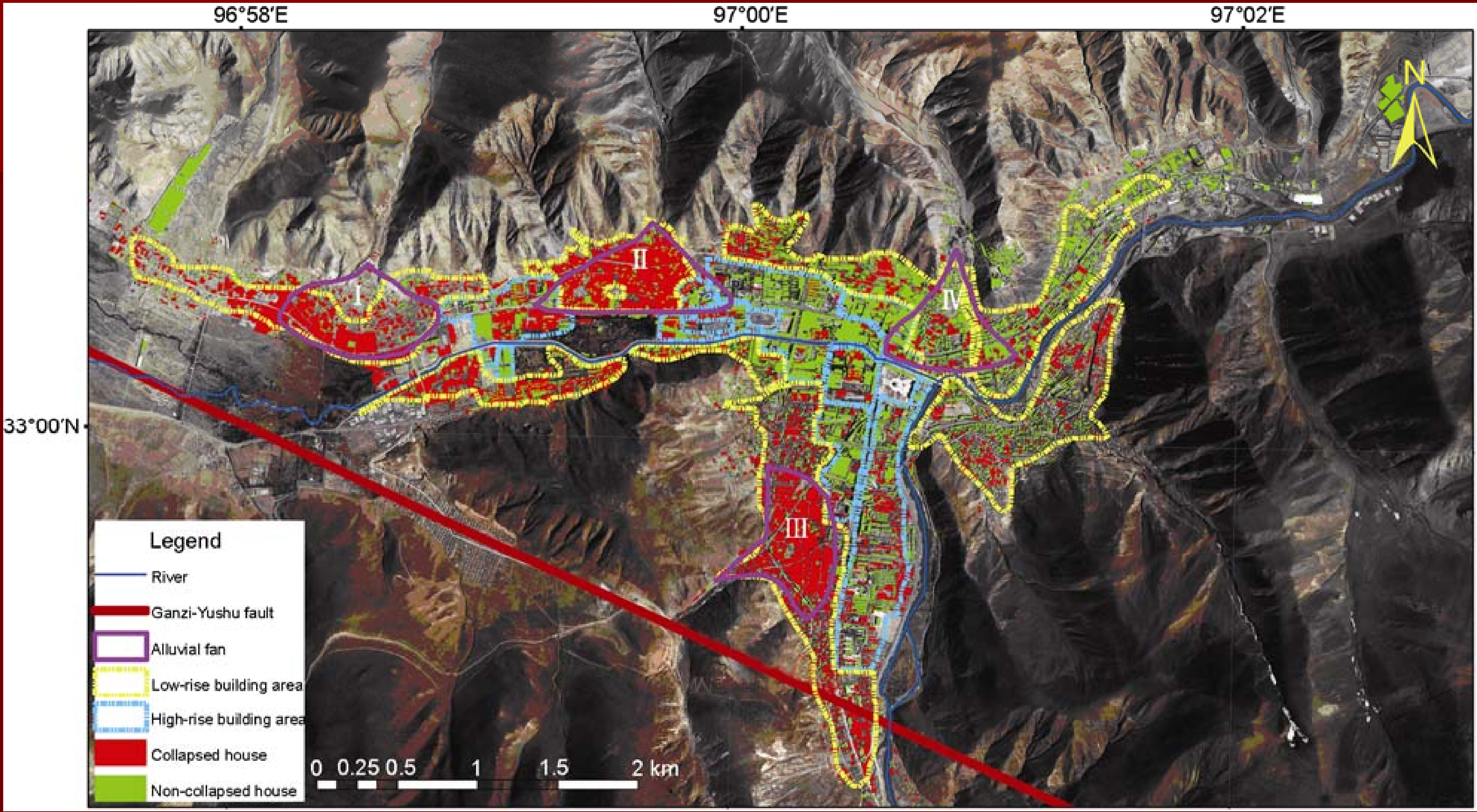
The rammed earth house with a square plan showed the first large cracks after the second stroke After three strokes, one section of the wall separated and after four strokes the house collapsed

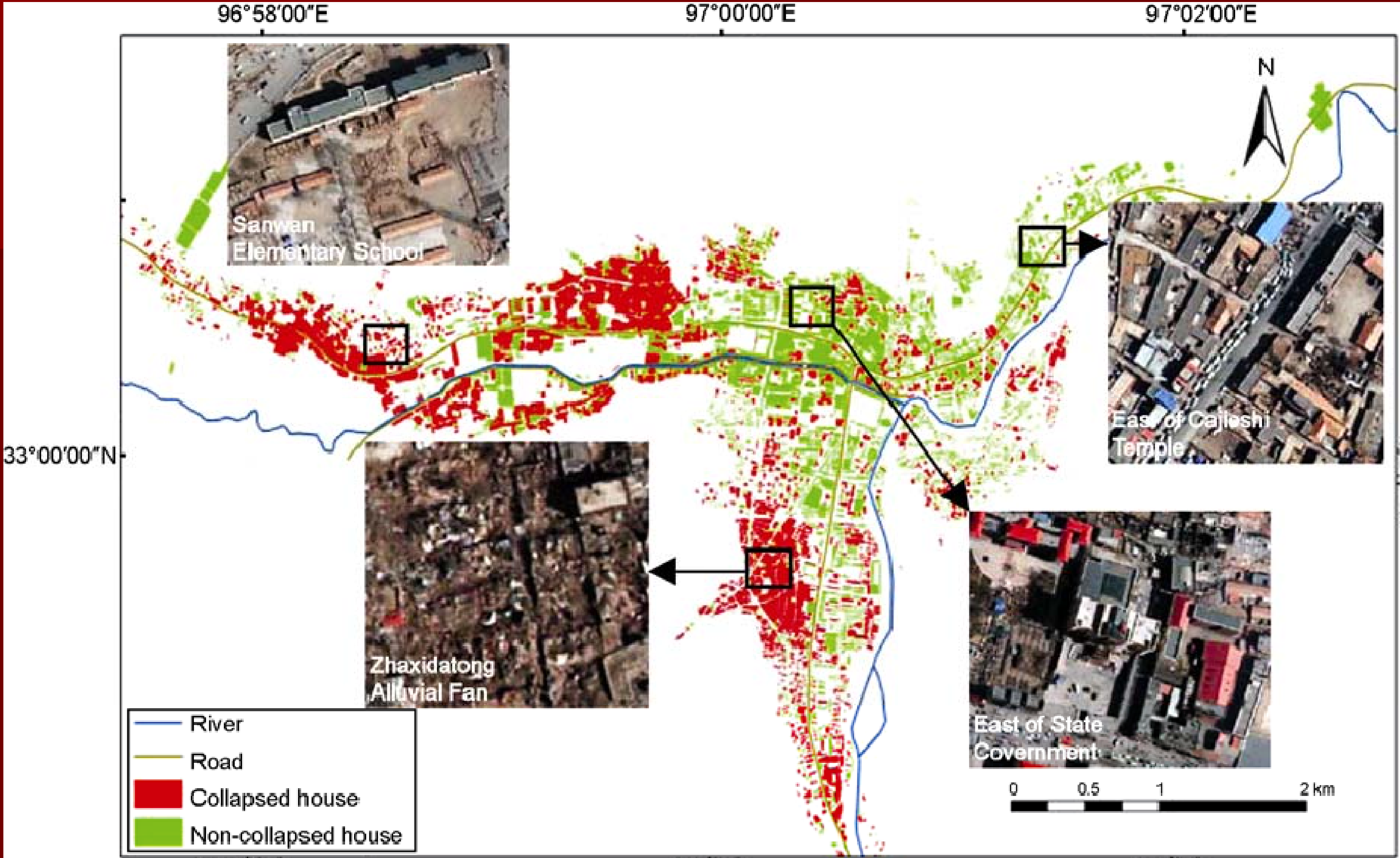
The rammed earth house with circular plan, however, displayed initial cracks only after three strokes and one small section of the wall separated only after six strokes

Satellite image of Yushu



Collapsed houses distribution on satellite wiew of Yushu




96°58′00″E
97°00′00″E
97°02′00″E
33°00′00″N
N
Sanwan Elementary School
East of Cajieshi Temple
East of State Government
Zhaxidatong Alluvial Fan
River
Road
Collapsed house
Non-collapsed house
0 0.5 1 2 km

Structural types of building. Analysis of the spatial distribution and architecture type of collapsed buildings shows that the one-storey and low-rise buildings of wood structure (within the yellow boundary in Figure 2) in the western and southern urban areas were severely damaged

A comprehensive analysis shows that collapse of buildings is closely related to the distance from the principal fracture, the “spongy” alluvial foundation, and building structure type.

The buildings are easily collapsed when located close to the principal fracture, located on the alluvial fan, and built of wood structure. The houses over the alluvial fan were mostly built in wood structure in Yushu County town.

The houses on the Zhaxike, Qianjin Village, and Zhaxidatong alluvial fans, which are close to the principal fracture, had the most severe damages in Yushu earthquake. However, the houses on the Shengli Village alluvial fan suffered less severe damages due to the farther distance from the principal fracture.

Aerial wiew of Gyegu after the earthquake

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ASIA Staff distributing help kits in Yushu

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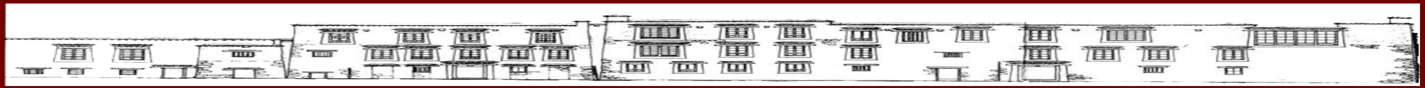

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Design principles

1. *Locally embedded*

   The design is embedded in the local cultural context (e.g. socially, economically and technically); it can be produced locally, aims at improving local employment and know-how and strives to minimize the need for import and transportation.

2. *Design the whole life cycle*

   The future disassembly and material-use are an integral part of the design. All organic and technical materials can be separated. Natural resources are renewable.

3. *Climate*

   The design makes optimal use of its location and surrounding climate conditions in order to minimize energy consumption.

4. *Size*

   The design adheres to local building standards.

5. *Structure*

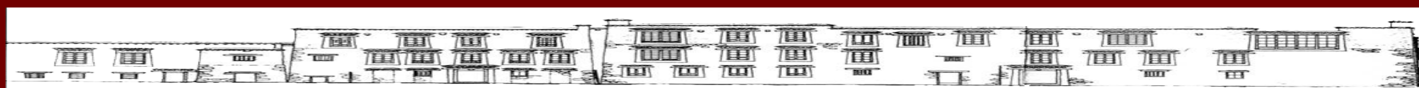
   The Load---bearing structure is separated from the building skin.

6. *Connections*

   All connections between the components and the load---bearing structure are dry and demountable. This makes re---assembly easy and clean.

7. *Installations*

   All installations must guarantee a flexible organization of the household and provide a sustainable way of living. The installations are smart, safe, upgradeable and adapted to the local ecology.



General framework of the project

Basic points to be considered in earthquake prone areas

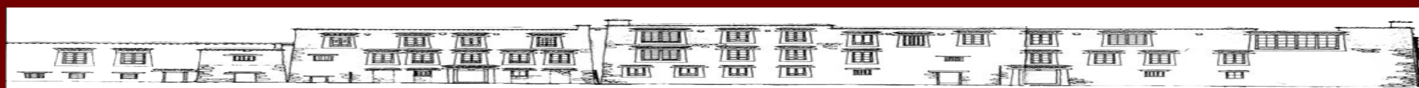
Not an earthquake kills people but buildings do. Therefore a proper and high quality and durable reconstruction work is essential. To achieve an anti-seismic structure after reconstruction of a damaged area, the following principles have to be considered:

Site selection

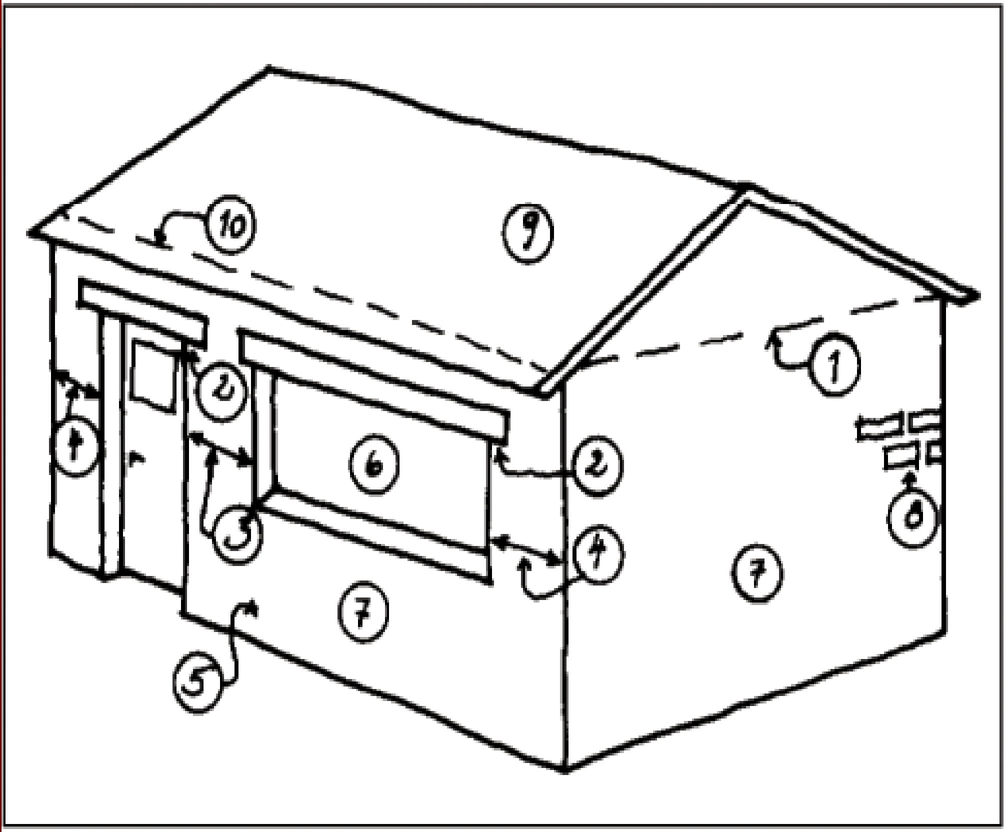
- Local geology, seism tectonic, socio-economic and cultural aspects have to be taken into account.

An anti-seismic design

- All new structures should be designed against earthquake. In this regard there are different ways of reconstruction with their advantages and disadvantages.



Typical design mistakes



4-7 Typical design mistakes which might lead to the collapse of the house

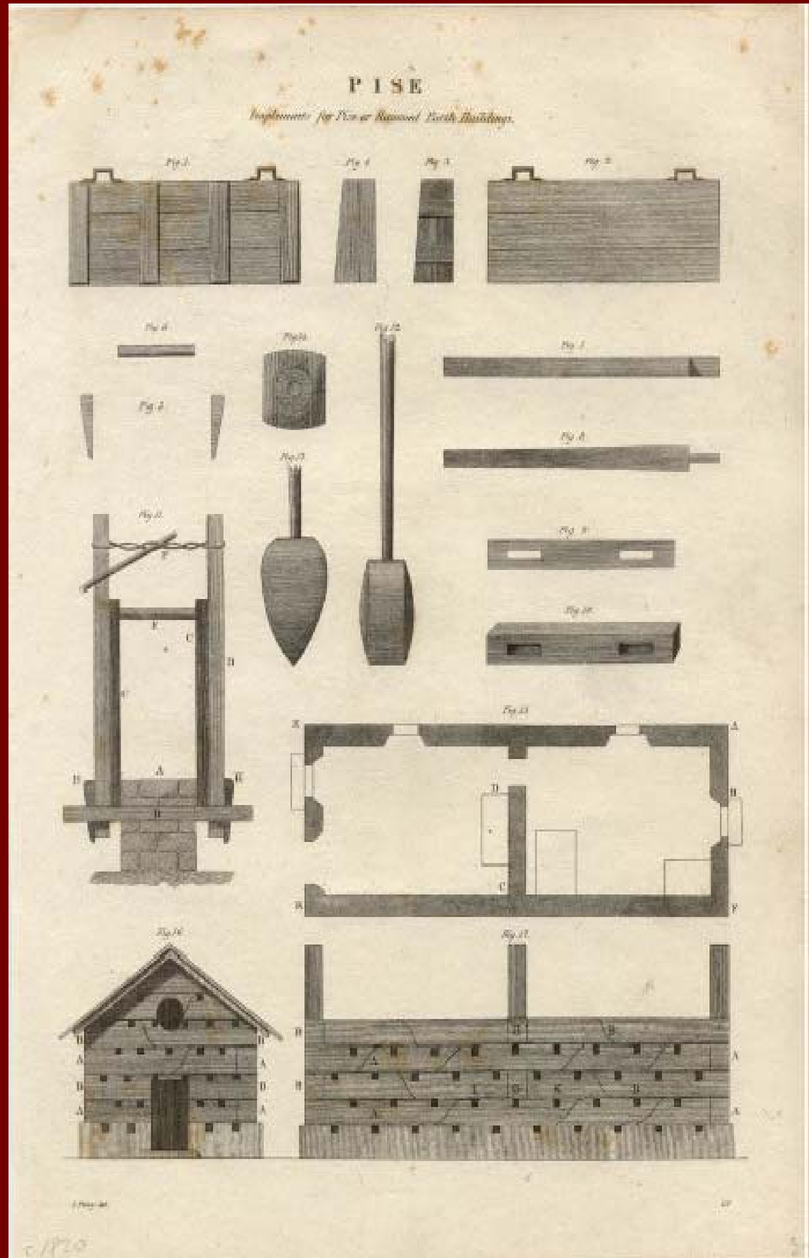
1. Ring beam is lacking.
2. Lintels do not reach deeply enough into masonry.
3. The distance between door and window is too small.
4. The distance between openings and wall corner is too small.
5. Plinth is lacking.
6. The window is too wide in proportion to its height.
7. The wall is too thin in relation 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.

Construction material

- The quality and environmental capability of construction material is a very important element in an earthquake resistant structure.
- High quality construction material should be used in order to assure an anti-seismic construction.
- Furthermore the material has to be accessible to give people the opportunity to be able to repair in case of a later damage and to have the possibility to extend their houses at a later stage.
- There should not be any restriction on choosing the most suitable material.

The construction work

- The construction work should be done either by certified construction companies or by trained people under the direct supervision of certified engineers.



Quality and supervision

- Quality control and supervision of all the above mentioned principals is the key element to successful reconstruction. Therefore training of personnel, organizations and people involved in reconstruction work is highly needed.
- It is fundamental to guarantee that from the start of physical reconstruction, earthquake resistant techniques and standards are included in the plans;
- that greater technical support and supervision of commercial and family reconstruction process is offered;
- that on-site training programs are implemented and are aimed at men and women participating in the reconstruction process;
- that the local habit and tradition is respected and the maintenance of appropriate urban planning is taken into consideration.

The specific aims of the project are:

- In the village ……..a number of….**private houses** are reconstructed or rehabilitated and people have returned to their houses.
- A **social cohesion** in order to establish community participation for the reconstruction work is created.
- Know-how is exchanged and local expertise in the reconstruction work of earthquake-resistant building is created (**skills training**).
- The local characteristics in the reconstruction work are matched.
- The living condition of inhabitants of the village of …….. has improved in general.

The standard of reconstruction work

In setting up a standard for reconstruction it is important to have:

- **first** a detailed look at how the situation in general was predating the earthquake: what were the social and economic objectives in the region, which was the traditional way of construction and why, which were the mistakes and what are the lessons learned.
- **Secondly** an assessment of the ongoing situation has to be done: what is the traditional way of living, what are the weather conditions and what are the needs and expectations of the local population.
- **Thirdly** the resources have to be considered: which material is locally available (in order to enable people to enlarge their houses or repair them if necessary) and which knowledge is available or can be trained.

For all points it is important to merge with the culture, climate and life-style of communities as well as apply a disaster-resistant technology that is seismic-resistant as well as resistant against strong desert winds as a preventive measure.

Only this guarantees to structure reconstruction around a local demand.

The design of a floor and house plan

One of the biggest mistakes beside the construction itself is the design of the floor plan. Because of the vibrations and therefore the static pressure the following basic rules have to be considered:

Windows and doors have to be placed in the middle of the wall (stability).

Windows and doors should be placed in the same way (i.e. opposite each other).

Asymmetric buildings (like L or U) might be used but are not the best solution.

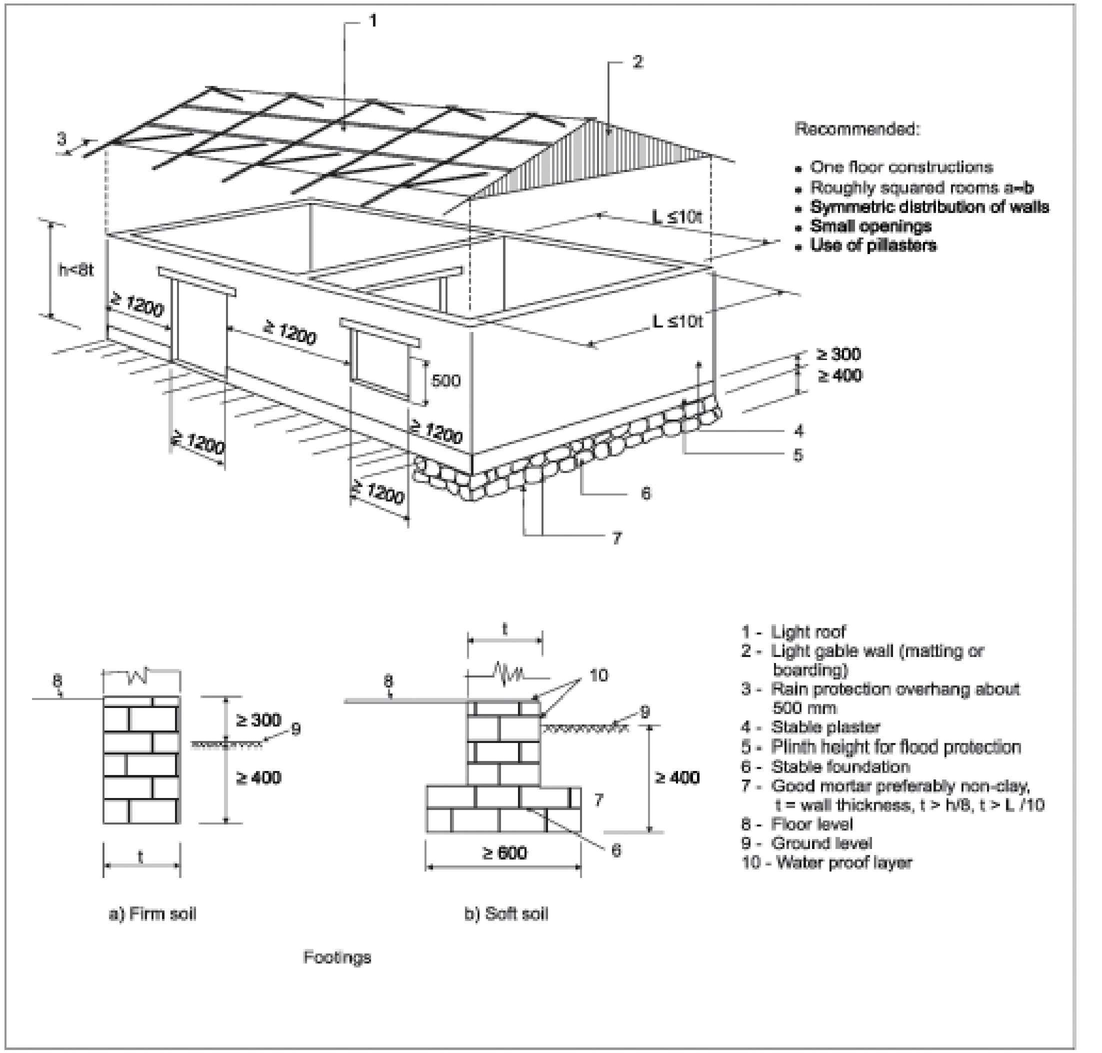


Figure 7.5 :: Adequate Configuration

Solution: The above mentioned owners to extend on a later stage if they have the necessary resources. The minimum size according to the national standard in rural areas is 60 sqm, in towns 100 sqm. The idea is to dimension a house of the project 60 sqm but with aspects are taken into account while creating the outline. The design is a nucleus with the possibility for a smaller size for families under 4 persons. This is still under ongoing discussion with the government.

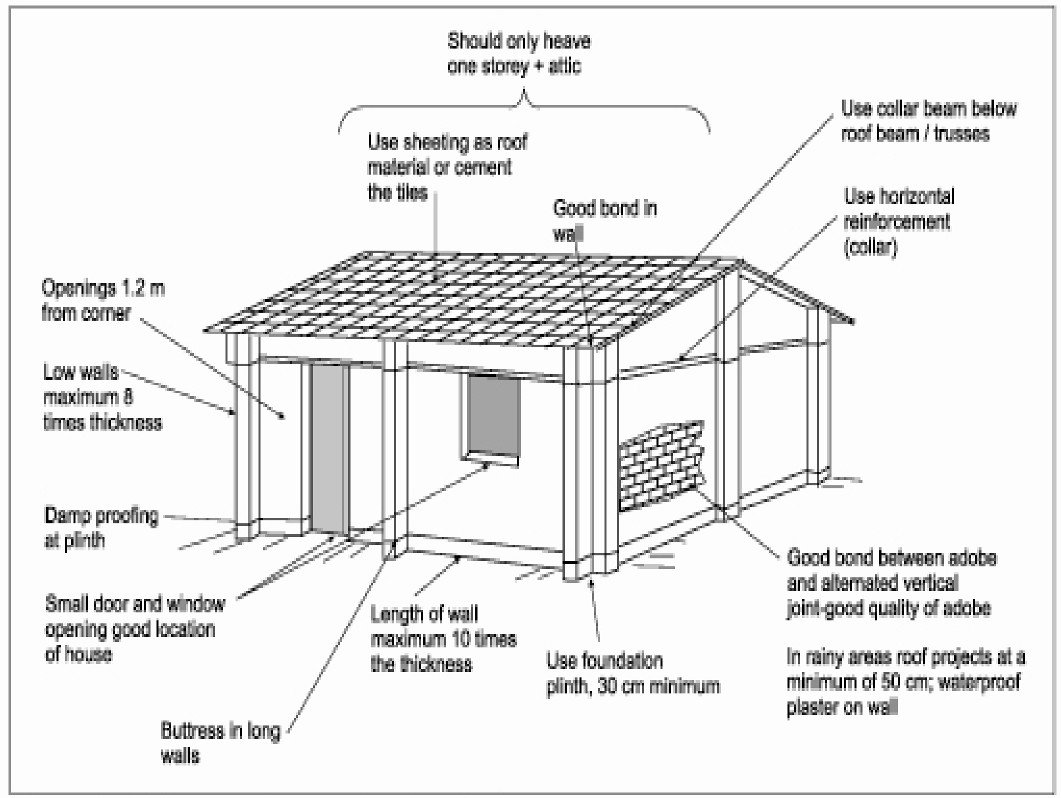
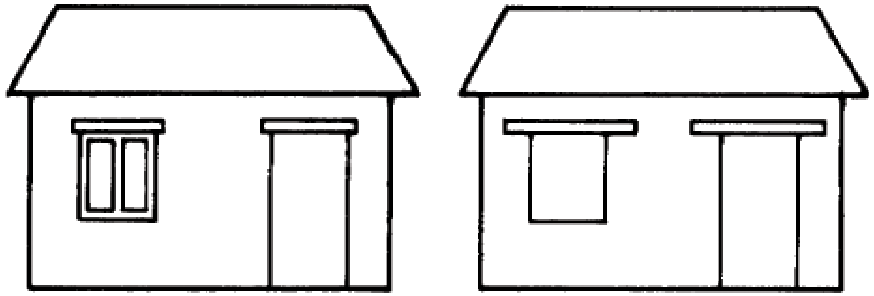


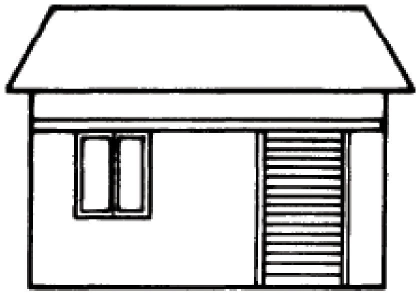
Fig 7.14 Good features of earthquake resistant construction

Doors and openings

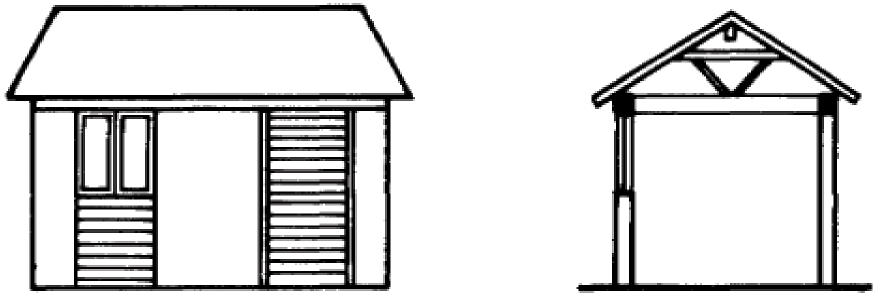
Openings destabilise walls and should be carefully proportioned



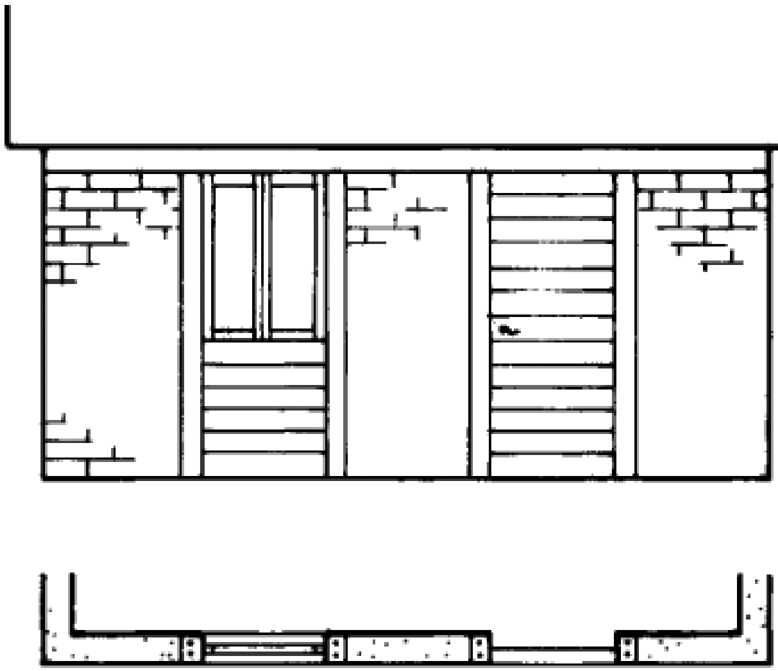
13-1 dangerous acceptable



13-2 better

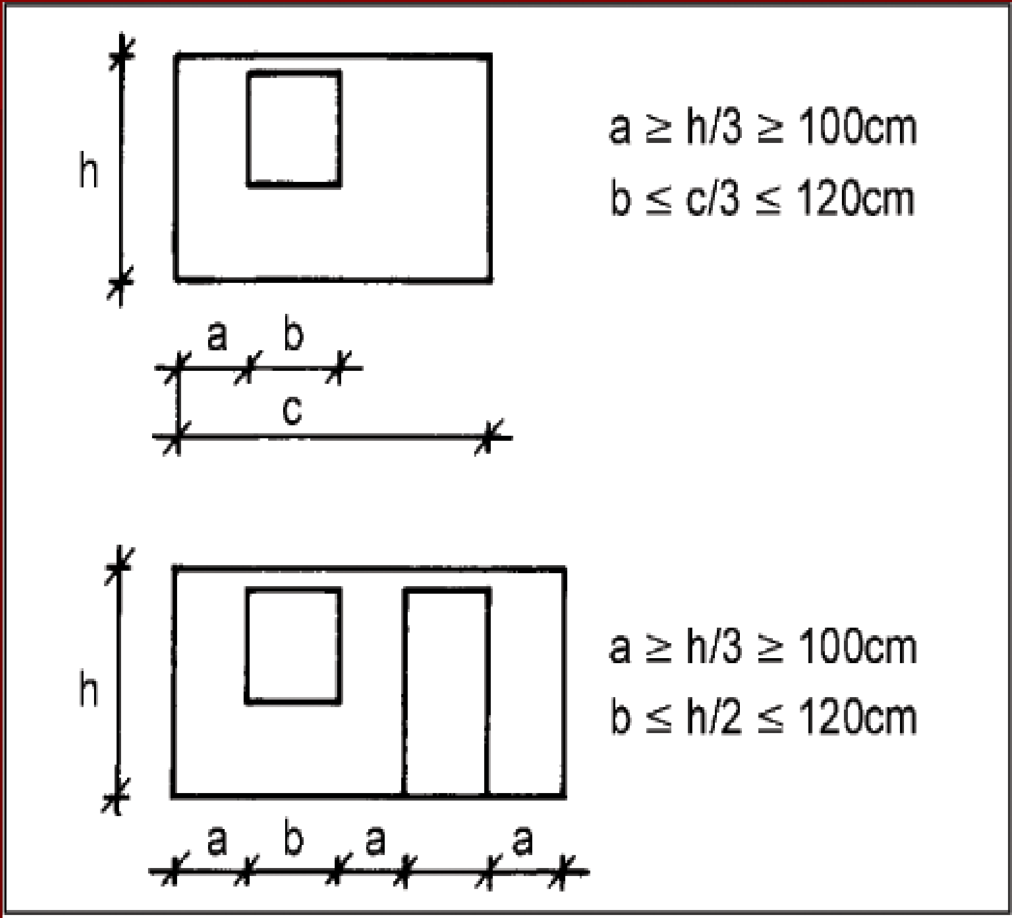


13-3 best

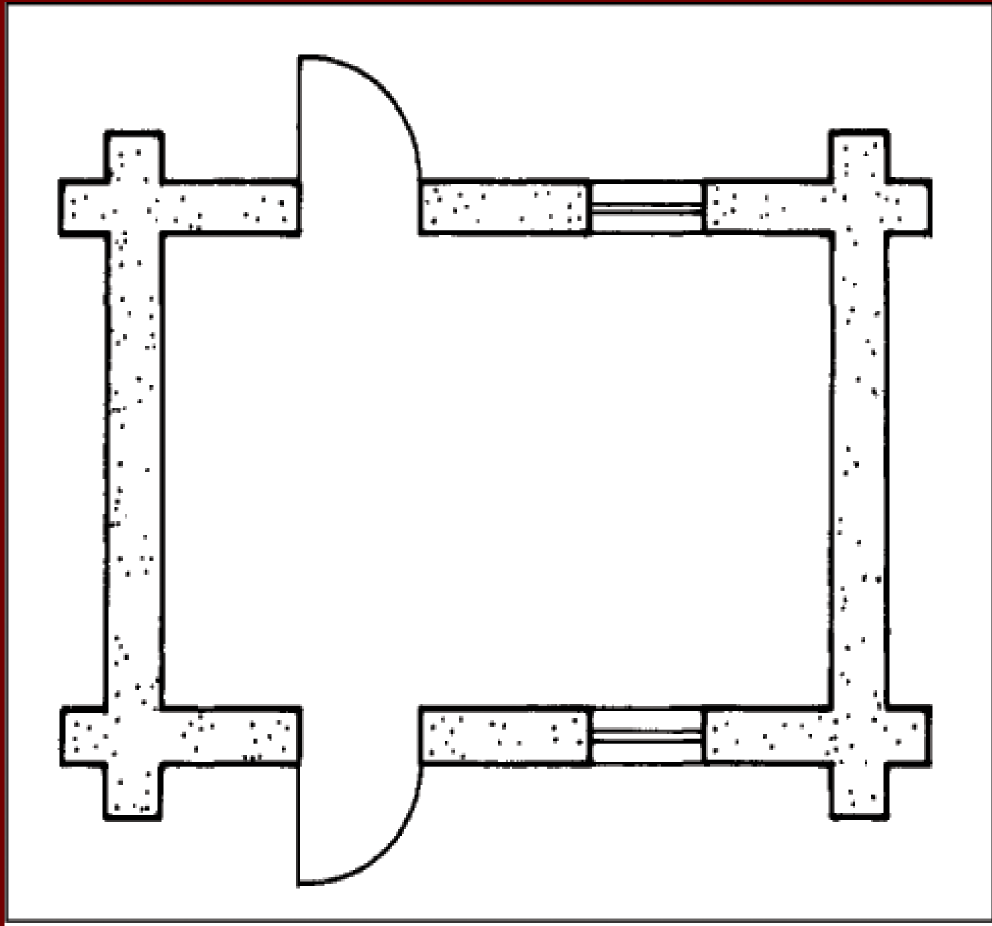


13-4 Stabilized openings

Dimension and position of openings



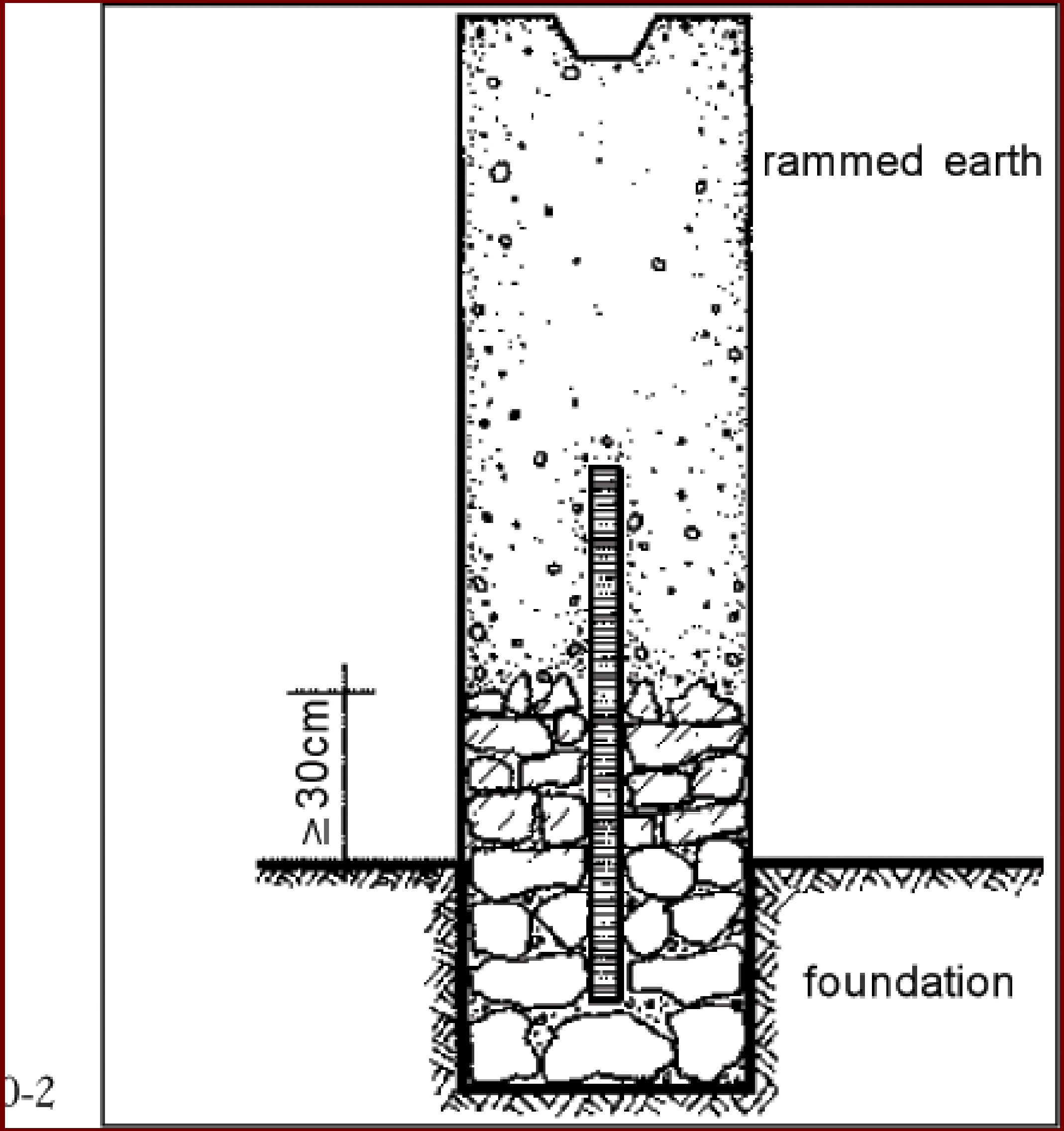
13-5 Recomendable dimensions of openings



13-6 Recommendable positions of openings

The foundation

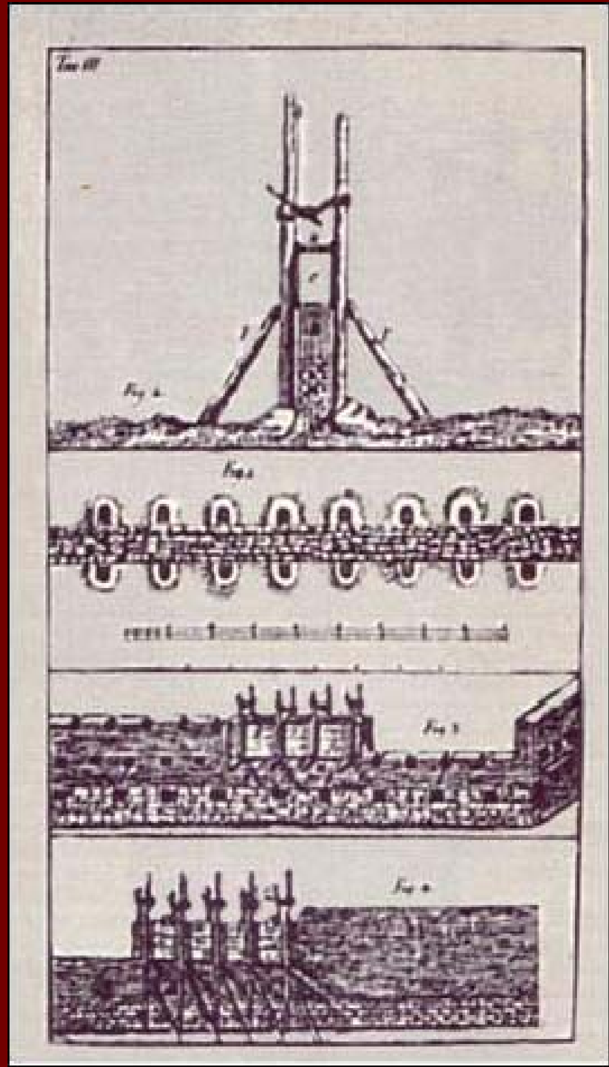
- If there have been foundations, generally they were done in a proper way.
- **Solution**: The foundation has to be higher than the ground outside (because of water) and it is important that it is done deep enough (around 120cm); Furthermore the mixture of the concrete has to be supervised very closely.



Thick walls and the effect of heavy roofs

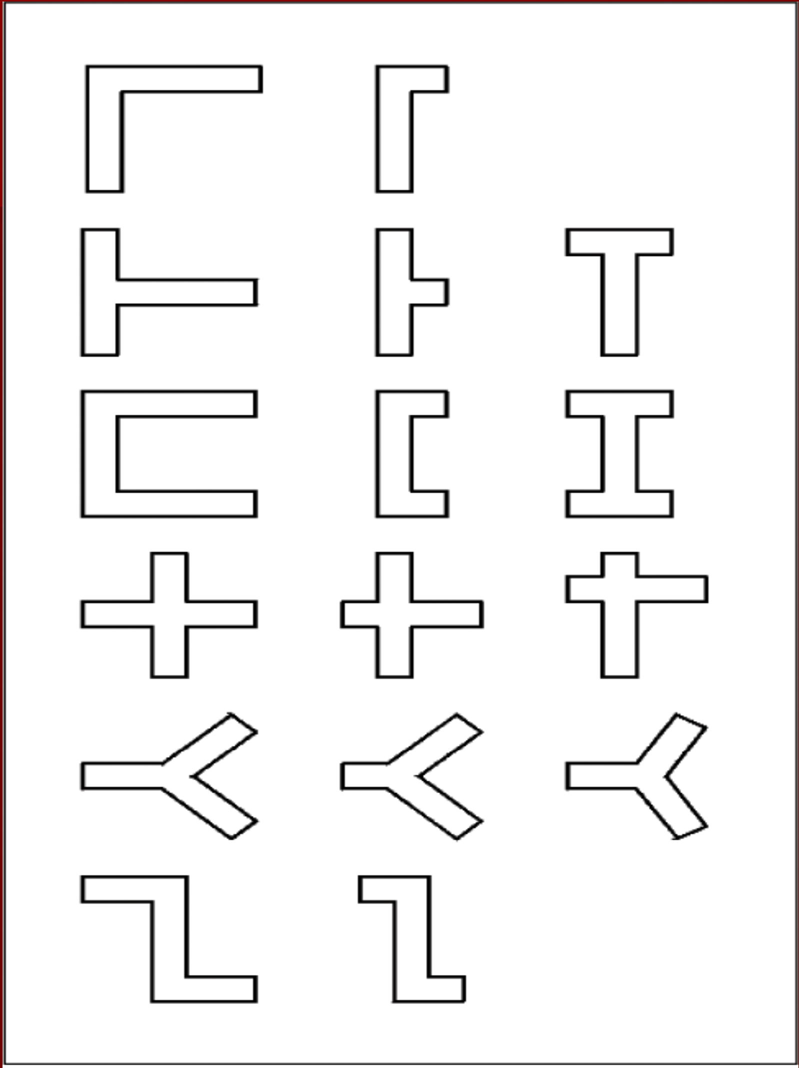
- In order to protect homes against high and cold temperatures, the walls and roofs were built -for insulation purposes- very thick and therefore heavy. The majority of the houses were totally destroyed because the amount of material for the roofing was too heavy for the improper design of the houses with a flexible construction.

- **Solution:** There is no equally effective possibility to protect against heat and cold at the same time in such an efficient way than building thick walls. Thick mural-work (30 to 60 cm) can be earthquake resistant if there is reinforcement every approximately 60 cm that is connected from the basement to the pillars and the ceiling. At the top of the walls there will be a ring-beam reinforcing the whole structure. This gives a stable structure that - during an earthquake - will move as one entity and therefore not break apart.

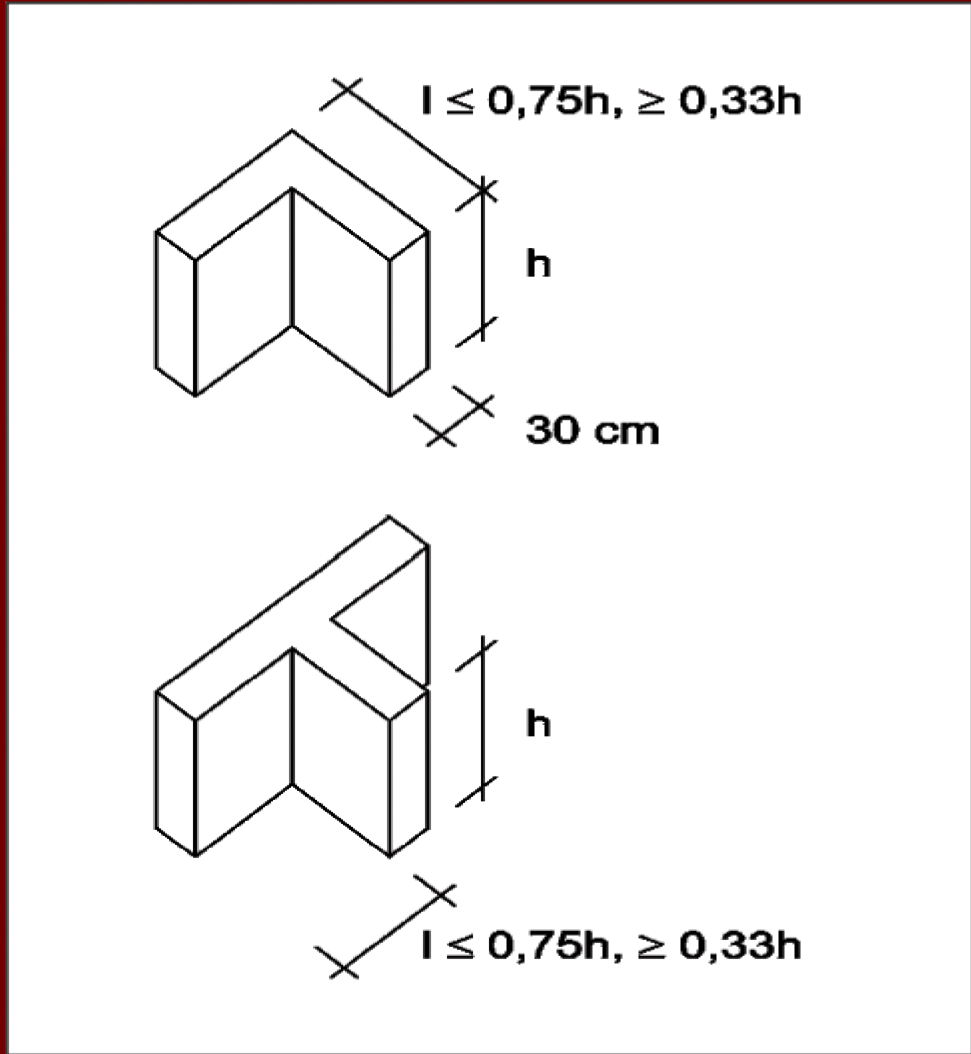


The base of the ram should not be too sharp, so that the formwork, if bade of bimbe, is not damaged.
The base should be no smaller than 60 cm2, and no larger than 200 cm2.
The weight of the ram should be between 5 and 9 kg.
It is preferable to use a two-headed ram with a round head on one side and a square one on the other.
This allows the ram to be used with the round side for general work, and with the square edge to compact corners effectively.

Wall reinforcing shapes

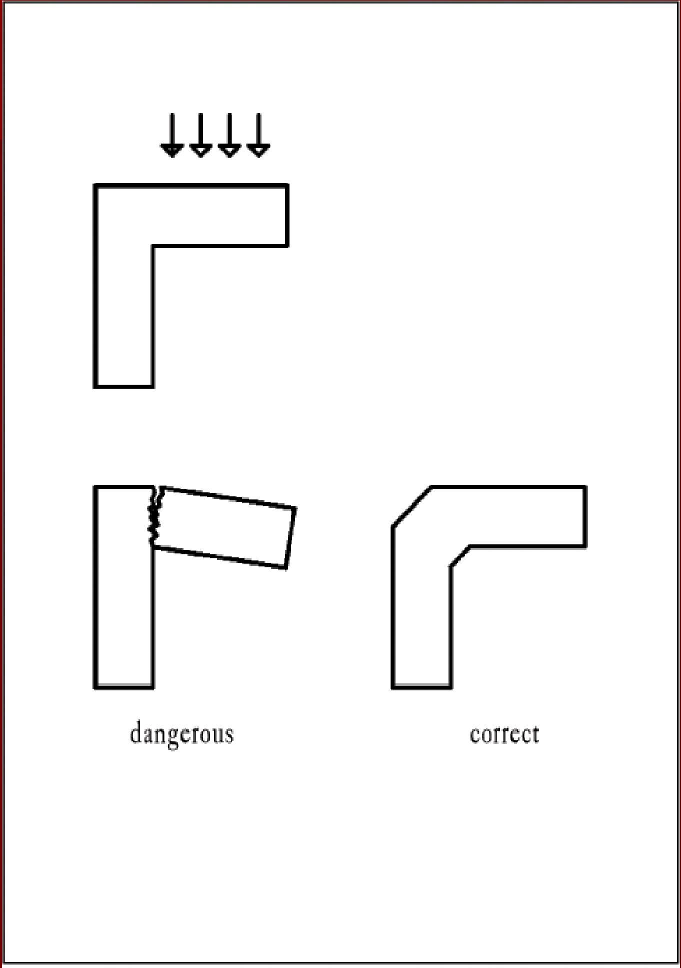


6-5 Wall elements stabilized by their shape

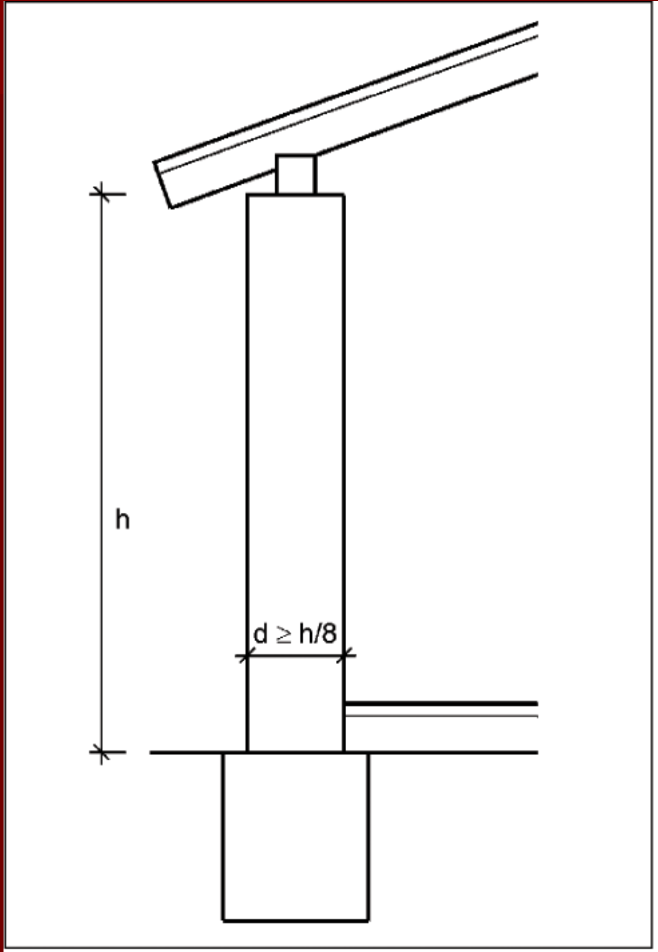


6-6 Recommended proportions

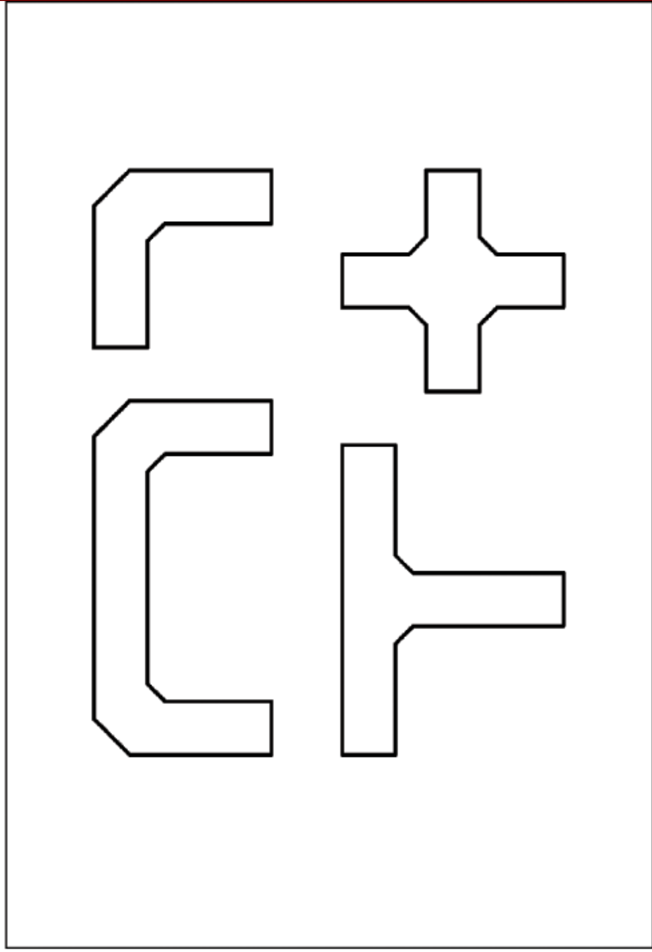
Corner solutions



6-8 Corner solution



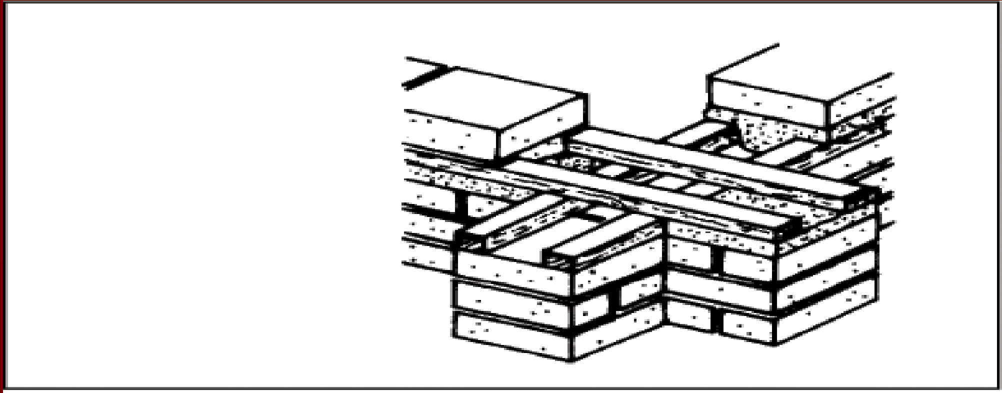
6-7 Expedient proportion of wall

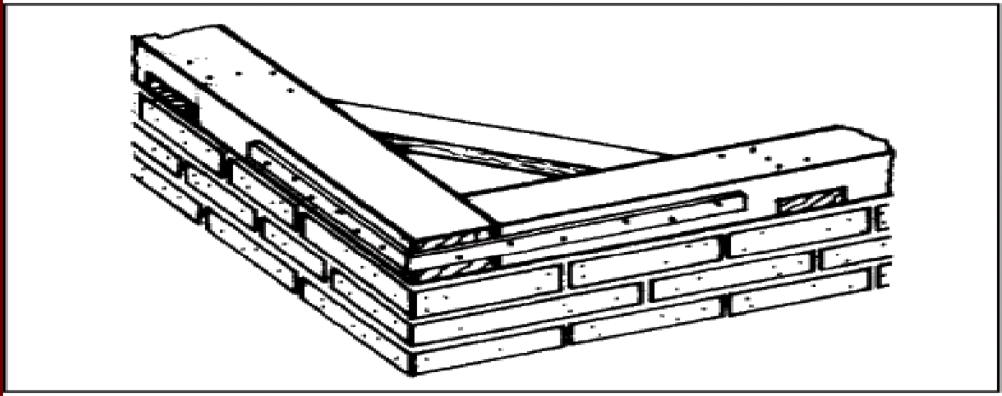


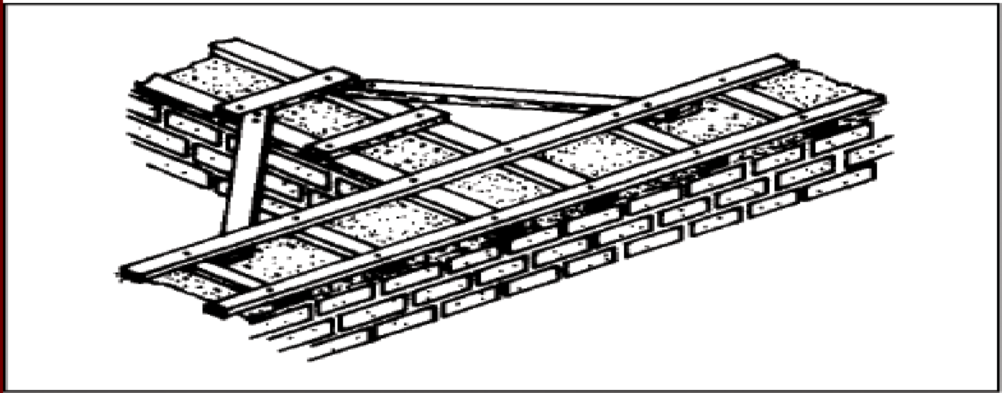
6-9 Elements with correct corner details

Corner reinforcement

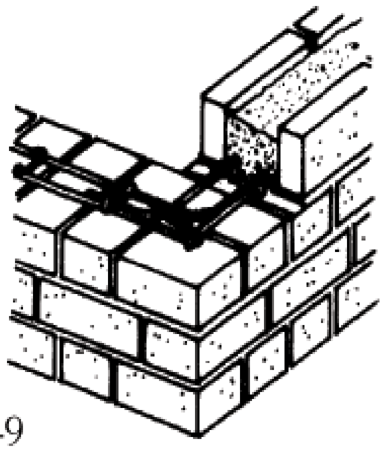
Wall corners, joints between walls and across walls, as well as door openings have to be stiffened by vertical posts of either timber or reinforced concrete, which are structurally fixed in the foundation, or by buttresses, so that horizontal forces do not open these elements



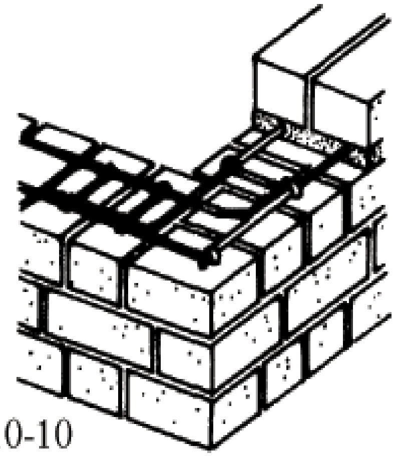




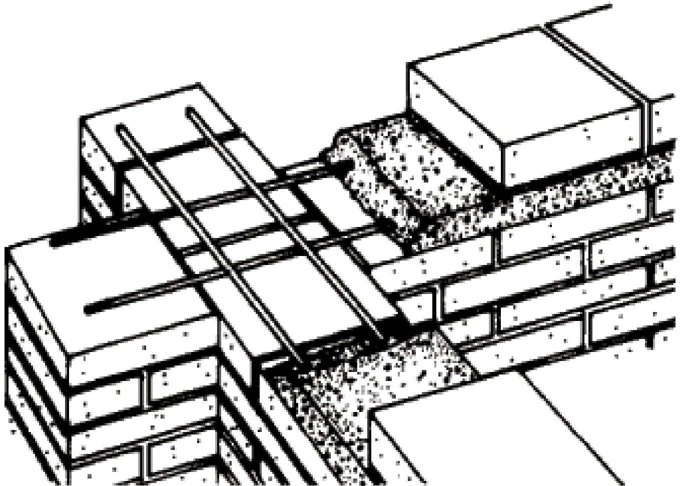
Reinforced corner solutions



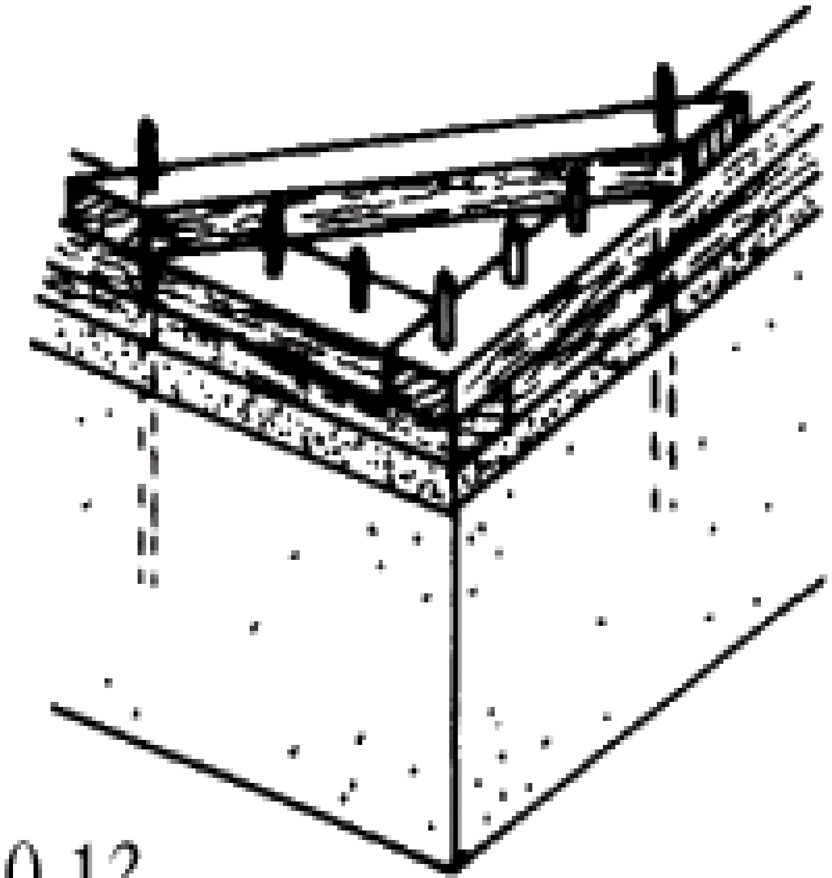
10-9



10-10



10-11

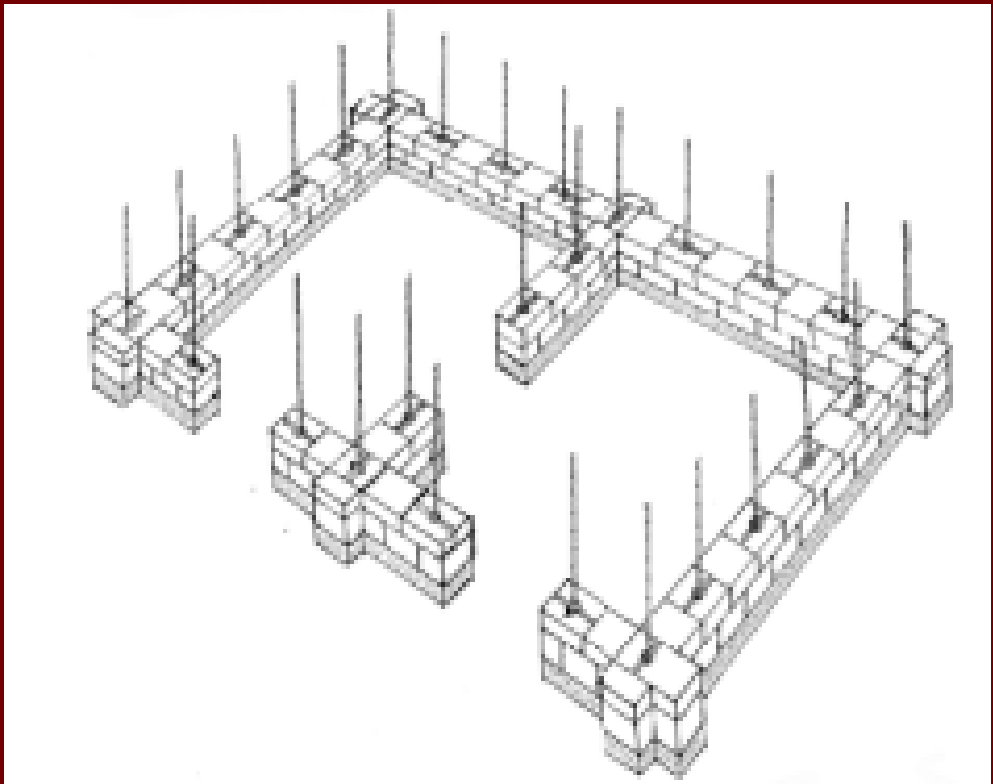


10-12

Wall reinforcing shapes

Walls must be stable against bending and shear forces.

Masonry work must have fully filled joints and strong mortar.



The bond between the different building parts

- Indispensable for a sustainable construction is a proper connection between the different material and the different parts of the building.
- The connection of the bricks was done with a mixture of clay, hay and often excrements from animals. The climatically and traditional conditions also today, still determine the way of construction. In some few cases steel beams were used which created a very dangerous combination of flexible steel frame with a stiff cladding, as the walls were not reinforced and therefore there was no connection of the two materials.
- Solution: As the welding work is poor and the error ratio is high, the model of an iron-skeleton has to be checked very closely.

  The risk that it will be done in an improper way it high, in particular because of the connection between the reinforcement of the walls and the skeleton itself.

  Therefore the solution with concrete reinforcement seems from a technical point of view more suitable for vertical as well as horizontal earthquake loads.

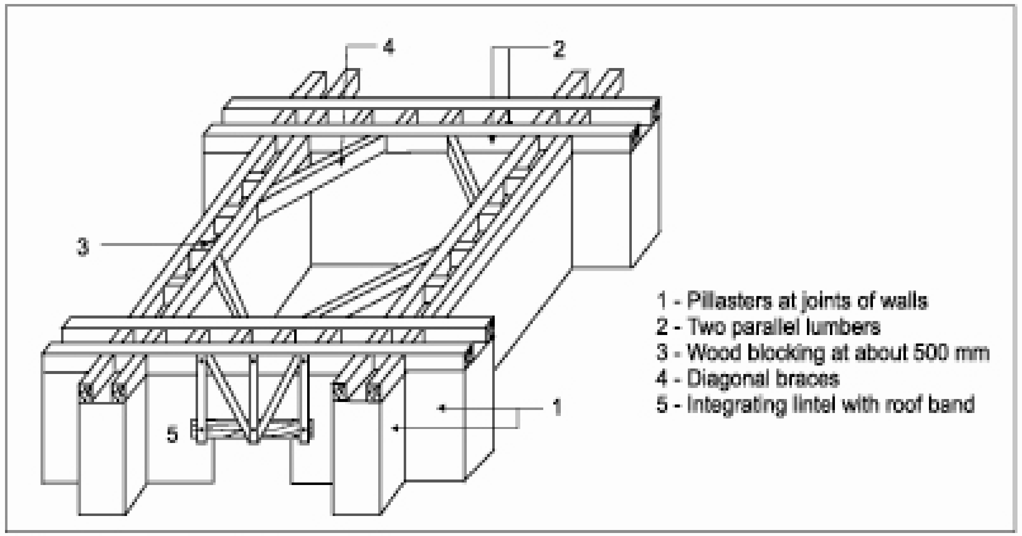
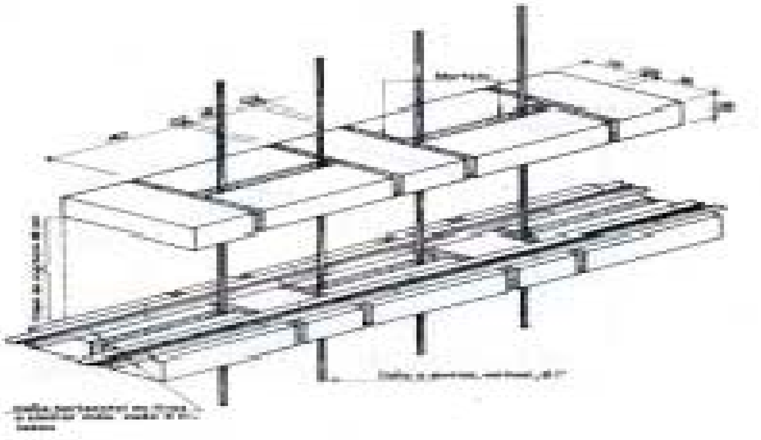
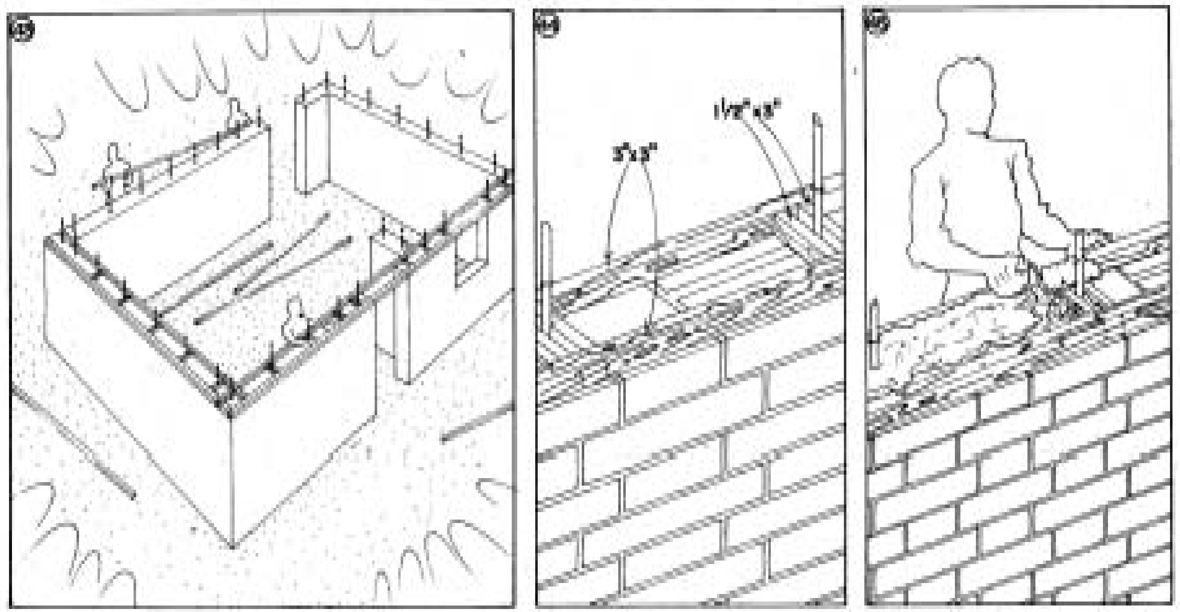


Fig 7.11 Roof band on pillastered walls

Bond between different building parts



EJEMPLO DE USO DE CAÑA ENTRE ADOBES
DE .18 x .40 x .08



HACER LA SOLERA CON VIGAS DE MADERA UNIDAS CON TRAVESAÑOS, TAMBIEN DE MADERA.

FIJAR LAS CAÑAS VERTICALES CLAVANDOLAS A LOS TRAVESAÑOS.

RELLENAR CON BARRO ENTRE LAS VIGAS.

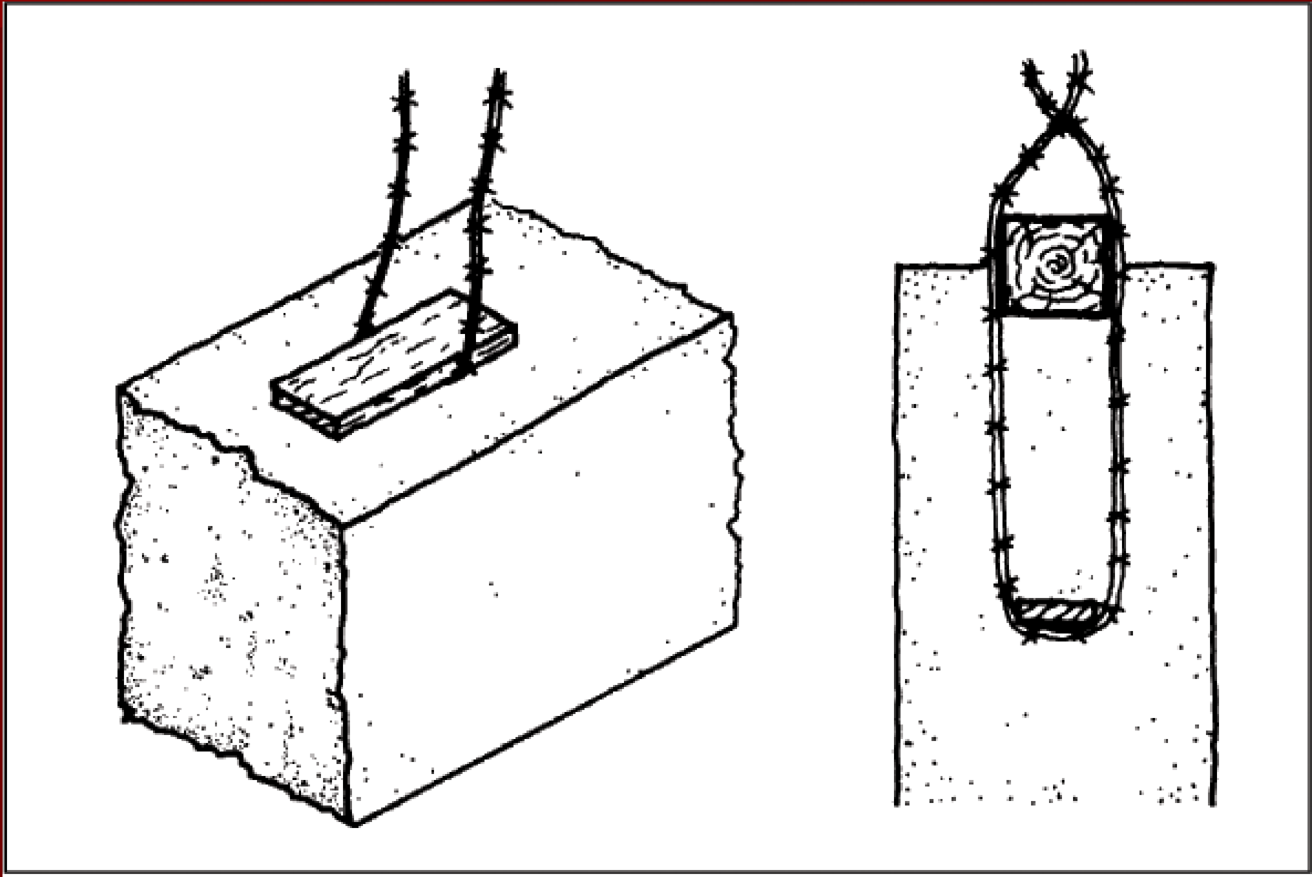
Bond between different building parts

The roofing

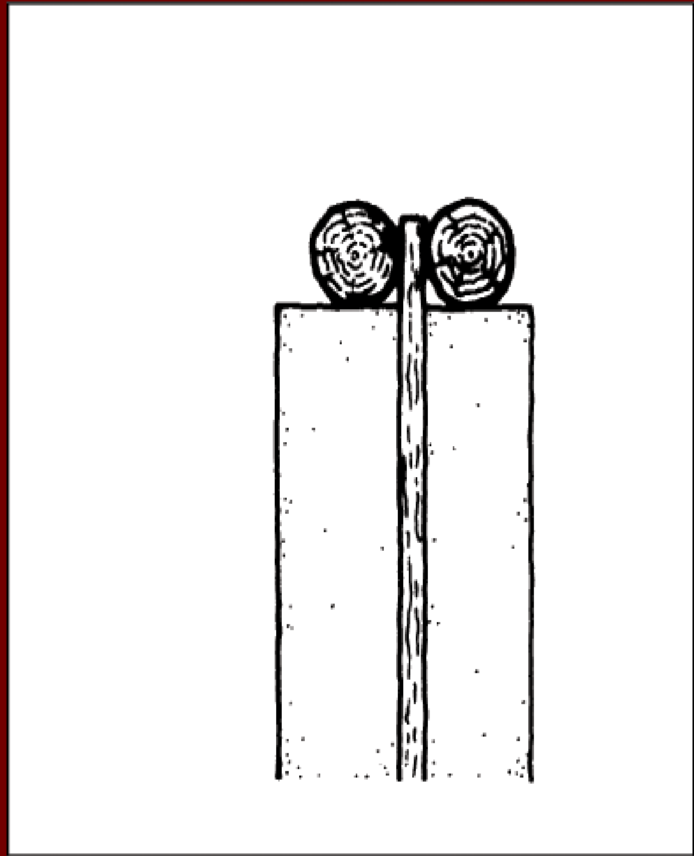
- Villages, had a lot roofs that often collapsed because of the weight or the weak walls.
- **Solution:** it is more reasonable to strive for a common solution with a flat roof with reinforced concrete beams and an air condition. For isolation reasons the reinforced concrete roof (12 cm) will be covered by a thin layer of a clay-hey mixture.
- To prevent ponds of water on the roof and consequent leakage the roofs must be laid with a minimum slope and must overlap the walls on the edges.
- Still, the solution with traditional roofing (or partly traditional roofing) can be checked individually with the respective owners of a house as the traditional way of building harmonizes very much with the environment.

Correct fixing of ring beam

Walls have to be finished on top by a ring beam, which has to be adequately fixed to the walls.

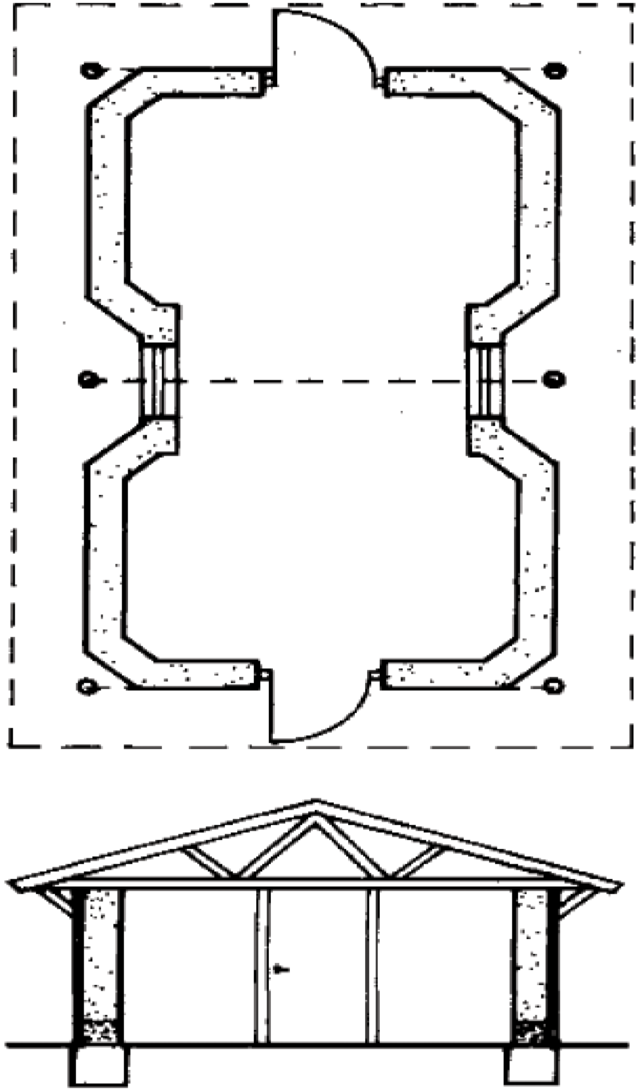


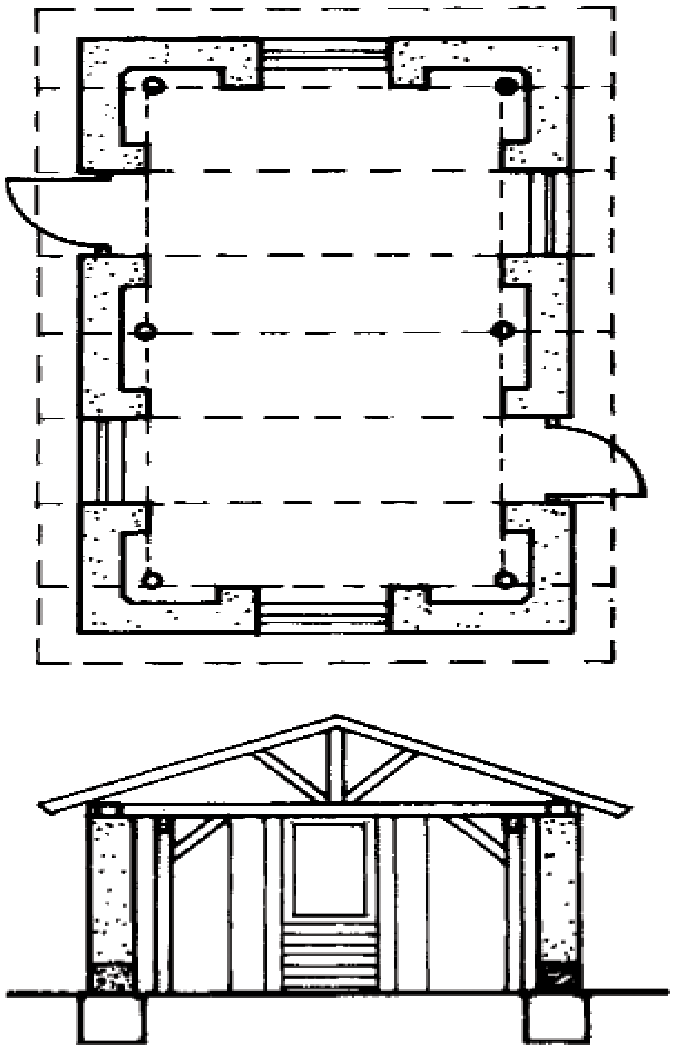
10-4 Fixing of ring beam



10-5 Fixing of ring beam

Separated roofs

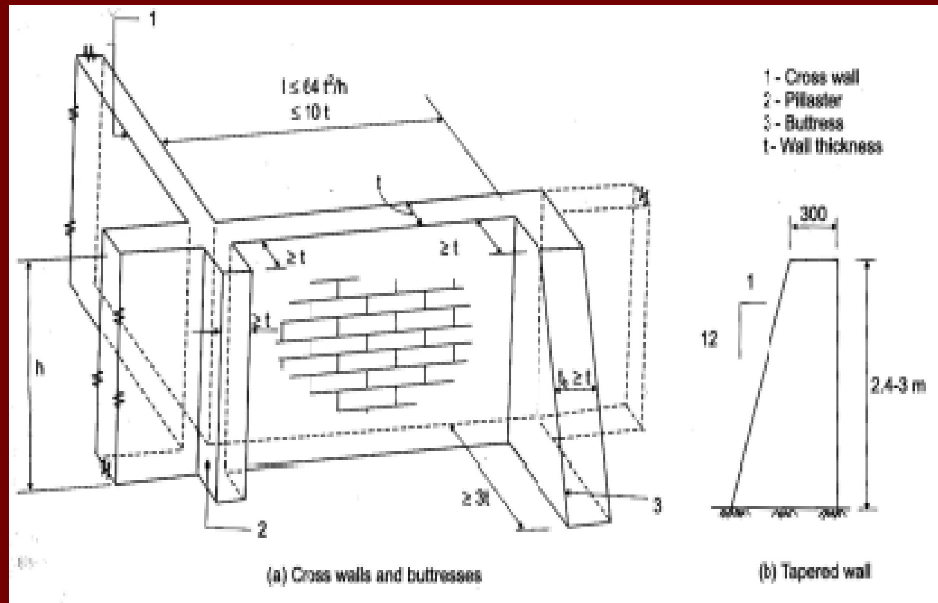




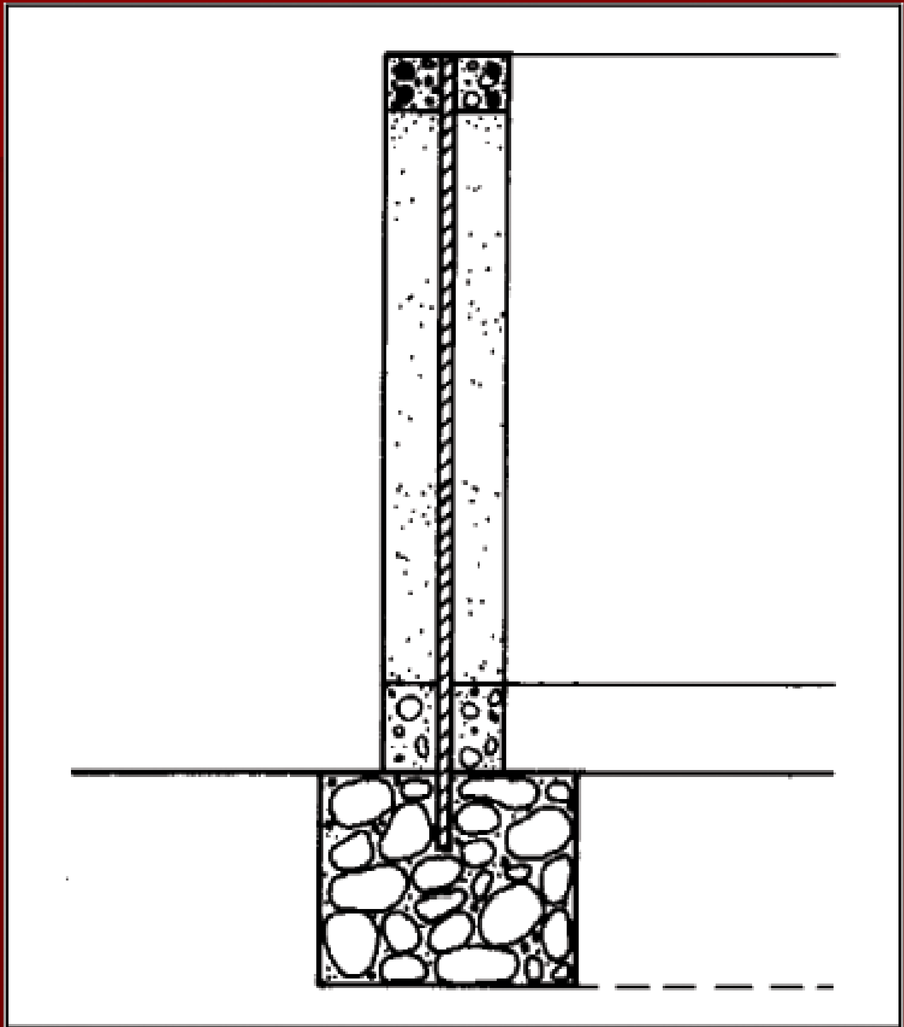
The height of a building

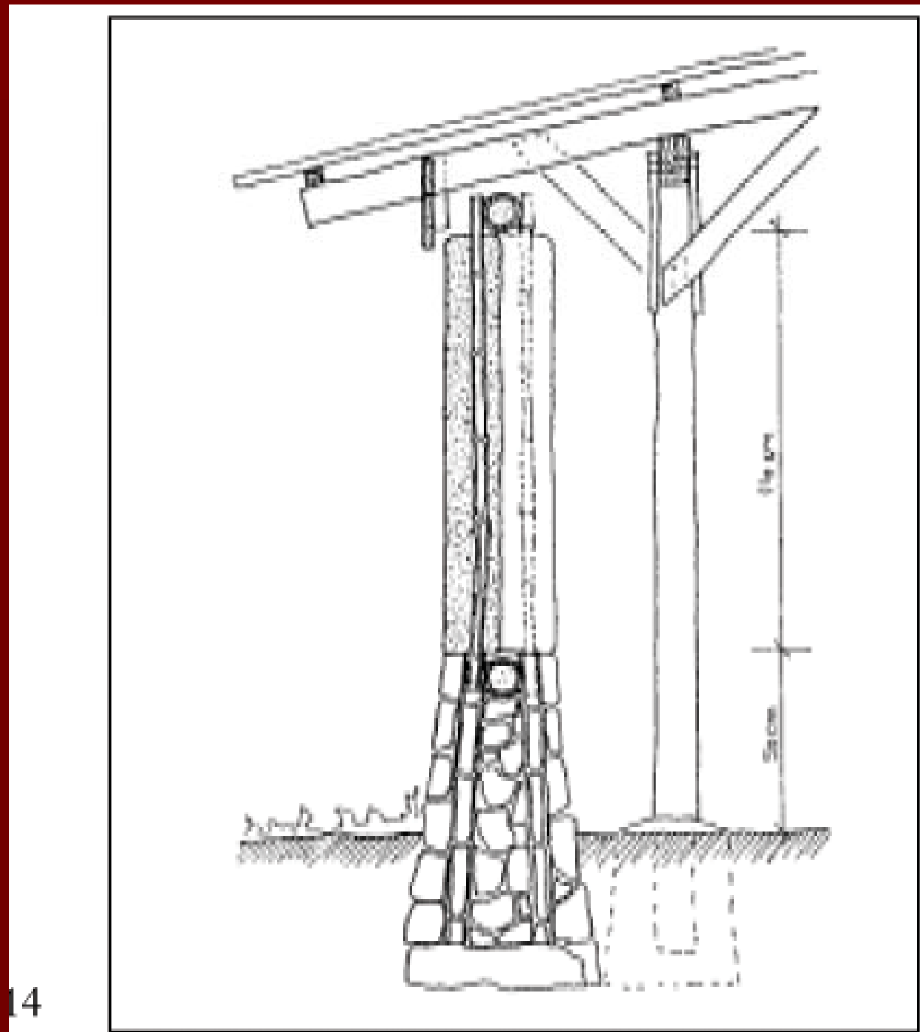
- An important factor for the risk of a building is the height. The higher the building, the bigger the sideways amplitude of the upper floors is.
- If the connections between the ceiling and the supporting structure are not done in a proper way, the ceilings or the respective beam knock over the walls and fall on the subjacent floor.
- This activates a chain reaction. in villages the traditional way was a one-story building, therefore the problem came up just very rarely.

- **Solution:** Although the buildings in villages have been one story building mainly, the house has to be strong enough for a second floor as this might be the intention of an owner one day.


1
$l \leq 64\ t^2/h$
$\leq 10\ t$
1 - Cross wall
2 - Pilaster
3 - Buttress
t - Wall thickness
t
≥ t
≥ t
≥ t
h
$t_p \geq t$
≥ 3t
2
3
300
1
12
2.4-3 m
(a) Cross walls and buttresses
(b) Tapered wall

Internal reinforcement



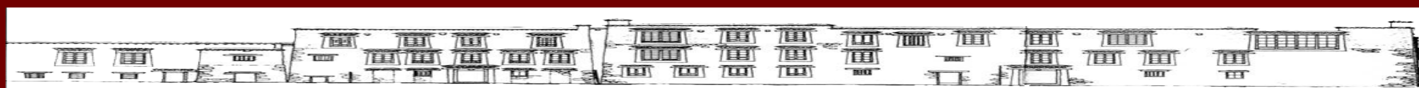


The quality of the material

- Often simple bricks of air-dried clay mixed with hay (Adobe) or fired bricks were used. Mostly there was neither a steel frame nor a concrete structure as both are costly.

- **Solution:** Another matter that must be dealt with is the use of proper construction materials, the availability of the same and the environmental impact of using certain local materials. Looking at the condition of the area, the construction with Adobe-bricks would sound very interesting.

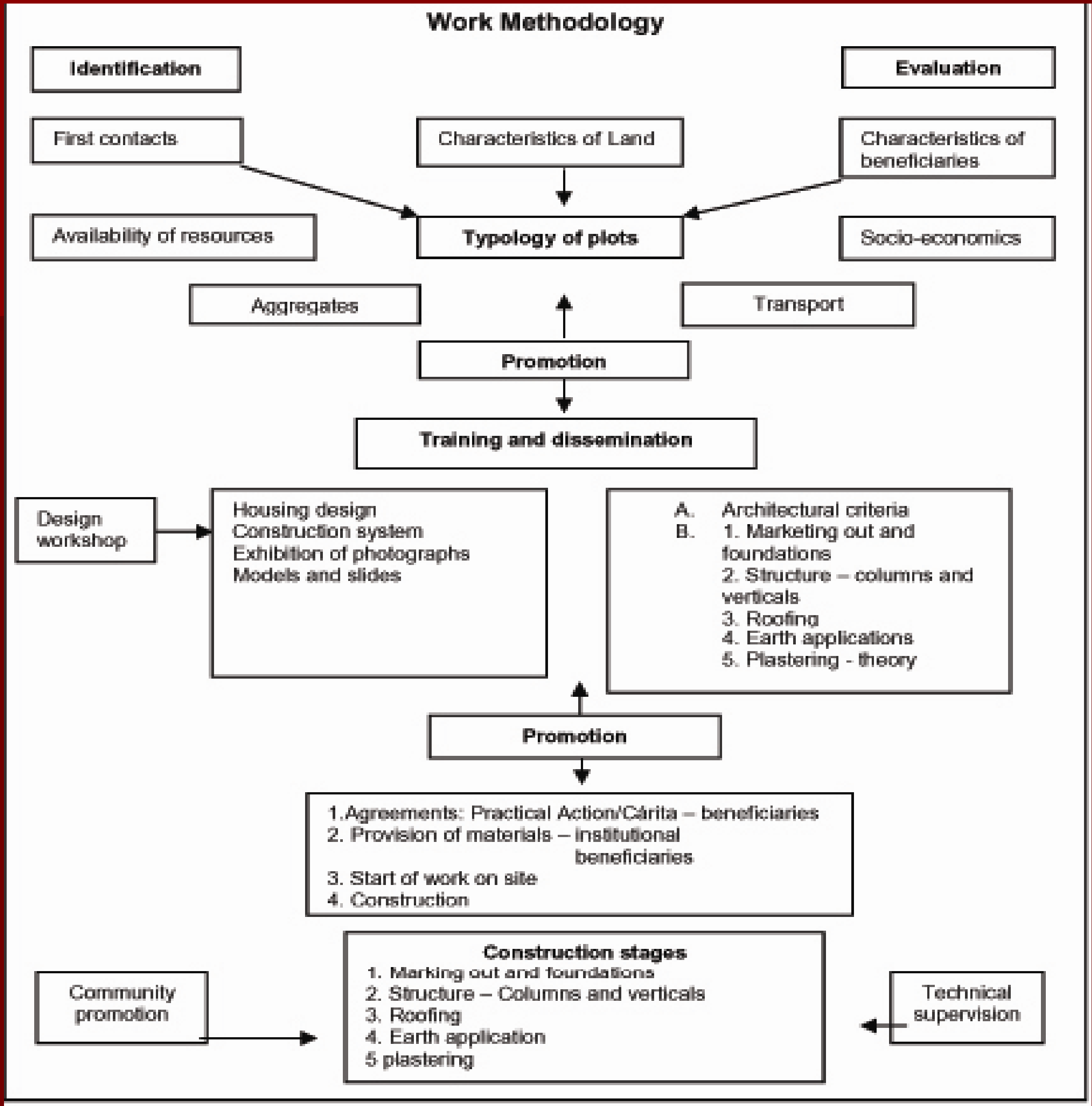
- Some of the old fired bricks can be used again, as the material itself was from good quality but the connecting material was bad, the bricks just fall apart but did not break. It is a long and intensive manual labour to clean them but it will be worth it as the material partly could be reused again.



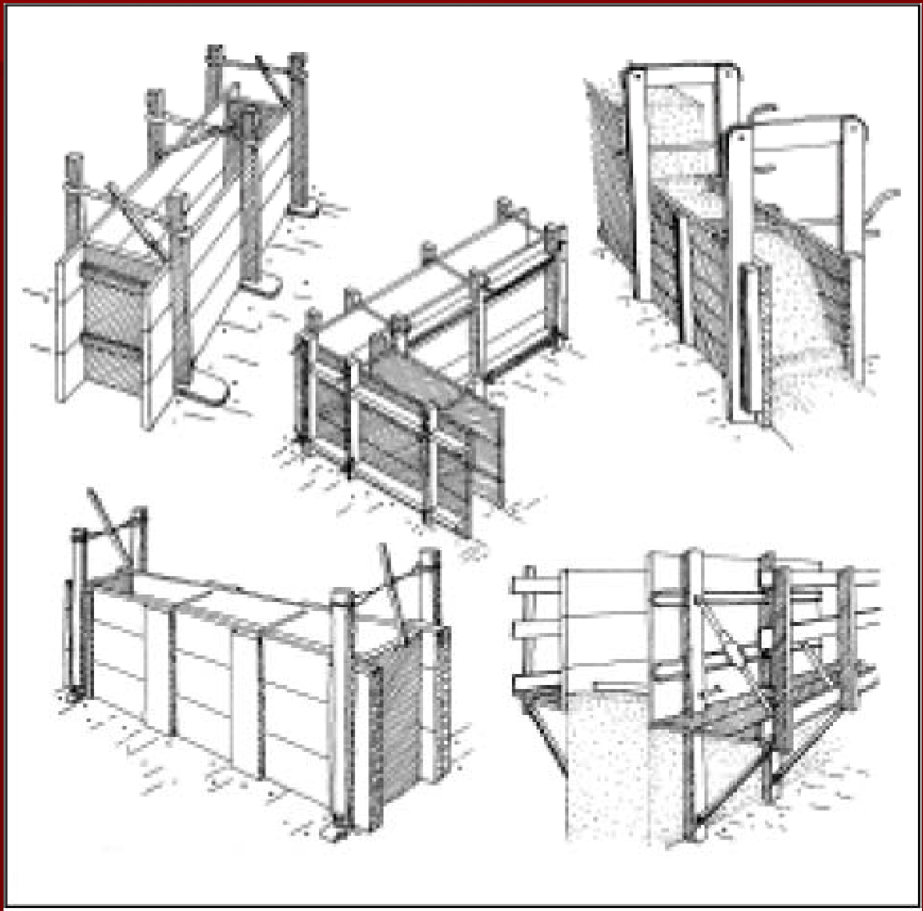
The quality of the work

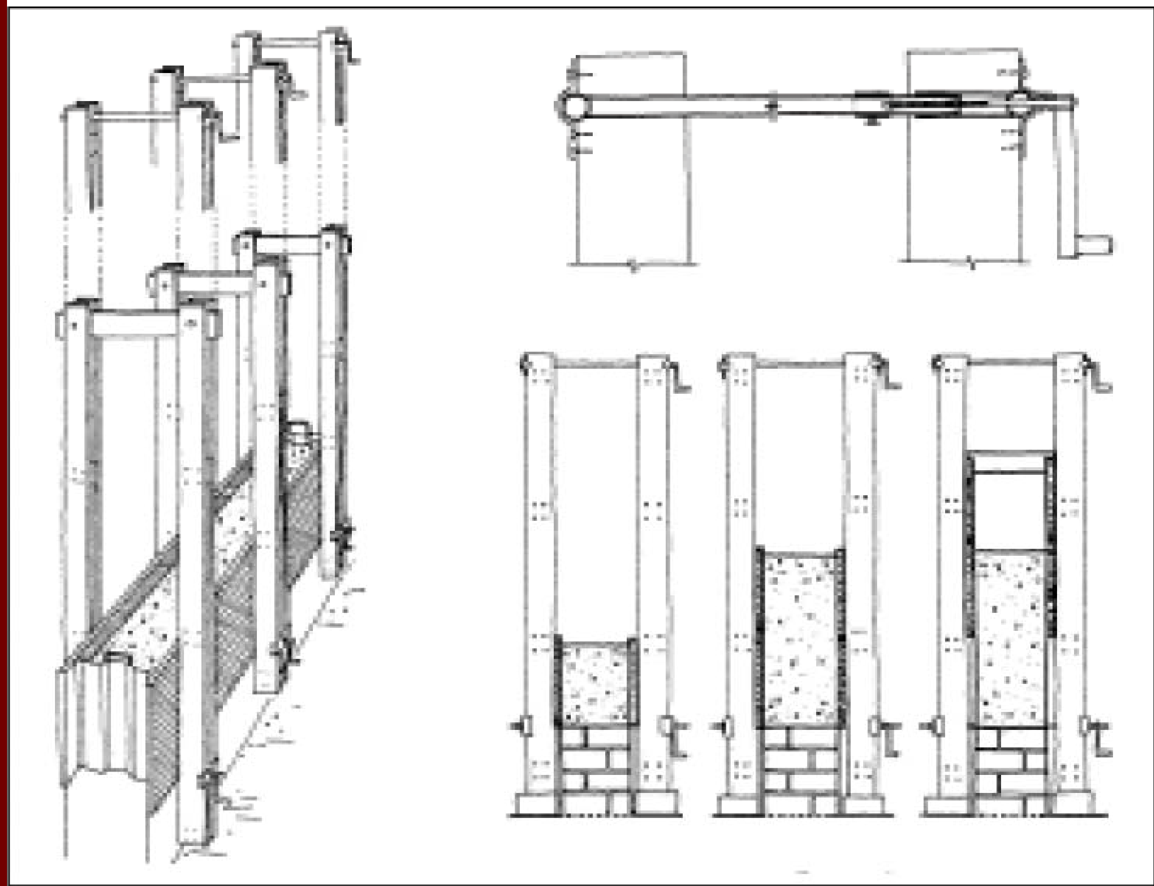
- There was poor workmanship and lack of supervision.

- Solution: A training component as well as a close monitoring of the work by professional people is essential (see training component). In order to make sure that people involved in the reconstruction process are able to understand the way and the sensitive parts of the construction of an earthquake resistant house, ASIA will built one first house as an example. Different stages of construction will be visible and trained people can explain to the population how the process works. If all houses in …… are completed, also the "example-house" will be finished and will be used as a community centre for the village.

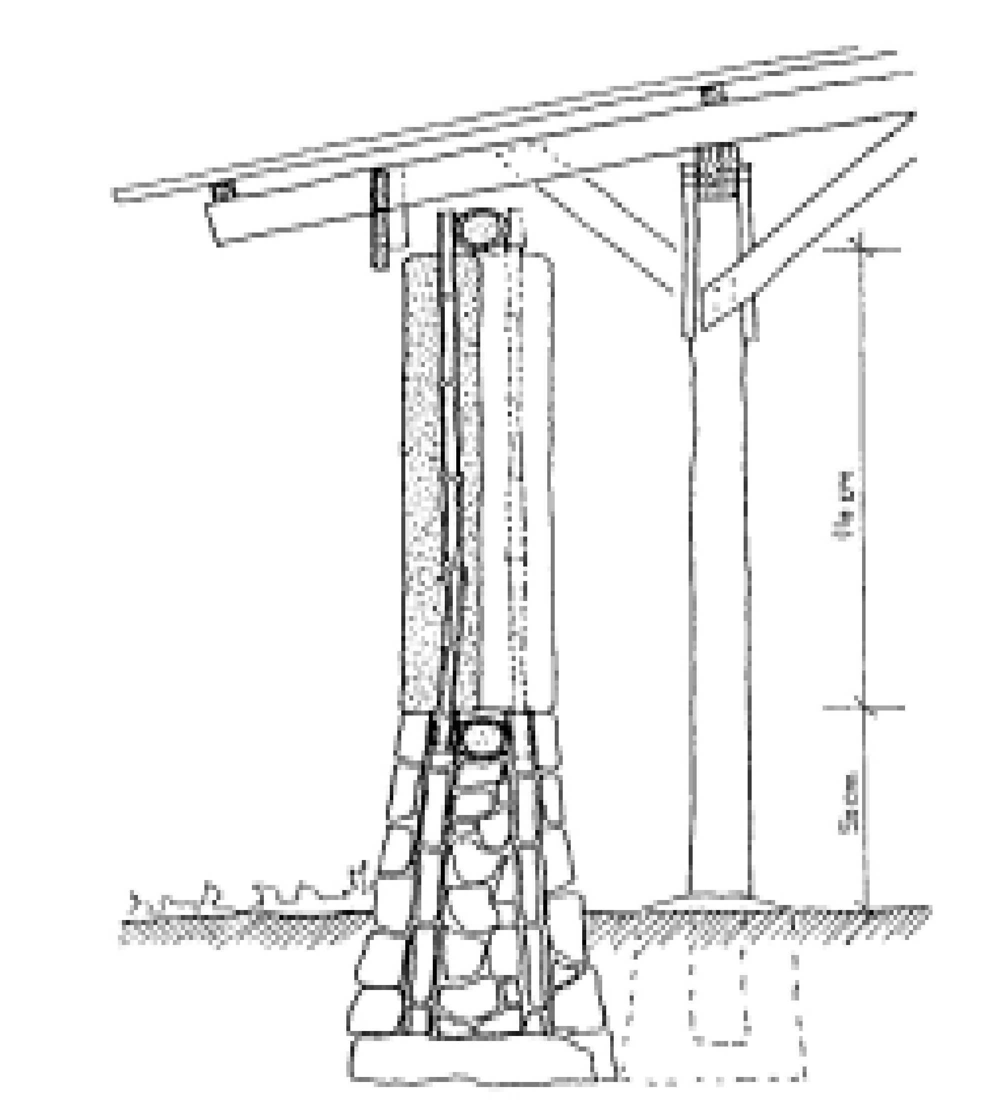

Work Methodology
Identification
Evaluation
First contacts
Characteristics of Land
Characteristics of beneficiaries
Availability of resources
Typology of plots
Socio-economics
Aggregates
Transport
Promotion
Training and dissemination
Design workshop
Housing design
Construction system
Exhibition of photographs
Models and slides
A. Architectural criteria
B. 1. Marketing out and foundations
2. Structure – columns and verticals
3. Roofing
4. Earth applications
5. Plastering - theory
Promotion
1.Agreements: Practical Action/Cárita – beneficiaries
2. Provision of materials – institutional beneficiaries
3. Start of work on site
4. Construction
Community promotion
Construction stages
1. Marking out and foundations
2. Structure – Columns and verticals
3. Roofing
4. Earth application
5 plastering
Technical supervision

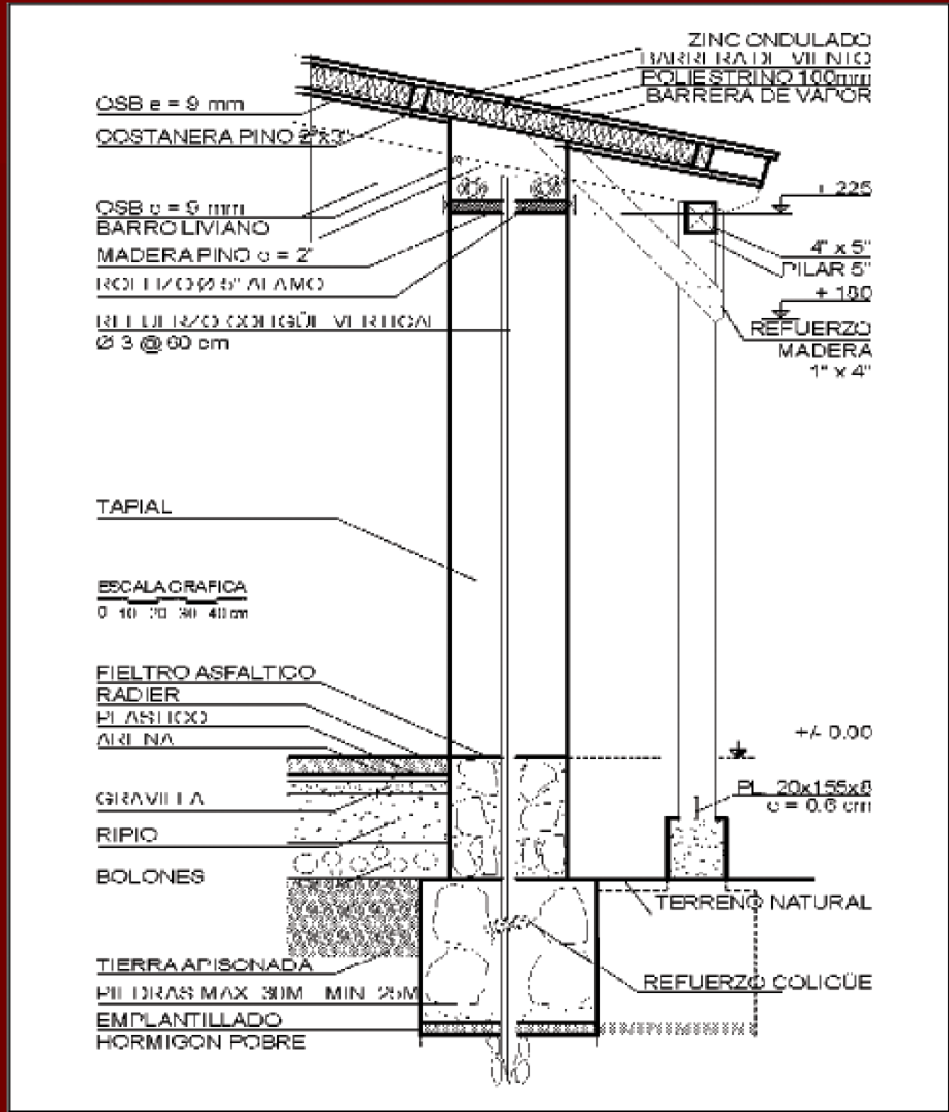
Formwork for rammed earth





Reinforced rammed earth wall system





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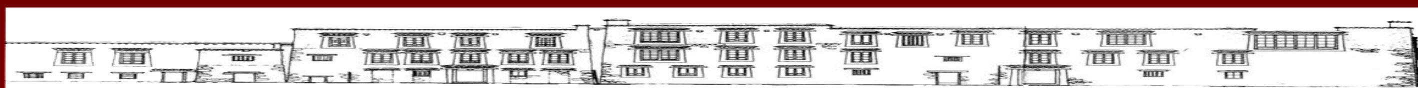

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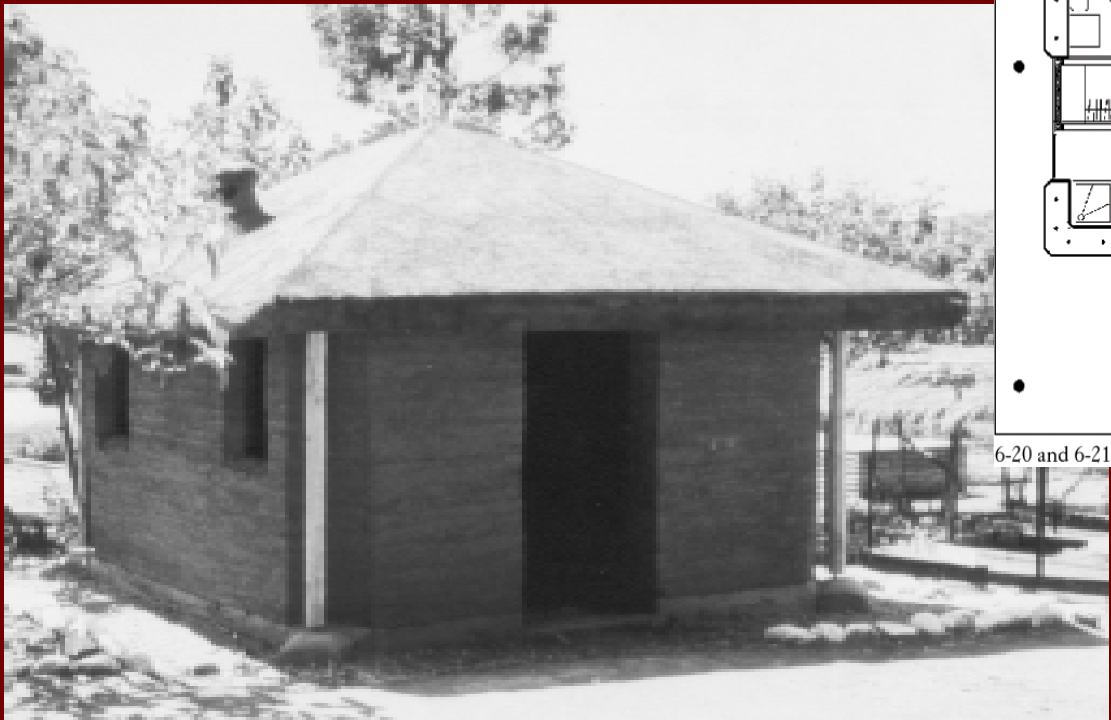
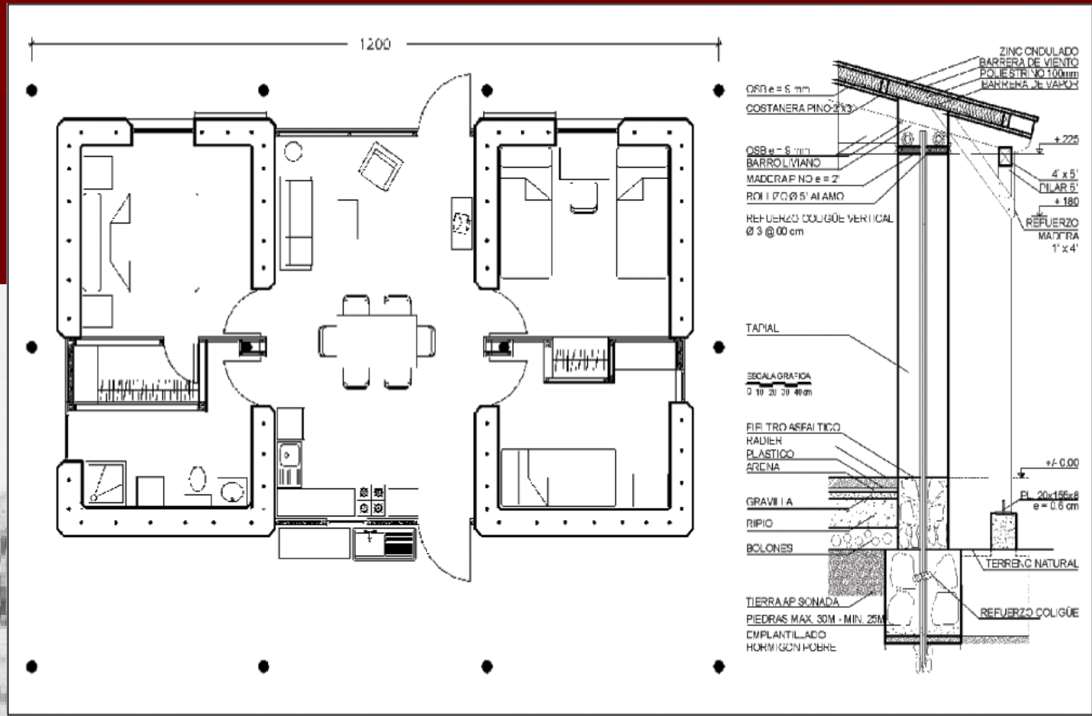
Earthquake resistant low-cost house





6-20 and 6-21 Earthquake resistant prototype building, Alhué, Chile 2001

Arup in Ladakh   Druk White Lotus School

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Internal reinforcement in Druk White Lotus School

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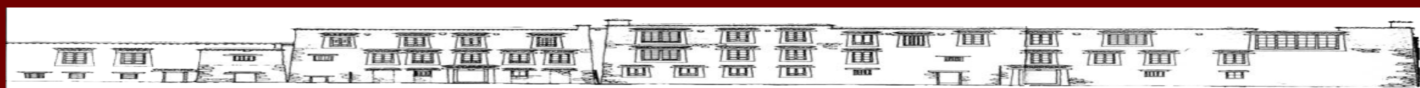
Structural design

The key aspects governing the structural design were earthquake loading, durability and appropriateness.

The kindergarten buildings have cavity walls on three sides with granite block in mud mortar as the outer leaf and traditional mudbrick masonry for the inner leaf; this gives increased thermal performance and durability compared to the rendered mudbrick walls commonly used.

The Ladakhi style heavy mud roof is supported by a timber structure independent of the walls to provide the earthquake stability.

The large spans needed in the classrooms, combined with the open glazed south facing façade and the high weight of the roof makeup, required large timber cross-sections and steel connections to ensure that they resist seismic loads and to warrant life safety in the case of an earthquake.



Gansu School

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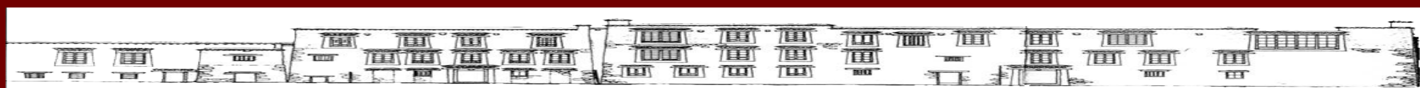

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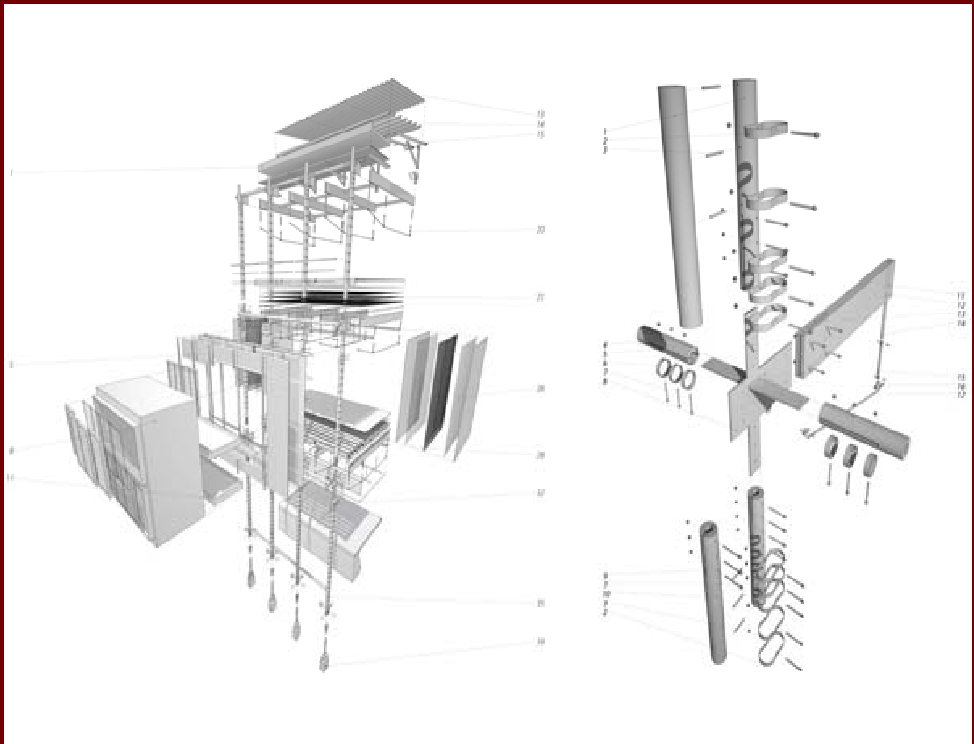
Earth and wood earthquake resistant house



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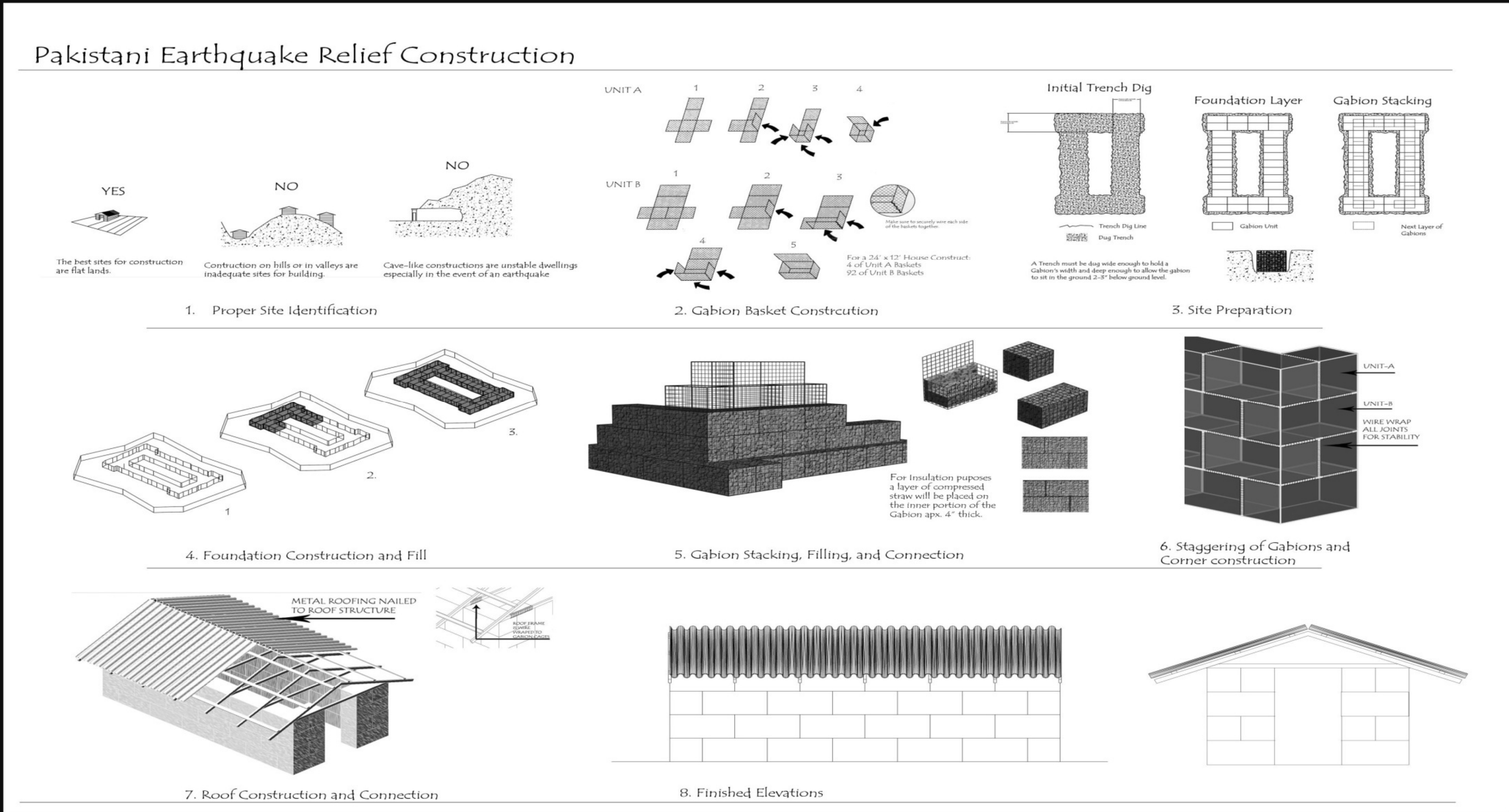
Pakistan Earthquake resistant house



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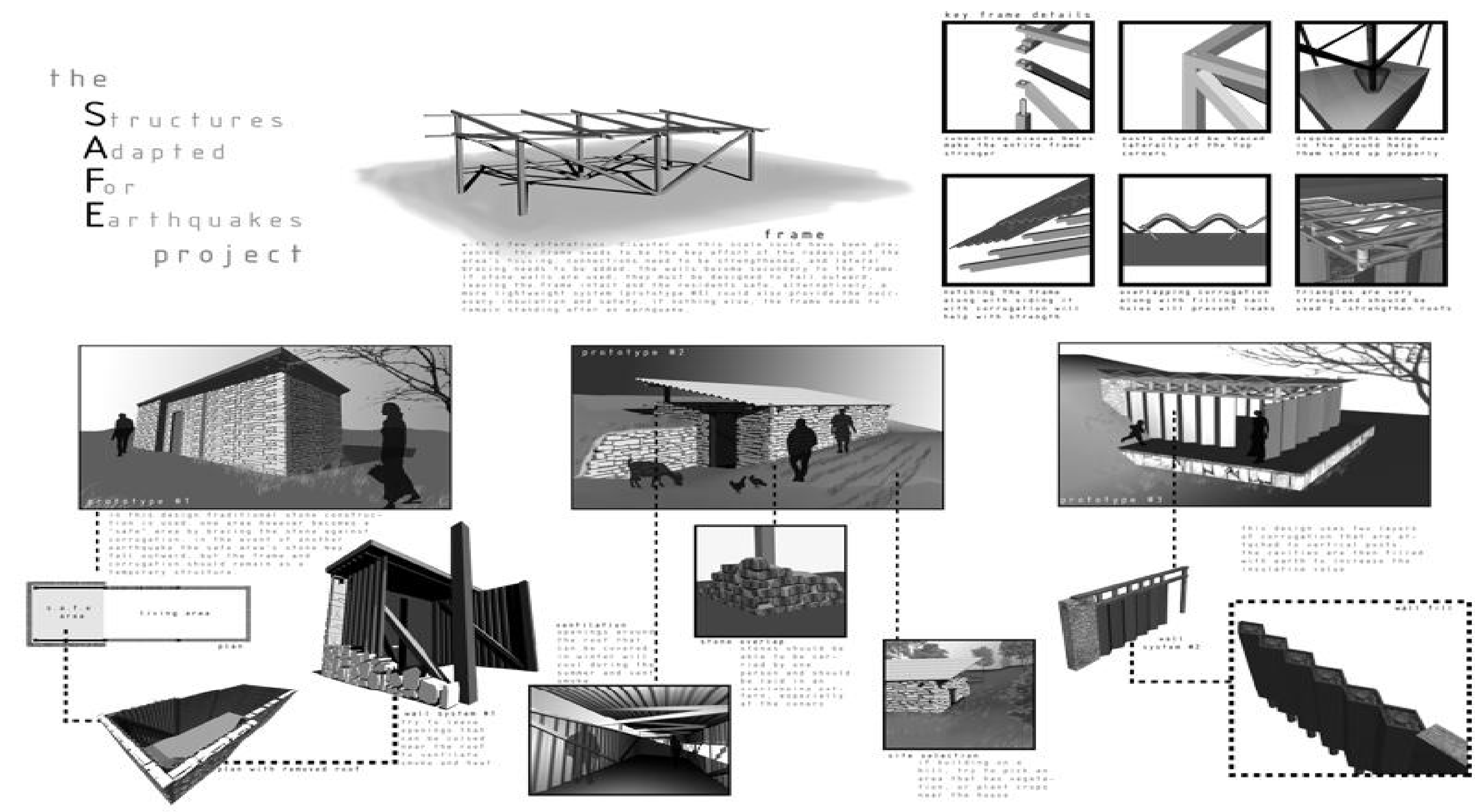
Safe project for earthquake resistant house



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Safe project for earthquake resistant house

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Multi storey european earth building house

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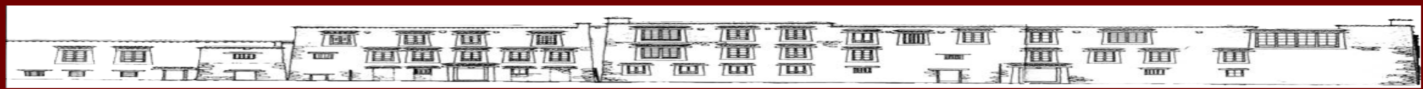
Modern earth building houses



Modern earth building houses

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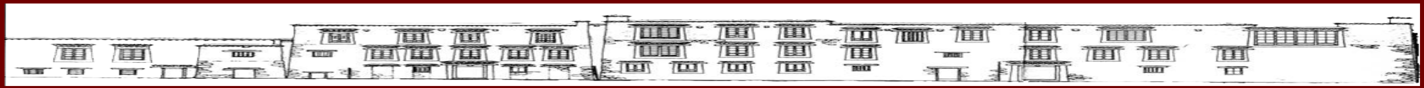

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Modern earth building houses

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