

Building earthquake resistant clay houses

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Article Info

Received 16 May 2015, accepted 18 May 2015, published 20 May 2015

internal review by: Kathleen Draper

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Please cite as:

Please cite as: Minke G, Schmidt HP (2015): Building earthquake resistant clay houses, Ithaka-Journal for biochar materials, ecosystems and agriculture (IJ-bea), Arbaz, Switzerland, ISSN 1663-0521, pp. 349 -355, www.ithaka-journal.net/87

Many thousands of clay houses crumbled during the recent earthquakes in Nepal. But that did not happen because of insufficient strength of the clay as a building material, but rather because basic construction rules were disregarded. Gernot Minke, an international expert on clay building, explains in this interview how to build clay houses that resist earthquakes even better than many concrete buildings. He also describes what construction errors should be avoided to make sure your house will keep you safe when the earth starts to shake again in Nepal, Bhutan, Pakistan or anywhere in the world.

1. Building Material

Driving around Nepal after the earthquakes, one of the first things to notice is that most steel reinforced concrete buildings are still standing with only minor damages while many traditional clay and clay-brick buildings crumbled or were severely damaged. This raises the logical and compassionate question: Is it possible to build earthquake resistant houses with clay or must Nepal replace clay and clay-brick when rebuilding the country?

Minke: It is not the building material clay or clay-brick which causes the collapse in an earthquake but the structural system and the design of the houses. For instance in Mendoza, Argentina old houses with thick rammed earth walls withstood all earthquakes of the last centuries, whereas all modern buildings built of adobe (unburned clay bricks, mud bricks) or burnt bricks collapsed. I saw also in Bam, Iran after the heavy earthquake in 2003 that some of the adobe vaults resisted, whereas all brick and even steel-skeleton structures collapsed.

Do you have an easy test to check if the clay-soil found close to the building site of a house is suitable as building material either for bricks, rammed earth walls, or joints between bricks or plaster?

Minke: Clayey soils are always different and there are simple field tests to check their quality. They should have enough clay content but also enough coarse sand and fine gravel to provide stability. If the soil has too much clay and silt (very fine sand), the soil will get many cracks after drying. If it has enough coarse particles it will dry without getting cracks.

Is it better, from an earthquake resistance perspective, to use burnt clay bricks or build with massive rammed clay-soil walls?

Minke: *There are* generally two possibilities to build earthquake-resistant houses with earth. Either using thick massive walls from rammed earth or large adobes or using a flexible structure of timber or branches filled with earth, like the wattle-and-daub-system. Fig. 1 shows such a house



Fig. 1: Wattle and daub structure, after a heavy earthquake in Guatemala (Minke 2000)

which withstood a heavy earthquake in Guatemala. In this case the kinetic energy of the earthquake was absorbed by deflection. Either thick and massive walls or thin and flexible walls!

Does it help to add some cement to a local clay-soil mixture? And if yes, how much cement should be added?

Minke: No, it is not necessary to add cement, only if you use earth plaster and want to make it water-resistant. But it might be dangerous if you add only up to 5% of cement to the earth, than the mixture is less resistant against compressive forces than without cement!

Are there other locally available materials to add to the clay-soil mixture to improve its strength like cow dung, straw, lime etc.?

Minke: If the soil has little clay-content it is good to add cow dung, also to make an earth-plaster more resistant against rain. Fine natural fibers help to reduce shrinkage during drying.

2. Placement of the building site

Most of the building sites in Nepal are steep or terraced on steep slopes. How should a house be placed in this difficult topography?

Minke: The house should not stand on a slope nor cut into a slope. If a slope is the only option, a platform has to be formed and the house has to be placed at sufficient distance from the slope (Fig. 2-1 to 2-5).

3. Foundation

Do you have a rule of thumb about how deep the foundation of a house should be? What conditions, if any, might cause this to vary? Should the foundation of a clay house be made from different materials than the house itself?

Minke: The dimension of the foundation depends on the

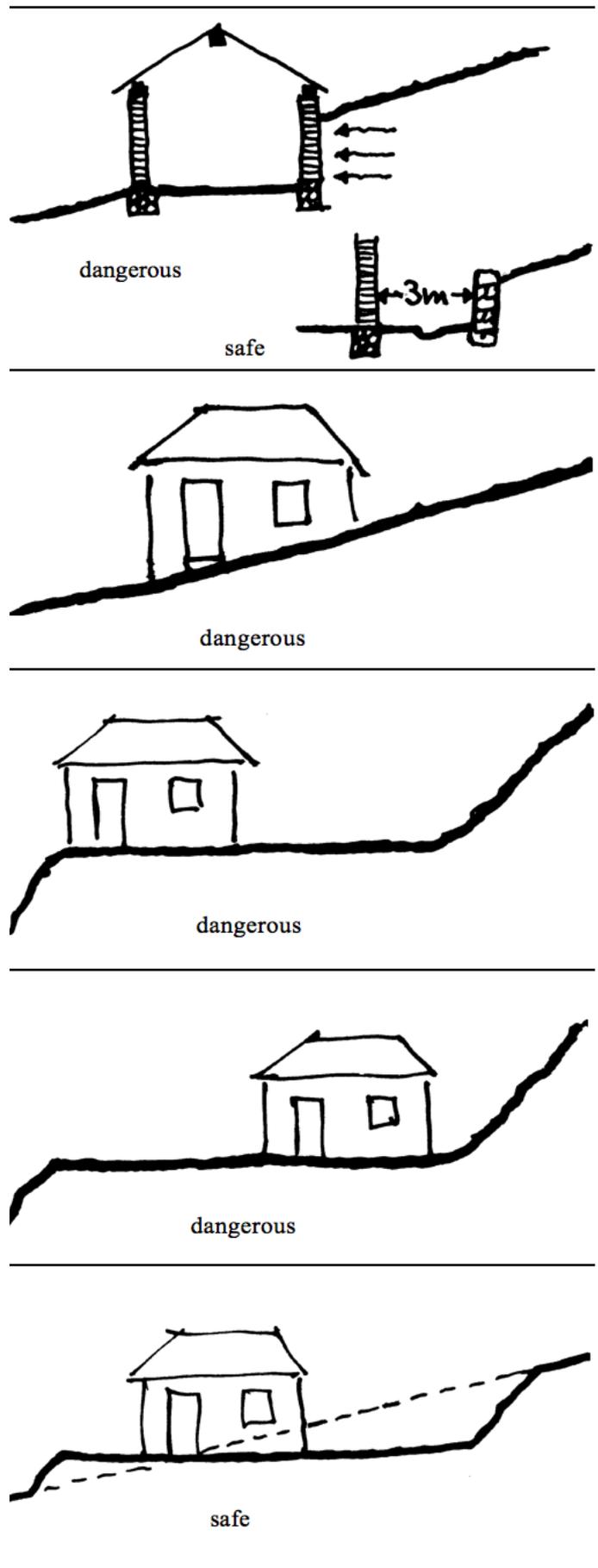


Fig. 2-1 to 2-5: Dangerous and optimal placements of a house on a slope. Only the placement as shown in Fig. 2-5 can be considered as safe.

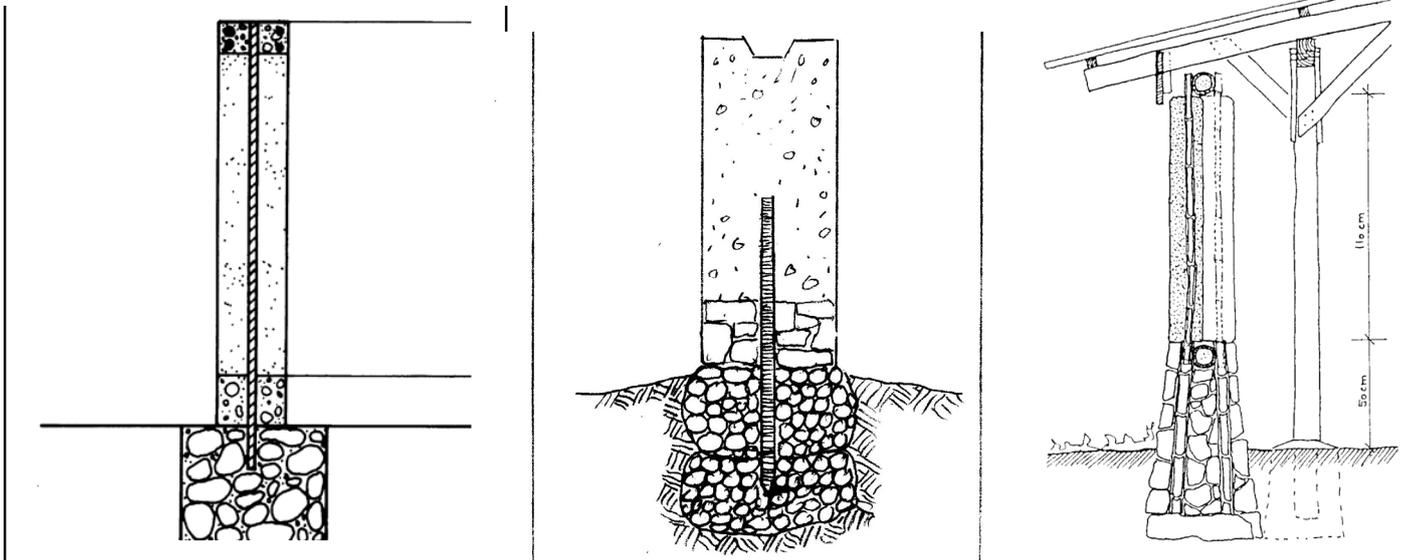


Fig. 3-1 to 3-3: Foundation of external walls should be at least 40 cm deep and made with stones. A floating foundation made with plastic bags filled with round pebbles makes a more flexible foundation that resists better in earthquakes. Separation of roof system and wall system with ring beam on top of plinth and on top of the wall. Wall reinforced by vertical bamboo rods.

soil quality. Normally a depth of 40 cm is sufficient and the width should be at each side 10 cm wider than the plinth. The strongest solution is to use concrete with large aggregates (cyclopic concrete). Normally stones or burnt bricks with a mortar of cement or cement and lime are used. There must be a good bond between foundation and plinth and between plinth and wall. Therefore it is recommended to integrate a wooden or bamboo rod of 2.5 to 5 cm every 40 to 50 cm. (Fig. 3-1).

A „floating foundation“ is a clever solution to absorb horizontal shocks from an earthquake. A simple solution is reached by putting two or three layers of plastic bags filled with round pebbles from a river underneath the plinth. They have to be rammed to form a plane surface on which the plinth is build (Fig. 3-2)

4. Form of the house

Most of the houses in the hills of Nepal are rectangular as they are built parallel to the terraced slope. Are rectangular forms a good choice or should people rather build their houses in square shapes or even round?

Minke: The shape of the plan of a house has an important

influence of its stability against earthquakes. The square shape is better than a rectangular shape. The best is a round shape and the worst a L-shape. If the rectangular shape is very long, it should be divided into two parts, these parts can be interconnected by a light flexible corridor.

If the footprint is too narrow to build square shaped houses should people rather build several square shaped houses in row?

Minke: Yes, see fig. 4.2

5. Wall thickness

Is there any rule of thumb on how thick a clay-soil wall would have to be to resist an earthquake?

Minke: Minimum thickness is normally 30 cm and the height should never be higher than 8 times the thickness. If you want to build higher than 2m40 (from the foundation to the beginning of the roof) then you must increase the thickness of the wall accordingly or you must integrate buttresses (Fig. 6-2).

Can the thickness of the clay wall be reduced when vertical bamboo, steel or other type of rods are used inside the

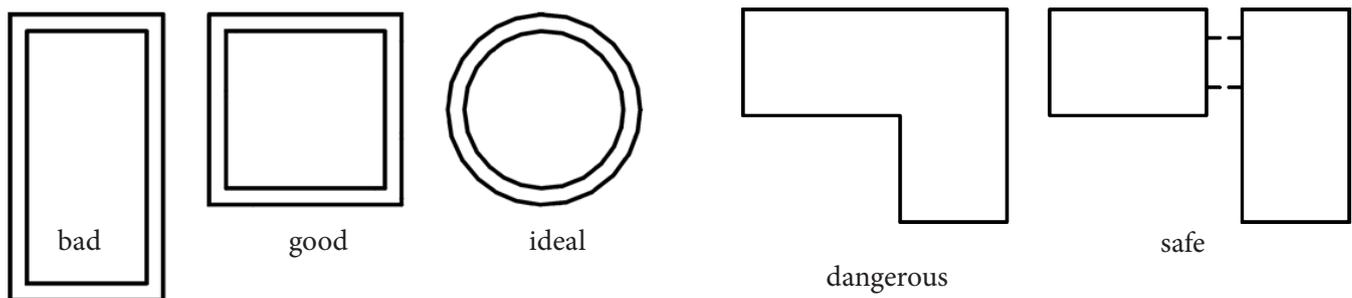


Fig. 4-1 and 4-2: The shape of house plans already decides about the final stability.

wall? Is this something that would be recommended?

Minke: Yes, vertical elements like bamboo rods of 2.5 cm diameter every 30 to 50 cm well fixed into the foundation give additional stability, whereas horizontal elements may weaken the structure against the horizontal forces from the earthquake.

6. Structure

What are the weakest points and main structural failures of clay-soil buildings?

Minke: Within a research project we analyzed the typical design mistakes, which led to collapse in rural houses during earthquakes in South America. The main mistake is the lack of a ring beam (see Fig. 8-1 & 6-2) that keeps the tops of the walls together. The second widely found mistake is, that the lintels do not reach deeply enough into the walls on both sides of the window: 40 to 50 cm should be the minimum. The best solution is to avoid lintels by having windows that reach up till the ring beam, using the ring beam at the same time as lintel.

Another mistake is the shape of windows: They should always be higher than large (vertical proportions!) and the horizontal distance between openings in the walls should be at least 1 m (Fig. 11-1).

Should special attention be given to the corners of a building?

Minke: Yes, the walls which meet in a corner should be good interconnected and well fixed to the ring beam, which must have a stiff corner. With masonry walls it is favorable to build buttresses (Fig. 6-1), with rammed earth walls it is good to avoid sharp corners as shown in fig. 6-2.

7. Buttress

How long should a wall be without adding buttresses in between? Does the height of the wall impact this?

Minke: Of course, it depends of the height and the thick-

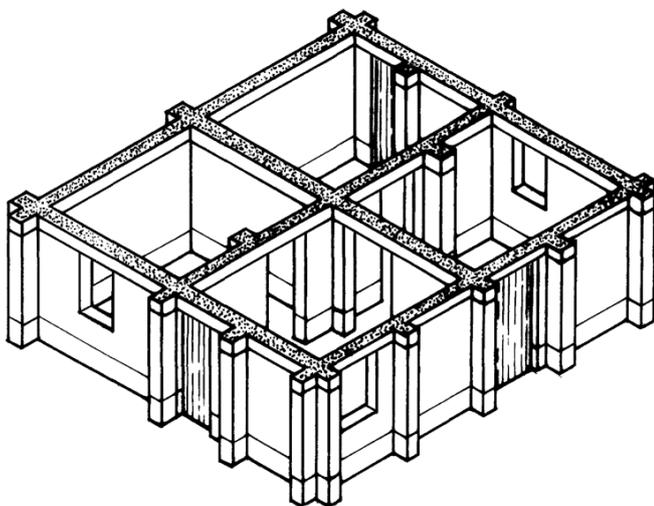


Fig. 6-1: Adobe walls reinforced by buttresses and ring beams on the top of the walls

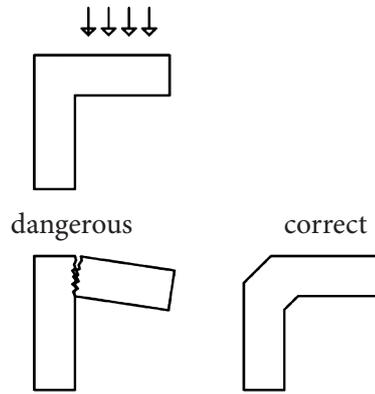


Fig. 6-2: Always construct with cut or rounded but not rectangular angles!

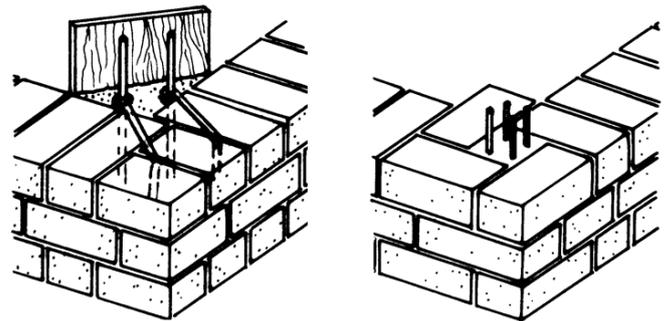


Fig. 7-1: Stabilizing the corner with a column of reinforced concrete.

ness of the wall. If the wall is relatively thin a buttress could be every 1,50 m to 3,00 m

How should buttresses be built and what material would you propose?

Minke: The buttresses are normally of the same material as the walls. But there is another simple and effective method to stabilize the corner by integrating a small column of reinforced concrete into the masonry (Fig. 7-1)

8. Ring Beam

It seems that a strong ring beam at the top of the wall is the best assurance for the resistance of a house.

Minke: Yes, a ring beam that is structurally well interconnected with the walls is an absolute must. The better the ring beam is fixed to the wall the better it can hold the wall (Fig.: 8-1, 8-2)

What materials should be used for a ring beam? Does it have to be steel enforced concrete or hard wood or could bamboo also be used?

Minke: The best is steel-reinforced concrete, but it could be also wood or bamboo. But in these cases there must be a stiff connection at the corners, which requires normally an extra element, which is forming a triangle over the corner (Fig. 8-3, 8-4).

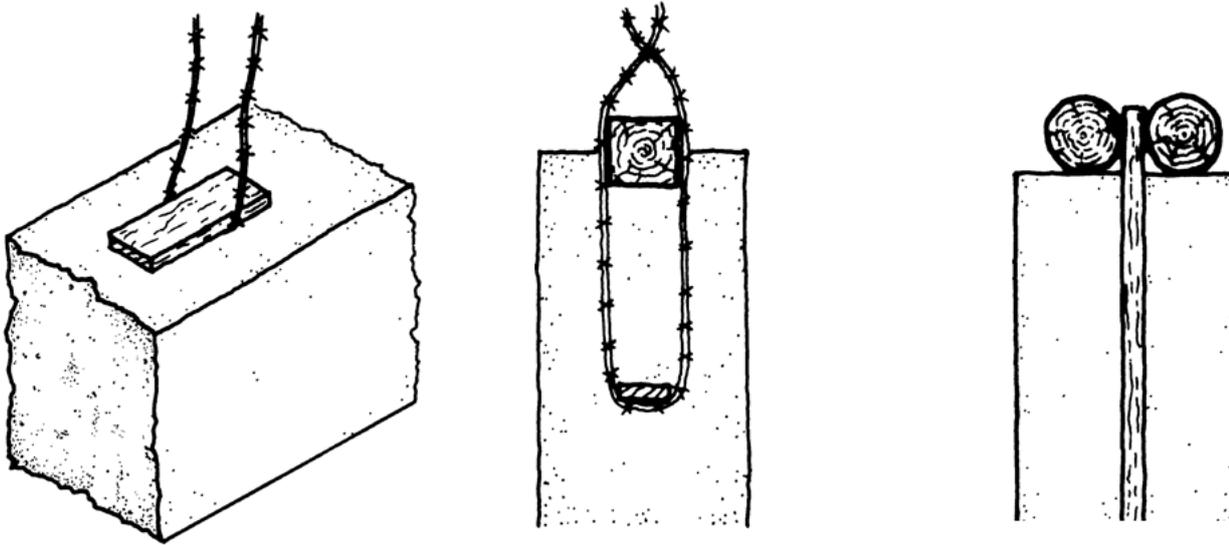


Fig. 8-1 & 8-2: Possibilities of fixing the ring beam in a rammed earth wall.

How strong should ring beam and the wall be interconnected? Are there special techniques especially when bamboo is used?

Minke: In any case we need 40 to 60 cm long vertical sticks of thin branches or bamboo rods 1.5 to 2 cm thick that interconnect with the ring beam and wall every 40 to 60 cm. If we build the ring beam from bamboo we need a structure like a ladder of two parallel columns interconnected with smaller rods every 30 to 50 cm.

Should the ring beam be held on independent pillars?

Minke: It can indeed be fixed to vertical posts. Then they form a structural skeleton, a so-called post-and-beam structure, and the adobe acts as infill. But in this case there must be a good connection between the posts and the adjacent adobe, otherwise the adobe will fall off with the horizontal shocks of the earthquake.

If my clay house has no ring beam, do I have to take off the roof, build a ring beam on top of the outer walls and reinstall the roof? Or may I build a ring beam on the inside or outside of the walls and support it with pillars or buttresses?

Minke: Yes, you may build the ring beam also on the outside of the wall (not at the inside!) and support it with pillars. But it has to be strongly interconnected at the corners, so that this connection does not open in the earthquake. And the roof must be connected to the ring beam as well.

Would you agree that a clay house without ring beam couldn't resist a stronger earthquake?

Minke: Yes, absolutely. Don't sleep in a house without a ring beam which is well connected to the wall and the roof!

9. Plinth

Many clay houses have no special plinth and are directly built on the foundation. Is a plinth really necessary to rein-

force the house structure?

Minke: The plinth is only necessary to avoid erosion by splashing rain. If we have heavy rains and an earth wall, which is not protected against rain we need a plinth of 40 to 50 cm height, normally built of stone or burnt bricks.

10. Roof

In an earthquake the horizontal movement of the roof is higher than at the base of the house. This is the reason why the roof exerts strong force on the walls and is often the reason for the collapse of a house. Would you propose putting the roof on an independent structure?

Minke: Yes, we built in Guatemala and in Chile in earthquake prone zones houses in which the roof structure is resting on posts, which are separated from the wall by 50cm. In one case the posts were inside, in the other case outside the walls. The idea is, that the roof, which has a different frequency of movement than the wall, can move independently and therefore not increase the horizontal forces against the wall (see Fig. 3-3).

Since the introduction of corrugated tin roofs, roofs have more and more only one slightly inclined plane. Would it be better to use two or four (pyramidal) planes although it's more difficult to construct?

Minke: A roof with only one inclined plane is the simplest solution. Only if the span is very large and no strong beams are available, would a solution with two inclined planes be recommended.

11. Doors and windows

Observing many cracked houses in Nepal, one can see that most cracks start from the corner of window frames.

Minke: Yes, as I said before, it is one of the crucial and widely found mistakes that the lintels do not reach deeply enough into the walls on both sides of the window and doorframe.

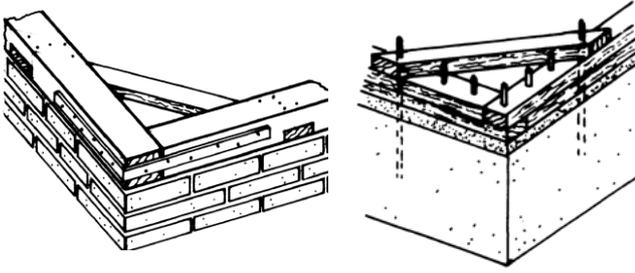


Fig. 8-3 & 8-4: Solutions of stiffening corners and connecting ring beams.

Is there a rule of thumb about how much longer than a window- or doorframe a lintel should be?

Minke: They should reach on both sides of the frame at least 40 to 50 cm into the wall.

Is it better to let door and window frames reach the ring beam at their upper end? Even if the door would than be higher than usual?

Minke: This is the very best solution: Avoid lintels by having window and door frames which reach up till the ring beam, using thus the ring beam as lintel.

What about the distance between windows and between window and door openings? Is there a minimum distance that will provide increased resistance to earthquakes?

Minke: The horizontal distance between openings in the walls should be at least 1 m. They should further be larger than 1/3 of the height of the wall (fig. 11-1). Windows should always be higher than large (vertical proportions!)

Do you have any advice for the size of a door?

Minke: Doors should not be larger than one meter. And they must be opened towards the outside and be large enough to act as emergency exit. A house should also have a second door at the opposite side of the main door.

12. Inside of the house?

Where is the safest place to put the bed?

Minke: Near the door.

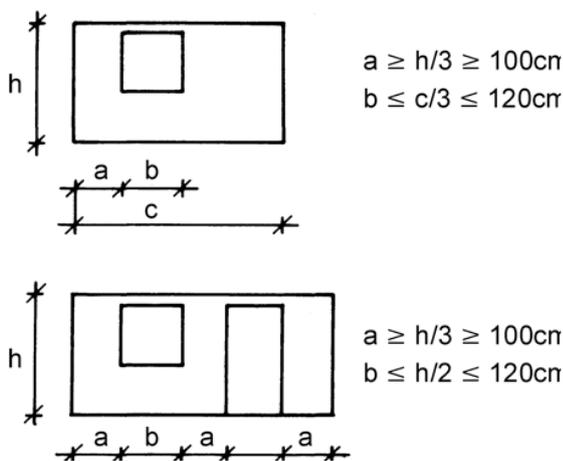


Fig. 11-1: Recommendable dimensions of openings.

13. The most important points to respect for better earthquake resistance of houses

1

The house should not stand on a slope, nor be built into a slope.

2

The house should not have a L-shape plan and not be too elongated; a square or round form is better.

3

The house must have a ring beam, which is well connected to the walls and the roof.

4

The windows should have vertical instead of horizontal proportions and should reach without lintel up to the ring beam.

5

The thickness of adobe, brick or rammed earth walls should be at least 1/8 of its height.

6

The roof should be light and well-fixed to the ring beam

7

The wall segments between openings and between opening and corner should be at least 1 m wide and more than 1/3 of its height.

8

The openings for windows and doors should be no more than 1 m wide.

9

The mortar joints between the bricks should not be thicker than 1/2 inch.

10

There should be 2 doors, each on opposite side of the rooms opening to the outside.

Gernot Minke

Gernot Minke is an architect and a retired professor from Kassel University, Germany, where he directed the Forschungslabor für Experimentelles Bauen (FEB) (Building Research Laboratory). Since 1974 more than 40 research and development projects have been realized in the field of ecological building, low-cost-housing and especially building with earth.

In his private architectural office he has designed many private and public buildings, all of them having earth as a predominant building material. His buildings stand not only in Europe, but also in Central and South America and India.

He is the author of several books and more than 300 articles. His book "Building with earth" was published in 8 languages. He has been invited to more than 60 international conferences and was visiting professor in Mexico, USA, Guatemala, Paraguay, Colombia and Venezuela.

Please see also the website of Prof. Gernot Minke with many more valuable information about clay building: <http://www.gernotminke.de>.