

**Confined Masonry:** Walls first, columns later

Version 31oct08

- In feet and inches
- With in-situ concrete slab
- With additional seismic bands

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# Confined Masonry

For one and two storey buildings in  
low-tech environments

**A guidebook for technicians**

**For the technical inputs** I would like to thank:

*René Guillod* of WGG Schnetzer Puskas Ingenieure in Basel, Switzerland, who did the calculations keeping always in mind the low-tech possibilities of poor countries.

*Marcial Blondet* and *Angel San Bartolomé* of the Pontificia Universidad Católica del Perú for commenting the 2007 field version of this manual, *Milan Zacek* of the Ecole Nationale Supérieure d'Architecture (ENSA) de Marseille-Luminy, *Andrew Charleson* of the Victoria University of Wellington, New Zealand, *Svetlana Brzev* of the British Columbia Institute of Technology, Canada, and *Tim Hart* of Dasse Design Inc., California for reviewing the present version of the manual.

My 40+ local field training team in Pakistan, *UN Habitat*, *ERRA* and *NESPAK* for their feedback during the reconstruction process.

**For the financial support** I express my gratitude to:

The Swiss reinsurance company *SwissRe* in Zurich, the *International Committee of the Red Cross ICRC* in Geneva, *UNESCO* in Paris, the *Swiss Solidarity* fund raising organisation in Geneva and of course, the *Swiss Agency for Development and Cooperation* for which I worked as a technical advisor in Pakistan in 2006-7,

**For their encouragements** and most welcoming attitude special thanks go to the members of the Confined Masonry Network, and in particular to:

*Sudhir K. Jain*, *C.V.R. Murty* and *Durgesh C. Rai* of the Indian Institute of Technology Kanpur (IIT-K), and

*Marjorie Greene* of the Earthquake Engineering Research Institute (EERI).

**For the logistical support**, thanks to:

My colleague *Beniamino Sartorio* for sharing his office space with me.

The present manual is the end product of an earlier version drafted in 2005, adapted to the field necessities in early 2007 and extensively field tested for one year in 2007-8 during the reconstruction phase following the October 2005 earthquake in the Kashmir mountains.

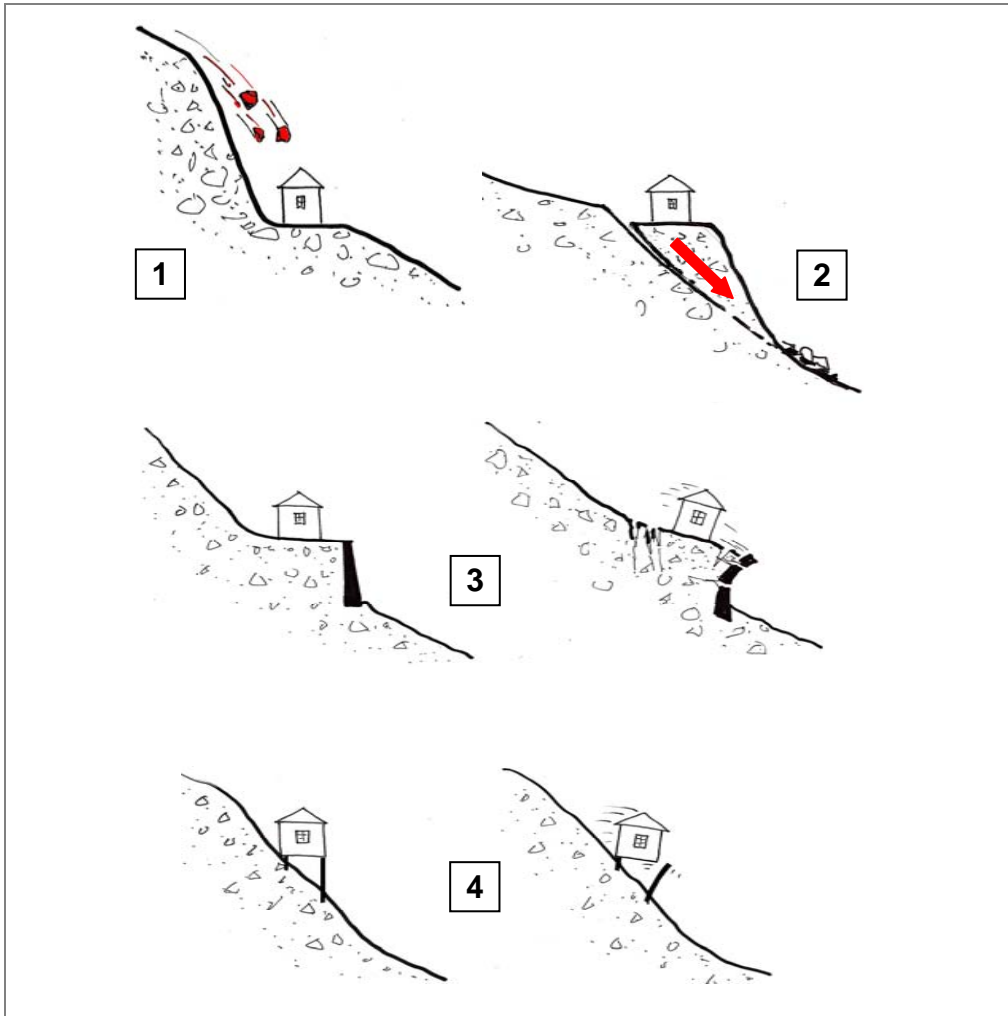
The present manual is based on a selection of relevant seismic codes and recommendations from various countries. Calculations are based on

- Swiss Norms 260 (Basis of Structural Design), 261 (Influence on structures), 262 (Concrete Structures), 266 (Masonry)
- European Norm EN1998 Eurocode 8 (Design of structures for earthquake resistance)

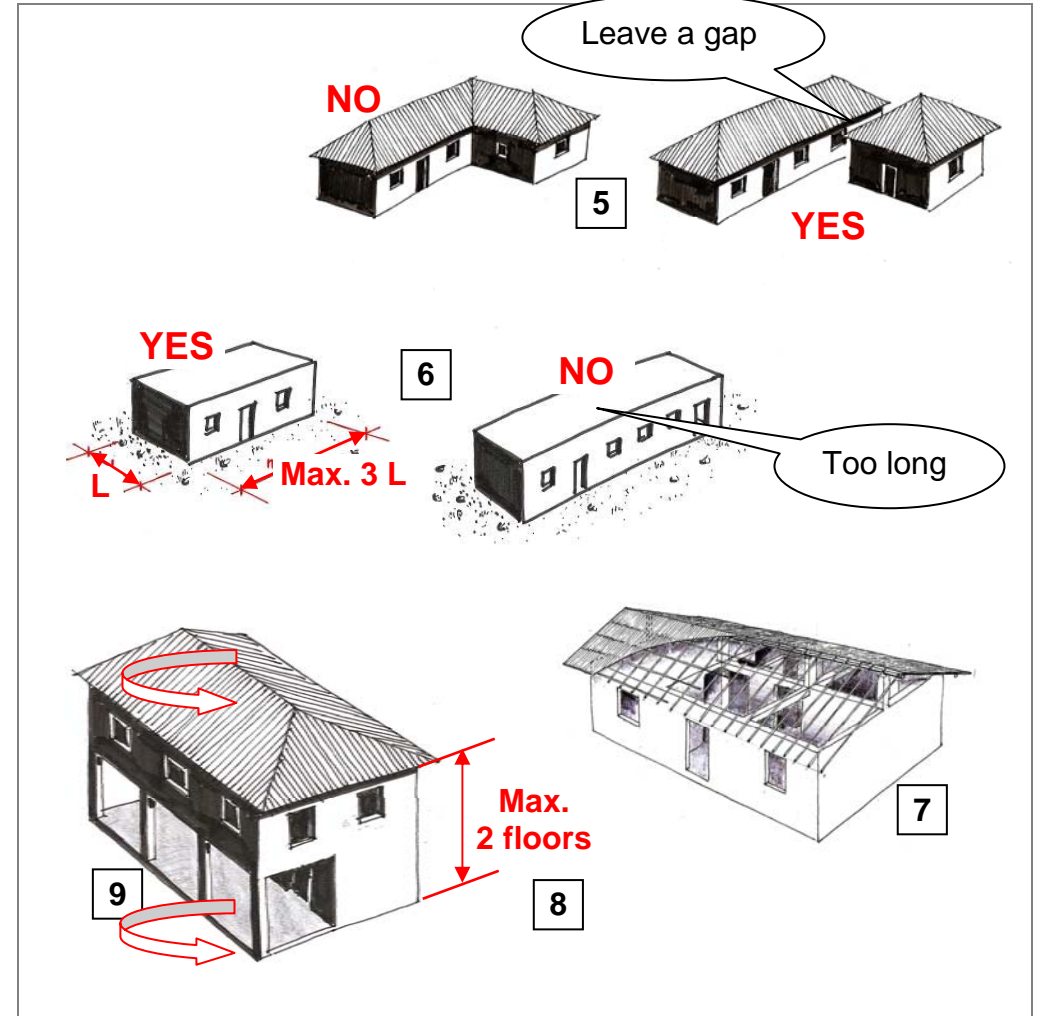
The construction details presented in this manual allow for a peak ground acceleration of 0.35g and have been calculated for a maximum building height of two storeys. Don't use this manual for higher buildings.

The quality of the building materials (bricks, steel, mortar, concrete) as well as the quality of the execution will greatly influence the level of the end result. Equally, the consistency of the ground, the assumed ground acceleration and the local legislation do vary from place to place and country to country.

This manual presents the concepts and constructive details which, if applied correctly, offer a fairly earthquake resistant building. However, nobody can guarantee a 100% safe house under all conditions. The author therefore cannot be held liable for any damage or loss incurred by persons making use of these guidelines.

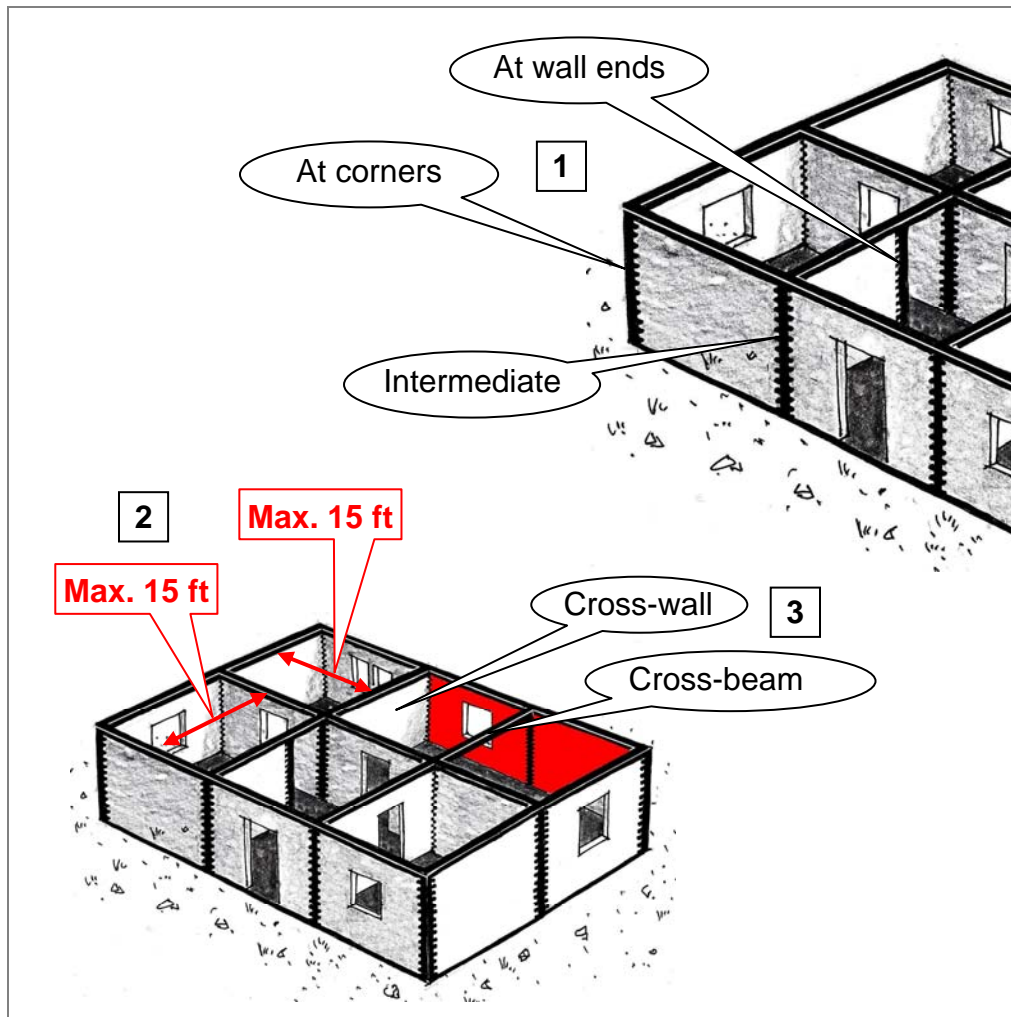


1. Don't build next to a steep slope: stones might fall on your house.
2. Don't build next to a precipice: it might break off.
3. Don't build next to a retaining wall: it might break away.
4. Don't build on stilts: they will fall over during an earthquake.

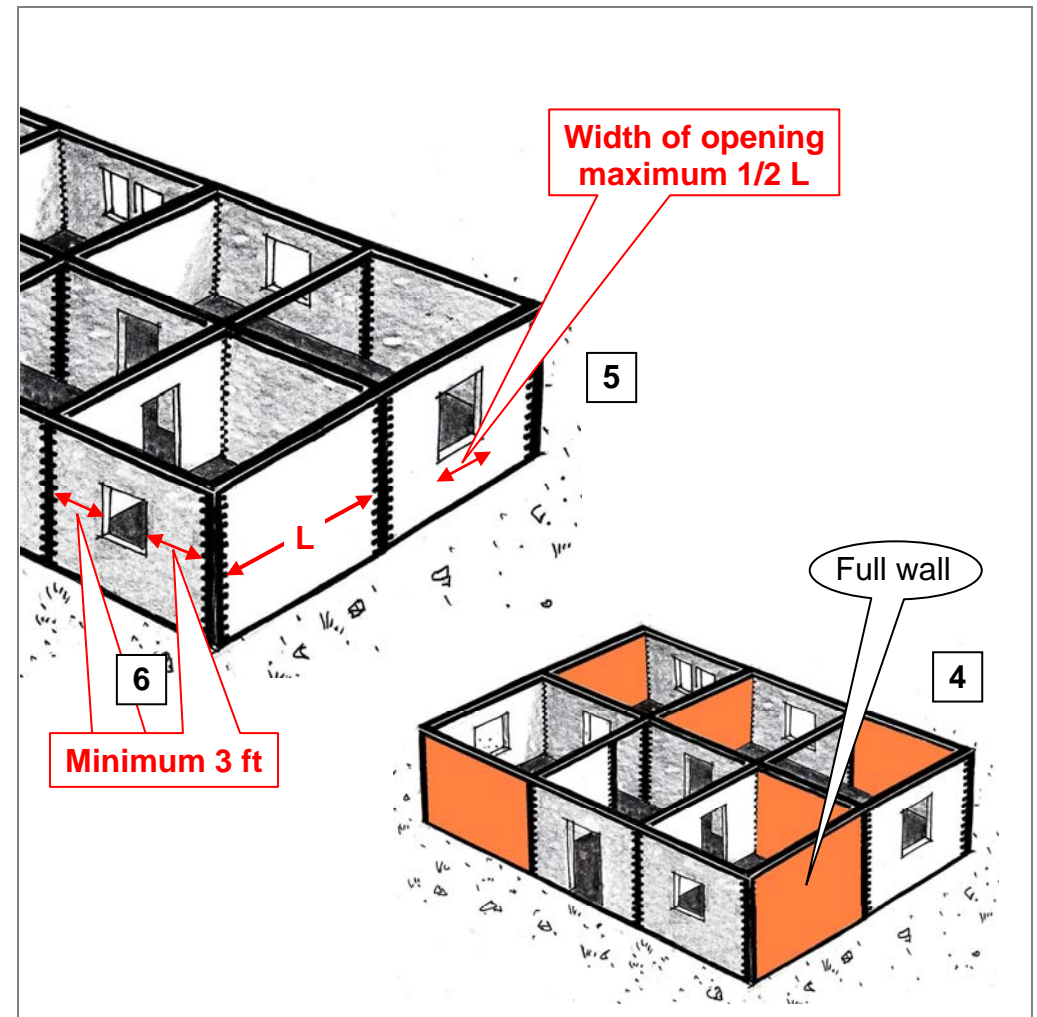


5. A house must have a simple form.  
If necessary, divide it into rectangular parts.
6. A house must not be longer than 3 times its width.
7. A light, pitched roof is better than a heavy concrete slab.
8. Don't build higher than 2 floors.
9. Don't build on columns. Columns are weaker than the walls and the house will twist and collapse during a quake.

## 1. Site selection and form of house



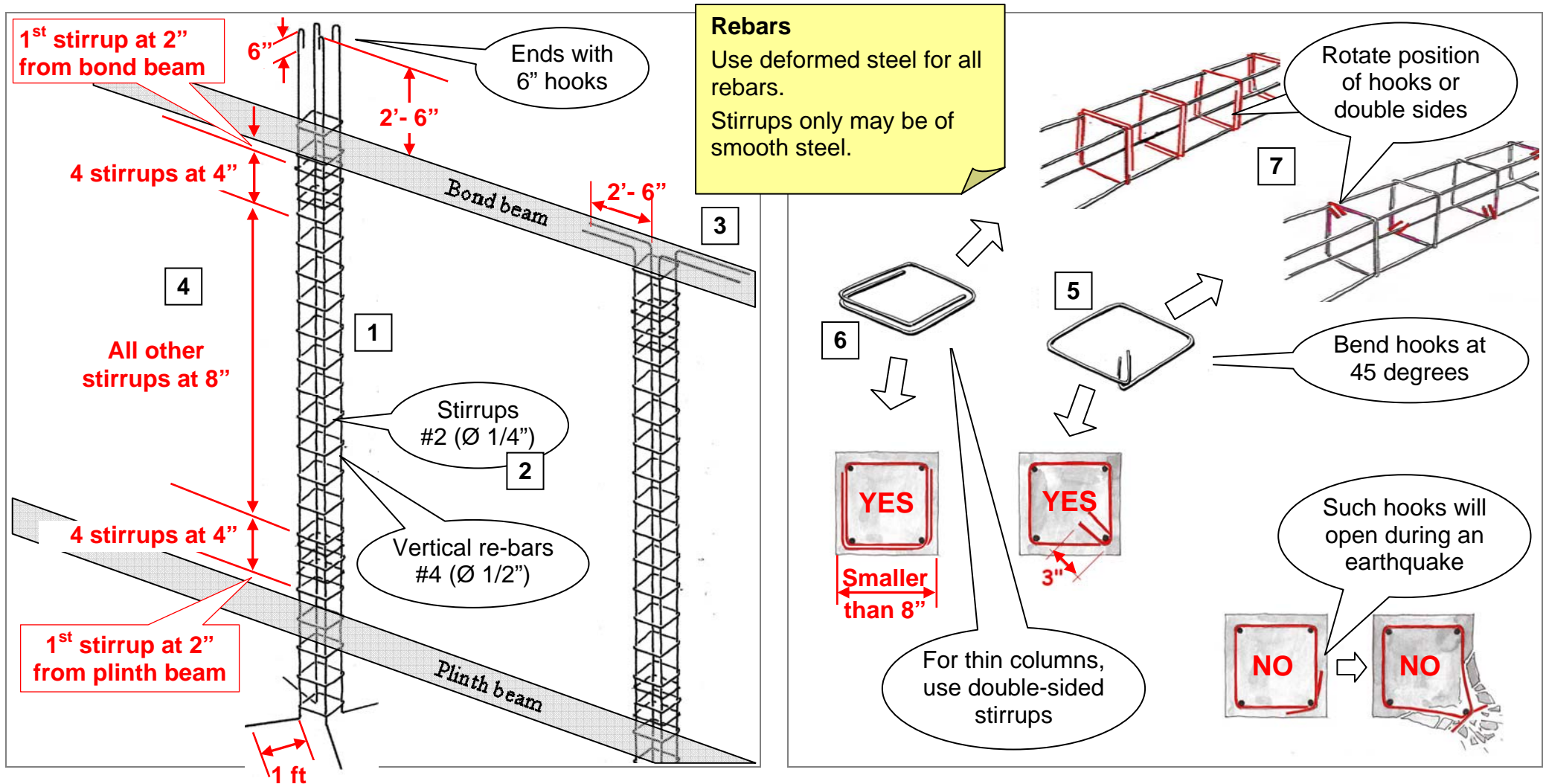
1. Tie-columns are placed where walls meet and where walls end.
2. Connect walls to cross-walls at least every 15 feet.
3. Avoid long walls without cross-walls. If you make a big room (not more than one per house) add a cross beam to connect the central tie-column of the long wall to the opposite wall. If the house is covered by a concrete slab, the cross-beam is not necessary.



4. Solid full walls without windows or doors are stronger. Build as many full walls as you can and distribute them evenly across the house.
5. Maximum width of openings is half the distance between columns.
6. Leave at least 3 feet between opening and tie-column.

## 2. Basic rules

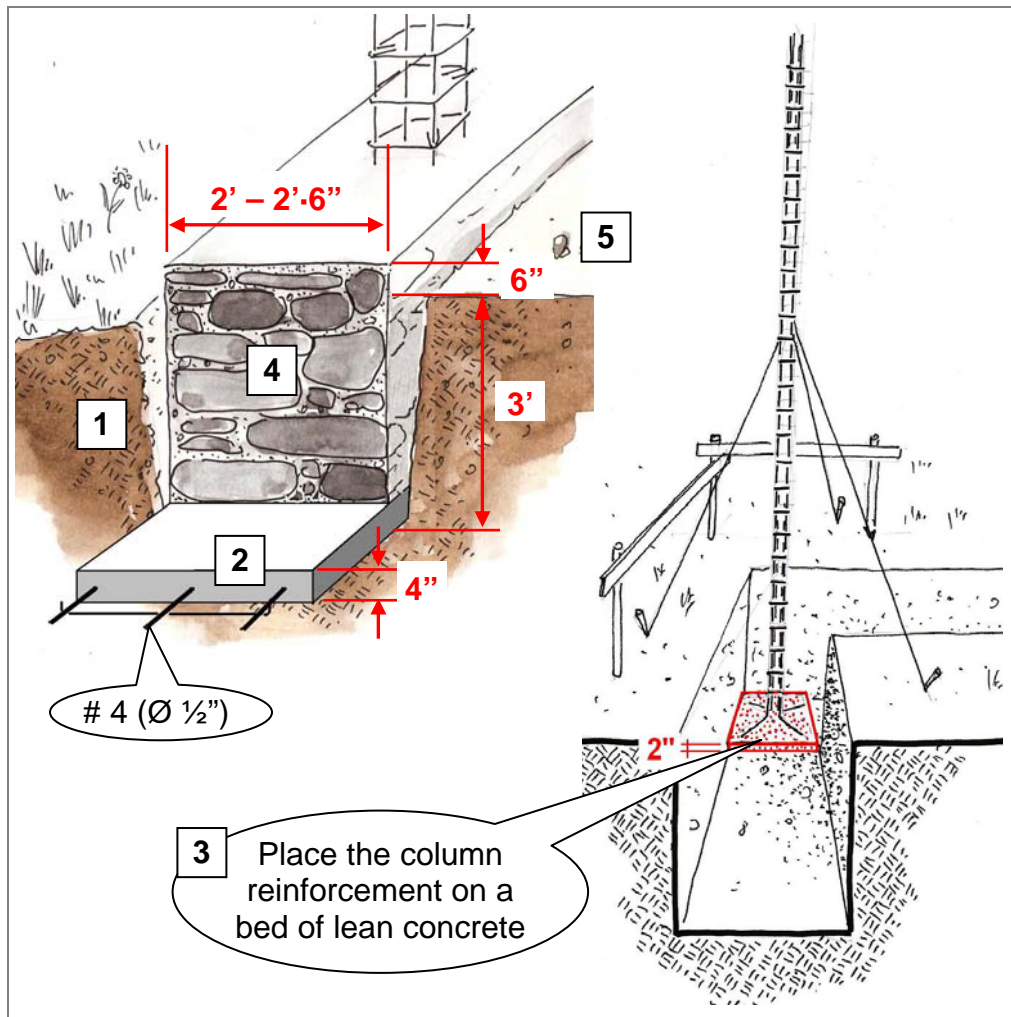




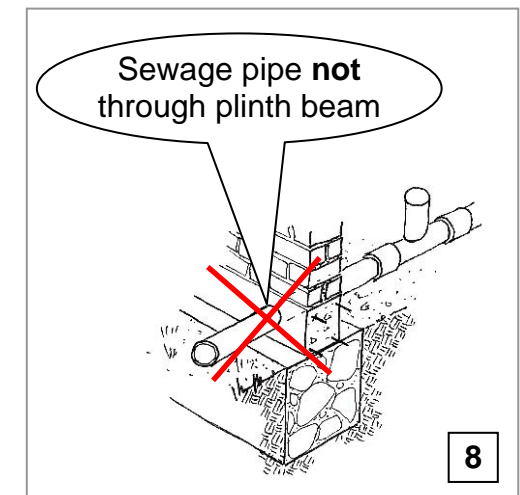
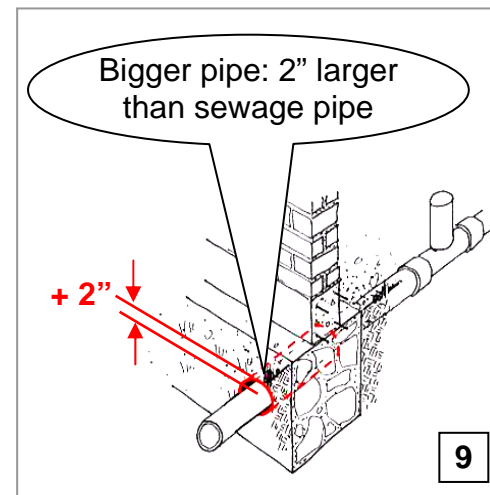
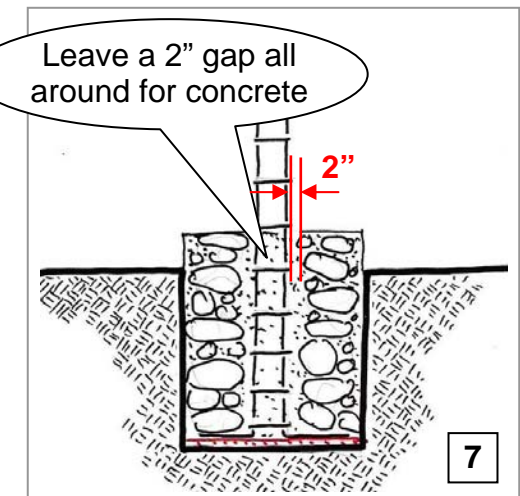
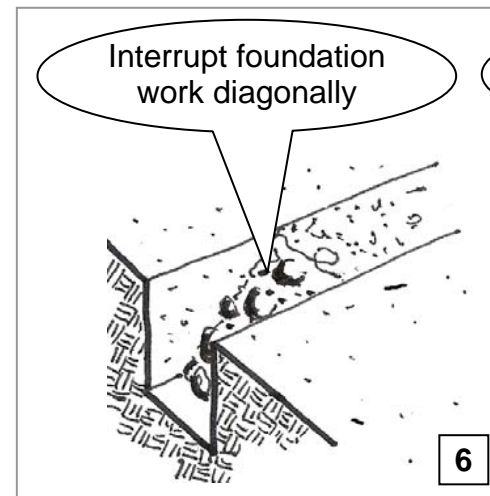
1. Calculate length of the vertical rebars from the bottom of the foundation up to the top of the bond beam. Add 2'-6" for connection above the slab and 1 ft for the footing.
2. **Verify that #2 rebars for stirrups really do have 1/4" diameter, otherwise use 8mm bars.**
3. If you don't plan to leave the rebars stick out of the roof for future construction, bend them horizontally into the bond beam.

4. Distribute the stirrups as shown. First and last at 2" from plinth and bond beams, then 4 stirrups at 4" spacing, then the rest at 8" spacing.
5. Bend stirrup ends at 45 degree angles
6. **In thin columns of less than 8 inches use double-sided stirrups to leave enough space for the concrete to go down correctly.**
7. Alternate the position of the hooks or the double sides of the double-sided stirrups.

### 3. Column reinforcement

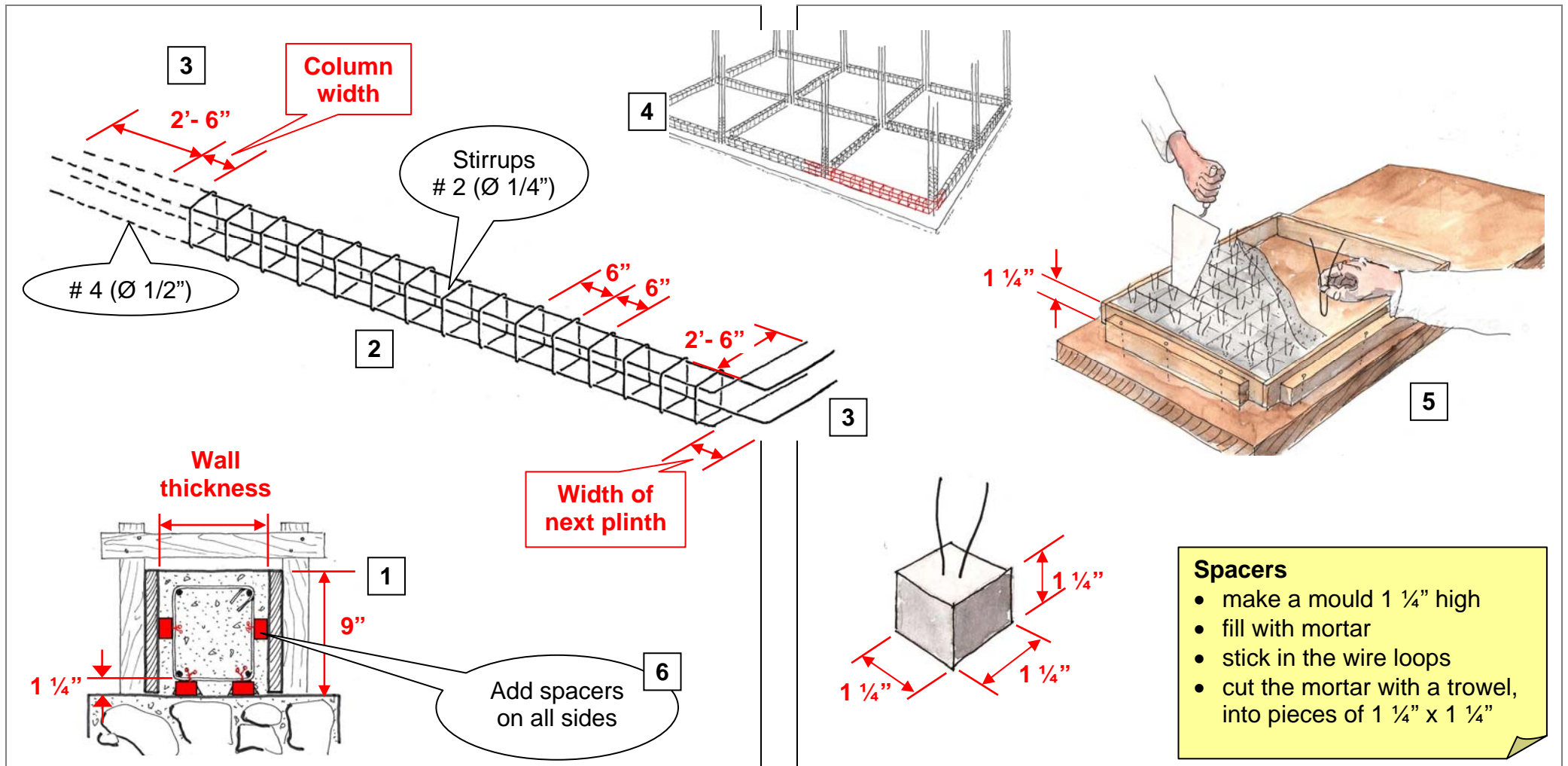


1. Dig the trenches 3 ft deep and 2 ft wide on hard soil (2'-6" on soft soil).
2. On soft soil make a 4" bed of concrete with three #4 rebars in it.
3. Place the column reinforcement on this bed of concrete (on hard soil make independent 2" beds of lean concrete just under the columns).
4. Build the foundation using stones and concrete.
5. Let the top of the foundations be 6 inches above ground.



6. If you have to interrupt foundation work, leave a slope with stones sticking out.
7. Leave a gap of 2" around the reinforcement to ensure the passage of concrete and that stones are not touching the rebars.
8. Sewage pipes must not go through the plinth beam.
9. Place a bigger pipe into the foundation to leave a passage for the sewage pipe. Never use a crushed concrete bag for this!

## 4. Foundations

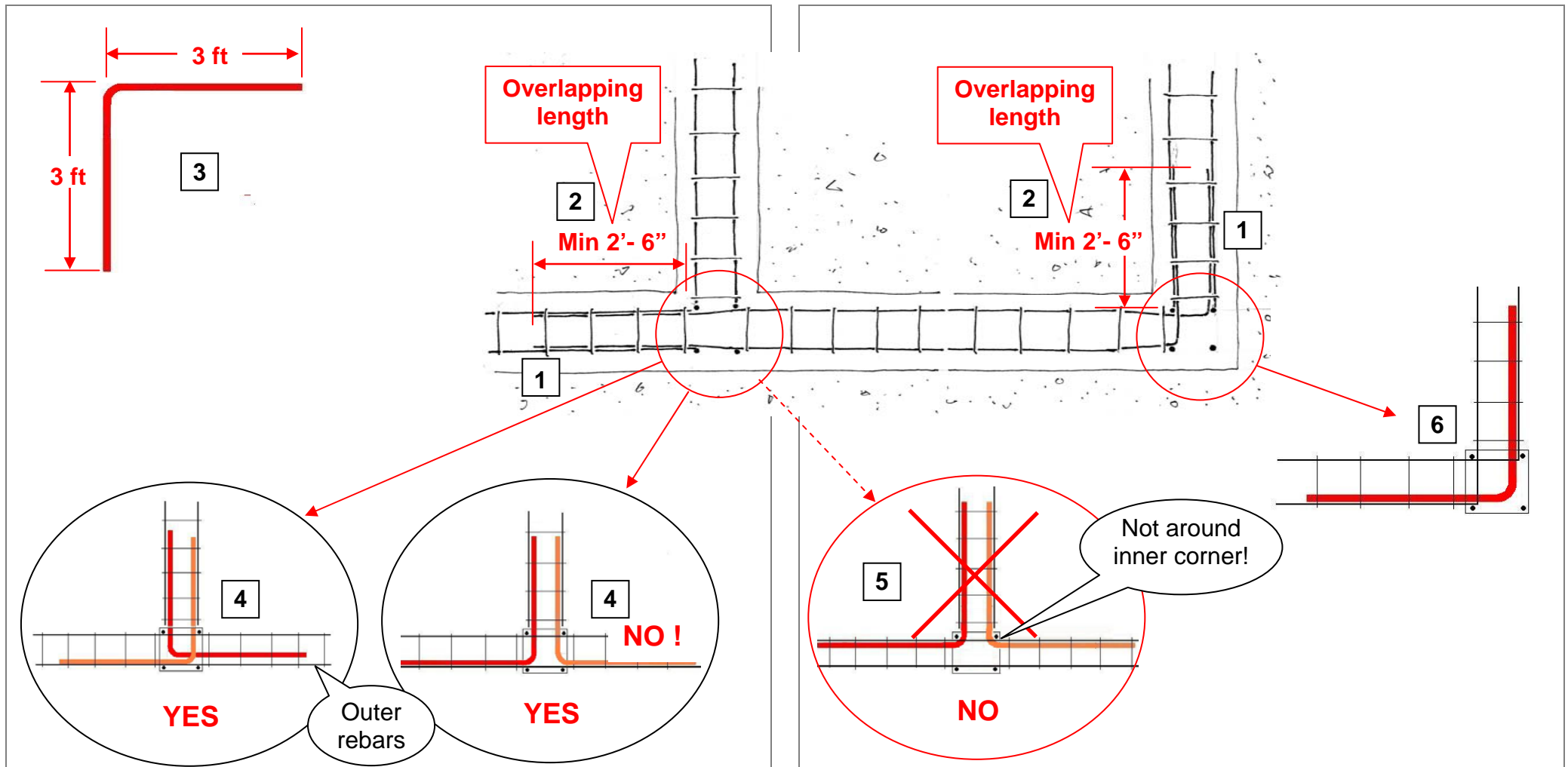


**Spacers**

- make a mould 1 1/4" high
- fill with mortar
- stick in the wire loops
- cut the mortar with a trowel, into pieces of 1 1/4" x 1 1/4"

1. Plinth is 9 inches high and as wide as the wall above.
2. Prepare the plinth reinforcement with stirrups at 6" spacing. Bend the lengthwise rebars only on one end.
3. If the plinth continues, leave 2'-6" overlapping length after the columns.
4. Place the plinth reinforcement between the columns.
5. Prepare spacers as shown above.
6. Place the spacers under and on the sides of the plinth reinforcement every 2 to 3 feet.
7. Spacers are important to ensure that the steel rebars remain in the right place and are well covered with concrete. Concrete protects rebars against rust so that they maintain their strength.

## 5. Plinth beam

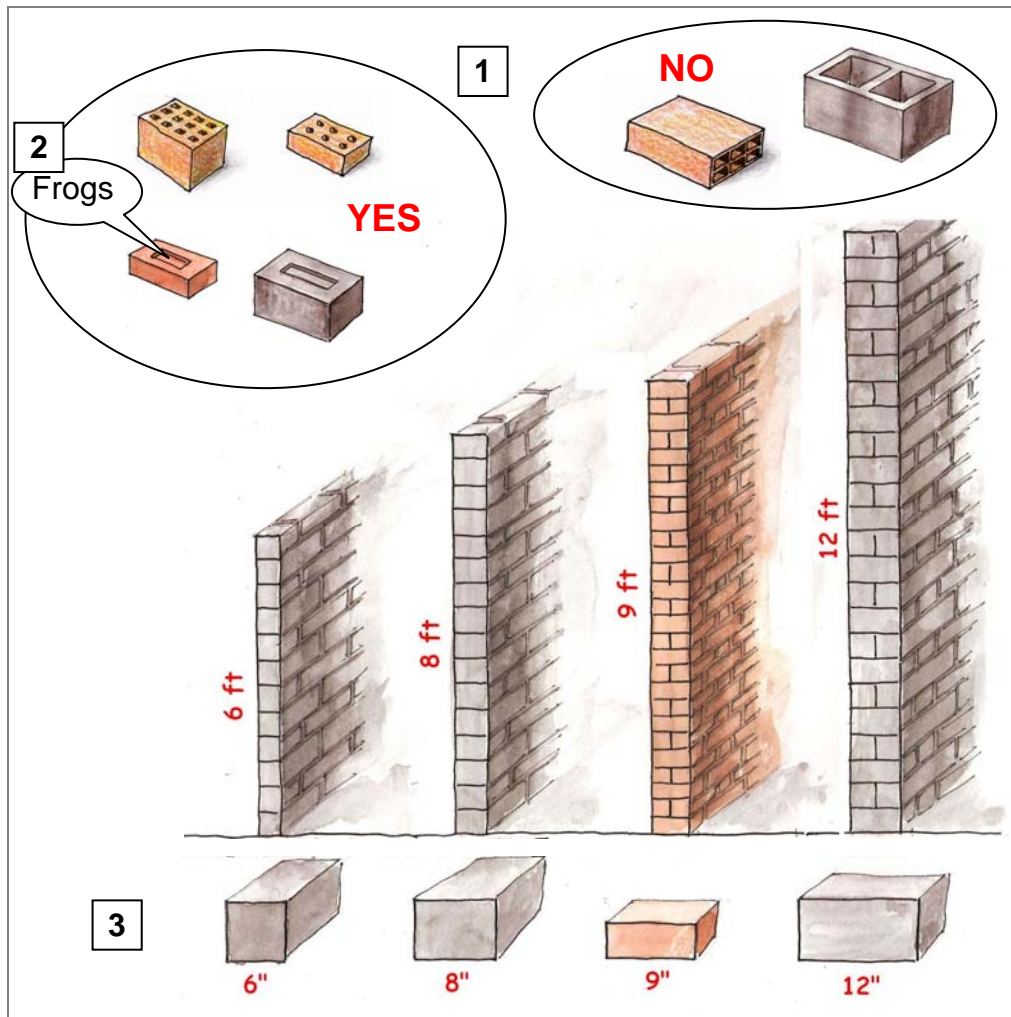


1. Connect the beam reinforcement by inserting the ends **into** the next beams.
2. Overlapping lengths for #4 rebar must at least be 2'- 6".
3. Prepare L-shaped connection bars with side lengths of 3 ft.

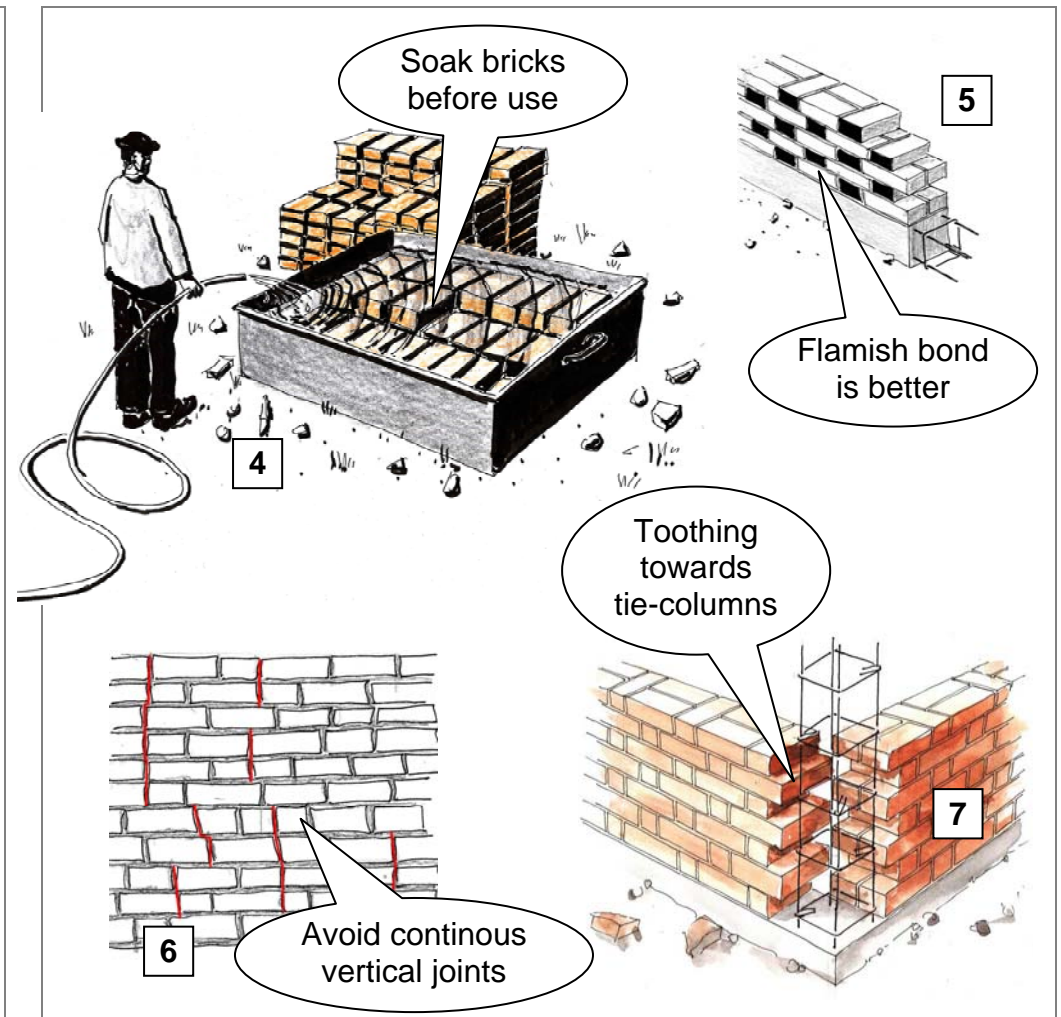
4. On T junctions, insert 4 L-shaped connection bars (top and bottom) and fix them against the **outer** rebar.
5. Never bend connection rebar around inner corners.
6. At the corners add 2 external connection bars (top and bottom) and fix them against the **outer** rebar.

## 6. Plinth and bond beam connections





1. Use good solid bricks or blocks. Don't use hollow blocks or light bricks with this building method.
2. To ensure a good connection with the mortar, all bricks or blocks must have holes or 'frogs', even concrete blocks. This is a small but important detail!
3. Walls must not be higher than 12 times their thickness: that is, for every inch of thickness one foot of height.

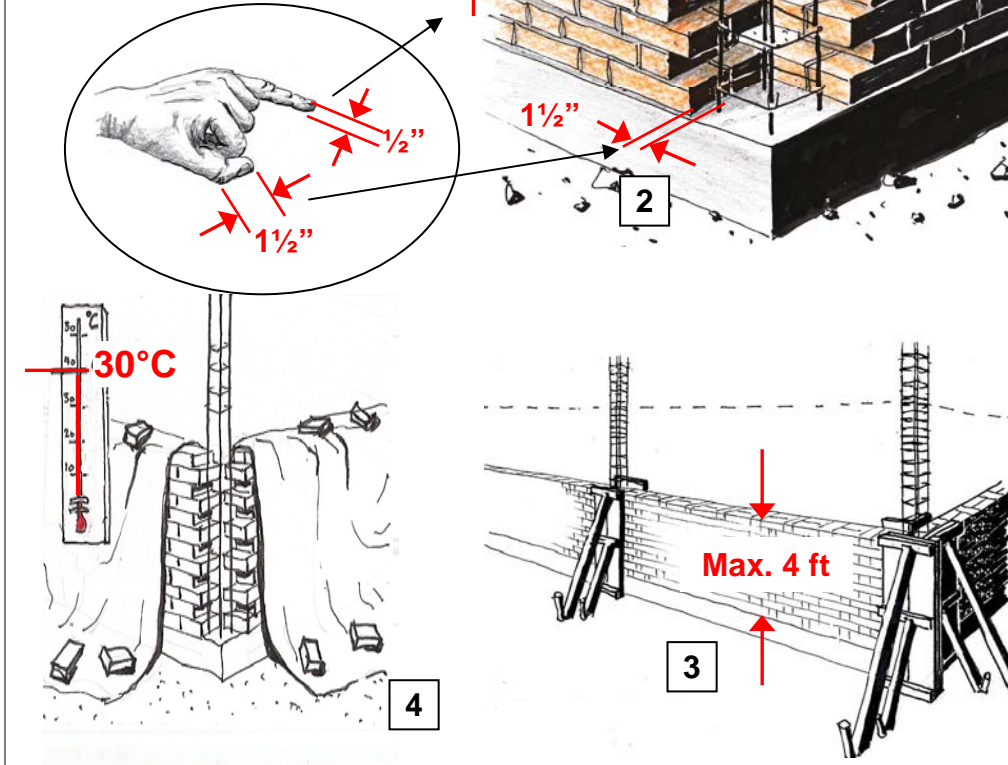


4. Soak the bricks in water 5 hours before use.
5. Use a Flemish rather than an English bond. The number and the thickness of joints are more regular.
6. Avoid continuous vertical joints.
7. Wall ends towards tie-columns must be toothed.

## Mortar

- Cement: 1 part
- Sand: 4 parts

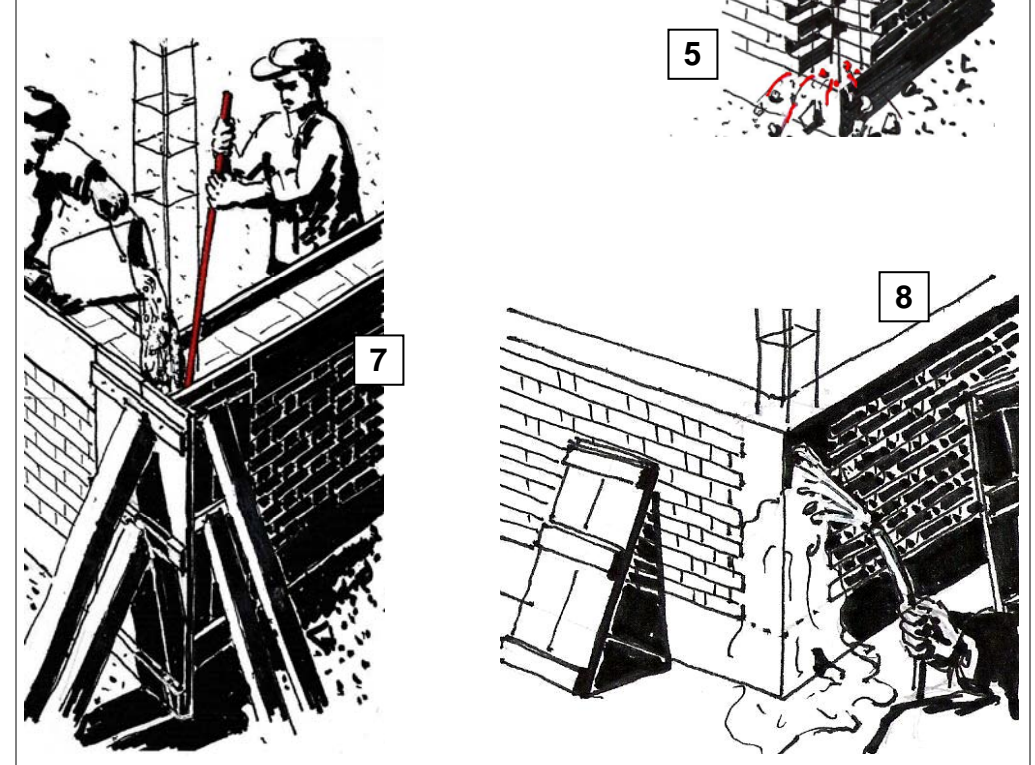
Mix while dry, only then add water



1. Mortar beds and joints must not be thicker than 1/2 inch.
2. Keep end bricks 1 1/2" away from the stirrups to leave room for the concrete of the tie-columns.
3. Don't build higher than 4 feet per day.
4. Protect the wall in warm weather with a plastic sheet or wet cloth so the mortar will not dry out.

## Concrete

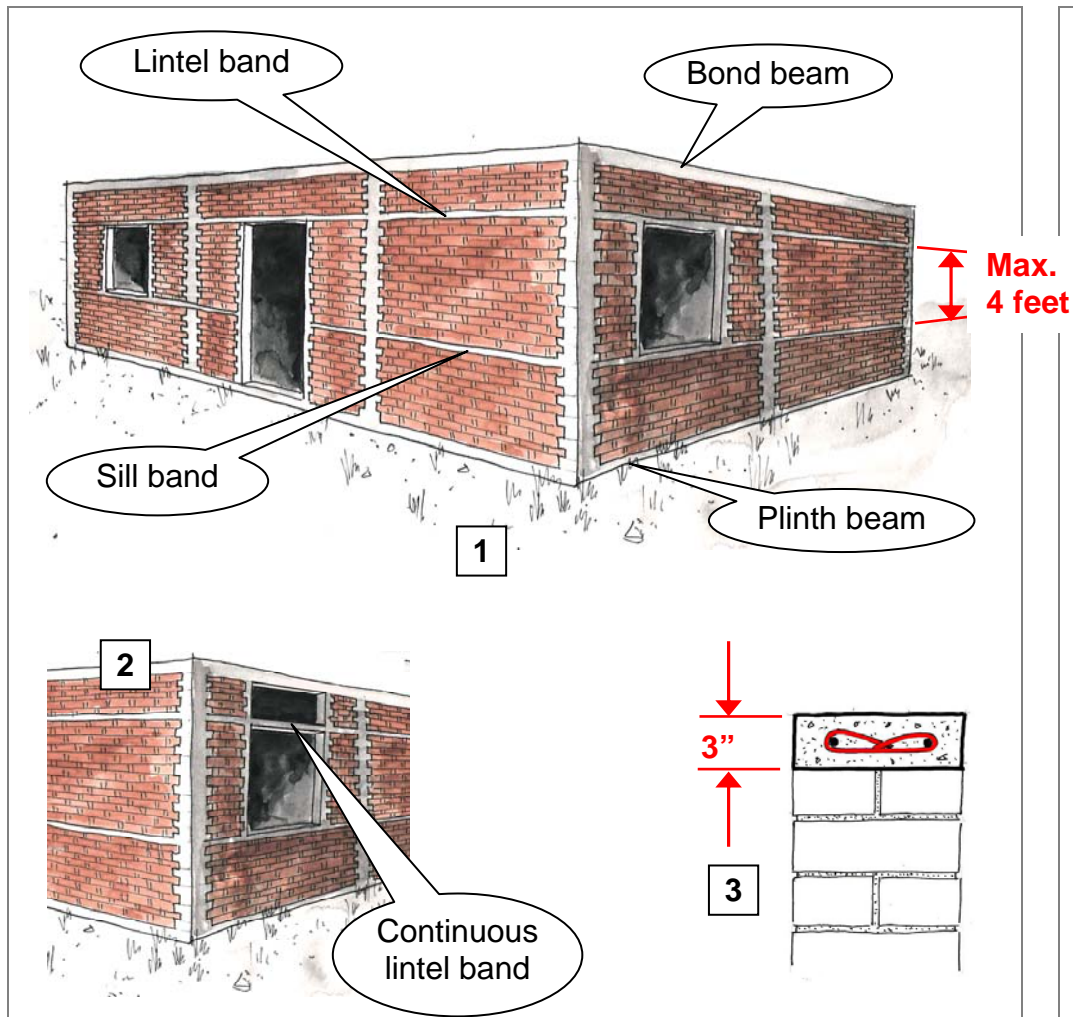
- Cement: 1 part
- Coarse dry sand 2 parts
- Crushed gravel 3/4": 4 parts
- Water: 1 part



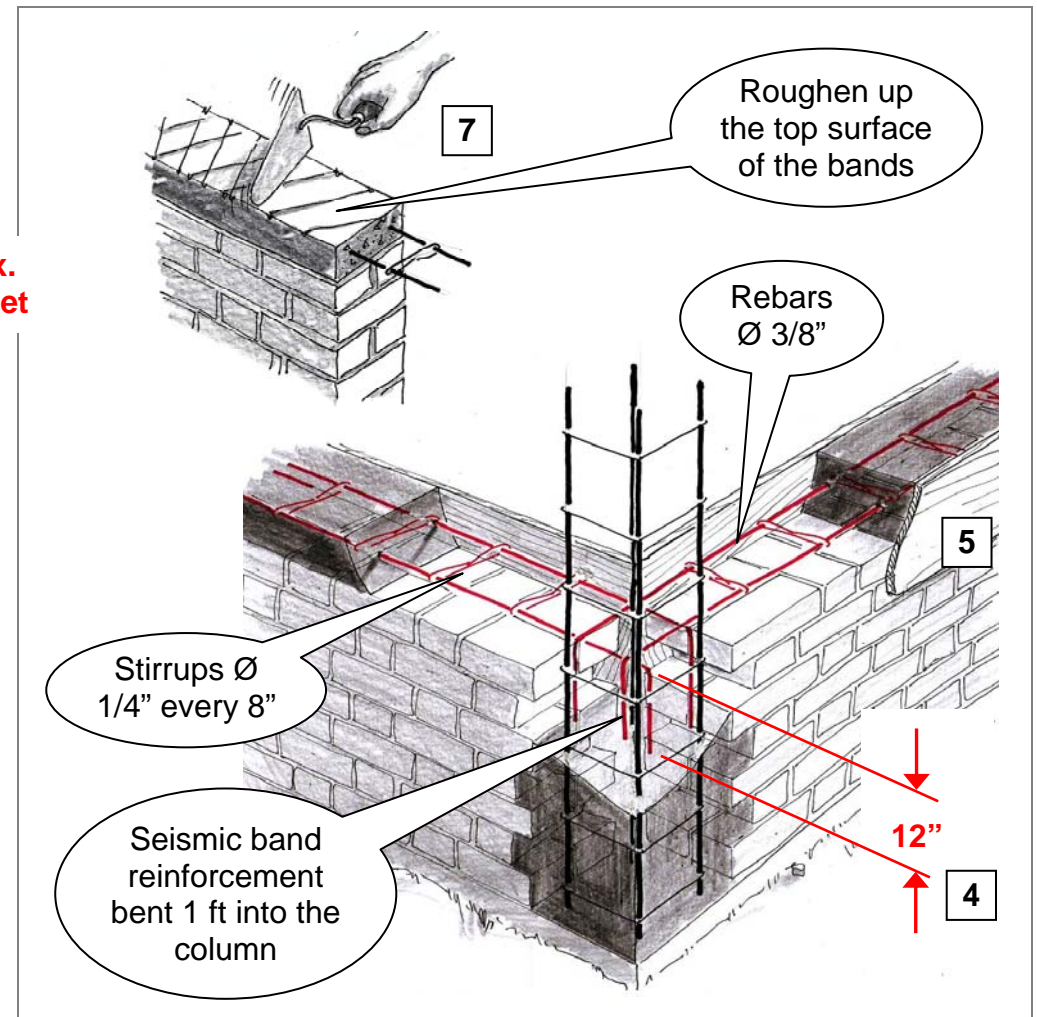
5. Clean the column space of all rubbish before adding the formwork.
6. Pour the concrete for the bands and the columns at the same time.
7. Compact the concrete vigorously with a stick to get the air pockets out of the mix. Also, hammer against the formwork to compact the concrete. Don't add water to make concrete 'go down'.
8. Water the concrete twice a day for at least 3 more days. Cover with a plastic sheet in summer or in a dry climate.

## 8. Tie-columns

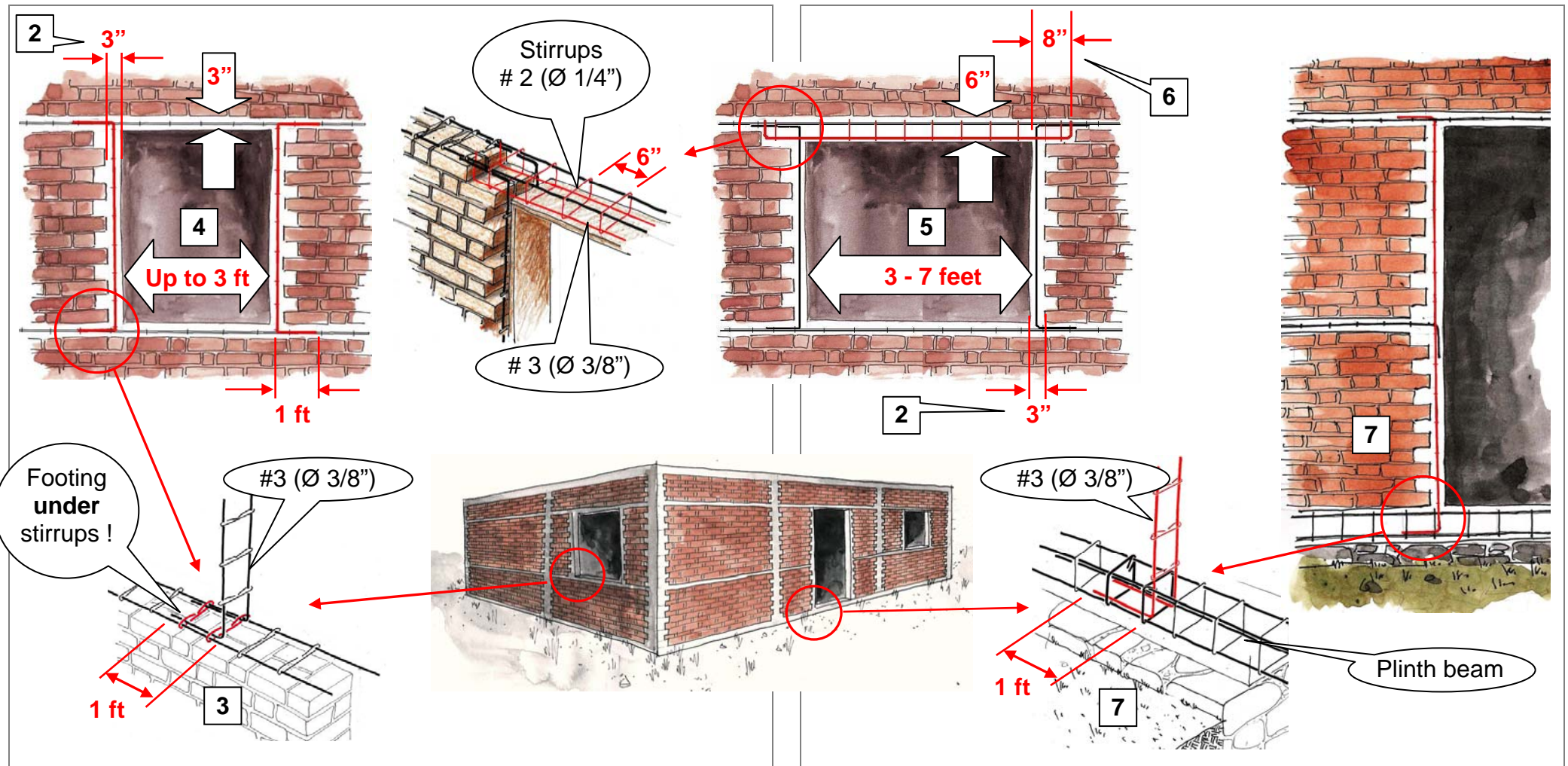




1. Place a seismic band at sill and lintel level, even if there is no window. Maximum distance between bands is 4 feet.
2. If a window is higher, let the lintel band go through.
3. Seismic bands are only 3" high



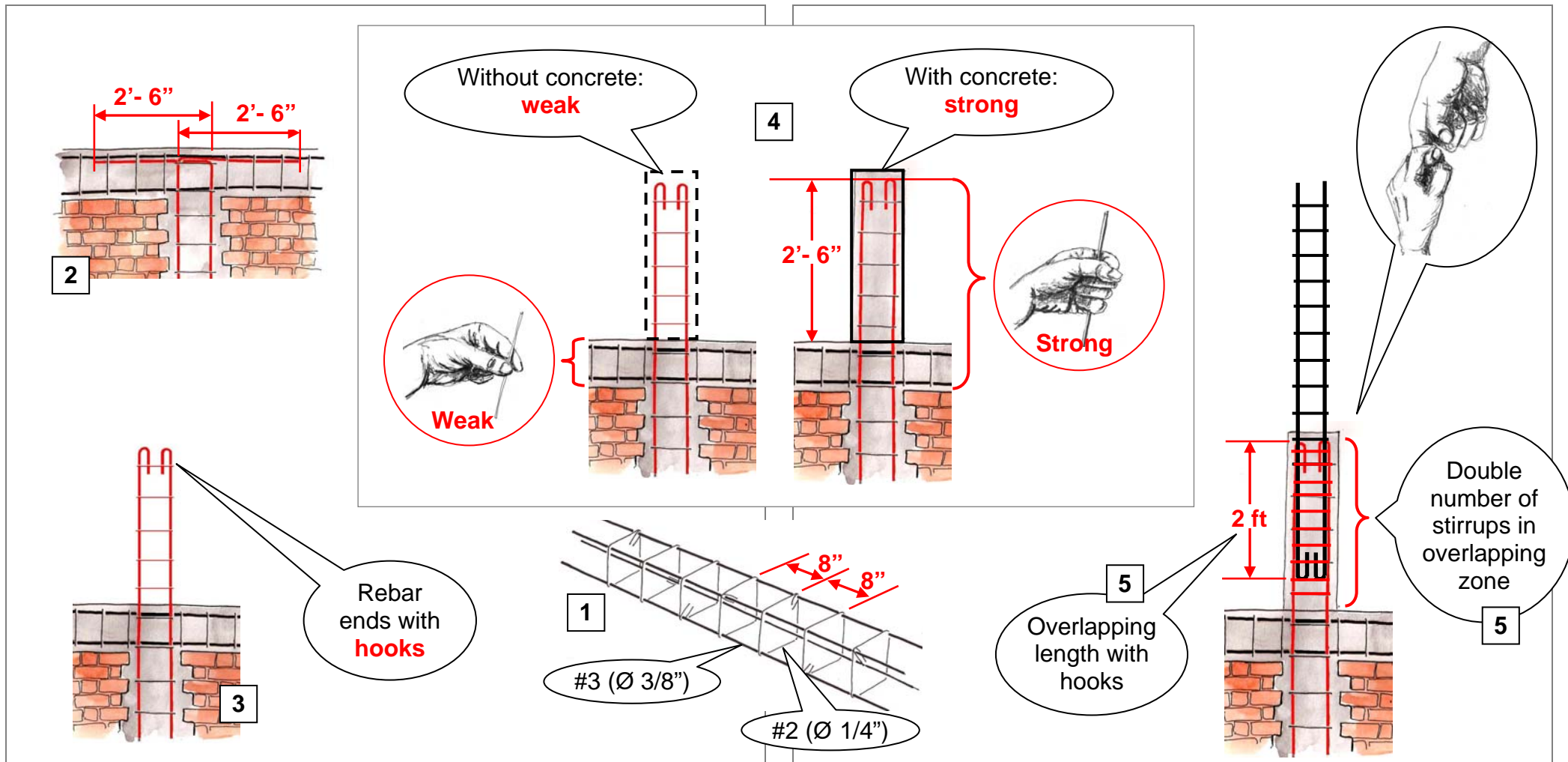
4. Bend the rebar into the columns (1 foot long).
5. Place the form work for the bands.
6. Pour concrete for the bands and the columns at the same time.
7. Roughen up the top side of the concrete band to increase adherence of the mortar for the wall above.



1. All windows and doors are framed by vertical concrete bands.
2. Vertical bands are at least 3" wide.
3. Introduce the 1 ft footing of the vertical rebar carefully under the stirrups of the seismic bands.
4. Small windows up to 3 ft wide: the normal 3" high seismic band can be used directly as lintel.
5. Bigger windows 3 to 7 ft wide: minimum lintel height is 6 inches.
6. With bigger windows, increase the lintel support area to 8 inches.
7. For doors, don't forget to place the vertical band reinforcement into the plinth reinforcement **before** completing the plinth.

## 10. Windows and doors





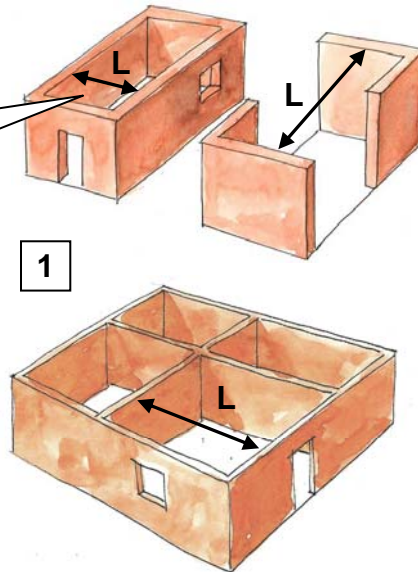
1. Prepare bond beams with stirrups at 8 inches.
2. If you don't plan to add another floor, bend the rebars into the bond beam to ensure a good connection.
3. If you leave vertical rebars for a future floor, end all rebars with hooks.

4. Tie-columns and bond-beams must be well embedded in concrete to ensure a strong connection.
5. Add also hooks to the rebars of the added columns. With hooks on all rebars, the overlapping length can be reduced to 2 feet.

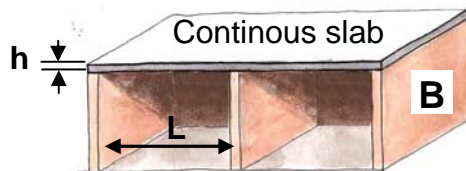
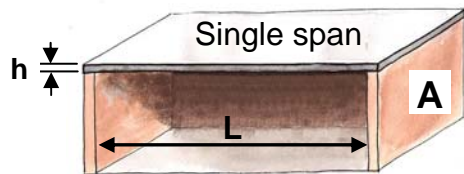
## 11. Bond beam – tie-column connection

## Span L:

Span **L** is the shortest distance between two opposing walls.



1



1. Look for the shorter span of the biggest room. This will define the slab height of all rooms, even if smaller rooms would need thinner slabs.
2. Calculate the slab height and the reinforcement bars according to table 1.
3. Where upper reinforcements is needed (see next page), use the same rebar diameters and distances as for the lower one.

## Steel reinforcement (rebars):

Primary rebars are those put in the shorter direction (span). They are placed first.

Secondary rebars are put on top of the primary re-bars.

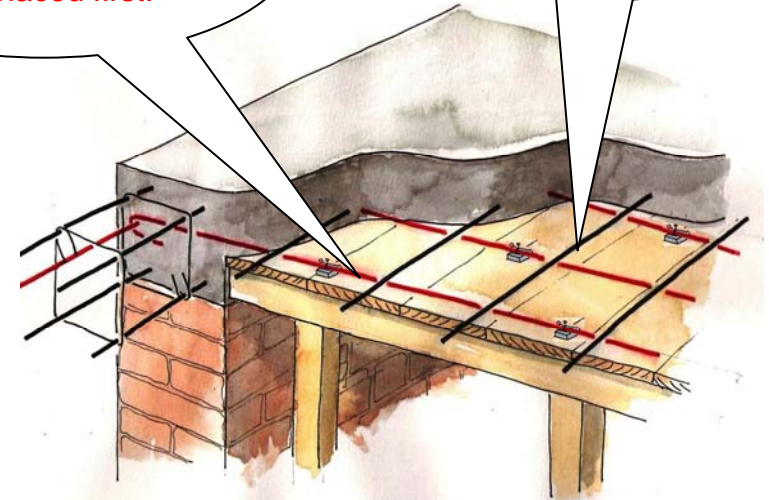
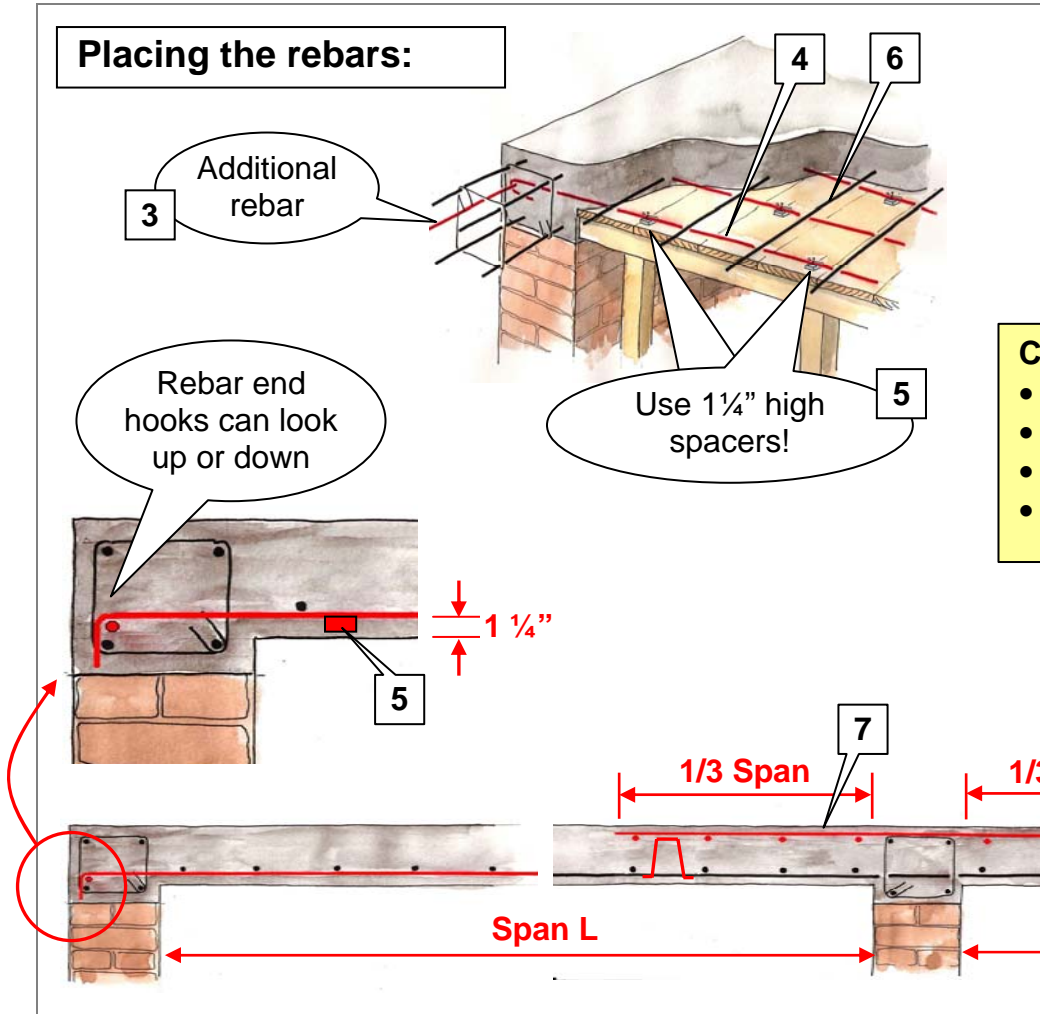


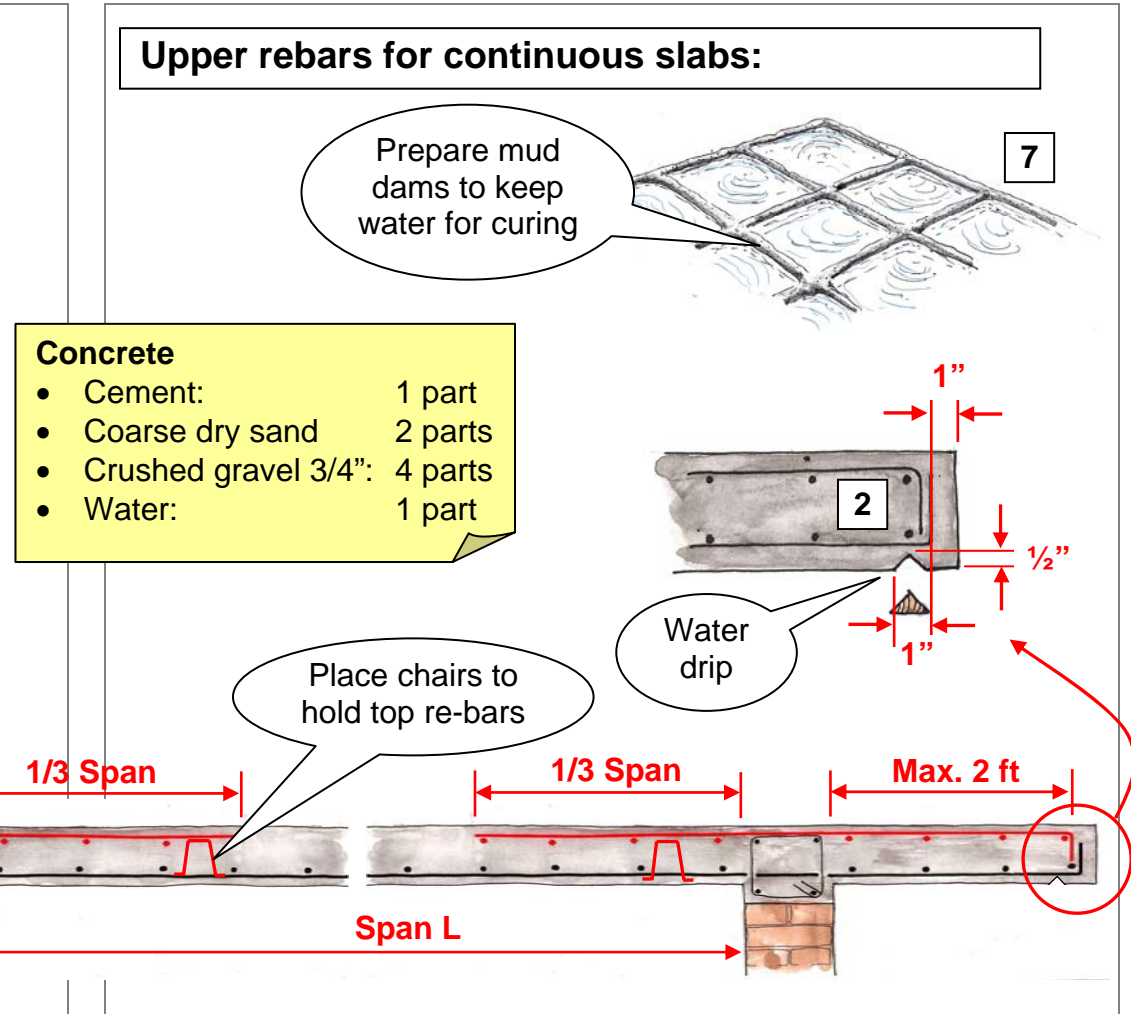
Table 1: Reinforcement bars

Span L	Slab height h	Primary	Secondary
Up to 8'-0"	4"	#3 (Ø3/8") @ 6"	#2 (Ø1/4") @ 10"
8'-1" – 10'-0"	5"	#3 (Ø3/8") @ 6"	#2 (Ø1/4") @ 10"
10'-1" – 12'-0"	6"	#3 (Ø3/8") @ 8"	8 mm or #3 (Ø3/8") @ 12"
12'-1" – 14'-0"	7"	#3 (Ø3/8") @ 8"	8 mm or #3 (Ø3/8") @ 10"
14'-1" – 15'-0"	8"	#4 (Ø1/2") @ 8"	8 mm or #3 (Ø3/8") @ 10"

### Placing the rebars:



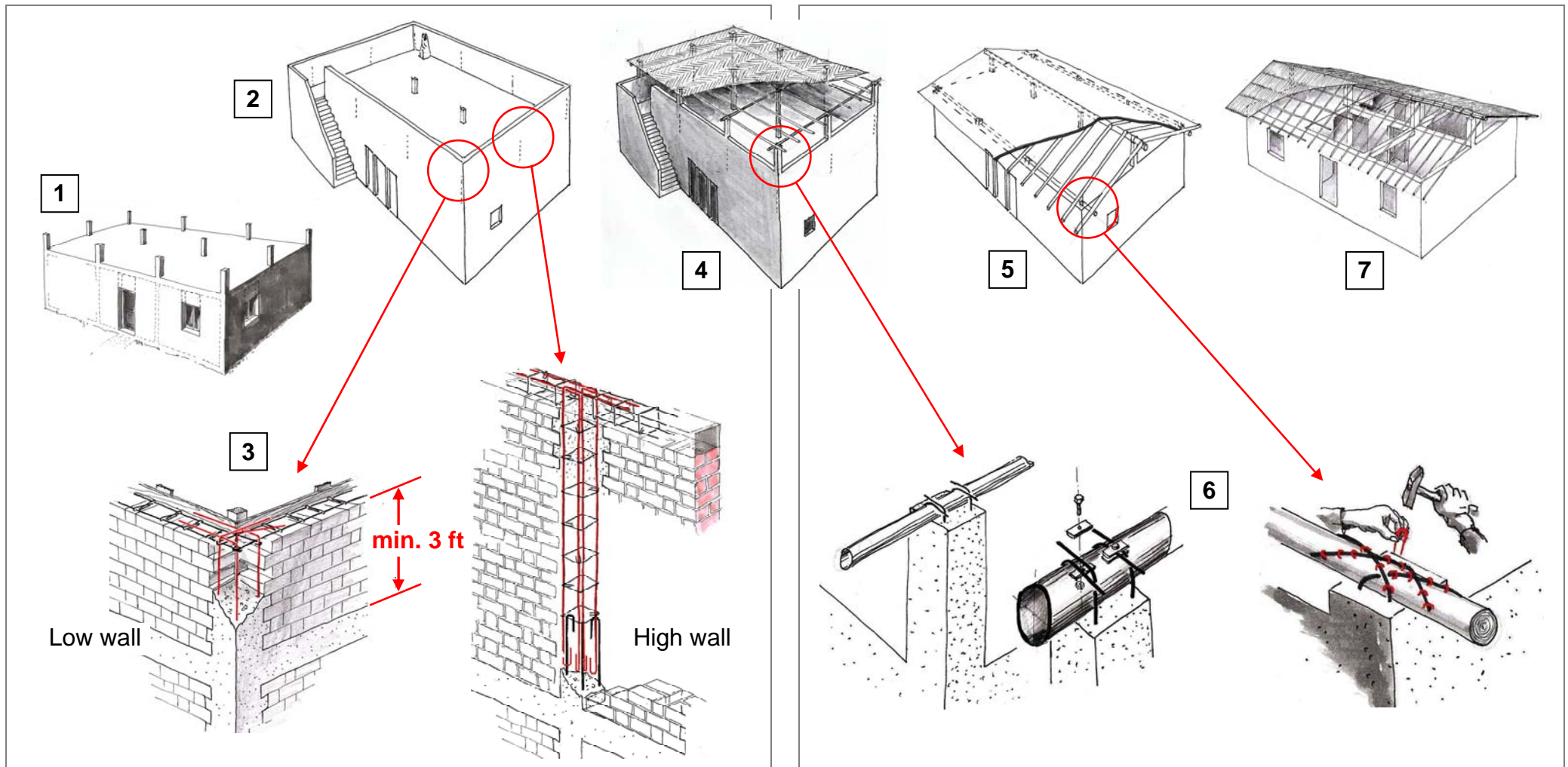
### Upper rebar for continuous slabs:



1. Make sure your form work for the slab is watertight. If necessary fill the cracks with mud.
2. Create a water drip by nailing triangular lists along the edge of overhanging slabs.
3. Place additional rebar into the bond beams to receive the hooks of the primary bars.
4. Place primary rebar in the direction of the shorter span.

5. Place 1 1/4" spacers under the primary rebar every 2-3 ft.
6. Add secondary rebar.
7. Add top bars where necessary and place them on chairs.
8. Pour the concrete and cure it (keep humid) for 2 weeks. To keep the water on the slab, make small dams with mud and sand.
9. Take off form work after 3 weeks only.



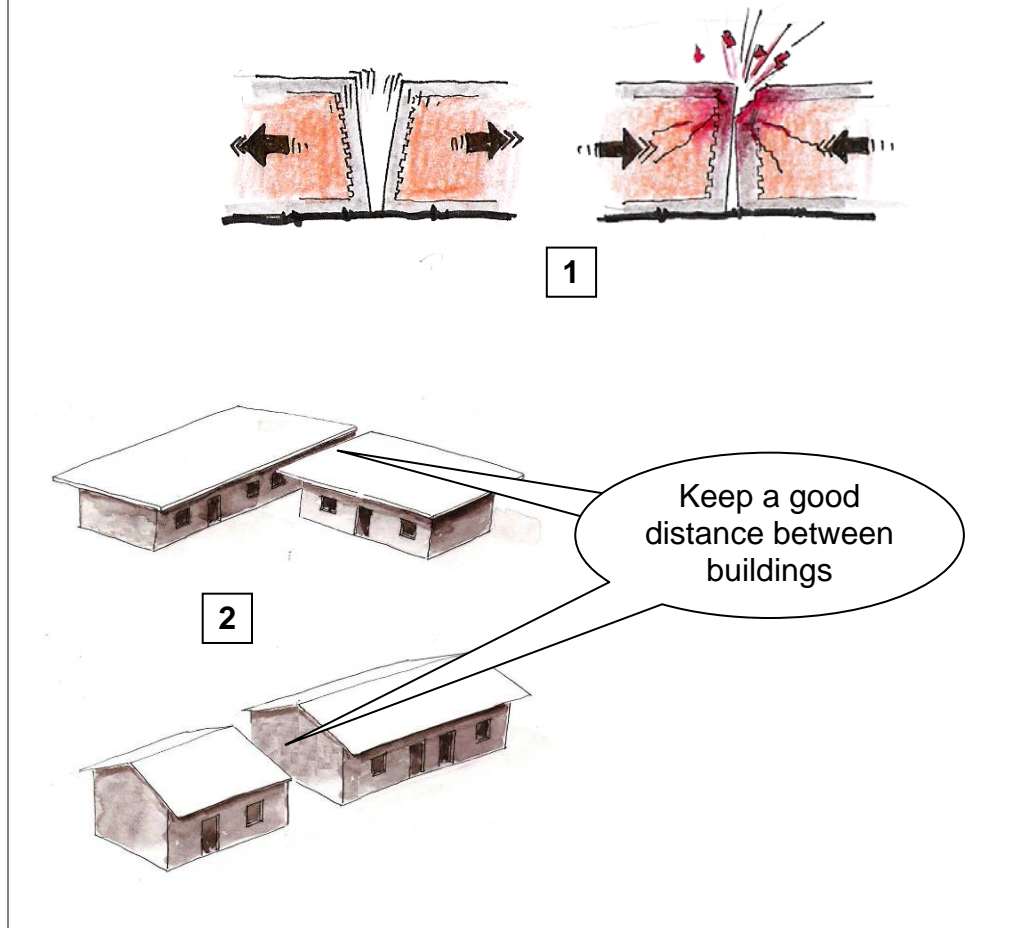


1. Rebars coming out of the slab must be cast in lean concrete to protect them against rust. Otherwise they cannot be used later in columns.
2. Terrace walls must be confined like any other wall, or they will fall on people during an earthquake.
3. For security reasons low walls must be lower than 3 ft.

4. In a hot climate, add a shade roof. The house will remain cooler.
5. In a rainy area, add a CGI sheet roof. It will protect the house against rain and provide shade in hot periods.
6. Use the column rebars to fix beams or pipes.
7. You can also make a house without a roof slab and fix the CGI sheet roof directly over the bond beams.

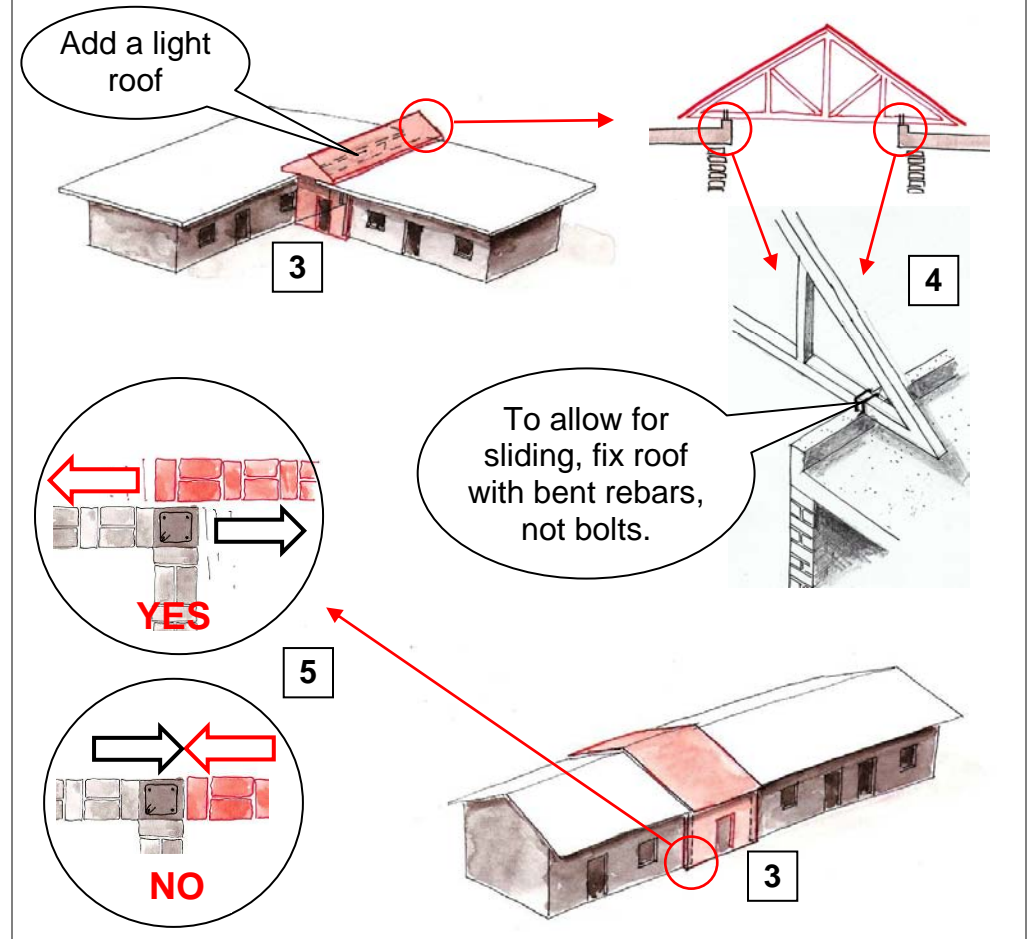


### Solution 1: Seismic gaps between buildings

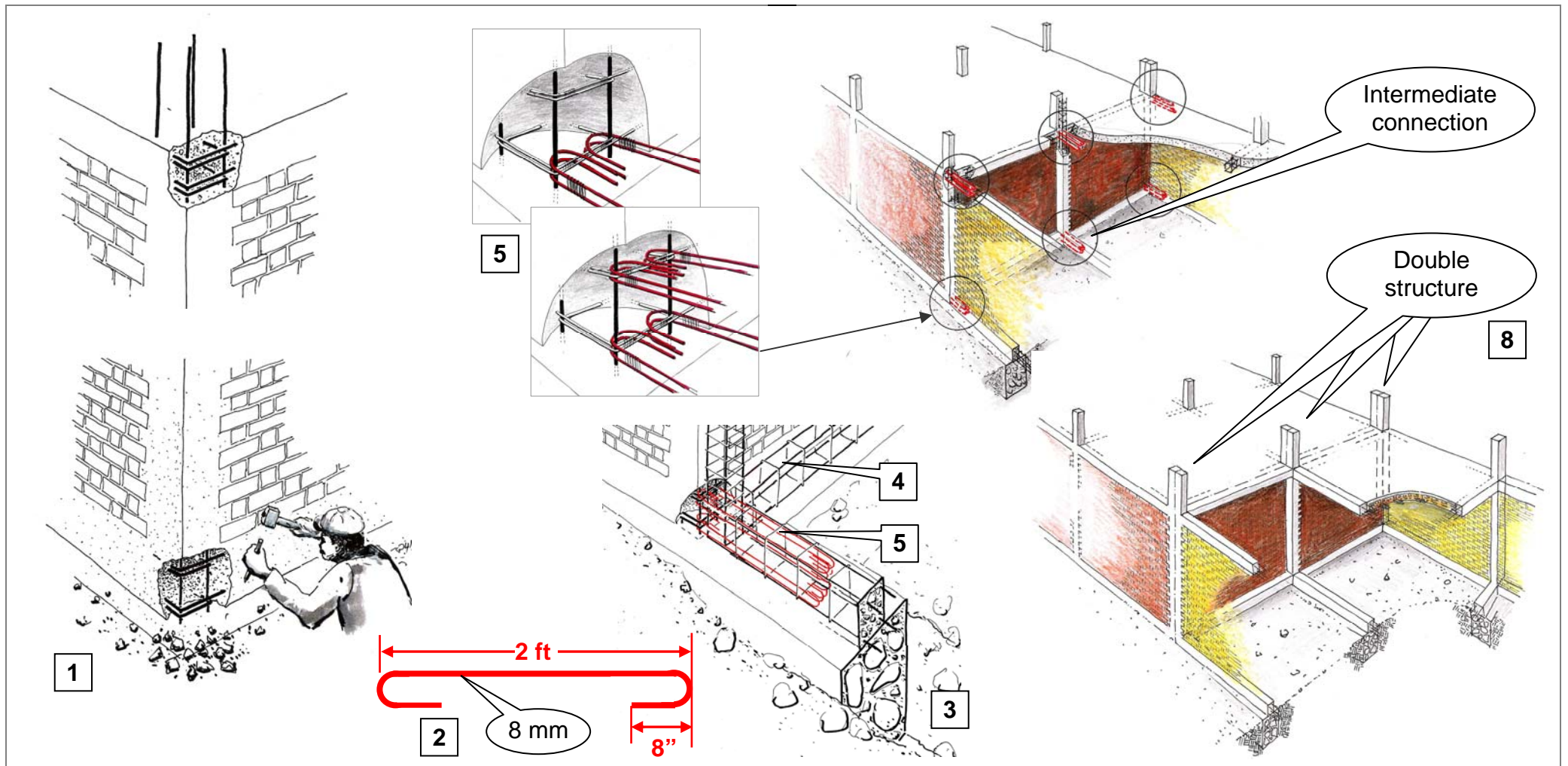


1. If buildings are too near, they will hammer against each other during an earthquake.
2. Therefore keep a good distance between buildings to avoid damage.

### Solution 2: The crush-zone principle for one storey buildings

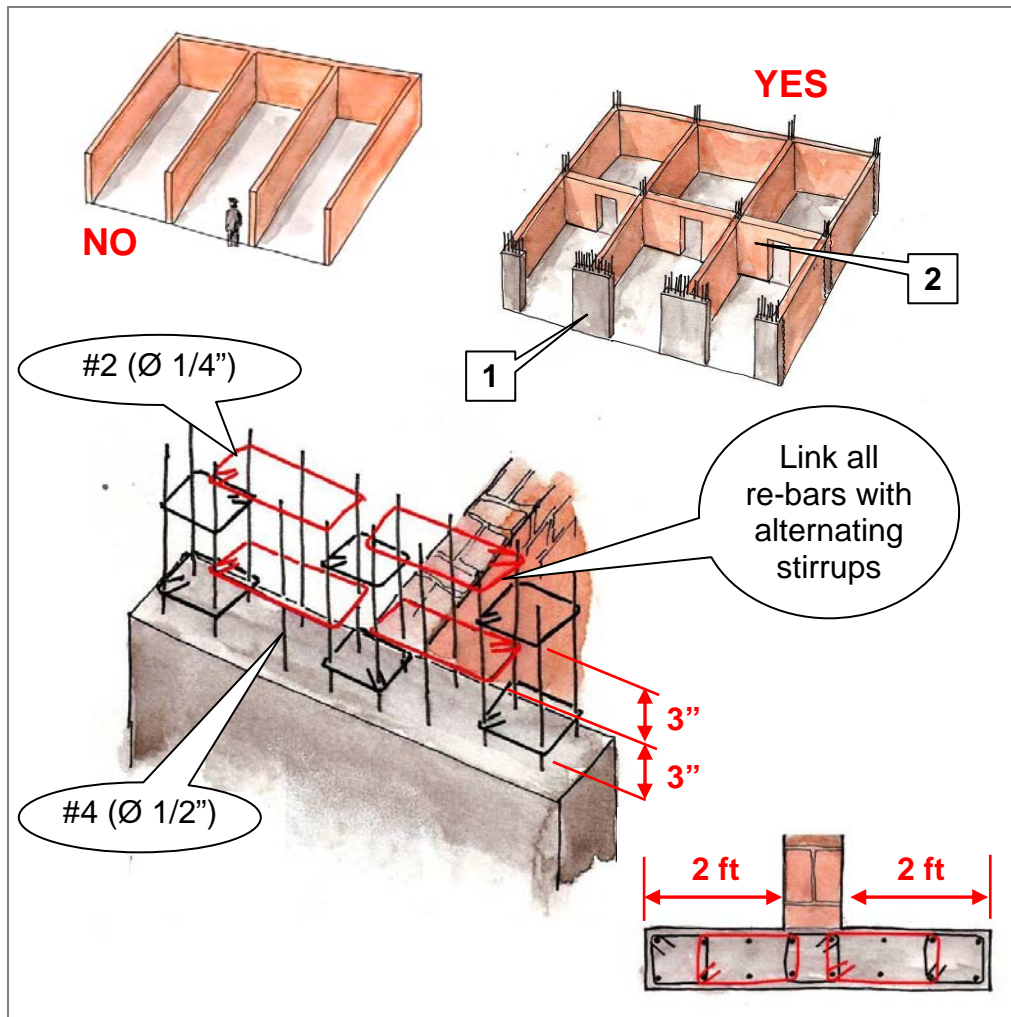


3. If you want to connect buildings, put a room in between where people stay only for a short time, like a deposit or a toilet.
4. Fix the roof with bent rebar instead of bolts, so it can slide slightly during an earthquake.
5. Don't put walls in between, but against the buildings. This way they can slide during an earthquake and fall away.



1. Open carefully the corners and intermediate connections.
2. Prepare 8 anchor bars for every connection.
3. Prepare foundations for additional rooms.
4. Place column and plinth reinforcements
5. Add anchor bars as shown: one end around the vertical rebars above and below each stirrup, the other end into the plinth beams.
6. Cast the plinths and make sure that the holes broken out of the original columns are filled well with concrete
7. Build the walls and cast the tie-columns.
8. Note: The final structure will be doubled where the new rooms meet the original building.
9. The new house must maintain a simple shape (see page 1).

## 16. Adding more rooms (attached)

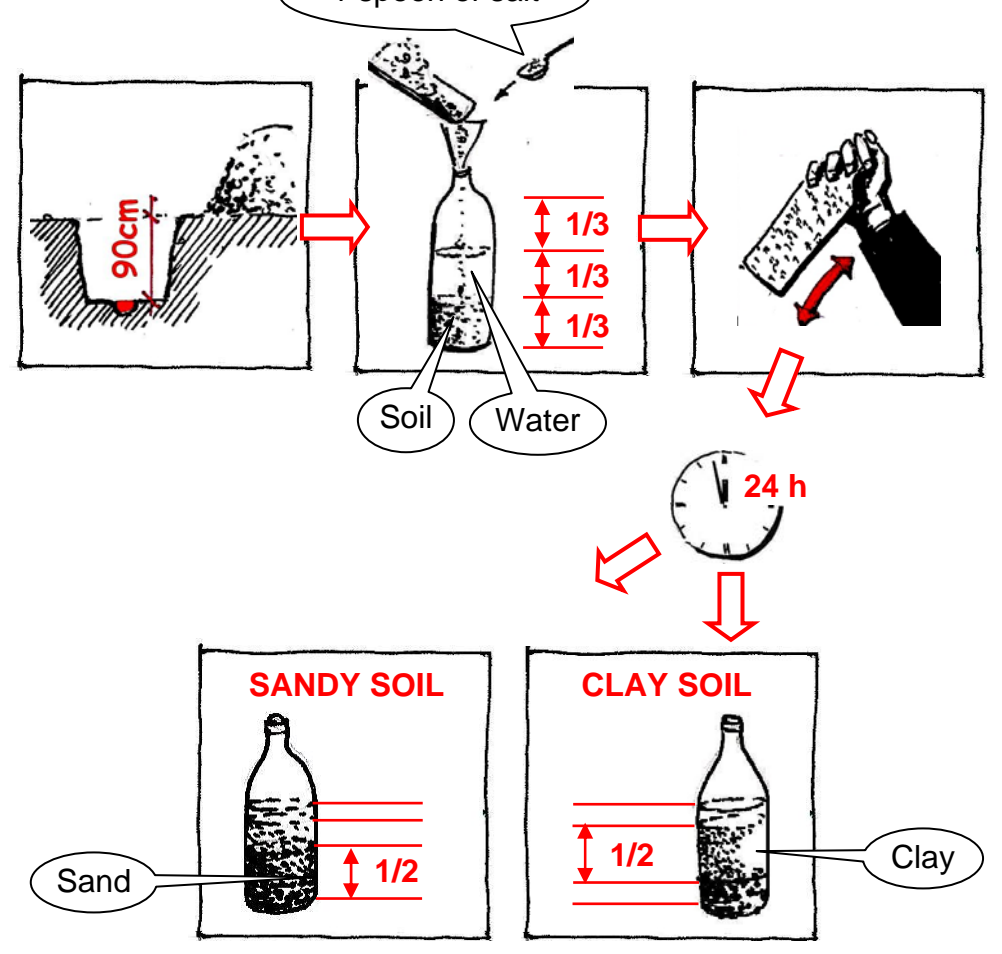


Shops are dangerous structures when it comes to earthquakes. Their big windows weaken the building and internal walls are often too long.

1. Reinforce the sides of the shop windows with 2 ft large RC columns.
2. Subdivide the long walls by introducing perpendicular walls.



## Soil test



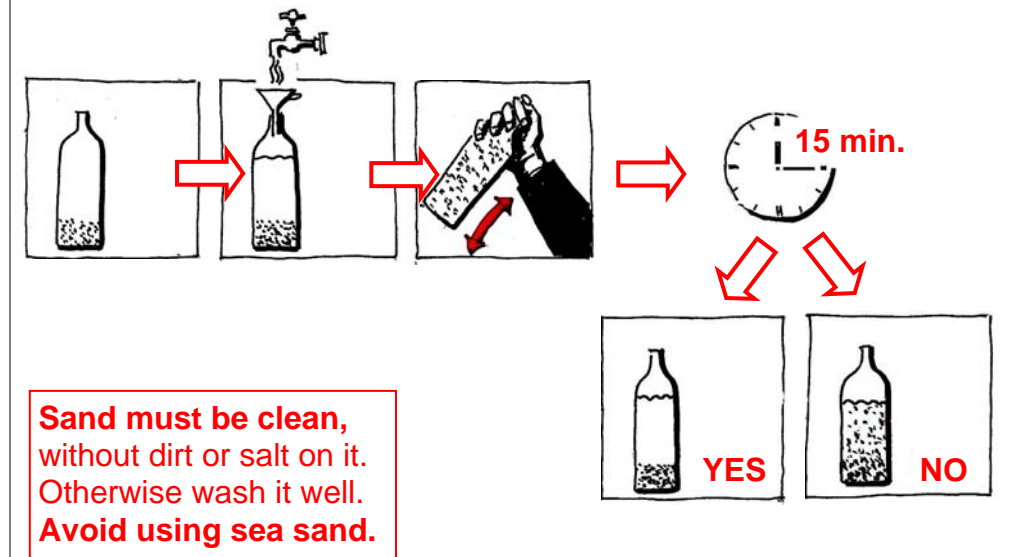
### Soil test:

Fill 1/3 of a bottle with soil from the bottom of the foundation. Add one spoon of salt and fill another third of the bottle with water. Shake and let deposit for 24 hours.

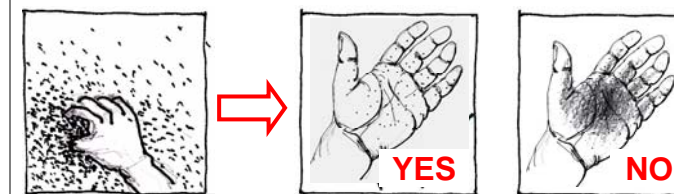
If the bottom part (sand) is half of the volume, the soil is sandy.

If the central part (clay) is half of the volume, the soil is clay.

## Sand test (proper method)



## Sand test (simplified method)



### Sand test (proper method):

Put some sand in a bottle, fill up with water and shake thoroughly. Leave 15 minutes to settle. If the water remains rather clear, sand is okay. If the water remains dirty, the sand is not useable.

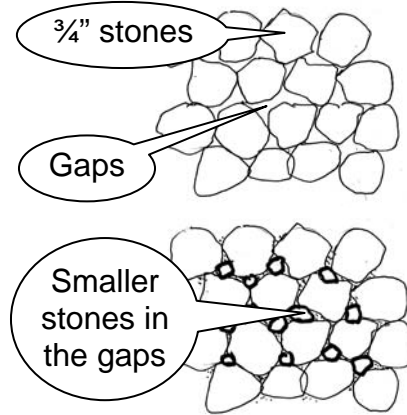
### Sand test (simplified method):

Take a handful of sand. If your hand remains rather clean, the sand is okay. If the hand remains dirty, the sand is not useable.



### Aggregates (gravel):

- Gravel should be “crushed”. Round gravel from rivers makes a weaker concrete.
- Gravel should be “graded”. Don’t use only ¾” size stones, but mix them with smaller ones. These smaller stones will help to fill the gaps between the stones and make a better concrete.



### Water:

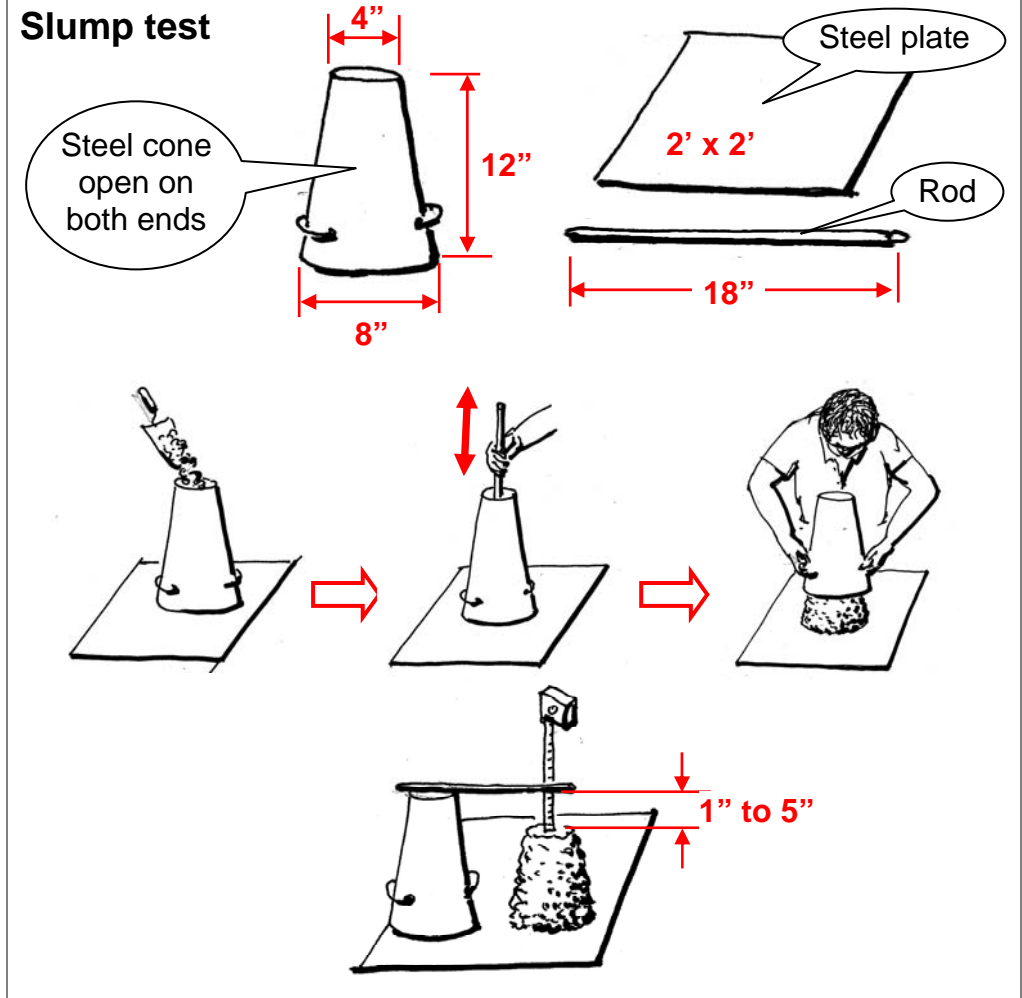
- Concrete does not “dry”, but needs water to become hard. That’s why concrete needs “curing”. That is, you have to put water over it once the concrete is already a bit hard (after some hours)
- But too much water makes your concrete weak. Don’t add water to make the concrete go down into the column formwork.
- Never “refresh” dried concrete by adding water. Dried out concrete must be thrown away.



### Concrete curing times:

Days	Strength at 4°C	Strength at 20°C
4	20%	40%
7	40%	65%
28	77%	100%

### Slump test



### Slump test:

Fill half of the cone with concrete and compact with the stick. Fill the second half and compact again.

Lift the cone vertically off the concrete without twisting.

Measure the difference in height between the cone and the slump. 4” of difference is about right for concrete work. If the slump is higher than 5”, the concrete must not be used (too much water).

## Technical specifications:

1. Use deformed (rippled) bars except for stirrups which may be smooth.



2. The following specifications must be followed:

- Steel quality: ductility class A,  $f_y$  420 N/mm<sup>2</sup>
- Concrete quality:  $f'_c$  30 N/mm<sup>2</sup>
- Admissible live load: (200 kg/m<sup>2</sup> or 40 psf) 2 kN/m<sup>2</sup>
- Concrete cover (unified for all situations): 1 ¼" (30mm)

### Rebar conversion table

<i>Nr.</i>	<i>Inch</i>	<i>Metric in mm</i>	<i>replace with</i>
#2	1/4"	(6.35)	6 mm
(no imperial equivalent)			
#3	3/8"	(9.52)	10 mm
#4	1/2"	(12.70)	12 mm
#5	5/8"	(15.87)	16 mm

If an 8mm rebar is required but unavailable, replace it with 3/8".

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