Tom Schacher

CONFINED MASONRY

For one and two storey buildings in low-tech environments

A guidebook for technicians and artisans

nicee

NATIONAL INFORMATION CENTRE OF EARTHQUAKE ENGINEERING

The present manual is the end product of an earlier version (version 1) drafted in 2005, adapted to the field necessities in early 2007 (version 2) and extensively field tested for one year in 2007-8 during the reconstruction phase following the October 2005 earthquake in the Kashmir Mountains.

National Information Centre of Earthquake Engineering (NICEE) was established in IIT Kanpur with the mandate to empower all stakeholders in the building industry in seismic safety towards ensuring an earthquake resistant built environment. NICEE maintains and disseminates information resources on Earthquake Engineering. It undertakes community outreach activities aimed at mitigation of earthquake disasters. NICEE's target audience includes professionals, academics and all others with an interest in and concern for seismic safety. Any opinion, finding, conclusion, or recommendation expressed herein are the author's and do not necessarily reflect the views of the NICEE.

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Version 3.0: In imperial units (feet and inches)

Foreword from NICEE

The National Information Centre of Earthquake Engineering is happy to present this manual by Architect Tom Schacher on *Confined Masonry* for worldwide distribution and dissemination.

The unreinforced masonry buildings as prevalent in India are highly prone to damage during earthquakes and have caused thousands of casualties in some of the recent earthquakes in the subcontinent. Further, many reinforced masonry buildings in the developing countries are not constructed with appropriate quality control in design and construction, making them highly vulnerable to strong earthquake shaking. Hence, confined masonry is an effective construction technology for seismic areas for countries such as India. If done with nominal care, it performs very well in the event of earthquakes, and does not require substantial amount of expertise in design or construction.

This manual is meant for artisans, masons, and homeowners engaged in construction of one- and two-storey dwellings in a low-tech environment. It provides clear guidance on the construction aspects as well as the do's and don'ts. While developing this manual, Mr Schacher brings with him a rich hands-on experience of propagating this technology in Pakistan after the 2005 Kashmir earthquake. For those interested in learning more about the confined masonry and its applications for larger buildings, NICEE has brought out another monograph on confined masonry authored by Svetlana Brzev.

It is hoped that this monograph will help propagate a better construction technology in the Indian subcontinent and elsewhere. Financial support from Poonam and Prabhu Goel Foundation at IIT Kanpur has made it possible for NICEE to undertake this publication and is gratefully acknowledged.

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Preface from the author

Over the last decades reinforced concrete (RC) frames with masonry infills have become the preferred construction technique for earthquake resistant low-rise buildings worldwide. Yet, due to their need for precise detailing and execution on one hand, and the frequently inadequate level of craftsman-ship on the other, RC frames have proved to be excessively vulnerable to earthquakes. The technically less sophisticated Confined Masonry technique presented in this manual has proved to perform well under earthquake conditions and thus represents a valid alternative.

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. Itis 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.

Acknowledgements

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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.

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

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the *Swiss Solidarity* fund raising organisation in Geneva

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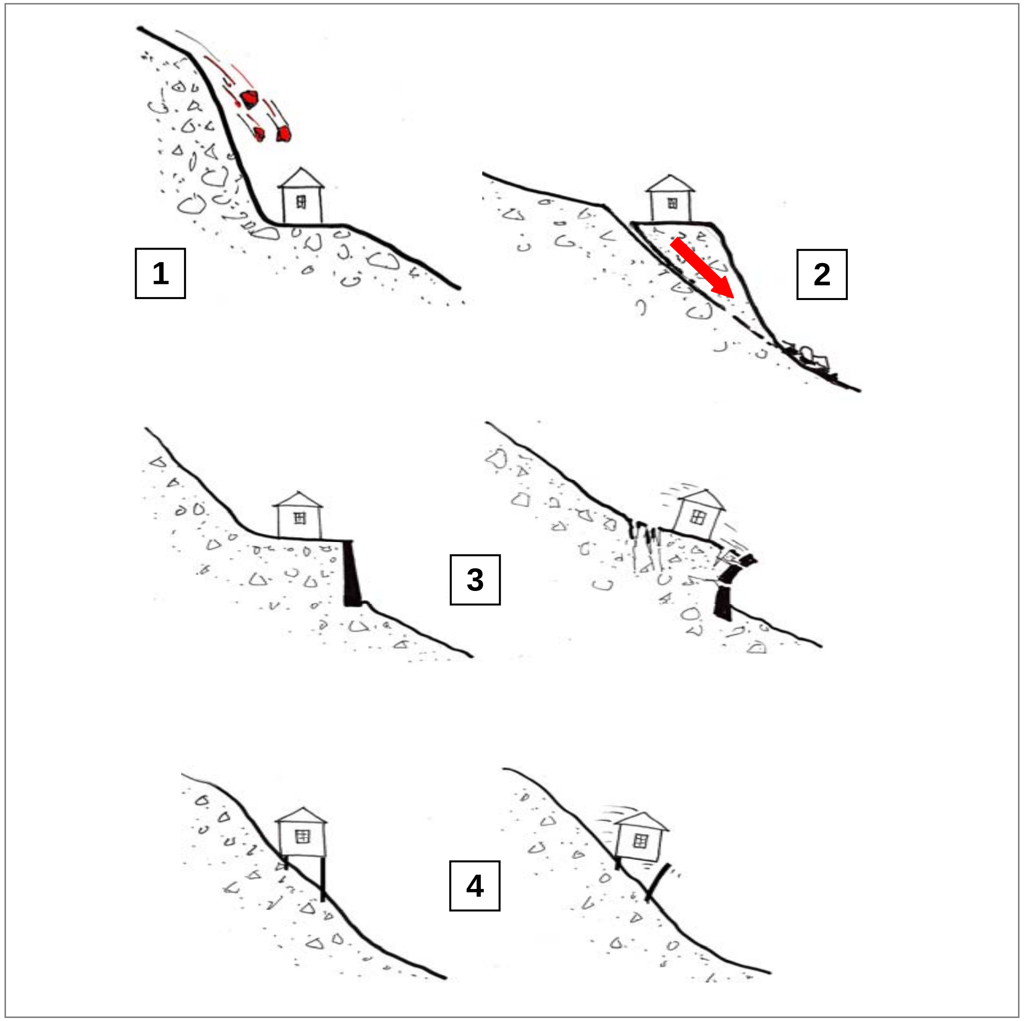
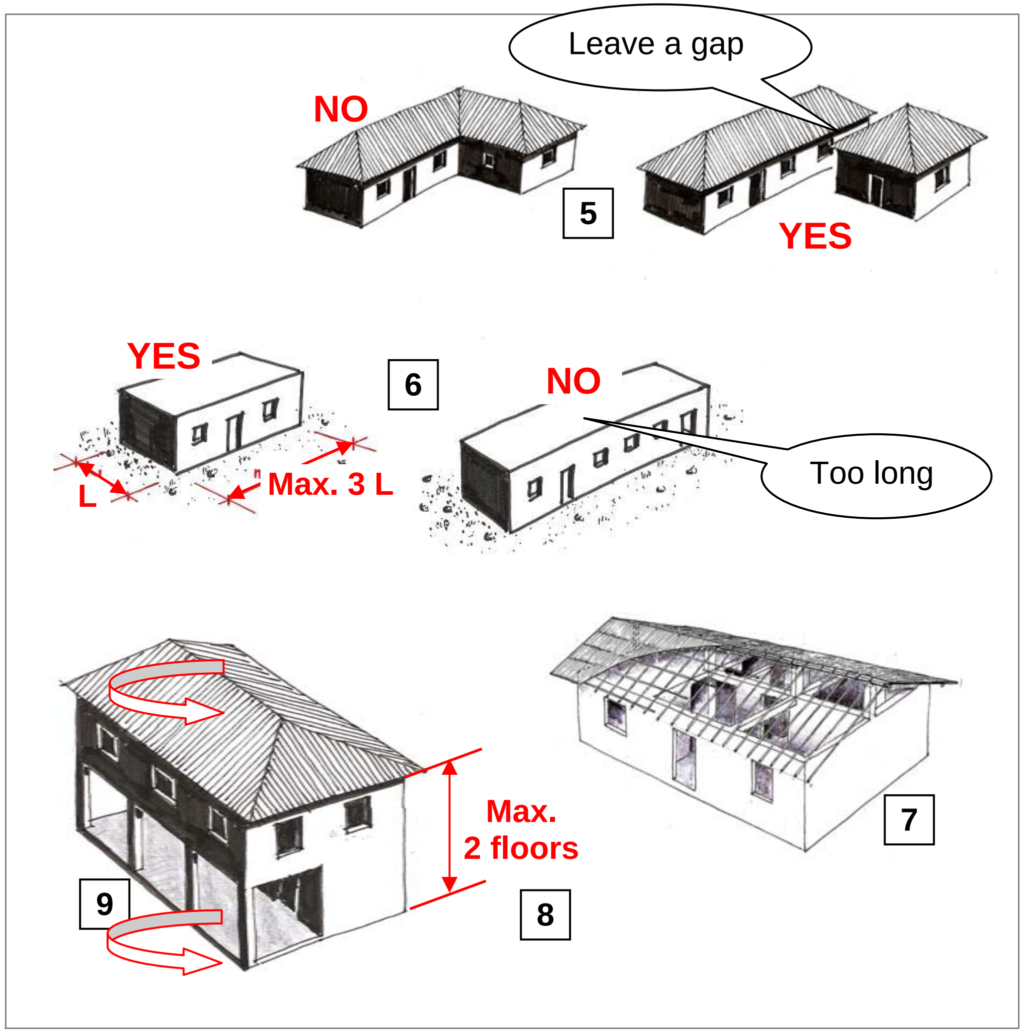
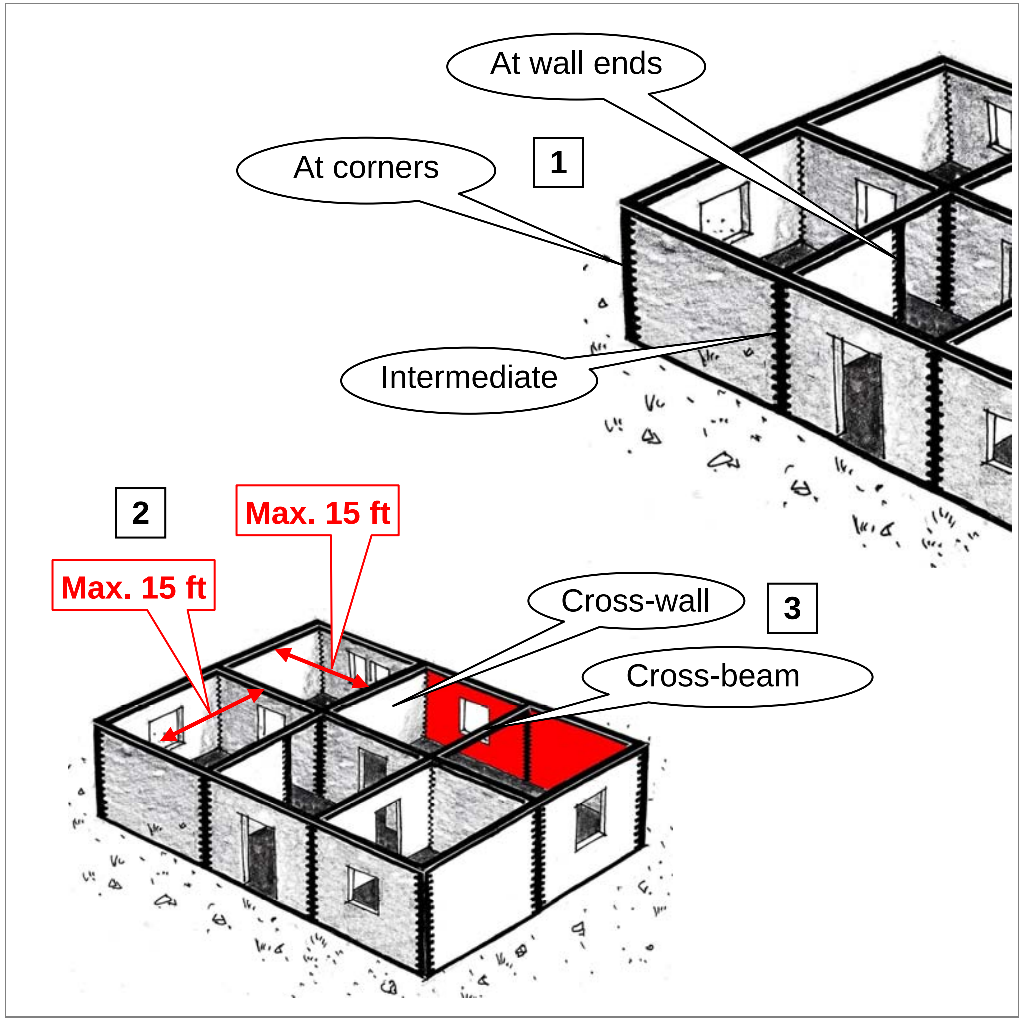
Marjorie Greene of the Earthquake Engineering Research Institute (EERI).

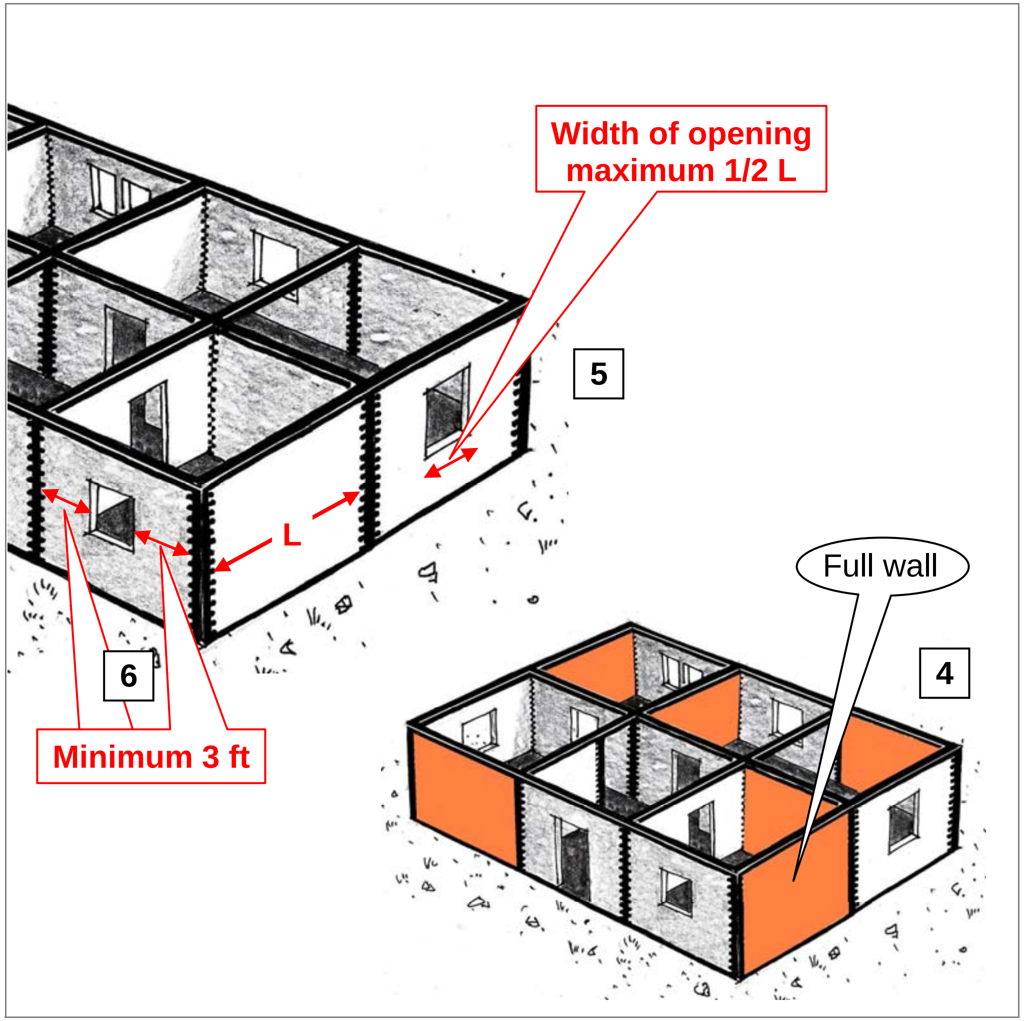




1. Don't build next to a steep slope: stones might fall on your house.
2. Don't build next to a precipice: it might break off.
3. Don't build next to a retaining wall: it might break away.
4. Don't build on stilts: they will fall over during an earthquake.

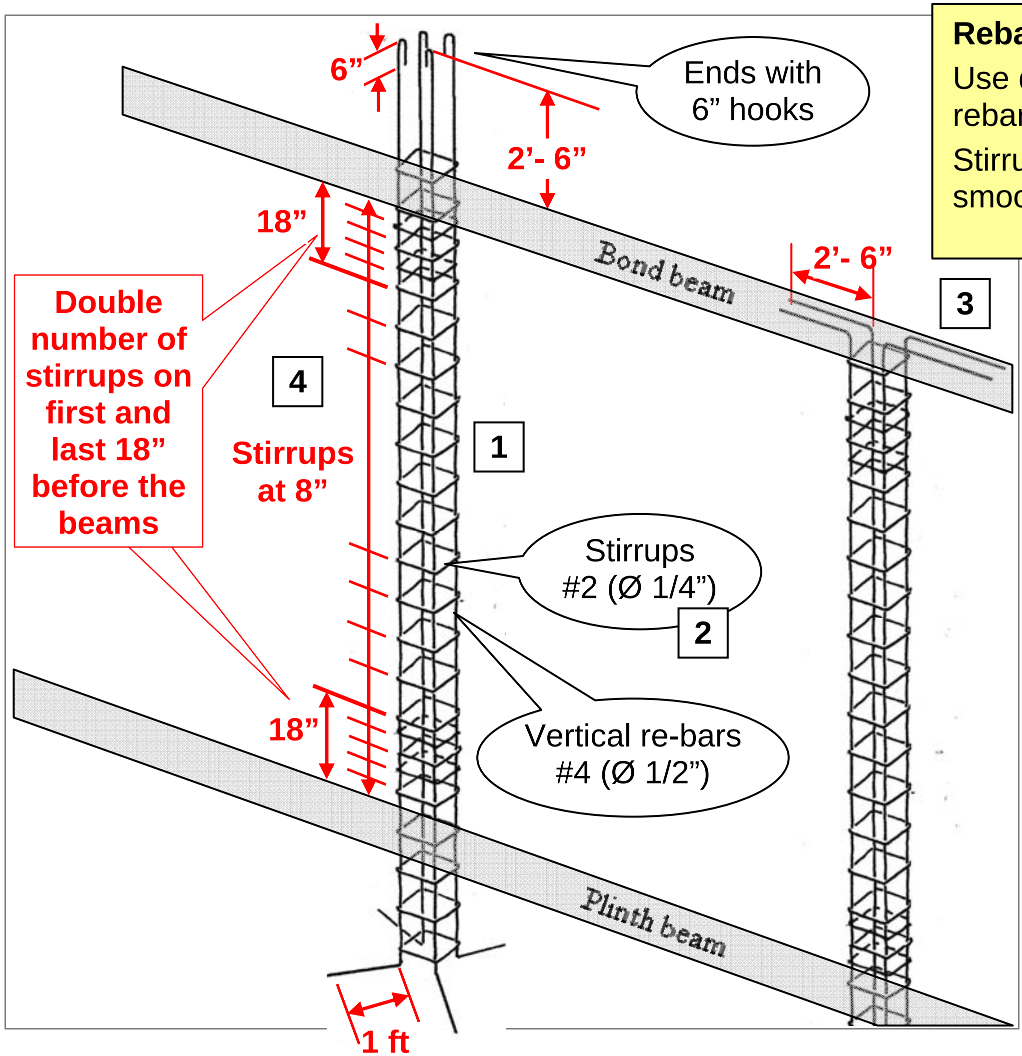
5. A house must have a simple form.
   If necessary, divide it into rectangular parts.
6. A house must not be longer than 3 times its width.
7. A light, pitched roof is better than a heavy concrete slab.
8. Don't build higher than 2 floors.
9. Don't build on columns. Columns are weaker than the walls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





1. 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.

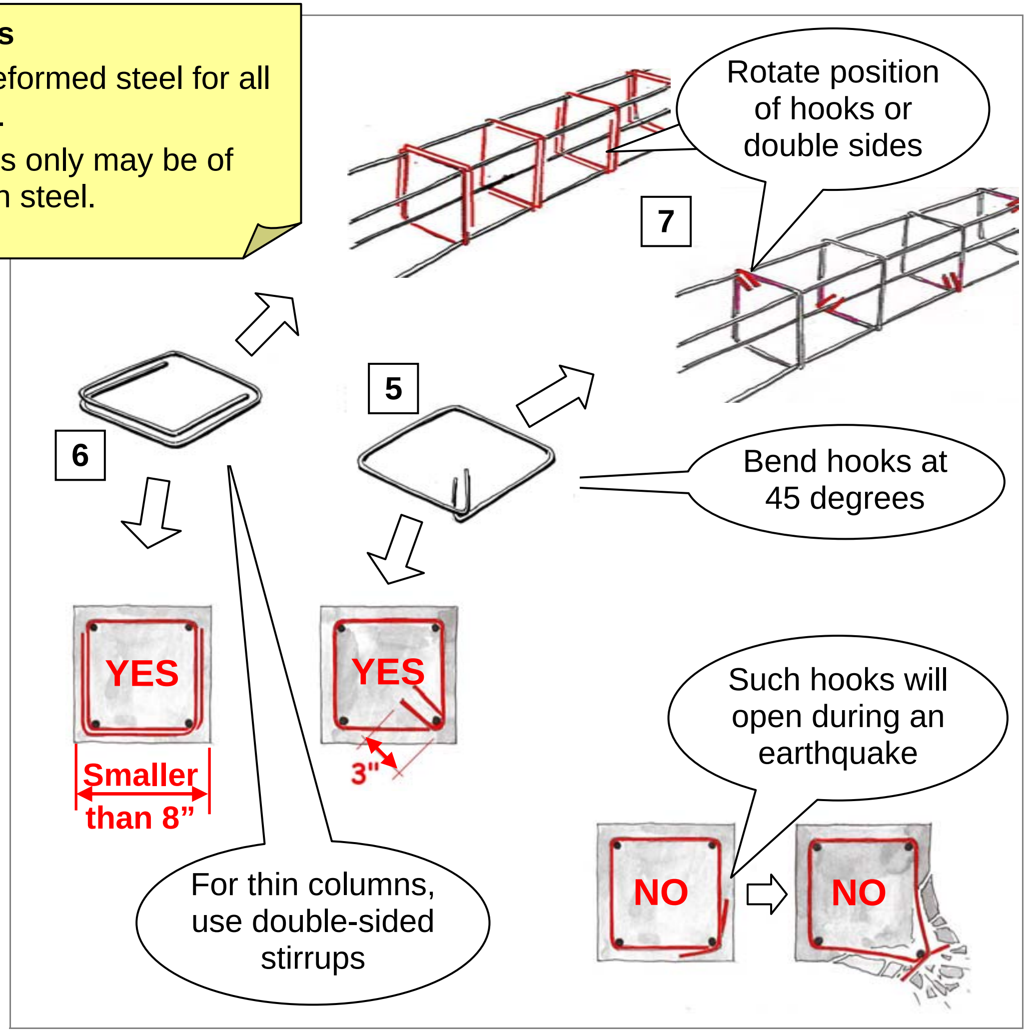
2. Basic rules



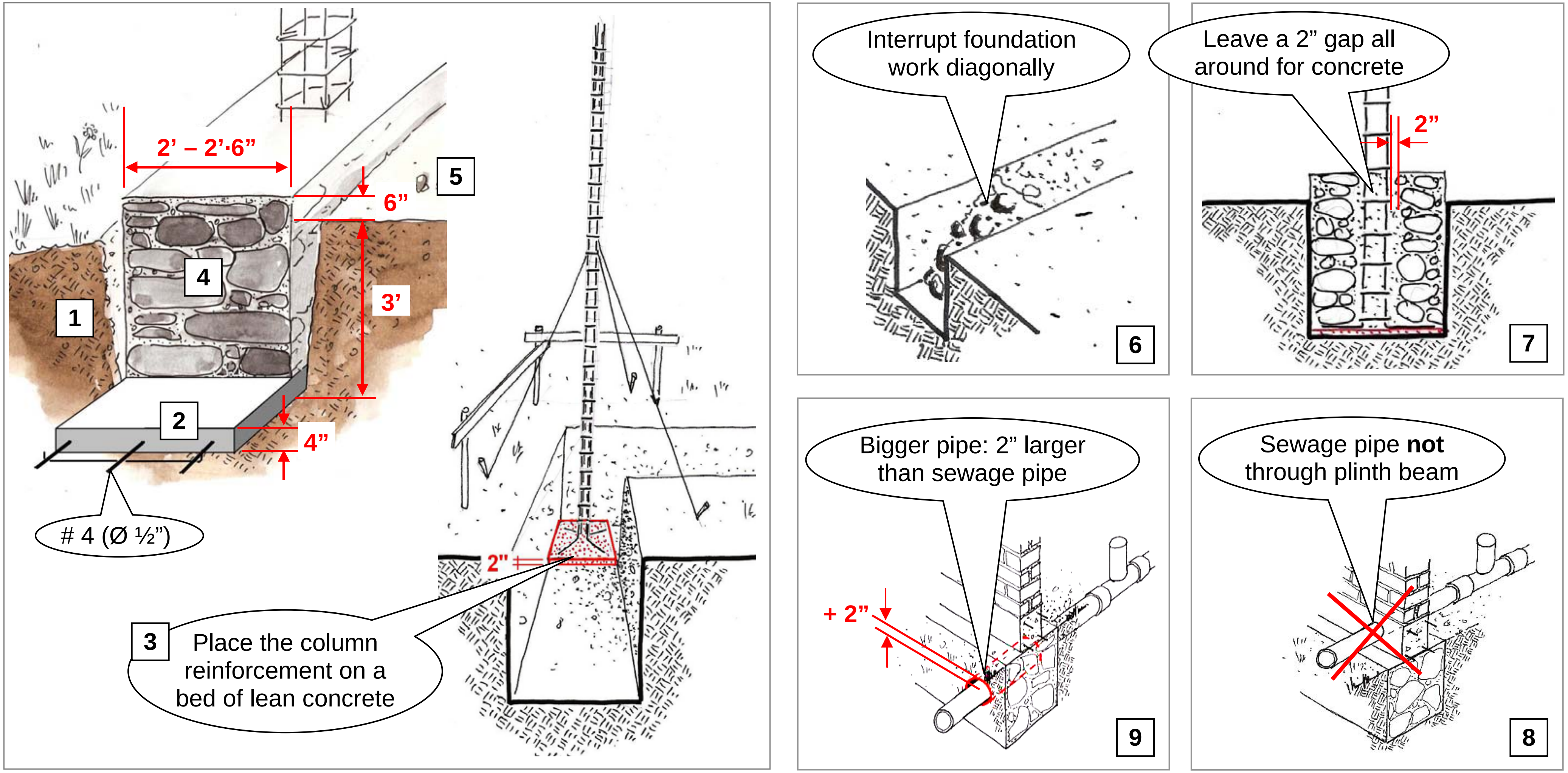
Rebars

Use deformed steel for all rebars.

Stirrups only may be of smooth steel.

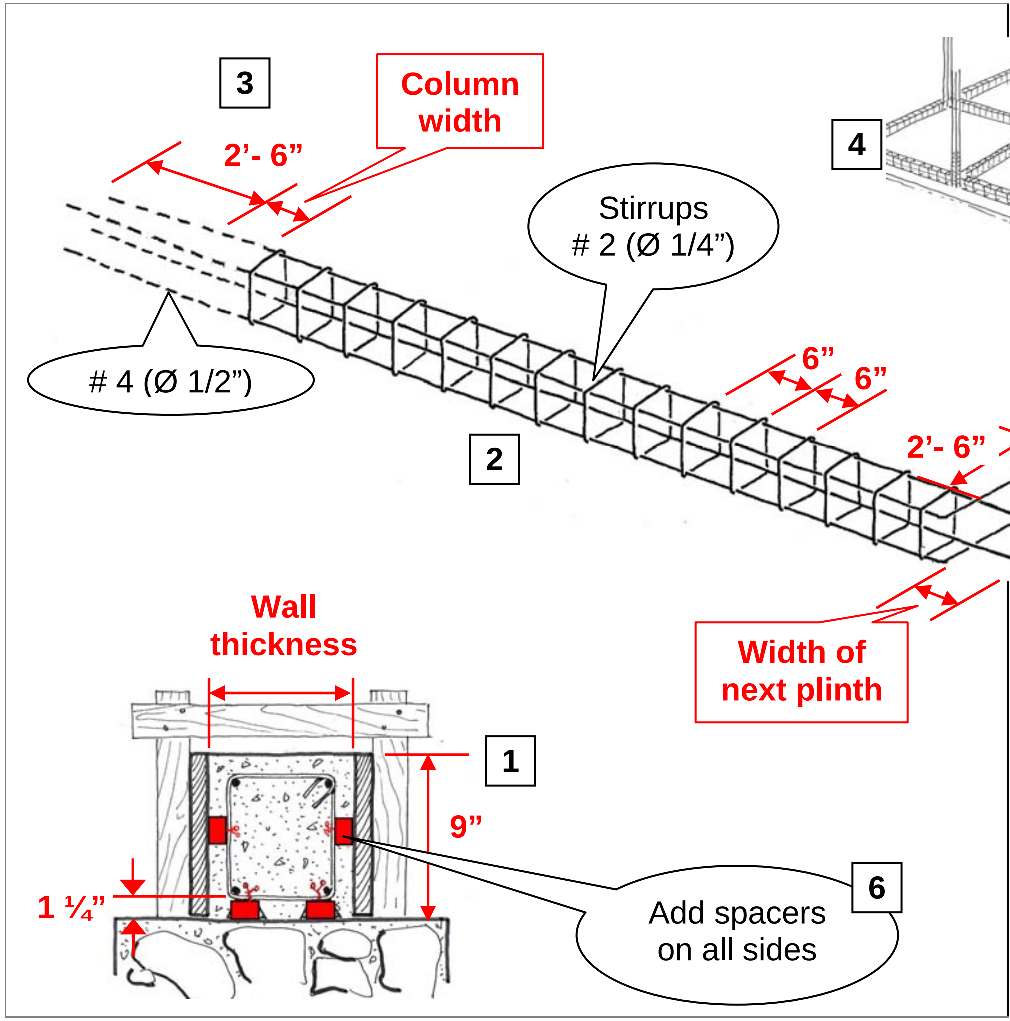


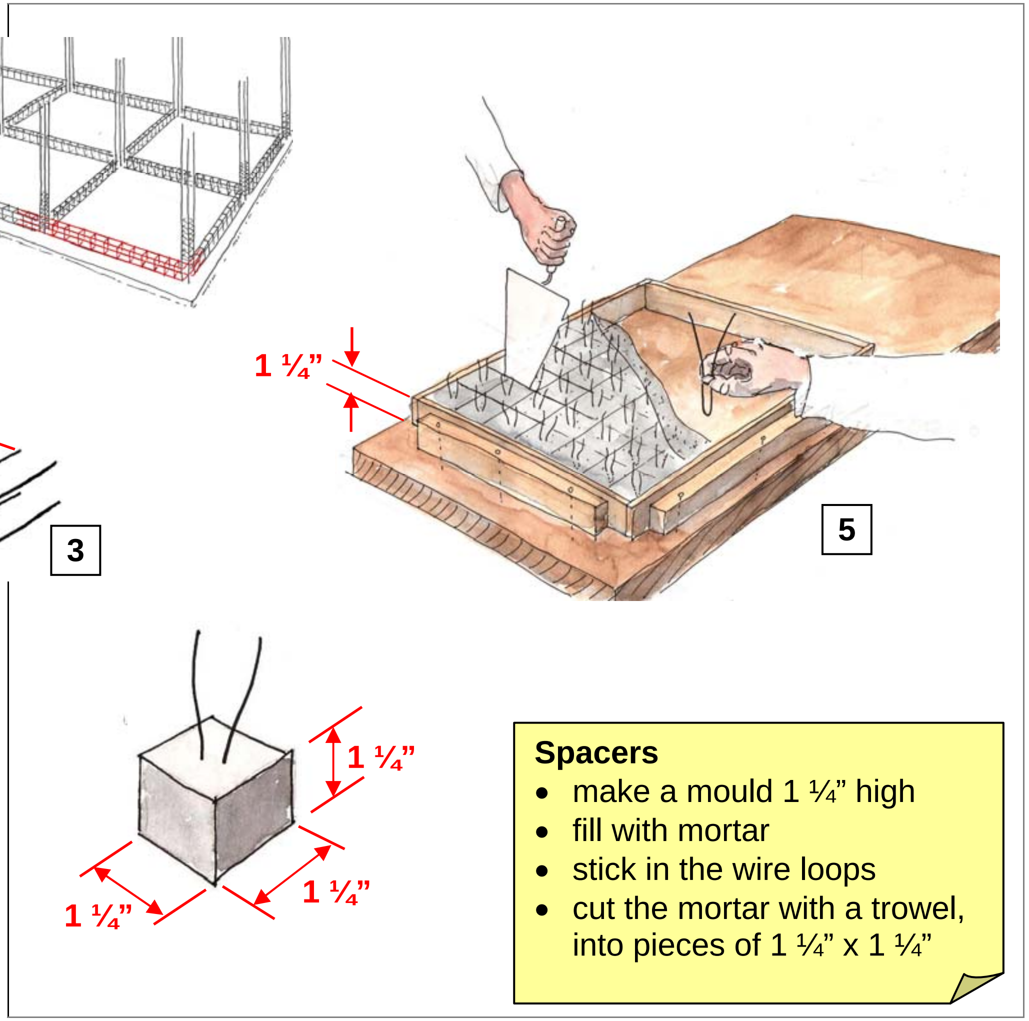
1. Calculate length of the vertical rebars from the bottom of the foundation up to the top of the bond beam. Add 2‘-6” for connection above the slab and 1 ft for the footing.
2. **Verify that #2 rebars for stirrups really do have ¼” diameter, otherwise use 8mm bars.**
3. If you don’t plan to leave the rebars stick out of the roof for future construction, bend them horizontally into the bond beam.
4. Place all stirrups at 8” CC spacing, and double their number on the first and last 18” of the column (resulting in 4” CC spacing in these parts).
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.



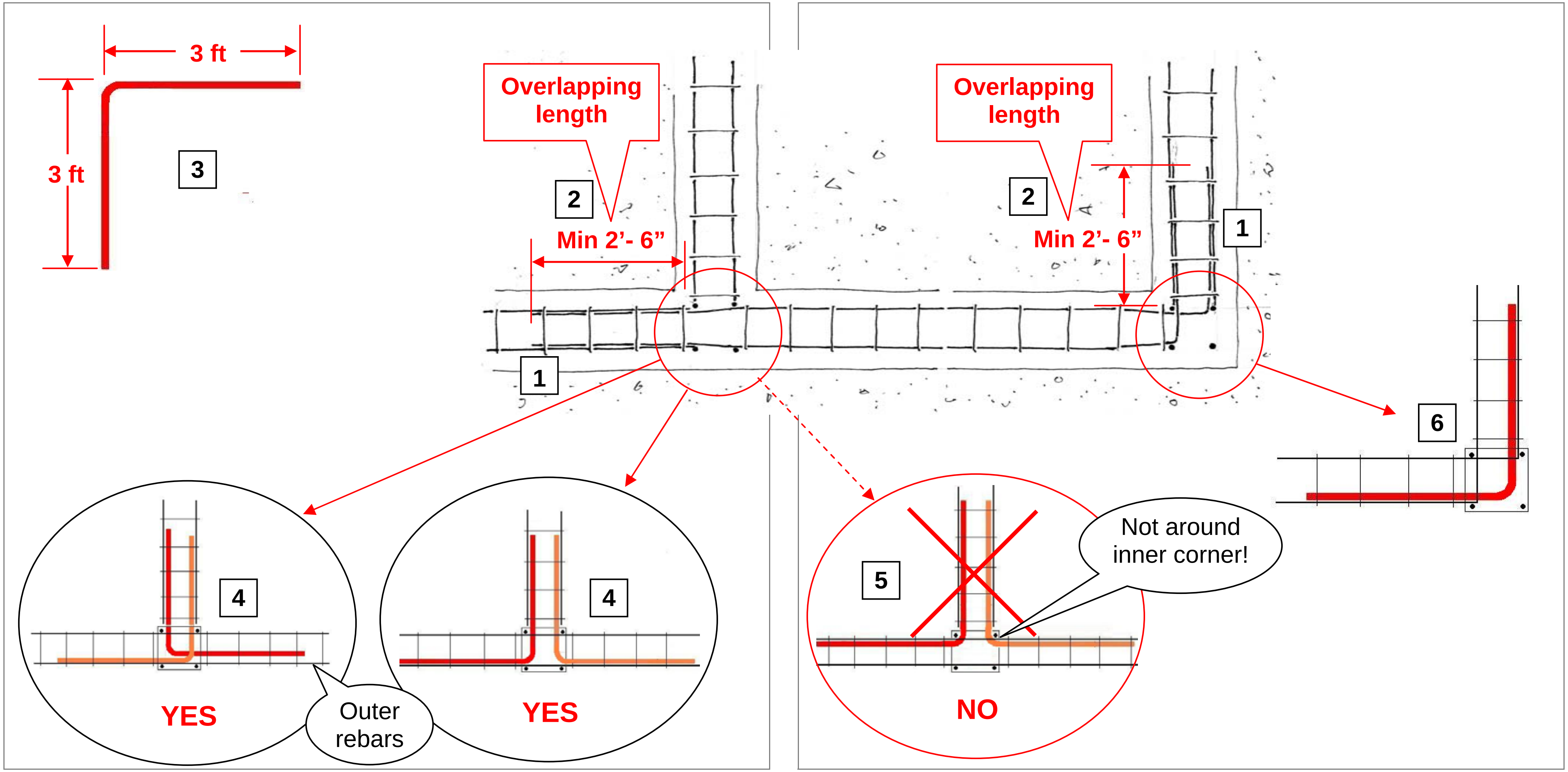
1. Dig the trenches 3 ft deep and 2 ft wide on hard soil (2'-6" on soft soil).
2. On soft soil make a 4" bed of concrete with three #4 rebars in it.
3. Place the column reinforcement on this bed of concrete (on hard soil make independent 2" beds of lean concrete just under the columns).
4. Build the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



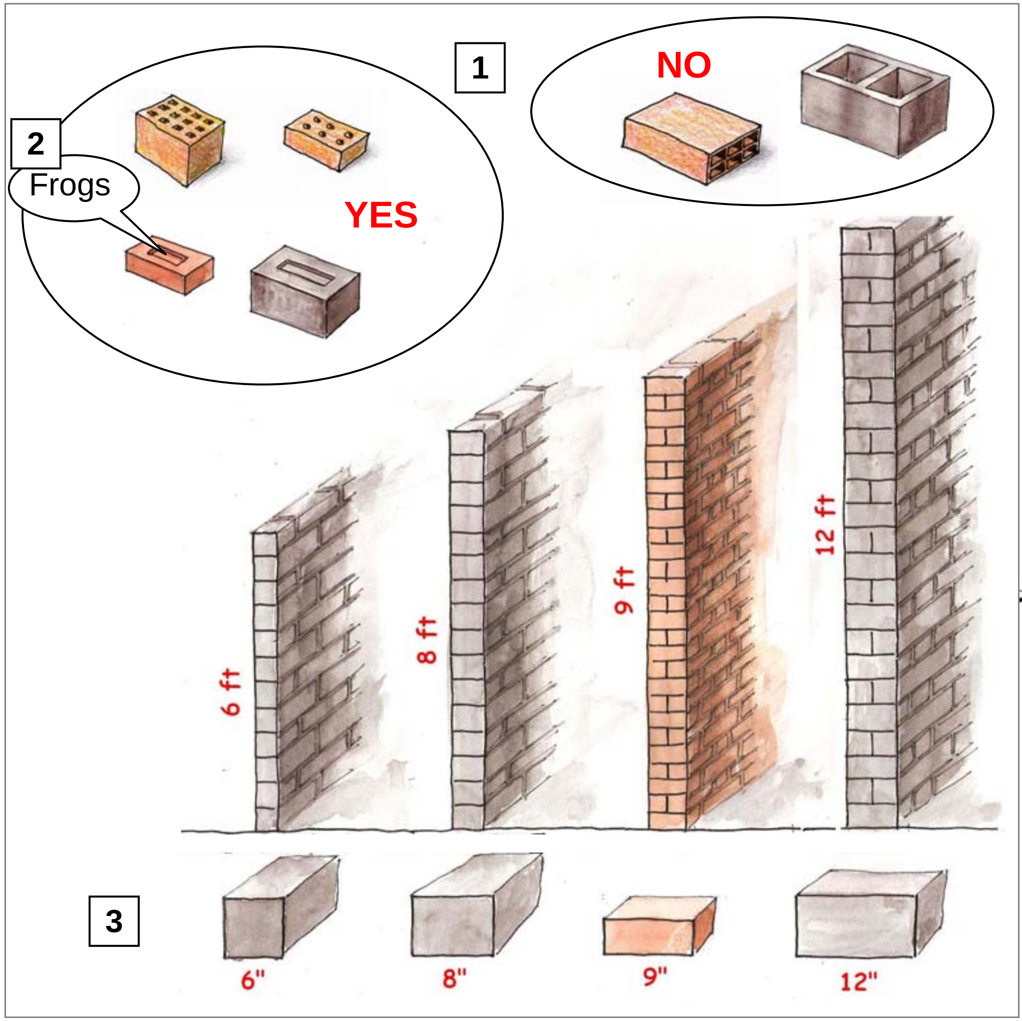


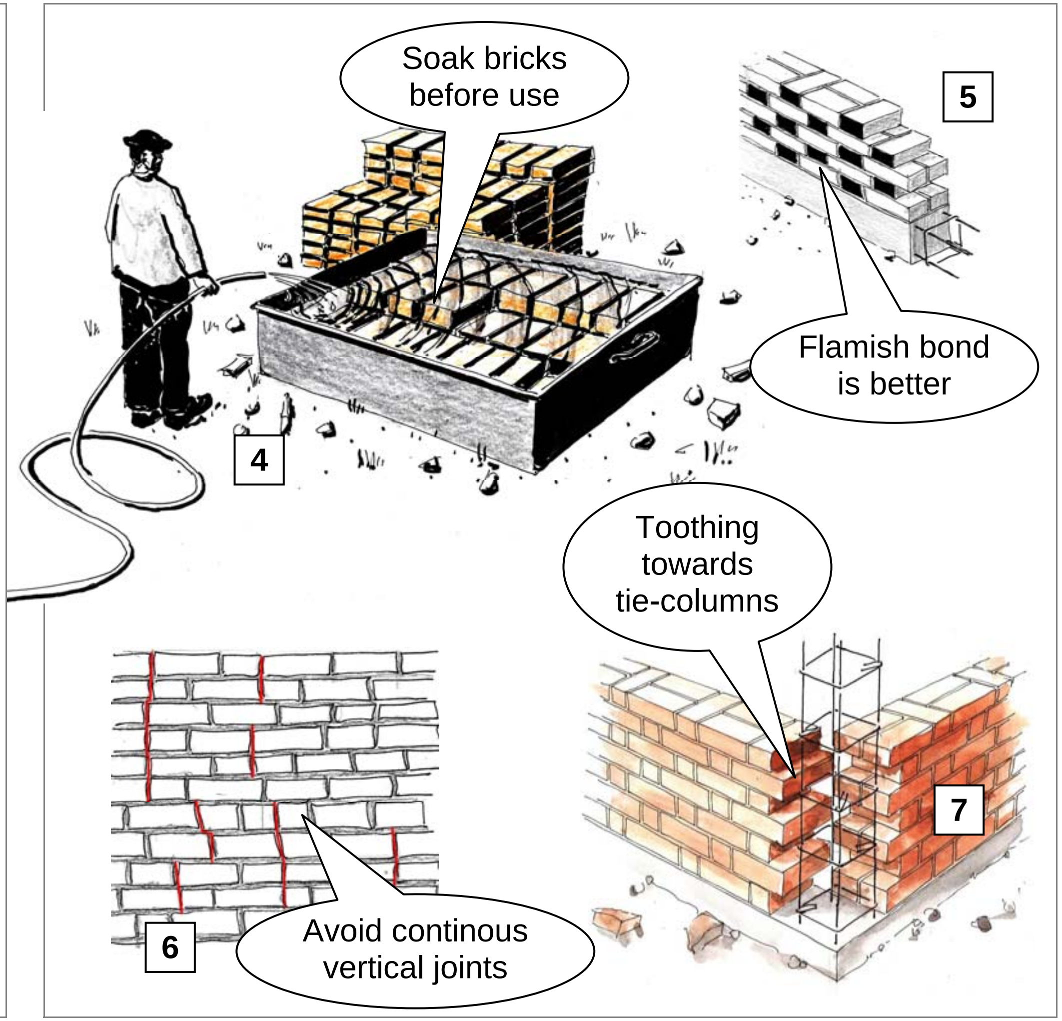
1. Plinth is 9 inches high and as wide as the wall above.
2. Prepare the plinth reinforcement with stirrups at 6” spacing. Bend the lengthwise rebars only on one end.
3. If the plinth continues, leave 2’-6” overlapping length after the columns.
4. Place the plinth reinforcement between the columns.
5. 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.



1. Connect the beam reinforcement by inserting the ends **into** the next beams.
2. Overlapping lengths for #4 rebars 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** rebars.
5. Never bend connection rebars around inner corners.
6. At the corners add 2 external connection bars (top and bottom) and fix them against the **outer** rebars.

6. Plinth and bond beam connections



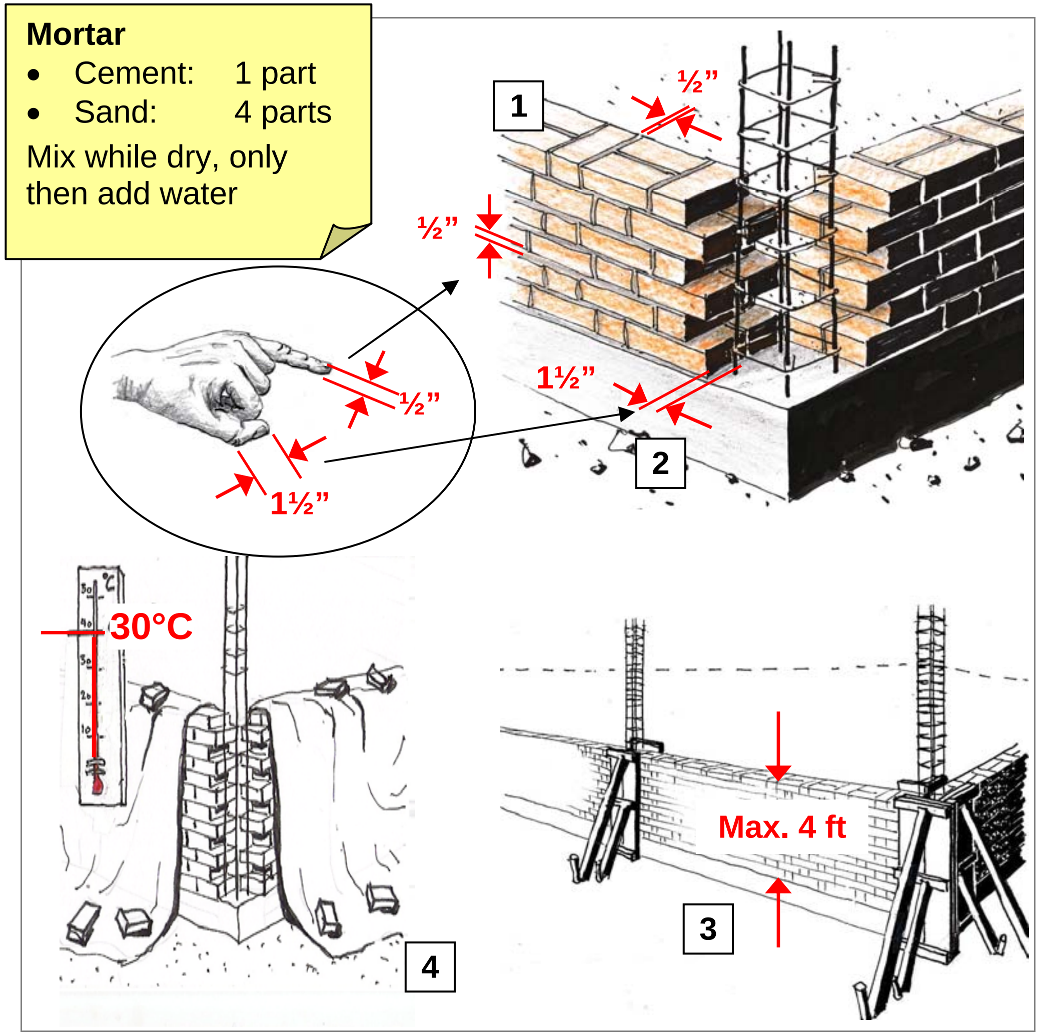


1. Use good solid bricks or blocks. Don't use hollow blocks or light bricks with this building method.
2. To ensure a good connection with the mortar, all bricks or blocks must have holes or 'frogs', even concrete blocks. This is a small but important detail!
3. Walls must not be higher than 12 times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

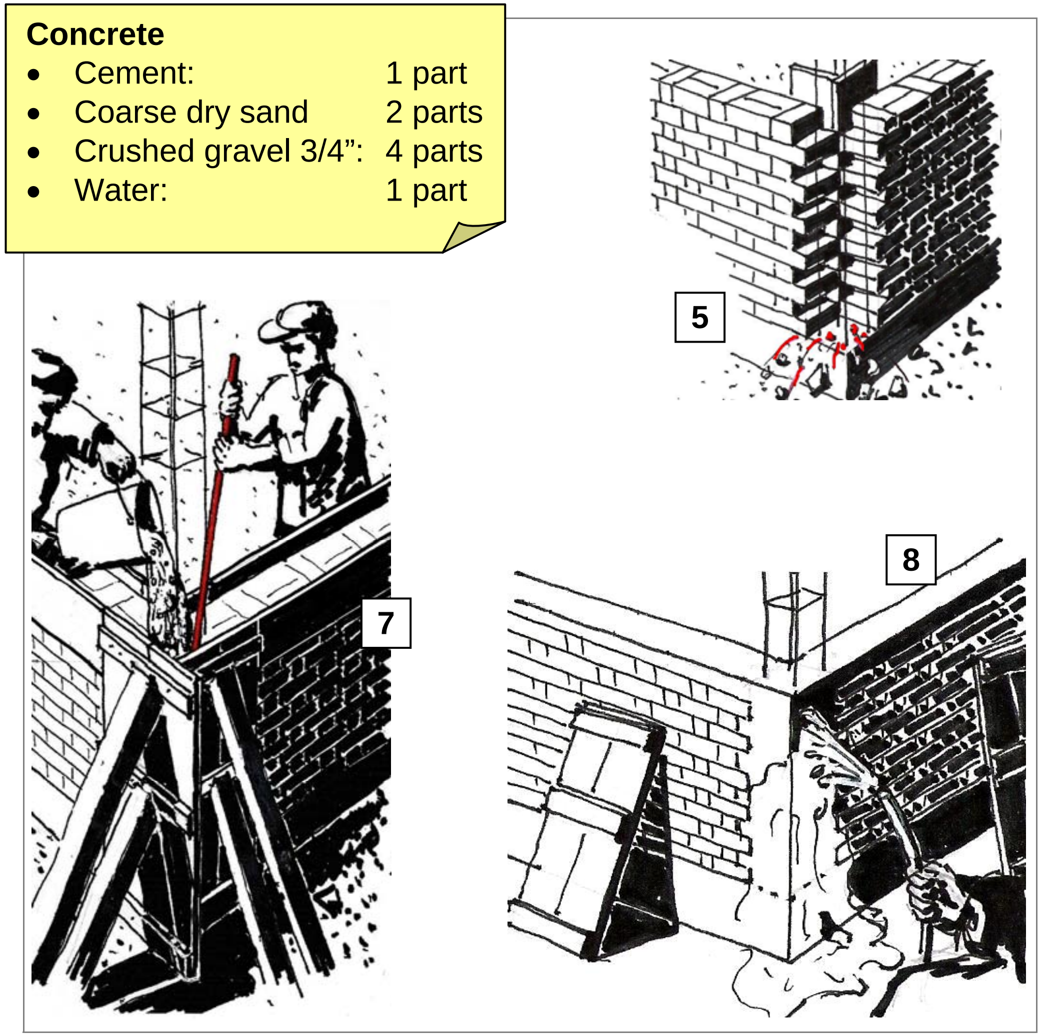
- Cement: 1 part
- Sand: 4 parts

Mix while dry, only then add water



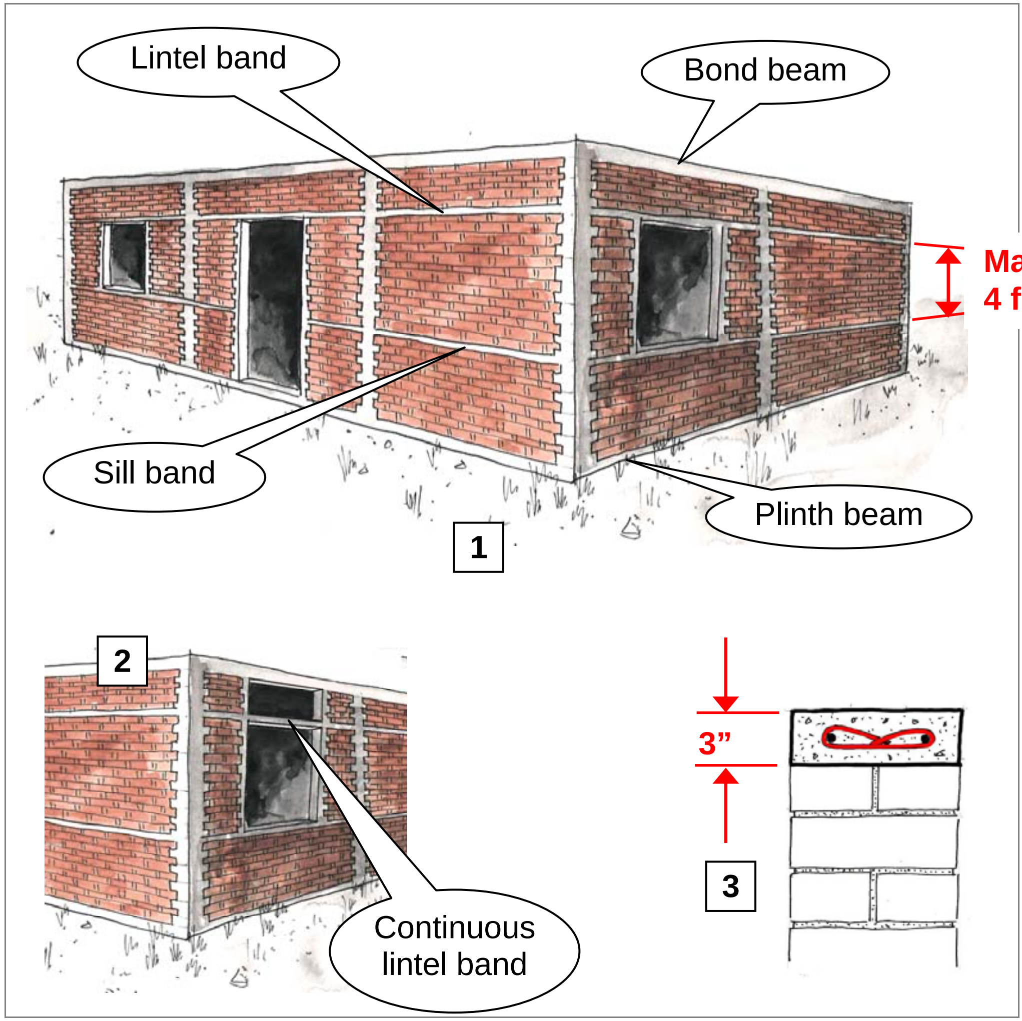
Concrete

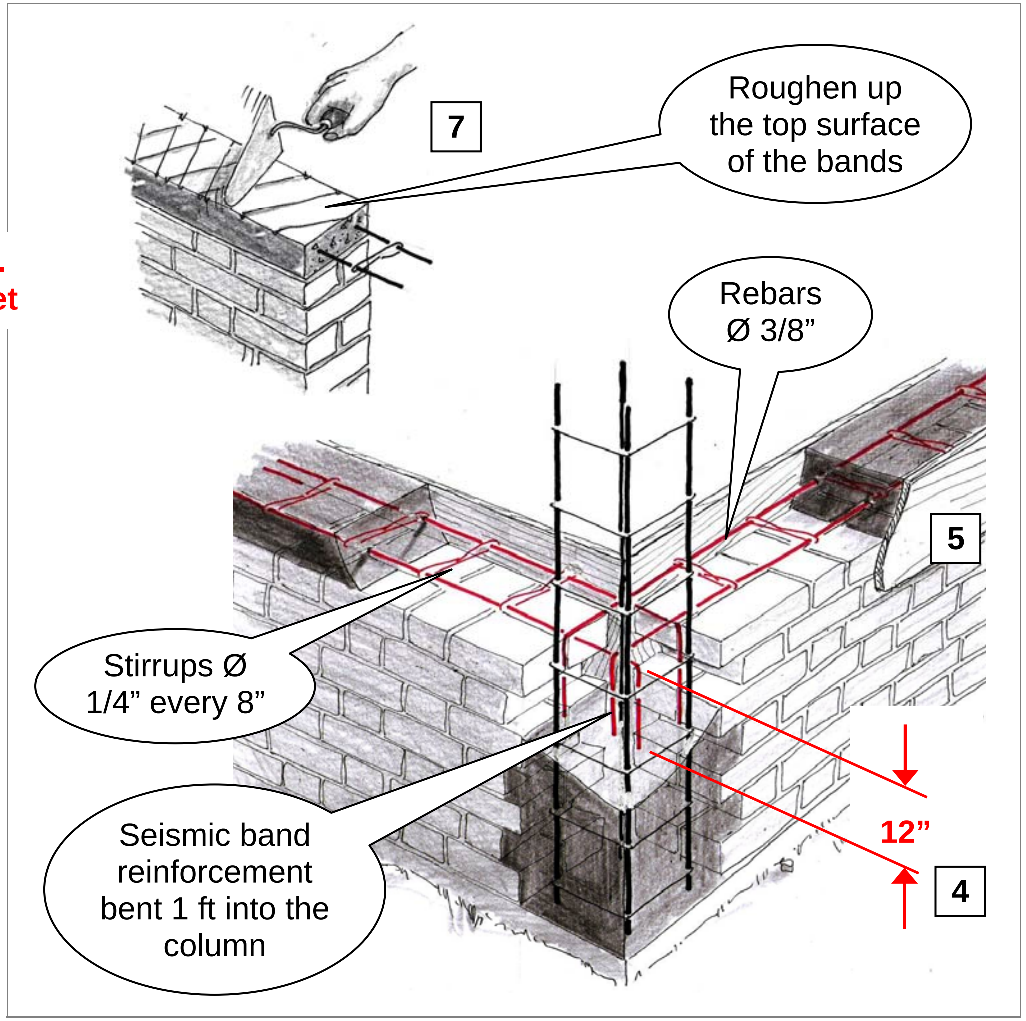
- Cement: 1 part
- Coarse dry sand 2 parts
- Crushed gravel 3/4”: 4 parts
- Water: 1 part



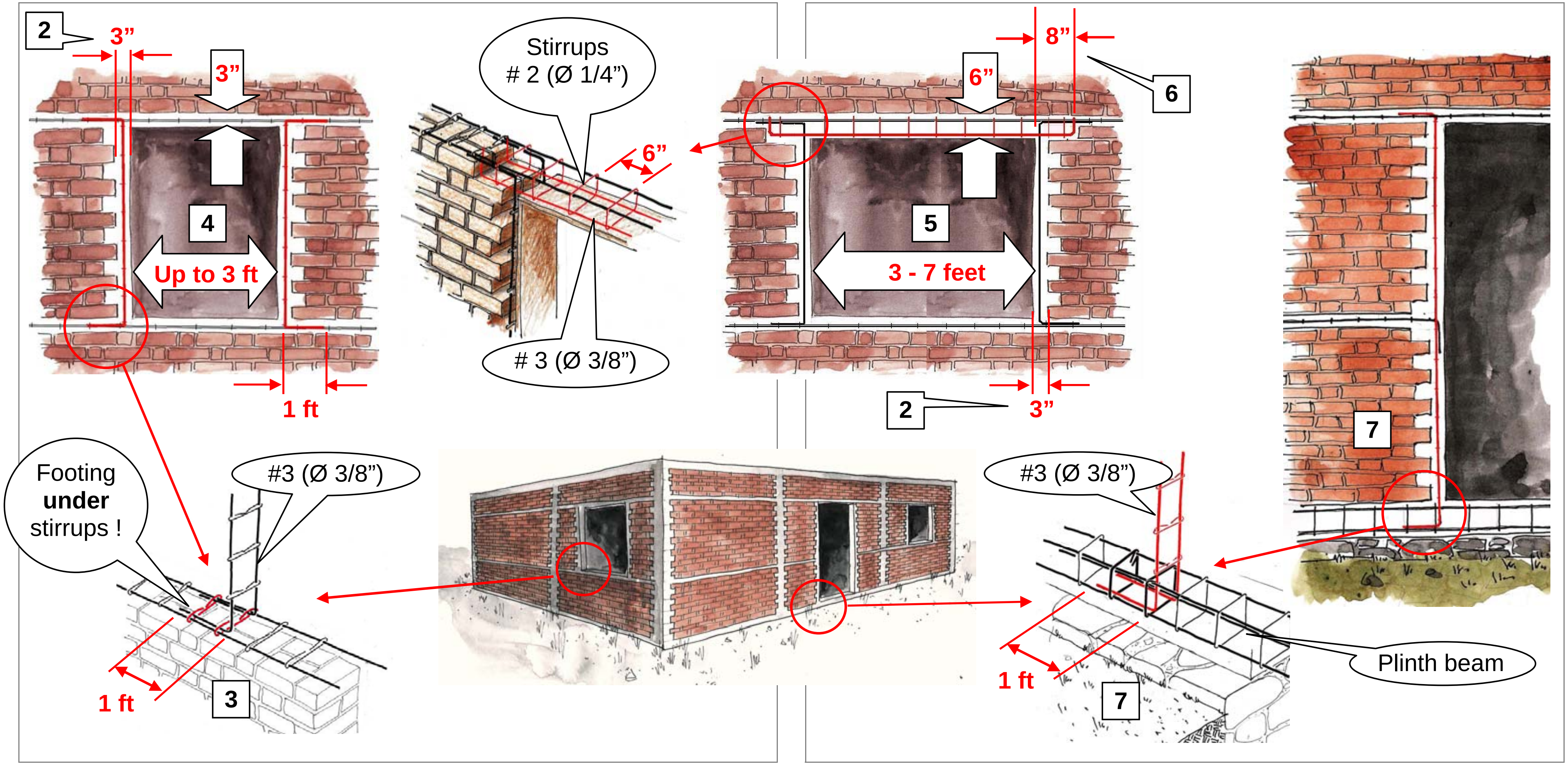
1. Mortar beds and joints must not be thicker than ½ inch.
2. Keep end bricks 1½” away from the stirrups to leave room for the concrete of the tie-columns.
3. Don’t build higher than 4 feet per day.
4. Protect the wall in warm weather with a plastic sheet or wet cloth so the mortar will not dry out.
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



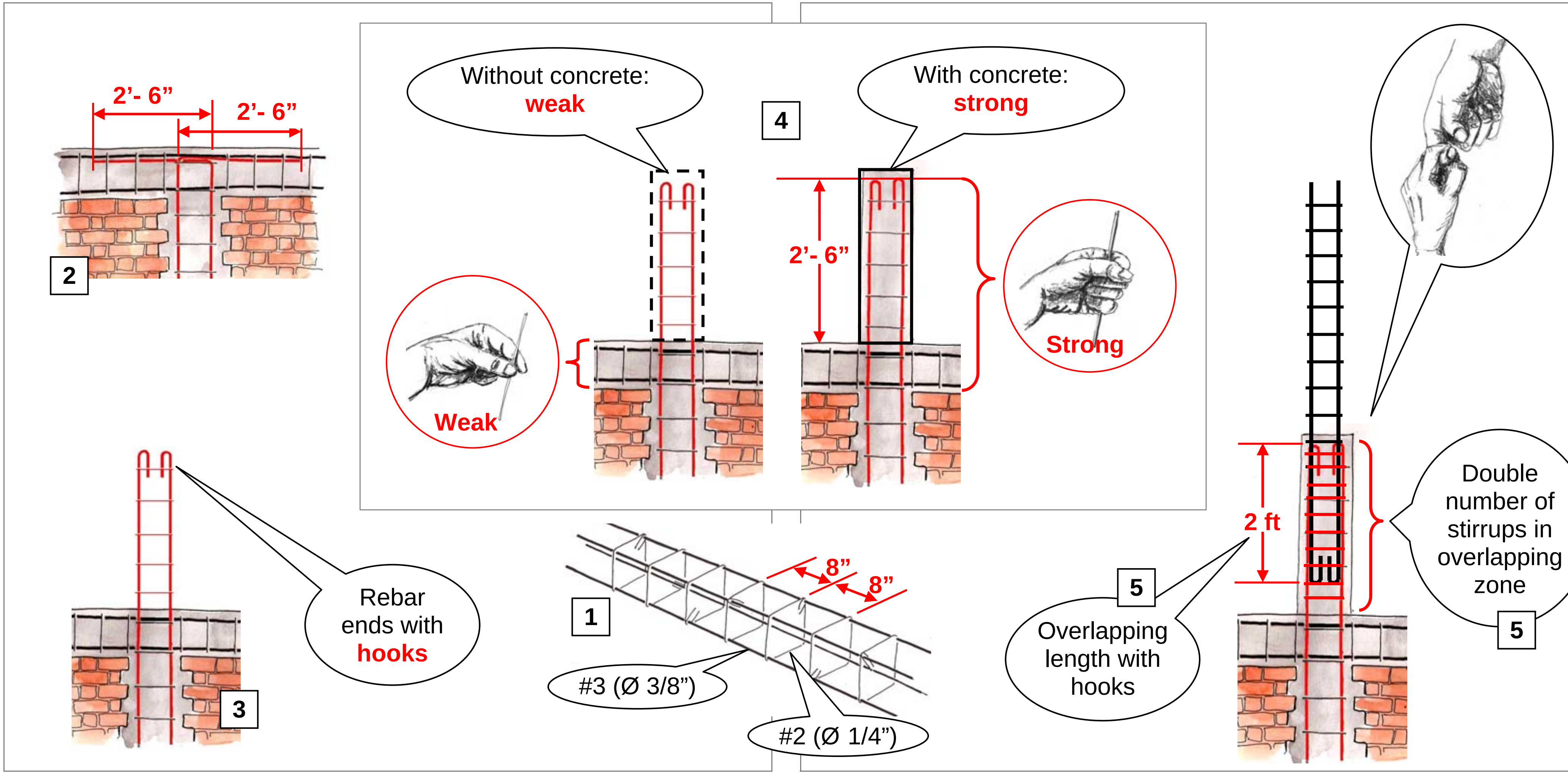


1. Place a seismic band at sill and lintel level, even if there is no window. Maximum distance between bands is 4 feet.
2. If a window is higher, let the lintel band go through.
3. Seismic bands are only 3" high
4. Bend the rebars into the columns (1 foot long).
5. Place the form work for the bands.
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 rebars 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

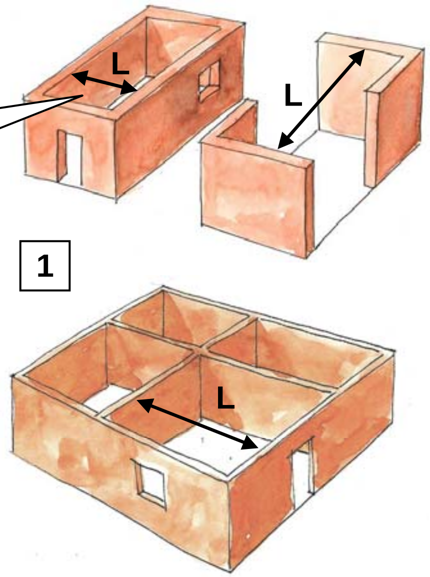


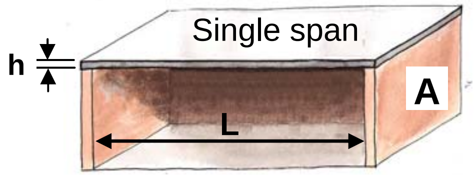
1. Prepare bond beams with stirrups at 8 inches.
2. If you don't plan to add another floor, bend the rebars into the bond beam to ensure a good connection.
3. If you leave vertical rebars for a future floor, end all rebars with hooks.
4. Tie-columns and bond-beams must be well embedded in concrete to 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.

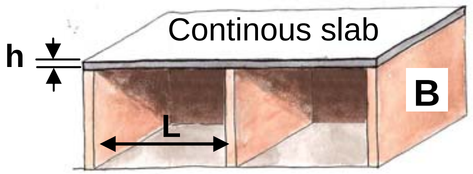
11. Bond beam – tie-column connection

Span L:

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







1. 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.

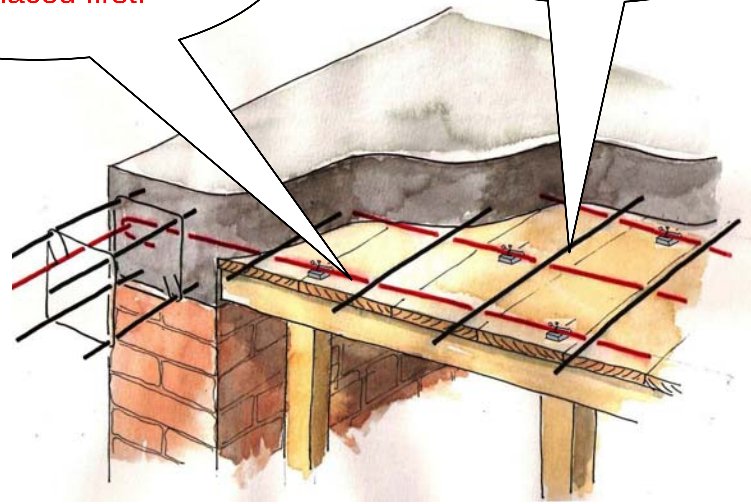


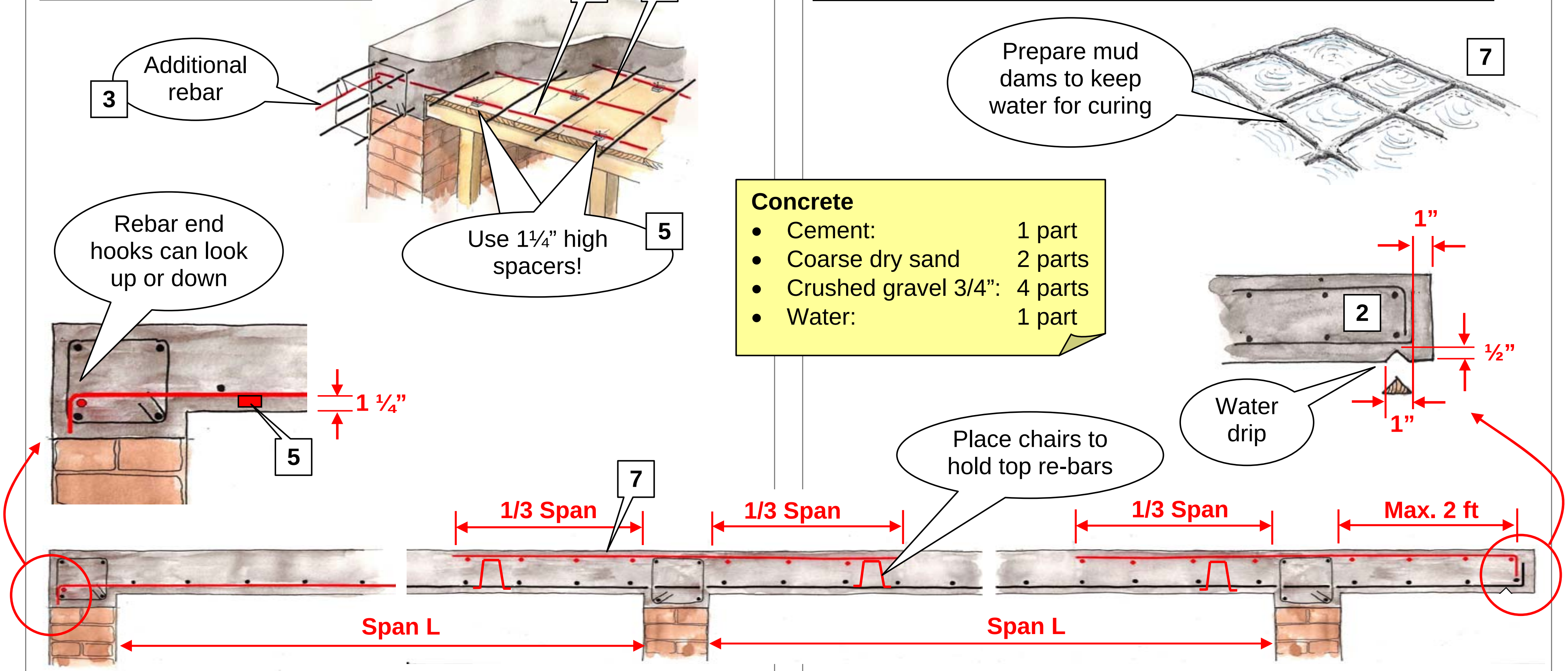
Table 1: Reinforcement bars

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”

12. Concrete slab: dimensioning

Placing the rebars:

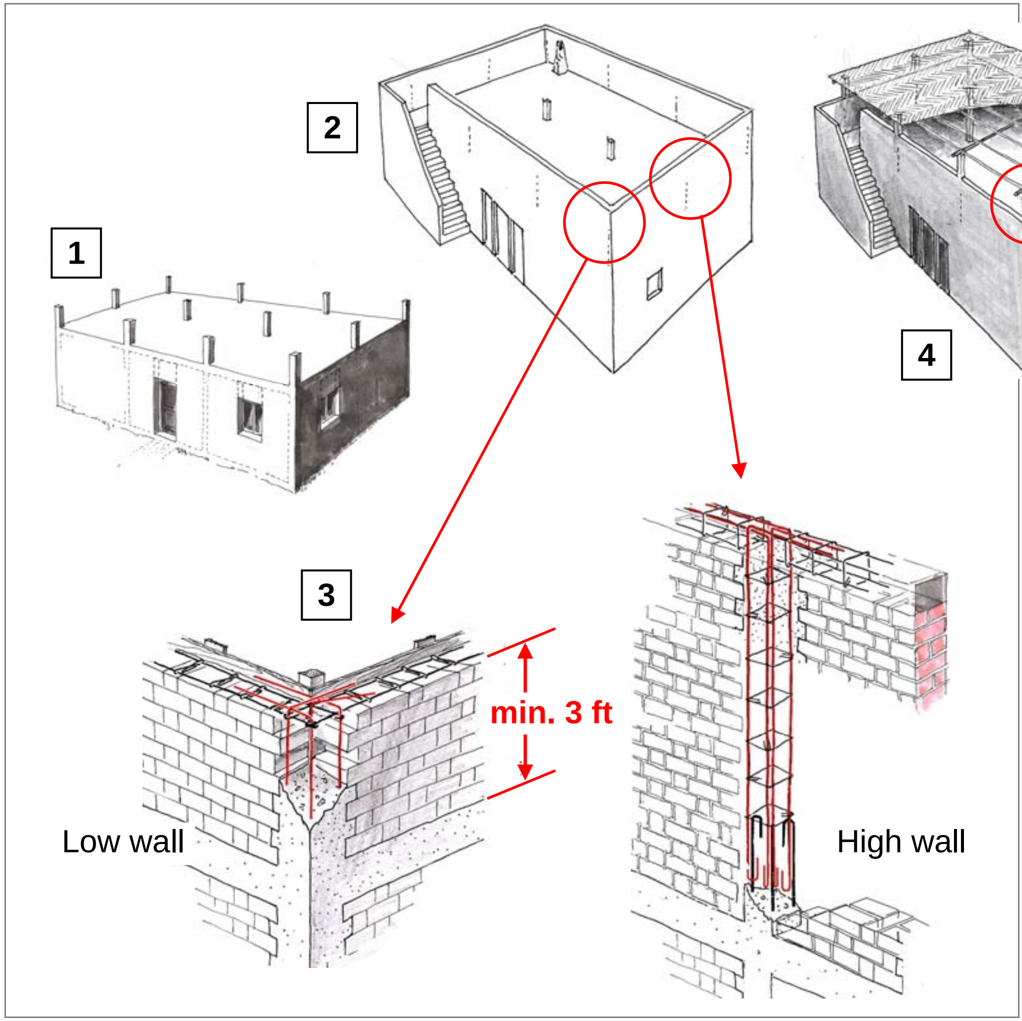
Upper rebars for continuous slabs:

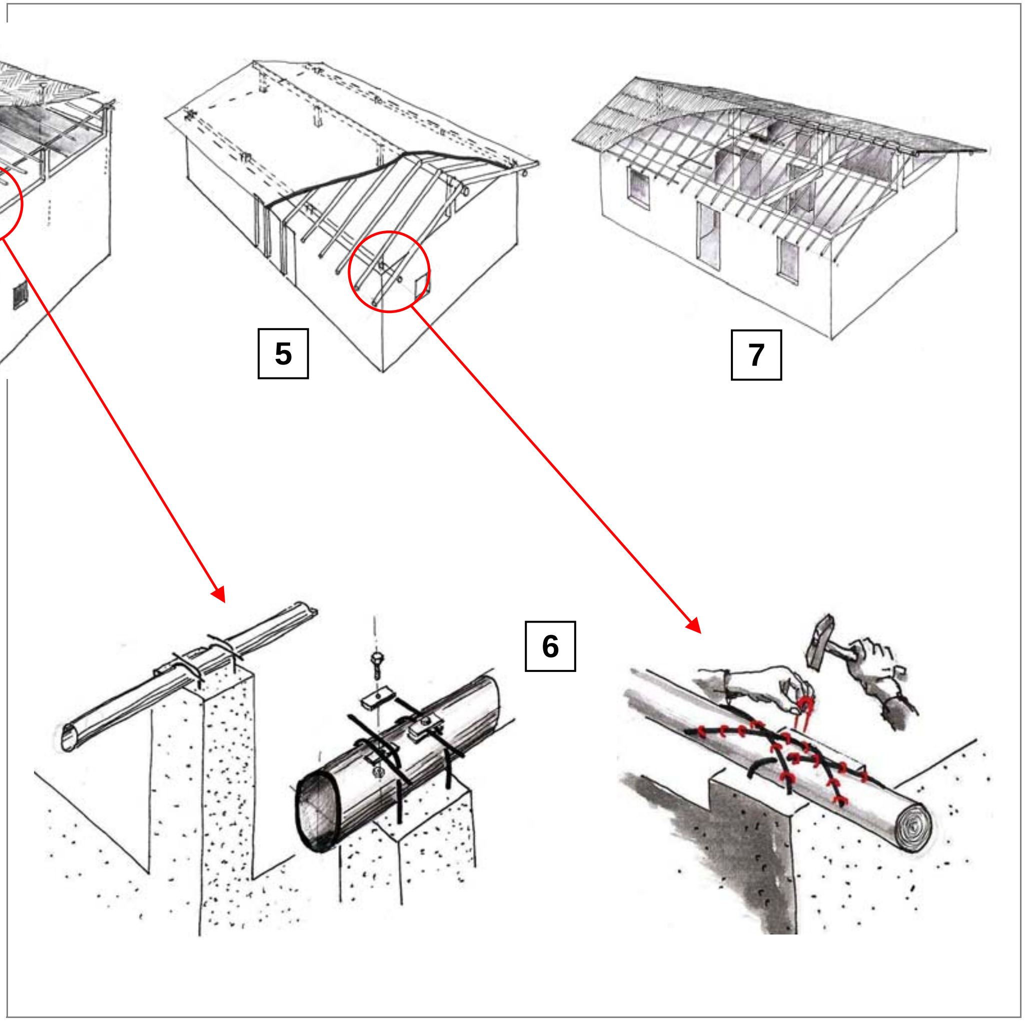


Concrete

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

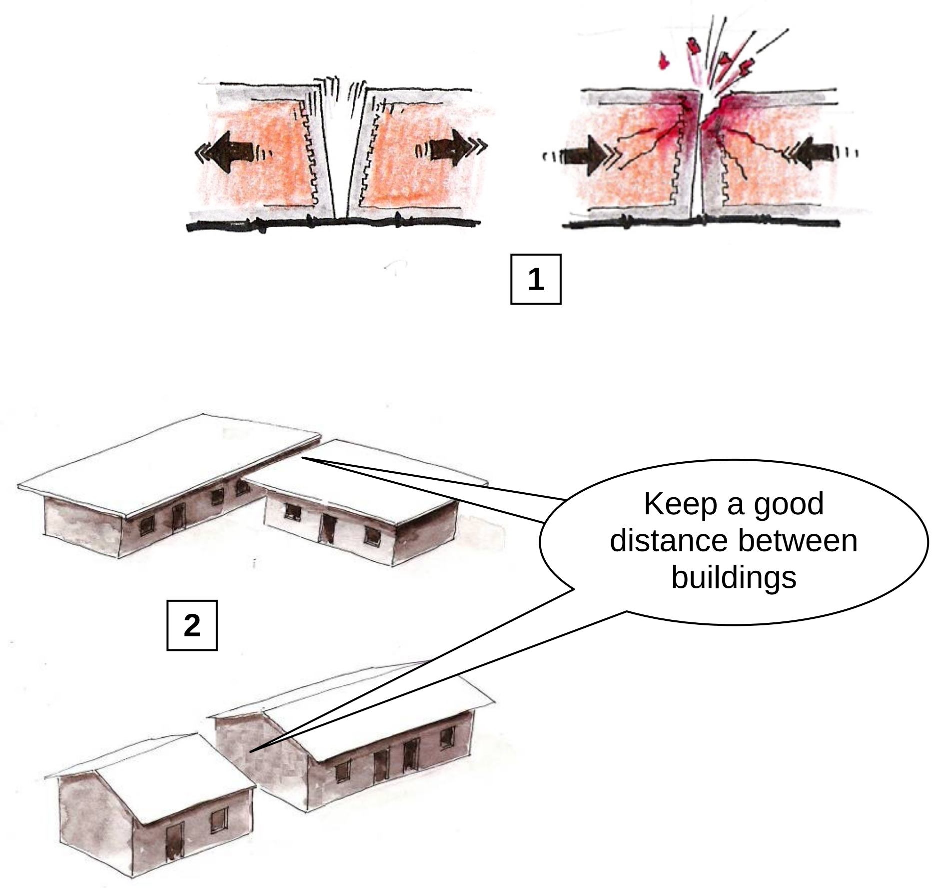
1. Make sure your form work for the slab is watertight. If necessary fill the cracks with mud.
2. Create a water drip by nailing triangular lists along the edge of overhanging slabs.
3. Place additional rebars into the bond beams to receive the hooks of the primary bars.
4. Place primary rebars in the direction of the shorter span.
5. Place 1 ¼" spacers under the primary rebars every 2-3 ft.
6. Add secondary rebars.
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.



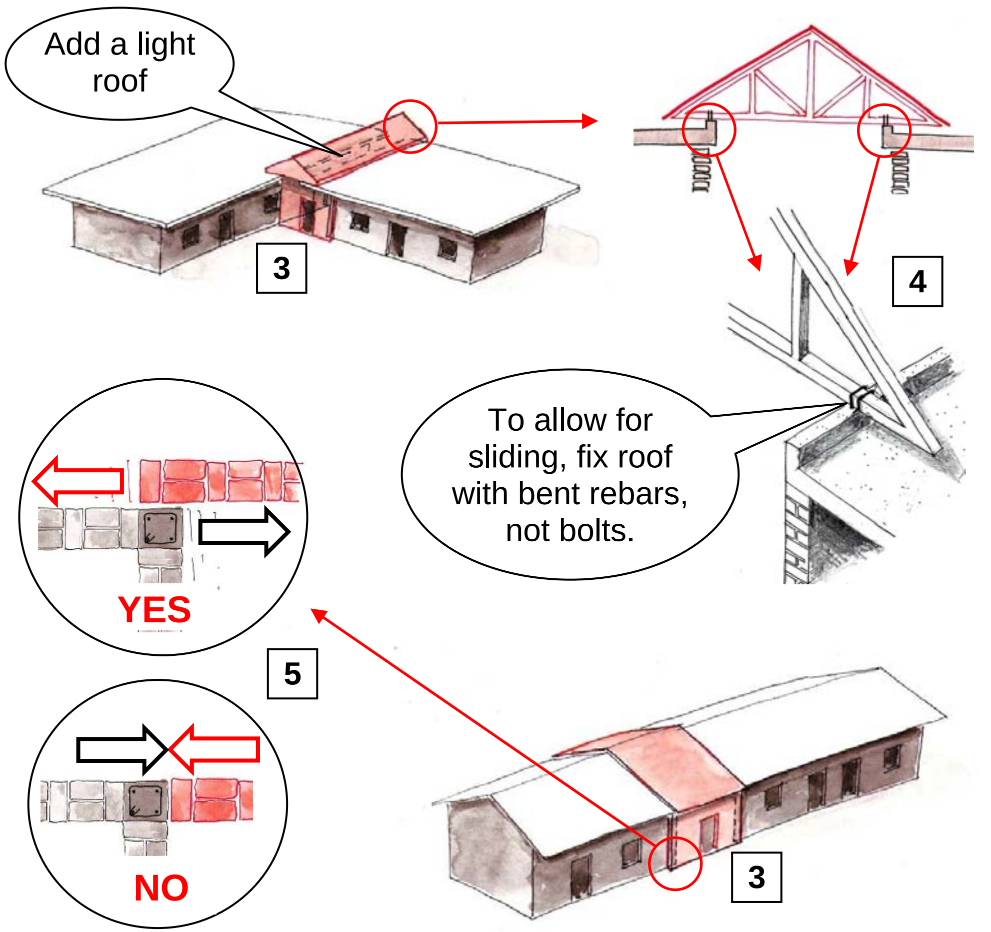


1. Rebars coming out of the slab must be cast in lean concrete to protect them against rust. Otherwise they cannot be used later in columns.
2. Terrace walls must be confined like any other wall, or they will fall on people during an earthquake.
3. For security reasons low walls must be lower than 3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

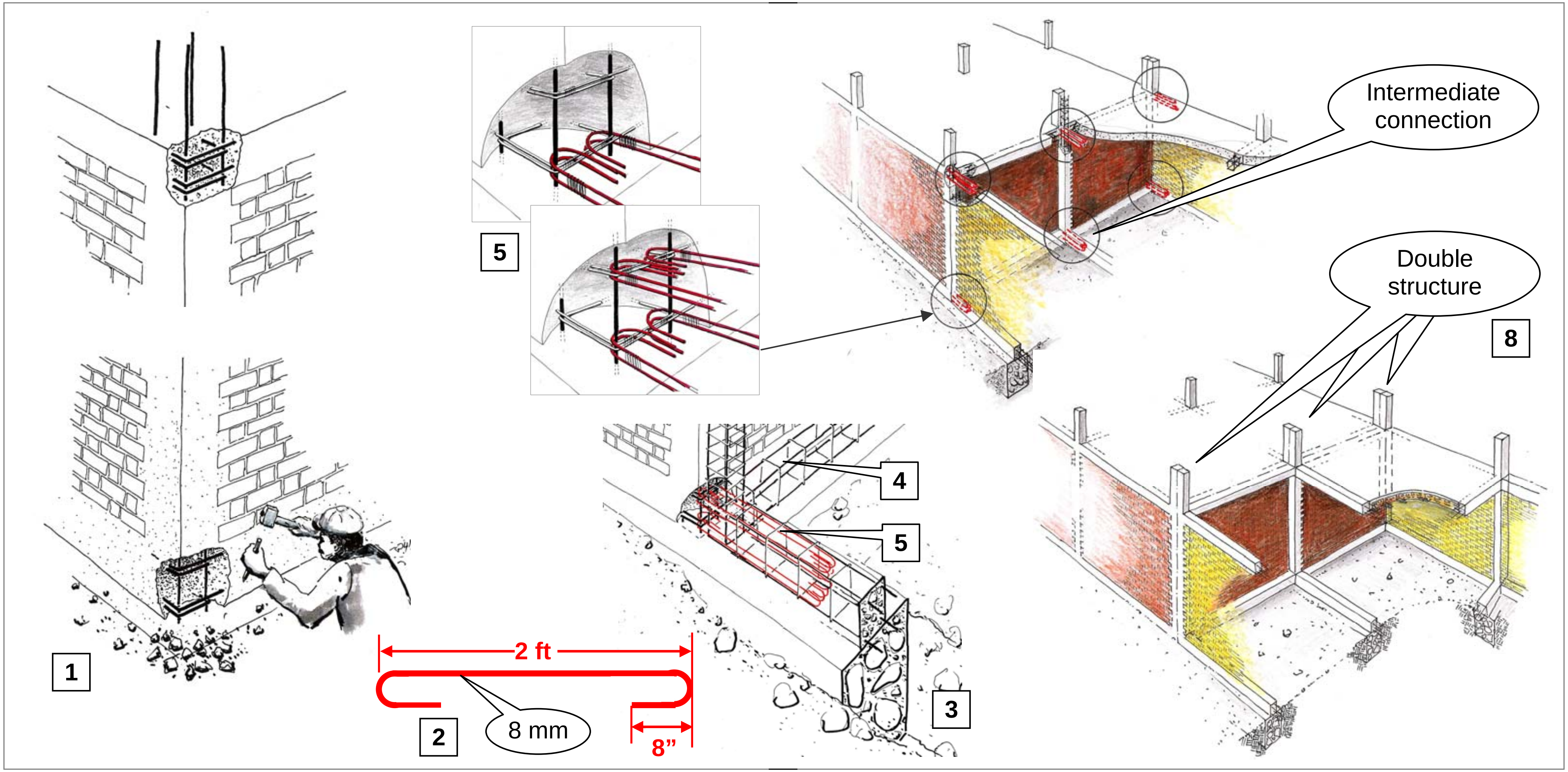
Solution 1: Seismic gaps between buildings



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

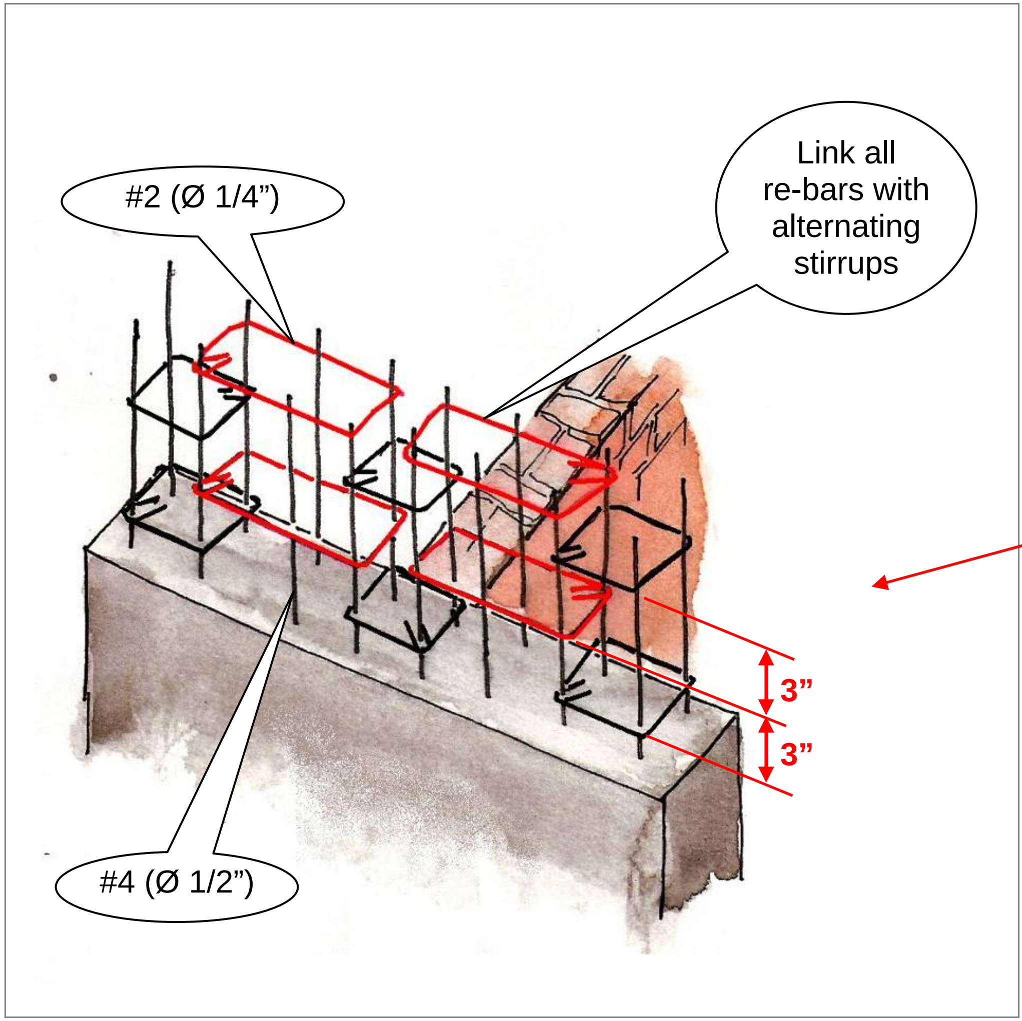


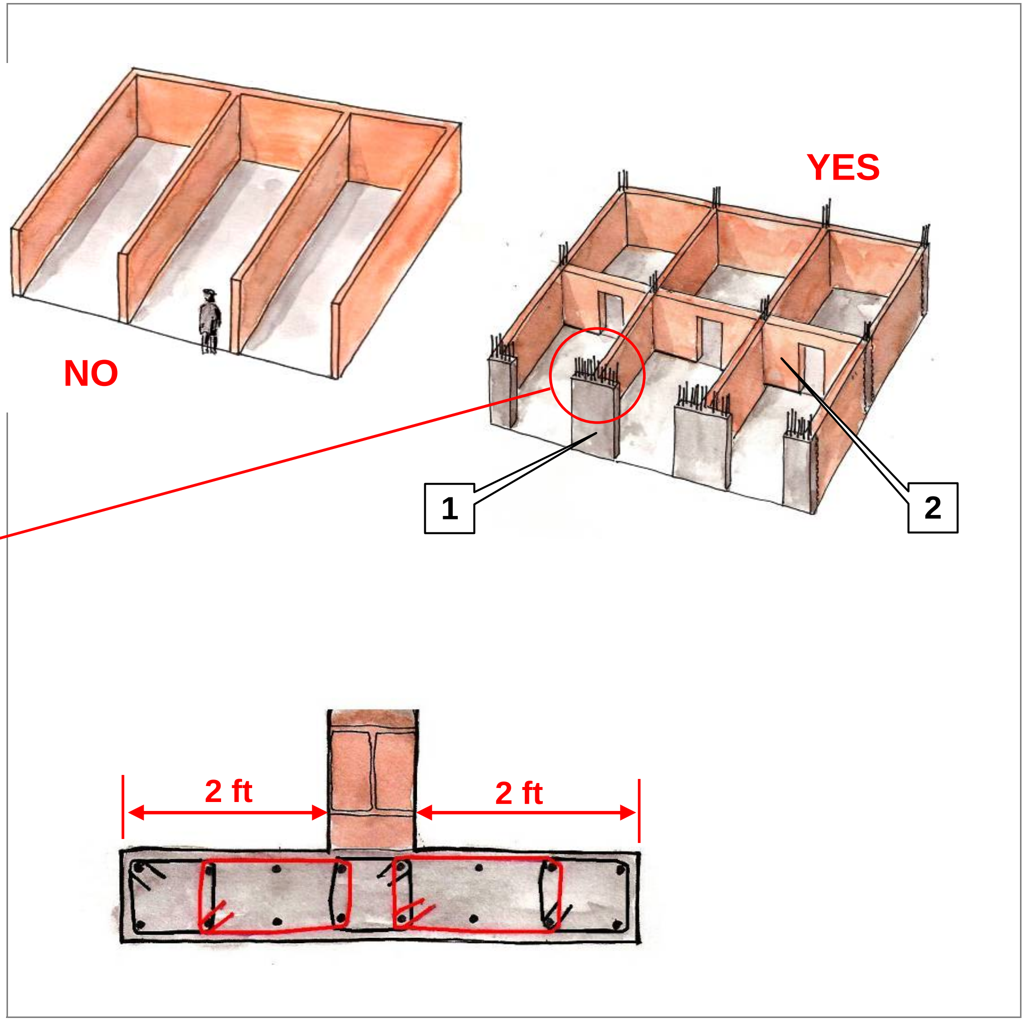
1. If buildings are too near, they will hammer against each other during an earthquake.
2. Therefore keep a good distance between buildings to avoid damage.
3. If you want to connect buildings, put a room in between where people stay only for a short time, like a deposit or a toilet.
4. Fix the roof with bent rebars 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).

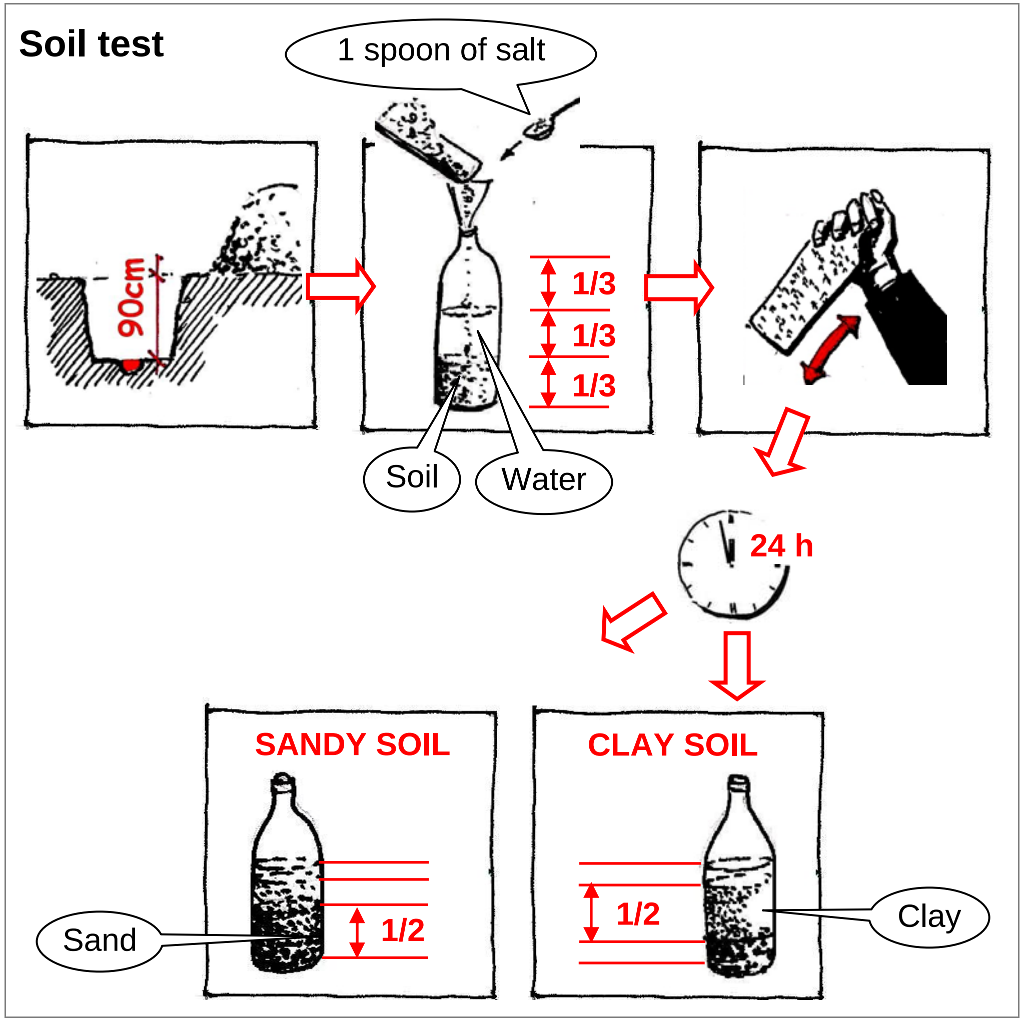
16. Adding more rooms (attached)

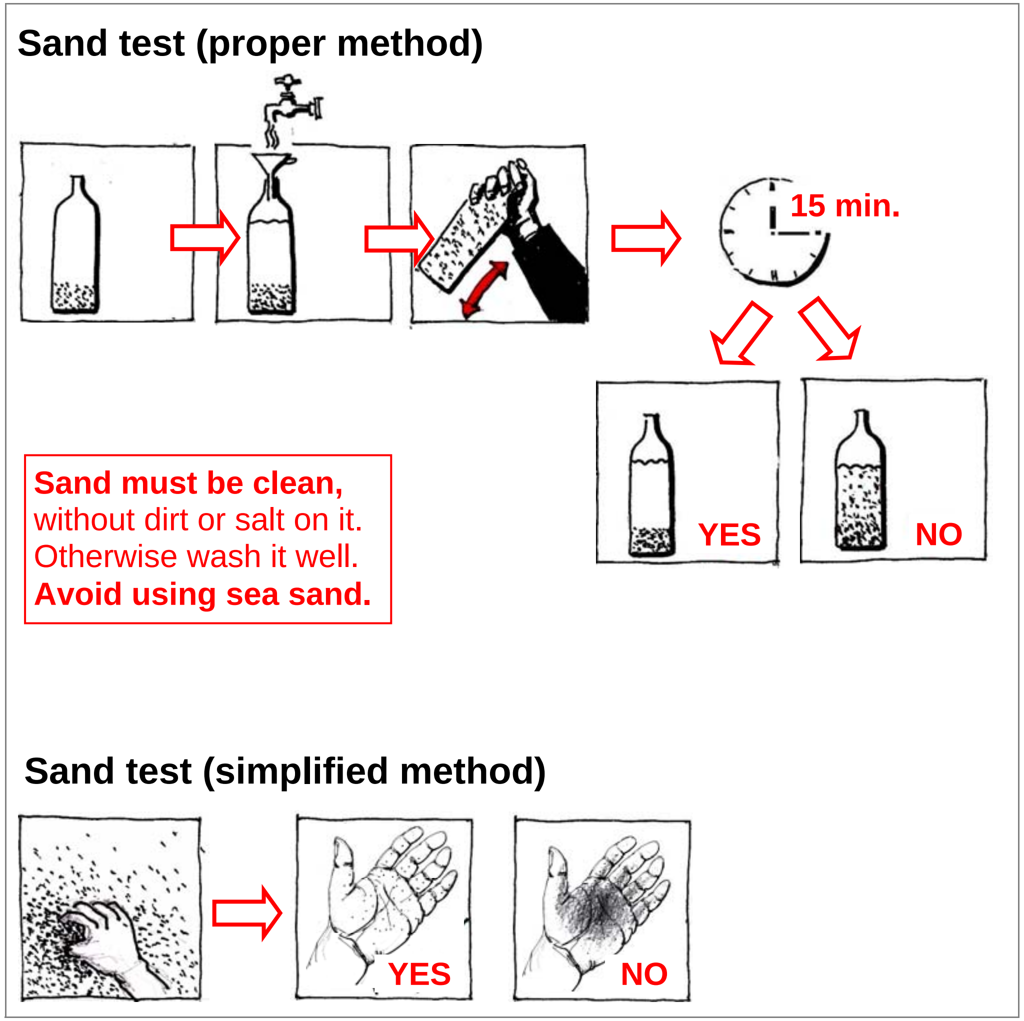




Shops are dangerous structures when it comes to earthquakes. Their big windows weaken the building and internal walls are often too long.

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:

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):

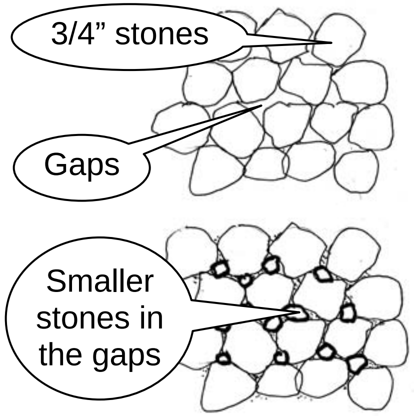
Put some sand in a bottle, fill up with water and shake thoroughly. Leave 15 minutes to settle. If the water remains rather clear, sand is okay. If the water remains dirty, the sand is not useable.

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.

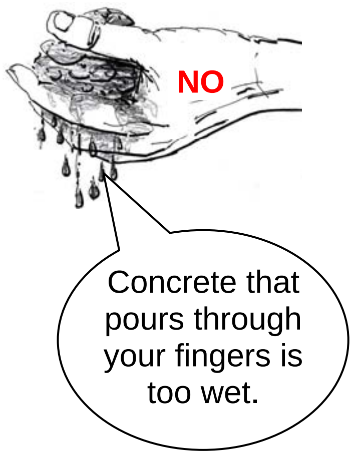
Aggregates (gravel):

- Gravel should be “crushed”. Round gravel from rivers makes a weaker concrete.
- Gravel should be “graded”. Don’t use only 3/4” 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.

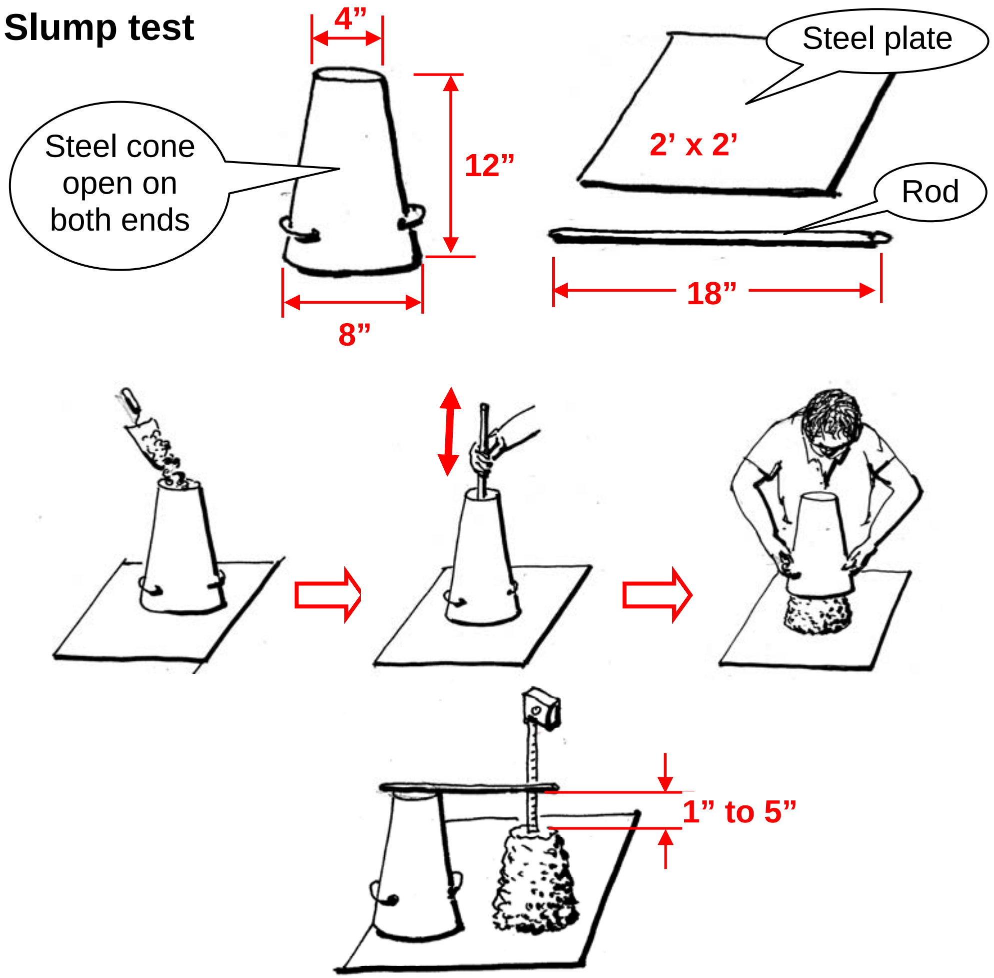


Water:

- 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.



Slump test



Concrete curing times:

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

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, fy 420 N/mm2
   - Concrete quality: f'c 30 N/mm2
   - Admissible live load: (200 kg/m2 or 40 psf) 2 kN/m2
   - Concrete cover (unified for all situations): 1 ¼" (30mm)

Rebar conversion table

Nr.	*Inch*	*Metric in mm*	*replace with*
#2	1/4"	(6.35)	6 mm
(no imperial equivalent)			8 mm
#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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The National Information Center of Earthquake Engineering (NICEE) at Indian Institute of Technology Kanpur maintains and disseminates information resources on Earthquake Engineering. It undertakes community outreach activities aimed at mitigation of earthquake disasters. NICEE's target audience includes professionals, academics and all others with an interest in and concern for seismic safety.

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About the Manual

This manual is intended for technicians, contractors and workers who are physically involved in the construction of earthquake resistant one and two storey buildings. It is a step-by-step guide to Confined Masonry, a technique which has evolved over the last hundred years through an informal process and has given excellent results with regard to its earthquake resistance, both in engineered and in non-engineered buildings.

In order to improve communication and thus ensure accurate execution, much care has been taken to develop simple technical solutions and details, and present them in easily understandable drawings.

About the Author

Over the last twelve years, architect Tom Schacher has been actively involved in post-disaster rehabilitation and reconstruction projects in various countries (Kenya/Sudan, Rwanda, Turkey, Ethiopia, Iran, Pakistan). From 1982 to 1994 he ran his own architectural practice in Switzerland, specialising in modern housing and renovation of traditional stone masonry and timber buildings. He received his MSc in Architecture at the Federal Institute of Technology of Lausanne, Switzerland, and an MSc in Project Planning and Management at the University of Bradford, UK.

As a ‘technical advisor on site’ for the Swiss Agency for Development and Cooperation, Tom Schacher was heavily involved in the promotion of appropriate earthquake resistant reconstruction techniques both in Iran, after the Bam earthquake of 2003, and in Pakistan, after the Kashmir earthquake of 2005.

His current work focuses on the development and rediscovery of earthquake resistant construction techniques in tune with the material, economic and technical resources of local societies, as well as on appropriate means of communication of these techniques through the development of training material for workers and technicians.

Tom Schacher is also a technical expert for the Swiss Solidarity fundraising organisation and a senior researcher at the University of Applied Sciences of Southern Switzerland.

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