



Tom Schacher

CONFINED MASONRY

For one and two storey buildings in low-tech environments

A guidebook for technicians and artisans



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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Copies of this monograph may be requested from:

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Version 3.1: In imperial units (feet and inches) - November, 2011

Foreword from NICEE

This is the revised and updated version of the confined masonry manual published by National Information Centre of Earthquake Engineering (NICEE) in February 2009. The 1000 copies printed earlier were received very well by all – professionals, technicians and the general public. This prompted us to print more copies and also presented us with an opportunity to update the manual incorporating further experience gained by the author while addressing real-life problems encountered in the practice.

It needs to be emphasized that the confined masonry as a building typology has a history of proven seismic performance in many seismic regions of the world. Unexpected level of damage to popular RC frame and infill masonry constructions observed in the recent Sikkim earthquake of September 18, 2011 has again highlighted their seismic vulnerability when the strict adherence of various technically sophisticated requirements could not be ensured. In such situations, confined masonry offers a suitable alternative for building construction in low-tech environments of many high seismic regions.

This manual is specifically written for the confined masonry construction of one- and two-storey dwelling units and can be easily followed by the masons and the owners alike. As a part of the general seismic risk reduction strategy, NICEE would like to propagate its usage by making this manual available in local Indian languages. Members of NICEE family are welcome to help us translate this manual.

It is hoped that the contents of this manual will enthuse a better construction technology in the Indian subcontinent and other parts of the world. The printing of this monograph has been possible due to the financial support from Poonam and Prabhu Goel Foundation at IIT Kanpur and the assistance is gratefully acknowledged.

Durgesh C. Rai
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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 craftsmanship 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. It 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

Acknowledgements

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 Pontifica 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 *SwissRe* reinsurance company in Zurich,

the *International Committee of the Red Cross ICRC* in Geneva, *UNESCO* in Paris,

the *Swiss Solidarity* fund raising organisation in Geneva

the *Holcim Foundation* in Zurich, for the *Holcim Award 2008* prize money which has been invested in this project,

the *Swiss Agency for Development and Cooperation SDC* for both its financial support to this project and for contracting me as a technical advisor in Pakistan in 2006-7.

For their encouragements and assistance in publishing 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).

Foreword from NICEE - Version 3.0

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.

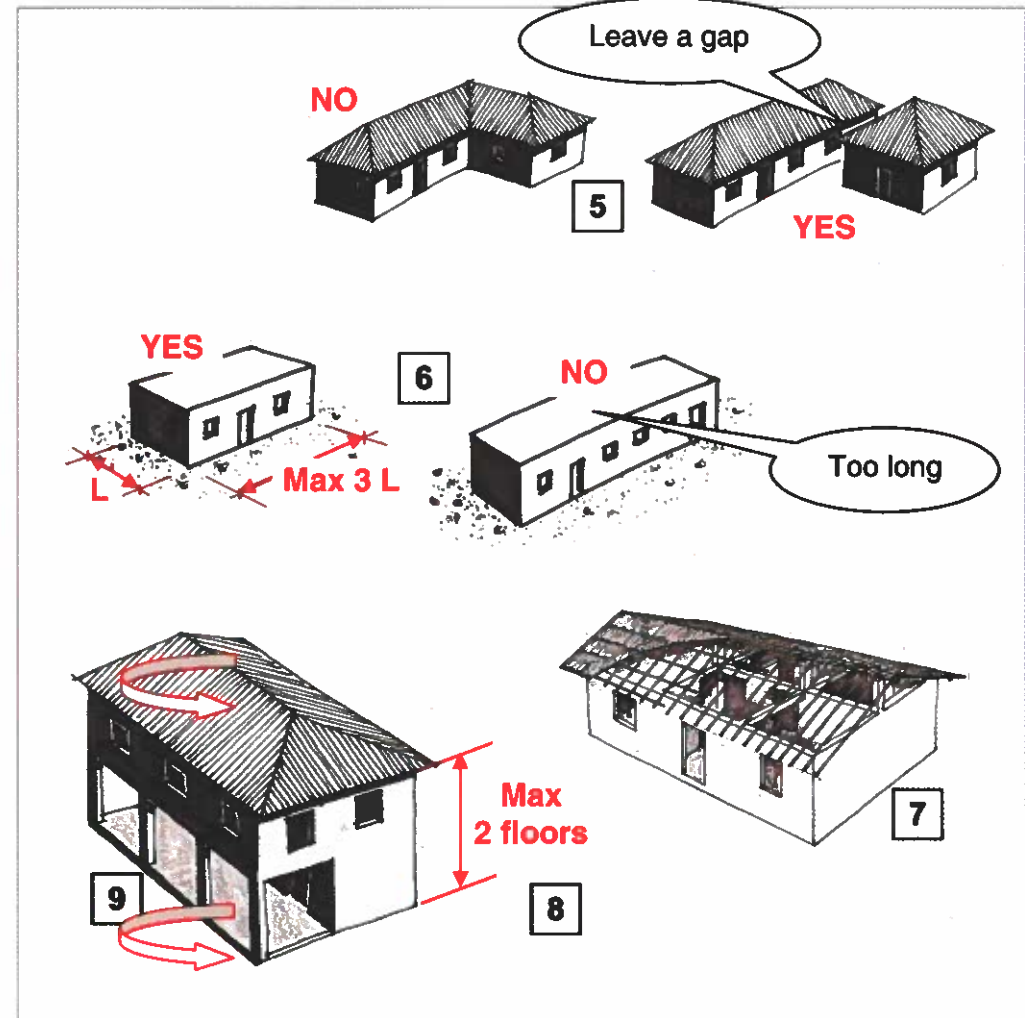
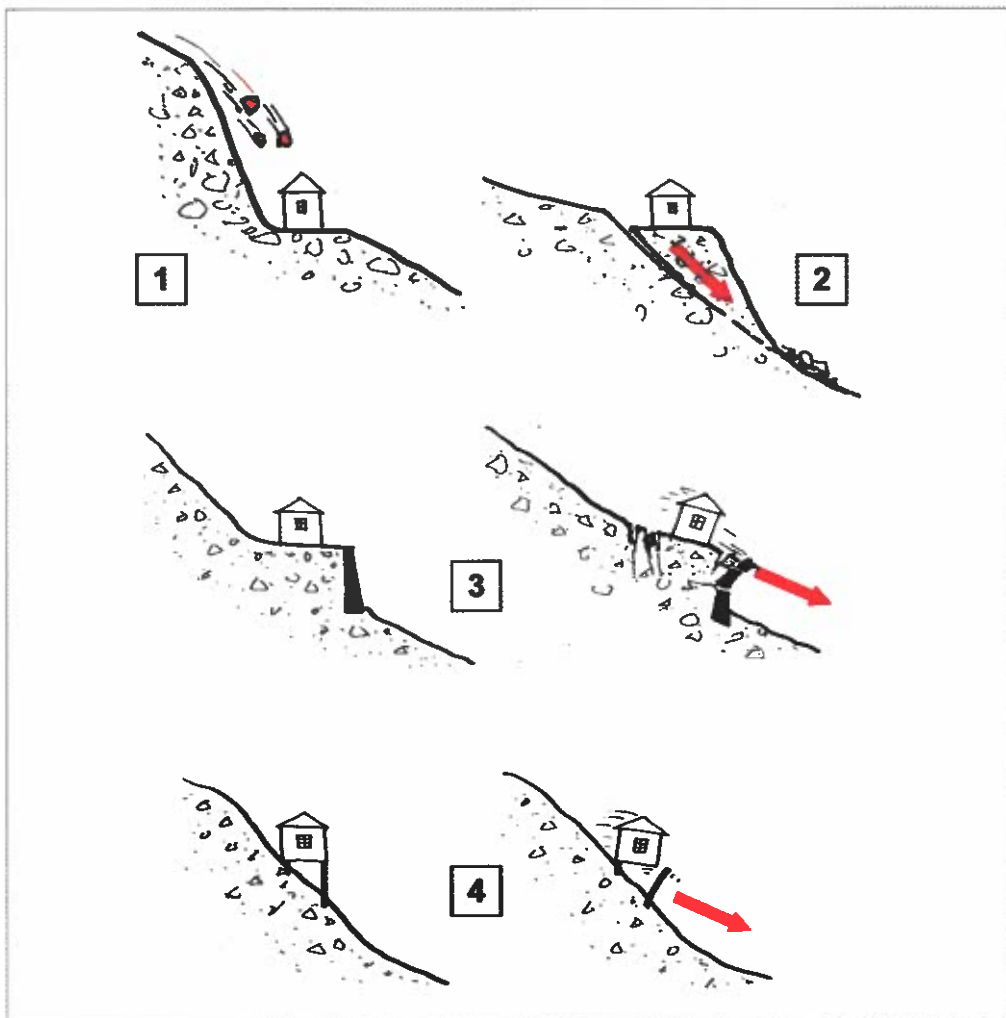
This manual is meant for artisans, masons, and homeowners engaged in construction of one- and two-storey dwellings in a low-tech environment. It provides clear guidance on the construction aspects as well as the do's and don'ts. While developing this manual, Mr Schacher brings with him a rich hands-on 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.

Sudhir K. Jain

Coordinator, NICEE

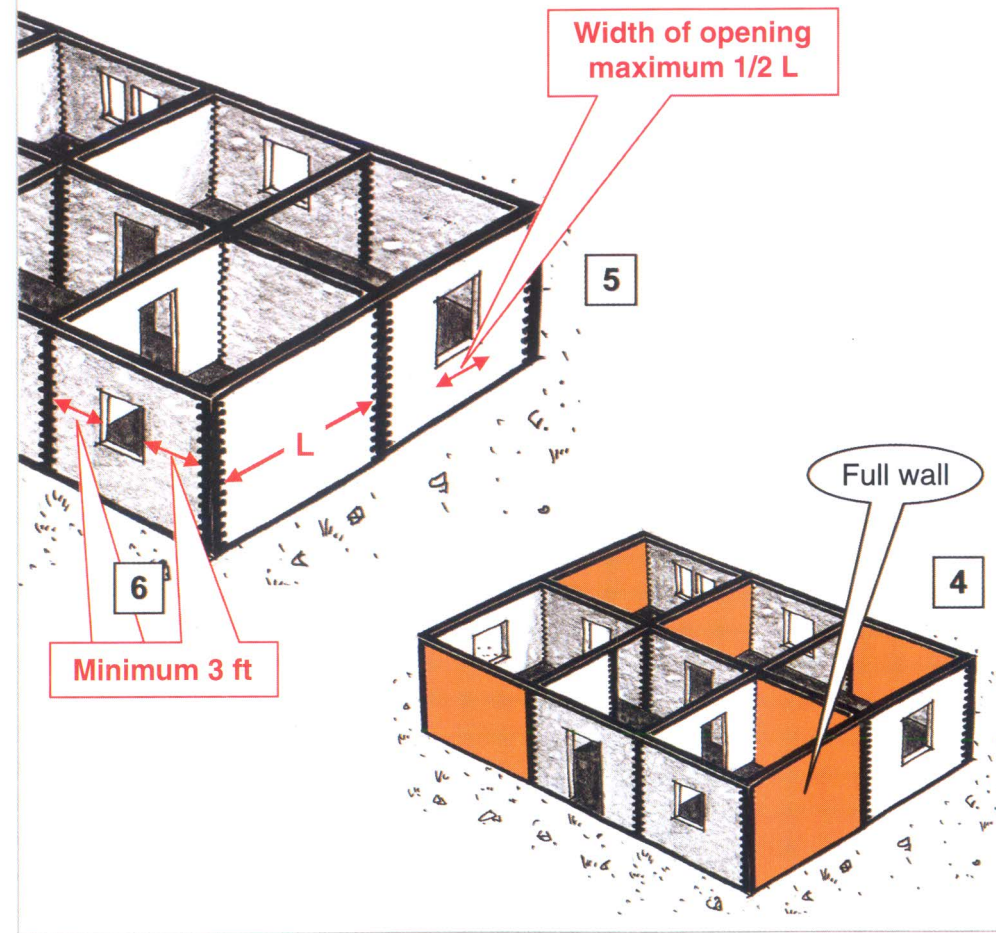
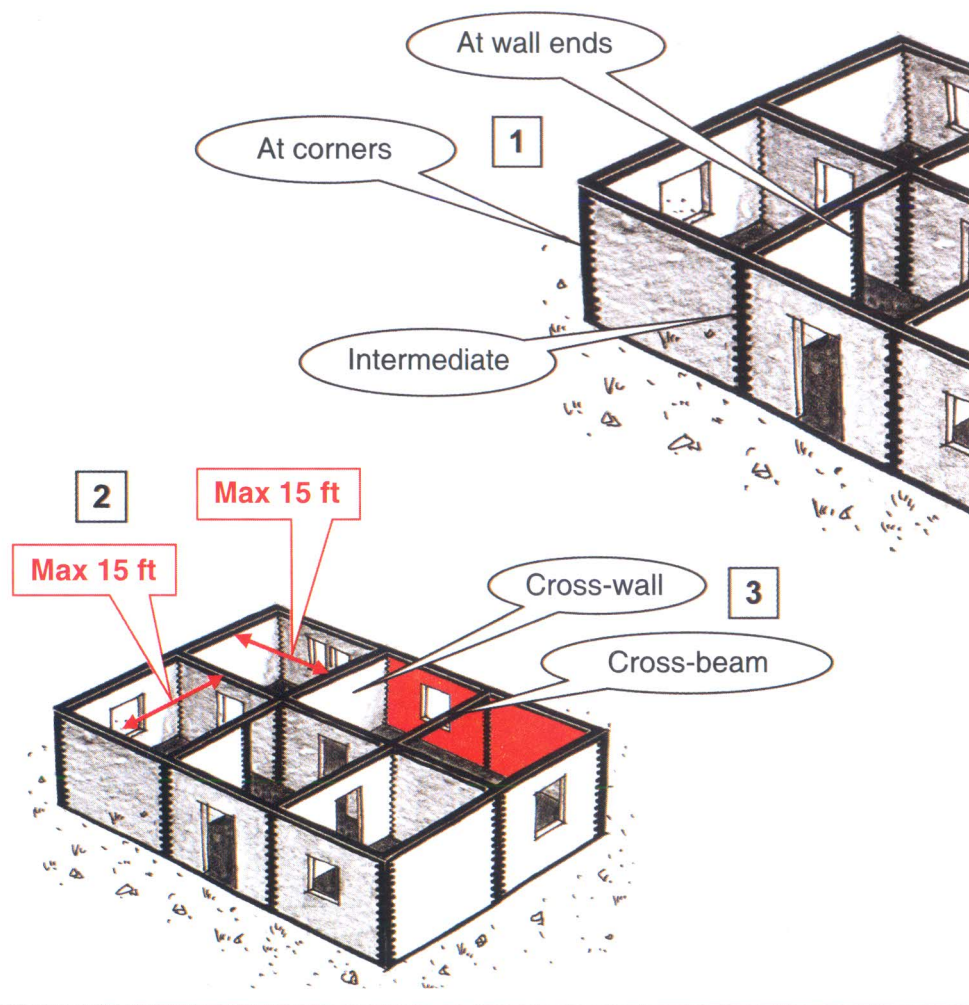
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1. Don't build next to a steep slope: stones might fall on your house.
2. Don't build next to a precipice: it might break off.
3. Don't build next to a retaining wall: it might break away.
4. Don't build on stilts: they will fall over during an earthquake.

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.

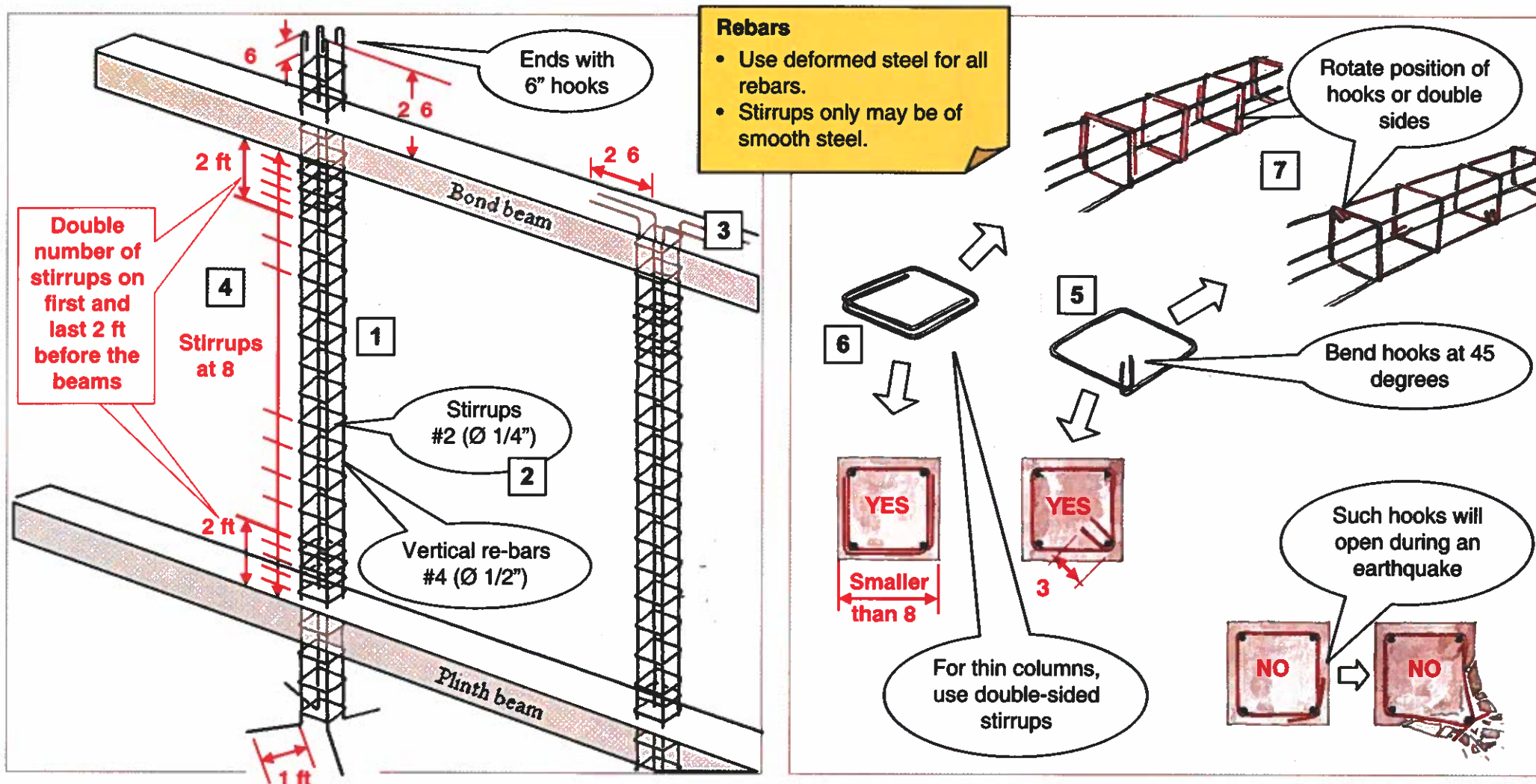
1. Site selection and form of house



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 (shown in red). 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.

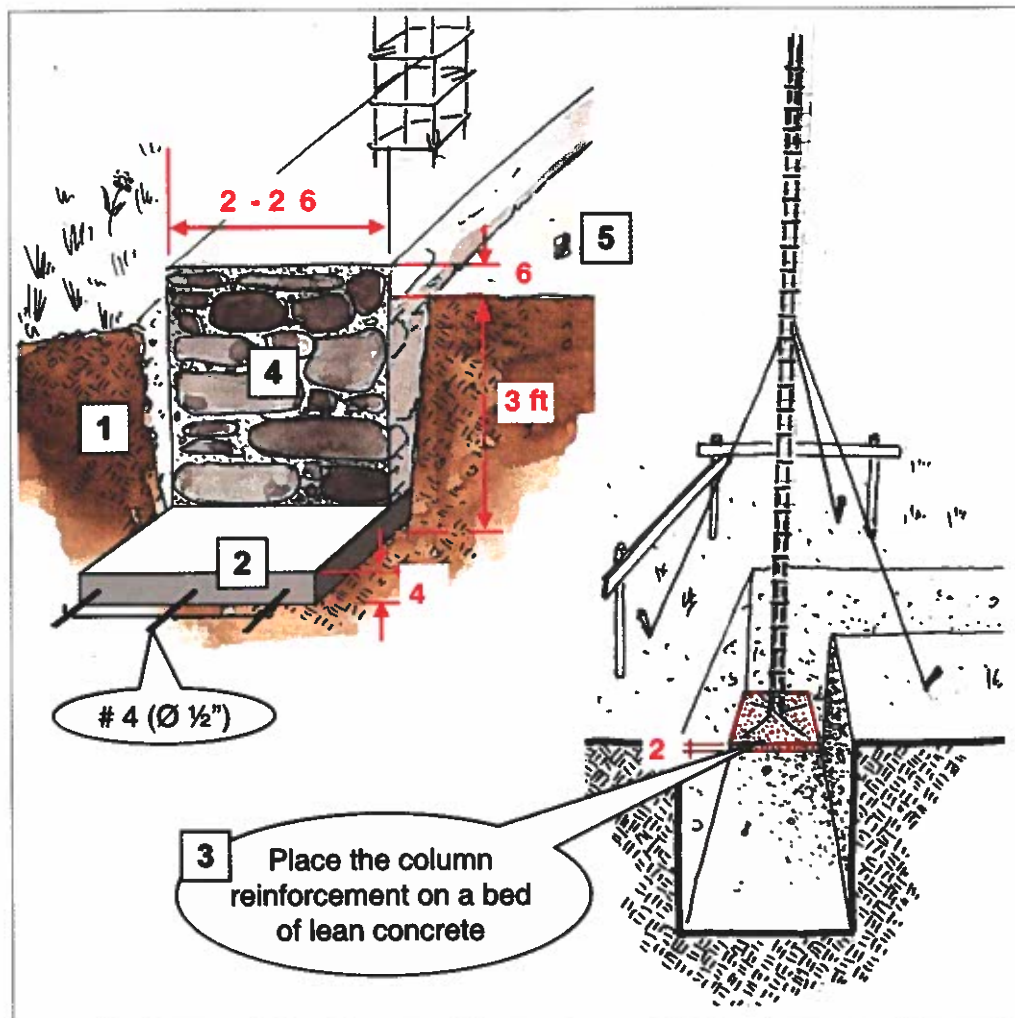
4. Solid full walls without windows or doors are stronger. Build as many full walls as you can and distribute them evenly across the house.
5. Maximum width of openings is half the distance between columns.
6. Leave at least 3 feet between opening and tie-column.

2. Basic rules

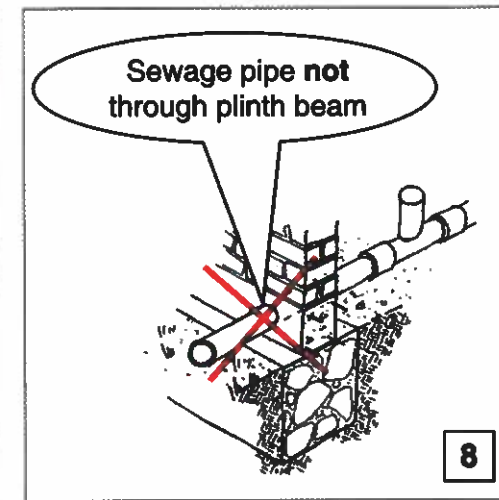
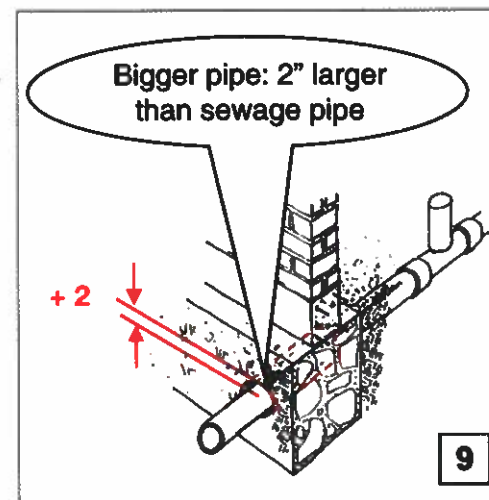
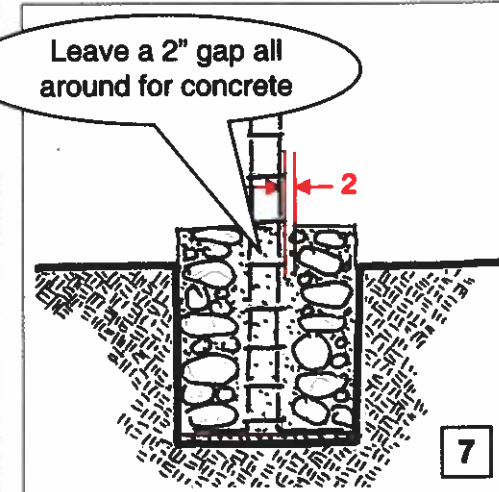
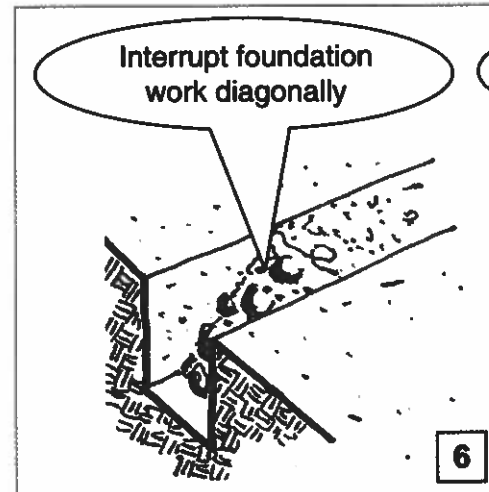


1. Calculate length of the vertical rebars from the bottom of the foundation up to the top of the bond beam. Add 2' 6" for connection above the slab and 1 ft for the footing.
2. Verify that #2 rebars for stirrups really do have ... diameter, otherwise use 8mm bars.
3. If you don't plan to leave the rebars 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 2 ft 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.

3. Column reinforcement

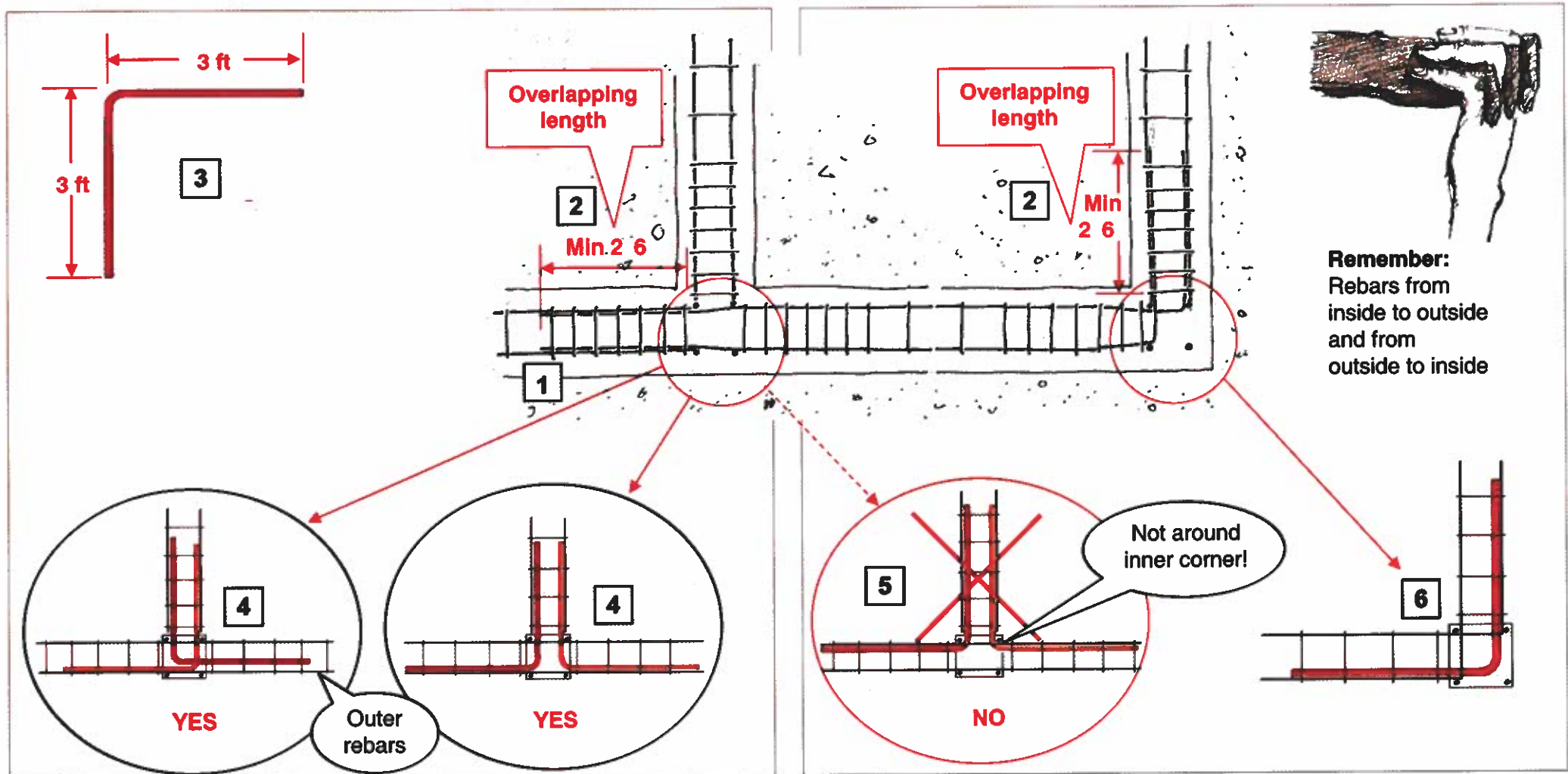


1. Dig the trenches 3 ft deep and 2 ft wide on hard soil (2'-6" on soft soil).
2. On soft soil make a 4" bed of concrete with three #4 rebars in it.
3. Place the column reinforcement on this bed of concrete (on hard soil make independent 2" beds of lean concrete just under the columns).
4. Build the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



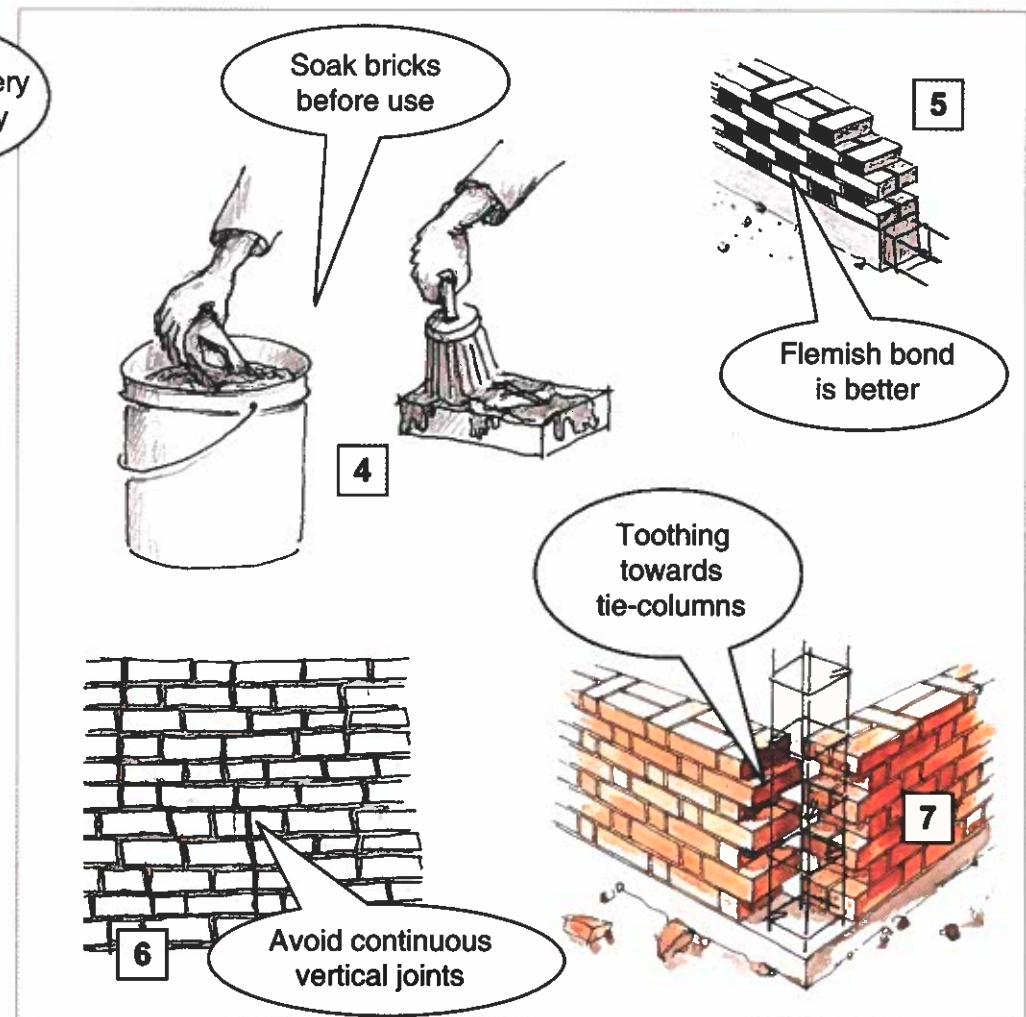
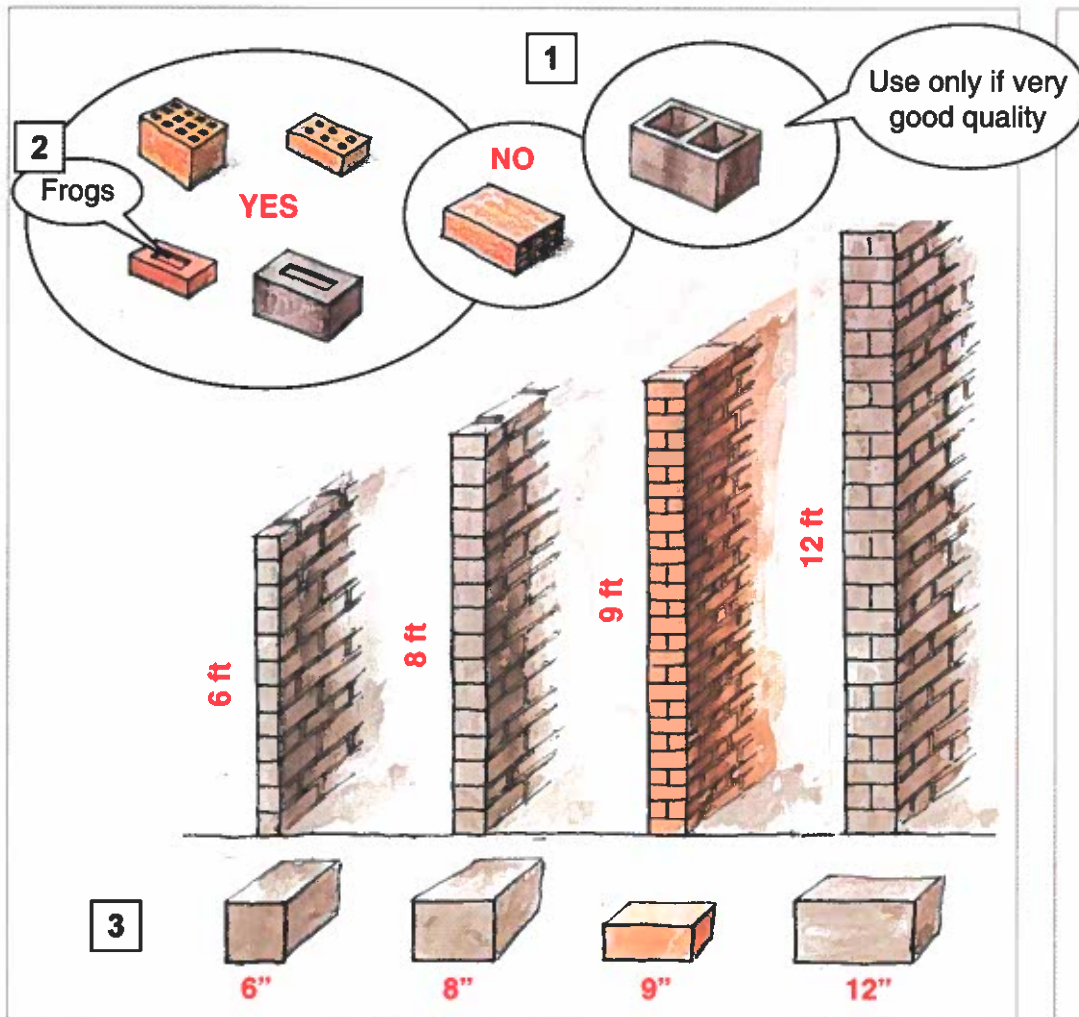
6. If you have to interrupt foundation work, leave a slope with stones sticking out.
7. Leave a gap of 2" around the reinforcement to ensure the passage of concrete and that stones are not touching the rebars.
8. Sewage pipes must not go through the plinth beam.
9. Place a bigger pipe into the foundation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

4. Foundations



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", for #3 rebars it is 2ft.
3. Prepare L-shaped connection bars with side lengths of 3 ft for #4 rebars (2' 6" for #3 rebars).
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 light bricks with horizontal holes. Use concrete blocks only if of very good quality.
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 should not be higher than 12 times their thickness: that is, for every inch of thickness one foot of height. Maximum height is 15 times the wall thickness.

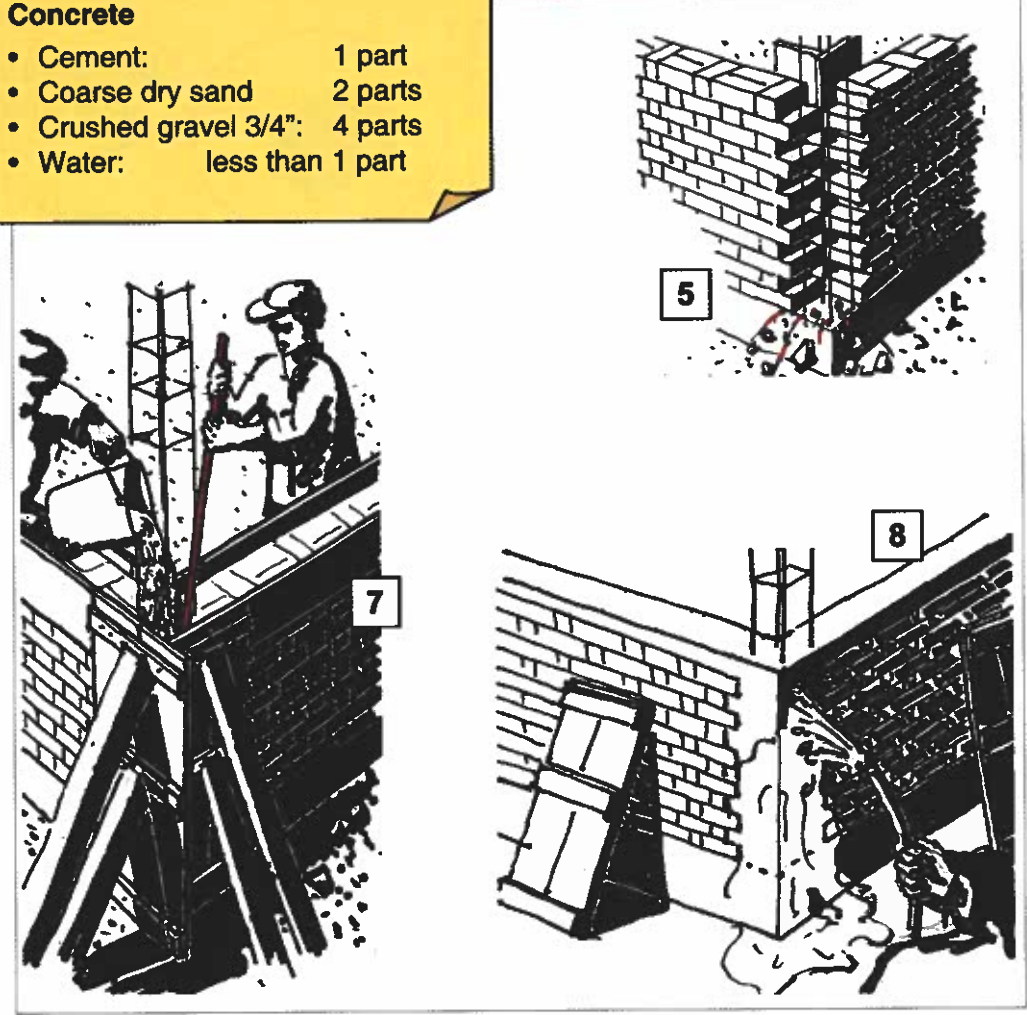
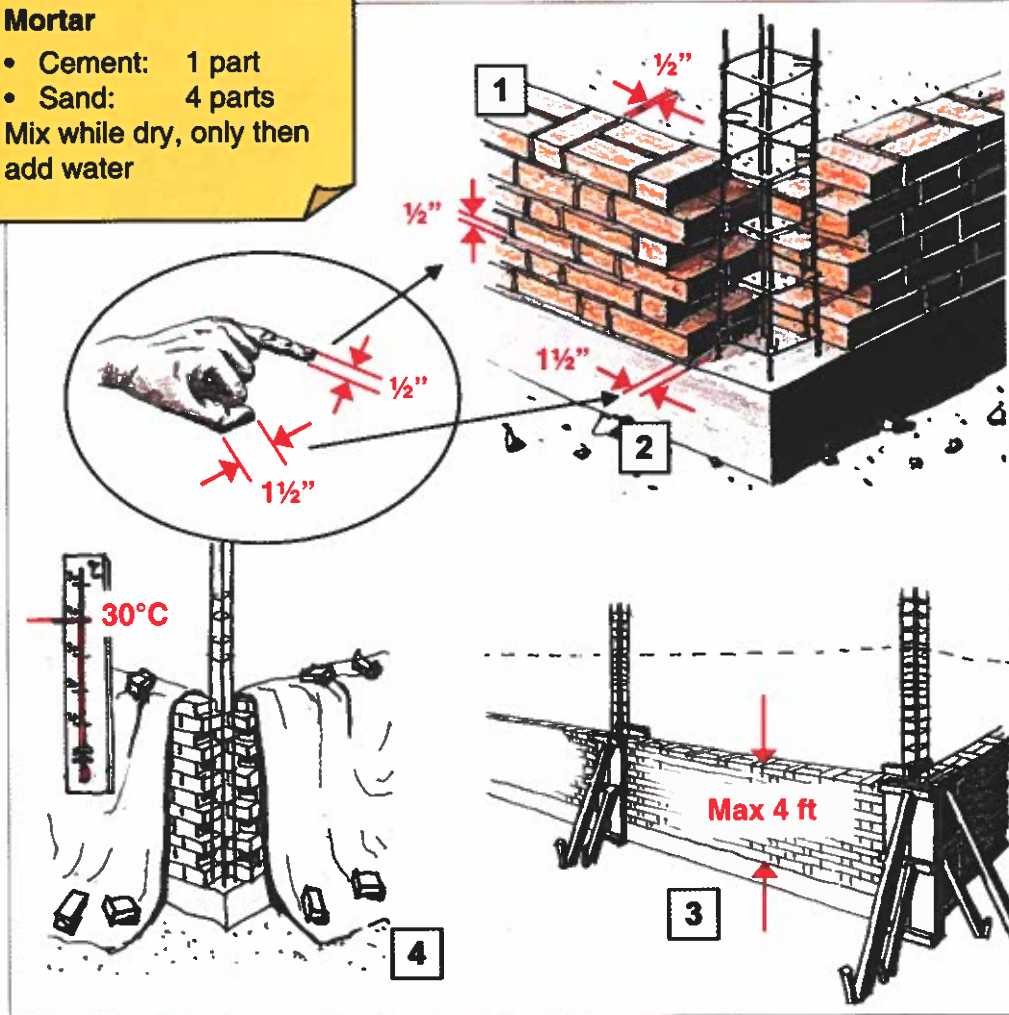
4. Bricks must be made wet before using them.
5. With bricks, use a Flemish rather than an English bond. The number and the thickness of joints are more regular.
6. Avoid continuous vertical joints.
7. Wall ends towards tie-columns must be toothed.

Mortar

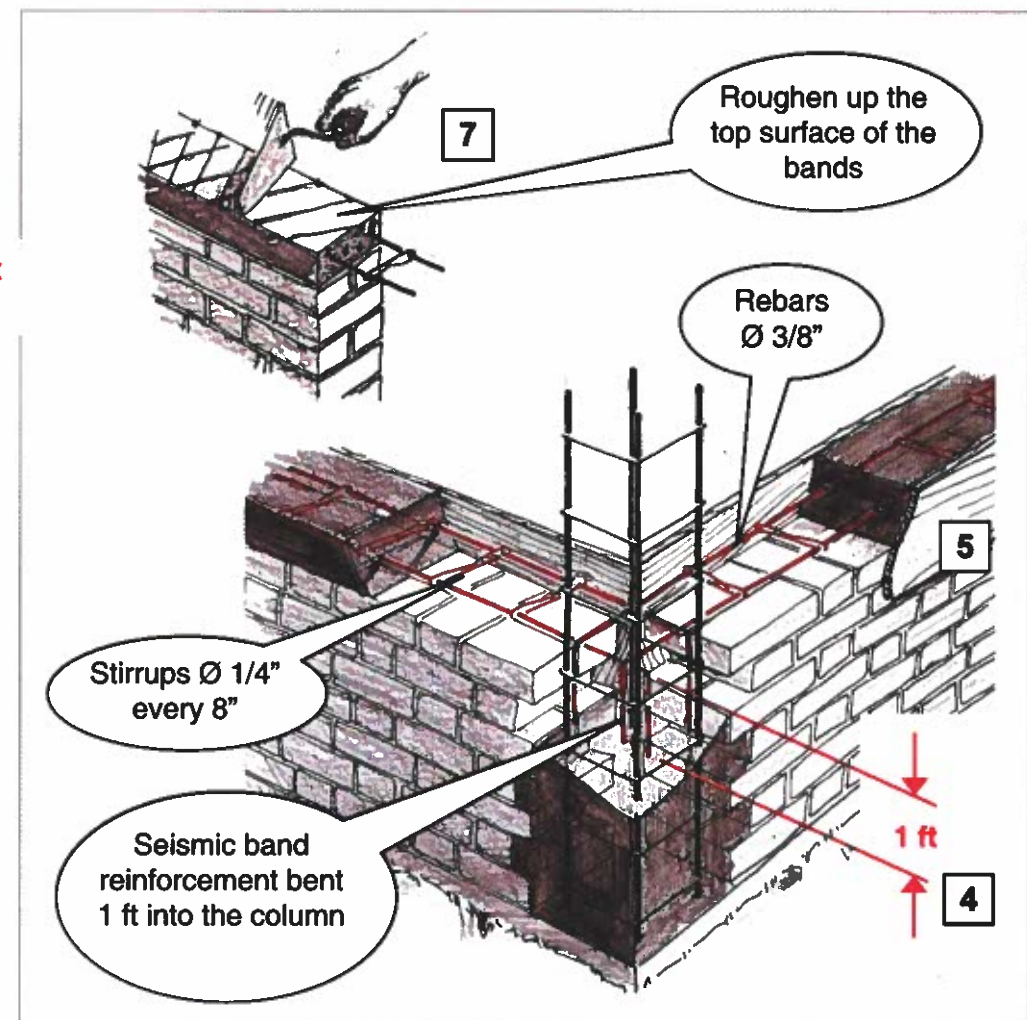
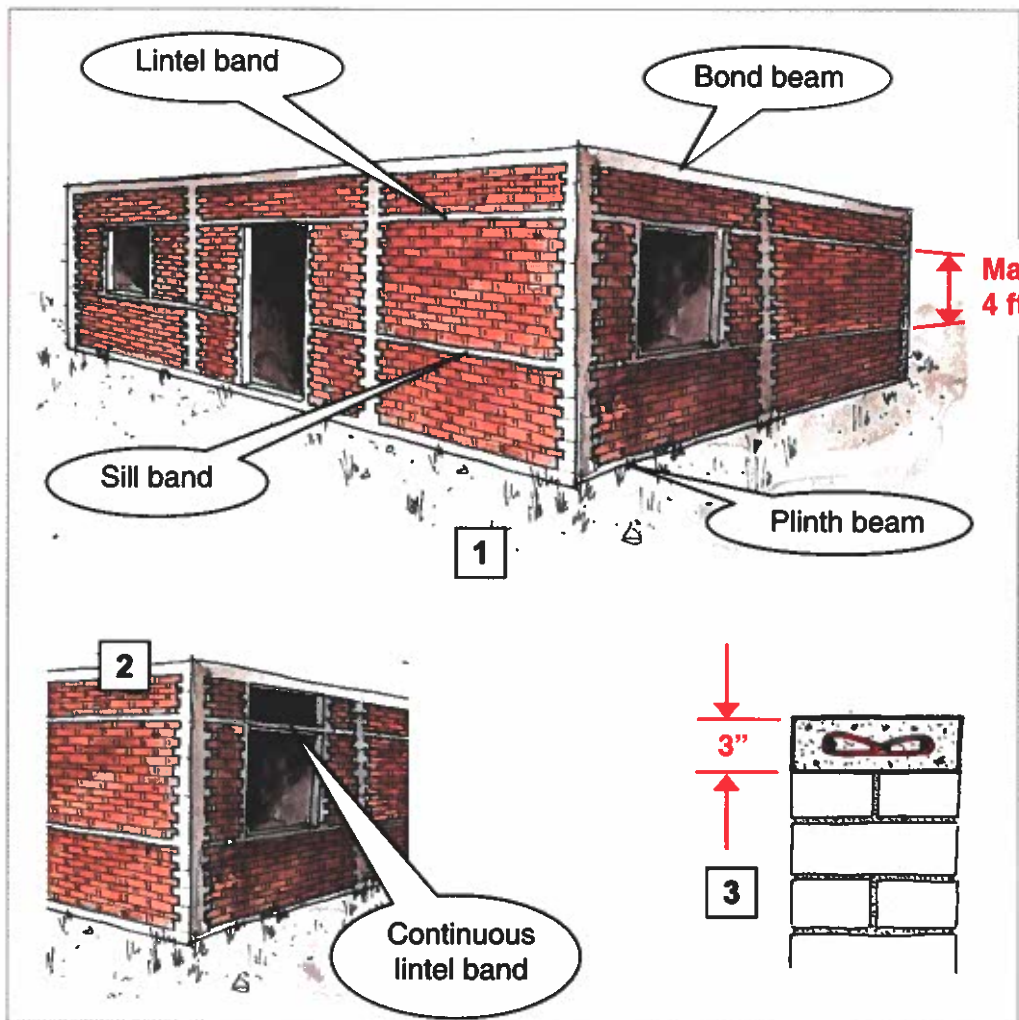
- Cement: 1 part
 - Sand: 4 parts
- Mix while dry, only then add water

Concrete

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



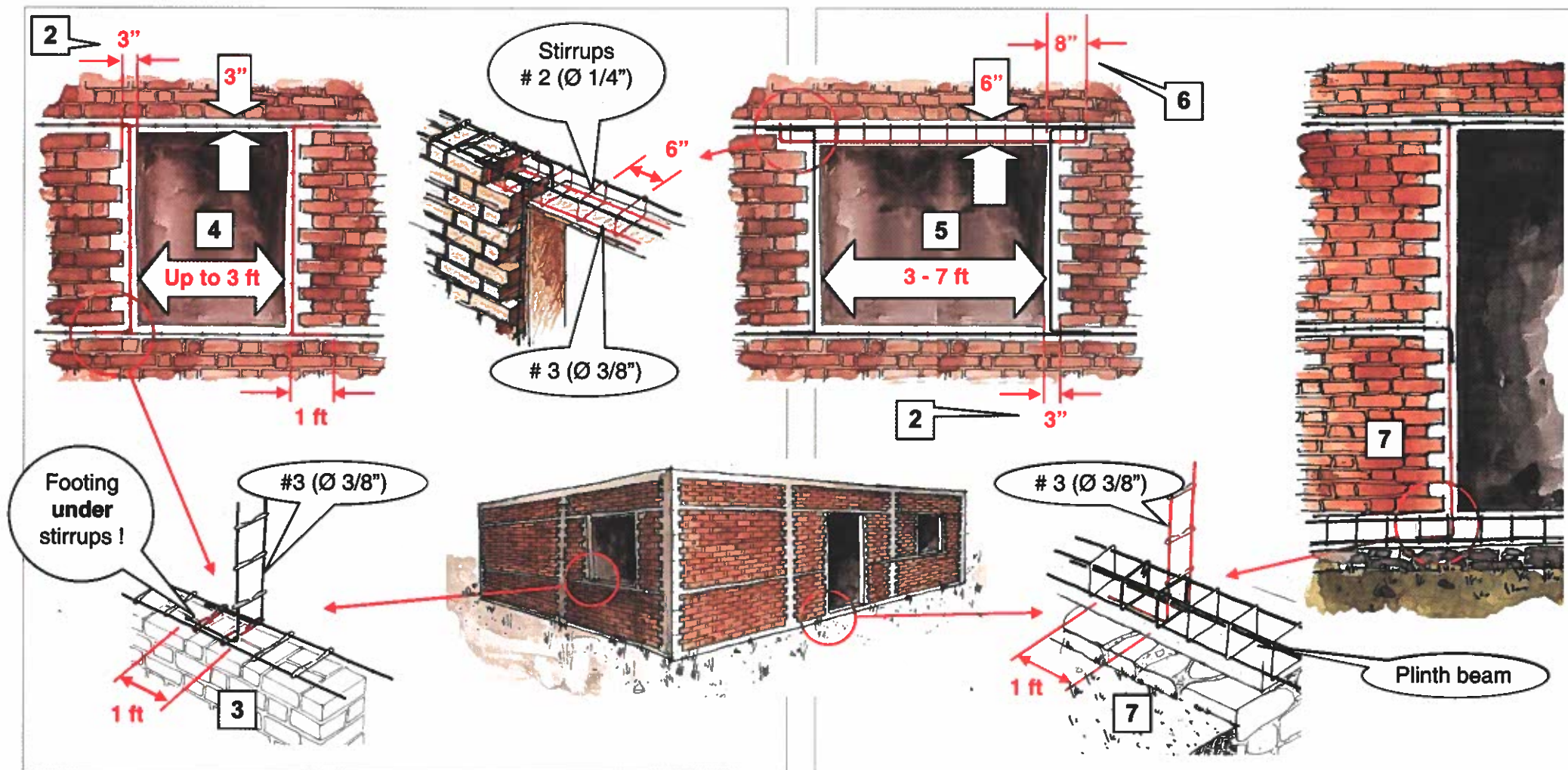
8. Tie-columns



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

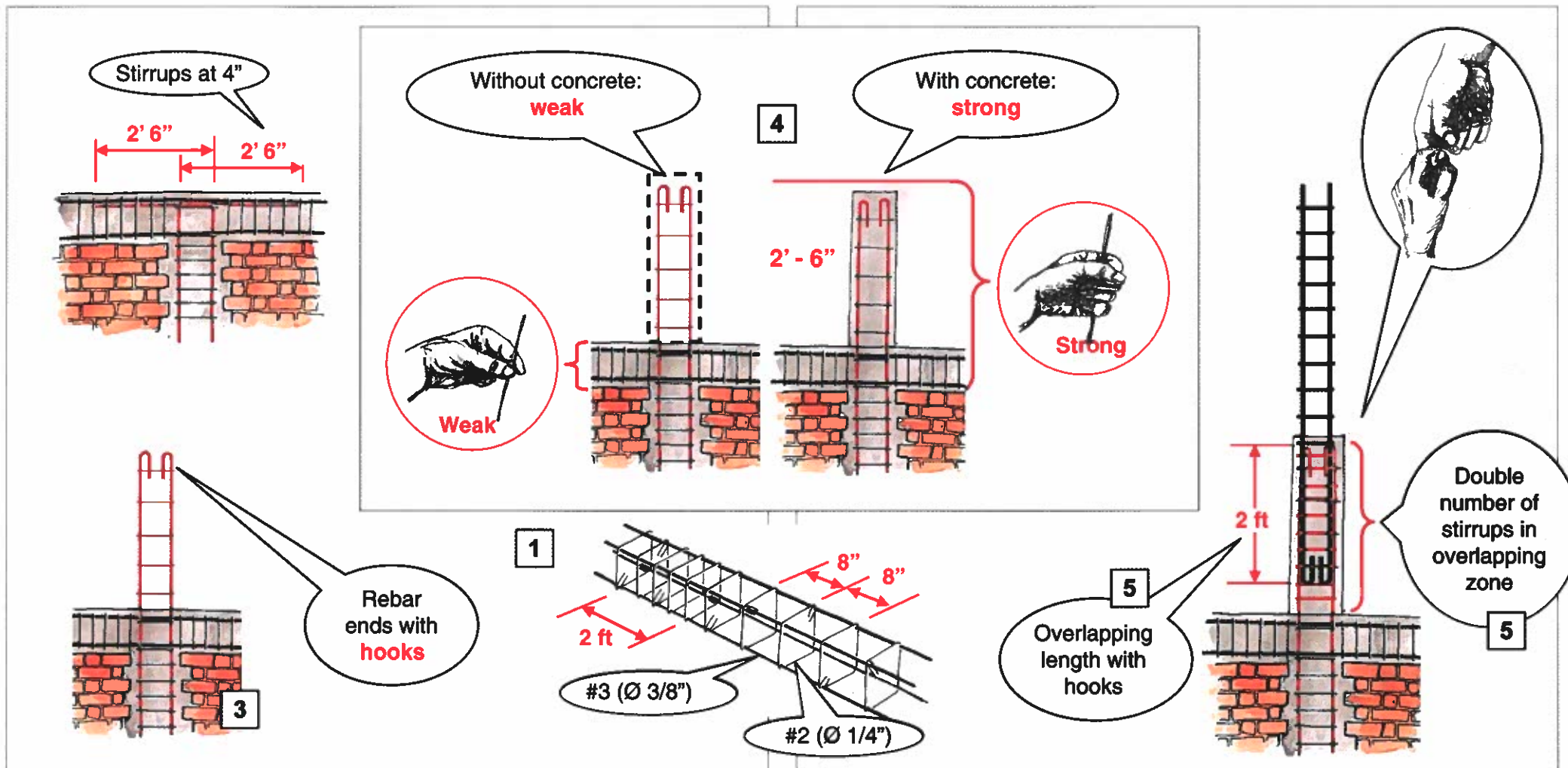
4. Bend the rebars into the columns (1 foot long).
5. Place the form work for the bands.
6. Pour concrete for the bands and the columns at the same time.
7. Roughen up the top side of the concrete band to increase adherence of the mortar for the wall above.

9. Seismic bands



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

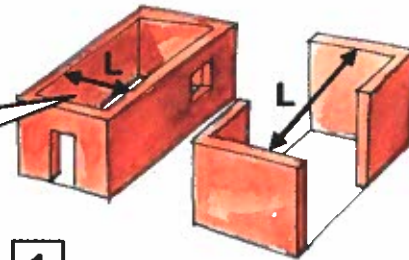


1. Prepare bond beams with stirrups at 8"CC (4"CC on the first 2 ft on both ends).
2. If you don't plan to add another floor, bend the rebars into the bond beam to ensure a good connection.
3. If you leave vertical rebars for a future floor, end all rebars with hooks.
4. Tie-columns and bond-beams must 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.

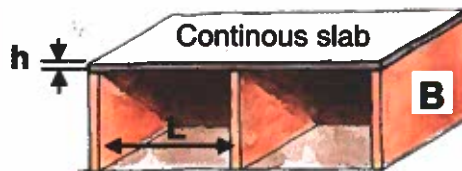
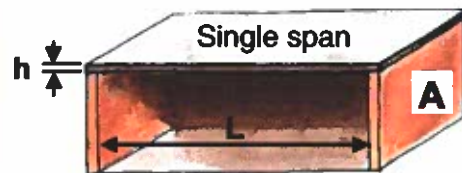
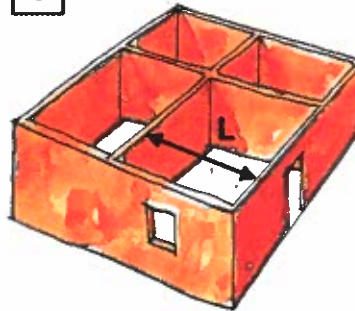
11. Bond beam – tie-column connection

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 ones.

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.

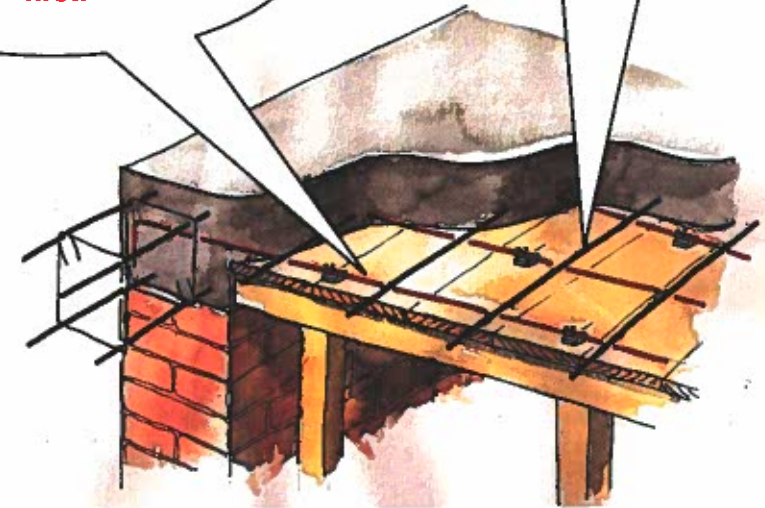
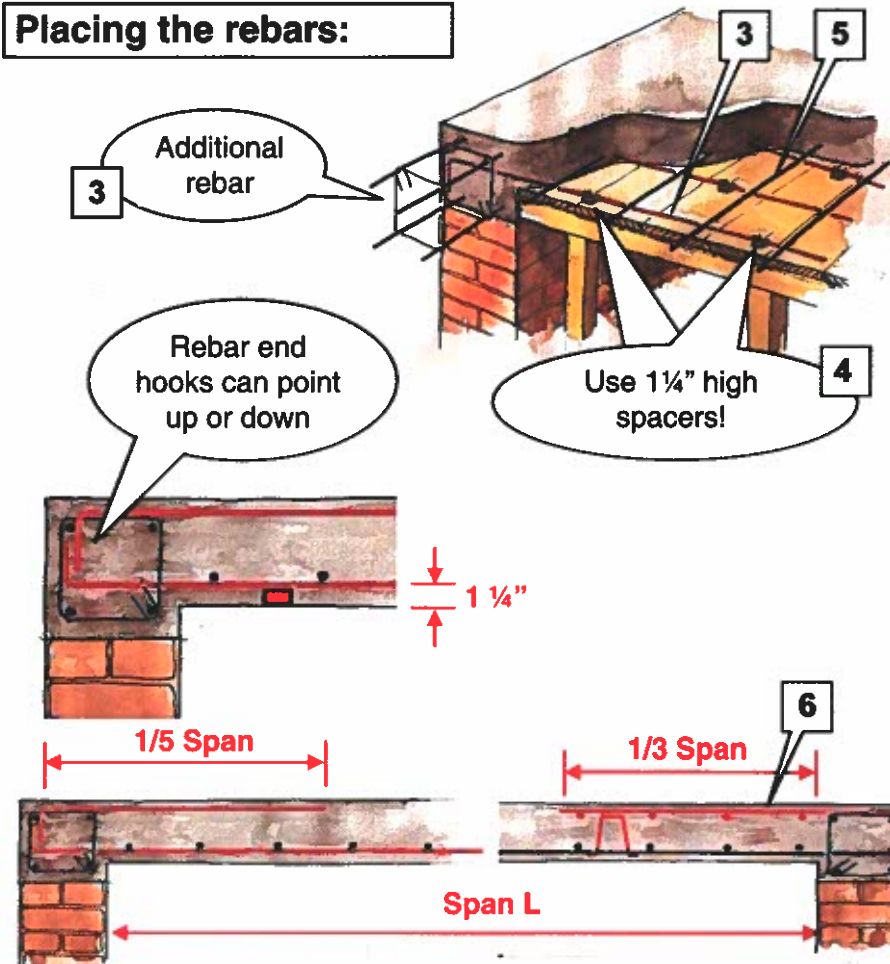


Table 1: Reinforcement bars (for steel bars grade 50 = 360 N/mm²)

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

12. Concrete slab: dimensioning

Placing the rebars:

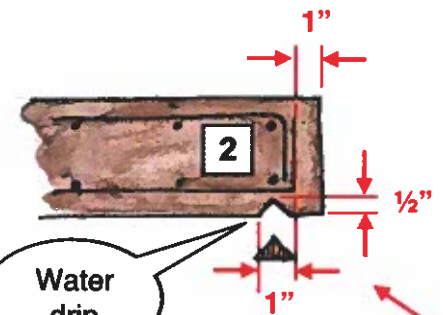
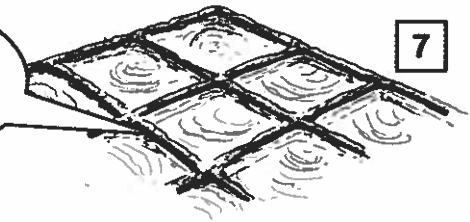


Upper rebars for continuous slabs:

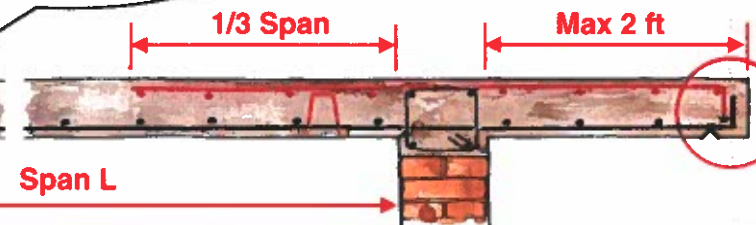
Concrete

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

Prepare mud dams to keep water for curing

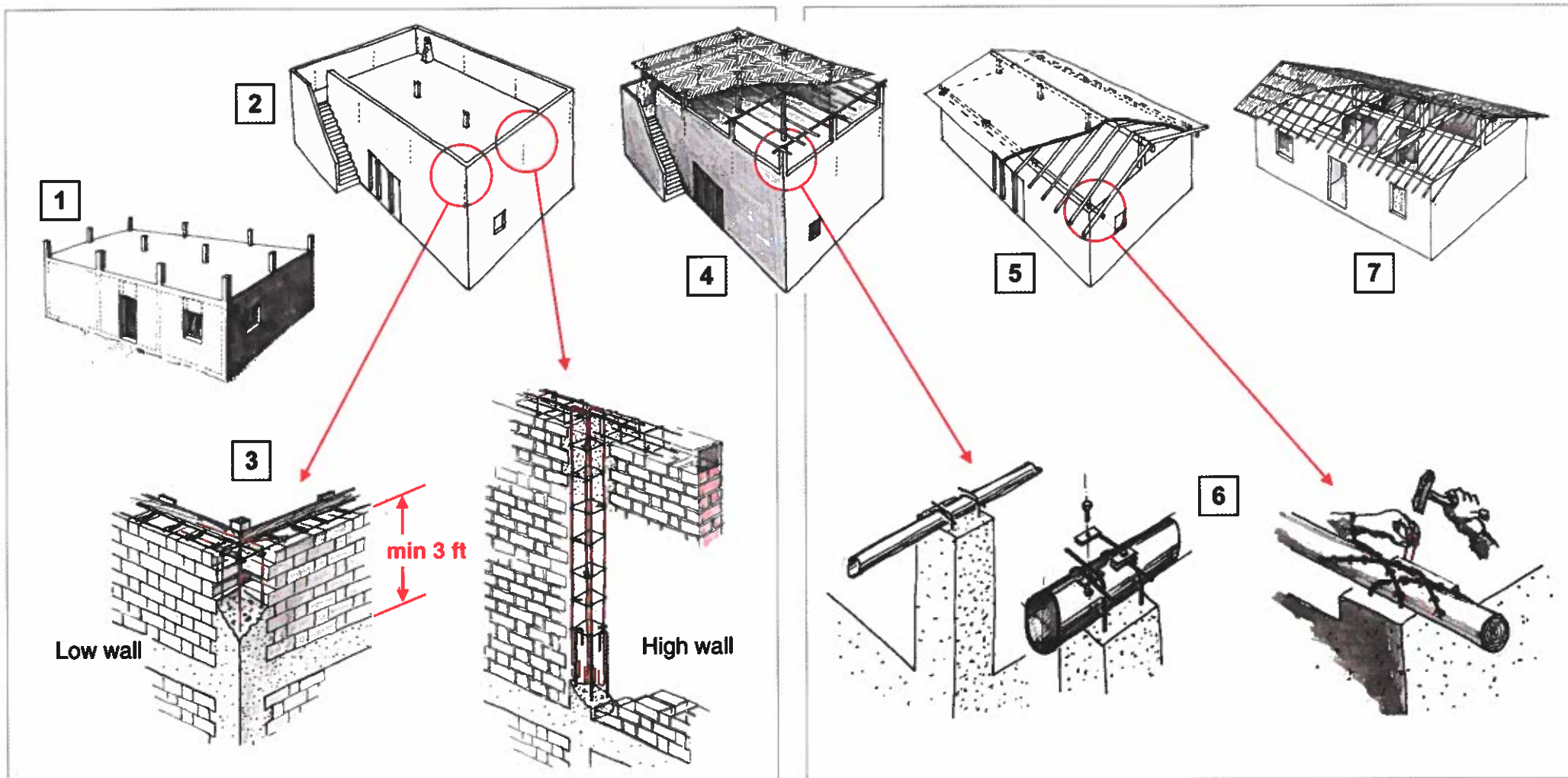


Place chairs to hold top re-bars



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 primary rebar in the direction of the shorter span.
4. Place 1 1/4" spacers under the primary rebar every 2-3 ft.
5. Add secondary rebar.
6. Add top bars where necessary and place them on chairs. Chairs must be placed on lower reinforcement not on form work.
7. 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.
8. Take off form work after 3 weeks only.

13. Concrete slab: construction

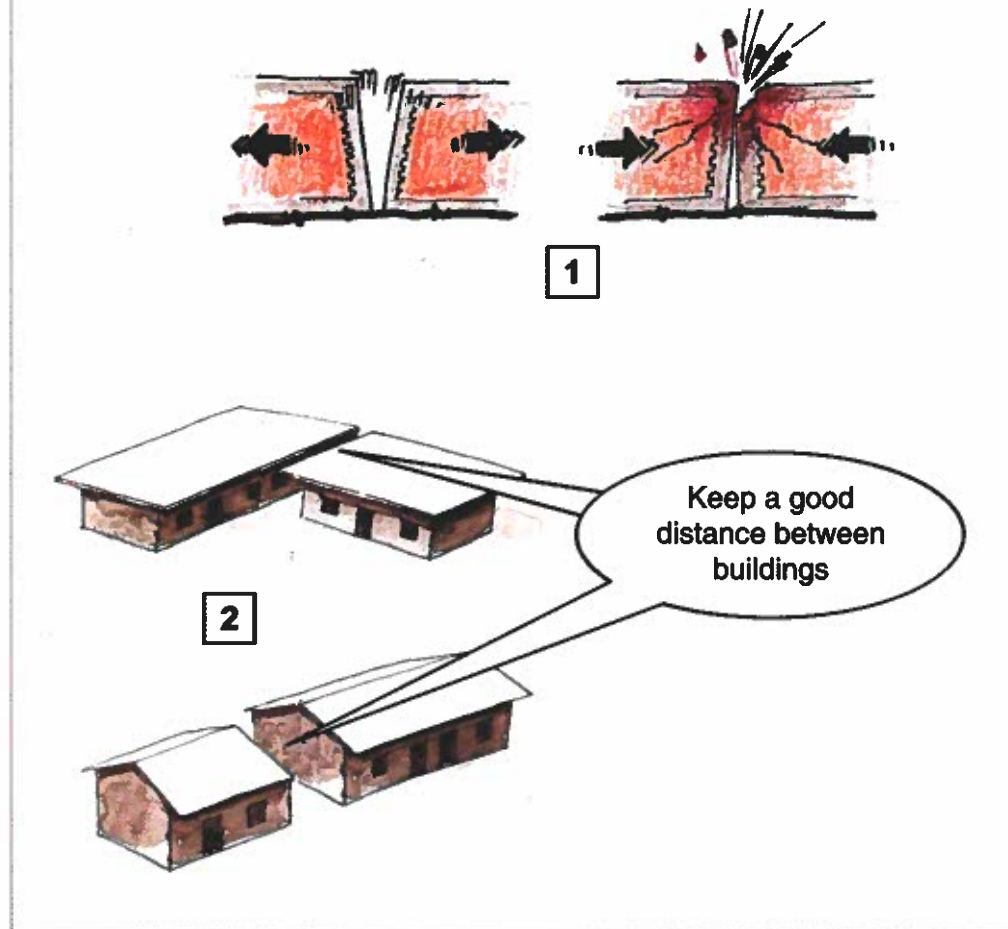


1. Rebars coming out of the slab must be cast in lean concrete to protect them against rust. Otherwise they cannot be used in columns later on.
2. Terrace walls must be confined like any other wall, or they will fall on people during an earthquake.
3. For security reasons low walls must be at least 3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

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 light roof structure directly over the bond beams.

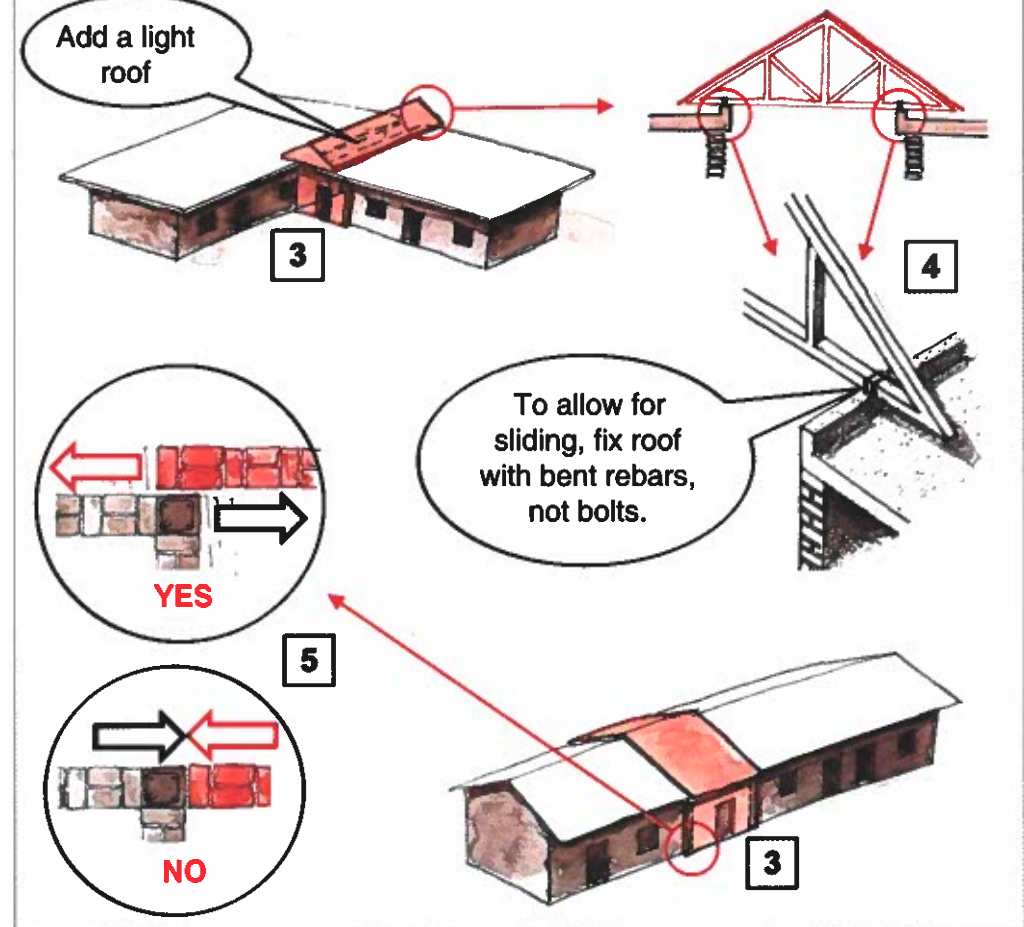
14. Roof

Solution 1: Seismic gaps between buildings



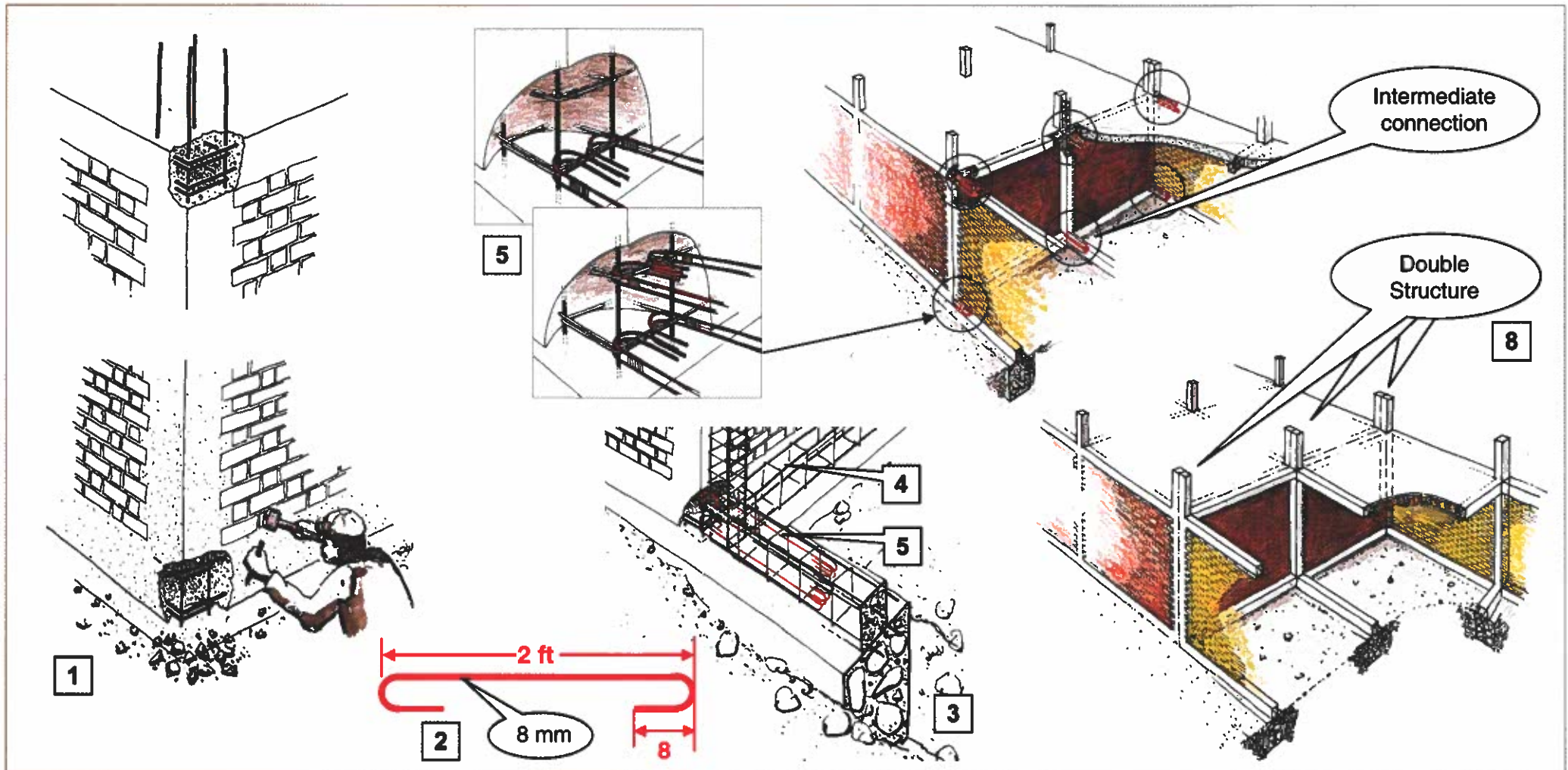
1. If buildings are too near, they will hammer against each other during an earthquake.
2. Therefore keep a good distance between buildings to avoid damage.

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



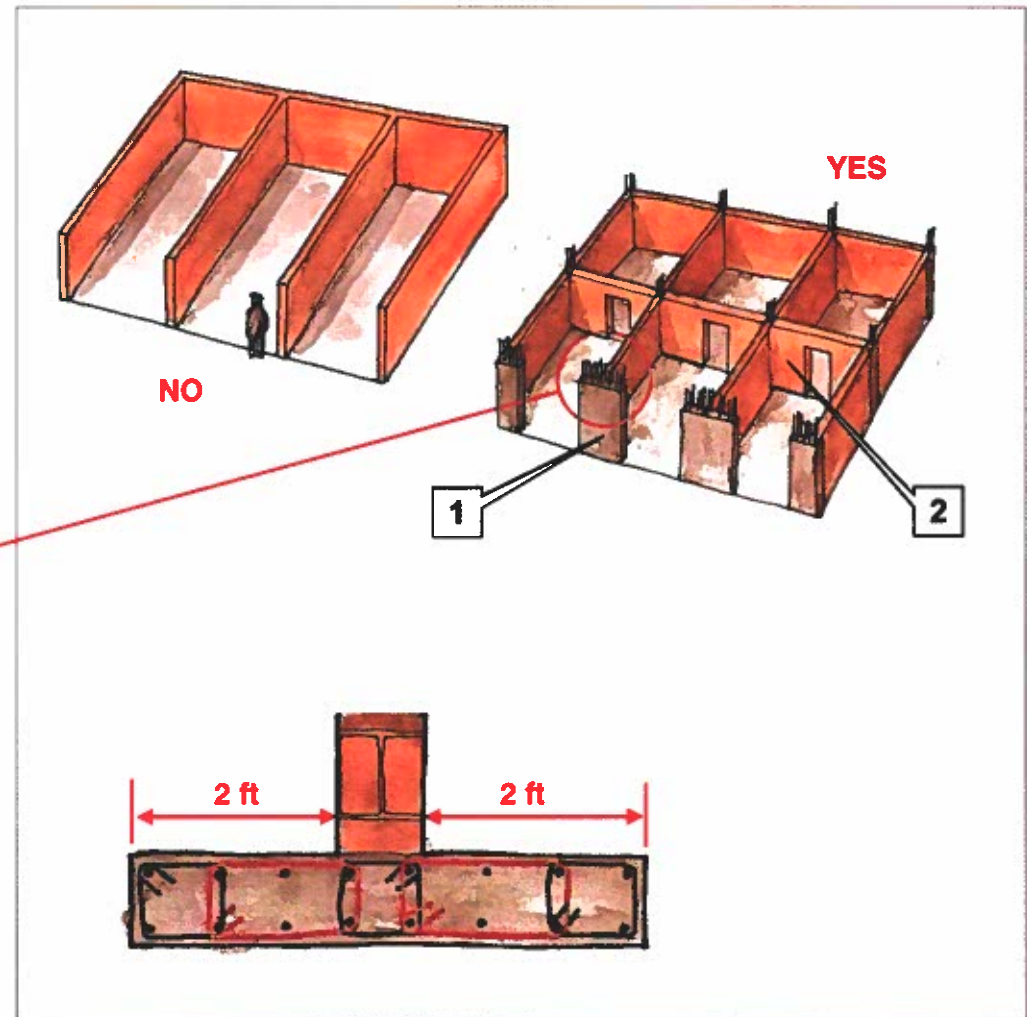
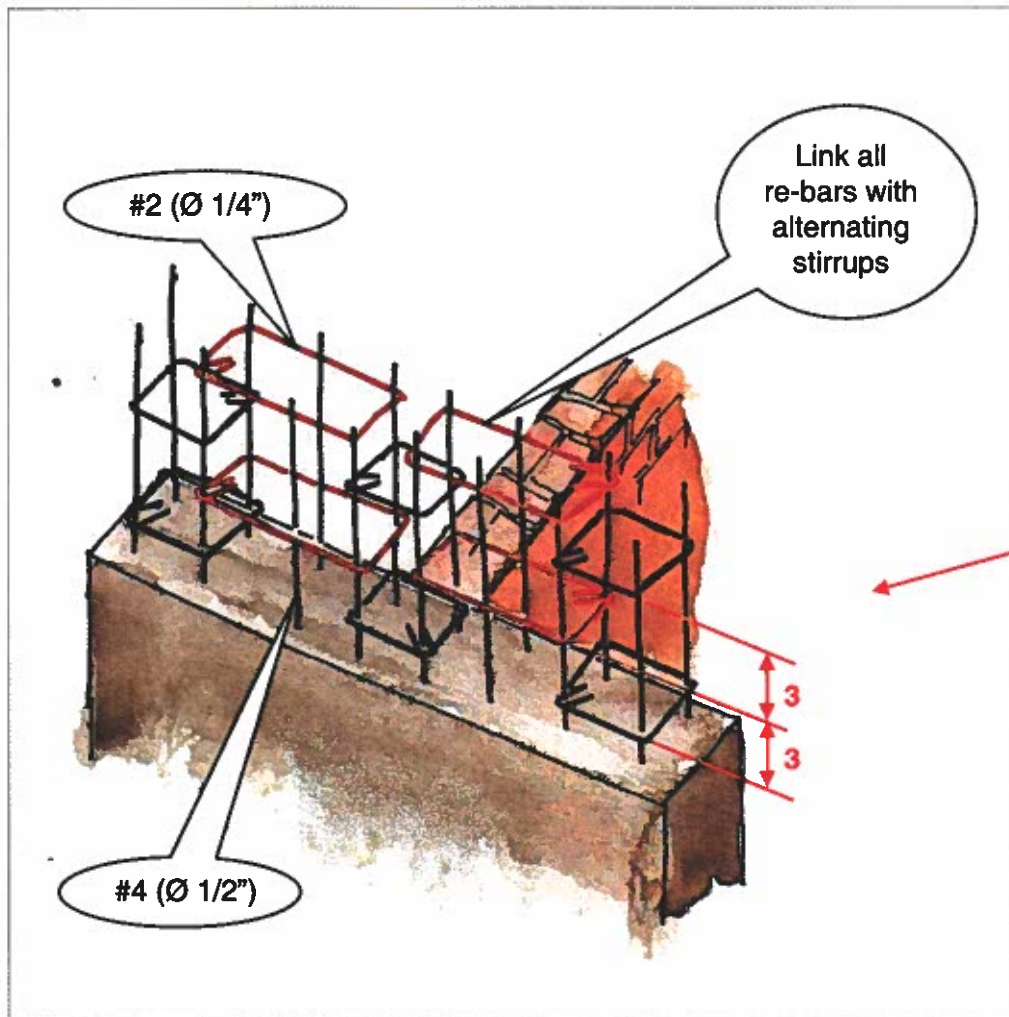
3. If you want to connect buildings, put a room in between where people stay only for a short time, like a deposit or a toilet.
4. Fix the roof with bent rebars instead of bolts, so it can slide slightly during an earthquake.
5. Don't put walls in between buildings, but against them. This way they can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

15. Adding more rooms (detached)



1. Open carefully the corners and intermediate connections.
2. Prepare 8 anchor bars for every connection.
3. Prepare the foundation 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. Make sure that the extended house still maintains a simple shape (see page 1).

16. Adding more rooms (attached)

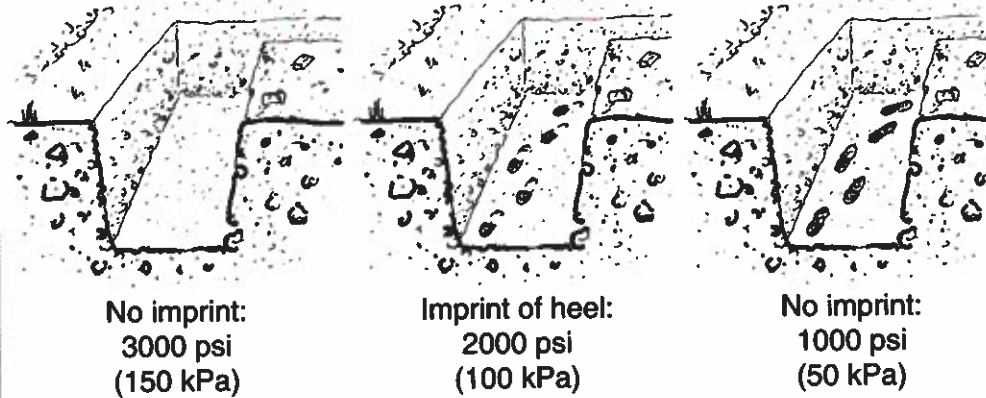
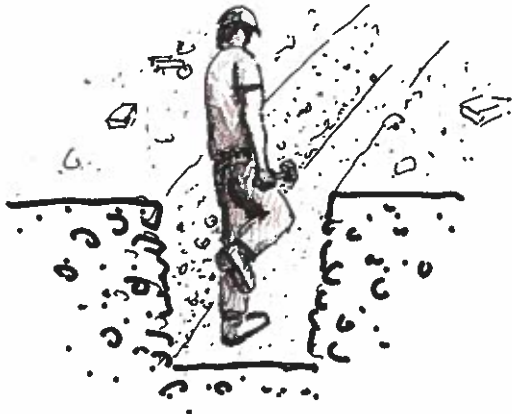


Shops are dangerous structures when it comes to earthquakes. Their big windows weaken the building and internal walls are often too long.

1. Reinforce the sides of the shop windows with large RC columns sticking out 2 ft on either side.
2. Subdivide the long walls by introducing perpendicular walls which must be confined by tie-beam columns and tie-beams.

17. The shop window problem

Soil test



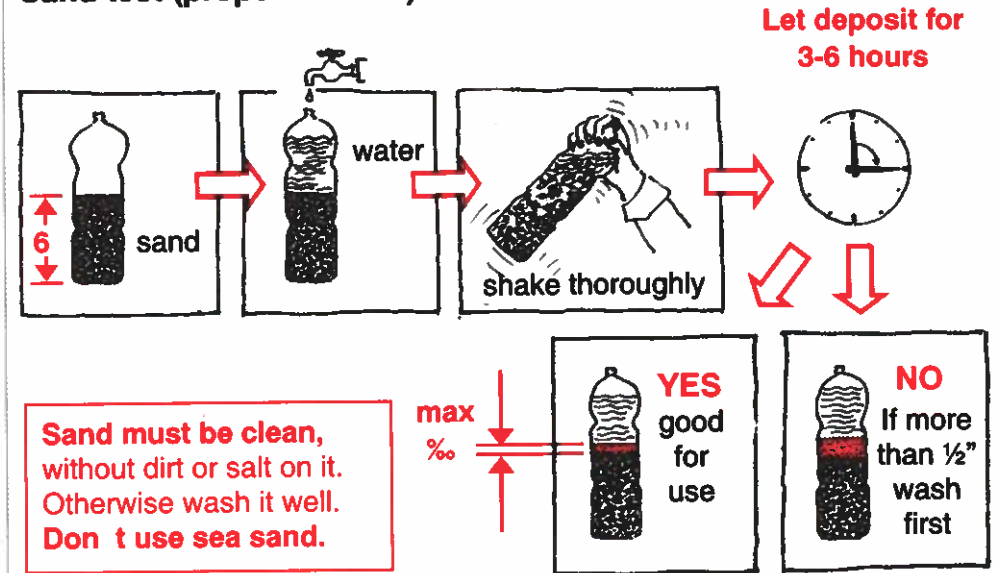
Soil test:

While walking at the bottom of a trench,

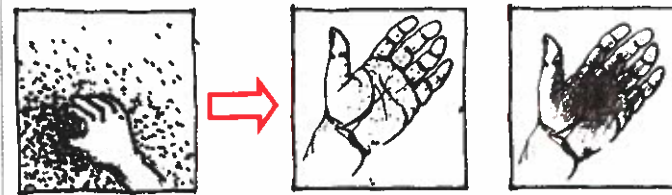
- if your weight on one heel doesn't leave a trace the soil is hard and needs a minimum width of foundation.
- if you see only the imprint of your heel, the soil is of minimum strength.
- if you see the imprint of the whole sole, the soil is soft and requires a maximum width of foundation.

18. Material testing

Sand test (proper method)



Sand test (simplified method)



Sand test (proper method):

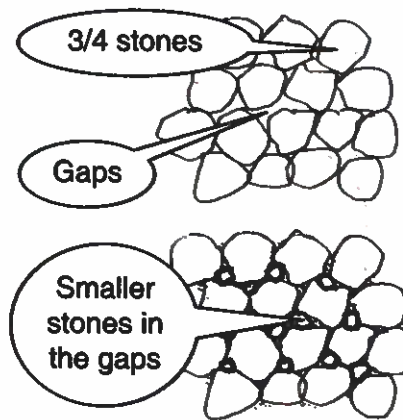
- Put 6" of sand in a transparent bottle. Fill up with water. Shake thoroughly and leave it for 3 to 6 hours to allow the particles to settle.
- A layer of fine particles will form on top of the sand. If this layer is higher than 1/2", the sand is too dirty and needs to be washed before use.

Sand test (simplified method):

- Take a handful of sand. If your hand remains fairly clean, the sand is okay. If your hand remains dirty, the sand needs to be washed.

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.

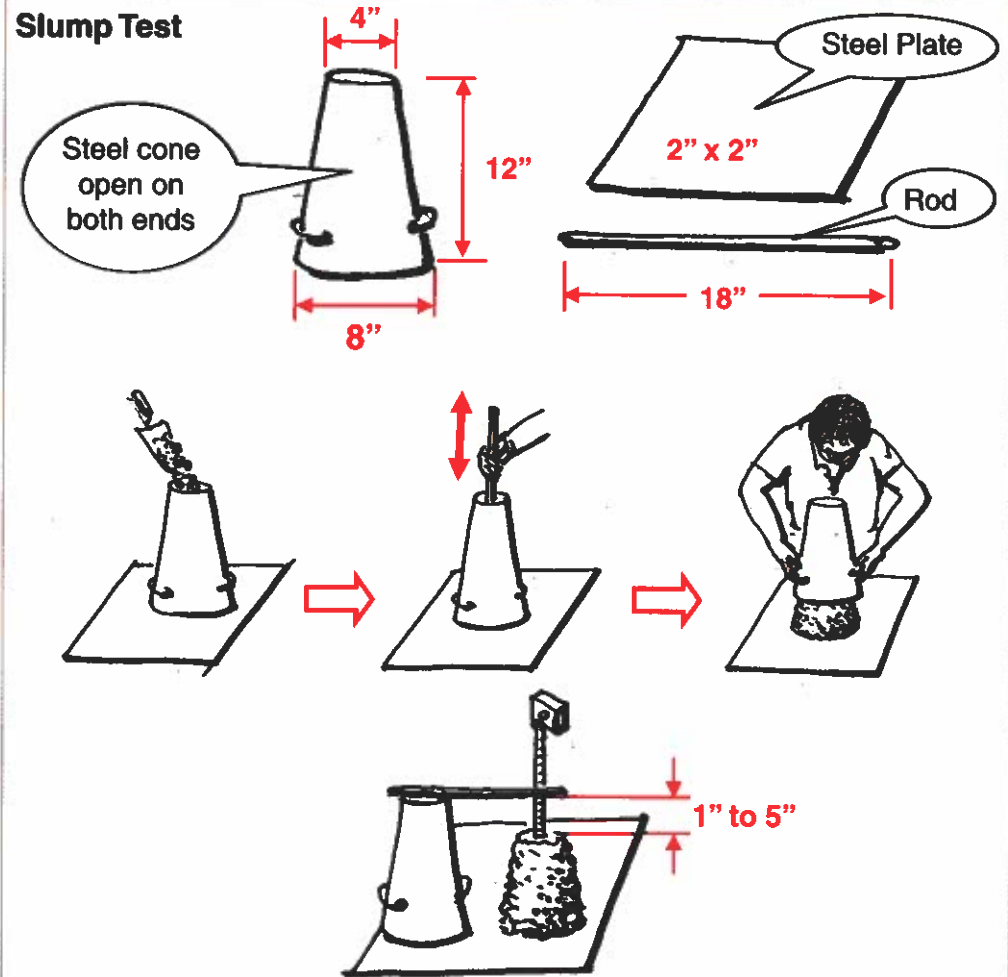


Water:

- Adding too much water into the concrete mix 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 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)



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 are minimum requirements:

- Steel quality: ductility class A (grade 60) f_y 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)			
#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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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 fourteen 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 and Haiti). 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 in Iran, after the Bam earthquake of 2003, in Pakistan, after the Kashmir earthquake of 2005 and in Haiti, after the 2010 Earthquake.

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 held a position of technical expert for the Swiss Solidarity fundraising organisation and was a senior researcher at the University of Applied Sciences of Southern Switzerland.

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