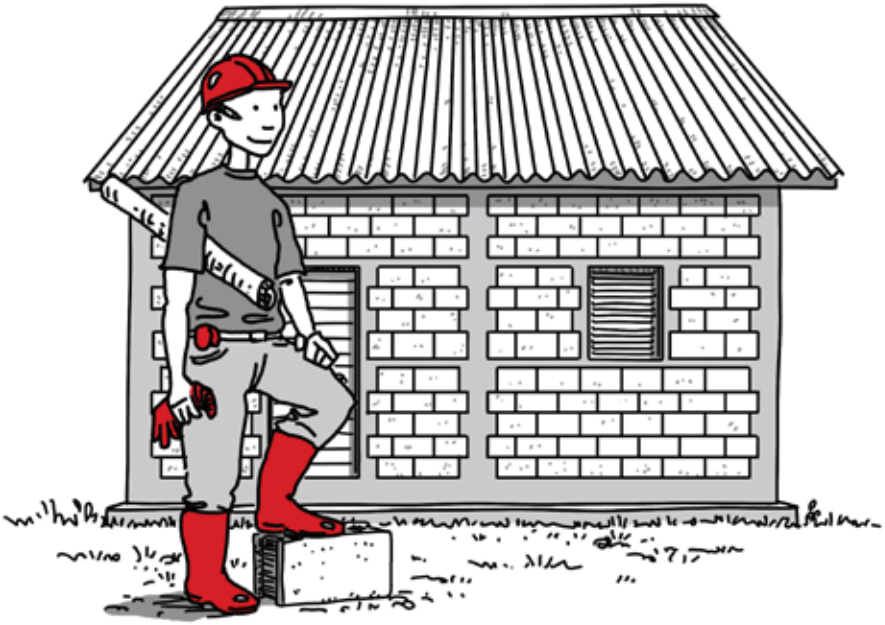
Guide book for building earthquake-resistant houses in confined masonry



NON-COUNTRY SPECIFIC VERSION

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development
and Cooperation SDC

EERI

Guide book for building earthquake-resistant houses in confined masonry

Guide book for technical training for earthquake-resistant construction of one to two-storey buildings in confined masonry

GUIDE BOOK FOR BUILDERS
masons - steel trades - carpenters

COMPETENCE CENTER FOR RECONSTRUCTION - CCR

SWISS AGENCY FOR DEVELOPMENT AND COOPERATION
HUMANITARIAN AID - SDC/HA

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
EERI

Non-country specific version, revised june 2018

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Non-country specific version, revised june 2018

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NON-COUNTRY SPECIFIC VERSION

This version of the Guide is non-country specific, and is the result of the compilation of international building codes and construction practices.

You might find other versions of the Guide, made specifically for certain countries and adapted to their construction codes, building materials characteristics and local building cultures.
For this reason, some information may vary among versions, such as mixing proportions, dimensions, tools, etc.

SDC declines any reponsibility regarding the translation and technical content of the other context-specific adapted versions.

INTRODUCTION

This Guide is intended for the training of professional masons in confined masonry. It can be used as a building guide at construction sites or as a training resource. It is presented in a simple manner and explains in a step-by-step sequence how to build a one or two-storey confined masonry house.

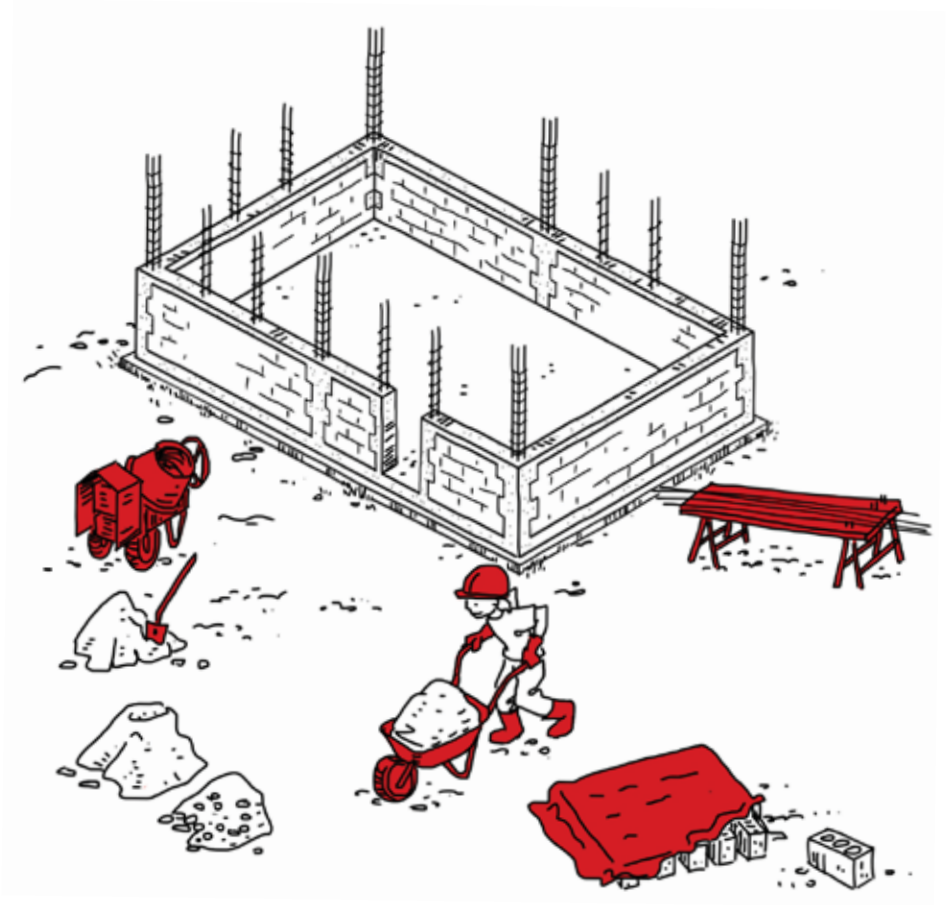
The Guide was developed for masons working in developing countries. The recommendations are intended to be conservative (on the safe side) and to ensure life safety of the occupants of the house.

This Guide needs to be adapted in consideration of the type and quality of locally available materials and local capacities. The technical recommendations contained in the Guide should be in compliance with local construction codes and other regulations (when available).

Illustrations included in the Guide may be adapted to suit the local culture and perceptions and to ensure good acceptance. The text may be translated into a local language that the masons are able to read and understand.

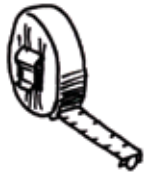
While the authors have tried to be as accurate as possible, they, the organizations they are affiliated with, and the sponsoring organizations cannot be held responsible for any construction, or any misinterpretations, that might be based on the material presented in the Guide.

THE MASON'S WORLD



Mason's tools - 1

Guide book



tape measure

straight edge

level

pencil

plumb line

string

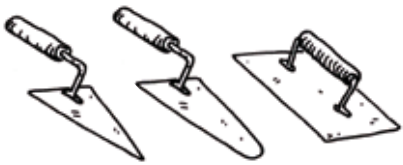
nail

chalk line

aluminium screed

machete

screen (05, 03)



trowel

float

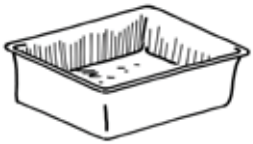
hammer

chisel

club hammer

Mason's tools - 2

bucket



mixing box

big brush

cone for slump test

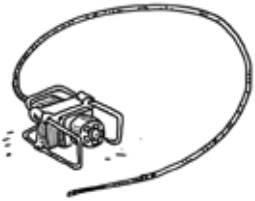
transparent water hose 10 -20 m

pickaxe shovel

long handled cold chisel

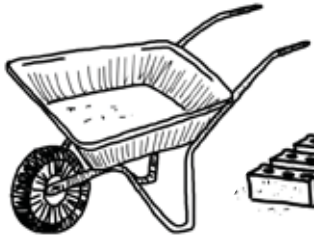
rammer

grinder

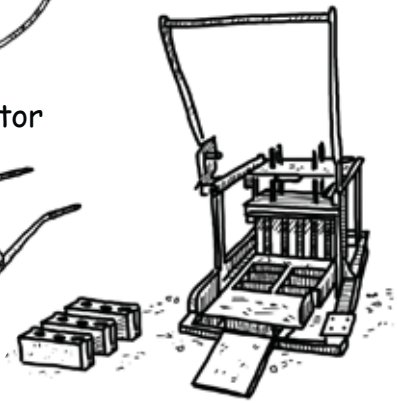


needle vibrator

concrete mixer



wheelbarrow



vibrating block/brick press

Formwork tools

Guide book

tape measure

straight edge

level

pencil

plumb line

string

nail

hammer

chisel

crowbar

axe

saw

plane

Steel reinforcement tools

Guide book

tape measure

straight edge

level

pencil

chalk

plumb line

string nail

wire twister or pincer

pliers

tin snips

hammer

chisel

plastic pipes of different diameters

hacksaw

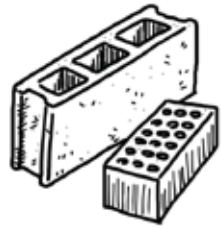
rebar bender

chain bolt cutter

Quality of materials

The quality of materials is essential to ensure safe construction.

Water :
clean and non-salty



Blocks & bricks : (ch. 9)
minimal size and strength

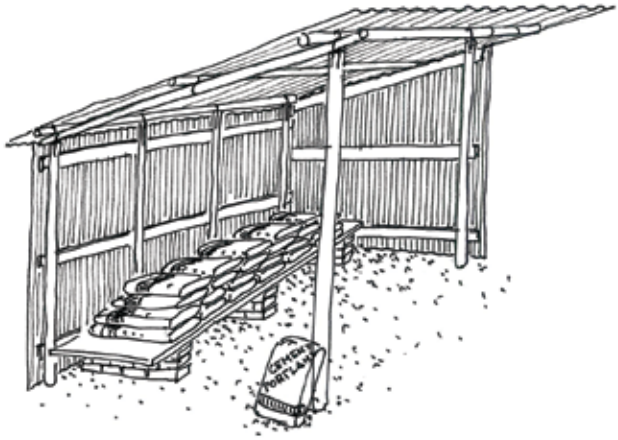
Sand :
river sand,
washed and dry

Cement :
portland cement,
new and dry bags

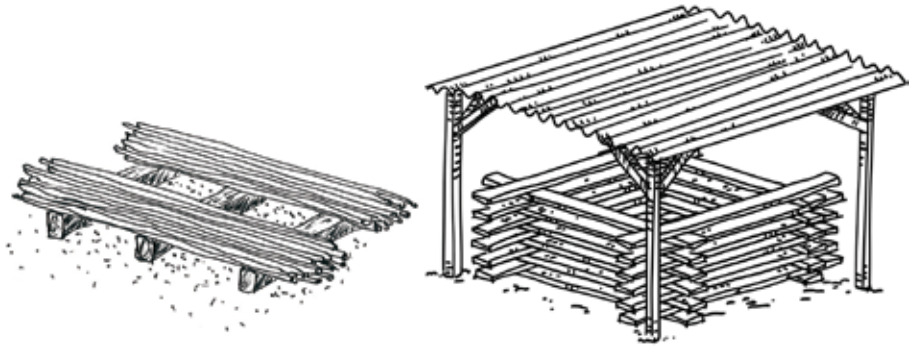
Gravel :
crushed or round,
from hard rock and clean,
well-graded, max size 18-20 mm

Steel bars :
standard size,
ribbed steel, grade 60
new and not corroded

Storage of building materials on site



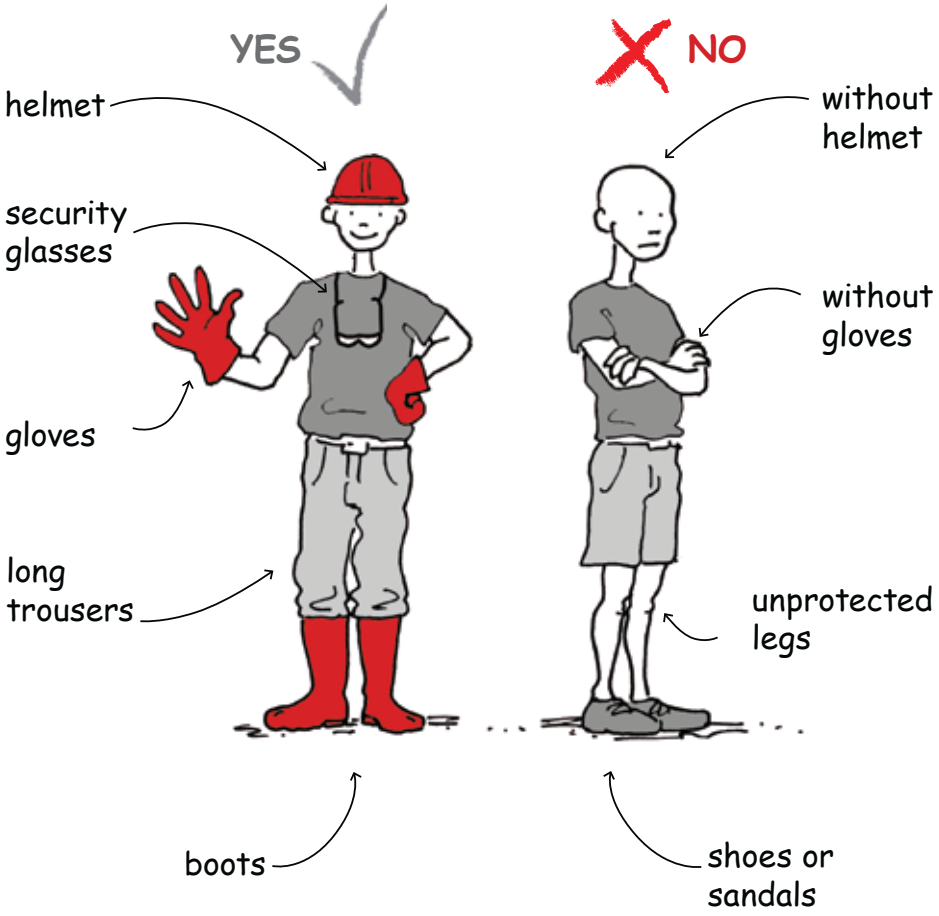
Store cement bags away from the sun
and protected from humidity.
Do not place on the ground !



Store wood and steel bars in a dry environment.
Do not place on the ground !

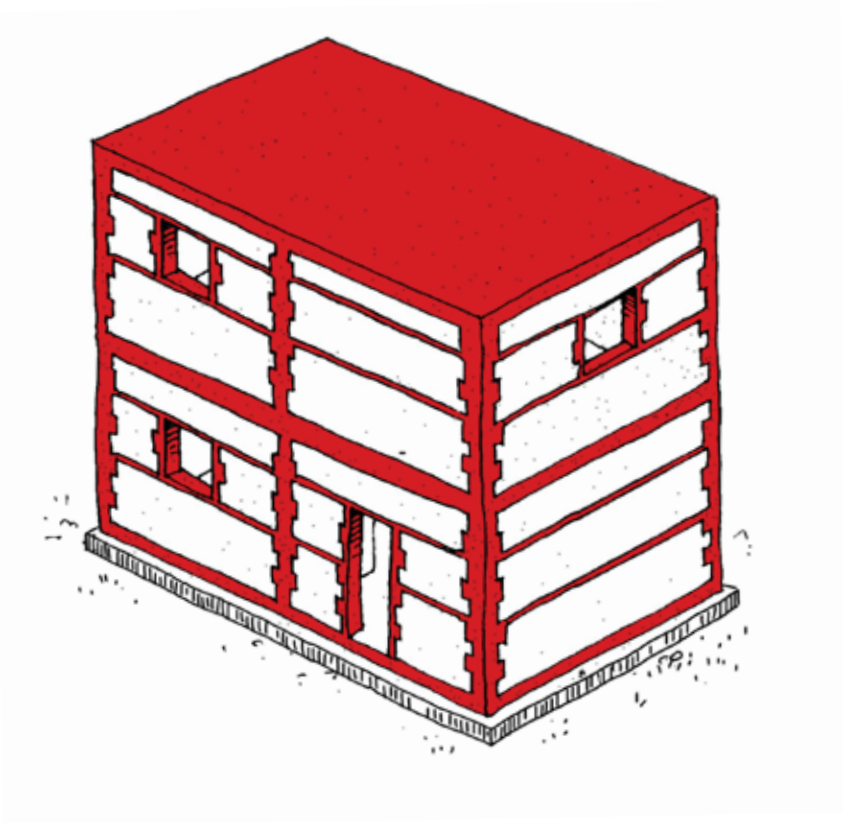
Protection on the construction site

Do not forget that health and security concerns everybody, starting with oneself.



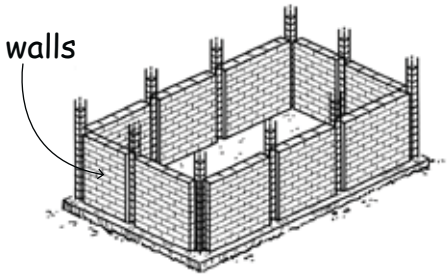
If people are injured on a construction site, wash the wound with clean water and soap and go to a doctor.

CONFINED MASONRY FOR TWO-STOREY HOUSES

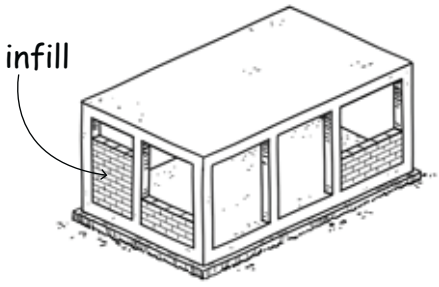


What is confined masonry ?

Confined masonry is a construction technique where walls are built before the reinforced concrete elements.



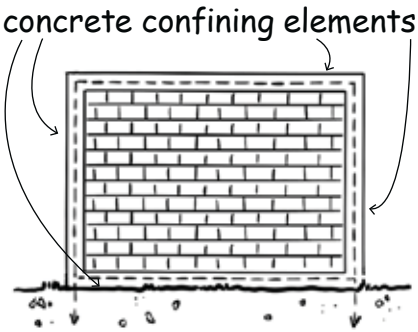
Confined masonry :
walls and "tie-columns"

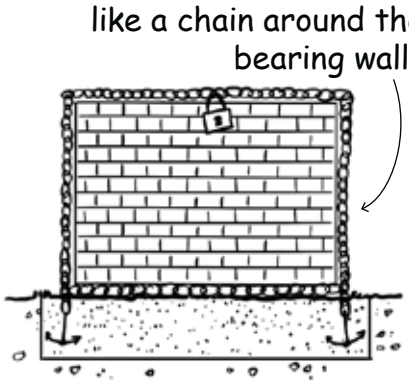


RC frame :
columns and infill walls

In confined masonry, **the walls carry the weight.**
The tie-columns ensure that the walls don't fall apart.

The concrete elements work like a chain around the masonry walls, preventing them from collapsing during an earthquake.



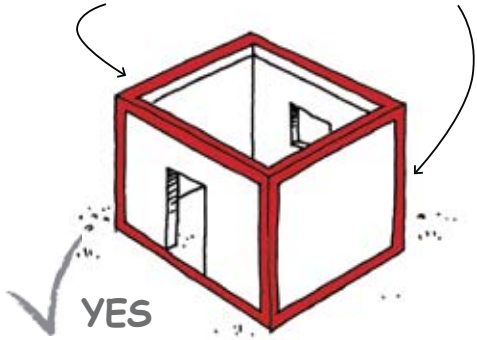


In confined masonry, these concrete "chains" are called **tie-columns** and **tie-beams**.

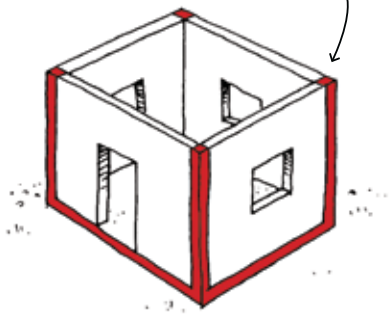
Confining elements (ties)

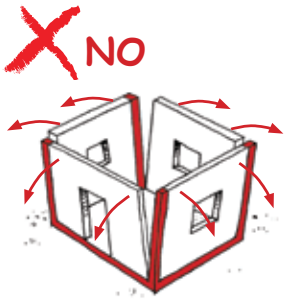
Confining the walls is like holding a pile of books together with a string : they can still move but they will not fall apart.

Horizontal ties (tie-beam) and vertical ties (tie-column).

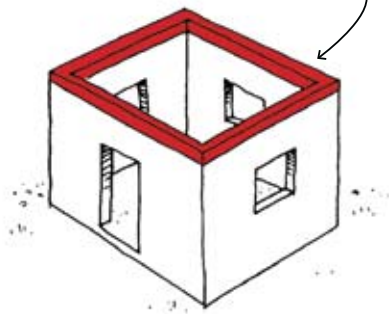


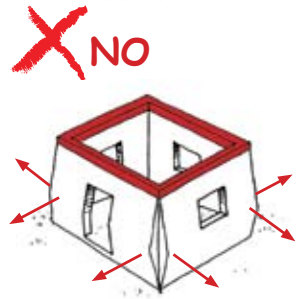
only tie-columns is not good enough





only tie-beams is not good enough



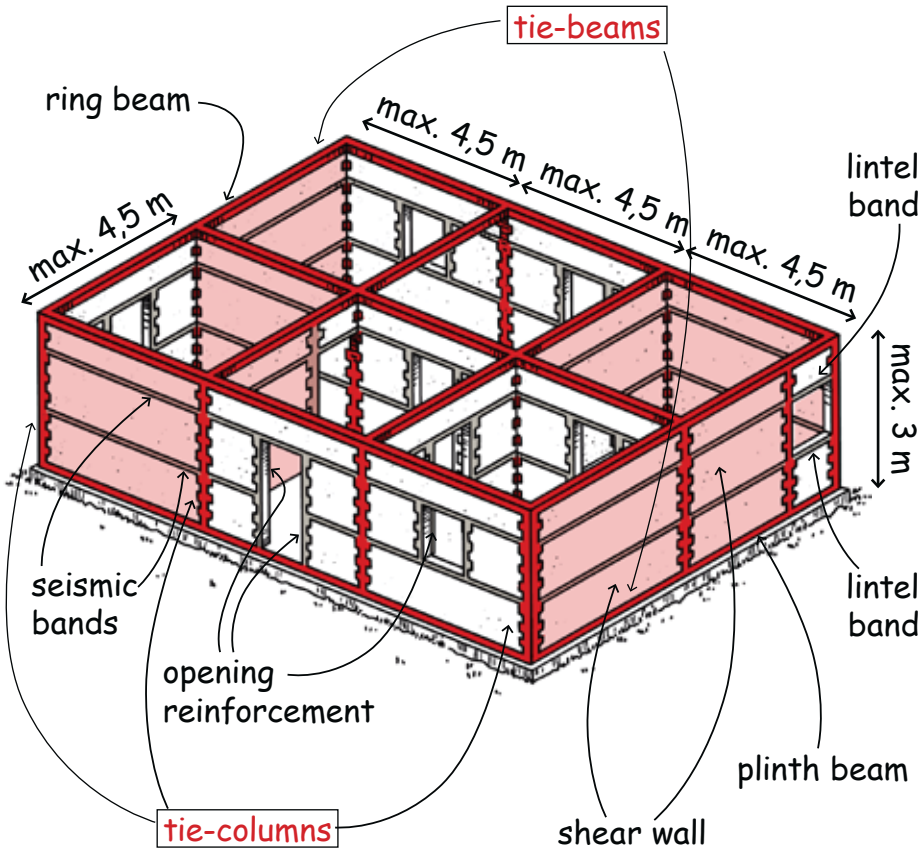


A strong house

All walls and openings should be confined
to ensure stability during an earthquake.

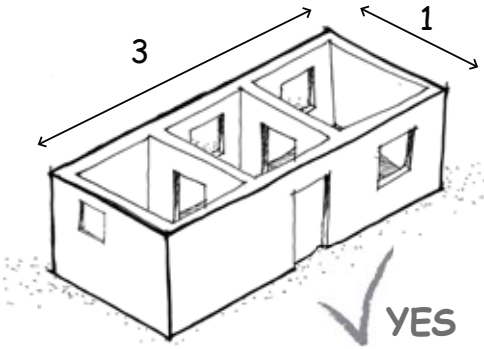
Confining elements in red : (chap. 6-8)
tie-column and tie-beams (plinth beam and ring beam)

Anchoring bands & opening reinforcement in grey: (chap. 11)
seismic bands (lintel & sill bands) and vertical reinforcement

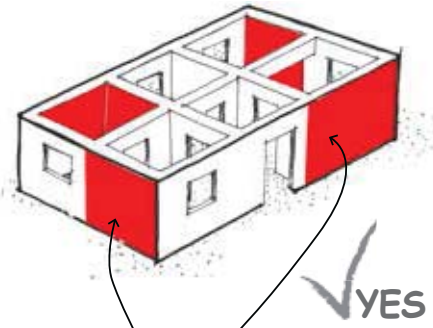


Shape of the house

YES, THIS IS CORRECT !

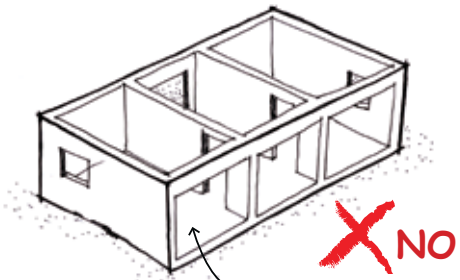


Maximum ratio 1 to 3.

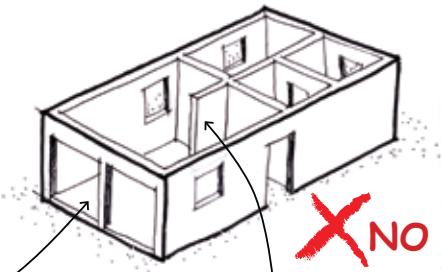


Each facade must have at least one tied wall without openings = shear walls.

NO, THIS IS NOT CORRECT !



Openings are too big.

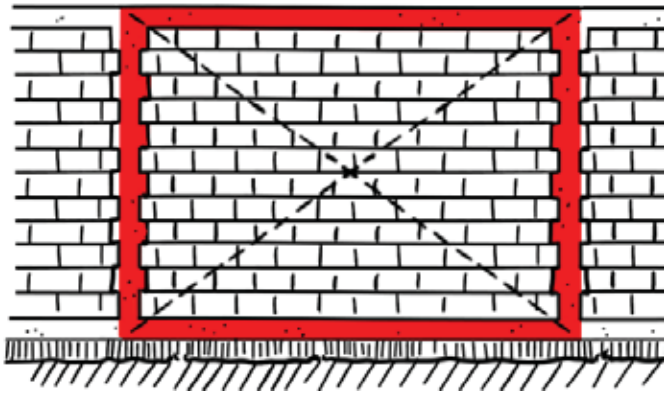


Free standing wall without any tie.

Shear walls - 1

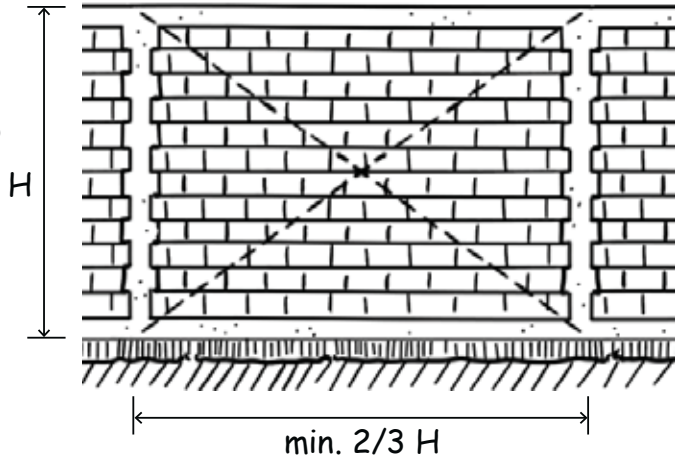
Shear walls are walls without openings,
which follow these two rules :

YES



Rule 1 : the wall must be confined on all four sides with reinforced concrete elements.

YES

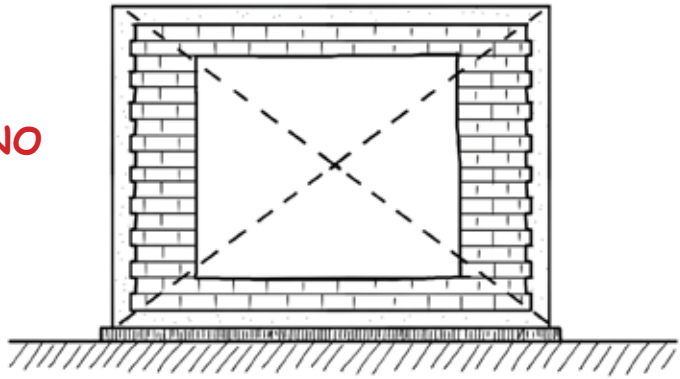


Rule 2 : the length of a shear wall must be minimum 2/3 of its height.

Shear walls - 2

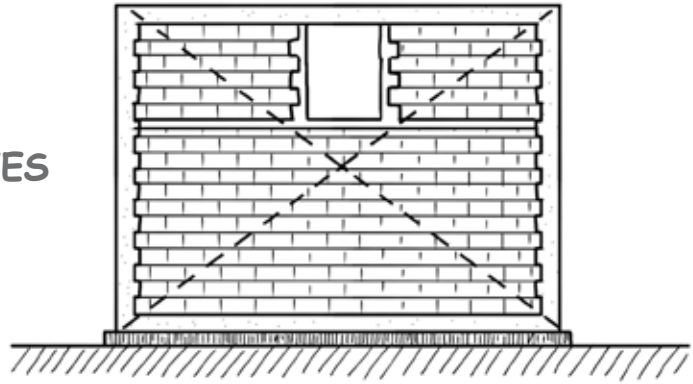
Shear walls are walls without windows or
with a small window outside of the diagonals of the wall.

NO



Opening is too big:
not a shear wall !

YES



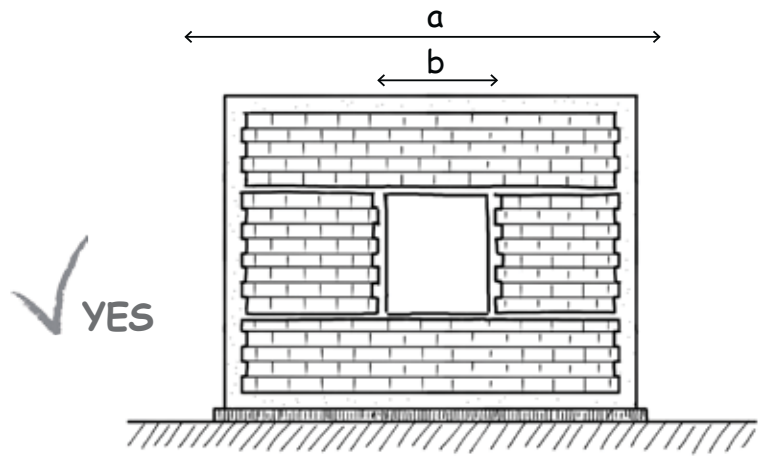
Opening is small and outside the diagonals :
it is a shear wall !

Size of openings

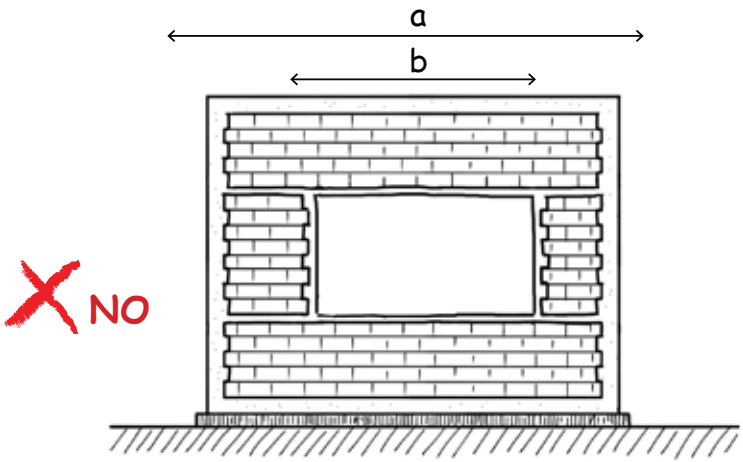
In walls that are not shear walls, the width of the openings should not exceed half of the lenght of the wall.

Note : for larger openings, consult an experienced engineer.

Rule : b smaller than a/2



Correct : b smaller than a/2

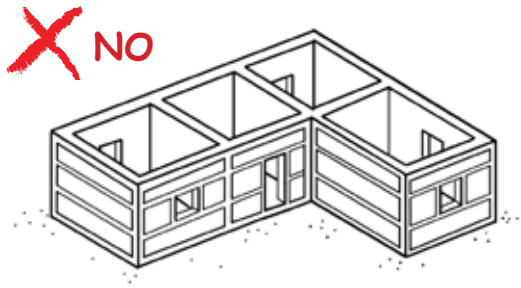


Incorrect : b bigger than a/2

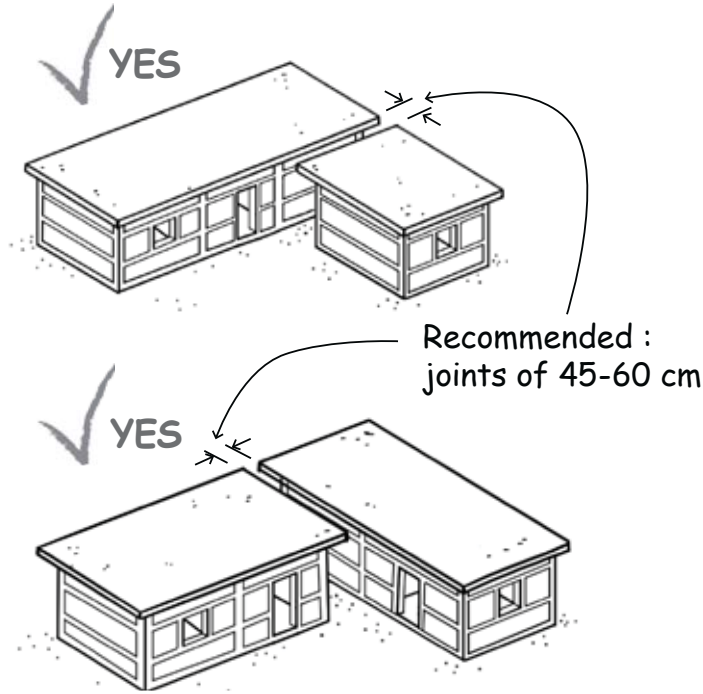
Seismic gap

Avoid complex shapes by creating seismic gaps.

Complex shape : WEAK, will break

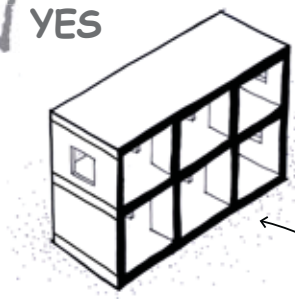


Simple shape : STRONGER



Vertical continuity of walls

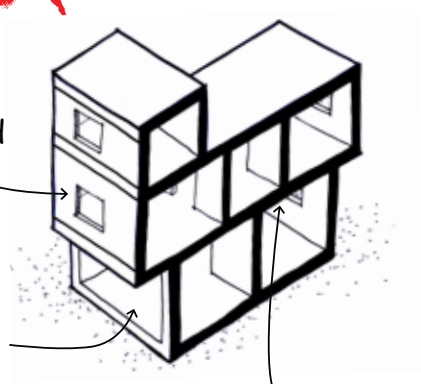
YES



Vertical structure

Walls must be placed continuously one on top of the other, from the ground to the roof!

NO



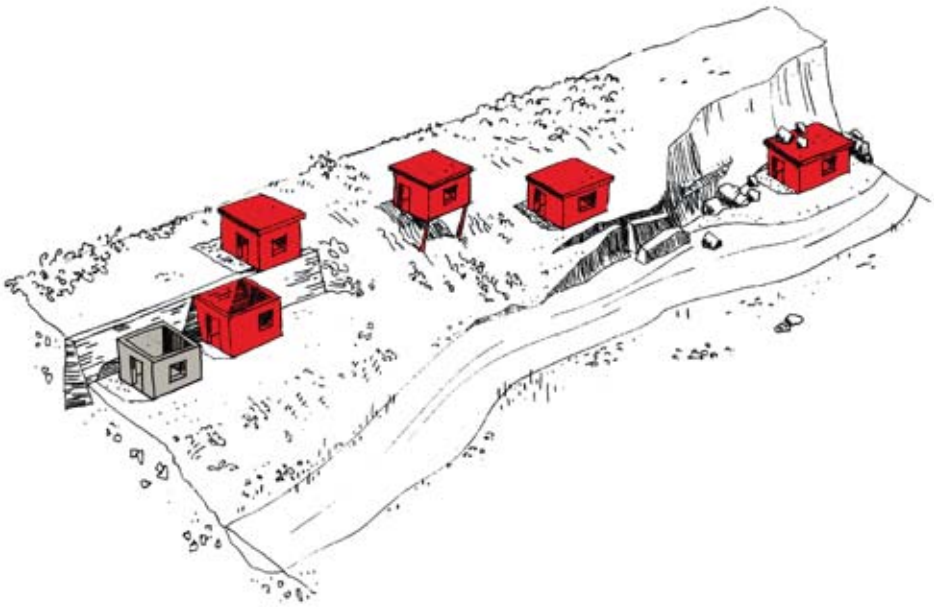
Cantilevered

Large openings are dangerous

No vertical continuity between the upper and the lower wall.

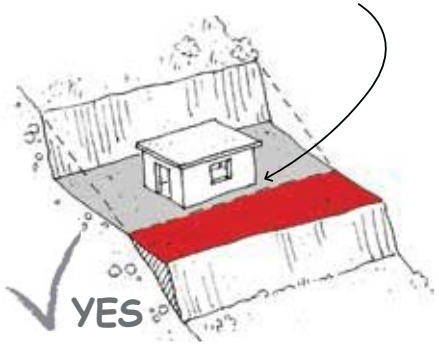
ADEQUATE LOCATION

3

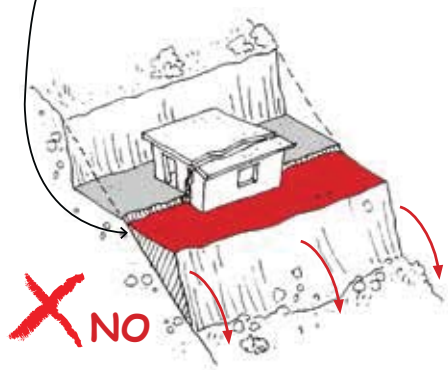


Site selection - 1

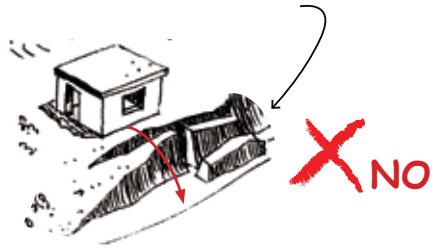
Keep enough distance on each side of the house.



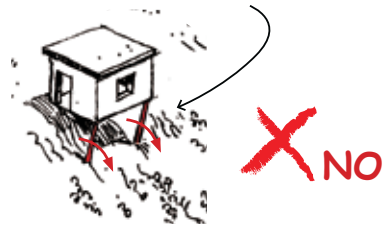
Don't build on fresh embankments.



Don't build on embankments.

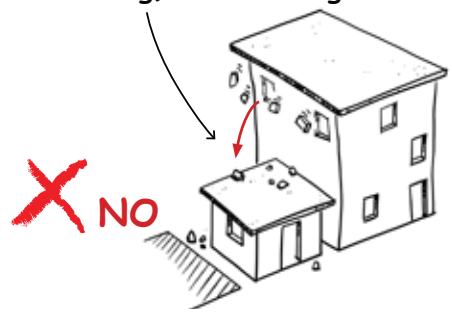


Don't build on stilts.

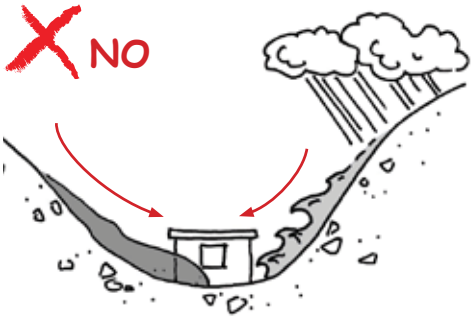


Don't build too close to a cliff.

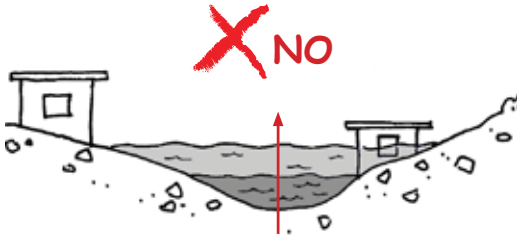
Building near high buildings can be dangerous (objects falling). Ask an engineer.



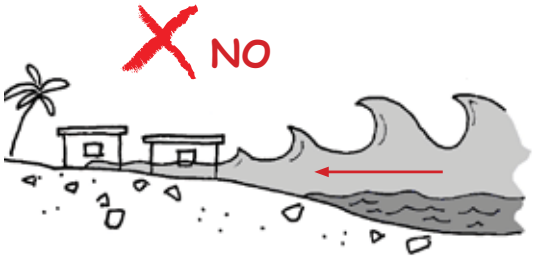
Site selection - 2



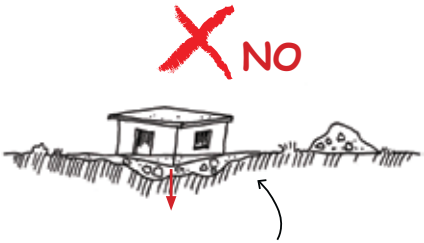
Don't build at the bottom of a canyon.



Don't build near a river.



Don't build near the ocean (due to tsunami hazard).



Don't build on fresh embankements.

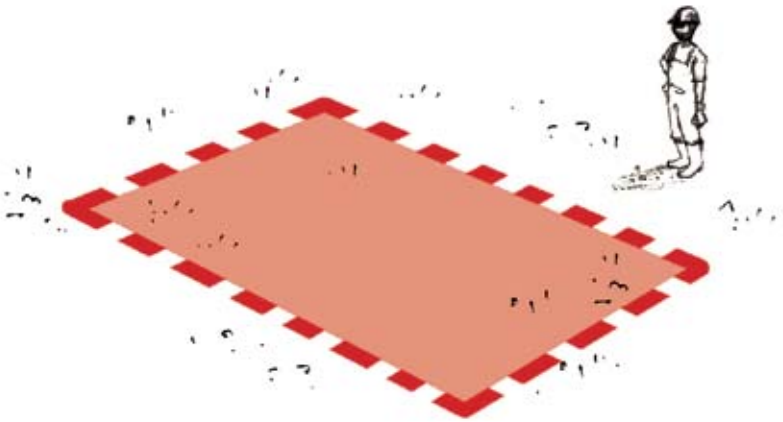
Building on a slope

Build **between** retaining walls.

Don't build against a retaining wall.

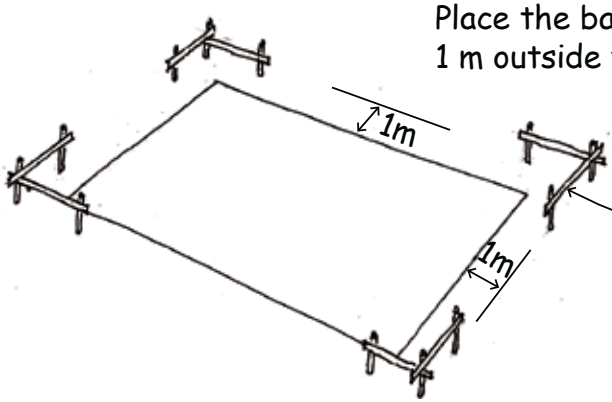
Don't build on top of a retaining wall.

LAYOUT



Layout

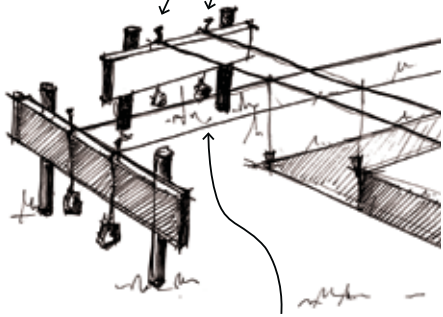
Place the batter boards
1 m outside the trenches.



batter board

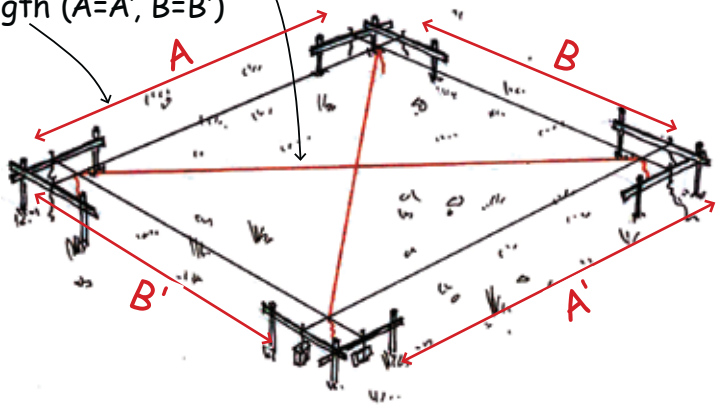
nail

Drive in nails in order
to pull strings.

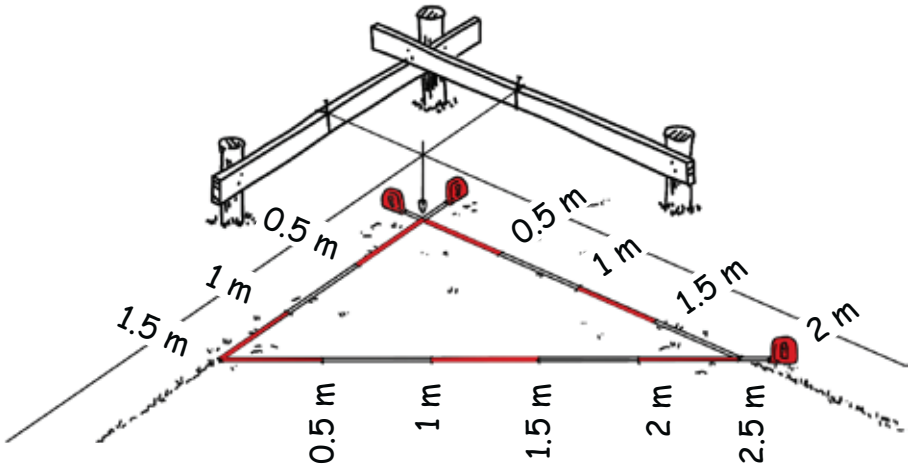


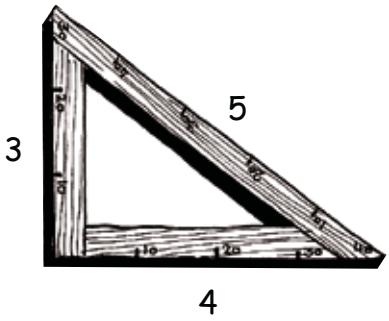
marking strings

It is a rectangle :
- if diagonals are of the same length, and
- if the opposite sides are of the same length (A=A', B=B')



Tracing a right angle (3 : 4 : 5)



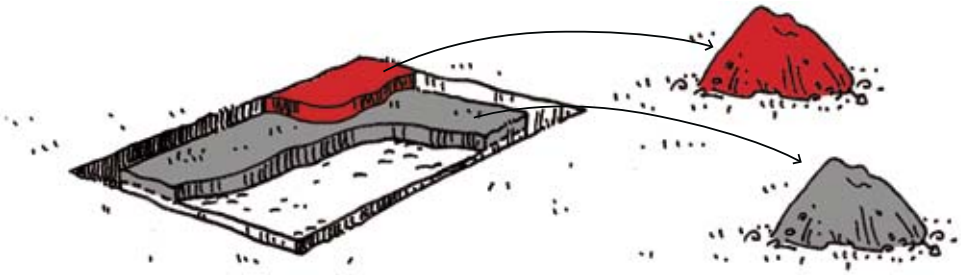


Proportion rule :

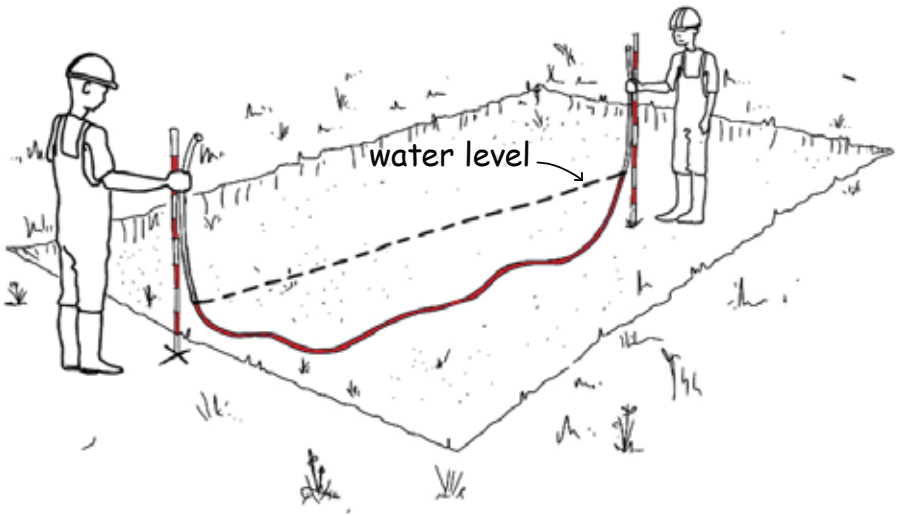
3	4	5
30 cm	40 cm	50 cm
60 cm	80 cm	100 cm
90 cm	120 cm	150 cm
1,5 m	2 m	2,5 m
2,1 m	2,8 m	3,5 m
3 m	4 m	5 m
3 ft	4 ft	5 ft
6 ft	8 ft	10 ft
9 ft	12 ft	15 ft

Site preparation

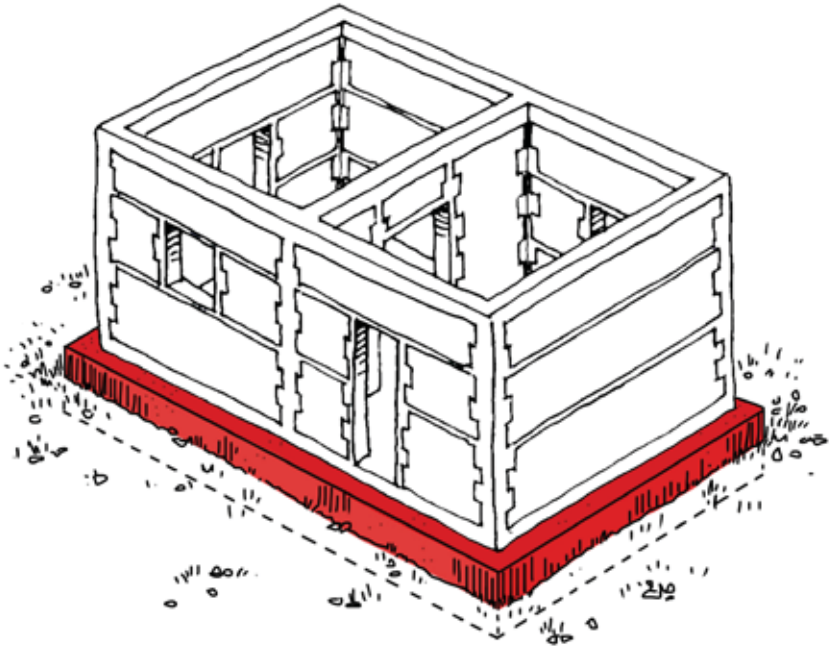
Remove the topsoil and the excavated material, and place them in different heaps, away from the excavated area.



Check whether the ground is level by using a transparent hose filled with water.



STONE FOUNDATION



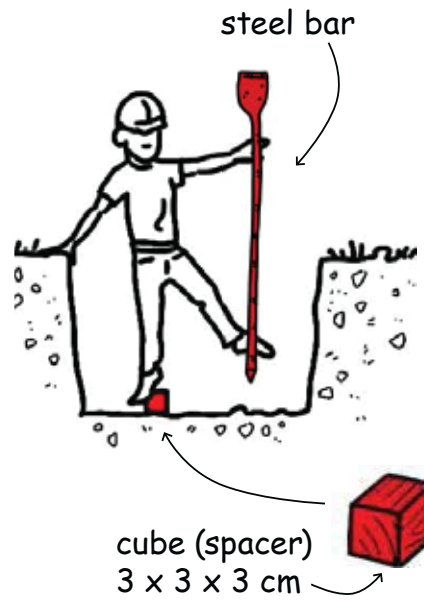
Excavation

Dig until you find firm soil.

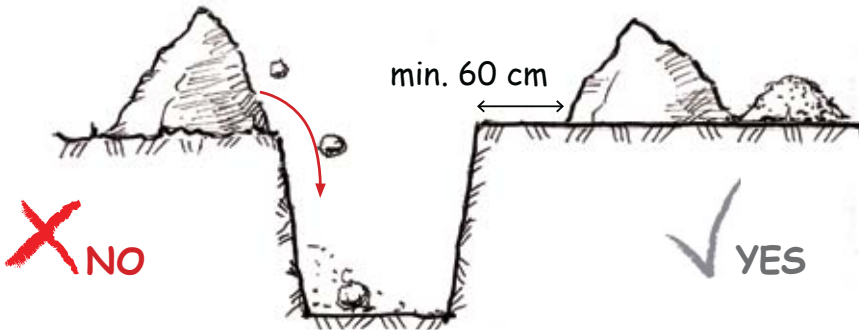
Soil test :

1. Drop the steel bar. If it remains standing, the soil is to soft. If the steel bar falls down, the soil is hard.

2. Place a concrete cube of 3x3x3 cm (can be a spacer) at the bottom of the excavation. Have a person stand on top of it. If the cube sinks in, the soil is too soft. If not, then the soil is hard.

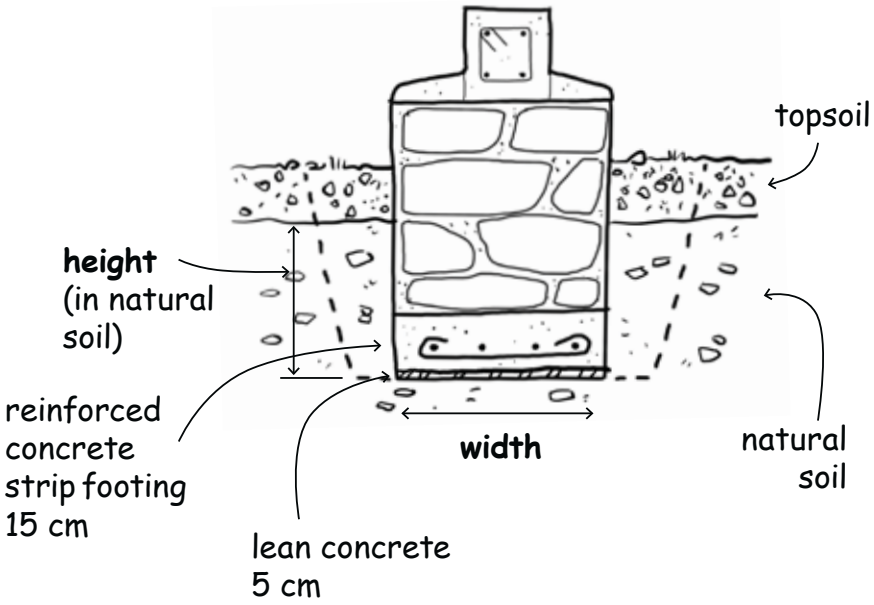


Place the soil you have dug up to a **minimum of 60 cm** away from the trenches, to avoid its falling back into the excavation.



Stone Foundation

Dig until you find firm soil,
and then build the foundation with the proper width.

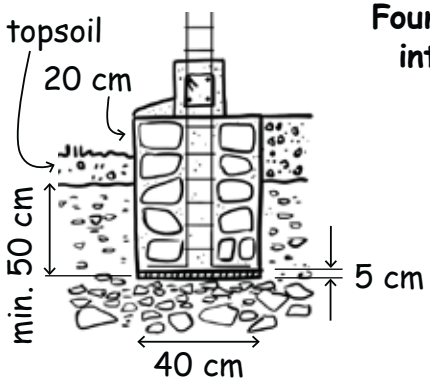


Foundation height :
Minimum 50 cm height
(under the topsoil),
until you find firm soil.

Foundation width :

hard soil :	40 cm
rammed soil :	50-60 cm
soft soil :	70 cm

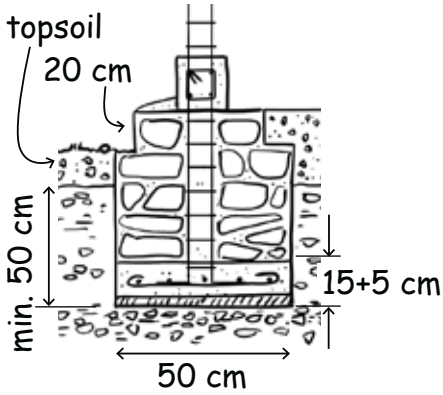
Foundation dimensions



Foundations must reach min. 50 cm into firm ground (under topsoil).

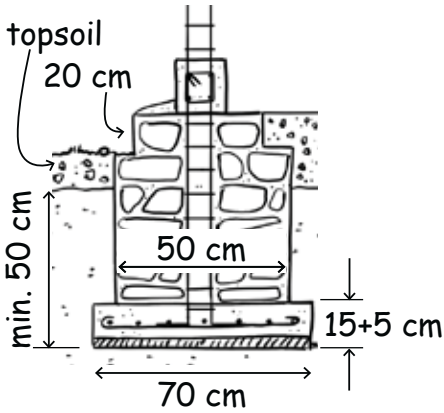
Hard soil :

- width : 40 cm
- height : min. 50 cm
  (lean concrete : 5 cm)



Rammed soil :

- width : 50 cm
- height : min. 50 cm
  (strip footing : 15 cm)
  (lean concrete : 5 cm)

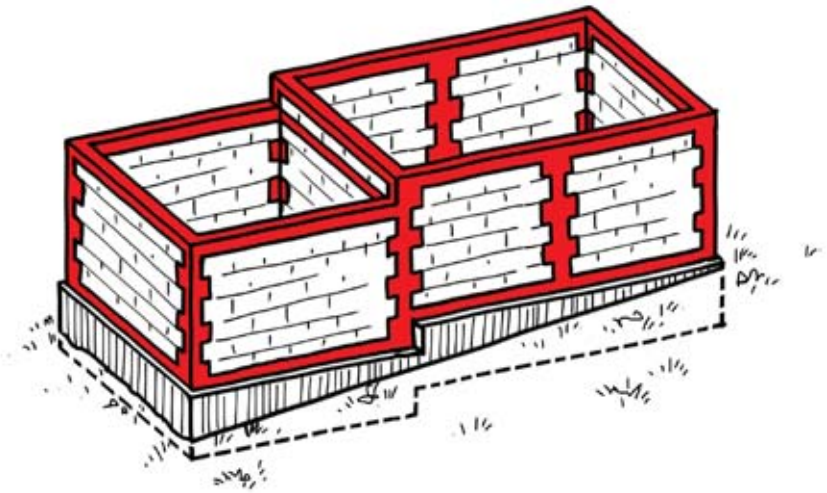


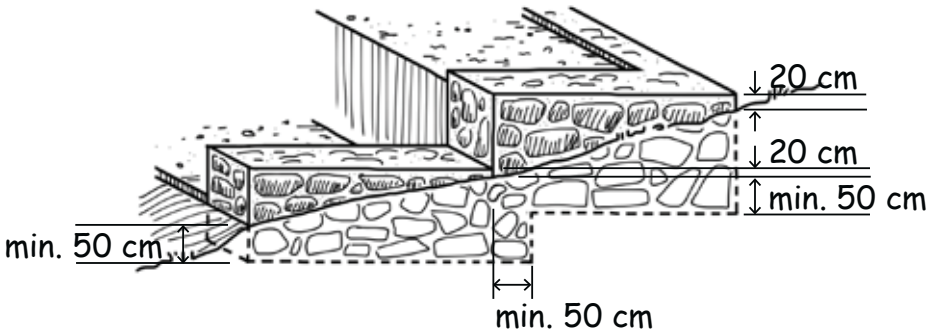
Soft soil :

- strip footing width : 70 cm
- foundation width : 50 cm
- height : min. 50 cm
  (strip footing : 15 cm)
  (lean concrete : 5 cm)

Stepped foundations

If you build on a slope, the foundation must be stepped, **keeping the bottom of the trench always horizontal.**

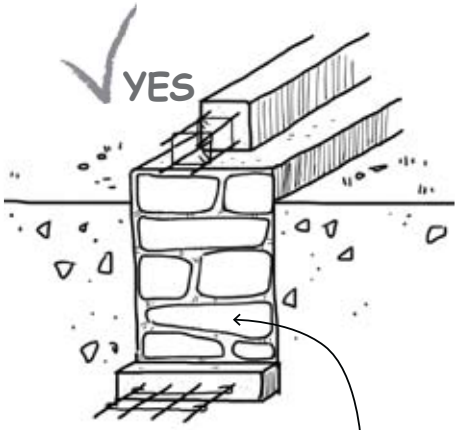




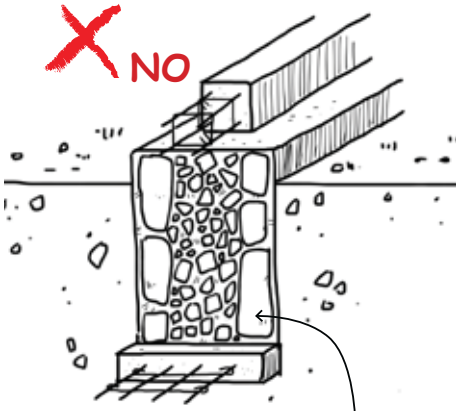
Avoid building parallel to the slope.

Stone masonry foundation

Always use running foundations in confined masonry.

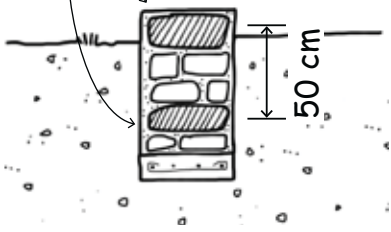


Place all the stones in a horizontal position.

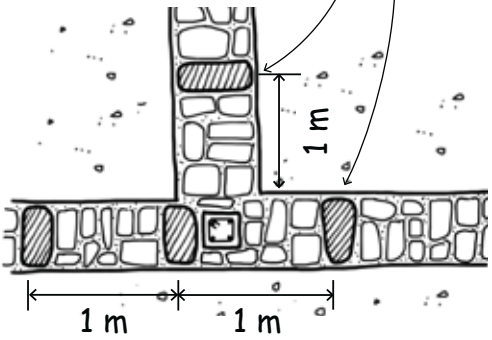


Do not place the stones in a vertical position.

Place through-stones :
Horizontally : at least every **1 m**
Vertically : at least every **50 cm**



(view in section)

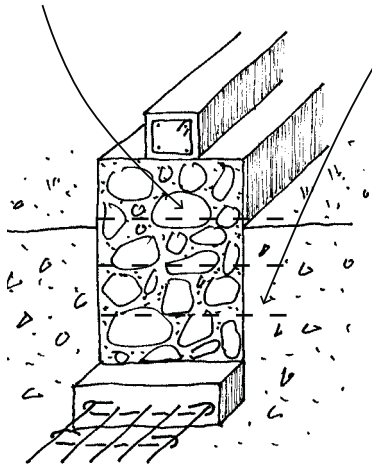


(view in plan)

Cyclopean concrete foundation

Use concrete with a 1:2:4 mix (cement:sand:gravel)
with 60% of concrete and 40% of stones.

Stones 30 cm.

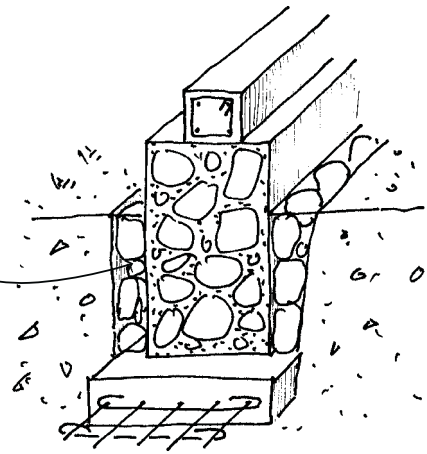


1. First pour the concrete in layers of 10 - 30 cm.

2. Then in each layer of fresh concrete place the stones with the 40% - 60% rule

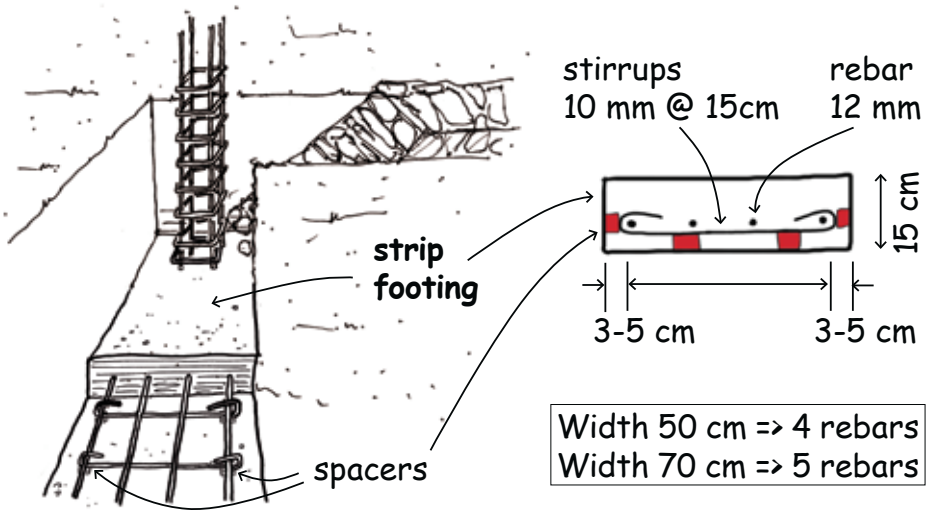
Note : It is very important to pour the concrete before placing the stones, to avoid creating empty pockets under the stones.

If the strip footing is larger than the foundation : instead of formwork, it is possible to place stones on each side, without mortar, before pouring the cyclopean concrete.

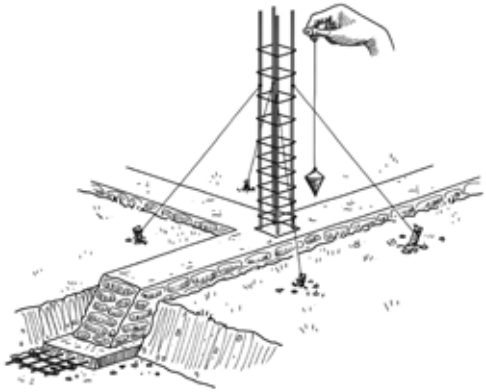


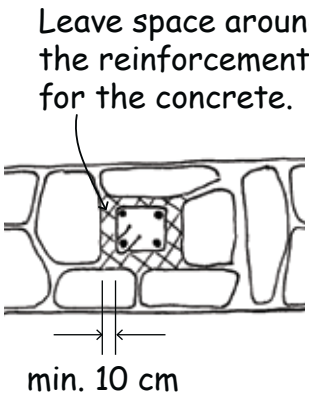
Reinforced concrete strip footing

A strip footing must be used for soft soil conditions.
It is also recommended for other soil conditions.



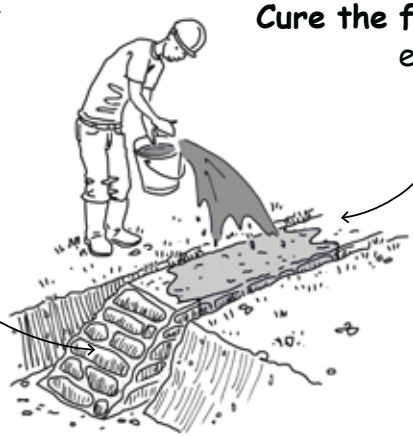
Before pouring the concrete,
make sure the reinforcement is perfectly vertical.





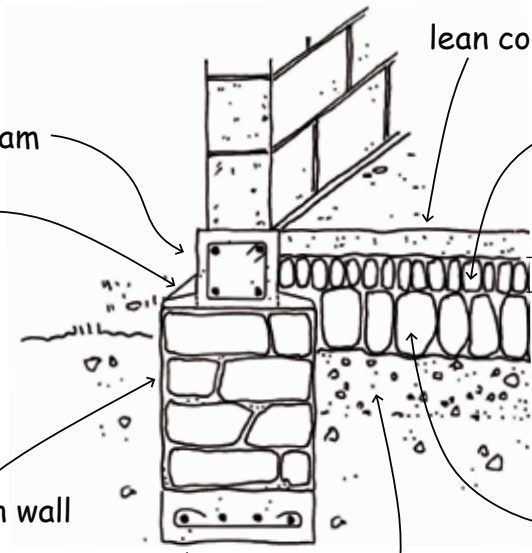
Curing and ground floor

Always interrupt foundation work on a sloped and stepped line.



Cure the foundation walls : every day, for the three first days.

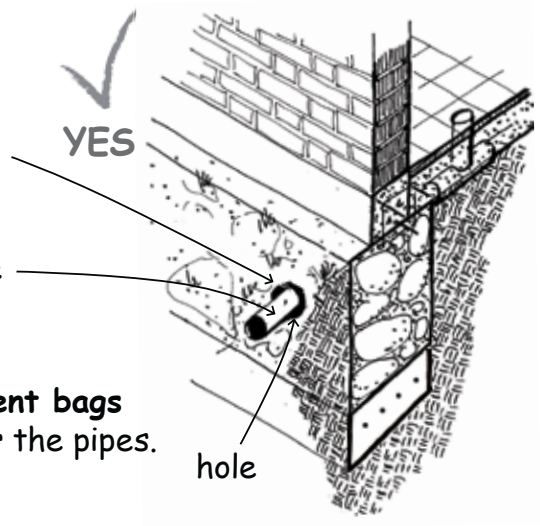
Build a "drainage bed" with round stones, to prevent humidity from coming up from the ground.



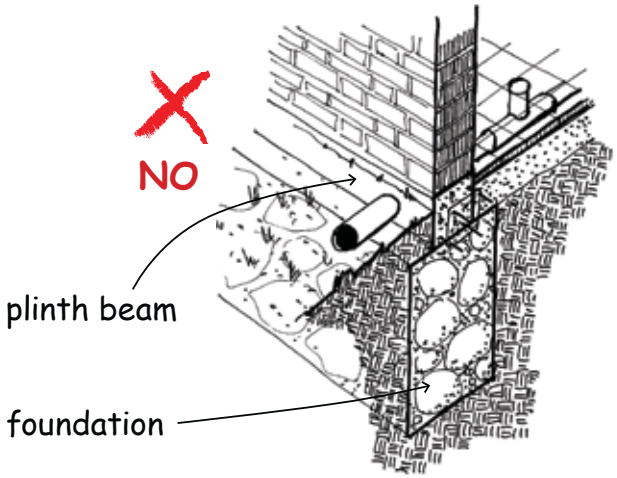
Placing sewage pipes

The pipes must go through the foundation,
under the plinth beam.

Place a larger diameter tube first, and place the final pipes inside.

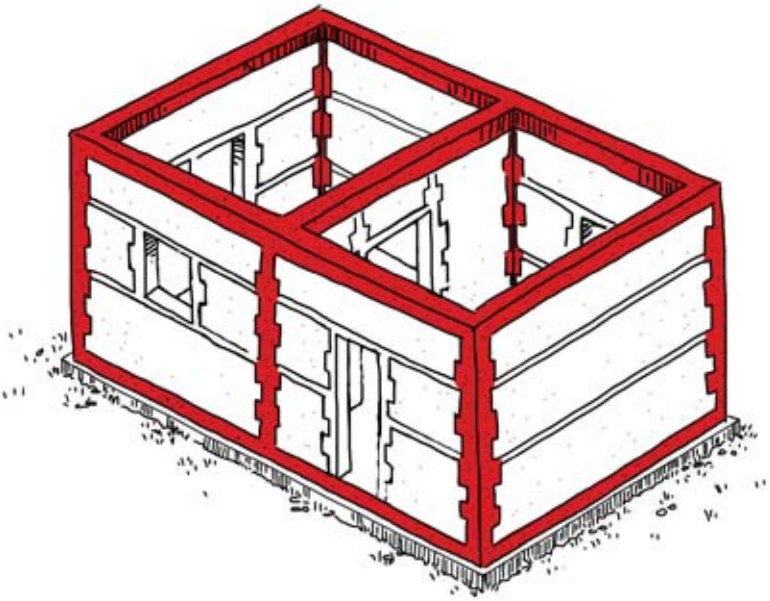


Never use empty cement bags to create a passage for the pipes.



Do not go through the plinth beam.

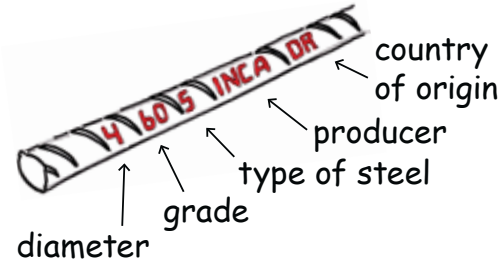
Reinforced Concrete Ties



Types of steel rebars

Always use ribbed steel.

Do not use second hand rebars.

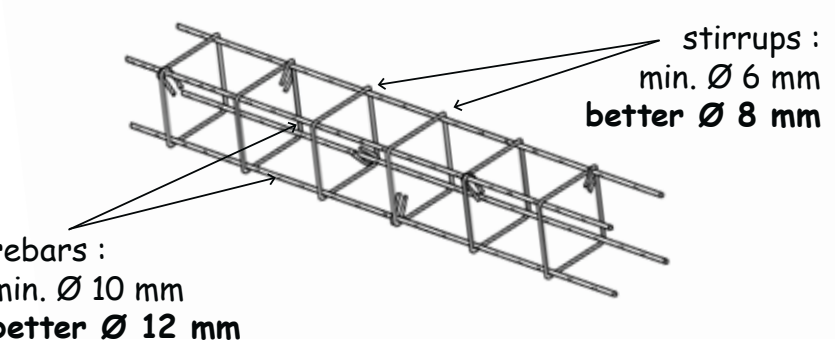


Rebar diameter (metric and imperial systems) :

metric	imperial	inch
12 mm	#4	1/2"
10 mm	#3	3/8"
8 mm	- no equivalent -	
6 mm	#2	1/4"

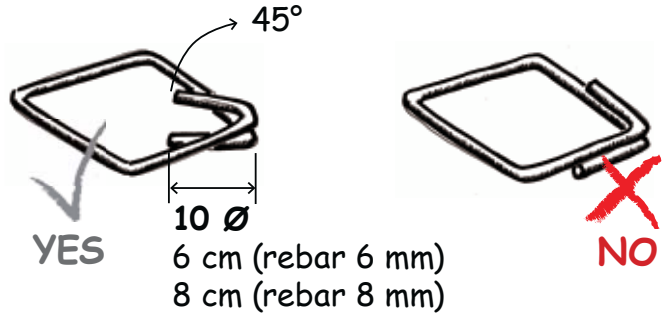
For confined masonry **Grade 60** should be used.
Always use **standard rebars** (not sub-standard).

Recommended diameters for vertical and horizontal ties :

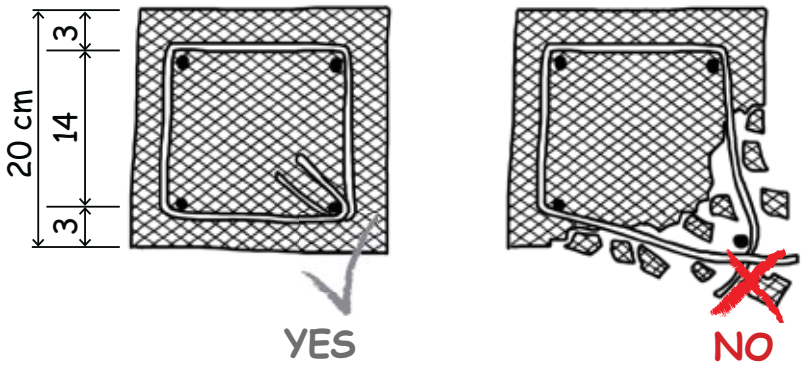


Stirrups

Bend stirrup ends at 45° to make proper hooks.



If stirrups are not bent at 45°,
they will open during an earthquake.



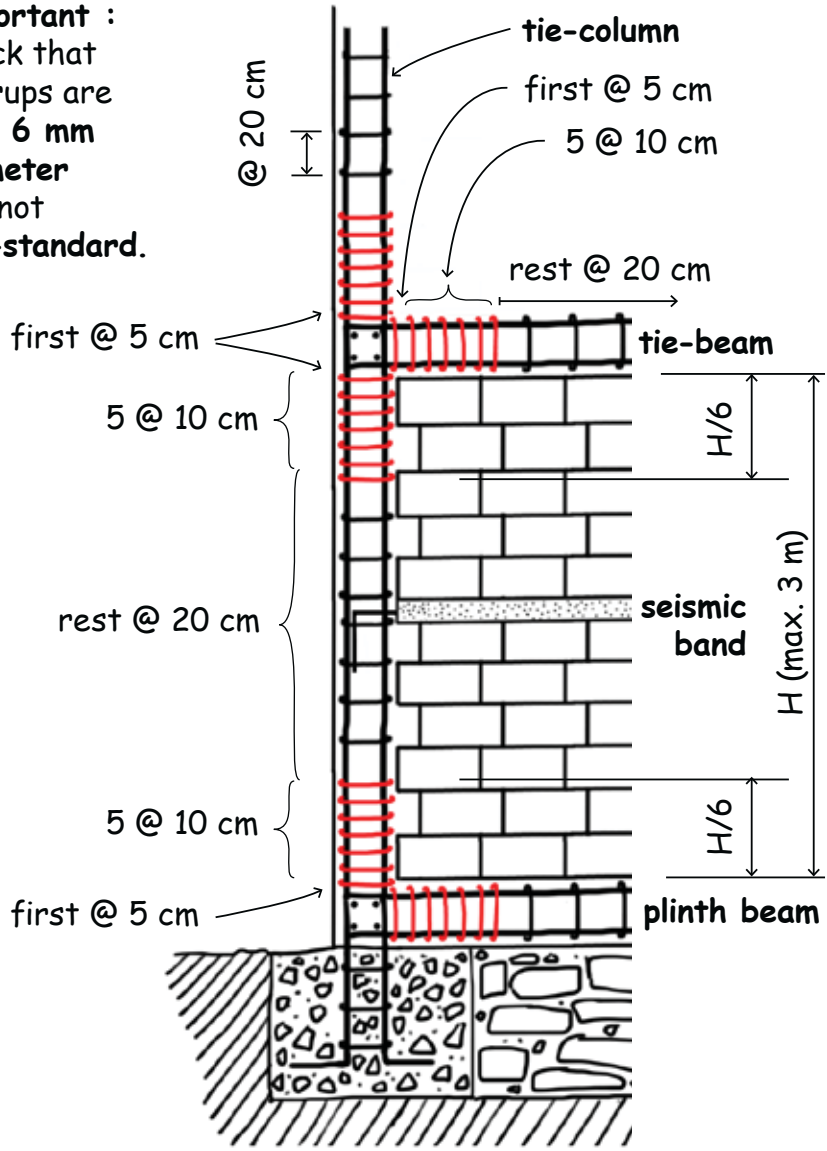
Stirrups for ties
(columns and beams) :

Stirrups for seismic bands
and opening reinforcements :

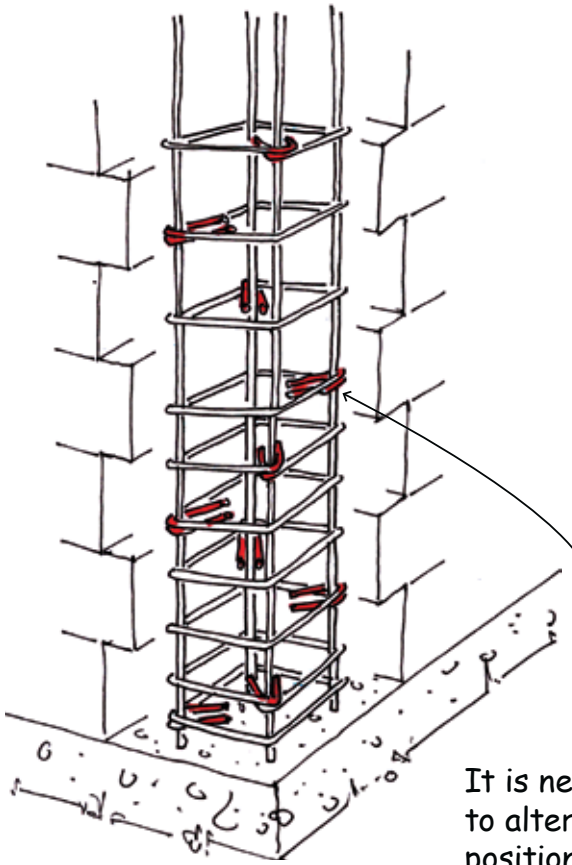
Stirrup spacing

with stirrups of **min. 6 mm** (better 8 mm)

Important :
Check that stirrups are **min. 6 mm diameter** and not **sub-standard.**



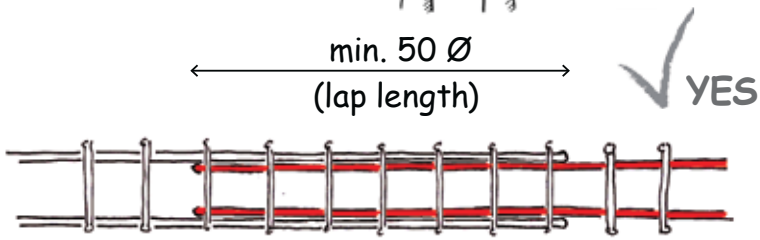
Alternate stirrup positions



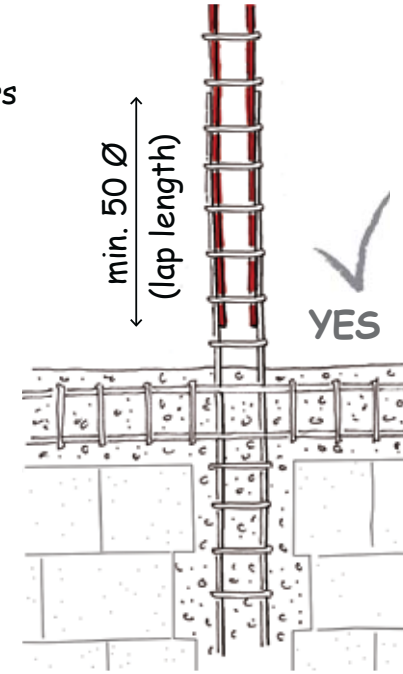
It is necessary to alternate position of stirrup hooks.

Lap length

The concrete keeps the rebars together like tight fists :
the more fists we have (longer overlap)
the stronger the connection !



Tie wires only hold the rebars in place. They don't add strength to the connections.

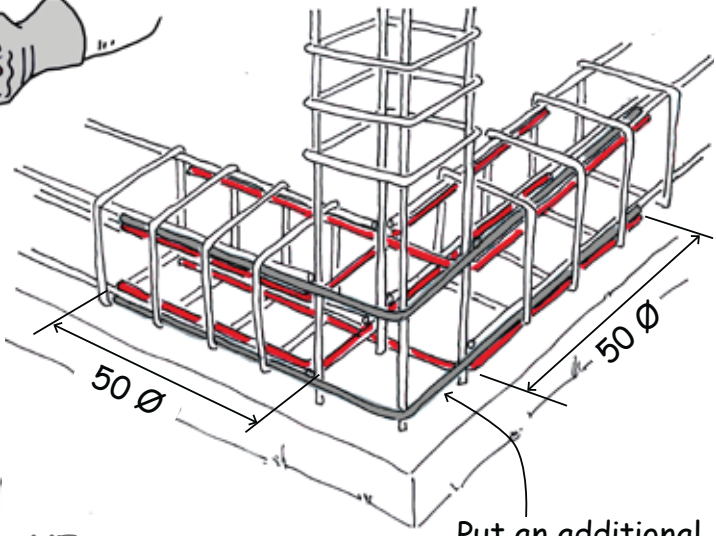


Lap length :
(overlapping)
50 x Ø
(50 times the diameter)

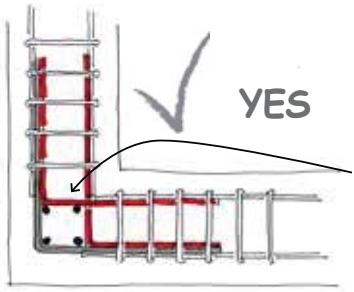
for 10 mm rebar = 50 cm
for 12 mm rebar = 60 cm

Tie-beam : L-connection

Rebars must cross like the fingers of a hand.

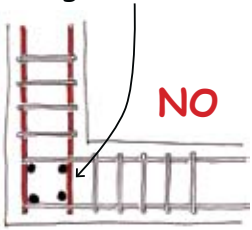


Put an additional rebar around the outer corner.

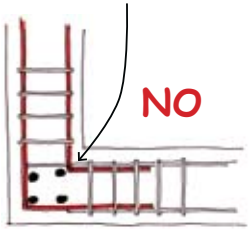


Extend bent bars **from the inside to the outside.**

Connection with straight bars.

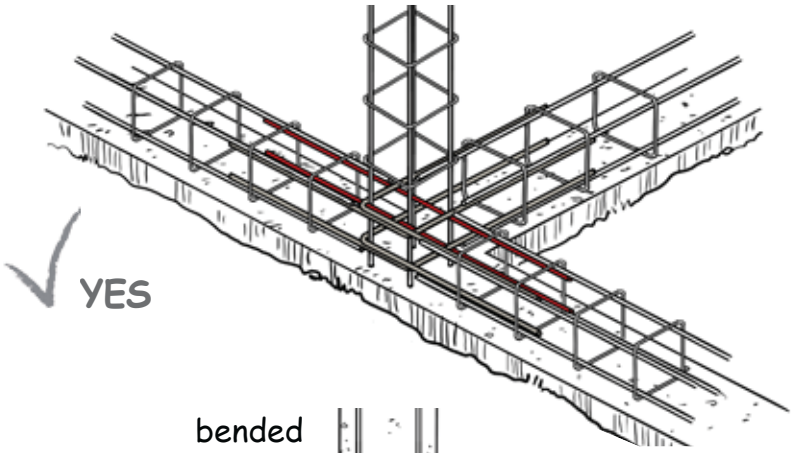


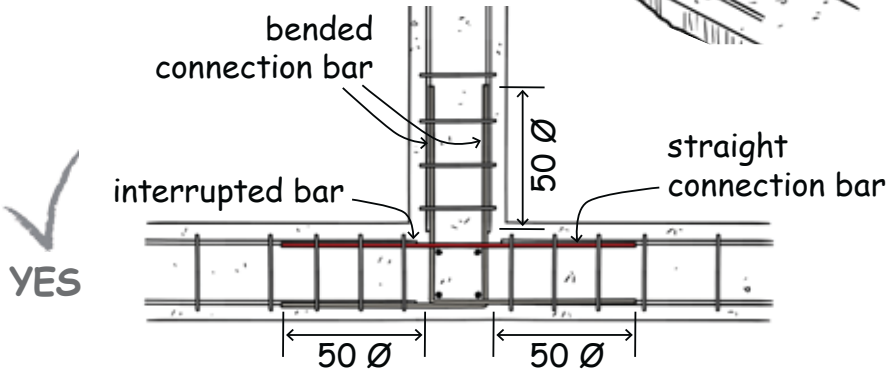
Connection from inside to inside.

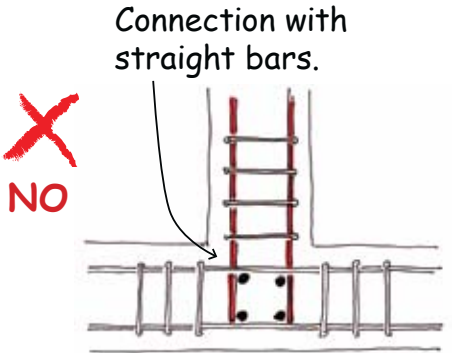


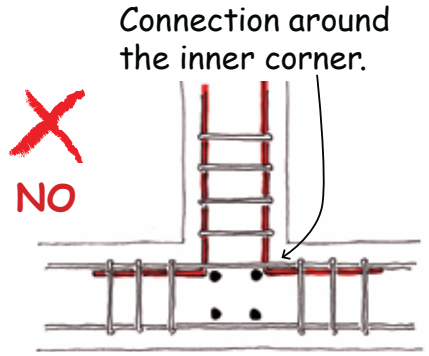
Tie-beam : T-connection

Always extend bent bars **from the inside to the outside.**



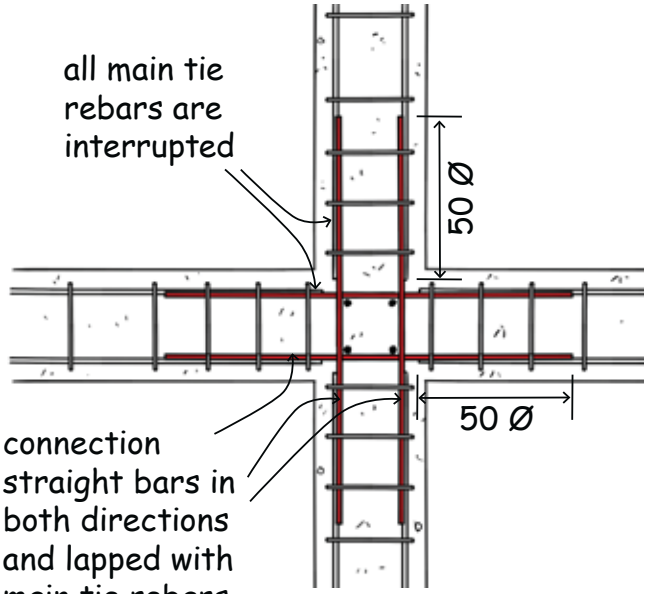




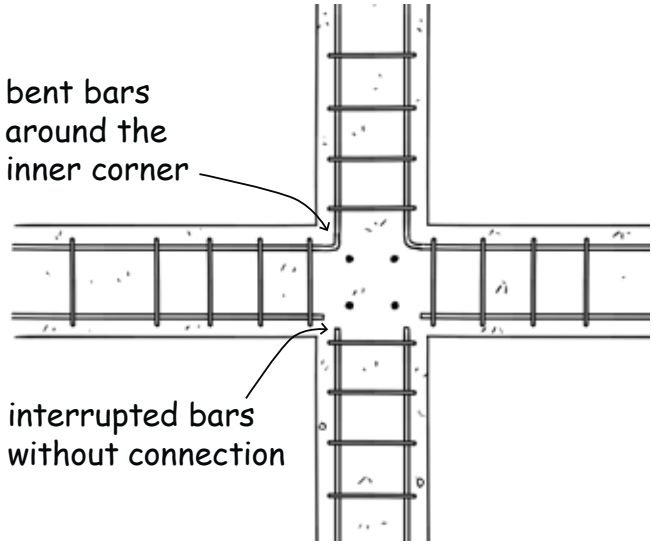


Tie-beam : X-connection

YES

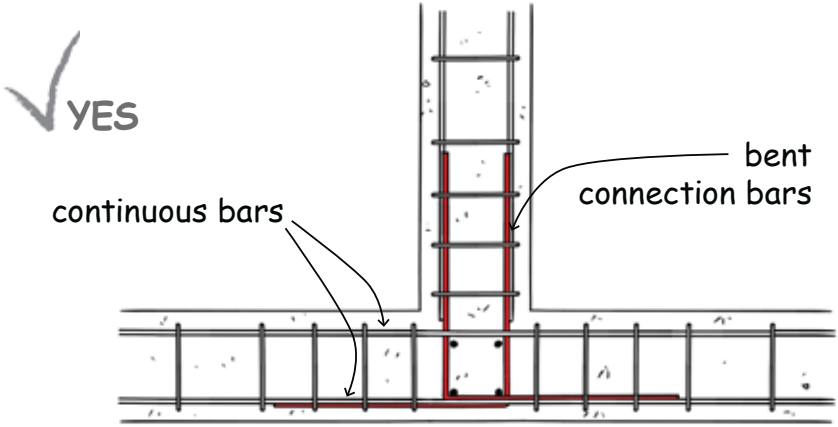


NO

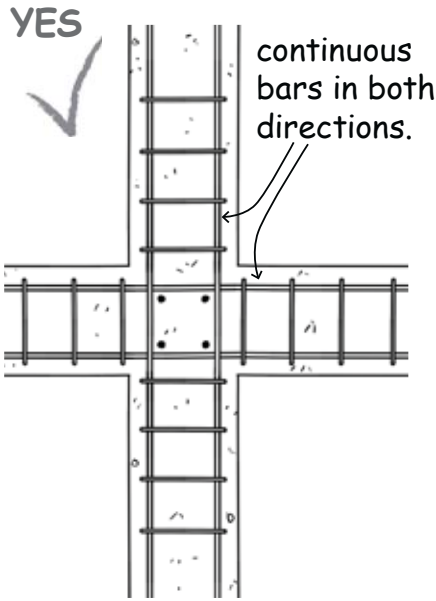


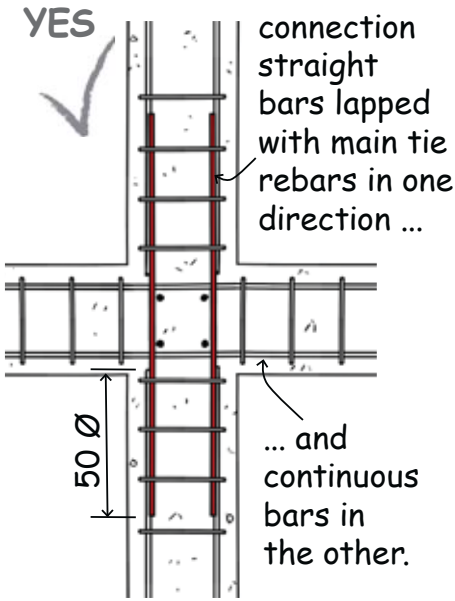
Connections with continuous rebars

Solution for T-connection :

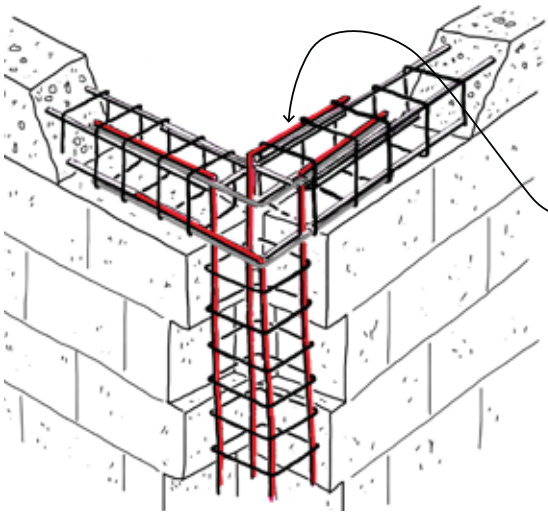


Solution for X-connection :



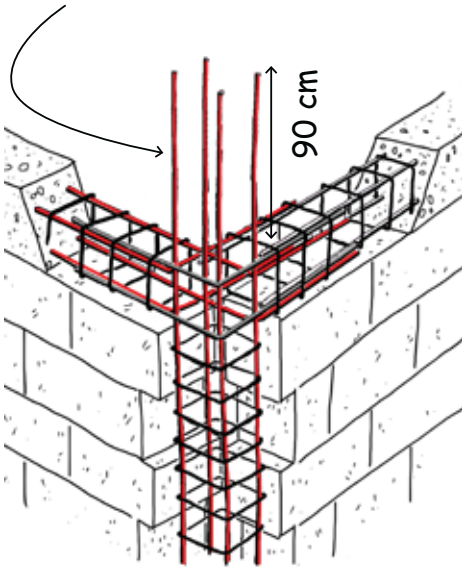


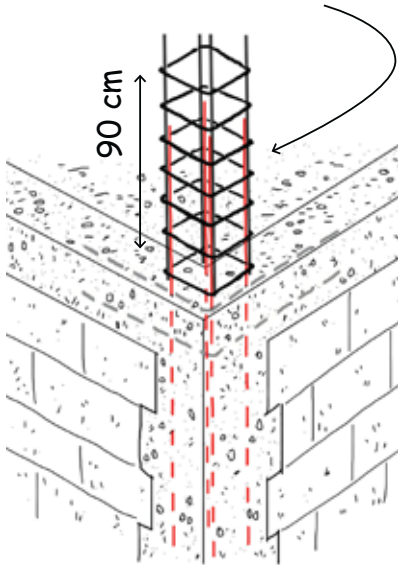
Tie-beam to Tie-column connection



In the last storey, bend the vertical rebars toward the tie-beam and into the strirrups.

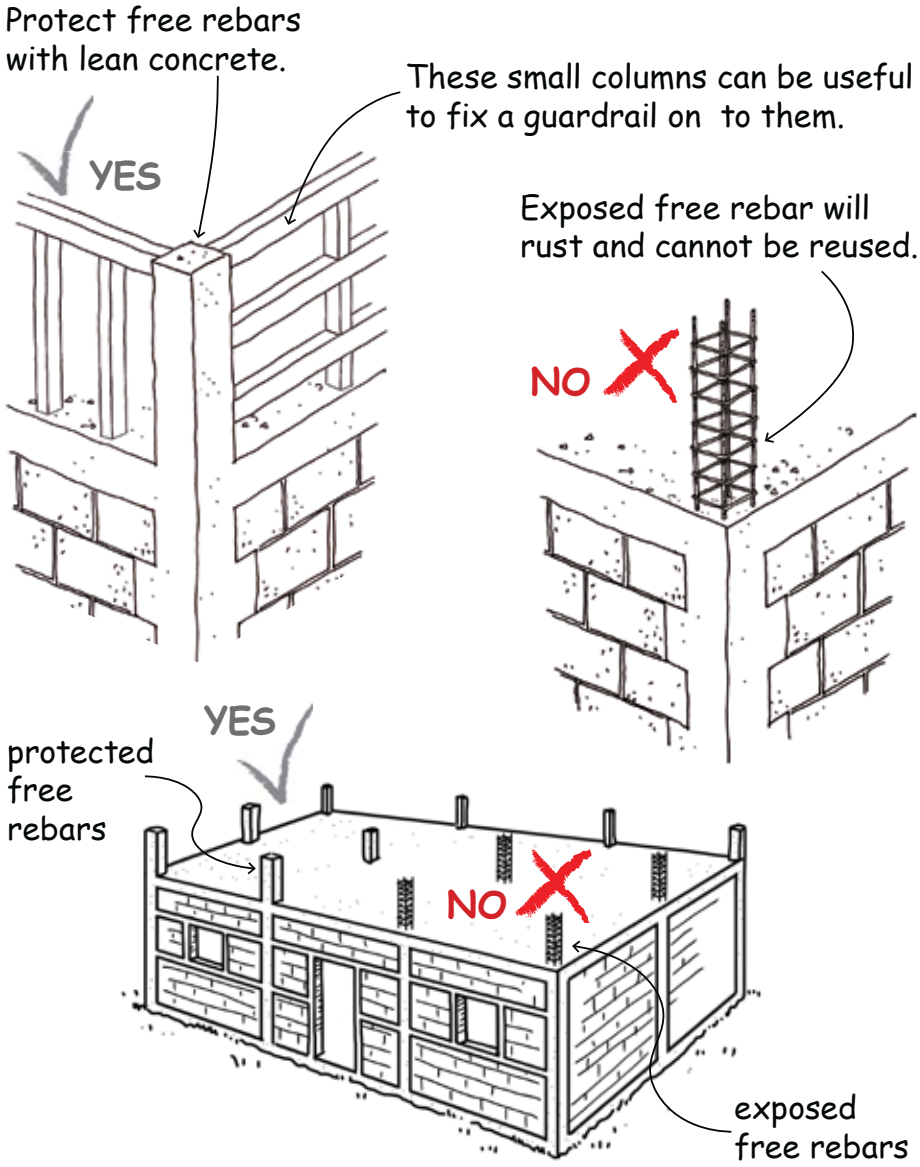
If a second storey will be constructed in the future, leave 90 cm high free vertical rebars.



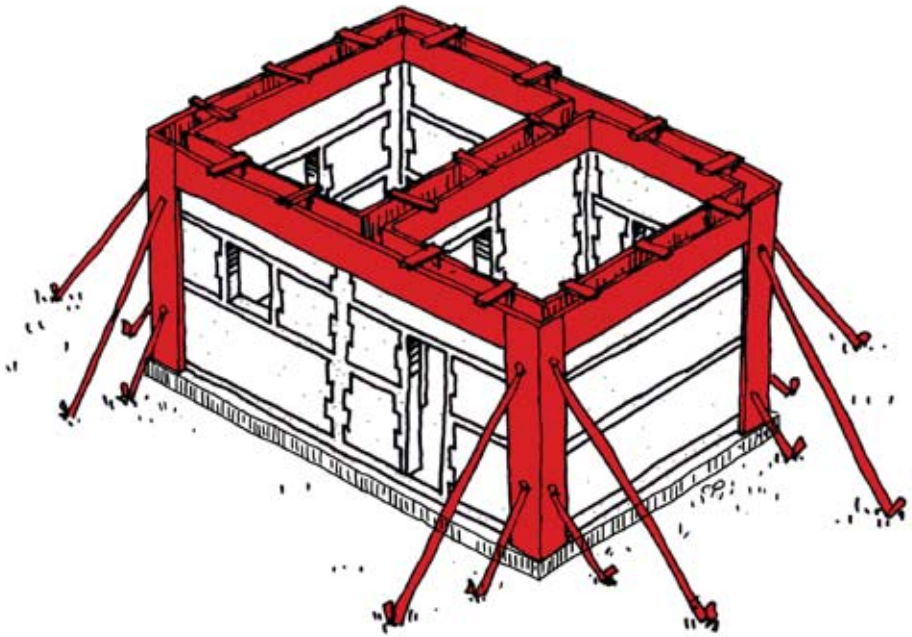


Protection of free rebars

Allowed only on top of the first floor.



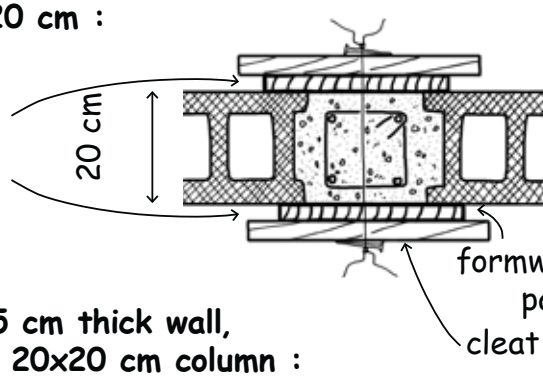
FORMWORK



Formwork for tie-columns - 1

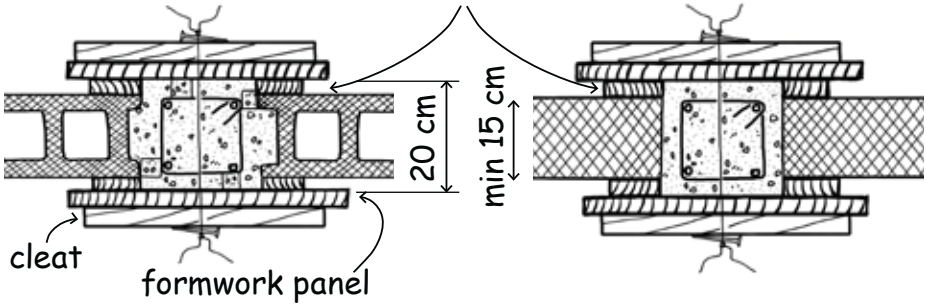
Wall thickness 20 cm,
Column dimension 20x20 cm :

place formwork
panels on both sides.



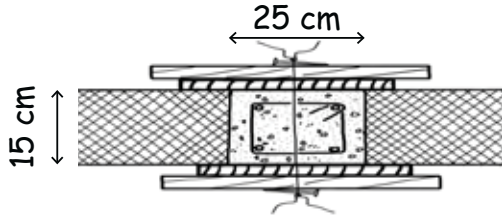
15 cm thick wall,
with a 20x20 cm column :

Place a 25 mm board under the formwork panel.



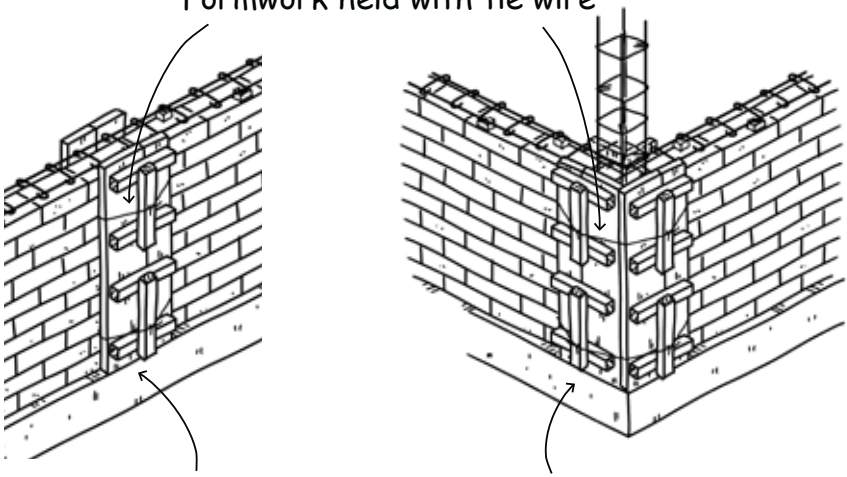
15 cm thick wall,
with a 15x25 cm column :

Columns of the same width as a 15 cm wall must measure min. 25 cm, to allow the vibrating needle to enter.

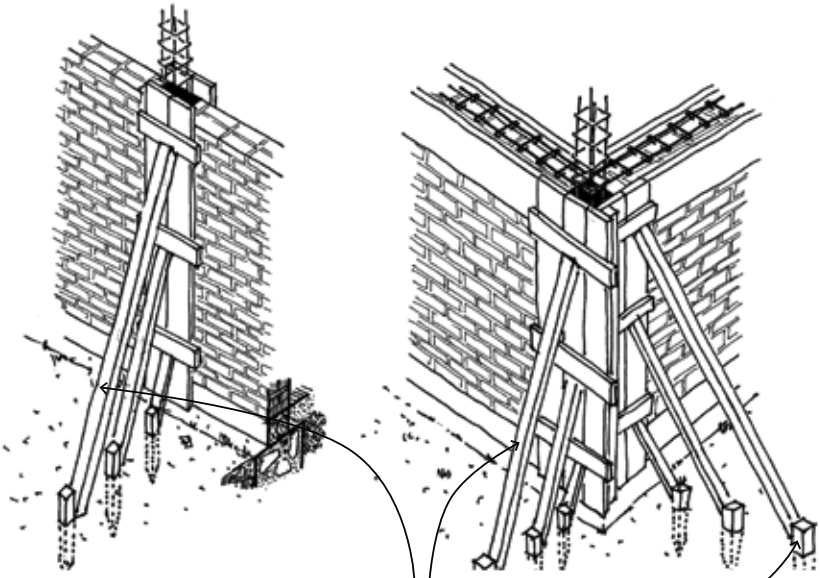


Formwork for tie-columns - 2

Formwork held with tie wire



Warning : wait until the masonry and the mortar have hardened before placing this type of formwork. Otherwise the tie wire will move the bricks or blocks.



Formwork held with bracings and stakes.

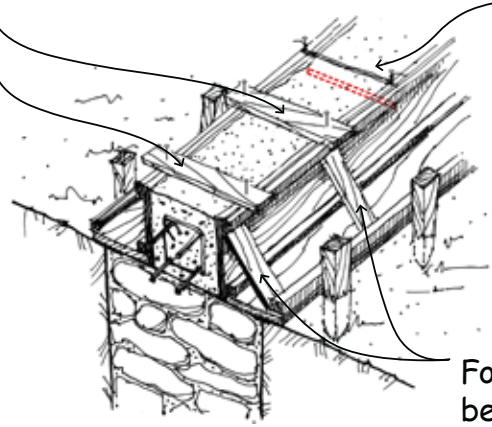
Formwork for tie-beams

YES

NO

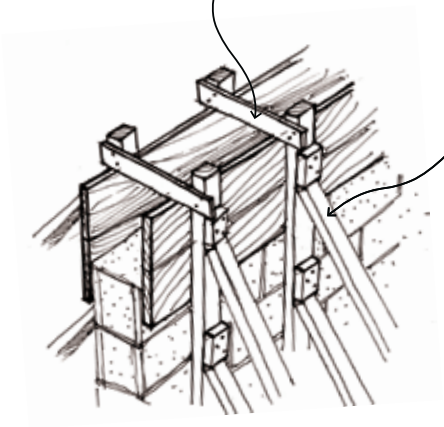
Use wooden planks to connect the formwork.

Don't use tie-wire to maintain distance.



Formwork must be well fastened.

Wooden planks provide more accuracy and stability than tie-wire.

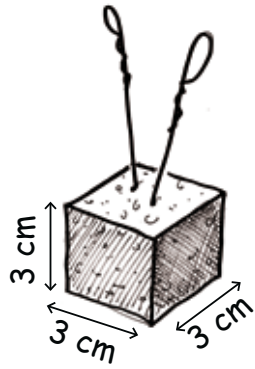


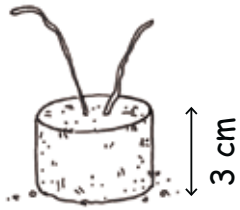
Formwork must be well braced !

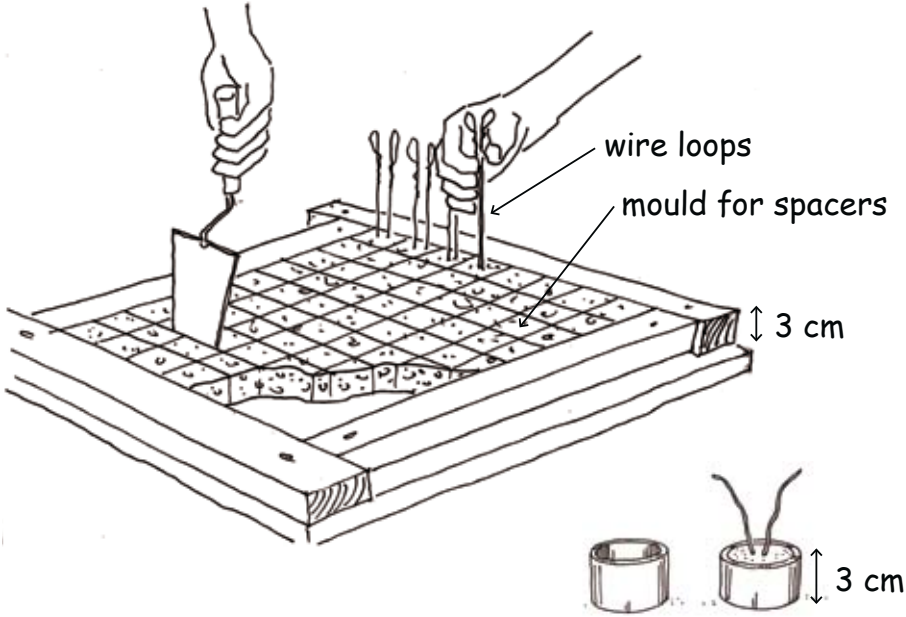
Spacers - how to make them

Spacers are very important : they ensure that the rebars remain in the right place and are well covered by concrete.

Don't use stones to fix the rebars,
use spacers with wire loops instead !

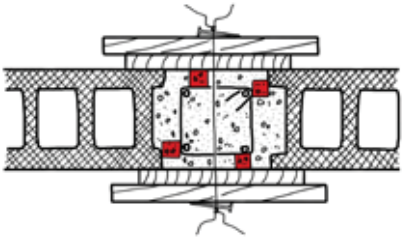




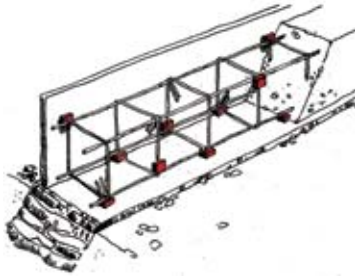


Spacers - how to use them

Add spacers on all sides
to avoid rebars touching the formwork.

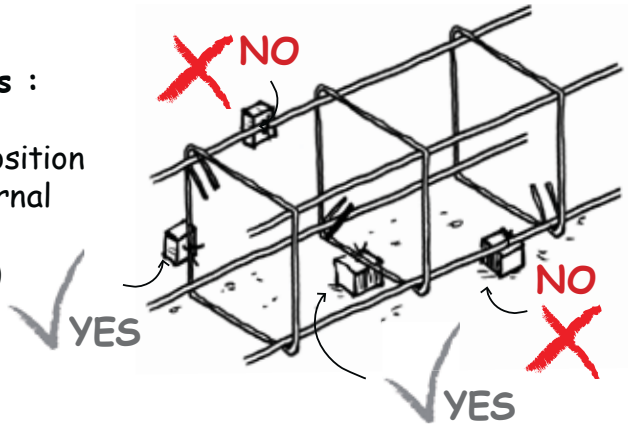


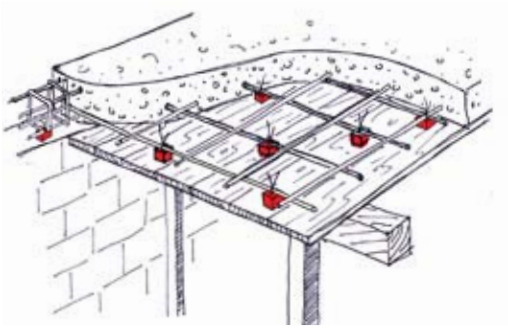
tie-column



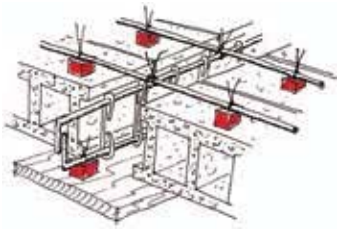
tie-beams

Placing the spacers :
- every 50 cm
- alternate their position
- on the most external rebars (stirrups on confining elements)



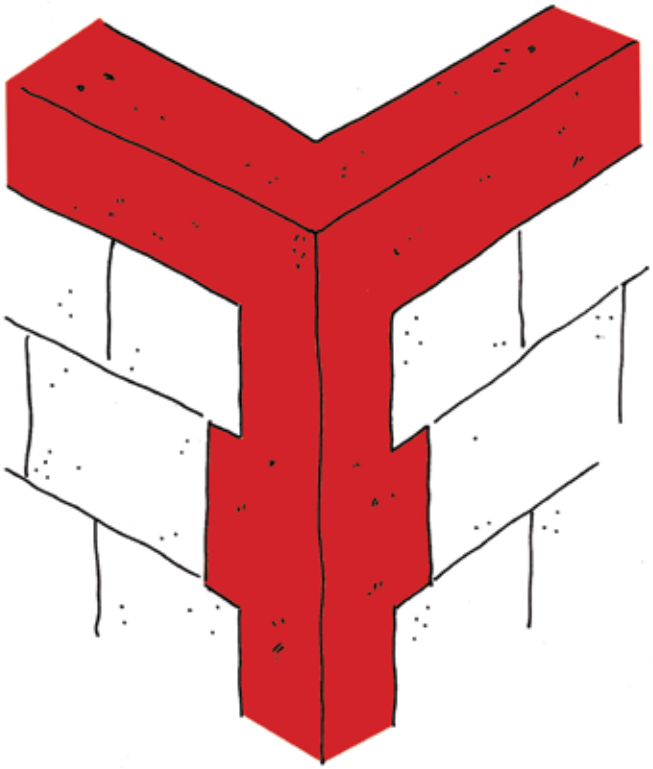


reinforced concrete slab



joist and pan slab

CONCRETE



Concrete mix (1 : 2 : 3)

The most common and preferred mix is = 1 : 2 : 3

1 part cement

3 parts gravel (round and max. 18-20mm diameter)

2 parts clean sand (washed and dry)

3/4 part clean water

Table of various concrete mixes (by volume) :

Use	**cement**	**sand**	**gravel**	**mix**
cyclopean foundation	1	2	4	200 kg/m3
tie columns & beams	1	2	3	250 kg/m3
free columns & beams	1.5	2	3	350 kg/m3
lean concrete	1	3	5	

Note :

A concrete of 250 kg/m3 contains 250kg of cement per cubic metre of concrete.

Mixing concrete

Mixing the concrete by hand :

1. Make a pile with the gravel, the sand and the cement but **without water**.

2. Mix the pile without water and **move it twice** with a shovel.

3. Add the water **only now** and mix again.

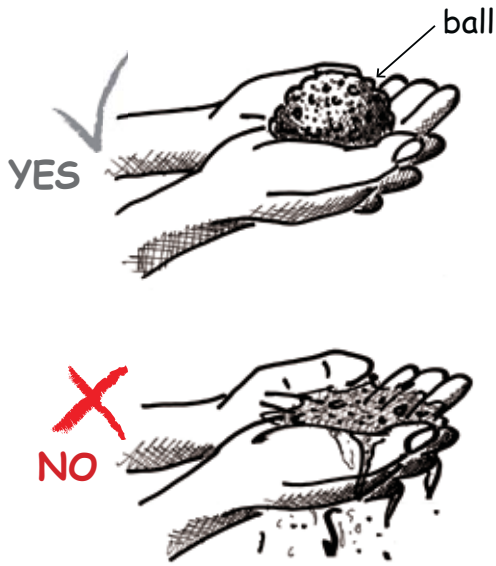
Mixing with a concrete mixer :

1. Add 1/2 water and cement, mix 1 minute.
2. Add aggregate, mix 1 minute.
3. Add rest of water slowly, mix 3-4 min.

Always use the concrete within 1 hour after mixing.

Concrete test

QUICK TEST :
Take a handful of concrete. If the concrete leaks through your fingers, it is too wet !

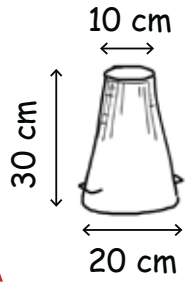


Concrete must be **used in less than 1 hour.**
Never "refresh" dried concrete by adding water.
Don't mix too much concrete at a time.

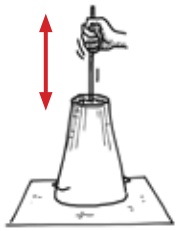
Slump test

SLUMP TEST PROCEDURE :

Use a standard Abrams steel cone :



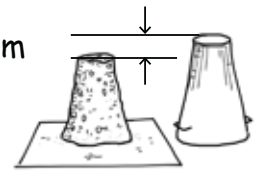
1. Fill cone in 3 equal layers.



2. Tamp down each layer 25 times with a rod (rebar).

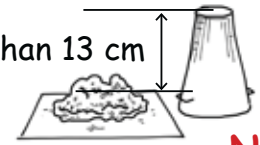
3. Lift the cone vertically and place next to the slump.

3 - 13 cm



YES

more than 13 cm



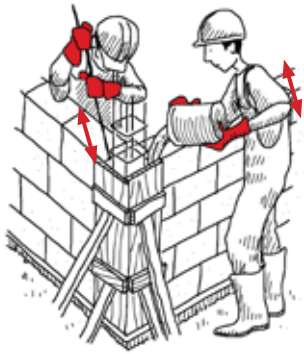
NO

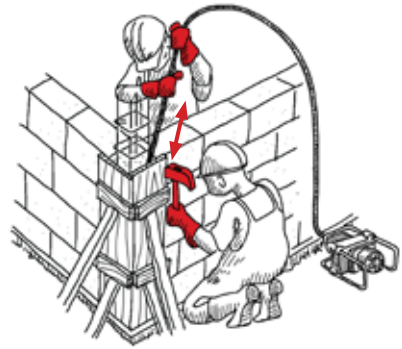
Explanation of the results :

Recommended 3 - 10 cm

workability	**mm**	**usage**
very low	0 - 30	Very dry mix : for street works only.
low	30 - 50	Foundations with few reinforcement.
medium	50 - 100	Compacted and vibrated concrete.
high	100 - 130	Parts with many reinforcements and/or thin structural elements.

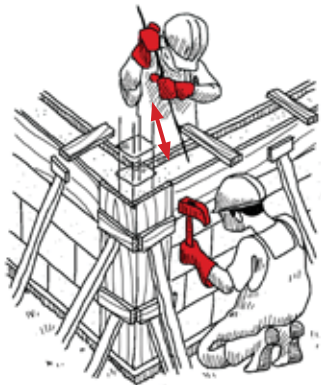
Pouring concrete

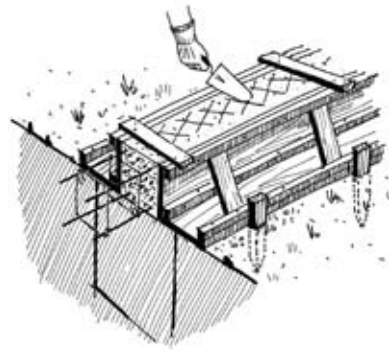




Pour concrete in layers of 30 - 50 cm and compact it with a rod (rebar) and a hammer to avoid air pockets, or **better : use a needle vibrator** if available.

Never add water to make the concrete more liquid to "flow down better".



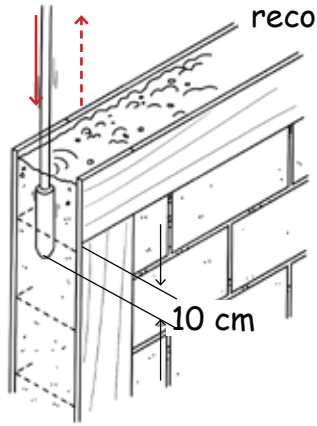


Roughen up the top surface of the plinth beam to increase bonding of the mortar of the wall.

Compacting with a needle vibrator

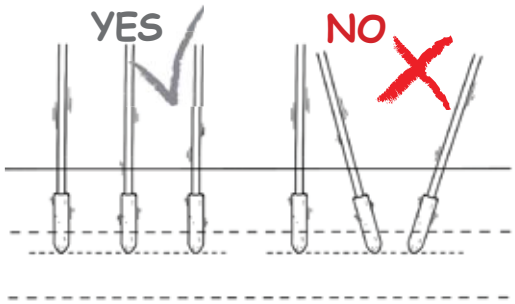
The concrete has to be compacted to remove air pockets, the needle vibrator will cause the air to move upwards.

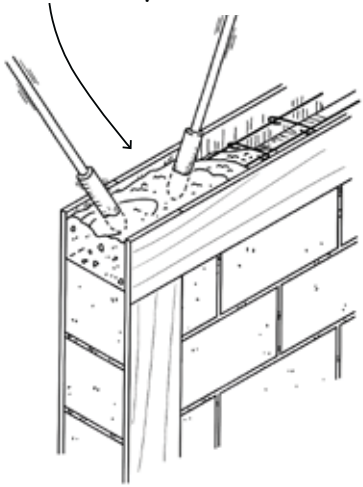
1. Insert the needle vertically until it enters 10 cm into the previous layer.
2. Leave it 10 to 20 seconds for standard concrete. Not more or the concrete will desegregate! With very fluid concrete (not recommended) vibrate 5 to 10 seconds.



3. Lift the needle slowly (the air moves up 2.5 to 7.2 cm per second).
4. The concrete will not be vibrated by solely touching the rebars with the needle.
5. Do not use the needle to move the concrete sideways.

Progress regularly in one direction, keeping in mind that the range of the needle is 8-10 times its diameter.





Curing the concrete

Concrete must not "dry", otherwise it will be weak.
Concrete needs water to harden!

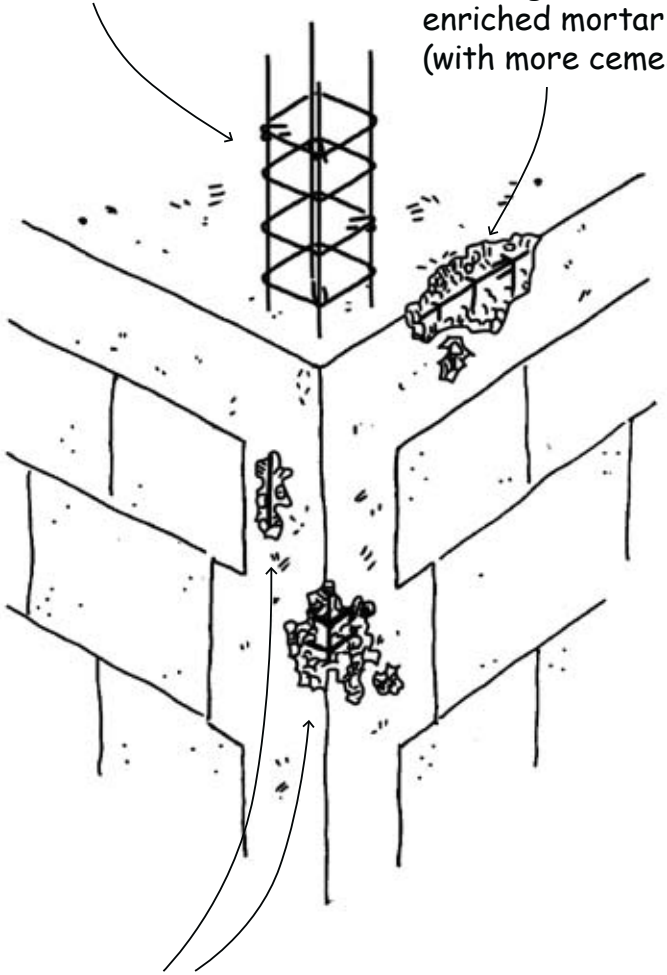
After pouring concrete, cure the concrete by wetting the formwork 3 times a day for 3 days. Remove formwork only after three days.

After the formwork is removed, cure the concrete for 7 more days, and cover it with plastic sheets.

Ensure good quality concrete

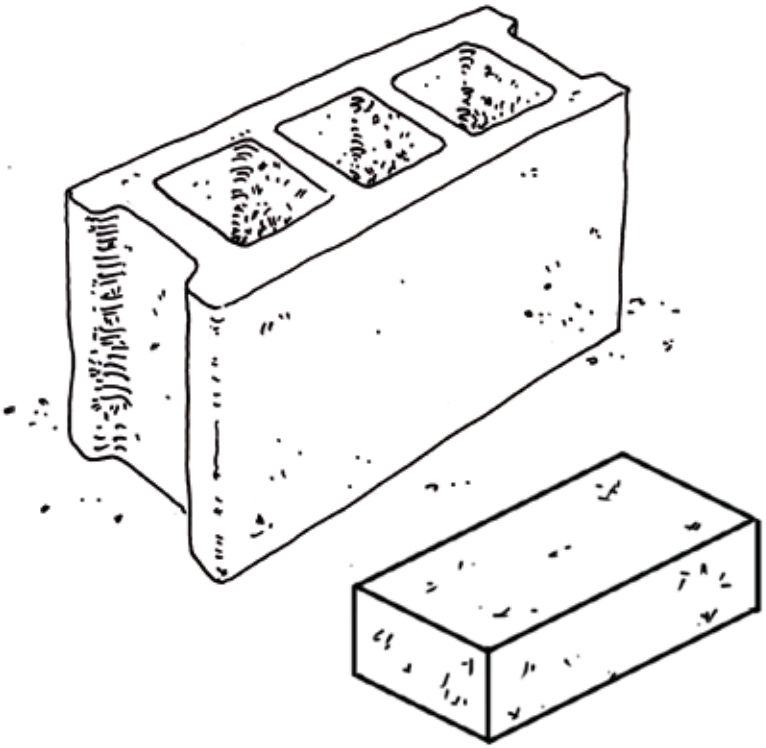
Protect the free steel reinforcements by casting a small column with lean concrete.

Protect exposed rebars from rusting by rapidly covering them with an enriched mortar (with more cement).

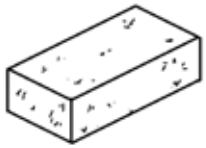


Cavities caused by air pockets due to poor compaction and when removing a vibrating needle too fast.

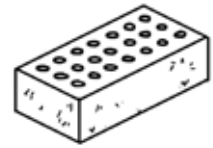
BRICKS & BLOCKS



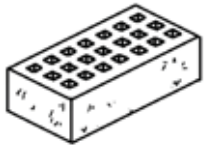
Which clay bricks to use



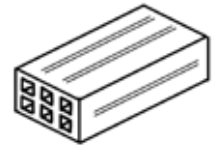
Best brick :
solid burnt clay brick.



Good brick :
vertical holes less then 50% of surface area.

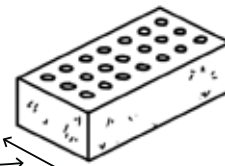


Bad brick :
vertical holes more than 50% of surface area.



Bad brick :
with horizontal holes (cannot carry weight).

Solid bricks are better then multiperforated ones.



With less than 12.5 cm bricks build double layer walls !

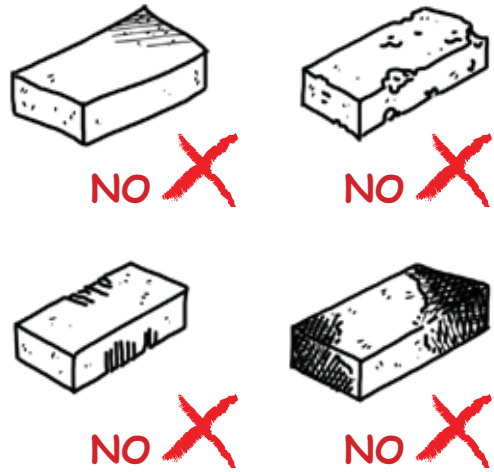
Note : we recommend to use 10 MPa bricks.

Brick test

Visual test :

Bricks need to be :

1. regular in form
2. uniform colour
3. not warped
4. no visible flaws or lumps



Physical test :

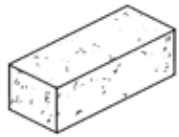
1. Bricks cannot be easily scratched by a knife.

2. Resists the **"3 point test"** : Person standing on a brick spanning between two other bricks.

3. Bricks must give a ringing sound when struck against each other.

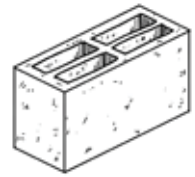
Which concrete blocks to use

Use heavy blocks and never light blocks.



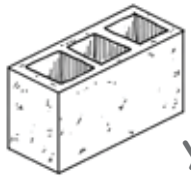
YES

Best block :
15-20 cm thick,
solid block.



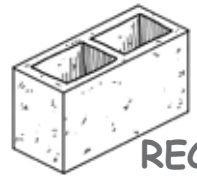
YES

Good block :
15-20 cm thick,
with 4 holes.



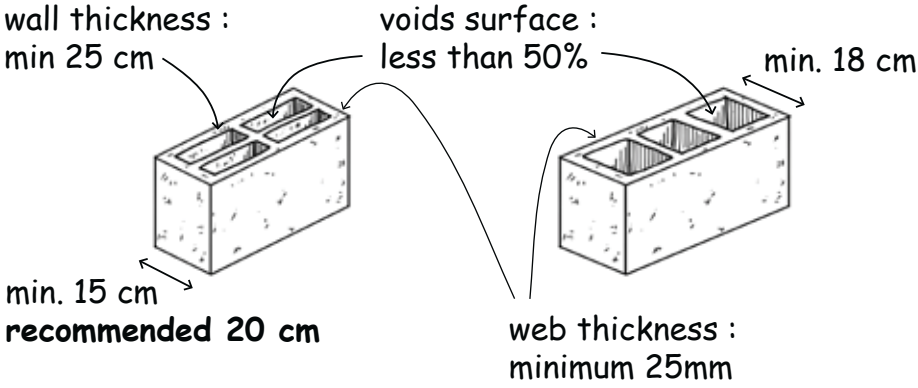
YES

Satisfactory block :
18-20 cm thick,
with 3 holes.



NOT RECOMMENDED

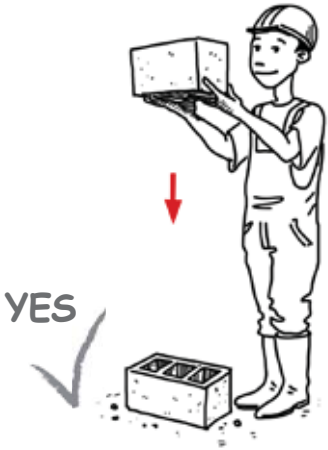
Blocks with 2 holes are too weak for confined masonry. 20 cm and **only top quality** !



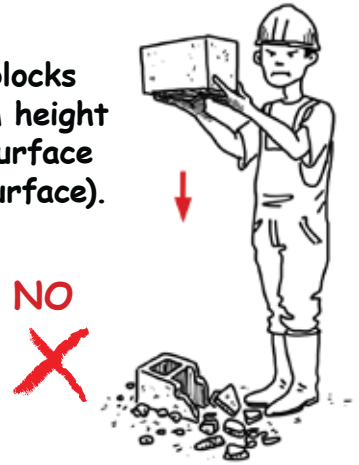
Note : we recommend to use 10 MPa blocks.

Block test

Test blocks before buying them !



Drop 5 blocks from 1,5 m height on hard surface (concrete surface).



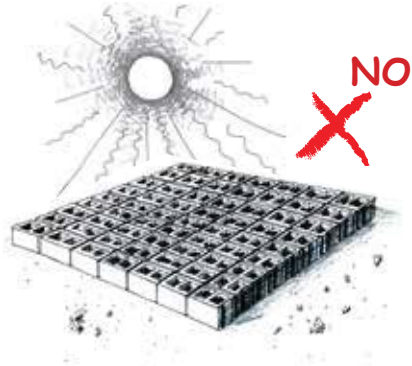
Acceptable quality :
(1 or less broken)

Bad quality : don't buy !
(more than 1 broken)

Check if blocks were cured in the shade !

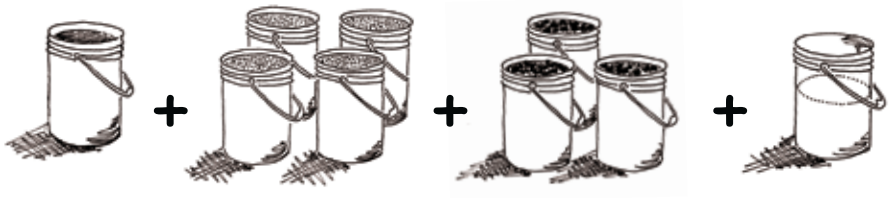
Stored in the shade : good.

Stored under plastic sheets : good !



Blocks which dry in the sun : very bad !

Concrete mix for blocks (1 : 4 : 3)



1 part cement | 4 parts clean sand | 3 parts gravel (5-10mm) | 3/4 part clean water

Sand should be crushed, washed and dried.
Do not use sea or beach sand !

1. Make a pile with the gravel, the sand and the cement but without water !

2. Mix the pile without water and move it twice with a shovel.

3. Add water and mix again.

Add water only at the end.

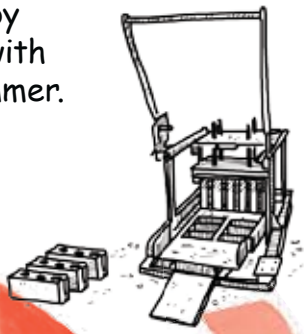
Making the blocks

Wait 18 days before using the blocks !

Fill the molds
with the mixture.

Compact the mix by
hitting the mold with
a shovel and a hammer.

If possible use a
vibrating machine.

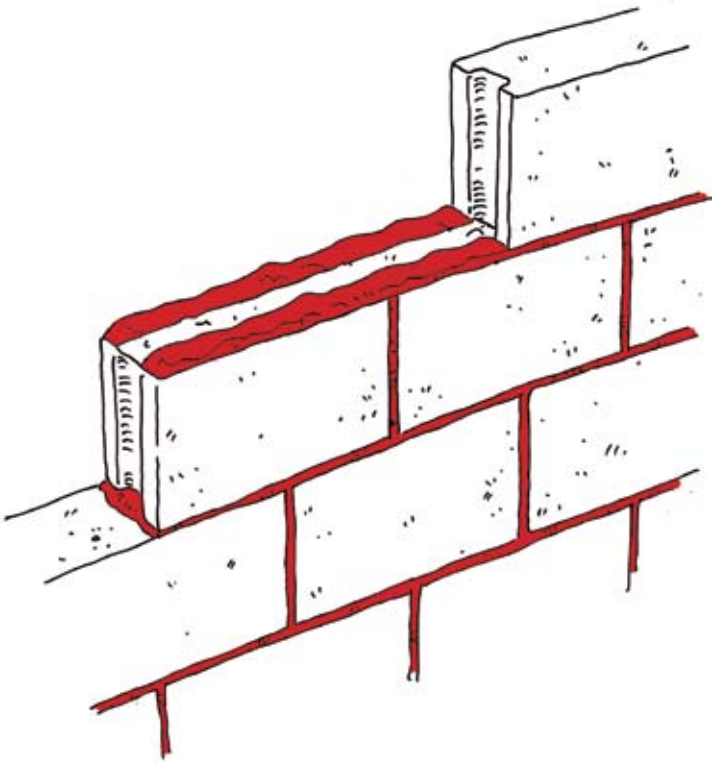


Cover the blocks with plastic
sheets immediately !

Cure the blocks 3 times a day
for a **minimum of 7 days** and
cover with plastic sheets.

Store the blocks in the
shade for **10 days.**

MASONRY WALLS



Cement mortar mix (1 : 4)

1 part
cement

+

4 parts
clean sand
(washed and dry)

+

3/4 part
clean water

For walls 15 cm or less thick use a 1:3 mix ratio.

1. Make a pile with the sand and the cement but without water !

2. Mix the pile without water and move it twice with a shovel.

3. Add the water and mix again.

Add water only at the end.

Cement-lime mortar

Cement-Lime mortar
has lower compressive strength
than simple cement mortar,
but offers a better workability,
higher elasticity, and it is more economical !

Recommended mix : 1 : 1/2 : 4.5

1 parts
cement

+

1/2 parts
lime

+

4.5 parts
clean sand

+

3/4 part
clean water

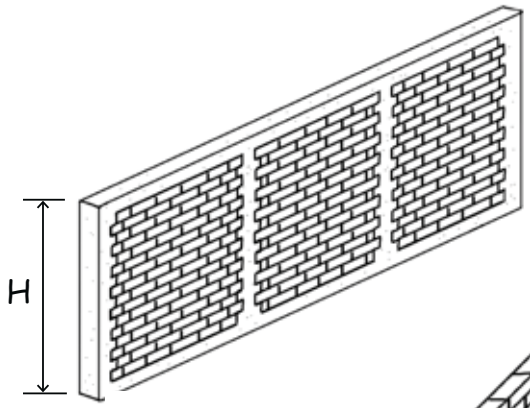
Mix first without water, add water only at the end.

Masonry walls height

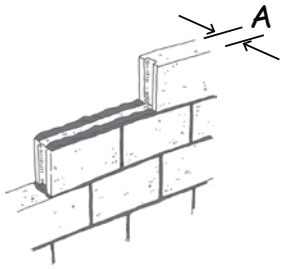
Two rules to respect :

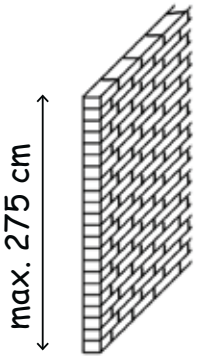
1. The height of the wall should be smaller than 22 x the block or brick's width (A).
2. The maximum height (H) of any wall type is 3 m (or consult an experienced civil engineer for higher constructions).

H = max. 3 m

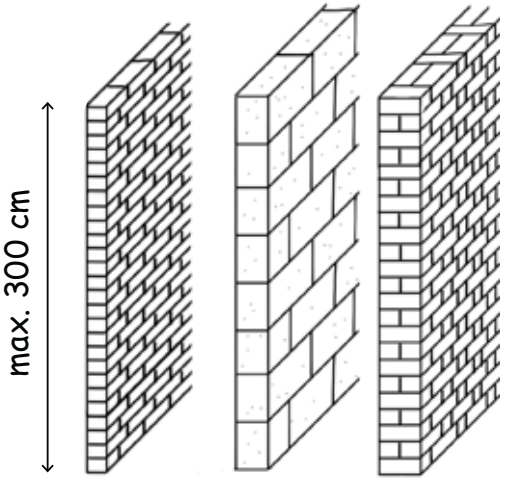


H = max. 22 x A



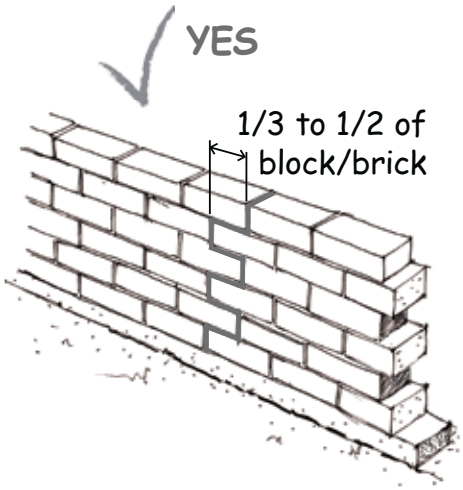


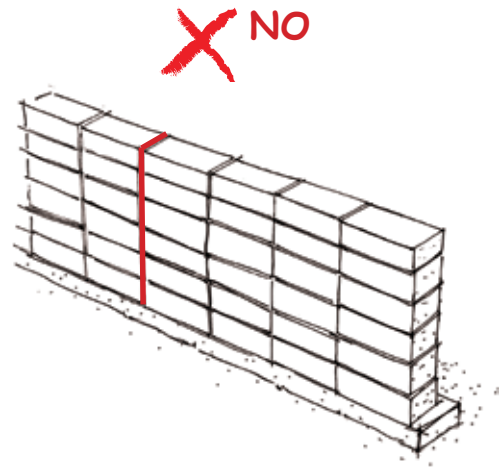
wall thickness
12,5 cm



wall thickness
15cm / 20 cm / 24 cm

Masonry bonds



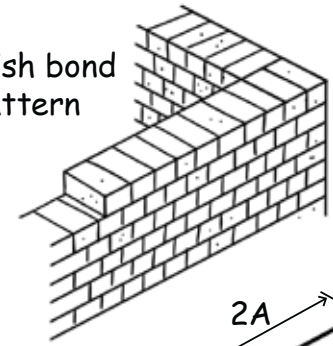


Solid wall = **Running bond**
vertical joints
are not continous.

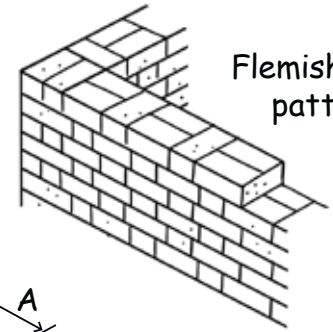
Weak wall = **Stack bond**
vertical joints
are continuous.

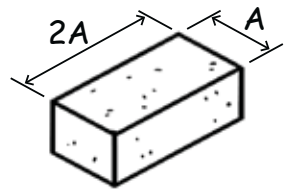
If using bricks less than 12,5 cm wide, build double layer brick walls, with either the English or the Flemish bond pattern :

English bond pattern



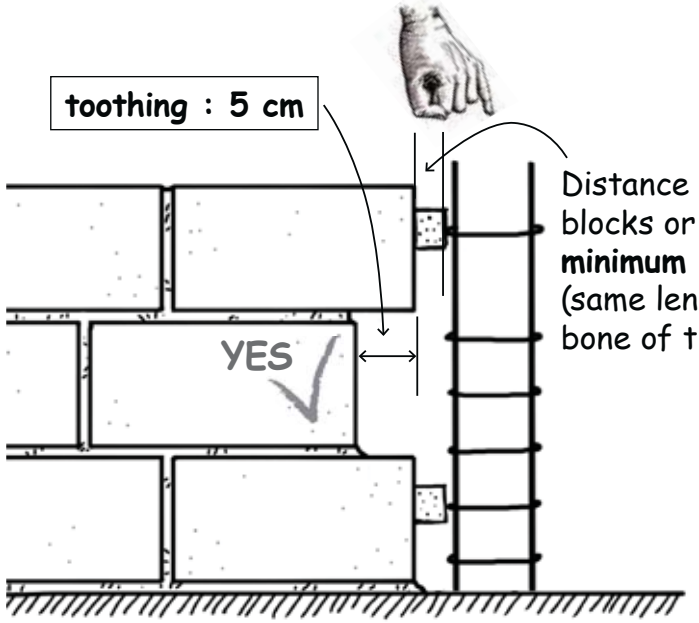
Flemish bond pattern



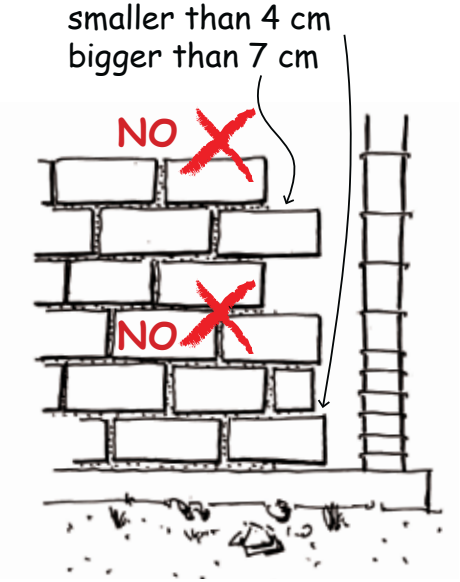


In both cases the lenght must be twice the width.

Toothing



Distance from blocks or bricks : **minimum 3 cm !** (same length as last bone of thumb).



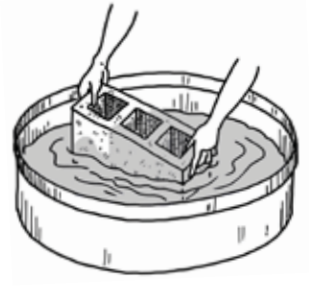
If the toothing is bigger than 7 cm, the concrete cannot properly penetrate and fill the voids.

If it is smaller than 4 cm, the toothing is useless, and will not ensure good anchoring of the masonry wall.

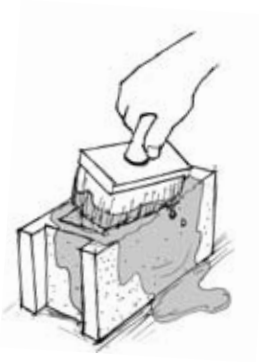
Preparing the masonry units

Dried blocks and bricks will absorb the water from the mortar. Therefore it is important to water the masonry units before using them.

There are various ways to moisten them. Be careful not to wet them too much.



Soak the blocks in water for a while.

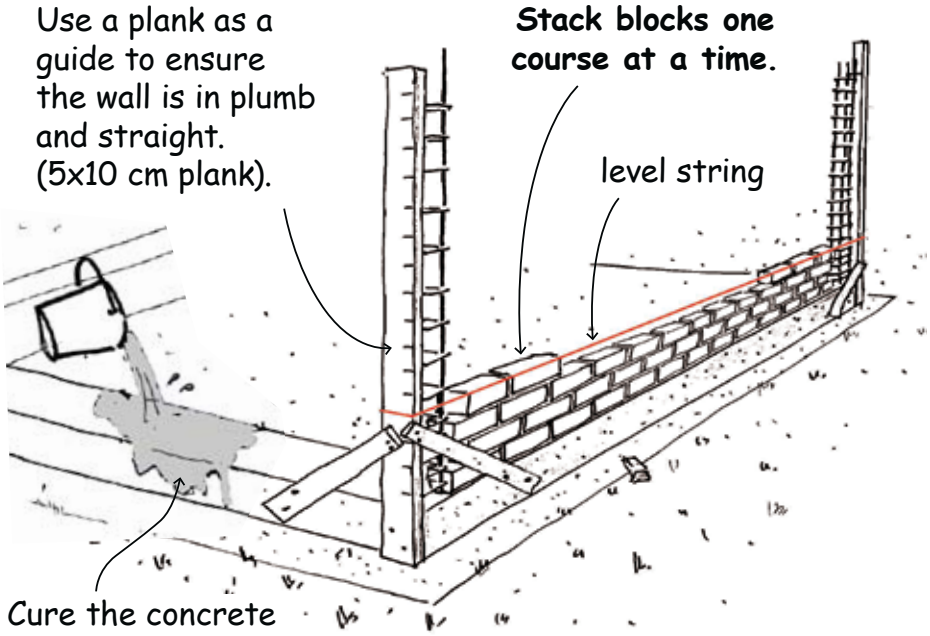


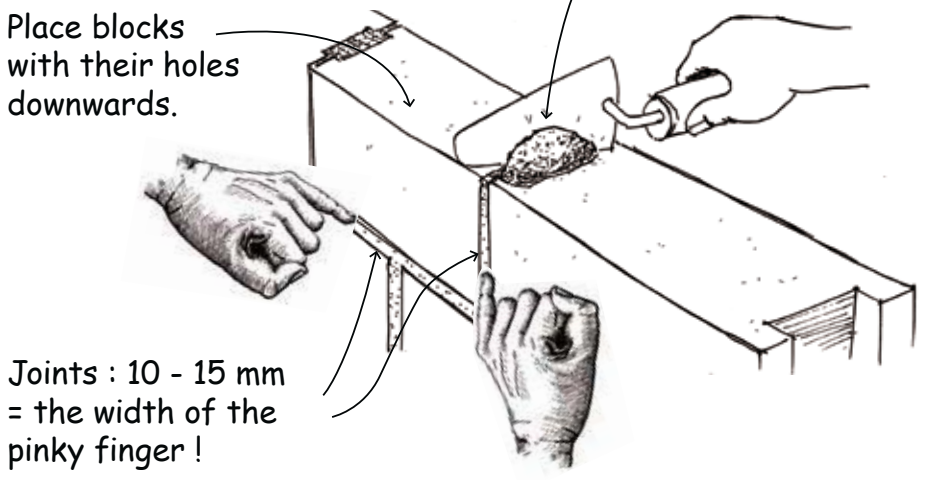
Water them with a brush before use.

Water all blocks together.

Water them well, half an hour before using them.

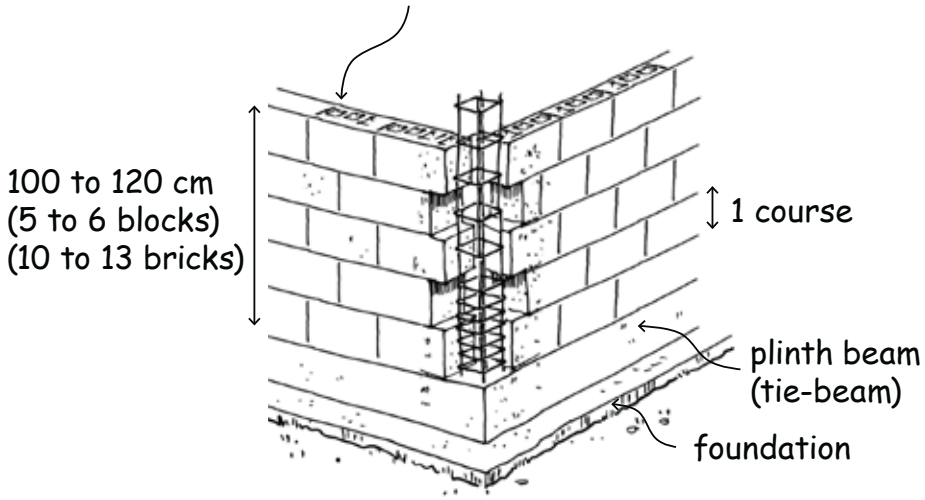
Good masonry practice - 1



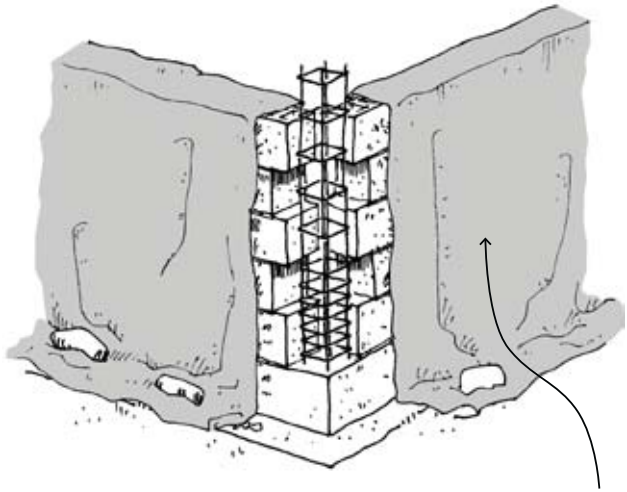


Good masonry practice - 2

Don't build more than 120 cm high of masonry per day.



Protect the wall in warm weather :
mortar must not dry out in the sun.

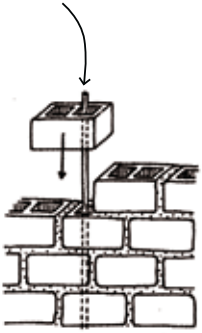


Keep walls moist by pouring water on them 3 times a day for 7 days and/or by covering them with a plastic sheet for 7 days.

Integrating pipes and tubes

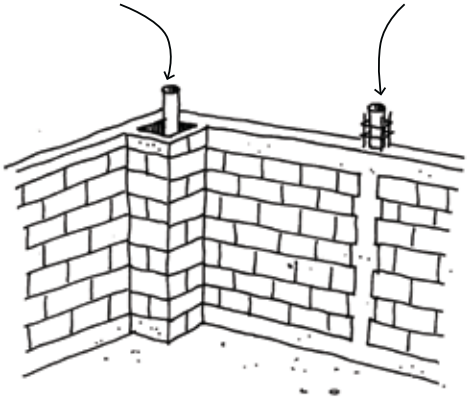
YES

Place pipes in block holes.



YES

Place pipes in service duct.

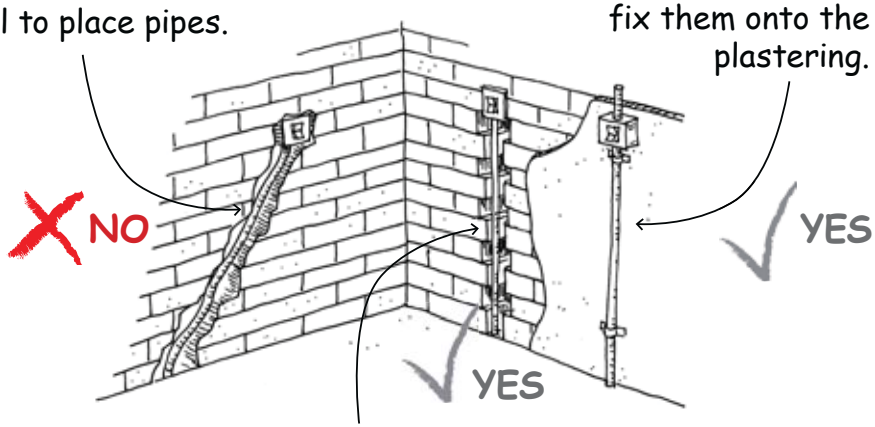


NO

Don't place pipes in walls or in ties.

Never break the wall to place pipes.

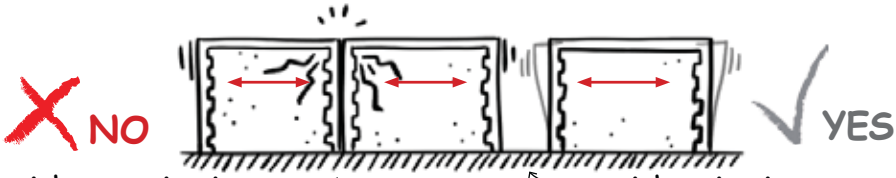
The best way to place the electric tubes is to fix them onto the plastering.



Leave space in the masonry for the electric pipes, that can be later filled with mortar.

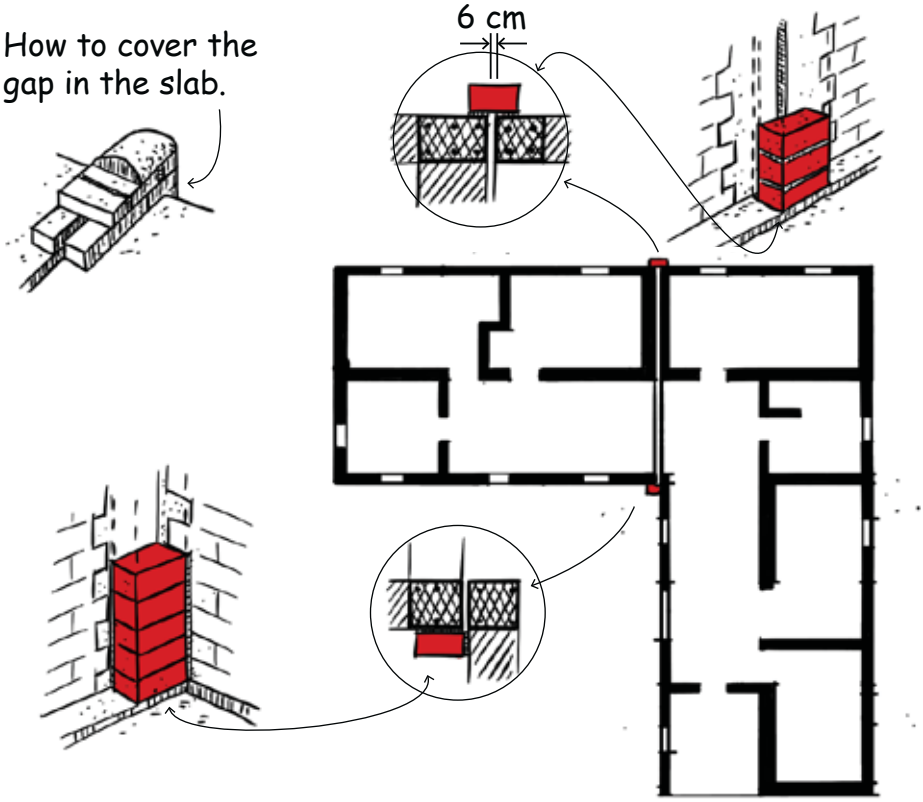
Cover seismic gaps

Seismic gaps are needed to prevent independent walls in a building from colliding during an earthquake and therefore affect the whole building stability.

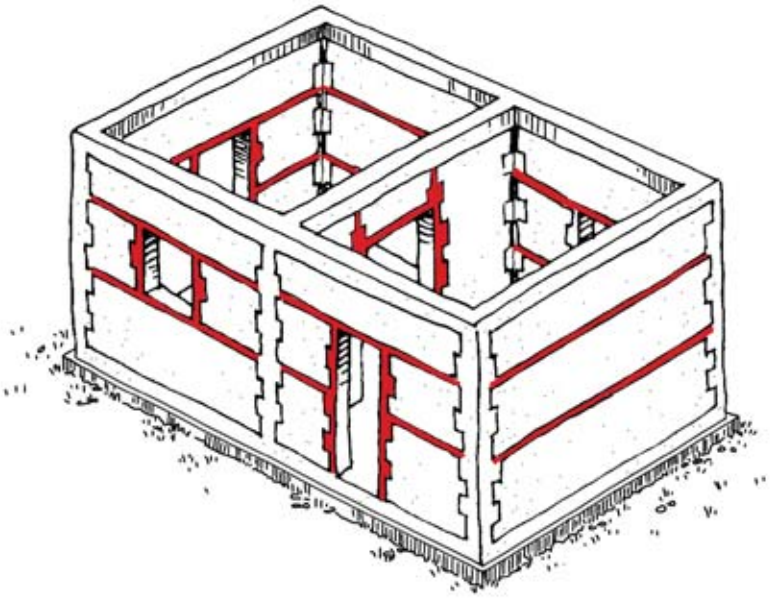


Seismic gaps can be covered with bricks or blocks placed over the gaps and fixed with mortar.

How to cover the gap in the slab.

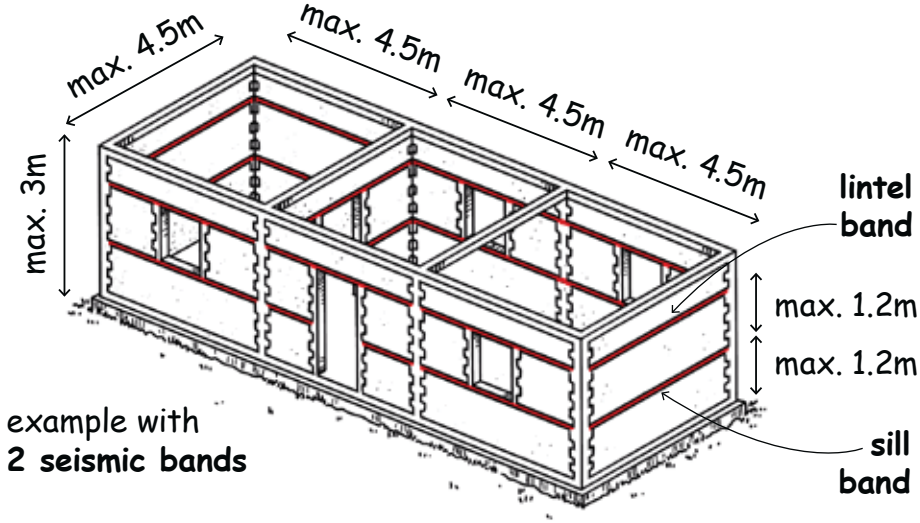


SEISMIC REINFORCEMENT

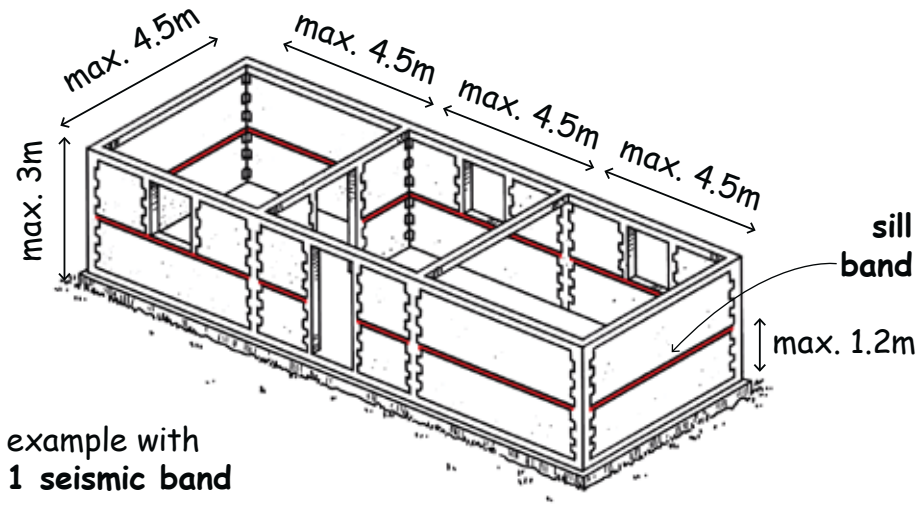


Seismic bands

Place a seismic band **below and above every opening**.
Don't go higher than 6 courses of blocks, **don't exceed 1.20m.**

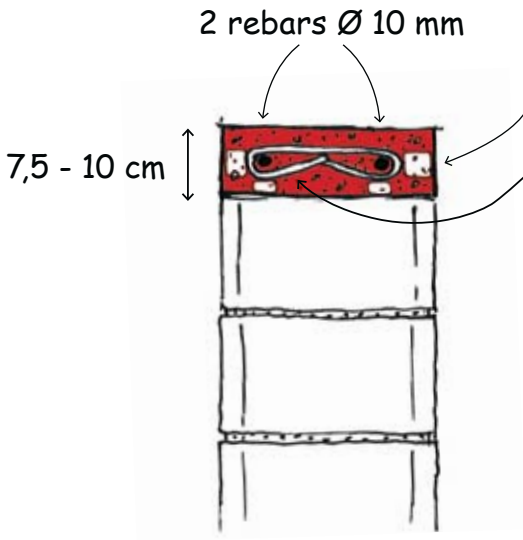


example with
2 seismic bands



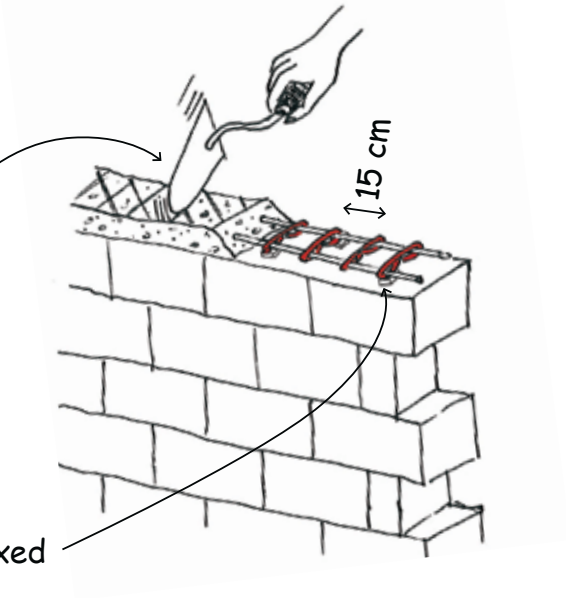
example with
1 seismic band

Seismic band details



Seismic band :

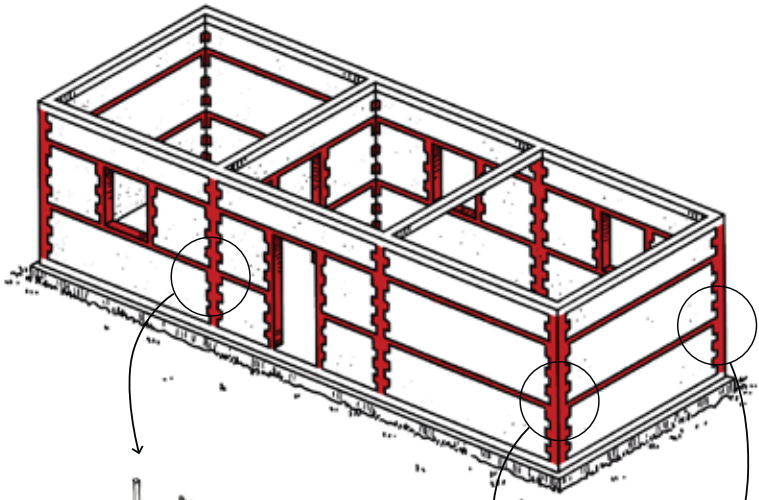
Height (bricks) : 7.5 cm
Height (blocks) : 10 cm
2 rebars : 10 mm
Stirrups : 6 mm @ 15 cm

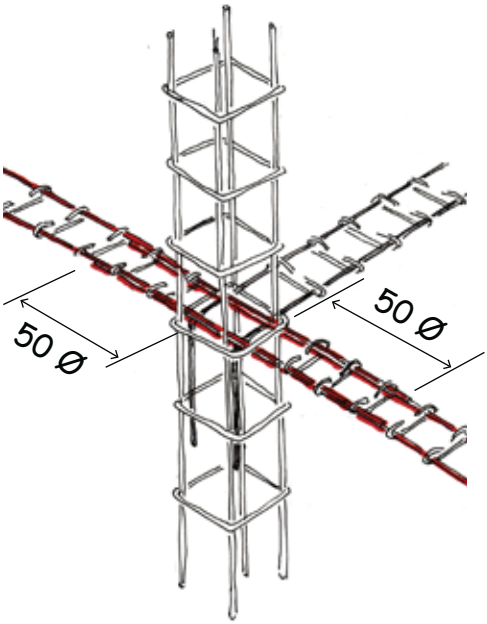


Roughen up the top suface of the bands to increase bonding of the masonry mortar.

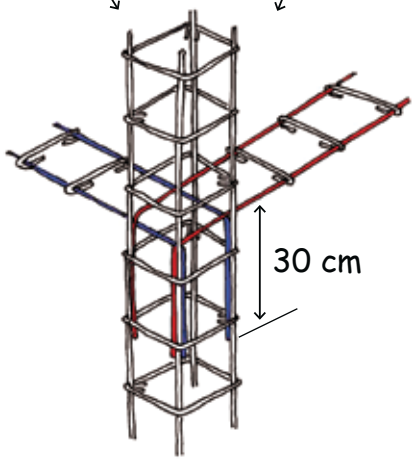
Spacers must be fixed **onto the stirrups**, not onto the rebars.

Connect seismic band to tie-column





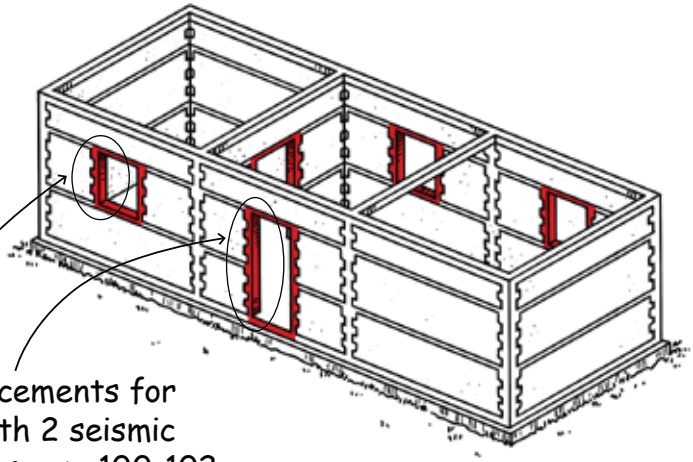
In case of overlap
in the tie-column : respect
minimum lap length.



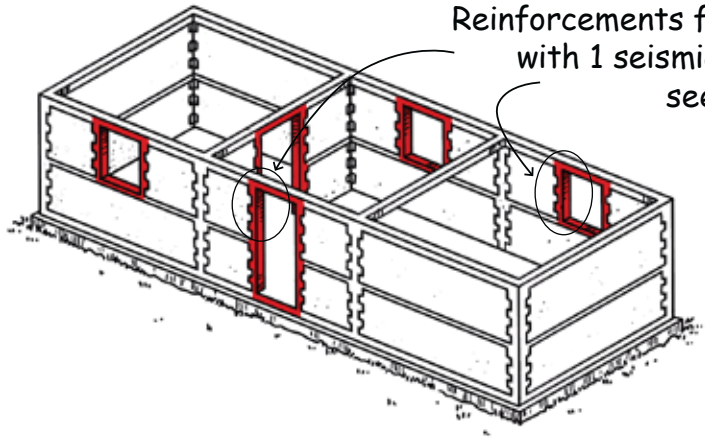
Hook seismic bands
reinforcement and lap with
tie-column reinforcement.

Opening reinforcement

All openings must be framed with vertical reinforcements and seismic bands or tie-beams.



Reinforcements for walls with 2 seismic bands : see p. 100-102.

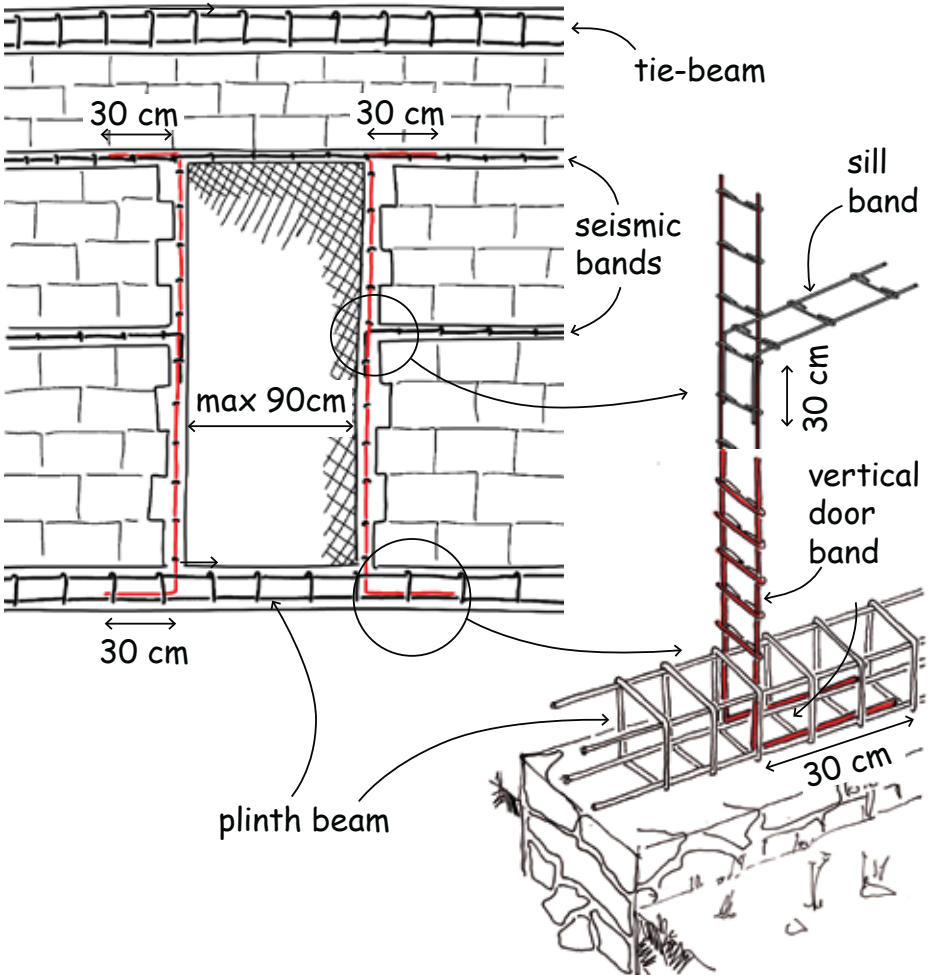


Reinforcements for walls with 1 seismic band : see p. 103.

Door reinforcement

Case with 2 seismic bands :

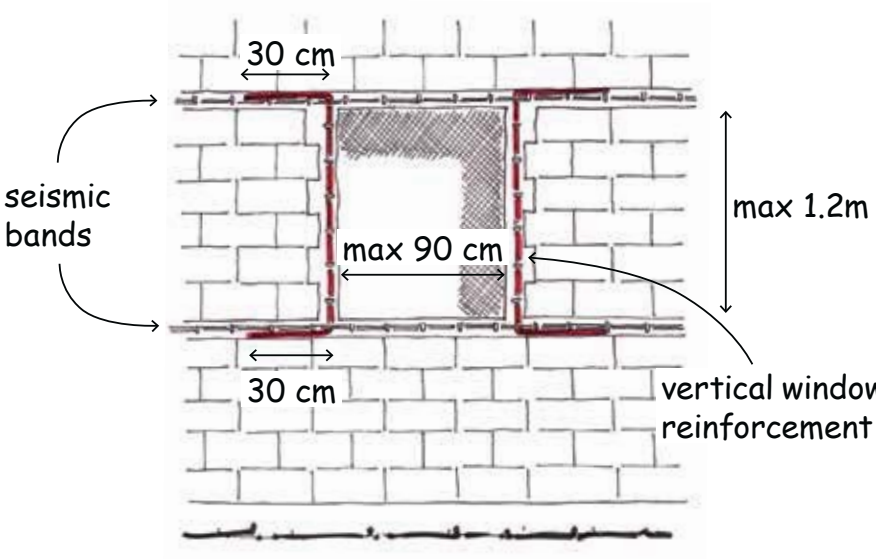
Hook the door vertical reinforcement and lap 30cm with the plinth beam and upper seismic band (lintel), under the stirrups. Do the same with the lower band (sill) in the vertical band.



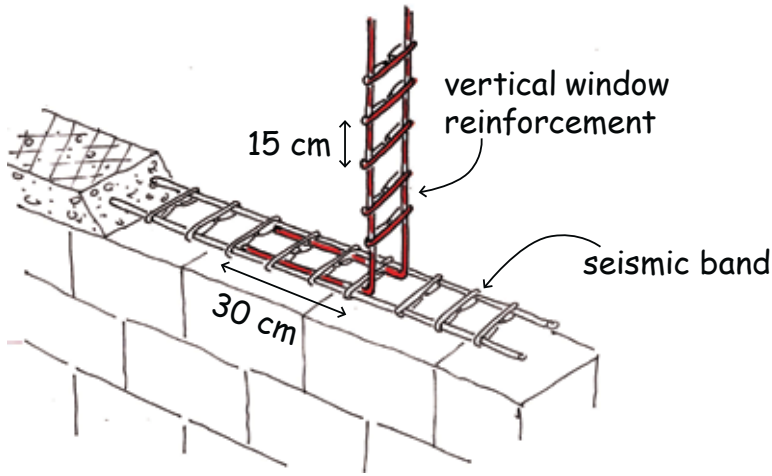
Small window reinforcement

Case with 2 seismic bands :

For windows smaller than 90 cm.



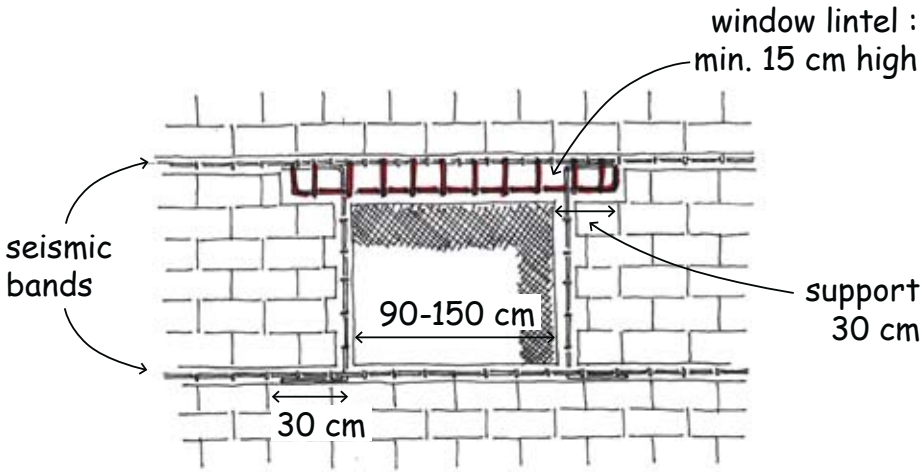
Hook the window vertical reinforcement and lap 30 cm with the seismic band reinforcement, inside the stirrups.

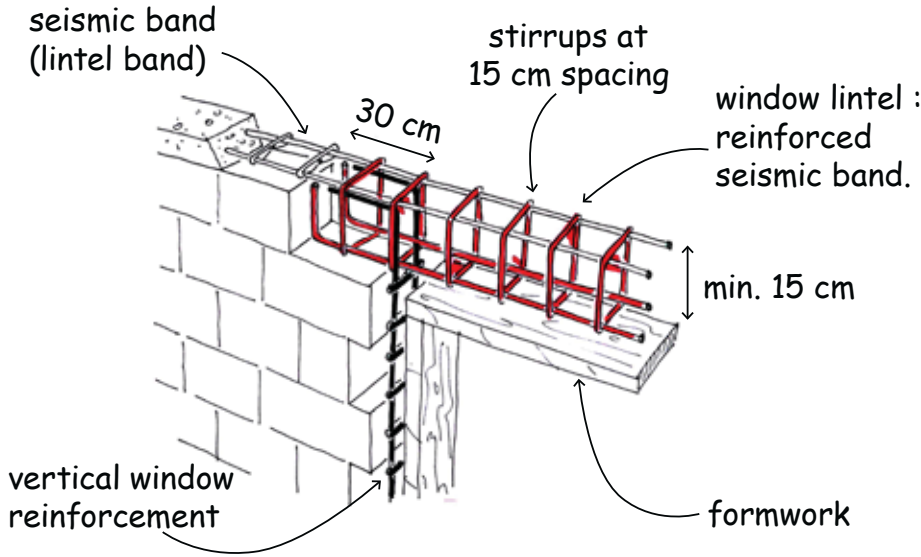


Large window reinforcement

Case with 2 seismic bands :

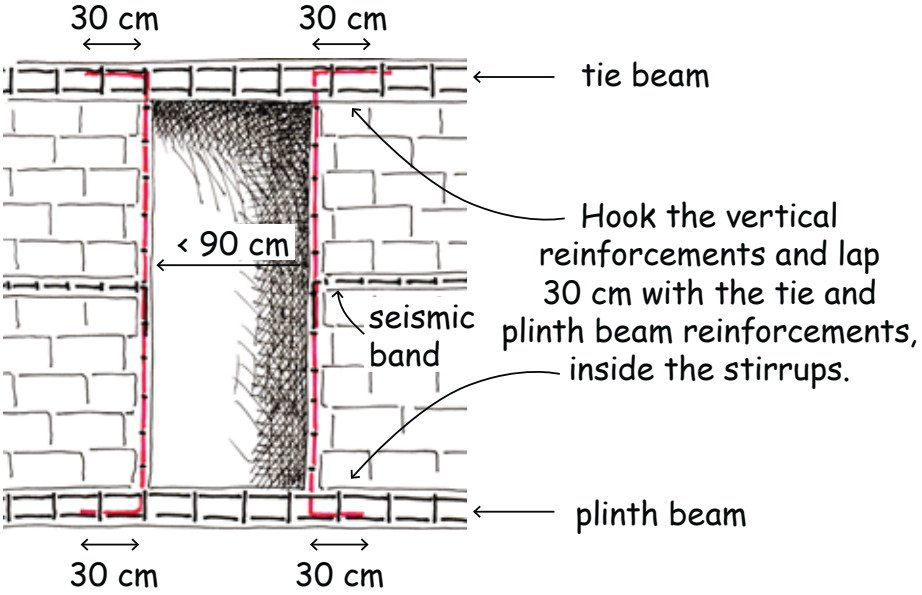
For windows wider than 90 cm.

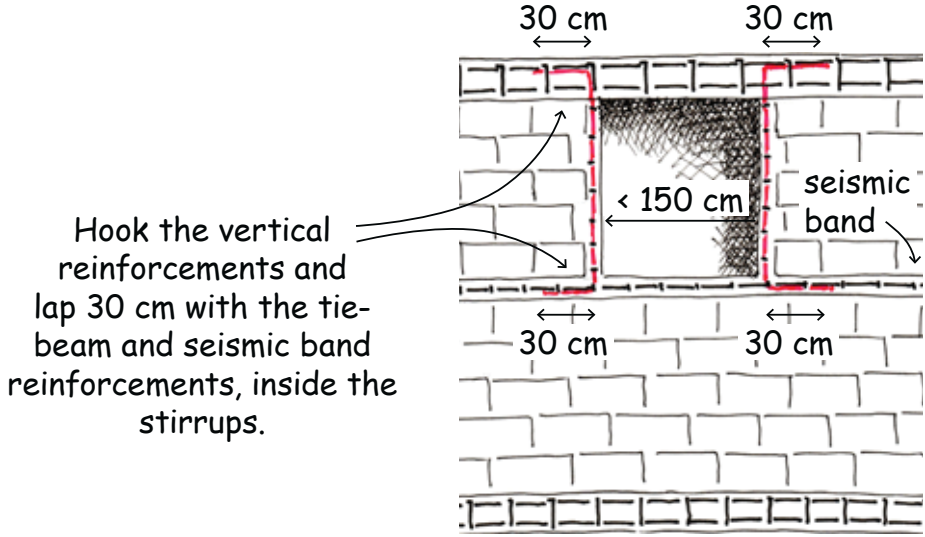




Openings up to the tie-beam

Case with 1 seismic band :

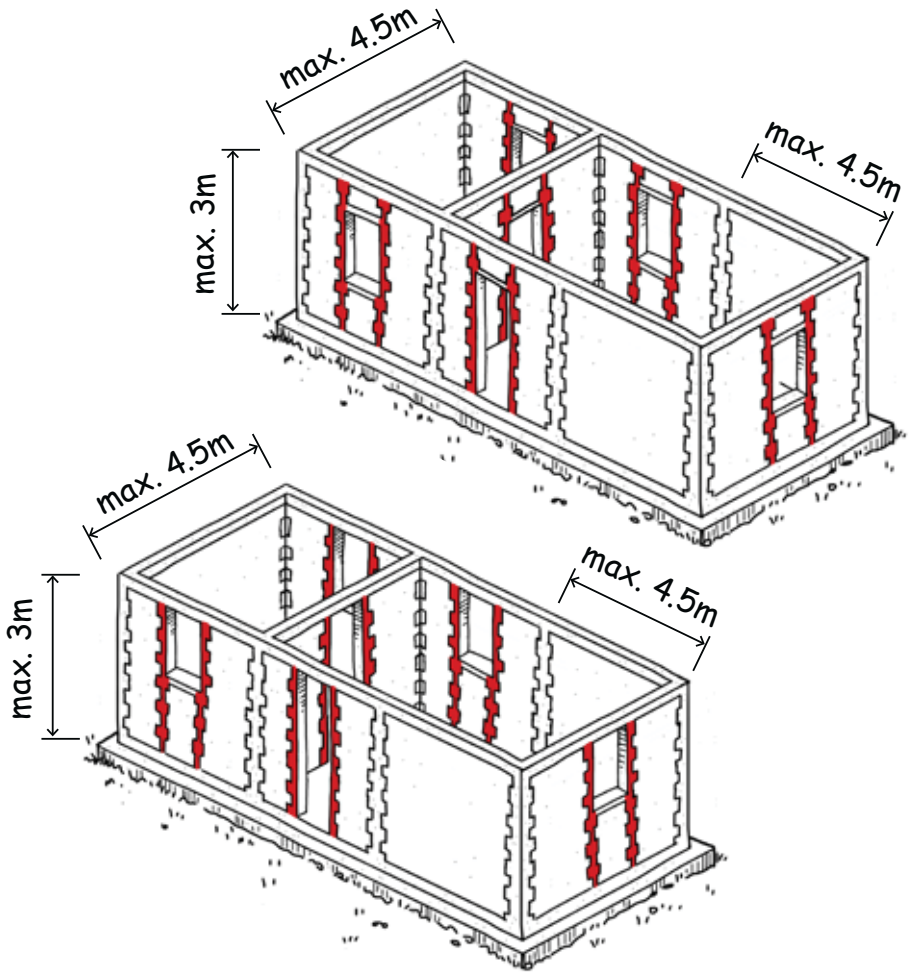




Vertical reinforcement

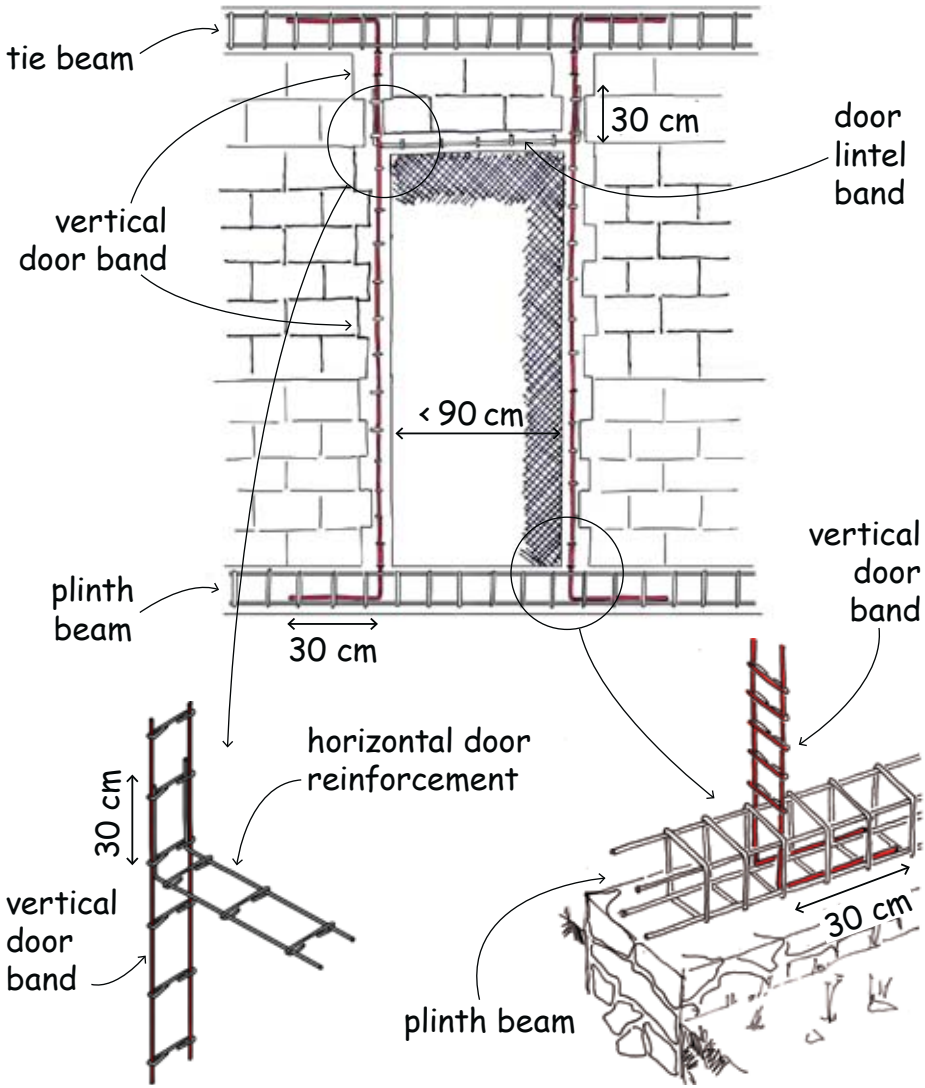
This is an alternative solution with vertical reinforcements. **We do not recommend it**, as it is more complicated to build and walls without opening will have poorer seismic reinforcement.

Place a vertical band on each side of every opening. Add a horizontal reinforcement band below and above all openings.



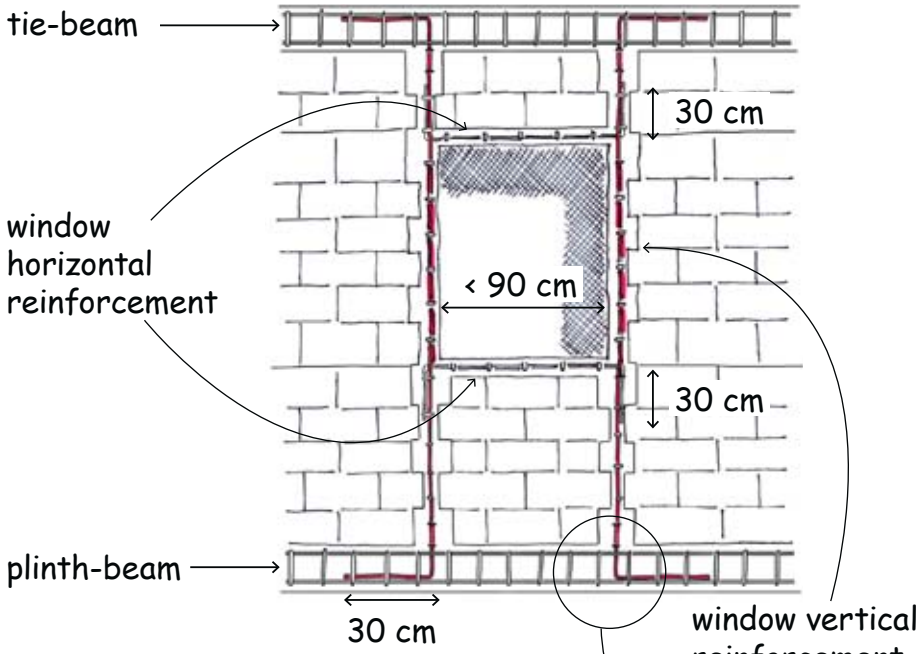
Vertical reinforcement : door

Hook the door vertical reinforcement rebars and lap 30cm with the tie and plinth beam rebars, under the stirrups. Do the same with the lintel band in the vertical band.



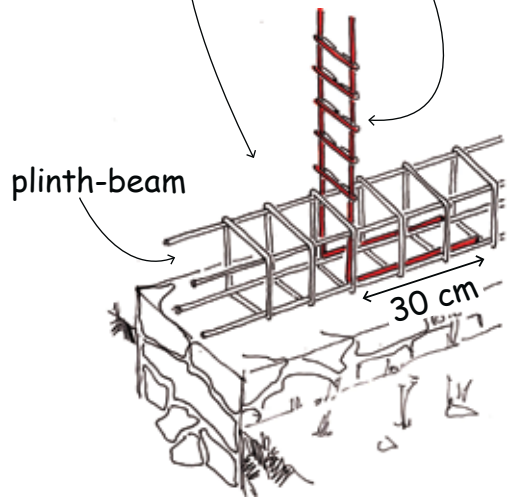
Vertical reinforcement : window 1

For windows smaller than 90 cm.



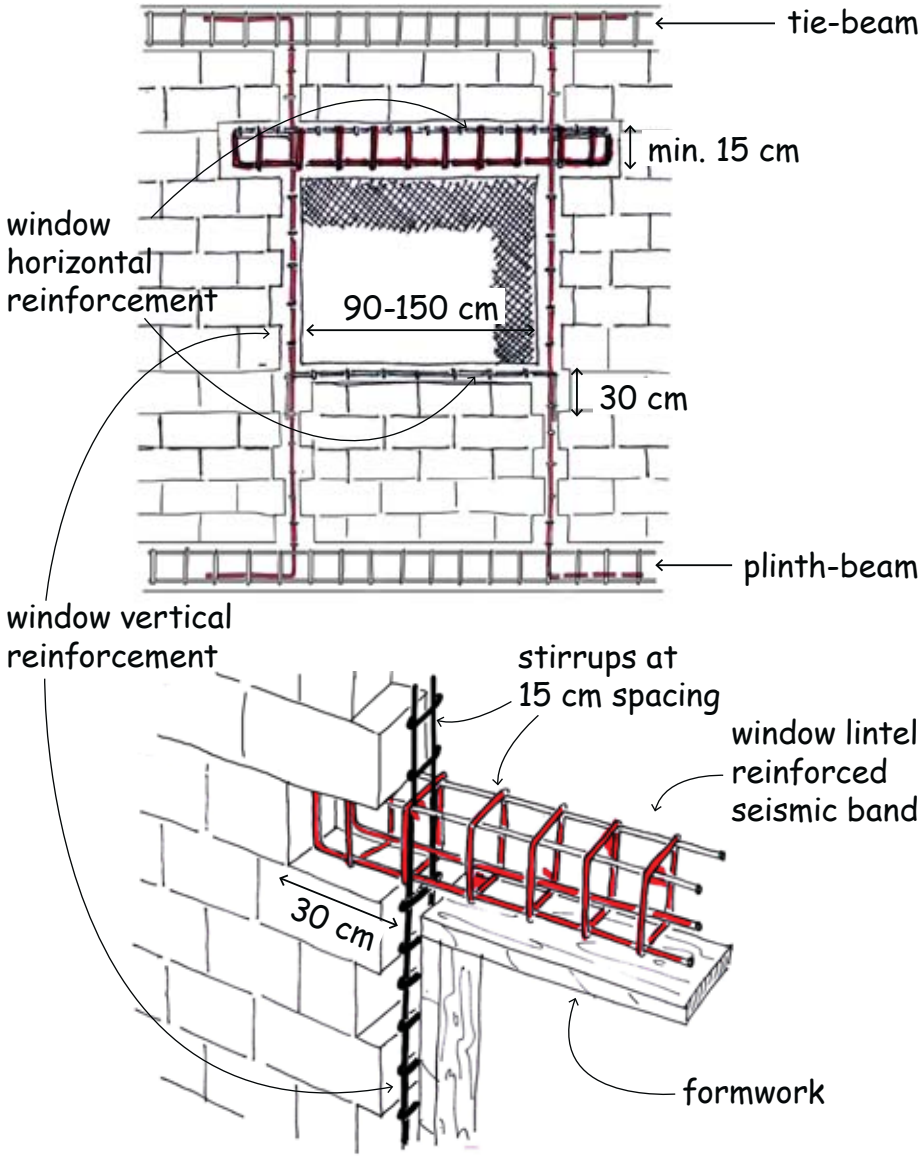
Hook the window vertical reinforcements and lap 30 cm with the tie and plinth beam reinforcements, inside the stirrups.

Do the same with the horizontal reinforcement and the vertical bands.



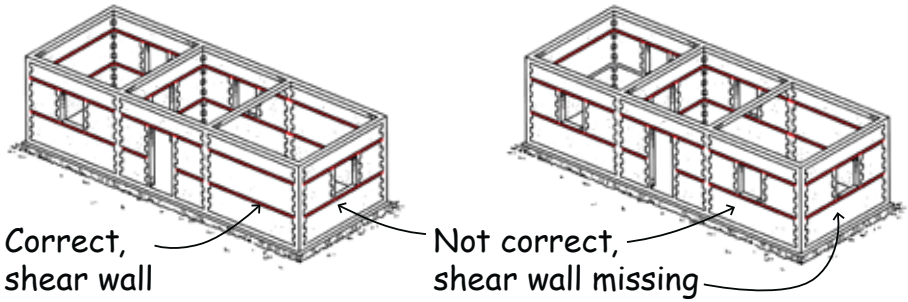
Vertical reinforcement: window 2

For windows wider than 90 cm.

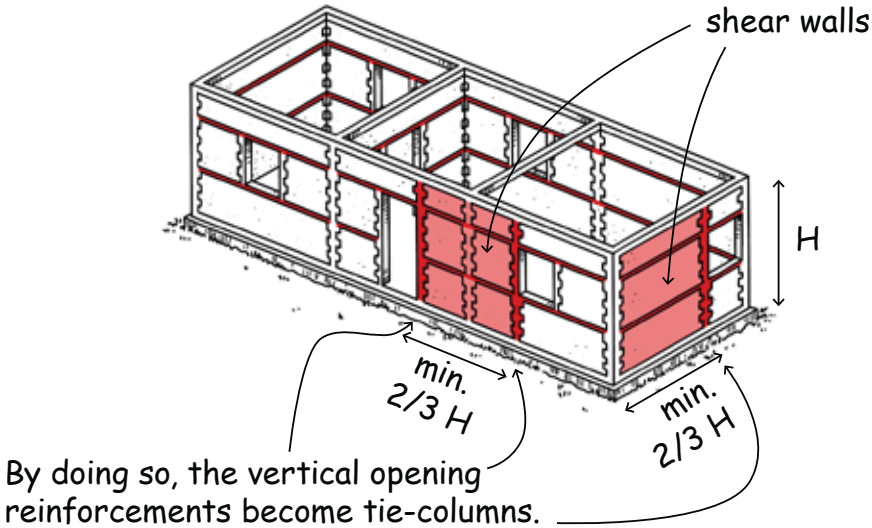


Shear wall reinforcement - 1

In some cases, the need for openings makes it impossible to make shear walls in each facade.

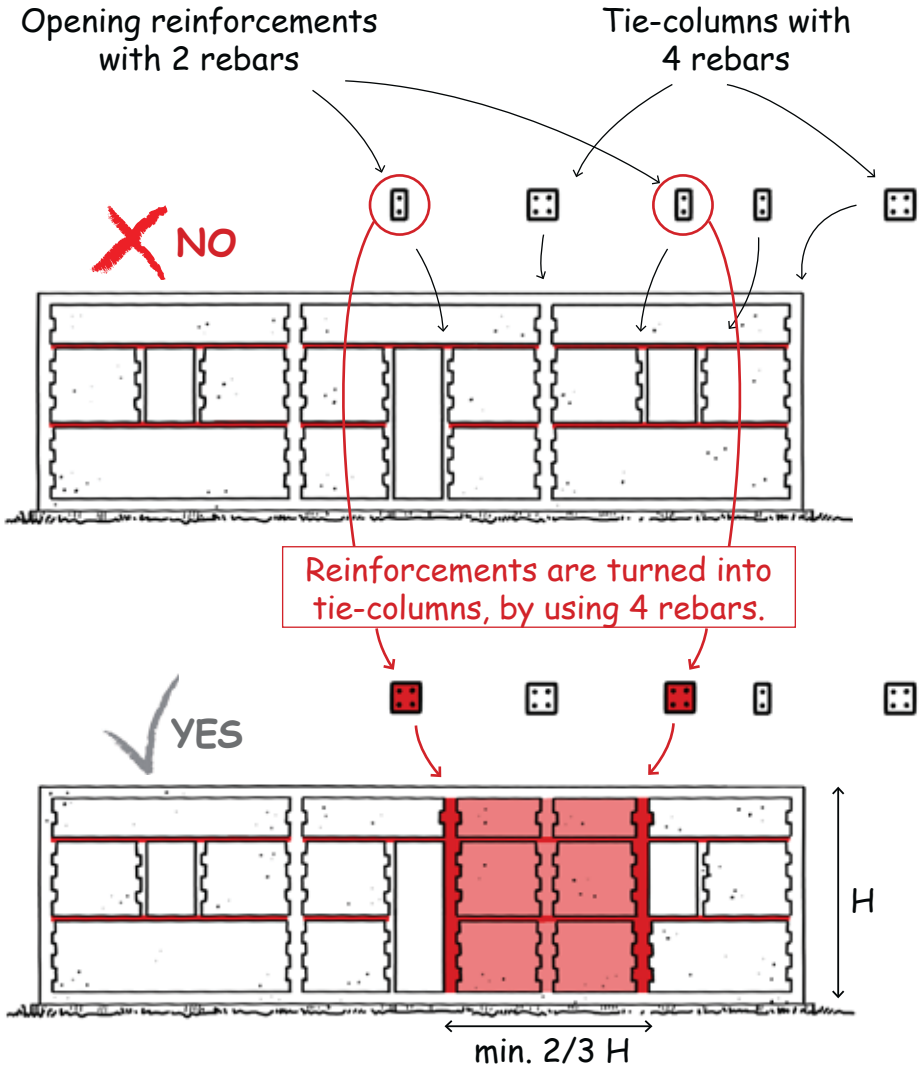


In such cases, **shear walls can be created** by adding tie-columns next to the openings (4 rebars instead of 2, from plinth-beam to ring-beam).

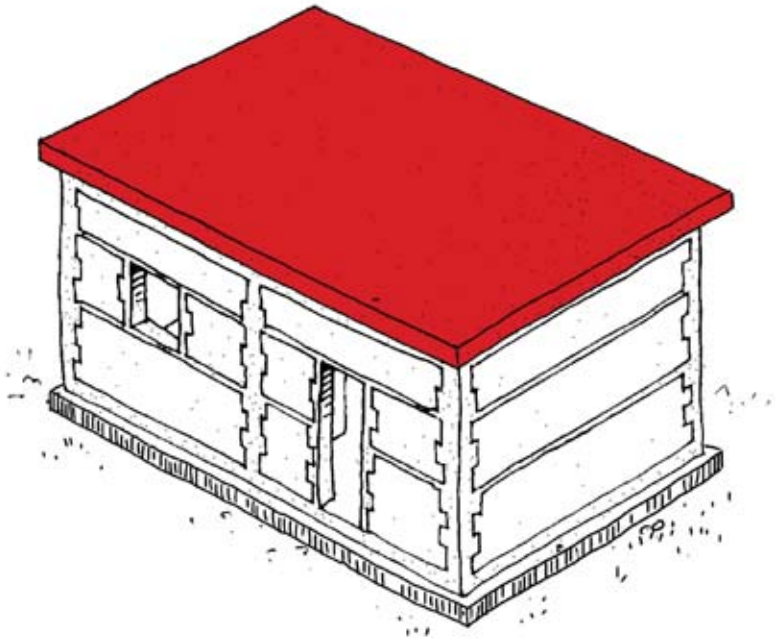


Shear wall reinforcement - 2

Vertical opening reinforcements (2 rebars) can be turned into tie-columns, using 4 rebars connected with the tie-beam.



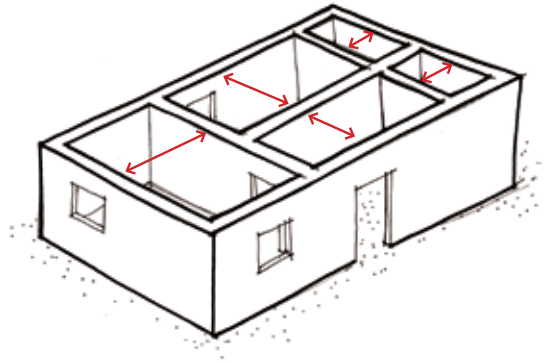
SLAB



Hollow block slabs

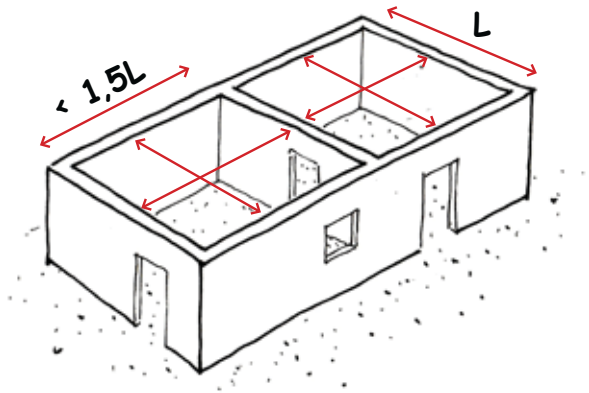
Unidirectionnal slab

In a **uni**directional slab, the primary reinforcement spans only in **one** direction : **the shorter one**.



Bidirectional slab

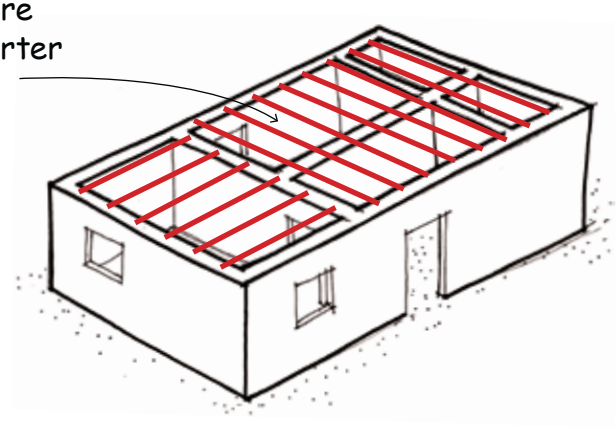
In a **bi**directional slab, the primary reinforcement spans in **two** directions simultaneously.
This type of slab is used for square-like spaces.



Unidirectional slab - 1

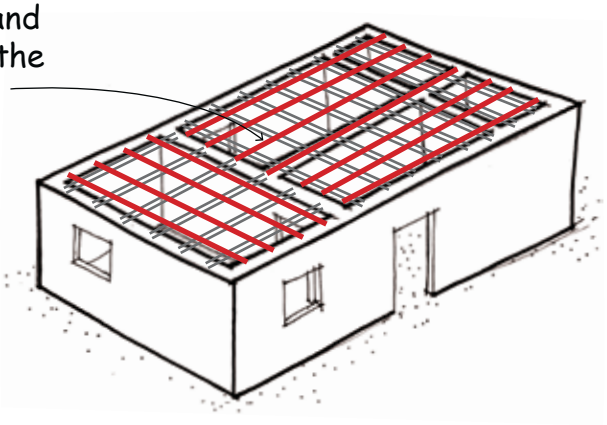
Primary reinforcement

Primary rebars are placed in the shorter direction (span).



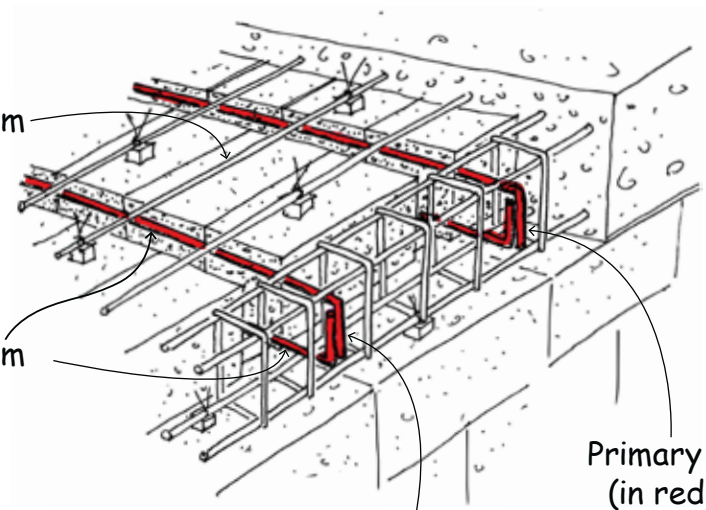
Secondary reinforcement

Secondary rebars are placed on top of and perpendicular to the primary rebars.

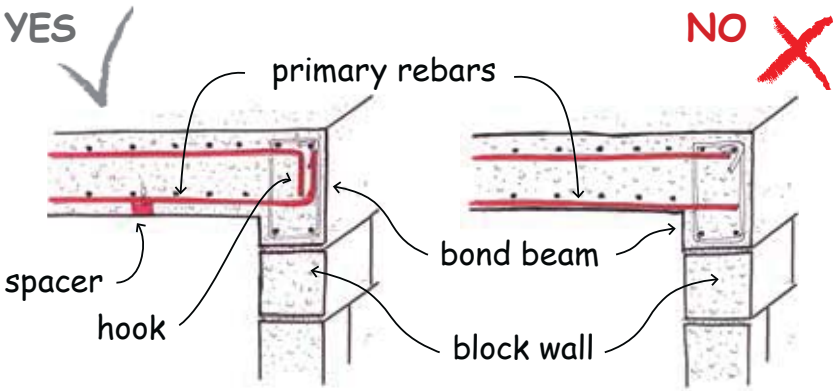


Unidirectional slab - 2

Primary reinforcement (Ø 12 mm)

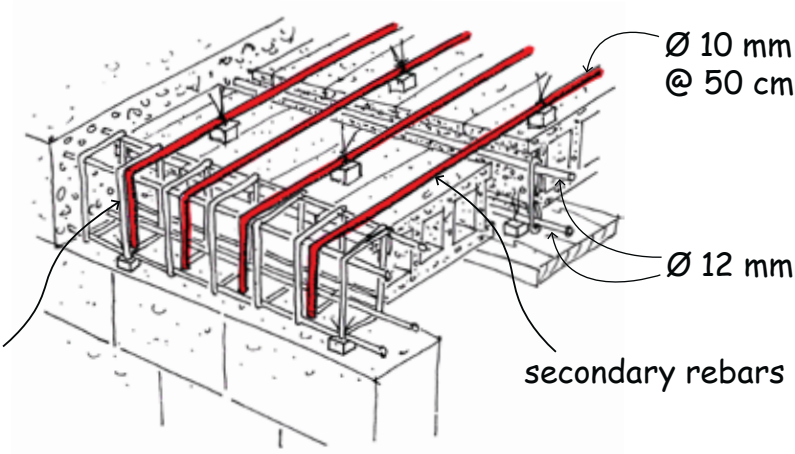


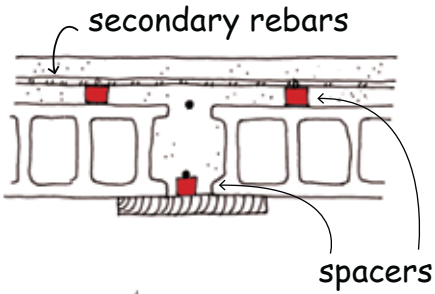
To ensure good anchoring, it is important to insert the hooked slab rebars deep into the bond beam.



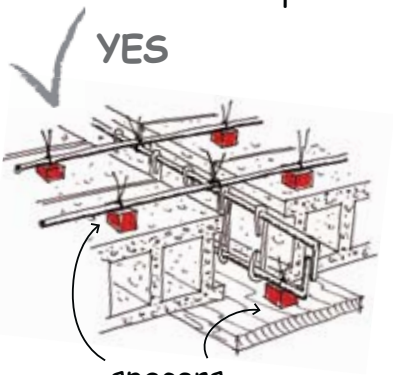
Unidirectional slab - 3

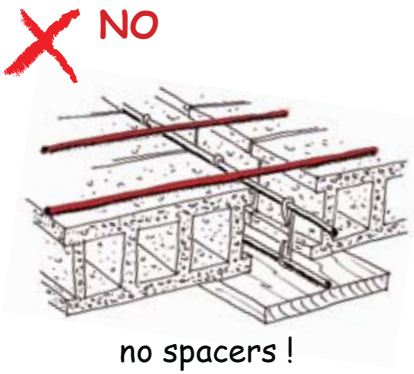
Secondary reinforcement (Ø 10 mm)





Secondary rebars must be placed, using spacers, in the middle of the concrete covering the hollow blocks.

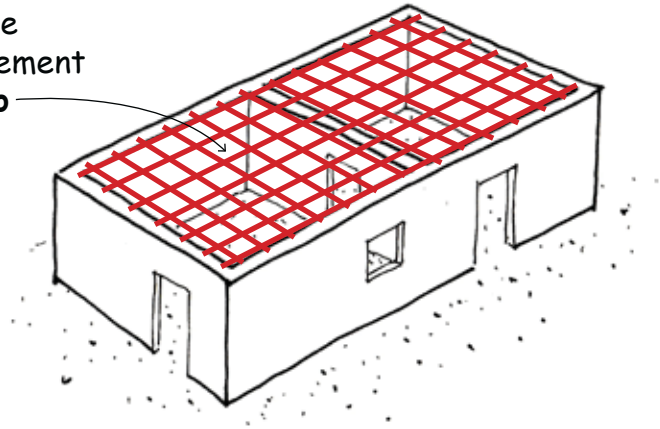




Bidirectional slab - 1

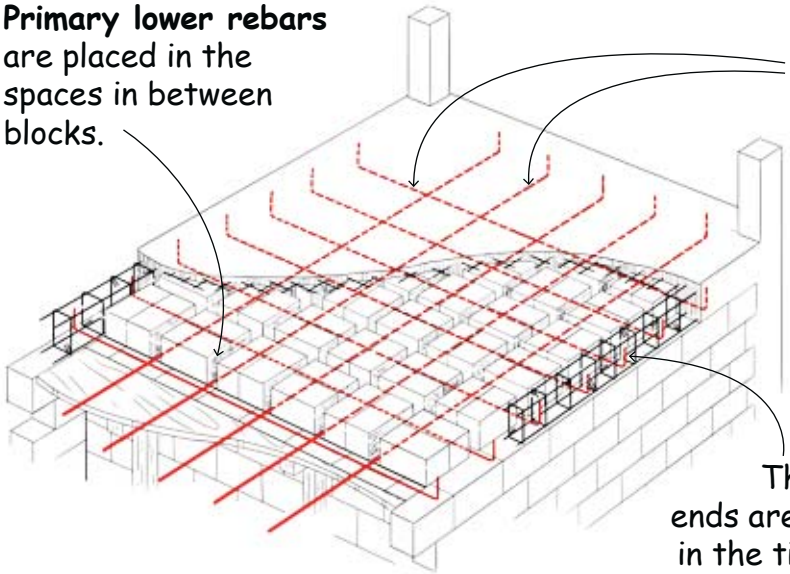
Primary reinforcement

The rebars of the primary reinforcement are placed **in two directions**.



The rebar's diameter depends on the span :
Span 0-3 m : Ø 10 mm every 40-50 cm
Span 3-4,5 m : Ø 12 mm every 40-50 cm

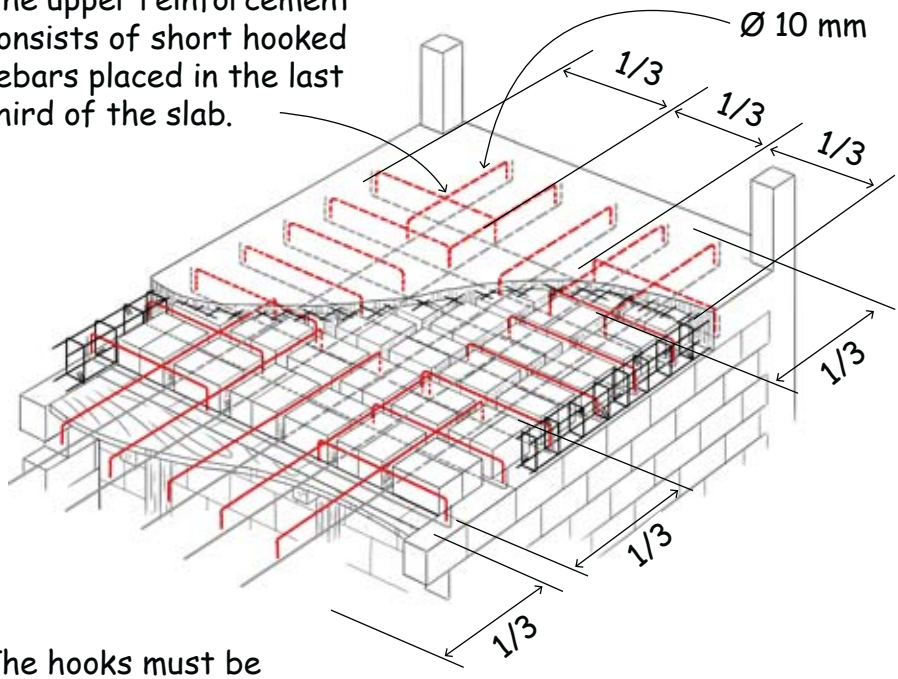
Primary lower rebars are placed in the spaces in between blocks.



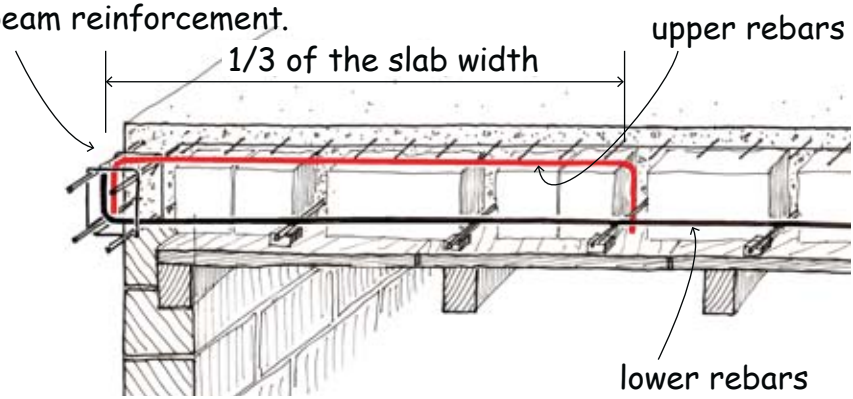
Bidirectional slab - 2

Primary upper rebars

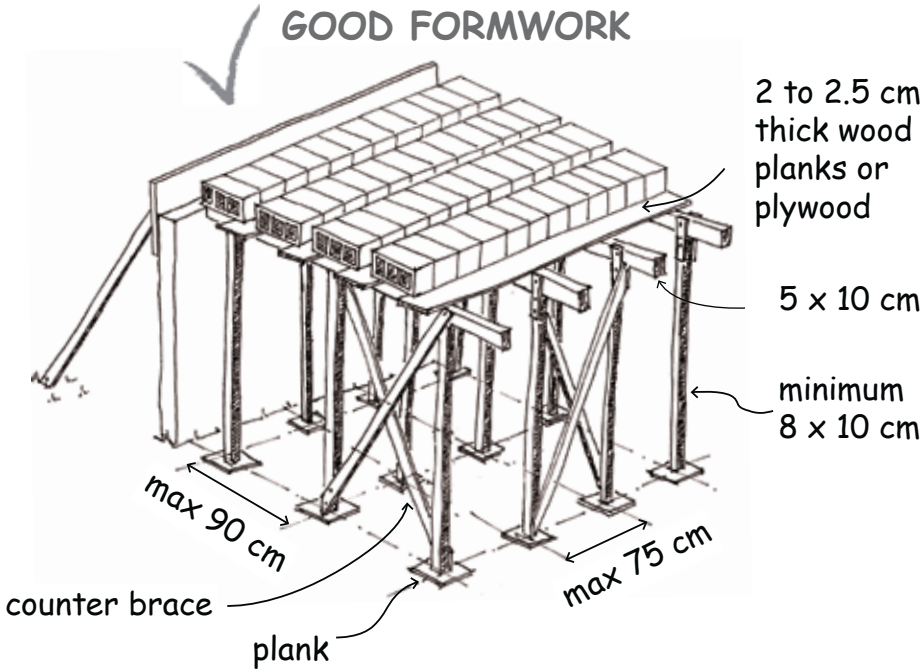
The upper reinforcement consists of short hooked rebars placed in the last third of the slab.

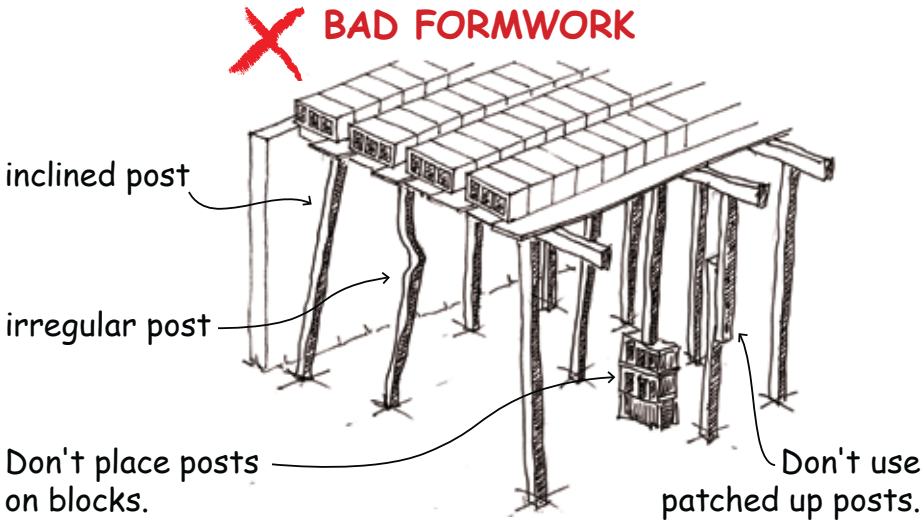


The hooks must be inserted deeply in the tie-beam reinforcement.



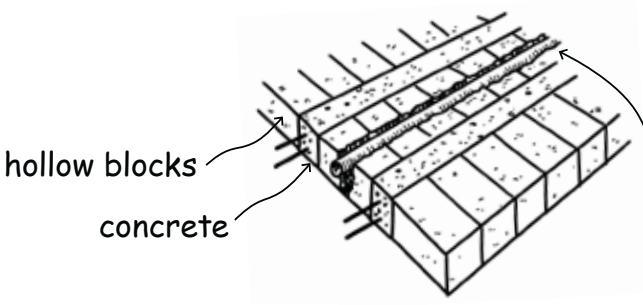
Hollow block slab : formwork





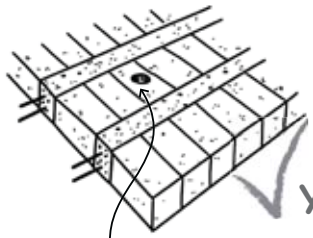
Hollow block slab : placing pipes

Avoid horizontal tubes : use vertical technical ducts next to wet spaces (kitchen, bathroom).



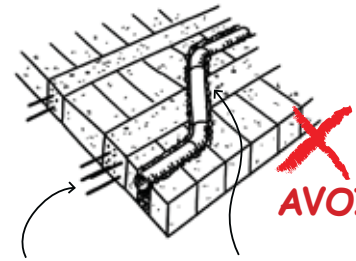
YES

Pipe passes through hollow blocks



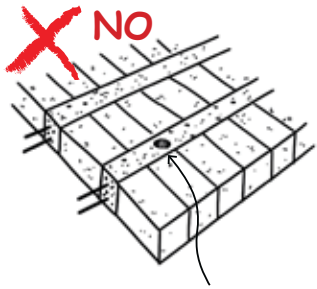
YES

Drill through hollow blocks.



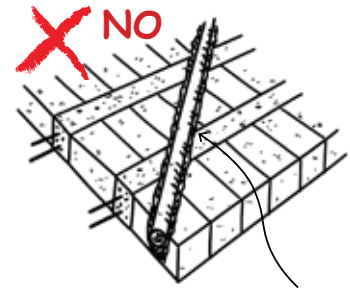
AVOID

Pass pipes through the hollow blocks and cross only one concrete beam. Reinforce joist with additional rebars.



NO

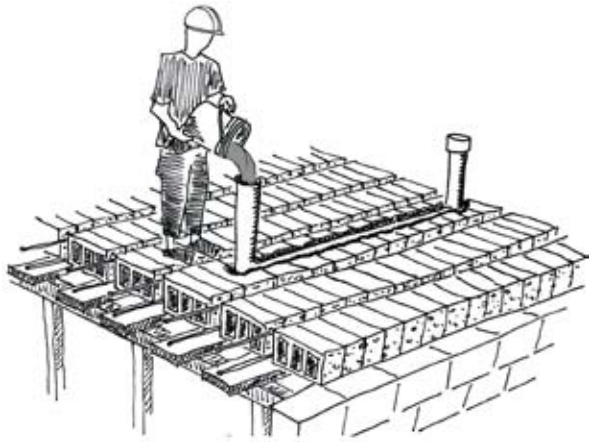
Don't drill through a concrete beam.



NO

Don't cross more than one concrete beam.

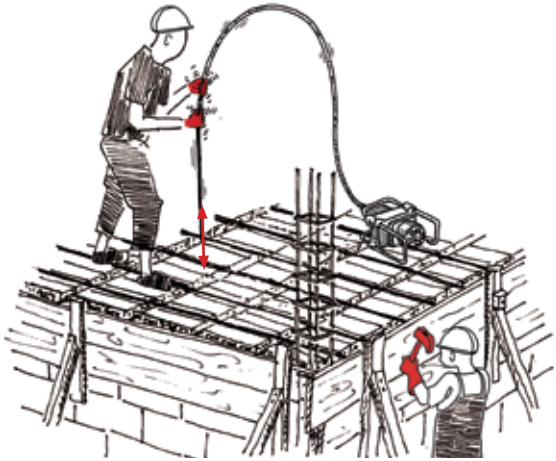
Hollow block slab: before concreting



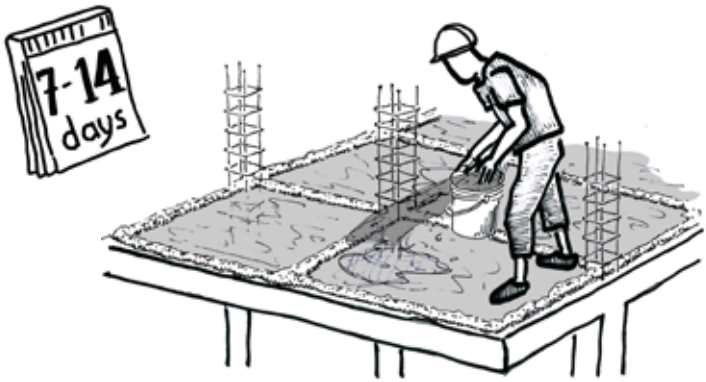
Test watertightness of the pipes before pouring concrete,
by filling them with water and waiting 4 hours
to ensure pipe connections are still watertight.

Water the formwork before pouring concrete.

Hollow block slab : concreting



Use a vibrating needle to compact the concrete and avoid air pockets.

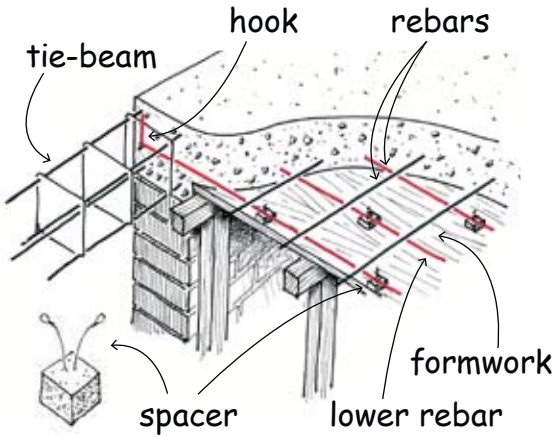


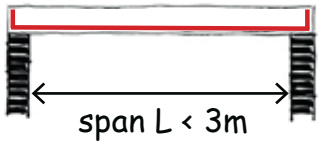
It is essential to maintain the slab humid during **the first 1-2 weeks.** The easiest way to cure the slab is to create ponds with sands or mud and fill them with water for a **minimum of 7 days**.

Full concrete slab - 1

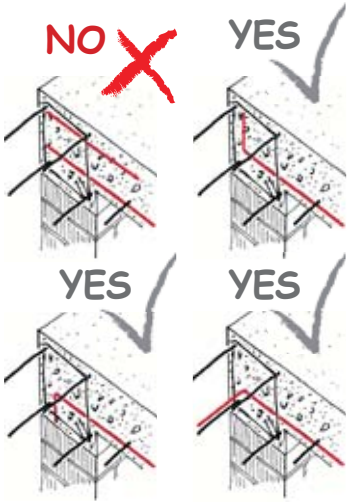
Full concrete slabs are made without hollow blocks. Place lower rebars on spacers across the shortest direction (span). Place upper rebars perpendicularly on the lower ones and hook both deep into the tie-beam reinforcement.

For span up to 3m :

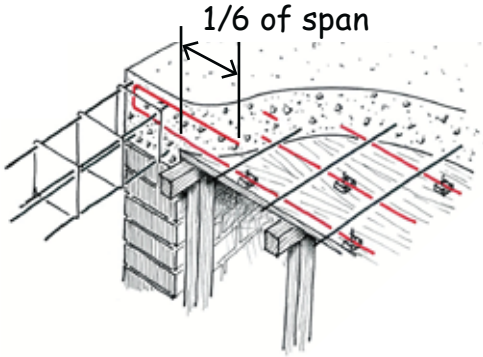


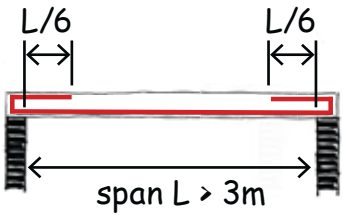


Hook options:



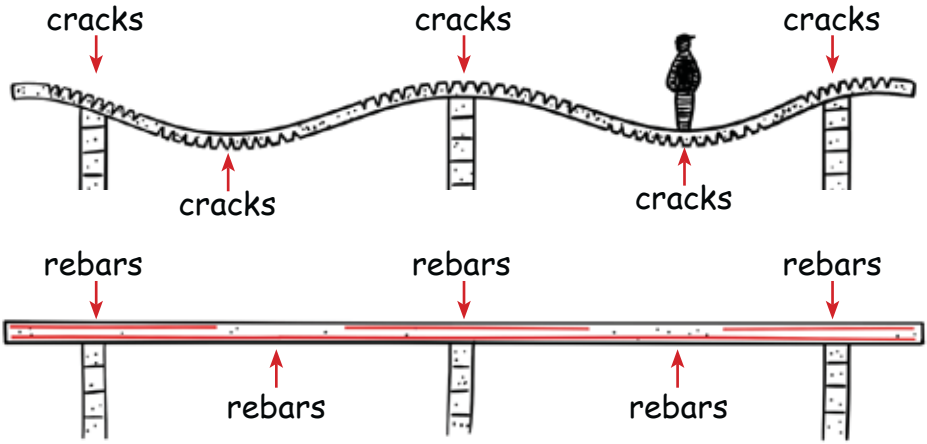
For span bigger than to 3m :



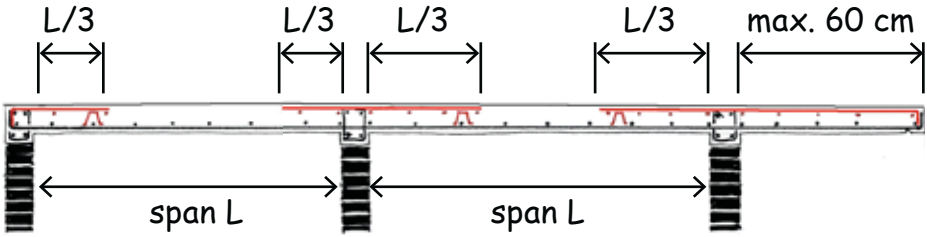


Full concrete slab - 2

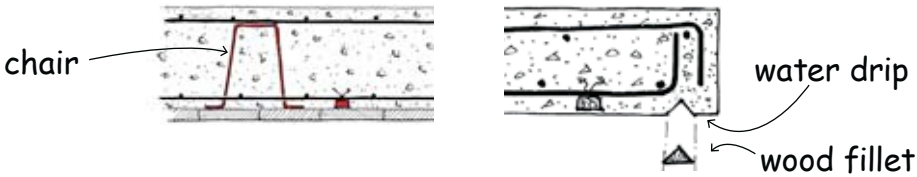
The weight will cause the slab to deform.
To avoid cracks from appearing, rebars must be placed on the exterior side of the curves.



Additional upper reinforcement in continuous slabs:



Place upper reinforcement on chairs and create a water drip:

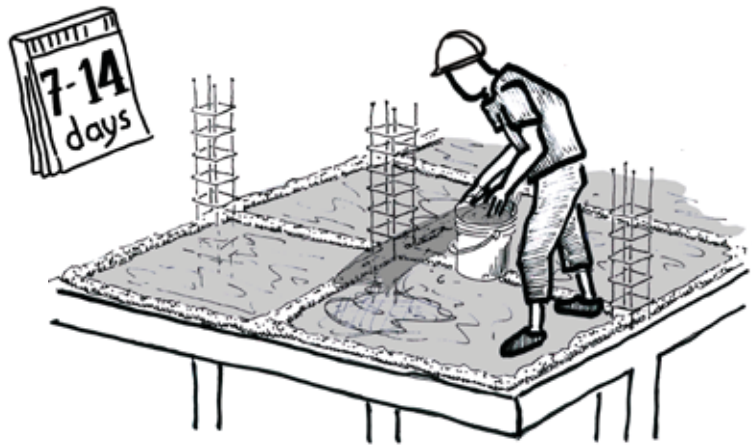


Full concrete slab - 3

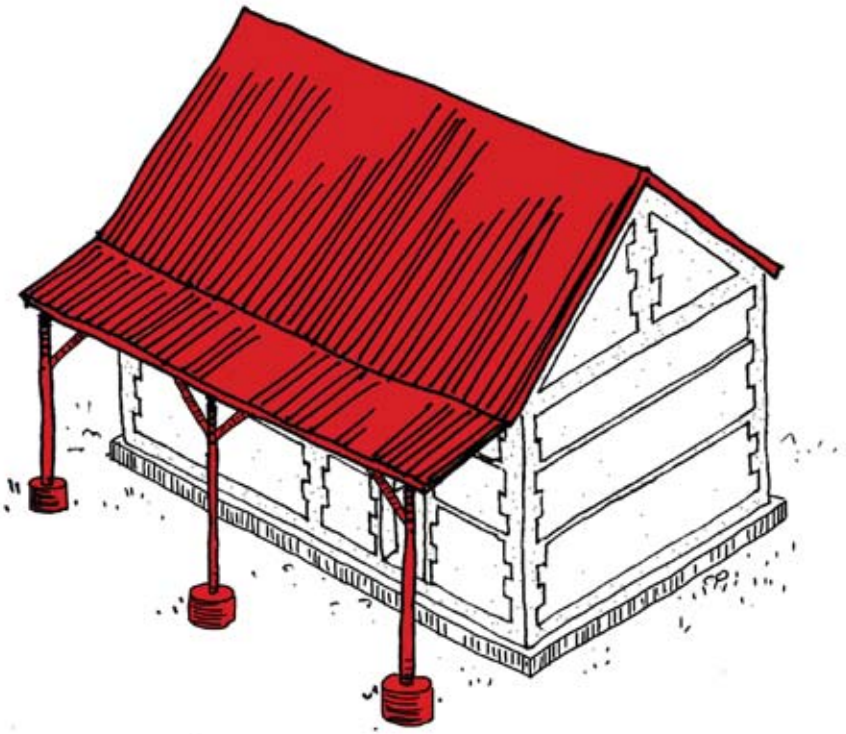
Reinforcement of full concrete slabs:
min. rebars steel grade : grade 60

span L	slab thickness	primary reinforcement	secondary reinforcement
up to 3,0m	15cm	Ø 10mm @ 12cm	Ø 8mm @ 15cm
3,0m-3,6m	18cm	Ø 12mm @ 15cm	Ø 8mm @ 20cm
3,6m-4,2m	20cm	Ø 12mm @ 15cm	Ø 8mm @ 20cm
4,2m-4,5m	22cm	Ø 12mm @ 15cm	Ø 8mm @ 20cm

Curing the concrete is essential. Create ponds with sand or mud and fill them with water for **7 to 14 days.**



LIGHT ROOF



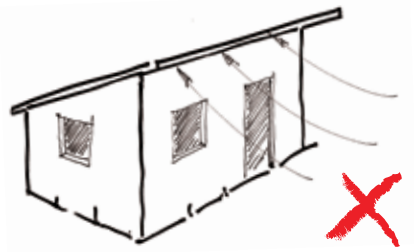
Roof shape

4 hipped roofs are particularly suitable for areas prone to strong winds and cyclones.

Good
YES

Better
YES

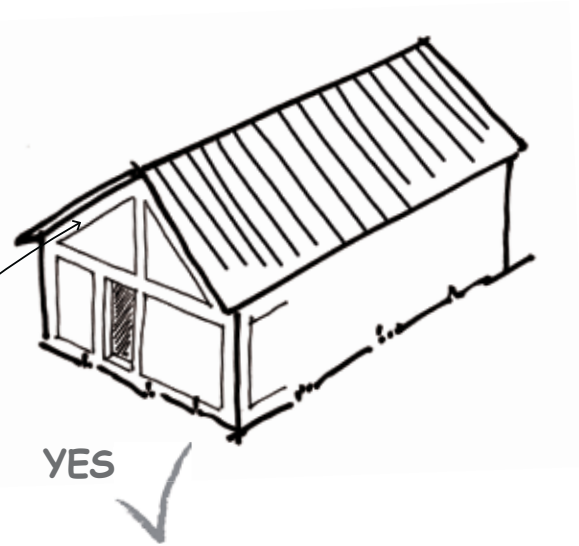
Better
YES



Not so good
AVOID

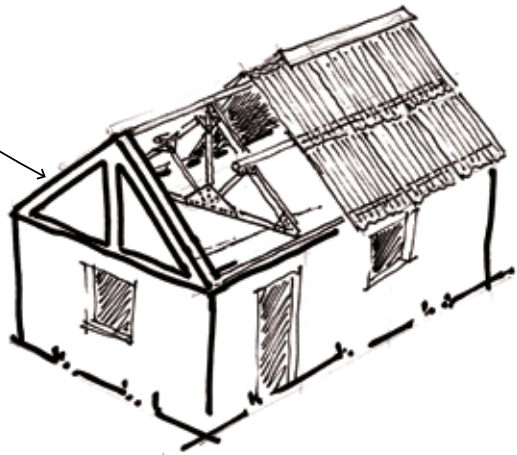
1 hipped roofs do not resist strong winds well.

Gable wall



YES

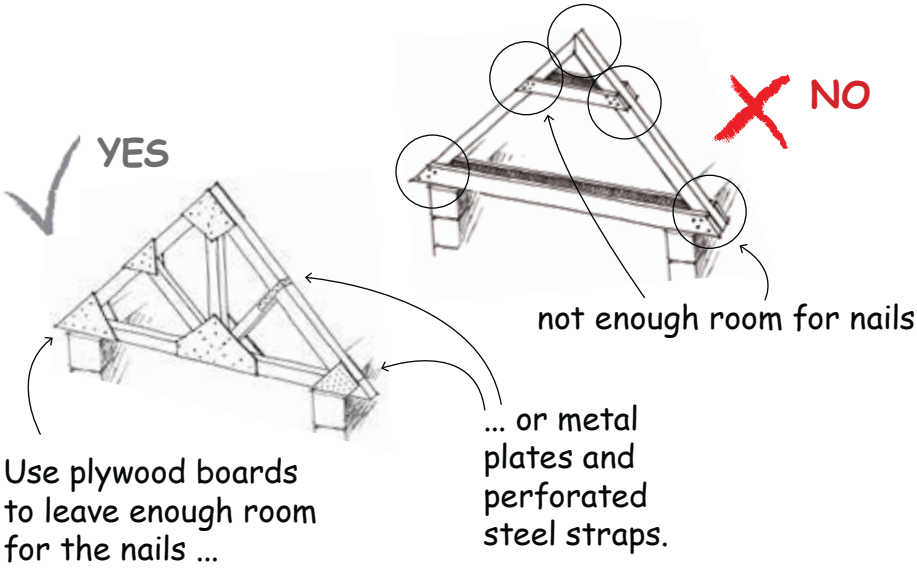
Concrete tie on top of the gable wall.



YES

Roof structure - trusses

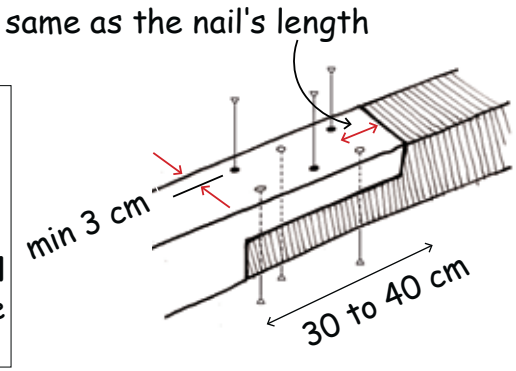
Don't build trusses with boards :
there is not enough room for the required nails.
Moreover the boards will split due to the nails.
Preferably use screws instead of nails.



Timber connections :

Put at least
3 nails in each direction.

Nail length should be **equal to the thickness** of the united timber elements.



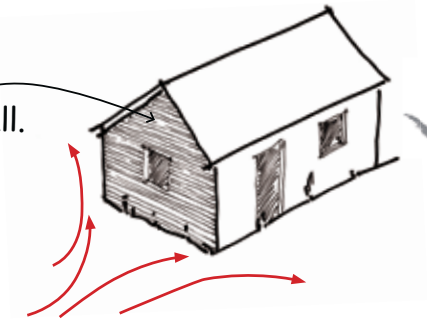
Cyclones

YES

YES

Keep verandas independent
from the main roof :
so that if the wind tears it off,
the main roof stays in place.

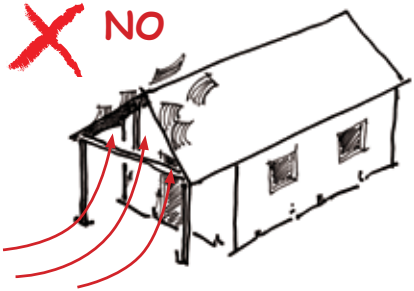
Closed gable wall.



YES

NO

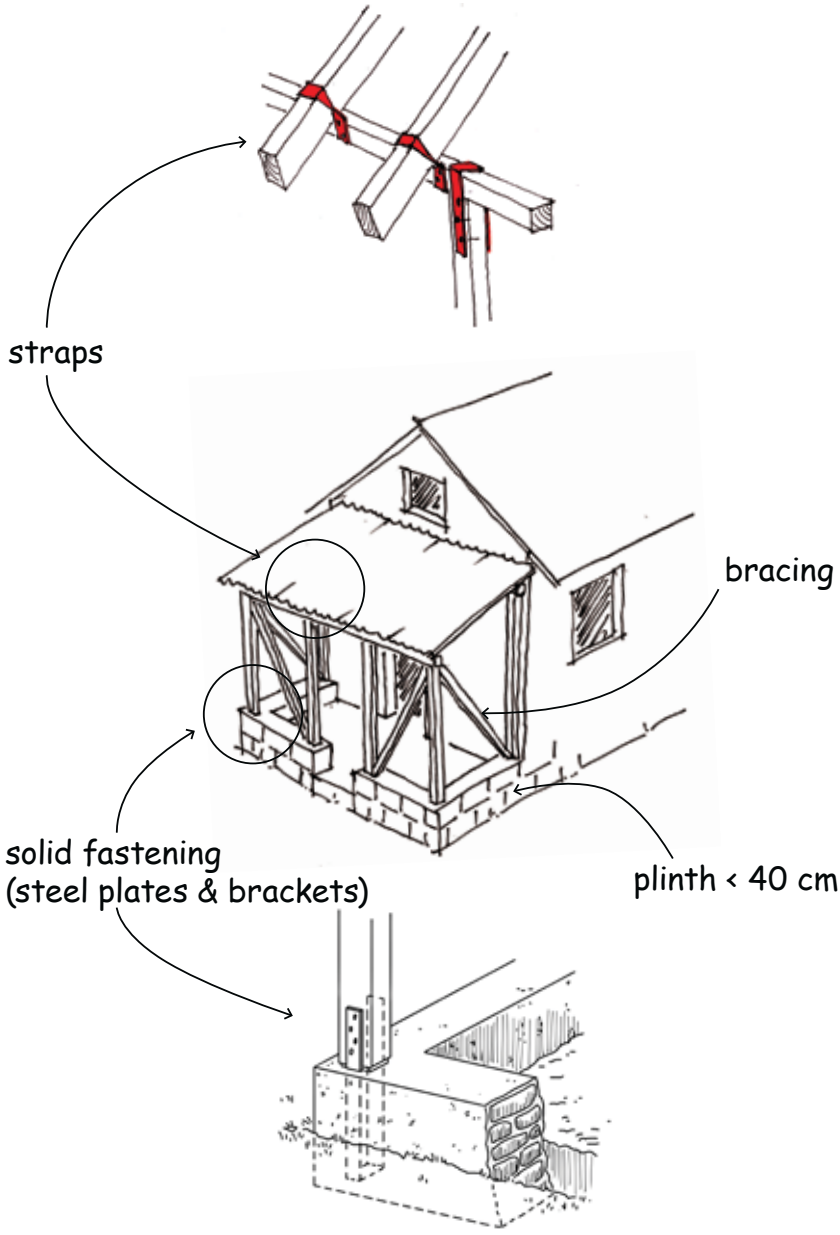
Opened gable wall.



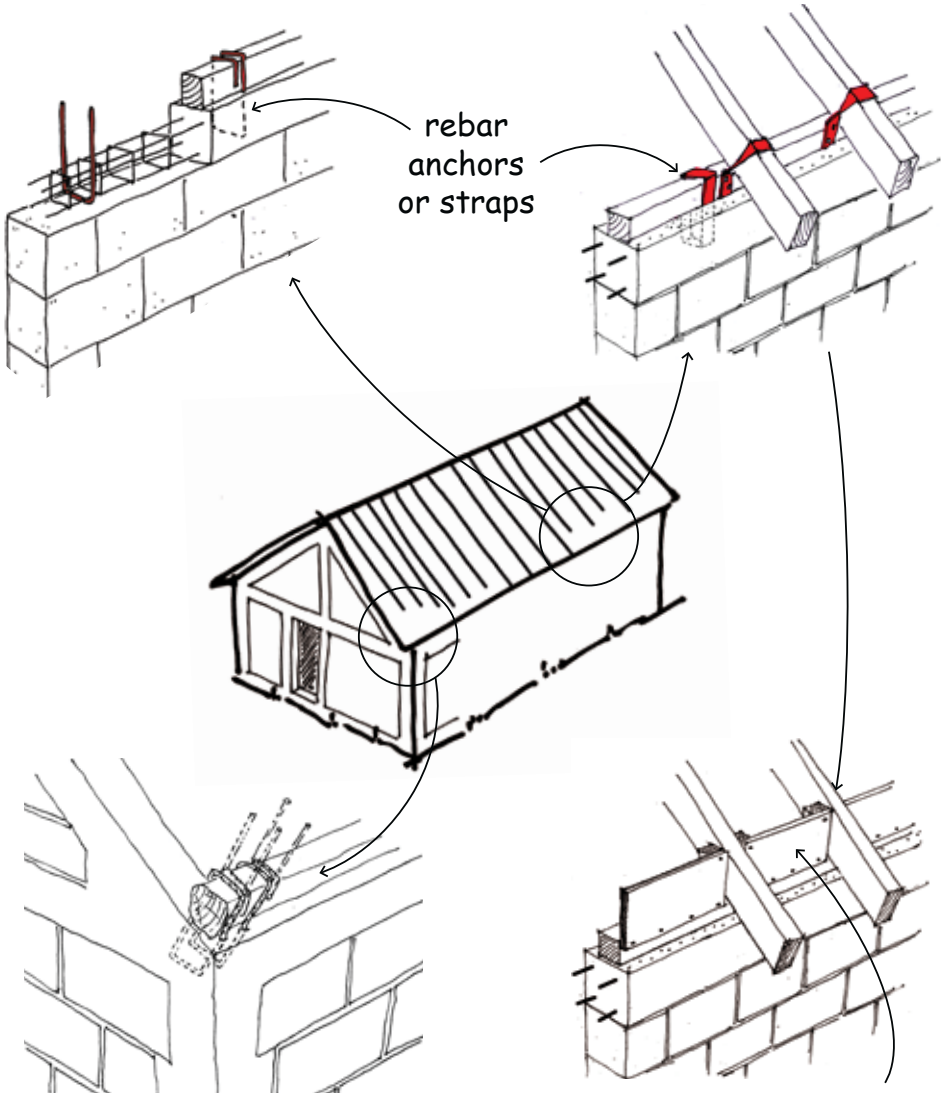
NO

Main roof extending over veranda.

Fastening of the veranda framing



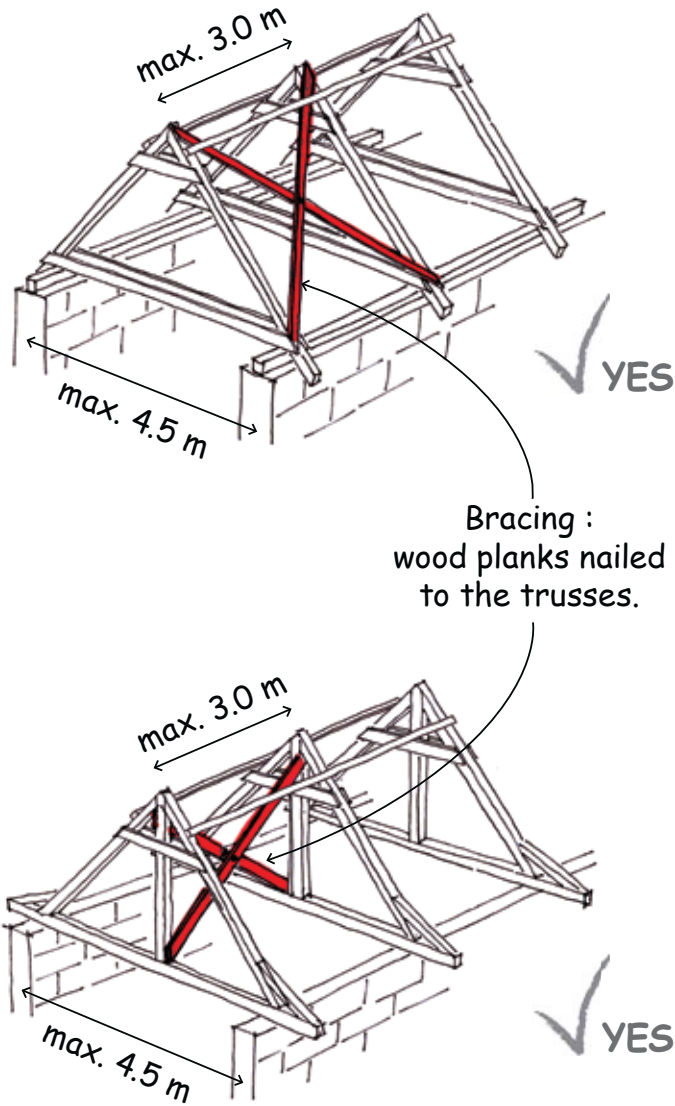
Fastening of the roof structure



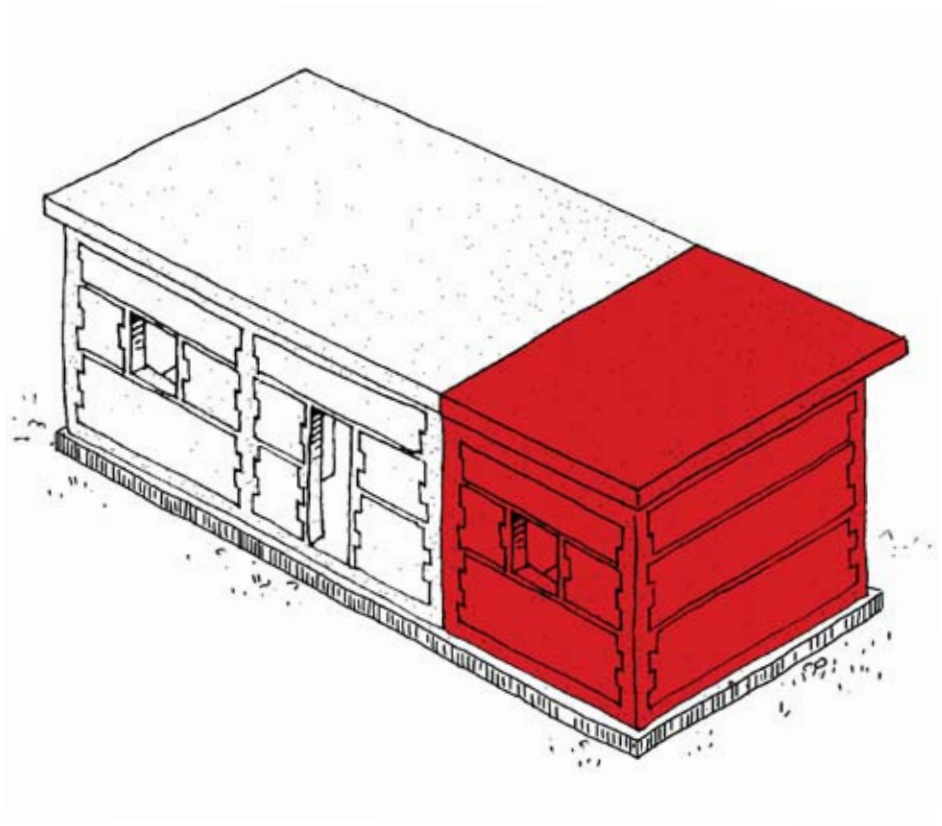
Solidly fasten the anchors or straps to the wood framing.

Close the spaces between trusses with a plank or a screen to avoid insects.

Bracing

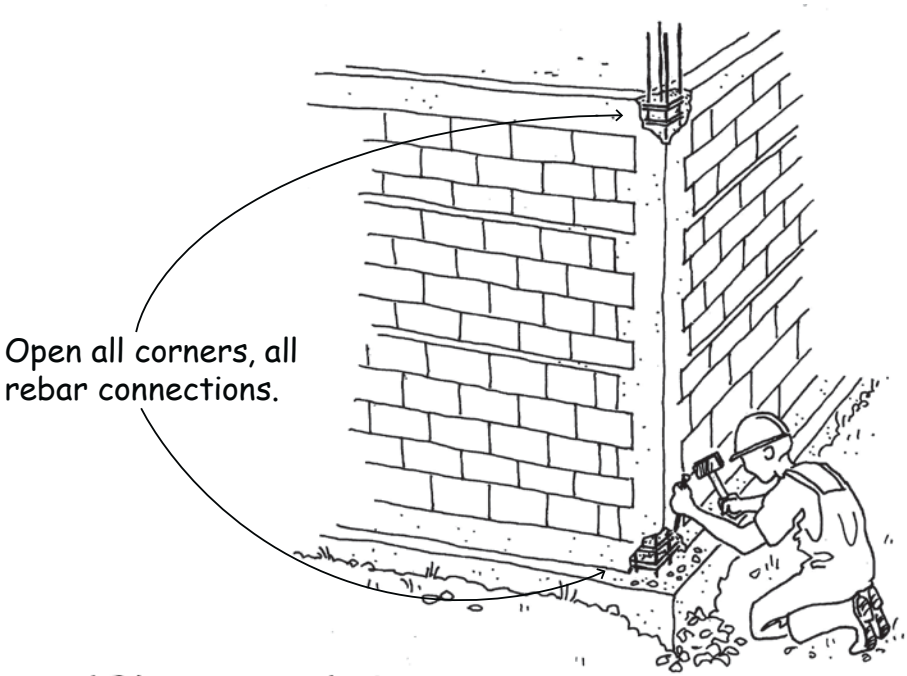

max. 3.0 m
max. 4.5 m
YES
Bracing :
wood planks nailed
to the trusses.
max. 3.0 m
max. 4.5 m
YES

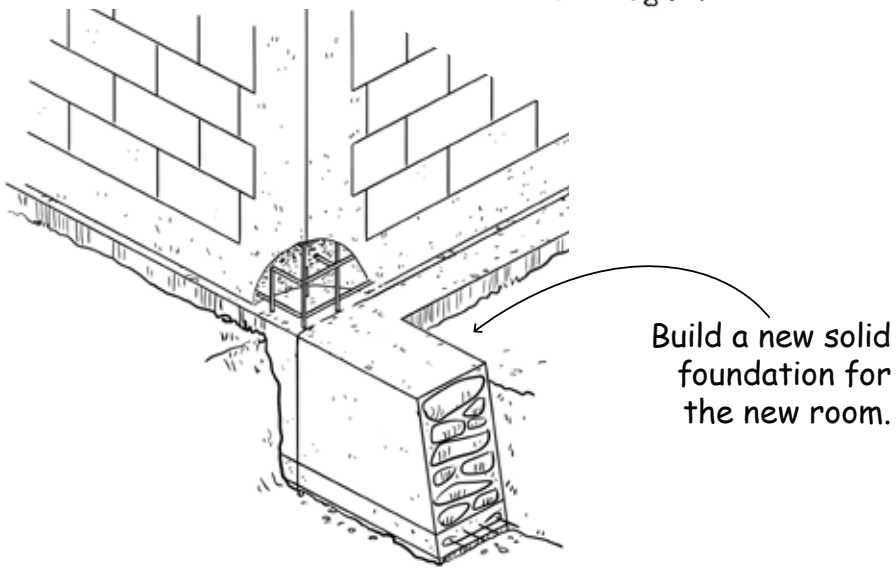
FUTURE EXTENSIONS



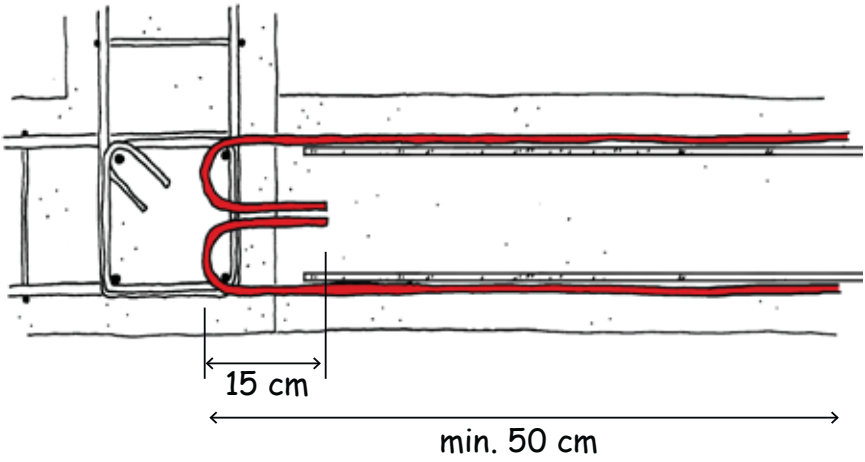
14

Preparation

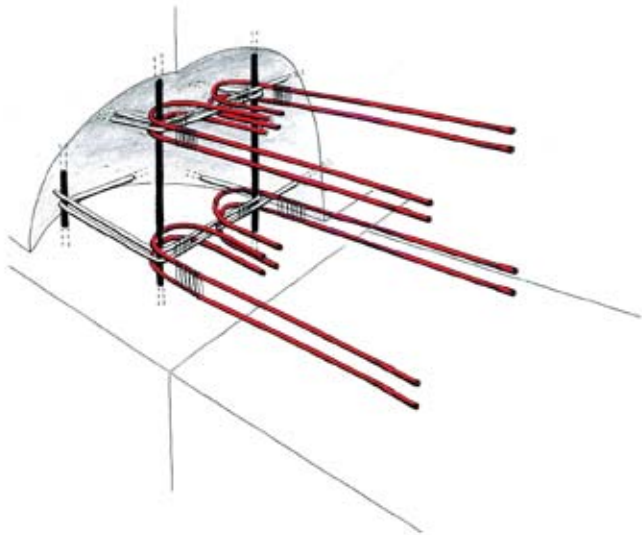




Add anchor bars

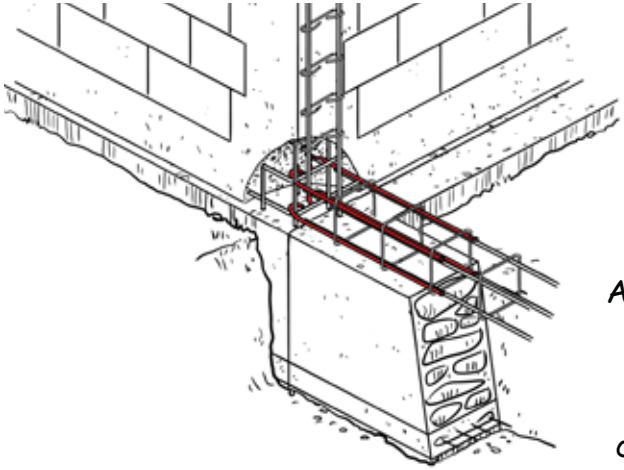


Add hooks : 10 mm rebars.



Place the hooks around the vertical rebars :
one on top and one under each stirrup.

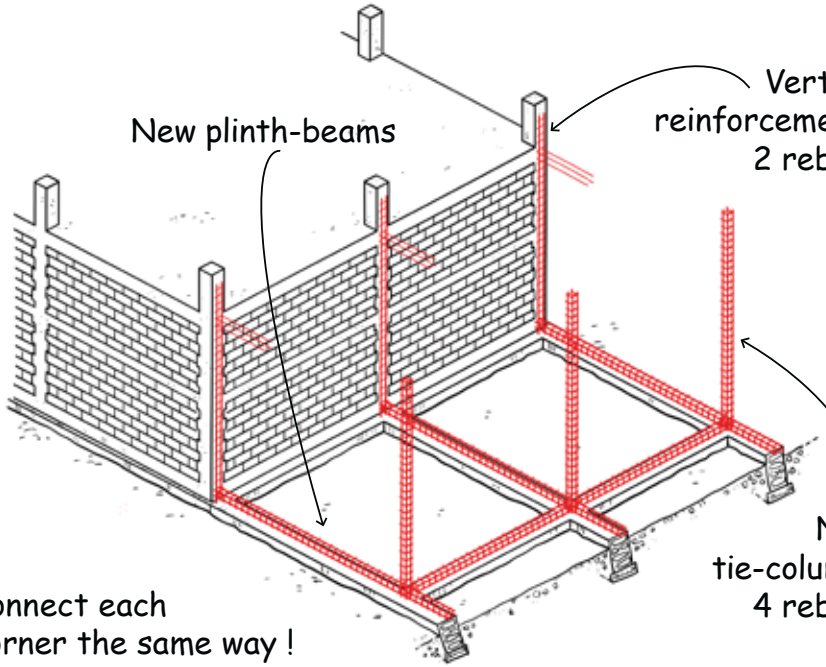
Place reinforcement



Connect the new plinth beam to the existing one with the hooks around the existing reinforcements.

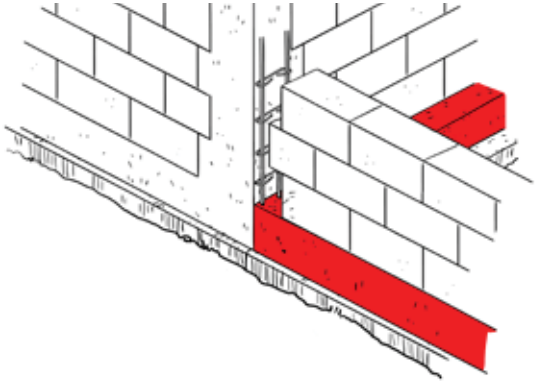
Add a vertical 2-bars reinforcement next to each existing tie-colomn to confine the new wall.

Place the 10 mm hooks and then place both the plinth beam and the tie-columns reinforcement.



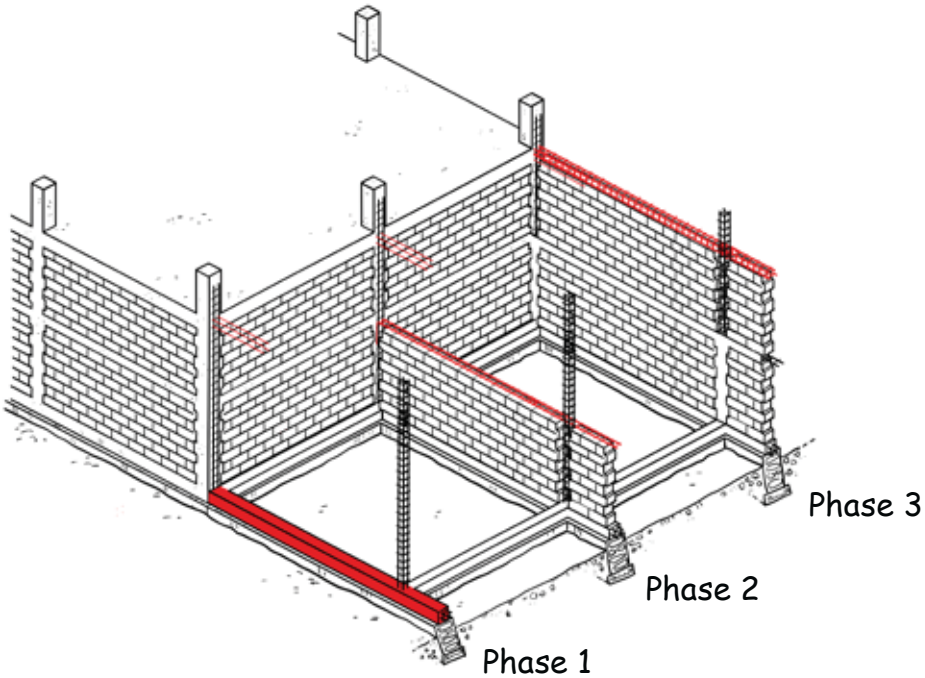
Connect each corner the same way !

Extension of the structure - 1

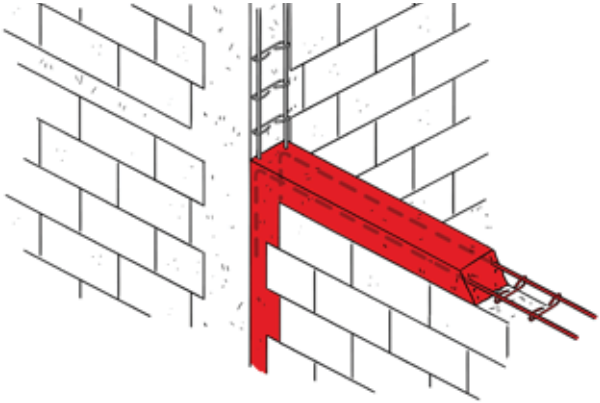


Pour concrete for the plinth-beam and fill completely the opened corners (phase 1).

Build the masonry walls first until the seismic band (phase 2) and only after pour the concrete for the tie-columns and vertical reinforcements (phase 3).

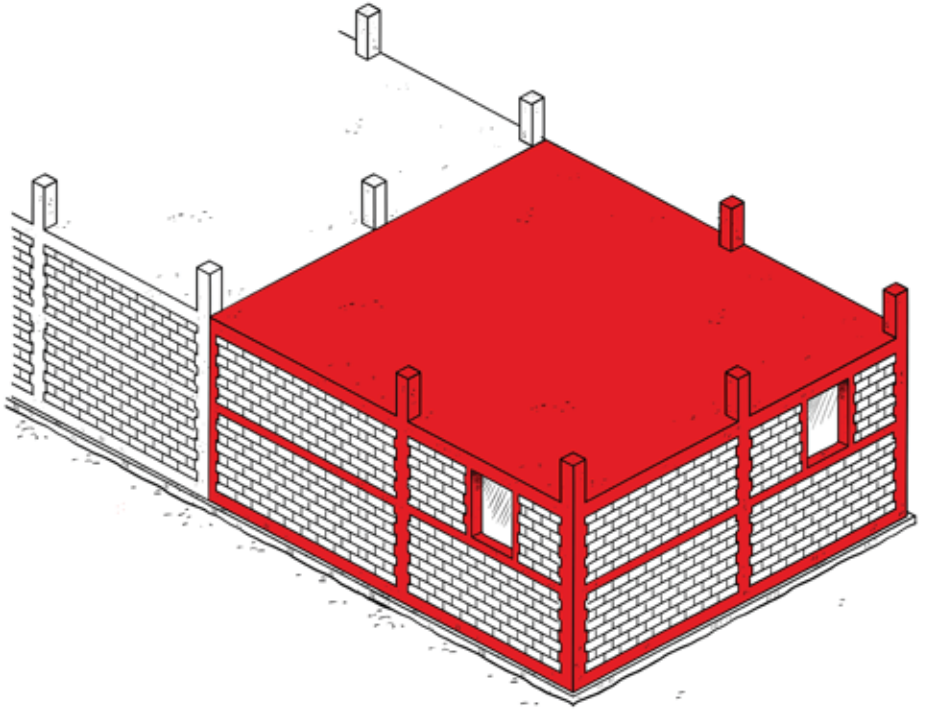


Extension of the structure - 2

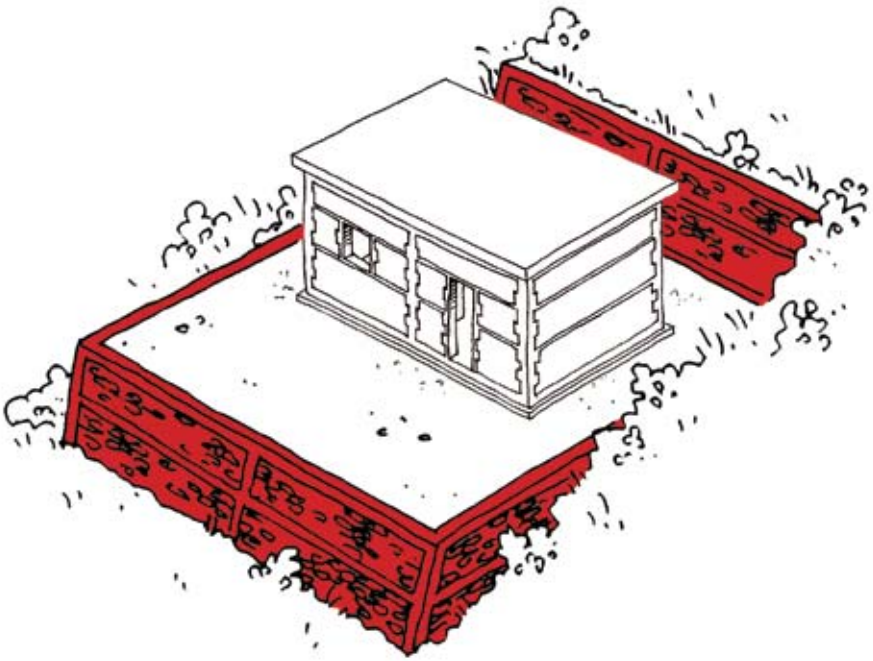


Build the seismic bands at the same height as in the existing building (min. every 1.2 m).

The walls and tie-elements for future extensions should align with the existing structure (existing tie-elements).

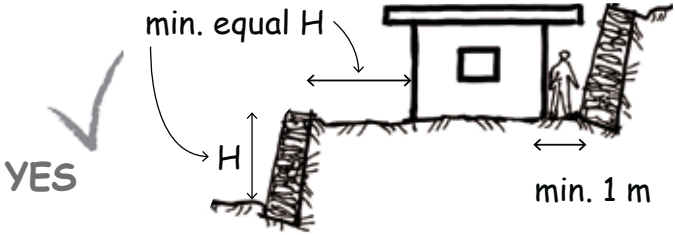


RETAINING WALLS

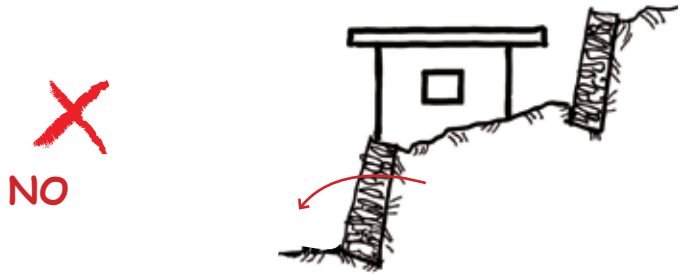


Where to build with retaining walls

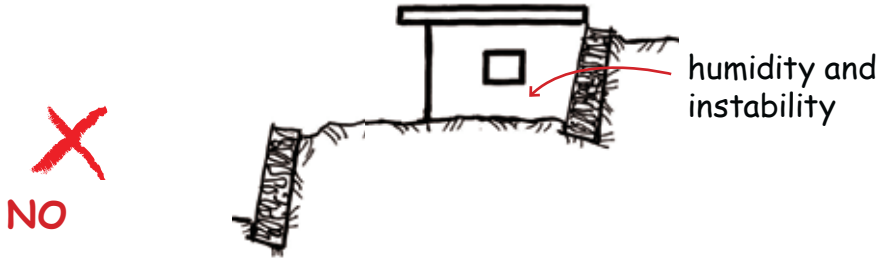
A retaining wall doesn't support a house.
A retaining wall only holds back the ground !



Don't built your house too close to a retaining wall.

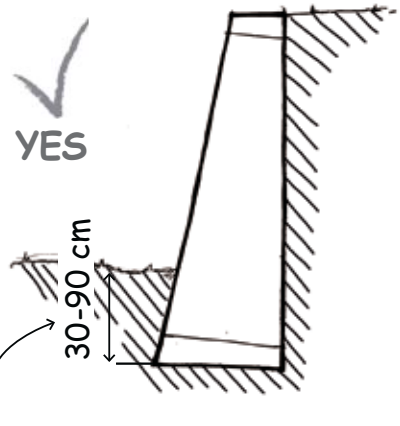


Don't build your house on top of a retaining wall.



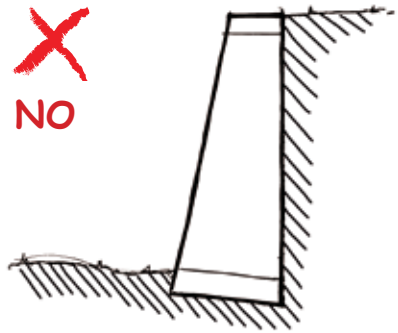
Don't build your house against a retaining wall.

Rule 1 - Wall footing



Height : depends on the type of soil.
(bottom of wall to firm soil)

- rock :	30 cm
- hard soil :	30 cm - 60 cm
- medium soil :	60 cm
- soft soil :	60 cm - 90 cm
- freezing soil :	60 cm - 90 cm



Rule 2 - Slope of the wall (5 : 1)

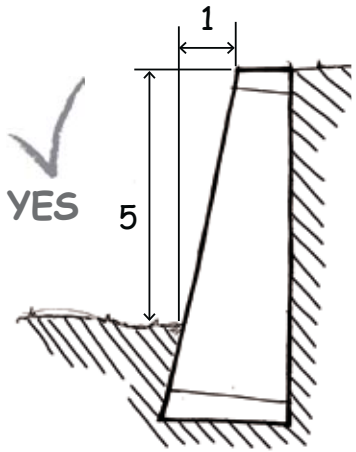
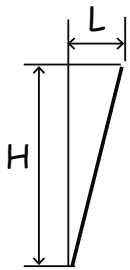
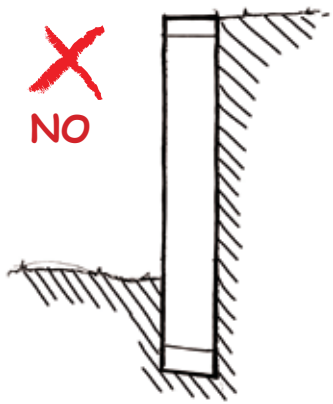


Chart
H : L = 5 : 1

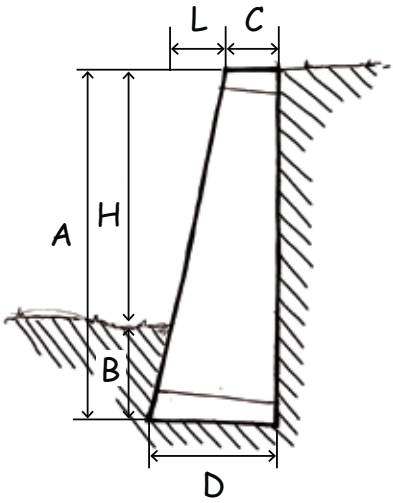


H	L
100	20
125	25
150	30
175	35
200	40
250	50

Slope 5:1
Every time you go up 5 cm, move back 1 cm.
Every time you go up 1 meter, move back 20 cm.



Rule 3 - Dimensions of the wall



Height above ground (H) :
H max = 2.50 m

Top (C) : min 50cm
50 cm : H ≤ 150 cm
55 cm : H > 150 < 250 cm
60 cm : H ≥ 250 cm

Total height (A) :
A = H + B
(-> B = 30-90 cm)

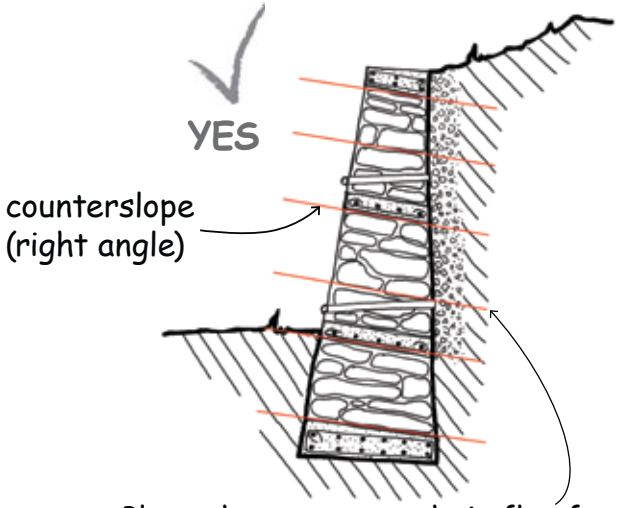
Wall base width (D) calculation :
The base of the wall (D) equals the total height (A) divided by 5, plus the top's width (C) :

D = A/5 + C

Table

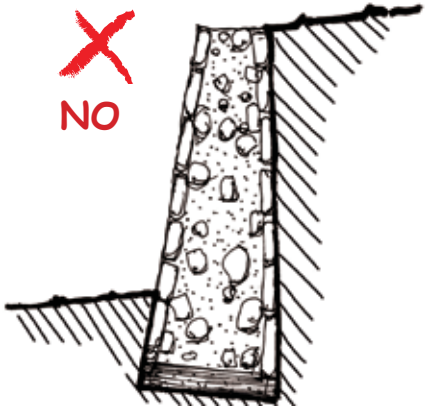
H	C	B	A	D
100	50	30-80	130-190	75-90
125	50	30-80	155-215	80-95
150	50	30-80	180-240	85-100
175	55	30-80	205-265	95-110
200	55	30-80	230-290	100-115
250	60	30-80	280-340	115-130

Rule 4 - Placing the stones

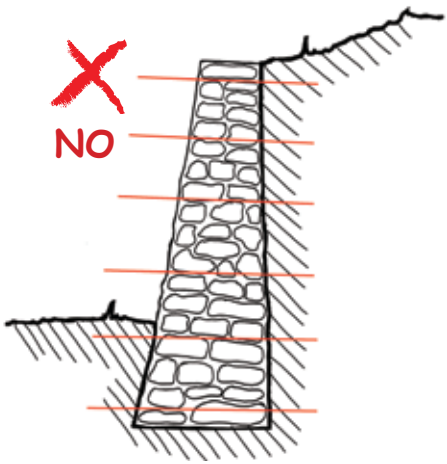


Place the stones on their flat faces
and tilt them towards the back.

Place the stones at right angles to the wall's external face.

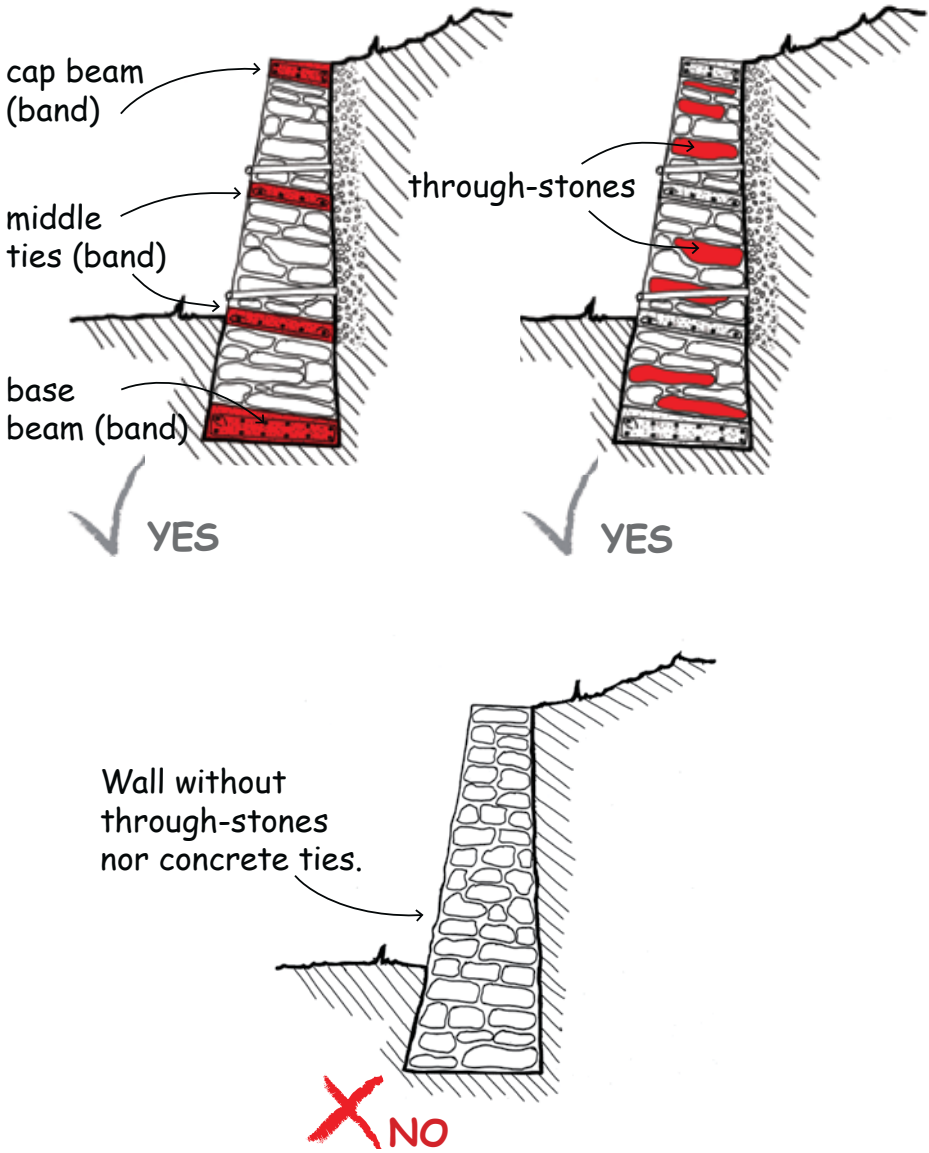


Don't place the stones
in a vertical position !

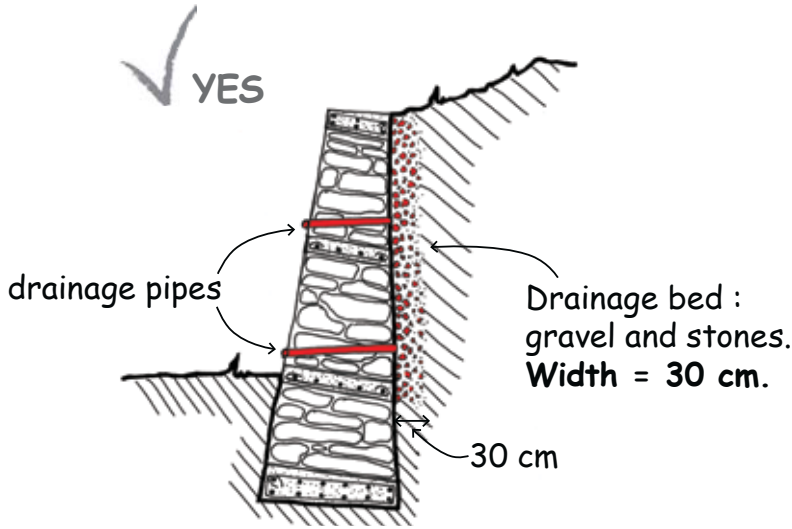


Don't place the stones
at grade !

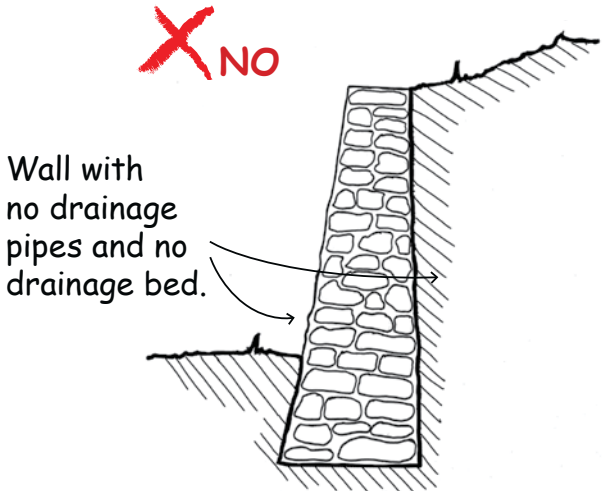
Rule 5 - Through-stones (or bands)



Rule 6 - Drainage

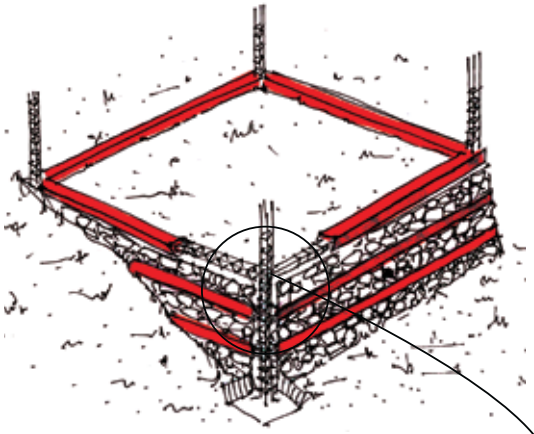


Place a drainage pipe every 1.50 m.
(vertically and horizontally)



Retaining wall - Confining elements

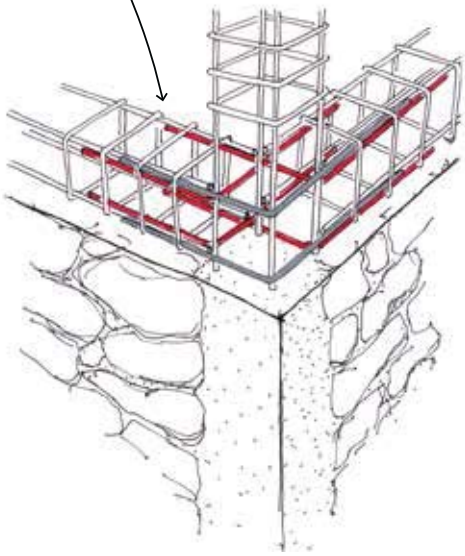
If there is no other solution than building on a retaining wall, then use these recommendations.

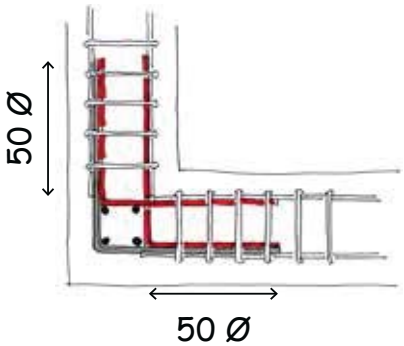


Tie-columns
Every 3 - 4.50 m

Tie-beams
Must go all around the foundation.
Every 1 m height
Add one at the top.

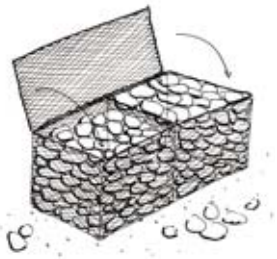
If possible : avoid building the house on retaining walls !





Gabion walls - 1

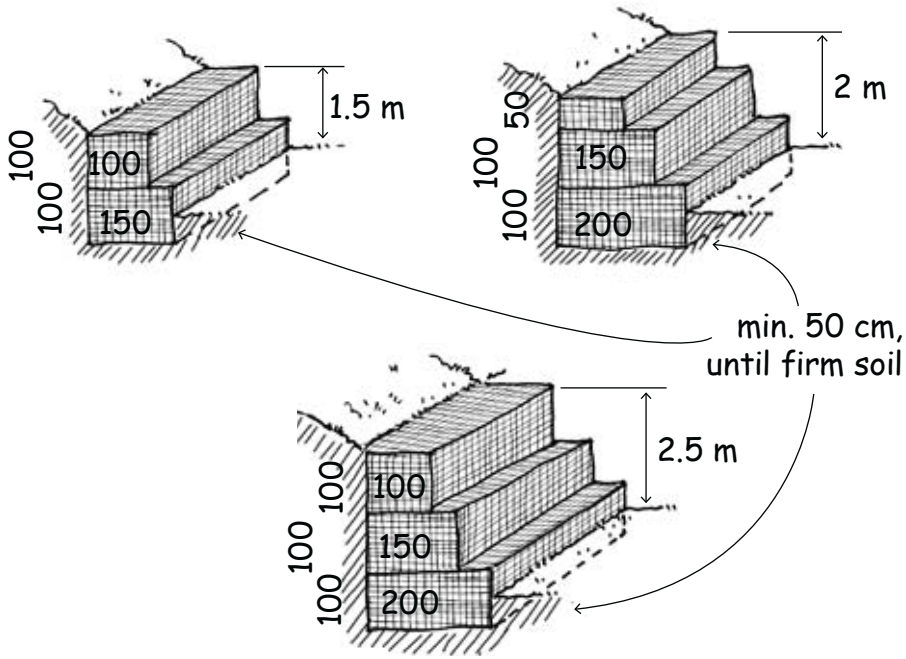
Gabion walls are made of galvanized wire mesh cages filled with stones.



The stones must be placed by hand, in an interlocking manner. Don't just dump them !

There are various ways to pile the cages. All of them are valid.

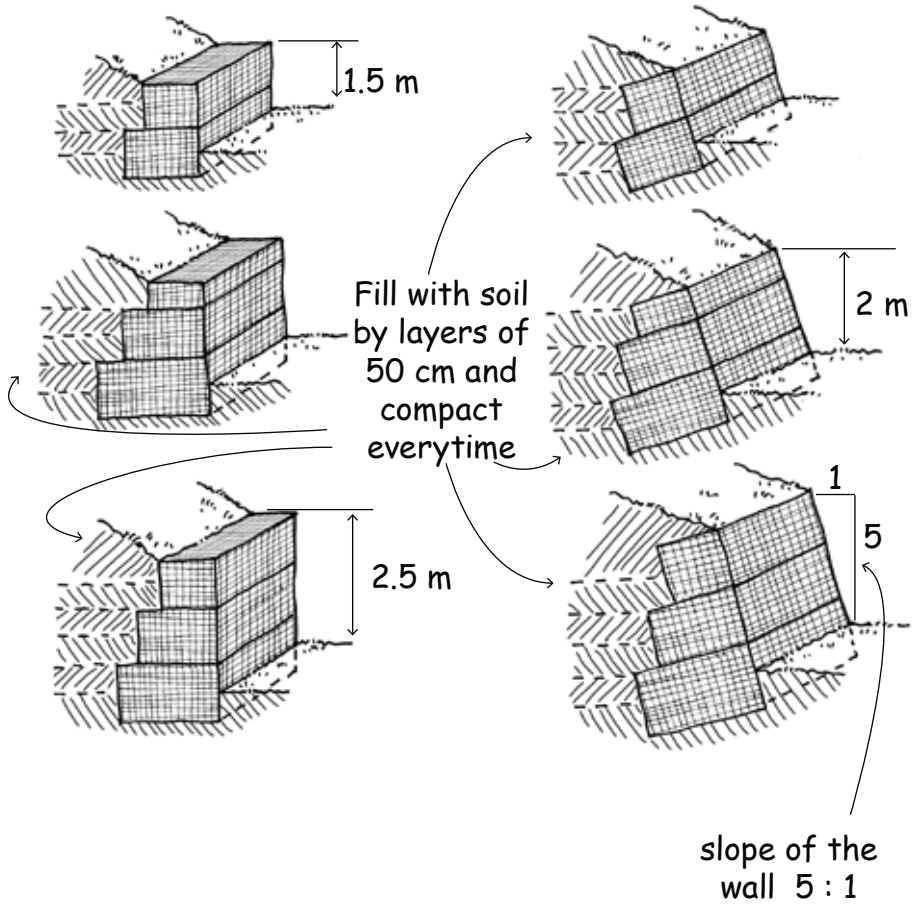
Method 1 : stepped face



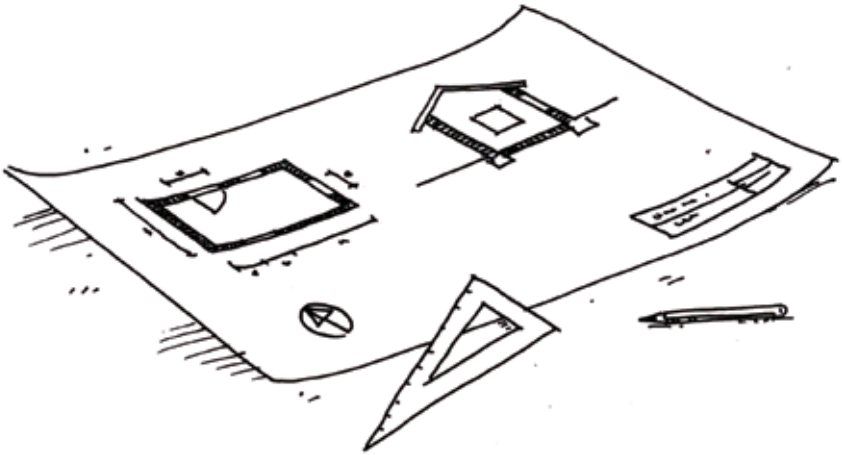
Gabion walls - 2

Method 2 :
flat vertical face

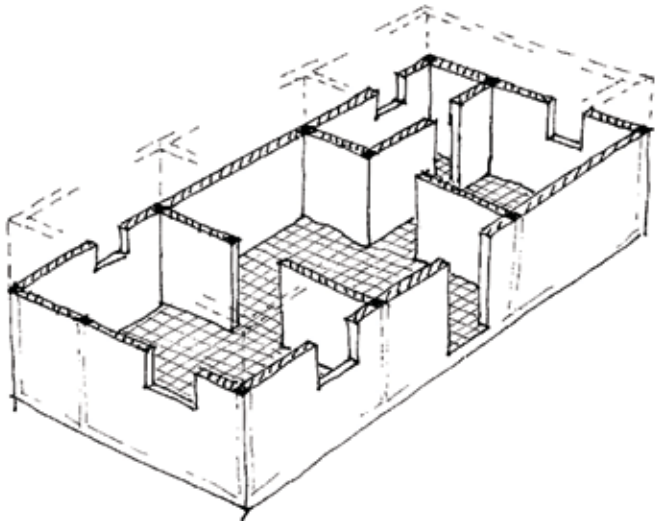
Method 3 :
flat inclined face



CONSTRUCTION DRAWINGS

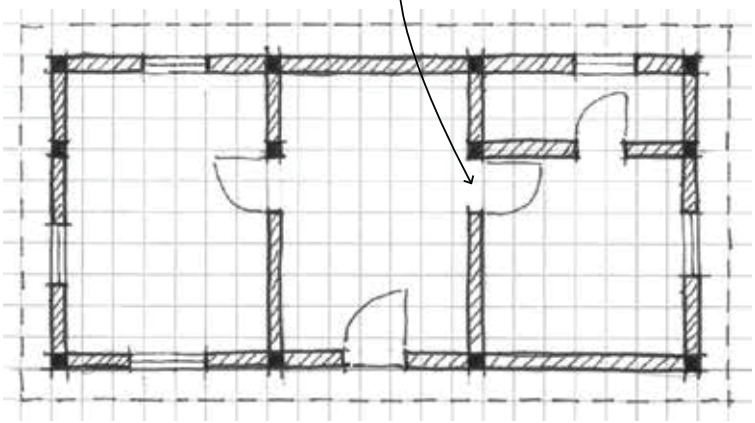


Reading plans



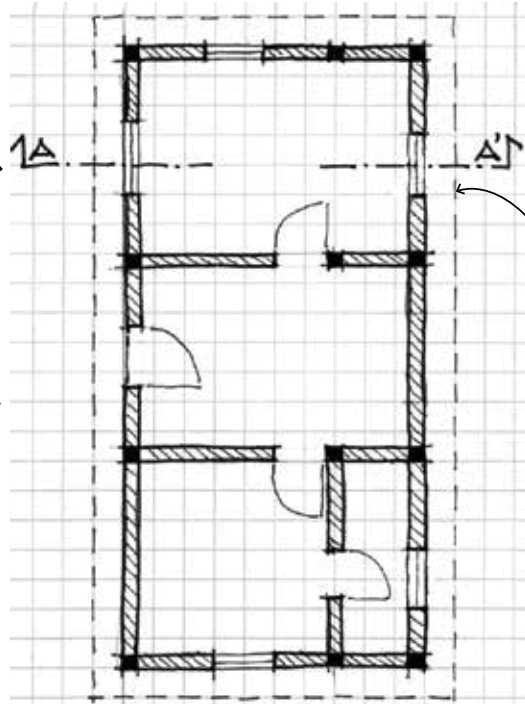
A plan represents a house, seen from above,
as if it was cut at window height.

Door symbol :
indicates the direction
of opening of the door.



House plan (seen from the top).

Reading sections



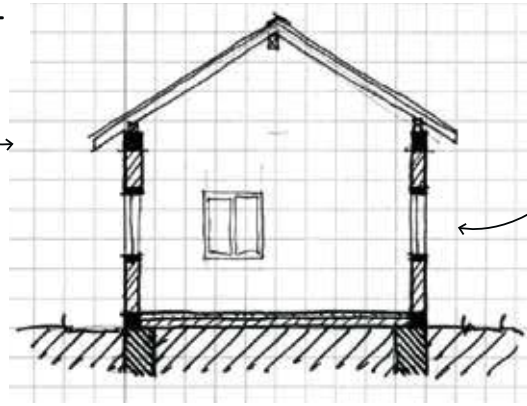
If you vertically cut the house on the line AA' ...

the same window : seen from above,

Plan

... this is what you will see !

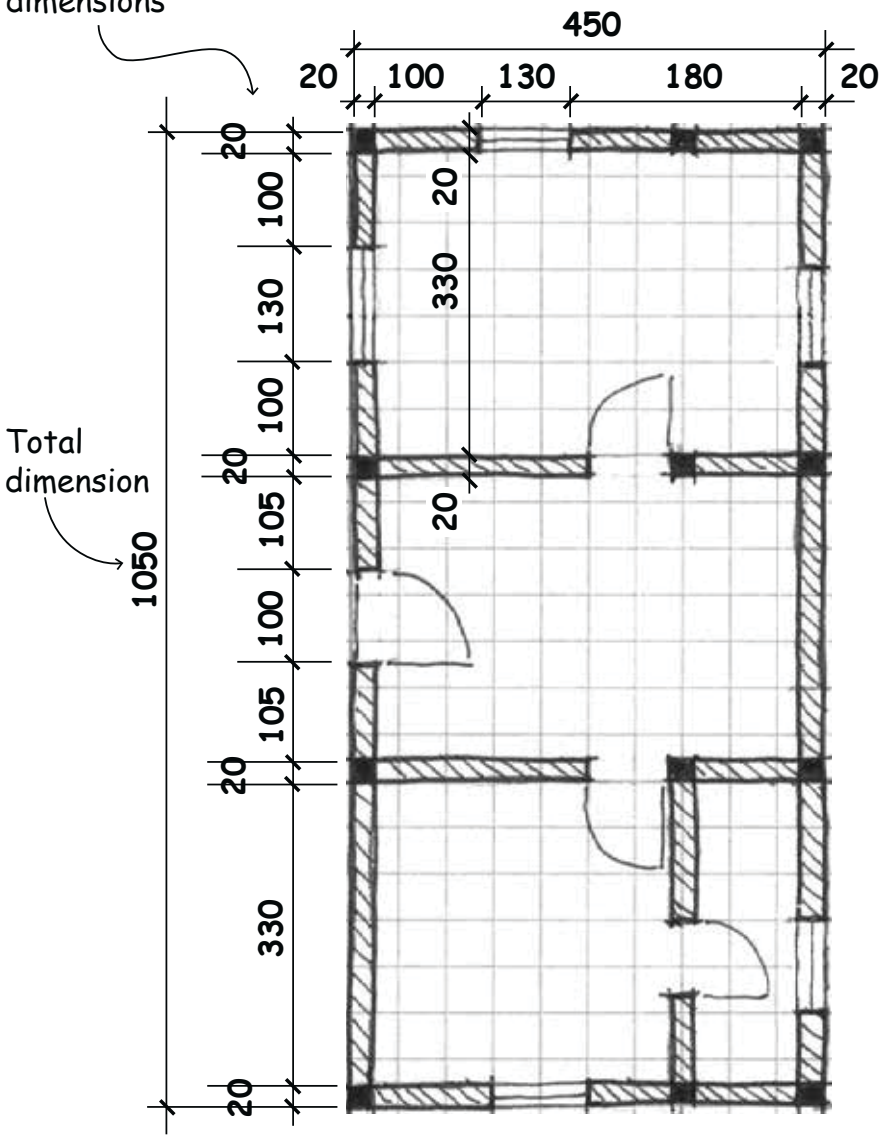
and seen from the side



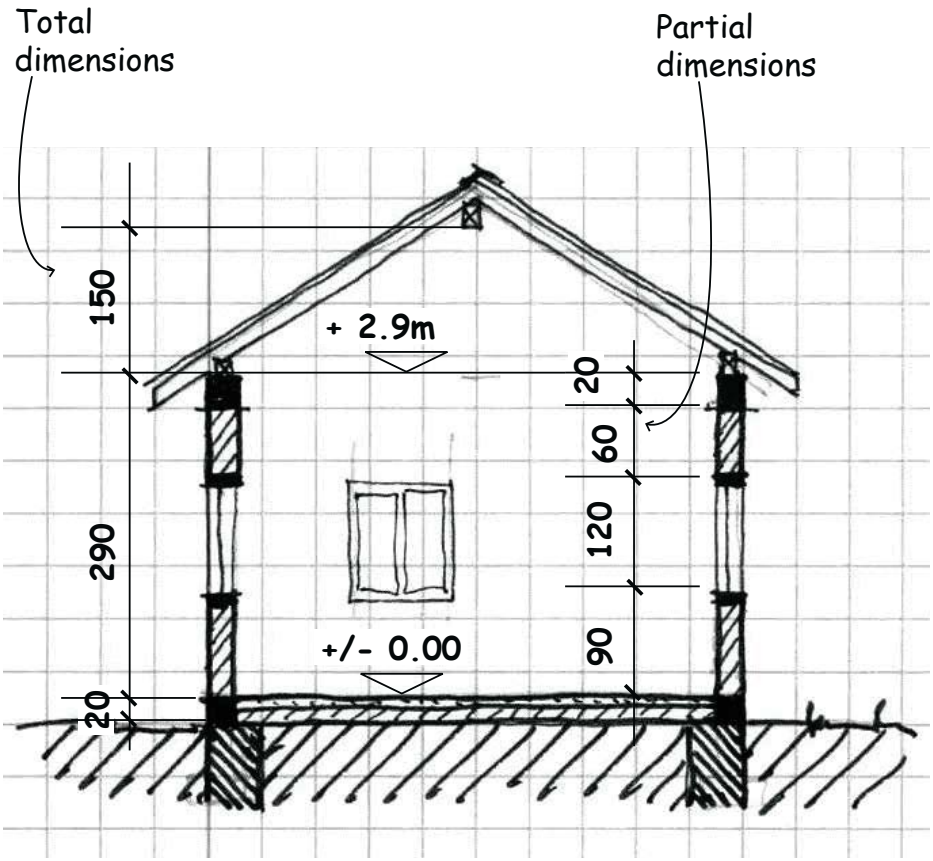
Section AA'

Plan dimensions

The sum of all partial dimensions must result in the total dimension.



Section dimensions



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This Guide was originally developed by the Competence Center for Reconstruction of the Swiss Agency for Development and Cooperation (SDC) after the devastating January 2010 Haiti earthquake.

It was developed as a resource for the mason training programme related to confined masonry construction practice, which was launched as a response to the urgent need to establish an earthquake-resistant construction practice in Haïti. Its main purpose was to improve construction practices in areas where housing construction occurs without technical input.

This guide was used at construction sites and as a resource material for mason training programmes. It offered simple but essential advice on building safer houses using the confined masonry construction technology.

This version of the Guide was adapted by SDC together with members of the Confined Masonry Network of the Earthquake Engineering Research Institute (EERI) for use in various countries and regions of the world.

It is hoped that this resource that was first developed in Haiti will be useful in other countries facing the same challenges. The users may include local governmental and non-governmental organizations, international humanitarian and development agencies, and most importantly skilled and unskilled masons around the world.

Non-country specific version, revised june 2018