Guide book for building earthquake-resistant houses in confined masonry
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

Revised version, August 2015
Technical team
Architects CCR, CSA (Swiss Humanitarian Aid Unit)
Nadia Carlevaro (EERI), Guillaume Roux-Fouillet

Illustrations
Architects CCR (Competence Center for Reconstruction, Haïti)
Guillaume Roux-Fouillet, Tom Schacher, Nadia Carlevaro
Martin Siegrist, Dorothee Hasnas

Review team
Tom Schacher - architect CSA, EERI
Svetlana Brzev, Tim Hart - Confined Masonry Network, EERI
Marjorie Greene, Maggie Ortiz - EERI
Andrew Charleson, World Housing Encyclopedia

Published by
Swiss Agency for Development and Cooperation - SDC
Humanitarian Aid - HA
Sägenstrasse 77, Köniz
3003 Bern - Switzerland

and
Earthquake Engineering Research Institute - EERI
449 14th Street, Suite 220
Oakland, California, USA, 94612-1934

Revised version, August 2015
Table of contents

Introduction 09

1 The mason’s world 11
Mason’s tools 1 12
Mason’s tools 2 13
Formwork tools 14
Steel reinforcement tools 15
Quality of materials 16
Storage of building materials on site 17
Construction site protection 18

2 Confined masonry for two-storey houses 19
Confining elements (ties) 20
A strong house 21
Shape of the house 22
Shear walls 23
Seismic gap 24
Vertical continuity of walls 25

3 Finding an adequate location 27
Site selection: where to build 28
Flood related hazards 29
Building on a slope 30

4 Layout 31
Site preparation 32
Tracing a right angle (3 : 4 : 5) 33
Layout 34
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Stone foundation</td>
<td>35</td>
</tr>
<tr>
<td>Excavation</td>
<td>36</td>
</tr>
<tr>
<td>Foundation dimensions</td>
<td>37</td>
</tr>
<tr>
<td>Special foundations</td>
<td>38</td>
</tr>
<tr>
<td>Stepped foundations</td>
<td>39</td>
</tr>
<tr>
<td>Stone masonry construction</td>
<td>40</td>
</tr>
<tr>
<td>Reinforced concrete strip footing</td>
<td>41</td>
</tr>
<tr>
<td>Curing and ground floor</td>
<td>42</td>
</tr>
<tr>
<td>Placing sewage pipes</td>
<td>43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Reinforced Concrete Ties</td>
<td>45</td>
</tr>
<tr>
<td>Types of steel rebars</td>
<td>46</td>
</tr>
<tr>
<td>Steel bar diameters</td>
<td>47</td>
</tr>
<tr>
<td>Stirrups</td>
<td>48</td>
</tr>
<tr>
<td>Alternate stirrup positions</td>
<td>49</td>
</tr>
<tr>
<td>Stirrup spacing</td>
<td>50</td>
</tr>
<tr>
<td>Lap length</td>
<td>51</td>
</tr>
<tr>
<td>Tie-beam : T-connection</td>
<td>52</td>
</tr>
<tr>
<td>Tie-beam : L-connection</td>
<td>53</td>
</tr>
<tr>
<td>Tie-beam to Tie-column connection</td>
<td>54</td>
</tr>
<tr>
<td>Protection of rebar ends</td>
<td>55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Formwork</td>
<td>57</td>
</tr>
<tr>
<td>Formwork for Ties</td>
<td>58</td>
</tr>
<tr>
<td>Vertical formwork</td>
<td>59</td>
</tr>
<tr>
<td>Horizontal formwork</td>
<td>60</td>
</tr>
<tr>
<td>Spacers - 1</td>
<td>61</td>
</tr>
<tr>
<td>Spacers - 2</td>
<td>62</td>
</tr>
</tbody>
</table>
8 Concrete
Concrete mix (1 : 2 : 3)
Mixing concrete
Concrete test
Slump test
Pouring concrete: Tie-Columns
Pouring concrete: Tie-Beams
Curing the concrete elements
Ensure good quality concrete

9 Bricks & Blocks
Which clay bricks to use
Brick test
Which concrete blocks to use
Block test
Concrete mix for blocks (1 : 4 : 3)
Making the blocks

10 Masonry walls
Cement mortar mix (1 : 5)
Cement-lime mortars
Masonry wall heights
Masonry bonds
Toothing
Toothing options
Dowels
Preparing the masonry units
Good masonry practice - 1
Good masonry practice - 2
11 Seismic reinforcement
Vertical reinforcement (V) 94
Horizontal reinforcement (H) 95
Adding vertical bands 96
Adding horizontal bands 97
Sill band and lintel band 98
Connect seismic band to tie-column 99
Size of openings 100
Door reinforcement (V) 101
Small window reinforcement (V) 102
Large window reinforcement (V) 103
Small window reinforcement (H) 104
Large window reinforcement (H) 105

12 Slab
Placing of slab reinforcement 108
Hollow block slab : formwork 109
Hollow block slab : main reinforcement 110
Hollow block slab : secondary rebars 111
Hollow block slab : positioning pipes - 1 112
Hollow block slab : positioning pipes - 2 113
Hollow block slab : pouring concrete 114
Full concrete slab 115

13 Light roof
Roof shape 118
Gable wall 119
Roof structure - Trusses 120
Cyclones 121
Fastening of the veranda framing 122
Fastening of the roof structure 123
Bracing 124
14 Future extensions
Preparation
Add anchor bars
Place reinforcement
Extension of the structure

15 Retaining walls
Where to build with retaining walls
Rule 1 - Wall footing
Rule 2 - Slope of the wall (5 : 1)
Rule 3 - Dimensions of the wall
Rule 4 - Placing the stones
Rule 5 - Through-stones (or bands)
Rule 6 - Drainage
Retaining wall - Confining elements

16 Construction drawings
Reading plans
Reading sections
Plan dimensions
Section dimensions
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 which the masons are able to read and understand.

While the authors have tried to be as accurate as possible, they cannot be held responsible for construction that might be based on the material presented in this guide. The authors and their organizations disclaim any and all responsibility for the accuracy of any of the material included 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
- cone for slump test
- big brush
- transparent water hose 10 -20 m
- pickaxe
- shovel
- 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!
Construction site protection

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
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

Only tie-beams

Yes

No

No

No
A strong house

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

**Confining elements**: (chapters 6-8)
tie-column and tie-beams (plinth beam and ring beam)

**Anchoring bands and opening reinforcement**: (chapter 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

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

Full shear wall

- Yes
- No

Opening is too big: Not a shear wall!
Opening is small and outside the diagonals: It is a shear wall!
Seismic gap

Avoid complex shapes by creating seismic gaps.

Simple shape : BETTER

YES

Minimum 10 cm (better 45-60 cm)

Complex shape : WORSE

NO
Vertical continuity of walls

Walls must be placed continuously one on top of the other. From ground to the roof!

Vertical structure

YES

Cantilevered

NO

The opening is too large.

No vertical continuity between the upper and the lower wall.
FINDING AN ADEQUATE LOCATION
Site selection: where to build

- Don’t build at the foot of a cliff.
- Don’t build on stilts.
- Don’t build on fresh embankments.
- Don’t build too close to a cliff.

Keep enough distance on each side of the house.

- Don’t build on embankments.
- Don’t build on embankments.
- Don’t build on stilts.
- Don’t build at the foot of a cliff.

YES

NO

NO

NO
Flood related hazards

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).
Building on a slope

✔ YES

Build between retaining walls.

✗ NO

Don’t build against a retaining wall.

✗ NO

Don’t build on top of a retaining wall.
LAYOUT
Site preparation

Remove the topsoil and the excavated material, and place it in 2 (or more) different heaps, away from the excavated area.

Check whether the ground is level by using a transparent hose filled with water.
Tracing a right angle (3 : 4 : 5)

<table>
<thead>
<tr>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm</td>
<td>40 cm</td>
<td>50 cm</td>
</tr>
<tr>
<td>60 cm</td>
<td>80 cm</td>
<td>100 cm</td>
</tr>
<tr>
<td>90 cm</td>
<td>120 cm</td>
<td>150 cm</td>
</tr>
<tr>
<td>1,5 m</td>
<td>2 m</td>
<td>2,5 m</td>
</tr>
<tr>
<td>2,1 m</td>
<td>2,8 m</td>
<td>3,5 m</td>
</tr>
<tr>
<td>3 m</td>
<td>4 m</td>
<td>5 m</td>
</tr>
<tr>
<td>3 ft</td>
<td>4 ft</td>
<td>5 ft</td>
</tr>
<tr>
<td>6 ft</td>
<td>8 ft</td>
<td>10 ft</td>
</tr>
<tr>
<td>9 ft</td>
<td>12 ft</td>
<td>15 ft</td>
</tr>
</tbody>
</table>
Layout

Place the batter boards 1 m outside the trenches.

Drive in nails in order to pull strings.

It is a rectangle if each diagonal is of the same length.
STONE FOUNDATION
Excavation

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.

WARNING: dig until you find firm soil and then build the foundation with the proper width!!!

Foundation height:
- hard soil: min 30 cm
- rammed soil: min 50 cm
- soft soil: min 80 cm

Foundation width:
- hard soil: 40 cm
- rammed soil: 60 cm
- soft soil: 70 cm
Foundation dimensions

**Hard soil**
- height: 30-50 cm
- width: 40 cm
- strip footing: 40 cm

**Rammed soil**
- height: 50-80 cm
- width: 50 cm
- strip footing: 50 cm

**Soft soil**
- height: min 80 cm
- width: 70 cm
- strip footing: 70 cm

**Warning**
- height above the ground: maximum 20 cm!
Special foundations

If the part above ground is higher than 20 cm, then the foundation acts as a retaining wall.
Do not exceed 40 cm above the ground!

The external face of the foundation wall must be inclined!

Foundation height:
- Rammed soil: min 50 cm
- Soft soil: min 80 cm

Foundation width:
- Rammed soil: min 60 cm
- Soft soil: min 70 cm

Avoid building in a flood-prone area!
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 construction

Place all the stones in a horizontal position!

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

Do not place the stones in a vertical position!

Place through-stones in section:

Place through-stones in plan:
Reinforced concrete strip footing

A strip footing is a must for soft soil conditions! It is also recommended for other soil conditions.

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

Strip footing:
- Width 40 cm = 4 rebars
- Width 50 cm = 4 rebars
- Width 70 cm = 5 rebars

Leave a space around the reinforcement for the concrete.
Curing and ground floor

Cure the foundation walls!
Wet every day,
for the three first days!

Always interrupt foundation work on a sloped line.

Build a “drainage bed” to avoid moisture coming in!

- Plinth beam
- Flashing
- Foundation wall
- Strip footing
- “Drainage bed”
  - 7-10 cm lean concrete
  - 15-20 cm small stones on top of big stones
  - Good compacted soil
Placing sewage pipes

The pipe must go through the foundation, under the plinth beam!

For tolerance, leave a hole larger than the sewage pipe, using a larger diameter pipe. Don’t use empty cement bags!

Do not go through the plinth beam!
Reinforced Concrete Ties
Types of steel rebars

Use ribbed steel for all rebars. Only stirrups can be made of smooth steel.

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

Strength indication are written on the rebar:

Country of origin
Producer
Grade
Diameter

Do not use second hand rebars!
Steel bar diameters

For rebars:

YES

NO

For stirrups:

YES

Rebars diameters (imperial and metric):

<table>
<thead>
<tr>
<th>imperial</th>
<th>inch</th>
<th>metric</th>
<th>rebars</th>
<th>stirrups</th>
</tr>
</thead>
<tbody>
<tr>
<td>#6</td>
<td>3/4 in.</td>
<td>19 mm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>#5</td>
<td>5/8 in.</td>
<td>16 mm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>#4</td>
<td>1/2 in.</td>
<td>12 mm</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>#3</td>
<td>3/8 in.</td>
<td>10 mm</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>-</td>
<td>1/3 in.</td>
<td>8 mm</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>#2</td>
<td>1/4 in.</td>
<td>6 mm</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

Rebar dimensions for vertical and horizontal ties:

stirrups:
min Ø 6 mm
better Ø 8 mm

rebars:
min Ø 10 mm
better Ø 12 mm
Stirrups

Bend stirrup ends at 45°!

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

Possible stirrup types:
It is necessary to alternate position of stirrup hooks!!
Stirrup spacing

Rules for stirrup spacing:

1. At the top and bottom of each tie-column and ends of tie-beams place the first stirrup at 5 cm spacing, then place stirrups at 10 cm spacing over a length of H/6 (better 60cm).

2. Place stirrups at 20 cm spacing elsewhere.
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!

<table>
<thead>
<tr>
<th>Lap length: (overlapping)</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50 \times \varnothing$</td>
<td>YES</td>
</tr>
<tr>
<td>(50 times the diameter)</td>
<td></td>
</tr>
</tbody>
</table>

for 10 mm rebar = 50 cm
for 12 mm rebar = 60 cm
Tie-beam: T-connection

Always: extend hooked bars from the inside to the outside!

Lap length: (overlapping) $50 \times \varnothing$
(50 times the diameter)
for 10 mm rebar = 50 cm
for 12 mm rebar = 60 cm

Connection with straight bars.

Connection around the inner corner.
Tie-beam: L-connection

Rebars must cross like the fingers of a hand!

Put an additional rebar around the outer corner.

Extend hooked bars from the inside to the outside!

Connection with straight bars.

Hooked bars from inside to inside.

NO

YES
Tie-beam to Tie-column connection

If the wall ends here, bend the vertical rebars into the tie-beam.

One-storey building

If the wall continues, add vertical rebars with an 50 Ø overlapp.

Two-storey building
Protection of rebar ends

Protect rebar ends with lean concrete.

Exposed rebar ends will rust and cannot be reused.

Protected rebar ends.

Exposed rebar ends.
FORMWORK
Formwork for Ties

**Block walls:**

- **20cm wall thickness:** place formwork boards on both sides.

**Brick walls:**

- **15-24cm wall thickness:** place formwork boards on both sides.

**Sizes of tie-columns and tie-beams:**

- **20 x 20 cm recommended / 15 x 20 cm minimum!**
Vertical formwork

**Vertical formwork at upper floor level:**

- Wooden scantling
- Tie wire
- Nails for tie wire
- Shuttering

Ø 8 mm rebars built in tie-beam

**Vertical formwork at ground floor level:**

Formwork must be well braced!
Horizontal formwork

Use wood planks to connect formwork.

Formwork must be well fastened!

To be able to reuse the formwork, use small nailed planks. Do not use tie wire!

Formwork must be well braced!
Spacers - 1

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 instead!

![Diagram of spacers and wire loops]
Spacers - 2

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

Alternate the position of the spacers around the stirrups!

- tie-column
- plinth beam
- tie-beam
- reinforced concrete slab
- joist and pan slab
CONCRETE
Concrete mix \((1:2:3)\)

1 part cement

3 parts gravel (max. 18mm)

2 parts clean sand (washed and dry)

3/4 part clean water

Table of various concrete mixes (by volume):

<table>
<thead>
<tr>
<th>Concrete Mix</th>
<th>Cement</th>
<th>Sand</th>
<th>Gravel</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>200 kg/m³</td>
</tr>
<tr>
<td>Preferred</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>250 kg/m³</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>350 kg/m³</td>
</tr>
</tbody>
</table>

Preferred mix = \((1:2:3) = 250 \text{ kg/m³}!\)

Note:
Concrete should have a minimum amount of 300 kg of cement per cubic metre. The values taken into account in this manual are lower (min. 200 kg/m³), to allow for a concrete not made properly by untrained workforce.
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 and mix again. Add the water only at the end!

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 90 min 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 90 min.
Never “refresh” dried concrete by adding water! Don’t mix too much concrete at a time!
Slump test

Use a standard steel cone:

SLUMP TEST PROCEDURE:

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.

Result: the difference between slump and cone should be less than 12.5 cm!
Pouring concrete : Tie-Columns

Never add water to make the concrete more liquid and “flow down better”!

Use a stick (or rebar) and a hammer to help the concrete flow down, to compact it and avoid air pockets. Use a mechanical vibrator if one is available!
Pouring concrete: Tie-Beams

Use a stick (or rebar) and a hammer to help the concrete flow down, to compact it and avoid air pockets. Use a mechanical vibrator if one is available!

Roughen up the top surface of the plinth beam to increase bonding of the mortar for the wall.
Curing the concrete elements

Concrete needs water to harden!

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

After formwork is removed, cure the concrete for 7 days, and cover it with plastic sheets.
Exposed rebars will rust!

Poor compaction: the concrete is weakened!
BRICKS & BLOCKS
Which clay bricks to use

Best brick:
solid burnt clay brick
with frogs.

Good brick:
vertical holes less than
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 than multiperforated ones!

Vertical holes should
be less than 50%
of the horizontal
surface area!

min 11 cm
(recommended 12.5-15 cm)

Note: we recommend to use 10MPa bricks.
Brick test

Visual test :

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

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

Satisfactory block:
15-20 cm thick, with 3 holes.

Only if excellent quality!
20 cm thick, with 2 holes.

web thickness
min 25mm
voids less than 50%

min 15 cm thick
recommended 20 cm !!!

Note: we recommend to use 10MPa blocks.
Block test

Test blocks before buying them!

Drop 5 blocks from 1.5 m height on hard surface! (concrete surface)

Acceptable quality: (less than 1 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 that dry in the sun: very bad!
Concrete mix for blocks (1 : 4 : 3)

1 part cement
4 parts clean sand
3 parts gravel (8-10mm)
3/4 part clean water

Sand should be crushed, washed and dried.
Do not use sea 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 8 days before using the blocks!

Fill the molds with the mixture.

To compact the concrete, hit the mold with a shovel and a hammer.

Cover the blocks with plastic sheets immediately!

Store the blocks in the shade.

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

If possible use a vibrating machine!
MASONRY WALLS
Cement mortar mix (1:5)

Mix the mortar:

1 part cement + 5 parts clean sand (washed and dry) + 3/4 part clean water

Add the water only at the end!

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

Use 1:3 mix ratio for 15cm or less wall thickness!

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

3. Add the water and mix again.
Cement-lime mortars

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

Recommended mortar mix proportions:

<table>
<thead>
<tr>
<th>Cement</th>
<th>Lime</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>preferred</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>minimum</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Mix the mortar:

X parts cement
Y parts lime
Z parts clean sand
3/4 part clean water
Masonry walls height

The Width of masonry unit defines the wall height.

For bricks: Height smaller than $25 \times$ wall Width
For blocks: Height max $22 \times$ wall Width

$\text{Height} = \text{maximum} \ 3m$!
Masonry bonds

Solid wall = Running bond
vertical joints are not continuous.

Weak wall = Stack bond
vertical joints are continuous.

1/3 to 1/2 of block/brick
Toothing

Toothings:
- min 5cm / max 13cm

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

Toothing 1/3-1/4 of a block:
- (max 1/2 of brick length)
  GOOD!

Toothing 1/2 of a block:
- (> 1/2 of brick length)
  TOO BIG!
**Toothing options**

**Clay bricks (23-24 cm):**
- 50% running bond (half of a brick)
- Tooothing = max 12 cm

**Concrete blocks (40 cm):**
- 50% running bond (half of a block)
- Break 1/3 of last block!
- Tooothing = min 5 cm

**Concrete blocks (40 cm):**
- 33% running bond (1/3 - 2/3 of a block)
- Tooothing = max 13 cm
Dowels

Although tothing is the optimal method, the use of dowels can be an alternative.

Dowels are 6mm rebars

Place dowels:
- \(50 \text{ cm}\) within the bed joints of the wall
- **place in pairs** every 2 layers of blocks every 4 layers of bricks

Note:
Dowels should be covered with enough mortar to protect them properly. **Test if dowels can be placed properly!**
Preparing the masonry units

Soak the blocks in water for a while...

... or ...

... water them with a brush before use.

... or ...

... water all blocks together.
Good masonry practice - 1

Use a plank as guide to ensure the wall is in plumb and straight.

Joints: 10 - 15 mm = the width of the pinky finger!

Stack blocks one course at a time!

Cure the concrete with water before laying the blocks.

Important: fill vertical joints with mortar!

plinth beam

level string

Cure the concrete with water before laying the blocks.
Good masonry practice - 2

Don’t build more than 6 courses of masonry per day!
And then add a seismic band if needed.

100 to 120 cm
(5 to 6 blocks)

1 course

plinth beam
(tie-beam)

foundation

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

Keep wall 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.
SEISMIC REINFORCEMENT
Vertical reinforcement (V)

Place a vertical band on each side of every opening!
Add a horizontal reinforcement band above all openings!
Horizontal reinforcement (H)

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

Place vertical reinforcement on each side of every opening.

Vertical bands are "half tie-columns": add two rebars.

If a wall between openings functions as shear wall, the vertical reinforcement is identical to a tie-column: add four rebars!

Vertical bands: (for openings)
Width: 10 cm
2 Rebars: 10 mm
Stirrups: 6 mm (@ 15 cm)

2 rebar  4 rebar  2 rebar

max 4.50 m

min 2 m / max 4.50 m
Adding horizontal bands

Add horizontal bands to the walls if:
- the quality of materials and construction is not ensured
- if the Height is smaller than 1.5 of the Length

Rule:
\[ H < 1.5 \times L \]

H smaller than 1.5 x L

H = bigger than 1.5 x L
No seismic band

H = smaller than 1.5 x L
With seismic band
Sill band and lintel band

7.5 - 10 cm

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

Seismic bands:
Height (bricks) 7.5 cm
Heights (blocks) 10 cm
2 Rebars: 10 mm
Stirrups: 6 mm @15 cm

Use spacers

Place a stirrup every 15 cm!

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

Spacer
Connect seismic band to tie-column

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

30 cm
Size of openings

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

Rule:
\[ b \text{ smaller than } a/2 \]

Correct: \( b \) smaller than \( a/2 \)

Incorrect: \( b \) bigger than \( a/2 \)
Door reinforcement (V)

Hook the door vertical reinforcement rebars and lap 30cm with the tie-beam rebars, under the stirrups. Do the same with lintel band and the vertical bands.
Small window reinforcement (V)

For windows smaller than 90 cm.

Hook the window vertical reinforcement and lap 30 cm with the tie-beams reinforcement, inside the stirrups.

Do the same with the horizontal reinforcement and the vertical bands.
Large window reinforcement (V)

For windows larger than 90 cm.

- **tie-beam**
- **window lintel**
- **min 15 cm**
- **30 cm**
- **vertical window band**
- **window horizontal reinforcement**
- **plinth beam**
- **stirrups at 15 cm spacing**
- **window lintel**: reinforced seismic band.
- **formwork**
- **min 15 cm**
- **30 cm**
- **window vertical band**
Small window reinforcement (H)

For windows smaller than 90 cm.

Hook the window reinforcement and lap 30 cm with the seismic band reinforcement, inside the stirrups.
Large window reinforcement (H)

For windows larger than 90 cm.

- lintel band
- window lintel
- min 15cm
- 30 cm
- max 1.2m
- vertical window reinforcement
- sill band
- vertical window reinforcement

- seismic band
- stirrups at 15 cm spacing
- 30 cm
- window lintel: reinforced seismic band.

- formwork
- vertical window reinforcement

30 cm

90-150 cm

min 15cm

max 1.2m
SLAB
Placing of slab reinforcement

Placement of primary rebars.

**Step 1**

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

Placement of secondary rebars.

**Step 2**

Secondary rebars are placed on top of and perpendicular to the primary rebars.
Hollow block slab: formwork

**GOOD FORMWORK**
- 2 to 2.5 cm thick wood planks or plywood
- 5 x 10 cm
- maximum 90 cm
- minimum 8 x 10 cm
- max 75 cm
- counter brace
- plank

**BAD FORMWORK**
- Inclined post
- Irregular post
- Don't place posts on blocks.
- Don't use patched up posts.
Hollow block slab: main reinforcement

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

YES

primary rebars

spacer

hook

NO

primary rebars

bond beam

block wall
Hollow block slab: secondary rebars

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

Yes

No
Hollow block slab: positioning pipes 1

- Drill through hollow blocks!
- Pass pipes through the hollow blocks and cross concrete only in one spot. Reinforce joist with additional rebars.
- Don't drill through concrete!
- Don't cross concrete all the way!
Hollow block slab: positioning pipes 2

- **YES** Place pipes in block holes.
- **YES** Place pipes in service duct.
- **NO** Don't place pipes in walls or in ties!

Test watertightness of the pipes before pouring concrete by filling them with water.
Hollow block slab: pouring concrete

Water the formwork before pouring concrete.

Use a stick (or rebar) and a hammer to compact the concrete and avoid air pockets.
Full concrete slab

Curing the concrete:
create ponds with sand or mud and fill them with water for a week.
LIGHT ROOF
Roof shape

- **Good**: YES
- **Better**: YES
- **Better**: YES
- **Not so good**: AVOID
Gable wall

Concrete tie on top of the gable wall.
**Roof structure - Trusses**

- **AVOID**
  - Building with planks: **AVOID**
  - Building with solid timber: **GOOD**
  - Building with plywood gusset: **BETTER!**

**Timber connections:**
- Put at least **3 nails in each direction**!
- Nails length should be **twice the thickness of the timber**.

- **min 3 cm**
- **min 6 cm**
- **30 to 40 cm**
Cyclones

Keep verandas independent from main roof: cyclones may tear off the verandas.

Closed gable wall.

Opened gable wall. Main roof becoming veranda.

If a veranda is part of the main roof, then a cyclone could tear off the whole roof.
Fastening of the veranda framing

straps

bracing

solid fastening

plinth < 40 cm
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:

- Wood planks nailed to the trusses.

Dimensions:
- Max. 3.0 m
- Max. 4.5 m

Status:
- Yes

124
FUTURE EXTENSIONS
Preparation

Open all corners, all rebar connections.

Build a new solid foundation for the new room.
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.

Place the 10 mm hooks and then place both the ring beams (tie-beams) and the tie-columns.

Connect each corner the same way!
Extension of the structure

Pour concrete for the plinth beam and fill completely the opened corners.

Build the masonry walls first and only after pour the concrete for the tie columns.

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: bottom of wall to firm soil!

- hard soil: 30 cm
- rammed soil: 30 cm - 60 cm
- soft soil: 60 cm - 90 cm
Rule 2 - Slope of the wall (5 : 1)

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

Chart
$H : L = 5 : 1$

<table>
<thead>
<tr>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>125</td>
<td>25</td>
</tr>
<tr>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>175</td>
<td>35</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
</tr>
</tbody>
</table>
Rule 3 - Dimensions of the wall

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):

\[ D = \frac{A}{5} + C \]

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

Top (C) : min 50 cm!
50 cm : H \leq 150 cm
55 cm : H > 150 < 250 cm
60 cm : H \geq 250 cm

Total height (A):
A = H + B
(\rightarrow B = 30-80 cm)

### Table

<table>
<thead>
<tr>
<th>H</th>
<th>C</th>
<th>B</th>
<th>A</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>50</td>
<td>30-80</td>
<td>130-180</td>
<td>75-85</td>
</tr>
<tr>
<td>125</td>
<td>50</td>
<td>30-80</td>
<td>155-205</td>
<td>80-90</td>
</tr>
<tr>
<td>150</td>
<td>50</td>
<td>30-80</td>
<td>180-230</td>
<td>85-95</td>
</tr>
<tr>
<td>175</td>
<td>55</td>
<td>30-80</td>
<td>205-255</td>
<td>95-100</td>
</tr>
<tr>
<td>200</td>
<td>55</td>
<td>30-80</td>
<td>230-280</td>
<td>100-110</td>
</tr>
<tr>
<td>250</td>
<td>60</td>
<td>30-80</td>
<td>280-330</td>
<td>115-125</td>
</tr>
</tbody>
</table>

135
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 vertical position!

Don't place the stones at grade!
Rule 5 - Through-stones (or bands)

Wall without through-stones nor concrete ties.
Rule 6 - Drainage

**YES**

Drainage pipes

Drainage bed: gravel and stones.
Width 30 cm!

**NO**

Wall with no drainage pipes and no drainage bed.

Place a drainage pipe every 1.50 m!
(vertically and horizontally)
Retaining wall - Confining elements

These recommendations are for building a house on retaining walls: **only if there is no other solution**!

**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 !!!

139
CONSTRUCTION DRAWINGS
Reading plans

To draw a plan, cut the house at the 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 this line ...

... this is what you will see!

same window
Plan dimensions

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

Total dimensions

Partial dimensions

+ 2.9m

+/- 0.00
COPYRIGHT

This guidebook as well as its use (unless otherwise indicated) are protected by a license. The author is the Swiss Agency for Development and Cooperation (SDC).

creativecommons (Attribution - NonCommercial - ShareAlike )

Attribution - You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

NonCommercial - You may not use the material for commercial purposes.

ShareAlike - If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original.

This work is licensed under the Creative Commons Attribution - NonCommercial - ShareAlike 4.0 International License. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-sa/4.0/ or send a letter to Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.
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.

Revised version, August 2015