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1. Konstriksyon Fondasyon an
2. Bati miray blòk yo
3. Konstri kolòn yo
4. Pou attache deuzièm etaj e plafon an
5. Kantite mur ki genyen nan yon kay ki ka resist tranblemanntè

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Description of this Translation

This document replaces the original manual (Seminar Handout Revision, April 12, 2010) which was adapted and translated from part of the original document, “Construction and Maintenance of Masonry Houses,” edited by Marcial Blondet. There have been a number of changes to the format, the graphics, and the content to better reflect its intended audience. Some of the changes were also in response to the workshops that took place in April 2010 in hopes of improving the quality and delivery.

This document is adapted from part of the original document, “Construction and Maintenance of Masonry Houses,” edited by Marcial Blondet. Changes have been made to represent concrete block construction. © Marcial Blondet © Pontificia Universidad Católica del Perú © SENCICO.

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Appreciation

This construction book is an example of the on-going efforts to help in the reconstruction of Haiti. It has been prepared as a collaboration between AIDG (Appropriate Infrastructure Development Group), Architects Without Borders - Oregon (AWB) and HaitiRewired, who came together in response to the earthquake in Haiti to help with the reconstruction efforts. The loving hands that have touched this effort include:

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This is a gift to the people of Haiti with the hope that it will help you build back better futures for your families. Let it be a small reflection of the hope of the people of Haiti.
The Earthquake-resistant House

A confined block masonry earthquake-resistant house is designed and constructed so that its walls are able to resist earthquakes. Its plan view must be simple and symmetrical. Its bearing walls must be well constructed and must always be confined by reinforced concrete columns and beams.

**Walls**
These are the most important elements of a masonry structure. They are used to transmit all vertical load from the lightweight slab to the foundation and to resist seismic forces. The walls must be built with structural block and must be confined by concrete beams and columns. Only confined walls are able to resist earthquakes.

**Confining beams and columns**
These are reinforced concrete elements surrounding the walls.

**Lightweight slab**
Transmits all the load it bears (self-weight, partition walls, furniture, persons, etc.) to the walls. The slab is connected to the walls, so it permits both elements to work together during an earthquake.

**Foundation**
Transmits all the loads from the structure to the ground.

**Plinth**
Transmits the loads from the walls to the foundation, and confines and protects the first floor walls.

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**Recommendation:**
Walls confined by beams and columns resist earthquakes. If you want your house to be earthquake-resistant, we recommend that it should have the greatest possible quantity of confined walls in both directions. Partition walls, made with lightweight hollow clay tile, should be used only to separate rooms inside the house.
Plans for Earthquake-safe Houses

If you want your house to resist earthquakes successfully, your design must have a good shape and an adequate distribution of walls.

Yes!
Build the block walls first then pour the columns and floors directly against the blocks.

No

Yes!
Build window and door openings up to the level of the collar beam and locate them in the same position on every floor.

No

Yes!
Openings weaken the walls. Do not make openings larger than half the length of the wall. (Distance A must be less than half of distance L.)

No

Yes!

Adequate opening proportions

Inadequate opening proportions

Good location of window and door openings.

Poor location of window and door openings.
The adequate location of second floor walls is very important. Always build second floor walls directly over first floor walls.

Confined walls are the elements that resist earthquakes. Your house must have a similar number of walls in both directions.

The shape of your house has to be as symmetrical as possible, both in plan view as well as elevation. Lightweight slabs must not have too many openings.
It is important for slabs to be well proportioned and to be the same shape on every floor.

The plan length of your house should not be greater than 3 times the plan width.

Columns must be spaced no more than 4.5 meters apart. The floor heights must be no more than 3 meters.
The Unsafe House

This drawing shows the most common errors in houses that have not been built by professionals. These houses are not safe during earthquakes.

- Insufficient number of resistant walls in both directions
- Many openings in the walls
- Excessively long walls
- No vertical continuity of openings
- Exposed reinforcement bars
- Many openings in roof slab
- Irregular shape in plan view
- Non-uniform joints
- Columns and beams with voids in the concrete
- Cantilevers
- Walls without the columns
- Footing over loose soil or sanitary waste landfill
The Safe House

This drawing shows the characteristics of a well-designed, safe house that will resist an earthquake.

Well-proportioned house

- Second floor walls supported over first floor walls.
- Columns and beams without air pockets in concrete.
- Uniform thickness of mortar joints between blocks.
- Confined walls.
- Many confined walls in both directions.
- Well-located and well-proportioned door and window openings that reach the roof slab.
- All walls plumb.
- Footing over firm soil.
1. Constructing the Foundation

**Continuous footing**

In the following drawing you can see the minimum required footing dimensions.

**Stepped footing**

Construct stepped footings when the terrain is sloped.

**Recommendations**

Hard soils such as rock or gravel are the best foundation soils. Gravel is made up of different size stones and course compact sands. Sometimes it is difficult to excavate these soils with a shovel and you have to use a large drill. Find out about the footings of nearby houses. If nearby houses have settled under their weight, then your foundation should be wider and deeper than your neighbors.
1. CONSTRUCTING THE FOUNDATION

Before pouring the footing

Standing column reinforcing bars

Assemble the reinforcing bars for each column. Then stand the assembly in place where the column will be.

To assure that the steel assemblies are always vertical, fasten them with #8 wire.

The steel bars of the columns rest on the bottom of the foundation and must be bent with an anchorage length of 25 cm.

The correct way to bend stirrups:

- The distance between stirrups is measured starting from the plinth upwards and from the collar beam downwards.
- Try to alternate the position of the stirrup’s hook so that it is not located in the same corner of the column.

Reinforcement

Minimum reinforcement for columns is 4 x 3/8 in. steel bars. Column stirrups are 1/4 in. and have to be placed with the following spacing:
1 @ 5 cm + 4 @ 10 cm + rest at 25 cm on each end. The distance between stirrups is measured starting from the plinth upwards and from the collar beam downwards.

It is very important that the hooks stay in the interior of the column so they work adequately.
1. CONSTRUCTING THE FOUNDATION

Pouring Concrete for the Foundation

It is better if you rent a small capacity mixer to prepare concrete. This will help control quality and save materials.

Pour concrete for the foundation with wheelbarrows. As pouring continues, drop big stones in the foundation trenches. Do not place big stones near the columns. Leave approximately 30 cm on each side of the column free of big stones.

Be careful to ensure that each stone is completely covered by concrete.

Concrete for the foundation

Foundations are made of simple concrete

1 bucket of cement
10 buckets of aggregate
30% by volume of big stones (maximum size 10 in.)
1-1/2 buckets of water
Steel reinforcement in the Plinth

If your soil is sandy or clayish, it is better to place steel reinforcement in the plinth.

Concrete for plinth in firm soil

- 1 bucket of cement
- 8 buckets of aggregate
- 25% by volume of medium size stones (maximum size 4 in.)
- 1-1/4 buckets of water

Concrete for plinth in loose soil (sand or clay)

- 1 bucket of cement
- 2 buckets of aggregate
- 4 buckets of crushed stone (maximum size 3/4 in.)
- 1 bucket of water
2. Building a Block Wall

Making Concrete Masonry Block

1. Screen the aggregate through a 1 cm sieve.

2. Fill mold and compact with a shovel.

3. Spray completed blocks with water 3 times per day for 7 days after casting.

4. The block mix:
   - 1 bucket of cement
   - 8 buckets of aggregate
   - 1/2 bucket of water

5. Blocks must be 15 cm or more thick. Do not use 10 cm or 12 cm block for confined masonry walls.

Block “drop test”
Drop each block from about 1.5 m onto a hard surface. If the block breaks, do not use it.
2. BUILDING A BLOCK WALL

The Mortar

Mortar Mix

1 bucket of cement
4 buckets of river sand
water

1. Screen the sand with a 2mm sieve.

2. Dry mix the sand and cement.

3. Add water as required to make the mix workable.
Constructing the walls

For the construction of the first course, place mix uniformly over the plinth using a blocklayer's trowel. Set the block over the mix and verify that their edges touch the strings that connect the guide blocks. To set successive layers, alternate blocks so the ends do not line up and fill the vertical joints completely.

Laying the blocks

1. Constructing the walls

For the construction of the first course, place mix uniformly over the plinth using a blocklayer's trowel. Set the block over the mix and verify that their edges touch the strings that connect the guide blocks. To set successive layers, alternate blocks so the ends do not line up and fill the vertical joints completely.

2. Horizontal and vertical joints

Do not make joints more than 1.5 cm thick. Joints that are too thick will weaken the wall.

3. Level Control

Use the plumb-bob on every course to make sure the wall is vertical.
3. Creating the Columns

Column-Wall Connection

Leave toothed edges at the sides of the wall next to every column to provide adequate confinement for the wall.

In the foundation and the plinth, do not place big stones near columns.

The minimum cross section of concrete columns has to be 25 cm x the wall width.

Dimensions

Maximum distance between columns: 4.5 m

Maximum free height: 3 m

Level of slab on grade

Detail of the toothed wall edge

5 cm
2.5 cm

Collar Beam

Column

Wall

Footing

Dimensions

Wall

Level of slab on grade

Collar Beam

Column

Wall

Footing

25 cm

25 cm

25 cm

25 cm

25 cm

15 cm
3. CREATING THE COLUMNS

Examples of column and beam reinforcing
3. CREATING THE COLUMNS

Electrical installation in the Walls

Embed electrical conduit inside false columns that are formed between toothed walls without steel and filled with 1:6 concrete.

Never weaken the wall by breaking it to place electrical conduits or accessories.

Drain and ventilation pipes

Embed the drain and ventilation pipes inside false columns that are formed between the toothed walls. Place #8 wire every three layers and wrap the pipes with #16 wire.

Fill the false columns with 1:6 fluid concrete.
Pouring Concrete in Confining Columns

Formwork and pouring

After the walls are built, attach formwork to the walls for the confining columns. It is better if you use a portable concrete mixer to prepare concrete for columns. Use buckets to carry the concrete mix from the mixer to the upper part of the formwork.

To prevent air pockets in columns, use concrete mix with less stone in the first batches.

Lightly hit the form externally with a rubber hammer.

Vibrate the concrete with a long rod to prevent air pockets.

Use a plumb-bob to verify that the formwork is vertical.

Use braces to hold the forms.

Concrete for columns

- 1 bucket of cement
- 2 buckets of coarse sand
- 4 buckets of crushed stone
- 1 bucket of water
3. CREATING THE COLUMNS

Formwork removal

After pouring concrete into the columns, leave the forms up for 24 hours. Then carefully remove the forms and use them again for other columns.

Curing

Cure concrete after removal of the forms from the columns. Curing consists of watering the concrete elements at least 3 times a day to improve the hardening of the cement.

Cure every concrete element for at least 7 days.

 Recommendation

If a column has a large number of voids, immediately break and remove the concrete. Carefully clean the steel bars. Replace the formwork and pour the concrete again.
4. Attaching the Second Floor & Roof

**Confining Beams:** The confining beams of your house are important because they help confine the walls.

**Collar Beams:** Collar beams are the beams on top of the walls.

**Minimum Reinforcement**
Minimum reinforcement of all beams is: 4 steel bars Ø 3/8 in. with Ø 1/2 in. stirrups spaced 1 @ 5 cm, 4 @ 10 cm and the rest @ 25 cm from each end.
Beam-Column Connections

Carefully place reinforcement bars at beam-column intersections. When you pour concrete in these areas, vibrate the concrete extensively with a rod so that no air pockets form.

**Detail of plan view**

In case the beam is not continuous, bend the steel bar horizontally.

**Spacers for beams**

To keep beam reinforcing bars in a horizontal position, place 3 x 3 cm mortar cubes under them.

Use equal strength concrete for the mortar and beams (proportion 1:4)
Beam Rebar Assembly

After removing the formwork from the columns, place the steel reinforcement bars of the collar beams on top of the walls.

**Pouring of Beams**
All beams (collar, deep and flat) and lintels are poured simultaneously with the slabs.

**Concrete for beams & slabs**

- 1 bucket of cement
- 2 buckets of coarse sand
- 4 buckets of crushed stone (maximum size 3/4 inch)
- 1 bucket of water

**Connection between confining beam and joist rebar**
Tie joist upper reinforcement bar to confinement beam reinforcement with #16 wire.

**Pipes/Plumbing in beams**
Never bend beam rebars to pass drainage pipes.

Yes! No
5. Calculating the Walls needed for an Earthquake-resistant House

Your house has to have an adequate number of confined walls in both directions in order to resist an earthquake.

**Vulnerable House**
Few confined walls in the direction parallel to the street.

**Earthquake**

**Resistant House**
Adequate quantity of confined walls in both directions.

**Earthquake**

How do I calculate how many confined walls I must have in either direction?

The required number of walls depends on the type of soil where you build your house.
Wall Calculations

To calculate the number of walls needed for a house with a maximum of two stories, follow these steps:

1. Classify the soil of the place where you will build your house.

2. Determine minimum wall density needed in each direction, according to your soil type. Use the following table:

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Description</th>
<th>Minimum Wall Density Required (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard</td>
<td>Rock Gravel</td>
<td>3 %</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Hard Clayish Sand</td>
<td>4 %</td>
</tr>
<tr>
<td>Soft or Loose</td>
<td>Loose Sand Soft Clay</td>
<td>5 %</td>
</tr>
</tbody>
</table>

3. Calculate the roof area covering each floor in square meters.

4. Calculate the required horizontal area of confined walls for each floor.

\[
\text{REQUIRED HORIZONTAL AREA OF CONFINED WALLS IN FIRST FLOOR} = \left( \frac{\text{MINIMUM WALL DENSITY}}{100} \right) \times \text{ROOF COVERED AREA OF FIRST FLOOR} + \text{ROOF COVERED AREA OF SECOND FLOOR}
\]

\[
\text{REQUIRED HORIZONTAL AREA OF CONFINED WALLS IN SECOND FLOOR} = \left( \frac{\text{MINIMUM WALL DENSITY}}{100} \right) \times \text{ROOF COVERED AREA OF SECOND FLOOR}
\]
Example

Suppose that your house will be constructed over a compact gravel-coarse sand soil and that it will have 70 m² of roof covering area in the first floor and 50 m² in the second floor. Wall density required for hard soil is 3%.

To calculate the horizontal wall area needed in the first floor, consider the roof covering areas of the first and second floors. That is, the wall area required by the first floor will be:

\[
\text{Required Horizontal Area for Floor One} = \left(\frac{3}{100}\right) \times (70 + 50)m^2 = \left(\frac{3}{100}\right) \times 120m^2 = 3.60m^2
\]

To calculate the horizontal wall area necessary in the second floor, you only have to consider the roof area covering the second floor. That is, the wall area required for the rest of the second floor will be:

\[
\text{Required Horizontal Area for Floor Two} = \left(\frac{3}{100}\right) \times 50m^2 = 1.5m^2
\]

5. Verify that the total horizontal area of confined walls in your house in each direction is greater than the required area. In the elevation only include walls made of structural block whose length is greater than 1 meter and that are confined by reinforced concrete beams and columns. Do not include walls less than 1 meter in length. Also do not include unconfined walls or partition walls because these elements are not capable of resisting earthquakes. For each direction of your house evaluate the area of each confined wall and then add up the areas of all the walls. To calculate the horizontal area of each wall in m² multiply its length in meters by its thickness in meters.

Example

Horizontal wall area
\[3 \text{ m} \times 0.15 \text{ m} = 0.45 \text{ m}^2\]

Then verify that the horizontal area of confined walls in every floor of your house and for each direction is greater than the required area that you calculated in the previous step.

\[
\text{Total horizontal wall area (m}^2\text{) > required horizontal area (m}^2\text{)}
\]
REPAIR WALL CRACKS

IF ANY WALL HAS DIAGONAL CRACKS NOT MORE THAN 1.5mm THICK AND THE CONCRETE IN THE BEAMS AND COLUMNS IS NOT SEVERELY DAMAGED, YOU CAN REPAIR THE WALL IN THE FOLLOWING WAY:

1
REMOVE MORTAR FROM CRACKED JOINTS AND ELIMINATE ALL LOOSE MATERIAL. TRY NOT TO HIT NEARBY BLOCKS.

2
CLEAN CRACKED JOINTS THOROUGHLY WITH PRESSURIZED WATER. LET WATER DRAIN DURING 15 MINUTES.

3
REFILL THE JOINT WITH NEW 1:4 (CEMENT:SAND) MORTAR, APPLY AND COMPACT THE MORTAR UNTIL YOU COMPLETELY FILL THE JOINT.
REPLACEMENT OF DAMAGED BLOCKS

IF ANY WALL HAS BROKEN OR DETERIORATED BLOCKS, YOU CAN REPLACE THEM IN THE FOLLOWING WAY:

1. CAREFULLY REMOVE THE DAMAGED BLOCK, CLEAN UP THE MORTAR THAT REMAINS IN THE HOLE.

2. GET A NEW GOOD QUALITY BLOCK TO REPLACE THE REMOVED BLOCK.

3. THOROUGHLY WET THE BLOCKS IN THE WALL AND ADJACENT TO THE NEW BLOCK AND PLACE NEW 1:4 (CEMENT:SAND) MORTAR ALONG THE EDGES OF THE HOLE. CAREFULLY PLACE THE NEW BLOCK. TO FINISH, FILL ANY REMAINING SPACES AROUND THE NEW BLOCK WITH MORTAR.
REPAIR OF COLUMNS WITH POOR CONCRETE

1. Carefully break all deteriorated concrete until you get a rough undamaged surface.

2. Thoroughly clean the rusted bar with a steel brush. To eliminate residues softly sandpaper the steel.

3. Apply cement paste to old concrete so that new concrete will easily adhere.

4. Completely fill the hole left by the removed concrete with 1:4 (cement:sand) mortar. Carefully align the surface of the new concrete with the existing surface. Cure the new concrete for 7 days watering it every 8 hours.