Constructing Seismic Resistant Masonry Houses in Indonesia

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WORLD SEISMIC SAFETY INITIATIVE

TEDDY BOEN
Throughout the centuries, earthquakes have taken a high toll of human lives and caused property losses. Earthquakes do not kill people but the collapse of man made buildings does.

Until today, human beings cannot prevent earthquakes, however, human beings can try to reduce the impact by designing and constructing earthquake resistant buildings. Almost all of Indonesia is earthquake prone.

Currently people all over Indonesia build half brick masonry or concrete block houses. Masonry houses have become a new culture. Many of those masonry houses are built without confinement in the form of reinforced concrete beams and columns and in almost all past earthquakes, masonry houses without confinement generally were heavily damaged or collapsed. Half brick thick masonry wall houses without confinement is not recommended for earthquake prone areas.

Houses recommended to be built are half brick thick masonry wall with confinement in the form of foundation beam, practical columns and ring beam. Past earthquakes showed that such type of houses are earthquake resistant provided that they are built properly.

This guideline tries to explain in a simple way the principles of constructing half brick thick confined masonry houses.

This guideline contains the basic and elementary principles concerning how to lay bricks, how to prepare concrete mix, how to bend reinforcing bars, detailing of joints and other basic things already forgotten by local artisans, construction workers and by most engineers all over Indonesia.

The methods and details recommended in this guideline are basic and are minimum requirements for constructing earthquake resistant masonry houses.

Materials for this guideline are taken from ref 13, 15, 17, 19, 20, 22, 23, 24, 28, 30 and 35.

It is hoped that this guideline is useful for the common people in earthquake prone areas and for stakeholders involved in reducing the impact of future earthquakes.

Jakarta, April 2005

Teddy Boen & Associates
1. GENERAL REQUIREMENTS AND LAYOUT OF HOUSES

Items to be observed:
1. Distance of house from the property line
   Ratio of houses / property area
   Height of house shall be proportional
   Form should be suitable for local climate
2. Building line
3. Layout:
   - House
   - Septic tank
   - Leaching
   - Drainage
   - Water pipe
   - Well
4. Ground level shall be the 100 year flood level

2. CLEAN WATER AND SEWERAGE

leaching, length 3m, height 1.2m, width 1m
septic tank, length 2.7m, height 1.5m, width 1m
well
sewage pipe 6"
clean water pipe 1 1/4"
manhole 45x45x45cm
city drainage
garbage collection pit 150x90x75cm covered with galvanized iron sheet or timber
partition for organic & anorganic
rain water drain 30x30cm
3. PRINCIPLES OF SEISMIC RESISTANT HOUSE CONSTRUCTION

1. Good quality materials.
2. Good workmanship.
3. All building components (foundation, columns, beams, walls, roof trusses, roofing) MUST be TIED to each other, so that when SHAKEN BY EARTHQUAKES, the building will act as ONE INTEGRAL UNIT.

4. BUILDING MATERIALS

SAND:
- from rivers / quarries
- clean from mud
- clean from organic materials

GRAVEL:
- from rivers / quarries
- clean from mud
- clean from organic materials
- 1-2cm

CEMENT:
- Portland Cement
- not hardened
- dry
- in 40/50 kg bags
- not mixed with other materials
- uniform color

WATER:
- clean
- clear and does not smell
- no oil, acid, alkali, salt, organic materials that can affect the r.c. bars
- potable

BRICKS:
- completely burnt
- flat, not warping
- does not break easily
- uniform size
- corners not damaged
- minimum size 20x10x5cm

CONCRETE BLOCK:
- best from concrete mix
- corners not damaged
- no cracks

TIMBER:
- dry
- straight
- no cracks
- no notch
- treated against termite

RUBBLE STONE:
- size as uniform as possible
- rough surface, not smooth

R.C. BARS:
- uniform size
- conform with standard bars
- not rusted
- straight
- diameter in accordance with drawings
5. ERECTION OF BATTER BOARDS

ERECTION OF BATTER BOARD:
1. Batter board is used as benchmark for the levels of the house.
2. Batter boards shall be erected prior to construction.
3. Batter boards 2x20cm are supported by timber stakes 5/7cm and placed 2m apart.
4. Upper part of batter board is flat and smooth.
5. Upper part of batter board must be horizontal and this levelling is done using flexible water tube.
6. Corners must be perpendicular.

6. RUBBLE (RIVER / QUARRY) STONE FOUNDATION

Note:
Loose rubble stone and sand is needed if the bottom is muddy.
Prior to cutting reinforcing bars, the lengths of columns, beams reinforcing bars & stirrups and length of hooks must be determined from construction drawings.

After the reinforcing bars are cut based on the necessary length, the reinforcing bars are bent with appropriate bar bending tool and shaped into columns, beams, stirrups.

Bending bars after the reinforcing bars are assembled is not correct.

8. LENGTH AND BENDING OF REINFORCING BARS

8. A. BEAM REINFORCING BARS

1. OUTER BEAM REINFORCING BAR

Prior to cutting, reinforcing bar length to be measured from construction drawings, including the bends & hooks. Example: beam with 6m length from axis to axis, using bar ø10mm:

- A = 6000mm
- B = 40D = 400mm
- C = 6D = 60mm
- E = 2,5D = 25mm

Formula:  
\[ A + G + 2(B + C + E) - 2F \]

- D = bar diameter = 10mm
- F = concrete cover = 2,5cm from the main reinforcing bar axis
- G = column width = 120mm

Length of outer beam reinforcing bar:

- Length of bar is bent 40D = 400mm at one end
- Finally, the other end of reinforcing bar is bent 40D = 400mm

Length of bend is 6D = 60mm at both ends, distance of bend is 2,5D = 25mm
2. INNER BEAM REINFORCING BAR

Inner beam reinforcing bar calculation:
Formula: \( A - G + 2(B + C + E + F) \)
- \( A = 6000 \text{mm} \)
- \( B = 40D = 400 \text{mm} \)
- \( C = 6D = 60 \text{mm} \)
- \( E = 2.5D = 25 \text{mm} \)
- \( D = \text{bar diameter} = 10 \text{mm} \)
- \( F = \text{concrete cover} = 2.5 \text{cm from the main reinforcing bar axis} \)
- \( G = \text{column width} = 120 \text{mm} \)

Length of inner beam reinforcing bar:
\( A - G + 2(B + C + E + F) = 6900 \text{mm} = 6.9 \text{m} \)

![Diagram of inner beam reinforcing bar calculation](image)

8. B. COLUMN REINFORCING BARS

Prior to cutting, reinforcing bar length to be measured from construction drawings, including the bends & hooks.
Example: column with 3m height from axis to axis, using bar \( \phi10 \text{mm} \):
Formula: \( A + 2(B + C + E) \)
- \( A = 3000 \text{mm} \)
- \( B = 40D = 400 \text{mm} \)
- \( C = 6D = 60 \text{mm} \)
- \( E = 2.5D = 25 \text{mm} \)
- \( D = \text{bar diameter} = 10 \text{mm} \)

Length of column reinforcing bar:
\( A + 2(B + C + E) = 3970 \text{mm} = 3.97 \text{m} \)

Therefor, for 12m reinforcing bar, it can be obtained 3 column reinforcing bars for 3m height from axis to axis.

![Diagram of column reinforcing bars calculation](image)
Prior to cutting, stirrup reinforcing bar length to be measured from construction drawings, including the bends & hooks. The length is determined based on the stirrup axis with formula:

\[ \text{perimeter of column/beam} + 2 \times \text{hook length} - 8 \times \text{concrete cover from stirrup axis} \]

**Example:** stirrup of column 12x12 cm using bar \( \phi \) 8mm:

- \( A = \) column width at one side = 120mm
- \( B = \) column width at the other side = 120mm
- \( C = 6D = 48\text{mm} \)
- \( E = 2.5D = 20\text{mm} \)
- \( D = \) bar diameter = 8mm
- \( F = \) concrete cover from stirrup axis = 15mm

**Formula:**

\[ 2(A + B) + 2(C + E) - 8F \]

**Length of stirrup bar:**

\[ = 2(A + B) + 2(C + E) - 8F \]
\[ = 2(120 + 120) + 2(48 + 20) - 8 \times 15 \]
\[ = 496\text{mm} = 49.6\text{cm} \]

Length of reinforcing bar bend 90 mm from \( B - 2F \)

Both ends of the stirrups are bent \( 6D = 60\text{mm} \) at an angle of 45°.

Finally, the stirrups are bent 90mm from \( A - 2F \).

**8. SEISMIC RESISTANT DETAILING OF JOINTS**

**IMPORTANT:**

- reinforcing bar diameter
- bending method
- joint detailing

**Corner Joint**

**Middle Joint**

**Side View**

**Example:**

- \( D = 10\text{mm} \)
- \( 40D = 400\text{mm} \)
- \( 40D = 40\text{cm} \)
10. FOUNDATION BEAM REINFORCING DETAILING

10.A. MIDDLE JOINT

- Column reinforcing bar
  - Min. 10mm
- Anchor min. 10mm, length > 40cm every 6 layers of brick
- Beam reinforcing bars
  - Min. 10mm
- Stirrups min. 8mm
distance < 15cm

10.A. CORNER JOINT

- Beam reinforcing bars
  - Min. 10mm
- Reinforcing bars
  - Min. 10mm
- Top View

11. PREPARING CONCRETE MIX

1. First step, pour 3 pails of gravel & mix properly with a hoe.

2. Add 2 pails of sand & mix properly with a hoe.

3. Subsequently, add one pail of cement & mix properly with a hoe.

4. After the three ingredients are properly mixed.
Concrete mix that meets standard requirement:
Materials needed for 1 m$^3$ of concrete:
- 0.125 m$^3$ water
- 0.250 m$^3$ cement
- 0.500 m$^3$ sand
- 0.750 m$^3$ gravel

The ratio of water : cement : sand : gravel
1 : 2 : 4 : 6
or
½ : 1 : 2 : 3

Example: too much water: good

**Forming a Depression in the Center.**

1. Add ½ pail of water & mix properly.
2. Mix properly with a hoe.
3. Finally test the concrete mix consistency by placing in your hand.

**Concrete Mix: 1 pc (cement) : 2 sand : 3 gravel**

Mix properly with appropriate amount of water

**Concrete Mix:**
- 1 pc (cement) : 2 sand : 3 gravel
- Expected min. compressive strength: $= 150$ kg/cm$^2$

**PLACING CONCRETE IN FOUNDATION BEAM**

- Concrete mix: 1 cement : 2 sand : 3 gravel
- Stirrup min. $\phi$ 8mm distance < 15 cm
- Reinforcing bar $\phi$ 10mm
- Surface must be horizontal
- Concrete cover 2.5cm from axis of main reinforcing bar
- Expected min. compressive strength: $= 150$ kg/cm$^2$

**Curing:**
- Before & after the form work is removed, it must be sprayed routinely.
- This applies to all reinforced concrete components.
13. PLUMBNESS OF BRICK LAYING AND COLUMNS

Walls and columns must be plumb and can be done using plumb lines and pins (cord & plumb bob). Corners of walls must be perpendicular.

Note: Columns form work must be supported on 4 sides to warrant plumbness.

14. BRICK WALL

Mortar Mix:
1 pc cement
4 sand
mixed properly & add water appropriately

bricks must be soaked
minimum 10 minutes prior to
laying & shall be layed
immediately

pull a cord to lay each layer of brick
plus 1.5cm. The cord serve as
horizontal guidance.

timber pole 5/7 cm along wall height
erected to act as pilot for brick laying in
the vertical direction

cord
brick wall

timber pole 4/6 cm
vertical plumb line
timber pole 4/6 cm
as form work bracing

mortar thickness 1.5 cm
mortar mix 1 pc : 4 sand

surface must be horizontal

top view

Pull a cord to lay each layer of brick plus 1.5cm. The cord serve as horizontal guidance.

Timber pole to fix the cord is marked for every level of brick plus 1.5cm. The string is removed if the brick layer is completed.
**15. REINFORCING BAR DETAILING AND PLACING CONCRETE IN COLUMNS**

- **Concrete Mix:**
  - 1 pc (cement) 2 sand 3 gravel
  - Mix properly; add water appropriately. Expected min. compressive strength of concrete = 150 kg/cm²

- **Reinforcing Detailing**
  - Column reinforcing bar 4 X 10-12mm
  - Beam reinforcement bar 4 X 10-12mm
  - Column stirrup min. φ8mm distance < 15 cm
  - Beam stirrup min. φ8mm distance < 15 cm

- **Concrete Cover:**
  - 2.5cm from axis of main reinforcing bar

- **Concrete Mix:**
  - 1 pc cement : 2 sand : 3 gravel
  - Mix properly; add water appropriately. Expected min. compressive strength of concrete = 150 kg/cm²

**15.A.1. PLACING CONCRETE IN COLUMN SIMULTANEOUSLY WITH BRICK LAYING**

- Column reinforcing bars supported by timber bracing to prevent bending/leaning

- **Phase I:**
  - Placing concrete in column after the half height brick wall is erected
  - Anchor min. φ10mm, length > 40cm every 6 layers of brick
  - Half brick wall is provided with toothed edges to be filled with concrete
  - Column reinforcing bar

- **Phase II:**
  - Column is straight
  - Column with toothed edges brick wall
  - Rough surface brick at junction with column

- **Curing:**
  - Brick wall & concrete must be sprayed periodically
II. PHASE I: PLACING CONCRETE IN COLUMN AFTER THE HALF HEIGHT BRICK WALL IS ERECTED

1. Form work is erected for the second half wall height.
2. Placing concrete after the brick wall is completed.
3. The form work can be removed minimum 3 days after placing concrete.
4. Column is straight.
5. Note: placing concrete is done in one run and NOT IN STAGES.

Curing: brick wall & concrete must be sprayed periodically.

III. PHASE II: PLACING CONCRETE IN COLUMN

1. Form work is erected for the second half wall height.
2. Placing concrete after the second half wall height is erected.
3. To compact the concrete, a steel rod ø12mm is used to tramp & a club hammer to tap the sides.
4. Column with toothed edges brick wall.
5. Note: placing concrete is done in one run & NOT IN STAGES.

Curing: column is straight.

II. PHASE II: PLACING CONCRETE IN COLUMN

1. Placing concrete after half height brick wall is erected.
2. Form work is erected half column height.
3. Curing: brick wall & concrete must be sprayed periodically.
5. Note: placing concrete is done in one run and NOT IN STAGES.

Curing: concrete must be sprayed periodically.

15.B.I. PLACING CONCRETE IN COLUMNS IN STAGES PRIOR TO THE BRICK LAYING

II. PLACING CONCRETE LOWER HALF OF THE COLUMN

1. The form work can be removed minimum 3 days after placing concrete.
2. The form work is erected half column height.
3. Club hammer.
4. Stud 4/6 cm
5. Note: placing concrete is done in one run and NOT IN STAGES.

Curing: concrete must be sprayed periodically.

III. PLACING CONCRETE UPPER HALF OF THE COLUMN

1. To compact the concrete, a steel rod ø12mm is used to tramp & a club hammer to tap the sides.
2. Column reinforcing bar min. ø10mm
3. Column height
4. Anchor min. ø10mm, length > 40cm every 6 layers of brick
5. Form work is erected full height on 3 sides
6. Note: columns are supported on 4 sides to warrant plumbness during placing of concrete.

Curing: column is straight.

- Form work is erected full height on 3 sides.
- Stud 4/6 cm nailed to form work stud.
- Brace 4/6 cm nailed to form work stud.
- Timber bracing 4/6 cm to support form work.
- Curing: concrete must be sprayed periodically.
15.C. PLACING CONCRETE IN FULL HEIGHT COLUMNS PRIOR TO BRICK LAYING

Note: columns are supported on 4 sides to warrant plumbness during placing of concrete.

Anchor: min. \( \Phi 10 \text{mm} \), length > 40cm every 6 layers of brick

Brace 4/6 cm to tie form work (when needed, number of bracing can be added)

Form work is erected full column height & ready for placing concrete

Curing: concrete must be sprayed periodically

Note: placing concrete is done in one run and NOT IN STAGES

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16. JOINT DETAILS AND PLACING CONCRETE IN BEAMS

Concrete Mix:

Mix properly; add water appropriately. Expected min. compressive strength of concrete = 150 kg/cm²

Concrete Cover 2.5cm from axis of main reinforcing bar

Stirup min. \( \Phi 8 \text{mm} \) distance < 15 cm

Reinforcing bar min. \( \Phi 10 \text{mm} \)

Curing: brick wall & concrete must be sprayed periodically
Advantage of galvanized iron sheet roofing:
- Light in weight
- Easy to install