APPENDIX 4: DESIGN AND CONSTRUCTION GUIDELINES FOR CONFINED MASONRY HOUSING IN HAITI

DESIGN AND CONSTUCTION GUIDELINES FOR CONFINED MASONRY HOUSING
(narrative only, design drawings not included[1])

Build Change Post-Earthquake Housing Reconstruction Technical Assistance Program, Haiti

Prepared for

Build Change
Denver CO

31 January 2011

By
Guy Nordenson and Associates
Structural Engineers LLP

225 Varick Street 6th Flr New York
NY 10014 USA Tel 212 766 9119
Fax 212 766 9016
www.nordenson.com

[1] For the complete document, including appendices of drawings, go to www.buildchange.org/USAIDPrimers.html .

TABLE OF CONTENTS

1.0 DESIGN AND CONSTRUCTION GUIDELINES

The following rules should be followed when designing and building a one- or two-story confined masonry house.

1.1 Material and Construction Quality

1.1.1 Concrete Block

The seismic resistance of the confined masonry house designs depends upon the strength and quality of concrete block used. Therefore, the following table should be used to identify the concrete block strength required to achieve the desired level of seismic resistance, and a testing program (with a sufficient sample size) should be implemented to ensure that the blocks achieve the required compression strength.

Single Story House with Lightweight Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi) min	Permitted in all zones (Sds = 1.05g to 1.67g)

Single Story House with Concrete Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi)	Not permitted
6.9 MPa (1,000 psi) min	Permitted in orange and yellow zones only (Sds = 1.05g)
11.7 MPa (1,700 psi) min	Permitted in all zones (Sds = 1.67g)

Two Story House with Concrete or Lightweight Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi)	Not permitted
6.9 MPa (1,000 psi) min	Permitted in orange and yellow zones only (Sds = 1.05g)
11.7 MPa (1,700 psi) min	Permitted in all zones (Sds = 1.67g)

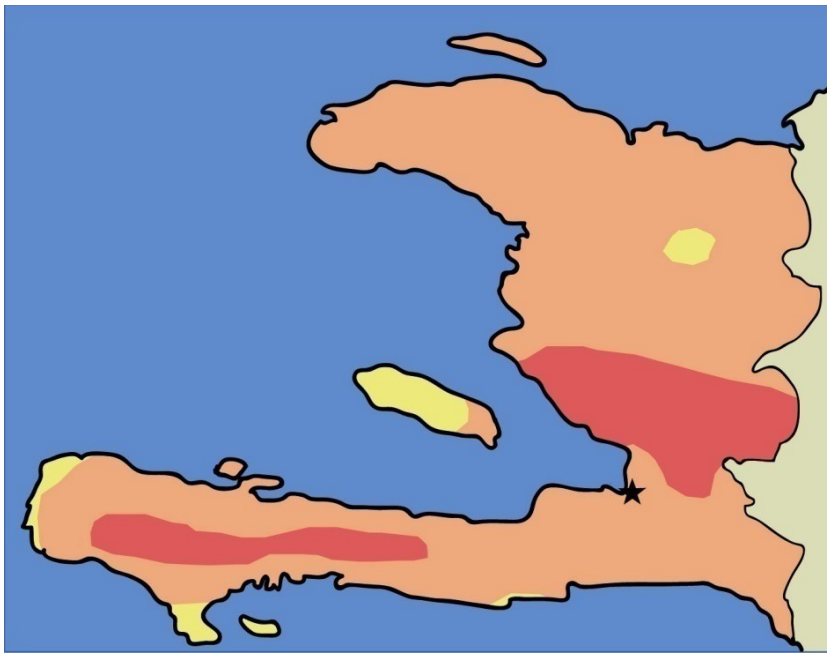

Figure 1.1 Map of Haiti showing severity of seismic demands by region based upon 2010 USGS data (Sds = 0.5g for yellow zones, Sds = 1.05g for orange zones, Sds = 1.67g for red zones)

In addition, the following quality control guidelines are recommended for the fabrication of sound concrete blocks with adequate compressive strength:

- Use a materials, mix proportions, and curing procedures consistent with tested blocks with required compressive strength
- Cement should be Type 1 Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand (or a combination of clean river sand and white quarry sand – the required proportion of each to be confirmed through testing)
- Do not use aggregate greater than 1 cm (3/8") in dimension
- Use clean water and only enough water to wet the mix (typically 7-8% max)
- Ram or vibrate block forms to consolidate
- Let blocks cure for at least 7 days prior to use in construction
- Do not allow blocks to cure in the sun. Cover blocks with a tarp and wet them with clean water while curing
- Do not re-use old concrete blocks
- Do not use irregular, chipped or cracked concrete blocks

1.1.2 Mortar

- Use a 1:3 mix ratio (cement : sand) for concrete block wall mortar (add 0.5 parts lime if available) to achieve 17 MPa (2500 psi) minimum compressive strength
- Use a 1:3:3 mix ratio (cement : sand : gravel) for mortar for foundation walls
- Cement should be Type 1 Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Use only clean river sand in the mortar mix

- Never use white quarry sand or beach sand
- Mix dry components until color is uniform prior to adding water
- Use clean water in mortar mix
- Add only enough water for workability
- Mix mortar for 3 minutes
- Use mortar within 1 hour
- Do not remix mortar

1.1.3 Grout

- For filled grouted cores, use a 1:2:2 mix ratio (cement : sand : pea gravel) to achieve 13.8 MPa (2000 psi) minimum compressive strength
- Cement should be Type I Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand and pea gravel in the grout mix
- Pea gravel should be maximum 0.6 cm (1/4") in dimension
- Never use white quarry sand or beach sand
- Use clean water in the grout mix and do not use too much water
- Use a rod to compact the grout within the filled block cavities

1.1.4 Cast-in-Place Concrete

- For beams, columns and roof slabs, use a 1:3:3 mix ratio (cement : sand : gravel) to achieve 21 MPa (3000 psi) minimum compressive strength
- For foundations and slab on grade, use a 1:3:6 mix ratio (cement : sand : gravel) to achieve 15 MPa (2200 psi) minimum compressive strength
- Cement should be Type I Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand in the concrete mix
- Never use white quarry sand or beach sand
- Use clean water in the concrete mix and do not use too much water
- Use crushed gravel rather than rounded river stones as the coarse aggregate
- Do not use gravel greater than 2 cm (3/4") in dimension
- Ensure that the concrete mix is consolidated and distributed around reinforcement with no voids (ram with rod or tap formwork with hammer)

1.1.5 Steel Reinforcement

- Verify grade of steel by checking marking on bars (Grade 40 or Grade 60)
- Use ribbed (ie deformed) reinforcement for all reinforcing steel
- Smooth steel is not permitted
- Do not use rusty or corroded reinforcement
- Do not reuse old or bent reinforcement

1.1.6 Timber

- Verify species and grade of timber by checking markings on pieces
- Verify type of plywood by checking markings on sheets
- Do not use lumber with large or frequent knots, holes, splits or checks
- Do not use green lumber or lumber with high moisture content

- Do not use CCA pressure treated lumber. Use naturally decay- and termite-resistant wood or an alternative natural treatment. Paint all wood in addition for weather protection and do not allow wood to come in contact with the ground

1.1.7 Roofing

- Verify panel type (strength and gauge) by checking markings on panels

1.1.8 Connections

- Do not use unprotected mild steel reinforcement to connect timber structure to concrete as it will corrode
- Verify type (grade and gauge) of stainless steel straps for timber-to-concrete and timber-to-timber connections
- Do not reuse old, rusty or bent nails, screws, straps or other connections

1.2 Siting

- Build on flat terrain with strong, stable ground
- Do not build on steep hillsides or next to a steep drop-off
- Do not build below areas that are vulnerable to landslides
- Do not build over riverbeds or in other areas prone to flooding
- Ensure that the concrete block strength used is sufficient to provide a design which provides adequate resistance to the expected ground motion at the site

1.3 Configuration

1.3.1 All House Types

- Limit length of layout to 3 times the width of the layout for single-story houses with lightweight roofs
- For single-story houses with lightweight roofs, strive for a layout that is symmetrical about both axes; the maximum asymmetry permitted is 3.5m in one direction
- A minimum wall area of 5% of the ground floor area is required in each direction on each floor (wall area equals wall thickness x wall length without windows or doors)
- A minimum of two separate lines of walls is required in each direction; an additional line of walls is required for each additional 3.5m of building dimension over 3.5m meters
- The maximum distance permitted between adjacent parallel walls (ie the spacing of orthogonal walls) is 3.5m
- Do not use walls that are angled or rounded in plan; all walls must be parallel or perpendicular to each other
- The maximum story height permitted for the first story is 2.7m from the ground floor slab
- Place tie columns at each corner and wall intersection and on either side of each door opening (and window openings where required)
- Use a continuous plinth beam below the masonry wall
- Use a continuous ring beam above the masonry wall

1.3.2 Additional Single-Story House with Concrete Roof / Two-Story Provisions

- Limit length of layout to approximately 2.5 times the width of the layout for single-story houses with concrete roofs and/or two-story houses
- Single-story houses with concrete roofs and all two-story houses should be square or rectangular with wall layouts that are symmetrical about both axes with walls and openings uniformly distributed
- Limit roof height of two-story houses to approximately 1.7 times the narrowest dimension of the layout
- The maximum story height permitted for the second story is 2.5m
- Vertically align all walls of first and second stories
- Do not build second story walls on eaves of first story concrete roof or over first story porch
- Construct the front porch and porch roofs using only timber
- Only support the concrete slab on masonry walls, not on concrete or timber posts

1.4 Windows and Doors

1.4.1 Window Openings

- Windows without confining elements are permitted only when centered on a wall panel AND when one of the following is satisfied: 1) the window opening is the only window opening located on that side of the building, 2) all openings adjacent to the window opening are surrounded by confining elements
- For windows in series on one side (or wall) of a building, every other window must have confinement
- For single-story houses with lightweight roofs, window openings should be centered on wall panels
- Confined windows do not need to be centered on wall panels if a concrete roof is used
- The top of window openings shall be aligned with the underside of the ring beam
- The maximum window opening height for unconfined windows shall be the minimum of 85cm or 33% of the wall height including the confining elements
- The maximum window opening width shall be the minimum of 1m or 1/3 of the wall width

1.4.2 Door Openings

- Door openings shall be a maximum of 1m wide
- Door openings shall extend the entire height of the masonry wall (the zone above the door may be filled with a perforated plywood panel for ventilation)
- Tie columns shall be located on either side of all door openings
- For single-story houses with lightweight roofs, door openings should be centered on wall panels
- It is not permitted to locate door openings adjacent to orthogonal walls or wall corners for single-story houses with lightweight roofs
- Full-height wall piers created by door openings shall be a minimum of 1m wide

1.4.3 Additional Two-Story Provisions

- Window and door openings shall be vertically aligned with identical widths on first and second stories of a two-story house

- The first story of a two-story house shall have at least as much solid wall area as the second story to prevent a soft story failure

1.5 Foundation

1.5.1 Strip Footings

- Footings shall be continuous below all walls
- The bottom of footings should be at least 75cm below grade (or as deep as necessary to bear on sound, undisturbed soil)
- Slope the sides of foundations trenches approximately 2:1 (rise to run) to maintain stability
- Width of concrete strip footing below all walls shall be at least 50cm for single story houses with lightweight roofs and 100cm for single story houses with concrete roofs or two story houses for soil of intermediate quality
- Width of concrete strip footing below porches and terraces (not supporting walls) shall be approximately 50cm
- Use 20cm wide concrete blocks for masonry foundation wall
- Extend reinforced concrete tie column to concrete footing. Build masonry foundation wall prior to casting concrete tie column extensions
- Use wire chairs or small concrete blocks to lift reinforcement off soil to achieve required 75mm concrete cover where tie column reinforcement is anchored into footing
- Space closed steel ties in tie column extensions at 10cm spacing between plinth beam and concrete footing
- Compact the backfill around foundation wall and footing

1.5.2 Ground Floor Slab

- The ground floor slab shall be raised a minimum of 30cm above grade (80cm in areas prone to flooding, although it is recommended not to build in these areas)
- Do not build ground floor higher than 80cm above grade
- Use 10cm compacted sand fill below concrete ground floor slab (consider use of crushed concrete debris as fill below ground floor slab)
- Use a 5cm unreinforced concrete ground floor slab
- Align top of plinth beam with top of concrete ground floor slab

1.6 Plinth Beam

- Use a continuous reinforced concrete plinth beam above the concrete block masonry foundation wall
- The plinth beam shall be 20cm wide and 15cm deep
- For a single story house with lightweight roof, reinforce the plinth beam with 4 #3 Grade 40 longitudinal steel bars and #2 Grade 40 closed stirrups spaced at 15cm near tie columns and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce the plinth beam with 4 #3 Grade 60 minimum longitudinal steel bars and #2 Grade 60 closed stirrups
- Maintain a minimum cover of 25mm on all sides, although greater cover will result in order for the longitudinal bars to pass through between the tie column reinforcement

- Provide adequate connection between reinforcement in intersecting and orthogonal plinth beams

1.7 Ring Beam

- Use a continuous reinforced concrete ring beam above the concrete block masonry walls
- The ring beam shall be 15cm wide and 15cm deep except when a concrete roof or floor slab is used. In this case, it shall be 15cm wide by 20cm deep
- For a single story house with lightweight roof, reinforce the ring beam with 4 #3 Grade 40 longitudinal steel bars and #2 Grade 40 closed stirrups spaced at 10cm near tie columns and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce the ring beam with 4 #3 Grade 60 longitudinal steel bars and #2 Grade 60 closed stirrups spaced at 10cm near tie columns and 20cm otherwise
- Maintain a minimum cover of 25mm on all sides, although greater cover will result in order for the longitudinal bars to pass through between the tie column reinforcement
- Provide adequate connection between reinforcement in intersecting and orthogonal ring beams
- If a concrete roof is used, provide adequate anchorage for the roof slab reinforcement in the ring beam
- If a timber frame roof is used, secure all embedded stainless steel straps for connections to timber structure to ring beam reinforcement prior to casting concrete

1.8 Tie Columns

- Cast reinforced tie columns after the concrete block masonry wall is built
- Place tie columns at each corner and wall intersection and on either side of each door opening and each window opening that requires confinement
- Tie columns shall be 15cm x 15cm in cross section with additional width due to toothing into concrete block masonry wall
- Ensure that concrete has completely filled toothed areas (it is not required for concrete to fill the concrete block cells
- For a single story house with lightweight roof, reinforce tie columns with 4 #4 Grade 40 longitudinal steel bars and #2 Grade 40 closed ties spaced at 10cm near top and bottom joints and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce tie columns with 4 #4 Grade 60 longitudinal steel bars and #2 Grade 60 closed ties spaced at 10cm near top and bottom joints and 20cm otherwise
- Maintain a minimum cover of 25mm on all sides
- Anchor tie column longitudinal reinforcement into foundation at bottom and ring beam at top
- Splice longitudinal reinforcement extended from foundation above plinth beam if necessary using detail provided
- If it is expected that a second story will be added to a single-story house with a concrete roof, instead of anchoring the tie column's longitudinal reinforcement into the ring beam, extend it above the ring beam by at least 70-90cm and cover it completely with lean concrete (which can be removed to create a splice when the

additional floor is added)

1.9 Masonry Wall

1.9.1 Masonry Wall Detailing

- Build concrete block masonry walls prior to reinforced concrete tie columns and ring beams
- Wet concrete blocks prior to placement
- Use 15cm-wide concrete blocks for all walls above the plinth beam
- Use 1.25cm-thick mortar joints between blocks
- Stagger joints on each course by 1/3 block
- Maintain a staggered edge (by 1/3 block) adjacent to all tie column locations
- Do not use 1/3 blocks to create staggered edge. Use either whole blocks or 2/3 blocks
- Do not use partial blocks unless they have intact cells
- A 1cm plaster finish on both the interior and exterior of masonry walls is recommended

1.9.2 Detailing of Unconfined Window Openings

- Use 1/3 or 2/3 blocks to create vertical edges at unconfined window openings
- Grout the vertical cell on each side of a window opening and reinforce it with one Grade 40 or 60 #4 bar anchored into the plinth beam and ring beam
- Use horizontal bed joint reinforcement in the course below each window opening, anchored into the nearest tie column on each side. Horizontal bed joint reinforcement should be either two Grade 40 #4 bars sufficiently embedded in a 2.5cm bed joint or a prefabricated truss-type system

1.9.3 Detailing of Confined Window and Door Openings

- Cast 15cm x15cm reinforced concrete tie columns on either side of window (see Section 1.8 for reinforcement and detailing)
- Cast 15cm wide reinforced concrete sill beam directly below window opening and extend beam to nearest non-window tie column on either side
- Reinforce sill beam with the same reinforcement as the ring beam

1.10 Roof System

1.10.1 Timber Frame Roof

- Use a gable or hipped timber frame roof (hipped is preferable)
- Use a minimum roof slope of 25 degrees
- Make porch roof independent of primary roof
- Use a maximum eave projection of 30cm
- Use a lightweight plywood gable wall (do not use a masonry gable wall)
- Use 2x4 dimensional lumber to fabricate roof trusses
- For gable roofs, trusses which span 3-3.5m between two supports without an intermediate support shall be spaced at a maximum of 0.5m on center

- For gable roofs, trusses which span over an intermediate support with 3-3.5m on each side may be spaced at up to 1m on center
- Avoid positioning roof trusses over window or door openings in walls
- Truss configuration shall be at least 1 central vertical member and 2 diagonals for spans up to 3.5m
- Purlins to be spaced at a maximum of 50cm orthogonal to gable trusses
- Connect bottom of truss chords with orthogonal 2x4 members on either side of center vertical
- Connect 2x4 truss members using 0.75" thick plywood gusset plates nailed on both sides
- Corrugated metal sheets shall be oriented with ribs perpendicular to purlins
- Connect roof trusses to concrete ring beams using stainless steel straps anchored to ring beam reinforcement
- Provide connections as shown in the drawings to allow for sufficient tie-down due to hurricane-level wind forces

1.10.2 Flat Concrete Roof

- A house designed with a concrete roof must follow the guidelines and block strengths required for two-story houses
- Use 10cm-wide blocks (on their sides) as slab void forms to create a two-way concrete beam system
- Group void forms into approximately 80cm x 80cm zones with approximately 22.5cm to 30cm continuous clear spacing between them to create continuous 22.5cm to 30cm wide roof beams in two directions
- Leave a small amount of space between the concrete blocks within each group to allow bond between concrete and blocks
- Wet blocks prior to placement to increase bond between concrete and blocks
- Use 10cm continuous cast-in-place concrete slab on top of void forms with #3 Grade 40 or 60 bars spaced at 20cm on center in both directions positioned at the center of the continuous slab
- Reinforce the concrete roof beams with 4 #4 longitudinal bars and #2 Grade 40 closed stirrups spaced at 10cm within 1.2m of walls and 20cm otherwise
- Maintain at least 25mm concrete cover over all steel using wire chairs or small concrete blocks
- Anchor all reinforcing steel in the roof slab into the ring beams on all sides
- Provide for adequate drainage of roof to prevent ponding
- Avoid eave projections which may invite discontinuous second story walls

1.11 Stairs

- Use exterior stairs for two-story houses
- Use either reinforced concrete stairs, wooden stairs or prefabricated steel spiral stairs
- Do not connect stairs to confined masonry wall panels
- Support stairs on independent spread footing foundation
- Provide cold joint between bottom of the stair and the footing with no steel reinforcement through the joint
- Reinforced concrete stairs should be a maximum of 1m wide
- See drawings for reinforcement and detailing required for a specific stair configuration

1.12 Future Expansion

- If it is expected that a second story will be added to a single-story house with a concrete roof, instead of anchoring the tie column's longitudinal reinforcement into the ring beam, extend it above the ring beam by at least 70-90cm and cover it completely with lean concrete (which can be removed to create a splice when the additional floor is added)
- If it is expected that a house may grow in footprint, provisions should be made to allow for adequate connection between existing and new confined masonry walls and to maintain a symmetrical layout with well-distributed walls and openings. See suggested details provided for horizontal expansion in drawings.
- The best solution for horizontal expansion is for new structures to be completely separated from existing structures by 3cm (for a single story structure) to 6cm (for a two-story structure)