D102: New Reinforcement Protects Resilient CE Earthbag against Stronger Earthquakes

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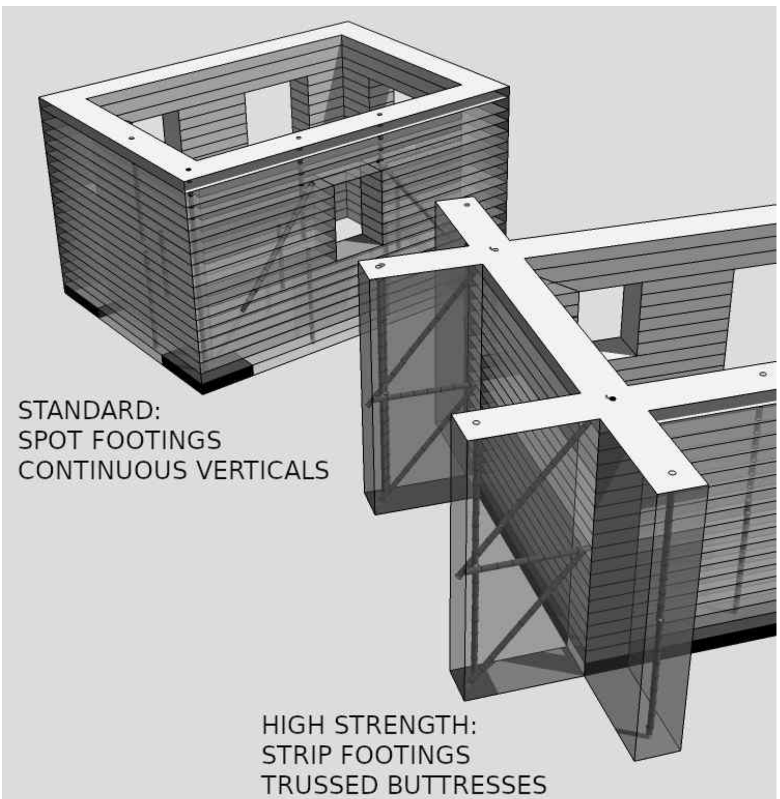
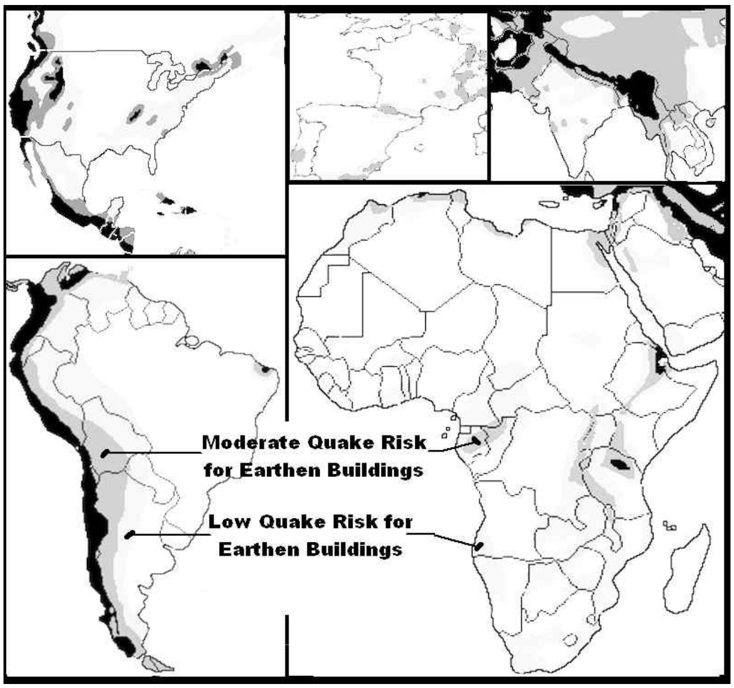


Figure 1: Choose the reinforcement right for your level of risk.

INTRODUCTION

Earthquake forces turn buildings of earth, stone, or brick into killers unless built very carefully.

Earthbag uses natural subsoil in fabric tube forms to provide low cost and low cement walls that wiggle more than crack. Barbed wire between courses adds toughness, plaster finish layers delay damage and protect from weather and inserted steel rebar provides stiffening.



Conventional earthbag buildings surprised Nepalis in 2015 by surviving horizontal quake forces 70% as strong as gravity.

Gray in Figure 2 shows where forces 60-170% of gravity is possible. The closer to black, the higher the forces. Black areas may have earthquakes even stronger.

Ask local experts what your risk is.

Well-built earthbag may be unlikely to collapse but can be damaged if high quake forces break door and window frames or warp walls.

Figure 2: Sketch map showing approximate areas dangerous for unreinforced earthen buildings.

RESILIENT CE IS NEEDED WHERE FORCES MAY BE MODERATE TO HIGH

Resilient contained earth (CE) earthbag needs embedded rebar with a little cement and strong fill soil. Wise builders who are very careful can keep their families safer even if they aren't rich.

Conventional earthbag is promoted as creating flexible walls that can resist earthquake vibrations. Earthbag walls with barbed wire continuous around corners are less likely to have sudden collapse than most traditional earthen walls. But research to date shows that even when rienforcement is improved, CE walls have limited strength and can be too flexible. Unless built with exactly the right soil and reinforcement detailing, earthbag walls act more like pudding than rubber.

Owners want buildings that can predictably resist specific levels of earthquake force, or it is not worth their while to invest precious time and materials in building. Resilient CE walls need to be stiffer and stronger than earthbag- then they will perform more like steel strings and less like jello.

Deformation and damage to buildings after a severe earthquake will be less with the reinforcement suggested in this booklet. Additional research is needed using these details to determine exactly how resilient CE walls can be safely planned for different seismic risk levels.

Spot or strip footings of reinforced concrete (RC) with gravel bags anchor vertical rebars that extend into a strong bond beam. How much steel depends on your building shape, wall height, roof weight and the building site.

Use standard or high strength footing and reinforcement connections with the best available quality of ‘raw’ (unstabilized- without cement) soil. Extra strength details can be used with high strength construction for maximum strength.

First check the cohesive (sticking) strength of your soil fill by crushing dried 30 mm balls or proving strength with more accurate testing. Then decide on your plan and choose details. Fill less than 1,7 MPa (250 psi) compressive strength often needs high strength details even for 0.7 g risk levels.

Earthbag has relatively low material costs, but requires a heavy labor of love. Respect the value of work needed to build. Read full instructions for your chosen type of resilient CE to learn all the techniques that give earthbag a chance to resist earthquakes. Documents explaining how to build standard grade or high strength CE or add extra strength details are free online at www.BuildSimple.org/Resources.

Most buildings for quake risk areas need special plans. Doors and windows must be far from corners so solid walls can hold up the perpendicular walls next to them. Buttresses can stick out past external walls to help keep earthen walls standing.

The system for checking bracing walls used in New Zealand’s science-based building code will be helpful when we are sure how resilient CE wall strength compares. The original standard *Earth Buildings not requiring Specific Design* 4299:1998 is online free. As Build Simple learns of better research, web pages will be updated with more accurate strength data that can compare to the New Zealand building guidelines. If our planned design guidelines are not online yet at BuildSimple.org/ Resources (look for *D102*), ask an engineer how long to make bracing walls for your building on your building site.

The details that follow provide a quick overview of reinforcement types. Choose either the standard grade or the high strength system since all elements of a building reinforcement system must be similar strength. Much more detailed instructions are included in booklets *B102*, *B103* and *B104* online at BuildSimple.org/ Resources.

Both metric and imperial units are used in this document. For approximate dimensions, both types of units are rounded even though they are not exactly equal.

BASICS OF IMPROVED CONSTRUCTION FOR STRONGEST CE

Keep soil fill material damp enough that a small handfull squeezed in a ball will split in several pieces when dropped from 1,5 m (5') high on a hard surface. Fill must consolidate when tamped.

STRONG BARBED WIRE

Place all barbed wire immediately after laying a course. Straighten wire and pull it taut. End strands in the middle of walls and overlap at least 600 mm (24"). Always bend wire sharply and tack at corners unless bent around rebar or tied (Figure 3).

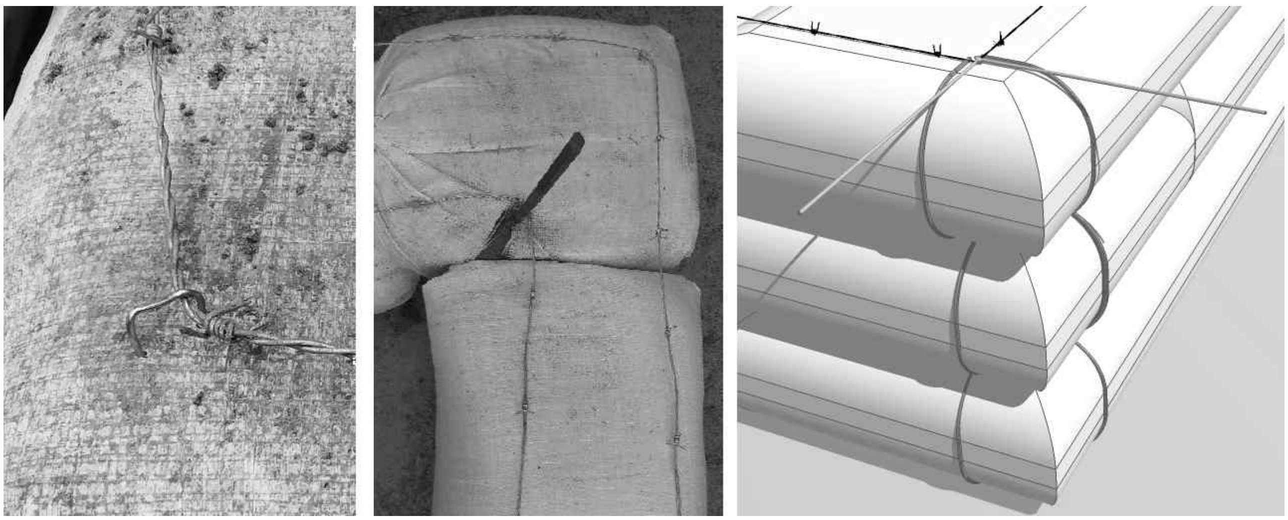


Figure 3 Barbed wire held taut by (left to right): a- electrician's staple; b- rebar; c- cord ties at corner.

On all barbed wire strands tie 760 mm (30") long pieces of cord to attach plaster mesh every 600 mm (24") in height and width. Let cord hang equally out both sides of walls.

CONNECTED GRAVEL BAG COURSES

Unite gravel bag courses with barbed wire tied around the courses (Figure 4a) that is also embedded in spot footings. Embed wire ends in concrete or fasten strongly (Figure 4b).

Below door sill level on standard grade CE buildings, bind around the entire foundation for good footing stability. For higher seismic risk and multiple courses of gravel bag in high strength CE buildings, bind each gravel bag course along straight segments. Also insert angled pins through two CE courses down into gravel bag courses to hold separate gravel bags together.

Figure 4 (left to right): Binding gravel bag courses: a- Wrap straight lengths; b- Attach securely.

Wrap barbed wire along straight lengths of wall (Figure 5a) where bags are laid continuous. On the next course lay bags and wrap wire in the other direction (Figure 5b). Add barbed wire on gravel bag for buttresses or stub walls every other course.

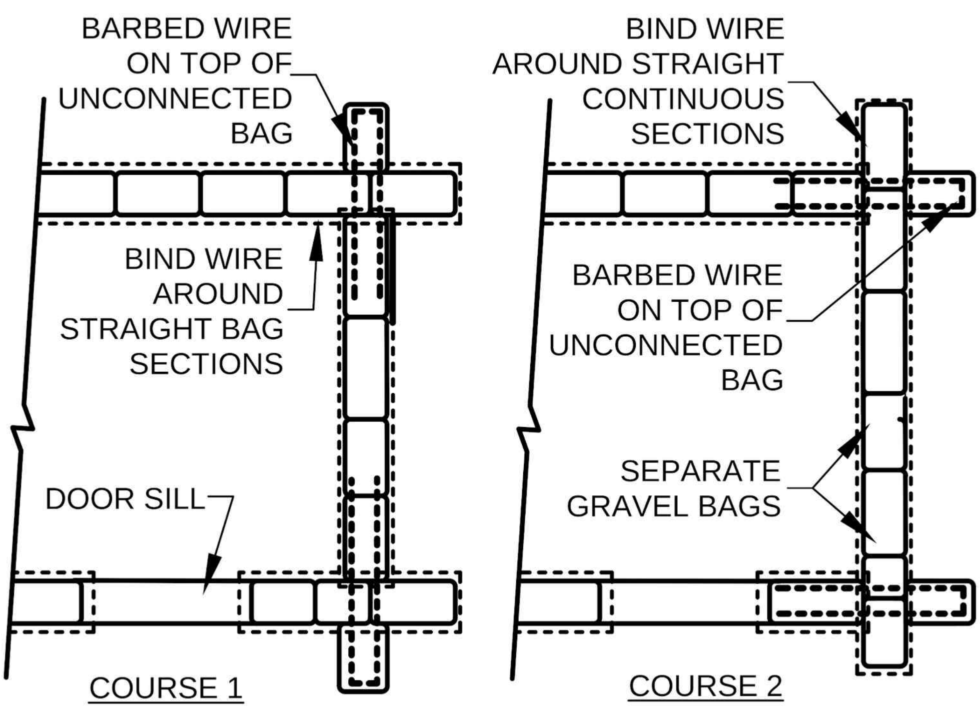


Figure 5 Bind gravel bag courses (right to left): a- Wrap straight sections excepting openings; b- Alternate laying wire on bags unconnected with binding wire from course to course.

Gravel fill doesn't shrink like CE from drying, so strap gravel courses vertically every 600 mm (24") so that plaster mesh can be tied to the wall base.

INTEGRATING GRAVEL BAG AND RC FOOTINGS

Building strength is based on how strong the footing is and how many of the vertical wall reinforcements are stiffly anchored in reinforced concrete.

Standard grade uses spot RC (reinforced concrete) footings at the corners of buildings that are strongly connected to gravel bag foundations between them (Figure 6).

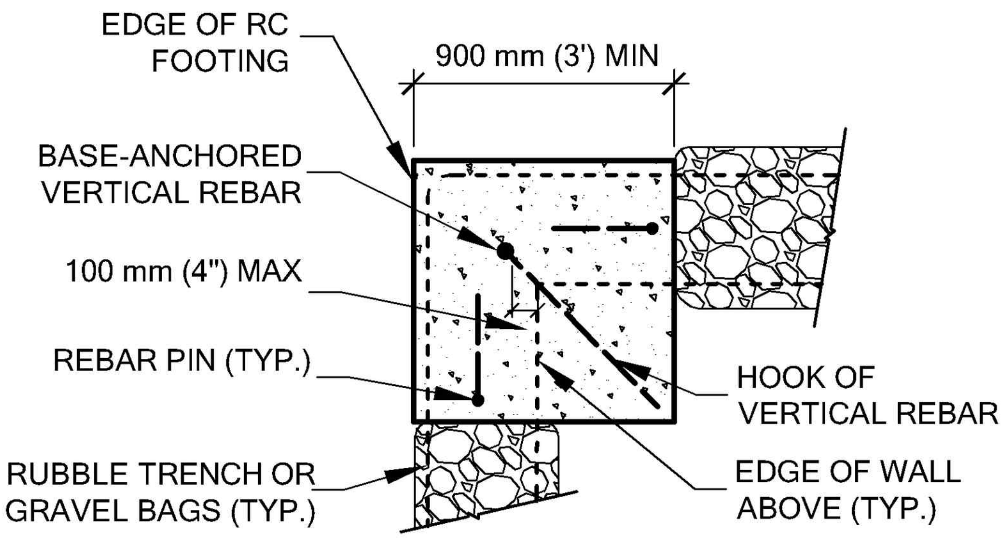


Figure 6: Spot footing to anchor long vertical rebar extending to the bond beam.

High strength CE uses continuous strips of RC that confine narrower portions of gravel bag and allow all vertical rebars to be base-anchored in the RC element (Figure 7). For highest risk designers can use full-width RC footings if needed.

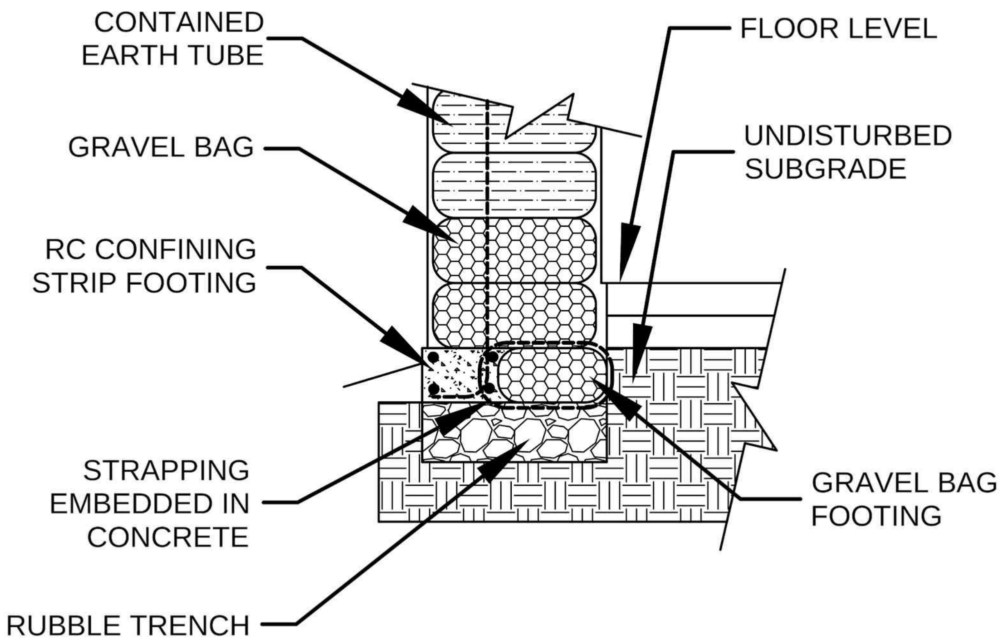


Figure 7: Confining strip footing holds gravel bags in place with modest concrete use.

EMBEDDING REBAR IN DAMP SOIL FILL

Steel reinforcement in resilient CE walls has best strength if it is embedded into a damp mass of cohesive soil that dries around and bonds tightly to the textured steel surface.

Insert rebar into earthen walls as soon as possible so steel bonds with damp fill, or use new techniques to build damp soil walls around base-anchored rebar by sliding tubes over holes ‘punching’ onto rebar (Figure 8a) or cutting small slits in fabric containers (Figure 8b).

Figure 8 Embed steel by (left to right): a- punching bags; b- cutting tubes to fit around rebar.

Punched-bag uses holes near the beginning of a tube on a rebar that extends no more than 1,2 m (4') above the current course. Pre-fill the tube 255- 300 mm (10-12") deep. Slide the tube onto the rebar. The tube is re-firmed and filling continues leaving no damage to the tube.

Since punching is only done at the beginning of a tube and highly reinforced have many base-anchored rebars, builders use cut at the other end of most tubes. Fill the tube next to the rebar, letting it hang half off of the wall. Cut the fabric and slide the tube into place surrounding the rebar. When tubes are cut for a rebar near the inside of a corner, the cut is protected from mechanical damage by the lapped tube nearby.

Cuts can alternate with punched-bags on walls. Builders can use splices at many locations to reduce the amount of cuts and punching on upper walls.

CONNECTING WALLS

Where walls intersect both tube and barbed wire must connect them. Alternate overlapping tubes from course to course and place barbed wire where it connects the building strongly. Run wire along exterior walls first continuous as much as possible (Figure 9a). Then run interior wall wire over crossing walls and continuous. In the same way connect buttresses (Figure 9b).

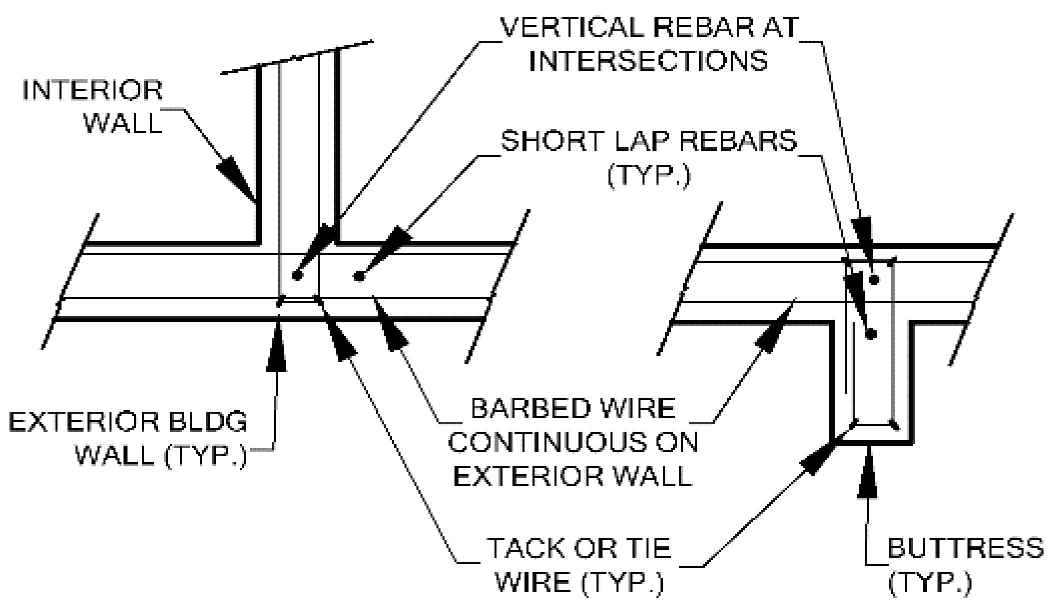


Figure 9 Barbed wire continuous along walls (right to left): a- runs across adjacent wall, b- runs across wall to end of buttress and returns.

VERTICAL REBARS

Some rebars are inserted like conventional earthbag, some are base-anchored but built in walls.

SPACE INSERTED REBAR

Protect dried soil masses in walls by spacing overlaps apart. Insert separate upper and lower rebars in the same locations. Use a shorter lap rebar that overlaps them both, as far away from the main verticals as the length of its overlap with them (Figure 10).

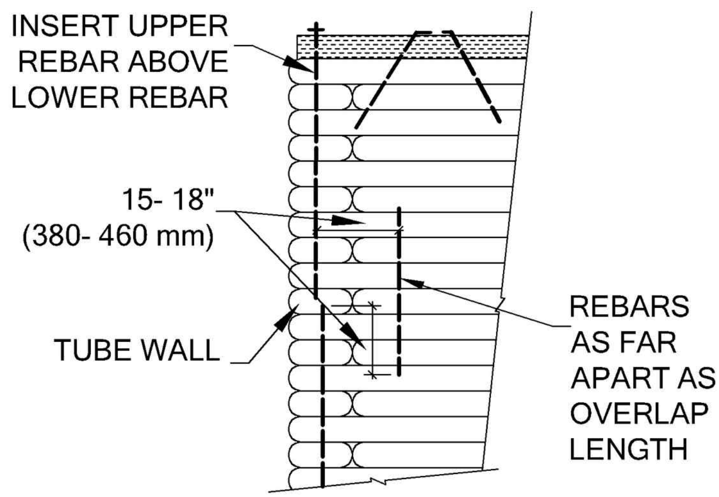


Figure 10: Improved overlapped inserted rebar technique uses a distant lap rebar.

OPTIONS FOR REINFORCEMENT ASSEMBLIES INSIDE EARTHEN WALLS

Connect rebars embedded in soil to other rebars using small concrete splices. Splices with hooks can have concrete poured as the wall is built (open type- Figure 11).

Figure 11 Open splice on top of a course (left to right): a- Tamp end of course at splice area; b- Insert rebars and turn hooks to fit; c- Pour concrete to embed steel into tube on top of course.

Connect low verticals to upper rebar and diagonals inserted from the same course (Figure 12) using a simple open splice. Walls above will need to all be punched and/ or cut to build around the anchored rebar.

A gap in the second course can allow poured concrete to connect a straight vertical without a hook in an open splice.

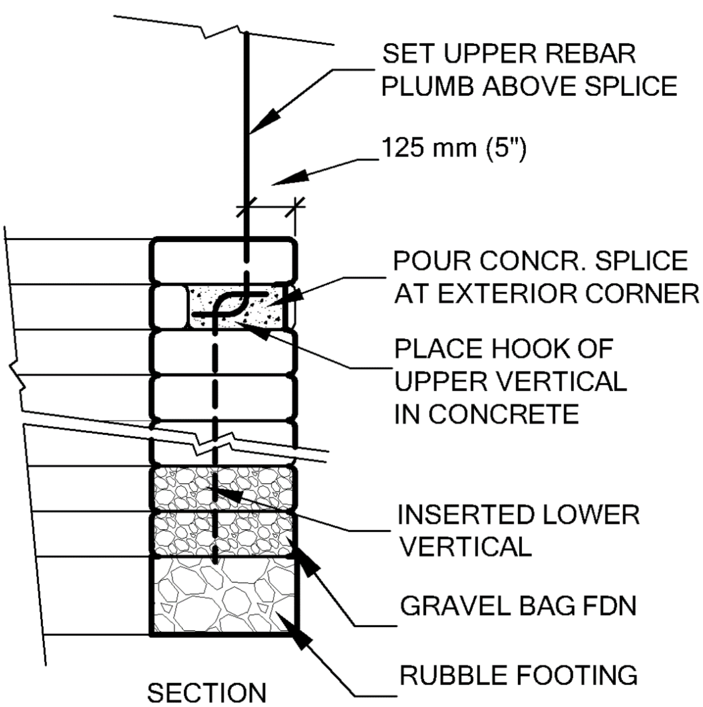


Figure 12: Connect verticals with hooks in one-course high open splice.

Other splices can be poured after the full wall height is completed and rebars are inserted from above (covered type- Figure 13.

Covered splices use sandbags placed where the splice will happen, and builders must aim carefully to hit the sandbag with the inserted rebars. Diagonals, horizontals and verticals can all be connected strongly together to create many kinds of reinforcement assemblies.

Insert rebars down into and through the target sandbag. Cut to remove sand and fabric. A one course-high form holds a dry mix of concrete. Use the mesh to squeeze the concrete into place around the rebar, then fill depressions with plaster.

Figure 13 Covered splice (left to right): a- target sandbag placed in mesh; b- building above the target bag; c- remove fabric and sand from target bag to create space for concrete.

Covered splices can be used to insert upper rebars and reduce the need for cutting or punching courses on rebar (Figure 14). The upper rebars are connected to lower rebars at corners, ends of walls, and next to wall openings.

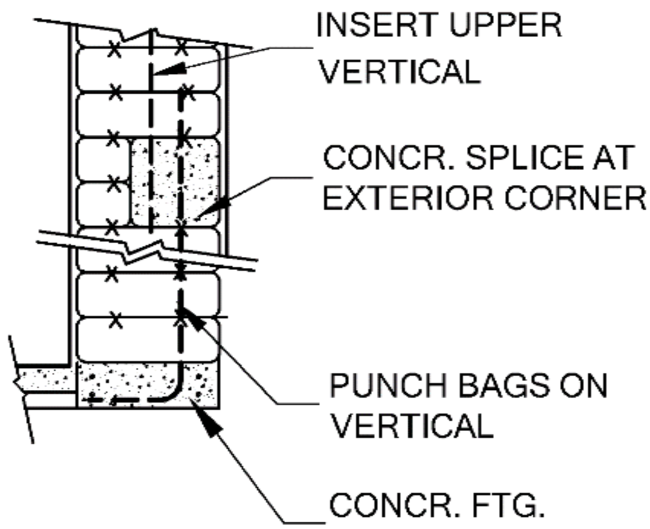


Figure 14: An upper rebar inserted into a splice two courses high.

Types of Rebar Reinforcement Assemblies

Triangular reinforcement assemblies have more intrinsic strength to resist warping than grid-type rectangular reinforcement connections.

In standard grade construction anchored rebars at external corners allow the use of diagonal braces (Figure 15) that form a triangle with verticals and bond beam horizontal steel.

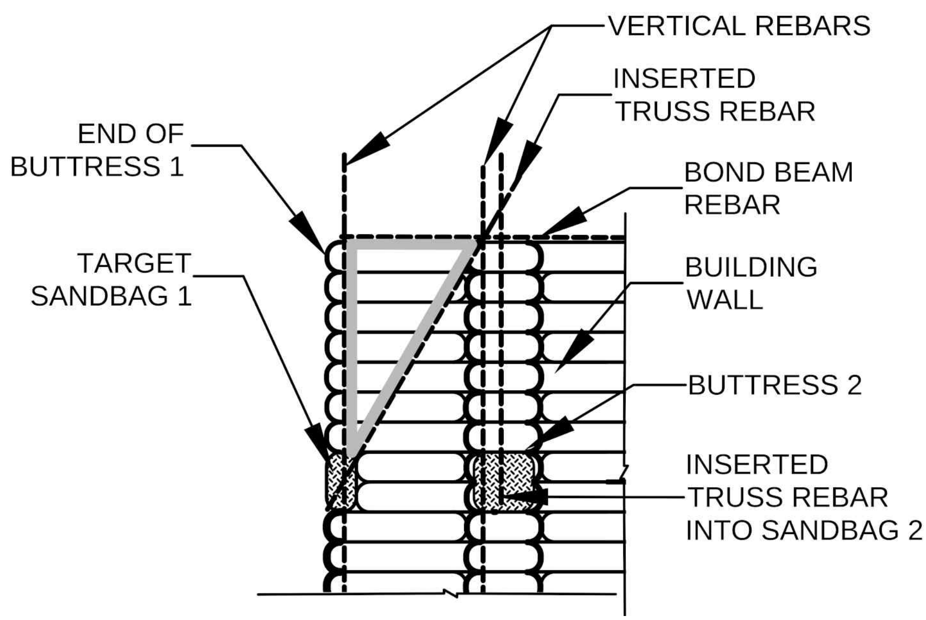


Figure 15: Standard grade reinforcement uses triangular bracing at external corners or buttresses.

Standard grade construction also allows walls next to doors and windows to be strengthened by connecting verticals to the bond beam and adding inserted diagonals from wood lintels (Figure 16). Additional diagonals can be connected to lintels to provide stiffening but little extra strength without connection at the bottom to a splice.

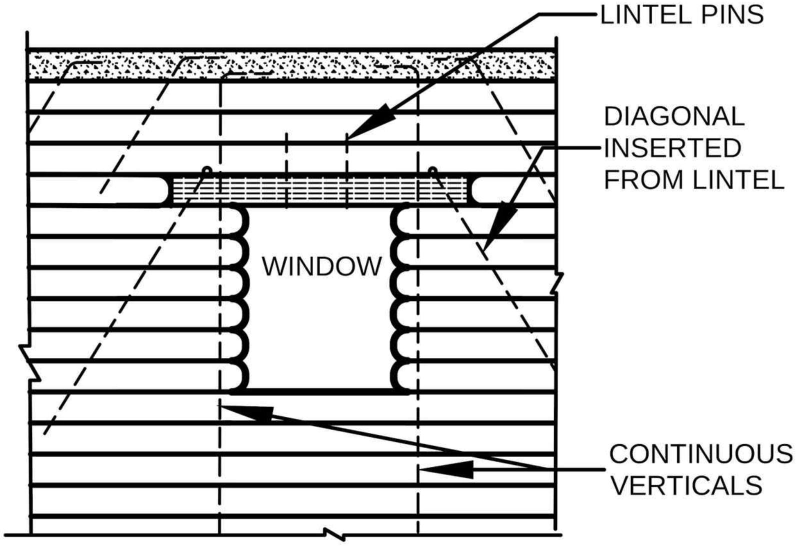


Figure 16: Wide wall openings can have strong connections to bond beams.

Greater strength can result from more complex reinforcement assemblies (Figure 17) that incorporate horizontal rebars inserted at mid-wall height. In high strength CE walls single or double braces are easy to build at exterior corners, in buttresses or stub walls, or next to doorways or tall windows.

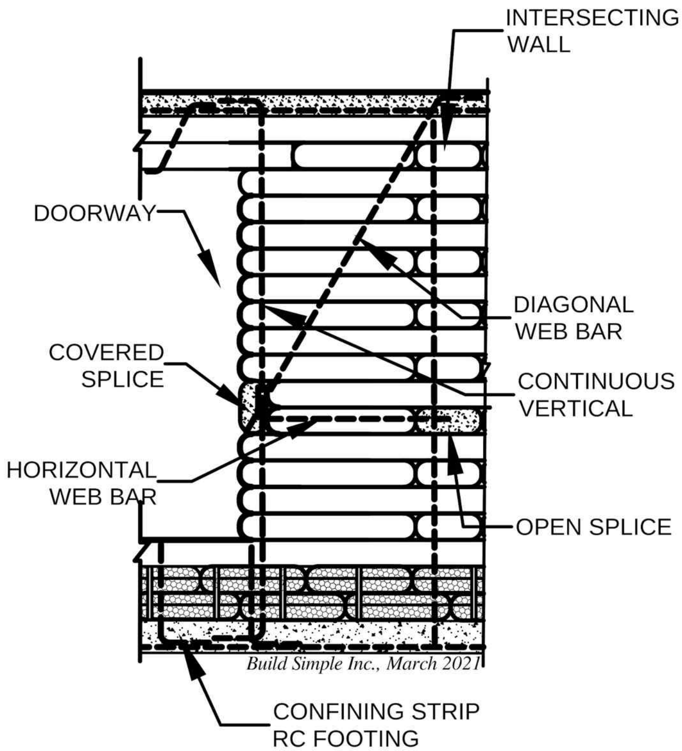


Figure 17: High strength CE can use single or double braces near doorways or corners.

Walls above doors and windows can also be strengthened by forming truss-type triangles connected to the bond beam (Figure 18).

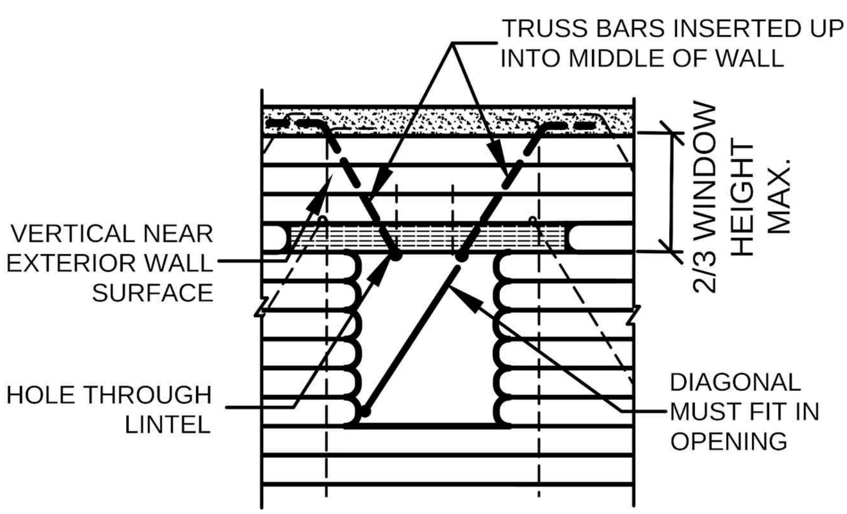


Figure 18: Diagonals connecting lintels to bond beams.

Full rebar truss systems with four force triangles (Figure 19) are extra strength details that can be used with high strength CE foundations. Rebar trusses can be built into walls next to the ends of buttresses or stub walls.

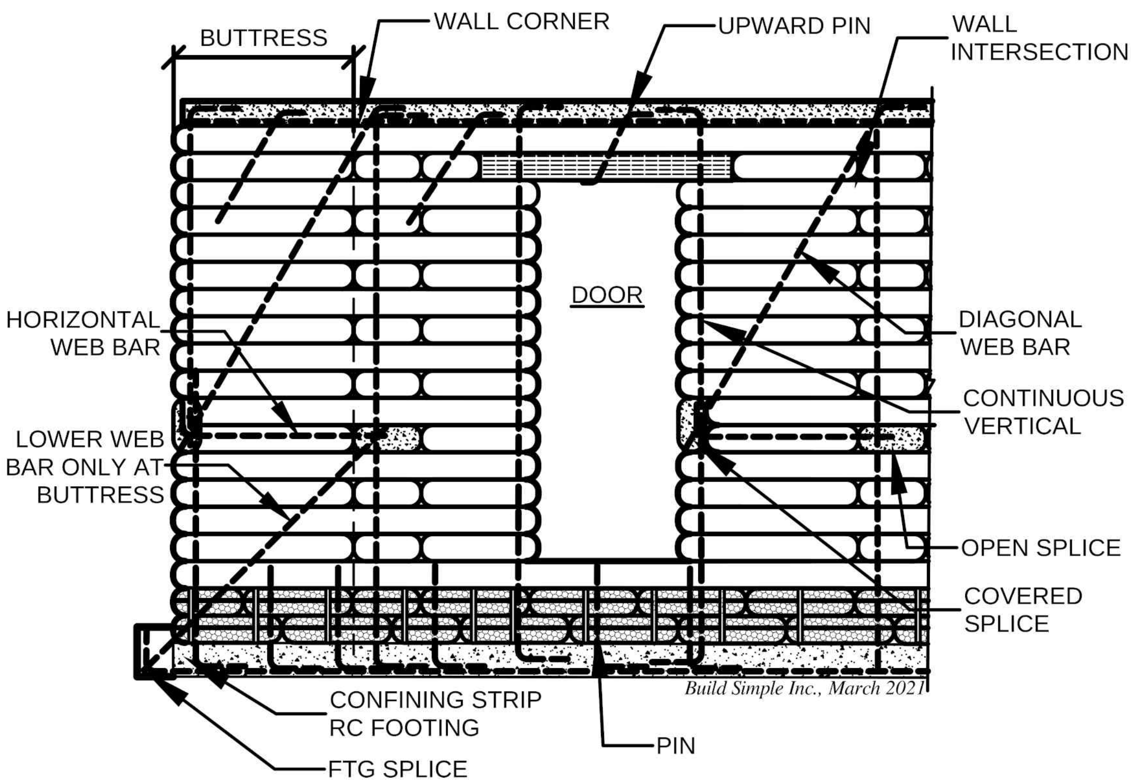


Figure 19: Full wall height rebar truss assemblies can be built with high strength CE footings.

Sometimes welded steel tube frames are used at doors and windows to reduce need for wood. Welded frames can have great stiffness and protect walls if they are well integrated into the structural frame. Connect the sides of frames to adjacent walls and bolt to vertical steel (Figure 20).

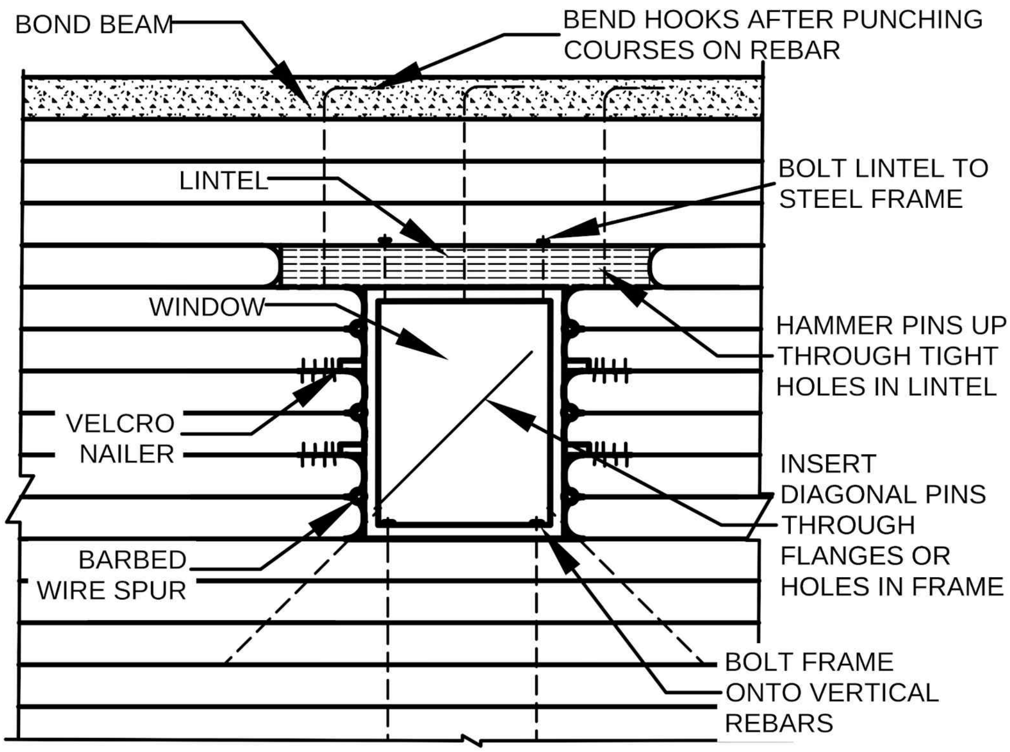


Figure 20: Welded steel frame connected to lower and upper rebars use velcro nailers and rebar spurs to connect into wall material on both sides.

Short horizontal rebar spurs every other course on both sides of the frame connect barbed wire. Flanges between attach velcro nailers. Fasten the frame onto base-anchored verticals topped with bolts. Attach the lintel and/ or frame to the bond beam using vertical rebars with short hooks inserted up through the lintel.

12 ABBREVIATIONS AND DEFINITIONS

Buttress	A stub wall added perpendicular to a building wall to brace it. Often used on exterior walls, especially at corners or wall intersections
CE	Contained earth (earthbag built with damp cohesive soil fill) in bags or tubes
CG	Contained gravel a.k.a. gravel bag (water-resistant earthbag filled with gravel) in bags or short tubes
CS	Contained sand (low strength earthbag with loose fill or dry fill) in bags
Covered splice	Section of concrete to connect lower rebars to an upper rebar in a void space below current course.
FDN	Foundation
Fork	Multiple lower diagonal inserted rebars spliced to an upper rebar.
FTG	Footing
Spaced lap	When separate rebars are inserted one directly over the other and a shorter lap rebar overlaps them both.
LVL	Level
MAX	Maximum
MIN	Minimum
Open splice	Section of concrete to connect lower rebars together or an upper rebar to lower rebars. Concrete is poured below building above the splice level.
O.C.	On center (similar to at __ centres)
Pier	An area of thickened wall. This can be a repeating identical element where a wall is thickened to stiffen
Stub	A short wall with only one end attached to another wall, lacking bracing at one end
TYP	Typical indicates that every where this element appears in the detail or plan it is the same