B101: BUILD LOW-CEMENT RESILIENT CE EARTHBAG

Connected Rebar on Gravel Bag for Low Seismic Risk

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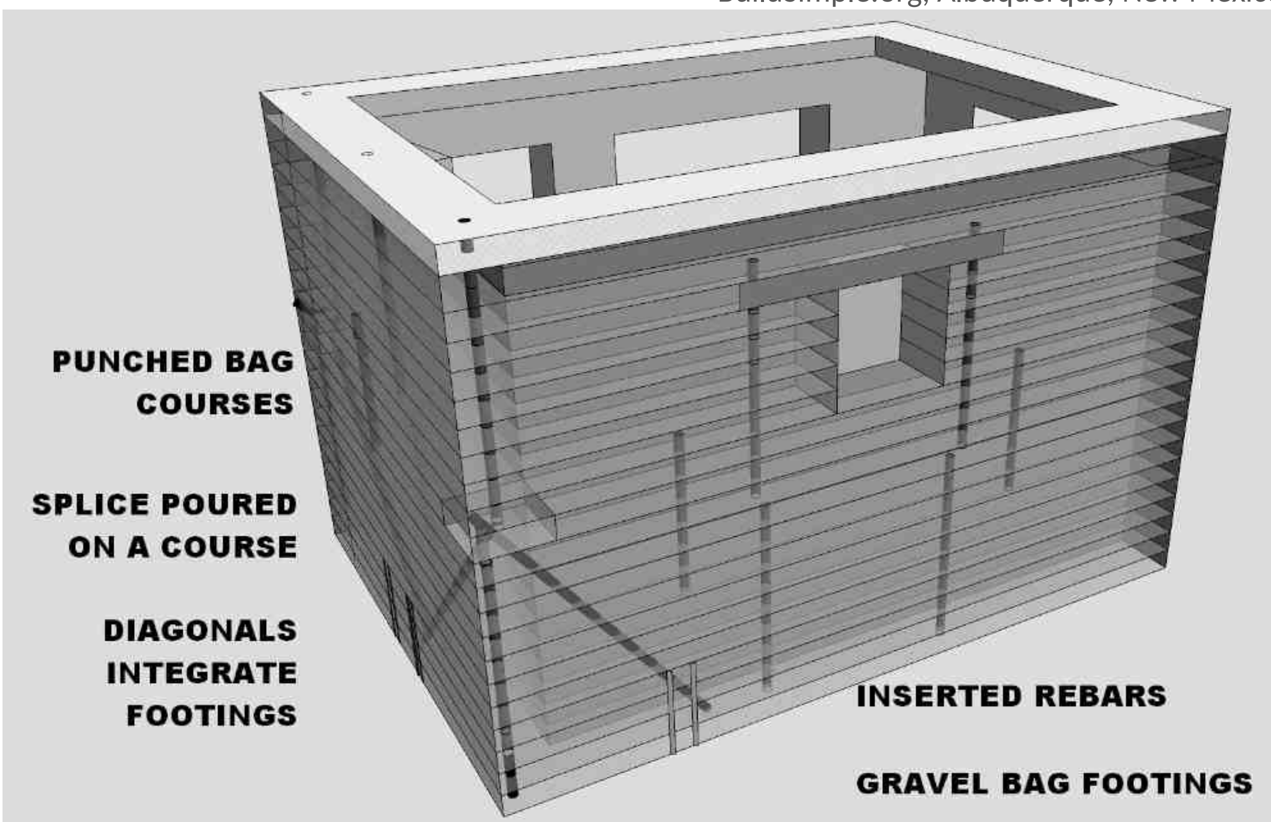

Figure 1: Strengthen corners by interconnecting upper and lower rebar to diagonals with a concrete splice poured during wall construction.

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INTRODUCTION

EARTHBAG VS. EARTHQUAKES

Conventional earthen buildings are well suited to areas with minimal or no seismic risk. But even low earthquake forces can damage or destroy unreinforced buildings of earth, stone, or brick unless they are built very carefully.

Earthbag on gravel bag base walls has been used in seismic risk areas because it provides a low cost and low cement way to build walls that resist quakes better than unreinforced earthen block or rammed earth walls. Barbed wire between courses adds toughness and unconnected but easily inserted rebar provides some stiffening. Unfortunately conventional earthbag buildings have to date only survived low earthquake forces (70% or less of gravity in Nepal’s 2015 quakes). Structural testing shows that they can be damaged. Quake forces can reach 170% of gravity and higher.

Earthbag buildings with conventional detailing are unlikely to collapse if barbed wire is continuous around corners and walls have well-spaced openings. But door and window frames may be broken and upper walls warped out of shape enough to require rebuilding.

Most communities want institutional buildings to *predictably* resist local quake forces and survive.

IMPROVED REINFORCEMENT FOR LOW RISK

Builders love earthbag because it uses local, natural materials and because it can be built without either power tools or a lot of fussy details. It also is exciting to see immediate walls rising without pre-forming blocks or forms. The type of builder who likes to build without a complicated process also doesn't like complex planning and plans.

With new details resilient CE (contained earth) on gravel bag foundations can predictably survive in low risk areas **if strongly cohesive soil fill is available**. The details included in this system of reinforcement do not need extensive pre-planning. Most reinforcement is inserted into walls, including stronger corners with connected rebar, and lintels that connect upper to lower rebar. The corner reinforcement now uses foundation weight to stabilize upper walls.

In areas with low seismic risk use these details if:

- soil fill for construction is 1,7 MPa (250 psi) compressive strength or higher
- builders are willing to take special care and use this whole system of detailing

If soil fill is weaker than 1,7 MPa (250 psi) or cannot be proven that strong, or if builders cannot or will not complete wire binding and splices, use details in *Standard Grade Resilient CE Earthbag* with reinforced concrete spot footings at corners (pdf online at BuildSimple.org/ Resources).

Plan carefully and build thoughtfully. The details for low-cement resilient CE earthbag are for use in buildings that are:

- less than 600 m^2 (6458 s.f.) for one story or 300 m^2 (3229 s.f.) per floor with a loft or upper story
- one story or one earthen story with a light upper level
- built on firm ground (> 600 mm/ 2' from a downhill slope and not erodible or likely to subside)

Contained earth earthbag has not been fully tested, but years of small scale research have proven which reinforcement techniques are buildable and cost-effective. The improved details that follow are the best known in late 2020.

The recommendations for level of seismic risk are conservative because they are based on 60% scale testing of earth-plastered samples with scale-reduced rebar and 80% scale testing of unplastered samples with faulty reinforcement. When you plan a building, check whether BuildSimple.org has better information, or ask an engineer if he or she knows more recent information about earthbag strength.

Details and specifications from the guidelines in New Zealand's *Earth Buildings not Requiring Specific Engineering* (NZS 4299) for unreinforced adobe should be compatible with these details for low-cement CE earthbag. The biggest difference is that NZS 4299 requires earthen walls to all be built on reinforced concrete full-width footings. Because earthbag walls have higher toughness (resisting and recovering from twisting forces) and and more tensile strength than unreinforced adobe or rammed earth walls, slight foundation adjustments and/ or settlement should cause less structural damage to resilient CE earthbag than to unreinforced earthen walls of other types.

WHAT IS 'LOW' RISK?

Earthquake risk varies a lot from area to area. The sketch maps below (Figure 2) give rough estimates of risk. The details in this booklet can probably apply to all the areas shown in gray, although builders in the US, Canada, Europe and Australia should check exact risk for their building site online. Areas shown as white may be safe for conventional earthbag and many conventional types of unreinforced earthen buildings.

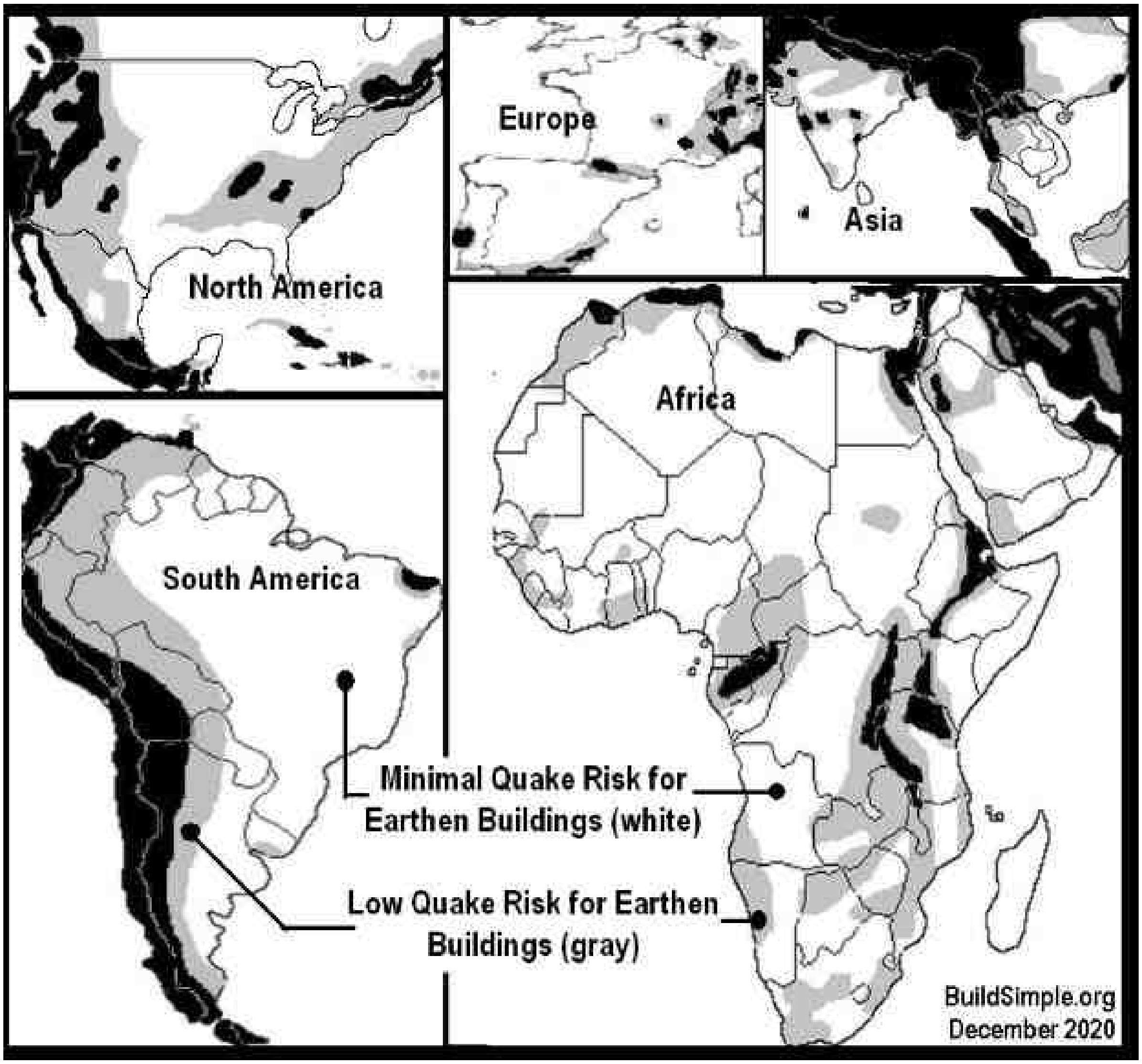

Figure 2: Approximate locations of earthquake risk relative to earthen wall strength.

Areas shown in Figure 2 above as black have moderate to very high seismic risk. Earthbag may be less liable to collapse than earth block building, but low-cement CE details are not strong enough to ensure buildings in the moderate to high risk regions will be useable there after strong quakes.

BuildSimple.org uses risk levels that match the most complete existing earthen building guidelines (developed for New Zealand) to define low risk as:

> *0.25- 0.59 g (gravity) peak ground acceleration (pga)*
> *occurring in pulses at a rate (0.2 second or 'Ss') that causes the most damage to low-rise buildings*
> *based on 2% probability of excedance (pe) in 50 years.*

Risk levels are complicated. Locations with soft soil or seasonal high groundwater have higher risk than areas with bedrock or hard stony ground. Ask an engineer or professor of engineering for advice if there are no clear seismic hazard levels defined by local government.

Professionals in different countries talk about risk using different scales of measurement. In Europe and some other areas planners use 10% in 50 year probability of excedance, as seen in the online world maps in the Global Earthquake Model (GEM)[1]. On these 10% pe maps the same level of 'low' risk is described differently. Dark blue or green areas on the GEM are like gray on Figure 2:

BuildSimple risk maps[2]	2% probability in 50 years	0.25- 0.59 g pga
GEM hazard maps	10% probability in 50 years	about 0.05- 0.1 g pga

New Zealand's code also has information for buildings in areas with seismic risk higher than 0.59 g at 2% pe, but fully reinforced rammed or earth block walls are required. The details in this booklet for low-cement resilient CE are not strong enough to predictably survive earthquake forces of 0.6 g or higher, even considering resilient CE's high ductility. Use standard grade or high strength resilient CE earthbag details (see documents B11 and B12 at BuildSimple.org/Resources) for areas with seismic risk of 0.6 g or higher.

RESILIENT CE EARTHBAG REINFORCEMENT SYSTEMS

Buildings often begin to fail at the single weak element that breaks or separates first. After one element fails, the rest of the building suffers increasing damage. Like a chain that is only as strong as the weakest link, buildings facing quake forces are only as strong as the weakest of their materials and connections.

Buildings facing earthquake forces need a full system of reinforcement with each element able to resist the same level of horizontal shaking. Other reinforcement systems are described online at BuildSimple.org/Resources. *B102 Build Standard Grade Resilient CE Earthbag* shows details for moderate seismic risk levels of 0.6g and above, and *B103 Build High Strength Resilient CE Earthbag* shows details for higher seismic risk levels. Get engineering advice before using individual details from different levels of strength in the same building.

Many of the differences between low-cement, standard grade and high strength reinforcement systems for resilient CE relate to their different foundation types and the amount of interconnected vertical reinforcement (Table 1).

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[1] Global Earthquake Hazard and Risk Model online at https://www.globalquakemodel.org/gem
[2] https://buildsimple.org/Resources >D21 Sketch Maps for Seismic Risk

TABLE 1: COMPARING REINFORCMENT SYSTEMS FOR RESILIENT CE

	Low-Cement	Standard Grade	High-Strength
Pdf	**B101**	**B102**	**B103**
Footings	Gravel bag	RC spot at corners	RC strip entire length
Base Wall	Detached angled pins	Covered splices	Covered splices/ continuous
Corners	Open splice + fork	Continuous verticals	Continuous verticals and buttresses with trussing
Intersections	Open splice + fork	Open splice + fork	Continuous verticals
Techniques	Punched	Punched and cut	Punched and cut
Rebar	Lapped @ openings	Spliced @ doorways	Continuous or spliced
Windows	Lap from bond bm	2 verticals to bond bm	Continuous to bond beam
Doorways	Connect to bond bm	2 verticals to bond bm	Continuous to bond beam
Lintels	Wood	RC or wood	Wood or RC
Bond beams	Wood	RC or steel (wood with ceiling diaphragm)	RC (steel with ceiling diaphragm)

NOTE ABOUT DIMENSIONS

To make this information accessible for builders worldwide, both metric and imperial units are used. When the measurement is an approximate one, both units are rounded even though they are not exactly equal.

MATERIALS FOR RESILIENT CE EARTHBAG

CONTAINED EARTH (CE)

The strength of the 'raw' or unstabilized dried soil masses in earthbag's walls determines wall strength. With minimal strength cohesive soil fill earthbag walls begin to warp under the sideways forces of earthquakes at low force levels. If walls warp sideways too far, they won't be able to keep adjacent walls perpendicular to them standing vertical. Serious damage could occur.

If earthbag walls are built with 1,3 Mpa (190 psi) compressive strength soil fill the low-strength details in this booklet may only protect walls up to 0.3- 0.4 g forces. Built with 2,1 MPa (300 psi) soil, these same details should protect walls up to 0.59 g forces.

Check the fill strength with field soil tests or better. Small samples can be dried within a day and tested quickly, some crushed underfoot or others crushed with a 20 L (5 gallon) bucket of dirt on a simple lever to estimate strength. See more information online at BuildSimple.org/Resources in documents *B30 Estimate Soil Strength with 3 cm Balls* and D*31 Field Tests for Strength of Building Soil*.

GRAVEL BAGS

Foundation walls for earthbag often use gravel in bags for moisture resistance. Short tubes or bags are filled after doubling them.

CONTAINERS

SMOOTH WOVEN FABRIC is the standard for earthbag, woven of flat polypropylene strands about 2mm wide. This breathable material serves as formwork and allows earthen masses inside the fabric containers to dry out gradually.

Use good condition fabric and protect from sun damage by plastering early- in the tropics or at high altitudes within 2 weeks. After the wall fill dries the container fabric is very important to prevent material loss if walls are damaged. If any soil masses are broken or crushed at specific stress areas, intact fabric containers hold the material in place and keep walls standing.

Smooth woven fabric is available in bags or tubes. Use tubes where possible in seismic risk areas.

Walls built with short bags take great care to ensure good overlaps of 230 mm (9") minimum. Many shorter lengths are needed in specific locations, slowing the work process. Extra-long bags or some short tubes are needed for good connections to inserted vertical rebar.

MESH TUBES can be used for CE earthbag and damp fill unites through the open course containers. The crocheted mesh tubes (like vegetable bags) are easy to work with but may cost more than solid fabric tubes.

These monolithic 'hiperadobe' walls flex less than CE in smooth woven fabric tubes and may have higher strength against warping or bulging damage to walls. Hiperadobe or 'solid' CE walls may need less barbed wire than CE in smooth woven fabric, but ductility may be less.

CONTAINER SIZES for tube or bag construction are measured laid flat. 460 mm (18") wide tubes or bags are standard for small buildings.

Wall thickness varies with course thickness. Holding bags or tubes more upright during filling and shaking fill down produces fatter courses. 460 mm (18") tubes produce 380 mm (15") thick building walls with 125 mm (5") high courses if filled to 130 mm (6") height before tamping. Filling the same size containers to 178 mm (7") height before tamping produces 150 mm (6") high courses in 370 mm (14.5") thick walls.

Mesh for solid CE walls makes flatter courses. Fill weight stretches mesh tubes wider, shortening the tubes, so lengths of hyperadobe mesh tube must be cut longer than the finished wall panel length. Ask suppliers for a sample and check the filled length, width and course height. Do not mix mesh and smooth fabric containers on the same courses.

REINFORCEMENT

Non-biodegradable reinforcement embedded inside earthen walls may last for generations. In warm climates insects may cause damage over time to important hidden structural elements, so bamboo or other natural materials are not recommended. For increased longevity, consider coating rebar in contact with soil with a rust-resistant but non-slippery paint, especially in areas with highly acid or alkaline soils.

Fiberglass or basalt rebar lack surface texturing for good bond. Do not use bars that cannot be bent to produce end hooks or welded to add top bolts or cross-pieces in seismic risk regions.

STEEL REBAR must be 'deformed' (textured) for good bond with dried soil. D12 (half-inch) diameter steel rebar is adequate for inserted vertical reinforcement without stiff base anchorage. With a reinforced concrete bond beam use D10 (3/8") rebar for angled pins at wall tops to allow easy bending in a 50 mm (2") radius.

BARBED WIRE barbs bridge the low-friction fabric surface between courses, creating a composite metal and natural soil layered wall. Use 4-point galvanized. High tensile strength wire costs less and has good strength. Low tensile strength wire is harder to work with but has longer barbs. The use of at least one strand of heavy low-strength barbed wire could possibly increase resistance to wall warping on courses subject to higher forces.

STRAPPING OR TIE CORDS can be common polypropylene electrician's pull cord or other lightweight non-biodegradable twine able to resist about 90 kg (200 lbs) pull force. Unless construction is overseen by contractors experienced in earthbag with adequate labor to complete the project quickly, use UV resistant cord. Use a trucker's hitch or other knots not subject to slipping.

Fiberglass packaging straps make a strong alternative for base course strapping if the tool to seal them is available.

OTHER MATERIALS

PLASTER MESH plays a critical role in overall wall strength. Chicken wire rusts and decays in contact with alkaline cement stucco or lime plaster, and plastic geomesh or fencing mesh is costly. Use weaker plastic bird netting or fishing net because the fine grid of individual strands embedded in plaster transmits force well.

PLASTER OR STUCCO must cover the walls to protect bags from UV damage in sunlight.

Earthen walls reach full strength when fully dry but survive being wetted in humid climates if walls can dry well between wettings. Plaster should let humidity out.

Earthbag built in smooth fabric containers may resist wetting better than hiperadobe because of small air gaps between dried wall material and plaster-coated fabric. Plaster made from hydraulic lime allows earthen walls to dry out better than cement stucco which holds dampness. Consider using lime or earthen plaster on at least a few upper interior courses of all raw earthen walls finished with cement stucco in humid regions.

BASIC EARTHBAG CONSTRUCTION

If new to earthbag construction, review the Earthbag Information slide shows B1- B5 online at BuildSimple.org/Resources and read a book like Hart's *Essential Earthbag Construction*. Videos by Geiger online at the Naturalhouses youtube channel, show generally accepted practices.

PREPARING FILLS

Soil fill must be slightly damp.

BUILDING WALLS

Gravel fill in water-resistant base courses can be settled but not compressed by tamping. Fill containers less full than for CE (contained earth earthbag) so course tops are level.

The end of any bag of contained earth should be overlapped on the course beneath at least 230 mm (9”). This is a fussy process requiring pre-planning on walls with corners when using separate bags of standard 690- 760 mm (27- 30”) lengths (Figure 3).

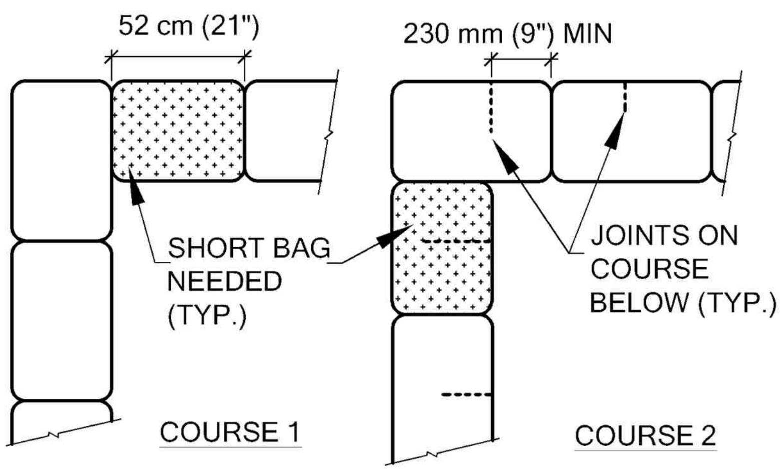


Figure 3: Shorter or longer bags are needed near corners and intersections for good running bond bag overlaps.

Building with tubes allows better connection between steel and dried earth. Less time is spent adjusting unit lengths and closing separate units.

BARBED WIRE ON CONTAINED EARTH (CE) COURSES

Lay barbed wire immediately. Pull wire taut along straight walls and wrap it around corners.

Two strands of barbed wire per course 80- 100 mm (3- 4") in from the wall edges (Figure 4) leaves about 180 mm (7”) available to insert vertical rebar and pins in the center of the wall thickness. Do not block the area for rebar or lay barbed wire visible in the nooks between courses.

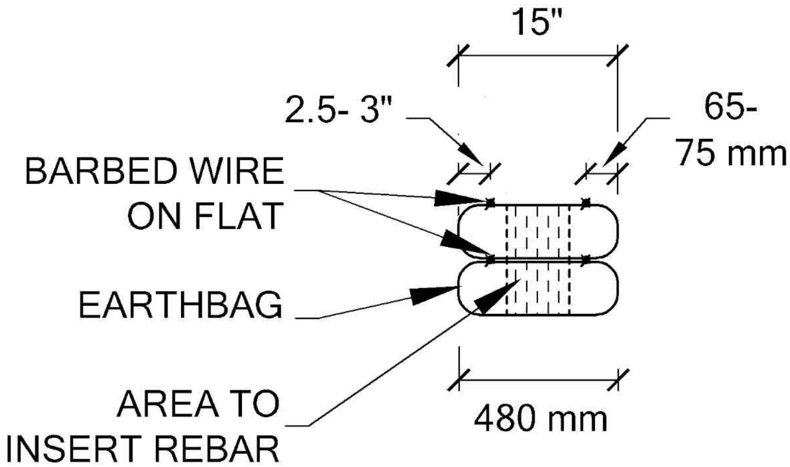


Figure 4 Barbed wire location on the flat course top near rounded course edges.

End barbed wire strands in the middle of a building side with at least a 600 mm (24") overlap (Figure 5a). At the end of a stub wall or near a wall opening, turn wire along the end and return into the wall (Figure 5b).

NEVER END A BARBED WIRE STRAND AT A WALL CORNER

OR AT THE END OF A STUB WALL.

Attach tie cords for plaster mesh to barbed wire letting cord hang out both sides. Space tie cords 600 mm (24”) on center vertically and horizontally.

Strips of strong geomesh or plastic fencing mesh can also be used as vertical strapping for gravel bag courses. Start under the first gravel bag course and attach to the barbed wire on top of the second earthen fill course.

Do not tie strapping over three or more contained earth courses. It can become loose if the soil fill shrinks slightly during the drying process, very likely with smooth clay-rich fill.

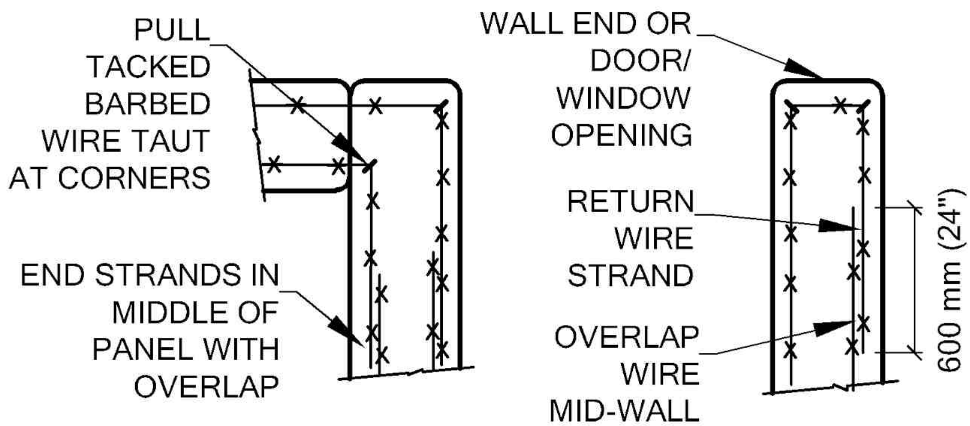


Figure 5 (left to right): a- Always run barbed wire continuous around corners and locate strand ends in middle of walls; b- Run barbed wire around wall end or opening edge and return.

BRACING EARTHEN WALLS

Earth walls are strong against compression and can carry great weights. But without reinforcement they are dangerously weak against other types of motion including twisting. All types of rectilinear earthen walls are strongest when connected to a perpendicular wall at each end. Curved walls with a radius between 1 and 3 m (3- 10') provide their own bracing, but rectilinear earthbag walls have traditionally been built with other walls or buttresses intersecting them every 3 m (10').

INTERSECTING WALLS

Unite wall intersections and corners strongly with tube overlaps, inserted rebars and barbed wire.

Always alternate the direction of tubes or bags at corners to provide good running bond. At wall intersections barbed wire must unite the separate wall segments. The strand near the exterior of the wall may receive higher stresses and should usually be continuous.

OPENINGS

Structural earthen walls must be more wall than openings. Narrow openings are better than large horizontal openings for windows or doors, 1,2 m (4') wide or less. Openings with frames of wood, reinforced brick or concrete, or welded steel should be 1,5 m (5') wide or less.

LINTELS

Lintels on earthen walls extend 300 mm (12") past the opening on both sides.

Distribute weight from above the lintel to a wider area next to the opening than for brick.

STEEL REBAR REINFORCEMENT

Rebar have traditionally been inserted in 1,5 m (5’) lengths as straight sections, with hooks bent on top to embed in a reinforced concrete bond beam.

Inserting Rebar

Rebar is hammered easily into damp earthbag walls after construction, even if soil fill contains some gravel. If your fill is very stony, try inserting rebar into a sample bag to check.

Wall material begins to firm up within hours of being tamped on a course. Inside the fabric container the interior dries very slowly, with the surface of each course or separate unit drying first. Insert rebar as soon as the wall section is finished and tamped to be sure that the steel embeds well with all the earthen material along its length.

Insert rebar near the center of the wall to avoid hitting any barbed wire. Insert diagonal reinforcement at an angle running along the wall, but vertical relative to the thickness of the wall.

PLASTER MESH

Mesh embedded in wall plaster is an important part of the reinforcing system of resilient CE earthbag. Attach mesh firmly to the wall base and wall top. Tie mesh to vertical strapping on walls, and tack to wood bond beams. Pull mesh over exposed rebar and embed it in RC bond beams.

Level walls with a sticky plaster of soil with straw to fill the 75 mm (3”) deep spaces between courses. Use ‘raw’ or unstabilized earthen plaster works under a lime plaster finish coat.

For a finish coat of cement stucco, don’t waste cement stucco on the nook layer which does not adhere well to the fabric. Use a sticky earthen plaster stabilized with 4- 8% Portland cement or hydraulic lime. Stabilized earthen plaster will bond better with cement stucco than ‘raw’ earthen plaster and cause less future cracking from temperature changes.

BOND BEAMS

All earthen walls must be carefully connected under a strong horizontal bond beam. Concrete bond beams are common, but wood or tubular steel can be used. Never build any heavy earthen wall portions (like chimneys or gable walls) above the bond beam.

PART II: RESILIENT REINFORCEMENT SYSTEM

Conventional earthbag walls have little resistance to sideways forces on footings. They also lack strong connections of lower walls to bond beam, so low-cement CE uses improved reinforcement (Figure 6) with tougher gravel bag courses and better vertical connections at corners.

Details include:

- Gravel bag footings with horizontal wire binding, vertical straps, and angled pins
- Corners with small concrete splices to connect vertical rebar with diagonal forks
- Bond beams strongly attached at corners to vertical rebar with hooks or nuts

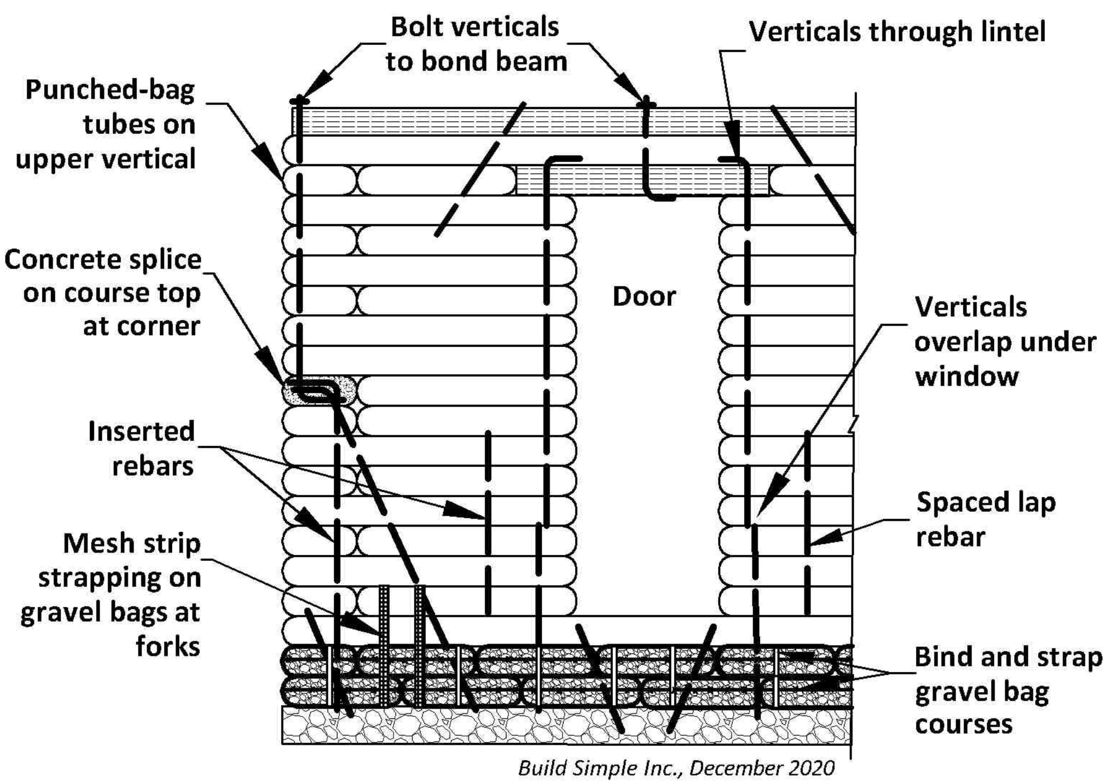


Figure 6: Improved reinforcement system for low seismic risk areas requires little Portland cement.

Additional needed wall strength also results from:

- Spaced lap rebars 300- 380 mm (12- 15") from aligned main verticals
- Inserted upper verticals long enough to reach below window sill level
- Lintels attached at ends to courses below by inserted vertical rebar

Wood bond beam and lintels used with these details result in less than 1 cf (28 L) of concrete for each exterior corner. Finish walls in earth or lime plaster for very low carbon building.

PLANS FOR RESILIENT CE FOR LOW RISK

Earthen walls do not have to be as strong as reinforced concrete walls. But they must be strong enough to resist warping into diamond shapes or bulging out of plane.

Vertical earthen walls resist these deformations by being strong enough wall, more wall than openings, and by most walls helping to hold up or brace walls that lean on them. This happens where walls intersect and at corners (Figure 7a). Nooks with extra corners (Figure 7b) and 1- 3 m (39”- 9’- 10”) diameter curves (Figure 7b) help to both stiffen and brace walls. When bracing walls are further apart in larger rooms, walls need longer bracing panels. Short walls called buttresses also brace buildings (Figure 7d). Piers stiffen walls (Figure 7e) but do not add much bracing.

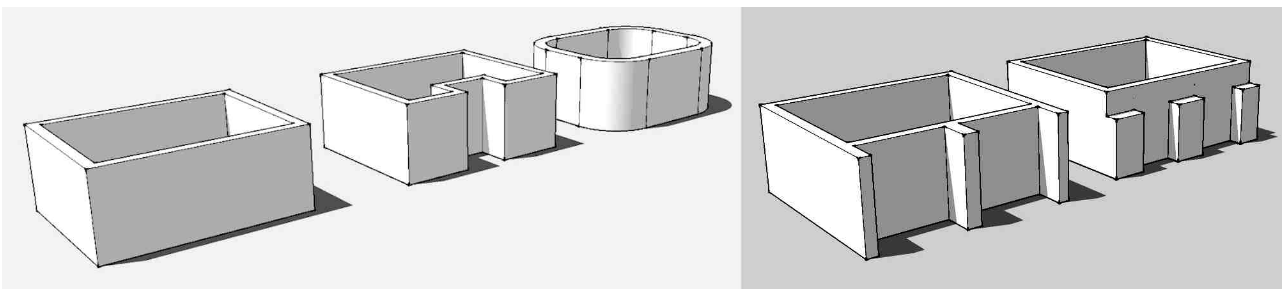


Figure 7 Structural wall elements (left to right): a- Corners on a rectangular building; b- Extra corners for nooks; c- Curved walls; d- Buttresses extending from walls; e- Piers that thicken walls.

Although in low seismic risk areas builders may be unfamiliar with earthquake risks and quake-resistant buildings, care during planning is an investment that will pay off for future generations.

DISTANCES BETWEEN OPENINGS

Only solid walls can help hold up the walls that touch them. Wall openings are weak. Locate them away from corners and wall intersections,

Don’t space openings too close since crowded embedded steel reduces wall strength where forces are concentrated. Space wall openings away from openings, corners and wall intersections to keep long vertical rebars 460 mm (18”) apart.

TABLE 3: RECOMMENDED MINIMUM DISTANCES FROM WALL OPENINGS

600 mm (24")	to a wall intersection or buttress
1 m (39”)	to building corners
1,07 m (42")	to another opening
1,2 m (48")	between two openings when a wall or buttress is located between them

THE BASICS ABOUT BRACING WALLS

Traditional spacing kept openings 1 m (39”) from corners but is not enough to hold up intersecting walls in earthquakes. Openings may need to be much further to leave enough bracing near a wall (Figure 8a). Buttresses (Figure 8b) can extend outward at wall intersections and between them.

Although the exact strength of resilient CE earthbag walls is not yet known, rough estimates extrapolated from small tests indicate that when built with strong soil fill (1,3 Mpa/ 250 psi) CE should be able to resist forces similar to unreinforced earth walls specified in one earthen building code based on structural research. The New Zealand Standards *Earth Buildings not Requiring Specific Engineering* (4299:1998) has clear details and guidelines that can be adapted for resilient CE in seismic risk areas of up to 0.59 g gpa risk at 2% probability or up to 0.1 g at 10% probability.

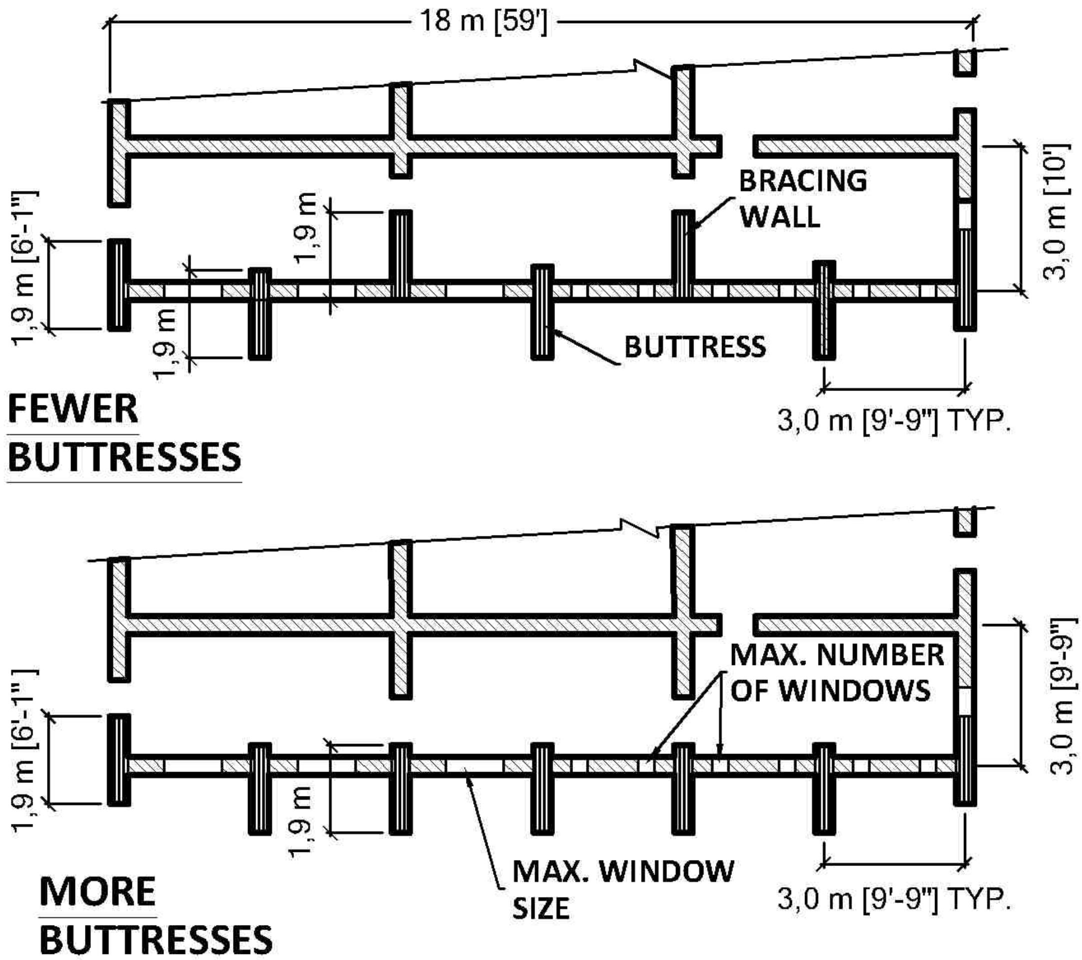


Figure 8 Bracing panels (above to below): a- A long supported right to left wall with few buttresses needs doorways far from wall corners; b- More buttresses allow doors closer to the supported wall.

First check the distance between bracing lines. Buildings do not need to be exact grids because bracing lines include walls or buttresses located within 300 mm (12”) of a bracing line. Figure bracing of east-west walls separately from the spacing of north-south walls. Different directions can have different spacing (Figure 8).

NZS 4299 lists bracing panel lengths for earth block walls with bracing lines spaced every 3 m (9’-10”), 4,5 or 6 m (15 or 20’). Earthbag flexes more than earth block and has been traditionally built with spacing of walls or buttresses at or near 3 m (9’- 10”). Bracing lines further apart can hold up perpendicular resilient CE walls but the supported walls may be likely to bulge under high stresses. Add buttresses or piers between bracing lines that are 4,5 m (15’) or further apart to stiffen the long sections of straight walls (Figure 9).

Check schematic plans with estimated bracing wall panel sizes based on NZS 4299 (Table 2).

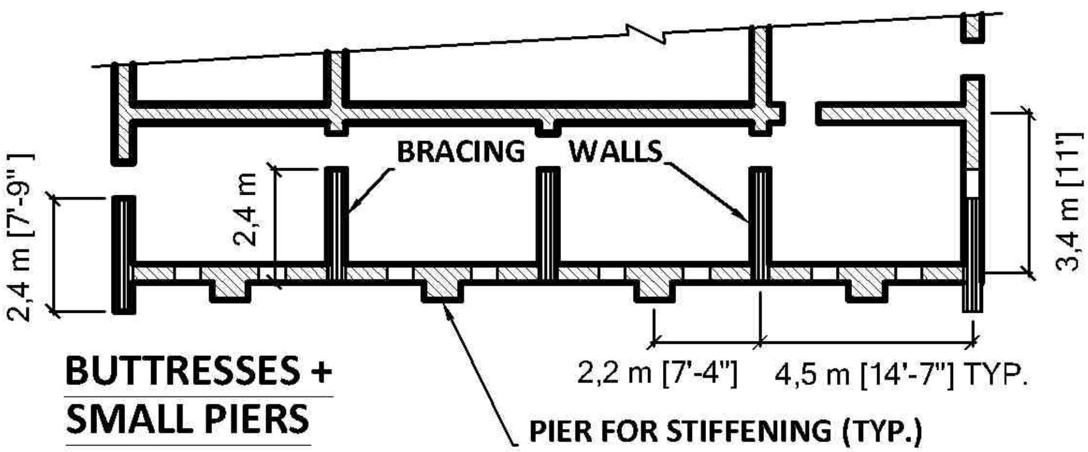


Figure 9: Bracing panels at 4,5 m (14’- 9”) spacing with piers between to stiffen walls.

The lengths shown in Table 2 are to resist approximately 0.59 g forces. For seismic risk of 0.4, bracing wall panel lengths may be as much as 25% shorter. If strong soil fill (2,1 MPa/ 300 psi) is used, panels may be 10% shorter than shown in Table 2.

The recommended length of bracing panels can be averaged between different length panels as long as the shortest is at least 1,5 m (5’) long.

The full process used in NZS 4299 is complex with bracing lengths also increased for heavier roofs, an upper story of light-walled loft, or taller wall heights. The information in Table 2 applies directly to exterior walls, but interior walls may need longer bracing panels. If overall bracing is adequate, one of the building's walls may also be allowed to have 30% less bracing than specified.

Table 2 can assist building designers and architects with preliminary building designs. But because engineers have special understanding of stresses on buildings and the meaning of test results, consult one if possible, or ask an engineering professor for advice.

General building shape, extent of symmetrical layout, and many other factors influence how well buildings can resist earthquakes. More information about safer building design for seismic risk is included in *D91 Design Resilient CE Earthbag Buildings for Seismic Risk* online at BuildSimple.org/Resources.

TABLE 2: BRACING WALL PANEL LENGTHS WITH MEDIUM SOIL FILL

Single story building with 2,4 m (7'- 10.5") high wall and light roof in areas of 0.59 g seismic risk[1]

Overall Length of Supported Wall	3 m (9'- 10") Bracing Line Distance		4.5 m (14'- 9") Bracing Line Distance		6 m (19'-8") Bracing Line Distance	
	Qty. Bracing Panels	Length of each Bracing Panel	Qty. Bracing Panels	Length of each Bracing Panel	Qty. Bracing Panels	Length of each Bracing Panel
9 m (29'- 6")	4	1,75 m (5'- 9")	3	2,15 m (7'- 1")	-	
	3	2,0 m (6'- 6")	2	2,65 m (8'- 8")	-	
12 m (39'- 4")	5	1,8 m (5'- 11")	-		3	2,65 m (8'- 8")
	4	2,0 m (6'- 6")	-		2	3,3 m (10'- 10")
15 m (49'- 3")	6	1,85 m (6'- 1")	4	2,4 m (7'- 10")	-	
	5	2,0 m (6'- 6")	3	2,8 m (9'- 2")	-	
18 m (59'- 0")	7	1,85 m (6'- 1")	5	2,35 m (7'- 9")	4	2,85 m (9'- 4")
	6	1,95 m (6'- 4")	4	2,65 m (8'- 8")	3	3,3 m (10'- 10")

[1] Panel lengths adjusted to 110% of measurements required for unreinforced adobe because earthbag is 9% thicker and heavier than earth block walls.

FOUNDATIONS WITHOUT CEMENT FOR LOW RISK

Engineers usually assume that buildings in seismic risk areas need a heavy reinforced concrete foundation to stiffen walls as well as preserve the building from potential subsoil cracking or material loss under the footing. Earthen buildings with 380 mm (15”) thick walls require a lot of cement to create 480 mm (19”) wide footings.

Resilient CE walls’ high flexibility and toughness work well on flexible gravel foundations.

But because rebar and barbed wire do not bond well with the fill inside gravel bags, CE buildings can resist more quake force if external wire binding and diagonal rebar pins give footings more resistance against deformation from forces perpendicular to the wall and from subsoil movement.

Buildings on soft or erodable subsoil, or near a downhill slope, may need footings with a confining reinforced concrete strip surrounding gravel bags. See *B103 Build High Strength Resilient CE Earthbag* online at the BuildSimple.org/ Resources and discuss options with an engineer.

WIRE BINDING FOR GRAVEL BAG COURSES

Below door sill level wrap wire around the entire building. Leave undisturbed subsoil in place next to the inner edge of gravel bag footings and binding will hold the foundation against the subsoil.

Above door sill level wrap wire around straight sections (Figure 10a).

Ends of barbed wire strands must be strongly connected (Figure 10b). Use a small nail or electricians staple inserted between the twisted wire near strand ends to pull them taut, then bend nail and hold in place with tie wire. Embed overlap in concrete for extra strength.

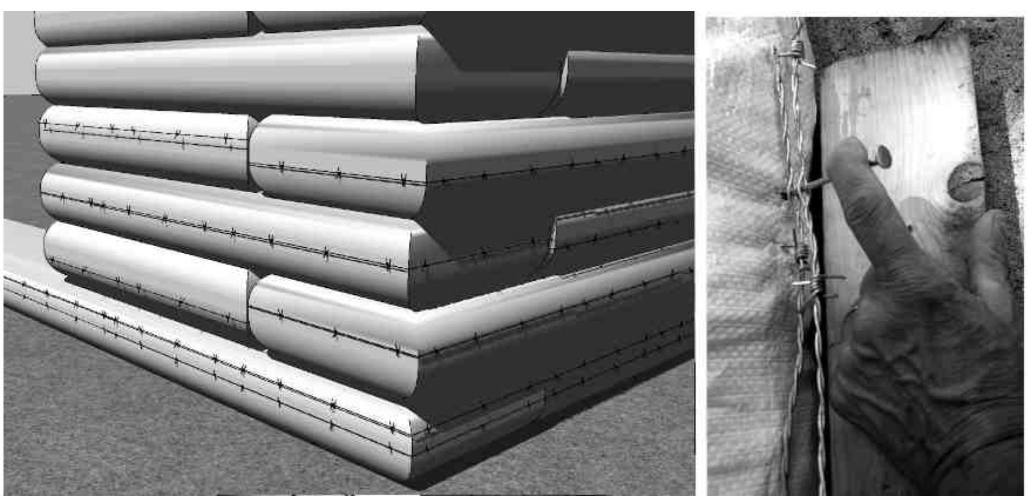


Figure 10 Wire binding (left to right): a- Bind around gravel bag courses; b- Pull both strands taut with a nail through wires at overlap.

On simple-shaped buildings wrap binding wire around more than one course without ending strands.

Before laying gravel bags, add lengths of strapping cord under each bag. For buildings with buttresses, wrap wire around the core of the building first (Figure 11a), then lay the buttress footings for that course level (Figure 11b). Strap the buttress footings vertically.

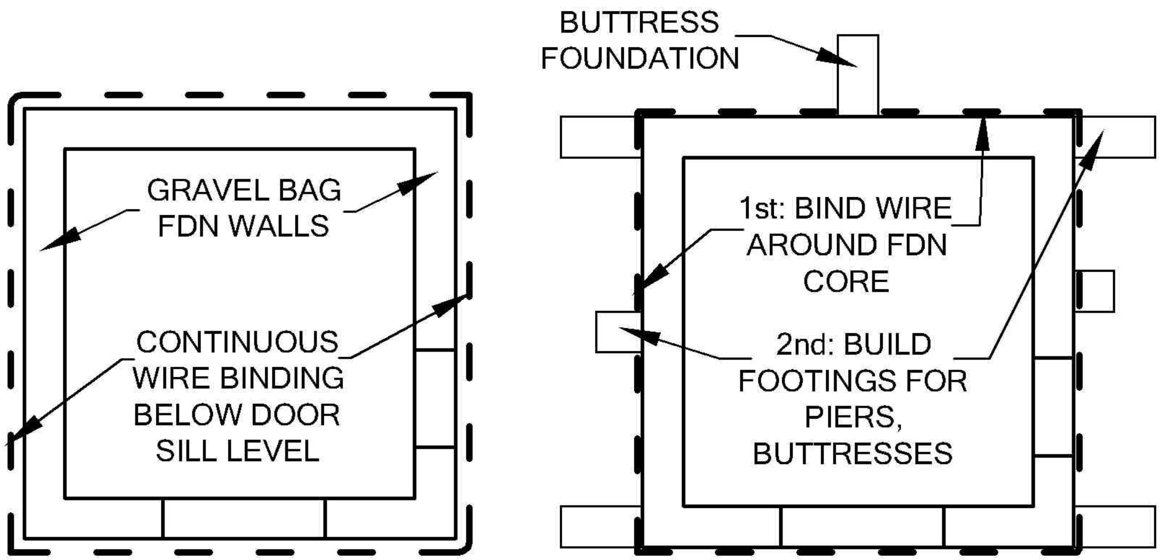


Figure 11 Bind to unify a building (left to right): a- with a simple shape; b- with buttresses bind main building core first, then lay footings for wall extensions.

Lay short barbed wire strands on top of the corner bags and extending out into the buttresses. Connect buttress footings to the core of the building with binding on every other course when binding straight wall sections (Figure 12) that continue into the buttress.

In buildings with complex exterior wall shapes, wrap barbed wire across gravel bags at any recessed corners (Figure 13), adding an extra if needed.

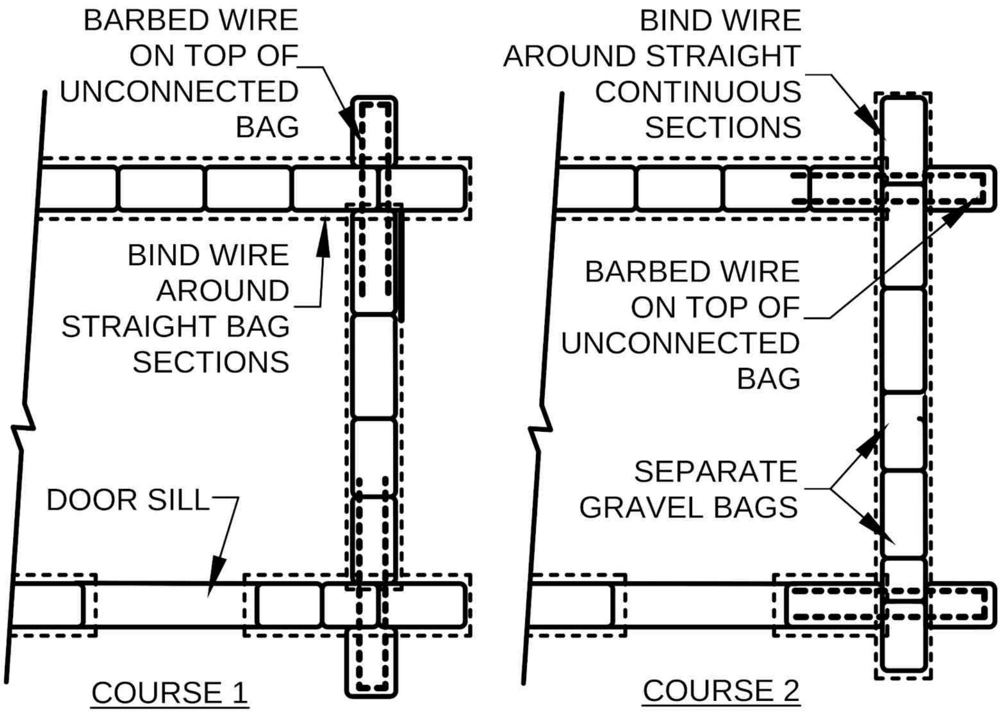


Figure 12 (left to right): a- Always bind the straight wall section that crosses a pier or intersecting wall first, then bind shorter sections next; b- Include buttresses in binding on alternate courses.

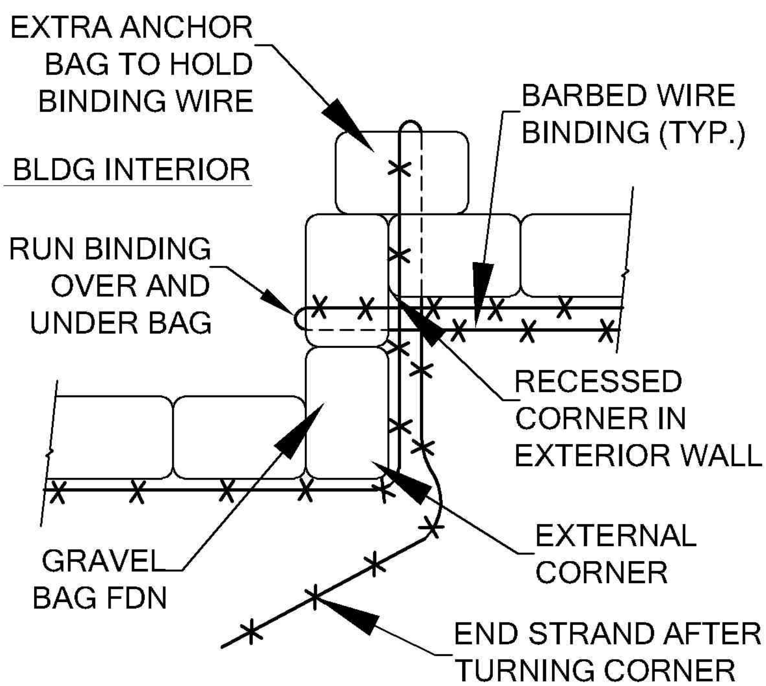


Figure 13: Start barbed wire at recessed corners by wrapping strands around a perpendicular bag.

BUILDING RESILIENT CE WALLS

Keep soil fill material just damp enough that a small handfull squeezed into a ball will split in several pieces when dropped from 1,5 m (5’) high onto a hard surface.

Let a fussy worker supervise the soil pile since precise moisture and well-stirred fill speeds building. In rainy regions, cover the soil pile when not in use. Fill that is too damp may become too sticky to shovel easily. When too wet it also can ‘jelly up’ or bounce instead of consolidate when tamped, delaying tamping for several hours and slowing work.

REBAR EMBEDDED IN WALL MATERIAL

Reinforcing steel is less well connected in CE built with separate bags (Figure 14). Tubes allow steel to embed in longer elements of contained earthen wall material.

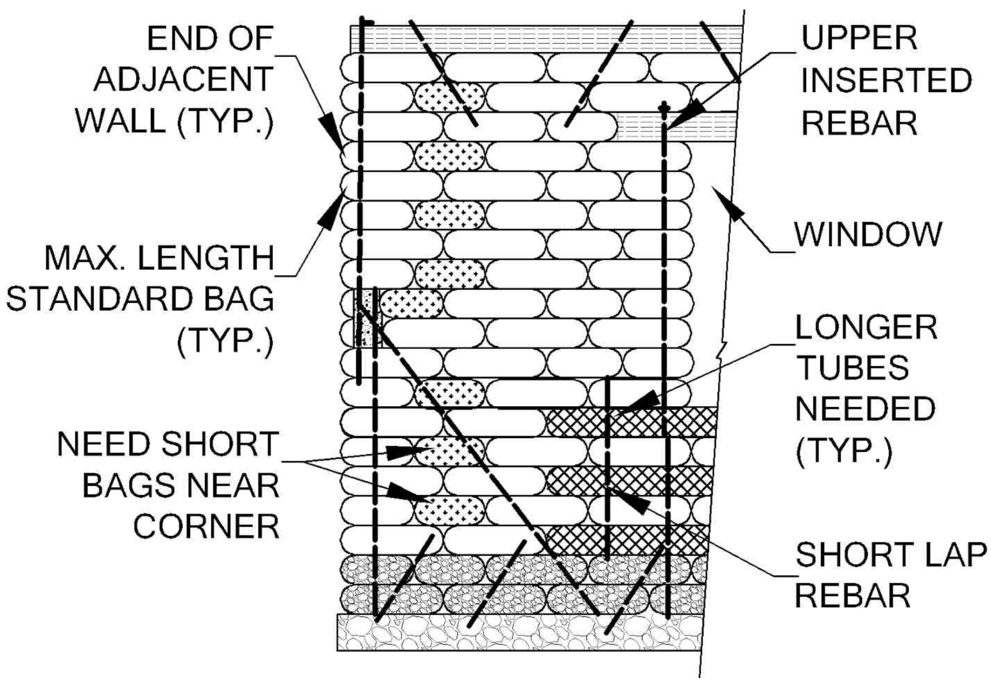


Figure 14: Bags limit rebar integration with wall material even when mixed with short tubes.

Locate all reinforcing rebar embedded within wall material. Do not use external pinning rebar.

Insert rebars into the center of the wall thickness to avoid hitting any barbed wire.

Use the correct end on all inserted rebars. Pre-weld a 175 mm (7”) long bolt on to the top of any rebar that is pre-anchored in a splice and will extend through a wooden bond beam. Use a 75- 100 mm (3- 4") hook on pins inserted through a wood element. Use a 255 mm (10") long hook on pins to be embedded in reinforced concrete.

Before inserting rebar through a wood lintel or bond beam, widen the hole to accomodate the 50 mm (2”) diameter curve at the rebar bend. Bend to 90 degrees before inserting, or bend after inserting into the wall. Where hooks are needed on diagonals, aim hooks across the course top.

Diagonal Wall Pins

Short rebars inserted at an angle help to connect lintels or bond beams to earthbag courses by engaging the weight of the courses that they pierce.

Alternating angles of pins can prevent uplift of bond beams or different courses, but connected verticals (at external wall corners) with hooks or bolts resist uplift well. Near corners insert pins down toward the center of the building (Figure 13) to resist uplift forces.

Locate diagonal wall pins where they will not conflict with future vertical or fork rebars, at least 100 mm (4”) apart on top of the course. Insert base wall rebar pins through the first two contained earth courses into and through all gravel bag courses. Use a 20° or steeper angle.

WALL INTERSECTIONS

Unite wall intersections by alternating tube directions every course and also running barbed wire continuous across the adjacent wall (Figure 15a) and then back into the wall. Use a vertical rebar at every wall intersection to pierce containers in both principal directions.

Buttress or stub wall wires can form a loop (Figure 15b). Tack barbed wire over the main wall wires to secure both strands. If possible, insert the tack directly over a barb.

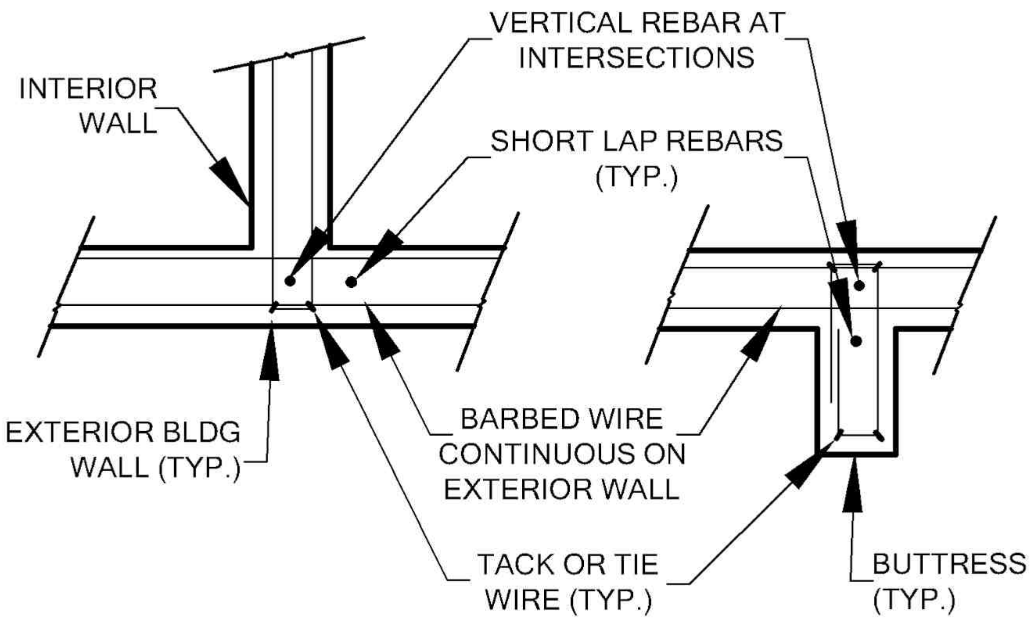


Figure 15 Barbed wire (right to left): a- at intersections crosses adjacent wall, b- at buttress loops.

THICKENED WALLS

Thickened wall areas stiffen long straight sections of flexible CE against possibly bulging outward.

PIERS

Build piers half the wall height or 1,8 m (6') maximum to reduce weight at the wall tops. Use piers that add one extra wall thickness. Build them in lengths that are multiples of the wall thickness. Run wall tubes continuous next to the pier every other course (Figure 16a, b).

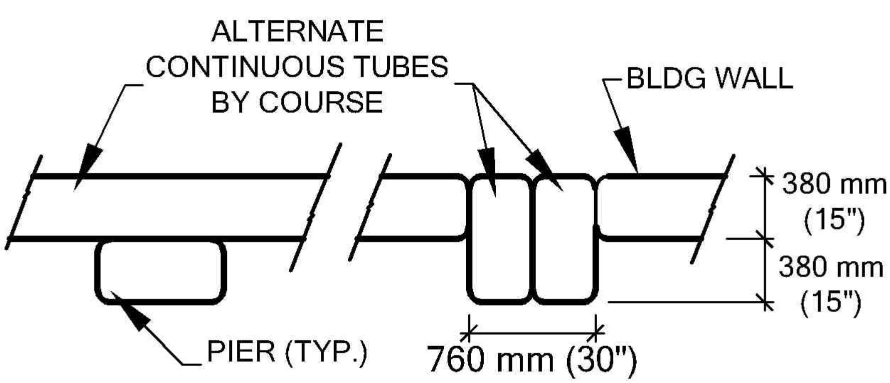


Figure 16 Piers integrated to the wall (left to right): a- Continuous tube lengths along the wall; b- Every other course interrupt the wall to run tubes across the pier and the wall.

Run barbed wire continuous along the wall, connecting a loop (Figure 17) to the course above.

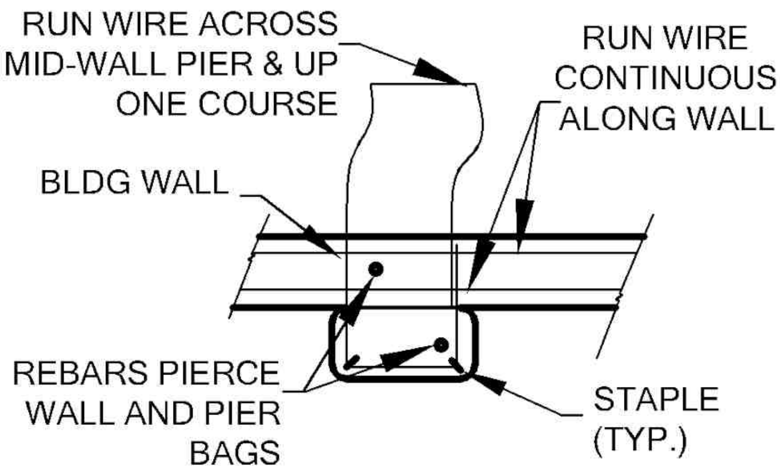


Figure 17 Barbed wire on piers should use a loop of wire woven to the next course.

Insert straight lengths of short pins at angles from adjacent walls into piers.

REINFORCED CORNERS FOR LOW RISK

The corners of rectangular buildings need high strength. External corners with connected vertical steel can reduce damage to the entire wall length of an earthbag building.

Horizontal forces (like earthquake shaking) on walls cause strong upward forces pulling the bond beam off of any vertical steel.

Anywhere that rebars are embedded in reinforced concrete bond beams or lintels, use hooks 255 mm (10”) or longer. Reinforcing steel embedded in concrete should always have 25 mm (one inch) of cover or more.

At every corner where barbed wire bends use a staple or nail on a barb to pin wire taut and give the corner added strength.

CONNECTING EMBEDDED REBAR

All inserted rebar can be connected at the wall top easily. But stronger reinforcement also connects rebars at their bottoms.

Rebars can be base-anchored and embedded in strong wall material, using small holes or cuts to fabric course containers. ‘Punching’ tube onto a rebar results in more, shorter lengths of tube, but also enables the use of rebar inserted before the story height is fully built to be embedded in courses above.

When any length of reinforcing steel is pre-anchored in concrete at its base, locate the rebar 125 mm (5") from edges of dried cohesive soil material. Barbed wire can be bent around the rebar, but the rebar is embedded far enough from the scalloped surface including nooks between courses.

Punched-Bag Construction

Punched holes in an earthbag tube for reinforcing rebar are so small they do not rdamage the fabric tube. For neat construction pre-measure and make a small cut for the rebar (Figure 18a).

Pre-fill the end of a tube 255- 300 mm (10-12”) deep. Shake down and compress the fill. Place a finger in the hole on the bottom of the course, line up above the rebar (Figure 18b) and slide the rebar through first the bottom and then the upper hole (Figure 18c). Reach inside the bag and re-firm or tamp the soil using a fist or 100×100 mm (4 x 4) piece. Continue to fill the tube. Tamp after adjacent tubes are in place (Figure 18d).

Figure 18 Punched-bag technique (left to right): a- Preparing holes near tube end; b- Slide partly-filled tube onto rebar; c- Slide top hole over rebar; d- Filled and tamped punched-bag tube.

Punching tube onto a rebar can only be done at the beginning of a tube length. At corners start building from the wall end with the punched tube. In any midwall locations for punching onto rebar (above windows), start a separate tube 125- 150 mm (5- 6”) away from the rebar, alternating sides at every course (Figure 19) for good running bond overlap of tube ends.

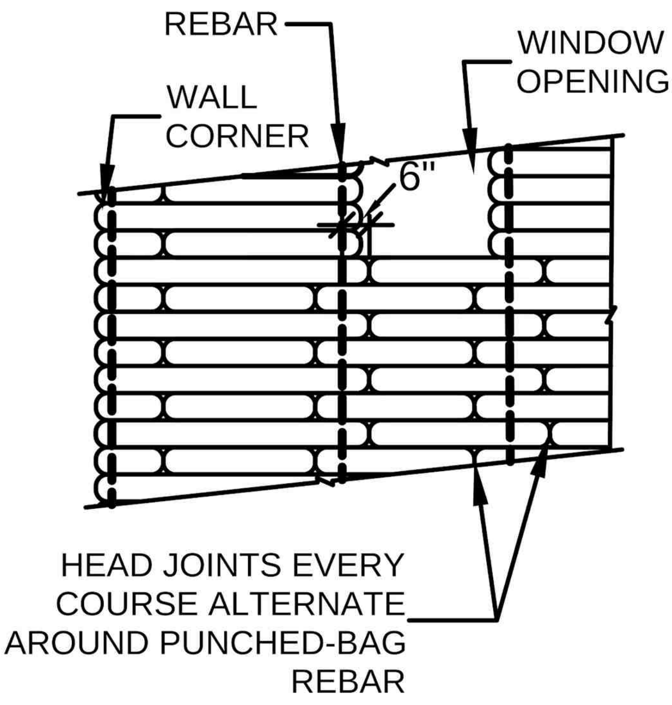


Figure 19: Punched-bag technique needs tubes starting on alternate sides of a vertical rebar to allow good overlap of tubes between courses.

SPLICES TO CONNECT REBARS

Separate rebar lengths spliced together with a concrete plug act structurally very similar to continuous rebar. Although a splice interrupts the running bond and continuity of fabric at the corners for a course, the barbed wire continues through the splice and the vertical and diagonal rebars bridge it.

Plan ahead because no rebar inserted from above will be able to pass through a splice.

At a corner place the rebar 125 mm (5") from the exterior edge to reduce the amount of concrete needed for the splice. The barbed wire above the splice can be run around the rebar, but below the splice use extra care to lay barbed wire closer to the edge of the wall than the inside, and insert rebar in the center of the wall thickness to miss the barbed wires (Figure 20).

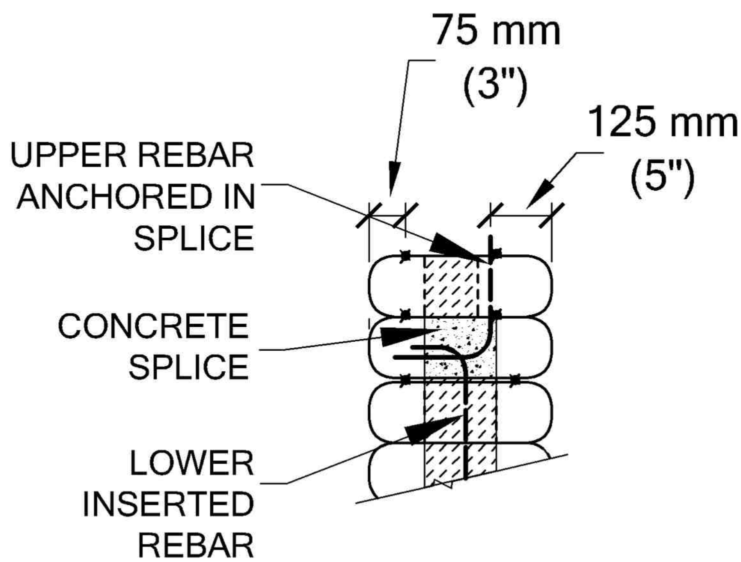


Figure 20: Barbed wire locations near punched-bag anchored rebar.

OPEN SPLICE CONNECTING LOWER REBARS

Concrete poured into an open space on top of a course makes an open splice. This concrete plug can easily connect vertical and diagonal rebars inserted from the same course.

Build tubes at the splice layer to within 180 mm (7”) of the corner in one direction, and 300 mm (12”) in the other, tamping against a brick or block (Figure 21a). Leave an exposed gap large enough to include the hooks of the rebars. Insert the lower rebars into the center of the wall thickness in the splice gap (Figure 21b), and brace the upper rebar in place 125 mm (5") from wall surfaces.

All rebars passing through the splice must have a 255 mm (10") long hook embedded in the concrete, whether bent before or after placing. Adjust the rebar depth so the hook is no more than 75 mm (3") above the course top.

Pour concrete into the space to connect the rebars. If possible, use the end of the tube as a form. Shake the concrete down in the tube and tuck the fabric end under (Figure 21c).

Figure 21 Splice on current course using tube as concrete form (left to right): a- Tamp against block to form gap; b- Hooks of inserted rebars; c- Both hooks within concrete poured into tube wall top.

Lay barbed wire on the course immediately, but do not continue building above the splice until the concrete is firm enough to survive tamping forces from above (4- 12 hours). When plastering this area tamp additional wall material or plaster in to fill any remaining depressions in the wall.

Support an upper rebar in place (Figure 22) or tie it to a short vertical pin inserted next to it.

Construction above the splice continues by punching tubes and sliding them down over the rebar. When tamping around vertical rebars already anchored in place, be careful to maintain the rebar vertical and at the correct distance from the wall end and wall surface.

Open Splice with Fork

If some diagonals are added before pouring the splice this group of rebars becomes a fork (Figure 23a). Forks use wall weight to hold upper wall corners and bond beams in place during earthquake motion. Spliced forks are also used at wall intersections, and can be used at buttresses or piers.

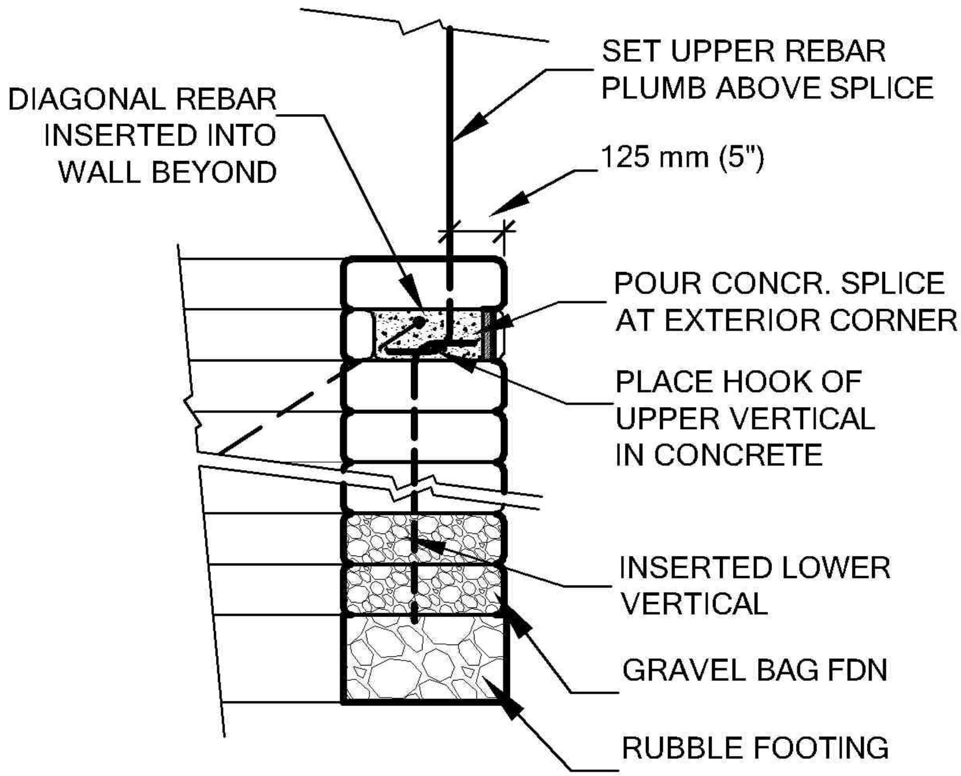
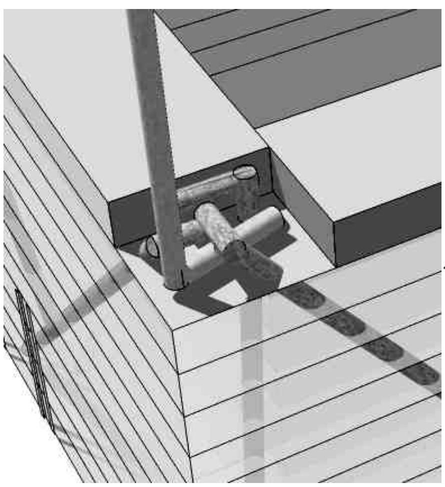


Figure 22 Concrete splice built on a course to connect rebars below and above.

A fork splice connects so many different rebars that some rebar locations are determined by space available for the rebar hooks. When inserting the lower rebars, leave room between the verticals for the hooks of the upper rebar (Figure 23b).



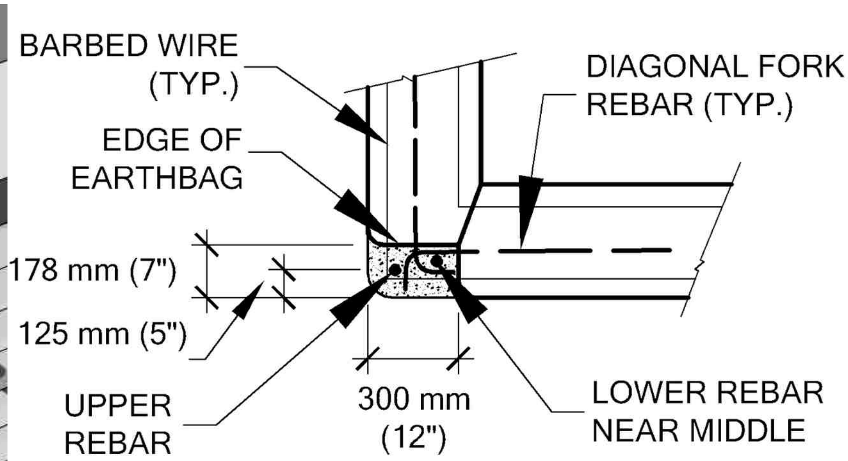


Figure 23 Spliced forks: a- hooks overlap at corner; b- Minimum size for a fork open splice.

EXTENDING WALLS FOR BUTTRESSES

If short wall portions like buttresses extend more than 600 mm (24”) from the wall, build them full height and include them under the bond beam.

BUTTRESSES

Buttresses with slanted sides can brace walls but add less weight to the wall tops. To provide predictable bracing, build buttresss ends vertical at least 1,8 m (6’) high and extend the bond beam to cover at least half the buttress length.

Never use stub walls or buttresses that extend more than 1,2 m (4’) long from walls.

Build buttresses the same width as walls, laying alternate course tubes continuous to the end of the buttress (Figure 24a, b). If buttresses or stub walls are opposite interior walls, run wire continuous from the interior wall to the end of the buttress. A mid-wall buttress (Figure 24a) should have the wire laid similar to a mid-wall pier (Figure 17).

At a corner, run the external strand of barbed wire continuous around the building, and use the interior wire strands to run from the building walls into and around the ends of the buttress (Figure 25) in both directions. Tie barbed wire where it bends if using optional improved details.

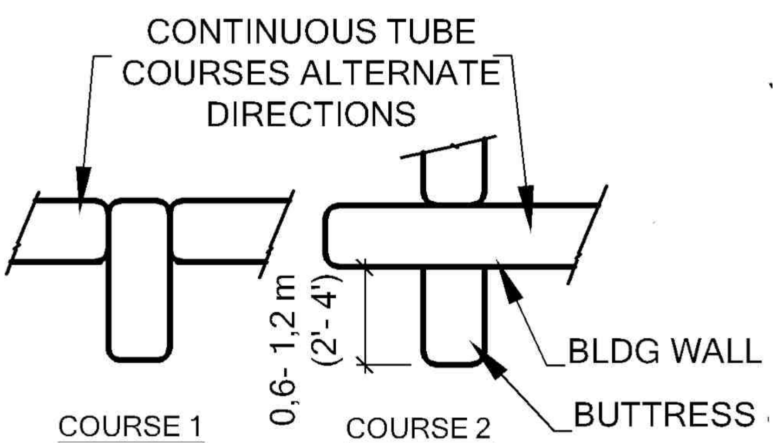


Figure 24: Continuous tubes and barbed wire unite walls to piers (left to right): a- Mid-wall buttress; b- Corner buttress tube layout.

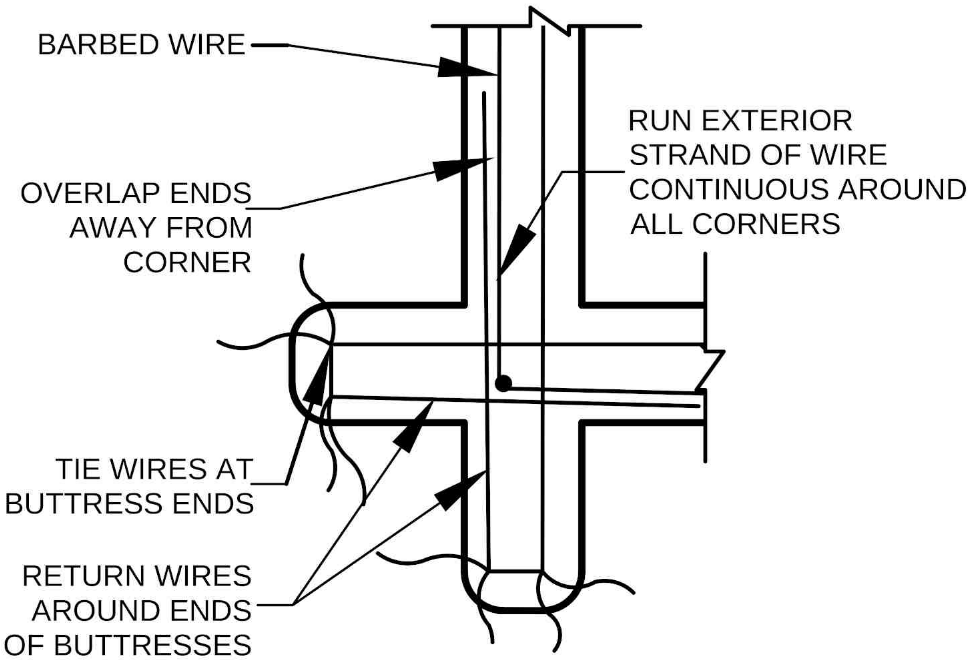


Figure 25: Run external strand of barbed wire continuous around building and use interior strands to unite buttress to building walls.

REINFORCEMENT NEAR OPENINGS FOR LOW RISK

Forces from along an entire length of building wall are concentrated between openings. Use the best quality of reinforcement detailing for wall sections between openings.

Resilient CE earthbag uses long inserted rebars near doorways. To insert them in precise locations check for plumb or have a helper hold a guide next to the wall. There are several tricks to more easily insert rebars longer than 1,5 m (5').

- Cut the tip at a sharp angle
- Hold the rebar in a narrow pipe a little shorter than the exposed rebar while hammering
- Use a special tool (Figure 26) so that workers do not need a ladder to reach the top of the rebar to insert lengths that extend far above the worker's head

Figure 26 Tools to insert rebars (left to right): a- Steel welded on a pipe; b- Post driver tool.

SPACED LAP REBARS

Inserted rebars near door or window openings must be about 150 mm (6") from the opening for good embedment and to miss the barbed wire. Do not place overlapped verticals near each other.

Forces on walls stress the bonds between earth and rebar. This affects an area that spreads out from the rebar end at a 45 degree angle. To allow your modest strength earthen wall to resist hazardous forces, space separate lengths of rebar as far apart as the length of overlap.

Align the main rebars one above the other at the same location. Locate a separate shorter lap rebar as far from the main verticals as the length of its overlap (Figure 27).

TABLE 6: SPACE LAP BARS AWAY FROM THE MAIN VERTICALS

Distance from vertical long rebars	Length of lap bar	Insert the lap bar how many courses above?
300 mm (12")	600 mm (24")	two
375 mm (15")	750 mm (30")	three but hammer 50 mm (2") below top
460 mm (18")	920 mm (36")	three

Build as many courses above the end of the lower rebar as needed to match the distance from the main rebar to the lap. Insert the lap rebar, then finish building the wall. Finish by inserting the upper long rebar almost directly above the lower long bar.

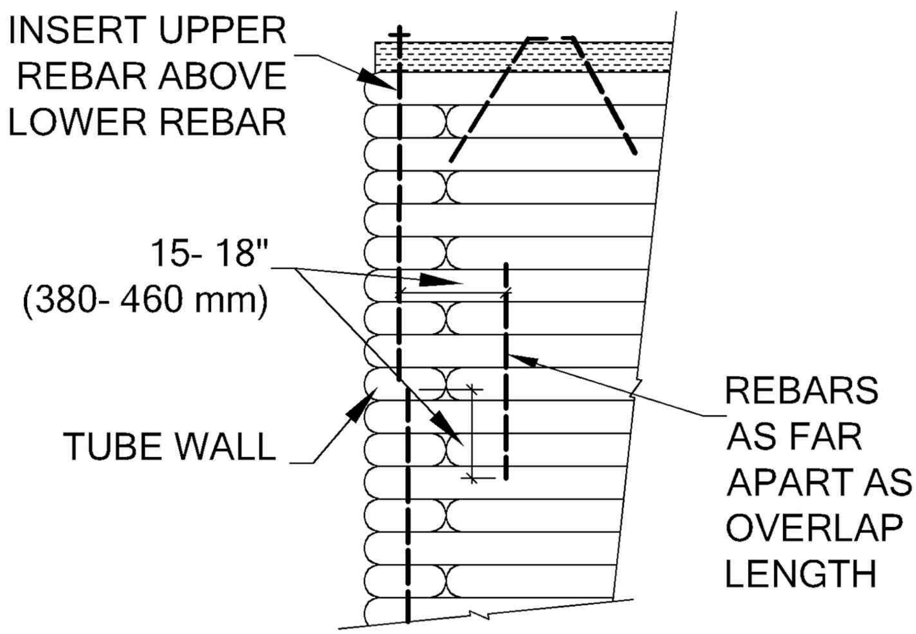


Figure 27 Improved overlapped inserted rebar technique uses a distant lap rebar.

LOCATE OVERLAPS BELOW STRESS POINTS

Extend long vertical rebars into the continuous walls below window openings. Near window openings insert a shorter lower rebar three courses below the window sill. Use a longer upper rebar, inserted through a hole in the lintel, to meet the lower rebar.

REINFORCING OPENINGS NEAR OTHERS

Separate aligned rebar sets can share the shorter lap rebar if it is located between them.

Aligned verticals each side of a window that extend three courses below the window sill can share the same lap rebar if the window is 600 mm (24") wide or more. Narrower windows will need to have separate lap rebars each side of the adjacent aligned verticals so that the rebars are not crowded under the window.

If windows are long and window sills relatively low, short lap bars spaced closer may be allowable (Figure 28a).

Aligned verticals on separate openings can share a central lap rebar between the openings if spaced 1 m (39") apart. Doors and/ or windows 1,07 m (42") apart leave room for a better overlap length (Figure 28b).

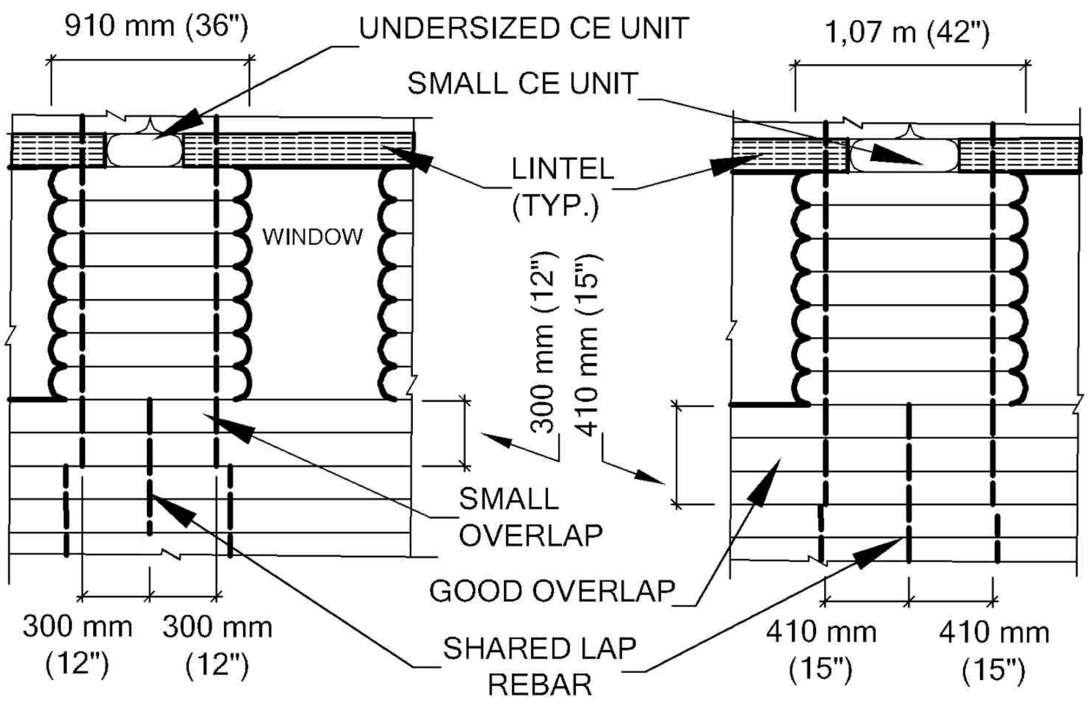


Figure 28: Spaced lap rebar dimensions (left to right): a- Minimum distance; b- Better distance.

Where wall intersections occur between openings larger distances of 1,2 m (48”) are needed for good rebar placement (Figure 29). Aligned vertical rebar in wall intersections should extend from bond beam to footing to unite wall intersections.

When long vertical rebars are close, instead of including a lap rebar, use a different course location for the break between upper and lower pieces. Sets of long rebars with different ending points can act as laps for each other.

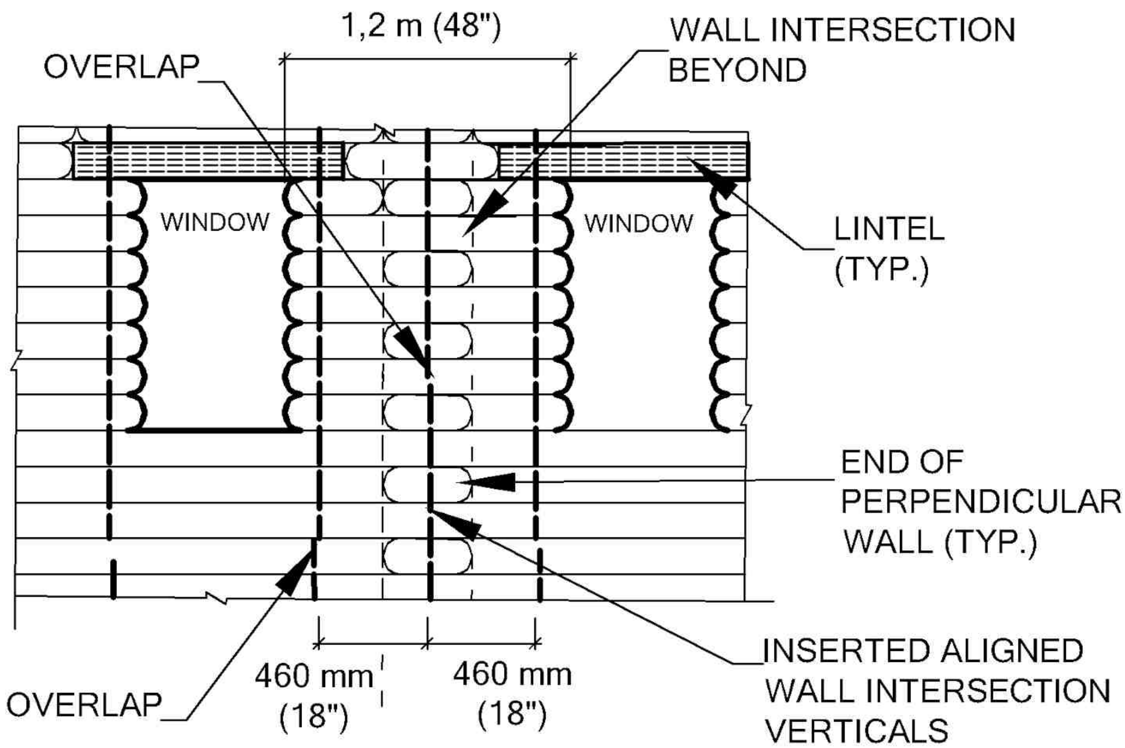


Figure 29: Use greater distance between openings when the area includes a perpendicular wall.

LINTELS

Extend lintels 300 mm (12”) or more each side of an opening. Place lintels narrower than the width of the flat portion of the earthbag wall (255 mm/ 10”) on a 250x50 mm (2 x 10) bearing plate on the wall top to spread the weight out across the whole flat surface of the earthen wall.

Lintel size and strength must relate to the span length and weight of wall above the opening. When lintels support up to 1 m (39”) height of earth wall above, use New Zealand’s guidelines. For spans of 900 mm (35”) or less use a single 100x300 mm (4 x 12) laid flat , or three 100x100 mm (4 x 4)s nailed together instead of the larger timber. For a span up to 1,5 m (5’) use a single 150x300 mm (6 x 12) laid flat or three 150 x 100 mm (4 x 6)s nailed together. For lintels supporting less weight use local building code for masonry buildings.

Lintels above doors in low-cement resilient CE walls are connected to bond beams by punching earthen tubes onto pre-anchored reinforcing steel above the lintel. Use them also above selected windows, spaced evenly about every 3- 4 m (10- 13') in a building wall.

Interconnect Lintels

Lintels must be well connected to the earthen wall material above and below them. Stronger walls need excellent connections between lintels and bond beams, because stresses are higher near wall tops.

For windows more than 600 mm (24”) wide or openings up to 1,5 m (5’) wide also center two or more D10 (3/8”), vertical rebar pins or heavy spike nails extending 150 mm (6”) from the upper surface of the lintel. Settle the earthbag course above down onto these nails or pins.

Lintels for unconnected windows have holes drilled on each end for the inserted long rebar near the window edges. Where lintels connect to the bond beam drill a third vertical hole in the center of the lintel.

Before placing a lintel, pre-drill vertical holes just large enough for the vertical rebar size. Drill one hole at each end 150 mm (6”) beyond the edge of the window or door opening. When the lintel is in place, drive vertical rebar through these holes down into the walls.

Use punched bag techniques when building above the lintels. Allow at least 6” between the tube end and the punched rebar holes, so that the vertical rebar will run in the center of a generous 300 mm (12”) tube end overlap.

For rebars adjacent to a tall window or a window with a high wall above it, insert a vertical rebar with a hook all the way down to the lintel level. so that the lap location is well below the window opening. Use a separate rebar with a small bottom hook inserted upward through holes in the lintel (Figure 30). Use punched-bag technique to embed the central vertical in the courses above the lintel.

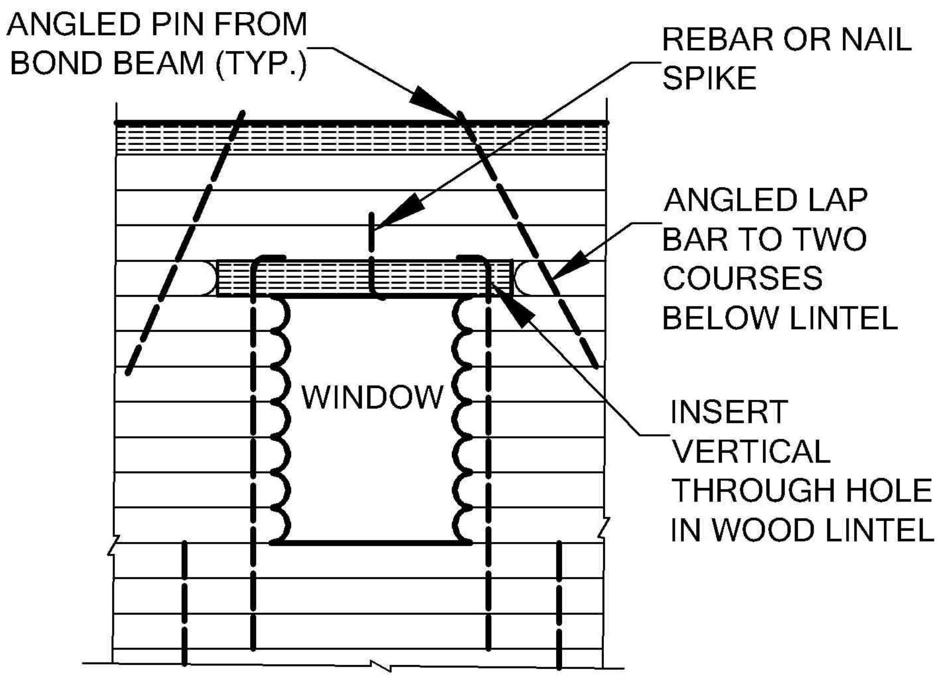


Figure 30: Vertical rebars adjacent to a window opening connect to the lintel.

For a door lintel attached to a reinforced concrete bond beam, also drill a hole in the center of the lintel. Insert a vertical rebar with a short hook from the bottom surface up through the lintel (Figure 31). The rebar must be long enough to bend a hook to embed in the bond beam.

For rebars adjacent to a door use a long rebar with a hook bent on the top, the maximum length that your workers can insert. A rebar with a welded bolt top allows workers to hold it in a pipe to prevent the long steel rod from bouncing under the mallet blows.

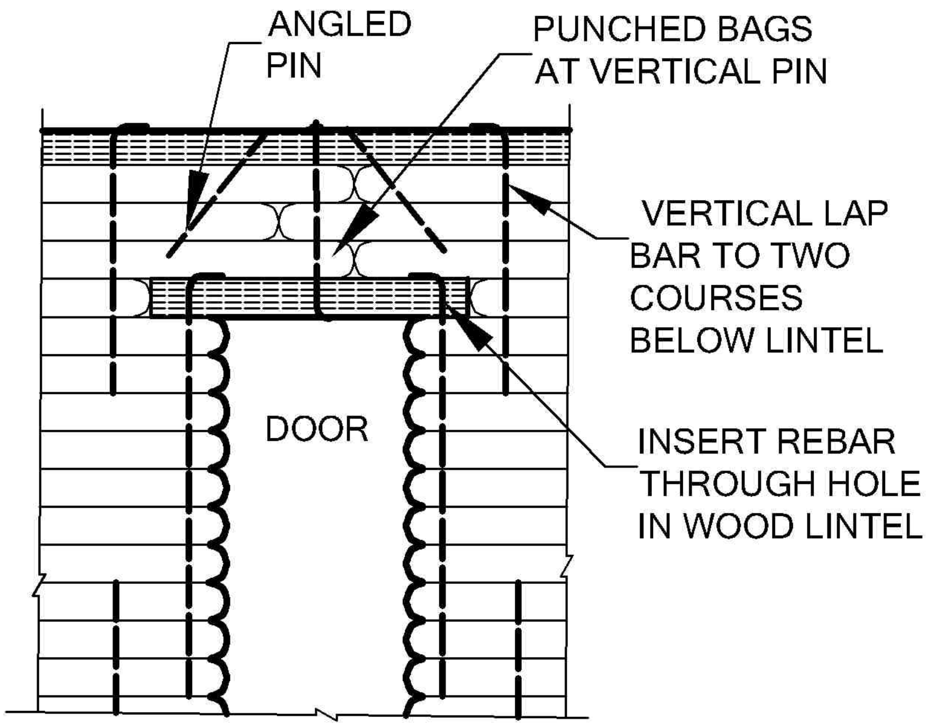


Figure 31: Vertical rebars adjacent to a door opening connect to the lintel.

BOND BEAMS FOR LOW RISK

The bond beam must be sized for the wall thickness, type of roof and/ or loft and for the distance between bracing lines.

The concrete must embed tops of all pins as well as bent tops of vertical rebar 255 mm (10”) or more long. Insert steel so the hooks will be contained within the depth and width of the bond beam.

Guidelines in New Zealand recommend bond beams 75% as wide as the wall, but standard earthbag courses built 125 mm (5”) high have a flat top surface 67% the width of the completed wall. Builders can side tamp the top course with workers standing on it to widen the flat top area by making the course side slightly flatter.

Insert diagonal pins joining wall tops with bond beams while wall material is damp (within 2- 3 days of construction). Space pins that extend 600 mm (24”) deep into the wall 600 mm (24”) apart on average at alternating angles, or 100 mm (4”) apart on the wall top. Resilient CE relies on bolts or strong hooks on tops of long, embedded vertical rebar to hold the bond beam to the walls, but angled pins may help to stiffen the upper courses.

A diaphragm at the ceiling level helps buildings resist stronger earthquake forces. It is a structure of ceiling joists and strong and strongly attached plywood or flooring. In some cases a diaphragm could consist only of welded steel tube. More information is contained in NZ Standards 4299, including specifications and examples of how this horizontal structure can increase allowable bracing line distances or reduce needed sizes of bond beams.

WOOD BOND BEAMS

New Zealand’s earth building guidelines can be adapted to resilient CE earthbag with the understanding that CE is tougher but flexes more than adobe or rammed earth. In its standard width CE is also 9% wider (and heavier) than the earthen walls specified for New Zealand.

The following sizes show bracing distances 90% of the New Zealand guidelines for low risk for earth block or monolithic rammed earth:

TABLE 7: WOOD BOND BEAM SIZE ESTIMATES FOR SINGLE STORY EARTH WALL

Bond beam thickness	Maximum bracing distance with light roof	Maximum bracing distance with heavy roof/ loft
250×75 mm (3” x 9.8”) OR 300×50 mm (2” x 11.8”)	4,3 m (14’- 1”)	3,8 m (12’- 6”)
250×100 mm (3.9” x 9.8”)	4,5 m (14’- 9”)	4,3 m (14’- 1”)
300×75 mm (3” x 11.8”)	5,1 m (16’- 9”)	4,6 m (15’- 0”)

Note: A 285 mm (11.2”) min. width is 75% of the width of a standard 380 mm (15”).

A wood bond beam must have corners strongly and stiffly attached with lap joints and/ or metal nailer plates and strong nails. India's building guidelines** for earthen walls have examples of strong bond beams built of doubled lumber if large beams are not available.

Pre-drill holes for rebar pins at the correct angles before placing the beams on the wall, and enlarge the hole top to accommodate the radius of the bend in the steel.

STEEL TUBE BOND BEAMS

Strong steel tube can be welded to form an integral bond beam and ceiling or loft diaphragm, but must be located with the inside of the tube near the center of the wall top so that vertical rebar and pins can be welded or bolted directly to the tubing. Because the steel tube frame will not cover 2/3 of the wall top, use strong strapping every foot from under the top two courses to integrate the bond beam to the upper courses and use stronger soil fill than the walls.

REINFORCED CONCRETE BOND BEAMS

Low-cement wall and footing construction techniques for resilient CE earthbag can be used with a reinforced concrete bond beam if other appropriate materials are not available. A reinforced concrete bond beam greatly increases cement usage, because a bond beam 250- 285 mm (10- 11.2”) wide and 100- 150 mm (4- 6”) thick requires between 6- 9 L of Portland cement for each linear meter of building wall (0.6- 1 cf per 10 linear feet). Each 10 m (33’) of wall will need four to six 41 kg (90 lb) bags of Portland cement for the bond beam.

New Zealand’s earth building guidelines can be adapted to resilient CE earthbag with the consideration that CE is tougher and flexes more than adobe or rammed earth. The following (Table 5) shows bracing distances 90% of the New Zealand recommendations for adobe or rammed earth in low risk areas:

Table 8: Reinforced Concrete Bond Beam Size Estimates for Single Story

Bond beam size	Rebar size	Maximum bracing distance with light roof	Maximum bracing distance with heavy roof/ loft
285×100 mm (3.9” x 11.2”)	Two D16 (5/8 inch)	3,2 m (10’- 6”)	3,0 m (10’- 0”)
285×100 mm (3.9” x 11.2”)	Two D16 (5/8 inch)	4,3 m (14’- 1”)	3,8 m (12’- 6”)

OPTIONAL IMPROVED WALL TECHNIQUES

Careful detailing can sometimes increase strength without increasing cost significantly.

SPECIAL BARBED WIRE DETAILS

Because barbed wire transmits forces along walls, extra connection to the dried soil fill can strengthen corners or other stress points against damage. These improvements are most important on strands that extend long distances along walls.

PIN BARBED WIRE

Place pins cut from metal mesh (Figure 32a) over barbs on the wire. Pins with three or more teeth stand up between courses to embed in both lower and upper courses. Bend them just before use (or they will tangle together).

TIE BARBED WIRE

Cord also adds strength to resist any potential gapping or twisting at corners. Tie strands that follow the outer edge of the wall (Figure 32b). Use UV resistant cord and tie it on a barb cluster so that it cannot slide along the wire.

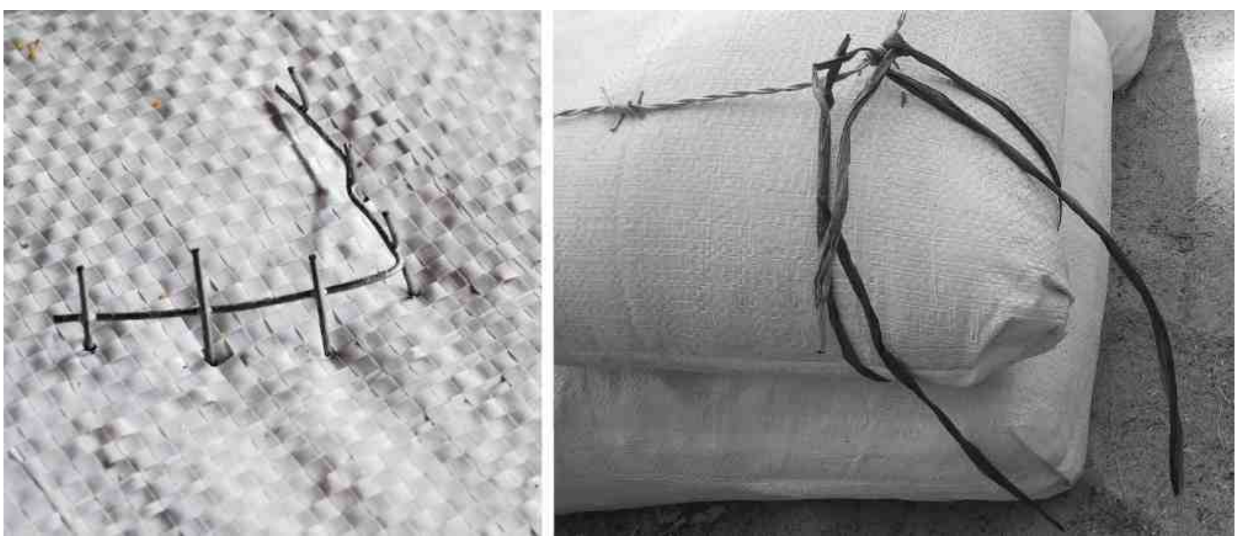


Figure 32 Add strength where barbed wire turns corners (left to right): a- Pins cut from wire mesh and bent can pierce upper and lower courses, b- Tie wire from bends in barbed wire out both sides and up to the next course.

STRONGER FILL INCLUSION

The compressive strength of dried soil fill determines how well wall masses resist cracking. Extra strength can be added to specific parts of walls where stresses concentrate, by increasing the proportion of strong clay.

Areas that will benefit from higher strength fill:

- the lowest course of building walls
- upper half of walls at corner rebar
- upper half of walls at wall intersections
- reinforced buttresses or piers

THICKER CORNERS

Without extra steel or cement for stronger reinforcement, buildings can be strengthened by thickened walls.

Piers less than 1,8 m (6') high that wrap a corner provide more mass to make wall corners more stable, which reduces motion at vulnerable corners. If bracing panel lengths can allow a limited 380 mm (15") extension at corners, build it as a corner pier (Figure 33).

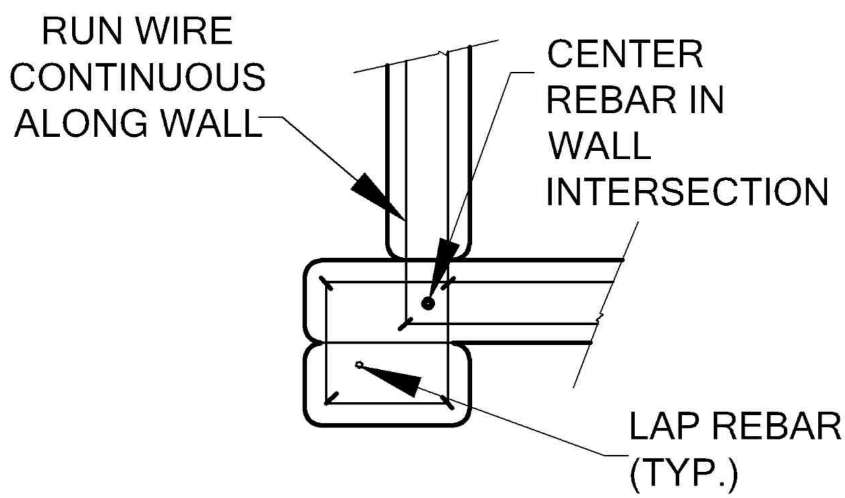


Figure 33 Corner pier barbed wire and rebar locations.

Plan ahead for piers or buttresses in the footings. Use inserted rebars in the center of the intersection between walls and piers or buttresses to unite these separate elements well.

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	Lower diagonal inserted rebars spliced to an upper rebar.
FTG	Footing
Lap Rebar	When separate rebars are inserted one directly over the other, a lap rebar overlaps them both.
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 for bracing purposes
STUB	A stub wall has only one end attached to another wall and lacks bracing
TYP.	Typical indicates that every where this element appears in the detail or plan it is the same