B102 BUILD STANDARD GRADE RESILIENT CE EARTHBAG:

Rebar in Spot Footings for Moderate Seismic Risk

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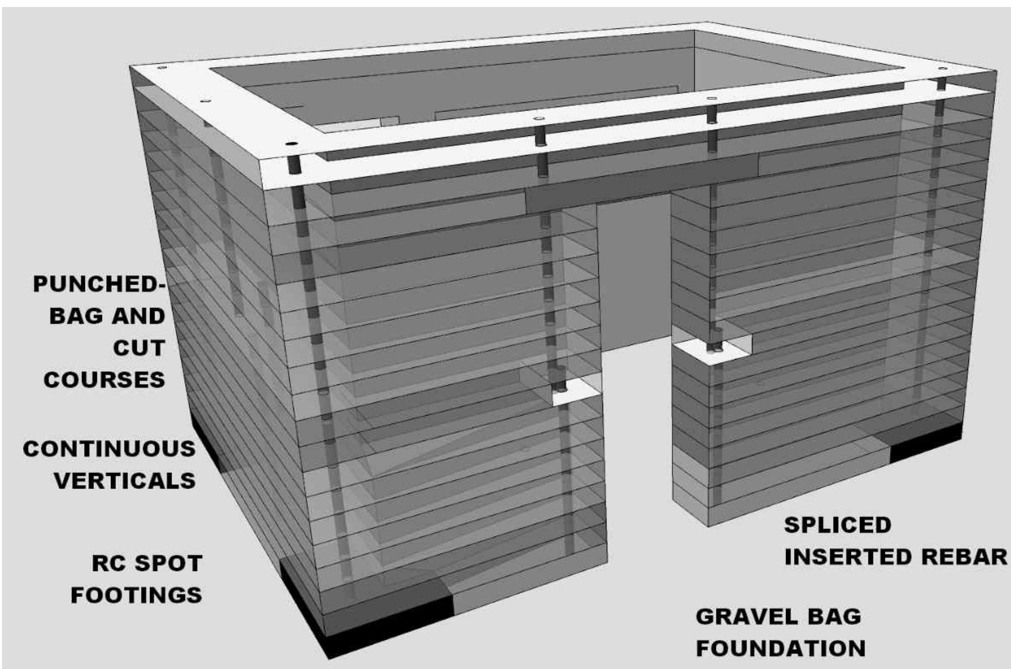


Figure 1: Corners strengthened by embedded continuous rebar base-anchored in spot reinforced concrete footings connected to gravel bag foundation.

CONTENTS:

PART I: BASIC EARTHBAG INFORMATION

PART II: RESILIENT REINFORCEMENT SYSTEM

Part I: Basic Earthbag Information

1 INTRODUCTION

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

EARTHBAG VS. EARTHQUAKES

Earthbag has been used in seismic risk areas because it provides low-cost walls that resist quakes for areas where unreinforced earthen or stone walls will collapse and kill those inside. Barbed wire between courses adds toughness. Unconnected but easily inserted rebar provides some stiffening. Carefully reinforced earthbag buildings of cohesive soil fill with strong bond beams and enough bracing are unlikely to have any corners break apart to cause wall and roof collapse.

But conventional earthbag buildings have to date only survived low earthquake forces (horizontal forces equal to 70% or less of gravity in Nepal's 2015 quakes). So communities investing in institutional buildings are unsure if they can count on earthbag structures after an earthquake.

Structural testing shows that earthbag walls can be damaged. Horizontal earthquake forces can exceed 170% of gravity. If wall strengths are inadequate for earthquake forces door and window frames in earthbag walls can be broken and upper walls can warp out of shape.

Builders need special techniques so earthbag walls can be strong enough for needed buildings.

IMPROVED REINFORCEMENT FOR MODERATE RISK

Builders love earthbag because it uses local, natural materials and can be built without either power tools or a lot of fussy details. The immediate walls rise without the need to pre-form blocks or use heavy forms.

With new details and tested fill strength resilient CE (contained earth) on low-cost part-gravel bag foundations can help carefully planned small buildings survive in moderate risk areas.

The soil and detail requirements in this booklet have been proven to increase strength. Raw soil fill (without chemical stabilizers) that is 23% stronger delays damage and allows walls to resist up to 40% more force. Continuous or spliced vertical reinforcement between strong footings and bond beams can increase corner and wall strength up to 50%. Adding connections between bond beams and door lintels prevents damage above and next to wall openings.

In areas with low to moderate 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, for moderate seismic risk areas use details in *B103 Build High Strength Resilient CE Earthbag* with confining strip concrete footings (pdf online at BuildSimple.org).

These details will prove the most helpful to buildings that are:

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

Plan carefully and build thoughtfully. Engineers may be able to design building plans using these standard grade CE techniques that can be safe in some higher seismic risk areas.

WHAT IS 'MODERATE' SEISMIC RISK?

Earthquake risk varies a lot from area to area. The sketch maps below (Figure 2) give rough estimates of risk. Areas shown as white or light gray have low risk levels.

The areas shown on the sketch maps in dark gray range from moderate to high risk. The closer to black, the higher the estimated risk.

Areas shown in black have much higher risk levels. The details in this booklet are not strong enough to ensure that buildings in the high risk regions will be useable after strong quakes.

This author uses risk levels that match the most complete existing earthen building guidelines (developed for New Zealand). Moderate to high risk is:

> *0.6- 1.7 g (gravity) peak ground acceleration (pga)*
> *occurring in 'Ss' pulses of 0.2 second and cause the most damage to low-rise buildings*
> *likelihood of 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.

Builders in the US, Canada, Europe and Australia can check exact risk for their building site online. Builders in other regions should ask local engineers or professors of engineering what level of risk will apply to their building site.

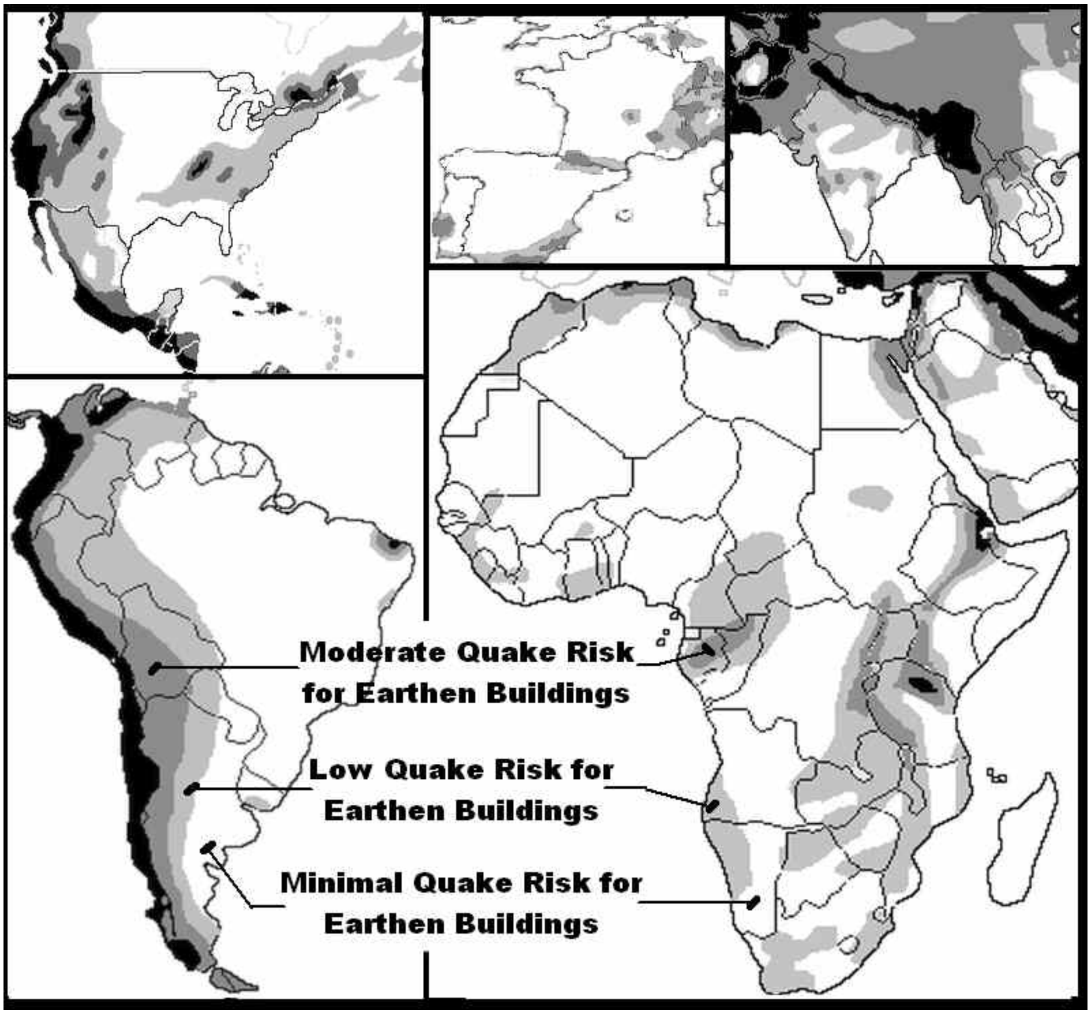


Figure 2: Approximate locations of earthquake risk relative to earthen wall strength.

Professionals in different countries talk about risk using different scales of measurement. In some areas planners use 10% in 50 year probability of excedance, as seen in the online world maps in the Global Earthquake Model (GEM)[1]. Users can zoom in on the GEM maps, but moderate risk is shown in yellow and labelled differently from the sketch map above:

BuildSimple risk maps[2]	2% probability in 50 years	0.6- 1.7 g pga
GEM hazard maps	10% probability in 50 years	~ 0.1- 0.34 g pga

[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

WHAT STRENGTH OF QUAKE CAN EARTHBAG SURVIVE?

Buildings survive earthquakes only when the structure is strong enough both for the intensity of ground motion and for the exact building layout. The question is not what earthbag can survive, but how to figure out if a specific building plan built of earthbag can survive.

Strength of the wall +

Long enough bracing panels in the building plan +

Foundation strength =

Building safety for a certain level of quake motion

Lone straight walls tend to tip over and fall down in earthquakes. Always build heavy walls with corners that will prop them up against toppling. If every structural wall in both of the main directions is connected to long enough solid wall sections to let it lean on them during an earthquake, the building will not be damaged. If the solid 'bracing' wall sections are a little too short, they may warp into diamond shapes but still hold up their neighboring walls.

To know if a building has long enough bracing walls, designers need to know the strength of real walls. But no one knows the exact strengths of earthbag built with strong cohesive dried fill.

Previous tests of earthbag (60% scale (small) earth-plastered samples or 80% scale (nearer full size) unplastered samples with faulty reinforcement) all underestimated strength. Smaller samples showed proportional improvement between different techniques, and that plaster provides half of wall strength. Rough estimates combining data from both sizes of test (Table 1) were only guesses until recently. Prelimanary results from current research of 80% scale walls with better attachments and cement stucco match or exceed these estimates. Full data will be published online as soon as possible.

Building guidelines for New Zealand show how to check earth block walls for bracing. *Earth Buildings not Requiring Specific Engineering* (NZS 4299:1998) has helpful information about building safely. If earthbag is as strong as the earth block walls in this code, designers can use or adapt the information to check out earthbag building plans.

Estimates from previous earthbag testing show conventional earthbag with inserted unconnected rebars is weaker than the NZS unreinforced adobe allowed in areas up to 0.59 g risk at 2% pe (~0.1 g at 10% pe) but much more flexible (Table 1). Because flexible buildings survive quakes better than brittle ones, conventional earthbag is likely to perform as well as New Zealand's unreinforced earth block walls in low risk areas.

Preliminary results from a current 80% scale earthbag test confirm the rough estimates for connected vertical CE in Table 1. Cement stucco covered CE with continuous rebar and good connections appears about half as strong as the reinforced earth block that NZS 4299 allows up to 1.7 g risk at 2% pe (~0.34 g risk at 10% pe). But the ductility (a measurement of flexibility that resists damage) with cement stucco appears much lower.

TABLE 1: COMPARING APPROXIMATE ESTIMATED PERFORMANCE OF EARTH-PLASTERED EARTHBAG TO ADOBE

(Earthbag based on testing through 2020; Adobe strengths based on published information about the development of New Zealand Standards 4299:1998)

	Tested ductility	Considered ductility	Force level deformation starts increasing	Maximum force
Resilient CE earthbag compared to <u>unreinforced</u> adobe allowed up to 0.59 g risk				
Overlap-reinforced CE (medium[1] fill)	2.5 x higher	2 x higher	similar	similar
Overlap-reinforced CE (strong[2] fill)	3 x higher	2 x higher	30% higher	30% higher
Resilient CE earthbag compared to <u>reinforced</u> adobe allowed up to 1.7 g risk				
Connected-vertical CE (strong fill[2]) with earthen plaster	1.75 x higher	1.5 x higher	74% lower	±53% lower

[1] Medium fill 1,38- 1,59 MPa (200- 230 psi)
[2] Strong fill 1,70- 2,07 MPa (250- 300 psi)

US engineering code allows wall ductility to reduce the need for strength. Rough estimates from current data above multiply approximate strength by considered ductility, since the American Society of Civil Engineering building code divides the level of force a building is required to face by the ductility factor. Where CE earthbag's high flexibility can be considered this characteristic can result in lower requirements for steel and cement than those required by the New Zealand standards for block or rammed earth walls.

Although standard grade earthbag is unlikely to be strong enough for use in areas of seismic risk near 1.7 g at 2% pe force levels without extreme lenghts of bracing walls, it is easier to build safely up to 0.85 g risk at 2% pe (or 0.17g at 10% pe). Details and specifications in New Zealand's code for <u>reinforced earth block</u> walls can be adapted for resilient CE earthbag.

Earthbag walls are 9% thicker and thus slightly heavier per wall length than earth walls considered in NZS 4299. Resilient CE earthbag walls may not need full width reinforced concrete footings but may need reduced bracing line distances or added piers between bracing lines to stiffen the very flexible CE walls.

More information and a system to check bracing wall lengths based on the New Zealand earth building guidelines will be supplied in *D91 Design Resilient CE Earthbag Buildings for Seismic Risk* online at BuildSimple.org/Resources.

Always check online for the most recent structural testing results that match your exact type of planned wall construction. Ask an engineer familiar with earthbag construction how long bracing wall panels should be to hold up walls in your plan for your site conditions. Or invest in engineering to minimize construction cost and maximize safety for your building.

For resilient CE buildings in areas with seismic risk above 0.85 g at 2% pe (~0.17 g at 10% pe) ask an engineer or engineering professor for advice.

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/or connections.

Buildings facing earthquake forces need a full system of reinforcement so that each part can resist the same level of horizontal shaking.

This document is part of a series. Other reinforcement systems are described online at BuildSimple.org/ Resources. The main differences in systems of reinforcement currently recommended for resilient CE earthbag are listed in Table 2.

Low-cement CE has no rigid footings and only has connected verticals at corners. Standard grade CE has connected verticals at corners and doorways, and spot footings only at corners. High-strength CE has connected verticals at all openings and continuous confining rigid strip footings.

Vertical rebars (at regular spacings) in long straight wall panels may also help earthbag to resist higher earthquake forces. Inserted rebars that are not anchored to the footing can be used between continuous base-anchored verticals. But since base-anchored rebar is the most effective at bracing against horizontal earthquake forces, designers may modify standard grade reinforcement by adding extra verticals at the ends of footings and/ or enlarging the standard corner spot footings.

Table 2: 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
Corners	Open splice + fork	Continuous verticals	Continuous verticals
Intersections	Open splice + fork	Open splice	Continuous verticals
Techniques	Punched	Punched and cut	Punched and cut
Rebar	Mostly inserted	Spliced @ doorways	Continuous or spliced
Windows	Lap from bond bm	Connect verticals to bond bm	Truss upward pins to bond bm
Doorways	Connect to bond bm	Connect verticals to bond bm	Truss upward pins to bond bm
Lintels	Wood	Wood or Reinforced concrete (RC)	Wood or RC
Bond beams	Wood	RC or steel (wood with Ceiling diaphragm)	RC or steel

NOTE ABOUT DIMENSIONS

To make this information accessible for builders worldwide, both metric and imperial units are used. For approximate dimensions, both units are rounded even though they are not equal.

2 MATERIALS FOR RESILIENT CE EARTHBAG

CONTAINED EARTH (CE)

Use subsoil to build earthen walls. Leave valuable topsoil for agriculture. Check by dissolving your fill in water. It should not have much organic material floating on top. Dig deeper to avoid topsoil.

The strength of the dried soil masses in earthbag's walls is critical. 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 standing tall. Serious damage could occur.

Stronger soil fill creates stronger walls. Built with 2,1 MPa (300 psi) soil, resilient CE walls may be strong enough to resist 40% stronger quake forces than walls with 1,7 Mpa (250 psi) fill. Although New Zealand's guidelines only require 1,3 Mpa (190 psi) fill as a minimum for earth block walls, resilient CE walls built with minimum strength soil fill may be too flexible and deform too much to be practical for important buildings in moderate risk areas.

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. Find information online at BuildSimple.org/Resources on how to test 3 cm balls *(pdf B30)* or fist sized samples *(pdf D31)* to estimate soil compressive strength.

GRAVEL BAGS

Foundation walls for earthbag often use gravel in doubled short tubes or bags to resist moisture.

REINFORCED CONCRETE

Resilient CE building walls have enough ductility to survive vibration on flexible wire-bound gravel bag base courses. But because these earthen walls warp instead of crack or crumble, at moderate earthquake forces base-anchored steel rebars can delay wall deformation significantly.

Reinforced concrete (RC) is very effective at forming a stiff anchorage and at uniting a horizontal area. When a continuous or strongly connected vertical steel rod is stiffly anchored it will not allow the wall to warp until its base either rotates upward (lifting the full weight of the wall bearing on the footing), or the steel rod bends. Longer sections of wall supported by concrete footings increase walls' resistance to damage significantly, so do not reduce sizes of spot footings.

Use clean washed sand and proportions of cement approved by experts for strong concrete.

CONTAINERS

SMOOTH WOVEN FABRIC of flat polypropylene strands is most commonly used for earthbag. Breathable PP material allows earthen masses inside the fabric containers to dry out gradually and creates a smooth, low-friction fabric surface between courses.

Flexible barbed wire barbs and embedded steel rebar bridging the fabric surfaces at course bed-joints create a composite layered wall of metal and natural soil that flexes before cracking. Fabric containers may help to resist walls bulging outward from sideways forces but do not increase wall strength to resist warping from forces in line with the walls.

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 in moderate to high seismic risk areas for best integration of steel reinforcement with wall material.

MESH TUBES can be used for CE earthbag and damp fill unites through the open course containers. 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. The crocheted mesh tubes (like vegetable bags) are easy to work with but may cost more than solid fabric tubes. Plaster adheres well to the textured wall surface of extruded dried soil and non-biodegradable mesh, but lacks the air gaps between solid woven fabric and dried soil that may reduce damage from surface dampening for conventional earthbag and CE.

Exact strength and ductility are not yet known. Without better research mesh tubing is not recommended for building walls in moderate to high seismic risk.

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

Wall thickness varies based on how high courses are built. Holding 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.

REINFORCEMENT

Reinforcement embedded inside earthen walls may last for generations if it is non-biodegradable. 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 in areas with highly acid or alkaline soils, consider coating rebar in contact with soil with a rust-resistant but non-slippery paint before building.

Fiberglass or basalt rebar lack surface texturing for good bond. If the bars cannot be bent to produce critical end hooks or welded to add top bolts or cross-pieces they are not recommended for seismic risk regions.

STEEL REBAR must be 'deformed' (textured) for good bond with dried soil. D10 (3/8") rebar for angled pins allows easy bending. D12 (half-inch) diameter steel rebar is common for inserted vertical reinforcement. These bar sizes keep their strength if bent in a 50 mm (2") radius. If bending before inserting, always bend to 90° to allow hammering.

With stiff base anchorage in spot RC footings, larger diameter steel can contribute to wall strength, so D16 (5/8") diameter rebar or larger may be used for base-anchored verticals.

BARBED WIRE should be 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. If builders want extra resistance to forces, it is possible that the use of at least one strand of heavy low-strength barbed wire could increase resistance to bulging and/ or warping damage on courses subject to higher forces (such as between the middle of windows and the course above the lintels).

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. But unless construction is overseen by contractors experienced in earthbag who have adequate labor to complete the project quickly, strapping should be UV resistant. Knots like a trucker's hitch should cinch tight and not slip.

Fiberglass packaging straps make a strong alternative for strapping with a sealing tool.

OTHER MATERIALS

PLASTER MESH plays a critical role in overall wall strength. Chicken wire is often used, but with time rusts and decays in contact with alkaline cement stucco or lime plaster. Plastic geomesh or fencing mesh is costly. Build Simple recommends weak plastic bird netting or fishing net because it is not costly and the fine grid of individual strands embedded in plaster transmit forces 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 some dampness in humid climates if the plaster lets 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 an upper interior area of all raw earthen walls finished with cement stucco in humid regions.

3 BASIC EARTHBAG CONSTRUCTION

For those new to earthbag construction, review the Earthbag Information slide shows *(B1- B5)* online at BuildSimple.org. Hart's book, *Essential Earthbag Construction* has many photographs and drawings of the traditional construction techniques used in minimal seismic risk areas. Videos by Geiger online at the Naturalhouses youtube channel show accepted practices.

BUILDING WALLS

Soil fill must be slightly damp and tamped to consolidate. Barbed wire must be laid immediately on each course and steel rebar inserted while walls are damp (within 2- 3 days of building).

The end of tubes of contained earth should overlap the course beneath at least 230 mm (9").

Vertical integration between courses comes from the barbed wire barbs embedding in soil fill and from any embedded rebars. Vertical strapping can unite base wall courses with gravel fill, but when tied over three or more contained earth courses the strapping is likely to become loose if the soil fill shrinks slightly during the drying process.

BARBED WIRE ON CE

Lay wire immediately on damp courses and on concrete splices. Pull barbed wire taut along straight walls and wrap it continuous at all corners.

Two strands of barbed wire per course should be laid 80- 100 mm (3- 4") in from the wall edges (Figure 3) leaving 180 mm (7") available to insert vertical rebar and pins. Barbed wire should not be visible in the nooks between courses and must not block the area to insert rebar.

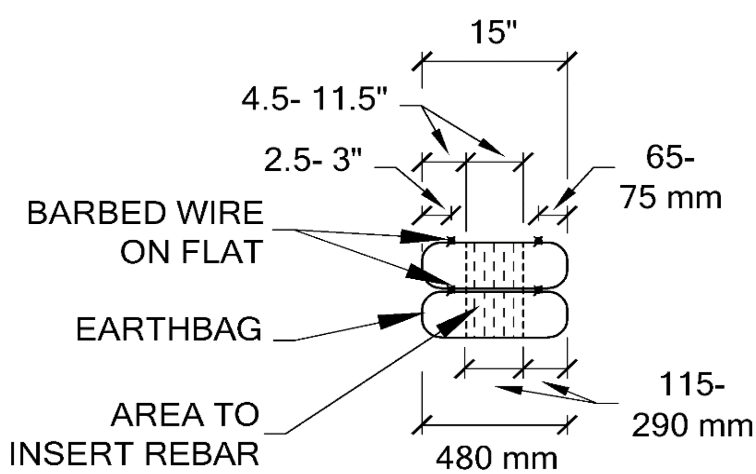


Figure 3: Barbed wire location on the flat course top near rounded course edges.

End barbed wire strands in the middle of a building side with at least a 600 mm (24") overlap (Figure 4a). At the end of a stub wall or near a wall opening, turn wire along the end and return into the wall (Figure 4b).

NOTE: NEVER END A BARBED WIRE STRAND AT A WALL CORNER OR AT THE END OF A STUB WALL.

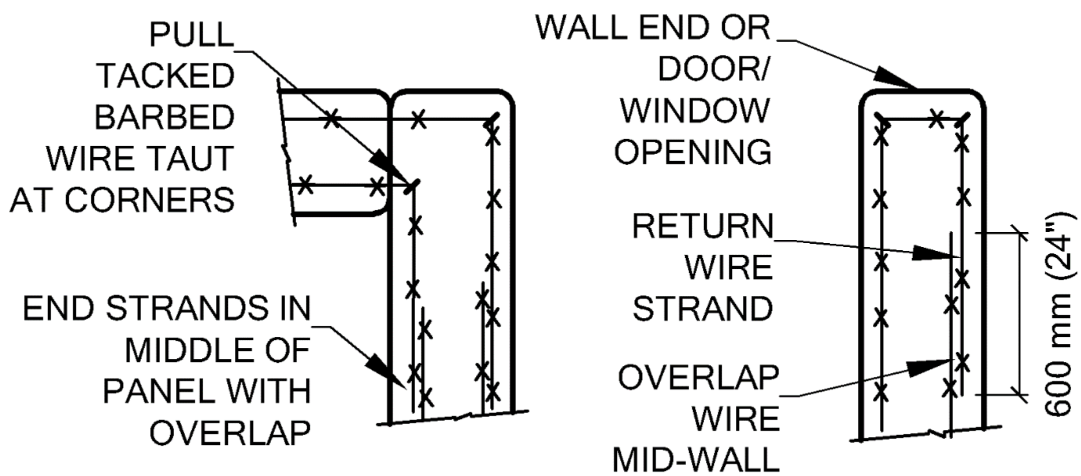


Figure 4 (left to right): a- Always run barbed wire continuous around corners and locate strand ends in middle of walls; b- Run barbed wire around wall end or opening edge and return.

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.

BRACING FOR 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 rely on wall corners for bracing strength, and 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. Rectilinear earthbag walls have traditionally been built with walls intersecting every 3 m (10’) or short walls called buttresses extending outward about 1 m (39”).

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.

Traditional earth builders know that more narrow windows are better than a few large horizontal openings for windows or doors. Maximum windows recommended are 1,2 m (4’) wide or less. Openings with included wood, brick or concrete structural frames should be widths of 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. Sometimes builders bend hooks on top to embed a vertical into a reinforced concrete bond beam.

INSERTING REBAR

Rebar is hammered easily into damp earthbag walls after construction. Soil fill that contains some gravel does not obstruct inserted rebar. If your fill is very stony, try 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 out very slowly, but the surface of each course or separate unit begins to dry first. Rebar should be inserted as soon as a course is finished and tamped to be sure that the rebar embeds well with all the earthen material along its length.

Any rebar inserted into a resilient CE wall must be located near the center of the wall to avoid hitting barbed wire. Diagonal reinforcement can be inserted at an angle running along the wall, but the rebar must be 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 all walls from base to wall top. Tie mesh to vertical strapping on gravel bag base walls. At the wall top run mesh under or tack to the side of wood bond beams, or pull it over exposed rebar and embed it in concrete bond beams.

The first plaster layer is usually a sticky soil with straw that adheres well to smooth woven fabric and levels the 75 mm (3”) deep spaces between courses. ‘Raw’ or unstabilized earthen plaster works well for this nook layer under a lime plaster finish coat.

For a finish coat of cement stucco, don’t waste cement stucco on the nook or leveling layer. Stucco does not stick well to the fabric. Instead, use a sticky earthen plaster stabilized with 4- 8% Portland cement or hydraulic lime. Stabilized earthen plaster will bond better with cement stucco than a ‘raw’ earthen plaster because stabilized material shrinks and swells with temperature changes similar to a cement-based stucco finish layer.

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 have also been used.

Never build any heavy earthen wall portions (like chimneys or gable walls) above the bond beam in seismic risk areas.

PART II: RESILIENT REINFORCEMENT SYSTEM

Resilient CE earthbag uses an improved reinforcement system (Figure 5) to give gravel bag courses more toughness and connect foundation weight to the full height of wall corner verticals.

Conventional earthbag walls have little resistance to sideways forces on the footing, and lack strong connections from foundation to bond beam. Resilient CE strengthens:

- Gravel bag footings with horizontal wire binding, vertical straps, and angled pins
- Corners with continuous rebar in RC spot footings
- Bond beams by attaching strongly at corners to vertical rebar with hooks or nuts

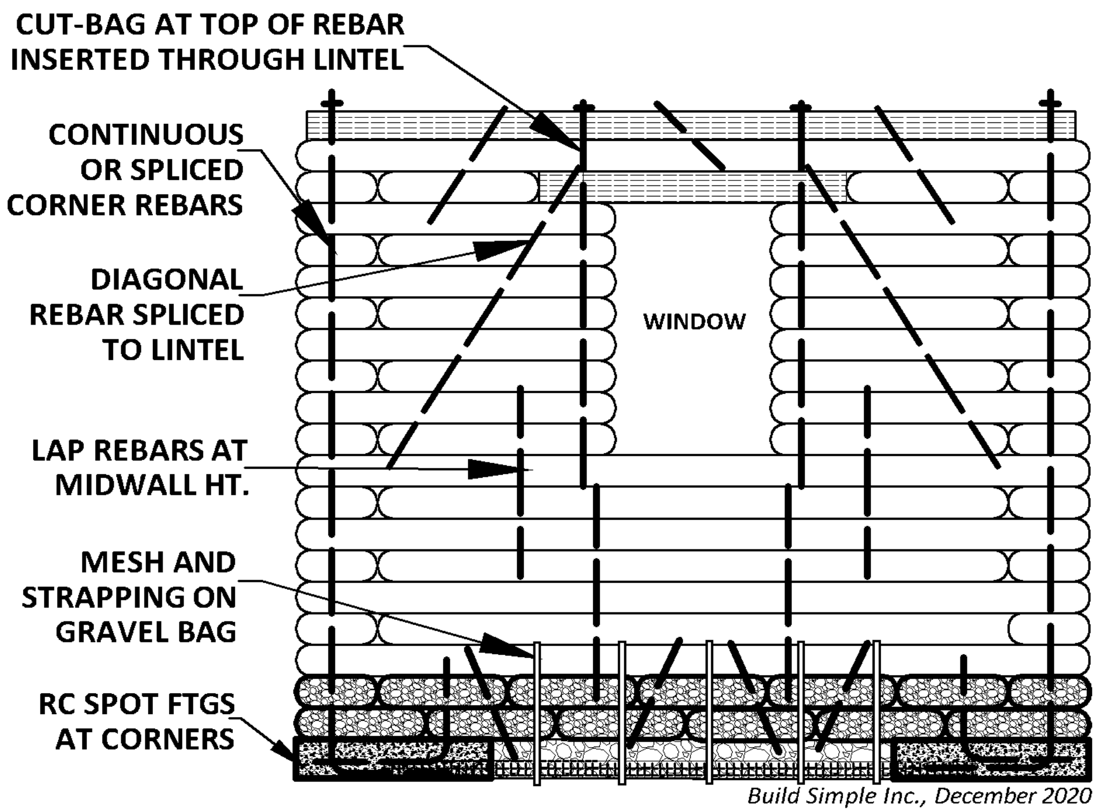


Figure 5: Improved reinforcement system for moderate seismic risk areas requires some Portland cement.

Additional needed wall strength also results from:

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

Wood bond beam and lintels used with these details allow construction to use about 136 L (4.8 cf) of concrete for each exterior corner.

PLANS FOR RESILIENT CE FOR MODERATE RISK

This reinforcement system is designed to help moderate-size low-rise buildings to resist earthquakes of moderate force levels. But reinforcement is not enough. The building plan must be specially designed to be stable and to provide enough bracing walls in each of the principal directions.

In heavy masonry walls of moderate-strength earthen materials, including earthbag, almost every wall needs to help hold up the adjacent walls. Since only solid walls without doors or windows have the strength to brace adjacent walls, doors or windows must be carefully located far enough from corners and intersections to provide enough bracing. Buttresses (short stub walls provided for bracing) can extend outward from the building to increase bracing if needed.

Buildings that are compact (closer to square) are safer than long narrow buildings. Symmetrical buildings are safer than asymmetrical. Don't use L shapes in one building. There are many ways to make buildings better able to resist deadly earthquake forces. For help with schematic design, please refer to pdf D91 *Designing Resilient CE Earthbag Buildings for Seismic Risk*, which should be posted online at BuildSimple.org/Resources sometime during 2021, and/ or seek engineering advice.

4 FOOTINGS FOR MODERATE RISK

Engineers usually assume that buildings in seismic risk areas need a heavy reinforced concrete (RC) 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.

Spot footings at corners can be connected to strong mesh confining mid-wall gravel bags to give the entire foundation wall more resistance against deformation from forces perpendicular to the wall and from subsoil movement. Leave undisturbed subsoil in place next to the inner edge of all footings so that the gravel bags can be firmly confined against the edge of the trench.

Buildings on soft or erodable subsoil may need stronger footings using more cement, such as a confining reinforced concrete strip surrounding gravel bags (see *B103 Build High Strength Resilient CE Earthbag* online at the BuildSimple.org resources page).

SPOT FOOTINGS

Footings attached to vertical rebar must be held down by heavy wall weight. Align the edge of spot footings at corners with the exterior surface of earthbag walls so the footing is under the maximum length of walls. Spot footings should have a minimum dimension of 900 mm (3’) unless otherwise recommended by an engineer.

All reinforced concrete footings need horizontal embedded steel continuous along the edges. Standard details for reinforcement of masonry footings can apply. Base-anchored vertical rebar must have good hook lengths. Use additional vertical rebars for a foundation pin at each end of the reinforced concrete.

Connect Spot Footings to Low-Cement Foundations

Either bind all gravel bag footings and embed the barbed wire strands in the spot footings, or use 150 mm (6”) wide strips of plastic emergency fence or geomesh on the external edge of all gravel bag footings. Run the mesh into the spot footings, connect the mesh and embed in the concrete (Figure 6).

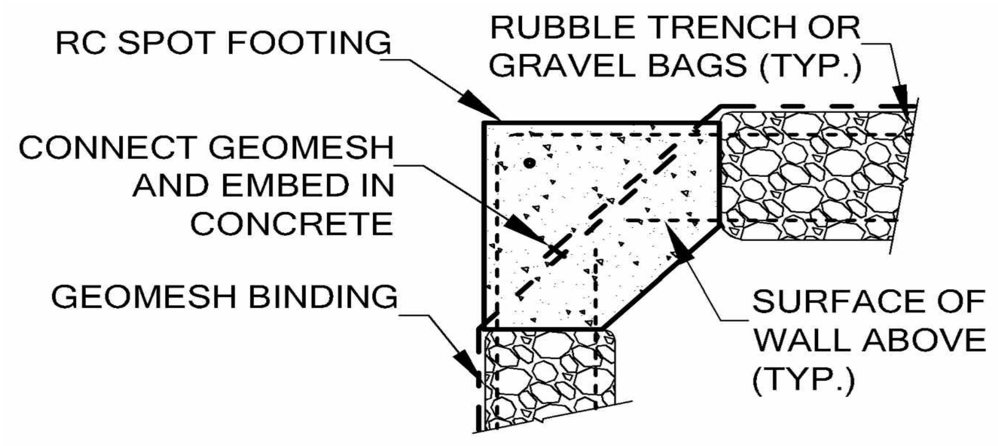


Figure 6 Geomesh embedded in spot footings at corners can confine adjacent gravel bag footings.

A rubble trench between RC spot footings can have the rubble wrapped with a strong mesh.

Locate Reinforcement for Type of Corner Construction

Vertical rebar must be near an interior corner for continuous rebar (Figure 7). The simplest corner reinforcement uses continuous verticals that are located near inside edges of building wall corners.

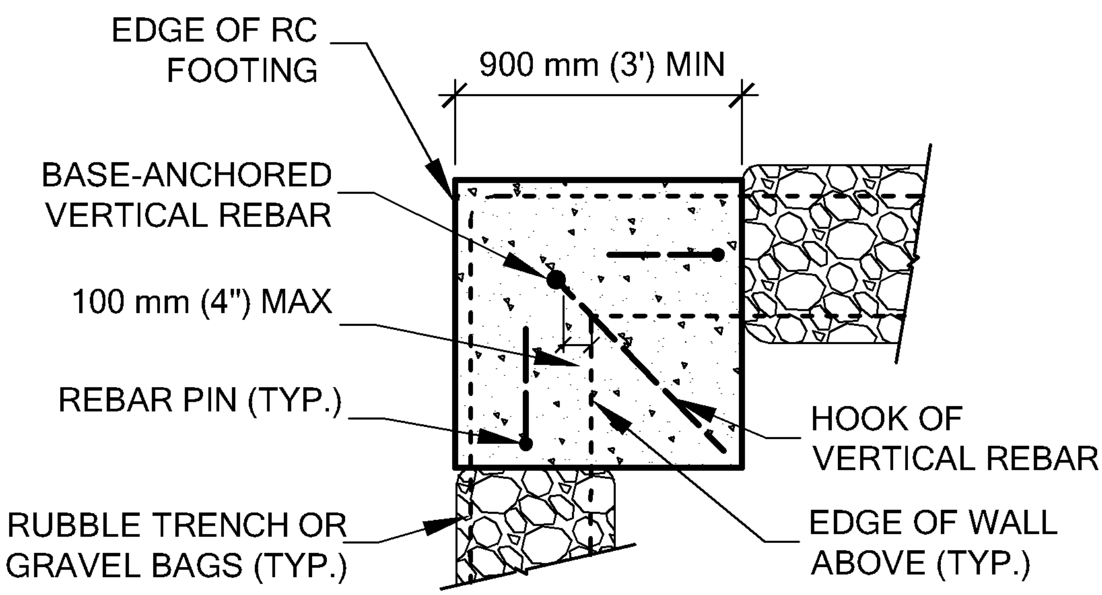


Figure 7: Spot footing to anchor long vertical rebar extending to the bond beam.

To splice shorter lengths of rebar with a standard open splice, locate the lower rebar near the exterior corner 125 mm (5”) from one surface and 255 mm (10”) from the other (Figure 8).

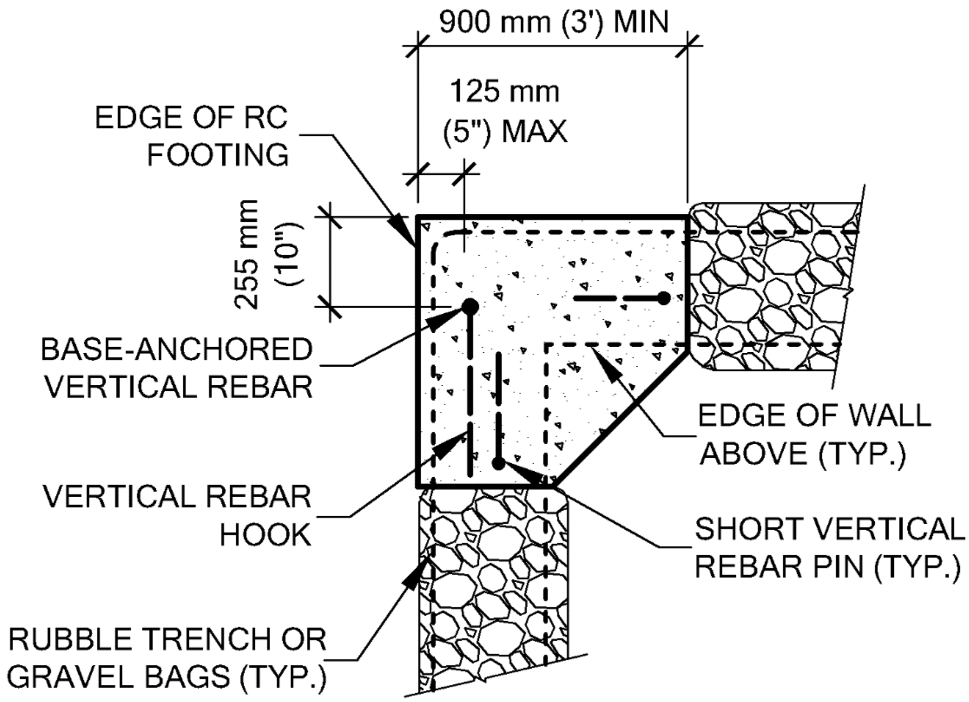


Figure 8: Spot footing to anchor short vertical rebar that will use an open splice.

For a covered splice, locate the lower rebar at the outer corner of the wall. A 255 mm (10”) square area on the course of the splice will be filled with sand and later emptied and replaced by concrete to make the splice (Figure 9).

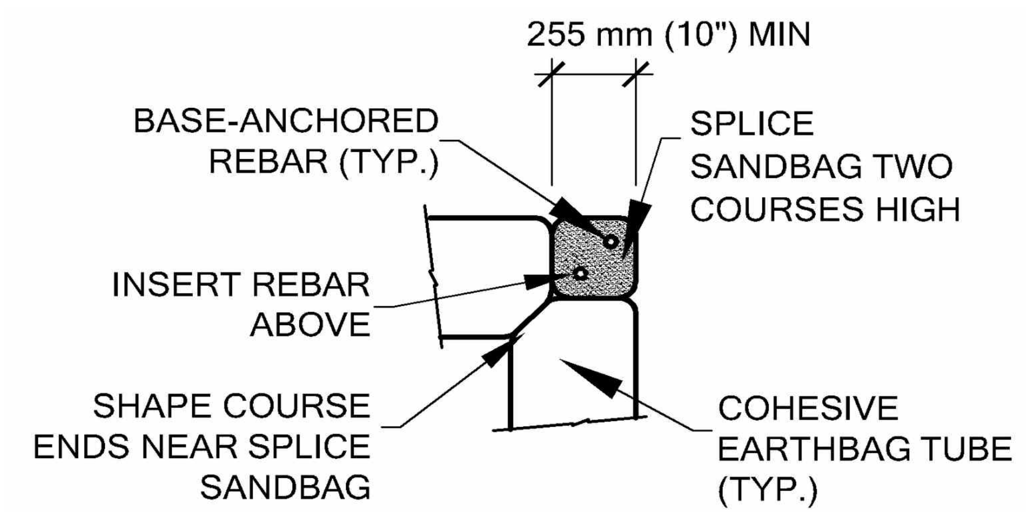


Figure 9: Covered splice sandbag location at mid-story height of external wall corners.

Locate the lower rebar 125 mm (5”) from the face of each side of the wall corner (Figure 10).

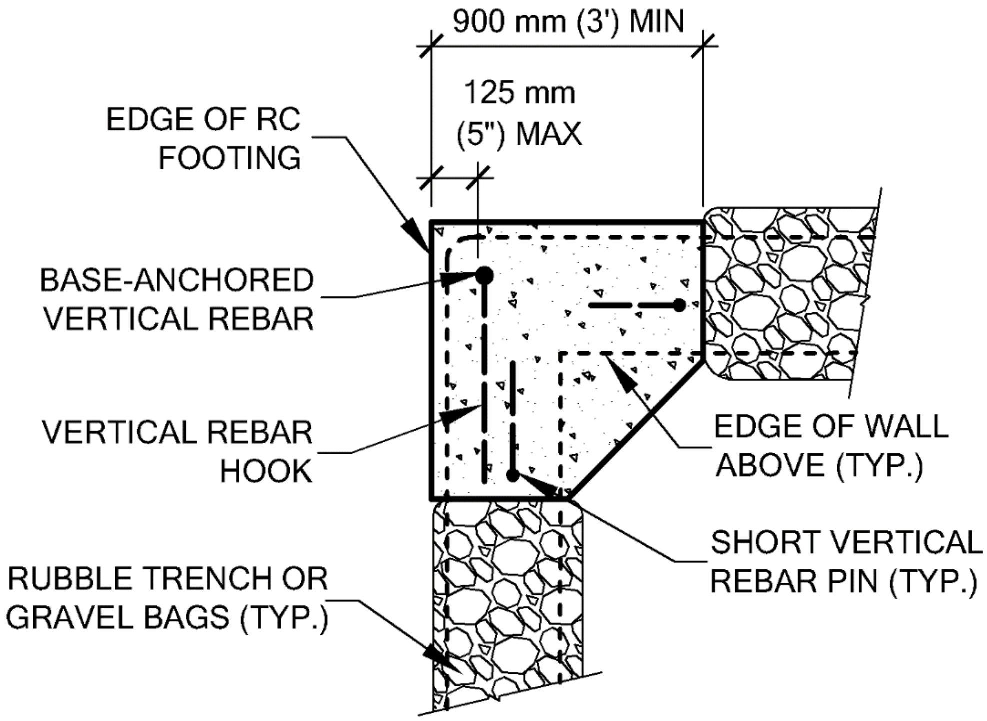


Figure 10 Spot footing to anchor short vertical rebar that will use a covered splice.

GRAVEL BAG FOUNDATIONS

Gravel bags provide well-drained base layer. Gravel fill can be settled but not compressed by tamping. Fill containers less full than for CE (contained earth earthbag) to prevent course tops from bulging upward. Double containers for good resistance to compression and friction between courses. But gravel bags do not bond to inserted rebar so have little vertical connection.

Use vertical strapping on every bag between spot footings. Decay-resistant tie cord or strips of strong geomesh or plastic fencing mesh can be used as vertical strapping. Before laying gravel bags, place ties under each bag. Start under the first gravel bag course and attach the strapping to the barbed wire on top of the second earthen fill course..

Binding Gravel Bag Courses

Separate gravel bags may not have enough friction to resist sideways force against the center of a wall during strong quake motion. where gravel bag courses are used between spot footings. Mesh confining the sides of bag footings provide better toughness. If a building uses more than one gravel bag course before beginning contained earth courses, increase its toughness also by binding the gravel bag courses horizontally (Figure 11a).

Use a small nail inserted between the twisted wire of each strand and lever it to pull them taut. Bend the nail and wrap it and the two wires with galvanized tie wire (Figure 11b).

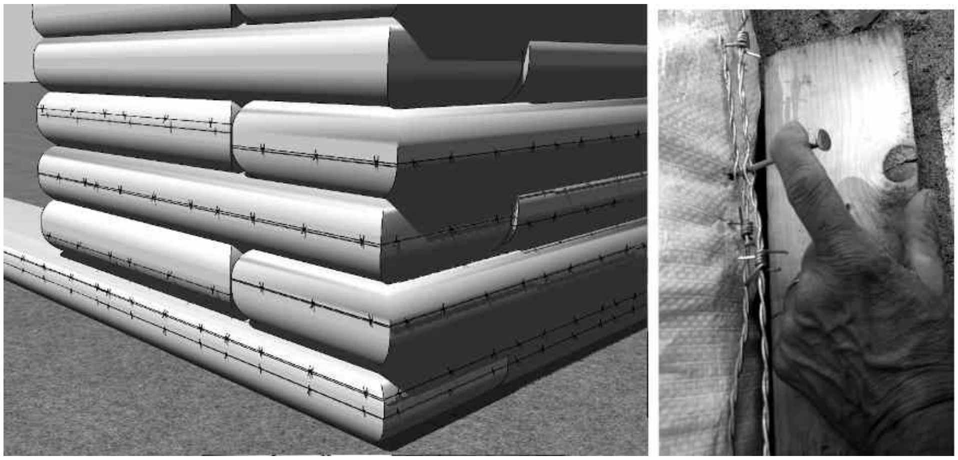


Figure 11 Binding gravel bag courses (left to right): a- Wrap around building below door sills, then straight lengths of bag or tube courses; b- Lever a nail between twisted wire to tighten.

To bind, wrap barbed wire along straight lengths of gravel bag wall (Figure 12a) where bags are laid continuous. Any buttress or stub wall that is not continuous on the course cannot be bound. On the next course that element will have bags laid continuous in the other direction (Figure 12b) and can be bound.

If walls have complex shapes, below door sills wrap the entire building but start the strand looping around a gravel bag at a recessed corner (Figure 13). Let wires pass one outer corner before the strand ends. Add an extra anchor bag overlapping the corner bags where needed to hold the barbed wire strand.

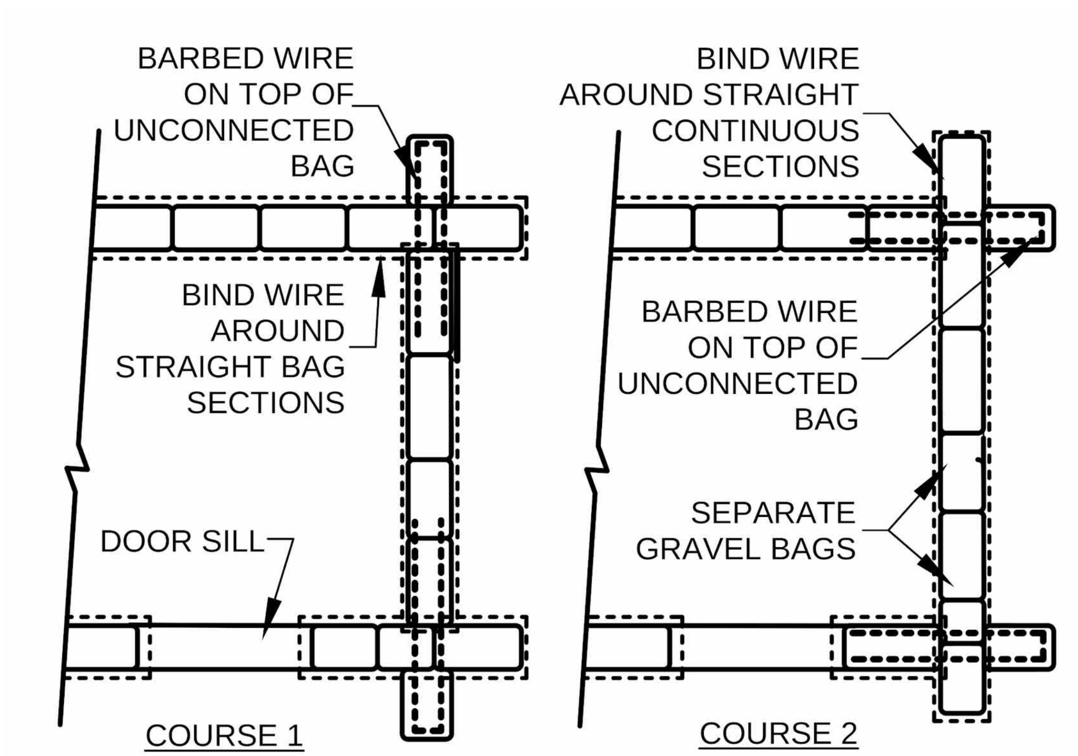


Figure 12 (right to left): a- Bind around straight sections of gravel bag and lay wire on top at buttresses; b- Bind straight sections of gravel bag in the other direction for the next course.

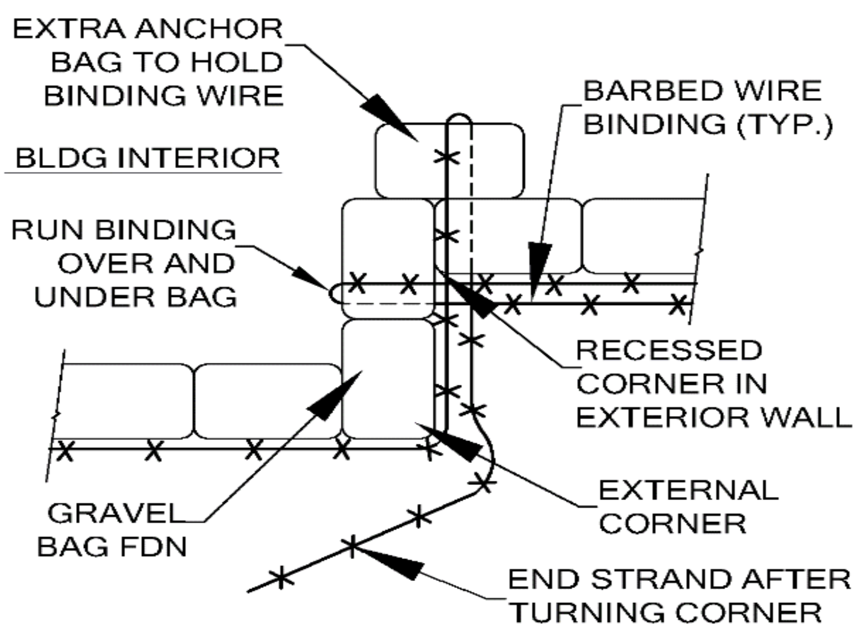


Figure 13: Start barbed wire at recessed corners by wrapping strands around a perpendicular bag.

5 BUILDING RESILIENT CE WALLS FOR MODERATE RISK

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. In rainy regions, cover the soil pile when not in use. Fill that is too damp may become too sticky to shovel easily. It also can be impossible to tamp until the course has dried, slowing work.

Special techniques are used in standard grade resilient CE to improve embedment of barbed wire and rebars in dried soil fill. Bags can be slid over rebar (Figure 14a) or cut (Figure 14b) to fit around base-anchored rebar reinforcement and barbed wire can be pinned.

Straighten barbed wire before placing and locate carefully. Make a sharp bend at a corner and hold it in place with an electrician's staple (Figure 14c). This will pin wire taut along the wall and give the corner some added strength. Place the staple on a barb at the bend in the barbed wire.

Figure 14 Better connections between steel and soil fill (left to right): a- Punch bags onto anchored rebar; b- Cut tubes to form around rebar; c- Tack wire corners taut with an electrician's staple.

REBAR EMBEDDED IN WALLS

The bond between dried strong soil fill and embedded reinforcement is what gives resilient CE the ability to resist earthquakes. Locate all reinforcing rebar embedded within wall material. Do not use external pinning rebar.

Use the correct end on all 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.

Rebar near openings or wall intersections can be inserted from above. Insert rebars into the center of the wall thickness to avoid hitting any barbed wire.

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 rebar at 90 degrees before inserting, or bend after inserting into the wall. If hooks are needed on diagonals, aim hooks across the course top.

Angled Wall Pins

Before inserting these short rebar sections for gravel bag foundations, build two courses of contained earth above the gravel courses.

Insert angled rebars at least 100 mm (4”) apart on top of the course. To prevent conflict between angled base wall pins and future vertical or fork rebars, mark on the top gravel course the location where vertical rebars will be inserted above 150 mm (6”) outside of each opening. Also mark the bottom end of the corner forks at 1 m (40”) from each corner.

Insert straight rebar pins through the first two contained earth courses into and through all gravel bag courses (Figure 5). Near corners insert angled pins down toward the center of the building to help resist localized uplift forces. Use a 20° or steeper angle.

Angled pins can also unite piers or buttresse to building walls. If diagonals are not spliced to verticals at corners or buttresses, insert a pin every 5 courses downward from the end of the buttress or exterior of the pier toward the wall.

Use angled pins to stiffen the wall top above lintels by inserting downward from the bond beam.

Base-Anchored Rebar Can be Embedded

Pairs of external pinning rebar were engineer’s first suggestions to reinforce earthbag walls, but research proves that deformed steel rebar embedded inside strong dried soil fill material improves strength more than rebar near the wall surface. Techniques to base-anchor rebar but still embed them in walls use small holes or small cuts to fabric course containers. These two techniques of punched-bag or cut-bag tubes are used on vertical rebars at specific locations. At corners use punched bag. Above lintels alternate punched with cut-bag.

Either use two separate tubes for each wall panel, or use the cut-bag technique for the end of a tube that starts with a punched-cag hole.

Cut-bag technique disrupts the container fabric a little when used on vertical rebar in straight wall sections. Structural testing showed that with damp fill the cut to the bag did not reduce wall strength. Cuts alternating with punched bag keep interruptions to continuous tube lengths at a minimum.

PUNCHED-BAG CONSTRUCTION

Punched bags can be placed onto rebar in many wall locations. They are easiest to do near the beginning of a tube that contains a small amount of fill. Punched-bag holes can also be used in the middle of a straight wall but will require the use of more separate tubes and will provide some disruption of the wall continuity.

For neat construction pre-measure and make a small cut near the stapled or sewn end of a tube (Figure 15a). Pre-fill the end of a tube about 255- 300 mm (10-12") deep. Shake the tube and compress the fill. Place a finger in the hole on the bottom of the course, line up the hole with the rebar (Figure 15b) and slide the rebar through the bottom and then the top hole (Figure 15c).

The fill will be loose when it has been slid down over the rebar. Reach inside the bag and re-firm or tamp the soil with a fist or 100 x 100 mm (4 x 4) wood piece to produce a firmly packed tube end. Continue to fill the tube and tamp after adjacent tubes are in place (Figure 15d).

Figure 15 Punched-bag technique (left to right): a- Prepared hole near tube end; b- Slide a partly-filled tube end down over a rebar; c- Filled and tamped punched-bag with no fabric gapping.

At a corner the rebar should be 125 mm (5") from the wall surface. In the middle of a straight wall, start a new tube at least 150 mm (6") away from the rebar location. Alternate sides so that there is a good overlap either side of the vertical rebar.

Remember the distances from the flat tube end and side must include enough fabric for the curving side and end of the tube.

Distance from seam, laid flat	For 125 mm (5") high courses	For 150 mm (6") high courses
To side of tube	165 mm (6.5")	178 mm (7")
To end of tube for overlap	191 mm (7.5")	204 mm (8")

CUT-BAG CONSTRUCTION

Cut-bag tested as strong as punched-bag construction even with cuts extending around half the container perimeter.

Fill the tube end next to the rebar but let it hang slightly over the edge of the wall on a metal ‘slider’ sheet so it doesn’t stick to the barbed wire. When the cut course is full past the cut location (Figure 16a), cut the bottom first and up to the top. Slide the tube into place with the fill surrounding the rebar (Figure 16b). Pull the metal out to set the fabric on the barbed wire below after the course is in place. Bend barbed wire around a vertical rebar if possible (Figure 16c).

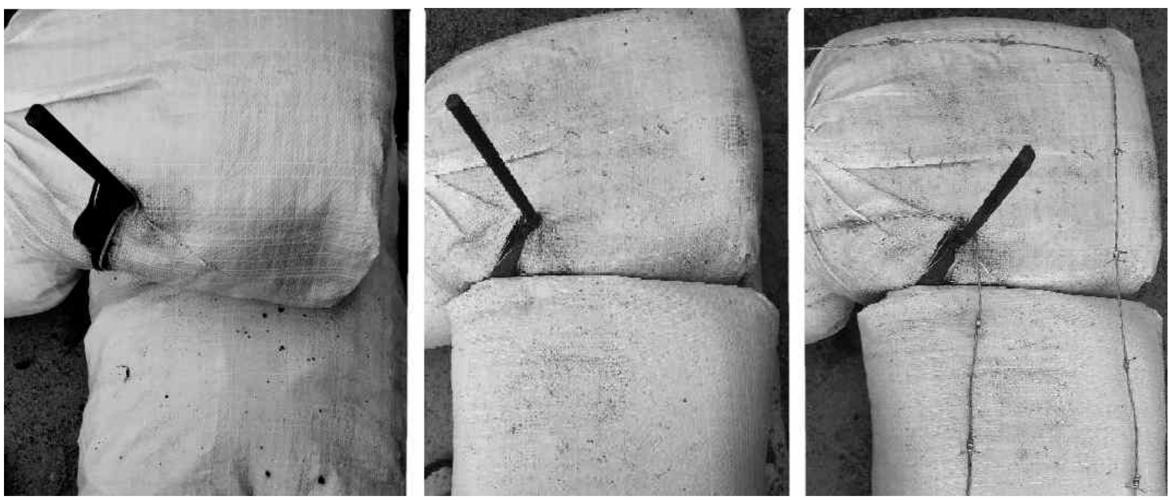


Figure 16 Cut-bag technique (left to right): a- Cut the tube next to the rebar; b- Slide the cut tube into position to surround the rebar; c- Running barbed wire past rebar.

Like any resilient CE earthbag, cut-bag construction must be built with fill damp enough to solidify. Always build the cut tube first, then place the adjacent tube next to it before tamping the course. If cuts must be placed in an exposed end or side of a wall an extra builder can hold a board against the cut during tamping to prevent a little soil loss. Or tuck a square of extra fabric inside the cut before continuing to fill a tube embedding a rebar.

Pre-cutting and taping at the cut locations may result in shorter and neater cuts.

WALL INTERSECTIONS

Unite wall intersections by alternating tube directions every course and also running barbed wire continuous across the adjacent wall (Figure 17a) and then back into the wall. Use a vertical rebar at every wall intersection to pierce the long tube containers that run in both principal directions.

At wall intersections and where walls are thickended for piers or buttresses, barbed wire must also unite the separate wall elements. The strand near the exterior of the wall may receive higher stresses and should usually be continuous. Tack barbed wire over the main wall wires to secure both strands. If possible, insert the tack directly over a barb.

Buttress or stub wall wires can form a loop (Figure 17b). Tack barbed wire over the main wall wires to secure both strands. If possible, insert the tack directly over a barb. If buttresses or stub walls are opposite interior walls, run wire continuous from the interior wall to the end of the buttress.

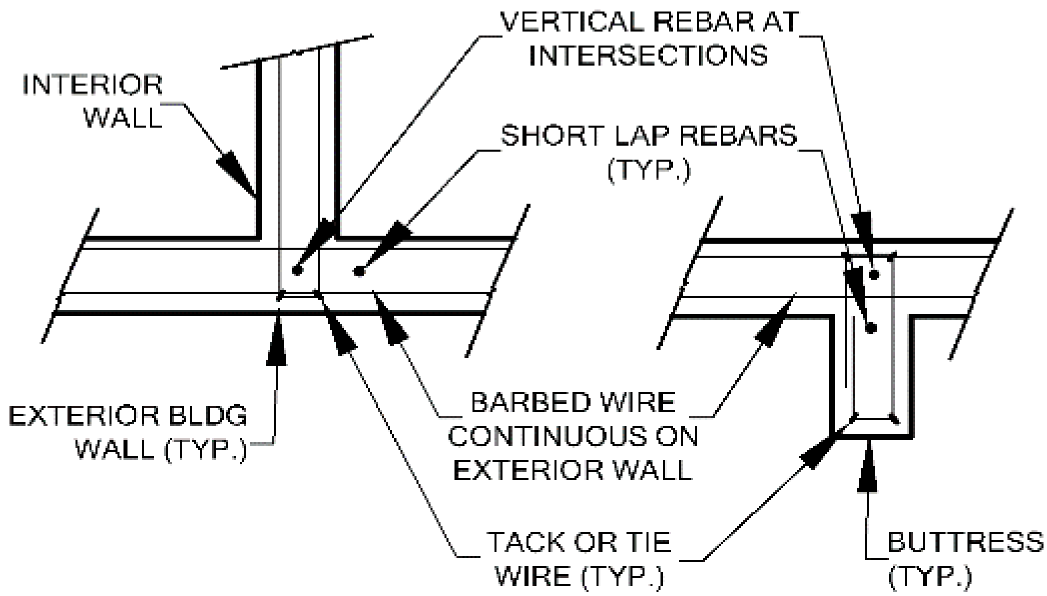


Figure 17 Barbed wire with both strands of barbed wire continuous along walls (right to left): a- At wall intersections run wire across adjacent wall, b- At buttress run wire across wall and return.

PIERS

Thickened wall areas can help stiffen highly flexible CE against possibly bulging outward.

PIERS

Because piers do not brace the walls that they are built on against uplift, limit pier height to 1,8 m (6’) or lower to reduce weight at the wall tops. To stiffen walls with large bracing line distances, build piers just over half of the wall height.

A pier is easy to build when it adds one extra wall thickness, and its length is a multiple of the wall thickness. Run wall tubes continuous next to the pier every other course (Figure 18a, b). Run barbed wire continuous along the wall. Use a loop to connect the pier course to the wall (Figure 19) and if possible weave this loop up onto the course above.

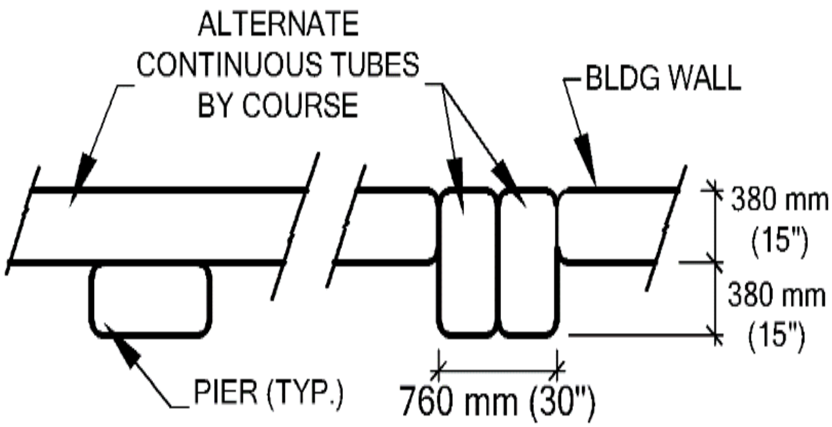


Figure 18 Piers integrated to the wall (left to right): a- Continuous tube lengths along the wall; b- Every other course interrupt the wall to run tubes across the pier and the wall.

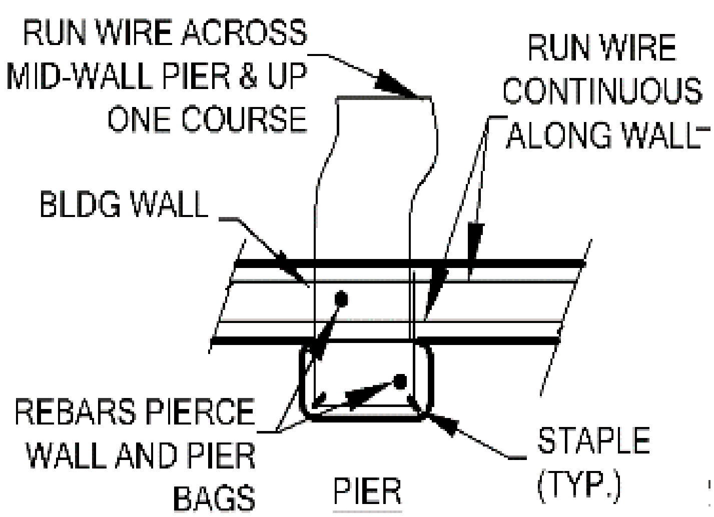


Figure 19: Barbed wire on piers should use a loop of wire woven to the next course.

Insert straight lengths of short angled pins at angles to unite piers to adjacent walls.

BUTTRESSES AND STUBS

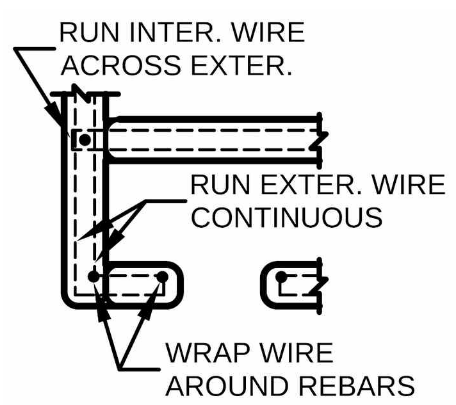
BUTTRESSES

Include these short wall portions under the bond beam. Because the ends of stub walls can increase damage from earthquake vibrations, don't build buttresses extending more than 1,2 m (4') long from walls.

Build buttresses the same width as walls, laying alternate courses continuous to the end of the buttress.

Lay the exterior barbed wire strand continuous (Figure 20b). At corners, run the interior strand of barbed wire continuous from the building walls into and around the end of the buttress (Figure 20b). It is more important that wire runs continuous than that it bends around a rebar. At corners a rebar is often needed to unite separate courses but if it is in the center of the wall, do not bend wire around it.

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 should have the wire laid similar to a mid-wall pier (Figure 19).



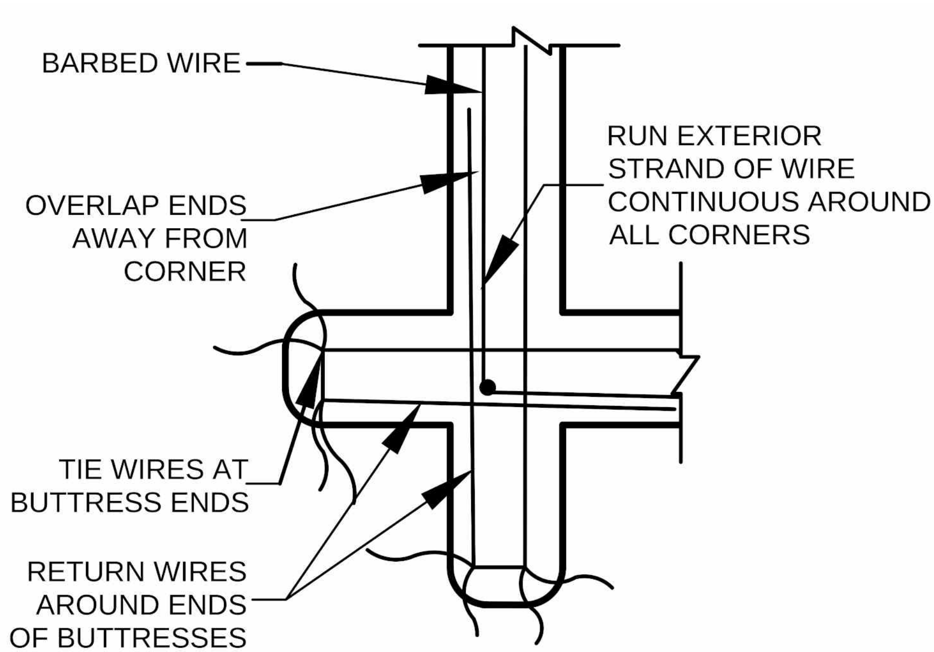


Figure 20: Continuous tubes and barbed wire unite walls to piers (left to right): a- Mid-wall buttress; b- Corner buttress tube layout; c- Corner buttress barbed wire and rebar.

6 BASE-ANCHORED CORNERS FOR MODERATE RISK

Rectangular buildings need corners with extra strength. External corners with connected vertical steel can reduce damage to the entire wall length of an earthbag building. Strong spot footings that hold embedded vertical rebar stiffly in place greatly increase the strength that resilient CE walls have to resist being warped and damaged by earthquake forces.

Vertical wall rebars should be located at least 125 mm (5") from a wall edge to allow enough cover depth for good soil embedment.

CONNECTING REBAR

Horizontal forces on walls from quake shaking results in strong upward forces pulling the bond beam off of any vertical steel. Holding the bond beam down on the rebar keeps the wall stronger to resist warping and is critical for best wall strength. Mechanical couplers have failed repeatedly in earthbag structural tests. Have the correct end on any steel rebar to be used in earthen walls.

For buildings with wood bond beams and lintels, all major verticals at corners and wall intersections, and the long rebars at lintels should have 7" (178 mm) or longer threaded rod pre-welded on the end unless a welder can work on the top of the wall to add a cross-piece after the rebar is inserted.

Smaller rebars inserted through wood lintels or bond beams may only need a short hook of 75-100 mm (3- 4”). Reinforcing pins inserted at an angle of 20° or more in buildings for low seismic risk may not need hooks bent on top if the hole is snug and the rebar end deformed slightly.

All rebars to be embedded in reinforced concrete bond beams or lintels must have long hooks. Reinforcing steel embedded in concrete should always have 25 mm (one inch) of cover or more.

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 both vertical rebars bridge it. The benefit from connecting the vertical steel rebars is much greater than the loss of longer wall masses on the course where the splice is located.

Builders may choose to use splices in some locations to reduce the need for punching tube courses. Plan ahead because no rebar inserted from above will be able to pass through a splice. The barbed wire above the splice can be run around the rebar, but below the splice use extra care to lay barbed wire near the edge of the wall, and insert rebar in the center of the wall thickness.

OPEN SPLICES

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. Tamp the shorter course against a concrete block (Figure 21a). Leave an exposed gap large enough to include the hooks of the rebars. Insert rebars into the exposed gap (Figure 21b). 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 tube end to connect them. Shake it down into the tube well and tuck the end under (Figure 21c).

Figure 21 Open splice on current course (left to right): a- Tamp against a block to form gap; b- Insert vertical and/ or diagonal rebars; c- Fill tube with concrete and tuck end under.

The concrete does not need to be completely smooth on top since the next earthen course can conform to its shape, but lay barbed wire on the course immediately to connect to the splice.

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 gaps.

Rebars inserted downward from the splice course can also be connected to the hook of a higher rebar. Support an upper rebar in place (Figure 22) or tie it to a short vertical pin inserted next to it. (Figure 22).

Open Splice Connecting Upper and Lower Rebars

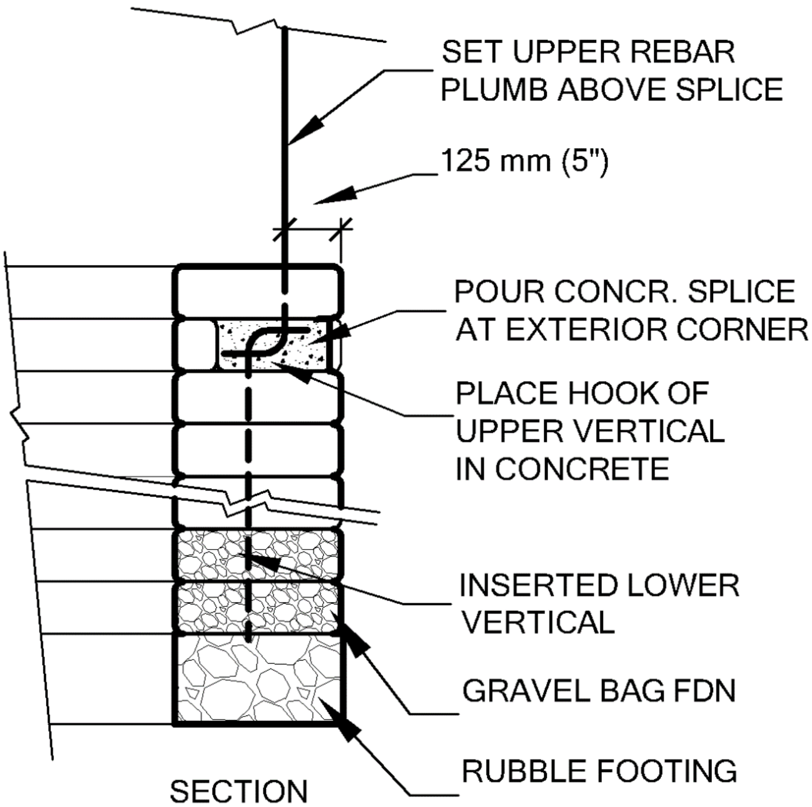


Figure 22: Open splice gap connecting upper to lower rebars.

The minimum size for a splice gap is about 180 x 300 mm (7 x 12") at a corner end (Figure 23).

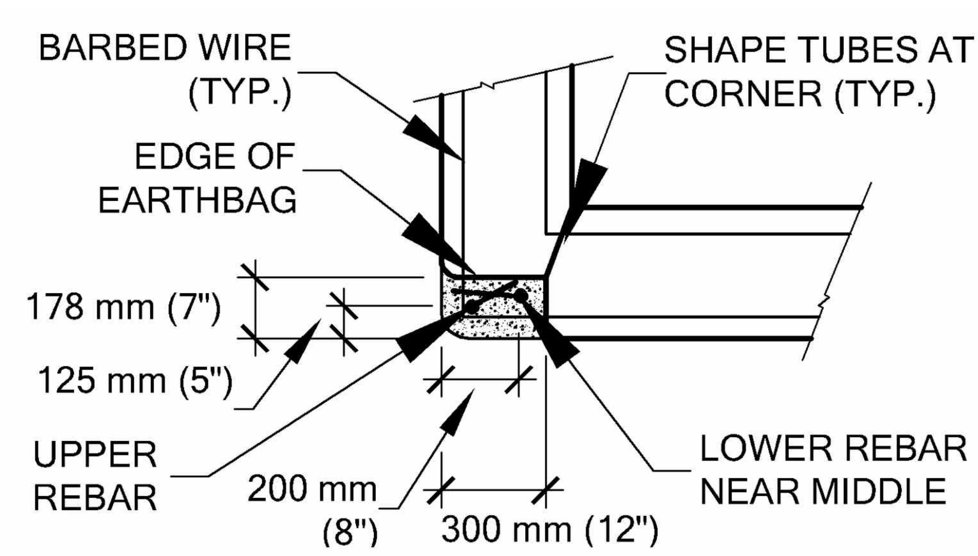


Figure 23: Use a narrow gap for an open concrete splice to connect upper and lower rebars.

At external corners the base-anchored rebar must be 125 mm (5") from one outside surface of the wall and 255 mm (10") from the other surface. Locate the upper rebar 125 mm (5") from both surfaces.

A section of mesh tube or a form to hold the concrete allow inspection of the upper rebar placement. Pour the concrete a full course deep and recheck the upper vertical for plumb.

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.

COVERED SPLICES

At exterior corners or wall ends, an upper vertical rebar can be inserted after the wall top is completed, reducing the number of new tube ends interrupting container continuity (Figure 24).

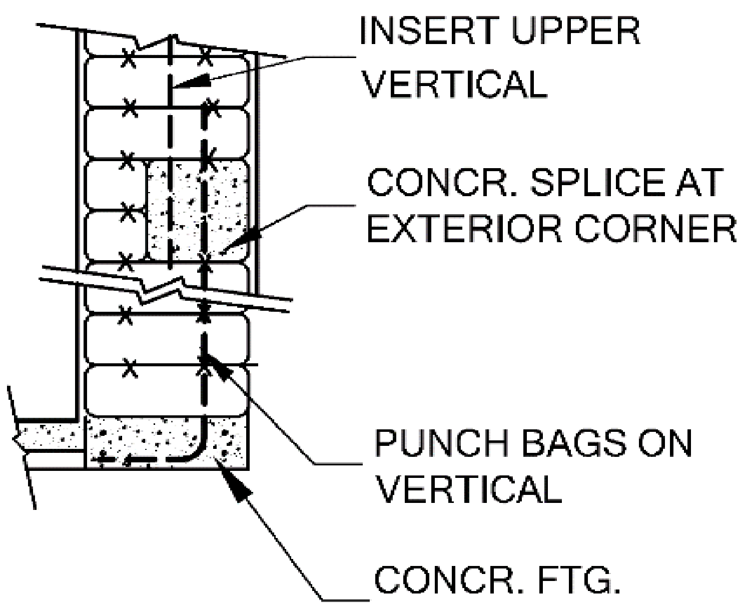


Figure 24: An upper rebar inserted into a covered splice bag two courses high, then the sandbag is emptied and filled with concrete.

But to embed a long enough section of rebar this type of covered splice must two courses tall. It must also be large enough so that builders can reliably pierce the sandbag with a rebar inserted from far above. Although only a 100- 150 mm (4- 6”) wide area of concrete is needed to connect the rebars. Sew or staple a length of tube to make the splice sandbag 255 mm (10”) in diameter and two courses high. A lay-flat width of about 195 mm (7.75”) must be at least 510 mm (20”) long.

Punch it over a mesh tube or mesh piece onto the lower rebar (Figure 25a) which extends through the sandbag and the course above. Barbed wire on the course next to the splice can be embedded in the concrete if cut near the corner with ends poked into the splice area.

Build the courses next to the sandbag. Fill the sandbag to the level of the second course top (Figure 25b) and lay barbed wire. Continue the wall above the splice level overlapping tubes at the corner (Figure 25c). At the top of the wall insert the upper rebar straight down into the splice bag.

Figure 25 An upright sandbag for a covered splice (left to right): a- Insert the sandbag onto the rebar in the mesh; b- Build courses next to the sandbag; c- Build above splice to final wall height.

Cut the sandbag and remove both sand and fabric (Figure 26a). Bend barbed wire into the space. Hold a metal or wood form one course high in place around the splice area (Figure 26b).

When placing concrete squeeze the mesh to guide concrete into the back of the void space. Strong plastic tube (like erosion control wattles) holds heavy concrete better than crocheted mesh (used to package vegetables). After concrete is firming up, trim the excess mesh (Figure 26c).

Figure 26 Making the splice (left to right): a- Remove sandbag fabric, b- Place form and use mesh to fill the top, c- Concrete splice with mesh trimmed.

7 REINFORCEMENT NEAR OPENINGS FOR MODERATE 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.

A rule of thumb used for higher strength earthbag walls is to insert verticals every 1,2 m (4’) on center minimum. But more reinforcement is not always better. Do not space long rebars closer than 460 mm (18”). Shorter angled pins should be at least 380 mm (15”) apart on average, since rebar too closely spaced in earthen walls can reduce wall strength.

Inserting Long Rebars

The longer an inserted rebar, the lower the end and any overlap with a separate piece occurs. Forces on walls from earthquakes multiply with higher distance from the foundation. A lower overlap may mean less wall damage in a serious earthquake. Next to door and window openings long rebars that extend well into the continuous walls below the openings reduce damage.

Rebar pieces as long as 2,1 m (7’) are recommended near doorways. There are several tricks to inserting 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 tool so that workers can pull the tool down around the rebar and insert lengths of steel that extend above the worker’s heads

Figure 27 Tools to insert rebars (left to right): a- Steel welded on a pipe; b- Post driver tool.

Long rebars must be inserted carefully to avoid hitting a barbed wire strand and bending out of the wall where they not wanted. Have a helper hold a guide next to the wall and/ or use a level to check for plumb when inserting long rebars.

SPACED LAP REBARS

Standard grade resilient CE earthbag can be built with less lap rebars than low-cement CE for low seismic risk areas. Some builders will choose to splice all verticals next to window openings, and may only have spaced lap bars located in the middle of longer wall panels.

For those who overlap verticals near window openings, reinforcing steel embedded 150 mm (6") from edges should be spaced as far from their paired aligned verticals as the length of overlap (Figure 27). This is important to avoid overcrowding steel too close together. Use lap rebars long enough for the distance to the main vertical rebars.

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. Insert the lap rebar in a course as high above the lower rebar as it can be located in distance. Hammer it flush with the course top. Finish by inserting the upper rebar almost directly above the first one.

TABLE 3: SPACE BETWEEN MAIN VERTICALS AND LAP BARS

Distance to vertical full-length rebar	Length of 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

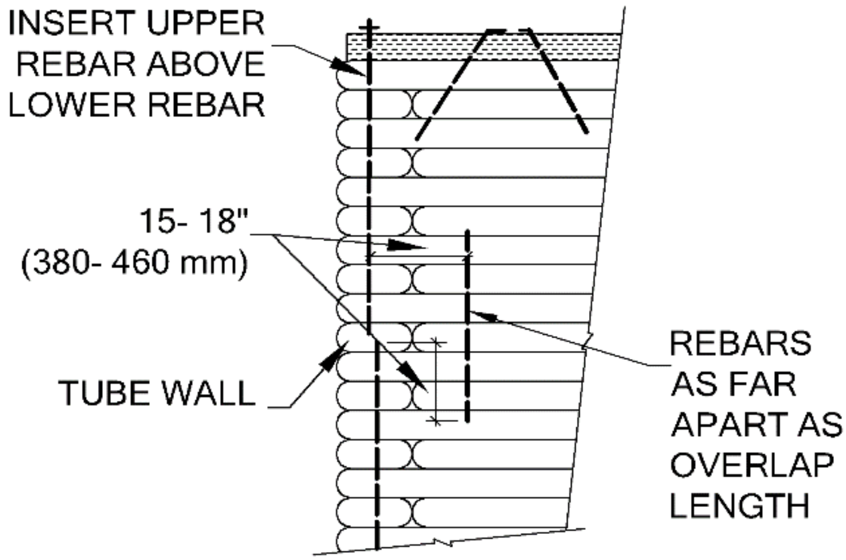


Figure 27: Improved overlapped inserted rebar technique uses a distant lap rebar.

OPENINGS

Space Wall Openings

Separate inserted lengths of aligned vertical rebar need a lap rebar that overlaps both bars. Separate aligned rebar sets can share the shorter lap rebar if it is located between them. But do not crowd rebars too close in earthbag walls.

DISTANCES BETWEEN OPENINGS

These space guidelines will prevent crowding vertical rebar reinforcement closer than 460 mm (18” apart).

Table 4: Minimum Distances between Wall Openings

600 mm (24")	between a wall intersection and center of a buttress
760 mm (30")	between two wall openings
1 m (39”)	between a wall opening and the outside edge of a building corner
1,2 m (48")	between two openings with a wall/ buttress between

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. Aligned verticals on separate openings can also share a lap rebar between the openings.

Where wall intersections occur between openings larger distances of 1,2 m (48”) are needed for good rebar placement (Figure 28). Aligned vertical rebar in wall intersections should extend from bond beam to footing to unite wall intersections. Instead of including a lap rebar, use a different course location for the break between upper and lower pieces so that rebar next to the window and within the wall junction can act as laps for each other.

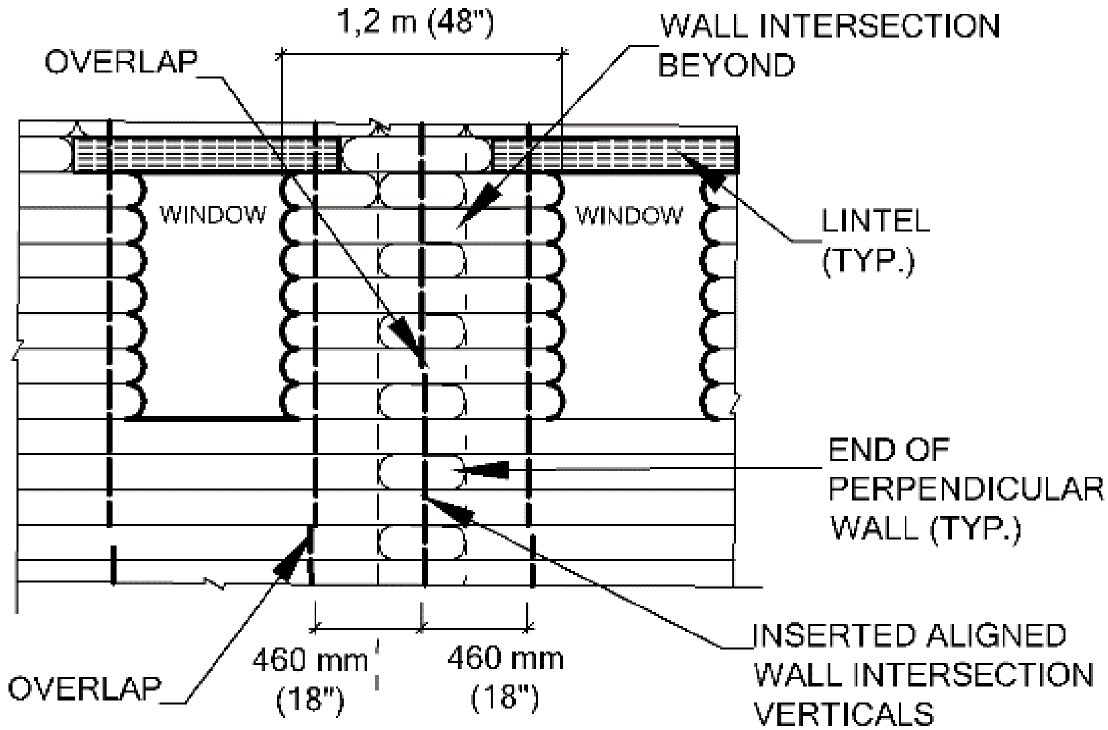


Figure 28: Use greater distance between openings when the area includes a perpendicular wall.

LINTELS

Lintel size and strength should relate to the span length and weight of wall above the opening, extending 300 mm (12”) or more each side of an opening. Wood lintels narrower than the width of the flat portion of the earthbag wall (255 mm/ 10”) should be placed on a 250 x 50 mm (2 x 10) bearing plate on the wall top to spread the weight out across the whole flat surface of the CE 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.

Use local building code for masonry buildings to choose lintels supporting less weight, and for reinforced concrete lintels.

For openings 1- 1,5 m (3' 3"- 5') wide drill holes for two or more D10 (3/8") or smaller diameter vertical rebar pins between other holes in the lintel. These spikes can be nails with small heads but should extend 150 mm (6") from the upper surface of the lintel. As the next earthbag course is filled, lift it and settle it onto these nails or pins.

Interconnect Lintels

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

Connect all windows to the courses above the lintel with a single D10 (3/8") vertical rebar pin or heavy spike nail extending 150 mm (6") up from the upper surface of the lintel. For openings more than 600 mm (24") wide or openings up to 1,5 m (5') wide use two or more pins or nails. Settle the earthbag course above down onto these nails or pins.

Connect all lintels to vertical rebars on both sides of the wall opening. 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 rebars through these holes down into the walls.

To connect a lintel to the bond beam either use separate above and below rebars, or one extra-long vertical rebar. Separate rebars going up to the bond beam on both sides of the opening need extra holes in the wood lintel. Drill holes and insert the above rebars through the lintel before placing it, 125 mm (5") from the interior wall surface and 75 mm (3") from the lintel ends. Set the lintel in place, and use holes 100 mm (4") distant and in the center of the wall for the downward inserted vertical rebars.

A single long vertical rebar connects to the bond beam when it is not inserted all the way down to the lintel level (Figure 29).

Alternately punch and cut courses above the lintel onto a pre-anchored vertical rebar. 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.

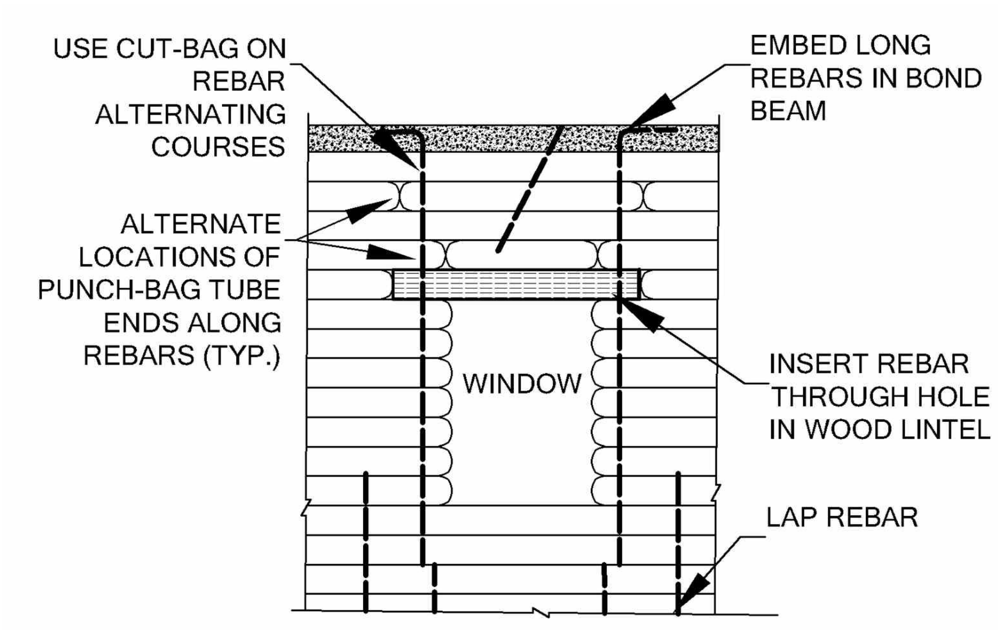


Figure 29: Vertical rebars adjacent to a window opening connect lintel to bond beam.

Always connect doorway lintels to the bond beam because doorways cause a major disconnect in one story buildings. On larger buildings also connect some window lintels to the bond beam at regular spacing.

Doorway Lintels

Attach all doorway lintels to bond beams and splice upper and lower rebars at all doorways. Connect lintels to the bond beam using punched-bag and cut-bag techniques on vertical rebars that were inserted into the lintels but left extending up to the bond beam height (Figure 30a). After courses above the lintel are finished, bend the rebar hooks down to fit above a wood bond beam or embedded in a RC bond beam.

Also connect lower vertical rebars to upper verticals with a splice at doorways. Use an open splice with an upper vertical extending above the splice, or a covered splice that upper vertical rebar is inserted into from the lintel level.

If the bond beam is reinforced concrete, separate rebars with small bottom hooks can be inserted upward through holes in the lintel (Figure 30b) after the wall is built. No punching or cut-bag techniques will be needed. Before pouring the RC bond beam, bend rebar hooks down to embed in it.

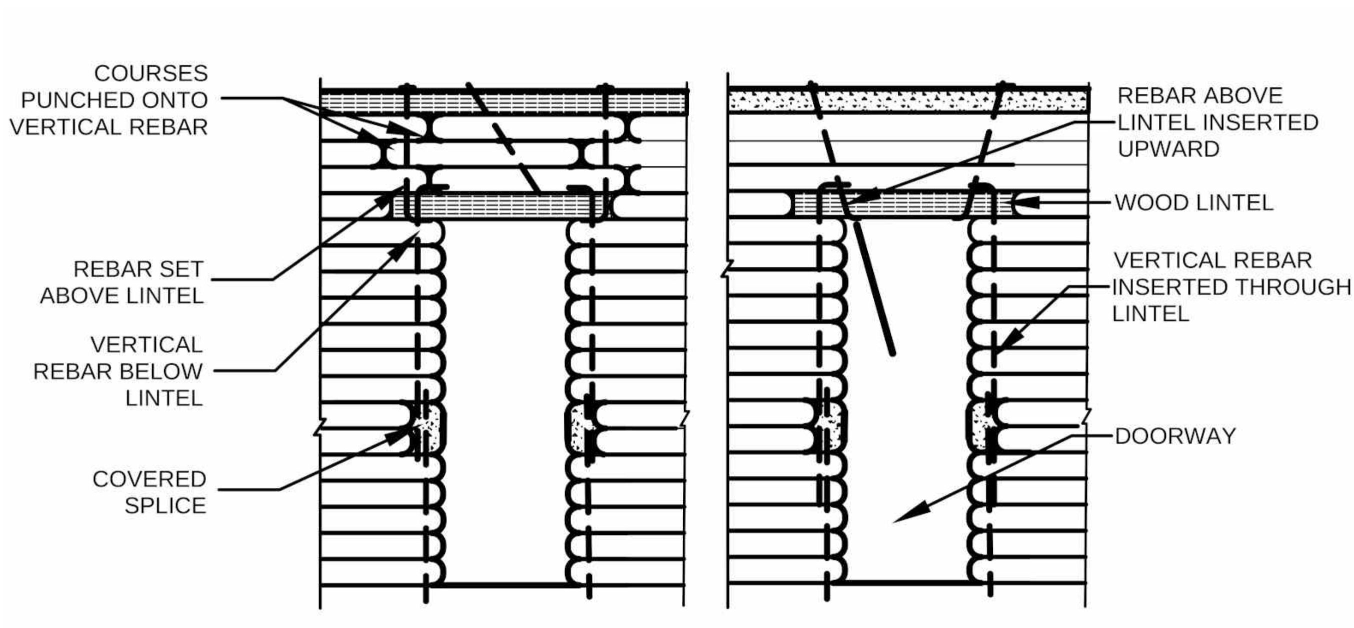


Figure 30: Splice vertical rebars next to doorways to provide vertical rebars extending below the door sill.

Window Lintels

Window lintels can be connected to the bond beam in the same ways. Rebars inserted upward can only be used when the height of wall above the lintel is less than 2/3 the height of the window.

8 BOND BEAMS FOR MODERATE RISK

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

Because bond beams receive higher force levels at the wall tops than most other parts of building walls if they undergo an earthquake, the connections to the wall and to the roof above must be stronger than many builders expect. Check with local engineers instead of assuming that traditional construction should be used.

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.

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. Conventional earthbag relies on alternating angles of pins to hold the bond beam to the wall. Because resilient CE relies on bolts or strong hooks on tops of long, embedded vertical rebar, less angled pins may be needed.

Wood Bond Beams

New Zealand’s earth building guidelines do not recommend wood bond beams at this risk level unless they are connected to a structural diaphragm.

A diaphragm at the ceiling level helps buildings resist 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.

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 tube 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

These standard-grade construction techniques for resilient CE earthbag should be used with a reinforced concrete 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.

In its standard width CE is also 9% wider (and heavier) than the earthen walls specified for New Zealand. The following (Table 5) shows bracing distances 90% of the New Zealand recommendations for adobe or rammed earth in low risk areas:

Table 5: Reinforced Concrete Bond Beam Size Estimates for Single Story

Bond beam size	Rebar size	Maximum bracing distance with light roof
285 x 150 mm (6" x 11.2")	Two D16 (5/8 inch)	4,2 m (13'- 9")
285 x 175 mm (7" x 11.2")	Two D20 (0.9 inch)	5,7 m (18'- 9")

9 OPTIONAL IMPROVED WALL TECHNIQUES

Often careful detailing can increase strength without increasing cost significantly. It may depend on the attention to detail that workers and contractors are willing to invest in a project.

SPECIAL 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.

PIN BARBED WIRE

Place pins cut from metal mesh 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. Use UV resistant cord and tie it on a barb cluster so that it cannot slide along the wire.

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

THICKENED CORNERS

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

Piers less than 1,8 m (6’) high provide more mass to make walls more stable, which can be helpful at wall corners. If bracing panel lengths can allow a limited 380 mm (15”) extension at corners, build it as a corner pier (Figure 31).

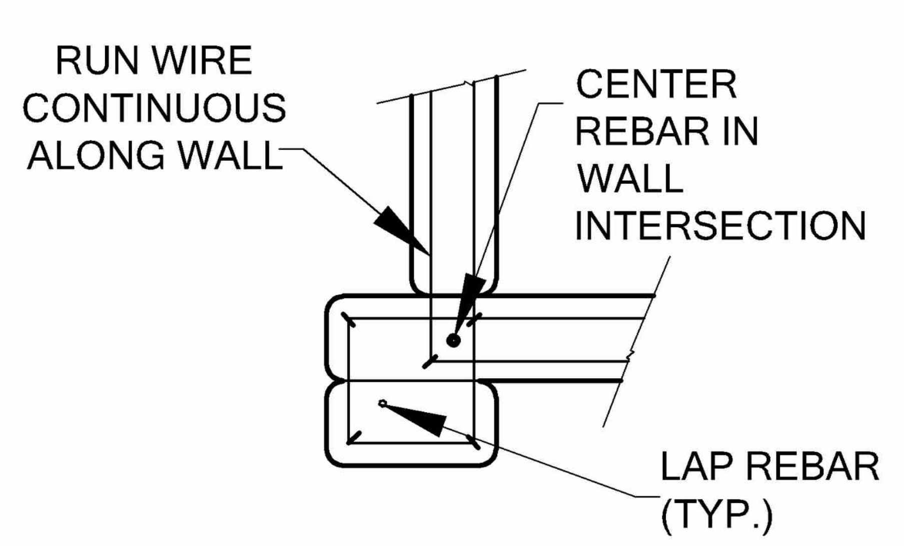


Figure 31: Corner pier

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.

FORKS AT INTERSECTIONS

Wall intersections often occur at the middle of exterior building walls. Standard grade resilient CE only has stiff connections from vertical rebars to RC footings only at wall corners. Forks use wall weight to hold wall intersections together during earthquake motion and to stiffen the response of a spliced rebar that is not base-anchored. Use a spliced fork for additional stiffening and resistance against warping where walls connect.

Build an open splice following directions on pages 33- 34. Enough room must be left in the gap to hold all the hooks after inserting the diagonals. Add some diagonal rebars from the splice to create a fork (Figure 32).

Spliced forks can also add strength to buttresses or piers.

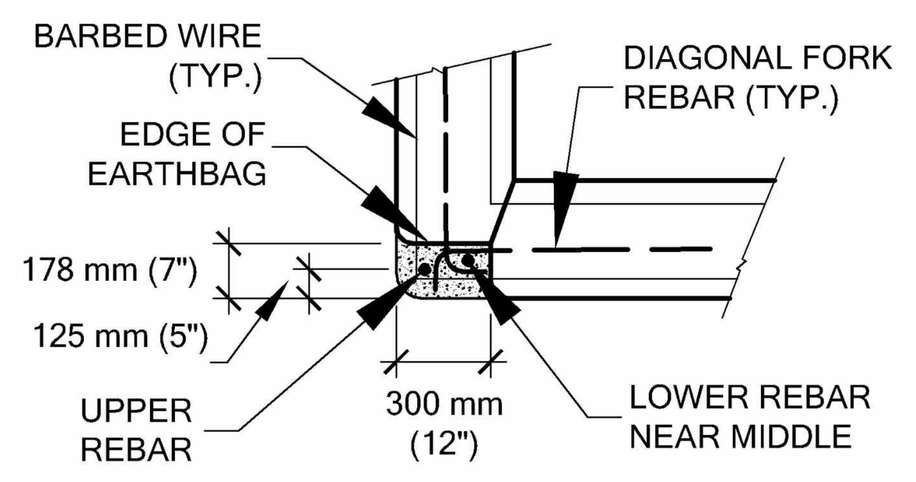


Figure 32: Reinforcement locations in a fork splice.

10 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
STU B	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