B104: EXTRA STRENGTH RESILIENT CE DETAILS

Maximized Reinforcement on Strip RC Footings

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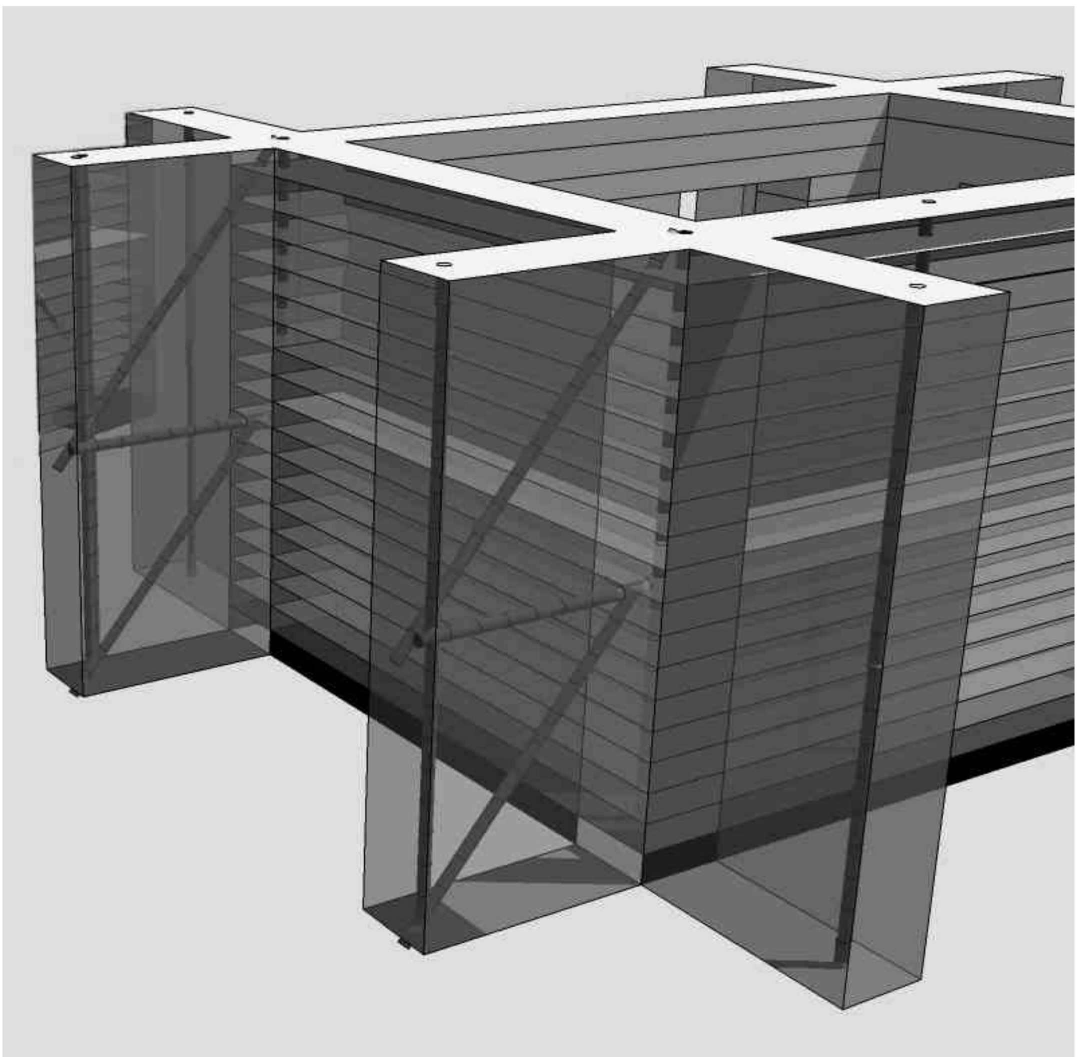

Figure 1: Embedded rebars can form trusses in contained earth buttresses or walls.

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No engineer has specifically approved the construction detailing contained in this volume. But thanks are due to engineers who have given invaluable comments about reinforcement techniques for earthbag, including:

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1 INTRODUCTION

Earthquakes often damage or destroy unreinforced buildings of earth, stone, or brick. Earthen walls are usually brittle, but earthbag shows surprising toughness and flexibility. Earthbag on gravel bag base walls has been used for low-rise buildings in seismic risk areas because it survives quakes better than traditional earthen walls.

Conventional earthbag building walls (Figures 2) use courses of natural soil interlayered with barbed wire under a stucco or plaster finish coat (Figure 3).

Figure 2: Earthbag building wall under construction in Nepal summer 2016.

Figure 3: Plastered School in Phuleli by Edge of Seven and Small World Nepal survived the 2015 earthquakes without damage.

Because these walls are more than 90% local subsoil and use limited amounts of manufactured materials, construction costs in the developing world are usually significantly lower than for fired brick or concrete block walls.

Earthbag's natural wall material is contained in fabric forms and lightly reinforced. Earthbag buildings survived moderate quake forces of 0.7 g levels (70% compared to gravity) in Nepal during 2015. Unreinforced or poorly-reinforced masonry buildings were severely damaged near many undamaged earthbag buildings.

No anecdotes can prove earthbag's ability to survive earthquakes, but one serious accident in rural Nepal was encouraging. A heavy commercial truck drove off of a steep hill top. The vehicle ended up on top of an earthbag residence (Figure 4). This 1.5 story building had earthbag walls and a welded tubular steel floor structure.

After the accident, the roof had to be rebuilt but earthen walls were not damaged.

Figure 4: Roof was damaged but not the earthbag walls by this truck accident (C. Ziegler, used by permission).

Seismic risk levels in the same areas of Nepal can exceed the force of gravity, so existing earthbag buildings there have not yet faced their highest possible earthquake forces.

Earthbag vs. Earthquakes

For buildings to predictably be usable after stronger earthquakes, resilient contained earth (CE) earthbag is an improved building technique that uses a combination of tested strength soil fill and reinforcement systems chosen for the expected level of earthquake force. For safety, one or two story building plans must contain enough lengths of bracing wall panels to keep adjacent walls upright. A bracing panel must be solid wall without doors or windows. The exact lengths of bracing panels must be matched to the specific level of wall strength, the spacing between bracing walls, the wall height, and the total weight of the roof and/ or loft or upper light story.

To help builders and designers understand that different levels of risk require different levels of wall strength, this author has defined several systems of reinforcement. Low-cement CE uses very little Portland cement, but has better connection of embedded rebar and foundation courses than conventional earthbag. Standard grade CE is significantly stronger because spot footings of reinforced concrete at corners allows vertical reinforcement to be more strongly braced against warping forces.

High strength CE exterior walls are built on footings surrounded by a strip of reinforced concrete that allows all vertical reinforcement to be base-anchored. The basics of high strength CE are detailed and explained in *B103 Build High Strength Resilient CE Earthbag* which can be found online at BuildSimple.org/ Resources.

The details in this booklet increase the overall wall strength and reduce potential deformation of high strength CE by specialized combinations of embedded steel reinforcement. Improvements possible include steel webbing in corners or buttresses and welded steel tube opening forms to natural earthen walls.

How Strong can Resilient CE Be?

Structural testing is not complete for resilient CE walls. But engineers designing buildings based on current structural data, and engineering students who hope to provide needed research will find the details in this booklet use strategies based on structural design and are also practical for ordinary contractors using common materials to build.

Designers and planners need to compare earthbag to existing research-based guidelines developed for earth block walls in New Zealand. When the performance of specific types of earthbag walls has been fully explored, engineers can adapt these guidelines for CE walls. Then designers will be able to more economically size buttresses and bracing walls and select intensity of reinforcement needed for specific small buildings in specific locations.

Most resilient CE earthbag wall samples tested to date have been 60- 80% scale, the larger tests without plaster. These tests showed that earthbag wall panels deform significantly but do not lose material or collapse. Corners with continuous barbed wire appear highly resistant to detachment or gapping. Finish plaster or stucco appears to provide a large proportion of earthbag’s resistance against in-plane forces. Intact fabric containers do not increase wall shear or out-of-plane strength. Unlike civil engineering soil bags, earthbag vertical wall strength is based on the compressive and/ or tensile strength of dried cohesive soil fill in the bags or tubes. The decay-resistant fabric serves the important function of containment- holding even deeply cracked wall material in place,

At this time actual strengths can only be approximately estimated. Research indicates that low-cement CE may perform under in-plane stresses similar to the unreinforced earth block walls specified in New Zealand’s earth building codes. Standard Grade CE appears to have higher ductility but only slightly higher strength against shear than unreinforced earth block walls which are allowed in moderate seismic risk areas up to 0.6 g pga risk at 2% probability of excedance or pe (equivalent to 0,12 g at 10% pe).

When compared to the intensively reinforced earth block walls specified for New Zealand's seismic risk levels up to 1.7 g pga at 2% pe (equivalent to 0.3 g at 10% pe), even the most hopeful estimates based on CE research indicate high strength resilient CE is unlikely to resist more than forces approximately half as high. Extra strength details will be very helpful for low-cost designs in regions where Ss (short-period) ground acceleration is expected to reach or exceed 1 g at 2% pe (or 0,2 g at 10% pe).

The details in this booklet require more care to build, but will increase strength and toughness beyond that of high strength CE walls. Builders without code restrictions or requirements from investors may not be willing to use more complex techniques or increase the amount of costly concrete and steel. But builders and owners who invest modest amounts of increased labor time and increased material costs will create stronger natural buildings.

Engineers who research reinforcement similar to that shown in this document will provide the incentive for builders to build more carefully, and may well save many lives and improve economic strength of quake-torn regions in the future.

Earthbag Construction

Those unfamiliar with earthbag construction should review the introduction in *B103 High Strength Resilient CE Earthbag* as well as some of the conventional earthbag construction resources mentioned there. Videos in Owen Geiger's series online are helpful, but working with an experienced builder or attending a hands-on workshop is critical to overcoming beginner mistakes. Earthbag is a low-tech process that requires few power tools, but it is a heavy and laborious process. Site supervisors must be skilled at maintaining plumb walls.

Keep in mind as well that resilient CE for seismic risk must have all building elements consistently stronger than for conventional earthbag. Safe buildings depend on quality of soil fill and consistent moisture levels and building plans suitable for seismic risk as well as these specific reinforcement details.

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 metric and imperial units are rounded even though they are not exactly equal.

2 EXTRA STRENGTH DETAILS FOR RESILIENT CE

Special details can be chosen for use throughout a building or for specific locations to reduce vulnerability to damage.

High strength resilient CE earthbag walls rely on embedded continuous or connected verticals which span from footing to bond beam. These rebars are stiffly base-anchored in reinforced concrete, either a narrow confining strip bound to gravel bags or a full-width RC footing.

The same kinds of steel connections used in high strength CE are combined into more complex reinforcement assemblies (Figure 5) that include doubled bracing panels or trusswork webbing of diagonals and horizontals connected to horizontal bond beam and/ or footing steel

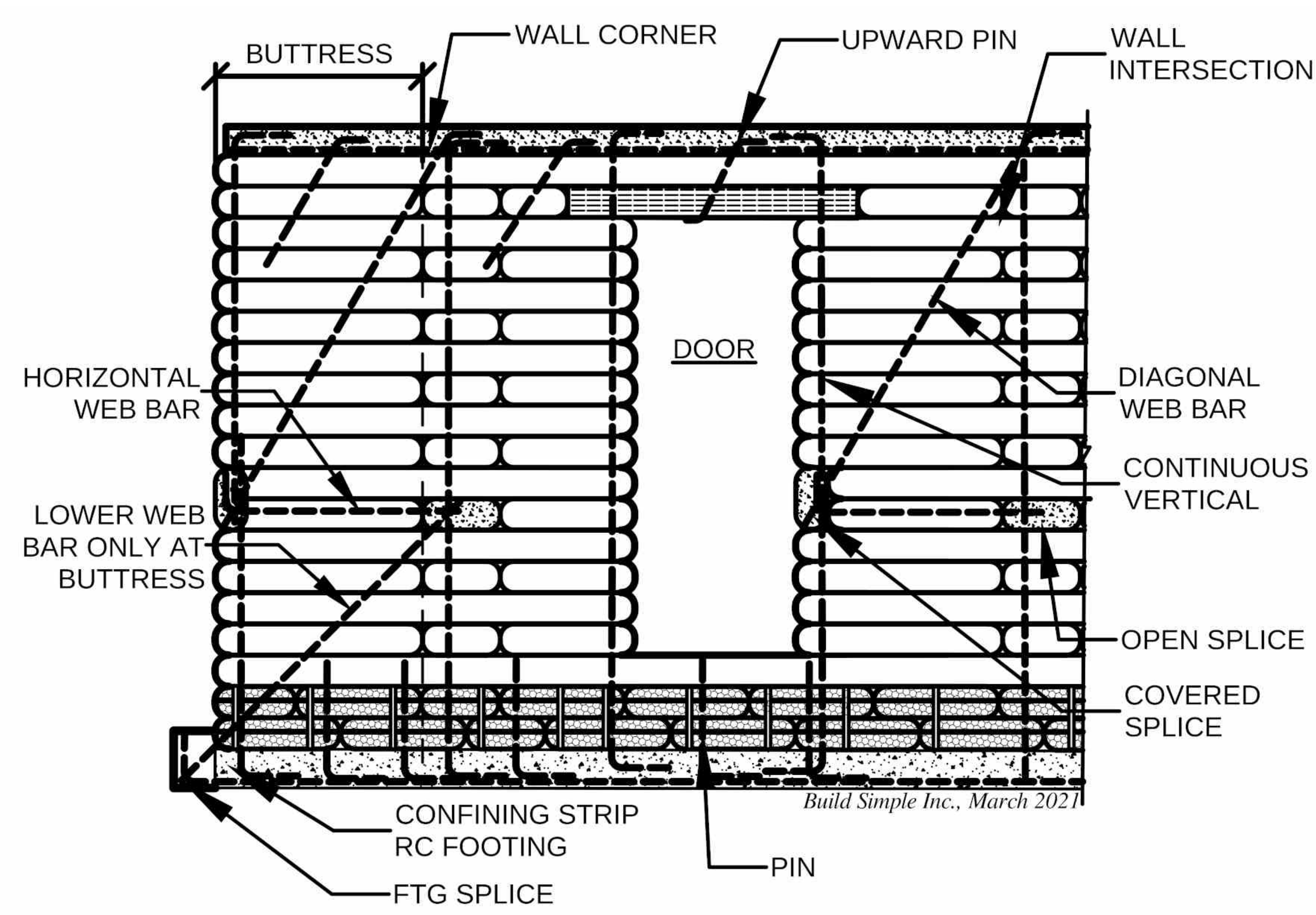

Figure 5: Improved reinforcement system for highest strength on RC strip footings.

Additional wall strength also results from:

- minimizing disruption to tube and dried fill continuity by careful use of punching, cut-bag and inserted steel
- integrating welded steel frames for doors and windows into vertical reinforcement (figure 6)
- inclusions of stronger soil fill at stress points

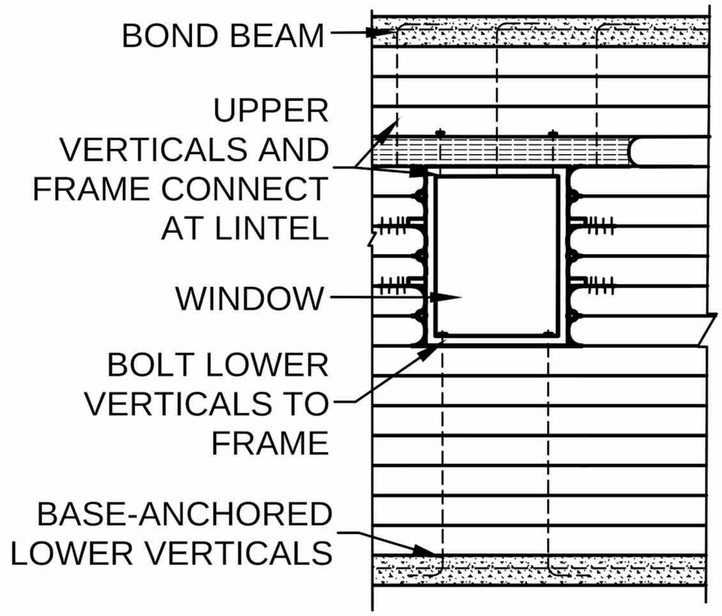

Figure 6: Welded steel frames can contribute to wall strength if well integrated to reinforcement.

Because there are so many options for reinforcement available to builders and designers, a section on locating reinforcement has examples for different possible combinations.

One of the most important ways to protect heavy building walls from earthquakes has never been attempted with earthbag, but should be mentioned. Base isolation and/ or vibration damping techniques have seldom been applied to inexpensive low-rise buildings.

Earthbag walls offer potential to reduce vibration or prevent transmission of dangerous quake forces from the ground upward, but will need specialized details. A final chapter includes some suggestions for ways to isolate resilient CE wall reinforcement from ground motion and/ or allow some possible vibration damping.

This author hopes that research facilities with shake tables will undertake needed exploration of this unusual material’s potential.

3 LOCATING REINFORCEMENT

Horizontal rebars in the reinforced concrete footing and bond beam join with vertical rebars to form a reinforcement grid. Vertical rebars that are connected to both a stiff footing and stiff bond beam embedment greatly increase strength and transmit forces to protect earthen wall material whether they are full-wall height or occur in shorter lengths that are spliced together with chunks of concrete.

Vertical rebars that are only attached at the top contribute stiffening and less strength.

In this booklet 'connected' vertical refers to a continous or strongly spliced rebar stiffly anchored in reinforced concrete at both top and bottom. The bottom is usually in an RC element of the footing, but if base isolation or damping courses are used (see section 7) the bottom may be anchored in an RC ring beam element above the interior floor level.

Vertical Reinforcement Spacing

Designers must choose between possible different intensities of reinforcement. Use elevation views to check spacing. For some buildings at modest risk sites connected rebars can be alternated with easier-to-build inserted rebars (Figure 7). Connected rebars may be most important near doorways and corners or buttress intersections. Locate connected reinforcement evenly spaced along walls.

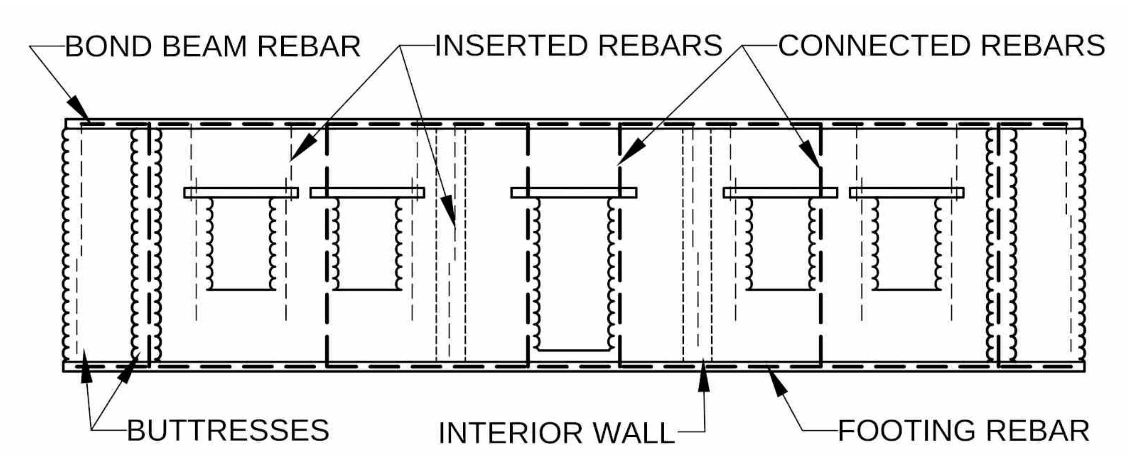

Figure 7: Evenly spaced connected verticals alternating with inserted rebars

Connected vertical reinforcement can also be densely repeated on walls:

- at corners and every opening on exterior walls
- also at 1- 1,2 m (3'-3"- 4') on center in wall panels without openings
- also at major intersections of interior walls and at the ends of buttresses

Since connected vertical rebars protect against both in line wall forces and perpendicular bulging forces, for high risk areas buildings can have most verticals connected to the footing and bond beam to reduce deformation in both directions (Figure 8).

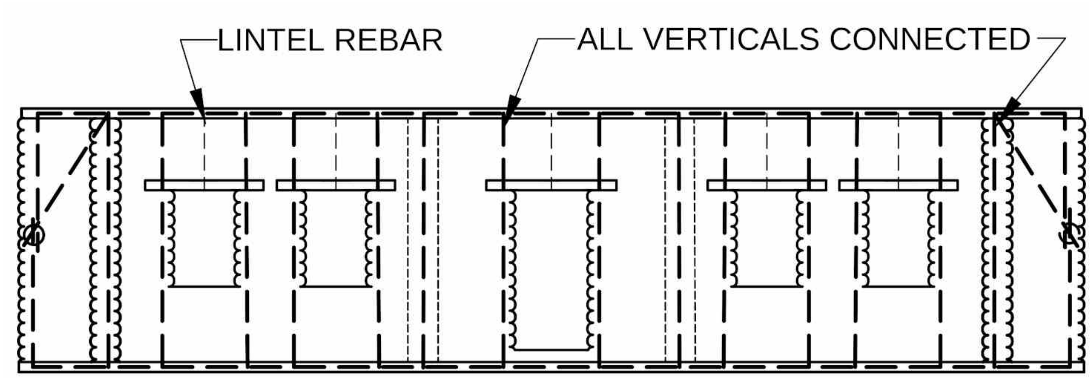

Figure 8: All verticals at all openings connected, with added pins above lintels.

Buttresses (short stub walls that extend outward from external walls to serve as bracing panels) can increase the bracing capacity (and the ability to survive shaking forces) of buildings. But as walls connected on only one end, buttresses can have lengths no longer than 1,2 m (4') maximum without increasing instability during earthquakes that have high motion levels perpendicular to the buttress.

High strength resilient CE has diagonal embedded rebar braces on at least one side of each corner (Figure 9a). Extra strength detailing can include stiffer doubled braces (Figure 9b) or full-height rebar trusses (Figure 9c). The more triangles that reinforcement forms, the more force the embedded rebar assemblies can resist. These doubled braces or full rebar trusses can be used where structural analysis shows a building needs extra strength and/ or stiffness.

Strength of wall panels containing these reinforcement types will depend on soil fill compressive strength, rebar diameter, quality of splice concrete and length of rebar embedment. Further testing is needed to prove actual performance.

Steel rebars in resilient CE walls increase material cost and take more time to locate and build around. Reinforcement intensity must be carefully chosen. Even if more steel increases wall strength, too much steel may make high strength earthen construction impractical.

Crowded steel reinforcement can concentrate stresses too much for moderate strength earthen wall masses. Don't locate vertical rebars embedded in earthen walls closer than 450 mm (18") apart. Research for cob wall shear strength indicated that at 300 mm (12") spacing (horizontal and vertical) rebars reduced wall strength.

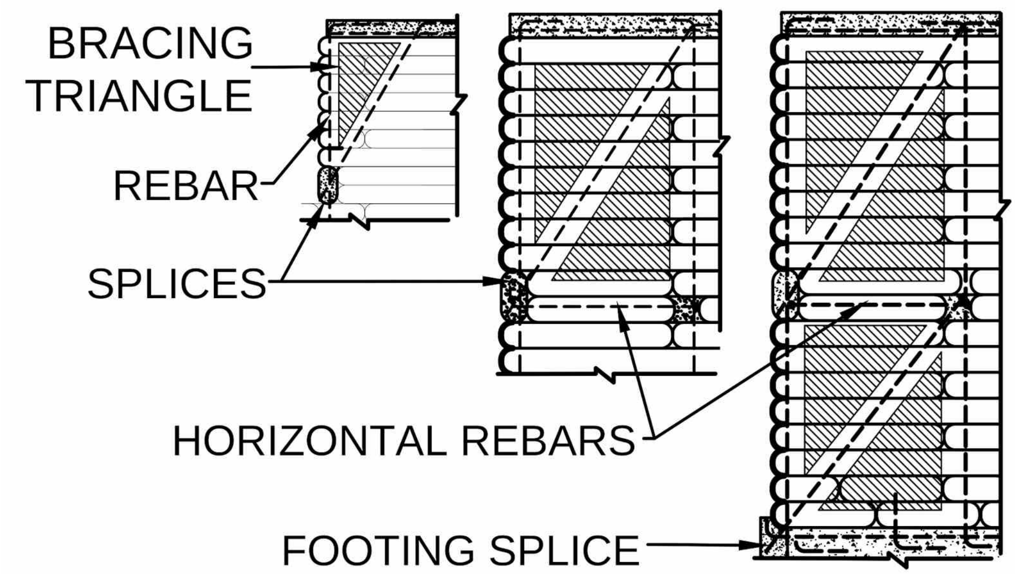

Figure 9 Embedded rebar bracing (left to right): a- One triangle at wall tops; b- Doubled bracing triangles with an added horizontal rebar; c- Full-height rebar truss at wall ends or corners.

Use braces at wall ends or next to corners or wall openings. In most buildings, stronger reinforcement is appropriate at exterior wall corners and/ or buttresses (Figure 10).

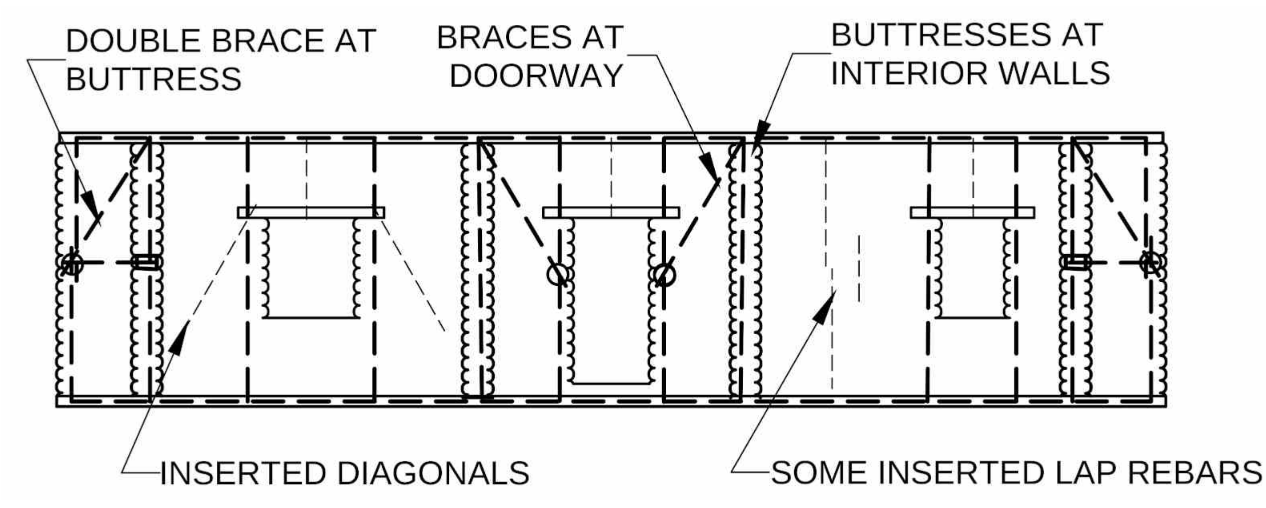

Figure 10: Most verticals connected near openings but inserted bars in larger wall panels.

Because doorways disrupt the wall continuity more than short windows, stronger double braces may be desirable on one or both sides of a doorway (Figure 11). Because upper walls are subject to the highest forces during horizontal shaking, wall material above windows may be stiffened with upward diagonal pins connecting lintel to bond beam.

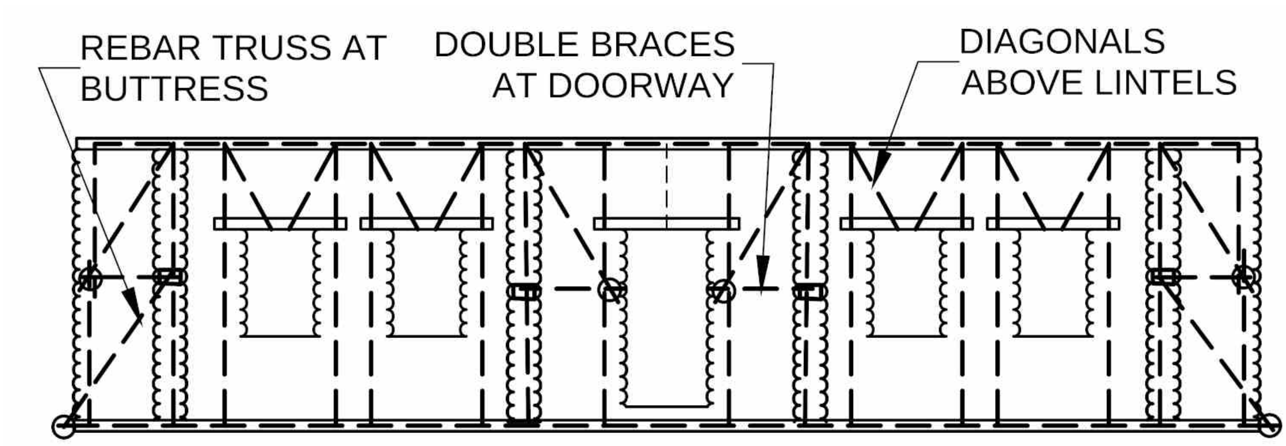

Figure 11: Maximum reinforcement for a building with closely spaced windows.

Although single or double braces can be used near openings, a full rebar truss can only be located at a wall end or buttress end so that the lower diagonal can be connected to the footing (see section 5).

Head Joints in Wall Material

Base-anchored rebars must have earthbag courses either punched onto or cut to surround the steel.

Cuts to fabric containers leave soil fill somewhat vulnerable to mechanical damage unless they occur inside the overlapped tubes found inside wall corners. Builders may be able to tuck a fabric patch into a tube cut to reduce risk of wall mechanical damage at straight wall rebar locations.

Punched-bag technique can only be applied near the beginning of a tube, and is hard to apply to rebars extending more than 1,2 m (4’) above a course. When builders punch a bag onto a steel rebar it causes no damage to the fabric container.

If courses are punched onto a mid-wall rebar, a new tube segment must be started nearby. Because rebars are needed near every wall opening or corner on high strength walls, the other end of a punched-bag tube always needs a cut to embed a rebar.

When connected vertical rebars are located in straight wall panels or near door or window openings, head joints disrupt the continuity of fabric containers and dried soil wall masses. A little less course disruption occurs when connected vertical rebars near wall openings are spliced instead of continuous. But splices cannot be easily built in straight walls, and take extra care and labor time next to wall openings. For this reason some inserted lap rebars may be chosen instead of all connected verticals.

Courses can be built around mid-wall rebars by mixing punched-bag technique with cut-bag technique. Tube ends must alternate sides of a connected rebar to allow good overlap at the head joints (Figure 12a). Punched-bag technique must have head joints 200 mm (8”) from vertical rebars because the tube end is only filled mm 255 mm (10”) deep or less. Strong builders may be able to punch some ‘heavy’ tubes filled up to 460 mm (18”) deep (Figure 12b). Under the sills of windows that are 600 mm (24”) wide or narrower, heavy punched tubes result in one central head joint.

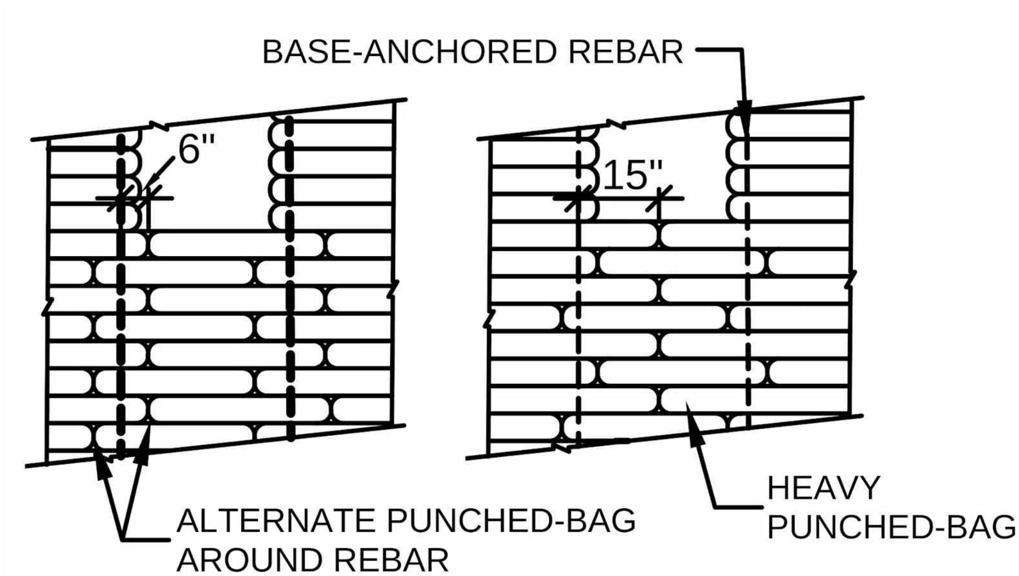

Figure 12 Punched tubes beneath a window opening (left to right): a- alternate around rebar for overlap distance; b- Use heavy punched tubes below center of window.

To alternate punched-bag with cuts, start punched-bag tubes at least 230 mm (9”) from the rebar (Figure 13a) for best overlap distances. Heavy punched-bags can provide even larger distances between cuts near vertical rebars and head-joints (Figure 13b).

Instead of starting at a building corner, punched bag course segments must be built from the punched rebar location outward. When cuts are used near wall openings, alternate between the wall side and the wall end where a frame in the opening will protect the cut tube ends.

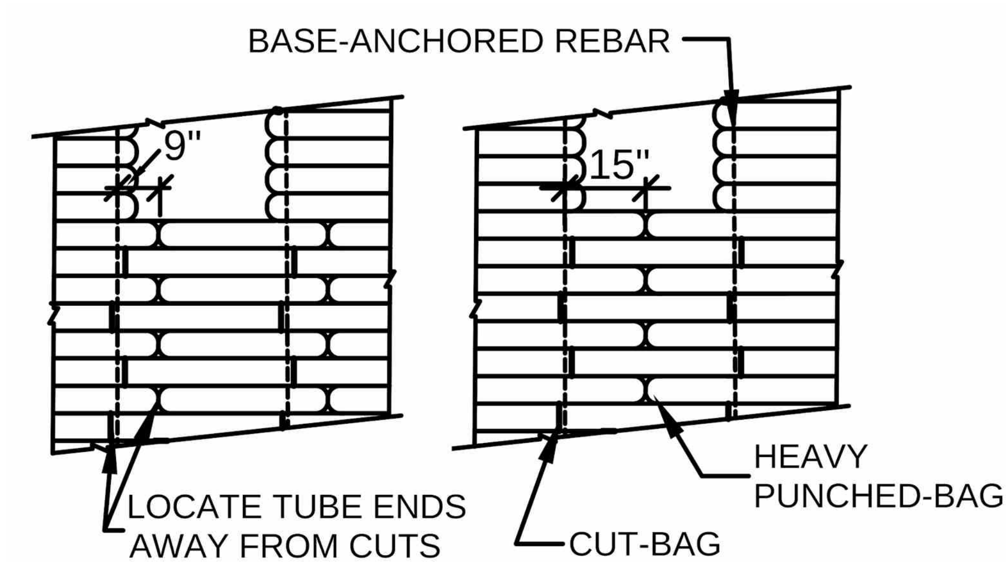

Figure 13 Punched- and cut-bag techniques alternating (left to right): a- tube ends when punched-bag is built in one direction only; b- less tube ends with heavy punched-bag.

Another way to minimize disruptions to course continuity may be possible if skilled builders merge head joints by removing fabric from tube ends at head joints so that the soil fill connects when tamped.

4 MODIFYING FILL

Resilient CE is a unique material. The bond between dried cohesive soil fill and embedded barbed wire barbs or deformed steel rebar determines wall strength. Stronger fill creates tough walls that can twist when high forces are applied to avoid permanent warping damage.

Because barbed wire barbs flex they allow walls to warp and then also retract somewhat. The performance of these types of geo-composite vertical walls have never been analyzed under vibrational forces.

Natural unstabilized subsoil may be responsible for some of CE walls' ability to warp without cracking the dried soil masses. Testing shows solid imprints around rebar that is still firmly bonded to fill without fill crumbling or cracking even after rebar has rotated 10 degrees under extreme stresses. Soil fill stabilized with Portland cement may not have that ability to compact near and/ or flow around embedded steel.

This author does not encourage the general use of chemical stabilizers for earthen building walls. Adding Portland cement does not always increase strength of soil fill. And because earthen walls are massive, relying on stability as well as strength, stabilized walls require large amounts of Portland cement, lime and/ or other chemicals. Careful analysis of costs may show that if earthen walls cannot be built unstabilized, other thinner walls of higher strength materials may in the end be less damaging to the environment.

Localized use of areas of stronger fill or chemically stabilized fill may sometimes be worth the extra labor and cost.

Increasing Fill Strength

Large amounts of moderate strength subsoil can have strength improved by adding smaller proportions of a soil that contains a strong clay. Natural additives can increase soil fill strength dramatically.

Additive mixes should use the most easily available materials in the smallest proportions. Choose exact mixes based on actual test results, even if the tests used are simple field approximations of unconfined compressive strength. 3 mm diameter balls can be dried and crushed under foot to estimate strength- see *B30 Estimate Soil Strength with 3 cm Balls,* online at BuildSimple.org/ Resources. For more accurate results to carefully choose the most helpful proportions of additives, use fist-sized samples made in toilet paper tubes and crush them under a small lever made of scrap wood- see Build Simple's *D31 Field Tests for Strength of Building Soil* online also.

There is no way to guess what mix will give soils of a specific strength. Stronger soils actually have particles of every size that pack together well. Sometimes the strength of a very smooth textured soils is increased by adding a small proportion of sharp sand.

Mixing even natural additives into a large soil pile takes time and energy. Both soil and additive must be measured before mixing. Builders must consider whether estimating soil pile volume and mixing in clay and/ or sand will be easier done to an entire pile with a bulldozer or animal labor, than to have laborers measuring each wheelbarrow load and stirring separately.

Mix materials in the easiest form. Dry clay is hard to crush, and powdered clay can cause lung disease if inhaled when mixing. Soak to soften and then pour liquid clay over other material to mix it in. Layer sand, grit or loose soils on stickier soils and tread them in to mix.

Stronger Fill Inclusions

Improved fill may be helpful even if it is only limited to specific areas of walls.

Add extra strength where stresses concentrate so that barbed wire barbs and steel rebar stay put without damaging dried soil masses. These include:

- upper half of walls within 300 mm (12”) of corner rebar
- upper half of walls within 300 mm (12”) of wall intersections
- within 460 mm (18”) of openings or corner areas with a bracing diagonal or trussed reinforcement
- specific bracing wall panels
- all buttresses, or some buttresses important for bracing

Designers may space buttresses at regular intervals for the sake of appearance, but check the plan for bracing need to see if some buttresses are more necessary than others. These important buttresses can also be strengthened with extra wire mesh pins or barbed wire as well. For more information about checking plans for bracing, see *D91 Design Resilient CE Earthbag Buildings for Seismic Risk* online at BuildSimple.org/ Resources.

Other locations may benefit from stronger fill to resist crushing. Horizontal forces pushing in line with walls result in wall ends rotating upward. Even if a wall segment is restrained by a connected vertical rebar, if there is any slack between the elements, a slight rotation can crush the ends of courses at the bottom of the rotating section. This pressure usually acts on the toe or bottom of the wall opposite the horizontal pushing force. During an earthquake as movement starts the heavy tops of wall rocking in line with the wall, the mass itself will tend to cause this type of crushing force to both ends of the wall base.

Crushed material is held in place by intact earthbag containers, but the course strength at that area is limited to the strength of the fabric, and the fill no longer attaches to reinforcement. In severe earthquakes, areas of wall between windows may also rotate upward and disconnect from the continuous wall courses under the windows (if connected rebar do not hold them in place).

Stronger soil fill may be helpful for high seismic risk areas if used in 400 mm (16”) length sections:

- on the bottom two earthen fill courses near doorways, wall ends and exterior corners
- on the course above the window sill level next to the window

Plan ahead carefully if using even small amounts of chemically stabilized soil. If builders choose to use chemical stabilizers to increase fill strength, be aware that rebar cannot be inserted through stabilized courses.

Cure time for stabilized soil is fast and the fill cannot be used if it sits too long. Also chemically stabilized fill cannot be reused if the wall is ever damaged.

5 EMBEDDED STEEL REBAR ASSEMBLIES

Interconnected steel shares forces throughout earthen walls to resist higher forces with lower amounts of damage. More complex assemblies can be located near corners, buttresses or wall ends. Simple braces can also be located next to doorways in wall panels, or modified to function above lintels.

CONNECT LINTELS TO THE BOND BEAM

Vertical rebars near wall openings must pass through lintels, so wood lintels can serve as connections between verticals above and those beneath. They can also connect multiple rebars spanning from the lintel to the bond beam.

Lintels over openings 760 mm (30”) or wider need pins on top to unite to the courses above. As the earthbag course above is filled, lift it and settle it onto one or more short vertical pins. Or provide stronger connections to the bond beam with diagonal rebars (Figure 14).

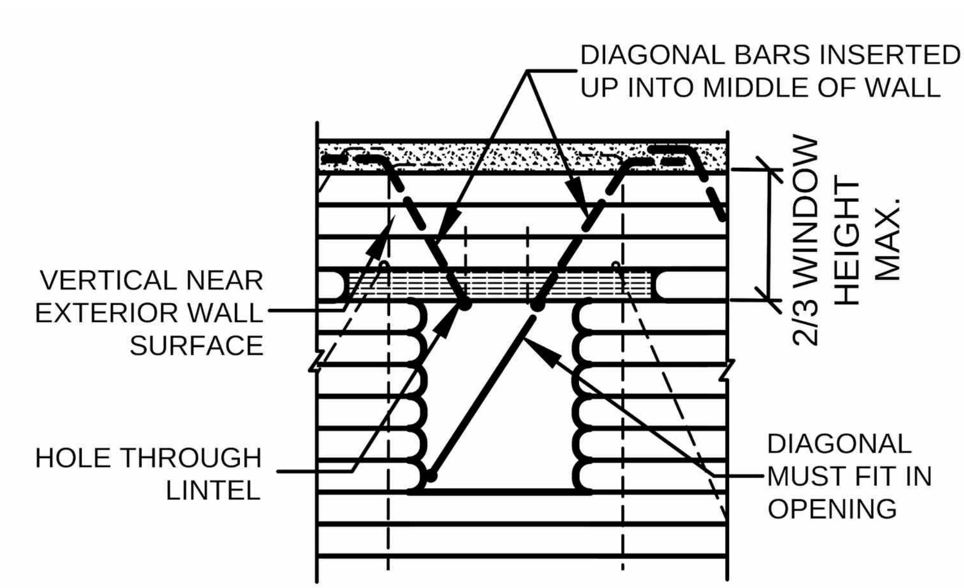

Figure 14: Diagonals above window openings provide extra connections to the bond beam.

When the height of wall material above a lintel is less than the height of the window, diagonal reinforcement can be inserted upward through a hole in the lintel. Use a rebar with a short 75- 100 mm (3- 4") hook bent on the end at 90°. Hammer this pin up through the center of the wall into the bond beam. Finish by bending a hook on top to embed in the bond beam.

Lintels used with diagonals should have verticals 230 mm (9”) from the opening. The height from the top of the window or door to the top of the wall must not be more than 2/3 the opening height. Drill the holes with a guide pole or string to give an accurate angle that will allow the rebar to fit in the opening correctly.

Bracing and Trussed Panels

Inserted diagonals next to corners or openings become braces when they connect vertical rebars to horizontals in the bond beam or the footing. The simplest brace is a single located near an exterior wall corner or the end of a stub wall or a buttress (Figure 9a).

If a horizontal rebar is added between two vertical rebars, the doubled force triangles add more strength to the upper wall (Figure 15). A covered splice is needed next to a wall end or opening, but the other end of the horizontal rebar can be inside a wall panel or wall intersection and embedded in a simple open splice.

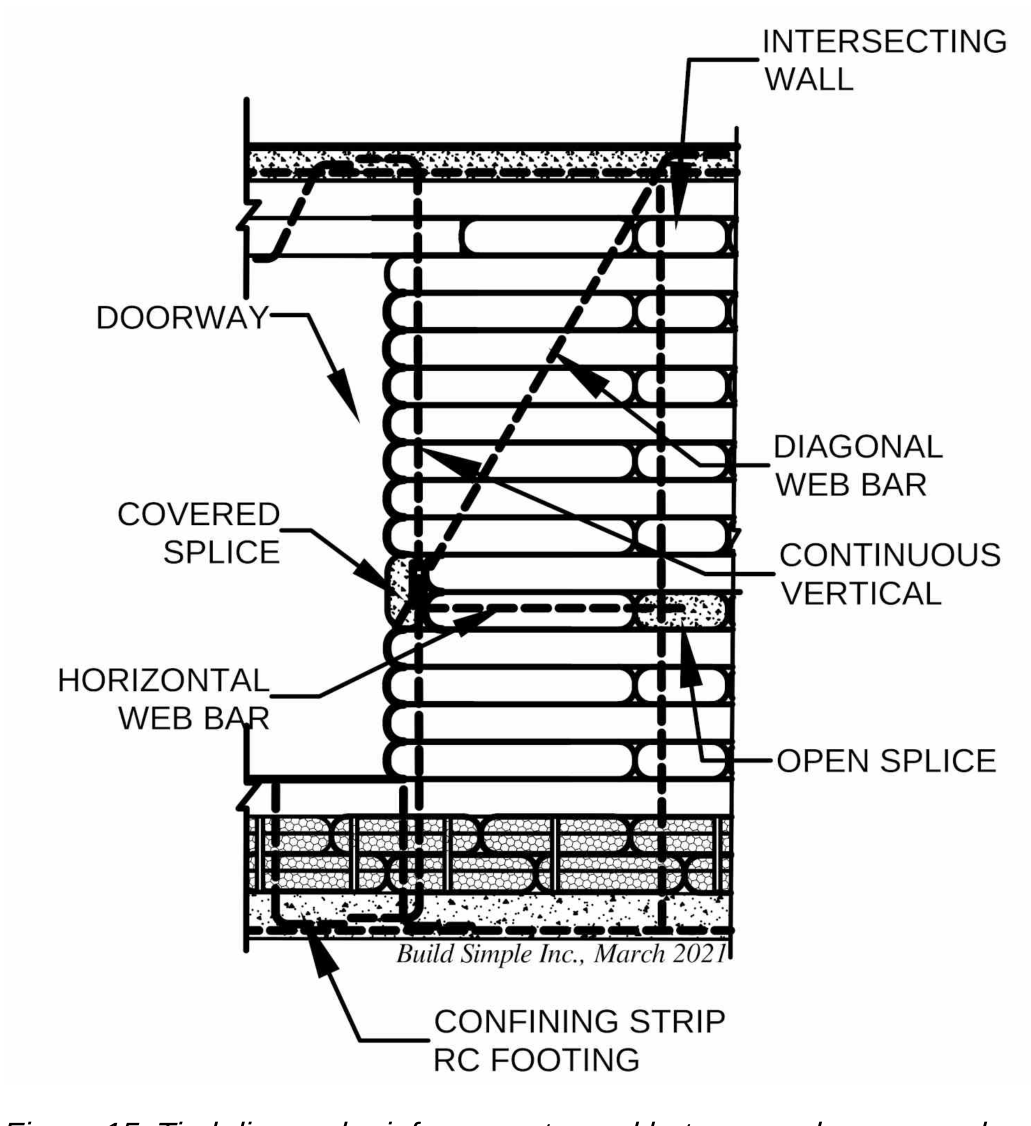

Figure 15: Tied diagonal reinforcement panel between a doorway and perpendicular wall.

Lay only the earthen tube element that will receive the horizontal. Lightly tamp the tube, then have a worker stand on top. Insert the horizontal rebar with extra length sticking out over the open splice location, then bend hooks on both ends. Next, finish laying that course, leaving a gap for the open splice. To strongly connect to a continuous vertical rebar, also leave a small gap in the next course to embed at least 255 mm (10”) total of the vertical rebar in concrete. Pour concrete into the open splice area to embed the steel.

Braced Corners with One Buttress

If only one buttress is needed at a corner, locate the corner vertical rebar 125 mm (5”) from one exterior wall surface at the inside of the corner made by the buttress (Figure 16). Cuts to the container fabric will be protected by the adjacent tubes, but no wire will be bent around the rebar..

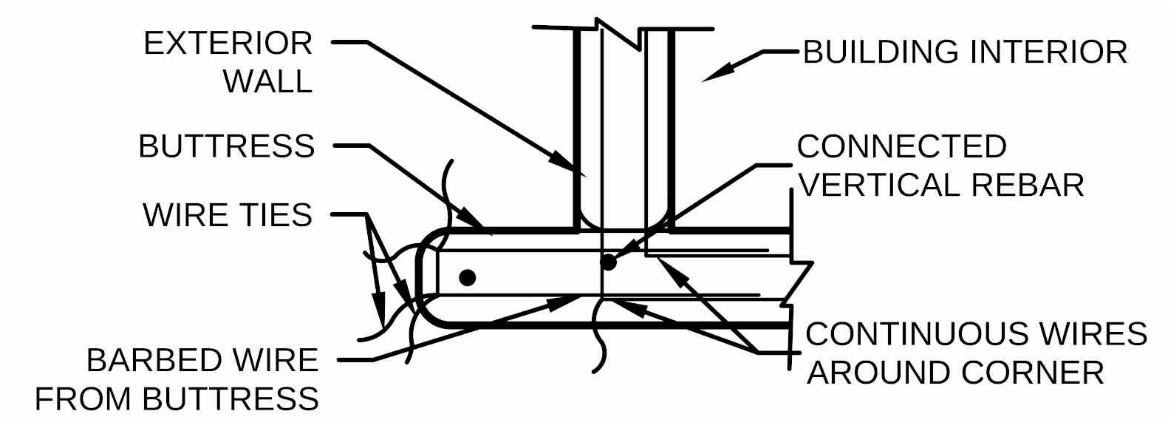

Figure 16 For a single buttress at an external corner locate vertical rebar near the external barbed wire strand but near the corner formed byt the buttress.

Run two continuous strands of barbed wire around the corner. The buttress barbed wire must be a separate overlapped strand, tied out the corner.

A lone buttress can be extend beyond a braced diagonal at a corner if the buttress ends below the target sandbag to allow access to the covered splice (Figure 17).

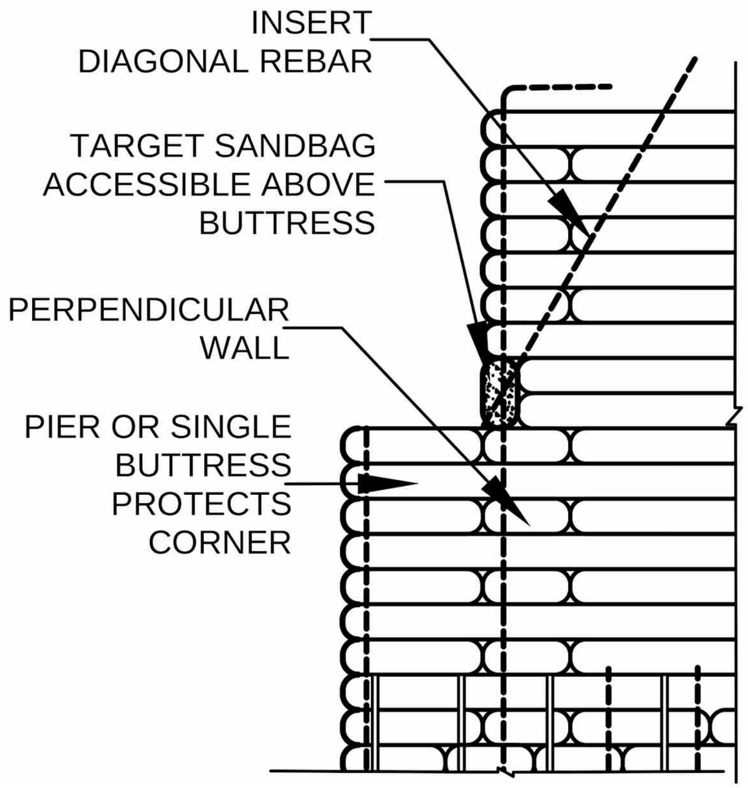

Figure 17 Half height corner piers combined with a spliced diagonal.

Braced Corners with Half-height Pier

Corner piers that are half the story height use less wall material but can also protect lower portions of external wall corners vulnerable to mechanical damage in combination with a braced diagonal in the upper wall. Corner piers half the story height also provide compact mass to make walls more stable.

Build piers twice as wide as walls, alternating tube directions. Place the vertical rebar near the exterior corner for good access to the splice above the pier top. Connect the pier and wall together with careful barbed wire detailing (Figure 18).

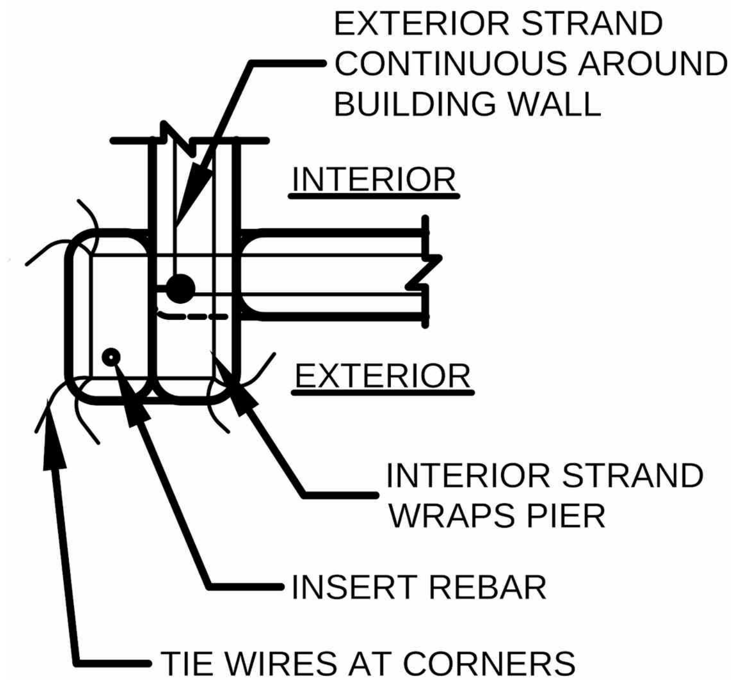

Figure 18: Corner pier is united to the corner with the interior strand of wire while the exterior strand runs continuous.

Full Height Truss Reinforcement

A trussed buttress or wall panel divided by embedded rebars into four force triangles provides extra strength to the entire height of a wall. This is located at the end of a stub wall or buttress so the lower diagonal rebar can be connected to the footing reinforcement with an extra splice located outside the wall foundation.

Steps to Make a Trussed Panel

1 PREPARE: Start building a full-height truss by leaving a gap and horizontal steel extending out the end of the buttress footing (Figure 19a).

2 INSERT the diagonal through an open splice area down into the footing opening (Figure 19b). Place a target bag at that level for the covered splice, insert the horizontal rebar between the open and covered splice. Leave a small gap on the course above the open splice for extra embedment length for the vertical rebar.

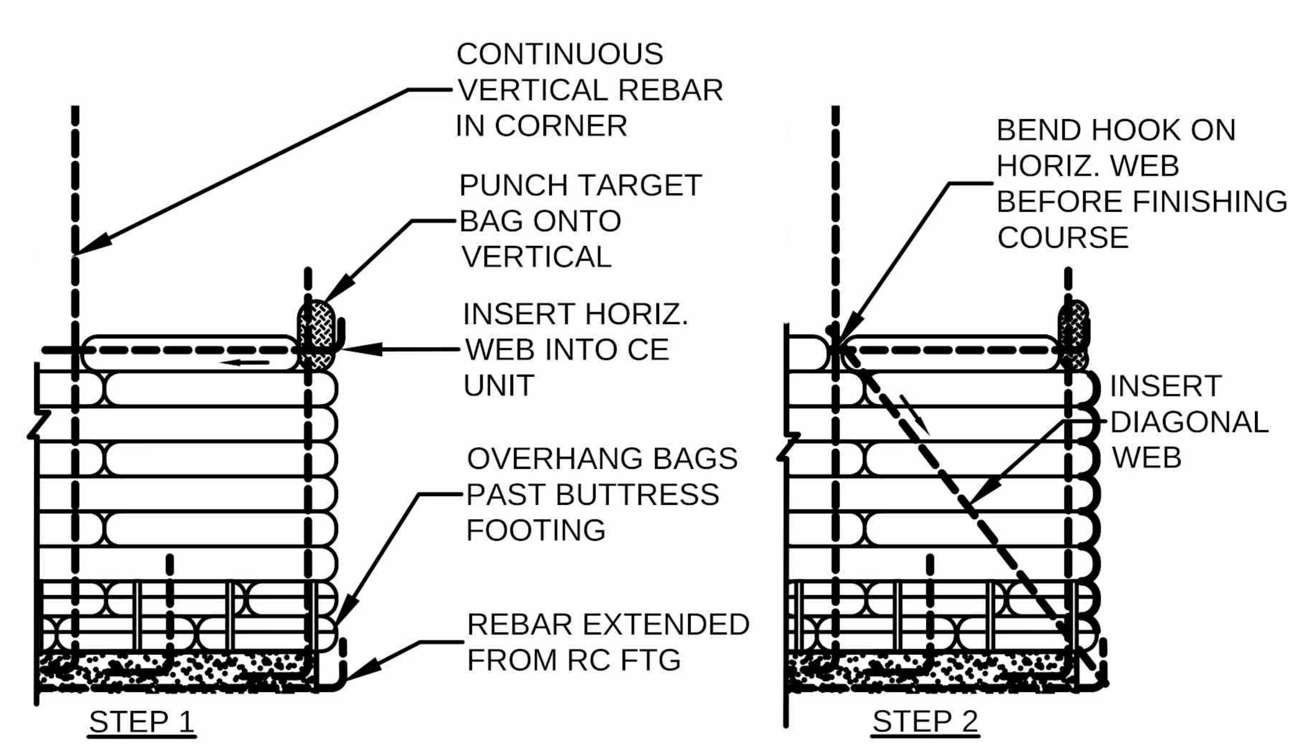

Figure 19 Start a truss reinforcement panel (left to right): a- Insert horizontal web bar; b- Finish the course and insert the diagonal web bar.

3 POUR CONCRETE into the splice gap on the course and next to the footing (Figure 20a).

4 INSERT UPPER DIAGONAL AND VERTICAL after walls are completed into the covered splice (Figure 20b).

5 POUR BOND BEAM AND COVERED SPLICE: Bend upper hooks and form and pour the reinforced concrete bond beam. Then remove sand from the target bag and pour concrete into the covered splice (Figure 20c).

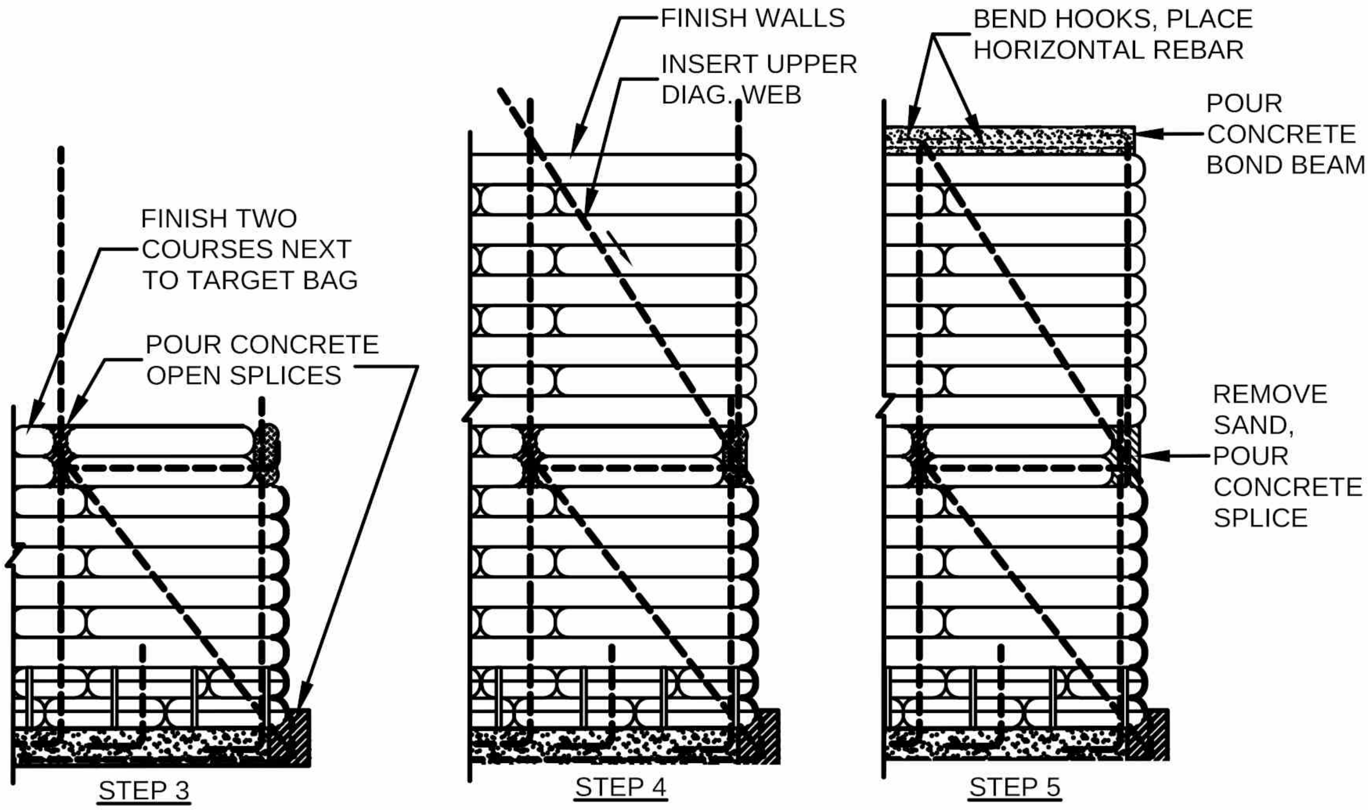

Figure 20 Finish a truss reinforcement panel (left to right); a- Pour concrete in the open splice and next to the footing; b- Build to the wall top and insert rebars; c- Bend the hooks and pour the concrete bond beam and covered splice.

6 INTEGRATING WELDED OPENING FRAMES

Strongly welded steel tube door and window frames used where wood resources are scarce can provide stiffening to flexible resilient CE buildings if well connected to walls.

Until further testing establishes clearly the performance of improved earthbag walls, this detail may help engineers to estimate wall strength based on the included steel assembly.

Integrating Window and Door Frames

To function well as an important structural element, welded steel opening frames must have fine-grained connections to adjacent walls and be bolted or welded to vertical steel (Figure 21).

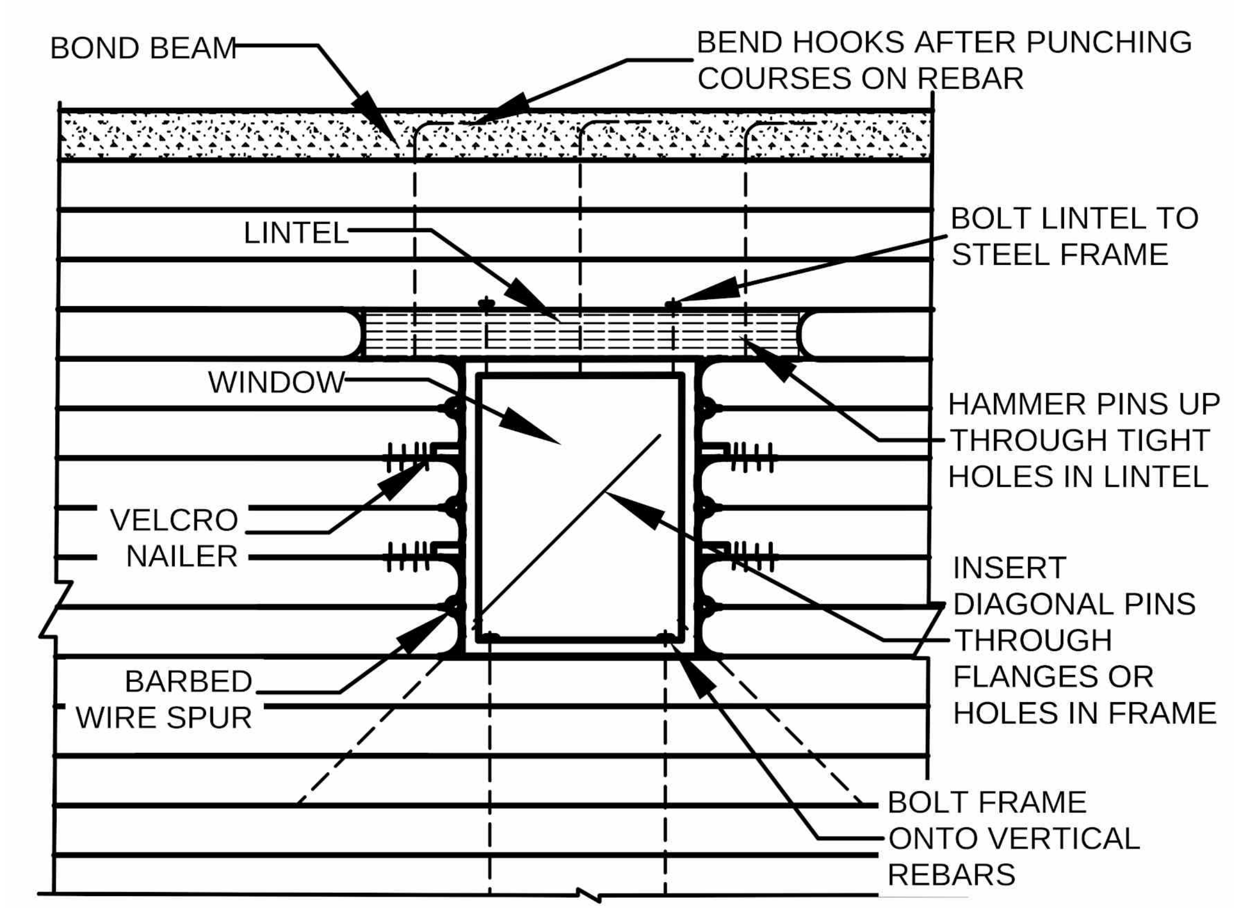

Figure 21: Welded steel frame connected to lower rebar and upper rebar uses velcro nailers and spurs to connect well to earthen courses on both sides.

On the welded frame, weld vertical bolts extending above the frame to attach the lintel. Also add horizontal rebar spurs about 180 mm (7”) long every 255- 300 mm (10- 12”) in height on both sides of the frame to attach barbed wire on every other course.

Fasten the frame onto base-anchored verticals topped with bolts. Build the wall around the frame. On alternate courses, use a velcro nailer plate (a wood or metal scab that has nails facing upward and downward to connect courses above and below). Screw the velcro nailer securely to the frame.

Diagonal pins can also be inserted through either sides or bottom through holes drilled into the frame.

Attach the lintel and/ or frame to the bond beam using vertical rebars. Rebars near the ends of the lintel must be inserted through holes before building the courses above, which use cut-bag and punched-bag technique. Rebars near the center of the opening can be inserted up into the wall above the opening after the earthen wall is completed. All of these verticals must have hooks bent on top after the earthen wall is completed.

7 FOUNDATIONS FOR BASE ISOLATION OR DAMPING

Engineers have successfully developed mechanisms to re-route or to reduce the effects from earthquake motion. These expensive systems are used in multi-story buildings to either turn vibration into friction (damping), or to allow upper building walls to stay relatively motionless (base isolation) while the ground moves below.

Engineers have proposed ideas for base isolation systems (such as the reinforced cut-wall) for single story mass wall buildings. Although some research has shown that fabric-contained gravel or sand can absorb vibration, no one has yet explored the potential that earthbag offers as either frictional base isolation or for vibration damping.

This section contains construction details intended for research purposes, to indicate to engineers some buildable types of wall bases that may be worth testing.

This author hopes to begin a dialog and would love to discuss research potential or results. Only by refining these details based on shake table testing can this needed category of base wall for seismic protection be developed.

Gravel Courses for Vibration Damping

Contained gravel courses used for water resistant base walls may dampen earthquake vibrations by transforming horizontal motion into friction between loose fill. Contained gravel courses can be pinned on inserted rebar, but any rebar in the damping base section must be completely discontinuous from reinforcement in the upper wall.

Two difficulties are apparent: the gravel containers must be permanently protected against UV damage from sunlight, and the base for the interior floor must have a crush zone to allow horizontal motion perpendicular to the walls (Figure 22).

Water-resistant gravel courses are usually built up to and one course above the interior floor surface. But wall materials at and below the floor level are virtually pinned against a compacted surface layer that supports the floor. The gravel courses may be more effective at damping if they are less restrained.

Builders should install some sort of crush zone adjacent to and on the inside of the exterior wall gravel bag courses, as well as surrounding the interior wall base walls. Options for the crush zone include bagged loose sand, bagged chunks or shreds of rubber tire mixed with soil, or uncompacted light plastic trash like bottles mixed with sand or soil.

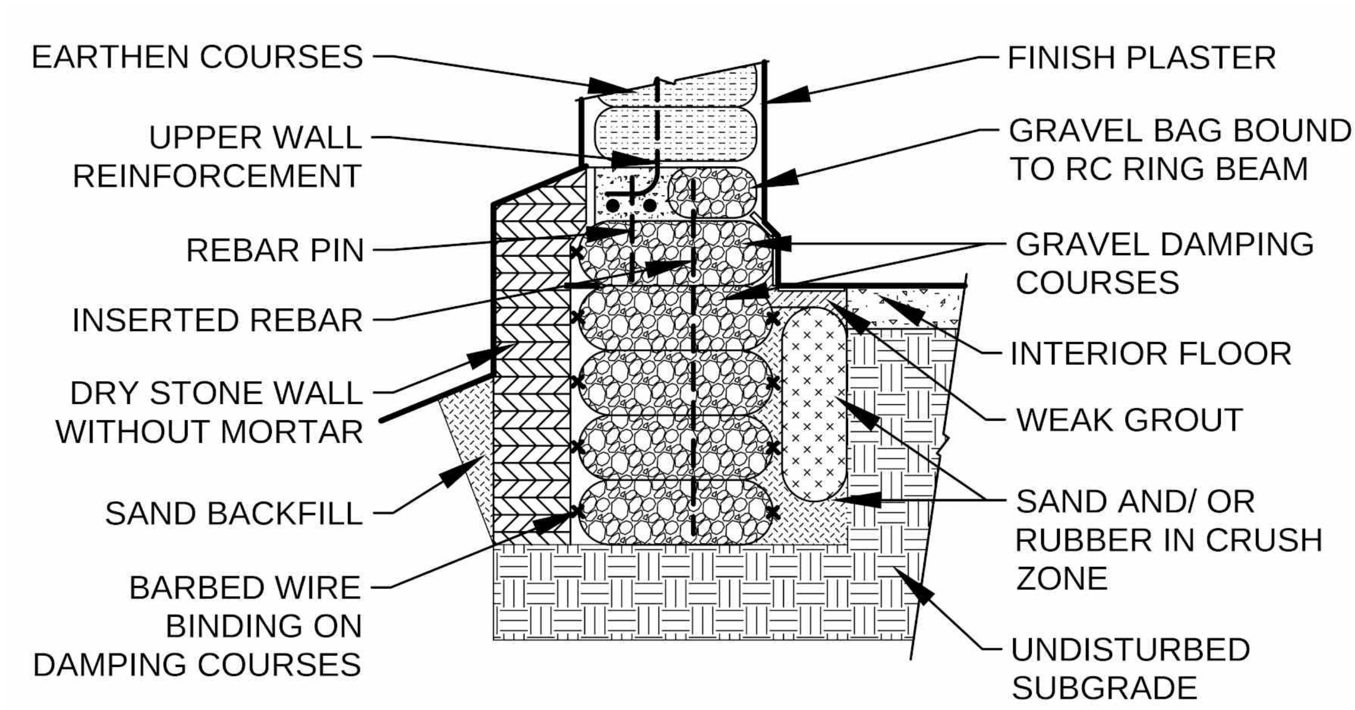

Figure 22 Gravel base wall with dry stone veneer and interior crush zone for vibration damping.

A weak grout layer with or without a separate strip of tiles should be used on top of the crush zone. Exterior backfill for buildings with foundation depths to avoid frost damage should also be soft material like sand. No damp cohesive fill should be placed next to any elements of a vibration damping base wall.

Exterior surfaces of gravel containers must not be finished with strongly reinforced material. They can be protected by dry stone veneer. A sheet of UV-resistant plastic could be hung over the gravel bag exterior surfaces before building the veneer.

An alternative would be to use a weak stucco finish without plaster mesh, and include expansion joint or flashing layed horizontally along each bed joint (Figure 23).

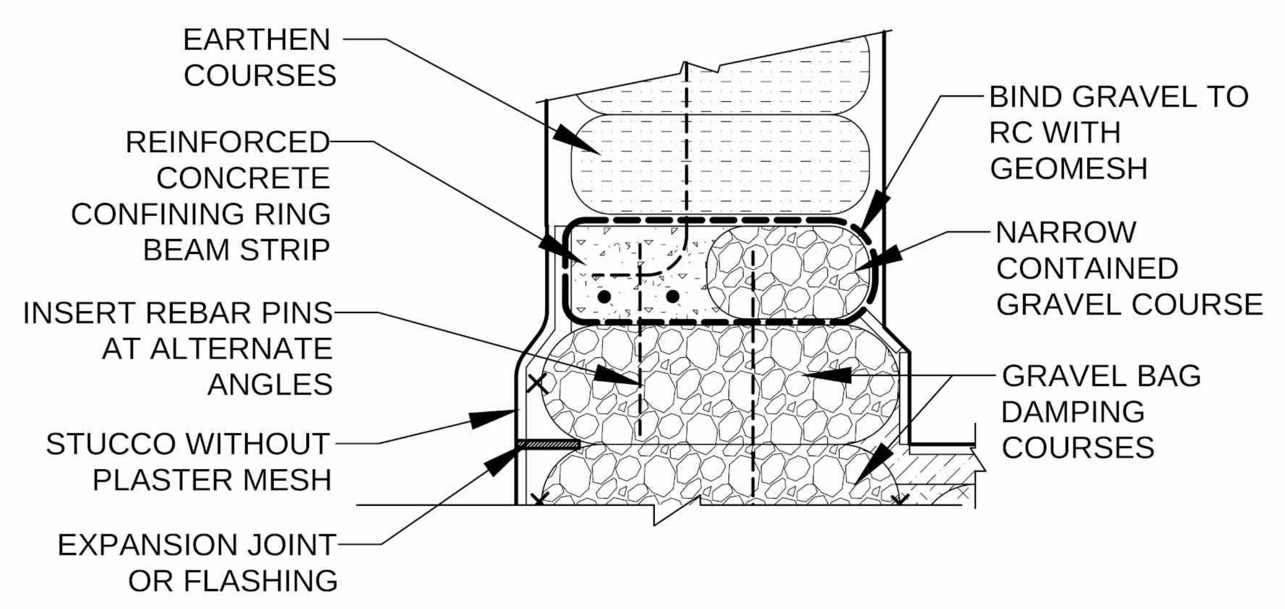

Figure 23: Close up of RC confining ring beam on top of vibration damping gravel bag courses with exterior stucco finish.

To reduce risk of loss of fill material if the doubled fabric bag layers are damaged by neglect or poor surface maintenance, contractors may prefer large strong mesh tubing to substitute for fabric containers. Common extruded plastic tubes used for erosion control straw wattles will contain gravel 75 mm (¾") diameter or larger and are a strong UV-resistant material. Much larger diameter tubes would be needed for full-width foundation courses.

Stability of the ring beam course and its connection to the wall base is critical for CE walls to survive earthquakes. These details show the gravel bag base wall wider than the upper CE wall. Two sets of rebar pins connect the gravel bag courses to the ring beam course. A short set of pins should be inserted at alternating steep angles, but only connect the RC element to the top gravel bag. The short pins could be spaced 460 mm (18") on center, with a longer set of rebars spaced 0,8- 1,2 m (32- 48") on center at slight alternating angles.

Specialized Earthen Courses for Frictional Isolation

Resilient CE's low-friction bed joints also offer unique potential for surfaces that allow repeatable but limited motion. This alternate system of reducing transmission of earthquake forces from the base wall to the upper building walls does not rely on the potentiall vulnerable fabric containers of gravel bag courses.

To allow sliding between courses do not use any rebar crossing the bed-joints of the courses intended as sliding isolators (Figure 24). Base courses for sliding along bed-joints may be wider than upper walls to ensure stability. Isolation courses should not be restrained by interior floor material so locate the lowest bed-joint higher than the interior finish floor level.

When using an earthen fill material, isolation base courses can be built in hyperadobe tubes but with one strip of ordinary woven polypropylene frabric from ordinary CE containers laid on each course before barbed wire is placed. This fabric layer will prevent soil fill from becoming monolithic through the mesh surfaces.

The mesh tubing provides a strongly toothed exterior wall surface that stucco or plaster adhere to easily. Soil fill usually extrudes slightly through the openings of the mesh, leaving the containers half-embedded and much less vulnerable to damage from UV than fabric containers.

Plaster depth can be minimized by side-tamping these specialized courses to flatten the course sides and reduce the nook depths, thus reducing potential grip between the plaster and the courses. Builders can apply a non-adhesive caulk along the joints between courses and then work a thin finish plaster coat directly into the textured course wall surfaces.

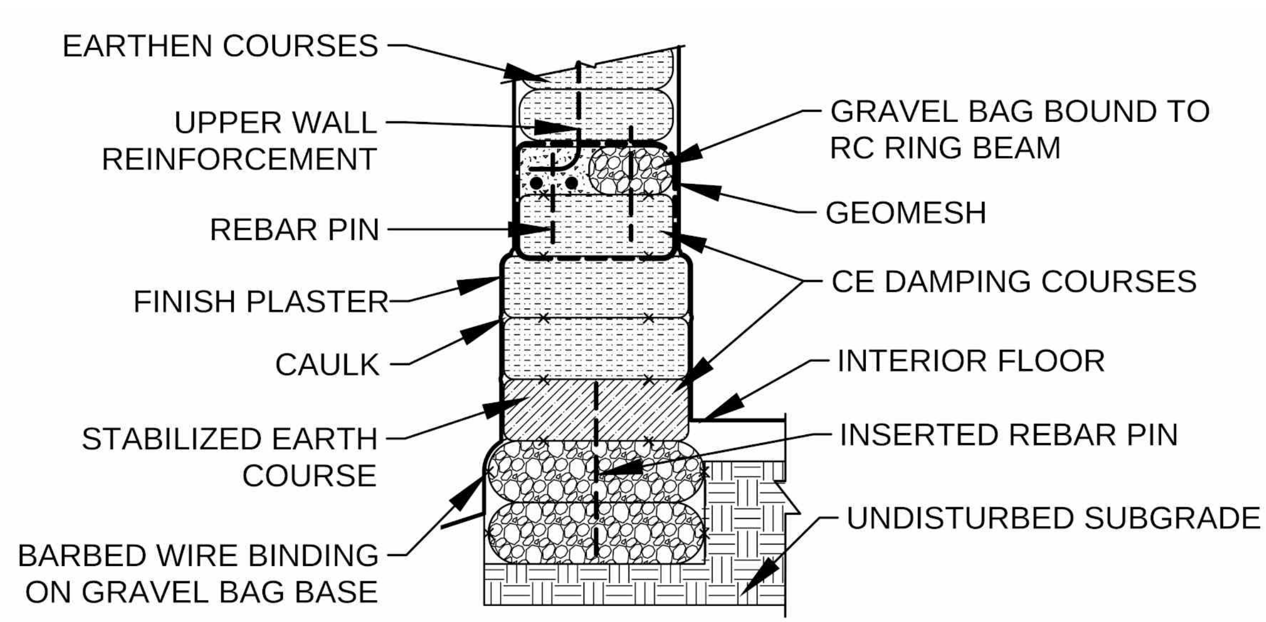

Figure 24: Base isolation contained earth courses form a wall base above the interior floor level.

A rebar pin connecting the lowest sliding course to the footing should be inserted down into the bedjoint surface of the lowest sliding isolator course. The ring beam could be tightly bound to the topmost sliding course with strong mesh and attached with inserted short rebar pins at alternating angles. Metal or cord strapping around the sliding courses may be useful.

If stronger limits to motion are needed, a completely non-embedded external framework of pinning rebars could be used at some locations.

8 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)
PIE R	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