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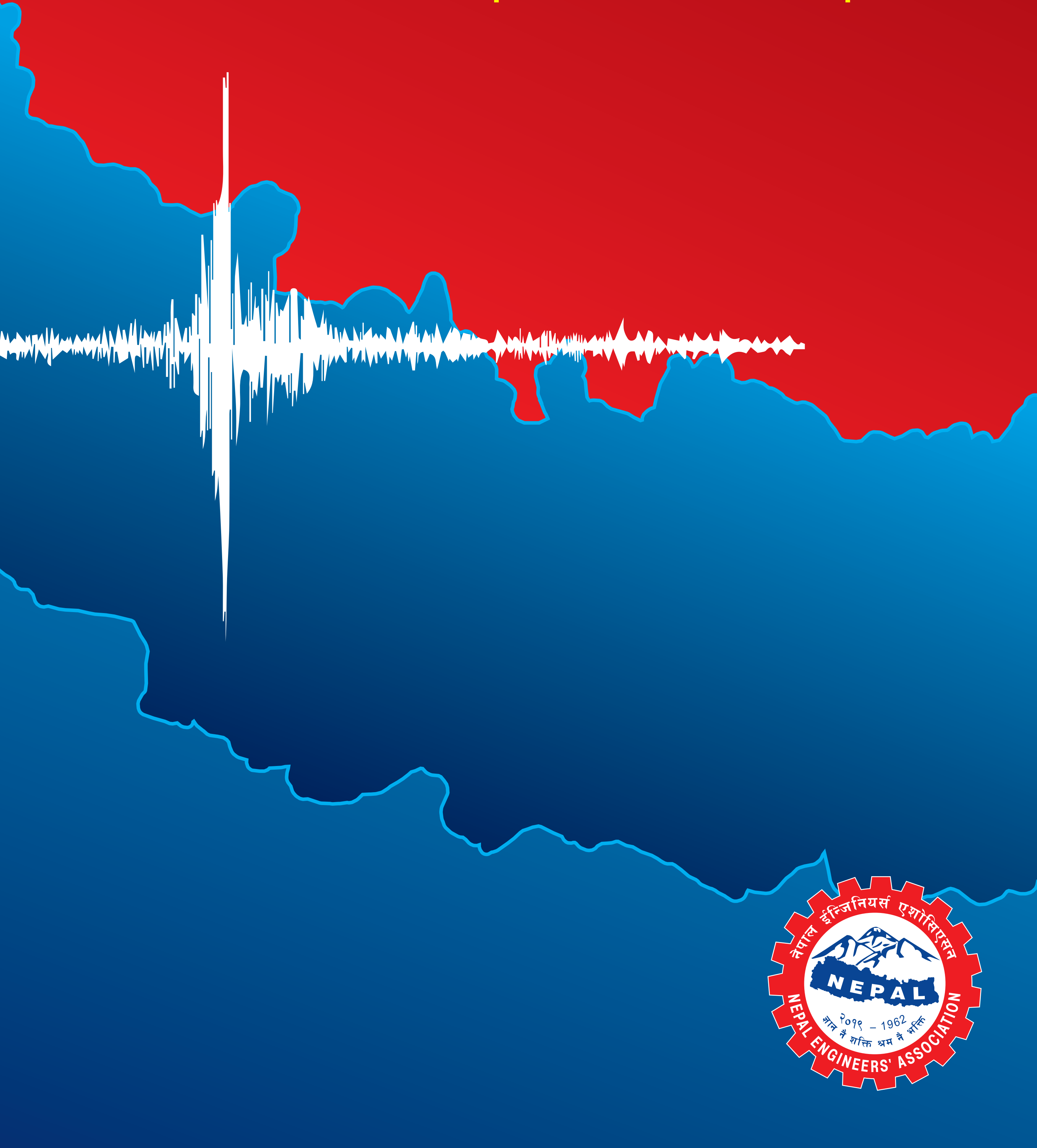
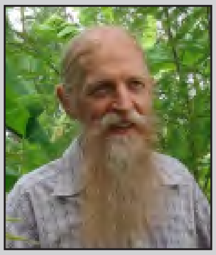


Earthbag Technology - Simple, Safe and Sustainable



Dr. Owen GEIGER
Director of the Geiger Research Institute of Sustainable Building, USA
naturalhouses@gmail.com

Kateryna ZEMSKOVA
Co-Founder and President of Good Earth Nepal, a New York based non-profit organization, USA
kateryna@goodearthnepal.org

ABSTRACT

Earthbag technology is an inexpensive, simple and sustainable method for *building* structures. Having evolved from military bunker construction and flood control methods, Earthbag buildings are notable for their ability to endure fire, flood, wind, *earthquake* and vermin, and are used in *disaster*-prone zones all over the world. In *Nepal*, all 55 Earthbag buildings survived a 7.8 magnitude earthquake with no structural damage. Because Earthbag technology makes minimal use of cement, concrete, steel and timber, and the fuel needed to transport them. This technique is easy on the *environmen*t, and doesn't deplete scarce natural resources. Earthbag technology also requires less expertise than other traditional building methods, and only the simplest of tools.

I. INTRODUCTION

Earthbag technology is a wall system with structures composed primarily of ordinary soil found at the construction site. The soil is stuffed inside polypropylene bags, which are then staggered like masonry and solidly tamped.
Barbed wire is used between the layers of bags and serves as mortar. For seismically active zones reinforcements like buttresses, vertical rebars and bond beams are recommended. The classical foundation used in Earthbag construction is a rubble trench foundation. The roof design can be of any preference as long as it is lightweight.

Figure 1: Earthbag Construction in Makwanpur, built by Good Earth Nepal **(Good Earth Nepal, 2015).**

Figure 2: Completed Earthbag House in Gorkha, built by Good Earth Nepal **(Good Earth Nepal, 2015).**

Earthbag construction minimizes the need for skilled labor, and does not require any special tools or machinery. An Earthbag building can easily be built by a group of unskilled workers under the supervision of a construction manager. Since Earthbag technology relies primarily on locally-sourced materials there is less need for transport, and lower fuel costs. This makes Earthbag building ideal for remote or isolated areas with bad roads and limited access.

Though Earthbag technology is relatively “new” its true origin dates back to thousands of years through the similar technique of rammed earth construction. Some call Earthbag technology “Rammed Earth in a Bag” or “Reinforced Rammed Earth”. Structures utilizing similar tamped, solid earth techniques still stand from the Alhambra palace in Spain to the Great Wall of China.

Figure 3: Kagbeni Rammed Earth Monastery, Nepal, built 1429 **(Geiger, O., 2013).**

In recent centuries, the idea of building walls using bags filled with sand or earth and stacking them has been utilized by the military and industrial concerns.

Figure 4: 200-300 military history **(Hart, K. & Geiger O. , (n.d.)).**

Municipalities have used it for flood control, erosion control and retaining walls. Road builders have also deployed Earthbags, placing them under highways.

Figure 5: Earthbags are used under highways **(Geiger, O., 2013)**

Figure 6: Sandbags are used for flood control **(Geiger,O., 2013)**

In 1976, Gernot Minke of the Research Laboratory for Experimental Building in Kassel, Germany began to investigate how natural building materials like sand and gravel can be used to build a residential house.

Figure 7: Minke prototype house, Guatemala, 1978 **(Hart, K. & Geiger O., (n.d.))**

In 1980s, Iranian-born architect Nader Khalili popularized the notion of building permanent structures with bags filled with earthen materials.

Figure 8: Nader Khalili **(Bidoun, 2004)**

Figure 9: Earthbag house built by Nader Khalili **(Turner, I., 2016)**

At present, there are over 15,000 Earthbag buildings worldwide with recent Earthbag constructions gaining approval under strict US building codes.

An estimated 55 Earthbag structures built in Nepal survived the 2015 earthquake, in regions ranging from Solokumbu to Sindhupalchok to Kathmandu.[1]

Figure 10: Earthbag School in Basa, Nepal built by Small World next to a damaged stone building (Good Earth Nepal, 2015)

Figure11: Earthjbag School built by First Steps Himalayas survived the earthquake with no damage, Sindupalchok (**Geiger,O., 2013)**

[1] For the details of Earthbag structures built in Nepal before the earthquake, please visit Natural Building Blog (http://www.naturalbuildingblog.com/)

II. EARTHBAG TECHNOLOGY

Earthbag building offers many advantages over existing technologies:

- *Safety*- Earthbag structures built in Nepal before the earthquake had no structural damage. More traditional building techniques were tragically failed.
- *Ease of Construction*- Earthbag technology can be easily learned by rural villagers.
- *Reduced Use of Materials*- Earthbag structures require a minimal amount of cement, concrete, wood and steel.
- *Reduced Use of Fuel and Transportation*- Use of local materials and less quantity of materials mean less need for transport and lower fuel costs.
- *Less Pollution*- Building with soil means fewer factories and smoke stacks, fewer pollution-belching trucks for transporting the load, and less depletion of Nepal's forests and natural resources.
- *Cost-Effective*- Building with Earthbags is inexpensive. For example, a typical Earthbag house might cost 900 NPR per square foot, versus 2500 NPR for concrete block construction.

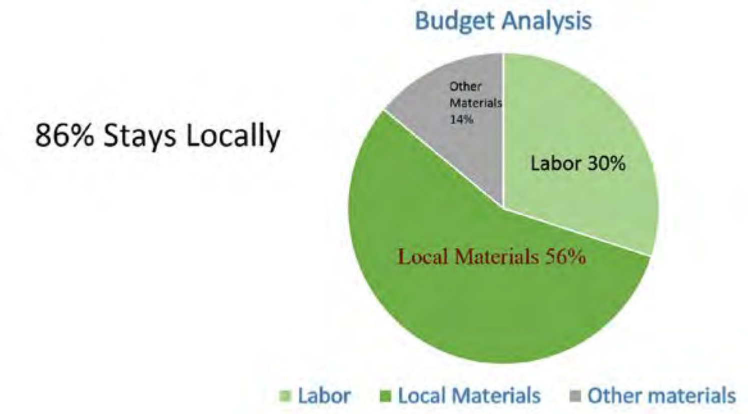


Figure 12: Earthbag Construction Cost Analysis **(Good Earth Nepal, 2015)**

MAIN BUILDING MATERIALS

Soil: The main material of an Earthbag structure is ordinary soil obtainable at the worksite. Most soils are adequate and precise ratio is not necessary, but there must be enough clay and moisture to bind the aggregate together. The soil can be easily tested without any equipment, using a drop test or a roll test. The most common mix is:
25%-30% Clay

70%-75% Sandy soil
10% Moisture (optimum moisture content)

Polypropylene bags or tubes: Earthbag construction is durable, and if the polypropylene bags are plastered properly the construction can last for hundreds of years. A study by the U.S. Federal Highway Administration found that the half-life of polypropylene fabrics in benign environments can be 500 years or more. The bags themselves have a tensile strength even higher than that of steel, and can resist circumferential forces generated from the weight above.

Figure 13: Rolls of polypropylene fabrics **(Hart, K. & Geiger O. (n.d.))**.

Barbed Wire helps to lock the bags together, and forms a matrix within the wall system. Barbed wire resists outward expansion of the wall caused by weight from above, and its tensile strength resists out-plane forces. Barbed wire should be 14 gauge, 4 pointed.

Figure 14: Barbed wire dispenser **(Geiger, O., (2015, September))**

Figure 15: Barbed wire layout **(Geiger, O. (2015, September))**

KEY COMPONENTS THAT MAKE EARTHBAG STRUCTURE EARTHQUAKE RESISTANT

Earthbag structures, despite being heavy, have high flexibility that makes them highly earthquake resistant.

1. **Rubble Trench Foundation**
   A rubble trench foundation was first popularized by Frank Lloyd Wright in 1922, and used for his Imperial Hotel design. This hotel survived the great Kanto earthquake, the most devastating in Japanese history[2].
   An Earthbag building uses its own weight to anchor itself to the rubble trench foundation. Since the superstructure is not attached to the foundation by bolts or rebars, the foundation and the superstructure are able to move independently minimizing the shock transfer to the walls. A rubble trench is also built of individual units rather than a continuous beam further absorbing the shock.

2. **Earthbags are resilient (helps to absorb the shock)**
   Earthbags are resilient. As per an experimental study on vibration reduction performed by three Chinese universities (Hohai University; Business School of Hohai University; Hefei University of Technology), Earthbags have a relatively high damping ratio with horizontal as well as well as vertical vibrations effectively reduced.

3. **Tensile strength of Barbed Wire**
   Barbed wire helps to lock the bags together and form a matrix within the wall system. It helps to resist any tendency of wall to expand outward due to the weight from above. During an earthquake tensile strength of the barbed wire helps resist the out-plane force.

4. **Thick walls (16’’-19’’)**
   Earthbag construction is flexible, and thick walls make the construction stable

5. **Concrete bond beam** provides integrity to the structure

   Figure 16: Concrete Bond Beam **(Good Earth Nepal, 2015)**

6. **Reinforcements. Vertical rebars** provide additional shear strength. **Buttresses** and **corner reinforcements** increase the in-plane stiffness of the wall.

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[2] Frank Lloyd Wright used rubble trench foundations successfully for more than 50 years in the first half of the 20th century, and there is a revival of this style of foundation with the increased interest in green building (Wikipedia, 2016)

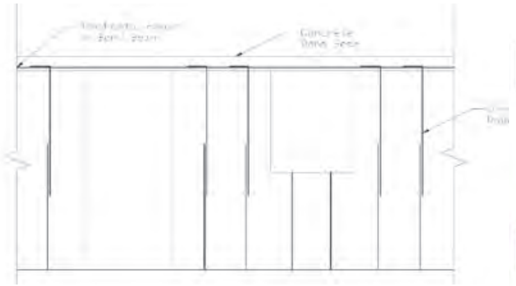

Figure 17: Vertical rebar reinforcement **(Good Earth Nepal, 2015)**

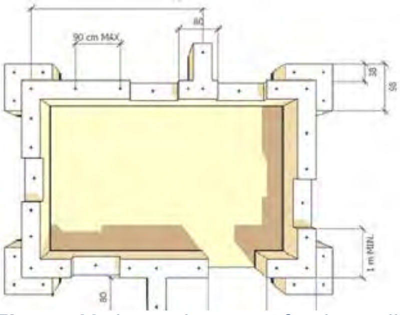

Figure 18: Lateral support for the wall **(Geiger, O. (2015, September))**

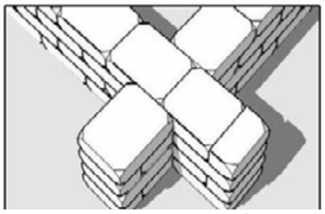

Figure 19: Corner reinforcement **(Geiger, O. (2015, September))**

7. **Thick plaster with galvanized or plastic mesh** provides additional strength to the wall to resist in-plane as well as out-place forces.

Figure 20: Plastic mesh and cement plaster **(Good Earth Nepal, 2015)**

8. **Rammed Earth in Polypropylene (PP) Bags**
   As PP bags have tensile strength even higher than that of steel, they can resist the circumferential force produced by the weight above before the earth in the bag has hardened. In between 2 to 3 months the earth in the bags hardens like a brick. Unless there is a movement the bag does not bear any forces.

All of these components make Earthbag structures extremely earthquake-resistant. Tests done in accordance with IBC standards have found that Earthbag construction far exceeds Zone 4 standards, devised to protect against the very highest level of seismic activity. Numerous Earthbag structures have been built in the United States. Earthbag structures are permitted by the California Building Code, the toughest in the United States due to high seismic activity.

EARTHBAG CONSTRUCTION DETAILS

1. **FOUNDATION**
   Earthbag structures generally employ a rubble trench foundation, though more traditional types of foundations can be used as well.
   Rubble trench foundation is suitable only for medium or hard soils. A 2’-3’ deep and 2’ wide trench is filled with rubble up to 6’’ below the ground level.

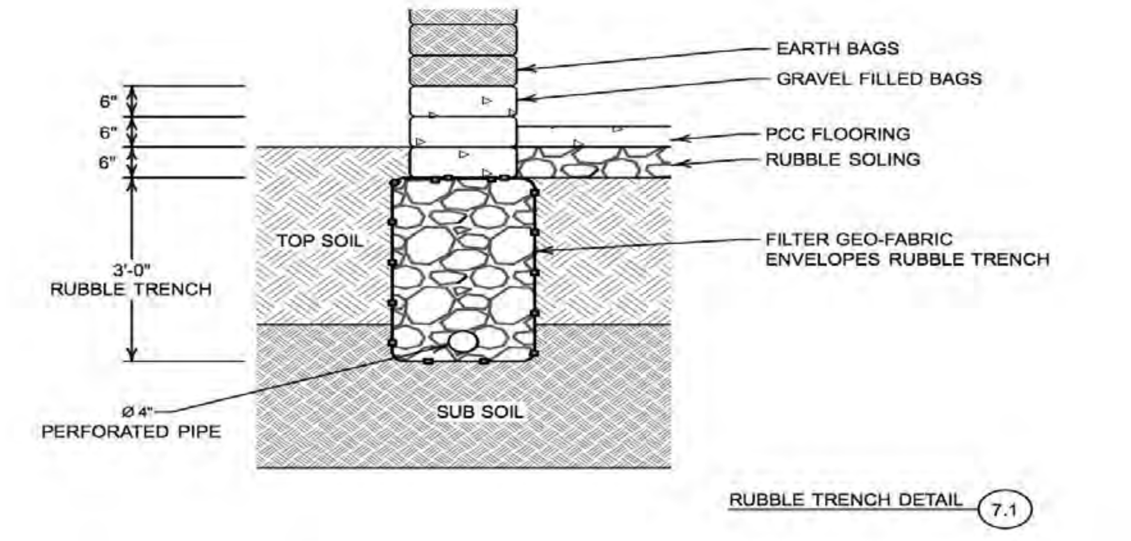

Figure 21: Rubble Trench Foundation **(Geiger. O., 2013)**

2. GRAVEL-FILLED BAGS

2-3 courses of bags filled with gravel are placed on top of the rubble trench foundation. The first course of gravel bags should be placed 6'' below the soil level. It is better to use double-bags for additional strength.
Gravel-filled bags starting below grade and extending well above grade in flood-prone areas reduce the risk of water damage.

3. EARTHBAG WALL

The Earthbag wall is composed of polypropylene bags or tubes filled with soil. At least two strands of 4-point barbed wire should be used in between each course of bags. Spacing of barbs should not be more than 100mm and minimum bending strength of barbs should be 200N.
Tamping is a very important step of Earthbag wall construction. It helps to maintain the level as well as solidify the soil inside the bags.

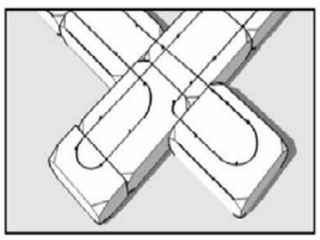

Figure 22: Earthbag wall with barbed wire **(Geiger, O. (2015, September))**

There are numbers of rules that need to be followed for the construction of an Earthbag wall:

- The height to thickness ratio of a wall should not be more than 8.
- Any opening in the wall should be small in size and centrally located. Openings are to be located away from inside corners by a minimum 900 mm. There should a minimum of 900 mm spacing between the openings. Maximum opening allowed is 1500 mm.

- The maximum length of unsupported wall should not exceed 10 times its thickness. If the wall is longer than 10 times its thickness, buttresses should be placed at intervals not exceeding 10 times the wall thickness.

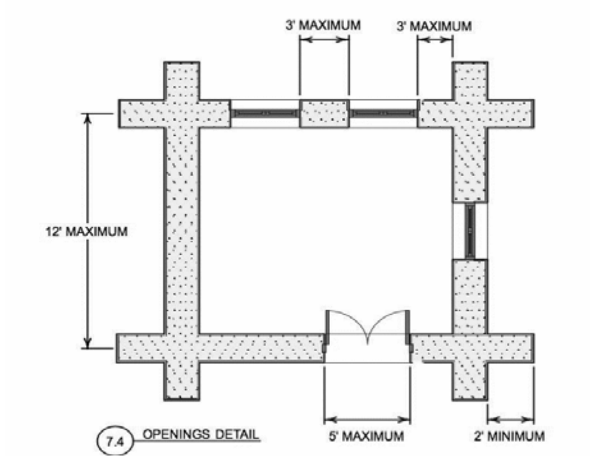

Figure 23: Specification of openings and unsupported wall length **(Geiger, O., Hart, K. & Stouter, P. (n.d.)).**

- Earthbag overlap: In order to achieve the full strength of Earthbag wall, the common bonds specified below should be followed.

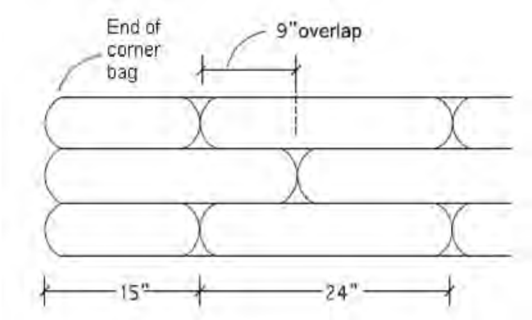

Figure 22: Good Overlap with 24" bags **(Geiger, O. (2015, September))**

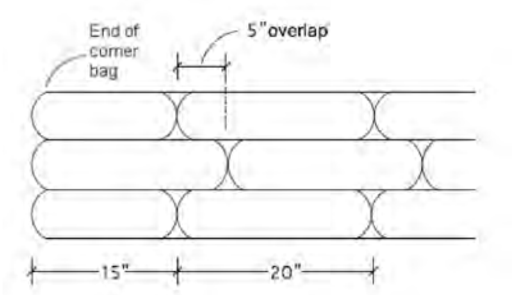

Figure 25: Poor Overlap with 20" bags **(Geiger, O. (2015, September))**

4. **CORNER REINFORCEMENT**

In earthquake-prone areas corner reinforcements are highly recommended. There are 5 types of corner reinforcements:

- **Corner Buttresses**

  Buttresses strengthen corners and stiffen straight walls. Straight walls need a buttress or a pier, an intersecting interior wall, or a minor corner every 3- 3.5 m (10'- 11'). They also make it easier to add on Earthbags to extend houses in the future. Buttresses can be straight, sloping, or stepped. Benches or wider wall bases will also strengthen straight walls if the bags are well woven into the wall. A vertical-edged buttress must stick out from the wall at least 60 cm (24"), and a sloping or stepped buttress 75 cm (30").

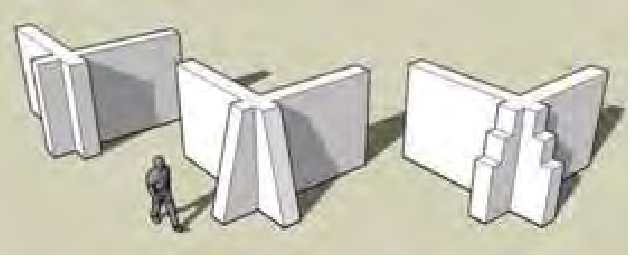

Figure 26: Corner Reinforcement Using Butresses **(Hart, K. & Geiger O. (n.d.)).**

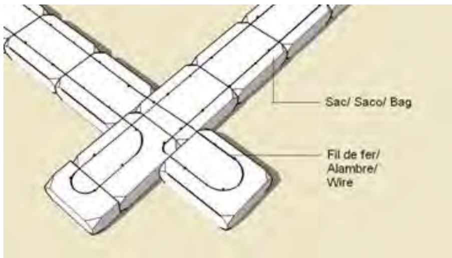

Figure 27: Corner Butresses with barbed wire **(Hart, K. & Geiger O. (n.d.)).**

- **Corner Rebars**

  This is the simplest way to strengthen corners of Earthbag buildings.
  When walls reach 1.5 m (60") height, a 1.5m (5') long piece of rebar is hammered through the corner bags. Bags are always alternated at corners and bag joints are staggered for strength.

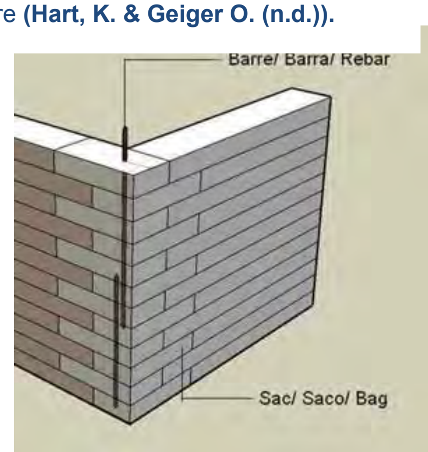

Figure 28: Corner Reinforcement Using Rebar **(Hart, K. & Geiger O. (n.d.)).**

- **Mesh Corner Reinforcement**

  A 1 m (39") wide strip of sturdy mesh is placed on the outside of the corner from top to bottom. The exterior mesh is fastened securely to the inside corner at every other course. Metal rod or bamboo rod or additional mesh should be placed on the interior corner. If bamboo is used it can be either well encased in earth or left uncovered for inspection. Earth-filled bags are alternated at corners.

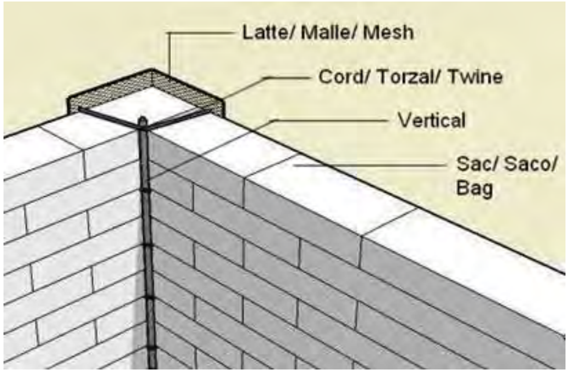

Figure 29: Corner Reinforcement Using Mesh **(Hart, K. & Geiger O. (n.d.)).**

- **Corrugated Metal Reinforcement**
  This corner reinforcement stiffens and strengthens as well as unites walls if repeated every 5 bag course. 60 cm (24") long rebar is driven through corrugated metal strip at the corner to tie the reinforcement to the wall below. Rebars repeat at ends of metal strip or every 60 cm (24").
  Corrugated metal roofing is cut into strips 20- 30 cm (8- 12") wide and at least 75 cm (30") long. They are overlapped at the corners and nailed into the bag below.
  Strong cord or mesh is used with wire or strapping every 60 cm (24") to secure three layers of bags tightly around the metal.

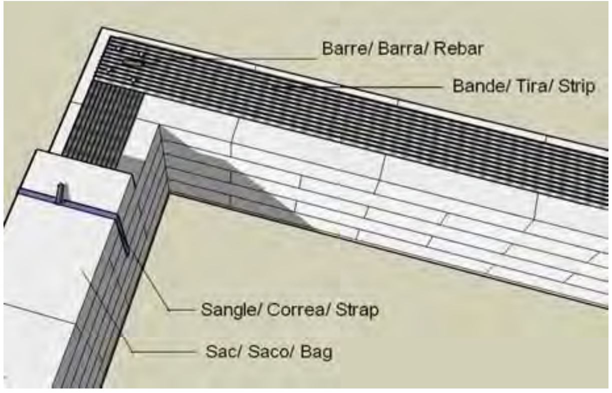

Figure 30: Corner Reinforcement Using Corrugated Metal Sheet **(Hart, K. & Geiger O. (n.d.)).**

- **Pier**
  A pier is usually a thickened wall section. It only projects out from the wall the width of a single bag.

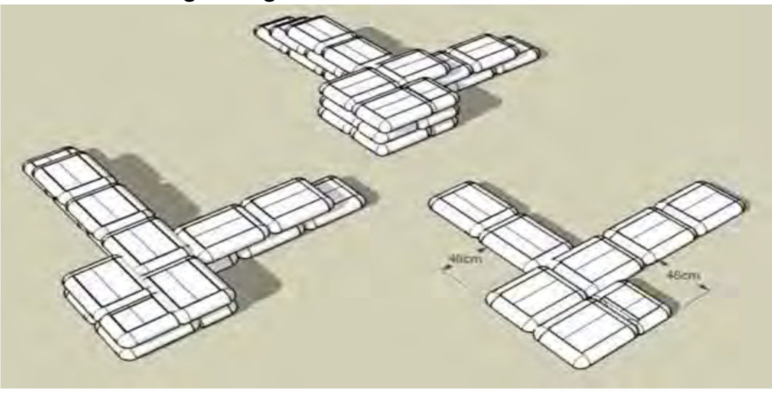

Figure 31: Corner Reinforcement Using Pier **(Hart, K. & Geiger O. (n.d.)).**

5. **VERTICAL REINFORCEMENT**
   Steel bars are installed at the critical sections (i.e. the corners of walls, junctions of walls, and jambs of doors) and every 1.2 m of the normal wall section.
   The vertical steel at the corners and junctions of walls must be taken into the roof band.

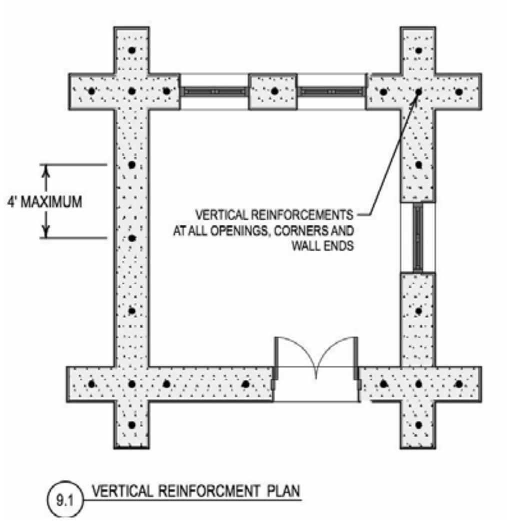

Figure 32: Vertical Reinforcement Plan **(Geiger O., (2015, September)).**

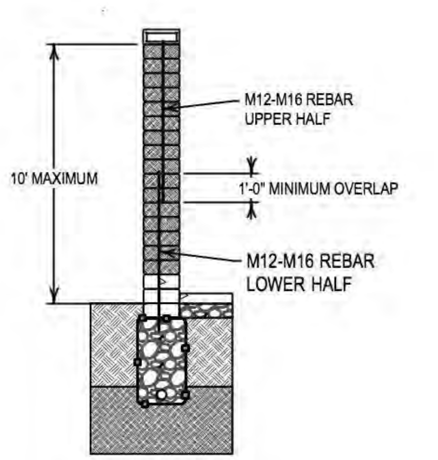

Figure 33: *Vertical Reinforcement (Sectional View)* **Geiger O., (2015, September)).**

6. **BOND BEAM**

Bond beam provides integrity to the structure. It ties the walls together and provides a rigid connection for the roof structure.

Concrete Bond Beam

Concrete bond beam is the recommended option. The depth should be at least 6'' and the width 2/3 of the bag width. It is singly reinforced. The length of the part of the rebars embedded into the bond beam should be at least 60 times diameter of the rebar.

Timber Roof Band

Timber band can be used as an alternative to concrete band where there is ample supply of timber and poor road access.

- Minimum 4"x6" structural wall plate member
- Vertical reinforcement rebar carries through the wall plate
- Cross bracing in all corners and junctions
- Trussed roof only so there is no lateral load from the roof

7. **ROOF**

As a general rule heavy roofs are more seismic hazard. Hence roofs as well as floors should be made as light as structurally and functionally possible. For Earthbag construction a trussed roof is recommended in all seismic zone.

CONCLUSION

Earthbag technology offers a safe, simple and sustainable building option. We encourage engineers and building professionals in Nepal and other countries to explore this exciting new technology, and its possible use in the communities most in need.

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