

**essential**

sustainable  
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essentials



# EARTHBAG CONSTRUCTION



**the complete step-by-step guide**

**Kelly Hart**

Praise for  
*Essential Earthbag Construction*

A must-have book for anyone interested in natural and sustainable building. It expands the possibilities with practical and essential information on this user-friendly method of construction.

— Will Beemer, Director of the Heartwood School for the Homebuilding Crafts and author of *Learn to Timber Frame*.

Kelly Hart and Dr. Owen Geiger ( who wrote the very informative Foreword ) probably know as much about earthbag building as anyone. Friend Kelly has always had a clear and concise way of explaining his subject, both in lectures and in his several books.

I've never built an earthbag structure, although we once did a cordwood building on an earthbag foundation in New Zealand. But I wouldn't even attempt it without studying this book thoroughly and referring to it throughout the building process.

— Rob Roy, Director, Earthwood Building School and author of *Essential Cordwood Building*

There is an urgent need for more sustainable homes and earthbag construction offers excellent, affordable, strong eco-friendly housing using natural and local materials. They are beautiful, comfortable and robust. This book is a comprehensive, practical and inspirational guide that is both detailed and easy to follow. Hart demonstrates that anyone can build a home, so use this book and give it a go!

— Jenny Pickerill, Professor of Environmental Geography, University of Sheffield, UK and author of *Eco-Homes: People, Place and Politics* (Zed Books)

Who doesn't love earthbags? Only people who don't know about this most versatile of earthen building techniques, suitable for building inexpensive low-impact homes on most parts of the globe. With just a pile of dirt, some bags, barbed wire, a tamper and a few basic tools, you can build an earthbag dome, retaining wall, or root cellar.

For over 20 years author Kelly Hart has been experimenting and promoting simple DIY ecological building techniques, especially via his excellent web sites.

Distilling both his own hard-won experience and the combined wisdom of the rapidly-expanding worldwide earthbag network, Hart delivers a thorough, detailed and readable guidebook that tells you everything you need to know for success with this potent technique.

— Michael G. Smith, co-editor, *The Art of Natural Building* and co-author, *The Hand-Sculpted House*



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the complete **step-by-step** guide

**Kelly Hart**







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Printed in Canada. First printing March 2018.

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Inquiries regarding requests to reprint all or part of *Essential Earthbag Construction* should be addressed to New Society Publishers at the address below. To order directly from the publishers, please call toll-free (North America) 1-800-567-6772, or order online at [www.newsociety.com](http://www.newsociety.com)

Any other inquiries can be directed by mail to:

New Society Publishers

P.O. Box 189, Gabriola Island, BC V0R 1X0, Canada

(250) 247-9737

**LIBRARY AND ARCHIVES CANADA CATALOGUING IN PUBLICATION**

Hart, Kelly, 1943-, author

Essential earthbag construction : the complete step by step guide / Kelly Hart.

(Sustainable building essentials)

Includes bibliographical references and index.

Issued in print and electronic formats.

ISBN 978-0-86571-864-7 (softcover).--ISBN 978-1-55092-656-9 (PDF).--

ISBN 978-1-77142-251-2 (EPUB)

1. Earth construction. 2. Earth houses--Design and construction.

I. Title. II. Title: Earthbag construction. III. Series: Sustainable building essentials

TH1421.H37 2018

693'.22

C2017-907827-5

C2017-907828-3

Funded by the  
Government  
of Canada

Financé par le  
gouvernement  
du Canada

**Canada**

New Society Publishers' mission is to publish books that contribute in fundamental ways to building an ecologically sustainable and just society, and to do so with the least possible impact on the environment, in a manner that models this vision.



# Contents

ACKNOWLEDGMENTS .....	xi
FOREWORD .....	xiii
CHAPTER 1: A Brief History of Earthbag Building .....	1
CHAPTER 2: Appropriate Uses for Earthbags .....	5
CHAPTER 3: Building Science Notes .....	7
CHAPTER 4: Material Specifications .....	13
Bags .....	13
Fill material .....	15
Barbed wire and other types of reinforcement .....	22
Plaster .....	24
CHAPTER 5: Tools .....	25
CHAPTER 6: Foundations .....	29
CHAPTER 7: Building Walls .....	35
Locate source of fill material .....	35
Filling bags .....	36
Placing barbed wire and twine .....	38
Laying bags in a pattern .....	40
Closing the top of the bag .....	41
Using a metal slider .....	42
Tamping the bags .....	43
Placing vertical reinforcement rods .....	44
Building domes .....	45
CHAPTER 8: Design Considerations and Constraints .....	49
Vertical walls .....	49
Domes .....	49
Vaults .....	52
Buttresses .....	53
Bond beams .....	55
Door and window openings .....	60
Door and window bucks .....	60
Arches and other shapes .....	62
Spacing openings .....	65
Vertical reinforcement for openings .....	65
Lintels .....	66
Wall thickness .....	67
More than one story .....	68

Below-grade construction .....	69
CHAPTER 9: Plastering the Walls .....	71
CHAPTER 10: Floor and Roof Options .....	75
Slab on grade .....	75
Masonry floors .....	76
Adobe floors .....	77
Suspended floors .....	78
Roofs .....	79
CHAPTER 11: How to Include Utilities .....	81
Plumbing .....	81
Electrical .....	82
Heating .....	83
Ventilation .....	85
Cabinetry .....	86
CHAPTER 12: Strategies for Seismic Reinforcement .....	87
CHAPTER 13: General Budgeting Information .....	91
CHAPTER 14: Maintenance and Renovation .....	93
CHAPTER 15: Building Codes .....	95
CHAPTER 16: Other Uses for Earthbags .....	97
Retaining walls .....	97
Cisterns .....	98
Dams .....	99
Root cellars and pantries .....	102
Sculpture and art .....	103
RESOURCES	
Author's websites .....	105
Other websites .....	105
Books .....	105
DVDs .....	105
Workshops .....	106
Bag supplies online .....	106
INDEX .....	107
ABOUT THE AUTHOR .....	111
A NOTE ABOUT THE PUBLISHER .....	112

## Acknowledgments

I WOULD LIKE TO RECOGNIZE and thank the many pioneers of earthbag building who have paved the way for the rest of us to explore this wonderful method. Through their ability to think outside the box while applying their inherent understanding of the physical world they have contributed greatly to our global heritage. From Germany, we have Gernot Minke;

from Iran and the United States was Nader Khalili; from Japan is Akio Inoue; from the United States are Joe Kennedy, Kaki Hunter, and Doni Kiffmeyer; from Poland and the United Kingdom is Paulina Wojciechowska; and from Brazil is Fernando Pacheco. Many more of us are continuing to evolve this technology all around the world and I thank everybody involved.



# Foreword

Written by Dr. Owen Geiger

A LOT OF THINGS HAVE CHANGED in the earthbag building movement since Kelly Hart and I started to disseminate free earthbag information on the Internet at Earthbag Building.com in 2007 and a few years later at NaturalBuildingBlog.com (formerly Earthbag BuildingBlog.com). Back then, there were not very many earthbag buildings or resources available. Today, there are thousands of earthbag buildings, countless online videos, as well as many websites and blogs, and numerous books.

The most prolific changes in this movement have come from abroad, in poor countries, where the need for safe, affordable housing, schools, clinics, eco toilets, and water tanks is staggeringly high. Developing countries urgently need these things. Other building materials and methods are often not affordable or practical.

Earthbag building is now very popular in Mexico, South America, Africa, Asia, and other places. Some of the most exciting development work is being done in Nepal since the 2015 earthquakes rocked that country. What caught the world's attention was the vast number (hundreds of thousands) of concrete and brick buildings that were destroyed, while all 55 earthbag buildings in Nepal that had been built before the quakes survived without major structural damage.

Earthbag building is quickly catching on in Nepal as the safest, strongest, lowest cost, most effective way of building. For instance, a 6-classroom school can be built in about two months

by local villagers for the cost of a car. These buildings are so strong that you could drive a speeding vehicle into the walls, detonate grenades, or shoot them with a machine gun with only minor damage.

In my article *Low Cost Village Housing for Nepal* on our blog, I explain how the greatest need for housing in Nepal is in poor rural villages. Most of these places are in remote mountainous areas far from roads. Not only can these villagers not afford cement and steel for conventional building, it's not practical to carry these heavy materials 1–2 days over steep mountain passes. Earthbag building is an excellent choice in this situation.

The following projects illustrate the wide range of uses for earthbags, and some of the many benefits.

Since 2015 Good Earth Global ([goodearthglobal.org](http://goodearthglobal.org)) has built four schools, one learning center, over 20 houses, one meeting center, and four model eco toilets in Nepal and India. They have taught earthbag building techniques to almost 1,000 rural village builders, students, engineers, architects, and community leaders in Nepal and India. They won the “Best Rural Design” award at a competition organized by the Nepal Engineering Association.

This NGO, partnered with Anna University, a leading Indian technical university, co-organized an international earthbag conference in India, and supervised the construction of a model Earthbag Meeting Center on the university's Madurai campus.

Good Earth Global has designed prototype earthbag toilets that are inexpensive, ecologically sustainable, and easily built using local labor and materials. Toilets can be built by four workers in two days at \$282 each for materials and labor. With sufficient support, Good Earth Global hopes to build thousands of earthbag toilets throughout India, potentially saving hundreds of lives daily.

In April 2017, Nepal's Ministry of Urban Development approved and published Good Earth Global's earthbag designs in the "Design Catalogue for Reconstruction of Earthquake Resistant Houses," giving millions of earthquake victims the opportunity to use government aid money to build safe and affordable earthbag homes. With this pioneering decision, Nepal became the first country in the world to officially endorse earthbag technology, and now emerging as a worldwide leader in sustainable building and development.

First Steps Himalaya ([firststepshimalaya.org](http://firststepshimalaya.org)) had just completed its first earthbag building days before the magnitude 7.9 earthquake struck Nepal in 2015. Despite being in one of the worst-affected areas where almost all buildings were flattened, the earthbag teacher training center survived with just a few cracks. First Steps Himalaya then organized an Earthbag Building Summit in Kathmandu in September 2015. Since then, they have provided hands-on training on earthbag building to numerous Nepali and international organizations and individuals. The charity has completed nine earthbag classrooms and an eight-bedroom accommodation building for trainees, with many more projects planned.

Over the last nine years, Edge of Seven ([edgeofseven.org](http://edgeofseven.org)) has completed four earthbag dormitory buildings for girls, and six classrooms using the method. Community leaders reported: "These were the only buildings where we truly felt safe after the earthquake."

Woven Earth ([wovenearth.org](http://wovenearth.org)) assisted non-profit Carisimo with several dozen earthbag houses in Nepal. Acting as technical advisors, in collaboration with Loving Arms Mission, Woven Earth assisted rural farmers in building 16 farm houses, some of these as training for the locals. And in collaboration with Common Action for Sustainable Development, they organized training for local workers to build one large Savings and Credit Cooperative Building for a local women's cooperative.

Woven Earth and Loving Arms Mission, with support from Kathryn Kaspar, have successfully carried out projects in which one member of each family worked on the construction of multiple houses in exchange for receiving one of the houses upon completion. Teaching the locals not only provides them with useful skills but also greatly reduces the cost of labor for the project. The local acceptance and understanding of a new building technique is also more likely because the recipients are involved in every step of the construction process.

Sacred Earth Trust (SET, [sacredearthtrust.org](http://sacredearthtrust.org)) is an NGO based in India working on sustainable development in sacred sites. SET has been building an eco training and plastic up-cycling center to demonstrate low-cost effective technologies which are also earthquake resilient. To address issues regarding availability of space a "thin-wall" technique was adopted for local use to construct the office and machine rooms on site. Instead of using common 18-inch (46 cm) wide earthbags, the thin-wall method was adapted and resulted in 12-inch (30 cm) wide walls. The project demonstrated thin-wall earthbag building is practical for two-story structures on small lots in urban areas where code approval is required.

Dada Krcpasundarananda ([news.dadaksa.com](http://news.dadaksa.com)) is a monk who has gained extensive experience with building and teaching others to build

Super Adobe domes. In Nicaragua, Mongolia, New Zealand, Ireland, Ghana, Canada, and other countries, Dada has been building/leading about one project a year on average. All the projects were domes, and generally they were for training purposes. He is seeing more interest now in alternative methods of building and more houses built, some of those as a direct result of his previous workshops.

Earthbag building is also growing in the Philippines, primarily for building hurricane resistant housing. One coastal village near Coron was devastated by Super Typhoon Yolanda in 2013, with about 90% of the houses in the village being completely destroyed. The Tamayo Foundation, a construction company in Manila, is funding 100% of a project to build a target goal of 100 earthbag houses.

Cyclone Pam hit Vanuatu as a category 5 cyclone in March 2015 and destroyed many houses and water tanks. For the first two weeks, the only clean water available in one village came from the earthbag water tanks at the earthbag Women's Center. The Tamayo Foundation has built 40 earthbag tanks since Cyclone Pam and they have started other women's groups on seven islands. These affordable (half the price of plastic water tanks) and easy-to-build water tanks could help solve the water shortage problem all across the Pacific islands and other drought-stricken parts of the world.

Project Somos Children's Village (project somos.org) created a Children's Village for Guatemalan children and mothers, with homes, staff housing, a culture dome, a preschool, and a community hall using earthbags. The Village is built to be eco-sustainable, with solar energy, rainwater capture, greywater recycling, and an organic farm.

Those at the Mlambe Project (themlambe project.org) in Malawi have been able to help hundreds of people by building schools with

earthbags. This building technique addresses the "triple bottom line," because it is environmentally, economically, and socially sustainable. Malawi has a major deforestation problem that is causing serious flooding; earthbag building helps protect local forests by reducing the use of wood.

Phangan Earthworks (phanganearthworks.com) has built five earthbag structures on the tropical island of Koh Phangan, southern Thailand. The structures include two darkroom meditation domes, a large two-room toolshed, and a spacious "cave" house that artfully combines granite, wood, and earth. The earthbag walls elegantly fill gaps between large boulders that were on the property.

Chiang Dao B&B in Thailand (chiangdao-roundhouses.com) was built with bags filled with rice hulls — an abundant, low cost, local material. There are ten round buildings, mostly 5 meters across. Rice hulls are not load bearing, so the buildings are post and beam, with bamboo trellises on which the bags of rice hulls are attached. The cost to build one of these roundhouses is about \$1,500, not including cost of local labor.

Japanese professor Akio Inoue has been a prolific earthbag builder and promoter, with about 30 projects, mostly earthbag domes on the campus of Tenri University in Japan; other projects are in India, Uganda, and elsewhere. Japanese architect Kikuma Watanabe has also created many earthbag projects around the world. Chinese professor Sunny Tsai and Colombian architect Jose Andres Vallejo have designed and overseen numerous other earthbag projects.

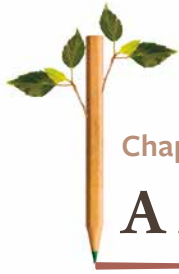
Precision Structural Engineering (structure1.com) has provided structural engineering for over 20 earthbag homes and the Seeds of Learning School in Nicaragua.

This brief list of projects shows the impact that sustained effort can have. Almost all of the



projects described here were completed on small budgets, relying on the help and generosity of volunteers and donors. These projects are way more than just a tally of buildings. They address very important issues: how earthbags help reduce deforestation and flooding, provide earthquake and hurricane resistance, reduce housing costs, provide clean toilets and water tanks, and make it possible to build in remote places where it's impossible to transport other building materials.

I believe we are nearing a tipping point of significant change since the proof of concept and list of achievements is so overwhelmingly convincing that major acceptance will likely soon happen. After all, how many thousands of projects have to be built to demonstrate to the world, the media, and major NGOs that earthbag building is safe, affordable, and practical? Let's all work together to raise awareness of natural building methods such as earthbag to make a bigger impact in the world.



## Chapter 1

# A Brief History of Earthbag Building

**B**AGS OF SAND OR DIRT have been used to build military bunkers or divert flood waters since at least the end of the 18<sup>th</sup> century. They are a good choice for this because they are easy to carry to where they are needed, can be quickly filled with local material, are inexpensive, and are quite effective at protecting people and property. Of course, these uses are generally only temporary. The use of sandbags (or, *earthbags*, as we refer to them here) for more permanent structures has only occurred in the last few decades.

In 1976, at the Research Laboratory for Experimental Building at Kassel Polytechnic College in Germany, Gernot Minke started experimenting with ways to make housing by stacking fabric tubes filled with loose natural materials. Pumice showed particular promise because it is both lightweight and insulating. At first, he built simple corbelled domes in an inverted catenary arch shape, using a rotating template to help place the tubes.

In 1978, Minke's team built a vertical-walled house in Guatemala using pumice-filled cotton tubes that were soaked in lime-wash as a preservative. Vertical bamboo poles were placed at intervals on both sides of the filled tubes and tied with wire between them to provide stability to the wall. The bamboo was also tied into the foundation and the top beam to create an earthquake-resistant structure.

In 1984, Iranian-born architect Nader Khalili proposed filling bags with moon dust as a way to build shelters on the moon. He refined this idea for building on Earth by placing strands of barbed wire between the courses of bags, thus unifying the shell into a more monolithic and

shock-resistant structure. Khalili evolved the sandbag idea into what he called *Superadobe* by filling polypropylene bags or long tubes with moistened adobe soil that would solidify as it dried.

Khalili publicized his Superadobe concept widely and began conducting workshops and seminars on the techniques that he had developed, mainly at his California Institute of Earth Architecture. Based on exposure to these ideas, many other people started experimenting with their own building projects. Joe Kennedy, Paulina Wojciechowska, Kaki Hunter, and Doni Kiffmeyer all initially studied with Khalili, and the more general term *earthbag building* became popular.

Paulina Wojciechowska wrote the first book on the topic of earthbag building: *Building with Earth: A Guide to Flexible-Form Earthbag Construction*, published in 2001. This was followed by the publication of *Earthbag Building: The Tools, Tricks and Techniques* by Kaki Hunter and Doni Kiffmeyer in 2004. Several other excellent books have been published since then.

Akio Inoue has done extensive experimentation with earthbag dome construction, both on the campus of Tenri University where he taught in Japan and in India and Africa, where many other domes were built for assistance programs.

I first began experimenting with earthbag building in 1997, after producing a video program: *A Sampler of Alternative Homes: Approaching Sustainable Architecture*. I later documented my experience in building my own home in another program titled *Building with Bags: How We Made Our Experimental Earthbag/Papercrete Home*.



**Fig. 1.1:**  
*The author's earthbag dome home under construction in 1999.*

CREDIT: KELLY HART

In 1999, Nader Khalili patented his *Superadobe* technique in the U.S. (despite the fact that patent law clearly states that such a patent cannot be obtained if the concept was publicized for over a year prior to the patent application). Khalili and his estate have rarely attempted to enforce the patent and say on their website, "*Superadobe is a patented system (U.S. patent #5,934,027) freely put at the service of humanity and the environment. Licensing is required for commercial use.*"

Besides filling bags with adobe soil, many people have successfully filled bags with other materials, including crushed volcanic rock, crushed coral, non-adobe soils, gravel, and rice hulls.

Around 2009, Fernando Pacheco, a Brazilian engineer, experimented with using open mesh bags or tubing, similar to the sort of material commonly used to package bulky produce. He called his technique *Hyperadobe* and suggested that it has many advantages, such as creating a more monolithic structure and eliminating the need for barbed wire and mesh for stabilizing plaster.

### Testing

In the mid-1990s, various engineering tests were performed on earthbag structures at Khalili's Institute, proving the efficacy of his techniques and enabling building department approval for some specific designs.

In 2006, at the request of Dr. Owen Geiger of the Geiger Research Institute of Sustainable Building, the Department of Civil and Mechanical Engineering of the U.S. Military Academy at West Point conducted several controlled and computer-monitored tests to determine the ability of polypropylene earthbags filled with sand, local soil, and rubble to withstand vertical loads. Their written report concluded that “overall, the earthbags show promise as a low cost building alternative. Very cheap, and easy to construct, they have proven durable under loads that will be seen in a single-story residential home. More testing should prove the reliability and usefulness of earthbags.”

Even with these tests (and many others), earthbag building has yet to be incorporated into the International Residential Code (IRC).

Nevertheless, hundreds of permanent and emergency earthbag dwellings have been built all around the world (and some of them are quite elegant). I wouldn't be surprised if many of these earthbag homes are still standing long after their conventional counterparts have disintegrated.

As an example of the robust permanence of earthbag building, all of the more than 55 earthbag structures that existed in Nepal prior to the devastating 2015 earthquake survived with only cosmetic damage. In some instances, whole villages were flattened with the exception of a few earthbag buildings. This has not escaped the attention of the international aid community and the Nepalese authorities; they are now recommending that communities rebuild with earthbags.





## Chapter 2

# Appropriate Uses for Earthbags

**E**ARTHBAG CONSTRUCTION is remarkably versatile, perhaps more than any other building technique. It can be employed both above and below ground without concern for rot or degradation. It can create thermal mass or an insulating barrier, depending on what the bags are filled with. It can be fashioned into a wide range of building shapes, from organically curvy to completely rectilinear, from domes to boxes — or combinations of any of these. It can be extremely durable, resisting fire, flood, earthquake, tornado, bullets, and time. It can also be quite economical — literally, dirt cheap. The techniques are simple to learn; for the most part, the work can be done by unskilled labor. The building shells are generally nontoxic, made of natural materials that can be returned to the earth or recycled at the end of their useful life. Often, very little wood or industrial materials

are needed, so the buildings are environmentally benign. A simple rubble trench foundation may be all that is required, eliminating the need for massive concrete foundations. Besides buildings, earthbags can be used to build dams, cisterns, retaining walls, and other landscaping features. What more could you want?

Of course, all of the above considerations depend on good design and proper execution for good results. As with any building method, it is essential to be educated about proper design principles and procedures *before* embarking on any project. This book will give you not only a better understanding of the technique of building with earthbags, it will give you all the information you need to actually *do it*.

Earthbag walls are usually rather thick and heavy, which does limit some of their possible uses. For instance, they may not be the best



**Fig. 2.1:** Looking straight up inside an earthbag dome shows the spiraling pattern of bags closing in to cap the dome. This was a small, mostly underground dome with earthen fill situated in the desert southwestern United States. CREDIT: KELLY HART

choice for interior walls, where space may be limited; they are not a good choice where plumbing or electrical needs to be run, or where there isn't an adequate foundation to support the weight.

In most climates around the world, it is best for the shell of a habitable building to be insulated from the extremes of ambient temperatures in order to have a comfortable and energy-efficient dwelling. Unfortunately, most soils are poor insulators, so filling earthbags with soil has limited utility. To remedy this, it is possible to either fill the bags with a more insulating material or to add a secondary insulating layer on the outside of the shell. Lightweight volcanic stone (such as *scoria* or *pumice*), perlite, vermiculite, and rice hulls are all insulating materials that can be used for fill. These materials are not available in all localities, or they might be too expensive for a given project. When investigating the possibility of building with earthbags, the availability of the most appropriate fill material needs to be a primary consideration.

While a wide range of building *shapes* are possible with earthbags, there are some design limitations. In general, vertical walls are quite stable when curved, but they usually require additional buttressing support when they are straight. Earthbags make great domes, but structures should be no larger than about 20 feet (6 meters) in diameter, and they cannot be hemispherical; catenary arches are the best dome shape to build. Domes need to be circular at the base so that all of the forces around them are equally balanced; otherwise, there is the risk of deformation and failure. Furthermore, earthbag domes are best limited to fairly arid climates, as it is difficult to assure that the final plaster will always be watertight in wetter climates. Vaults should be avoided (except for very narrow ones that are well buttressed); they are simply too

unstable. Walls that have many openings for doors and windows are probably best framed with wood because there are limits to how many such openings can be placed in an earthbag wall.

Most earthbag buildings are one story high, or just tall enough to accommodate a small loft area. While it *is* possible to build multi-story earthbag buildings, they would need to be carefully engineered to assure safety. I think that a basement with two additional stories above it would be the limit for any earthbag building.

Remodeling an earthbag building can present some challenges, especially in terms of cutting through existing earthbag walls for new doors or windows. If one anticipates the need to remodel or add more space to an earthbag building, it's best to create the opening at the time of original construction and simply fill it in with temporary earthbags; when the time comes to make the changes, it is easy to just knock out the dummy bags.

Hanging heavy things on earthbag walls can present problems. It is best to anticipate the need for hanging things (like cabinets, mantels, and heavy artwork) during the construction phase — and incorporating structures that will allow attachments as the building goes up. It is possible to retrofit for hanging, but it can be awkward or inconvenient to do so.

A general problem with earthbag building is that you may have to jump through some extra hoops to obtain a building permit — if one is required. Earthbag technology is simply too new and too alternative to have generated the necessary impetus for uniform codes to have been adopted. This means that in order to be acceptable to the authorities, any given plan may need to be signed by a licensed engineer or architect who will vouch for its safety, and this can add to the time and expense of a project.



## Chapter 3

# Building Science Notes

**T**HE PRINCIPLES OF BUILDING SCIENCE should be applied to all parts of a building's envelope during both design and construction. Managing the flow of heat, air, and moisture through the walls is essential to creating comfortable, energy-efficient, durable, and healthy buildings. All wall systems are composed of four different control layers: thermal control, air control, vapor control, and water control.

### Thermal Control: Principle

Heat always moves toward colder areas. A *thermal control layer* will slow the movement of heat, making the interior space more efficient and comfortable. There are three different ways that heat moves: *conduction*, *convection*, and *radiation*. An effective thermal control layer must be able to control all of these modes. Building codes and energy standards generally prescribe how effective the thermal control layer needs to be.

The usual way to express the effectiveness of a wall's thermal control layer is either through its conductivity (U-value) or its resistance (R-value), as a static-state value. But these values only give a general indication of how a wall will perform in the real world. This is because walls are not entirely uniform and variations will appear — where different materials come together, for example, or for other reasons.

### Thermal Control: Application for Earthbag Building

**Radiant heat** can emit from any source, including the sun, heating devices, human bodies, or other bodies of warm mass. The materials struck by this radiation absorb the heat energy. With earthbag walls, it is usually the plaster

that covers and protects the earthbag material that initially absorbs this radiant heat until its temperature matches that of the radiant source. Plaster is a fairly dense material and will absorb greater amounts of heat before reaching equilibrium than a more insulating material. The plaster will pass this heat on to the interior portion of the bag wall by conduction and convection. Being rather thin, the bag material will not impede the transfer of heat much, but the fill material might be either highly insulating or heavy thermal mass, which will greatly affect the performance of the wall. Insulation will resist absorbing this heat and thermal mass will absorb it.

**Conductive heat** energy moves by direct contact between materials. The interior and exterior plaster of an earthbag wall makes intimate contact with the thin bag material, and this heat is then conducted into the fill material. Solid earthen fill will readily conduct the heat through its entire mass—with some delay, depending on how thick the wall is. More insulating materials (perlite, rice hulls, etc.) have a greater resistance to conducting heat (and thus, higher R-values).

**Convective heat** exchange occurs via the movement of the air around and inside the wall. Air on either side of the wall rises as it is warmed and falls as it is cooled. These air currents make direct contact with the wall surface, imparting heat to or removing heat from the wall by conduction. The more air movement, the more heat can transfer. Within the wall itself, convective currents can occur as the plaster and the fill material heats small pockets of air, creating small convective cycles that speed up the transfer of heat. Within earthbag walls there is generally not



For a common 14-inch wall, R-values vary widely depending on fill material:

- The R-value of soil is typically somewhere between R-.25 and R-1 per inch; so a 14-inch-thick wall would be R-4 to R-14.
- Pumice and scoria (both natural, lightweight volcanic stone) have reported R-values of between R-1.5 and R-2 per inch. Thus, a 14-inch bag wall would yield between R-21 and R-28.
- Perlite is rated between R-2.5 and R-3.7 per inch, yielding a range between a whopping R-35 and R-52 for a 14-inch wall.
- Vermiculite is rated between R-2.1 and R-3.7 per inch, so a 14-inch wall would range between R-29 and R-52.
- Rice hulls have been tested at greater than R-3 per inch, so a nominal 14-inch wall would provide at least R-42.

much convective heat transfer going on because there is little air space for this, especially when the fill is thermal mass material.

### **Air Control (Thermal Performance): Principle**

The movement of air through a wall assembly reduces the effectiveness of any insulation because heat is carried through the wall at an accelerated rate. Even at a relatively low pressure difference between inside and outside, heat flow through a wall can be nearly 25–50% higher than the R-value of the wall would be with no air movement.

Controlling the movement of air through a wall is critical to maintaining a comfortable and energy-efficient interior climate. Developing a continuous barrier to the movement of air through the shell of a building should be a primary goal during both the design and construction phases. This applies to all penetrations, including electrical outlets, pipes, and service conduits.

### **Air Control (Thermal Performance): Application for Earthbag Building**

A typical earthbag building that has a continuous interior and exterior plaster maintains a very effective air control barrier. The flow rate of air through the bagged portion of the wall depends on the nature of the fill material, with solid earthen fill being the most resistant to the movement of air. The weakest links in an earthbag wall will occur at the seams between individual bags, especially at either end. Adequate tamping of the bags during construction will generally squeeze the bags fairly tightly together, diminishing the chance of air movement through the wall, but the plaster needs to be the primary guardian against air movement.

### **Air Control (Moisture Performance): Principle**

Any air that does enter a wall can carry water vapor with it. Warmer air holds more vapor than cooler air; as the warmer air cools, it can deposit moisture inside the wall if it reaches its dew point. The potential for moisture retained inside an earthbag wall to cause mold, rot, or deterioration makes it even more critical to seal the wall from air intrusion.

### **Air Control (Moisture Performance): Application for Earthbag Building**

To avoid the possibility of excess moisture condensing inside an earthbag wall, the best defense is a solid air barrier, as described above. Both the interior and the exterior plaster needs to be continuous — no gaps, cracks, or holes — as a defense against such moisture buildup.

### **Vapor Control: Principle**

In general, the air control layer will also act as a vapor control layer since most vapor entering

a wall will be carried by air. However, some moisture can still enter a wall through *diffusion*. It is possible for moisture to migrate at a molecular level through the pore spaces in a wall. This happens when there is a difference in moisture content on either side of a wall, causing vapor pressure.

To combat moisture diffusion, a *vapor barrier* or *vapor retarder* is installed in some building technologies. This generally not nearly as critical with earthbag walls because most fill materials are not adversely affected by some moisture. One exception to this is with rice hull insulation, which is best kept as dry as possible.

Different materials resist the diffusion of moisture to varying degrees. The ability of any given material to resist moisture diffusion is measured by *perms*. Vapor retarders are classified by these ratings:

Class I — 0.1 perm or less (qualifies as a vapor barrier, or is vapor impermeable)

Class II — 0.1 to 1.0 perms (vapor impermeable)

Class III — 1.0 to 10 perms (vapor semi-permeable or vapor permeable)

Class IV — 10 perms or greater (vapor permeable)

### Vapor Control: Application for Earthbag Building

Because of the wide range of possible fill materials used in earthbag building, it is hard to generalize regarding proper vapor barriers. We do know that earthen materials have the capacity to absorb a great deal of moisture without ill effect; in fact, the use of natural earthen plasters, as well as solid adobe, rammed earth, or cob walls, is often touted as one of the better ways to mitigate problems associated with situations of high humidity. This is because these natural materials allow moisture to move both in *and* out of a building — allowing the building to

“breathe” — in addition to their general lack of organic material that can rot or mold.

The various fill materials that act as insulation can absorb moisture to differing degrees and are potentially degraded by the retention of that moisture (also to differing degrees). In earthbag building, it is best if the earthbag wall remains vapor *permeable* — on both sides, if possible. Like straw bales, these wall systems should be kept breathable, with a rating of at least 4 perms. For earthbag buildings, this is almost always determined by the *plaster’s* perm rating.

**Table 3.1: Permeance of Plaster Skins**

	US perms	Metric perm
Typical vapor barrier (by definition)	<1	<60
1:3 cement:sand (1.5")	1	50
5:1:15 cement:lime:sand (1.5")	4	200
1:1:6 cement:lime:sand (1.5")	7	400
1:2:9 cement:lime:sand (1.5")	9	500
1:3 lime:sand (2")	9	500
Earth plaster (2")	11	600

### Water Control: Principle

Direct exposure to rain presents the greatest risk to most walls; this is best addressed at the design phase by planning for substantial roof overhangs, proper foundations, and window details that shunt water away from the wall assembly. Climatic conditions will dictate the extent of such measures, with arid climates presenting less need than humid or rainy climates; in windy climates, a design must be implemented that takes into account wind-blown moisture. The exterior plaster or cladding is generally the first guard in defense of moisture penetrating a wall.

### Water Control: Application for Earthbag Building

Most earthbag buildings can be adequately protected from water intrusion by having a good



**Fig. 3.1:** This small earthbag dome under construction in Mexico was plastered on the exterior with cement-based stucco that had a latex additive to make it more waterproof. In addition, it was painted with a couple of coats of water-impermeable roof paint. CREDIT: KELLY HART

plaster. This is particularly true with vertical walls that are well protected by a good roof eave.

In the case of domed earthbag structures, protection against the penetration of rain into the wall becomes much more problematic because the wall is *also* the roof, so it can be expected to receive considerable exposure to rain. One excellent way of offsetting the intrusion of moisture is

to apply a plaster of *low permeability*, like stucco that has a high percentage of Portland cement or magnesium oxide cement. The surface of the plaster can also be painted with a non-permeable paint formulated for use on roofs, or it can be coated with something that is somewhat more permeable, like potassium silicate paint. Unfortunately, these measures require regular maintenance and are no guarantee that water won't somehow find its way through cracks or unseen deformations at some point during the life of the building. If this does happen, the moisture entering into the bagged portion of

the wall may accumulate because the dome is no longer adequately breathable to allow the moisture to disburse. This can lead to soggy fill, mold, deterioration, or possible failure of the dome to support itself, endangering life and property. For this reason, I do not recommend that people build earthbag domes that rely on a plastered exterior in any climate other than rather arid ones.

One way to avoid the risks described above for earthbag domes in damper climates is to first of all use a solid, stabilized fill material that will not deform if for some reason it gets damp. Then, a secondary rainscreen cladding can be applied over the plastered earthbags, basically creating a separate roof structure that actively sheds the water away from the dome and leaves a space between the plaster and the rainscreen

that can ventilate and provide a pathway for moisture to evaporate. Obviously, this solution would add to the expense and construction time of the project, but it makes the building more secure in wetter climates.

Earthbag walls also need to be protected from the intrusion of water wicking *up* through the foundation. This can be accomplished in a variety of ways, such as installing a rubble trench foundation with a French drain flowing to daylight to keep the foundation from accumulating water. The first course or two of earthbags can be filled with gravel that will not wick moisture further up into the wall. Another safeguard is an impermeable moisture barrier placed between the foundation and the bagged wall.





## Chapter 4

# Material Specifications

### Bags

**W**HAT IS THE BEST KIND OF BAG MATERIAL to use for earthbag building? Here are what I consider to be the most important attributes of bag material:

- Strength — can withstand considerable pressure without stretching or breaking.
- Durability — will last for centuries without degradation (hopefully), especially when protected by a covering of plaster and not adversely affected by moisture or normal temperatures.
- Permeability — some ability to breathe is particularly important when the fill material is the type that needs to be dampened before being tamped into place; otherwise it will never dry out and become hard.
- Low cost — not too expensive for common use.
- Availability — readily available in a form that can be used.

Of all the modern bag materials currently being manufactured, the best candidate — and the one most commonly used for earthbag building today — is *woven polypropylene*. It is remarkably robust in tensile strength, measuring between 26 and 33/Mpa (megapascals). It is very durable, being resistant to damage from moisture, chemicals, and common atmospheric temperatures; the only real danger to its integrity is the sun, since it is rather quickly degraded by the ultraviolet radiation (UV) in sunlight. The woven polypropylene lattice provides sufficient permeability to allow the dispersion of moisture. Polypropylene bags are widely available around



**Fig. 4.1:** This close-up of a polypropylene bag shows the woven nature of the ribbons of the poly material, which allows for some breathability.

CREDIT: KELLY HART

the world at reasonable prices because they are so commonly used for other purposes, such as for containing grains, flour, and animal feed.

The burlap bags that were commonly used a few decades ago for sand bags and bunkers served that purpose well, but they eventually degrade when subjected to moist conditions; the durable synthetic fibers available today do not. Burlap bags are, however, somewhat more resilient when exposed to ultraviolet radiation than polypropylene is.

The open *raschel mesh* material used for *Hyperadobe* is most commonly made with polyethylene. It only has about half the tensile strength of polypropylene, but seems to be adequately strong for the job asked of it. The nature of the mesh material lets it stretch in all

directions until it reaches a certain level of tension, and then it becomes quite stiff.



**Fig. 4.2:** This open raschel mesh tubing can be used with the Hyperadobe method. CREDIT: ROSANA HART



**Fig. 4.3:** These rolls of polypropylene tubing are ready to be cut to lengths appropriate for building. CREDIT: KELLY HART

Both polypropylene bag material and polyethylene mesh material are available in huge rolls as tubing. It is this tubing that eventually gets cut and sewn into individual bags. The tubing itself can be used directly for either the *Superadobe* or *Hyperadobe* methods; there are many pros and cons to using it this way, which will be described more fully later.

It is possible to buy polypropylene bags and tubing that have been treated with a UV-resistant coating. This treated material really only *delays* possible degradation from UV by a few weeks, or months at the most, but this may be worth the expense in some instances (such as when there is a long lag-time between building and plastering or if it is inconvenient to keep the walls covered with tarps when construction is not happening). All earthbag walls need to eventually be protected by plaster or other cladding to be durable when exposed to sunlight.

One can sew bags or tubes from a variety of other fabrics, such as cotton or canvas, or make specialty bags that have two or three compartments that can be filled with different materials. Such bags are generally not available commercially, so would have to be made as a cottage industry. The value of such specialty bags would have to be analyzed separately.

Some commercial bags are sewn with gussets at the bottom. I've used both gusseted and non-gusseted bags, and I prefer the gusseted ones because the base of the bag doesn't produce pointed protrusions that need to be hammered back into the wall to make it smoother before applying a plaster.

Bags come in a lot of different sizes, but the most common size used for earthbag construction is about 18" × 30" (46 cm × 76 cm), a size that is often used to store 50 pounds (23 kg) of rice. This size bag produces a wall measuring about 16" (41 cm) wide (after being plastered). Somewhat smaller bags can be used for some

**Table 4.1: Environmental Impacts of Synthetic Bags**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<p><b>Moderate to High.</b> Polypropylene (PP) and polyethylene (PE) are nonrenewable resources made from crude oil and natural gas. Procuring the feedstock can cause habitat destruction and surface and ground water interference and contamination. Manufacturing can include significant air and water pollution. Weaving PP strands is a moderately intensive mechanical process with no significant impacts.</p>	<p><b>High.</b> 99.2 MJ/kg for PP; 83.1 MJ/kg for PE. PP is among the least energy intensive plastics to manufacture, and can be derived from recycled sources.</p>	<p><b>High.</b> 3.43 kgCO<sub>2</sub>e/kg for PP; 2.54 kgCO<sub>2</sub>e/kg for PE. Most bag material is manufactured in Asia so there is often significant transportation impact, although the quantity of material is low, which mitigates this.</p>	<p><b>Very Low.</b> These plastics have no significant impact on indoor air quality.</p>	<p><b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: The expected lifetime of these plastics is unknown if they are not exposed to UV in sunlight.</p>
<p><b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath</p>				

projects, but for most habitable buildings they are not stable enough. The bags commonly sold for use as sand bags for flood control are too small. Larger bags can also work, and may be preferable for projects that need a larger footprint at the base (such as a two-story building). But larger bags will take more fill material and more work to assemble and move, and they take up more space as well.

Polypropylene bags can be purchased from a variety of outlets, including farm supply stores. Often, the best deals can be found from online sources that sell large quantities, frequently in bales of a thousand bags, or huge rolls of tubing that measure over a mile (1.6 km) long. Sometimes you can find good deals on quantities of “misprinted” bags that were rejected by companies that print the labels on commercial bags.

Occasionally, it is possible to find used bags for sale, and if you are tempted to use these, I advise that you carefully assess the condition

of the bags and find out if they have ever been subjected to sunlight or hard wear; if so, you are better off not using them.

### Fill Material

One of the real advantages of earthbag construction is the wide range of materials that can reasonably be used to fill the bags.

The most readily available material is the earth itself, which can often be found right at the building site and is free for the digging. Good-quality topsoil is best held in reserve for gardening and landscaping, but the subsoil below that often works well as fill.

Basically, the same type of soil that lends itself to making good adobe blocks and rammed earth or cob walls is perfect for earthbags. This is soil that has roughly a ratio of one third clay to two thirds sand, but with earthbags there is much more latitude in this ratio. Because the bag confines the fill material from dispersing, it



becomes less important that the fill be able to form an absolutely solid block on its own. Some degree of consolidation is desirable to keep the soil from shifting in the bag, and, in case the bag material deteriorates for some reason, a solidified fill won't be as likely to erode away. As little as 5% clay might be sufficient to bind the ingredients into a solid-enough block. *Too much* clay can lead to shrinkage or expansion, so that should be avoided too.

You can figure out the relative percentage of materials in your soil by doing a simple jar test: Fill a clear glass jar about one third full of the soil sample, then add water to nearly the top and shake the whole mixture vigorously. Let this stand for a day to settle out. Eventually, the solids will settle to the bottom and the water will be fairly clear on top, with perhaps some organic material floating on that. On the very bottom will be the heavier aggregate; above that will be the coarser sand, then the finer sand and silt, and finally on the very top will usually be a clearly marked line of clay. You can compare the amount of each layer to determine the composition of your soil.

If you are using soil as your fill material, take the time to discard all organic material, as this can eventually rot and create voids in the wall. Also, larger stones should be cast aside since they might puncture the bag when it is tamped,

and they don't help with creating a monolithic block; a small quantity of smaller stones in the mix are of no real concern.

Soil sold as *road base* will often work well for earthbags, as it is formulated to pack into a fairly solid surface for roads.

It is a good idea to make a few test bags of any given soil to make sure that it will suffice for your project. To do this, slightly dampen the soil and place it in an empty earthbag. Use a heavy tamper to compact the soil in the bag as much as possible, then set the test bag aside (out of the rain) for several days or weeks until it is thoroughly dry inside. Once it is cured, drop the test bag from about knee height to see if it holds together in one piece. If it does, your fill is good; if it fragments into many pieces then you probably need more clay.

Loose gravel or gravel mixed with sand can be used to fill bags that will serve as a kind of foundation for an earthbag wall (or for other wall systems as well). The reason to do this is that such material won't wick moisture up into the rest of the wall, nor will it be damaged if it does get wet. The best gravel for this job is no greater than about 1 inch (2.5 cm) in diameter; anything bigger runs the risk of puncturing the bag when heavily compacted by the weight of the wall. In fact, I suggest *doubling* all gravel foundation bags (place one bag inside another

**Table 4.2: Environmental Impacts of Typical Soil**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Negligible to High.</b> The use of site soil is negligible; aggregates and binders that are quarried can have low to high impacts on wildlife habitats and on water contamination and flow.	<b>Negligible to Moderate.</b> 0.45 MJ/kg for delivered soil; no EE for site soil.	<b>Negligible to Moderate.</b> 0.024 kgCO <sub>2</sub> e/kg for delivered soil; no embodied carbon for site soil.	<b>Very Low.</b> Soil has no significant impact on indoor air quality.	<b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Soil can simply be returned to the site without any significant impact.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

one before filling). This will help protect the bag from ever losing integrity, which is essential in this situation.

Either rounded or crushed gravel can be used for this. The rounded variety does a somewhat better job of stopping capillary action, while the crushed gravel packs into a more tightly bonded monolithic unit.

As mentioned earlier, there are many other loose materials that have been used as fill material for earthbag construction. Most of these would be considered insulation, and they all have particular attributes. Lightweight volcanic

stone (such as scoria or pumice), perlite, vermiculite, and rice hulls are all insulating materials that can be used for fill. My favorite of these is scoria because once it is tamped into place, it tends to form a fairly solid shape that doesn't easily deform; also, it is unaffected by moisture. Scoria, pumice, and perlite are stable enough to rely on under compression to support heavy loads. Vermiculite and rice hulls will compress substantially under a load, so they should really only be used as infill in some other load-bearing structure, like post and beam or timber frame systems.



**Fig. 4.4:** Earthbags are being filled from a large pile of lightweight crushed volcanic scoria that serves as an insulating material. Each bag weighs only about 35 lbs. CREDIT: KELLY HART

**Table 4.3: Environmental Impacts of Sand and Aggregate Fill**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Negligible to High.</b> The use of sand or gravel found at the site is negligible; aggregates and sand that are quarried can have low to high impacts on wildlife habitats and on water contamination and flow.	<b>Negligible to Moderate.</b> 0.081 MJ/kg for delivered aggregate or sand; no EE for site-sourced aggregate or sand. Aggregate that is mechanically crushed has moderate use of fuel for machinery and dust dispersion.	<b>Negligible to Moderate.</b> 0.0051 kgCO <sub>2</sub> e/kg for delivered aggregate or sand; no embodied carbon for materials sourced on the site.	<b>Very Low.</b> Aggregate and sand has no significant impact on indoor air quality.	<b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Aggregate and sand can simply be returned to the site without any significant impact.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

**Table 4.4: Environmental Impacts of Crushed Volcanic Stone Fill**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Moderate to High.</b> Crushed volcanic stone is generally quarried and can have moderate to high impacts on wildlife habitats and on water contamination and flow.	<b>Moderate.</b> 0.083 MJ/kg for delivered crushed volcanic stone; crushed volcanic stone that is mechanically crushed has moderate use of fuel for machinery and dust dispersion.	<b>Moderate.</b> 0.0052 kgCO <sub>2</sub> e/kg for delivered crushed volcanic stone.	<b>Very Low.</b> Crushed volcanic stone has no significant impact on indoor air quality.	<b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Crushed volcanic stone might be returned to the site without any significant impact, or it might be transported to a more appropriate repository.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

**Table 4.5: Environmental Impacts of Perlite Fill**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Moderate to High.</b> Crushed perlite is generally quarried and can have moderate to high impacts on wildlife habitats and on water contamination and flow.	<b>Moderate to High.</b> 0.66 MJ/kg for delivered natural perlite; 10.00 MJ/kg for expanded perlite that has been processed and heated.	<b>Moderate to High.</b> 0.03 kgCO <sub>2</sub> /kg for natural perlite that is quarried and delivered; 0.52 kgCO <sub>2</sub> /kg for expanded perlite.	<b>Very Low.</b> Perlite has no significant impact on indoor air quality, particularly when bagged and plastered over; the dust can be an irritant when handling the material.	<b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Perlite might be returned to the site without any significant impact, or it might be transported to a more appropriate repository.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

**Table 4.6: Environmental Impacts of Vermiculite Fill**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Moderate to High.</b> Vermiculite is generally quarried and can have moderate to high impacts on wildlife habitats and on water contamination and flow.	<b>Moderate to High.</b> 0.72 MJ/kg for delivered natural vermiculite; 7.20 MJ/kg for exfoliated vermiculite that has been processed and heated.	<b>Moderate to High.</b> 0.03 kgCO <sub>2</sub> /kg for natural vermiculite that is quarried and delivered; 0.52 kgCO <sub>2</sub> /kg for exfoliated vermiculite.	<b>Very Low.</b> Vermiculite has no significant impact on indoor air quality and is completely nontoxic; there has historically been mined vermiculite that was contaminated with asbestos, but this has not happened recently.	<b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Perlite might be returned to the site without any significant impact, or it might be transported to a more appropriate repository.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

**Table 4.7: Environmental Impacts of Rice Hulls Fill**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<p><b>Low to High.</b> Rice hulls are a byproduct of the cultivation and processing of rice; such cultivation can have low to high impacts on wildlife habitats and on water contamination and flow.</p>	<p><b>Low to Moderate.</b> 0.24 MJ/kg for delivered rice hulls.</p>	<p><b>Low to Moderate.</b> 0.01 kgCO<sub>2</sub>/kg for rice hulls delivered to the site.</p>	<p><b>Very Low.</b> Rice hulls have no significant impact on indoor air quality and are completely nontoxic.</p>	<p><b>Low.</b> Construction: There is virtually no waste generated during construction. End of life: Rice hulls are biodegradable and will thus present no ultimate end of life problem; they could be used as agricultural mulch.</p>
<p><b>Note:</b> Data is extrapolated from data about straw within the Inventory of Carbon and Energy (ICE) 2.0, University of Bath</p>				



**Fig. 4.5:**  
The aftermath of a collapsed partial dome of earthbags filled with unstabilized fine sand.

CREDIT: KELLY HART

As for using sand as earthbag fill: it is generally best to avoid doing this. Sand is a notorious shape-shifter, as I discovered with my very first earthbag project: It was a small trial dome that was to become an outbuilding eventually, and I was filling the bags with the very fine sugary sand that was native to the region. All went well until I got up to about shoulder height, and then

when I was tamping that course of bags into place, the wall suddenly began to deform, caving inward in a slow motion collapse of the partial dome. I had to clean up the mess and start all over. (I used scoria the second time, which worked quite well.)

On another occasion I used the same kind of sand to fill bags for a vertical-walled circular



**Fig. 4.6:**  
*This circular vertical walled structure was built from earthbags filled with unstabilized sand, but it has stood the test of time.*

CREDIT: ROSANA HART

building that was to become an outdoor stage and shade structure. In this situation, because the bags were stacked vertically, and were well-integrated with barbed wire between each course, and the roof structure actually placed the entire wall under tension, I felt confident that the building would be stable over time. It was built about two decades ago, and it is still standing firm. But I caution you that using any loose fill can be risky, so proceed with doing this only if you are confident of the engineering.

*Stabilized soil* is soil that has been amended with something that will make it harden, or make it more stable in weather conditions. Traditional stabilizers have been Portland cement, lime, or emulsified asphalt (although I do not recommend using asphalt for earthbags). Soil stabilization is rarely needed in earthbag

construction in arid climates. Under some circumstances, it might be advised for parts of lintels or arches to make them more rigid, or if the fill material is too loose, such as with very fine sand that doesn't want to compact into a solid shape. Earthbag domes built in any other climate than very arid ones should definitely be built with stabilized soil; otherwise there is the risk of collapse if the fill gets too damp over time.

You generally only need about 4–6% cement or lime by volume to stabilize sand or soil. It needs to be mixed thoroughly and moistened to work. Hydrated lime can be used, and it is more environmentally benign than Portland cement since it reabsorbs the CO<sub>2</sub> released during its manufacture. You should add some lime along with cement if the soil has a lot of clay; tweak

the recipe to the point where you use the least amount of stabilizer possible. I suggest that you run some tests with your particular soil to see what works best. Try several batches with different ratios. Working with lime can be tricky, partly because it behaves differently with different soils.

I have heard of people using limestone *finer* from a lime quarry as earthbag fill, and this

worked out well, compacting into very solid blocks when dampened and tamped. The same is true of crushed coral mixed with sand found near a beach in the Bahamas. There are really many possibilities out there. Just be careful about using fill that might degrade if it gets damp or compresses too easily to support the weight.

**Table 4.8: Environmental Impacts of Lime Stabilizer**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>Moderate.</b> Limestone is a nonrenewable resource but is abundantly available. Large-scale quarrying can cause habitat destruction and surface and ground water interference and contamination.	<b>High.</b> 5.3 MJ/kg. Lime is processed at high temperatures, in addition to quarrying and crushing energy inputs.	<b>High.</b> 0.78 kgCO <sub>2</sub> e/kg. Lime will absorb CO <sub>2</sub> during the curing process, but due to fuel use during processing will still be a net carbon emitter, though accurate figures are difficult to assess.	<b>Very Low.</b> Lime-based plasters and stabilized earth can contribute to high indoor air quality, providing naturally antiseptic qualities and no toxic off-gassing.	<b>Low to Moderate.</b> Construction: Lime used as either a soil amendment or a plaster ingredient is not normally wasted. End of life: Lime can be left in the environment or crushed to make aggregate.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

**Table 4.9: Environmental Impacts of Cement Stabilizer**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>High.</b> High carbon emissions and harvesting impacts.	<b>High.</b> 4.5 MJ/kg. Cement is processed at high temperature, in addition to quarrying and crushing energy input.	<b>High.</b> 0.74 kgCO <sub>2</sub> e/kg.	<b>Low.</b> Cement-based plasters and stabilized earth are nontoxic and have no off gassing once they are cured.	<b>Low to Moderate.</b> Construction: Cement used as either a soil amendment or plaster ingredient is not normally wasted. End of life: Cement-based plaster or soil cement can be left in the environment or crushed to make aggregate.
<b>Note:</b> Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath				

### Barbed Wire and Other Types of Reinforcement

The use of barbed wire placed between each course of earthbags is usually recommended. The barbed wire is used for several reasons. It helps stick the bags together, keeping them from slipping relative to each other. It provides tensile strength throughout the entire wall, resisting any



Fig. 4.7: Two strands of barbed wire have been placed along the top layer of this wall; stones temporarily hold the wires in place in readiness for the next course of bags. CREDIT: KELLY HART

forces that might pull the wall apart, either from vectors resulting from the shape of the building or from seismic events. Barbed wire is always a good idea because it helps fix all of the courses of bags into a more monolithic whole.

The best barbed wire to use is called *four point* because the barbs form four points, like an X. This assures that, wherever the barbs occur, at least some of them will be piercing the fabric of the bag both above and below, thus sticking the bags together like Velcro. It is worth making an attempt to source four-point barbed wire because it really does a better job than the more common two point wire.

The gauge of the wire used is not terribly important; in fact the lighter gauge wire is easier to use, cheaper, and plenty strong for the purpose. I have recently used high-tensile barbed wire, 15.5 gauge, with a Class 3 zinc coating, and this was perfectly adequate for the job. All modern barbed wire is coated for durability. Look for the barbed wire at your local farm and ranch supply stores; they might have to special order it for you. You can find barbed wire online, but it is very heavy so the shipping cost can be very high.

There are many uses for long steel stakes during earthbag construction. Common concrete reinforcement rods, known as *rebar* work

Table 4.10: Environmental Impacts of Barbed Wire

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>High.</b> Steel and zinc are extracted in an intensive mining process, with impacts that include habitat destruction and surface and ground water interference and contamination. The use of recycled content can mitigate these impacts.	<b>High.</b> 36.00 MJ/kg. Steel and zinc are produced using very high heat input, requiring heavy use of fossil fuels. Impacts include air pollution, water contamination, and dangerous working conditions.	<b>High.</b> 3.02 kgCO <sub>2</sub> e/kg. It can be difficult to track all stages of extraction and manufacture involved, which are often international in scope.	<b>Very Low.</b> Steel and zinc wire does not off-gas or have toxic impacts once it is installed.	<b>Low.</b> Construction: Barbed wire is not normally wasted. End of life: Barbed wire can generally be recycled.

Note: Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath

just fine for this; they are sold in very long pieces, and it is easy to cut them to any appropriate length. I have mostly used the nominal half-inch (13 mm) rebar for my projects, and it does the job well; it is plenty strong and stiff enough to be able to pound it through even rather dense material, yet pliable enough to bend if necessary.

Having some polypropylene twine (like what is used for bales of straw) around can be useful. I often use it laid at intervals across the bags (at right angles to the barbed wire) during construction so that eventually it can be used to tie plaster reinforcement mesh to both the inner and outer walls.



**Fig. 4.8:**  
The author is driving a vertical rebar stake into a curved section of wall to help stabilize it.

CREDIT: ROSANA HART

**Table 4.11: Environmental Impacts of Steel Rebar Stakes**

Ecosystem Impacts	Embodied Energy	Carbon Footprint	Indoor Environment	Waste
<b>High.</b> Steel is extracted in an intensive mining process, with impacts that include habitat destruction and surface and ground water interference and contamination. The use of recycled content can mitigate these impacts.	<b>High.</b> 17.40 MJ/kg. Steel is produced using very high heat input, requiring heavy use of fossil fuels. Impacts include air pollution, water contamination, and dangerous working conditions.	<b>High.</b> 1.40 kgCO <sub>2</sub> e/kg. It can be difficult to track all stages of extraction and manufacture involved which are often international in scope.	<b>Very Low.</b> Steel rebar does not off gas or have toxic impacts once it is installed.	<b>Low.</b> Construction: Steel rebar is not normally wasted. End of life: Steel rebar can generally be recycled.

Note: Data is from Inventory of Carbon and Energy (ICE) 2.0, University of Bath





**Fig. 4.9:** *These participants in an earthbag workshop are inserting personal mementos into the freshly plastered wall. On the reverse side of the wall you can see how the chicken wire mesh was tied into place with pieces of twine.*

CREDIT: KELLY HART

## **Plaster**

The environmental impacts of the primary ingredients of plaster were covered earlier in the discussion of stabilizing fill material. The use and application of plaster is more thoroughly covered in Chapter 9.



## Chapter 5

# Tools

**T**HE TOOLS OF THE TRADE for earthbag building consist of just a small box of hand tools, a number of standard gardening implements, and a few specialty items that can be fashioned in the home workshop.

The tool box would include wire cutters, pliers, trowels, tape measure, level, hammer, rubber mallet, knife, stapler, scissors, and needle and thread. The wire cutters and pliers are used to cut barbed wire or make metal staples to hang plaster mesh. Trowels are used for spreading plaster. Measuring and leveling instruments are used during construction to make sure the design goes according to plan. The hammer or mallet can be used to tap in protruding bag corners, drive staples, or even out bumpy walls. The other items might be needed to cut bag tubing to the proper length or sew bags closed.

The gardening or household supplies would include shovels, wheelbarrow, buckets, gloves, tarps, ladder, and bricks or stones. The first items are all used to dig foundations and transport fill material. Tarps are used to cover bag walls to protect them from the sunlight. Ladders are useful for climbing onto walls as they get higher. Bricks, stones, or other heavy objects can be used to temporarily hold the barbed wire in place until it is covered by courses of earthbags.

The special tools would include a funnel or filling tube, bag stand, barbed wire spindle, tapper, metal slider, and any arch forms that may be needed.

It is convenient to be able to shovel or pour fill material directly into open bags without worrying about some of it spilling off to the side. With a special funnel or filling tube that is the right size to slip into the open mouth of a



**Fig. 5.1:** Here the author is about to slip a new bag over the narrow end of a chute that was originally the upper part of a commercial chicken feeder.

CREDIT: JULIE HICKS



**Fig. 5.2:** Fill material is being dumped from a bucket into the mouth of the bag being held open by the chute.

CREDIT: JULIE HICKS

bag, it is easy to channel all of the fill to where it belongs. Another approach to accomplishing this is with a bag stand that will prop up an entire bag and hold the mouth open for delivery. Either method works well, but when you are filling long tubes of bag material, the best way is with a funnel or tube that will allow long lengths of material to be scrunched onto it so that the fill can be placed near the very end.

I have used the upper part of a large metal chicken feeder as a funnel. This device is slightly tapered so it easily fits into the bag, and it's long enough to reach far down into the bag. Another possibility is to cut the bottom out of a five-gallon plastic bucket that is the right size to slip into a bag.

I have seen bag stands fashioned out of two long rectangles of metal bar that are connected to each other at two points that allow the rectangles to scissor and cross each other. This way they can be opened just enough to loop the open end of a bag over the top rims, and the bottom will firmly support the whole affair. The bag hangs down between the two rectangles. Usually, the height is adjusted so the bottom of the bag just rests on the ground.

**Fig. 5.3:** *The author's favorite tamper fits across the full width of a bag.*

CREDIT: KELLY HART



A spindle to reel off long pieces of barbed wire can be fashioned with a short piece of metal pipe that is placed through the center core of the spool of barbed wire. This pipe can be supported somehow between two heavy objects or in some kind of cradle that is made just for this purpose. This allows the wire to be pulled away while the spool just spins in place, so that the proper length can be measured and cut.

Tampers can be purchased ready-made at a hardware store, or you can make your own in a variety of ways. The commercial ones usually have a wooden handle that is firmly mounted to a cast iron plate with a flat bottom; these are usually square in shape, about 8 inches on a side.

I made my favorite tamper from a heavy piece of steel with a shallow U-shaped section. To this I had a steel handle welded in the middle. This combination made the tamper quite heavy, which I prefer because it does a great job of tamping without having to put much force into the downward stroke. Also, the head of my specially-made tamper measures about 6 by 14 inches, which means that I can tamp the full width of the bag with one stroke rather than having to go from side to side as I tamp down a course of bags.

Another common way to make a tamper is to take a wooden handle, like that from an old shovel, drive some nails or screws around one end, and dip that end into a small bucket or can of wet concrete. If you leave the handle undisturbed and let the concrete set up, you can then remove the bucket or can, and there is your tamper. These tampers usually have a round pounding end; in my opinion, a rounded end is not as efficient in thoroughly tamping the fill as a rectangular shape.

Using a *metal slider* is unique to earthbag building. What it enables you to do is actually place a filled bag exactly where it belongs on the wall without risking that the barbs pierce the

fabric before it is ready to be tamped into place. A slider is a piece of sheet metal cut about as long as the bag is; it is put down over the rows

of barbed wire where the next bag will be laid. The barbs will not catch in the metal; when all is ready, it can be pulled or yanked out from under

### Arch Forms

Arch forms are needed to make strong, uniform arched doorways or windows. The forms can be made from any material that is robust enough for the task. I have made them from two identical pieces of plywood cut to the exact shape that I wanted the arch to be. Between the pieces of plywood I nailed or screwed short pieces of 2×4s (5×10 cm) around the arch shape. These 2×4s can be cut to provide the appropriate depth of the form, which depends on the widths of the bags that will eventually form the arch; you want an arch form to fully support the weight of the entire bag until it is removed from beneath the arch. A bit of space (up to an inch [2.5 cm], say) can be left between each of the 2×4 spacers. A few of the spacers can be fastened across the bottom of the arch form, particularly on each side, allowing the form itself to firmly rest on some temporary support, like a stack of bags.

The form described above could also be made with plates of metal cut to the right shape and then spaced apart with wood or metal spacers. The whole arrangement could also be fabricated out of welded metal rods covered with a stiff metal mesh. In any case, these forms can be used over and over again.

Some of the simplest forms I've seen use existing objects, like very large tires or sections of culvert pipes to create the form. These can work well, but, because they are, by definition, semi-circular shapes, they can only be used to create fairly narrow arches. Arches more than about 3 or 4 feet (91 cm or 1.2 m) wide are stronger if they form a gothic, or pointed arch.



**Fig. 5.4:** *This 3-foot (91 cm) arch form is ready for bags to be placed over it.*

CREDIT: ROSANA HART

the top bag. A simple right-angle fold at the end of the sheet metal provides a sufficient handle to grab and pull. With a bit of practice, the art of doing this is quickly learned, and, with any luck, there is very little adjustment that needs to be made after the slider is removed. It may take one hand on the bag to keep it from moving while the metal is pulled with the other hand. See Figure 7.2 for an example of a metal slider being used on an earthbag wall, with the bag being filled right on top of the slider before it is laid down into place.

Beyond these simple tools that are all that are really needed for an owner/builder, there are a number of industrial implements that can make construction go faster. Mainly I am referring to mechanized solutions like bag-filling machines, backhoes for digging foundations, loaders for

moving or mixing large quantities of fill material, automated screening devices, conveyors to elevate material high up on a wall, and pneumatic tampers. Most of these devices would only be relevant for building contractors planning to engage in a number of earthbag building projects.

Most earthbag filling machines are set up to quickly provide closed sand bags suitable for flood control. Generally, such sand bags are too small to be ideal for earthbag structures, but often the machines can be adapted to fill larger bags and handle a variety of fill materials. I am aware of one machine in development that would be able to automatically fill and lay long tubes of material along a wall. Because lots of people around the world are working on improving earthbag building techniques, keep an eye out for new developments.



## Chapter 6

# Foundations

**F**OUNDATIONS NEED TO SERVE many functions at once. They evenly distribute the weight of the perimeter of a building and provide resistance to any upheaval or settling that the building might experience. Foundations should protect the building from moisture intrusion at ground level, as well as possible erosion of the soil. And they should firmly anchor the building in case of severe weather of all types, as well as earthquakes. This is a lot to ask, and it requires a very robust and well-thought-out system.

Earthbags are unique in that to some extent they can provide their own foundation; most building systems rely on a separate and substantially different arrangement for the foundation. The most common type of foundation — the

one most often prescribed in residential building codes — is a continuous reinforced concrete foundation that extends into the ground at least as deep as the annual frost depth at the site and is based on solid, undisturbed subsoil. A foundation of this sort will certainly work for earthbag construction — as long as it is wide enough to support the entire width of the bags. But it has a number of drawbacks, including the negative environmental impact of using all of that Portland cement and steel reinforcement. Also, such concrete foundations are quite time consuming and costly to prepare.

A more benign and easier foundation to create for earthbag buildings is commonly known as a *rubble trench foundation*. With this type of



**Fig. 6.1:** The rubble trench foundation has been prepared with finer gravel on the top, and now bags of gravel are being filled, laid, and tamped into place, right at grade level.

CREDIT: KELLY HART

foundation, the bags actually rest on a strip of rubble or cobblestones within a trench that is dug down to at least the frost level at the site. The trench should be a bit wider than the bags being laid upon it.

If there is any concern that the soil surrounding the trench does not drain water adequately to keep the cobble-filled trench from filling with water during a period of heavy rain, then you should slant the bottom of the trench enough to allow water to flow downward and away from the structure. This enables you to install what is called a *French drain*, which is basically a large (3- or 4-inch [8 or 10 cm] diameter) perforated pipe embedded at the base of the trench. This pipe is routed to an area on the property where it can surface to daylight and safely expel any water that might otherwise accumulate in the rubble trench. This is especially necessary in soils that have high clay content and don't drain well.

In some cases, particularly when the soil is very loose (like sand) and tends to cave into the gravel-filled trench, it may be desirable to line the trench with permeable landscape cloth to help keep the sides of the trench intact.

When filling the trench with cobbles, I like to grade the stones or rubble so that the larger aggregate is placed at the base, and then it graduates to smaller and smaller sizes higher up in the trench. The heavier cobbles might be up around 3 or 4 inches (8 or 10 cm) in diameter; this can graduate to fairly fine gravel, say  $\frac{3}{4}$ -inch (2 cm) minus at the top. With this approach, there is plenty of space between the stones for water to accumulate while the top surface provides a good bed to receive the earthbags without the danger of puncturing them. The larger aggregate could even be broken-up concrete (often called *urbanite*), and the finer gravel can be either sharp, crushed stone or smoother, washed river gravel.

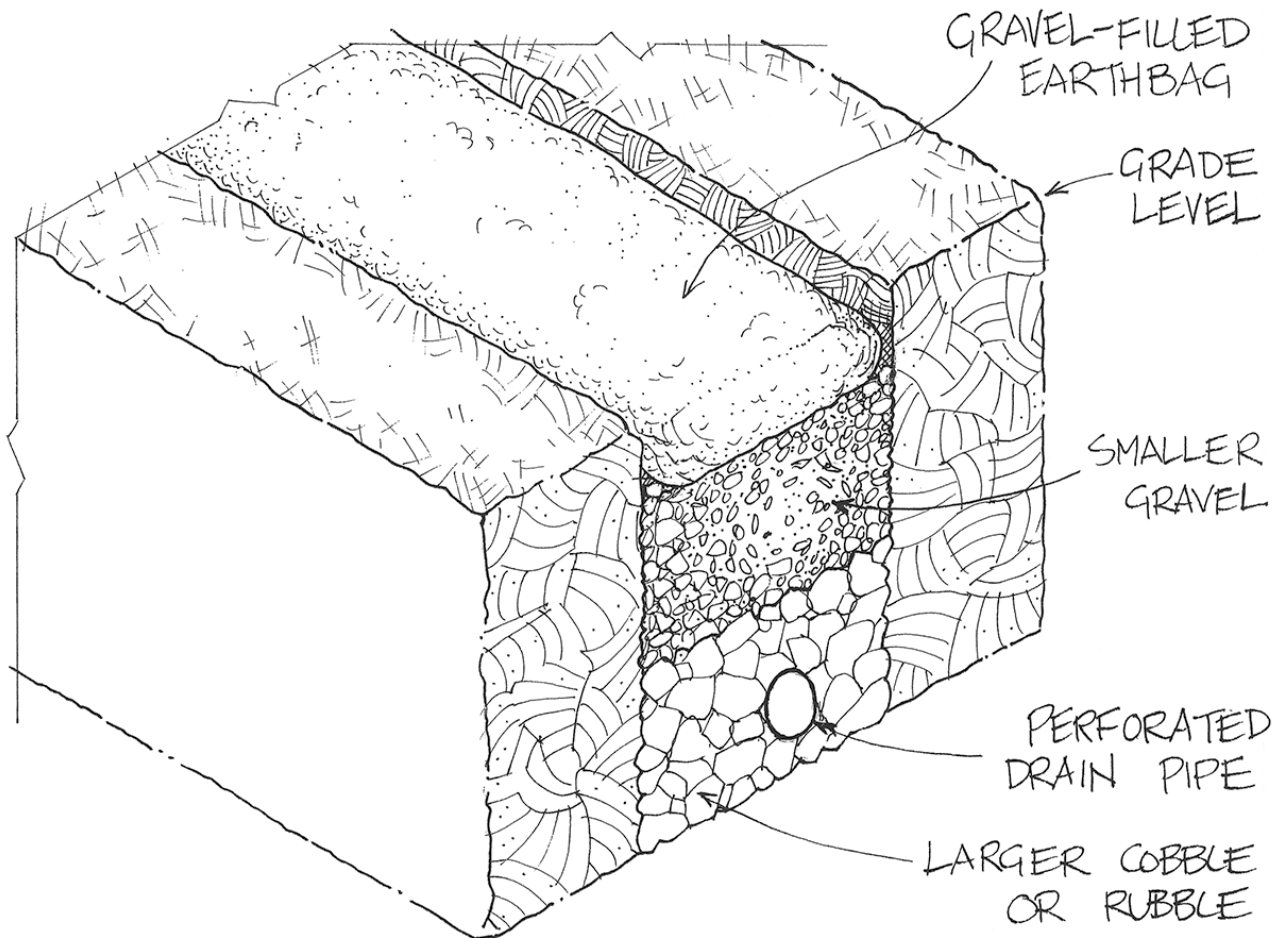
I advise that the trench not be filled to capacity, but rather enough space should be left at the top for a row of earthbags to be placed beneath the grade (ground level). The rationale for doing this is that then the building's walls will have a *toe into* the soil and therefore provide further resistance to any movement as a result of seismic events.

The first few courses of bags should be filled with material that will not wick moisture up into the wall above. This usually means either gravel or gravel mixed with some sand. Both rely on the bag material for containment. For this reason, I recommend double bagging these courses, with one bag placed inside the other for double protection of the integrity of the fill. Of course a substantial, stabilized plaster outer coat is also necessary to protect the bags.

You want the gravel bag foundation to extend high enough above grade to assure that surface water or accumulated snow will not penetrate the wall above it. This usually means at least three courses, with the first one being below grade. So the total above-ground portion of the stem wall should be at least one foot (30 cm). After the foundation wall is established and protected with plaster, the ground around the building can be graded as necessary to shed surface water away from the building.

The rubble trench/earthbag foundation described above can also be used for other building systems, such as for straw bale, cob, or cordwood walls.

Some building codes require a *grade beam* or *perimeter beam* of reinforced concrete to cap a rubble trench foundation. Such a concrete cap is no problem to integrate with earthbag walls; in fact, it would be possible to also place periodic rebar rods embedded in the concrete that would penetrate the first course of gravel bags to help anchor the building. If the top of the grade beam is high enough to elevate the first row of bags



well above grade, then this could diminish the number of courses of gravel-filled bags needed, or even allow the wall to commence without a gravel-filled course. In this case, a waterproof membrane would be needed between the concrete and the first row of bags to keep moisture from wicking upward.

In some instances, it may be desirable to create a *stem wall* that raises the point of transition to other types of fill material in the wall. This could occur when good gravel is difficult to source or when the climate dictates a high stem wall because of expected deep snow pack. Stabilized soil-filled bags can be used for this purpose. The most environmentally benign stabilizer is hydrated building lime of about 10 to 20%, and

this should be kept damp in the bags for several weeks to assure that it cures properly.

Pouring a concrete slab on grade can create both the floor and the foundation for the building in one operation. This is an accepted practice in most building codes, so the details for accomplishing it are well defined. It is not the most ecological choice because it relies on a great deal of reinforced concrete with all of the embodied energy inherent in that. Basically, a monolithic concrete floor slab is poured with suspended, welded wire mesh reinforcement embedded midway. At the periphery, a deeper trench is dug and this becomes the *thickened edge* foundation for the building. All of this is ideally lined with rigid foam insulation in most climates to isolate

**Fig. 6.2:**  
This diagram shows a basic rubble trench foundation with a French drain installed at the base.



the slab from thermal bridging with the soil under it. Generally, all necessary plumbing drains or supply lines are fixed under the floor before it is poured. Also, if hydronic heating is intended, the system has to be in place before the concrete is poured. In regions where frost upheaval is a concern, it may be necessary to insulate this type of foundation, as is done with the shallow frost-protected foundations described below.

Shallow frost-protected foundations are allowed in some building codes, and these could



**Fig. 6.3:** This earthbag wall will be substantially bermed with soil, and scoria is being placed between the wall and the plastic moisture barrier to insulate the wall. The twine that is visible was an experiment in providing a kind of mesh for plaster, a practice that I abandoned when I started using actual mesh material for that purpose. CREDIT: KELLY HART

work with earthbags. Basically, they allow much shallower foundations because the danger of frost upheaval is mitigated by placing subsurface horizontal panels of insulation extending beyond the stem wall. This insulation isolates the base of the foundation from the extremes of temperatures that might cause frost to get below the base of the foundation. Such foundations are usually only allowed for heated structures.

Sometimes it is desirable to insulate foundation walls to improve the thermal performance of a building. This can be accomplished by applying rigid panels of foam insulation that is rated for direct burial to the exterior of the stem wall. These panels would need to be plastered to protect above-grade portions.

Another approach to creating an insulated stem wall is to fill the bags with insulating material that is strong enough to withstand the weight of the building above it. Crushed volcanic stone, like scoria or pumice, can be used this way. Or the stem wall can actually be formed and poured with a mixture of Portland cement and pumice or scoria to make what is called *pumicecrete*.

Other types of foundations are also possible for earthbag walls. Dry stacked or mortared stone stem walls can be used if the builder is sufficiently skilled to lay them. Tires rammed with earth or gravel could work, but I am not a fan of these because they are very labor intensive to ram and they provide a footprint of tangent circles that requires a great deal of other types of fill material between the tires to make the continuous wall that would be necessary to provide good support for the bags laid upon it. The other options with earthbags outlined above are much easier.

The area where a foundation stem wall meets the grade of the surrounding soil is particularly vulnerable to erosion from surface water or splashback from rain. It is important to use very sturdy plaster here if the bags extend down that

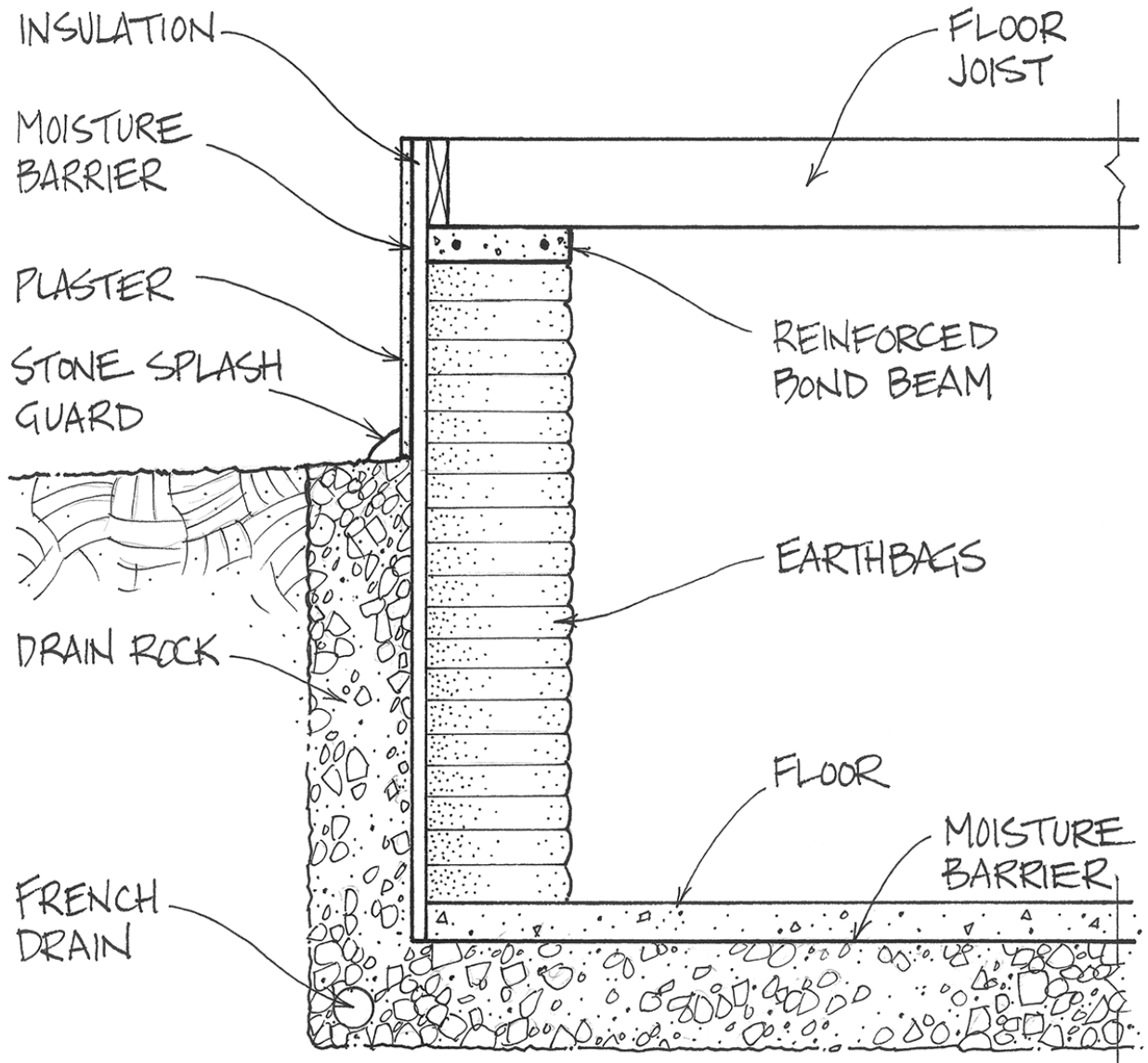
far. Another safeguard is the placement of natural stones along this edge so that the stones take the brunt of the weather.

Any time an earthbag wall will be sunk into the ground or bermed with soil, unless it is a stem wall as part of a foundation, there are special precautions that need to be made to assure that the wall remains dry over its life. Most likely, it will need to have a waterproof barrier installed on the outside to keep moisture from seeping through. I have used two layers of 6 mil polyethylene sheeting for this, but you could also use other material: a single layer of heavier plastic, butyl rubber, pond liners, or EPDM

membranes. This waterproof layer can be tucked between two courses of bags a few courses above grade and then draped down to the base near the foundation level. If it is desirable to insulate the wall from the outside, then this insulation can also be incorporated within the waterproof apron.

Additional drainage could be provided by filling a space between the waterproof layer and the soil with some gravel or sand as a secondary assurance that water won't pressure up against the underground wall. Such a drainage layer could be congruent with any rubble trench that the wall itself rests upon.

Fig. 6.4: This is one example of how a basement wall might be constructed.



It is possible to create a basement wall with earthbags that also serves as a foundation for the main floor above it. In this case, the lower bags need to be wide enough to provide for a stable foundation for the story above. For more information about how to create such basements, see

the section in Chapter 8 about building more than one story.

Earthbag *domes* may require special foundations as well to buttress the lower portion; see specifics about this in Chapter 8 where building domes is discussed.



## Chapter 7

# Building Walls

ONCE YOU HAVE ESTABLISHED your foundation, you can begin to create the earthbag walls. No matter what the fill material will be, the process of laying the bag wall is similar. The main difference is in the types of bags you will be using — either individual bags or segments of long tubing. I'll address both options below.

### Locate Source of Fill Material

The first order of business is to source the basic fill material and have it stationed as near to the foundation as is practical. In some cases, this might be a nearby pit or even an area inside the foundation where soil needs to be excavated. I have known of projects where soil was removed from a hole that eventually became a pond or

underground cistern associated with the house.

If you are mixing materials to provide the appropriate fill, then you need to arrange some way to actually do the mixing. This is usually best done in advance of filling the bags, or it might be done just prior to filling, possibly by another person, depending on the logistics of the process. Mixing can be done manually with shovels or with mechanized mixers such as cement mixers, backhoes, or front end loaders.

If the fill material is soil, or stabilized soil, then it should be dampened enough to be able to tamp it into a solid block. This should be just damp enough that moisture does not ooze from the bags when they are tamped; you don't want mud.



**Fig. 7.1:**  
*The fill soil for this dome project was brought to the site by dump truck and placed near where the work was being done.*

CREDIT: KELLY HART

## Filling Bags

To fill individual bags, it greatly helps to have a chute or funnel of some sort that just fits into the bags to facilitate this process. Either this or some kind of special stand that will hold the bag up and open to receive the fill. Both of these are described in Chapter 5.

You can use a shovel to fill the bags directly or a small bucket can be carried with fill material and dumped into the bag. The bucket approach becomes much more desirable as the wall gets higher and you want to fill the bags in place on the wall. A wheelbarrow is useful to transport fill material to the spot where the bags are being filled.

I much prefer to fill the bags right where they will be placed on the wall. Unless you are a football player who enjoys carrying 100-pound sacks of soil and hoisting them onto a wall, it is easier to fill the bags incrementally in place, and this will likely save a lot of back strain. If you have helpers, one person (or even a bucket brigade) can carry the fill to where it is needed while another person makes sure that the right amount of fill goes into the bag and lays the bag down into place when it is ready.

When the fill material is lightweight, like volcanic stone or perlite, then it might make more sense to completely fill the bags on the ground and *then* carry them to the wall being built. When

**Fig. 7.2:** *The bags on this dome are being filled in place with buckets of soil. You can see how the bag is placed on a metal slider in such a way that it can be laid down against the previously placed bag. The workers are standing on the loft platform that was already in place.*

CREDIT: KELLY HART





**Fig. 7.3:** A short section of mesh tubing is being fitted over a chute made by cutting the bottom out of a bucket. The tube is then filled on top of the wall right where it will be laid.

CREDIT: KELLY HART

I built a sizable earthbag dome house using scoria as fill, I could easily carry full bags up a ladder and place them on the wall because they only weighed about 35 pounds apiece. My wife was able to help by filling up a bunch of bags and leaving them near the pile of scoria for me to carry.

When you are laying long tubing, there is really no choice but to fill the tubes directly where they will go on the wall; you can't effectively carry a long tube that has been filled in advance. The process of laying tubing involves first measuring how long the piece of tubing should be to complete a section of wall and adding enough extra length to be able to close or seal each end. The end that will first be laid down can be permanently tied in a knot or hemmed with wire stitching or staples. The open end is then slipped over some kind of filling tube or chute that will allow most of the length of tubing to be scrunched up onto it.

The closed end is placed exactly where you want that row to start, and the fill material is poured by the bucketful or otherwise conveyed into the chute and allowed to settle all the way to the end of the bag. This process requires several people, with one person holding the chute and keeping it stable (sometimes with a leg that helps support the tubing at an angle as the fill descends) and at least one other person pouring in the fill material. A bucket brigade can make this an uninterrupted, continuous process. As the tubing at the base gets full of material, the person coordinating the chute position will be stepping backward to allow it to fall into place on the wall. It might help to have another person whose job is to precisely keep the tubing exactly where it should go so that another person can come behind with a tamper and do the final tamping. As you can imagine, a well-coordinated team could very quickly lay down a section of wall in this manner.

## Placing Barbed Wire and Twine

Before any of this happens, the section of wall that will receive the next row of bags or tubing needs to be prepared. This means that it should be well tamped and then have the barbed wire positioned where it should be. Also, if you want to later tie plaster mesh to both sides of the wall, you need to periodically place pieces of twine or wire across the wall with enough length extending on either side to eventually tie to the mesh. When I do this, I generally put a piece of twine over every bag on perhaps every third course to assure that there will be enough points of attachment.

To measure and cut the barbed wire, it helps to have the spool that it comes on suspended on some kind of device that will allow the spool to spin as the wire is pulled away from it. Barbed wire is dangerous stuff to work with; you should use heavy gloves and caution. It often has a mind

of its own and will spring away from where you want it with little provocation. Because of this, I sometime expend some effort to straighten it out so that will lay flatter than it would otherwise. Also, it is almost imperative to have some way of holding it down in place on the wall. I have used heavy rocks or bricks for this purpose, and I have seen people strap two heavy weights (like jugs full of water) together with some twine to drape over the wall and hold the wire in place. Another strategy is to actually pin the barbed wire into place with nails driven between the twisted wire and into the bags below; this has the advantage of alleviating the need to move multiple weights multiple times as the wall building progresses.

Ideally, you want to space two separate strands of barbed wire running parallel to each other down either side of the bags about 3 inches (8 cm) in from the sides. You want these lines



**Fig. 7.4:**  
*This barbed wire was spooled in such a way that it was possible to unroll it directly on the wall.*

CREDIT: KELLY HART

to be fairly straight, rather than weave back and forth down the row. The wire is there to lend tensile strength to the wall, and the lines need to be straight to do this.

It is best for as much of the barbed wire to be continuous as possible as it follows the shape of the foundation around the building, especially around corners. If you need to splice two strands of wire, you can overlap them a few feet and twist them together (carefully!). There are some alternative strategies for laying barbed wire that may increase the potential of a building to survive an earthquake; you can read about these in Chapter 12.

The *Hyperadobe* method of building earthbag walls provides a special case when it comes to

the use of barbed wire. The relatively large open spaces of the raschel mesh tubing material used with this method allows dampened mineral fill material to weld with that same material in courses both above and below, especially once the tubes are tamped. This means that to some extent the walls become rather monolithic, with two layers of mesh material embedded within the matrix at the junction of each course. In many applications this might provide sufficient tensile strength to suspend the use of barbed wire. This is particularly true of vertical walls; with domes, where the tensile strength of barbed wire is critical, it is probably more prudent to also include the barbed wire.



## Laying Bags in a Pattern

One of the basic principles of laying individual bags is to arrange each bag relative to the others in the wall as if it were a brick in a brick wall with a *running bond* pattern. This means that a bag is always placed over the space between the two bags beneath it. The more precisely you can adhere to this rule, the stronger the wall will be. To do this often requires smaller, half bags to be prepared to initiate or continue the pattern.

Another rule is that you never place a loose end exposed at an opening or at a corner where it might be vulnerable to spilling any of the contents. The sewn base of individual bags is much more secure in this situation, so when you start laying bags at a corner or an opening, always put the base outward and lay the bag down with the open end falling in the direction that course will proceed. The next bag laid down can be reversed so that the two open ends meet; they will be tamped together to seal them.



**Fig. 7.5:** The running bond pattern of this earthbag wall is obvious from the diagonal lines made by the end of each bag. You can also see how the bottoms of the bags are exposed where the wall ends. Also note the arch support: This is the shape that will provide a pointed, Gothic arch. CREDIT: KELLY HART

## Closing the Top of the Bag

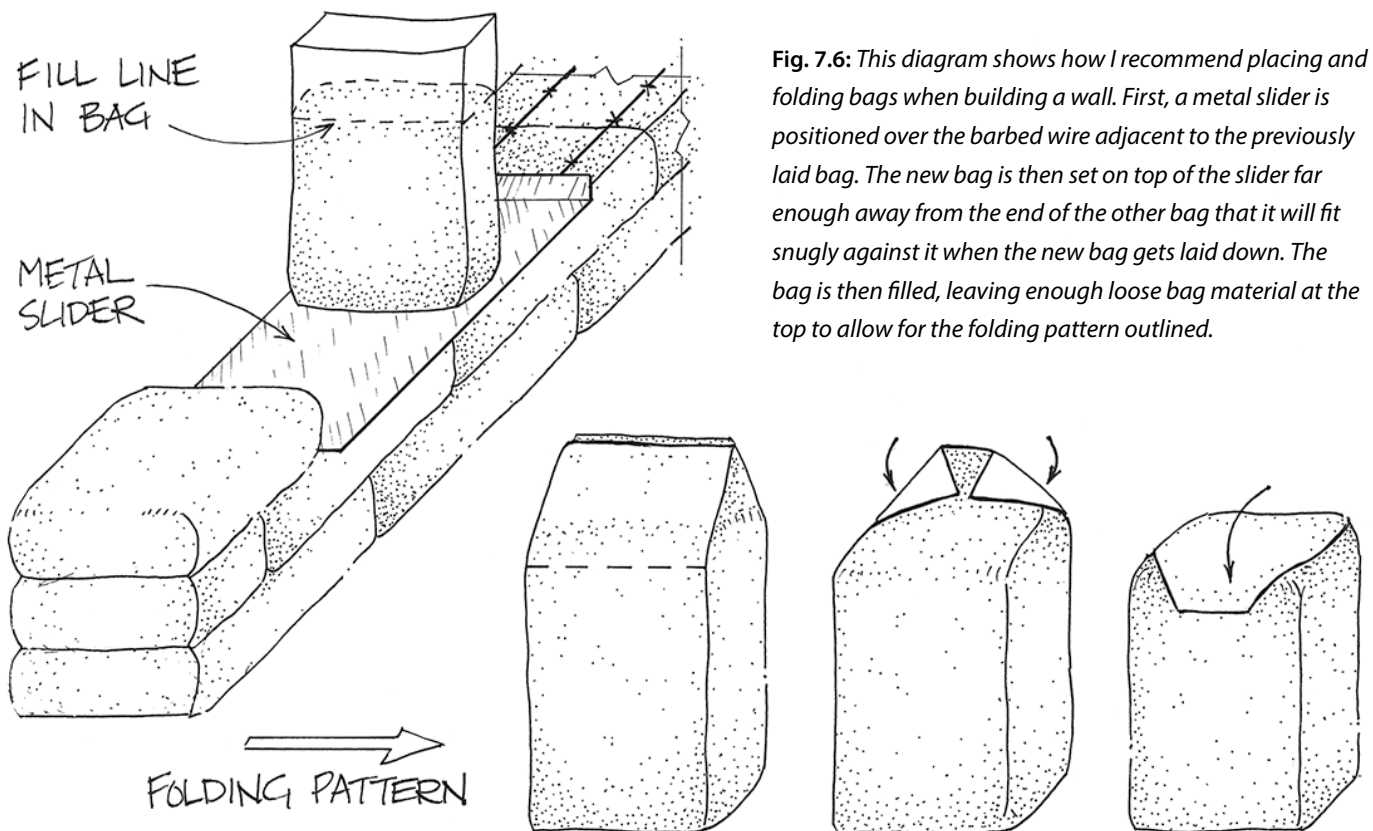
There are several ways of closing the top of the bags when they are laid down on a wall. The easiest is to just to leave enough of a flap of bag material exposed at the top so that it can be folded under on the side that will be laid down onto the bags below. I have found that about 8 inches (20 cm) of loose material is usually sufficient to seal the bags this way. Once the bags are tamped the contents are firmly trapped and cannot spill out. The way to do this is to always push the open end with the flap folded over tightly against the previously laid bag. The second bag in a wall might butt up against the first bag that was oriented in the opposite direction to avoid the open end facing out.

I discovered that when I am ready to fold over the top of the bag and lay it down, if I press the fill material a bit on both sides to form an A-shaped ridge going from one side of the bag to the other, it is easier to fold the material and get a good, tight closure. The two sides of the bag

top are brought together, and then I usually perform a quick tri-fold pattern similar to folding a diaper. I bring the top corners down to meet the line of soil and then grab the center tab that is formed and pull it down to tightly seal the top. While continuing to hold that tab in place, I gently lay the bag down into place, so that the top is pushed right up against the previously laid bag.

Another approach to securing the top of the bags when they are full is to actually hem and stitch them in place. This takes more time and care than the folding method, but it has the advantage that each bag can hold more material and ends up being longer. So it is more conservative of material and leads to a slightly stronger wall. Also, there are some circumstances, like when individual bags are used to create an arch over an opening, where having both ends completely secured is essential.

Hemming the top of the bag only requires 3 or 4 inches (8 or 10 cm) of loose material. Like with the folding method, it helps to form a bit



**Fig. 7.6:** This diagram shows how I recommend placing and folding bags when building a wall. First, a metal slider is positioned over the barbed wire adjacent to the previously laid bag. The new bag is then set on top of the slider far enough away from the end of the other bag that it will fit snugly against it when the new bag gets laid down. The bag is then filled, leaving enough loose bag material at the top to allow for the folding pattern outlined.

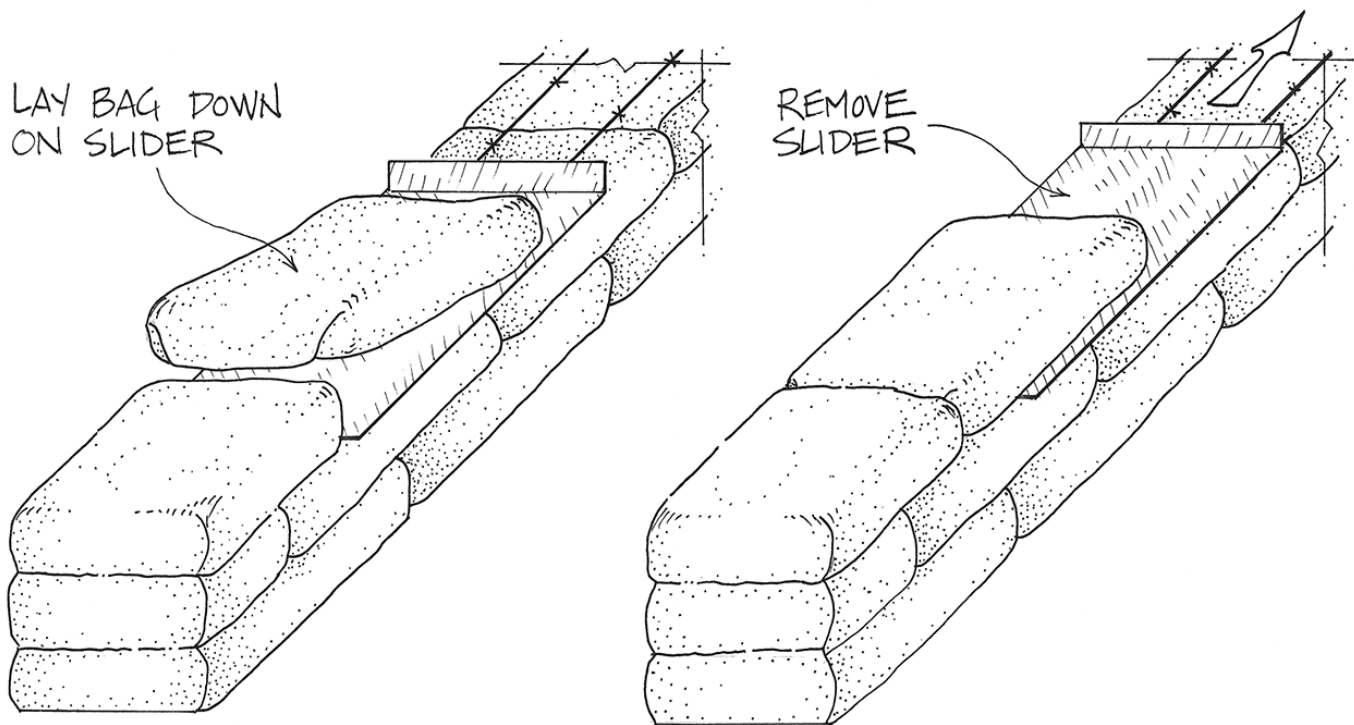
of an A-shaped ridge with the fill material so that the two sides of the bag come together in the middle. Then it takes two folds of about an inch (2.5 cm) of material each to form the hem. This is where having a stapler handy can assist the process by tacking the folded hem in place in several places so that it can be stitched with a needle and heavy nylon thread or with a stiff piece of wire that can be pushed through the several layers of material, woven in and out and left in place. The ends of the wire can be bent over to keep it from sliding out.

It is possible to just use the stapled hem as a final closure, especially if you know that the stapled end will be pushed up against other bags. However, when I used an ordinary paper stapler, sometimes the staples were simply not strong enough to hold under such pressure, and the stapled end burst, spilling some fill material when it was tamped. But a heavy-duty industrial stapler might do a better job and could be relied upon to hold indefinitely.

### Using a Metal Slider

This process of placing and aligning bags on the wall is facilitated by using a custom *metal slider*, as described in Chapter 5. Each time you are ready to place a new bag on the wall, whether it is empty or already filled, first put a slider down over the barbed wire where the bag will go. This protects the bag from catching on the barbs before it is in the exact position that it should be and can be tamped into place. Generally, this means that an empty bag is placed on the slider with enough space between it and the previously laid bag that the new bag can simply be pushed over and fall into place — snug against the other bag — once it has been filled and closed.

When you have the bag laid down exactly where you want it, place one hand on the bag to keep it from moving while you pull the slider out with the other hand. It might help to have a helper hold the bag while you pull the slider out, or vice versa. Figure 7.2 shows metal sliders being used on a dome wall.



**Fig. 7.7:** This diagram shows how the new bag is carefully laid down so that the folded end is up against the previously laid bag. It may be necessary to adjust the position of the new bag so that it is aligned with the wall and pushed up tightly against the previous bag, so that it is well sealed. At this point, the metal slider can be removed as show by holding the new bag in place while pulling on the slider.

## Tamping the Bags

I usually find it easier to wait until I have laid a whole course of bags, or at least a section of it, before I tamp it down, but then I often work alone. With more people working, or when laying the long tubes, having someone come behind and tamping as the course progresses may make sense.

It is important to tamp the bags regardless of what the fill is because otherwise the wall may settle over time, which can cause many problems better avoided. Also, tamping helps consolidate the fill into a more monolithic block, making the building stronger. The tamping process assures that individual bags get well pressed against each other so the seals are better and the contents more secure. The bags are forced into good contact so the barbed wire bites into both top and bottom bags to secure them further. And tamping can make the courses more uniform and level as the wall goes higher.

There are a variety of tampers described in the chapter on tools (Chapter 5). I prefer

tampers that have a rectangular base and are wide enough to reach across the entire width of a bag. This makes it easier to tamp the whole surface of the bag with just a few strokes.

When tamping damp soil or stabilized soil, you can tell by feel and sound when the contents are firm enough. At first, the tamping has a soft feeling, and then soon it becomes much more solid. And the sound changes from a light pushing sound to a real thud or even a slight pinging sound.

Besides the top of the bags, some people like to tamp the sides in order to make the wall flatter and more uniform. Doing this can diminish the amount of plaster needed to fill in the crevices between courses of bags. At the very least, it is a good idea to knock in any protruding bag corners that might stick out; with gusseted bags this is not as much of a problem. It can be awkward to use a tamper sideways, so using a large mallet can make the job easier.



**Fig. 7.8:** Tamping is usually best done while standing on the wall to be able to put some force into the stroke.

CREDIT: KELLY HART

## Placing Vertical Reinforcement Rods

Some designs call for metal pins to be driven through several bags at intervals along the wall as it is being built. This most often is needed when building straight vertical walls that may not be sufficiently rigid without this additional reinforcement. Pins are sometimes called for to help make the sides of window or door openings rigid. See Figure 8.17 for more information about suggested placement.

Sections of half-inch (13 mm) steel rebar are commonly used as reinforcement pins. It is easy to cut these to any necessary length. Generally, it is not practical to drive such pins if they are any longer than about 6 feet (1.8 m). This means that pins might be driven about halfway up the

wall as it is being assembled, and then again from the very top. Where upper and lower pins meet, it is good for them to overlap by several courses of bags to assure that the stiffening effect is maintained. The upper pins can be incorporated into the bond beam at the top, as explained in the section about making bond beams.

Such pins might be called for at intervals of every several feet (about 1 m). It is best for them to be driven so that they pierce as many of the bags as they can on the line they take going down the wall; they should not go through the intersection of any two adjacent bags in the wall. So, you must carefully select the place of entry and the alignment of the direction of pounding pins to assure this.



**Fig. 7.9:** A section of rebar is being pounded into this wall to help reinforce it.

CREDIT: KELLY HART

## Building Domes

Making domes is a special case when deciding how to place the bags. Most of the above considerations also apply to building dome walls, but there are several other factors to take into account.

Individual bags still need to be placed in a running bond pattern. With the long tubing, it is good to make tubes as long as they can be between openings; they can even be concentric rings.

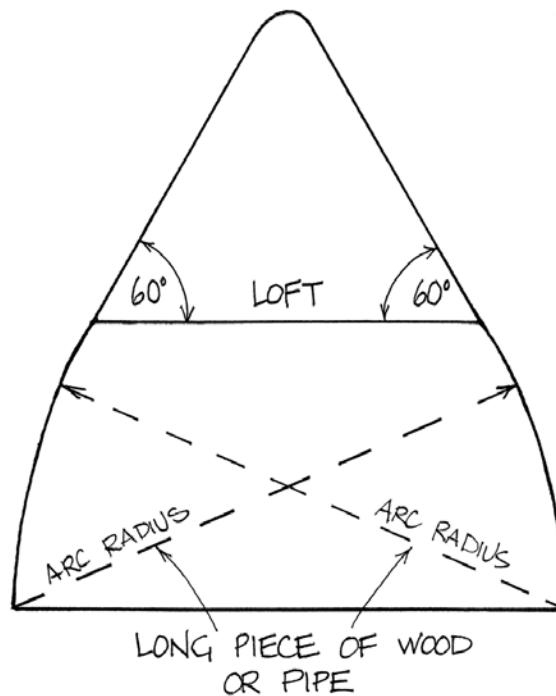
To shape the dome, you also need to curve the wall inward a certain amount as it rises, and this is accomplished by *corbelling*, or offsetting, each course of bags by incremental amounts. Just how much to offset the course is determined by using some sort of flexible guide that is prepared in advance, and this depends on the exact shape that you want to build. The next chapter will delve further into appropriate shapes and sizes for domes, but for now I will describe three main ways of creating a guide for placement.

The simplest kind of guide is just a straight stick or rod that can be used to scribe an imaginary arc that defines the interior surface of the dome. This only works when the chosen shape matches this sort of dome, but it is a very common shape, close to a catenary arch, that I have used for many of the domes that I have built. Basically, you make a measuring stick (it could be a long piece of wood or a stiff pipe) that is exactly as long as the interior diameter of the dome at its base. If you place one end of the stick anywhere along the interior perimeter at the base of the dome and cross it directly through the central axis of the dome, the other end of the stick will describe the proper arc as it is raised further and further into the air, always passing through the central axis.

You will notice that the dome barely moves inward at first, but with each course the degree

of corbelling increases and becomes quite noticeable near the top as it approaches closure. The point where a dome begins to curve inward like this is called the *spring line* of the dome. This method of determining the shape of the dome only works when the spring line of the dome starts right at ground level. In some instances, it may be desirable to raise the spring line to create more height in the dome, basically creating a cylinder at the base. If you want the spring line to start at a higher point in the wall, then it would be necessary to use the same type of diameter stick but start the base measurement at the higher level of the spring line.

The other two methods of determining proper dome shapes while building depend on establishing a physical axis pole rising perfectly vertically from the center of the dome. It needs



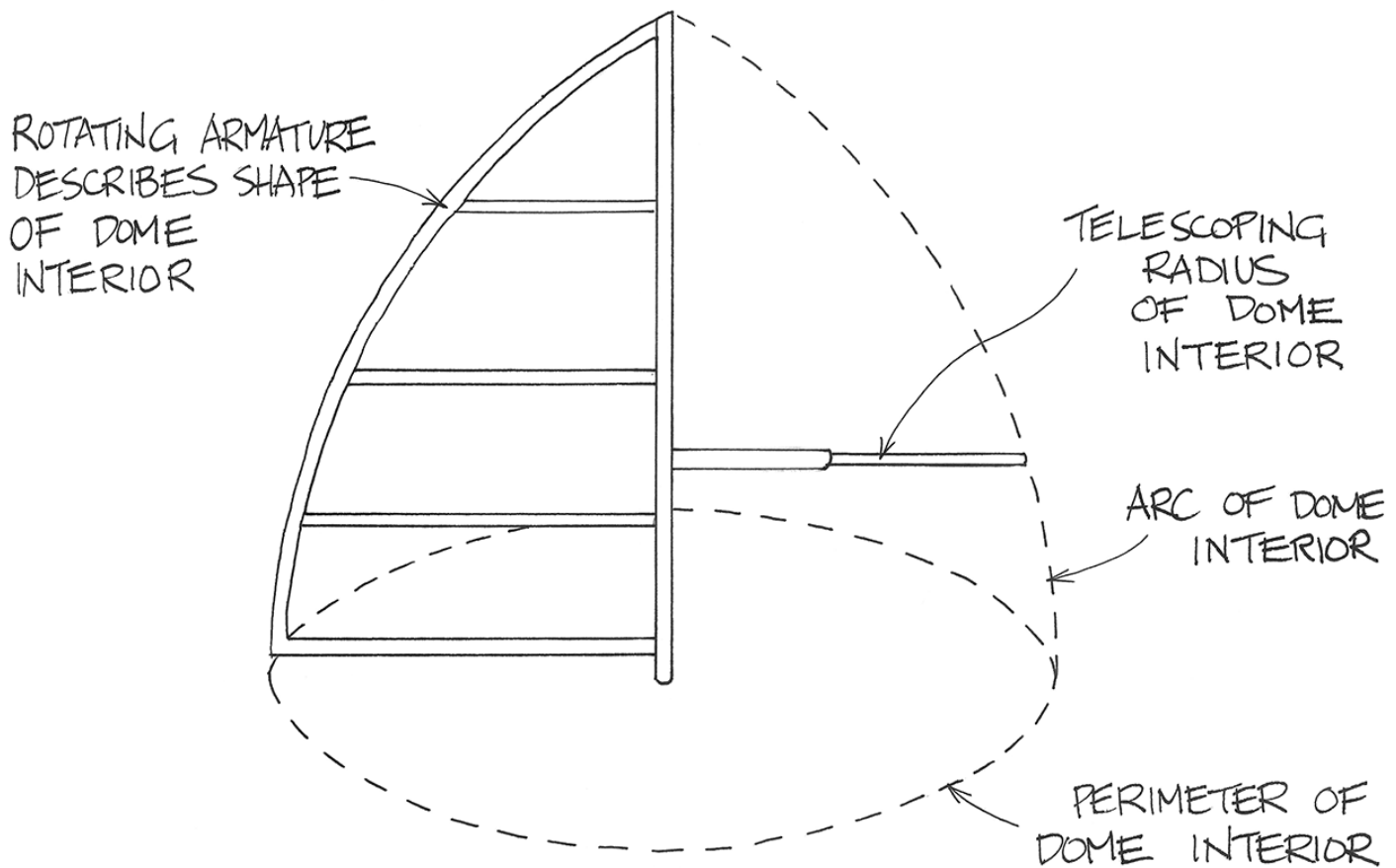
**Fig. 7.10:** This simple dome shape uses the interior diameter of the dome at the base as an arc radius for determining the curve of the walls as they rise. In the diagram, the walls above loft level are shaped more like an equilateral triangle to create more head space in the loft, but that area could theoretically continue to follow the arc defined in the lower portion.

to be quite rigid, which likely means burying it several feet into the ground; a steel pipe is often used for this. The axis pole acts as a device for the measuring instruments to rotate around.

It is possible to make a template of the entire shape of a half section of the dome that pivots around the axis and immediately shows exactly where the bags should go. The template can be fabricated out of metal, plastic, or wood. It is only the shape at the outer edge that is important; the rest of it just serves to rigidly extend this shape out from the axis so it can be rotated as the wall proceeds.

The last method I'll describe uses the central axis as a reference for rotating an adjustable rod that extends perpendicularly as a radius.

The length of this radius needs to be adjustable from the actual radius at the base of the dome to something much smaller. The idea with this is that a table or diagram is prepared in advance that shows the theoretical length of the proper radius at the height of every course of bags. In practice, with each course you set the radius pole to the exact distance it should be and also raise it up the axis pole to the proper height. If the radius pole is attached to a collar that can



**Fig. 7.11:** This diagram shows two different methods of determining where to place bags when building domes. On the left is a rigid armature of the exact shape desired that pivots around a central axis pole. On the right is an adjustable radius that also pivots around the central axis pole, but would be measured to a predetermined radius length for each course of bags.

slip over the central axis pole and rotate around it, then all that is needed is something to firmly hold it up at the appropriate level. This could be as simple as a clamp or pair of vice grips that will lock into place on the axis pole.

The dome shape can be modeled on paper with a known scale and then this can be used as a reference during construction to determine the right lengths of the various radius positions, or the model can help with scaling up the shape for the full-sized armature.

I think I should say that with earthbag construction there is no such a thing as perfection. It is not like carpentry or even masonry where the tiniest distances can make the difference between a good fit and something rather sloppy. With earthbags there is much more forgiveness in tolerances. The bags and fill material are both flexible enough to be pushed or tamped for a

reasonable fit. And then the eventual plaster will fill small voids or imperfections. So let your perfectionist self relax!

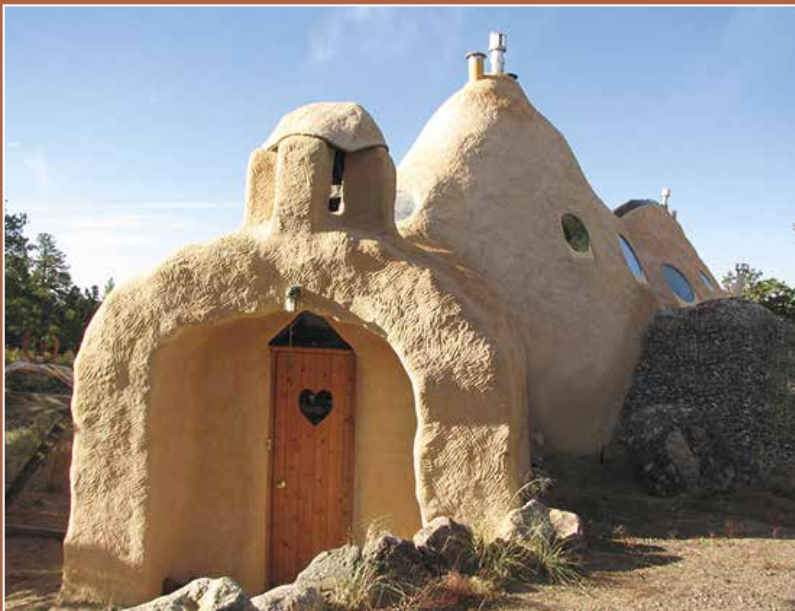
A final comment about wall building with earthbags: Remember that if you are using polypropylene bags, or any material that is adversely affected by the UV in sunlight, it is very important to limit the exposure of the bags to sunlight as much as possible. This means that it is prudent to keep the bag supply in the shade and also to keep all of the walls that have been assembled covered with tarps, except *while* they are currently being worked on. Once they have been protected with plaster, then obviously the tarps can be dispensed with. I know of far too many projects where the bags were left in the sun too long and the fabric flaked away, leaving the fill material exposed and no longer contained!







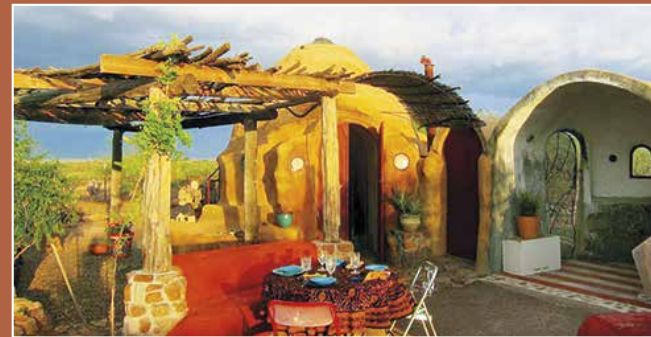
A view toward the loft of the large elliptical dome of the author's house shows the rigid pole framework used to stabilize the shape. CREDIT: KELLY HART



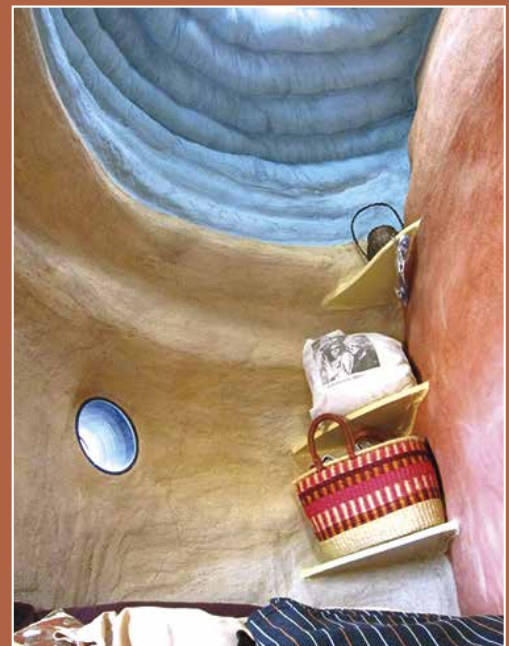
This view of the author's earthbag house features the vaulted entryway; a bell tower sits on top of it. CREDIT: KELLY HART



The southern view of the domed earthbag house built by the author shows its passive solar aspects. CREDIT: KELLY HART



Marcia Gibbons' Ransom Ranch homestead near Bisbee, Arizona, has been evolving over the last decade. It is a center for sustainable arts. CREDIT: MARCIA GIBBONS



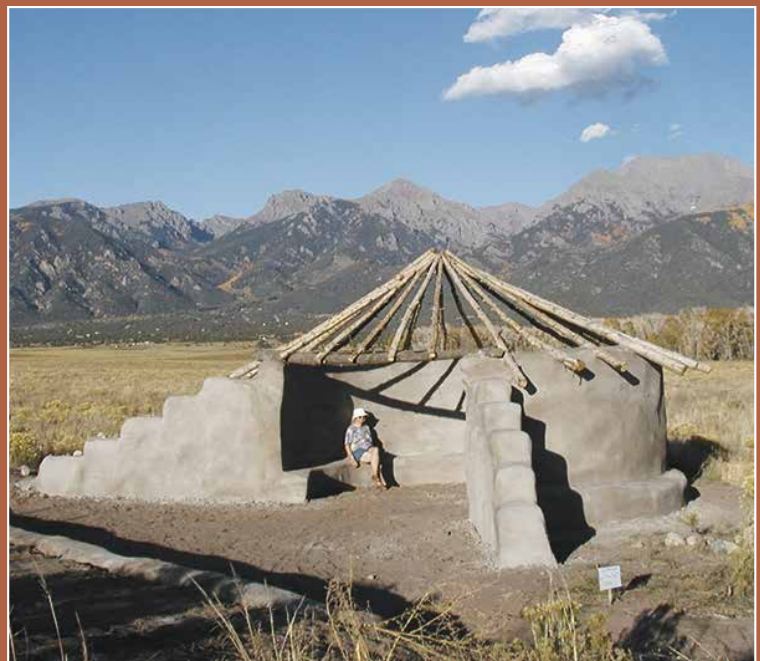
Here is a glimpse inside the Ransom Ranch dome. CREDIT: MARCIA GIBBONS

Baraka Burrill's house is under construction in the Colorado mountains; the author assisted with the design. CREDIT: KELLY HART



Center left: This experimental structure on the campus of the California Institute of Earth Architecture was built by Paulina Wojciechowska. CREDIT: KELLY HART

Center right: This structure, called the Glorieta, resulted from a workshop at an international conference in the mountains of Colorado; it was intended to provide shade and be a venue for amphitheater events. CREDIT: KELLY HART



This photo shows an early stage of Earthen Hand constructing a unique, experimental, "Regenerative House" in southern Colorado, using the Hyperadobe method with mesh tubing. CREDIT: SCOTT HOWARD





*This performance space at the Next Aid Child Support Center in South Africa is one of several earthbag buildings designed and built under the direction of Joe Kennedy.*

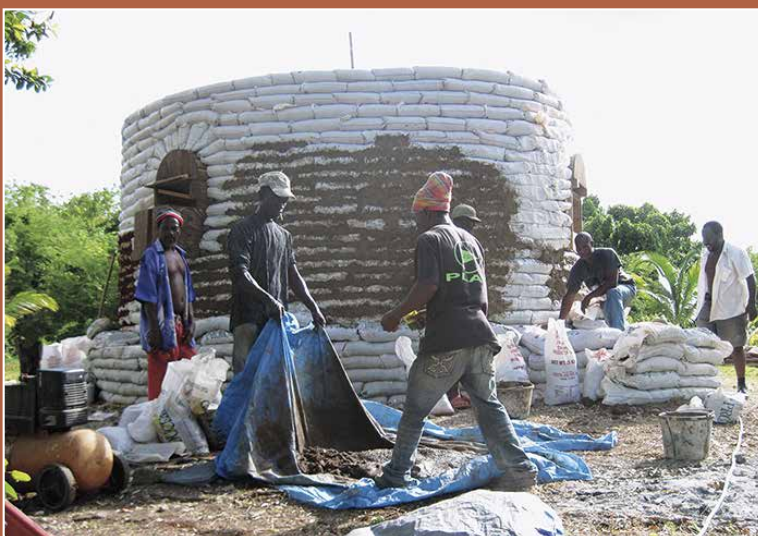
CREDIT: JOE KENNEDY



*This shot was taken during a dome workshop in Puerto Rico conducted by Earthen Hand. CREDIT: SCOTT HOWARD*



*Robin's house near San Miguel de Allende, Mexico, was built under the direction of Dorothy Watson and Andrew Gerhart. CREDIT: KELLY HART*



*This photo was taken during an Earthen Hand workshop in Jamaica. CREDIT: SCOTT HOWARD*



*This photo was taken during an Earthen Hand workshop in Jamaica. CREDIT: SCOTT HOWARD*

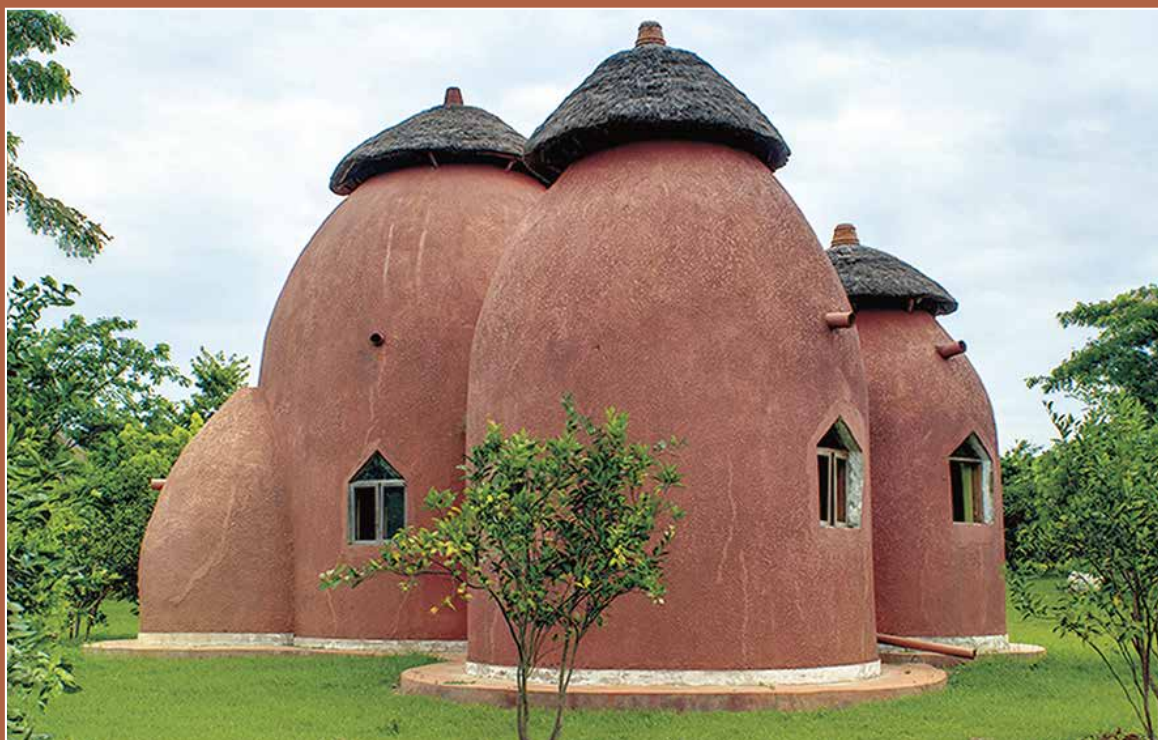
Akio Inoue of Tenri University, Japan, and architect Kikuma Watanabe teamed up to construct an ecovillage by Lake Victoria, Uganda, East Africa. Here you can see local workers and volunteers during the construction phase.

CREDIT: KIKUMA WATANABE



This is what the African ecovillage looked like after completion.

CREDIT: KIKUMA WATANABE



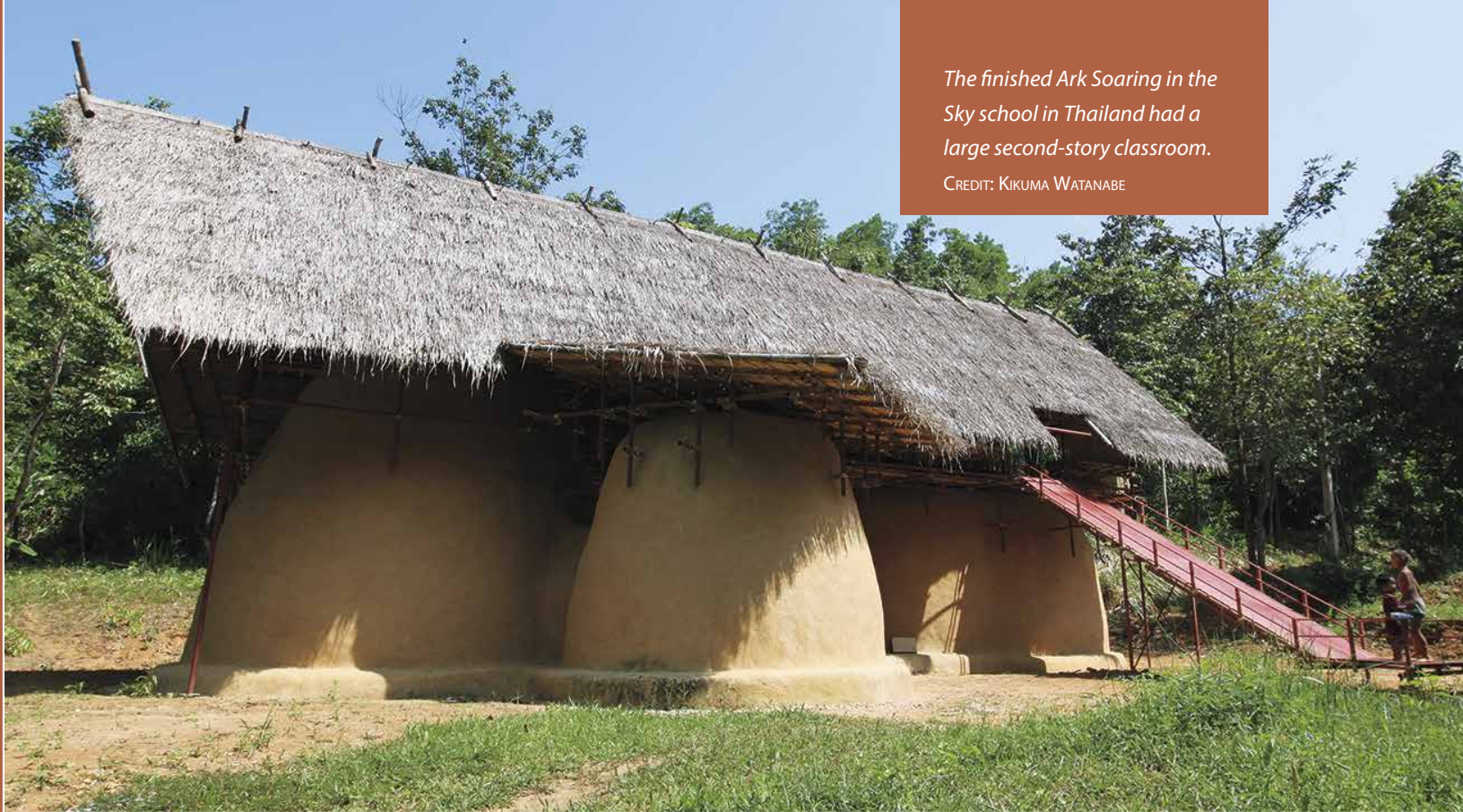
This school for orphans is in Sanghlaburi village, Thailand. Called Ark Soaring in the Sky, it was designed by Japanese architect Kikuma Watanabe. CREDIT: KIKUMA WATANABE



This Shinto Shrine for Remembering Our Origin, here shown under construction, was designed by Kikuma Watanabe for the "Water and Land Art Festival" held in Niigata City, Japan. CREDIT: KIKUMA WATANABE

*The finished Ark Soaring in the Sky school in Thailand had a large second-story classroom.*

CREDIT: KIKUMA WATANABE



*These kids were obviously having a lot of fun mixing mud for plastering their new school.*

CREDIT: KIKUMA WATANABE



*The Tenri University International Cooperation Project responded to the 2001 earthquake near Jamnagar, India, by sending a group of 15 students and other personnel, including Akio Inoue as the project leader. Here you can see them working on a community library.* CREDIT: AKIO INOUE

*This rather luxurious “cave” at Phangan Earthworks in Thailand artfully combines granite, wood, and earth and was constructed with freeform earthbags between some huge boulders.*

CREDIT: GOLDMUND LUKIC



*Center right: This freeform earthbag kitchen and lounge has a ladder to connect the lower open area to the second floor bedroom that has woven bamboo walls and a large window overlooking the bay at Phangan Earthworks in Thailand.* CREDIT: JULIEN BALMER



*Bottom left: The Kaya Kalpa dome at Phangan Earthworks in Thailand combines sacred proportions with complete darkness. The thick walls allow in only very minimal sound, so it effectively facilitates deeper states of meditative absorption.* CREDIT: JULIEN BALMER

*Bottom right: This shows the Kaya Kalpa dome at Phangan Earthworks in Thailand as it was nearing completion.*

CREDIT: JULIEN BALMER





*A tool shed and adjacent guest room is under construction at Phangan Earthworks in Thailand.*

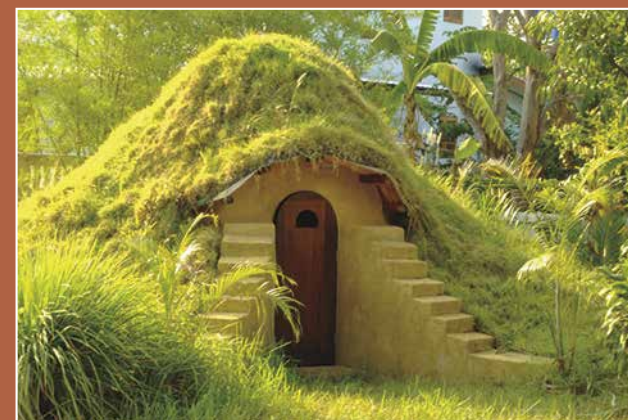
CREDIT: JULIEN BALMER



*The roof of this tool shed and adjacent guest room is used as a platform to view the surrounding jungle at Phangan Earthworks in Thailand.* CREDIT: JULIEN BALMER



*The Om Dome is a spiritual temple for the Pyramid Yoga Center in Koh Phangan, Thailand. It was built under the direction of Scott Howard of Earthen Hand.* CREDIT: SCOTT HOWARD



*Left: Owen Geiger built this small earthbag roundhouse studio in Thailand.* CREDIT: MEEMEE KANYARAT

*Right: This lovely earth-sheltered earthbag dome, built by Owen Geiger in Thailand, is used as a pantry.*

CREDIT: MEEMEE KANYARAT

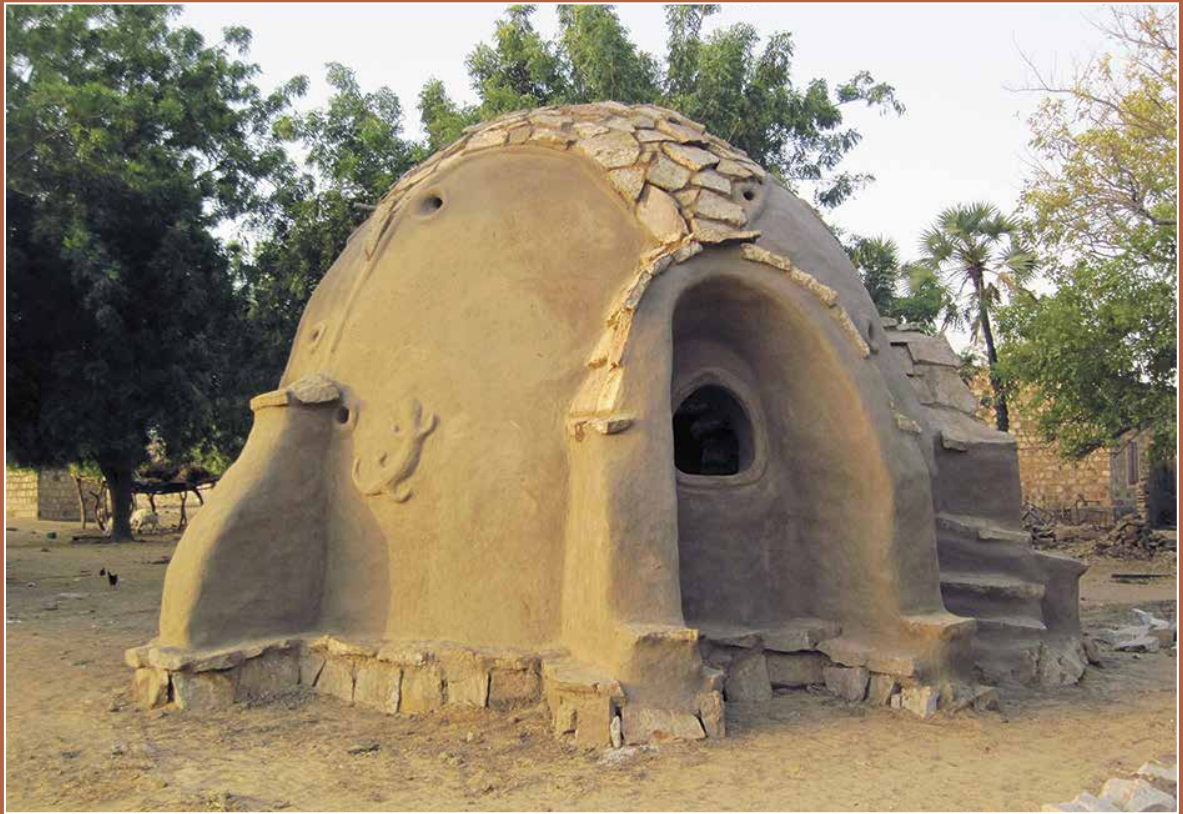




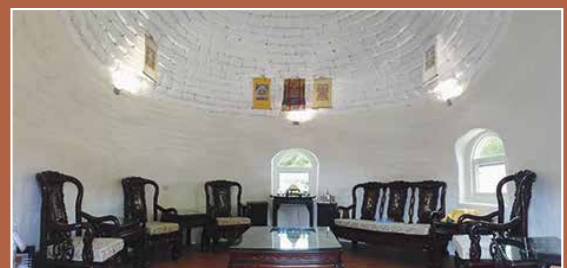
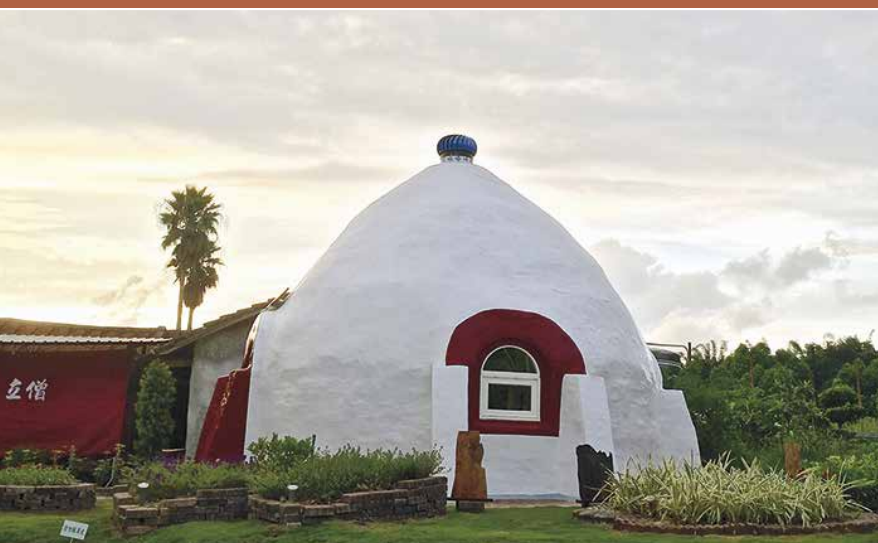
*This photo was taken during the construction of the library in Mali. CREDIT: SCOTT HOWARD*



*This library is a gift to the village of Tirelli, Mali; the project employed several local people during construction and was led by Scott Howard of Earthen Hand Natural Building. CREDIT: SCOTT HOWARD*



*This finished library is a true catenary arc dome and was the first earthbag dome in Mali. CREDIT: SCOTT HOWARD*



*Above: The interior of the dome features an unplastered vault. CREDIT: SUNNY TSAI*

*Left: This meditation dome in Taiwan built by Chinese professor Sunny Tsai used local earth, lime, glutinous rice juice, and rush grass in the plaster. CREDIT: SUNNY TSAI*



## Chapter 8

# Design Considerations and Constraints

### Vertical Walls

WITH VERTICAL-WALLED earthbag buildings, there are very few design constraints beyond those having to do with buttressing, door and window openings, and wall thickness and height. (These are discussed later in this chapter.) The perimeter footprint of the building can be of virtually unlimited size and shape; both straight and curved walls can be combined in any way imaginable. Vertical earthbag walls can enclose a tiny hut or a true mansion.

### Domes

Due to physics (and attested to by experience!), there are practical limits to the size and shape of earthbag *domes*.

The first rule is that the base footprint should be circular rather than oblong or elliptical. I

learned this the hard way when I tried to build a large 20 ft. × 30 ft. (6 m × 9 m) elliptical dome with earthbags. It all started out fine and was reasonably stable until I had built the walls well above loft level. Then, as I was getting closer to the top I realized that the shape of the dome was changing so that the longer sides were becoming flatter and potentially unstable. At this point, I stopped construction and decided to deconstruct all the work I had done and start over with a different plan. I realized that there was an inherent problem with executing an elliptical shape: the forces that keep circular domes stable and in balance do not apply to an elongated shape.

In that experiment, I really wanted to somehow make the ellipse work, so I devised a rigid framework with wooden poles, steel cable, and



**Fig. 8.1:** On the left is the large elliptical dome I built with a permanent pole frame structure to hold the shape rigid. On the right is a much more inherently stable circular bedroom dome.

CREDIT: KELLY HART

a steel hoop at the top of the dome that served as an armature for maintaining the shape that I wanted. Without this stiff armature supporting the dome, it would not have been stable and would likely have collapsed! So now I always advise folks to stay with circular domes for safety's sake.

The second rule is that earthbag domes cannot be truly hemispherical without some rigid framework to serve as an armature. I have seen hemispherical earthbag domes built over a geodesic framework, and that worked out fine. But without the framework, such a dome could become unstable during construction, particularly as the top of the dome is approached. Earthbags simply cannot be relied upon to support themselves when formed into such a relatively horizontal shape at the top.

The strongest and preferable shape for an earthbag dome is often referred to as an *inverted catenary arch*. Such an arch is sometimes

described as the shape that a chain will naturally take when it is suspended between two fixed points and allowed to hang. If you take this shape and invert it, you have the ideal shape for the cross-section of a dome.

This catenary shape can be approximated in various ways, similar to the ways described in Chapter 7; that is, you make a guide to describe the arc of the walls. Above loft level, I have often used a simple cone shape based on an equilateral triangle — with 60 degree angles at the base — to fashion the upper part of the dome. This has the advantage of creating more potentially usable standing space in a loft area. Figure 7.10 shows this arrangement.

The third rule is to keep the dome no larger than about 7 yards (6.4 m) in diameter at the base. There are definitely practical limits to how big you can expect an earthbag dome to be self-supporting. I don't know of any physical tests that have been conducted to find out what

**Fig. 8.2:** The top of this dome was finished with a hemispherical rigid geodesic framework that remained visible from inside the dome.

CREDIT: KELLY HART





**Fig. 8.3:** Joists for a partial loft in this small dome were simply placed on the bags and shimmed to bring them level. Earthbags were then inserted in the spaces between them in order to continue building the wall.

CREDIT: KELLY HART

the absolute limit might be, but I do know that if it is kept to the 7-yard (6.4 m) size, it will be safe enough. This size will surround approximately 350 sq. ft. (32.5 sq. m) of floor space, with an additional potential loft area of 250 sq. ft. (23.2 sq. m), thus providing as much as 600 sq. ft. (55.7 sq. m) of floor area within a single dome. If you need more space than this, consider combining several domes or other-shaped areas in the design. Furthermore, domes that are 7 yards (6.4 m) in diameter can easily accommodate a loft that is 8 ft. (2.4 m) above the first floor level and still provide some standing space in the loft. A rule of thumb is that the overall height of an

earthbag dome should be about the same as the diameter at the base.

For all earthbag domes, except the very smallest ones, it can be beneficial to add a loft. Lofts will noticeably stiffen a dome at that level and make the whole structure more secure. I have noticed this many times when building domes: as soon as a supporting framework for a loft is installed, the whole building feels more monolithic and stable. For this reason, even if you don't want to actually have a usable loft in the dome, you would be wise to place several horizontal poles going across at loft level; they will help stiffen and strengthen the building.

## Vaults

A vault is an architectural shape that resembles a long tunnel with an arched roof. Vaults commonly require considerable buttressing and massive walls because, unlike domes, they are not inherently self-supporting. This is especially true with earthbags, where there is virtually no resistance to deformation due to the effect of gravity on the vault. For this reason, I do not recommend that you include vaults in earthbag structure designs — except for very small ones that can be sufficiently buttressed.

I did execute a small vaulted entryway into an earthbag domed structure once, but it required some very careful design and construction. I used an existing entry arch form that was gothic

in shape and 6 feet (1.8 m) wide at the base as the temporary roof support during construction; I slid the form along some rails as I extended the vault forward. The base at floor level was 8 feet (2.4 m) wide, and the walls that rose upward from there to where the vault form rested were inclined inward and were massive. They were constructed by laying fully filled and hemmed bags in a cross-hatch pattern. To achieve this pattern, two bags were laid in one direction and, in the next course, two bags were laid perpendicular to these. So, basically, the walls were two bags thick. These massive inclined walls did sufficiently buttress the vault to keep the whole affair intact, but even so, the top of the vault squashed down some after the form was removed.



**Fig. 8.4:**  
*This vaulted entryway spanned 8 ft. (2.4 m) at the base and utilized a 6-ft. (1.8 m) wide Gothic arch form with a sliding track to move it forward. With the inclined sides and massive construction, it was self buttressing.*

CREDIT: KELLY HART

## Buttresses

Certain shapes and conditions require buttressing when building with earthbags. In other words, some walls might not be sufficiently self-supporting without some help. This is particularly true of straight vertical walls; they can topple or deform if lateral forces are applied. Buttresses can easily be built with earthbags; they are integrated with the walls and extend perpendicularly from them. Interior partition walls can also serve to buttress straight sections of walls, especially if walls and buttresses are sufficiently attached to each other.

A rule of thumb for spacing buttresses in straight sections of walls is to not exceed 10 feet (3 m) without securing the wall with either an interior or exterior buttress. Such buttresses need only extend about 2 feet (.6 m) out from an 8-foot high (2.4 m) wall if the buttress has a vertical outside edge. If the buttress is tapered or stepped, then it should extend at least two and half feet (76 cm) from the wall at the base. Walls higher than 8 feet (2.4 m) should have

proportionally deeper buttresses. See Figure 8.17 for a visual representation of this.

It is best to integrate any buttresses with the wall during construction by actually embedding every other course within the wall being built. This union can be further strengthened by pounding sections of steel rebar down through the center of the intersection of the buttress with the wall.

Wood-framed interior partition walls can serve to buttress an outer earthbag wall if the two are securely attached. This could be done with threaded rods that are cut so they will extend all the way through the earthbag wall and the stud at the end of the partition. Large plywood and/or metal washers on the outside will keep the rod tightly in place while the nut on the inside of the partition wall is tightened. See Figure 11.5 for an arrangement like this.

Another special case that requires buttresses is at door openings within domes. Not only is the dome wall vulnerable to distortion where doors penetrate, but it is difficult to



**Fig. 8.5:**  
This photo shows two different ways to provide doorway buttressing in a dome; the more massive column on the right is somewhat more stable. Both of the columns are interlaced with the dome wall.

CREDIT: KELLY HART

install a vertical door in a curved wall opening without providing a vertical wall enclosure. A well-designed buttress can serve both of these functions where the door goes through into a dome. Figure 8.5 shows the beginnings of such a buttress/enclosure.

Most vertical curved walls are sufficiently self-supporting that additional buttresses are not necessary. The curved footprint resists lateral motion, and earthbag walls are generally heavy enough to keep them from toppling or deforming. For this reason, I often advise curving

fences, garden walls, and retaining walls, to make them more stable. It is well known that curved or rounded buildings stand up to strong winds and earthquakes better than rectilinear ones do.

You often see buttresses that extend walls and cross at every corner of a rectilinear earthbag building. This practice definitely does help strengthen the building, especially in the event of an earthquake, and it adds a certain stylistic element, but I don't think that it is absolutely necessary in areas of low seismic risk. You can read about seismic reinforcement in Chapter 12.

**Fig 8.6:**  
*This round building is sufficiently buttressed to be quite stable, especially with the stepped buttresses extending outward from the opening which are both structural and aesthetically pleasing.*

CREDIT: KELLY HART



## Bond Beams

Bond beams are elements that rigidly hold earthbag walls into a specific shape and keep them from deforming from pressures that might otherwise cause them to lose their intended shape. Bond beams can occur at any level within a wall, but the most common place to find them is at the very top. At that level, bond beams can also serve as a solid plane for attaching roof elements.

Some designs may require bond beams midway in a wall, such as in straight walls that will need to support the lateral pressure of an exterior berm. Straight walls in general are more vulnerable to deformation, and thus bond beams are a necessary component.

A bond beam can be used as a lintel over doors or windows; sometimes designs call for this, especially where there are a number of such openings that have a common height.

Even domes may need a bond beam partially up the wall. The most common place to find such a beam is at the height where a loft might be located. At this level, the bond beam can serve as a convenient and solid attachment plane for the loft's supporting joists. Also, making the dome shape rigid at this point will help make the entire dome more solid and monolithic.

No matter what the bond beam is made of, it is important that it be well integrated with the earthbag wall below it. This usually means extending vertical pins that penetrate both the bond beam and earthbags below. A common way to do this is to use sections of steel rebar that can either be driven through the beam and into the wall, or have the rebar partially driven into the earthbag wall with enough of it extending above the bags that the pins will be incorporated into a poured concrete bond beam.

The length of such pins depends on a variety of factors, such as whether they also serve to help stabilize a wall or if they need to secure the

beam and roof assembly against uplifting forces. This might require pins that are only about a foot (30 cm) long, or they might need to be up to 6 feet (1.8 m) long. There is more information about this in the previous chapter about building walls.

In any case, it is a good idea to drive the pins at various angles, rather than putting them all perfectly perpendicular to the bond beam. Angling the pins will greatly increase a secure connection of the beam to the earthbags beneath and prevent any tendency for uplift. Also, if the top of the pin is bent over by 90 degrees, this will help secure the beam from uplift (but this sometimes easier said than done because it is not easy to bend rebar that sharply).

The most common way to create a bond beam is to make forms for reinforced concrete. This can usually be done to accommodate any wall shape if some type of flexible forming

The accepted convention for reinforced concrete is to use steel rods or mesh as the reinforcement agent, but this has a long history of limited durability. Unfortunately, steel corrodes even when embedded in concrete, and after 50 to 100 years, you can expect that the steel will rust to the point of no longer serving the function of reinforcing the concrete. There are some modern synthetic fiber and mesh materials that appear to have a longer expected life as reinforcement for concrete. Some of these are at least partially composed of polypropylene, the same material used for most earthbags. Another promising new material is fiber made from basalt stone that has been crushed and then made molten and extruded into fibers that can be joined to produce commercial mesh products that can replace wire mesh.

As for the steel pins that are driven into the bags to secure and reinforce the walls, these are obviously also subject to corrosion and could limit the durability of a building. Basalt rebar is now available that is stronger, lighter, and more corrosion resistant than steel, and this may be a better choice if durability is an issue. A quick internet search will reveal many outlets for this material.



material is available. Concrete bond beams should be at least four inches thick, so they can easily embed the steel reinforcement and the pins that are driven into the wall. If rafters, joists, or framing members will be securely attached to the bond beam, fasteners for all of them should also be embedded in the concrete at the time it is poured. This, obviously, requires planning ahead.

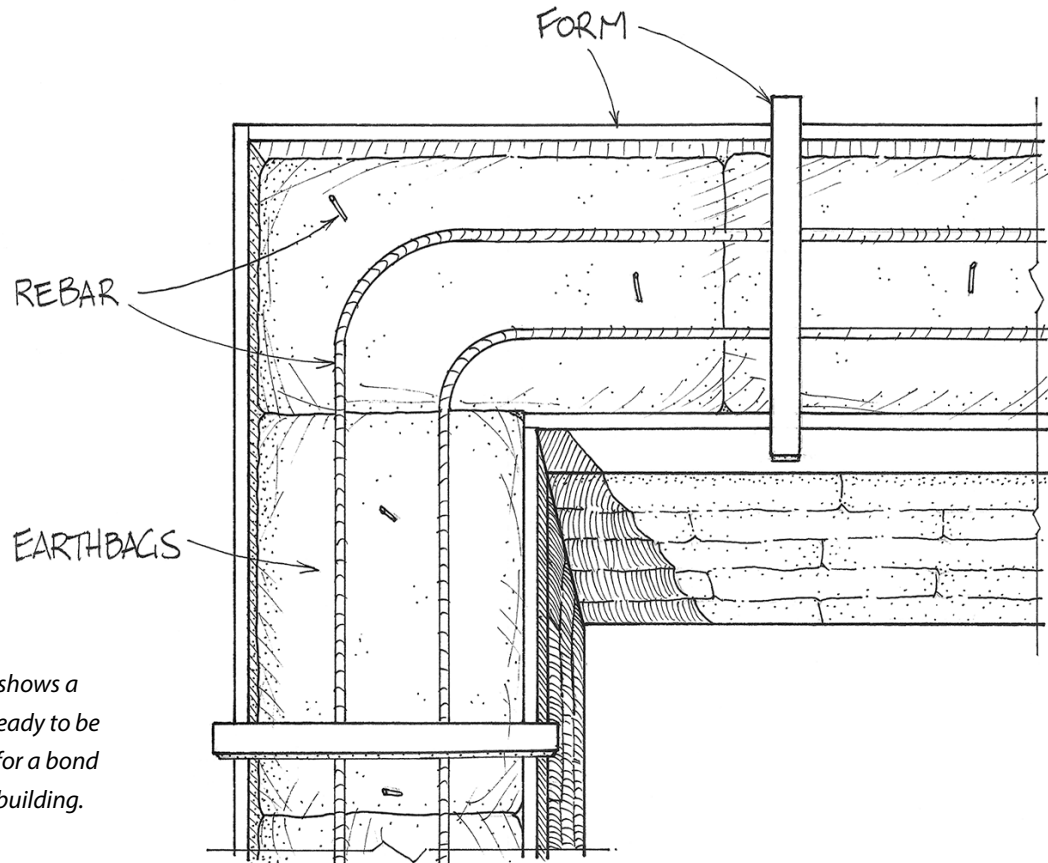
Rectilinear building shapes will also allow the fabrication of bond beams from other materials that are available in straight sections, such as wood or steel. With these, it is best to make the bond beam as monolithic as possible by using the longest lengths of the wood or steel available and making strong splices where one piece is connected to another. This will help rigidify the entire building.

Wooden beams should be made with at least nominal 2 inch (5 cm) thick planks that are no

less than nominally 6 inches (15 cm) wide. The wider the plank is, the better it will resist deformation under pressure. Holes can be pre-drilled at various angles and at pre-determined intervals, and then rebar pins can be easily driven into the bags below. Half-inch (13 mm) rebar is usually sufficient for this job.

Hollow rectangular-section steel beams of at least 2 inches (5 cm) by 4 inches (10 cm), can be attached to the wall in a similar manner.

Another possibility with either wooden or steel planks is to create a very thick bond beam by sandwiching several courses of earthbags between layers of wood or steel. In this case, the entire layered beam can be bound together with threaded rods that penetrate all of the elements. This approach makes it possible to also create hefty lintels over doors and windows. See the sidebar for instructions for making such a sandwiched bond beam.



**Fig. 8.7:** This diagram shows a simple wooden form ready to be poured with concrete for a bond beam on a rectilinear building.

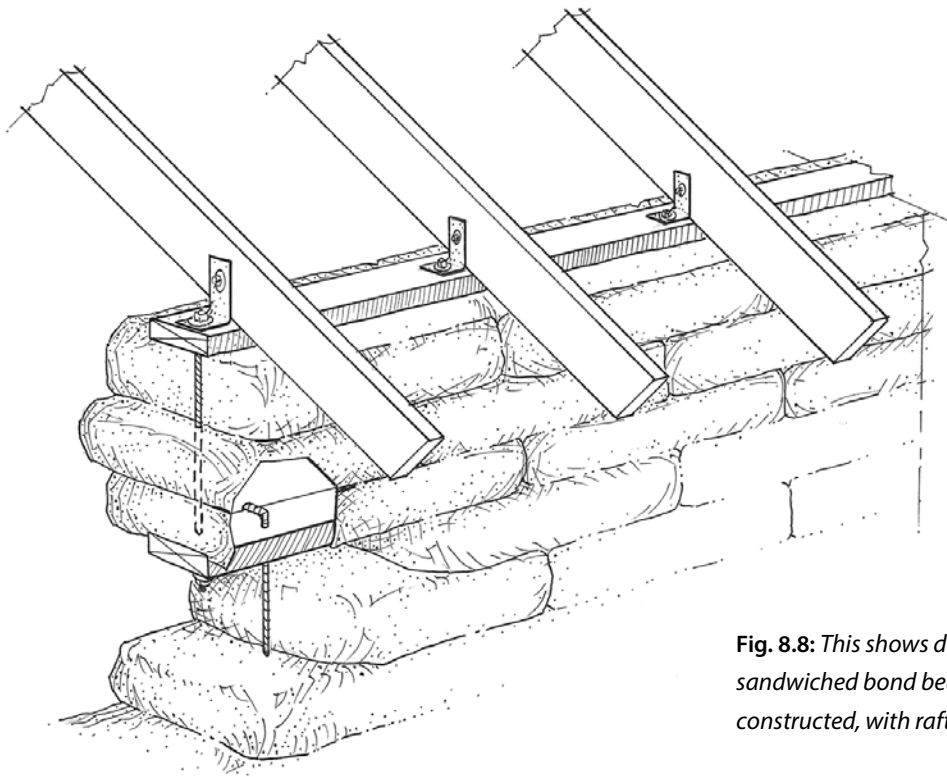
### Instructions for Fabricating a Sandwiched Bond Beam:

During construction, once you have arrived at the height where you are at the level of the top of any door or window (presuming that these are the same height), you lay down a piece of hollow, rectangular-section steel tubing or a wooden plank right on top of that last row of earthbags. Ideally it should be as long as the wall is, going from the center of one corner to the center of the other corner, but two pieces can be spliced together if necessary.

It would be a good idea to have made this area as level as possible, through tamping or even shimming some bags, so that the beam will lie as level as it can. Before putting this first beam in place, it should be pre-drilled with  $\frac{1}{2}$ " (13 mm) holes at 1-foot (30 cm) intervals all the way through both sides of the beam in the center of the short dimension. Also it would be a good idea to pound  $\frac{1}{2}$ " (13 mm) rebar pins

through all of the bags in the middle of every corner and adjacent to door and window openings.

If you look at Figure 8.8, you can see on the left a piece of  $\frac{1}{2}$ " (13 mm) rebar about 2 feet (61 cm) long with one end bent 90 degrees. Such pieces of rebar can be pounded down through every other hole in the beam and into the top courses of bags below. But don't pound them all the way down yet, because you also want to install some 2 foot (61 cm) sections of  $\frac{1}{2}$ " (13 mm) threaded rod (sometimes called *all-thread*) sticking up vertically in each of the empty holes that are left. These need to be secured with steel washers and nuts underneath the beam, so they can't be pulled out. Once all of the pieces of threaded rods are in place, you can finish pounding down all of the rebar anchors. Now the whole assembly should remain fixed fairly securely in place. 🐼



**Fig. 8.8:** This shows details of how a sandwiched bond beam might be constructed, with rafters attached to it.

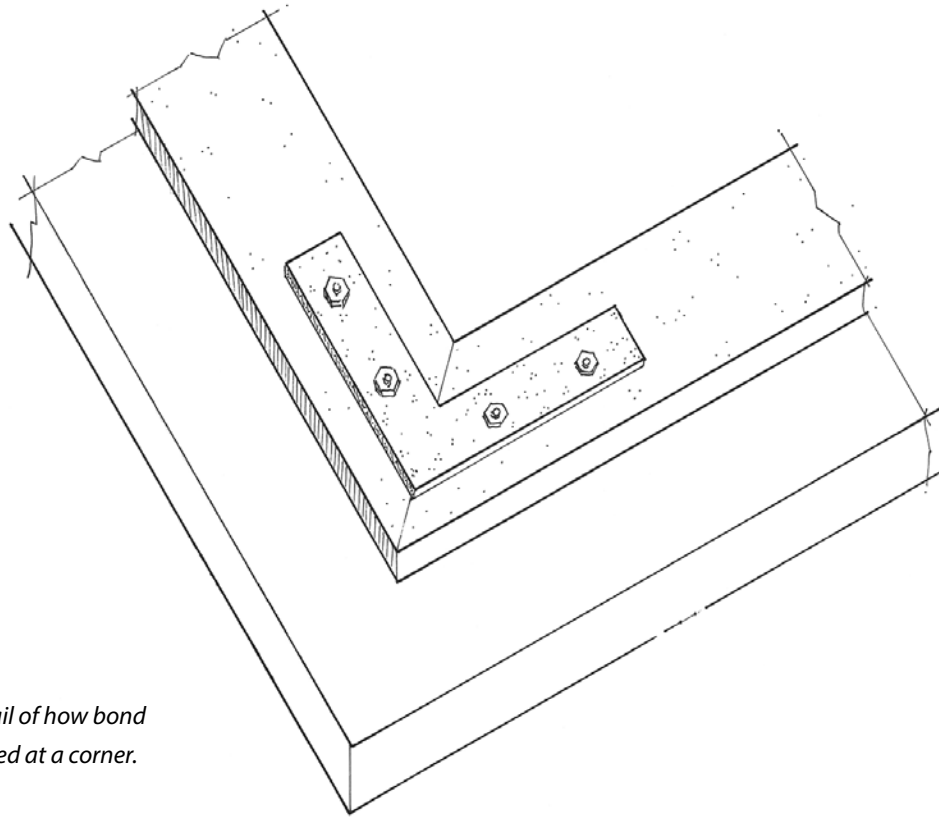
Wherever the threaded rods are over doors or windows, you may need to put a nut on the rod on top of the beam so that it won't fall through the hole. Also, the lower washer and nut can be recessed into the beam by drilling a large enough hole on the lower side of the beam to do so. This will allow other window or door assemblies to be joined flush with the beam.

Now you can place some extra pieces of the same type of tubular steel or wood over the door and window openings on either side of the original beam, so that they are long enough to extend maybe 1½ feet (46 cm) on either side of the opening. These can also be pinned into place with similar rebar pins. This will become a platform over which more earthbags will be placed.

As shown in Figure 8.9, at the corners where two bond beams meet, the wood or metal beams can be connected

rigidly with 90 degree metal brackets on either side of each beam, through-bolted in a similar manner. This will make the entire structure integrally connected, which should withstand considerable force from earthquakes or wind.

At this point you are ready to start laying more earthbags. These should be filled so that they will be 2 feet (61 cm) long when tamped into place. This may mean that they will need to be hemmed or stitched at the top, if there is not enough material to fold over and seal them that way. They will be placed directly between the threaded rods and tamped thoroughly into place. It might be possible to pierce the subsequent row of bags with the threaded rods in order to maintain the staggered, brick-like layering of bags, but it will be easier to just place them above each other and between the rods. Because these bags will be eventually clamped together to form the bond beam, it doesn't really

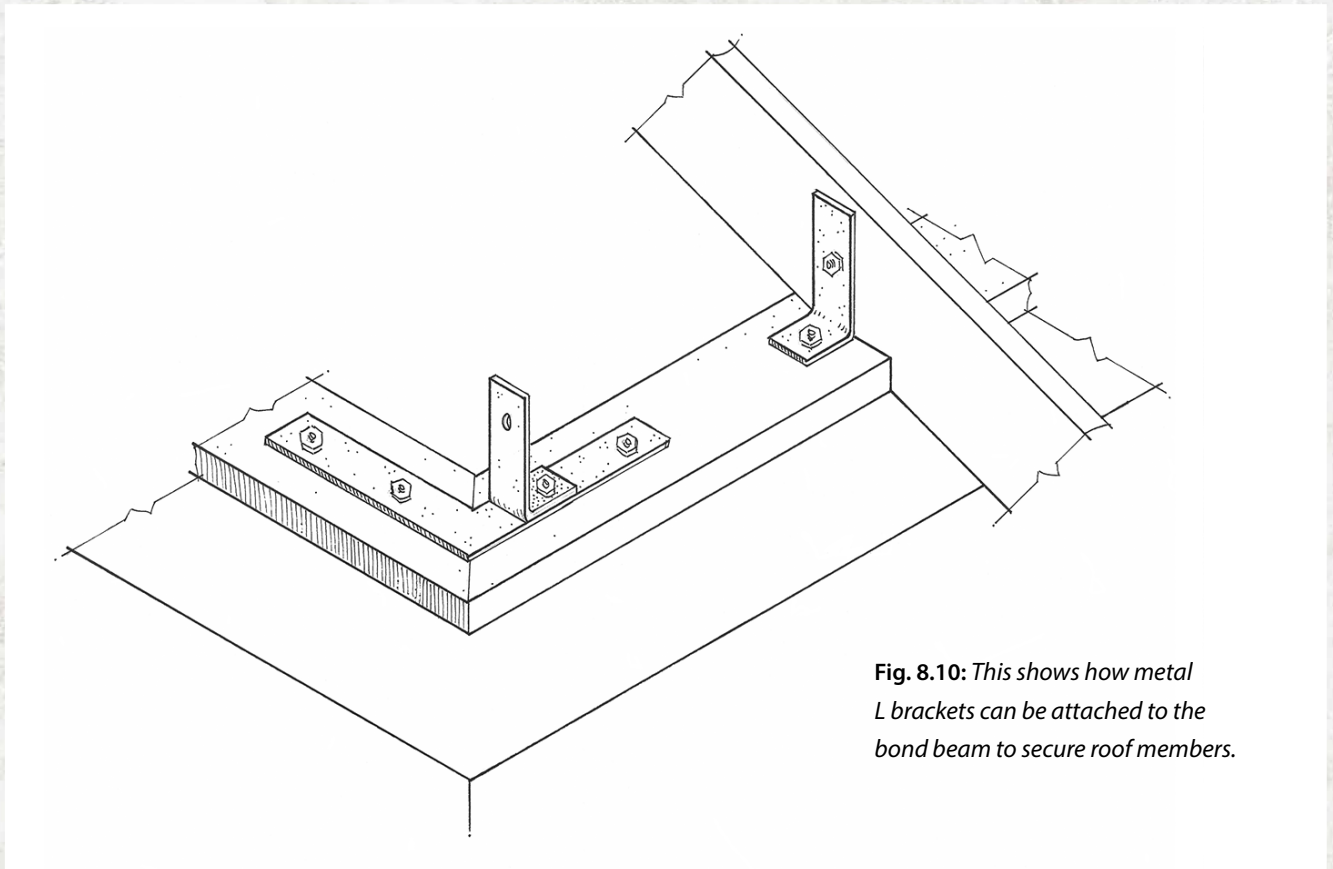


**Fig. 8.9:** *This is a detail of how bond beams might be joined at a corner.*

matter much whether they are staggered or not. In most cases, three rows of bags can be arranged this way, but depending on the intended height of the wall, you can also lay fewer or more rows, as long as the threaded rods are long enough to extend above the upper beam.

The upper beam needs to be prepared with  $\frac{1}{2}$ " (13 mm) holes drilled to match exactly the pattern of the lower one so that it can be placed in the middle of the top-most bags with the ends of the threaded rods protruding all the way through. In this case, there is no real need to also pound rebar pins through the bags, since this whole assembly will be clamped tight as a unit, so fewer holes need to be drilled through the upper beam. It may take some fiddling with the threaded rods and the beam to get them aligned, but it should be possible.

Before the washers and nuts are put onto the rods, you want to position metal L-brackets wherever there will be rafters or joists, as shown in Figure 8.10. These brackets will connect the rafters to the bond beam in a solid, yet flexible manner. As you tighten down the nuts on all of the threaded rods, be sure to check the level of the beam, making sure that it is as level as possible, so the roof itself will be level. It may be necessary to tighten some of them more than others. You want this whole assembly to be clamped tightly together so that there is no chance of any of the bags becoming dislodged, but there is no reason to overtighten them either; you don't want to overly bend or stress the metal or wood.



**Fig. 8.10:** This shows how metal L brackets can be attached to the bond beam to secure roof members.

## Door and Window Openings

Door and window openings are best made as the earthbag building is being constructed; it is very difficult to retrofit earthbag walls with such openings. In general, the fewer openings there are, the stronger the wall is, because the continuity of the earthbag and barbed wire matrix has fewer interruptions and thus the monolithic nature of the structure is less compromised.

### Door and window bucks

The most common way to establish a door or window is to place a frame for it exactly where you want it to be. Such frames are often called door or window *bucks*, and they provide a convenient stop for abutting earthbag walls, as

well as permanent rough frames for the doors and windows themselves. These bucks need to be quite sturdy to serve this purpose, so wood or metal is usually used. The wider they are, the better they will contain and define the space. Nominal 2-inch (5 cm) thick wooden planks are usually sufficient for the sides and the bottom, but if the top will also serve as a lintel that will support more weight above it, the top piece should generally be thicker.

Temporary braces can be used to prop the door and window bucks into place so they remain plumb and do not deform from the pressure of earthbags being tamped next to them. The bucks themselves can be permanently attached to the surrounding earthbags in several

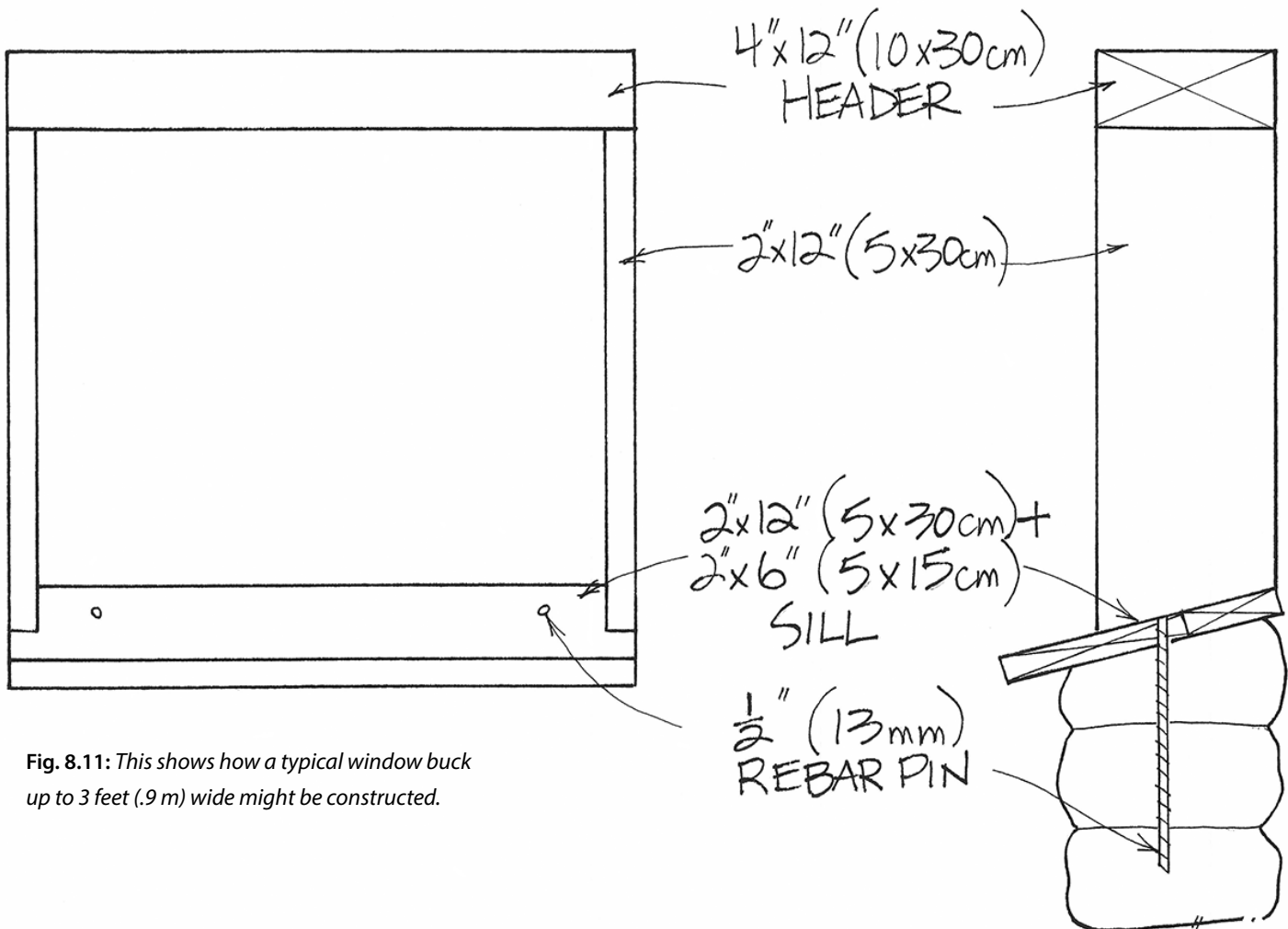
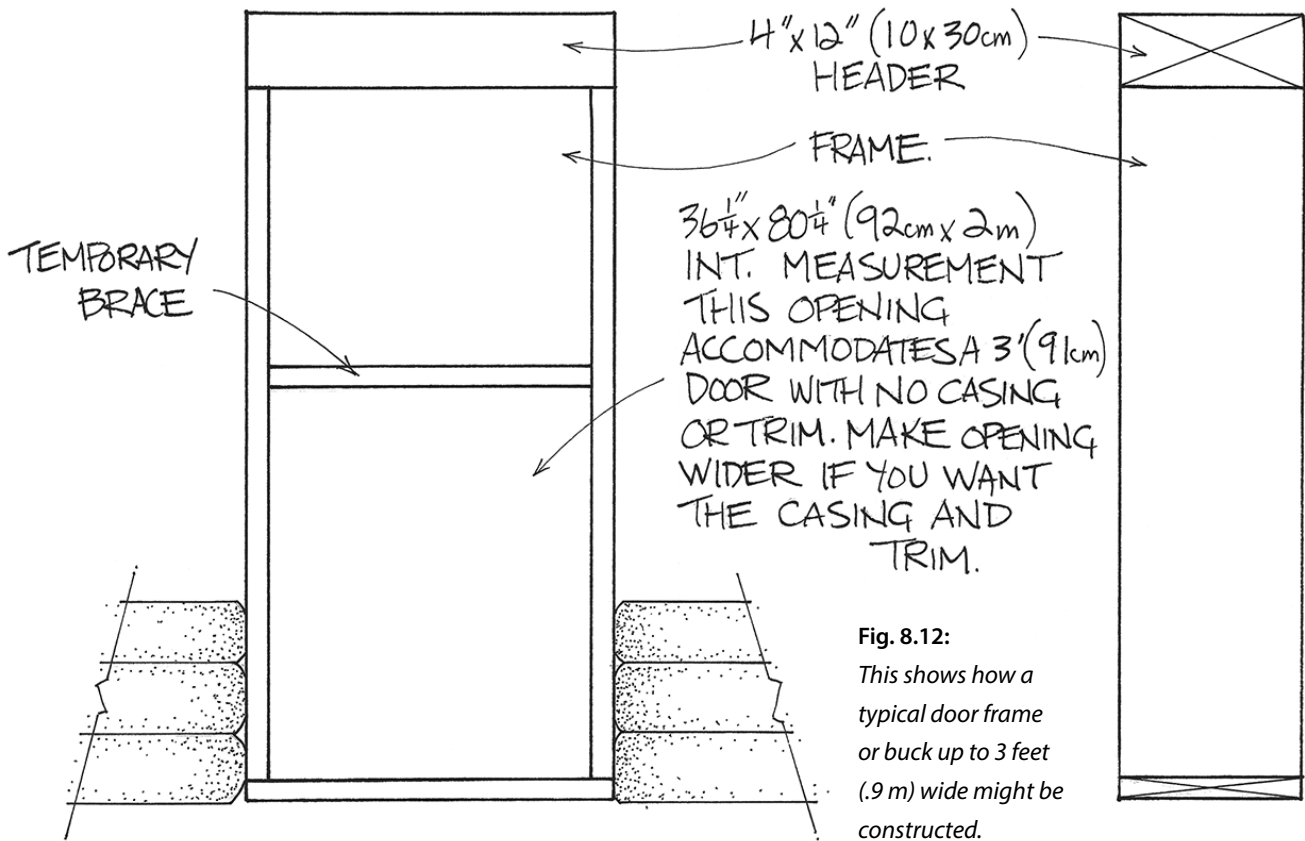


Fig. 8.11: This shows how a typical window buck up to 3 feet (.9 m) wide might be constructed.



ways. Steel pins can be driven through the bucks and into the earthbags (similar to how rigid bond beams are connected to the walls).

Another common way to connect the bucks is to periodically place connection plates between earthbags as the wall is being built. These plates might be made from sheet metal that has an L-shaped lip bent at one end that can then be attached with nails or screws to the buck (see Figure 8.13). Or they could be fabricated from plywood that has a solid wooden edge fastened to the end that abuts the buck, so that this can in turn be fastened to the buck. In either case, these plates need to be secured into place between the bags by piercing them with nails (preferably in both directions) that get embedded into the bags below and above them. Such plates need not be any more frequent than about every third course of earthbags.

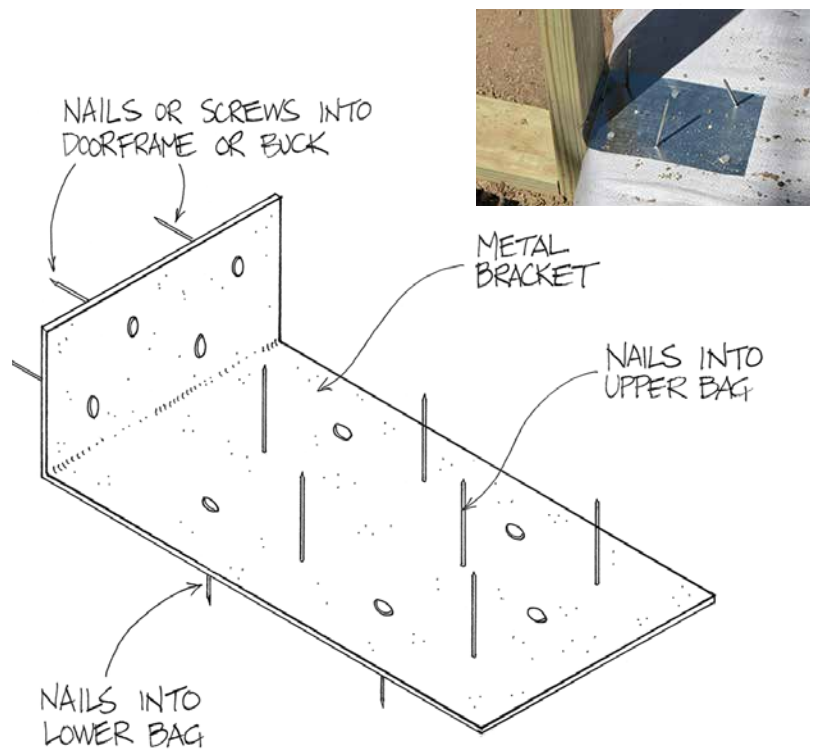


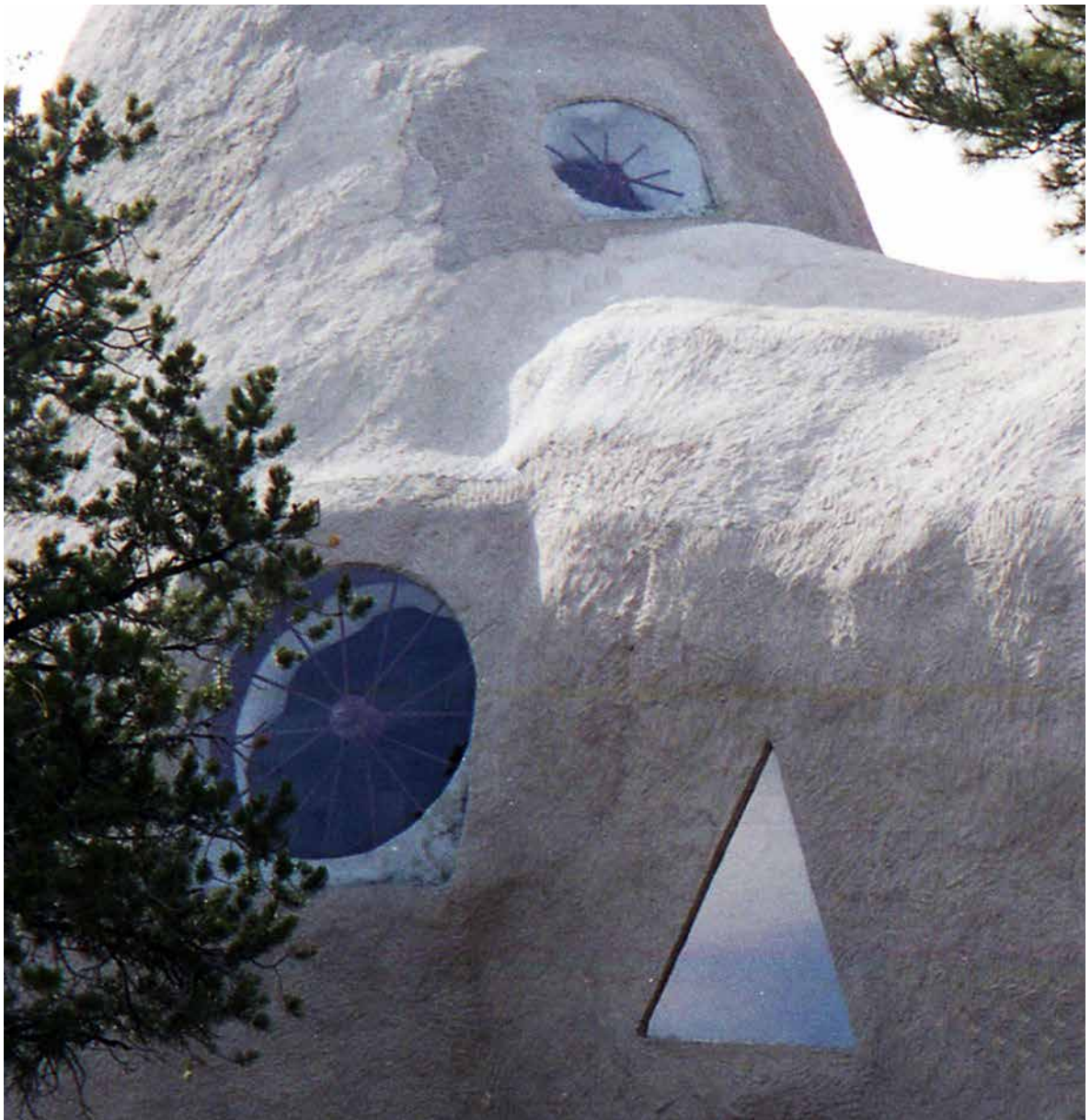
Figure 8.13: A simple metal bracket designed to connect door or window bucks to the earthbag wall.

### Arches and other shapes

Window and door bucks as described above are best suited to rectangular openings. Other window shapes are certainly possible, and even common, in earthbag construction. Circular or arched-shaped openings, as well as triangular ones, are fairly easily accommodated by just arranging the earthbags in an appropriate manner. These other shapes can provide sufficient

strength at the top that separate lintels are unnecessary.

I have used metal culvert couplers and sections of metal culverts, as well as wide-rimmed spoked tires as permanent frames for round windows. I have seen others use large tires as forms for round windows. Arched-shaped forms (and how to make them) are described in Chapter 5. Any temporary form must be positioned in such



**Fig. 8.14:**  
*Both circular and triangular shaped windows were incorporated into this earthbag structure.*

CREDIT: KELLY HART

a way that it can easily be removed once it has been covered by earthbags. This usually means that the form is raised into place on shims or something that can be knocked out or released when it comes time to remove the form. If provision for this is not made, you risk having the form locked into place by the weight and pressure of the surrounding earthbags.

There are various ways to arrange earthbags to form arches so that they become self-supporting once the form is removed. The general concept is to create wedge-shaped bags that compress into a solid arch, similar to how wedge-shaped blocks or stones might be arranged in masonry construction. It is important

that the surrounding walls that embrace the arch are in place *before* the arch form is fully released, or you risk the arch failing because it can expand outward on the sides.

The usual method of constructing earthbag arches is to work from the bottom up on both sides more or less simultaneously, so that the arch is balanced as it rises and the final *keystone* bag gets locked into place. To some extent, these arch bags can also be tied to the walls on either side with the barbed wire that is between the courses.

In my experience, semicircular arches do fine if they are no wider than about 3 feet (91 cm); wider ones tend to flatten out at the top too

**Fig. 8.15:**  
Here you can see how the individual bags were wedged around the arch form to create this arched doorway. Orienting the bags this way creates an extending “eyebrow” over the arch.

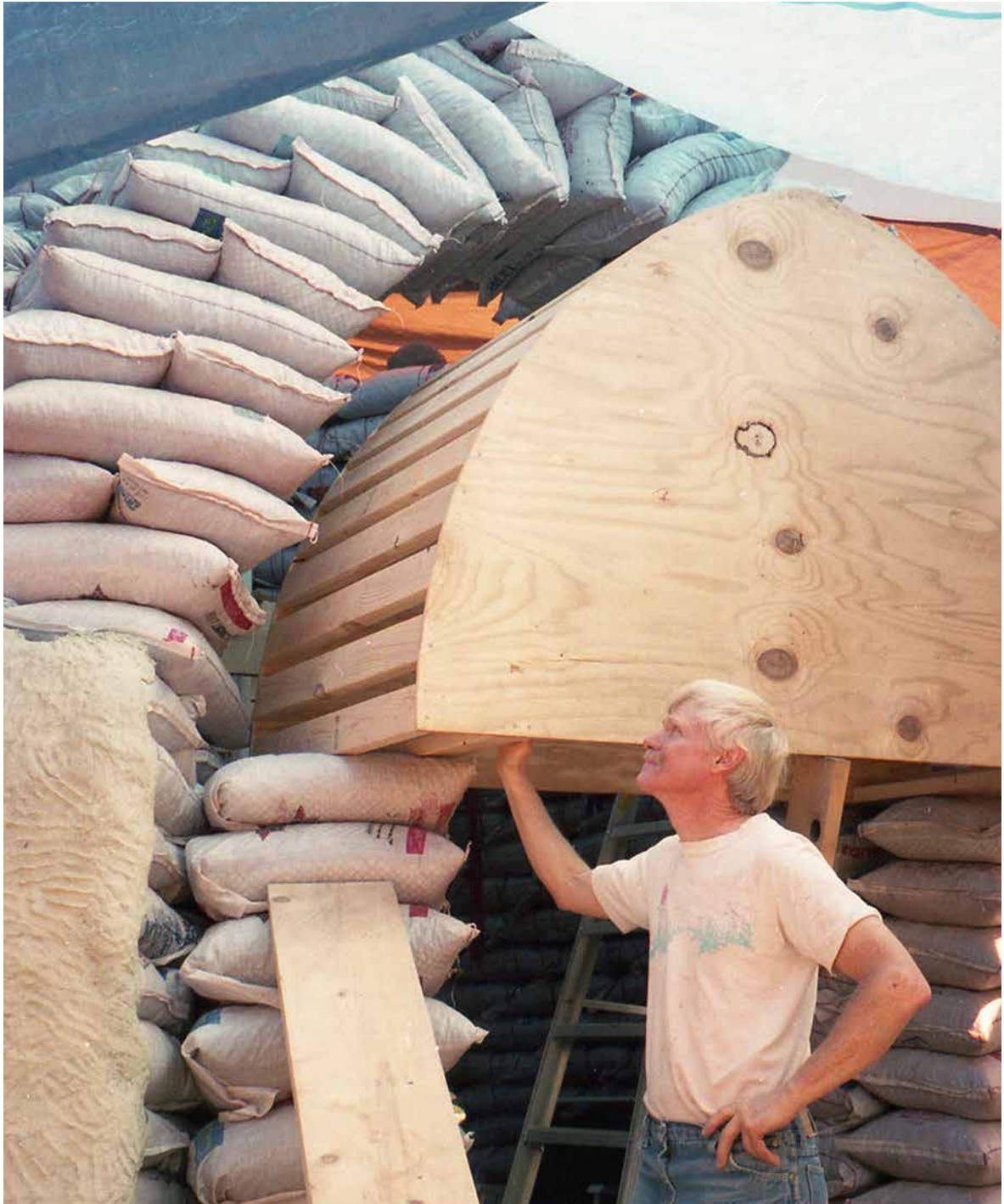
CREDIT: KELLY HART





much after they are released and weighted from above. Wider arches are best built in catenary or Gothic shapes that are more pointed at the top.

Sometimes earthbags that form arches are filled with stabilized material so that they become more solid and are less likely to deform from pressures over time. In fact, I have seen



**Fig. 8.16:**  
*This gothic arch form spanning 6 feet (1.8 m) was just released from the surrounding bags.*

CREDIT: ROSANA HART

arches that were formed by filling a single long tubular bag with stabilized fill (or even concrete) and placed over an arch form to cure in place.

There are several ways to orient the bags that are used for arches. One way is to keep the arch to the same thickness as the rest of the wall it is in. In this case, the bags can be positioned so that they radiate outward from the form with the bottom of the bag resting on it. The base of the bag should be tamped so that it tapers to create the wedge shape. The bag is filled to a uniform level, with the top of the bag folded over and tucked between adjacent bags.

Another approach allows you to create arches that are wider than the wall and thus form a kind of *eyebrow* over the opening that helps protect and shade the window to some extent. In this method, the bags should be filled to their capacity with just enough left at the top to be able to fold the material over a couple of times and be stitched into place with thread or wire. Then each bag is placed over the arch lengthwise, so the bag rests on its side and is tamped as a tapered shape that will form long wedges. The arch shown in Figure 8.15 was made this way.

I devised another method of forming arches with earthbags when I tried the above approach to make a 6-foot (1.8 m) wide door opening, and it failed soon after I pulled the arch form out. I realized that such wide arches made with earthbags really need to be made differently to be stable. I used a set of miniature earthbags I had made to experiment with and came up with a new method.

This method requires buttress columns to fully support the arch. (Such buttresses are a good idea to help stabilize the entire door or window opening, in any case.) I used fully filled bags that were hemmed on top to securely contain the fill. Then I laid two of these bags side by side to create a roughly square footprint for the buttress right at the base of the opening. As I built the

wall, I integrated the buttress by always placing two full bags perpendicular to the ones beneath it. This created the crosshatch pattern that tends to keep everything very securely in place.

As I approached the top of the doorway where the arch would begin, I positioned the 6-foot-wide arch form where it needed to be, and then simply continued with the crosshatch pattern of double bags all the way up over the arch. I did this on both sides of the opening so that by the time I got to the very top I was able to tie the sides of the arch together with more double bags right at the apex of the arch. I did orient the inner bags that touched the wooden form in a radiating pattern in the same way that smaller single bag arches are formed. Because of the monolithic nature of this technique of forming an arch, it was so stable that I could remove the arch form even before the sides of the walls were completely connected to it! An example of this method of forming an arch is shown in Figure 8.16.

### Spacing openings

There are limits to how many openings can be arranged in an earthbag wall. In some cases, it makes more sense to frame a wall with wooden components rather than with earthbags, as, for example, when there are many windows or doors designed into that wall.

A good rule of thumb is that there needs to be at least 3 feet (91 cm) between all openings and between any opening and a building's outside corner. This measurement can be somewhat shortened if the wall in between is buttressed, either on the inside or the outside.

### Vertical reinforcement for openings

To help keep all openings perfectly vertical and secure, it is a good idea to drive vertical rebar pins down through the earthbags that are adjacent to them. These pins should be placed near

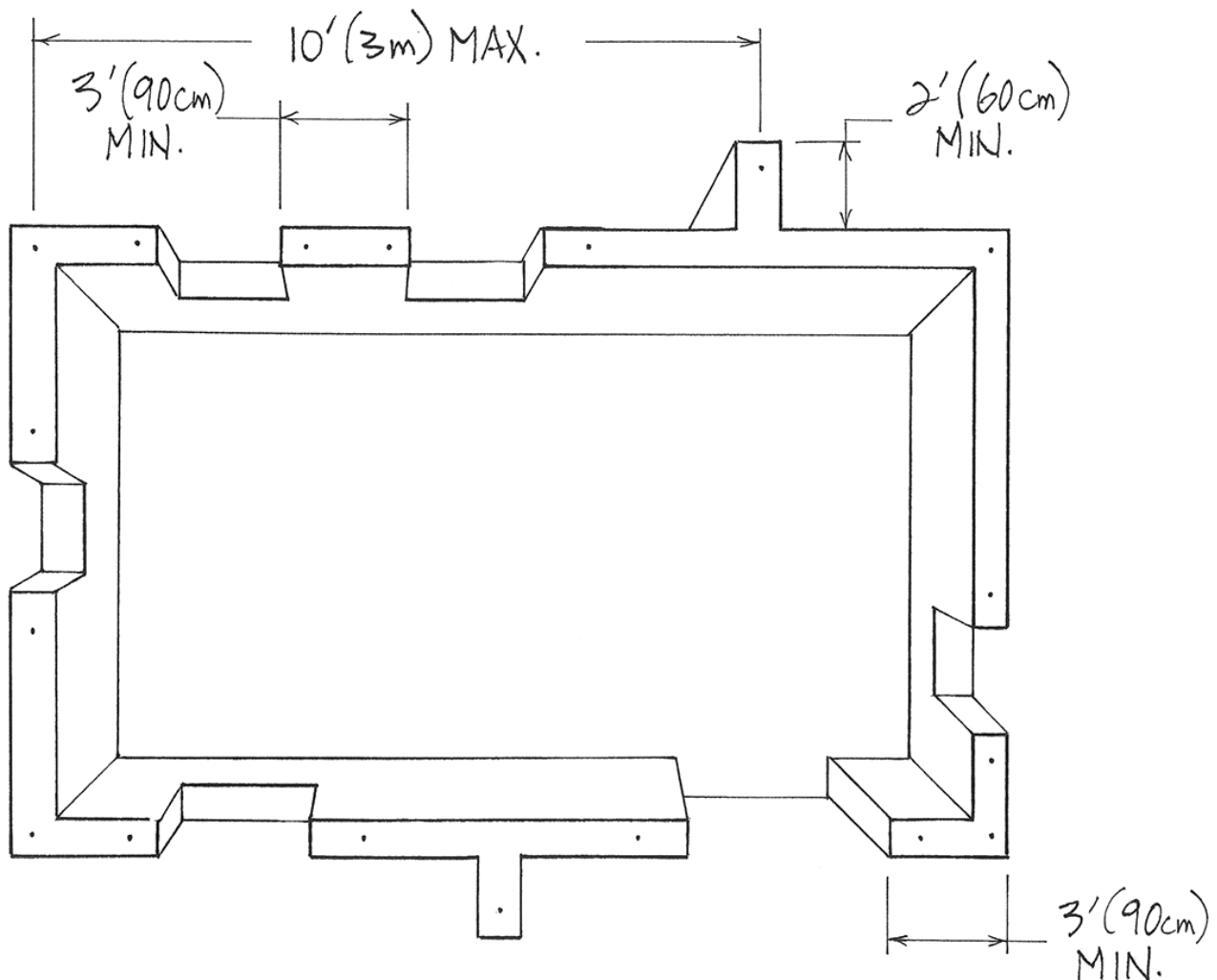
the center of the bag wall and approximately 6 inches (15 cm) from the edge of the opening, as shown in Figure 8.17.

### Lintels

Arched openings are great because they are strong without needing a separate lintel, or support, above the door or window; they naturally deflect the vertical forces off to either side of the opening. Rectangular openings *do* require

a lintel over them, not only to support the bags that are placed above them, but also to support some of the roof load that bears down on them.

Some designs allow the top bond beam to serve this purpose, but generally, separate lintels are necessary. With windows and doors no more than 3 feet (91 cm) wide, a thick top board on the window buck might suffice for the lintel. I suggest that these be at least 4 inches (10 cm) thick, as is shown in Figures 8.11 and 8.12.



**Fig. 8.17:**

*This diagram defines suggested distances for openings and buttresses in earthbag structures. Also shown are suggested positions for vertical rebar pins near all opening, as well as in the corners and in the buttresses.*

For wider door or window openings, a better strategy is to allow the bag wall on either side to help support the weight. In this case, a longer lintel that extends over onto either side of the wall by at least 1 foot (30 cm) is in order. Just how thick such a lintel should be depends on many factors, including the width of the opening, the expected loading from above, the material that the lintel is made of, and how wide it is. In general, wooden beams that are 4 inches (10 cm) thick and nearly as wide as the bag wall can suffice for openings up 3 feet (91 cm) wide. For wider openings, 6-inch (15 cm) thick lintels are better. These lintels can be built up with smaller-dimensioned lumber that is laminated or secured together. For metal, pre-stressed concrete, or boxed lintels, you should consult architectural span charts for appropriate sizes.

## Wall Thickness

How thick should earthbag walls be? The tradition that has evolved for most earthen building is that the wall at the base should be at least as thick as one tenth of the height of that wall (1:10 ratio). However, earthbag construction is usually not as monolithic in nature as other earthen methods, so I think a standard of 1:8 is a more reasonable ratio. While the wall could taper to a smaller width as it rises, this is rarely done with earthbags, partly because the bags are available in only a few sizes.

The most common-sized bags used for earthbag construction measure about 18 inches (45 cm) wide when flat. These bags produce a wall measuring about 14 inches (36 cm) wide after they have been filled and tamped. The rule of 1:8 would mean that an earthbag wall made with these bags should be no taller than about 9 feet (2.7 m) high, which gives you some design flexibility for most single-story buildings.

The bags usually used for flood control only measure about 14 inches (36 cm) wide when flat, so the final width would be more like 10 inches (25 cm). Theoretically, they could support a 6-foot (1.8 m) wall, which really only makes them big enough for something like a fence, but even there, a thicker wall would be much more stable.

## More Than One Story

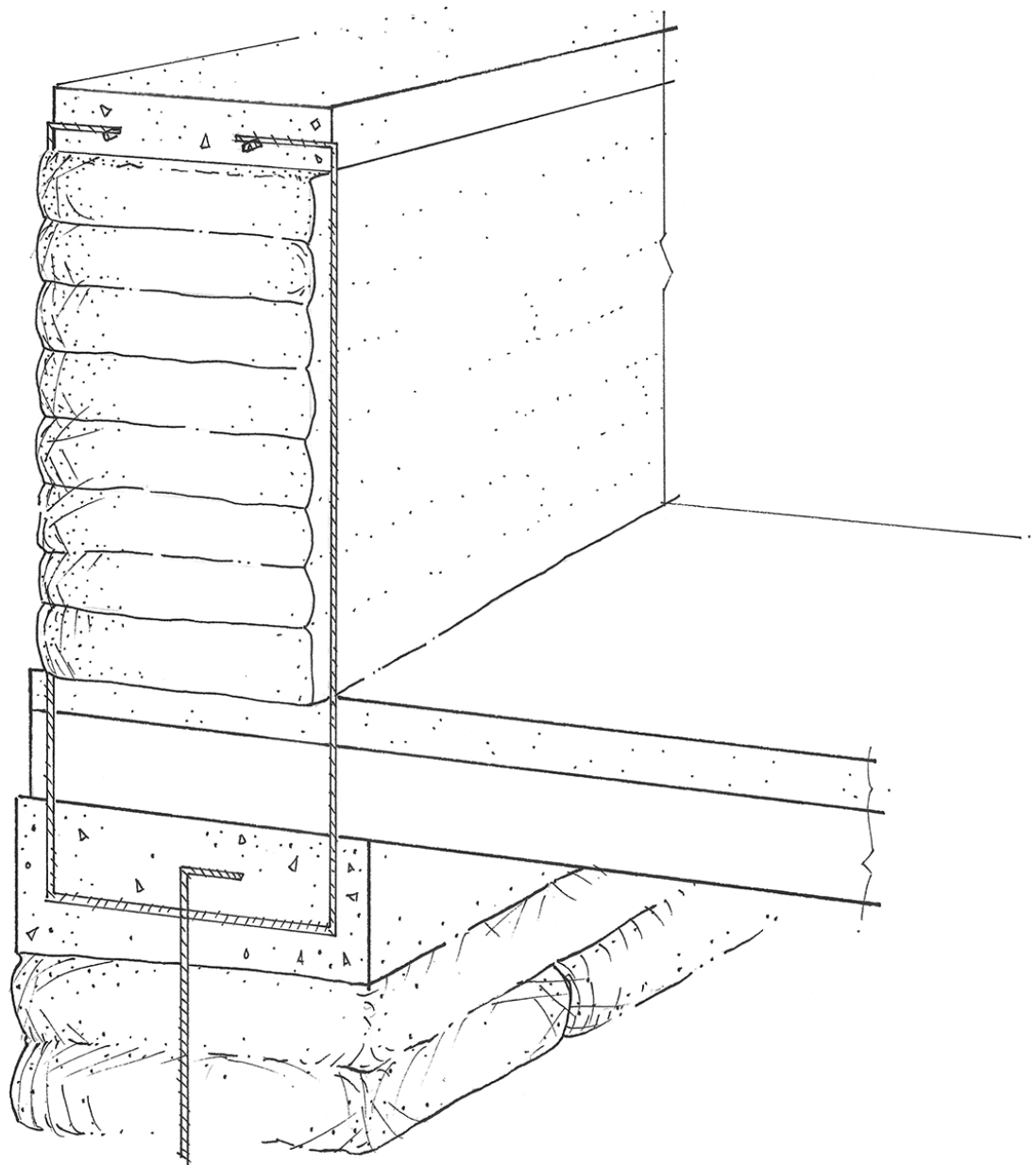
Two-story buildings or buildings with basements made with earthbags should be built using even larger bags for the first floor or the basement. If these larger bags are 24 inches (61 cm) when flat and 20 inches (51 cm) wide after being filled, they should theoretically support a wall that is about 13 feet (4 m) high. But, in reality, the dynamics are different because there will be a bond beam and complete floor diaphragm

separating the two stories, so bags this size should be stable enough for taller buildings.

The practical limit for earthbag buildings is two stories, and there are really very few examples available — aside from large domes with a loft. Staying with one story is advisable because the logistics and the engineering are much simpler. If you do want to attempt a taller building, look at Figure 8.18 and consult a practicing engineer regarding the details.

**Fig. 8.18:**

*This details how a second-story earthbag wall might be built and securely attached. Note that the first-story wall has wider bags and both walls have upper bond beams, with the second-story wall completely banded by external rebar.*



## Below-grade Construction

Earthbags are an excellent choice for below-grade construction. When filled with earthen or mineral materials, they are not prone to deterioration from moisture, which is always a concern with any below-grade construction. Of course, special precautions need to be made to assure that moisture does not intrude into the wall or the interior space.

Most likely, walls will need to have a waterproof barrier installed on the outside to keep moisture from seeping through. I have used two layers of 6-mil polyethylene sheeting for this, but you could also use a single layer of heavier plastic, butyl rubber, pond liners, or EPDM membranes. This waterproof layer can be tucked between two courses of bags a few courses above grade and then draped down to the base near the foundation level. If it is desirable to insulate the wall from the outside, then this insulation can also be incorporated within the waterproof apron, as shown in Figure 6.3.

Additional drainage could be provided by filling a space between the waterproof layer and the soil with some gravel or sand as a secondary assurance that water won't pressure up against the underground wall. Such a drainage layer could be congruent with any rubble trench that the wall itself rests upon. An arrangement like this is shown in Figure 6.4.



**Fig. 8.19:** *The author is making a mostly underground small earthbag dome on this desert property. He is about ready to start laying bags at the bottom of the trench, using the central column of soil as fill material.*

CREDIT: JULIE HICKS



**Fig. 8.20:** *This earthbag wall will be bermed with soil nearly up to the top of the plastic moisture barrier.*

CREDIT: KELLY HART





## Chapter 9

# Plastering the Walls

**I**T IS ESSENTIAL THAT EARTHBAG WALLS be protected from the elements, especially sunlight, and applying plaster is the most common way to do this. Plaster also forms a solid air barrier that helps keep the interior space thermally efficient and free from too much moisture. Even if the walls will receive a different sort of cladding as a final exterior treatment, it is a good idea to give them an initial coat of plaster to help seal the wall from air currents.

If it is anticipated that an earthbag building project will be extended over a lengthy time

period, it is a good idea to apply an initial coat of plaster over those portions that have been completed rather than waiting until the entire project has been completed. Tarps have a way of pulling loose in the wind and either tearing or deteriorating.

The most environmentally friendly plasters are earthen, derived solely from a combination of clay and sand, with perhaps some chopped straw or other fiber added for strength. Whole books are devoted to the art of plastering, with many formulae for mixing plasters and

**Fig. 9.1:**  
*This photo shows how both tarps and plaster are protecting the bag walls during construction.*

CREDIT: KELLY HART







instructions for applying them; I strongly suggest that you become familiar with this art before launching into your first project.

Simple earthen plasters work well on interior walls where they are protected from the elements, but on the exterior it is often advisable to stabilize the plaster from erosion or degradation by weather. Even on the inside, stabilizing a plaster will help keep it from dusting or rubbing off when handled. Various stabilizers can be added to the mix, similar to those used to stabilize earthen fill material. Portland cement, lime, flour, and cactus juice have all been used as stabilizers. These stabilizers will affect the permeability of the plaster, so consider this when choosing an appropriate stabilizer. In most cases, you want the wall to be sufficiently permeable to allow the dispersion of moisture. Permeability

**Fig. 9.2:** An initial rough coat of earthen plaster is being applied to this wall. CREDIT: KELLY HART



**Fig. 9.3:** The final interior lime plaster adds brightness to the author's earthbag dome home. CREDIT: KELLY HART

was discussed more thoroughly in Chapter 3. Table 3.1 gives ratings for the permeability of common plasters.

You can use straight lime mixed with sand and water as a plaster, in a ratio of about 1 part hydrated lime to 3 parts sand. My experience with lime plaster is that it works best in thin applications, partly because it takes a long time to dry, but also because it does shrink quite a bit. Like clay, it needs to be mixed with sand for greater durability and less shrinkage. A bit of latex paint can be mixed with this to keep it from rubbing off when touched. I have worked with lime putty that I had prepared in advance and then added white sand and a tad of white Portland cement to make it set up quicker. It can take quite a while to harden, especially in a humid environment. Lime plaster breathes well and is much more environmentally friendly than cement-based plasters. There is a long tradition of making and using lime plaster; I suggest you consult a book that describes this art in detail.

Stucco is usually made from Portland cement, sand, and water. Often, some lime is added to this to make it more plastic and sticky; the lime will also make it more permeable, which is generally a good thing for earthbag plasters. Stucco is quite durable and can last for decades. A common formula for it is 1 part Portland cement, 1 part hydrated lime, 3 parts sand, and enough water to make it spreadable, but not runny or droopy. Stucco sets up chemically, so don't mix any more than you can use within about an hour.

I experimented with using papercrete as a plaster on my first earthbag house. Papercrete is made from re-pulped paper fiber mixed with water and a small amount of Portland cement to bind the mass into a cohesive material. It requires a special machine, rather like a huge industrial blender, to make. I applied this inside and outside the structure as an initial

plaster coat. The plaster visible in Figure 9.1 is papercrete.

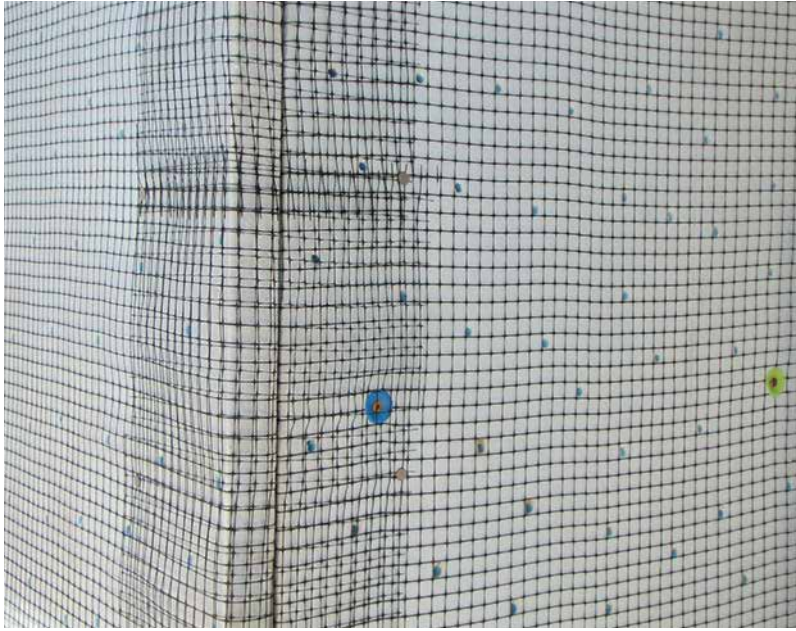
The papercrete generally worked well, as it makes an excellent substrate for applying other kinds of finish plasters. Once it cures, it becomes very dimensionally stable, neither shrinking nor expanding under various temperatures or moisture content. When subjected to moist conditions, it tends to absorb a great deal of moisture, acting almost like a sponge. When dry, it adds a layer of insulation that most other plasters will not, so that can be beneficial. And it readily fills in large gaps between bags, making it easier to render smooth walls.

On the inside of my experimental earthbag house, I covered the papercrete with a final coat of lime plaster, and this made for a very bright, naturally white surface, as shown in Figure 9.3. On the outside I left the papercrete exposed for a few years (the bags were filled with scoria that would not be affected adversely by any moisture that migrated in, although I never noticed that happening). Eventually, the papercrete was covered with a final coat of ordinary cement-based stucco, since I found that the papercrete did not weather well.

Most plasters can benefit from being applied over some kind of mesh material to both keep the plaster from fragmenting or flaking off over time and to hold the plaster up against the earthbag wall. This becomes even more important on the inside of an earthbag dome, where gravity is working against the adherence of the plaster. I have used chicken wire netting for this purpose, of both the 1-inch (25 mm) and the 2-inch (5 cm) varieties. For a view of how this type of wire mesh can be used, see Figure 4.9.

Lately, I have preferred to use a synthetic mesh material because I believe that it has the potential to last longer; metal wire will eventually rust and lose its integrity. There are various commercial plaster mesh materials available,

but my favorite is made with polypropylene, the same material used for most earthbags. This fiber is very tough and durable and stretches very little. I have found that the kind of mesh



**Fig. 9.4:** Half-inch (13mm) polypropylene bird netting mesh used by the author for a stucco project. CREDIT: KELLY HART

sold as bird netting to protect fruit trees from the predation of birds works perfectly for many applications. It comes in very large rolls — big enough to wrap an entire house. The type I used has half-inch (13 mm) squares. See Figure 9.4 for a picture of this mesh.

There are various ways of attaching the mesh to a bag wall. One way is with the cross-ties of twine that were mentioned earlier. Another way is with large metal staples that are pounded into the bags. Such staples can be made fairly easily by bending lengths of heavy-gauge wire into a U-shape.

The *Hyperadobe* method of building walls, which utilizes raschel mesh tubing for the containment of the fill, might also provide enough mesh reinforcement for the eventual plaster that a secondary application of mesh material is unnecessary.

Please refer to Chapter 3 for a thorough discussion about the role of plaster in controlling thermal factors, air, moisture, and vapor when choosing appropriate plaster for any earthbag project.



## Chapter 10

# Floor and Roof Options

**T**HERE ARE TWO MAIN OPTIONS for making floors for an earthbag building. One is to build the floor so that it is coupled to the ground, and the other is to suspend it above the ground. The most common, cheapest, and easiest to construct is a floor placed directly on top of the ground, and this can be done in a variety of ways.

### Slab on Grade

Pouring a concrete *slab on grade* can create both the floor and the foundation for the building in one operation. This is an accepted practice in most building codes, so the details for

accomplishing it are well defined. It is not the most ecological choice because it relies on a great deal of reinforced concrete — with all of the embodied energy inherent in that.

Basically, a monolithic concrete floor slab is poured with suspended welded wire mesh reinforcement embedded midway. At the periphery, a deeper trench is dug, and this becomes the *thickened edge* foundation for the building. Ideally, all of this is lined with rigid foam insulation (in most climates) to isolate the slab from thermal bridging with the soil under it. Generally, all necessary plumbing drains and



**Fig. 10.1:** This is an example of how plumbing drains and supply lines might be arranged prior to pouring a concrete slab floor.

CREDIT: KELLY HART

supply lines are fixed under the floor before it is poured. Also, if hydronic heating is planned, the system must be in place before the concrete is poured.

An alternative to this is to make the foundation in some other fashion, as described in Chapter 6, and then prepare and pour the slab on grade as a separate operation, just to create the floor.

Rather than using commercial foam board for insulating the floor, one can more ecologically use crushed volcanic stone, such as *scoria* or *pumice*. I have done this successfully with pads of between 4 and 6 inches (10 and 15 cm) of stone. Depending on the nature of the native soil, especially if it doesn't drain well, it would be prudent to place a moisture barrier over the soil before lining it with the crushed stone. In areas where radon gas is a concern, a solid moisture barrier is also advised.

Once a concrete pad is poured and cured, it can be given a variety of final finishes, such as tile, hardwood flooring, carpeting, commercial composite flooring, or just a simple concrete stain and/or polish.

## Masonry Floors

It is possible to make a floor directly on grade using other masonry components. I have seen some lovely floors created by carefully arranging fired bricks in patterns; you could possibly even use a variety of pavers that interconnect in interesting ways. This is typically done by first leveling a pad of several inches of sand over a plastic moisture barrier. The sand provides a firm bed to support the bricks or pavers and makes it easy to adjust them individually for a perfect fit.

A similar approach can be followed for laying flagstone — or other very flat stones — to form a floor. Because the stones tend to be quite irregular in shape, fitting them together to create a level-enough floor can be very challenging. It might require a thicker bed of sand, or it might even be desirable to pour a shallow bed of concrete to embed them in. In either case, it is usually necessary to fill in the spaces between the stones with some form of grout or mortar. There is definitely an art to making such a floor look good, so if this appeals to you I suggest experimenting first with a trial project to get some experience.

**Fig. 10.2:**

A pad of several inches (10 to 15 cm) of crushed volcanic scoria was laid to serve as insulation for the floor. The final floor material would be placed on top of this layer.



CREDIT: KELLY HART

## Adobe Floors

Another very natural way to make floors is to use adobe soil. The most common way to do this is by mixing the ingredients in batches and pouring the floor in sections. The mix is typically about one third clay and two thirds sand, with chopped straw added to help bind the mass together and provide some pretty flecks of gold to the surface. Enough water is added to make the adobe malleable enough to pour and spread around.

This is a very labor-intensive process; not only do you have to thoroughly mix all of the ingredients and pour them, but then you have to carefully trowel the mix to create the desired flat, level, and smooth surface. This usually requires several stages of successive troweling operations that are done over many days as the adobe slowly dries. In order to attain a nice hardened surface, it takes a fair amount of downward pressure while using the trowel, all while on your hands and knees and likely on some protective boards or covering to protect the emerging floor from scuffs.

Another approach to making an adobe floor is to tamp it rather than pour it. In this case, the adobe mix is made somewhat drier, with just enough water added for it to form a monolithic

solid when thoroughly tamped. I'm sure there is an art to being able to tamp such a floor so that it is perfectly flat and sufficiently hardened on the surface. I haven't tried this myself, but I once saw a demonstration of it being done.

Colorful clays can be added to the very top of the floor surface to make decorative or artistic finishes or patterns.

Once the floor has dried out (which can take weeks), it can be sealed with something like boiled linseed oil (possibly thinned with mineral spirits so that it soaks further into the adobe for the first coat or two). The oil should be allowed to soak in for a few hours, but then it needs to be wiped with a rag so that excess oil does not congeal on the surface. It may take several such applications before the floor is finished. Some people like to put a finish wax over this, but the wax may make it harder to repair or renew the oil finish if necessary. See Figure 10.3 for an example of what linseed oil looks like on adobe.

A good resource for learning about how to create earthen floors is this book: *Earthen Floors: A Modern Approach to an Ancient Practice* by Sukita Reay Crimmel and James Thomson, published by New Society Publishers.



**Fig. 10.3:** Fresh linseed oil has just been applied to this floor. On the right is flagstone and on the left is adobe that was scored to make it resemble stone. CREDIT: KELLY HART

## **Suspended Floors**

It is certainly possible to suspend a floor with floor joists in the same manner that it is done in more conventional buildings. In order to do this in the most efficient and secure manner, a bond beam should be fabricated at the level of the earthbag walls where you want the suspended floor to begin. This bond beam should be as level as possible so that the floor also ends up level.

To place the joists for the floor, first select the appropriate size for the spans involved. Then cut the joists long enough so that they will rest upon the bond beam but not go all the way through to the point where they would be exposed outside of the plaster. These joists can be spaced with blocks of wood (in the case of wooden joists) of the same dimensions as the joist itself, but cut to the exact length desired for spacing. Secure these blocks just beyond where the earthbag wall should continue rising, so that it is possible to actually place more earthbags on top of the bond beam between the joists. Once these bags

are in place, they can be thoroughly tamped so they are ready to receive more bags to continue upward with the wall. As soon as possible, you should resume placing the barbed wire between courses as usual. In this way, the floor joists become very firmly embedded in the wall system.

Although it is not an ecological choice, in regions where wood is not easily available, a floor can be made with reinforced concrete. This is typical for construction in Mexico. The first thing to do is to create a poured concrete bond beam as described; the concrete floor diaphragm will rest directly on it. Preparing the forms for the concrete floor involve establishing a substantial platform that is thoroughly braced from beneath to hold the weight of the wet concrete. The reinforcement mesh is positioned above the platform in readiness for pouring the concrete. Of course, this needs to be carefully engineered to be successful. An example of such an arrangement is shown in Figure 8.18.

## Roofs

All earthbag buildings, other than domes, require some kind of a separate roof structure. These can be as simple as a single-pitched shed roof or as complex as a hip roof or other shapes with multiple facets. Basically, the framing for such roofs is the same as it would be for other, more conventional buildings. The main interface between the bag walls and the roof will be a top bond beam that will receive the weight of the roof and direct those loads down through the walls to the foundation.

The upper bond beam needs to have provision for securely attaching the rafters or other framing members for the roof. Such fasteners need to not only position the framing members, but also to prevent uplift in the event of seismic events or high winds. One way to provide attachments for rafters is shown in Figures 8.8 and 8.10.

Circular buildings can easily accommodate a variety of conical roofs. A central supporting pole can secure radiating rafters that extend beyond the bag wall to form a protective eave. Yurt-style roofs that have no central support pole will need some kind of tension band toward the outer extremity in order to hold them rigid without the danger of collapsing; they also usually have a compression ring at the center to receive the radiating rafters. Another style of circular roof that is free standing is a reciprocal roof, where the rafter poles sequentially overlap each other as they pivot the center of the roof, as shown in Figure 10.4. Even rigid metal conical shapes, like those used to shed water off of grain bins, can be used on an earthbag roundhouse.

No matter what the style of roof employed, it is best to make sure that a substantial eave extends beyond the wall to protect the plastered walls from the erosion of precipitation.

**Fig.10.4:**  
*This reciprocal roof is actually supporting earthbags filled with lightweight insulating scoria.*  
CREDIT: KELLY HART









## How to Include Utilities

### Plumbing

**I**N MOST CASES, plumbing should be directed either under floors or within hollow interior walls. It is generally not a good idea to run plumbing lines within earthbag walls, primarily because leaks or repairs would be quite problematic. Since the craft of fashioning plumbing in these conventional spaces is well known, I suggest that readers refer to technical plumbing manuals for more information about this. See Figure 10.1 for a specific example of preparing plumbing under a slab floor.

If it is necessary to penetrate an earthbag wall with a plumbing line, this can be done in a variety of ways. It can simply be done at the time of constructing the wall by placing a section of the pipe across the wall where you want it and embedding it within the earthbag matrix. The ends of this pipe should extend far enough on either side of the wall to eventually connect it to its plumbing circuit. Another approach is to similarly embed a short section of pipe of a greater diameter than the intended pipe that then becomes a chase to channel the plumbing through.

If it is necessary to penetrate an existing earthbag wall to retrofit a plumbing line, it is usually possible to pound a short length of pipe through the wall. This could be either a chase for a smaller pipe, or it could be the actual pipe itself — if it is sufficiently stiff and would not be harmed by the act of pounding. It may be necessary to clean out the inside of the chase pipe if it gets full of the earthbag fill material when it is pounded through the wall. If you pound the actual pipe through, it is best to temporarily cap both ends to avoid contaminating the inside with fill material or damaging either end.

In some cases, it might be necessary to have a plumbing line run along an earthbag wall horizontally. This should be done on the inside of the wall rather than the outside to avoid any problems with freezing weather. The best place to locate such a pipe would be along one of the seams between courses of bags, fairly near the inside surface so that in the event of any need to repair the line, it would not be too destructive to dig through the plaster to expose it.

## Electrical

As with most conventional construction, it may be possible to run electrical circuitry within the voids of floor, ceiling, roof, or partition wall framing, and this is often the best choice.

On the other hand, it is also quite possible to route electrical lines within the earthbag walls themselves. Usually this is done after the wall has been erected, but before any plaster is applied. The easiest place to locate such wire for horizontal runs is tucked between the courses of bags; this makes it easier to hide it beneath the plaster. In fact, you should use wire that is rated for direct burial (UF) and it must be kept at least 2 inches (5 cm) away from the surface of the plaster.

In some instances, it might be preferable to attach conduit for running electrical lines, and this can also be hidden beneath the plaster. Both conduit and wire can be firmly pinned to the bag walls with large wire staples, similar to the ones used to attach plaster mesh to the wall.

Fixtures such as for outlets, switches, or junction boxes can be firmly attached to a bag wall

by first driving short (about 1 foot, or 30 cm) wooden stakes with a pointed end into the wall. Approximately 1 × 2 inches (2.5 × 5 cm) is plenty stout for this purpose. Such stakes can often be driven into the junction between bags so they are less likely to penetrate the bag material and potentially spill any contents. Friction and compression should be able to hold the stakes very solidly, so that the fixture box can be attached to them with screws (preferably two). You want to position the box so that the outward opening will be more or less flush with the final plaster and the face plate will present a pleasing appearance. A single stake is usually enough to hold smaller boxes, but larger entry service boxes or breaker switch boxes might require two or more stakes to hold them sufficiently firm.

In instances when it is necessary to run electrical circuits from inside to outside the building, this can be done by positioning a section of conduit through the wall, similar to how this is done for plumbing (see above).

**Fig. 11.1:**  
*Both a light switch and an electrical outlet are visible in this earthbag bedroom; the wire itself was embedded within the earthbag structure before the plaster was applied.*



CREDIT: KELLY HART

## Heating

Probably the most ecological way to heat a home is through passive solar design, and earthbags can contribute to such design in many ways. They can provide a reasonable measure of insulation for the building envelope when filled with insulating materials, or they can provide a considerable thermal mass when filled with earthen material. In one earthbag house that I built, I used earthbags filled with lightweight crushed volcanic stone to fill the bags for the primary walls, and then used bags filled with local soil for several features that were within that building enclosure. These features included a landing for a staircase, some buttress columns, and even a small spiral stairway up to a loft. One principle of good passive solar design is the incorporation of thermal mass materials within an insulated building enclosure.

It may be tempting to try to combine both thermal mass and insulating materials together as fill in order to gain the benefits of both.

This would *not* be a good idea because the combination would inevitably compromise the function of either separately.

Of course, one cannot rely entirely on solar heat to provide all the heat needed for comfort, so provision needs to be made for other forms of heating. Appliances such as wood or gas stoves will need to be vented somehow. If this venting is best done through an earthbag wall it needs to be done safely. I have used special *zero clearance* stove pipe (Metalbestos is one brand) to safely penetrate the wall, since this pipe is manufactured in such a way to safely rest against combustible materials. Most fill material and plaster is not adversely affected by heat. Always follow the manufacturer's recommendations for venting heating appliances.

As for central heating furnaces or HVAC units, these should generally be accommodated as convention dictates, with most of the ducting under the floor. There is no easy way to arrange for large ducts in earthbag walls.



**Fig. 11.2:**  
*This spiral stairway to a small loft in the bedroom was constructed of earthbags filled with soil to provide a considerable column of thermal mass for the passive solar design.*

CREDIT: KELLY HART



**Fig. 11.3:**  
*A zero clearance stovepipe was embedded directly into the earthbag roof of this small dome.*

CREDIT: KELLY HART

Heating with electricity is one of the least efficient ways to heat a building, but it is certainly possible to locate electric heating units wherever needed and run the supply wires within earthbag walls, as described in the above section on electric services.

One of the most comfortable and ecological ways to heat a building is with radiant heat emanating from the floor. Such hydronic systems

employ serpentine patterns of pipes or tubing that carry fluid that is warmed by a boiler and/or solar thermal panels mounted on the roof. Such solar heating might be effective in sites where passive solar heating is problematic. The hydronic tubing is most effective when embedded in concrete or adobe that serves as thermal mass to evenly distribute and hold the heat.

## Ventilation

All buildings need to provide for good ventilation, and the easiest way to do this is with operable windows. Windows alone are not always sufficient, however, so other means of ventilating the space may be necessary.

In one earthbag house I built, most of the windows were fixed glass and not operable, so I created both inlet and outlet vents directly through the earthbag walls. I placed large-diameter (about 8 inch [20 cm]) sections of pipe in a few strategic locations around the house as I built the walls so they were solidly embedded. Some of these were low for inlet air and some of them were high for exhaust air.

These air vents were either slightly inclined (so that any precipitation that might enter would immediately drain outside) or they were provided with bonnets. They were also screened on the outside to keep insects or varmints from entering.

I used inflatable tether balls as insulating closures when I didn't need the ventilation.

Other more conventional ventilation, including vents powered with fans can be employed where necessary, often through the roof or ducted through walls.

Some buildings that are designed to be especially airtight might require some sort of system that will automatically provide fresh air. The most efficient ones will have heat recovery ducting that preheats the incoming air with the outgoing air.

Appliances that need to be vented, such as space heaters, water heaters, range hoods, or bathroom vents, will need to be individually evaluated for the best way to accommodate their needs as defined by the manufacturer of the appliance. Some of these might be direct vented, where both the fresh combustion air and the exhaust air is vented through a dual pipe arrangement.



**Fig. 11.4:** Exhaust ventilation in this large dome was provided by two vents fitted with tetherball closures and long handles to remove or insert them. The central stove pipe was fitted with a zero clearance pipe, similar to that in Figure 11.3.

CREDIT: KELLY HART

## Cabinetry

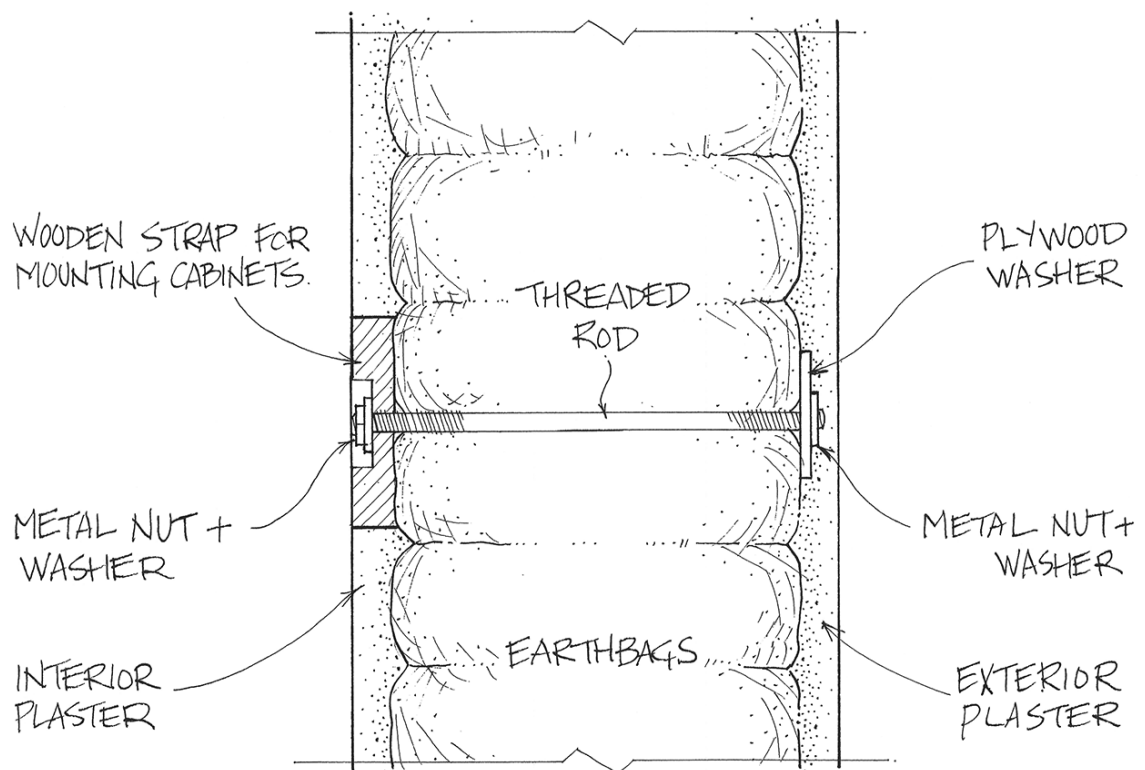
You cannot put screws into earthbags and expect them to hold much weight; even highly compacted or stabilized soil cannot reliably hold screws for heavy objects. Some other provision needs to be made to securely hold cabinetry in place on an earthbag wall. The best way to do this is to anticipate where you want to place cabinets on a wall and make provision for this as the wall is built, but there are also ways to do this later.

One good way to create a strong anchor for cabinets is to place long bolts or threaded rods directly through the wall with a very large washer made with plywood and backed up by a smaller metal washer. This can either be done as the wall is built, or it can be done later by pounding the bolts through the earthbags. These bolts or rods are then aligned with holes that have been bored through hefty wooden straps (like lengths of 2×4s [5×10 cm]) that will span the entire length of the intended cabinetry. If these holes are countersunk with a recess the size of the metal washer, and nuts are tightened to draw the whole assembly very snugly against the

wall, this will provide a surface that will support a great deal of weight. Any protruding portion of the bolt or rod can be sawed off. Cabinets can then simply be screwed into the wooden ledger. If this is done before the wall is plastered, the wood will be nearly flush with that plaster and the cabinets will fit snugly against the wall.

If an earthbag wall is already plastered and you want to attach some heavy cabinetry, it might be possible to drive long bolts or threaded rods through the finished wall. In this case, it is a good idea to drill a small pilot hole through the wall where you want the fastener to be, and then chisel away enough of the plaster on the outside to be able to embed the bolt end with its washers in some new plaster to match what exists. On the inside, it might be possible to drill matching holes through the cabinet itself, and bolt it securely with nuts and washers.

For relatively light fixtures or artwork, very long deck screws (at least 3 inches [76 mm]) might be adequate to support their weight. Depending on the nature of the interior plaster, you might need to drill a small pilot hole with a masonry bit before driving the screw.



**Fig. 11.5:**  
This diagram shows one way to attach a wooden strap for mounting heavy cabinets to an earthbag wall.



## Chapter 12

# Strategies for Seismic Reinforcement

**S**AFETY FOR A WIDE VARIETY of potential weather or earthquake events is of paramount importance for all buildings. It is the basis for much regulation and many building codes and is ideally backed up by solid experimental testing by qualified laboratories. Unfortunately, earthbag technology is new enough that very little relevant testing has been done. Also, there is no established industry with a vested interest in financing such testing as yet, so advances in scientific knowledge are slow in coming.

Our primary understanding of how well earthbag buildings hold up to seismic forces is mostly from empirical and anecdotal evidence. There have been a few actual scientific tests done over the last few decades, and these do suggest considerable robustness for common earthbag practice. For instance, in 1995, dynamic and static load tests were done on a small earthbag dome at the California Institute of Earth Architecture, and the results far surpassed the requirements of the International Conference of Building Officials (ICBO) at that time.

In 2008, testing done at Canada's Queen's University "determined that the compressive strength of unplastered earthbag housing specimens meet or exceeds the vertical compressive strength of conventional stud-frame housing technology using a variety of fill materials, with the greatest strength being observed for soil-filled bags." A study in 2010 at Bath University stated that "from testing it was concluded that earthbags are unlikely to fail due to compression within a structure."

In 2011, the periodical *Advanced Materials Research*, reporting on "Cyclic Simple Shear Tests on Base Isolation Using Soilbags," stated

that "soilbags have a relatively high damping ratio and variable horizontal stiffness so that they can be used as base isolation materials." I think that this is one reason why earthbag buildings stand up to earthquakes so well.

I believe that the very best real-world test of how well earthbag buildings resist fragmentation or failure from seismic events occurred in Nepal during the massive earthquakes that they suffered in the spring of 2015. Of the approximately 50 earthbag buildings that were known to exist in Nepal at that time, none of them fell or had any noticeable damage other than what would be considered cosmetic (cracked plaster). Some of these were domes built in 2006 as part of the Pegasus Children's Project, for an orphanage near Kathmandu. There were also a number of vertical-walled schools, mostly built in remote villages by volunteers from various NGOs (non-governmental organizations). What is particularly impressive is that there were instances where virtually all other buildings in these villages toppled during the earthquakes, except for the earthbag structures!

The obvious robustness of earthbag technology did not escape the notice of the general population or the Nepali government. Now, many people want to rebuild their homes with earthbags, and the Nepali government has approved specific designs that allow earthbag construction for both public and private buildings.

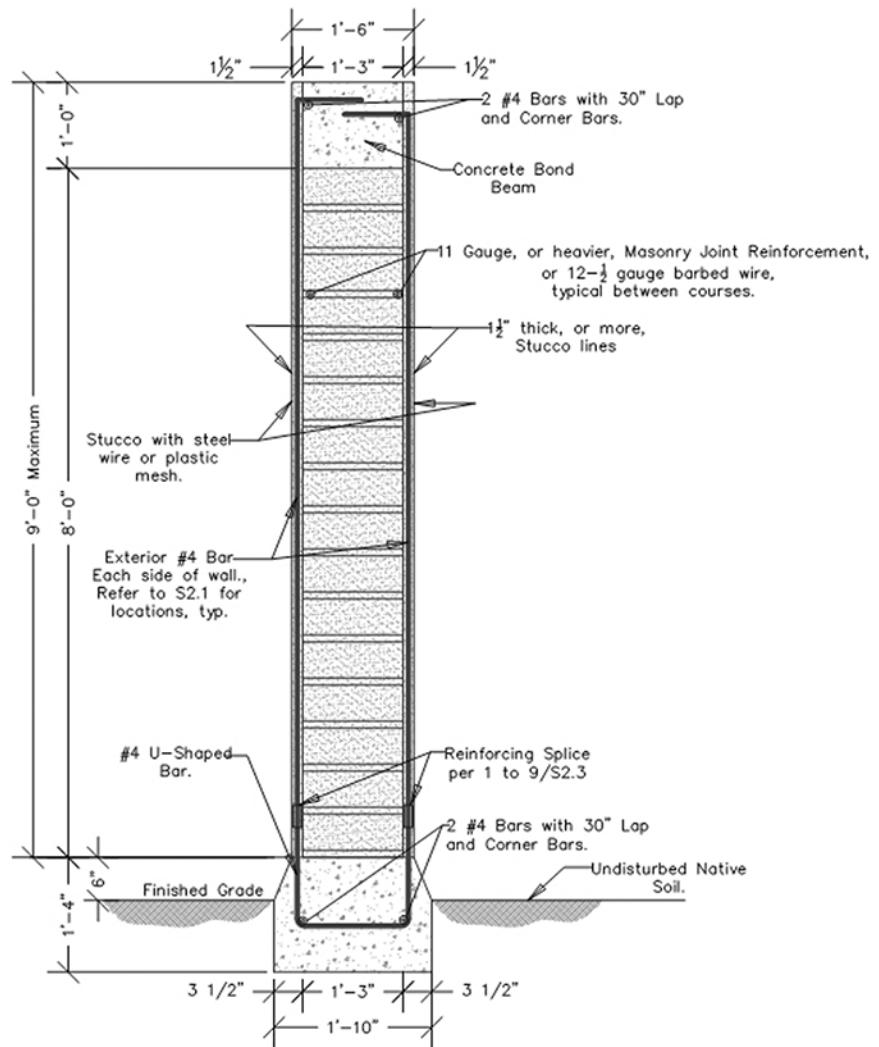
In general, the buildings that survived Nepal's earthquakes were built according to standard practices that are advocated in this book, so that is encouraging. The schools were built with extra corner buttresses, and that might have



contributed to their strength. Tests have shown that such corner buttressing does help reinforce structures built with other earthen-building techniques when they are subjected to seismic forces. To some extent, one can extrapolate from knowledge gained over the years about such traditional earthen building as adobe, cob, or rammed earth, and assume that some of the reinforcements used with those techniques would also benefit earthbag buildings.

On the other hand, earthbag building is unique in many ways, and it has some inherent

advantages that the more traditional earthen techniques don't share. In particular, the use of barbed wire between every course of earthbags lends a degree of resilience that is unmatched. The barbed wire acts to make the wall a cohesive matrix, and the tensile strength obtained from all of this wire is considerable. Also, the fabric used for containing the earthbag fill material is both pliable and strong, lending its own tensile strength and resistance to fragmentation. The generally looser nature of earthbag fill material relative to all other earthen techniques might



① TYPICAL EARTH BAG WALL SECTION  
Scale: NTS

Fig. 12.1: Nabil Taha of Precision Engineering provided this diagram of how one might reinforce an earthbag wall to help resist forces from seismic events.

contribute to a certain degree of pliability and resilience; it is like a tree being able to bend in the wind, rather than snap apart.

Even with the evidence presented so far, there are those who suggest that reinforcing techniques for earthbag buildings could be improved beyond what is commonly done. Nabil Taha, a licensed structural engineer,

recommends completely wrapping vertical earthbag walls on both sides with loops of steel rebar embedded in the concrete foundation and the concrete upper bond beam. These should occur near every corner and on either side of all openings. This would effectively diminish the possibility of a bag wall falling apart from severe shaking.

Patti Stouter of Build Simple, Inc. has done extensive research on the question of appropriate reinforcement for earthbag structures. Based on her own experiments and extrapolating from published codes for other earthen-building techniques, she has come up with some specific recommendations to improve seismic resistance. In general, she suggests that:

These guidelines only apply to single-story buildings of 3,300 square feet (307 sq. m) maximum area. The longest side must be no more than 2.5 times the length of the shortest side. The roof must be lightweight (no clay tile, slate or earth roofs). Roof spans must be 18 feet (5.5 m) or less. Gable walls or chimneys above the bond beam level must be built of lightweight materials. Keep walls no higher than 8 feet (2.4 m).

Bracing walls or buttresses should be perpendicular to longer walls. Interior earthbag walls function as braces if their doorways are at least 4 feet (1.2 m) away from the corner. Don't build buttresses sticking out more than 4 feet (1.2 m) from any walls, but 3 foot (91 cm) buttresses are better. Walls are strongest in earthquakes when attached to other walls at both ends.

A maximum opening width of 5 feet (1.5 m), or even better if kept to 4 feet (1.2 m); keep 4 feet (1.2 m) between openings and corners.

Barbed wire turning corners is one of the weakest points of earthbag walls. Extend both strands of barbed wire 2 feet (61 cm) past the end of wall or buttress. Pull straight, and weave barbed wire back into wall end above next course. Use strong wires at each place where the wires cross. Use nails through these wire ties to attach the wire more firmly to the earthbags at these stress points.

Drive vertical rebar reinforcement into the soil filled earthbags a minimum of every 4 feet (1.2 m) along the wall. Lintels over doors and windows of wood or metal extend 16 inches (41 cm) into the walls on both sides. Integrate bond beam and lintels over doors and windows so they are tied together. Reinforce the bond beam with two ½" (13 mm) horizontal rebar continuous, overlapped at least 2 feet (61 cm) and tied with strong wire.

Use cement stucco reinforced with poly or fiber-glass fiber for the exterior to strengthen the plaster.

Patti has many other specific suggestions for reinforcing earthbag structures that can be reviewed at her website, which is listed in the Resources section at the end of this book.





## Chapter 13

# General Budgeting Information

**E**ARTHBAG BUILDING can be extremely economical compared to many other building techniques. The essential tools and materials are usually easily accessible and not very expensive. The fill material might be available on the site where the building is done, so it could be free for the digging. Most of the labor of building walls is not particularly skilled, so this increases the opportunity to use volunteer or general laborers. In some instances, domes do not require separate roofs, and rubble trench foundations require no cement. All of this reduces the potential cost of earthbag building.

On the other hand, all buildings, especially residential ones, have many components that can add up to a lot of money. Flooring, roofs, insulation, doors, windows, plumbing and electrical supplies, interior and exterior finishes, cabinetry, and mechanical appliances are all necessary expenditures for a finished house. Accurate budgeting must include all of these items.

There are many variables that can make a big difference in the cost of a project. Do you need to buy plans and apply for a permit? Is excavation needed to prepare the site? Does fill material need to be delivered? Will you be hiring labor or doing most of the work yourself? Do you plan to buy most of the necessary materials new or try to find used or salvaged materials? What about extra systems such as for solar electricity and water acquisition and storage? What country or region will you be building in?

Around 2000, in the western United States, I built a multi-domed earthbag house for about \$16 per square foot (.09 sq. m). Some of the components were salvaged, and I did most of

the work myself over a period of about three years. I used crushed volcanic scoria as the fill material, which had to be delivered to the site. The bags I used were new misprints that cost less than 20 cents apiece.

The time involved in assembling earthbag walls can be surprisingly little. Here is an example: I facilitated a workshop on various aspects of sustainability for an international conference held in Crestone, Colorado. My particular task was to coordinate about a dozen people at a time in building a sort of earthbag gazebo and amphitheater (see Figure 4.6). We were filling the bags with the local sandy soil dug right on the site. We only worked about three hours each day for a total of five days, which works out to about 180 person-hours to complete the building of the walls. The total surface area was about 700 square feet (65 sq. m), which meant that each person working at this rate was creating about 4 square feet (.4 sq. m) per hour. Of course, these were complete novices, and they were also clearing the land, digging and transporting the soil, and doing a lot of standing around and talking. This rate could easily be doubled or tripled under different circumstances.

When I was building my house, I used to lay two or three courses around a perimeter of about 75 feet (23 m) in one day. This works out to about 14 square feet (1.3 sq. m) per hour. I was filling the bags from a nearby pile of scoria. You might calculate that a team of three people who were well coordinated should be able to lay perhaps 300 square feet (28 sq. m) of wall in one 8-hour day.

If you happen to build in a fairly arid region and like the idea of domes, you might be able to

get by with the least possible cash outlay. You might be blessed with perfect adobe soil that compacts nicely and have a temperate climate that suits an earthen house of this sort. If you use the *Hyperadobe* method that employs long tubes of open mesh material, you might be able to get by without using barbed wire between the courses — or even additional mesh on the walls before it gets plastered. A simple rubble trench foundation might be made from local stones and the floor could also be made from the adobe soil. Then, if you find salvaged windows and doors and do all of the work yourself to assemble this little house, the total outlay for materials could be astonishingly small, perhaps a few hundred or maybe a thousand dollars!

For most people, the above scenario is neither realistic nor desirable; climate and

preferences will dictate more expensive choices. If you want to estimate the cost of having an earthbag house built for you by a contractor or hired help, the cost of building varies somewhat from region to region, but most plans can be built for no more than the average building cost per square foot for new construction in your area. (You can ask local realtors, contractors, or bankers what that average cost is for your area.) Some designs that call for expensive solar equipment might cost more, whereas simple designs might cost less. Other factors, such as how much you are willing to do yourself and how good you are at finding deals on building supplies, can make a difference. So in other words, it all depends.



## Chapter 14

# Maintenance and Renovation

**T**HE MAINTENANCE required for most earthbag buildings is primarily related to keeping the plaster in good shape. One of the worst things that can happen to an earthbag wall is for the plaster to be compromised to the point where the bag material becomes exposed and the fill material is vulnerable to being dispersed. Maintenance of the roof, floor, or interior systems would be similar to any other house, and beyond the scope of this book.

The durability of plaster varies according to type and exposure. Cement-based stucco is probably the most durable of all; it can last for decades without much attention. If it happens to cover a dome, then it may not be sufficiently waterproof to rely on to keep all moisture from entering the building, and in this case the stucco should probably be painted as a final coat. Paint, especially on a dome, will need careful observation and maintenance over time, likely requiring regular renewal.

Lime plaster is nearly as durable as stucco, but it does need occasional attention. Sometimes a simple whitewashing with lime mixed with water will renew the brightness of the plaster and fill any hairline cracks that may have developed.

Earthen plaster that has been stabilized with either cement or lime is more durable than it would be without the stabilization. It still needs to be periodically examined to make sure that it isn't wearing away from exposure to the elements, cracking, or *spalling* (falling off in big chunks). The same is true for unstabilized earthen plasters. In either case, it may be necessary to apply a completely new coat of plaster, or at least to repair any deficiencies.

Beyond the plaster, it is important to examine the foundation for any sign of erosion or moisture affecting its integrity. The same is true for roofs and detailing around doors and windows. Moisture entering the earthbag walls from these places can become sources for various problems that are best avoided.

Renovating an earthbag house can be a bit tricky, especially if the renovation entails cutting through an existing earthbag wall. As mentioned earlier, it is wise to anticipate any remodeling that is likely at the time of constructing the walls. For instance, if you know that a door or window will likely be placed in a particular spot, you can actually frame that opening as if it were a reality, and then simply fill in that space with temporary bags and plaster over them. That way when the time comes to cut through the wall and establish the opening, all you have to do is remove the plaster and knock out the extra bags, and there you have it.

Retrofitting doors or windows in an existing wall that has not been prepared as explained above would require some very careful and tedious work. One would need to open up the wall with digging and cutting implements. Barbed wire would have to be cut, as would any vertical rebar stakes. Creating nice horizontal and vertical planes for window or door frames to be placed against would take some very careful work. These frames would ideally be as deep as the wall is to seal the exposed bags. In some cases, it might be necessary to remove partial bags where the contents are spilling out, and replace them with new, smaller bags to fit the space.

There would be the added danger of the upper portion of the wall above the new opening



**Fig. 14.1:**  
*This domed bedroom was completed to this point when construction ceased for the winter. The doorway into the rest of the eventual house is on the right; it was temporarily bagged up and plastered to keep all the walls in good shape until construction resumed.*

CREDIT: KELLY HART

falling out of place. It may require careful temporary bracing to keep this area in place until a new frame and lintel could be fitted. Or it might be necessary to remove those bags entirely until it is possible to replace them, leaving just the upper bond beam to hold the wall and roof structure in place.

The frame for the new window or door needs to be pinned into the earthbag wall that surrounds it. This could be done with rebar pieces that are about a foot long driven through pre-drilled holes in the frame. There is really no way to positively pull the frame and wall tightly together, so the next best thing is to rely on friction and stout materials to do the job. I suppose some measure of connection could be created with a bridge of plaster mesh attached to both the frame and the wall that gets embedded in plaster.

Adding new walls to existing earthbag walls requires some means for making a firm connection between the two. If the additional wall happens to be a wood-framed partition wall, it can be attached to an earthbag wall in the same way that cabinets are attached, by pounding threaded rods completely through both and binding them together with large washers and nuts (see Figure 11.5).

Probably the best way to anchor two earthbag walls together is with rebar pins driven at angles through one wall and into the other. These could be a couple of feet (61 cm) long, perhaps, and driven through every other course. Plaster mesh should bridge the connection between the two walls, so that it is less likely for cracks to develop there.



## Chapter 15

# Building Codes

AS MENTIONED in the Chapter 12 discussion about seismic reinforcement, there are no established building codes for earthbag building at this time. This is partially because the art of building with earthbags is relatively new, so there hasn't been time for such codes to have evolved or been adopted. The adoption of codes is also impeded by the general lack of adequate scientific testing, and this is the case because there is no established industry that stands to profit from such testing and therefore willing to fund it. Most of the testing that has occurred has been generated by institutions of higher learning, motivated primarily by curiosity and in the interest of pure science.

Those engineers who might try to define safe practices for earthbag building are likely to base their suggestions on their understanding of other more traditional building practices, such as with other earthen materials. Or they might come up with solutions that might be regarded as overly stringent, just because they want to be absolutely sure that nothing that they design could ever fail and reflect badly on their reputation. Also, this attitude would serve to make building inspectors more likely to approve their plans, which is supposedly to everybody's advantage.

There are pros and cons to having established building codes that are acceptable to various building authorities. Obviously, adopted codes can smooth the way to actually having more earthbag projects built in areas where codes are enforced. If no code covers earthbag building in your area, it may be necessary to permit the project as *alternative*, which means you'll have to find a state-licensed engineer to vouch for the safety of the project; this is an extra expense at best and impossible to achieve at worst.

Building technologies with established codes tend to be considered "mainstream" and are therefore more acceptable to both the authorities and the general public. A downside of this acceptance is the need for rigid adherence to what are often extremely prescriptive codes that leave little room for innovation or changes that might reflect an owner's building philosophy.

A better approach to establishing building codes is to base them on *performance* rather than *prescription*. This would mean that as long as it can be shown that a given plan meets the intent of a set of codes for safety or performance, then that plan should be acceptable to the authorities. There are some jurisdictions around the world that have adopted such performance codes, but this does mean that the authorities who review the plans must be able to determine if the plan actually does meet the performance criteria. Often, these authorities don't want to take on that responsibility.

Before any codes are adopted, somebody or some committee must actually draft the wording of the code and submit it to the body that publishes popular building codes, such as the International Code Council, so they can adopt and fold the new codes into their code publications. As mentioned, there is currently no industry (other than bag manufacturers) that would stand to gain by having earthbag codes adopted, so the text of such codes is unlikely to be generated via representatives of industry. It is more likely that codes will be introduced by a non-profit organization, such as the Earth Builders Guild, that realizes the huge benefit to society that earthbag technology has to offer.







# Other Uses for Earthbags

## Retaining Walls

**E**ARTH BAGS MAKE EXCELLENT retaining walls because they are not bothered by moisture and they are well suited to keeping soil from sliding behind them. In fact, geotextiles are a common tool used by civil and environmental engineers in large earthworks projects, including for roads, airfields, railroads, canal embankments, and erosion control.

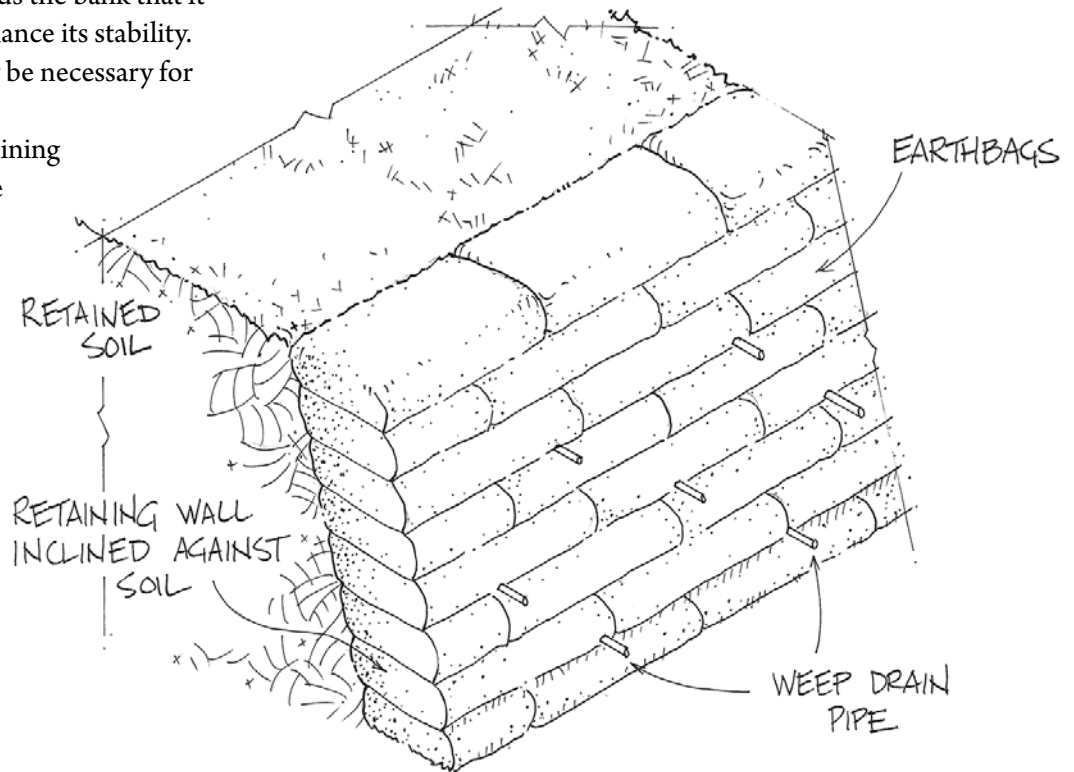
Earthbag retaining walls can basically be built the same way that walls for other structures are assembled, by using barbed wire between the courses and staggering the bags in a running bond pattern or using long tubing. It is often advantageous to design a retaining wall in a curved or serpentine pattern to help with stability. Also, inclining a wall inward, towards the bank that it is supporting, will greatly enhance its stability. In some cases, buttresses may be necessary for additional support.

As with other types of retaining walls, it is a good idea to place small drain pipes (called *weep holes*) in numerous spots to allow water that might otherwise be impounded by the retaining wall to readily drain to the other side. This helps relieve the wall from the considerable pressure that water can exert against a retaining wall. These pipes might be about 1½ inch (4 cm) diameter and spaced perhaps every 4 feet (1.2 m) near the base of the wall, as well as higher up in the wall

if it is over 3 feet (91 cm) high. Other measures, such as laying perforated pipe surrounded by gravel behind the wall (like a French drain) or grading the soil above the wall to direct surface water away from the wall, can be beneficial.

Protecting the earthbags with a durable plaster or stucco with a plaster mesh embedded in it as the most durable. The stucco can be colored as desired for aesthetics. It should wrap entirely over the wall and down the back, well below where the soil will eventually backfill. As added protection, the top of the wall could be capped with stone, tile, or pavers. Less durable plasters are more likely to need periodic maintenance.

**Fig. 16.1:** This diagram shows how an earthbag retaining wall might be inclined against the bank of soil and have periodic weep holes for draining accumulated water behind the wall.



## Cisterns

Earthbags have successfully been used to make both aboveground and belowground cisterns of many sizes. Very large cisterns are best kept below ground level, or at least bermed substantially with earth on the outside, as this will help counteract the huge pressure of water. Buried cisterns have the advantage of being much more protected from the danger of freezing where that may be a concern. Cisterns that are made from coils of long tubing are stronger than those made with individual bags, but either method can be used. It is very important to use the two strands of barbed wire between all of the courses of aboveground cisterns because they help provide tension rings to resist the outward pressure of the water; with belowground cisterns, the wire is not as crucial because the bank of soil on the outside serves the same function.

Earthbags alone cannot be relied upon to retain water without leaking, so some form of lining is needed inside of the structure. The most secure lining would be a pool liner, EPDM membrane, or very heavy-duty polyethylene sheeting. This liner could be placed over a layer of sand at the base that would help protect it from being punctured. If the liner is brought all the way over the top of the bag enclosure and tucked under the top row of bags, then it would be firmly in place. Another option would be to place it over the next to last course of bags and then cap it with the final course.

It would be possible to plaster the inside of the cistern with an impervious plaster. One

option is cement stucco that has been amended with an additive that will chemically form large crystals that effectively block moisture from passing through it. Another option is magnesium oxide cement that is naturally waterproof. Either of these should have a plaster mesh embedded in it. There are numerous products that are designed to waterproof concrete as a secondary paint or coating, but these may not be as effective as the above options, nor may they be safe for potable water, if that is a concern. In any case, all exposed bags need to be protected with a plaster, just as they are with any earthbag building project.

It is usually desirable to cover a cistern to keep the water clean and keep out the light that would allow algae to grow. Covers can be as simple as a tarp pulled tightly over the structure, or they can be more elaborate, like an actual framed roof. The metal top for a grain bin might serve as the cover. Or a prefabricated Ferro cement roof with a bit of a dome shape could work. There are many options. In any case, some means for occasional entry into the cistern to make repairs or clean the inside should be provided.

A completely buried cistern would need a very hefty roof to support the weight of soil placed above it. The most likely material that could meet this requirement is reinforced concrete, as has been well proven with buried concrete septic tanks. Fabricating such a cover would be a bit tricky, but not impossible. As with the above options, some kind of entry hatch should be provided.

## Dams

I once built a small dam with earthbags, and it worked great. We had a seasonal stream bed near our house that ran after heavy rainfall or during the winter snow melt. We decided that if we made a dam across the little valley where the water ran, we could create a small pond that would give us some emergency water, as well as a lovely place to have some aquatic plants and fish.

The top of the dam was about 20 feet (6 m) long and about 5 feet (1.5 m) deep at the lowest point. I made it with a convex curve that faced into the direction of the water flow, as is done with larger dam projects. I tapered the dam from the base to the top, with it being about 4 feet (1.2 m) wide at the base and tapering to the width of one bag at the top.

The native soil there is nearly pure sand that is easy to dig and fill the bags with. I started laying bags right on the native soil in the shape that I wanted, outlining both sides of the dam with bags. In between these rows of bags I simply filled the space with loose soil, so I could corbel the next course to make the tapered shape I wanted, and the whole dam would eventually be solid (but contained) soil. Barbed wire between the courses would help keep the dam intact, but I am not sure it was entirely necessary, given the forces the dam would encounter.

Once I had stacked the bags all the way to the top single course, I stretched heavy-duty black plastic over both sides of the dam and up the valley as far as it needed to go to contain all of the water when the dam was full. Then, to



**Fig. 16.2:**  
*This is what the earthbag dam looked like after the first three courses of bags.*

CREDIT: KELLY HART

protect the plastic from UV degradation and inadvertent puncture, I put a layer of gravel over the plastic on the gentle slopes. On both sides of the dam itself I stacked larger stones all the way to the top. Along the ridge I capped the dam with more stones set in a thin mortar to protect that vulnerable area.

Above the water level of the dam, I created a smaller dug-out pool area for a silt trap in an attempt to keep silt from entering the dam proper and filling it up over time. The small silt trap could be cleaned out as necessary. I also made a diversion pipe that skirted the pond so that when the dam was nearly full of water, the extra water would be diverted via this pipe to an area

below the dam. This served the same function as a spillway does for larger dams and kept water from spilling over the dam and possibly eroding things.

All of this worked beautifully for several years, and we eventually had a few dozen goldfish living and breeding in the pond. Then one summer day we had a spectacular rain storm that messed up local roads and dumped so much water and mud down our little valley at once that it overwhelmed all of my protective systems. The dam was completely filled with mud and debris and there was no more pond or fish. Ah, the power of Mother Nature! But the earthbag dam held tight, even with that onslaught.



**Fig. 16.3:** *This shows how the earthbag dam was lined with heavy plastic completely over the dam and down the back and then protected with stones on the backside.* CREDIT: KELLY HART



**Fig. 16.4:** *Once the dam was finished, it provided a lovely habitat for goldfish and even some frogs that found their way there. CREDIT: KELLY HART*

## Root Cellars and Pantries

Earthbags work very well for constructing underground root cellars or pantries. If all sunlight is excluded from the room, it may not even be necessary to plaster the bags. Root cellars are usually allowed to become quite humid, as that is often desirable for the type of produce stored. In this case, it may not be necessary to place a moisture barrier between the bag walls and the berm of soil.

I once built an underground pantry that was also a room to keep a large plastic cistern for a rainwater catchment system. This pantry wasn't entirely buried; in fact, it had an entrance at the ground level. It actually had two levels inside, with steps going down to the lower floor. I

inclined the walls outward to help stabilize them against the surrounding soil.

In this case, I wanted to keep the space dry, as it was intended primarily as a multipurpose pantry. So I did line the walls on the outside with black plastic; in fact, I started with the plastic fixed right at the base of the walls and made it long enough that when I wasn't working on the wall I could simply fold the extra plastic up and over the wall to keep all sunlight off of it.

When I built this pantry I had the initial hole dug out by an excavator down to within a couple of feet (61 cm) of the intended depth and a bit larger than where the walls would go. Then I dug a trench around the base exactly where I wanted the walls to start, about two feet (61 cm) below

**Fig. 16.5:**  
*This underground pantry has outwardly inclined walls to resist the force of the berm.*

CREDIT: KELLY HART



the bottom of the hole. The soil from the trench was just tossed into the center of the room. Then I was ready to start laying earthbags for the walls, filling them from the pile of soil at hand, and placing them at the bottom of the trench.

After the first course of bags was laid, I put the black plastic around the outside of the bags and fixed it in place by backfilling with soil up to the top of the bags. Each successive course was offset just enough to give me the outward incline that I wanted for the wall, and backfilled just enough to keep the plastic snug up against the bags.

At about the point where the bag wall was level with the original base of the hole, I started to dig out the center of the room to fill the rest of the bags for the wall. In this way I had a ready supply of soil available for fill and ended up getting down to bottom floor level by the time the walls were getting pretty high. At that point, I could fill the rest of the bags from the soil that had originally been discarded off to the side by the excavator.

I felt confident enough that the walls would stay put (because of the outward incline) that I dispensed with laying barbed wire between the courses. But the barbed wire should be used in most other situations, especially if the walls are more vertical, or if the risk of earthquakes is a factor.

Because the soil at this site was quite sandy and drained very well, I wasn't concerned about moisture wicking up through the floor, so I left the natural soil bare at floor level. If this were not the case, I might have sealed the floor with more plastic and provided a base of gravel or pavers for the floor. It might have also been necessary to prepare some sort of French drain outside the walls to keep too much moisture from building up there. If I wanted more of a genuine root cellar, I could have dispensed with the plastic liner and allowed much more moisture to enter the room.

## **Sculpture and Art**

I know that earthbags have been used as a medium for large outdoor art or sculptural pieces. If carefully built and finished, such artworks can be very robust and last for decades or centuries.

Such sculptural creations could serve as play equipment for children. I know of one earthbag dome-like structure that served as a sound barrier at a school that was located near a busy airport; children could run into the thick-walled dome to escape the noise. The possibilities are limited only by your imagination.





## Resources

### Author's websites:

[earthbagbuilding.com](http://earthbagbuilding.com)

The author's comprehensive site devoted to everything earthbag.

[greenhomebuilding.com](http://greenhomebuilding.com)

The author's site all about sustainable architecture.

[dreamgreenhomes.com](http://dreamgreenhomes.com)

The author's site with some plans that could be built with earthbags. See the links for materials, earth, and earthbags.

[naturalbuildingblog.com](http://naturalbuildingblog.com)

A blog featuring lots of earthbag information, hosted by Dr. Owen Geiger with the author's occasional input.

[earthbagstructures.com](http://earthbagstructures.com)

Specializes in earthbag solutions for disaster-prone regions.

### Other websites:

[buildsimple.org](http://buildsimple.org)

Patti Stouter's website has many suggestions for seismic reinforcement of earthbag structures.

[structure1.com/sustainable-projects/earthbag](http://structure1.com/sustainable-projects/earthbag)

Nabil Taha, structural engineer and founder of Precision Engineering, offers engineering services for earthbag structures.

[calearth.org](http://calearth.org)

Home of the California Institute of Earth Architecture, Nader Khalili's earthbag works.

[earthhandsandhouses.org](http://earthhandsandhouses.org)

Paulina Wojciechowska's organization, centered in Poland, focuses on many earthbag projects.

[unitedearthbuilders.com](http://unitedearthbuilders.com)

This site features a portfolio of earthbag projects.

### Books:

*Earthbag Architecture: Building Your Dream with Bags* by Kelly Hart, 2015, Hartworks LLC. (Available through the author's websites.)

*Earthbag Building Guide* by Owen Geiger, 2011, digital PDF. (Available through the author's websites.)

*Emergency Sandbag Shelter* by Nader Khalili, 2008, Cal Earth Press.

*Earthbag Building: The Tools, Tricks and Techniques* by Kaki Hunter and Donald Kiffmeyer, 2004, New Society Publishers.

*Building with Earth: A Guide to Flexible-Form Earthbag Construction* by Paulina Wojciechowska, 2001, Chelsea Green Publishing.

### DVDs:

*Basic Earthbag Building: A Step-by-Step Guide* by Owen Geiger. (Available through the author's websites.)

*Building with Bags: How We Made Our Experimental Earthbag/Papercrete House*, produced by Kelly Hart, 1½ hr. (Available through the author's websites.)

*A Sampler of Alternative Homes: Approaching Sustainable Architecture*, produced by Kelly Hart, 2 hr. (Available through the author's websites.)

*Emergency Shelter* by Cal-Earth Institute.

**Workshops:**

[AuwaEarth.com](http://AuwaEarth.com)

Offers earthbag and earth construction workshops in Australia and Brazil.

[calearth.org](http://calearth.org)

Nader Khalili's earthbag works.

[earthbaghouse.com](http://earthbaghouse.com)

Has general information, work/trade opportunities, workshops, etc.

[earthenhand.com](http://earthenhand.com)

Conducts workshops mostly in the northwestern U.S., but also around the world.

[earthhandsandhouses.org](http://earthhandsandhouses.org)

In Europe.

[Espiritu y Lluvia \(superadobedelsur.blogspot.com\)](http://Espiritu y Lluvia (superadobedelsur.blogspot.com))

located in Argentina conducts earthbag workshops throughout South America.

[starseedcreative.com](http://starseedcreative.com)

Offers earthbag workshops mostly in Australia and Bali.

[naturalhomes.org](http://naturalhomes.org)

Lists worldwide workshops.

[phanganearthworks.com](http://phanganearthworks.com)

In Thailand.

[tsatsa-house.com](http://tsatsa-house.com)

In India and Japan.

[ulewatitlan.com](http://ulewatitlan.com)

Provides workshops and accommodations at Lake Atitlan, Guatemala.

[unitedearthbuilders.com](http://unitedearthbuilders.com)

Provides educational and charitable services regarding earthbag homes.

**Bag supplies online:**

[ace-bag.com](http://ace-bag.com) new bags

[agriculturebag.com](http://agriculturebag.com) new bags

[allinsafety.com](http://allinsafety.com) new bags

[bagsupplies.ca](http://bagsupplies.ca) new and misprinted bags, tubing

[bagsupplies.com](http://bagsupplies.com) mesh bags and tubing

[centralbagcompany.com](http://centralbagcompany.com) new bags and tubing

[chinawovenbag.com](http://chinawovenbag.com) new bags and tubing

[commercialbagsupply.com](http://commercialbagsupply.com) new bags

[eclatindustries.com](http://eclatindustries.com) new bags

[esandbags.com](http://esandbags.com) new bags

[farberbag.com](http://farberbag.com) new bags

[innpack.com](http://innpack.com) new bags

[jumbosack.com](http://jumbosack.com) new bags

[maxkatzbag.com](http://maxkatzbag.com) new bags

[nmdirtbags.com](http://nmdirtbags.com) new bags

[nyp-corp.com](http://nyp-corp.com) new bags and tubing

[onlinefabricstore.net](http://onlinefabricstore.net) new bags

[pac-packaging.com](http://pac-packaging.com) new and misprinted bags

[polytex.com](http://polytex.com) new bags

[rich-source.com.cn](http://rich-source.com.cn) mesh bags and tubing

[sandbagexpress.com](http://sandbagexpress.com) new bags

[suncoastpkg.com](http://suncoastpkg.com) new and misprinted bags

[superpoly.ca](http://superpoly.ca) new and misprinted bags

[syfilco.on.ca](http://syfilco.on.ca) mesh bags and tubing

[unitedbags.com](http://unitedbags.com) new bags

[wftonghui.com](http://wftonghui.com) new bags and tubing

[whitebag.com](http://whitebag.com) new and misprinted bags

# Index

Page numbers in *italics* indicate tables.

## A

adobe floors, 77  
*Advanced Materials Research*, 87  
air control, 8  
Anna University, xiii  
arches  
    forms, 27  
    windows and doors, 62–65  
artwork, 103  
asphalt, 20

## B

bag stands, 26  
bags  
    closing top, 41–42  
    environmental impacts, 15  
    filling, 25–26, 36–37  
    for first courses, 30  
    laying pattern, 40  
    material specifications, 13–15  
    for multi-stories, 68  
    open mesh, 2  
    sizes, 67  
    tamping, 43  
    testing fill material, 16  
    UV exposure, 14, 47  
barbed wire  
    material specifications, 22  
    placing, 38–39  
basements, 33–34, 68  
Bath University, 87  
below-grade construction, 33–34, 69  
bond beams, 55–59, 78–79

budgets, 91–92  
building codes, 6, 95  
building design. *See* design  
building science  
    air control, 8  
    thermal control, 7–8  
    vapor control, 8–9  
    water control, 9–11  
building shapes, design  
    limitations, 6  
burlap bags, 13  
buttresses, 53–54, 65

## C

cabinetry, 86  
California Institute of Earth Architecture, 87  
catenary arches, 6, 50  
cement stabilizer,  
    environmental impacts, 21  
Chiang Dao B&B, xv  
cisterns, 98  
Common Action for Sustainable Development, xiv  
concrete, in bond beams, 55–56  
conductive heat, 7  
convective heat, 7–8  
costs, 91–92  
curved walls, 54

## D

dams, 99–100  
design  
    below-grade, 69  
    bond beams, 55–59  
    building shapes, 6  
    buttresses, 53–54

domes, 49–51  
    multi-story, 68  
    roofs, 79  
    vaults, 52  
    vertical walls, 49  
    wall thickness, 67  
    window and door openings, 60–67

domes  
    bag placement guide, 45–47  
    design of, 6, 49–51  
    rain exposure, 10–11  
doors  
    openings, 60–67  
    retrofitting, 93–94

## E

earthbag construction  
    in developing countries, xiii–xvi  
    history of, 1–3  
    limitations of, 5–6  
    other uses, 97–103  
    versatility of, 5  
earthen plasters, 71–73  
earthquakes, xiii, 3, 87–89  
Edge of Seven, xiv  
electrical, 82  
environmental impacts  
    bags, 15  
    barbed wire, 22  
    gravel, 17  
    perlite, 18  
    rice hulls, 19  
    sand, 17  
    soil, 16  
    stabilizer, 21  
    steel rebar, 23

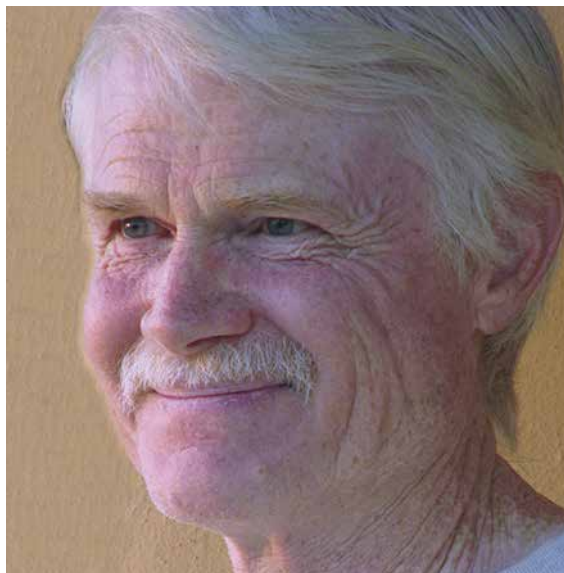
- vermiculite, 18
- volcanic stone, crushed, 18
- F**
- fill material
  - air control and, 8
  - environmental impacts, 16, 17, 18–19, 21
  - for first courses, 30
  - funnels for, 25–26
  - for insulation, 6, 17
  - preparing, 35
  - stabilizers, 20–21
  - testing, 16
  - types of, 15–17, 19–21
- filling tubes, 25–26
- First Steps Himalaya, xiv
- flagstone floors, 76
- floors
  - adobe, 77
  - masonry, 76
  - slab on grade, 75–76
  - suspended, 78
- foundations
  - basement walls, 33
  - insulation of, 32
  - role of, 29
  - rubble trench, 29–30
  - slab on grade, 31–32
  - water control, 32–33
  - water exposure, 11
- French drains, 30
- funnels, 25–26
- G**
- Geiger, Owen, 2–3
- Good Earth Global, xiii–xiv
- grade beams, 30–31
- gravel
  - environmental impacts, 17
  - as fill material, 16–17
  - for first courses, 30
- Guatemala, xv
- H**
- heating, 83–84
- housing, affordable, xiii–xvi
- Hunter, Kaki, 1
- Hyperadobe
  - bags, 13–14
  - barbed wire use, 39
  - development of, 2
  - plaster adherence, 74
- I**
- India, xiii–xiv
- Inoue, Akio, xv, 1
- insulation
  - fill materials for, 6, 17
  - of foundation, 32
  - under slab, 75–76
- K**
- Kaspar, Kathryn, xiv
- Kennedy, Joe, 1
- Khalili, Nader, 1, 2
- Kiffmeyer, Doni, 1
- Krpasundarananda, Dada, xiv–xv
- L**
- lime
  - environmental impacts, 21
  - plasters, 73
  - as stabilizer, 20–21
- lintels, 66–67
- Loving Arms Mission, xiv
- M**
- maintenance, 93
- Malawi, xv
- masonry floors, 76
- material specifications
  - bags, 13–15
  - barbed wire, 22
  - fill, 15–21
  - plaster, 24
  - rebar, 22–23
- mesh bags, 13–14
- mesh material, for plaster
  - adherence, 73–74
- metal sliders, 26–28, 42
- Minke, Gernot, 1
- Mlambe Project, xv
- moisture control, 8–11
- monolithic concrete floor slab, 31–32, 75–76
- multi-story design, 6, 68
- N**
- Nepal, xiii–xiv, 3, 87–88
- O**
- open mesh bags, 2
- P**
- Pacheco, Fernando, 2
- pantries, 102–103
- papercrete plaster, 73
- perimeter beams, 30–31
- perlite, 17, 18
- perms, 9
- Phangan Earthworks, xv
- Philippines, xv
- plaster
  - air control and, 8
  - mesh material, 73–74
  - options, 71–73
  - permeance, 9
  - thermal control and, 7
- plumbing, 81
- polyethylene mesh bags, 13–14, 15
- polypropylene bags, 13–15, 15
- Portland cement
  - in plaster, 73

- as stabilizer, 20  
Precision Structural Engineering, xv  
Project Somos, xv  
pumice. *See* volcanic stone, crushed
- Q**  
Queen's University, 87
- R**  
radiant heat, 7  
rain exposure, 9–11  
rainscreen, 11  
raschel mesh bags, 13–14  
rebar  
  in bond beams, 55–56  
  corrosion, 55  
  environmental impacts, 23  
  material specifications, 23–24  
  for openings, 65–66  
  placing, 44  
renovations, 6, 93–94  
retaining walls, 97  
rice hulls  
  environmental impacts, 19  
  as fill material, 17  
  vapor control, 9  
road base material, 16  
roofs, 10–11, 79  
root cellars, 102–103  
rubble trench foundations, 29–30  
R-values, 8
- S**  
Sacred Earth Trust, xiv  
sand  
  environmental impacts, 17  
  as fill material, 19–20
- scoria. *See* volcanic stone, crushed  
sculptures, 103  
seismic reinforcement, 87–89  
slab on grade, 31–32, 75–76  
soil  
  environmental impacts, 16  
  as fill material, 15–16  
  stabilizers, 20–21  
stabilizers  
  environmental impacts, 21  
  for soil, 20–21  
steel rebar. *See* rebar  
stem walls, 31, 32  
Stouter, Patti, 89  
straight walls, bond beams, 55  
stucco, 73  
Superadobe, 1, 2  
suspended floors, 78
- T**  
Taha, Nabil, 89  
Tamayo Foundation, xv  
tampers, 26  
Thailand, xv  
thermal control, 7–8  
tools, 25–28  
Tsai, Sunny, xv  
twine, 23, 38
- U**  
utilities  
  cabinetry, 86  
  electrical, 82  
  heating, 83–84  
  plumbing, 81  
  ventilation, 85  
UV exposure of bags, 14, 47
- V**  
Vallejo, Jose Andres, xv
- Vanuatu, xv  
vapor control, 8–9  
vaults, 6, 52  
ventilation, 85  
vermiculite, 17, 18  
vertical reinforcement. *See* rebar  
vertical walls  
  design, 49  
  reinforcement pins, 44  
volcanic stone, crushed  
  environmental impacts, 18  
  as fill material, 17  
  for floor insulation, 76  
  for stem wall insulation, 32
- W**  
walls  
  bag pattern, 40  
  closing bag top, 41–42  
  dome bag placement, 45–47  
  filling bags, 36–37  
  placing barbed wire, 38–39  
  placing vertical reinforcement rods, 44  
  plaster protection, 71–74  
  preparing fill material, 35  
  tamping bags, 43  
  thickness of, 67  
Watanabe, Kikuma, xv  
water control, 9–11, 32–33  
waterproof barriers, for below-grade construction, 69  
windows  
  openings, 60–67  
  retrofitting, 93–94  
Wojciechowska, Paulina, 1  
wood bond beams, 56–59  
Woven Earth, xiv



## About the Author

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