# 5. MATERIALS

## THE PRIMARY BUILDING BLOCKS OF THE VESSEL

– What they are
– Why we use them

The nature of the materials used to execute an Earthship design is explored. The earth-rammed automobile tire is presented as the most appropriate method for its strength, economy, lack of skill needed, and the fact that it makes use of an otherwise discarded "natural resource." The aluminum beverage can used as masonry unit for filler walls is also presented for similar reasons.

*What if we found a way to make building blocks out of compressed oxygen. We simply extracted the oxygen out of the air and compressed it into bricks. This would be great because oxygen is everywhere. However, we are intelligent enough to understand that we breathe oxygen. It is what enables us to stay alive. We would not want to deplete our life giving breath would we? Trees are a source of oxygen on this planet. We currently build with trees as well as simply clear them out of the way for more important things - like cattle.*

## THE NATURE OF THE MATERIALS

In keeping with the design and conceptual information presented in the previous chapters, the nature of the building materials for an Earthship must have certain characteristics of definition established before we can go looking for them. The following outline will establish the nature of the materials necessary to build a vessel that aligns with rather than deteriorates the environment of the planet. We will think in terms of ideals here in an effort to lift us from the conventional alleys that have lead us to our present dilemma.

### Indigenous

Ideally the materials for an Earthship would want to be indigenous to many parts of the planet. Shipping materials for long distances presents an energy impact not in keeping with the Earthship concept. In order for the Earthship to be easily accessible to the common person and to maintain a low impact on the planetary energy situation, a "building block" found all over the globe would be required.

### Able to be fashioned with little or no energy

If a building material was found that was indigenous to many parts of the planet but it required massive amounts of energy to fashion into a usable form, we still would not be meeting the conceptual requirement of an Earthship. The major building materials for an Earthship must require little or no manufactured energy to fashion into use. This keeps them easily available to common people and at the same time would allow the large scale production of Earthships to maintain a relatively low impact on the planet. Since there are so many of us, if we are to survive without literally consuming the planet, everything we use must be chosen with consideration to the impact of large scale application. We must explore building materials and methods that are not dependant on manufactured energy and that have the potential to contribute to the general well-being of the planet rather than exploit it.

### Mass

The materials that surround the spaces of an Earthship must be dense and massive in order to store the temperatures required to provide a habitable environment for humans and plants. The Earthship itself must be a "battery" for storing temperature. This massive battery must be achieved without large amounts of energy. This suggests built-up dense mass in "bite-size" human manageable pieces. This built-up mass must also have the capacity for structural bearing and a cohesive homogeneous quality. Any light porous material, no matter how strong, is ridiculous for a building material if it has no mass. In anything but a temperate climate where no heating or cooling is necessary, mass is a primary factor in selecting a building material. Making houses out of heavy dense mass is as important as making airplanes light. Obviously a heavy airplane takes more fuel to fly. Obviously a light house takes more fuel to heat or cool. Why do we see the forest but not the trees?

## Durability

We have built out of wood for centuries. Wood is organic and biodegradable. It goes away. So we have developed various poisonous chemical products to paint on it and make it last. This, plus the fact that wood is light and porous, makes it a very unsatisfactory building material. This is not to mention the fact that trees are our source of oxygen. For building housing that lasts without chemicals we should look around for materials that have durability as an inherent quality rather than trying to paint on durability. Wood is definitely a good material for cabinet doors and ceilings where mass is not a factor and where it is protected so it will not rot, but the basic massive structure of buildings of the future should be a natural resource that is inherently massive and durable by its own nature.

## Resilient

Earthquakes are an issue in many parts of the world. They are actually a potential anywhere. Any method of building must relate to this potential threat. Since earthquakes involve a horizontal movement or shaking of the structure, this suggests a material with resilience or capacity to move with this shaking. Brittle materials like concrete break, crack, and fracture. The ideal structural material for dealing with this kind of situation would have a "rubbery" or resilient quality to it - something like jello. This kind of material would allow movement without failure.

## Low specific skill requirements

If the materials for easily obtainable housing for the future are to be truly accessible to the common person they must, by their very nature, be easy to learn how to assemble. If it takes years of apprenticeship to learn a skill then that method is not the answer for housing. The nature of the materials for building an Earthship must allow for assembling skills to be learned and mastered in a matter of hours, not years. These skills must be basic enough that specific talent is not required to learn them. **General application of common human capabilities must guide in the evolution of materials and methods for housing of the future.**

## Low tech use/application

Some systems of building today are simple if one has the appropriate high-tech expensive energy dependant device or equipment. This, of course, limits the application of these methods to the professionals who have invested in the technology to enable them to use such methods. Because of the expense and energy required to get set up for these systems the common person is left totally dependent on those professionals for accessibility to these particular housing systems. Therefore the common person must go through the medium of money (bank loans, interest approvals, etc.) to gain access to a housing system that usually dictates performance and appearance. The point here is that if high-tech systems and skills are between the common person and their ability to obtain a home, we are setting ourselves up to place the very nature of our housing in the hands of economics rather than in the hands of the people themselves. This situation has resulted in inhuman, energy-hog housing blocks and developments that make investors some quick money and leave the planet and the people with something that requires constant input of money and energy to operate. The technology required to build an Earthship must be beyond the type of technology that we are so impressed with today. Earthship technology is the technology of natural phenomenon like the physics of the sun, the earth and people themselves. The methods and materials for obtaining housing of the future must be within the immediate grasp of the common person with a minimum of easily accessible devices. We must employ a much more thorough understanding of the nature of ourselves and the physics of our environment.

The requirements above describe the nature of the ideal "building block" for constructing Earthships - Housing of the future. Many conventional materials satisfy one or two of these requirements but no conventional material satisfies all of them. We will be evolving a new material or building block for the primary structure of the Earthship.

## THE PRIMARY BUILDING BLOCK

Obviously all of the materials used in an Earthship would want to meet the requirements outlined above. However, as a first step toward a vision we must begin with the primary building block - that which provides the major structure and performance of the Earthship. The major structure and performance of the Earthship is encompassed in the design element termed a "U" in the previous chapters. Modules are constructed in this "U" shape for reasons already described. This "U" shape must therefore be constructed of a primary building block that meets all of the above requirements. Throughout twenty years of exploring the ideals that have resulted in the concept of the Earthship, we (Solar Survival Architecture) have developed/found a natural resource that meets these requirements. This building block is a rubber automobile tire rammed with packed earth. Let's take it through the outline of requirements and see how it "stacks up".

**Indigenous**

The rubber (sometimes steel belted) automobile tire is indigenous all over the world as a "natural resource". Every city is a natural supplier of this item. It can be "harvested" with absolutely no technical devices or energy other than two human hands to pick it up and throw it into a pickup truck. The automobile tire is definitely an indigenous material to every heavily populated area of the planet. It is readily available without the energy and economic impact of shipping to every potential building site.

**Able to be fashioned with little or no energy**

The rubber automobile tire can be used as found without any modification. The process of ramming them full of densely packed earth is achieved with simple human labor and can be done with whatever type of earth is available on the building site. Common people of all shapes and sizes can easily learn to gather tires and pack them full of earth with simple hand tools and with the same type of human energy that they use while trying to tone up their bodies in the local spa. The impact of large scale use of this idea would result in depletion of the giant tire mountains that have become a serious problem in many cities, and in many people getting in a lot better shape without having to spend money for a spa membership. This building block is therefore achieved with little or no manufactured additional energy.

**Mass**

There are few materials of any kind that would provide better, more dense mass for storing temperature than rammed earth. The rubber tire casings provide a natural form for humanly manageable production of thermal mass building blocks with little more than human energy. There are also very few materials that would provide the structural bearing capacities and homogeneous qualities of an earth rammed tire wall. The diameter of the tires (2'-4") sets the thickness for the walls surrounding the "U" modules - 2'-8" with plaster. This amount of dense mass surrounding every room of an Earthship would provide a thermal battery like no other in construction history.

## Durability

The durability of tires filled with earth can not be surpassed. A buried tire (which is in effect what we have in a tire wall) will virtually last forever. The only thing that deteriorates rubber tires is sunlight or fire. Since they are filled with earth and ultimately covered with earth they never see sunlight when built into an Earthship. Tires only burn when surrounded by air. When they are filled and coated with earth, trying to get them to burn would be like trying to light a phonebook on fire as compared to a wad of paper. The very qualities of tires that makes them a problem to society (the fact that they won't go away) makes them an ideal durable building material for Earthships. Earth and tires by virtue of their very nature will last forever.

## Resilient

Whereas a rubber tire/rammed earth wall is amazingly strong, it is obviously not brittle. It can vibrate or move without fracture or failure. Since these walls are so wide and the loading on them is widely distributed, the entire structure would have the potential of absorbing and moving with a considerable horizontal shock from an earthquake. There is probably no other material available at any price that has the reliance that earth rammed tires would have. They do provide a dense, rubbery, flexible wall much more akin to the nature of "jello" than any other material.

## Low specific skill requirements

Over the past fifteen years many people of all shapes and sizes have been taught to "pound tires" (the term used for the process of densely packing the tires with earth). Within one or two hours the average human can be an expert. It requires physical energy more than brute strength. A team of two people, one shoveling and one pounding, can pound about four tires an hour. The shoveling job is easiest while the pounding requires a little more strength and energy. The general application of common human capabilities is definitely all that is required here. This is a skill that the very lowest people on the labor force can become good at.

## Low tech use/application

The only real major piece of equipment needed to build a tire building is a backhoe. This is a common piece of equipment needed for all building of any type. Backhoes and operators rent almost anywhere for 30 to 50 dollars per hour. Other typical tools needed are a chain saw, skill saw, and a cement mixer. Common people use these tools all the time and they are very easily accessible to all. This places the building of an Earthship easily within reach of typical contractors and owner builders.

# SECONDARY MATERIALS

The same requirements should be related to for the secondary materials. Some secondary materials such as glass are the same everywhere while others will vary with different locales. The secondary materials are those which make up the fill in walls, ceilings, floors, glazing, and miscellaneous carpentry.

## Fill in walls

The most significant secondary material is that used for bathroom walls, closet walls, non-structural end walls of the greenhouse hallway, and all other miscellaneous infill areas. The material we have found for these areas is one that meets all the requirements outlined in the nature of materials except for mass which in the case of fill in walls is not necessary. This material is a little durable aluminum brick that appears "naturally" on this planet. It is indigenous to most parts of the planet that are heavily populated. It is also known as the aluminum beverage can. Its evolution as a low tech, easy to use brick has been taking place for almost twenty years in New Mexico. It has been used for structural walls, non-bearing interior walls, filler walls, domes, vaults etc. Whole buildings have been built with aluminum cans. Due to its light weight, the fact that it requires very little skill to learn to use, that it can be plastered over without conventional metal lath, that it will never wear out or burn and that it is very easy to obtain; it has become the ideal material for fil in walls in Earthships. It is another natural resource of the twentieth century.

## Ceilings

The ceiling decks and beams of the Earthship can be made of whatever local beams and decking are available. In New Mexico standing dead trees are cut for round log beams called vigas. Decking is usually made from wood planks. The ceiling decks and beams are usually made from some kind of wood, however this is not mandatory. Concrete or steel beams and decking could be used as well as any other method of spanning distances of ten to twenty feet. We are currently experimenting with a product made by A.I.R. Research of Wisconsin that is made by grinding up garbage and mixing it with a slurry of adhesives to produce a poured beam almost as strong as and having similar qualities of concrete. Conventional vapor barriers and rigid insulation (R60) are used above the ceiling. See chapter six for specifics on these materials and their detailing.

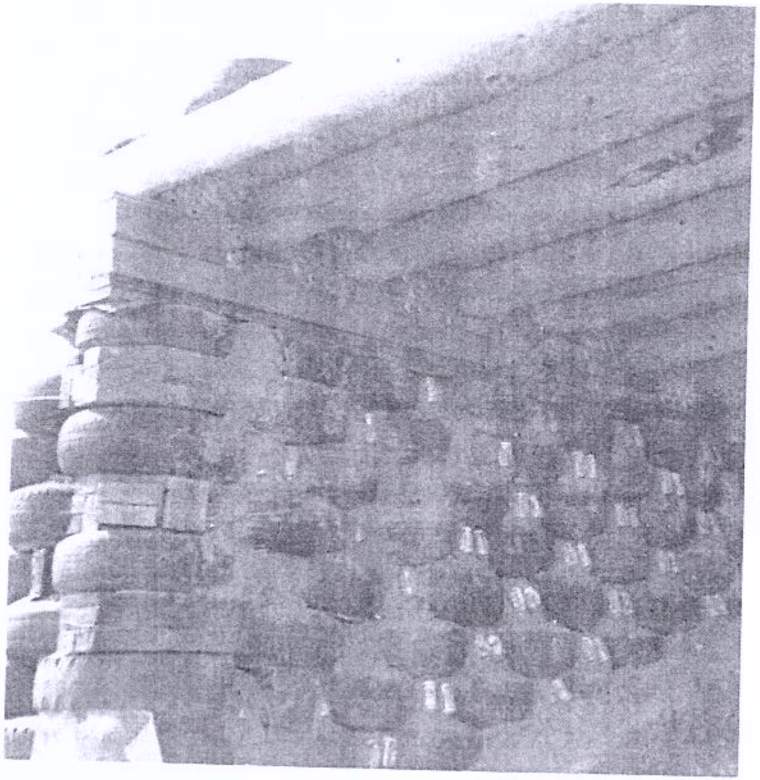
## Floors

Floors can also be made from any local indigenous material from concrete to flagstone to tile or wood. Some Earthships in New Mexico have used adobe mud floors which are traditional in the area. They are very beautiful and will work anywhere. Floors should take advantage of local materials that are of a low energy impact nature, however they are quite conventional in the application to the Earthship structure.

## Glazing

The southern glazing on Earthships that wants to collect heat should be double-paned, insulated glass as manufactured by most glass companies in standard sizes. The size most often designed for in typical Earthships is 46" x 90". All other glazing should be either triple pane or one of the new heat retaining glazings (consult your local glass dealer).

If Earthships were to become the way of the future, on a large scale, the resulting impact would be significant. There would be a radical reduction in the use of global energy to both manufacture and transport the various materials that dominate the housing industry. There would also be a radical reduction in the amount of automobile tires discarded on the planet and the need to find some way to dispose of them. There would also be a significant reduction in deforestation which is and will be a continuous threat as long as wood is a major building product for housing. Anything that we do on as large a scale as housing must (like the trees) be born of something that we ourselves produce. Our numbers are too great for the planet to continue being the sole supplier of our needs. The by-products of the tree itself, through decay and biodegrading, provide soil for the nourishment of its offspring. Likewise **the by-products of our society must provide the materials for housing our future generations.**



# 6. THE "U" MODULE

## THE DETAILS AND SKILLS USED TO BUILD THE "U" MODULE

The fundamentals of how to build your own Earthship are presented here. A well illustrated and explained collection of easy to learn skills, available to all types of people of various strengths, shapes and sizes is presented. This includes how to lay the rammed earth tires, how to lay the aluminum cans in mortar, connections, mistakes commonly made, etc...

Fig. 1

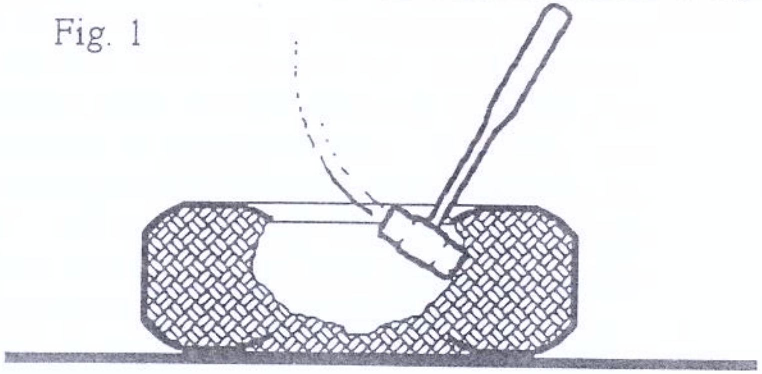
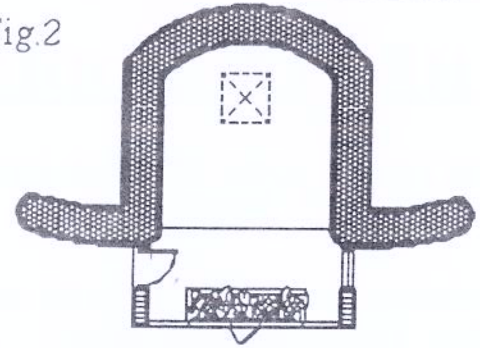
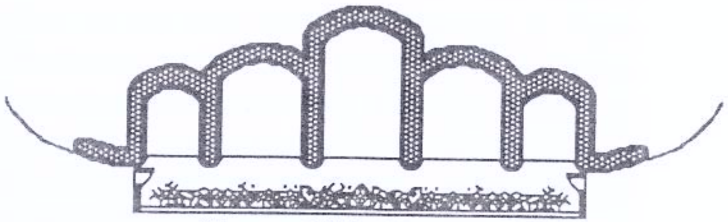


Fig.2



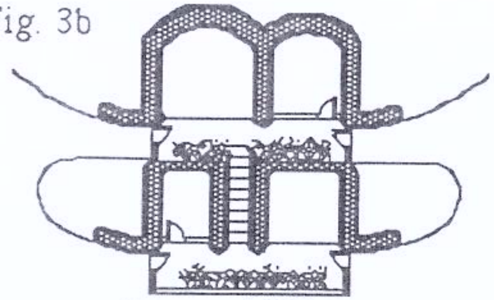
Single "U" plan

Fig.3a



Plan of "5-U" house

Fig. 3b



Stepped "U" Plan

This chapter begins with an explanation and illustrations of how to pound a rammed earth tire. This is the building block of the "U" module. (Fig. 1)

Next, the construction materials and methods used to build the entire "U" module out of these rammed earth building blocks will be explained and illustrated. (Fig. 2)

Our objective is to provide a thorough understanding of how to build one single "U" module. Since the Earthship is made up of several of these "U" modules, an understanding of how to build the module is a basic understanding of how to build the Earthship. Chapter 8 will deal with how to assemble the modules into an Earthship. (Fig. 3a - 3b)

Fig. 4

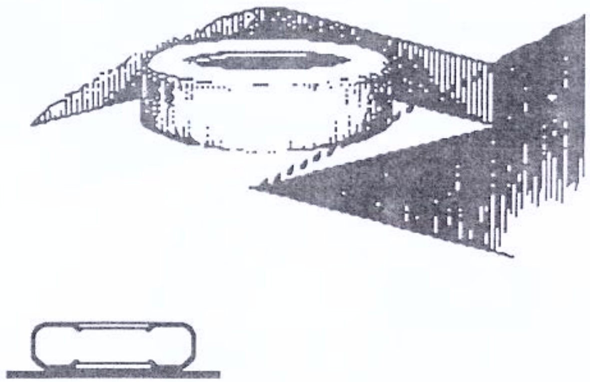
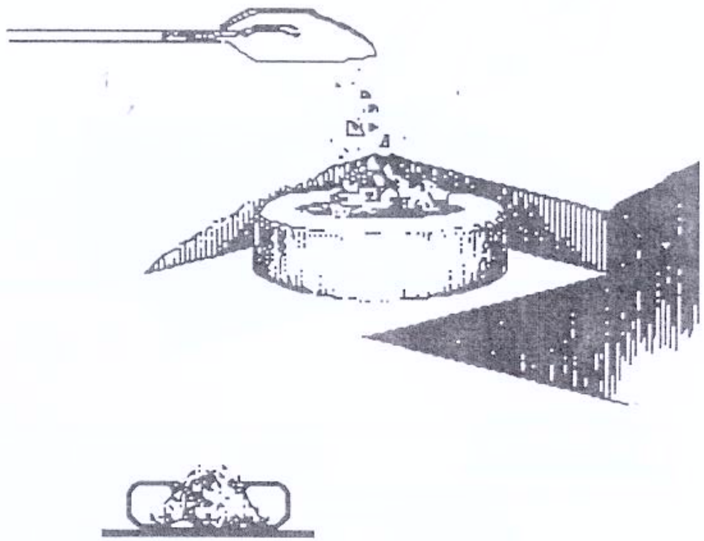


Fig. 5



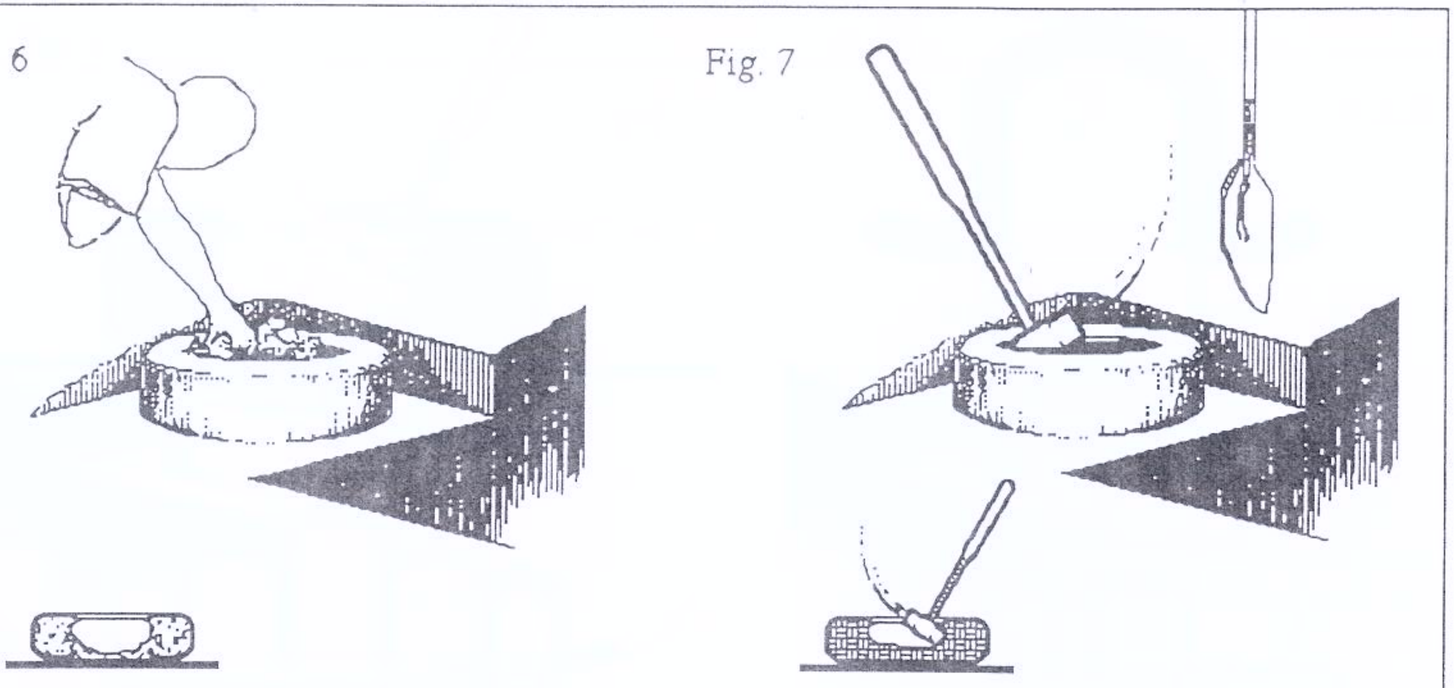
## HOW TO POUND A TIRE

Tire walls are made by laying tires in staggered courses like brick or concrete block. Each tire is filled with compacted earth, so that it becomes a rammed earth brick encased in steel belted rubber. As you will find, a pounded tire weighs over 300 pounds, so all tires are pounded in place and only minor movements can be made.

First, level a section of undisturbed earth large enough to receive a 2'-4" tire. This is approximately 3'-0" square. Remove all loose topsoil which would otherwise settle under the weight of the wall. Set the tire on the leveled undisturbed ground. (Fig. 4)

Tire pounding should be done in teams of two people, a shoveler and a pounder. Depending on your strength and endurance, a team should be able to pound a tire in 5-15 minutes. First,

Fig. 6 Fig. 7



one person fills the tire with dirt from the site. (Fig. 5)

Slightly damp soil is easiest to compact, however any type of soil with or without gravel will work.

The dirt is pushed by hand into the casing by the pounder. Gloves are advised for both workers. (Fig. 6)

Keep pushing the dirt into the casing until it is as full as you can pack it by hand. Now begin pounding the dirt into the casing with a 9 pound sledgehammer.

The shoveler continues to add more dirt, while the pounder packs it in. (Fig. 7)

Fig. 8a

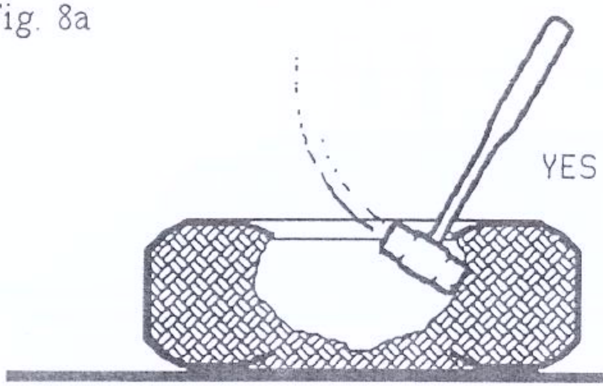



Fig. 8b

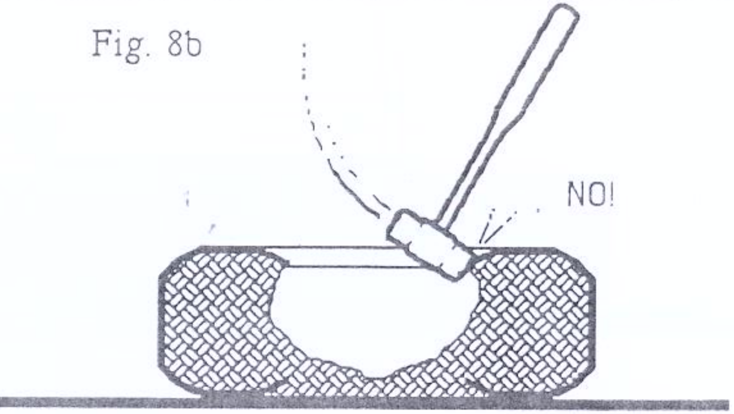



Fig. 9

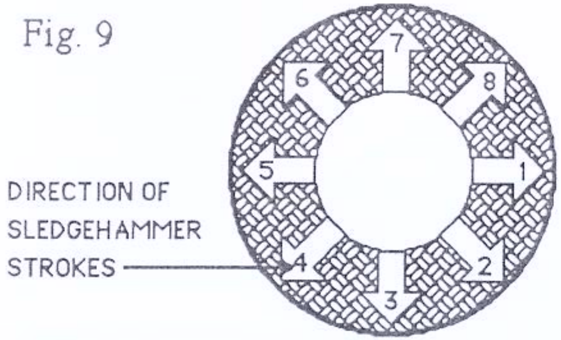
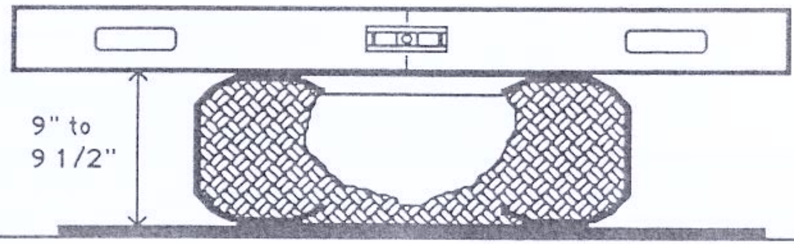



Fig. 10




Each tire takes about three or four wheelbarrows of dirt. When serious pounding begins, large amounts of dirt will be generated from the initial excavation (which is explained later).

The tire will become full of dirt and begin to swell up.

The sledgehammer strokes shown go <u>into</u> the casing. Do not hit the casing itself. (Figs. 8a-b)

As you pound the dirt, move around the tire to keep the tire pounded evenly. (Fig. 9)

This is done until the tire has swelled to about 9 or 9 1/2 inches. After the outer casing is sufficiently packed and swollen, it will need to be leveled. Lay a 4'-0" level across the tire, letting it rest on the swollen rubber casing. (Fig. 10)

Make sure that the tire is level in all directions. Add more dirt to build up the tire if necessary.

Fig. 11

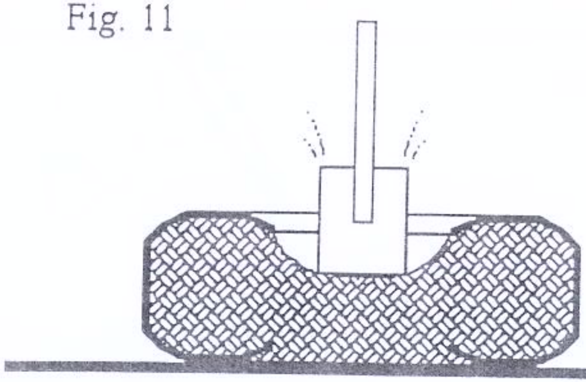


Fig. 12

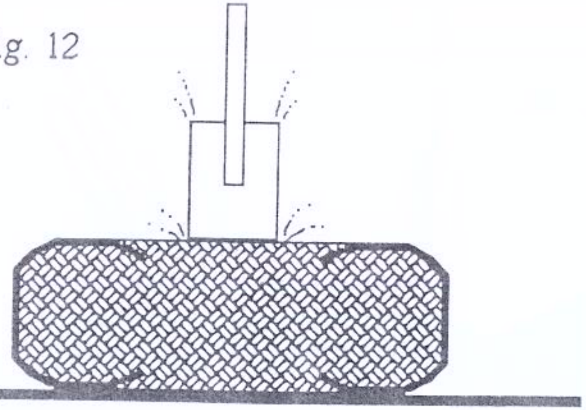
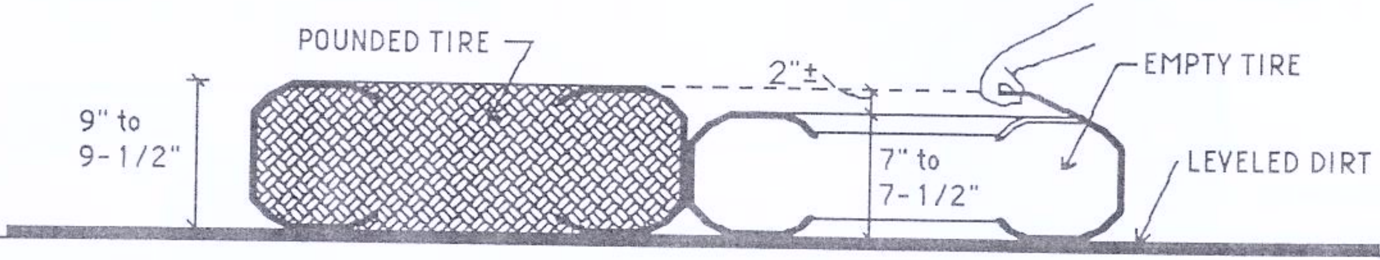


Fig. 13




Next, the interior of the tire is filled with more dirt and tamped until it is packed as tightly as the inner casing. Do not fill completely and then tamp. Tamp as you fill; i.e. fill a little then tamp a little. This allows a tighter tamping job. (Fig. 11-12)

This ensures that the whole tire brick has consistently packed earth throughout.

The ground next to the pounded tire must be leveled now in preparation for pounding another tire. Level the ground so that it is 9" to 9-1/2" below the top of the pounded tire. An unpounded tire is 7" to 7-1/2" high. This allows for about 2" of swell when pounded. (Fig. 13)

Fig. 14

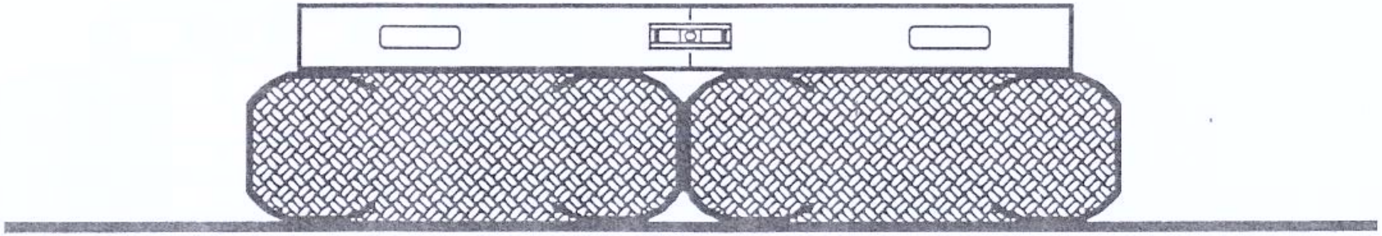
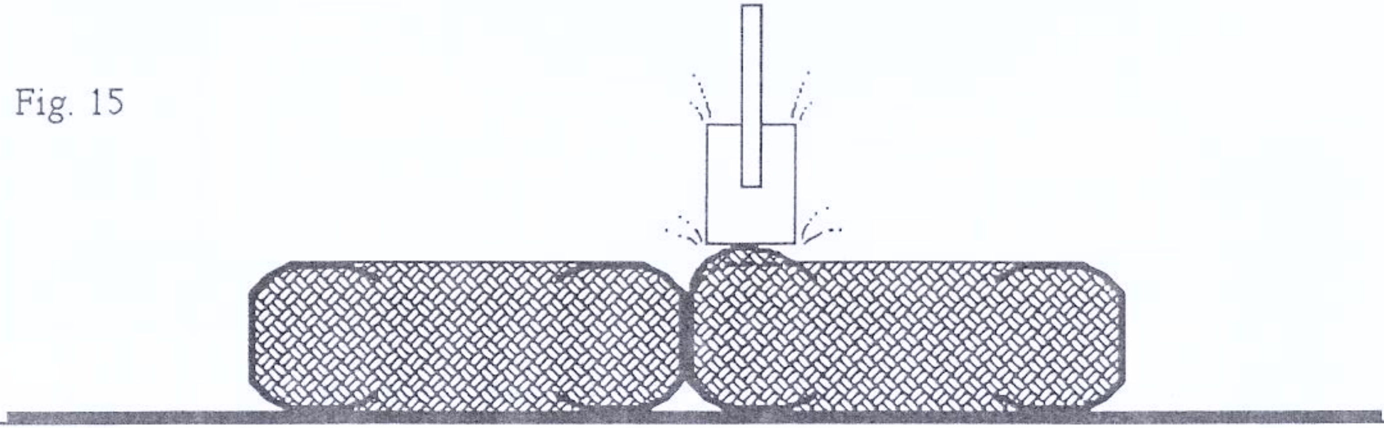


Fig. 15

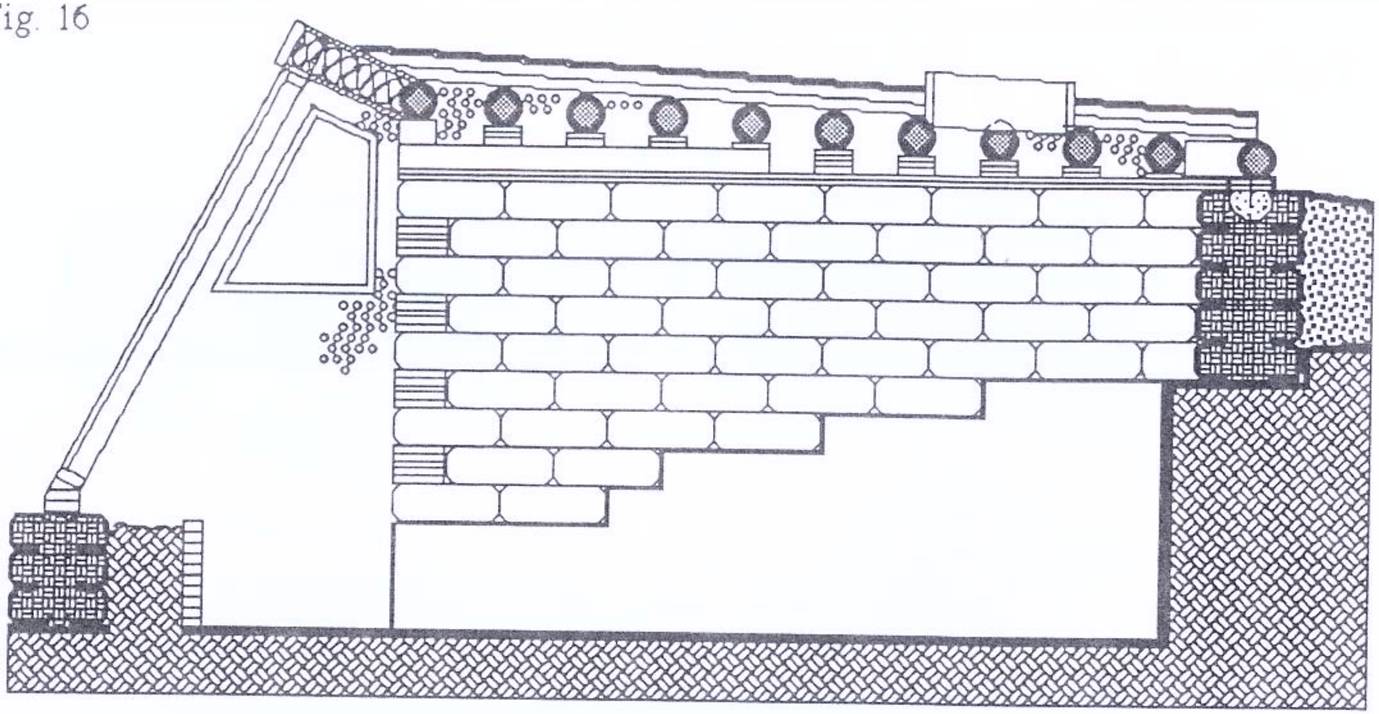


Continue the above procedure, laying the second tire so it is touching the first. After the next tire is pounded, level it with the first tire. (Fig. 14) Also level it with itself in the other direction.

If you are too high with any part of the second tire, it can be beat back down with the tamper. (Fig. 15)

It is important that each tire be level in itself and with the adjacent tires, so eventually the entire course will be level. This is the procedure for the ground course of tires.

Fig. 16



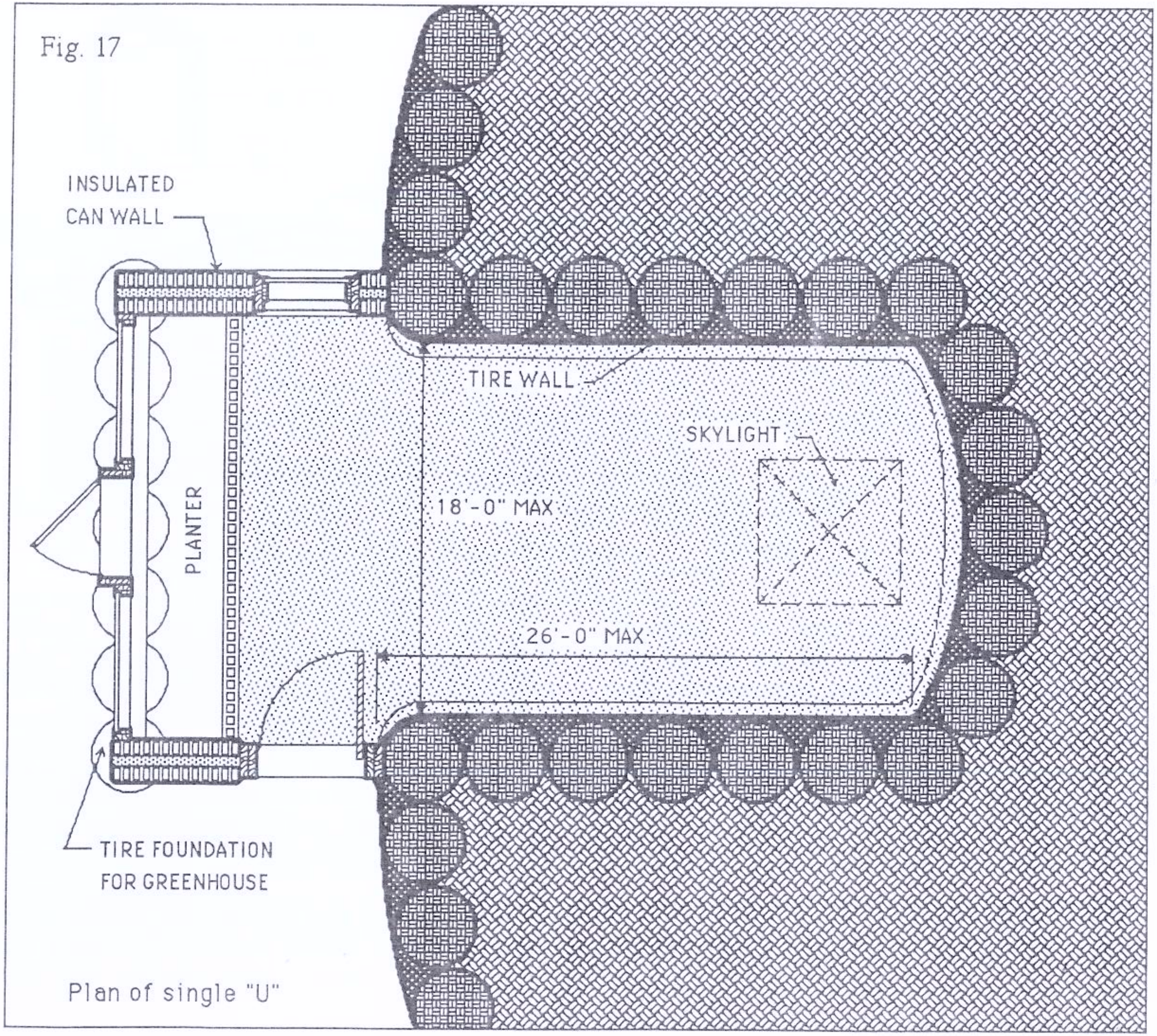
Section of single "U"

## SCOPE OF THE PROJECT

Now that you know how to pound a tire, you are ready to begin a "U" module. Here is a set of diagrams for this module, including a cross section and floor plan. (Figs. 16-17) It is a good idea to get a feel for the general scope of the project before you begin. The example shown is a building on a sloping site. For your own project, use the information you learned in Chapter 2 - Location, to locate your Earthship.

These "U" modules can vary in width and depth, however the basic details remain the same. Maximum recommended width is 18'-0" and maximum recommended depth is 26'-0".

Fig. 17




Plan of single "U"

Fig. 18

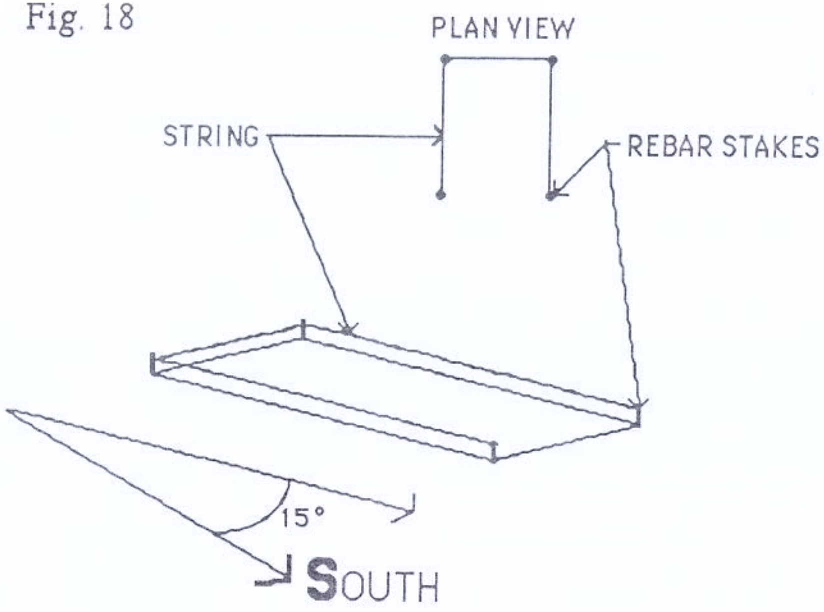
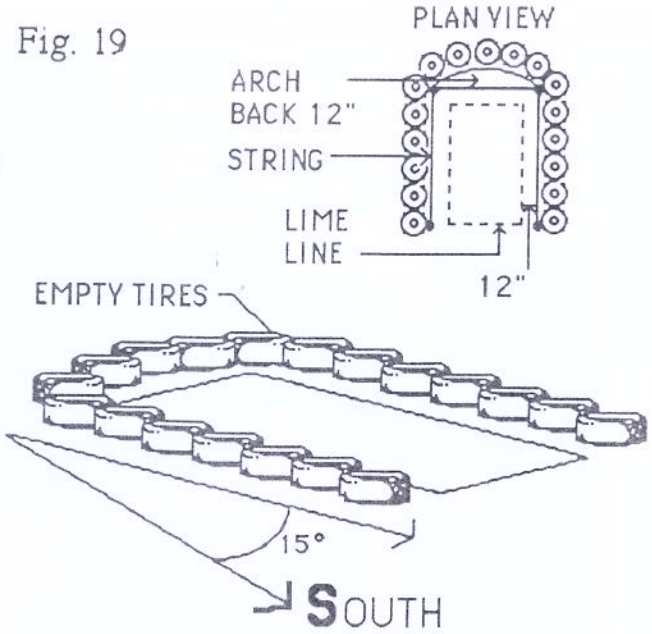



Fig. 19




## LAYOUT

First, you will need to stake out a rectangle which will be the size of the interior of your room. Stretch a string line around rebar stakes to mark this line. (Fig. 18) Orient this room 15 degrees east of south to catch the morning sun (see chapter two).

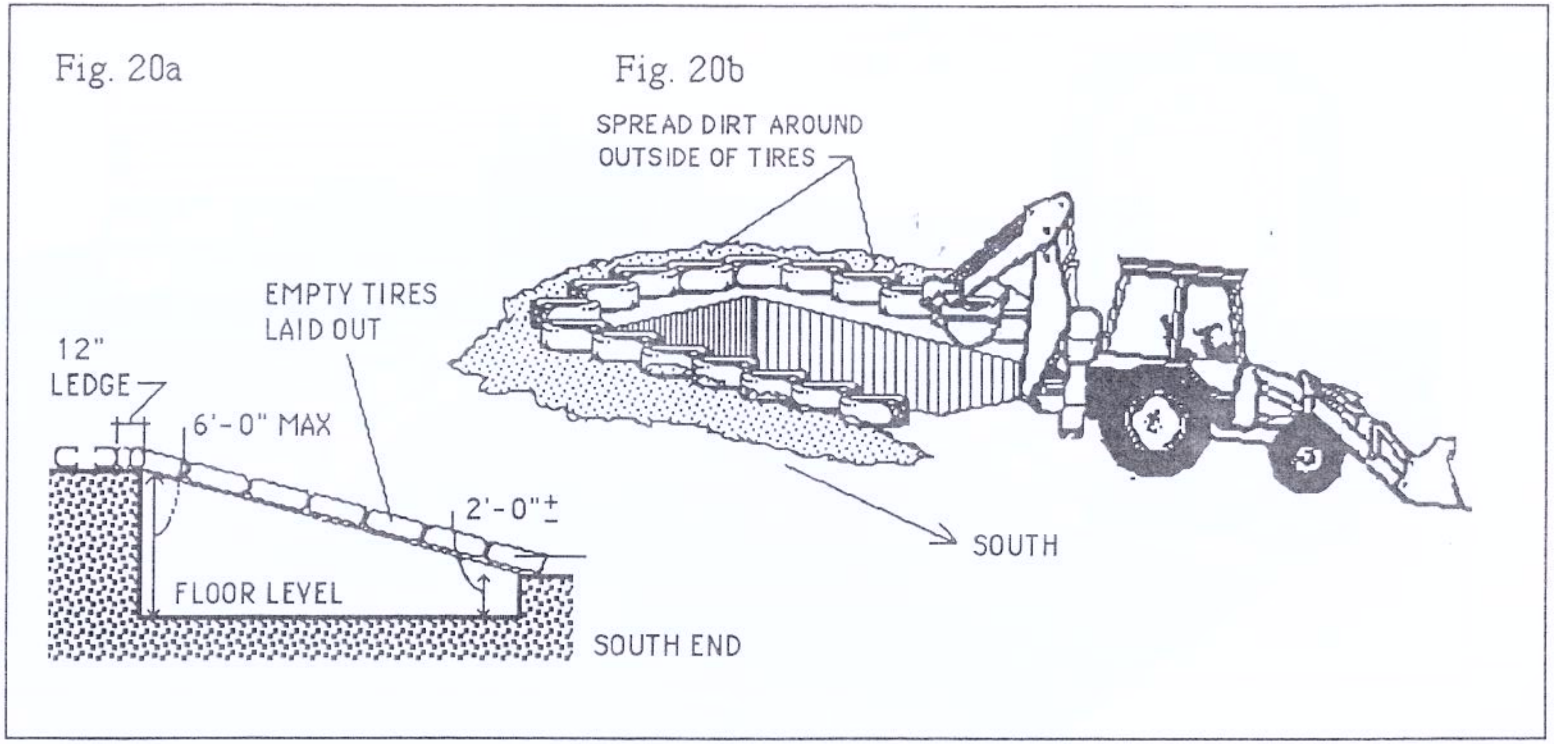
## INITIAL EXCAVATION

Lay out your first course of empty tires along your string line, allowing for your arch in the back. (Fig. 19)

The arch should be a <u>minimum</u> of 12" from the string line. As discussed in Chapter 4 - Structure, the arch is for additional support against the burial.

Always use larger tires, #15 and #16, on the first course. #15's will be used throughout the body of the wall, and #14's will be used for the top course.

After you have laid out the tires, (touching the string on the sides) measure 12" from the string to the interior. Mark this line with lime




on the ground - it will be the outer limit of the initial dig. **<u>Do not let the initial dig get any closer than 12" from the tires.</u>** This is an earth cliff and must be protected from erosion by being further from the tires now than the final design requires. It will be carved back by hand later.

Have the backhoe driver dig out the room as marked within the lime lines, (Fig. 20a - 20b).The maximum depth on the north end is 6'-0". The depth on the south end will vary from zero to 3'-0" according to your specific site slope, the depth of the rooms, and other site conditions.

As the dirt is dug out of the ground, have the backhoe driver spread it around the outside of the U. This dirt will be used to fill the tires later.

Fig. 21

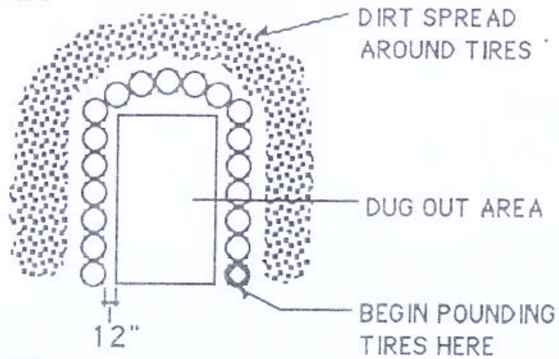



Fig. 22

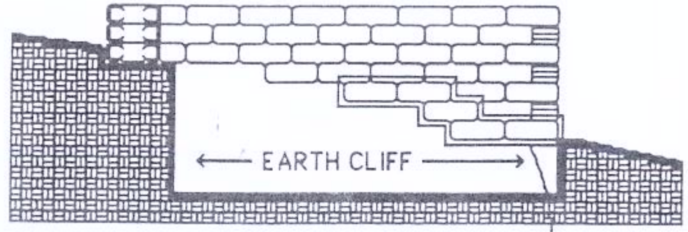
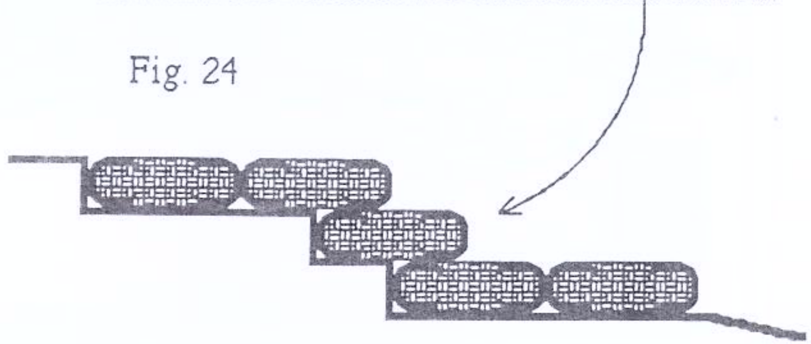



Fig. 23

Fig. 24



## THE FIRST COURSE OF TIRES

Beginning with the front right tire, level a section of earth, then pound and level the first tire. (Fig. 21 & 23)

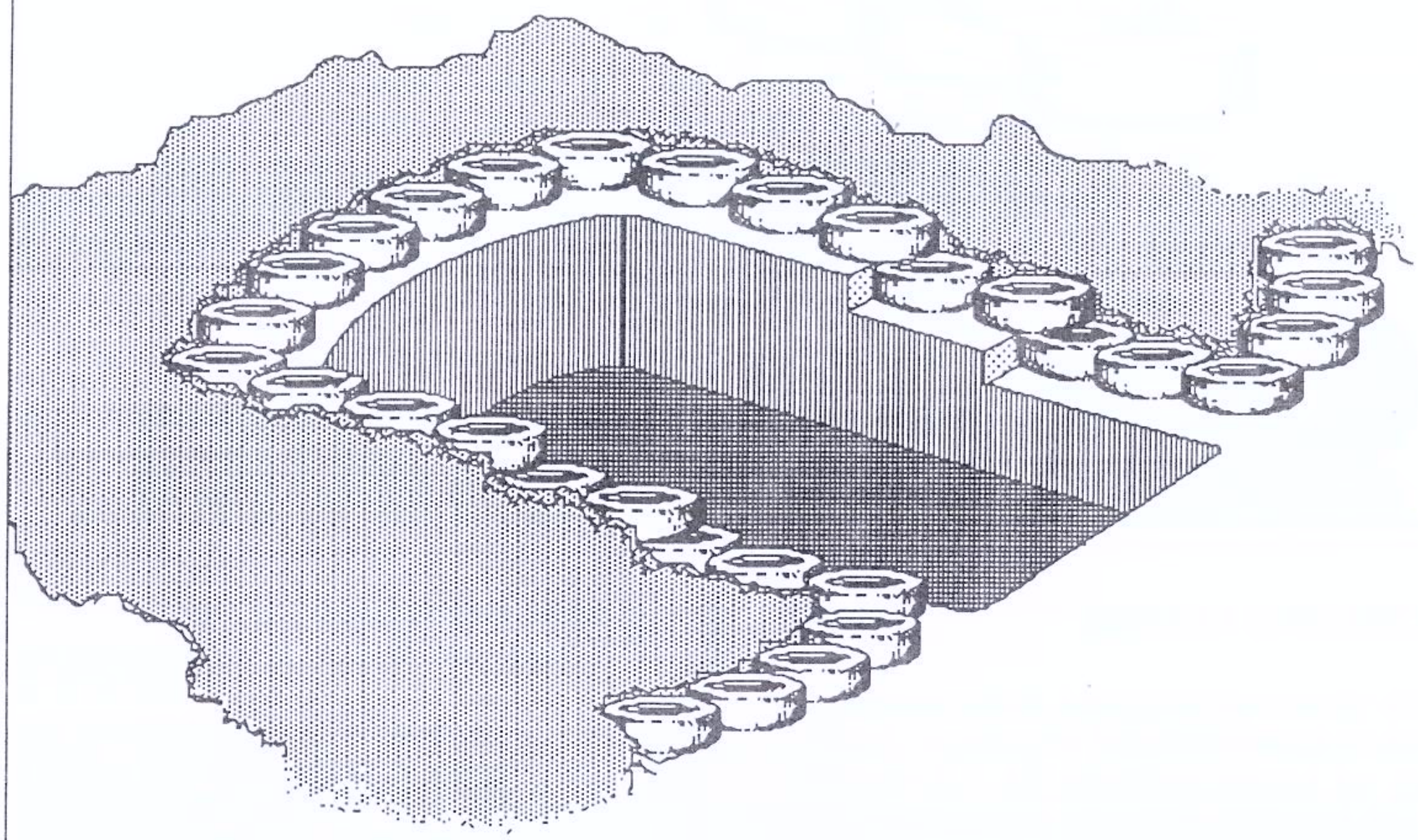
How you proceed will depend on the slope of your specific site. On a steeper site, you can step the tirework up the hill. (Figs. 22-24)

This results in less tires to pound on the up hill side of the "U".

On a flatter site, the entire first course will set on the same level.

Fig. 25 shows the first course of tires on a typical sloped site. Notice the wing walls going to the east and west. These only occur when another "U" is not being placed next to the one you have started i.e. they occur at the east and west ends of the building. If you are just building one "U" both wing walls occur as shown.

Fig. 25



First course of tire work and initial excavation.

Fig. 26

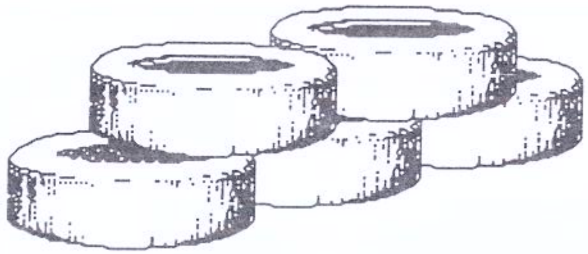


Fig. 27a

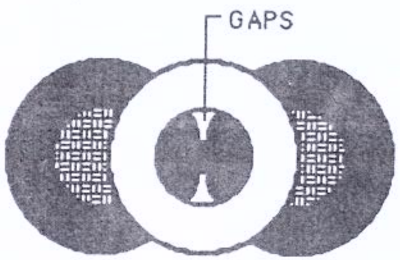



Fig. 27b

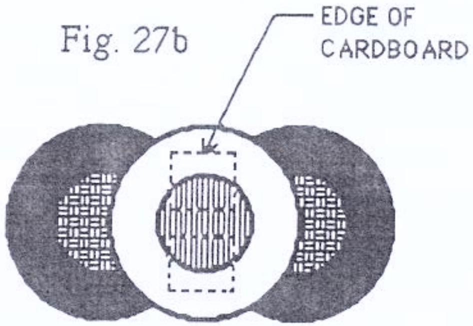
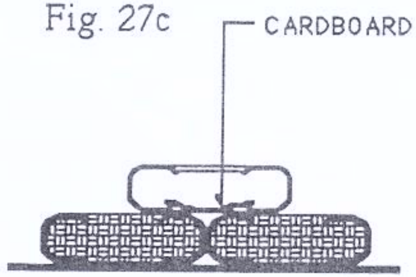



Fig. 27c




## THE SECOND COURSE

Courses of tires are staggered, in the same way as brick or concrete block. (Fig.26)

You will find that when you lay a tire for the second course, the dirt will fall through the gaps created where the tires round inward. To remedy this, lay a piece of cardboard inside the tire to temporarily hold the dirt.
(Figs. 27a-c)

This is usually done with two pieces as it is easier to fit two small pieces in than one big one. Use discarded boxes from the grocery store. After the tire is pounded, the compacted dirt will no longer need a form; and, since both sides of the tire wall will eventually be sealed and covered by dirt or mud plaster, the cardboard can decompose without affecting the structure. <u>The cardboard is only a temporary device.</u>

Fig. 28

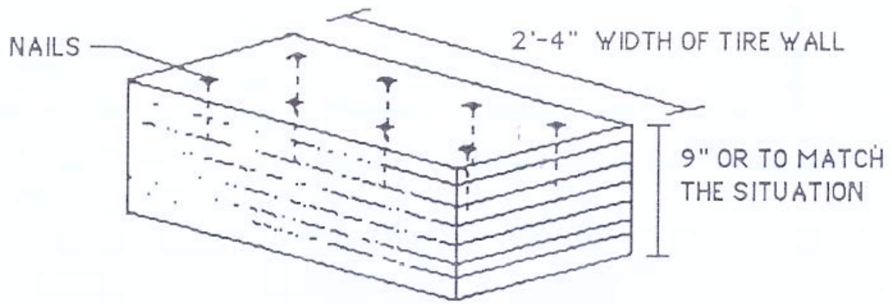



Fig. 29


## BLOCKING

There will be times when a half tire is necessary. In these situations, solid wood blocking is used. It is constructed by laminating 1x12 and 2x12 pieces of lumber and plywood scraps together. (Fig. 28) There are four different types of blocking -

1.spacer blocks 3.L connection blocks
2.end blocks 4.Y connection blocks.

In a single "U", you will use only spacer blocks and L connection blocks. The other types are used when two or more U's are joined together. This will be discussed in Chapter 8. **All blocking should be coated with two coats of wood preservative and wrapped in two layers of 6 mil plastic.** Slash the plastic on the side of the blocking that faces the inside of the room so that it will not trap moisture.

### Spacer blocks

Because of the irregularities in the size of tires, you will encounter situations where the tires will begin to line up vertically, rather than be staggered. When this occurs, a solid

Fig. 30

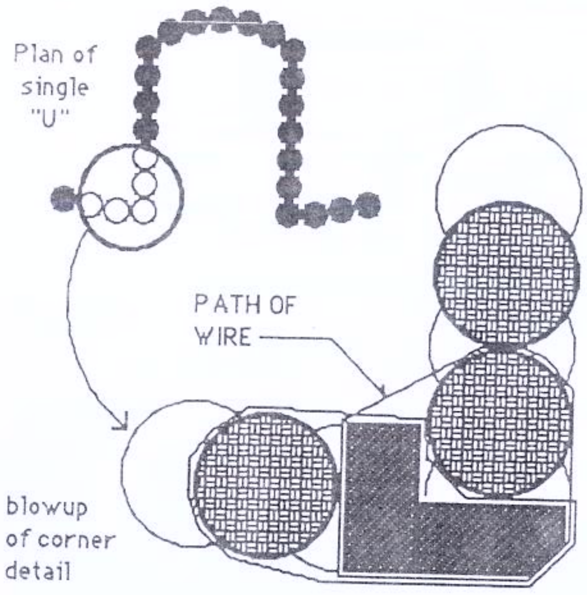
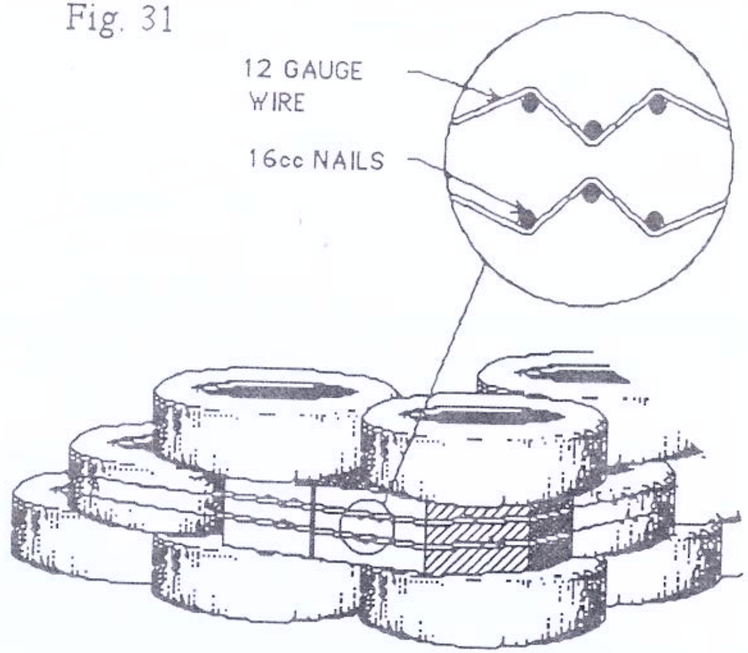



Fig. 31




wood block, the size of a half tire, should be inserted. (Fig. 29)

This will put you back on staggered coursing. Staggered coursing is important, as it knits the wall together.

If a spacer block is necessary on the ground course, put a board on either side of the tires and fill the space with concrete as it is not a good idea to put wood on the ground.

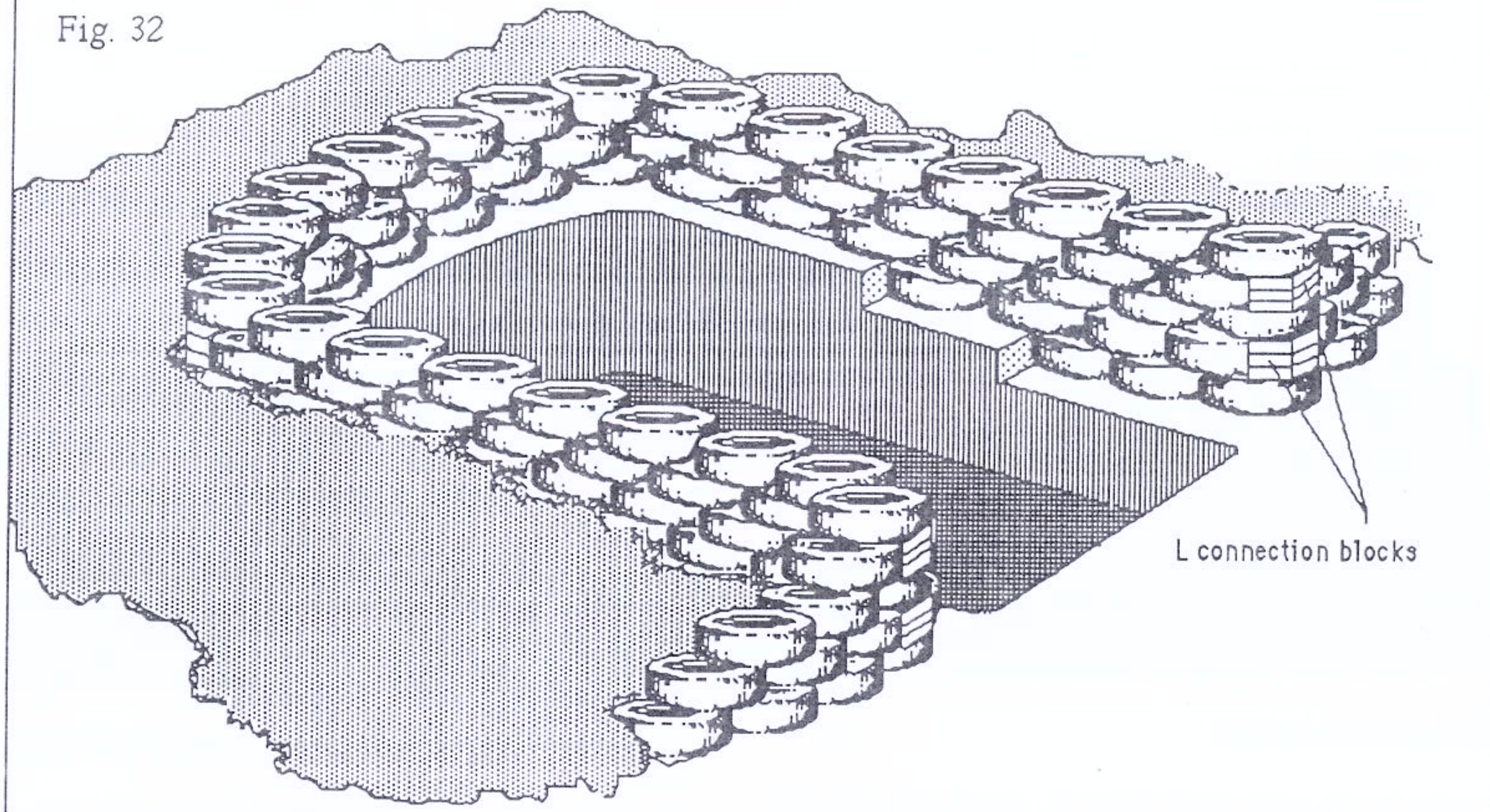
## L connection blocks

These will vary with each situation and must be custom fit. This can be done with two blocks. One example is shown. (Fig. 30)

Tie these blocks into the tire walls, using 12 gauge wire. Nail the wire to blocks and tires with 16 cc nails. Use the placement of the nails to stretch and tighten the wire. (Fig. 31)

Tires do vary in diameter. It is a good idea to lay out empty tires around the U for each entire course, selecting tires larger or smaller

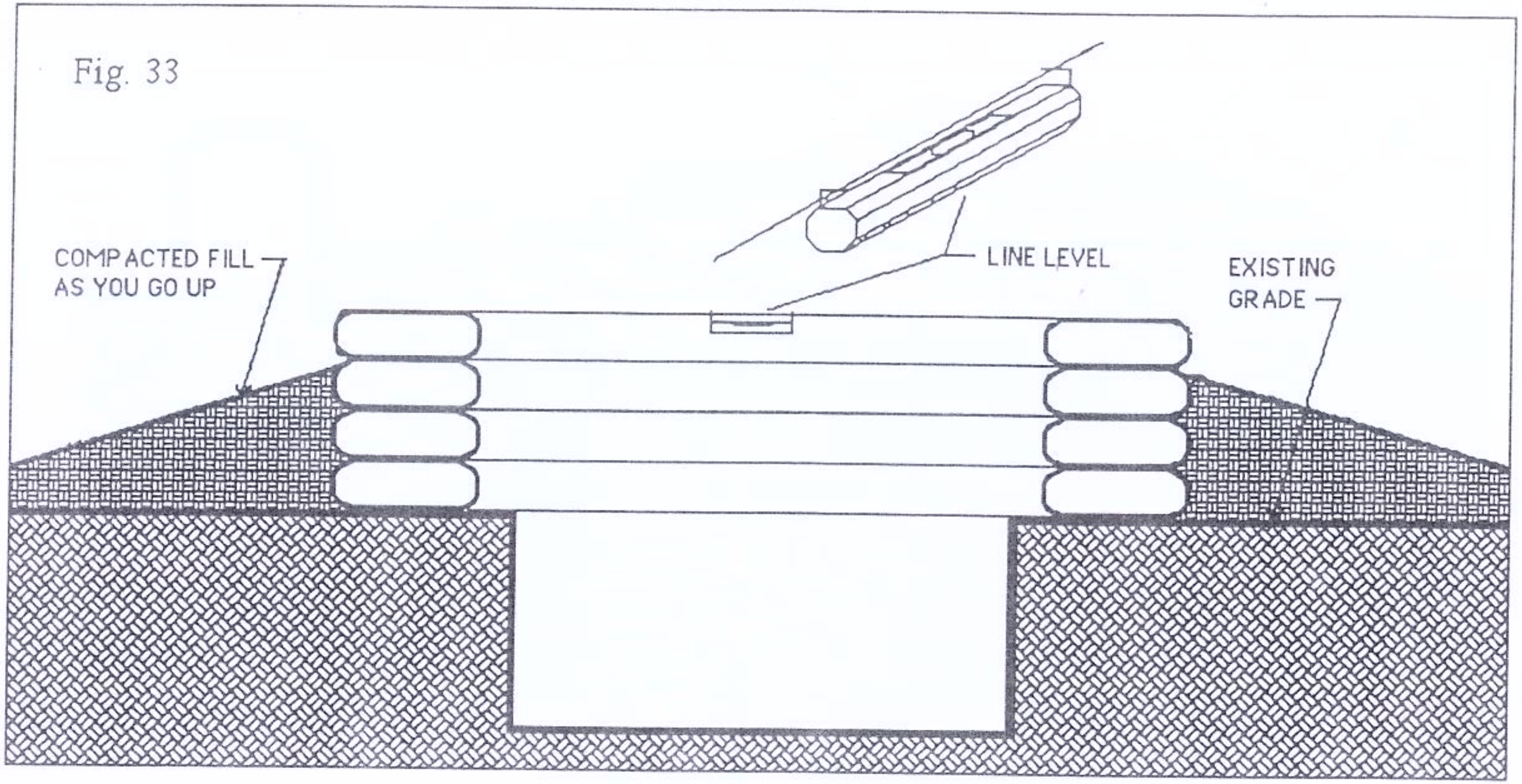
Fig. 32




Typical "U" all pounded out and ready for backfilling and bond beam plates.

to try and achieve a layout that requires little or no blocking. Blocking is time consuming, more expensive, and not as thermal as earthrammed tires.

In many simple buildings, spacer blocking can be totally avoided.




## BACKFILLING

Backfill behind the tires as you get higher. This will allow you a place to stand while pounding. This dirt needs to be compacted. Some compacting will be achieved through normal work traffic, but compacting by back dragging with the scoop of the backhoe is also necessary. <u>Drop</u> the fill against the tire wall. **<u>Do not push it up against the tire wall or you will push the wall out of plumb.</u>**

## LEVELING COURSES

As you finish each course of tirework, check to make sure each course is level by stretching a line level (Fig. 33) from east to west, or shooting elevations with a transit, across the U. When you are completely finished pounding tires, level across the U, from east to west, in several places. It is important that this is level, so that the roof structure can rest on a flat surface, distributing its weight evenly throughout the wall.

Fig. 34

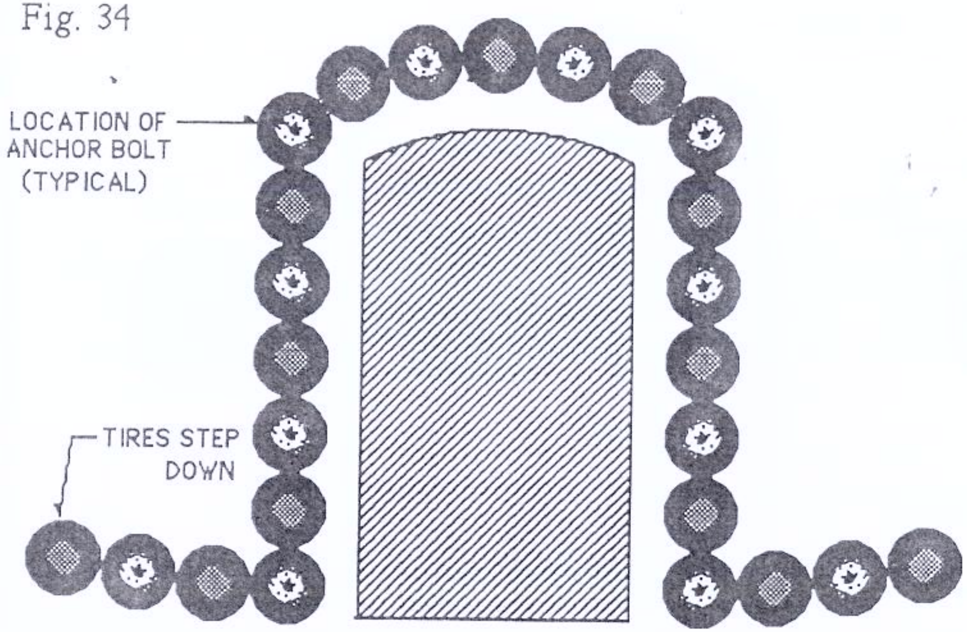
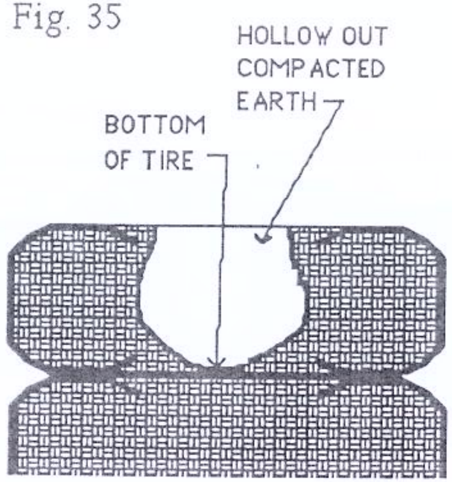



Fig. 35




## SETTING THE ANCHOR BOLTS

The roof structure will be fastened to the tire wall using anchor bolts set in concrete. Bolts will be located in every other tire on the top course. (Fig. 34)

If it doesn't work out even, then double two bolts in adjacent tires.

To set the bolts, first hollow out about one gallon of compacted earth from the tires indicated. (Fig. 35) Hollow out all the way down to the bottom of the tire.

Fig. 36

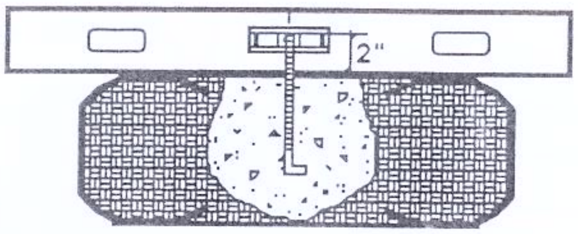
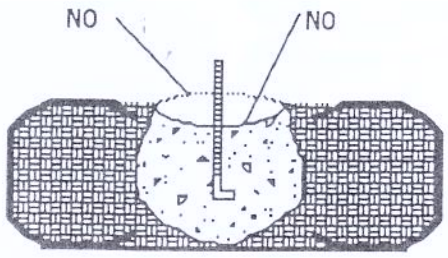



Fig. 37




Next mix the concrete, using a concrete mixer or a wheelbarrow. The mixture is 3 parts sand to 1 part cement.

The mixture should be what is called a 'stiff mix' (ie. not soupy), so that the bolts can set up straight in the concrete.

Now, fill the void with concrete, flush with the bottom of the level. Set one 1/2" diameter, 8" long anchor bolt in the center of each concrete filled tire. Allow the bolt to stick out 2" above the top of the tire. (Fig. 36)

It is important that the cement be flush with the top of the tire as in Fig. 36. Do not let the cement get above or below (Fig. 37) as this will cause problems with the wood plate that will be anchored on next.

Fig. 38

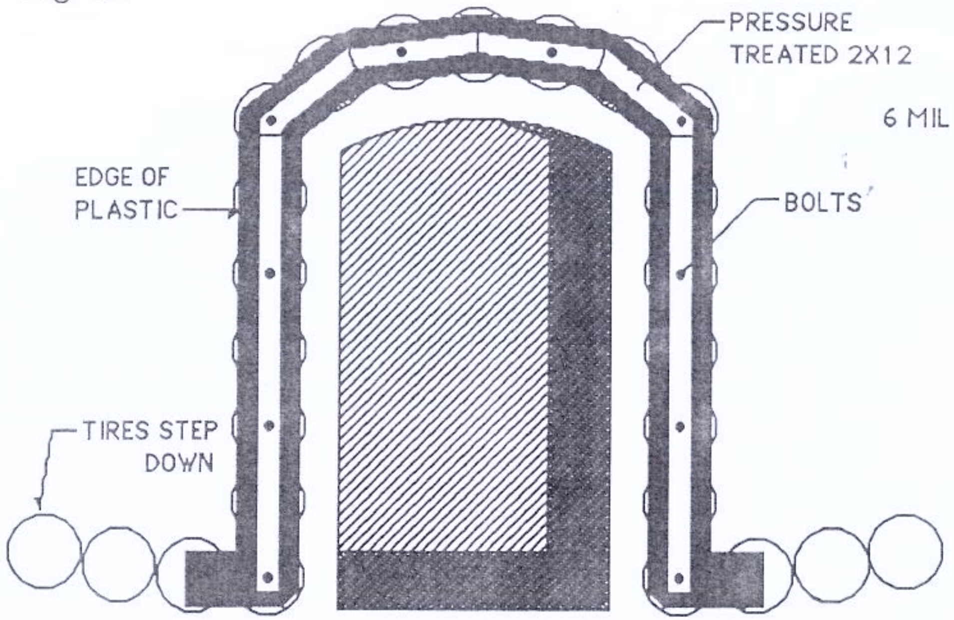
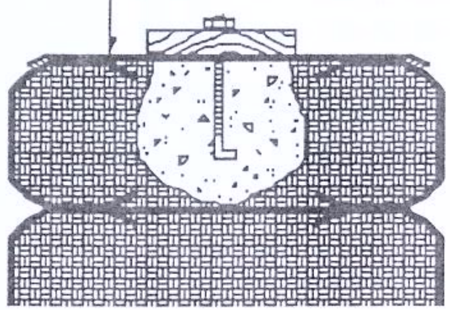



Fig. 39




## THE TOP PLATE

After the concrete has dried, apply 2 layers of 6 mil. plastic over the entire top of the wall. Staple it down with a staple hammer.

The top plate will be made of 2 layers of 2x12 pressure treated dimension lumber (or two layers of rough sawn 2x12's coated with wood preservative), centered over the bolts. (Fig. 38)

Drill 1/2" holes in the first layer to match the location of the bolts. This can be done by placing the board over the bolts and tapping with a hammer so the bolts leave an indention in the wood. Drill at the indentions. Bolt this wood down with washers over the plastic. (Fig. 39)

**Tighten the bolts with washers <u>just snug:</u> if they are too tight, they will pull the concrete loose from the tire.**

Fig. 40

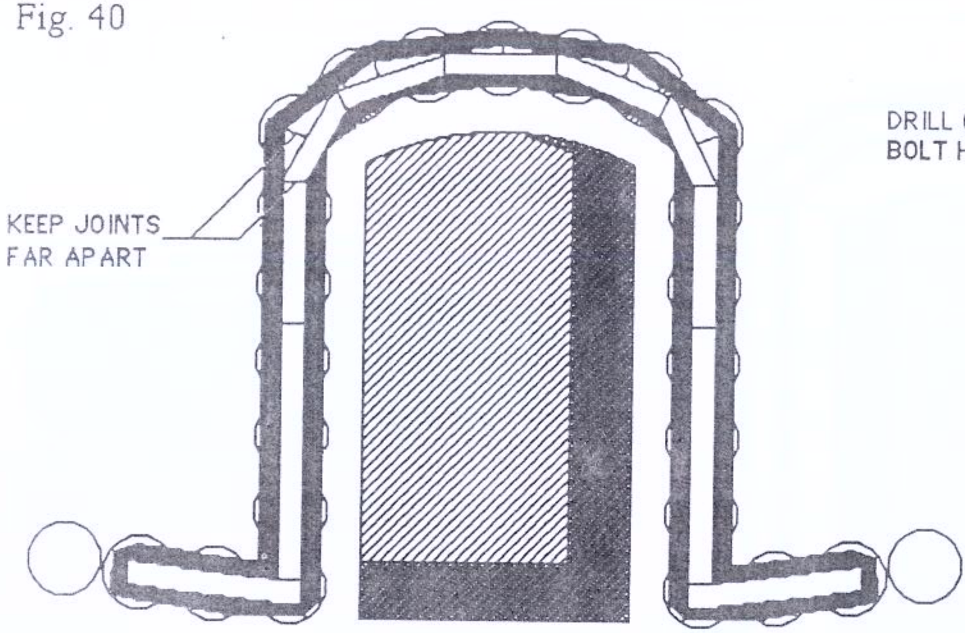
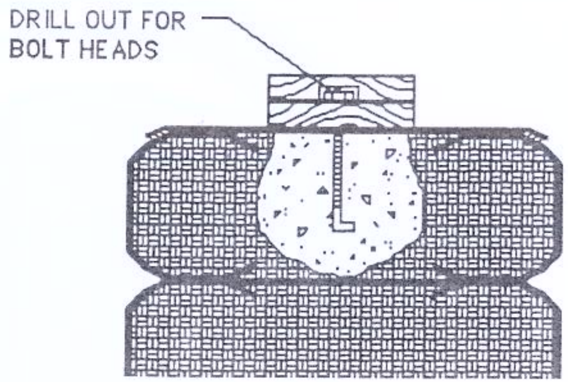



Fig. 41



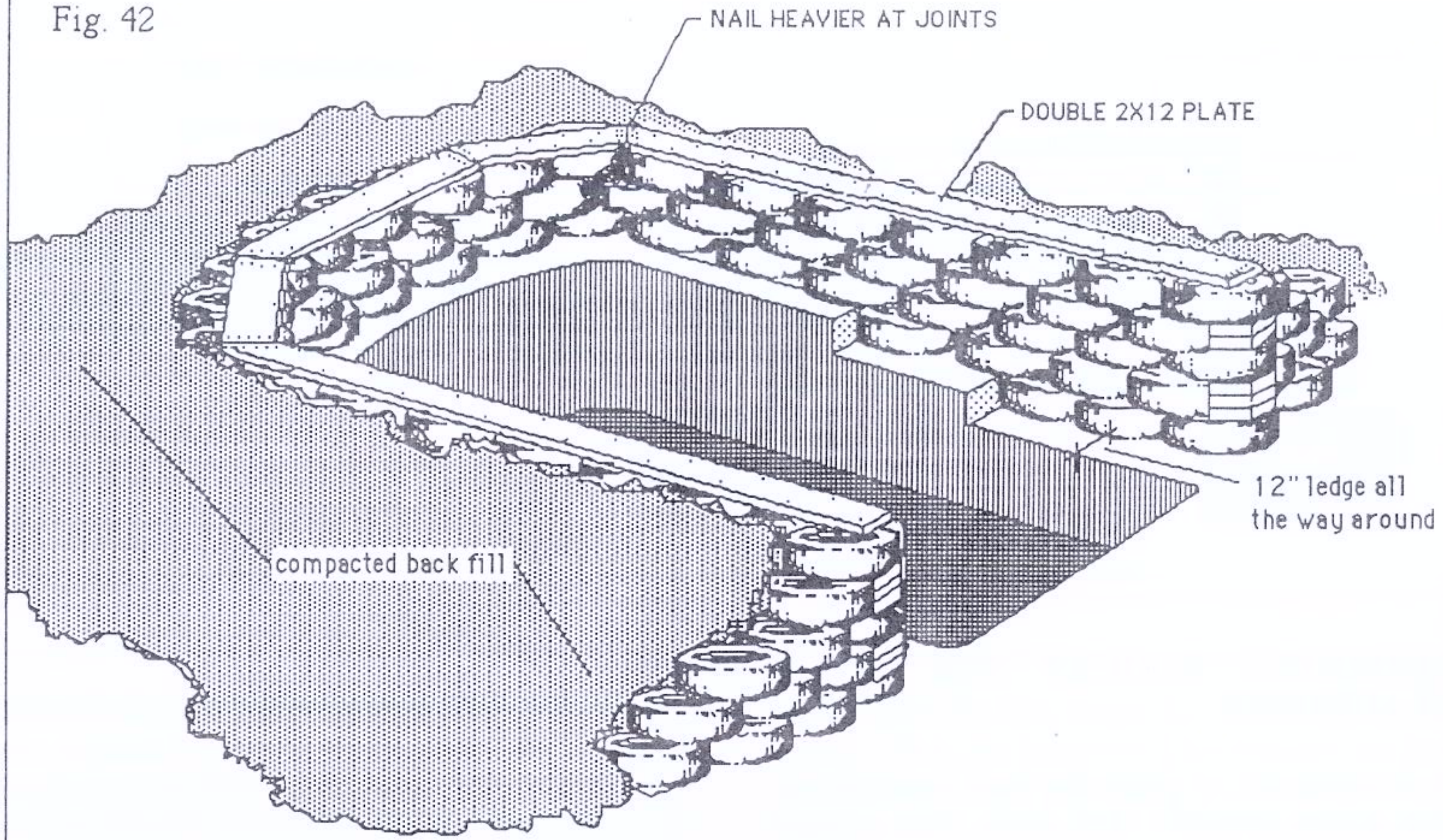

The second layer of 2x12's should be placed so that the joints are well away from the joints of the first layer. This provides a continuous 4x12 treated wood bond beam. (Fig. 40)

With a spade bit, drill holes in the second layer to match the bolt locations. Drill holes big enough to cover the nut and washer, usually 1$\frac{1}{4}$" diameter. This will allow the wood to set flat on the first layer. (Fig. 41)

Nail the wood down with 16cc nails in several places, with at least 4 nails per foot. Nail more heavily around all joints.

Now you can backfill up to the top of the tirework. Compact this fill by back dragging with a backhoe.

Fig. 42




The "U" is now ready to place beams.

Fig. 43

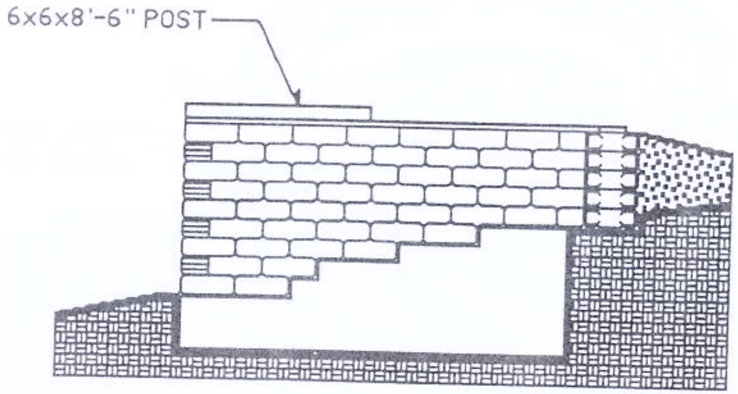
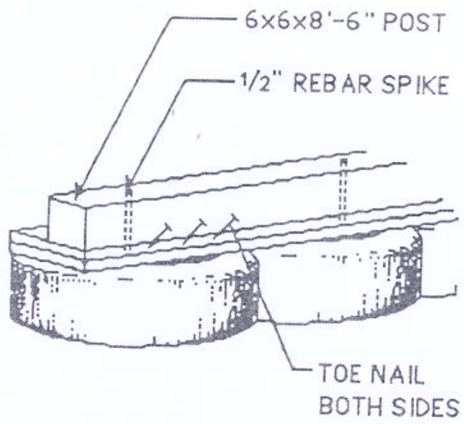



Fig. 44




## SHIMMING BLOCKS FOR BEAM PLACEMENT

It is necessary to slope the roof structure, so that it may properly shed water. To achieve this slope, you will need to 'shim up' the beams. This process should be done on the east and west walls at the same time.

Locate a 6x6x8'-0" long post on the top plate, flush with the inside of the plate. (Fig. 43 and 44) Toe nail it in on the sides.

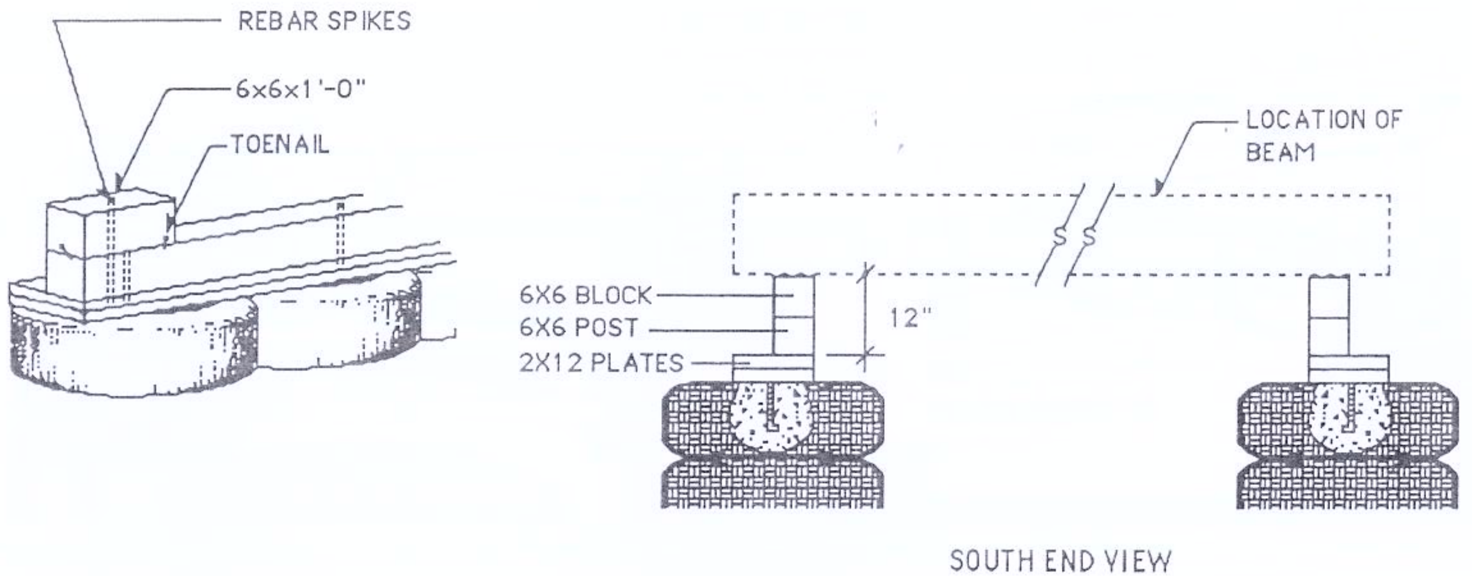
Drill a 1/2" hole through the 6x6 and the top plate with a 16" auger bit.

Be careful not to drill through the plate into the concrete. This would destroy the structural integrity of the concrete and dull the bit.

Pin the 6x6 to the plate with a spike made from 1/2" rebar. This spike is then driven like a nail into the pre-drilled hole (Fig. 44) **Do not drive the spike into any of the concrete. This will crack it and destroy its ability to hold the anchor bolt.**

Fig. 45a

Fig. 45b

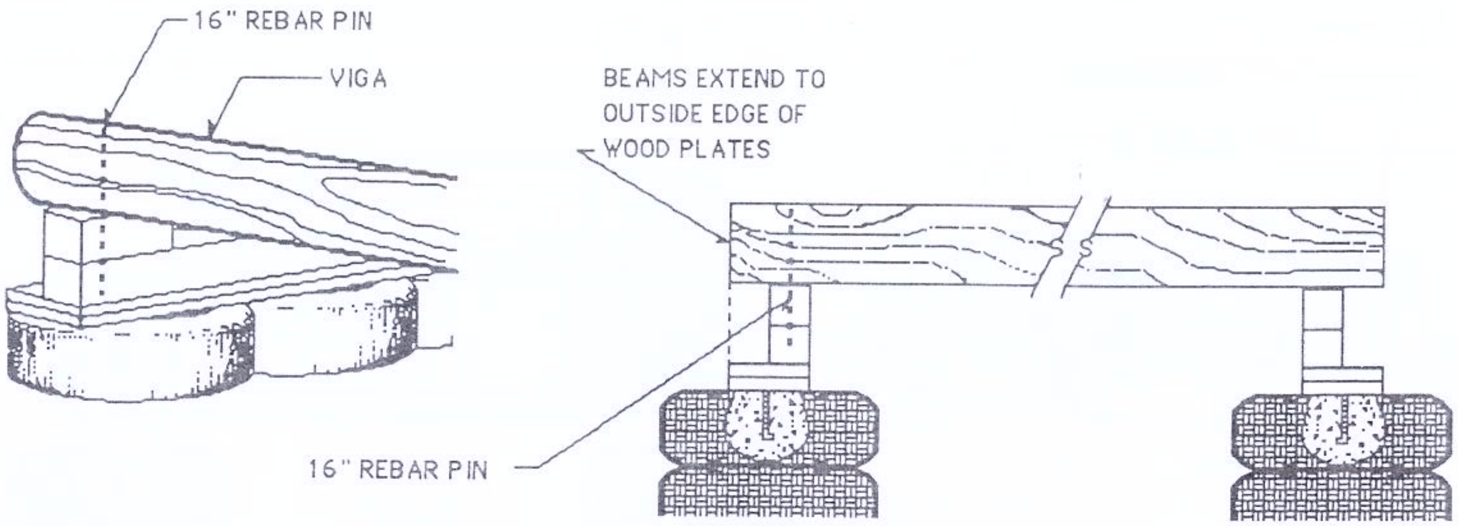



Rebar comes in 20'-0" lengths; it can be cut to the various lengths needed for spikes, using a hacksaw, welder's torch, or a rebar cutter at a lumber yard. Drive the spikes in with a hand sledge.

Cut another 6x6, 1'-0" long. Using the same method, fasten this block to the one below it, staggering the spikes. (Fig. 45a-b)

This places the first beam 12" above the wood plates. The last beam will be directly on the wood plates thus providing a 12" drop from front to back of the "U". This same process may be done with 8x8 stock for deep "U's" thus creating a steeper slope.

Fig. 46a Fig. 46b




## BEAMS

In New Mexico, where most of the prototypes for this construction exist, vigas (round logs) are used for beams. Vigas are preferred because they require less energy to "manufacture" than dimension lumber. In many regions these are not available, so you will have to substitute standard wood beams. The size of these will depend on variables, such as snow load, distance of spans, etc.

An engineer or builder should be consulted to size beams for specific situations. These beams can be rough sawn timbers or laminated from 2" thick lumber. They are usually 6" wide and 10" deep. All types of beams are placed 2'-0" on center.

After the first blocking has been secured, lay the first beam across the structure flush with the front of the tire wall. Pin this beam with rebar spikes, similar to the way the blocking shims were installed. (Figs. 46a-b)

Fig. 47

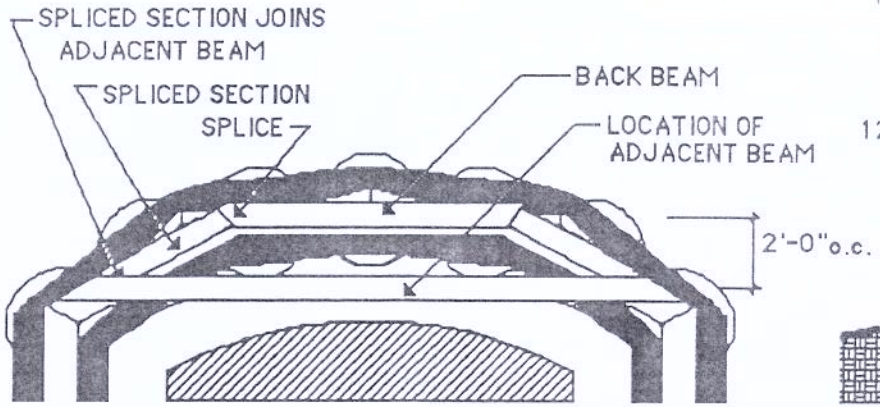
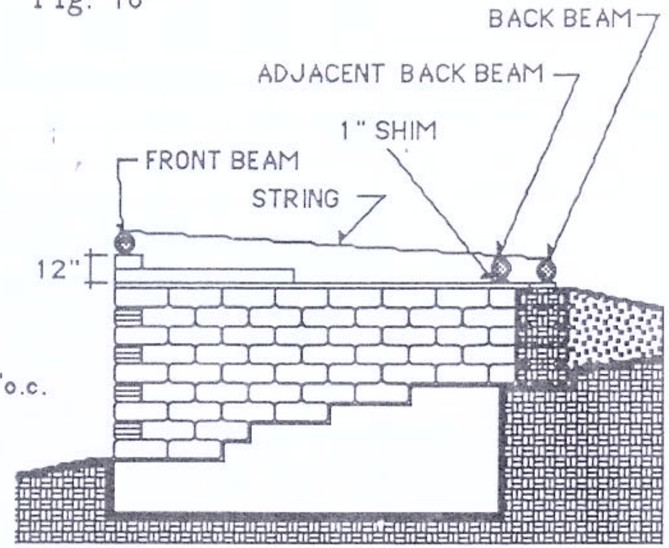



Fig. 48

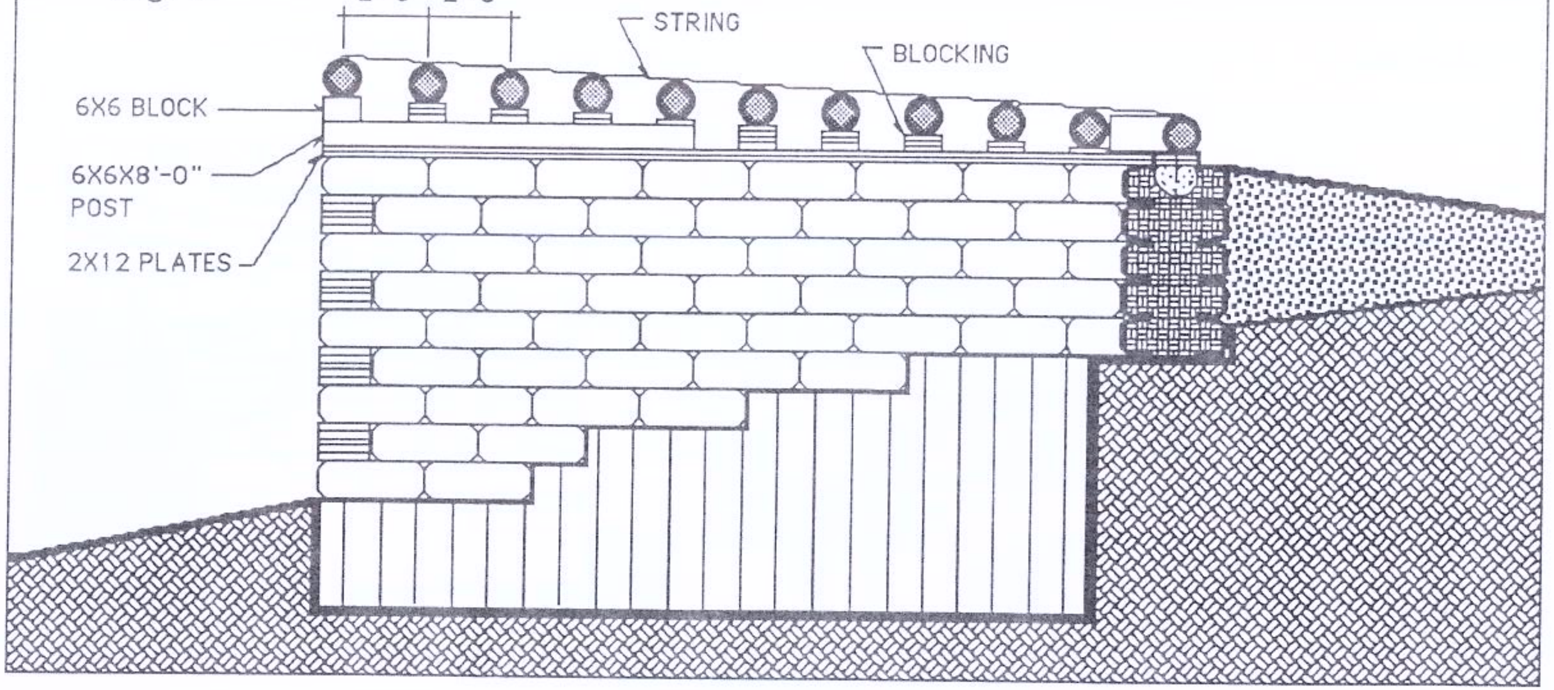



Next locate a beam directly on the plate at the back of the "U", flush with the outside of the plate. This beam will have to be spliced to two other short sections of beam in order to follow the curve of the back plate. It will not span it will simply be sitting on the plate. Extend the spliced section until it joins the location for the adjacent beam which is 2'-0" away. (Fig. 47 and 50)

The beam adjacent to the back beam will shim up about 1" higher than the back beam to maintain a slope. (Fig. 48)

Now, stretch a string from the front beam to the beam adjacent to the back beam. Do this on each side centered over the wood top plate. This will be the guide for the height of the beams in between these two, thus illustrating the roof slope. (Fig. 48)

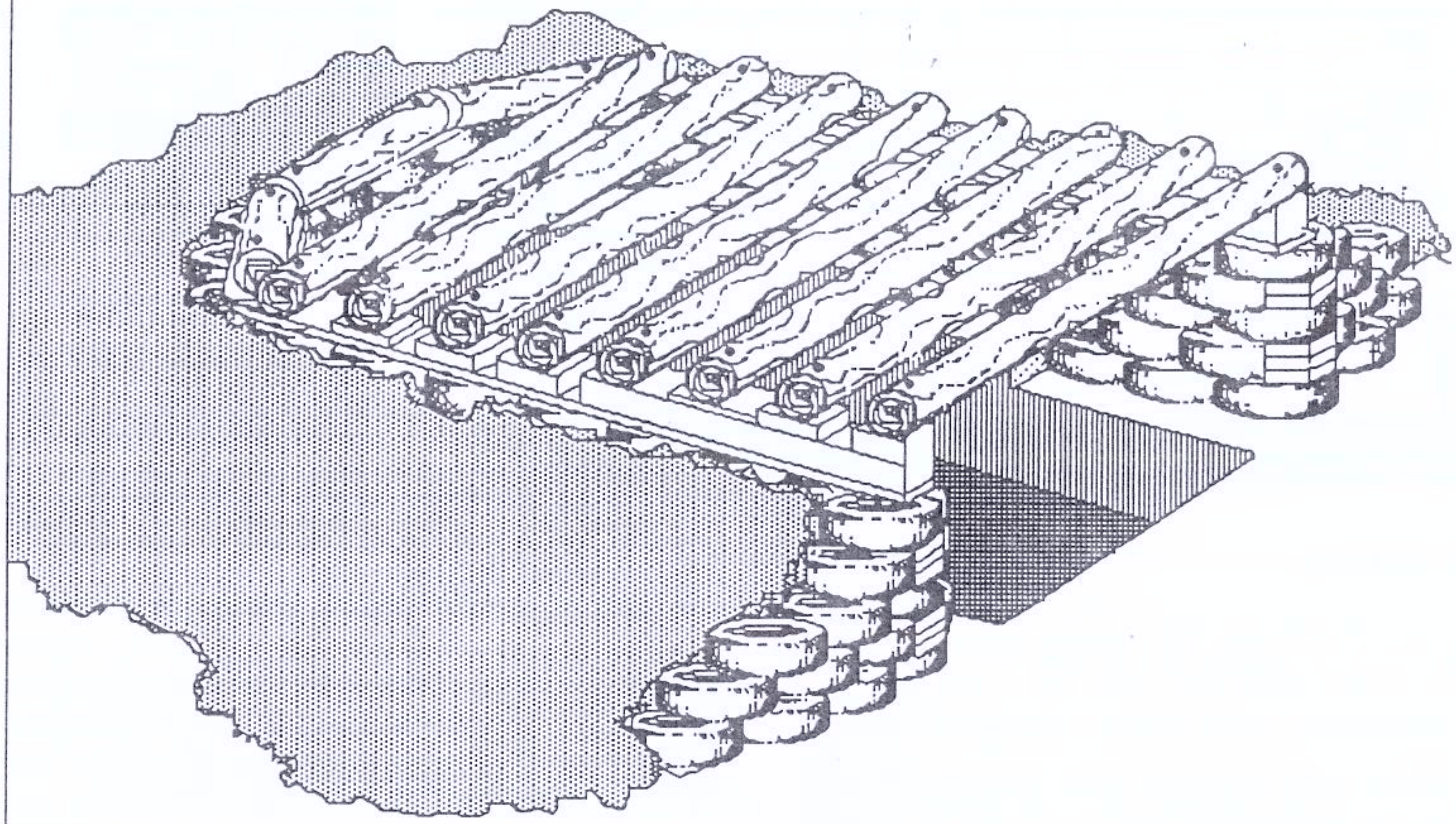
Fig. 49




The beams will be 2'-0" on center. Cut and nail 2x6's to make blocking which will raise the beams to the correct height. Small blocks can be nailed into the plate and to each other. Continue pinning the beams with rebar **through the blocking into the plate.** (Fig. 49) Be careful not to drive pins into concrete around anchor bolts. The concrete will shatter and the anchor bolts will be worthless.

When vigas are used, alternate large and small ends for a neater over all appearance.

Fig. 50



The "U" module is now ready for can infill, roof decking, and perimeter insulation.

Fig. 51

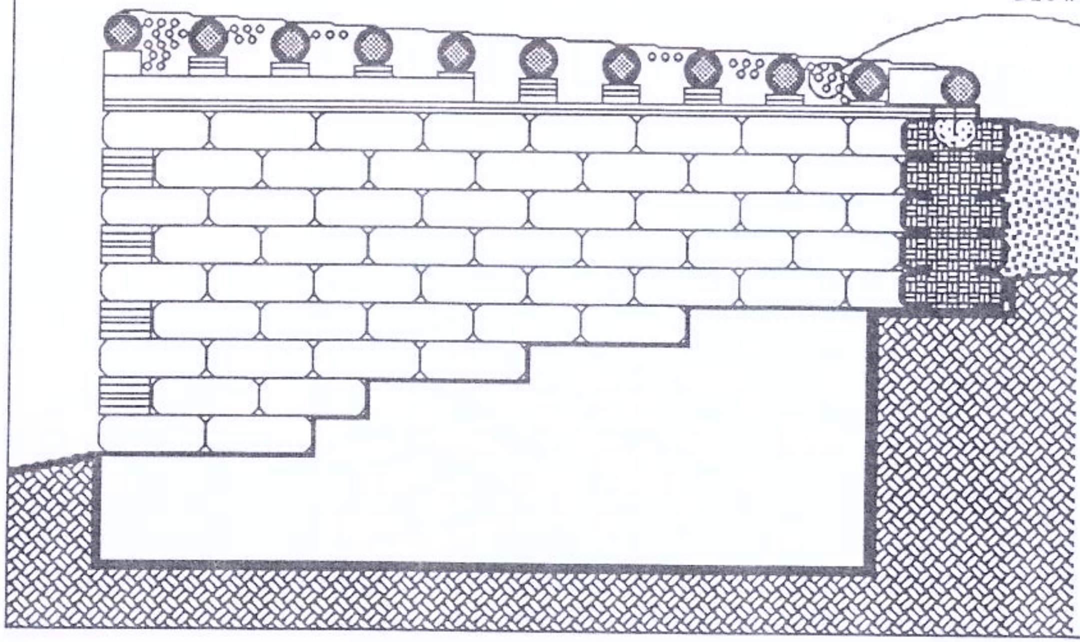
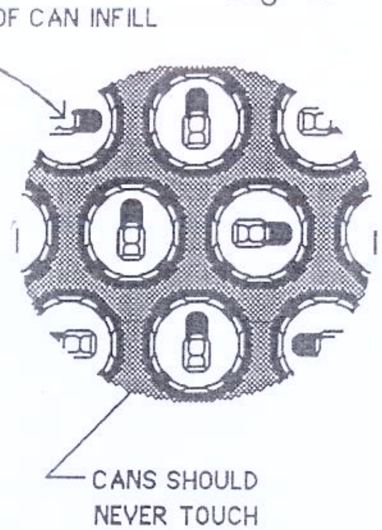


Fig. 52




## CAN INFILL

The spaces between the beams and blocking will be filled, from the plate up to the string, with aluminum cans set in a cement mortar. (Fig. 51)

Cans are laid in a cement mortar mixture which is 3 parts course sand to 1 part portland cement. This can be mixed in a wheelbarrow or a concrete mixer, depending on how much you will be mixing at once. <u>Regular portland cement should be used</u>.

<u>The cans themselves are not structural</u>; they act as spacers within a perforated concrete network. **It is the matrix of concrete which gives the can wall its strength.**

In this situation, all cans should be laid with the mouth facing toward the inside of the room. The mouths will act as a metal lath to hold the plaster later. (Fig. 52)

Fig. 53

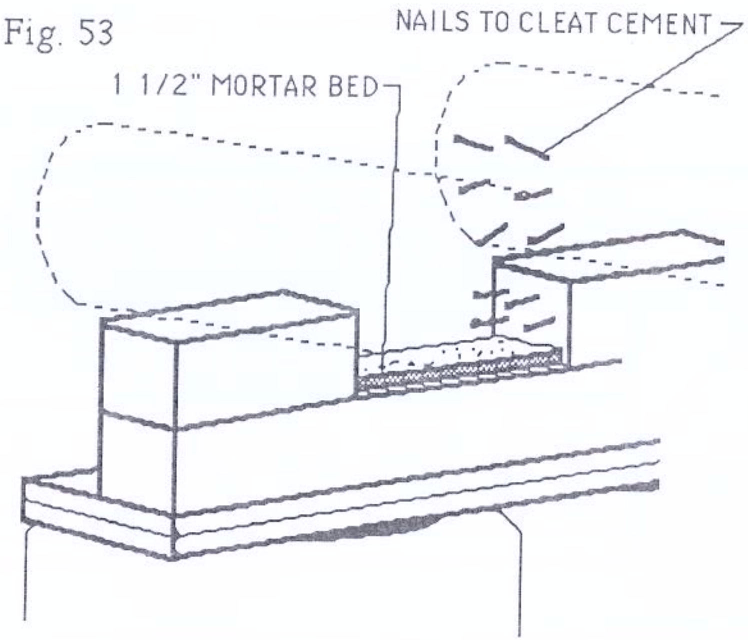
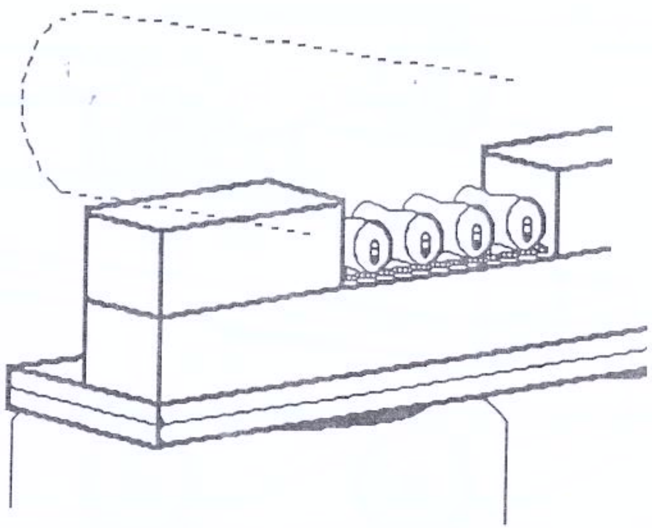



Fig. 54



Always wear rubber gloves whenever you are working with portland cement. It will irritate your skin.

The mortar should be a stiff mix, so that it does not ooze out from around the cans. A loose wet mix would make this operation very difficult.

Drive a few nails in the wood where the cans and cement will make contact with the wood. This anchors the cement work to the woodwork.

Now, lay a 1 1/2" bed of mortar on the blocking. It should be about 3 1/2" wide. (Fig. 53)

Slightly crimp each can, so that once the mortar is dry, it cannot be pushed out of the wall. Lay the cans about 3/4" apart, flush with the inside of the blocking. (Fig. 54)

**Never let the cans touch each other. This would interrupt the structural concrete matrix.**

Fig. 55

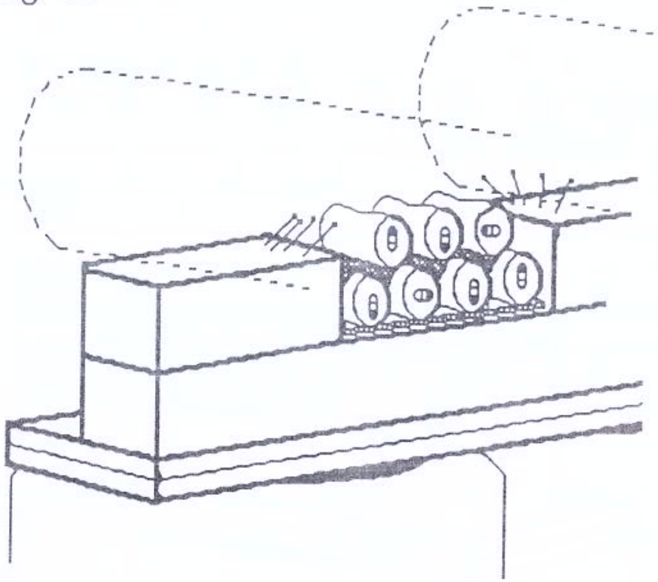
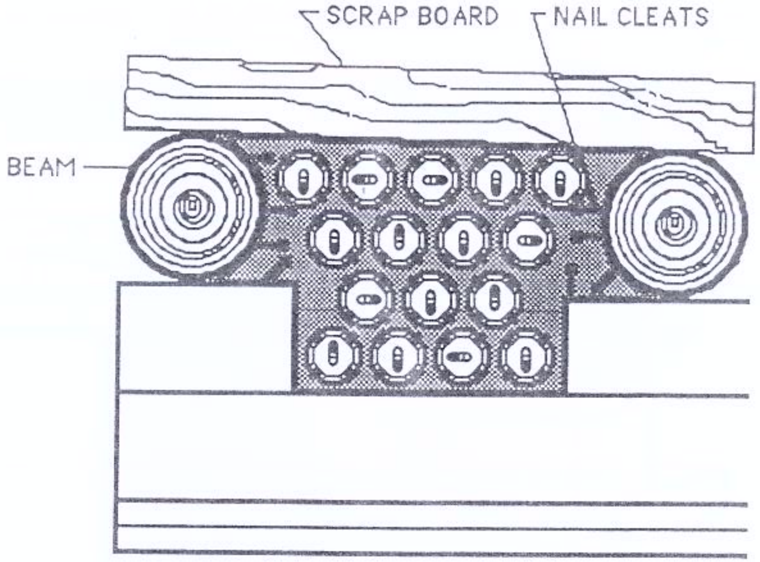


Fig. 56




Lay another bed of mortar on the center of the first course of cans, and add another row of cans. If the mortar is oozing out and running, it is too wet. (Fig 55)

Continue the process until you reach the string. (Fig. 56) Use a scrap board for a straight edge to assure that you have cement coming up to the line of the decking which will be applied later.

This process should be done with hands only - (wearing household rubber gloves). Trowels and regular masonry tools will simply slow you down. Your mortar should be stiff enough to allow the whole area to be filled at once.

Fig. 57

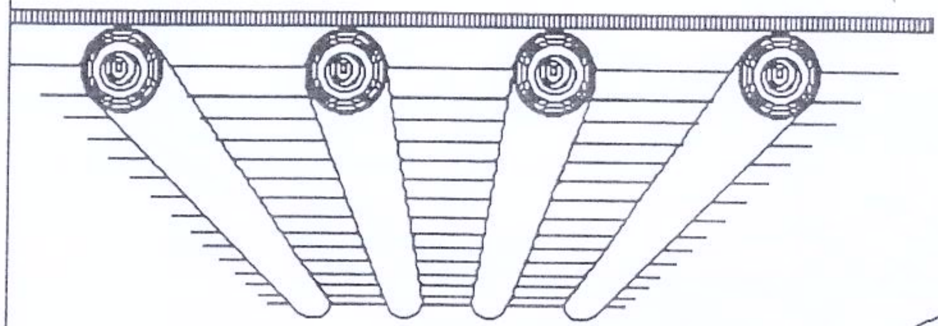


Fig. 58

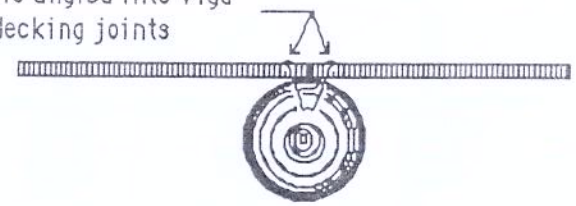
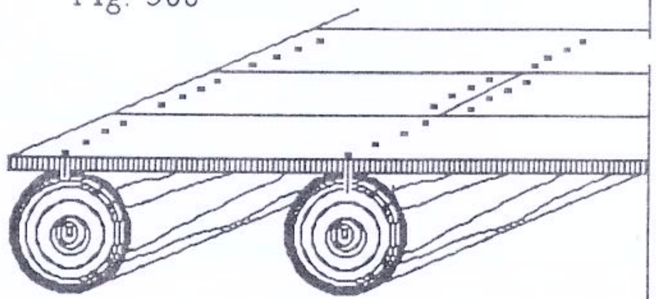



Fig. 58b



## ROOF DECKING

The roof decking can be made of any wood material, but keep in mind that this will be visible as your ceiling. (Fig. 57)

This wood should be a minimum 5/8" thick. Rough sawn 1x12 lumber is recommended, because it is cheap and looks nice, however it is not always available. Other usable materials include 1x8 dimension lumber, 1x6 tongue and groove, or any planking 6" or wider.

Lay the roof decking side by side, perpendicular to the beams. Nail it down into the beams with 16cc nails. (Fig. 58b). Keep the nailing over the center of the beam or it will show from below. Slope the nailing at the joints (figure 58a). This will keep nails from showing below. Start from one side and work towards the other side.

Stop at the point where the skylight is to be placed. Install the skylight and then continue laying the roof deck around the skylight box. (Fig. 59)

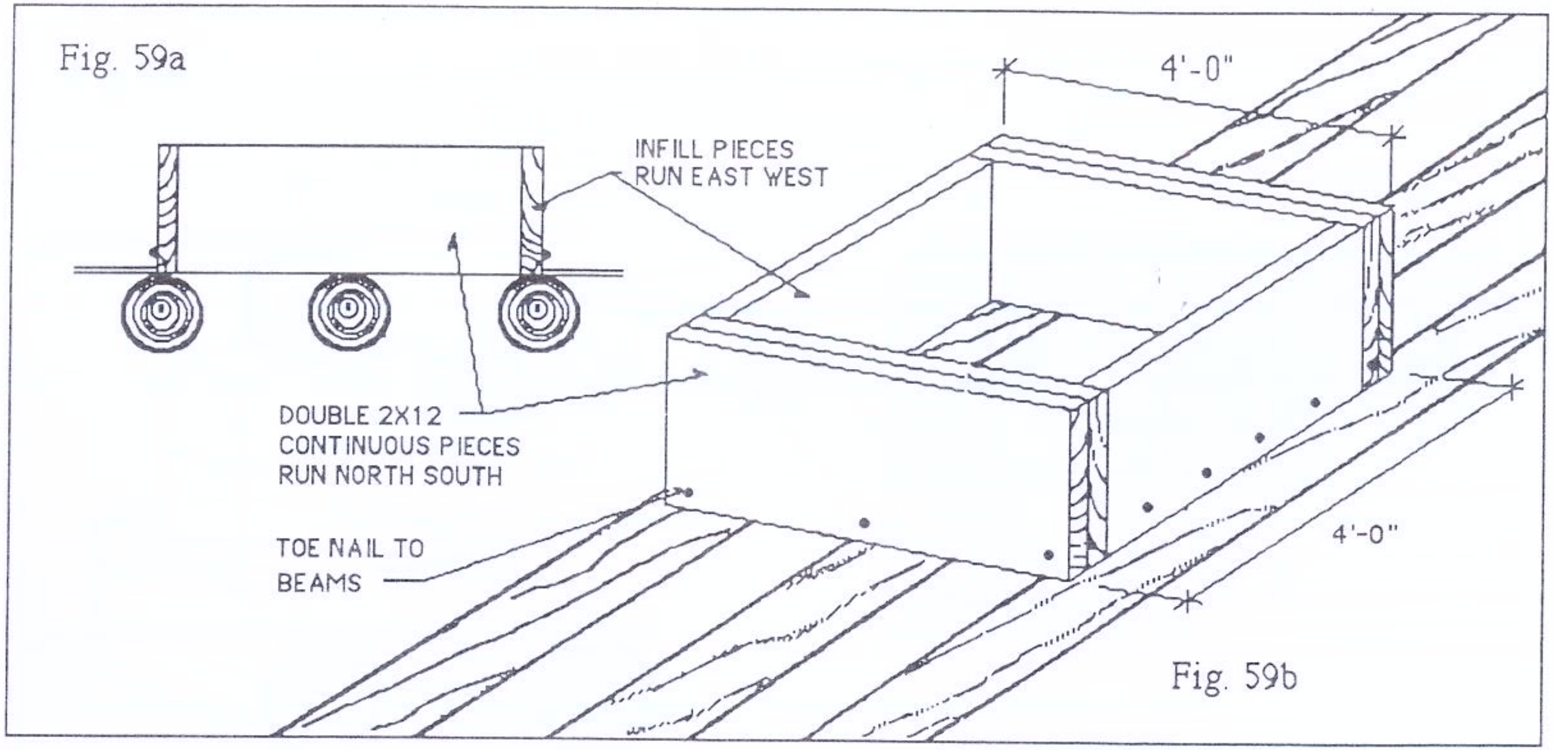
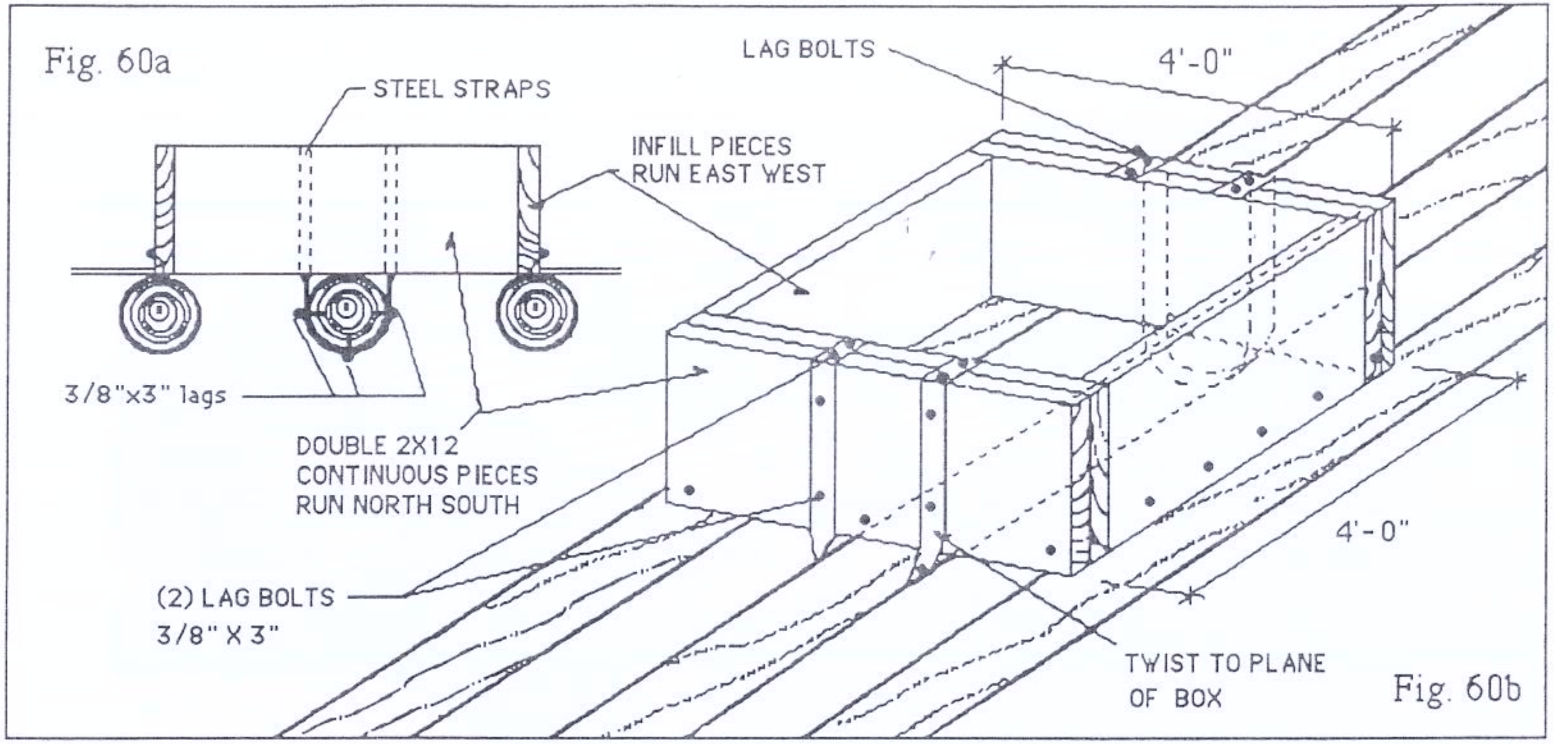



Fig. 59a

Fig. 59b

## SKYLIGHT BOX

The skylight box is simply a 4'-0" square box made from 2x12 stock. In piecing together the box make sure the pieces that run north-south are continuous for the full 4'-0". They should also be doubled. They must get a good "seat" on the beams. Sometimes the middle beam is later cut out and the cut ends are hung from this double member. Toe nail the skylight box to beams. Make sure the skylight box is built and installed square.

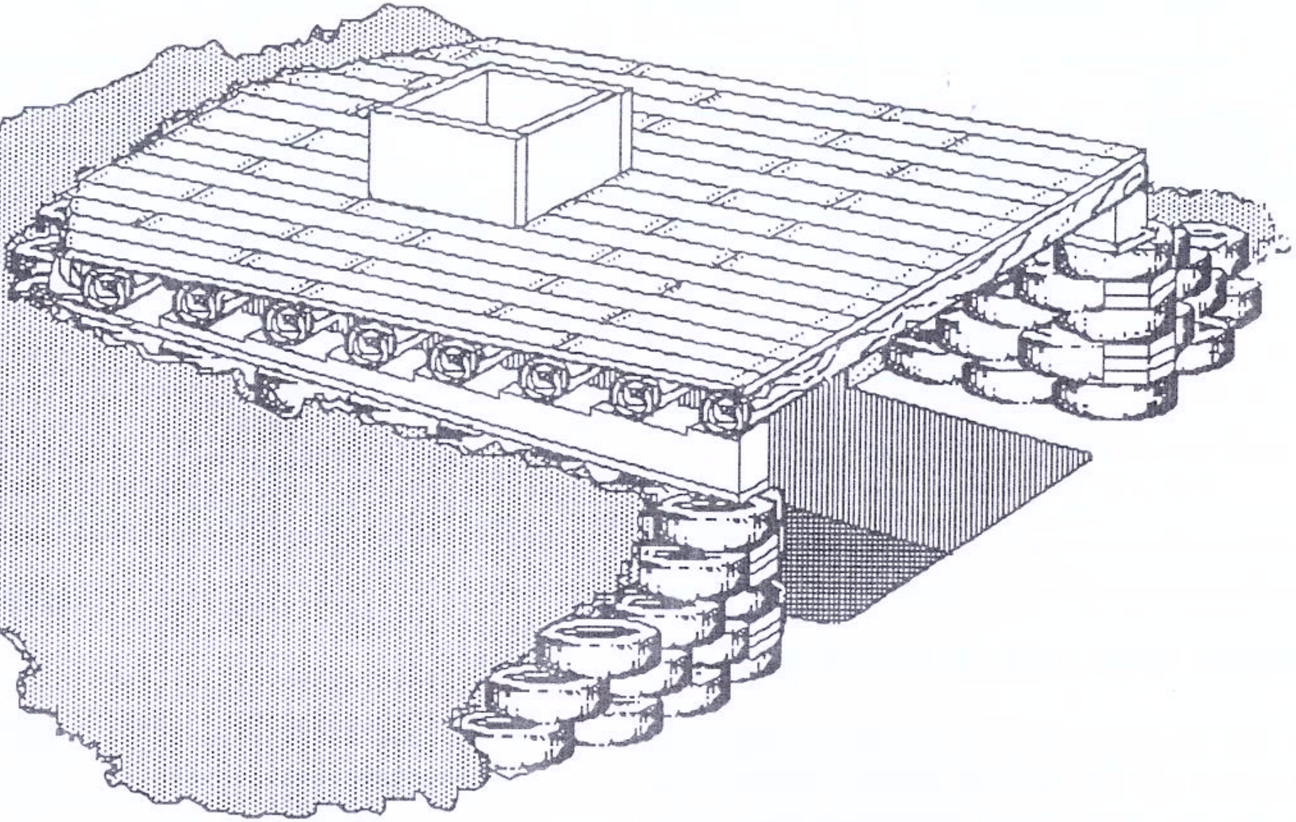



## CUTTING OUT THE MIDDLE BEAM

After the skylight box is installed you may want to cut out the middle beam. Before you cut it out, the ends of the beam are hung with 1/8" x 2" steel straps as shown in Fig. 60. The straps are wrapped around the beam then twisted to the plane of the box and folded over the top of the box. Use 3/8" x 3" lag bolts to screw the straps to the skylight box as shown. The straps must also be screwed to the beam with (3) 3/8" x 3" lag bolts. This is to insure that the strap will not slip off the beam. The beams tend to shrink and the strap gets loose without these bolts.

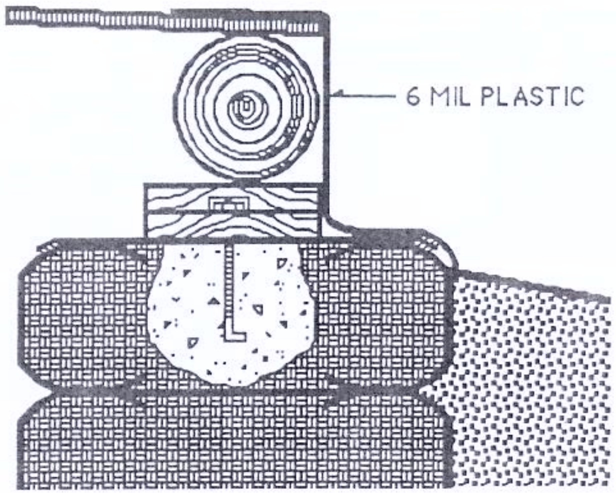
Now the beam can simply be cut out with a chainsaw.

Fig. 61



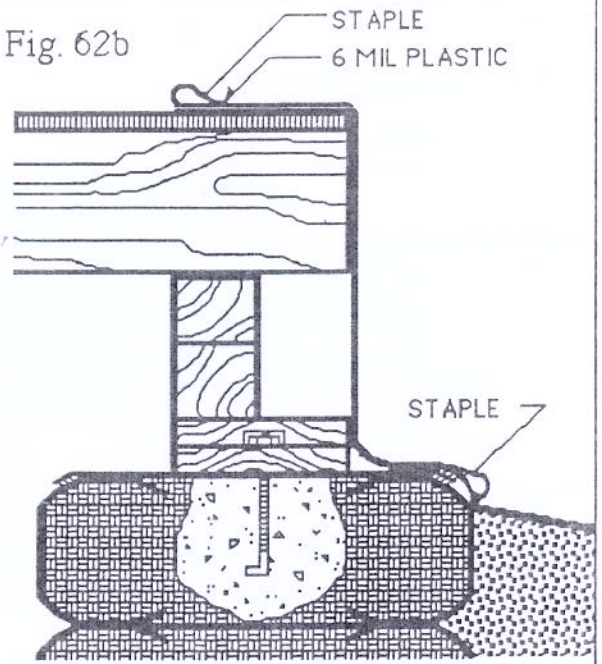
Your "U" module should now look like this.

Fig. 62a




NORTH END SECTION DETAIL

Fig. 62b




EAST OR WEST SECTION DETAIL

## VAPOR BARRIER

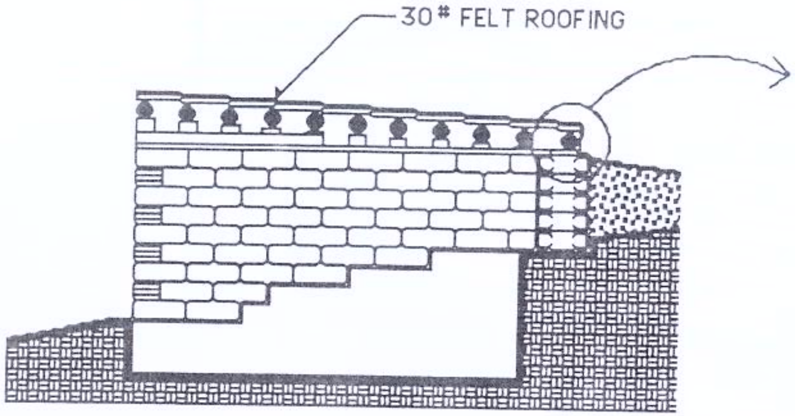
Now, paint all the wood on the perimeter with 2 coats of wood preservative. This will guard it against moisture and bugs.

Then, a vapor barrier must be applied. A vapor barrier usually goes on the warm side of the insulation.

Staple 6 mil. plastic to the perimeter of the roof decking and drape it over the wood, down over the top tire. (Figs. 62a-b)

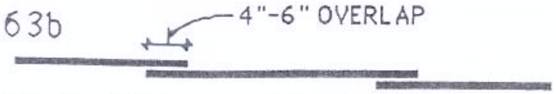
Fold over the end of the plastic to make it double ply, so that the staples do not tear the plastic.

Fig. 63a



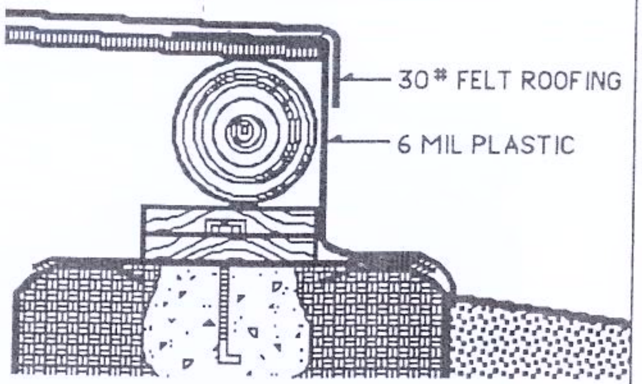

SINGLE "U" SECTION

Fig. 63b




OVERLAP OF 30# FELT ROOFING

Fig. 63c




NORTH END SECTION DETAIL

Next, you will apply 30# felt roofing to the roof deck. (Fig. 63a)

This material comes in a roll. Begin at the north end, rolling out the roofing and stapling it to the roof deck. Overlap the seams about 4"-6" and staple. (Fig. 63b)

This should also overlap the 6 mil. plastic at the perimeter. (Fig. 63c)

This 30# felt provides a vapor barrier on the warm side of the roof insulation.

The wind will rip this material off no matter how much you staple it. For this reason you should do it just before you insulate the roof.

Fig. 64

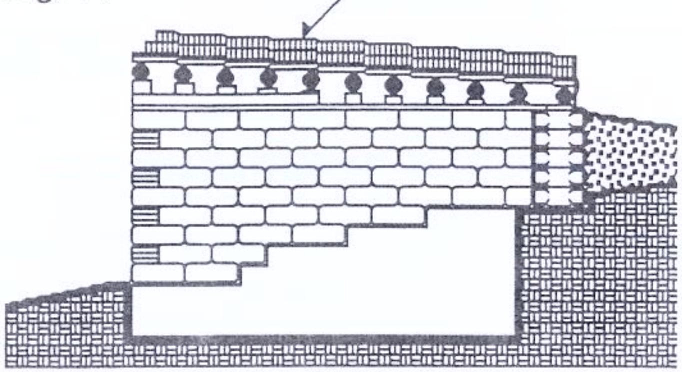
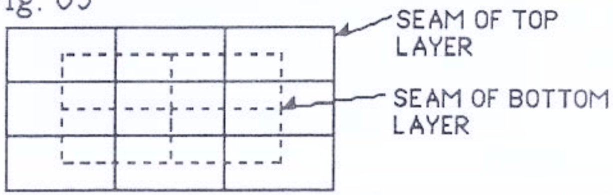
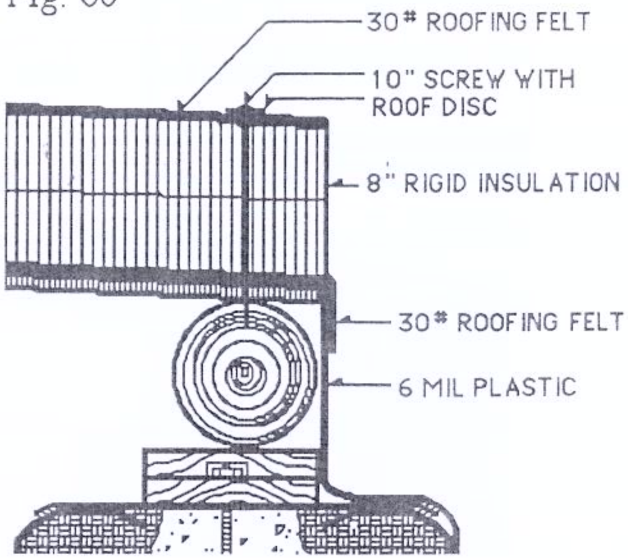



Fig. 65




PLAN VIEW OF INSULATION LAYOUT

Fig. 66




NORTH END

## INSULATING THE ROOF AND PERIMETER

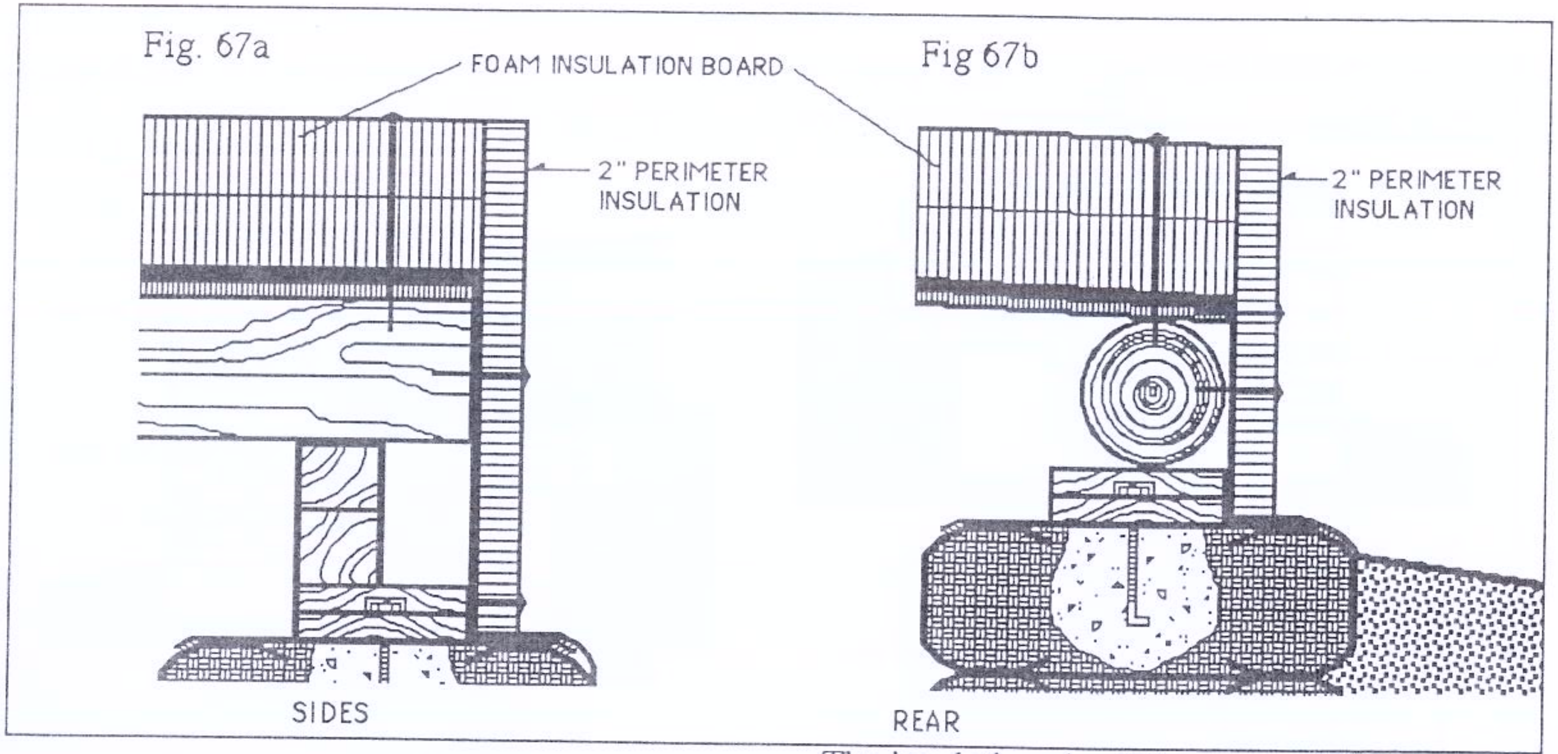
Insulative qualities are measured in "R-values." Since most heat would be lost through the roof of the structure, it should have a <u>minimum</u> R-60. 8" of foam insulation board, plus the added insulative qualities of the deck and roofing materials, will be sufficient. (Fig. 64)

There are many brand names of rigid insulation. Choose one that provides R60 (or close to it) for 8".

Foam insulation board comes in 4'x8' sheets, 4" thick. You will use two layers. The seams of the two layers should be staggered to prevent any seams from lining up for the full 8" (Fig. 65).

Screw the insulation through the decking into the beams using 10" deck screws with roof discs. (Fig. 66). 9" gutter spikes with roof discs can also be used for this.

It is important that you bolt or spike <u>into the beams</u>; otherwise the bolts will show on the interior ceiling.



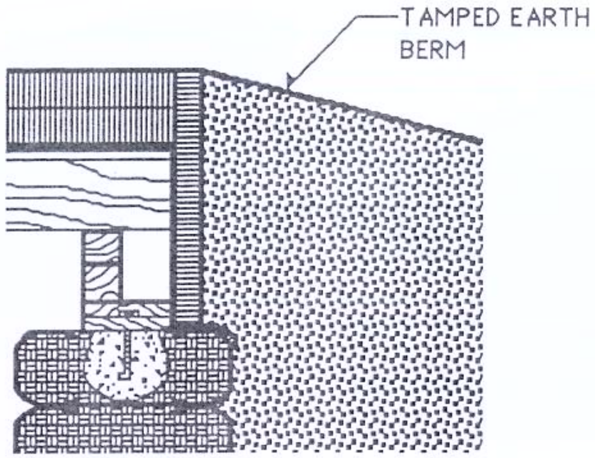

It is best to tack the first 4" layer of insulation down with a few 6" barn spikes (over the beams only). Then apply the next layer staggering the joints and using the 10" screws or spikes with roof discs. Again just tack it down with a few screws or spikes as it will be permanently fastened with the application of the roof underlayment.

The deck screws are difficult to find. They can be ordered through a commercial roofing contractor.

The insulation should be stopped 12" short on the south end, where the greenhouse will attach. (Fig. 69a) This gap will be filled in later. Stop insulation flush with the beams at the sides and rear.

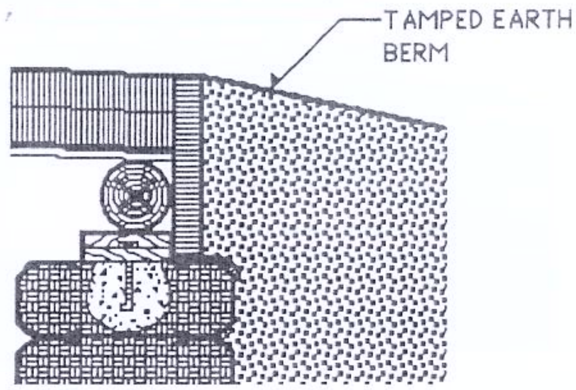
The perimeter space behind the can infill and beams down to the tire wall will also need to be insulated. Using 16cc nails driven through roof discs, nail 2" of rigid waterproof perimeter insulation into the beams, all the way around the structure. This should be level with the top of the foam insulation board. (Figs. 67a-b)

Fig. 68a




SIDES

Fig. 68b




REAR

## THE FIRST BURIAL

Next, finish berming up to the top of the roof insulation. Now, have the backhoe driver tamp this earth by back-dragging with the scoop. (Figs. 68a-b)

The underlayment for the roofing can be installed now. It is 30# or 40# roofing paper. It is spiked or screwed on through the insulation to the beams with spikes or screws and roof discs.

This process permanently installs both the insulation and the roof underlayment. This should happen very soon after tacking down the rigid insulation as the rigid urethane type insulation should not get wet. Use about 8 screws or spikes per 4x8 sheet. Place screws or spikes over beams. Locate the beams on top of roofing paper and snap a chalk line to guide your nailing.

Fig. 69a

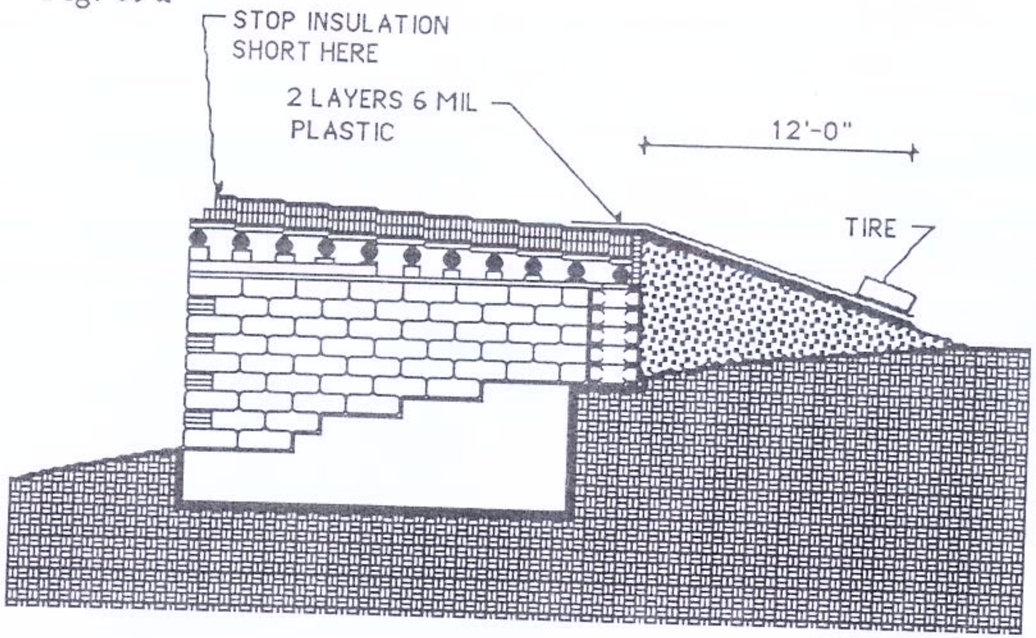
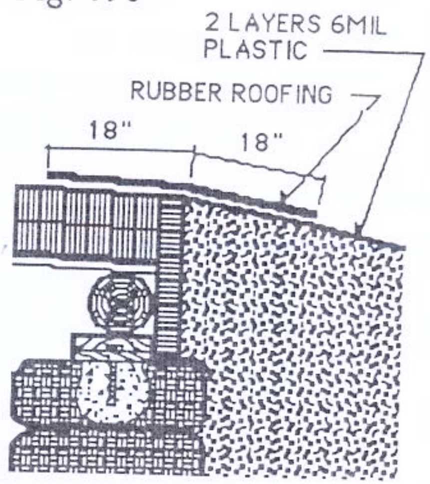



Fig. 69b



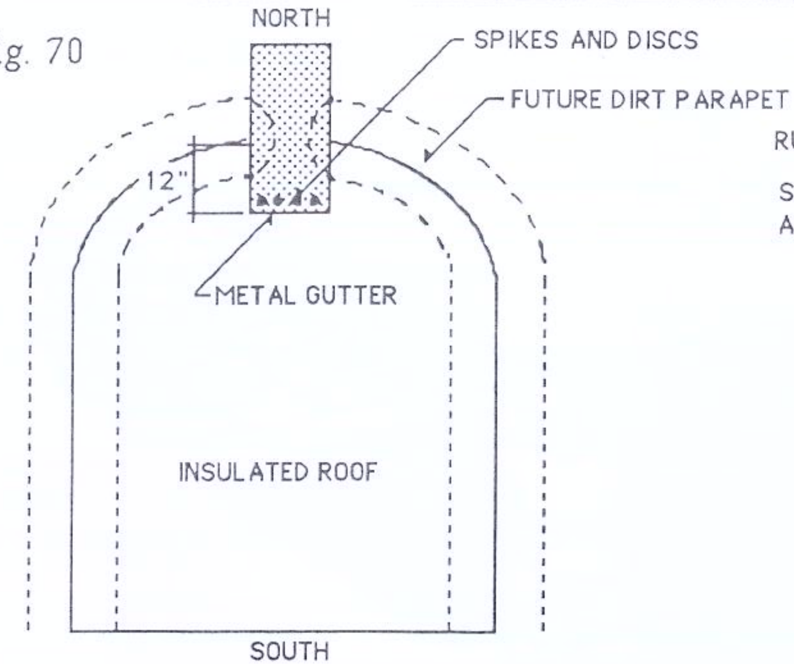

## ROOFING OVER THE BERM

Staple 2 layers of 6 mil plastic (or one layer of 10 mil) to the foam insulation. Drape it over the sloping berm all the way around the "U" until it is about 12'-0" away from the structure. Weight it down temporarily with empty tires. (Fig. 69a)

The joint between the structure and the dirt must now be covered and reinforced with heavy rubber roofing. (Fig. 69b) It comes in a roll and there are many manufacturers. Consult a roofer or building supply store.

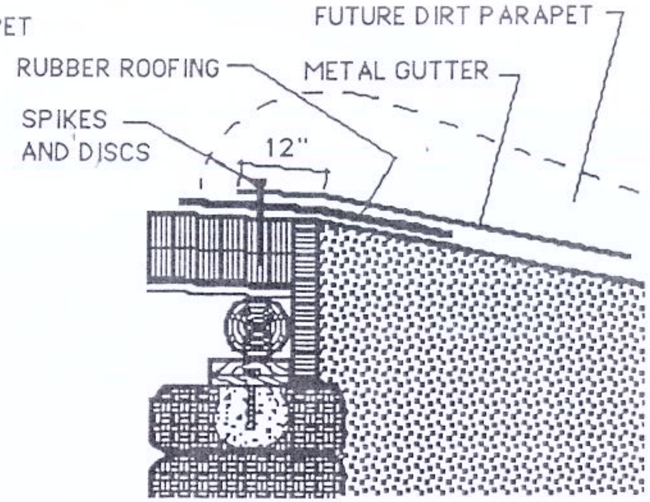
This roofing comes 3'-0" wide and should be installed half on and half off the structure for a good overlap at the joint. It can be melted on or glued with tar. A roofing contractor should be consulted for roofing materials in your area. Listen to the roofing contractor as far as how to handle the materials but follow these instructions for roofing this type of building.

Fig. 70




PLAN OF ROOF

Fig. 71




## DRAINAGE

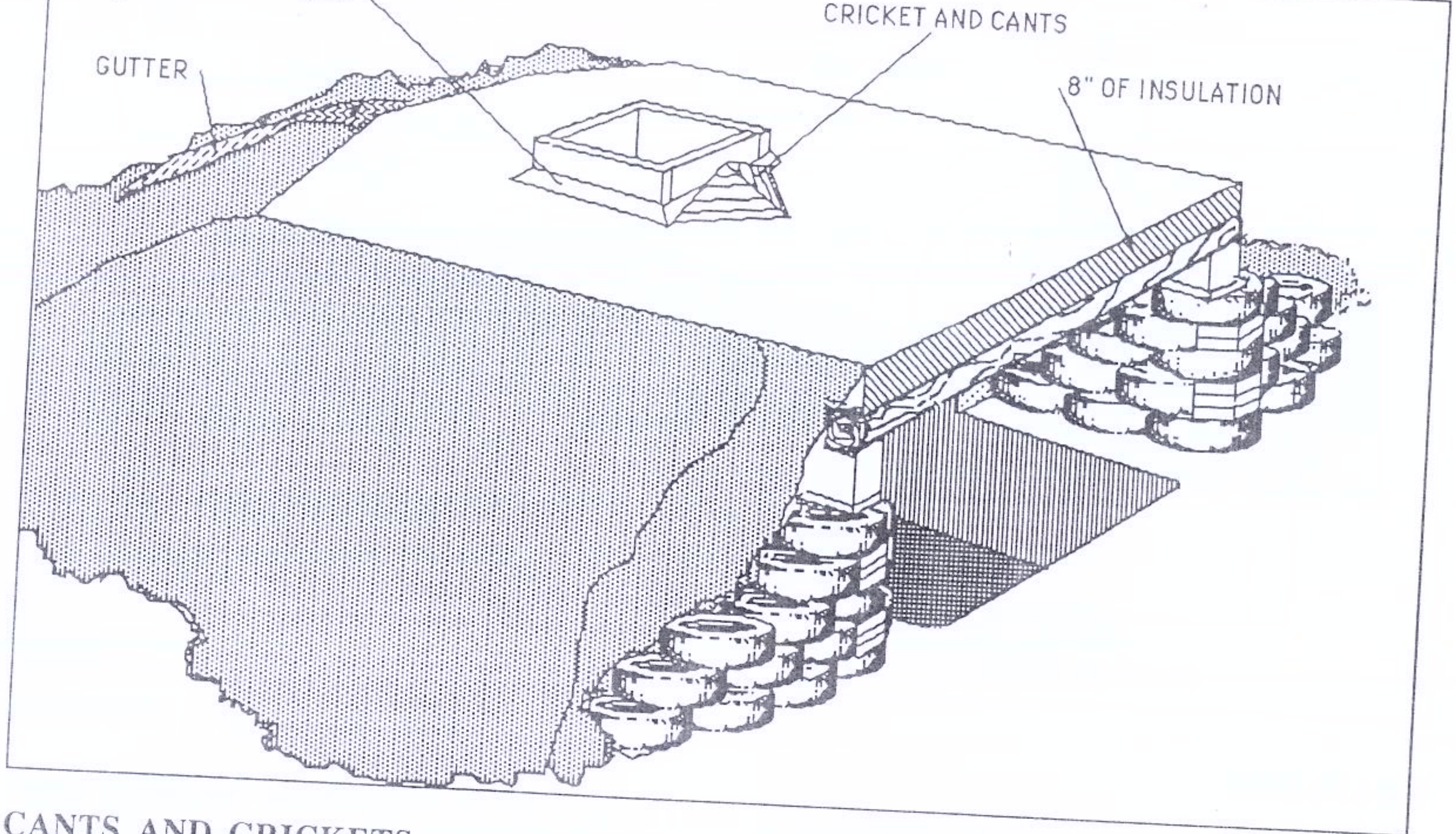
Water will be channeled from the roof down a canal until it is well away from the structure. This will be achieved by forming a dirt parapet which will channel water into a metal gutter. The metal gutter is laid before the final roofing, and before the dirt parapet is formed .

The canal is centered in the back of the U, at the lowest point of the roof. (Fig. 70)

Lay a 3'x8' piece of 26 or 28 gauge sheet metal overlapping on to the roof by about 1'-0" and sloping down over the berm. (Fig. 71) Spike or screw it in with the same spikes and discs you used for attaching the insulation.

The sheet metal used should be painted with tar on the underside and with an earth color paint on the top, to prevent it from rusting.

Fig. 72

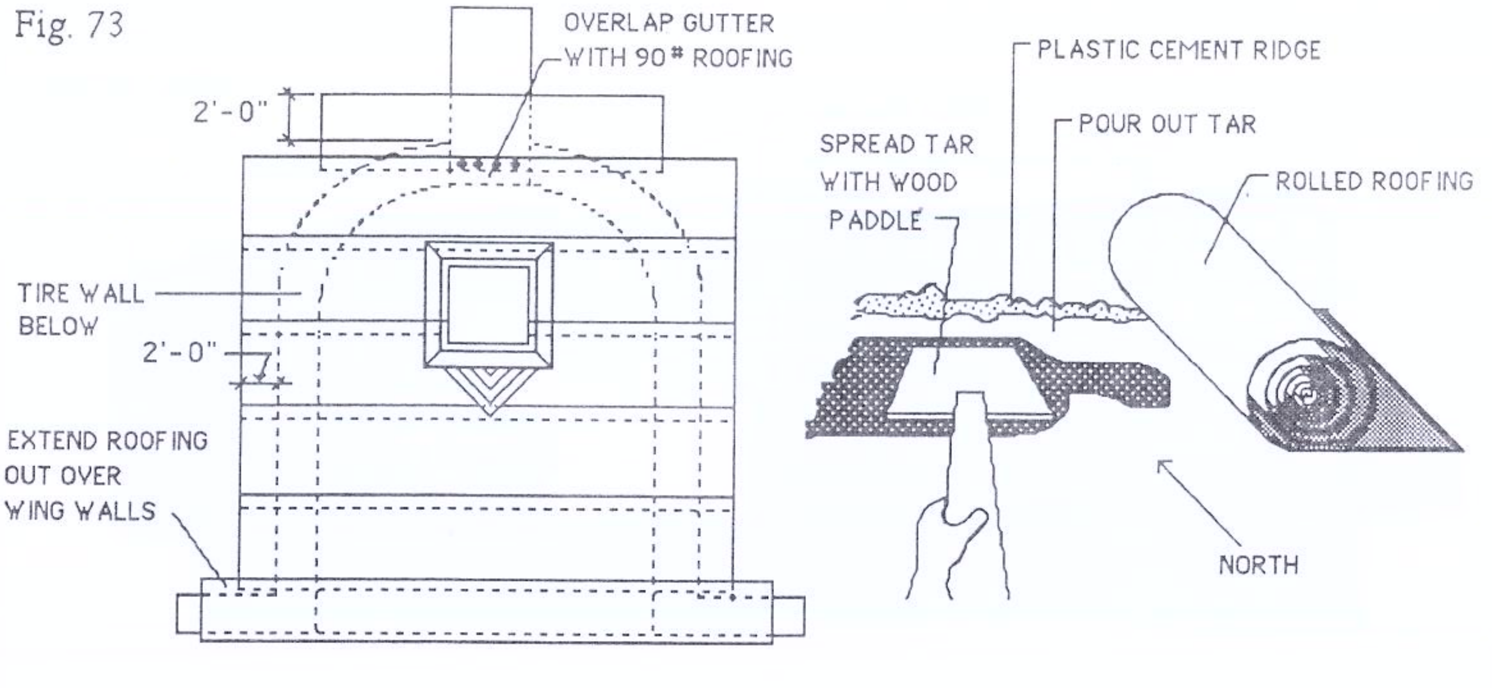



## CANTS AND CRICKETS

Cants are angular (45°) prisms of foam insulation board placed against the skylight box on four sides. The cants guide the roofing up against and on to the skylight box (figure 72). These are installed now and roof underlayment (30# felt) is installed over them.

Crickets are built up layers of plywood or celotex on the uphill side of roof openings to direct water around them. These are glued down with tar, spiked and roofed over (figure 72).

Fig. 73

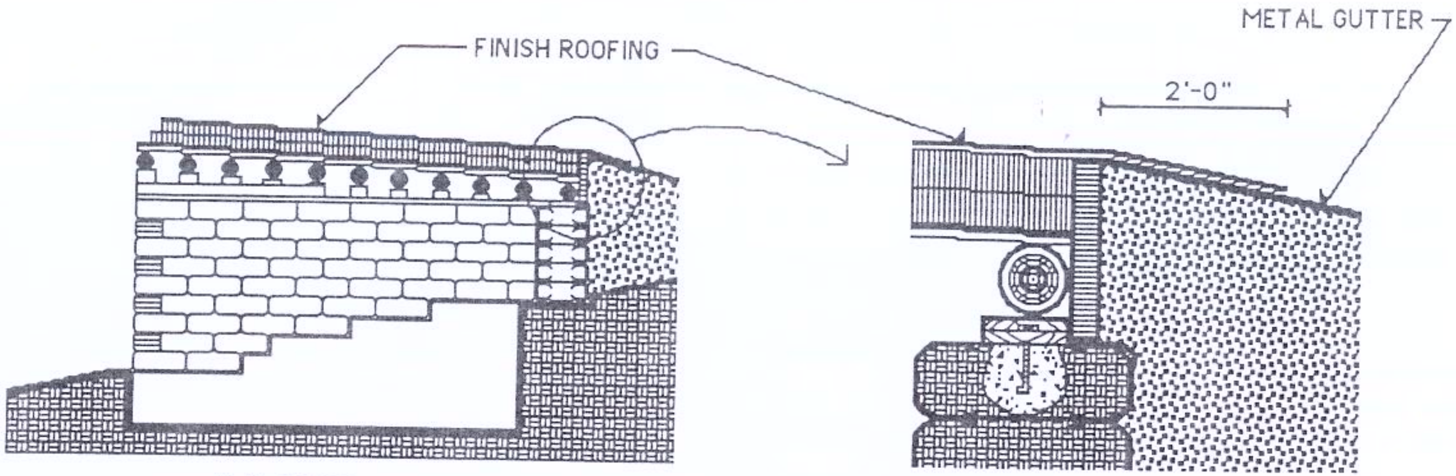



## COLD PROCESS ROOFING

Now 90# rolled roofing is applied over the underlayment with cold process tar. This tar is available at builders supply store along with the 90# roofing. The tar is poured out in the path of the roll, spreading it out with a scrap wood paddle. This is very similar to applying paste for wallpaper. Due to the roof slope, the tar will run north. This can be prevented by first running a little ridge of plastic cement (another tar product) along the north edge of the roll. This will act as a seal for the lap joints as well as a dam for the cold process tar.

Take roofing out 2'-0" over the edge of the building, and extend roofing out over tamped earth at wing walls (Fig. 72).

Fig. 74a Fig. 74b




"U" SECTION REAR DETAIL

## ROOFING ALTERNATIVES

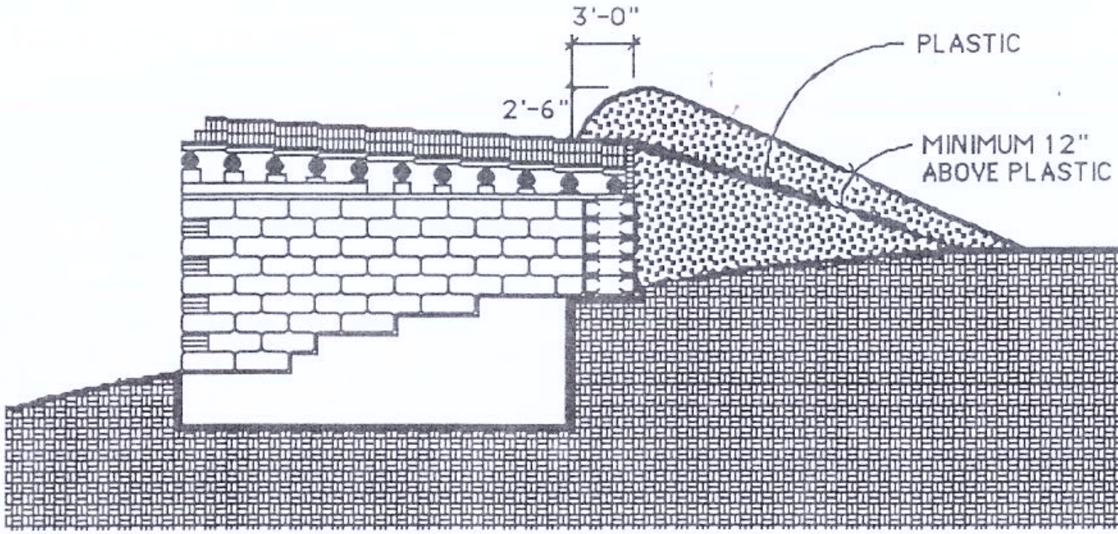
Several different types of roofing can be used for the final layer. Your choice will depend on your budget. The rubber roofing, which is applied using a heat process, is recommended, however it is relatively expensive. Consult a roofer in your area for other choices.

A cold process tar roof is the cheapest and easiest and can always have a rubber roof installed over it later.

When you begin, bring the roofing out over the rubber roofing used to cover the seam between structure and dirt (discussed Fig. 69b) and out over the first 2'-0" of the metal gutter (figure 74b).

Regardless of the type of roofing you use, always begin at the back or north of the structure and overlap the seams 4" to 6" (Fig. 63b).

Fig. 75



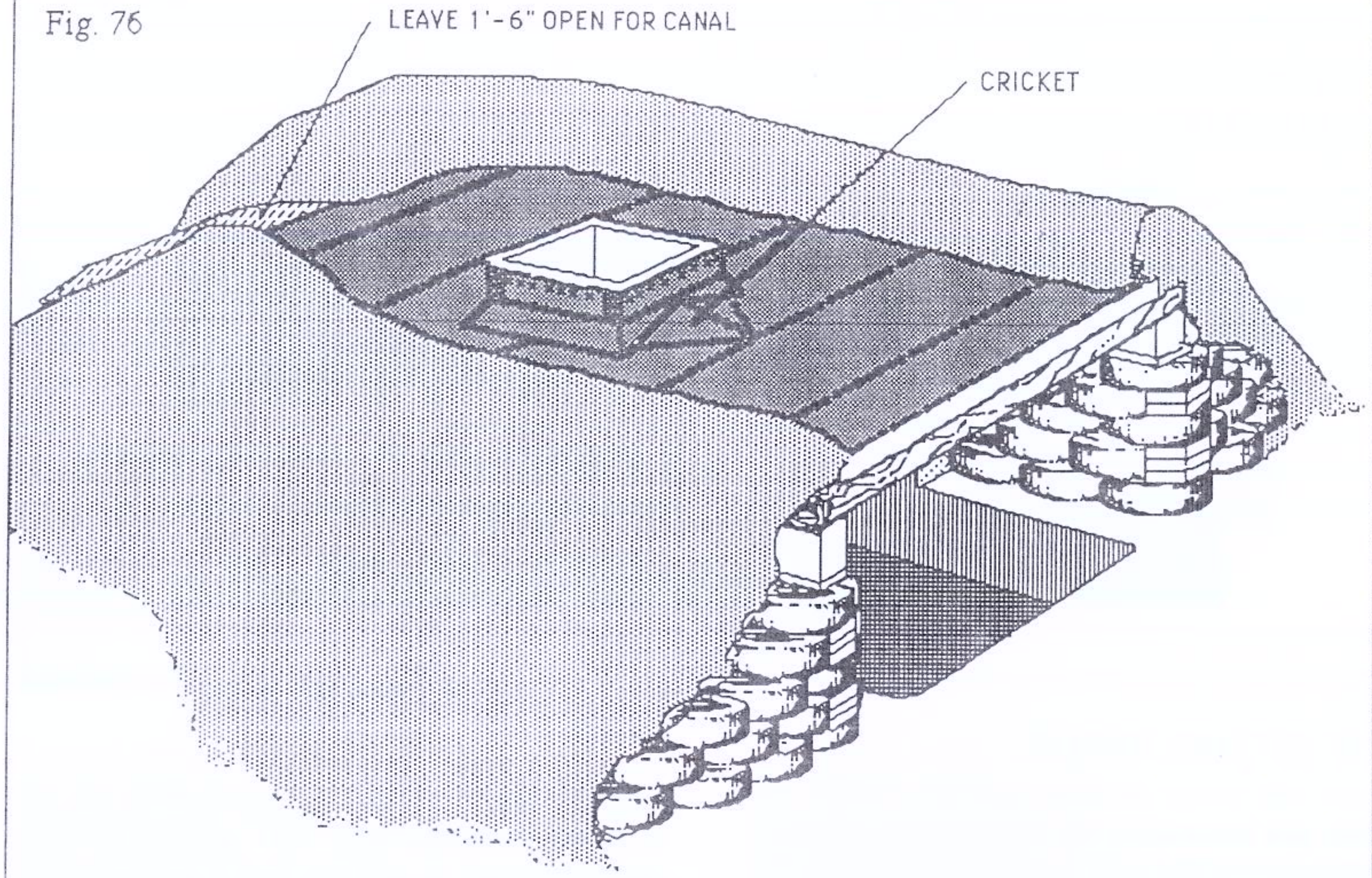

## THE SECOND BURIAL

Now, you must form the dirt parapet. Simply berm up over the roof to a height of about 2'-6". This will overlap the roof structure about 3'-0". Continue the berm out to cover the plastic with a minimum of 12" of earth compressed with the backhoe. (Fig. 75)

Taper the berm down toward the canal, leaving about 1'-6" of sheet metal showing. (Fig. 76)

You now have a weather proof "U". It is very important to note that the greenhouse and other detailing should not be started until the "U" is "captured and "dried in" to the extent illustrated here. A common mistake is not weatherproofing the "U" before going on to other details. This method of construction requires immediate roofing and site shaping around "U"s, as illustrated in fig. 76,to divert surface water.

Fig. 76




A captured "U".