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Section I — Introduction

Domes have been a primary shelter for man for centuries. Many primitive people used blocks of snow to make igloos (a dome) or reeds tied in a circular fashion for a shelter (also a type of dome). The wickiup, the yurt, and the wigwam are all types of domes.

Most domes were built where large structural pieces were not available. Today it is quite easy to span one, two or even several hundred feet with modern steel beams and even laminated wood beams. But in the past, the architects had only small pieces with which to make that span. These small pieces could be placed in the shape of a dome to create very large structures.

Most of the surviving structures of the Roman Empire and the Middle Ages that have any size are rock domes. These were created by using the same features as the arch, except that in the case of a dome, there is an infinite number of arches through any one place. The rock would be piled on special scaffolds that would create the infinite arches and then the scaffolding or the dirt that was holding the rock up would be removed.

The Roman Pantheon is a good example of a building constructed about 126 A.D. utilizing concrete in place of rock This is the first major "monolithic" concrete structure. Still in use today, the Pantheon has a diameter of 140 feet.

In about 1940, Bill Neff came up with his method of building inflated structures. He would inflate a dome and spray concrete onto it from the outside. This is still being done by a few contractors. Lloyd Turner was the next serious entrant into building inflatable form structures. He would inflate a plastic membrane and spray it with polyurethane foam. He later amended his patent to include the use of concrete on a self-supporting foam dome.

The first Monolithic Dome was built in 1976. This was a major breakthrough. No longer was the foam doing the supporting of the structure. Concrete was holding the structure up. By utilizing this technique, very large domes can be air formed.

To date, Monolithic Domes have been used for schools, churches, factories, storages for both bulk material and others, cold storages, homes, etc.

The huge advantage of the energy efficient Monolithic Dome over conventional structures is even more pronounced in the third world countries where the large structural beams are not readily available.

Section II — Site

The first consideration for the Monolithic Dome is its site or location. No construction should be started until the site has been analyzed. There MUST be adequate drainage for the structure both during construction and after completion. The Monolithic Dome is virtually independent of soil bearing for many applications. The "footprint" of the Monolithic Dome is generally very light.

The enormous strength derived from the dome shell makes it very tolerable to differential settlement and other site problems. Nevertheless, site conditions should be known for any necessary engineering adjustments to be made ahead of the actual start of construction.

If the site should require leveling, it should be done with comparable compaction underneath the entire footing. In other words, if some areas are going to be excavated and other areas filled, those areas to be excavated should be over-excavated, and the entire area should be filled to insure even bearing under the structure. If the structure differentially settles, it will not do nearly as much damage to the structure as it will to the interior structure (floor, columns or whatever is on the inside of the building).

In extreme cases, the soil bearing for the floor loads is far more important than the soil bearing for the structure. Obviously, these can all be checked ahead of time, and if some settlement of the floor is not a problem, then many sites can be used that would otherwise require piling.

In general, piling will not be required for Monolithic Domes. They can easily be built on piling if that is deemed necessary. Most often granular fill is all that is necessary under the footings. The higher the dome is raised on granular fill, the larger the trapezoidal area and thence the smaller the soil bearing has to be. It is not unusual to put a Monolithic Dome on 1000 PSF soil. In extreme cases, they have been put on ground with much lighter loadings.

In addition to considering the soil bearing and the drainage, accessibility of electrical power and water is necessary. Water should be potable. It is primarily used for cleaning the concrete equipment. In some cases, the water is used in making the concrete.

The electricity should be an absolute minimum of a 100 amp 220 volt single phase circuit. It takes approximately this much electricity to run the foam machine, adequate lights and the scaffolding.

As construction proceeds very rapidly, it is important that the electricity, water and road accessibility be in place before any construction begins.

In addition to the other necessities, sometimes it is very helpful to have on site a construction office, a construction shop, and a storage location.

If there is a potential danger to any visitors, the area should be fenced. Again, common sense should prevail on these auxiliary measures. These measures would include yard lighting, security, etc.

Section III – Footing

Once a site has been selected, and the soil bearing has been determined, the engineer must design the footing.

This construction manual will not treat footing design except to say that you as the contractor must look at the footing for its width and its depth and compare it to previous norms for the structure intended. Obviously, you would not want a very narrow footing if terrible soil conditions exist. On the other hand, it does not make sense to have a wide footing if you are building on a granite mountain.

The footing should be cast in place per the engineers specifications. The following are a few items that should always be considered:

Soil Compaction

Be sure the soil has been compacted evenly under the footing, and that good bearing contact has been made with the ground.

You are building a structure with a life span measured in centuries. It is important, therefore, that care be taken to protect the reinforcing steel by having adequate concrete cover. Most buildings will last only a few decades and corrosion of the reinforcing steel is not much of a problem.

The steel that holds up the building is primarily located in the footing. This, of course, gives it good fire protection but the rebar reinforcement needs to be protected.

If the soils are damaging to concrete, extra care should be taken. Probably the best protection for concrete is to use adequate amounts of cement. Normally a three thousand pound concrete mix is all that is needed in the footing. If the soils are high in sulfates or where concrete has been known to be attacked, be sure to use sulfate resistant cement and increase the richness of the mix.

In addition to a richer mix, more cover over the rebar on all dimensions should be used. If there is going to be an even more severe attack on the concrete, silica fume additives, fly-ash additives, or asphalt coatings on the concrete should be considered.

Doorways

The footing should be set so that it does not extend as high as the bottom of the door. It is very difficult to take the steel under the door if you do not have an adequate footing. The steel reinforcing that goes under the door may be such it requires an extra wide and/or an extra deep footing in the area of the door.

Attaching the Airform

Always remember that the Airform has to be attached to the foundation. This can be done simply by attaching it to the exterior of the foundation by a series of anchor bolts. Where the Airform comes to the ground level, it is nice to have it tucked in with some back fill.

Back Fill

The back fill, should be such that it provides adequate drainage away from the dome. It is a great help, particularly if concrete attacking soils are present, to keep the water away from the footing. Keeping the water from the footing can be accomplished by:

1. Raising the entire structure on a bed of gravel.
2. Placing clay around the exterior on an incline, so that water is forced away from the footing.
3. By asphalting the footing thoroughly before the structure is built. This latter method is somewhat controversial and difficult, but is certainly better than nothing.

Reinforcing Steel

The reinforcing steel in the footing should be placed per the engineer's specifications. The rebar should be blocked up off the bottom of the footing trench by using little concrete blocks rather than stakes driven into the soil. The little concrete blocks become embedded in the concrete footing and provide protection for the rebar.

If a steel stake is driven into the ground and rebar tied to it, corrosion can follow the steel stake out of the ground and up into the footing. Therefore leaving the stakes permanently should be avoided.

Reinforcing for the footing should be lapped per the engineer's specifications and the laps should be staggered around the entire building.

Vibrator

The footing should be placed by using a vibrator. A stinger vibrator not only facilitates the placing of the concrete, it greatly facilitates the concrete entirely encasing the reinforcing steel. In the end analysis, it is the reinforcing steel that is carrying the weight of the building.

Obviously the concrete footing is carrying the load onto the ground, but the tension steel in that footing is holding the building up. By using the vibrator, air can be forced to the surface of the footing, a much lower slump can be used, and a generally better placement is accomplished.

The lower the slump, the stronger the mix. Obviously, it is crazy to attempt to pour "no slump" concrete into a footing. It is recommended that the concrete have a three to six inch slump. It is also imperative that it be a three thousand PSI mix. Therefore, the slump should be considered by the concrete supplier in determining the proper mix design.

Rebar Dowels

The dome will sit on the footing and tend to slide over the footing (or expand), therefore it is important that dowels be brought up from the footing that will be used in the shell. These dowels are as specified by the engineer, sized and spaced as directed. Obviously they must be bent down during the placing of the Airform and the spraying of the foam, and then bent up into the concrete shell. Great care should be taken in placing these dowels so they are properly spaced. The dowels must also be the correct distance from the Airform, otherwise instead of coming up in the concrete, they may come up in the foam, which is wrong and of zero value.

After the dowels are placed, a notch is created in the top of the footing as shown on the engineering drawings. This notch can be made in various ways such as:

1. Using a two by four to tamp out a notch. This usually results in excess concrete being "pounded" up to the

surface. This excess material can then be removed.

2. Forming a notch using little short blocks of wood entirely around the dome. This method is very neat and precise and generally not necessary.
3. The simplest method is to put a rubber glove on or use a small trowel and just dig out an area the size of the notch from the concrete as it begins to set. By digging out this notch, it leaves a rough surface which is perfectly OK, as we are actually wanting a mechanical bond between the shell and the footing.

Screeding

The footing should be screeded off. It is not necessary that it be troweled, and probably not even a good idea to trowel it in the area where the shell sits, as a friction mechanical bond is desirable in this area. That part of the footing that is exposed to the outside and the inside can be dealt with appropriately as needed.

Example

The following is a simple method of installing a good, shallow footing:

1. Level the entire building site to at least 5′ beyond the exterior perimeter.
2. Locate a center stake with a pin or nail to attach a tape measure. The stake must be solid enough to withstand firm tape measure pull without deflection and top of stake should be about one foot above ground.
3. Hook a tape to the pin in the center stake and use the radius of the building size to establish a continuous mark forming a complete circle. A thin line of white cement or lime makes a good marker for this ring.
4. Excavate a trench 3′ wide centered over the mark. The depth of the trench should be the predetermined footing depth. Throw the excavation dirt outside of the trench and level it off. (Note this is an example, dimensions may vary depending on engineering.)
5. Drive stakes 2′ o.c. in the bottom center of the footing all the way around the excavation. Use circle radius measurement for exact location of stakes from the center stake. Stakes should be placed so that inside of stake is the point of measurement. Stakes can be either of metal or wood, but need to be firm. The tops need to be at least one foot above the bottom of the trench. (Remember the thickness of the form material.)
6. Set up a level in the center area and mark all stakes to predetermined top of footing grade.
7. Cut strips of 3/8″ plywood (Masonite Siding works well also) into strips 12″ wide the length of the circle perimeter.
8. Attach the plywood strip to the stakes on the inside with wires or nails. The top of the plywood must be held at the top of the footing grade.

Stakes

A predetermined number and size of reinforcing steel bars must be placed in the footing area. Drive temporary 1/2″ rebar stakes (these are temporary and may not be necessary) into the footing area about 3″ inside of the plywood form. Set these temporary stakes about 8′ on center. The tension rebar should attach to these stakes by wire at the spacing called for in the engineering specifications.

Install ties as required. Be sure to put reinforcing on concrete blocks and remove any rebar in contact with the soil, i.e. the temporary stakes.

NOTE: Do not forget the extra rebar that is to be placed under the doors.

Placement of Concrete

1. The concrete is poured inside of the plywood single side form. A stiff mix should be used, 2 to 6 inch slump and the concrete vibrated or rodded around the tension steel. The footing is shaped as it poured by leveling the top to the form on the outside, keeping the top level for at least 12". The inside edge can be tapered to the inside dirt form. The footing top should be left somewhat rough—do not trowel.

2. While the concrete is still workable, a small amount of concrete should be removed or molded for the keyway.

Placing the Rebar

While the concrete is workable, the vertical rebar should be placed in the concrete. Have all rebar dowels cut in advance. The forms should be marked in advance where the extras are to be placed. The rebar should be placed as shown by the engineering specifications.

After the footing concrete has set, the plywood forms should be stripped from the concrete.

Connecting Steel

To allow the Airform to be placed, the connection steel must be bent over. These rods should be bent in on an angle so that the ends are only 2' from the inside of the foundation.

Marking the Center Point

Before the Airform is placed and the center point is lost, the center point should be marked well enough that it can be easily found during any step of the construction process. This can be done by driving the stake deep enough that the stake top is below the ground level and cannot be knocked out by equipment in the building.

A similar stake should be driven just inside the footing in the center of any doorways and other necessary references.

A grade reference should be established inside the Airform area for use in establishing window, door heights and other elevations.

Footing/Floor Combination

Often for small buildings and especially for poor soil conditions the floor may be poured with the footing. This is a simple variation that can be handled by competent workmen.

Airform itself. Forklift operators should be cautioned not to accidentally poke the forks of the forklift into the Airform. This causes a great deal of grief as it will create holes in many places in the Airform.

No sharp instruments such as pliers should be used on the Airform. It is very handy for the workmen to grab the Airform with a pair of pliers. This creates a weak spot. It is not a good practice. It will not create a disaster, but nevertheless is not a good idea.

Placing the Airform

The Airform should be placed in a position that allows it to be unrolled as per the manufacturer's directions. In general, the manufacturer will have the Airform rolled in such a way that the air lock will be at the bottom of the pile when the air form is set down. Therefore, you should set the Airform at the location of the air lock and then proceed to unroll it.

Unrolling the Airform:

The Airform is generally rolled up with the air lock and the air tube at bottom dead center. The Airform should therefore be placed at that location of the building. It can then be unrolled towards the center and then unfolded. Note: The following is very important: Various points around the foundation should be marked and located to match the similar points on the Airform. Generally this is done by dividing the number of major gores in the Airforms by the circumference, marking those locations and putting the Airform on the foundation at those locations. It is extremely important that the Airform be evenly spaced around the footing or it will tend to deform when it is inflated. The Airforms may fit tight. This is minimize bulging at the bottom. Because the Airform stretches it is made smaller than it will be when inflated. If we made them smaller in proportion at the footing line you could not get them over the footing. Therefore they are made larger but hopefully not to large at the footing. Your feedback as to fit and sizing is greatly appreciated. It allow us to update our patterning for the next Airform.

On larger Airforms it is often very helpful to use air under the Airform as it is being spread. This can be done by using grain dryer fans under the edges of the Airform. This will necessitate moving the air dryer fan as the Airform achieves lift. Another method is to attach fabric tubes to the regular inflators and run them underneath the Airform. Blowing air under the Airform as it is laying on the ground will break the friction with the ground and allow the Airform to be moved much easier.

<u>**Always, always**</u> check the area the Airform is going to be spread over for any sharp protrusions or items that will cut or abrade the Airform. It is our recommendation that anything left under the Airform should be covered with material that will protect the Airform from abrasion or puncture.

The Airform should not be unrolled over wet ground or over sharp objects. If the rebar has been placed in the dome before the Airform is unrolled, all of the ends should be thoroughly inspected, and those ends with sharp edges should be covered with appropriate material and taped. If the floor is wet or muddy, or has any product on it that will adhere to the underside of the Airform, the entire floor should be covered with plastic. A thin film of plastic will save an enormous amount of grief on

Section IV – The Airform™

The Airform is a very highly engineered fabric structure. Great care is taken to allow for the stretch factors in the air form as well as any other anomalies so the inflated building is of the proper shape. Obviously it is an inflated building, and equally obvious it is impossible to predict precisely the shape of the structure. Therefore, it is important that allowances be made for a slightly larger or a slightly smaller structure.

We endeavor to furnish to our customers the most perfect Airform we can. However, Airforms are made by people. They are made by seaming pieces of fabric together into larger pieces of fabric. Some of the Airforms weigh many tons. These fabric Airforms and other items are usually built for very specific applications. In spite of best efforts, it is possible for mistakes to leave our shop. It is also very possible that damage can occur to the fabric as it is being shipped, and/or loaded and unloaded. Furthermore damage can be expected as the material is being unrolled, spread, and put to use. On site damage is of grave concern as there are usually many ways to cut or tear an Airform at installation time. Note: This manual is not all inclusive. It is not a warranty. It is simply a guide to some of the ways to repair and/or handle the Airform.

Loading, Unloading and Shipping the Airform:

Smaller Airforms are usually shipped on a pallet. At the customer request they can be crated – at an additional charge to cover the cost.. Crating provides more physical protection, but certainly will not stop a forklift that has run amuck from penetrating the box and the Airform. The Airform should be treated as gently as possible. We liken the handling of the Airform to that of a elephant. You have a tremendous amount of weight, and nothing to really get a hold of. If you do get a good hold, it is easy to tear with mechanical equipment. In general we will bind the Airform with webbing. This webbing can often be used to lift the Airform from above. This can be done either by running the forks through the webbing or attaching to the webbing from the forks, or by attaching from a crane. The smaller Airforms are usually left on a pallet and can be handled by a forklift in a more conventional manner.

The large Airforms are so difficult to handle without damaging it is recommended they be put on an open truck by themselves where they can be tarped, and not be moved or shuffled from trailer to trailer during transit. At the job site they can best be unloaded using a crane of proper capacity and proper length of spreader bar.

Many factors enter into the inflating of an Airform. If it is done during extremely hot weather, the fabric will stretch more than if it is inflated during cold weather.

Because of the cost, care, and expense of this Airform, extreme care should be taken not to damage it. The most likely time to damage the Airform is while transporting it to the job site and while spreading it out getting it ready to inflate. Some of the points to consider in this operation are:

Handling the Airform

The Airform should be handled without using sharp instruments against the

the Airform when it is inflated. This thin film of plastic also serves to force the water to stay in the ground rather than to condense on the underside of the inflated Airform.

As water is the worst enemy of urethane foam, moist soil conditions almost always dictate a covering of the floor. If the floor is going to be covered anyway, it should be done before the Airform is rolled out to keep the Airform clean. As the urethane must adhere to the Airform, it is doubly important that it be kept clean.

Even concrete floor should be covered for condensation control — not mention help with the clean up. **Do not be fooled by dry ground.** It will still have moisture in it. Be sure by covering it.

Spreading the Airform

The Airform should be unrolled and spread out properly. Most Airform materials have a thick side and a thin side. The thick side will be the smooth side. The thin side will be the rougher side. The thick side should be to the weather. This provides more protection from the sun to the threads.

The Airform that has air under it will slide and spread much easier than one that does not. Therefore it is often appropriate to start the inflators as the Airform is being spread, and direct the air underneath the Airform. This creates an air bearing which greatly facilitates the spreading of the Airform.

It is imperative that the Airform be spread evenly around the footing. This can only be done by measuring the footing carefully and marking it into sections that correspond to sections marked on the Airform. Never just pull it on like an old sock. If the Airform is not spread evenly it can create a great amount of strain in the wrong areas even causing destruction of the Airform.

Fastening the Monolithic Dome Airform

1. Count the number of gores around the Airform. Label them on the seams with a ball point pen. Start with zero.

2. When you have an accurate count of the gores, measure the actual distance around the foundation. (Do the same with an EcoShell). Divide the perimeter by the number of gores and then mark with a heavy marker on the foundation where each of the gores will go. On large domes this may be done on every third gore, or just the master gores, depending on the size of the dome.

3. The Airform should be laid out over the foundation. The entire circumference of the foundation should be covered before any tie-steel is bolted on. This is to permit any adjustment of the alignment of the Airform to the foundation that may be necessary. The fan inlet and airlock connection must be properly aligned to the doorway.

4. Be sure you attach the Airform on one side, then it's opposite. then attach the quarter points, and their opposites, and continue evenly all the way around. If you start at one place and go all the way around, you will be wrong almost every time. The Airform will stretch to fit the foundation tightly. The rope in the bottom of the Airform should be pushed down 3 inches. The tie-steel is placed above the rope and secured by the tie-bolts. Spacing of the tie down bolts should be 6" to 24" on center depending on pressure and bolts used.

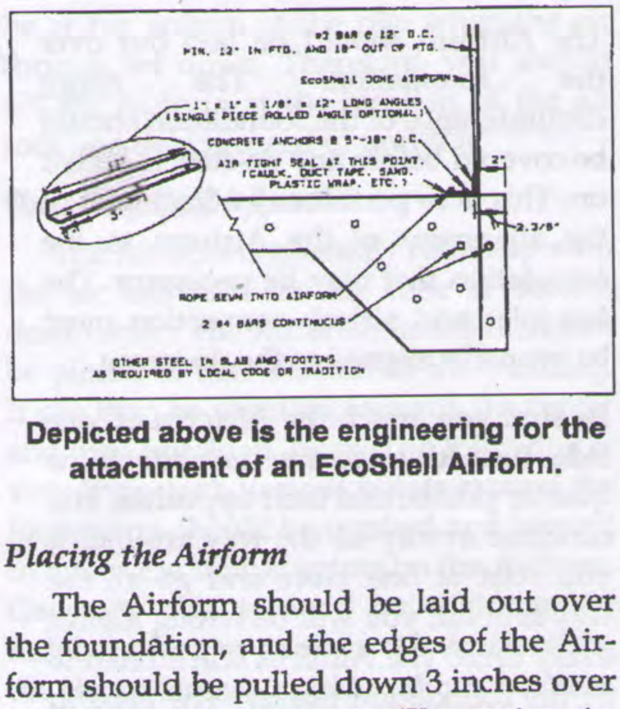
5. The airlock is then attached to the appropriate opening in the Airform.

If for any reason your Airform fits the foundation loosely, then it is important that you pull the slack to the center of the airlock and fold a tuck there, or at the center of a main opening like a double door.

We need to know if it fits perfect or if it fits imperfectly. We are constantly working on this technology. We need your help in perfecting the engineering and manufacturing.

Fastening an EcoShell™ Airform

The EcoShell Airform should be laid out the same as the Monolithic Dome Airform. However, it must be fastened to the floor per the illustration.



Depicted above is the engineering for the attachment of an EcoShell Airform.

Placing the Airform

The Airform should be laid out over the foundation, and the edges of the Airform should be pulled down 3 inches over the edge of the concrete. The entire circumference of the foundation should be covered before any tie-steel is bolted on. This is to permit any adjustment of the alignment of the Airform to the foundation that may be necessary. The fan inlet and airlock connection must be properly aligned to the doorway. The Airform should be even all the way around.

The rope in the bottom of the Airform should be pushed down 3 inches. The tie-steel is placed above the rope and secured by the tie-bolts. Space the tie down bolts about 24 inches on center. This process is to be done around the entire circumference.

The airlock is then attached to the appropriate opening in the Airform.

Preparing for Inflation

After it has been determined that the Airform is properly spread out, an appropriate amount of the Airform may be folded back. Any supplies or tools that cannot be taken through the airlock can be placed inside now.

Next the Airform is pulled back over these supplies and bolted to the footing in preparation for inflating. If the Airform is going to be left UN-inflated for any period of time, it should be secured preventing wind damage. Needless to say, but I will remind you anyway, that any equipment placed inside must be inspected and all sharp corners covered with padding to protect the Airform. This padding should be fastened securely in place.

*Airform is a trademark of Monolithic Constructors, Inc.

Inflating the Airform

Once the Airform is in place, bolted down, and thoroughly inspected, it can be inflated.

NOTE: The measurement of air pressure referred to here will be inches of water column abbreviated WC. This is the amount of air pressure differential needed to raise water in a column.

The inflating should NOT be done in strong winds. The air form is most vulnerable when it is partially inflated. A time should be selected for the inflating when the winds will be at a low point--less than 10 to 15 mph. Less than 5 mph is certainly most desirable. If the Airform is inflated during mild windy conditions, it is doubly important that all exposed surfaces on equipment inside be padded.

The inflating usually takes less than 30 minutes on small buildings. During the time of inflating it is absolutely essential that inspecting continue. The inflating procedure should follow these guidelines:

1. The inflator fans are started and the Airform inflated. The air pressure should be regulated. The easiest way to adjust the pressure as the building inflates is to open the doors to the airlock. When the Airform first becomes tight, the inside air pressure will be at a minimum (about one to two-tenths of one inch).
2. The Airform should then be checked for weak spots, holes, etc. The Airform tie-down should then be completely checked.
3. At this point, a check should be made on the pressure gauge. The pressure gauge (manometer) may be nothing more than a clear drinking glass half-filled with colored water having a small (1/8") clear tube run from the water through a hole in the Airform to the outside. The additional air pressure inside the Airform will force water up the tube to a level higher than the water in the glass. The difference in vertical distance is the actual air pressure reading in inches of water.
4. The air pressure is then gradually increased until it measures two inches of water column. While this is being done, the Airform and tie-downs should be checked for any problems.
5. The EcoShell is usually built at 6" of pressure.
6. Whenever possible, let the Airform stand at least 12 hours before continuing construction. this will give it time to stretch.

Regulating the air pressure

Regulating the air pressure is a very important part of the construction of the dome. The job supervisor should be aware of the following:

1. It takes very little pressure to inflate the Airform to its proper shape. It can be tempting to open the airlock door while the foam is being applied to circulate fresh air into the building. If this is done, the pressure will be lowered and there is a good chance of deforming the shape of the building while the foam is being applied. If the fan will keep up a small vent can be cut in a window or other opening to allow some air flow. Be sure and close the air flow if drying occurs in the concrete phase of the construction.
2. As air pressure is increased on a bare Airform, the chance of Airform breakage is also increased. In general the smaller air forms will easily handle

most air pressures up to several inches of water column.

3. The tighter the Airform is (more pressure), the less chance there is of deforming the shape of the dome during the application of the foam and the concrete.
4. The amount of air pressure used should be a happy medium between high enough to hold the Airform tight and low enough so that the Airform will not break. In the smaller domes uplift must be considered. Uplift is approximately 5 pounds per square foot of floor area per inch of water column. The footing must be heavy enough to hold this weight down. This is another reason the floor and the footing are often combined on the smaller structures.
5. It is possible to raise the pressure in the dome as weight is added to the Airform, thus keeping the same skin tension as well as supporting the weight of the steel and concrete that is added. This method creates at least two problems and therefore should not be used.
   - If there is any over-inflation after the initial concrete is applied, the Airform can stretch and crack the concrete.
   - The high pressure on the Airform at the doorways, where there is no foam or concrete, may cause the Airform to break or deform at the entrance way.
   - An increase in air pressure can stretch the Airform additionally. The rebar will not allow this. Therefore rebar hangers may be pulled out of the foam.
6. It is recommended to regulate air pressure during construction by raising the air pressure to a certain level and leaving it at that level during the entire construction process. This pressure level should be a minimum of 2" of water pressure and a maximum of 4" for a safe working pressure for the Airform.
7. Note: The EcoShell™ Airform is usually inflated to 8 or more inches of water column. Please check EcoShell construction instructions for special considerations.
8. After the Airform is inflated it is often very useful to be able to measure the Airform to get an exact profile. The following two pages have been furnished by Monolithic Constructors. They are instructions on how to accurately measure an inflated Airform. Whenever possible Airforms should be measured and the information returned to Monolithic Constructors, Inc. This helps immensely in building a database that is utilized to help predict the exact size and shape of the inflated Airform.

Cleaning the Airform

At times it is appropriate to clean the Airform. This may be necessary from dirt accumulated from shipping, construction, or from our not so clean environment. Dirt may be removed by washing with a mild soap and water. We recommend dish water detergents. These are mild detergents that will not affect the finish on the Airform. Do not use high pressure washers as these can damage the finish and shorten the life of the surface of the Airform.

If there is paint on the Airform, it should be removed as soon as possible. A small area should be tried first. If it is a water based paint, sometimes just detergent mixed in water will wash it off. A plastic scrubber can be utilized to help. If the paint is older and has a better bond, chemicals such as industrial strength cleaners may need to be tried. Mineral spirits would be another choice. Acetone (nail polish remover) and methylethyl keytones (high power paint thinner) can be used. They should be utilized with great caution, both to protect the individual doing the repair and the surface of the Airform. These harsher solvents can do damage to the surface of the Airform as well as the surface of the repairmen. It is advised to do a small area first and then proceed to the larger areas. Once the paint has been removed, the area should be washed with soap and water to remove all residue of the paint remover.

A complete cleaning of the complete dome is not always necessary, but is sometimes very nice to have done. The most satisfactory method is to tie off the center anchor point and work from a rope as a mountain climber would. The workmen should wear smooth or soft soled shoes — tennis shoes. The workman or workmen can then wash the dome as they would a big car. First soap and area then rinse it off. If there is not an anchor point on your dome, consider installing one. It is extremely important to use all safety precautions. These safety precautions mean not working alone. They mean being tied off with a proper climbing harness and proper safety ropes. Ladders and long handle brooms, and cleaning brushes can also be effectively used on some of the domes. Note: Safety is the key. Consult with professionals when working from a rope.

Repairing the Airform

Repairs can be divided into three kinds. First is purely cosmetic. The second is necessary, but non-structural, and thirdly is structural repairs. We will try to cover each one individually. Repair of nicks and scrapes can be done simply by gluing on a patch or heat welding on a patch. If the repairs can be made from the back side, this is preferable because it is less noticeable than from the front side. If for some reason the back side is not available, then care should be utilized to make a patch no bigger than is necessary. Usually the patching material should reach two inches beyond whatever the repair is.

If you repair a hole, two inches in all directions. We recommend using H66 — a vinyl cement to adhere patches. Some customers have used super glue. There are various types of super glue. We suggest you try a test patch before you use any product.. A second method for patching is to heat weld it. The heat welding could be done by anyone with the equipment and the knowledge. What is required is a specially designed electric heat gun that provides the heat source, these units are usually owned by single ply roofing companies as well as ourselves. The repairs are made by melting the two materials and rolling them together with a silicone covered roller.

Structural repairs are where large pieces have been ripped either by mishandling, or from damage by a storm during inflation. These tears may be relatively small, in which case they are probably not too big of a problem. Or the damage may be as extreme as having the Airform split into three sections. High winds will induce and extremely high lift to an inflated Airform. If an Airform "pops" under high winds it will usually tear three lines from the top to the bottom.

The most obvious repair of major proportions is to send it back to the factory. This is not generally necessary unless field conditions dictate this as a solution.

Very satisfactory repairs can be made in the field even to catastrophic rips. This is usually accomplished by butting the torn material together and using a 4 to 8 inch wide repair strip to cover the butt joint. Obviously the joint will show less if the strip is on the underside but a repair will work equally as well from either side. The strip may be applied by using adhesives, welding and or riveting. Each have their merits. Hot Air welding is probably the simplest and best for large rips. A second very effective method is to use a good vinyl adhesive. If the vinyl adhesive is used we suggest a series of rivets be inserted as an extra mechanical precaution.

A 4 inch strip is satisfactory for domes under 100 feet in diameter. A 6 inch strip would be indicated for larger domes. The 8 inch strip would be used when field conditions were bad and a larger safety margin for the adherence was indicated. The rivets are double safety. They should be used with the adhesives unless there is a cosmetic problem. Liquid vinyl can be purchased to touch up the repairs.

Openings

A Monolithic Dome with no openings, would not be too practical unless it is for a water tank. And even in the water tank we need hatches and pipe entries. The following suggested methods have been tried, and work when making openings.

Frame Openings

In a smaller dome, it is probably well to make a frame that fits immediately against the Airform. It can be held in place by the sprayed urethane. Then the steel is placed and concrete sprayed around this frame to permanently anchor it.

The frame can be made of wood, steel or aluminum. It must be light enough not to distort the Airform. It can be braced from the ground, although care should be taken not to have the braces interfere with the spraying.

The openings that are high up on the dome can have a frame placed and supported entirely by the urethane foam.

Small Openings

Small openings such as for pipes, can be cut through the foam and the concrete, or may be sleeves set in the foam and/or the concrete during construction.

"Framing" Openings

It is extremely important that the openings be "framed" with a beam if they are in the tension portion of the dome. This usually means in the lower 1/3 of the dome. This is especially true for doors that reach clear to the footing.

A "beam" is constructed by using additional reinforcing steel under the door, alongside the door, across the top, and thickening the concrete in those areas. The net effect is that the dome does not see the opening at all. The tension is carried around the opening through the beam without any change in tension in that area.

In the upper portion of the Monolithic Dome, openings do not require significant treatment. They obviously should be checked by an engineer, but in most cases a simple wrap of rebar around the opening is all that is necessary.

If a large opening is to be left in the top of the dome, and a particularly large load is being super-imposed on top of the dome, then the concrete around that opening should be thickened and contain additional reinforcing steel. Again the engineer should be consulted for the exact amount of steel and thickening. This creates a compression ring that will stand up to the snap-through buckling tendencies in that area.

If the penetrations are to be quite small, then it is probably better to drill them after the concrete is set. A much more accurate placement is obtainable.

Whenever a penetration is made, it is a place where a leak can occur. Careful thought should be used when flashing around these penetrations. If in doubt, contact a single-ply roof contractor. The Airform is nothing more than an extra-strong single-ply roof membrane. Single-ply roof contractors usually have caulkings and flashings that work extremely well with the Airforms. (Note: Always use urethane caulkings.)

By properly placing the reinforcing, it is not unusual to have very large openings in a Monolithic Dome. It is not unusual to have a large number of openings. In all cases, please have the engineering checked for those conditions.

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Measurements for Airform Profile

Point B is (description — by door on North side, East side, etc.)	
Point B is (to the right facing center from point A)	(distance)
Point C is (to left facing center from Point A)	(distance)
Point B to C (this is check distance)	(distance)
Center to A (this is check distance)	(distance)
Center to B (this is check distance)	(distance)
Center to C (this is check distance)	(distance)

Points	Distance A to D	Distance B to D	Distance C to D
D1			
D2			
D3			
D4			
D5			
D6			
D7			
D8			
D9			
D10			
D11			
D12			
D13			
D14			
D15			
D16			
D17			
D18			
D19			
D20			

Date: __________

Project Name: __________

Weather Conditions: __________

Measurements by:
(Name) __________

Color: __________

Airform fabric (if known) __________

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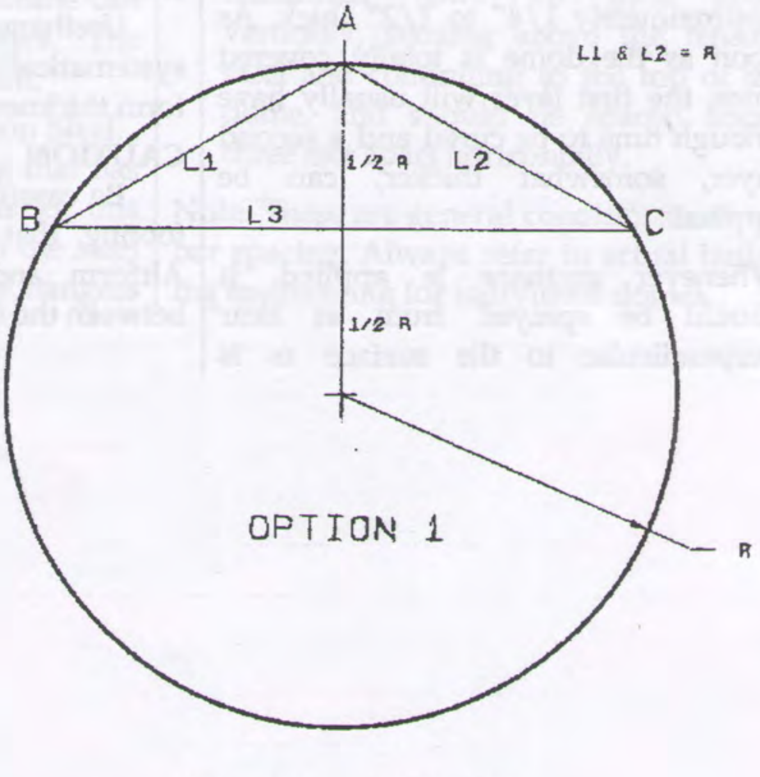
How to Measure the Airforms

By using three measurements to any point on the Airform that point on the Airform can be accurately calculated. It is important that the measuring points be identified and be a reasonable distance apart. The enclosed plan view is a suggested layout. Use it to establish the base line points.

1. Establish point A any place where the Airform attaches to the foundation. It should be marked with an identifying crayon/pencil.
2. Next establish points B and C. It is not imperative that B and C be any prescribed distance. Our suggestion is that they be a minimum of the radius of the building from Point A. They can be farther but not be much closer. B and C are also at the intersection of the footing and the shell. It is assumed the footing is level or at least in one plane.
3. A series of points (D1, D2, D3, etc.) should be marked on the underside of the Airform going approximately vertical from point A to the top center of the dome. It is not critical that they be perfect or in a straight line or any special distance apart. My suggestion would be 5 feet on center for small domes and 10 feet on center for large domes. The ten feet does not have to be accurate, it can be guessed.
4. Measure the distance to each of these vertical points D1, D2, D3, etc. from A, and then from B, and then from C, going to the center of the dome.

This measures the dome profile on one vertical line. It is suggested that a profile be measured on each of the four quadrants. That would mean reestablishing new points A, B, C, and D for each of the four sets of measurements. For small domes the points B and C can be located at the midpoints and all of the vertical lines be measured from one set of points -- A, B, C.



PLAN VIEW

Section V – Urethane Foam

To insure a good bond between the foundation and the dome concrete (to be applied later), the foundation should be masked. A strip of masking should be laid over the bent steel and foundation. The outside edge of the masking should be held back from the Airform a distance as thick as the insulation. The masking can be secured by taping it to the rebar.

1. Apply urethane per manufacturer specification.
2. As urethane foam cures, it tries to contract. The thicker the layer of foam is, the more pull it will exert as it cures. If the foam is applied to the skin in thick layers, the skin will be distorted by the contracting foam.
3. The first layer of foam should be approximately 1/4" to 1/2" thick. As soon as the dome is totally covered once, the first layer will usually have enough time to be cured and a second layer, somewhat thicker, can be applied.
4. Whenever urethane is applied, it should be sprayed from as near perpendicular to the surface as is practical. After the second layer is applied, the thickness of the layers can be increased up to about one inch. The layers should be applied in about 6′ high passes starting at the foundation and working up to the top. Each layer should be applied over the entire area before the following layer is started. The passes of the successive layers should overlap the joints of the preceding layer to prevent uneven thickness of foam because of cumulative joints. Thickness can be checked by carefully depth probing with an ice pick (a nail or rebar hanger). Even layers are applied until the thickness is as specified. Minimum depth probing is advisable.

IMPORTANT

Urethane foam should be applied very systematically and evenly to insure uniform thickness.

CAUTION

Be careful when spraying next to the footing, that the foam is sprayed to the Airform and not just filling the gap between the footing and the masking.

Section VI – Installing Rebar Hangers

When to install

The rebar hangers can be installed any time after the second layer of foam is applied, but before the last 1" of foam is applied. If they are not covered with enough foam, they will not be secure enough to hold the rebar.

A good rule to follow is to apply them in about the center of the foam. This means that on a dome with 3" of foam, they will be 1" to 1.5" from the Airform.

NOTE:

After the rebar hangers are placed, it is doubly important to spray the remainder of the foam from a perpendicular angle to prevent excess foam build-up on the hangers.

The reinforcing steel

The reinforcing steel in the dome can be divided into four categories. The hanger location is different for each.

1. Footing to Building Connection Steel... This is the steel in the footing that has been bent down. The hangers for this steel should be placed to hold the steel when it is bent back. These hangers should be in rows about 10 inches above the footing, and each 10 inches thereafter to the top of the dome.
2. The tension rebar are the continuous rows around the base of the dome. They are attached to the upright steel out of the footing and do not require rebar hangers.
3. The concrete should be reinforced around any door, window, or other openings. Special hangers are needed here to hold the steel in place. These hangers should be placed precisely. Rebar is sometimes used to outline the openings.
4. From the top of the tension steel, 3/8" bars are placed on a 10 inch grid. The hangers holding this grid are placed in horizontal rows 10 inch apart vertically, starting above the tension steel and continuing to the top of the dome, and should be spaced about three feet apart horizontally.

Note: These are general conditions and rebar spacing. Always refer to actual building engineering for individual domes.

Section VII – Reinforcement

Placing the rebar is easy and simple if directions are followed closely. Always think.

Install horizontal rebar

Install the horizontal rebar first. Next, bend the foundation to dome connection steel back upright. This can be accomplished by hand with the aid of a piece of pipe or a "hickey". The tension should be removed so the rebar will stand without excessive pulling on the dome. It should be tied to the bottom rows of the horizontal rebar.

The extra tension steel

The tension steel should be placed against the upright rebar (out of foundation) and wired on at the proper spacing.

3/8" rebar

Place the 3/8" rebar over the rest of the dome:

1. Tie horizontal bars in continuous rows around the dome on rebar hangers 10 inches apart. These rows go all the way to the top.
2. Tie vertical rods on the horizontal rods. Keep the spacing not more than 10 inches apart. Be sure to have the proper overlap at all times.

Tie the steel

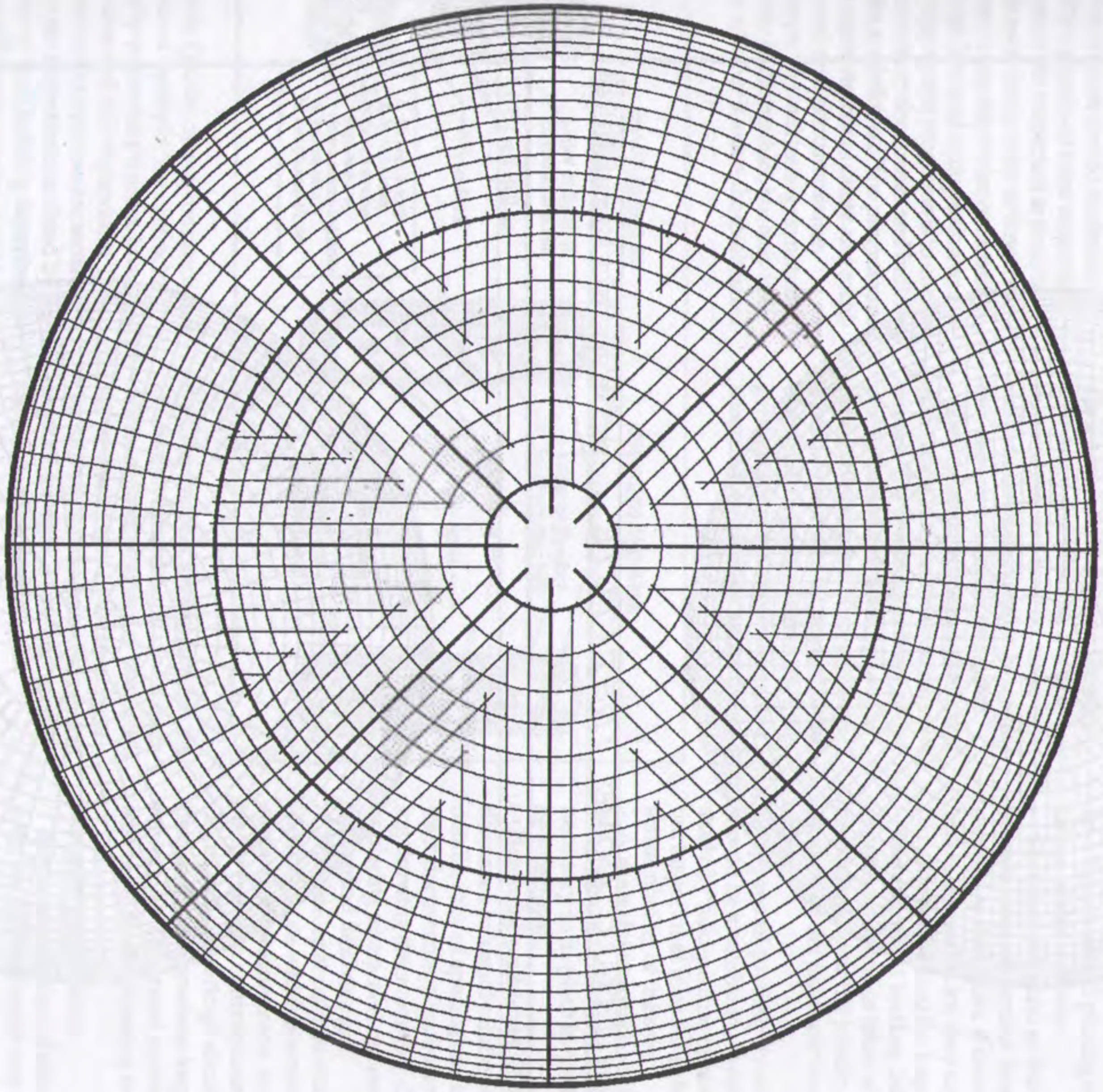
Tie the reinforcing steel that is required around any doorways or windows (the amount of this reinforcement should be determined by the engineer).

Special reinforcing steel can be placed for extra strength areas or hangers. This steel should be specified by the engineer for the particular use.

Rebar Pattern

The vertical rebar can be placed in the following patterns:

1. Modified starburst. This is probably the easiest and best system. The maximum spacing of 10 inches must not be exceeded.
2. Radial Pattern: This is simple, but uses more rebar. Drop off the bars as the spaces narrow. Always maintain 10 inches as maximum distance between bars.
3. Starburst Pattern: This pattern uses the least amount of rebar. There is more cutting of the rebar with this alternative.



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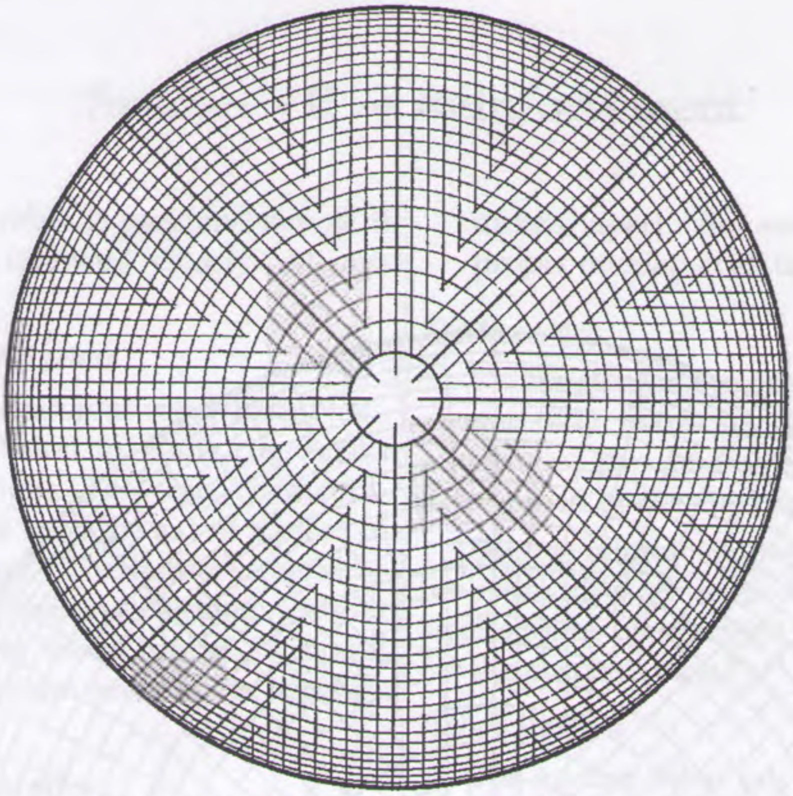
REBAR PATTERN #2 - STARBURST

JULY 1997



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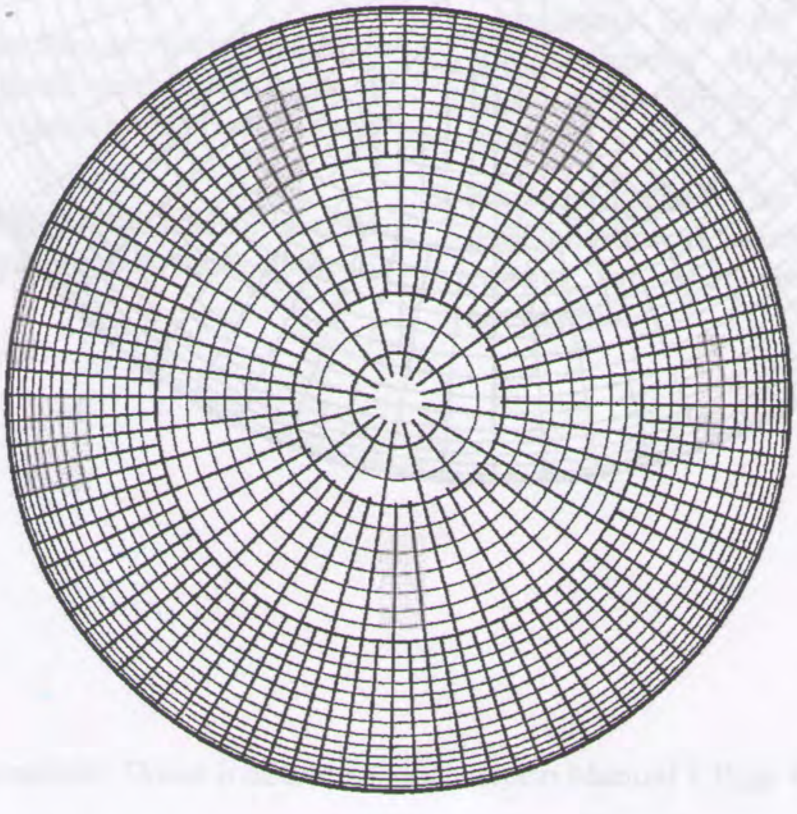
REBAR PATTERN #1 - RADIAL

JULY 1997



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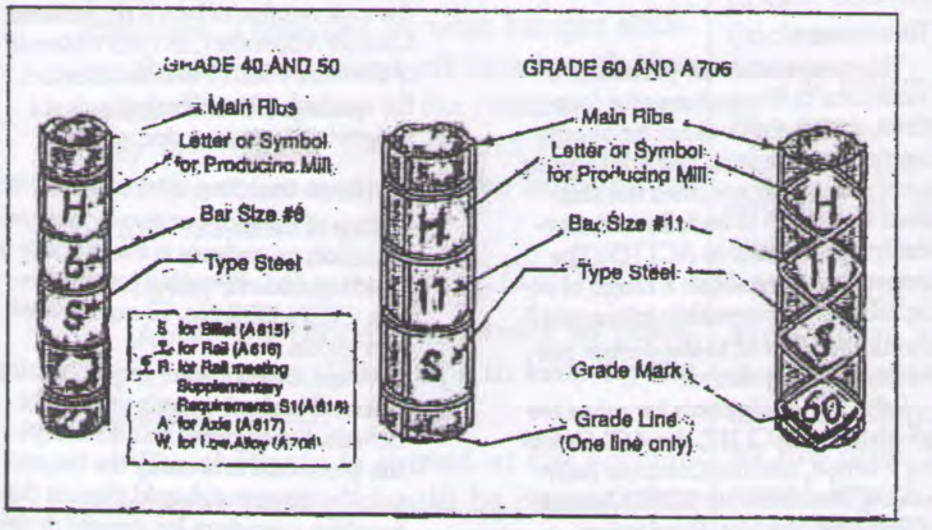
Rebar inspection

Establish a checklist of procedures and determine minimum requirements for inspection acceptance

Contractors should understand the process of rebar inspection, whether the inspection is done by their own forces or by an inspector representing the owner or building official. The goal of inspection or quality-control programs is to ensure that contract documents and building codes are followed. The programs also ensure structural safety and architectural aesthetic compliance.

Inspection and testing do not add quality to the product, but only confirm whether it meets the established criteria. Quality during construction is achieved mostly by the contractor's quality-assurance program, involving workers and field supervisors. The contractor's inspectors are separate from the inspectors mandated by the owner or local building department. The contractor's quality-control inspection helps assure that the finished construction meets the owner's requirements. Inspections by the material producer and supplier assure that products meet material specifications.

Inspectors should be familiar with the project contract documents (especially structural and rebar placing drawings) and building code requirements, and have access to material standards and references, codes, and industry manuals or reports.



The inspection program should be established at a pre-construction conference. The size or complexity of the project determines the scope of the inspection program. This meeting should be attended by representatives of outside inspection agencies, the general contractor's superintendent, concrete subcontractor's superintendent, the supplier's representative, the ironworker foreman, and others, such as the architect, engineer, or engineer's site representative. At the meeting, a checklist of procedures and minimum requirements for inspection acceptance should be established.

Checklist

The list should cover (but not be limited to) the following:

A construction schedule from the general contractor is important so the inspector can follow the placing crew and inspect in-place rebar before the scheduled placing and finishing of the concrete.

Certified mill test or bar coating reports may accompany material shipped to the jobsite. If the reports are sent to the contractor, they should still be made available to the inspector.

Independent testing laboratory reports on samples taken at the fabricator's shop or the jobsite offer verification of the producer's mill test report.

Approved placing drawings should be available for review and study by field-placing personnel and the inspector at least 1 day before the actual placing of the rebar.

A material shipment schedule should be provided and updated as necessary so in-place inspections can be scheduled.

Potential problems should be discussed to identify difficult-to-place details, lack of specifics on the contract documents, possible engineering drawing discrepancies, detailing or placing errors, and approval of implemented field changes.

Tolerances should be discussed to identify those which are critical, the method of measurement, and the basis for rejection or acceptance.

Periodic meetings should be held to discuss previous inspection reports, problems and solutions, and the schedule of upcoming work.

Material inspection

In-place inspection of rebar starts with the mill test report and may be supplemented by a report from an independent testing laboratory. Reports should state grade of steel, tensile properties, chemical composition (and carbon equivalent if rebar is to be welded), and spacing and height of deformations. Compare these values with those in the applicable

ASTM standard. Examination of the bar mill markings will identify the producing mill, the type and grade of steel, and the bar size.

Reinforcing bar inspection

Visually check bar diameter and shape (if bent); measure bar lengths, spacing, embedment, and bearing on a wall or beam. In a slab, count the total number of pieces and measure the slab bar spacing. Check these figures against the approved placing drawings in conjunction with the structural drawings. Similarly, check beam longitudinals, column verticals, and stirrup and tie spacings.

Bar supports

Measure chair heights to verify that the specified cover and clearances will be satisfied. It is extremely important to check the chairs or standees supporting slab and mat top bars for height. The entire mat and cages also should be checked for stability, since they can easily be displaced during concrete placement. Normally side supports are not provided unless called for in the contract documents. Where specifications require corrosion-protection measures, verify the class of protection of the bar supports furnished.

Rebar tying requirements

Reinforcing bars are tied together to form a rigid mat for footings, walls, and slabs. A rigid cage is formed when beam or column longitudinals are tied to the stirrups and ties. Ironworkers usually tie a minimum number of rebar intersections. If the specifications are not precise about the number of tied intersections, the work should be accepted unless it is apparent the mats or cages of reinforcing steel will be displaced from their inspected position during concreting. The placer is responsible for tying bars so they will remain in position. Tack welding of rebar to rebar should not be allowed, and only coated tie wire should be used to tie coated bars.

Splices

Length and location of lap splices should be specified in the contract documents and on the approved placing drawings. If mechanical connections are required in lieu of lap splices, the placing foreman or the mechanical connection supplier should provide the inspector with evidence that the architect or engineer has approved use of the connection, and provide literature describing the recommended installation procedures.

Special attention may be needed in the inspection of mechanical connections or welded splices, as well as critical components and activities that are not routine for either the placer, contractor, or inspector.

Coatings

Inspectors should not reject rebar with a light coating of rust. However, dirt, grease, or other deleterious adhesions must be removed before concrete placement. Water-soluble cutting oils do not significantly affect bond. Review the contract documents for acceptance or rejection criteria if there is damaged epoxy or damaged galvanized coating. Corrective actions should follow recommended touch-up procedures and should be completed before acceptance by the inspector.

Tolerances

Tolerances establish permissible variations in dimensions and locations, and should neither be overly restrictive or lenient. The engineer or architect usually specifies the standard tolerances to be followed, normally by reference to ACI 117. The inspector will establish a range of acceptability. Incompatible tolerances should be referred to the design professional for resolution.

Fabricating tolerances for rebar are tabulated by ACI 117, the *ACI Detailing Manual*, and the Concrete Reinforcing Steel Institute (CRSI) *Manual of Standard Practice*. Fabricating shops do not have problems meeting the recommended tolerances. Typically, the tolerance for length of straight bars and out-to-out dimension of bars with hooks or bends at one or both ends is ±1 inch.

Placing tolerances recognize the imprecise nature of the placing operation and allow deviation criteria. ACI 117 indicates bar placing tolerances including clear distance to forms and resulting concrete surfaces (varies with member size, ±½ inch for members 12 to 24 inches), uniform spacing or positioning of bars in slabs or walls (±3 inches), stirrup and tie spacing in beams and columns (one-twelfth beam depth or column width), location of bar bends and bar ends (±2 inches, except ±1 inch at discontinuous ends of members), length of lap splices (-1½ inches), and embedded lengths (-1 inch for bar sizes from #3 to #11). Tolerances also are stated for beam and column form dimensions.

Potential problems develop when tolerances of fabricated bars and formwork conflict. For example, in a 16x16-inch interior column with specified 1½ inch cover to ties, the fabrication tolerance on stirrup size is ±½ inch and the form size tolerance is +½ / -¼ inch. If the ties are +½ and the forms are -¼, the concrete cover would be reduced to ⅞ inch, which conflicts with provision 2.2.2 of ACI 117 that permits only a ½-inch reduction in cover for this example. Conflicts like this are best resolved with assistance from the designer and when discovered early.

Inspection of bar placement in walls and slabs is usually straightforward. Ironworkers often shift rebar to avoid obstructions, such as small openings, pipe sleeves, electrical outlets, and similar items. This usually is acceptable if the total number of bars is not reduced. Consult Appendix C in CRSI's *Manual of Standard Practice* to determine first bar spacing, if that information is not shown in the contract documents.

In-place bending and rebending

One of the more controversial construction procedures is the practice of bending and rebending installed rebar. CRSI's EDR No. 12 can be used as a guide.

When the contractor requests using planned prebent dowels or straight dowels, the engineer should accept the procedure and notify the inspector. The inspector should discuss the bending procedure for straight dowels with the placing foreman to assure that the bends conform to ACI 315. Where large diameter bars are involved, some preheating may be recommended by the designer to avoid brittle failure.

Conclusions

Mistakes can and will happen, but an inspector is expected to find them and have them corrected. A quality-control program by the contractor helps reduce errors and makes final inspection easier. The inspector should perceive his job as supplementary to the workers in support of good construction techniques and practice.

Section VIII – Shotcrete

Again think.....first. The placing of the concrete is simple when done right. Remember it is approximately twice as heavy as water. It takes 2 inches of water column pressure to hold up 1 inch of concrete in theory. In reality figure 3/4 inch of concrete as a maximum. The concrete must be cured enough to support itself before more can be added. In hot weather that can be in a few hours. In cold conditions it can be at least a day or more.

Monitoring Gauges

Gauges for monitoring the concrete depth should be placed on the surface of the foam. These can be wire hanger stickers that have been cut off to a length that equals the thickness of the concrete where they are placed. They should be applied over the entire surface of the building on 4′ to 8′ maximum grid

Spraying The Concrete

Apply the concrete as evenly as possible at all times. This helps in keeping the thickness correct.

The shotcrete is started at the bottom. The entire footing should be covered first with a thick layer that extends about 1′ up the wall. This is to make sure that the concrete on the footing is good concrete and not just shotcrete rebound.

A layer about 1/2″ to 1″ is then sprayed on the surface from ground level up to about 6′ high. From 6′ high on up to the top third of the dome, a 1/2″ layer is applied. The top third of the dome is covered with 1/4″ to 1/2″ of shotcrete.

B. The Second Layer is usually applied the second day. It is also started from the bottom. Up to a 1″ layer is applied from ground level to approximately 8′. From 8′ to the top, a 1/2″ layer is applied.

C. Third Layer is usually applied on the third day. This is an exact duplicate of the second layer except that the dome will support more weight and the layers can go thicker higher. Always if possible apply at least 1/4″ to the top of the dome or you wind up having to spray just the top on the last days spraying. By the third day, the concrete around the base of the dome will be strong enough to support additional concrete if it is need for extra thickness.

The fourth day is a repeat of the third. The base should be worked for smoothness on this layer. Particular attention should be given to the depth gauge stickers.

The final layer should be at least 1/2″ everywhere and the final smoothing and depth checking should be done with this layer. If adequate thickness is not reached by this time, it is necessary to spray additional layers as needed. The final layers should be relatively thin (1/2″) to permit a smooth finish.

The final layers of concrete should be sprayed from the top down. It seems easier to make a nice finish if the concrete layers start at the top.

NOTE: It is very difficult to judge the depth of sprayed concrete as it is being applied. A 1″ layer can look very much like a 1/8″ layer. To be sure of a uniform build-up of thickness, a very uniform spraying pattern should be followed. This pattern can vary according to the nozzleman, but it should be consistent. To insure proper thickness, check the depth gauges.

If at any time during the concrete application there is so much concrete being applied that the skin sags, the concrete should be immediately removed and the skin returned to its normal shape. A lesser amount of concrete should then be applied.

It is important to use good shotcrete techniques when shooting around rebar, that is, shoot from close enough to the bar and with enough force that the concrete cannot build up on the face of the bar but closes around it from the back.

After the final concrete is applied, the air pressure should be left at 2" of pressure for 24 hours. At that time, the blowers can be turned off.

Section IX – Floor

The floor of the Monolithic Dome can be independent form the dome itself. There is no need to tie the one to the other. This means the floor can be left dirt, it can be compacted earth, it can be asphalt paved or concrete paved

The floor of a Monolithic Dome will generally have much less thermal stress than floors in conventional structures. Therefore the control joints can be further apart. They probably should not be farther than thirty feet apart in each direction.

There is no need for expansion joints around the interior perimeter of the dome. Normally concrete shrinks and does not expand. If expansion joints are needed, it will be around some imbedded item such as an access to a basement.

In areas where differential settlement is suspected. and if the product can stand to be on a non-paved floor, a tamped limestone or a tamped clay floor might be very adequate. Then as the dome settles, the floor will not be disrupted. If the differential settlement is to be small, then certainly there will not be a problem in either case.

Often it works best in the small domes, for the floor and the footing to be in one piece—Monolithic.

Section X – Connections

In many cases it is very desirable to connect other structures to the Monolithic Dome. These structures may include complete other buildings, entries, windows, window wells, sky-lights, etc.

First and foremost, remember the Monolithic Dome is a concrete structure. Therefore, any attachments that are to be made must be made so that they will interact properly with the concrete Monolithic Dome. This may be as simple as just bolting on a wood frame (always use pressure treated wood for long life). The wood frame can be bolted on at virtually any location. Conventional carpentry can then be used to complete the addition, whether it be an entry way, window frame or whatever.

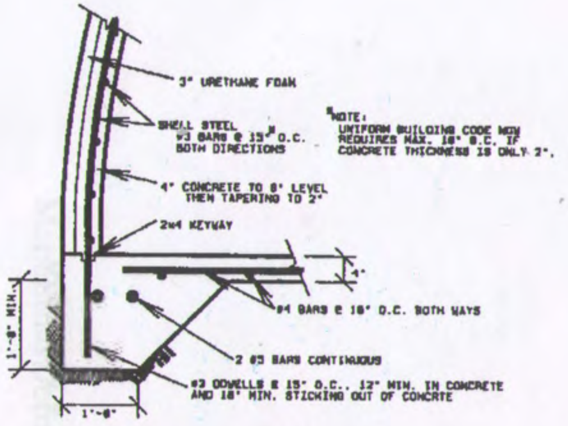
In many cases, it is desirable to attach a concrete structure to the concrete dome. In this case, it must be remembered that a crack will be developed where the two structures attach. This crack can constitute a leak, therefore it is important that flashing and counter-flashing be used as in any conventional structure. It is a good idea to physically attach the two concrete structures, either by concrete bolts into the existing Monolithic Dome or by having placed rebar in the dome that can be turned out into the attaching structure. The attaching structure can derive strength from the dome, and this can be calculated by the engineer.

All attachments should be done per the engineer's specifications.

Section XI – Sample Engineering

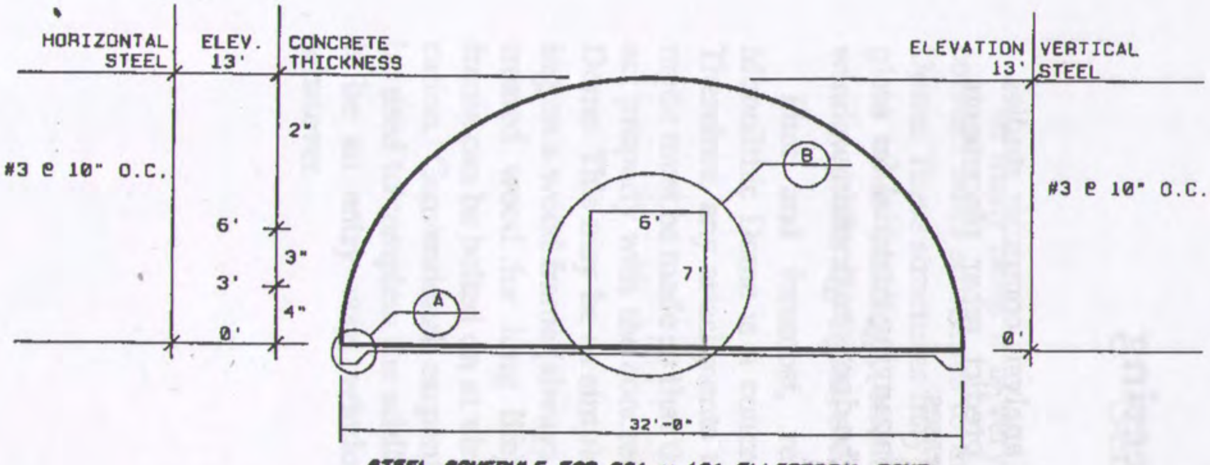
The engineering for a Monolithic Dome is generally best done by an expert in thin shell structural shells. Concrete in a shell (double curved) shape is far stronger than conventional flat shapes. As the curves become more difficult to define, finite elemental analysis computer studies are needed to predict rebar placements and shell thicknesses.

See the accompanying material for actual samples of the dome engineering.



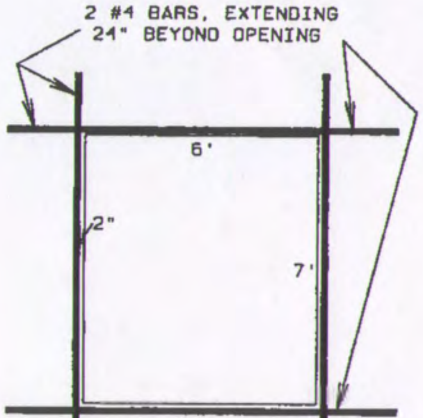
DETAIL - FOOTING (B)

SCALE: 1/2" = 1'-0"



STEEL SCHEDULE FOR 32' x 12' ELLIPTICAL DOME

SCALE: 1/8" = 1'-0"



STEEL SCHEDULE AT OPENINGS (TYP. OF 6'x 7' OR SMALLER) (B)

SCALE: 1/4" = 1'-0"

NOTES:

1. SHELL CONCRETE: f'c = 4ksi, AIR ENTRAINED 5 TO 7 PERCENT.
2. FOOTING CONCRETE: f'c = 3ksi.
3. STEEL: REINFORCING OF GRADE 60. Fy= 60ksi.
4. ADD 2 #4 REBAR AROUND 4' DIA. OR SMALLER SKYLIGHTS OR OPENINGS.
5. DESIGN LOADS: DEAD LOAD OF SHELL PLUS 10psf CEILING & ROOFING. PLUS LIVE LOAD OF 40psf. WIND LOAD= 50psf.
6. LAP REBAR FOR TENSION SPICE IN SHELL. CLASS B ACI 318-85 #8...47", #6...28", #5...23", #4 & #3...18". IF MORE THAN 50% OF SPLICES OCCUR WITHIN THE LAP SPLICE LENGTH THEN INCREASE LAP BY 1.7 TIMES.
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9. LOCATE REBAR IN CENTER OF SHELL CONCRETE THICKNESS
10. SPACING OF REBAR: CLEAR DISTANCE BETWEEN PARALLEL BARS IN ONE LAYER SHALL BE NOT LESS THAN d_b NOR 1".

OBERON 2

MONOLITHIC DOME INSTITUTE
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Section XII — Safety

It is the intent of Monolithic Constructors, Inc. to comply with the Williams-Steiger Occupational Safety and Health Act (PL 91-596), commonly called OSHA.

Monolithic Constructors, Inc. strongly suggests anyone building and particularly anyone building Monolithic Domes adopt a similar safety practice. The following is as an example and not necessarily complete. You must find and set up your own guide.

MCI (Monolithic Constructors, Inc.) will implement and enforce practices and procedures designed to provide for its employees a work place which is free from recognized hazards that are causing or likely to cause death or serious physical harm. In accordance with this statement of intent, the following is set forth as company policy.

SAFE OPERATIONS AND PRACTICES

Rules and Guidelines

All persons employed by MCI shall be required to follow these rules and guidelines as well as supervisory direction concerning them. It is further required that each employee promptly report any unsafe condition to the proper authority.

Accident Prevention Instruction

Employees shall be given frequent accident prevention instruction as needed, but in any case not less than monthly. Topics of instruction will be documented and names of individuals will be recorded.

Under the influence

Reporting to work while under the influence of alcohol or illegal drugs will not be tolerated. Drinking, using or possessing alcoholic beverages or illegal drugs on the work site is not permitted. Smoking is not permitted in the work area.

Interference

Threatening, intimidating, coercing or interfering with others will not be tolerated. Horseplay, scuffling and acts which affect the safety of others will not be allowed on the work site.

Hard Hats

Hard hats are to be worn at all times on the construction site. Long hair shall be worn with a net and kept under the hard hat.

Protective Clothing and Safety Equipment

The use of appropriate safety equipment is required. this includes face shields, welding goggles, respiratory protection (as needed) and gloves. Shoes with badly worn soles and inappropriate to the task are not permitted. Boots with protected toes will be worn when needed.

Obey Signs

All safety signs, notices, and tags must be obeyed. Barriers, barricades, and safety tape will be utilized when deemed necessary to protect MCI personnel.

Cylinders

Compressed gases shall be stored, transported, and used in accordance with OSHA/MSHA standards. "NO SMOKING" and "NO OPEN FLAME" signs will be used as required.

Fumes and Vapors

An effort shall be make at all times to control or manage fumes and vapors so as not to create a health hazard.

Ladders

All ladders, scaffolding, etc. must be approved by OSHA/MSHA and tied off at the top and bottom. The top of the ladder shall extend 3 ft. above the landing to which it is secured.

Fork Lifts, Hand Jacks, and Construction Equipment

Under no circumstances should anyone other than a properly trained and certified person operate a forklift. Drivers must be sure that there is clear visibility in all directions before driving. The riding on equipment, except in the seat provided by the manufacturer, is strictly prohibited. Back-up alarms are required.

Fall Protection

Fall protection shall be provided for all employees working in elevated work areas. These measures include full decking, complete guard rails, toe boards, safety belts, and life lines (when required).

Electrical Equipment

Insure that all electrical equipment used is a type appropriate to the hazard classification of the area where work is to be performed. Electrical lock-out procedures must be followed when working on electrical or rotating machinery. Do not lift or lower power tools by their cords. Do not leave the cords of electric tools where cars or trucks will run over them.

Vehicles and Machinery

Do not operate equipment without permission unless such operation is part of your regular duties. Machinery shall not be repaired or adjusted while in operation, nor shall oiling of moving parts be attempted, except on equipment that is designed or fitted with safeguards to protect the person performing that work. Do not work under vehicles supported by jacks or chain hoists, without protective blocking that will prevent injury if jacks or hoists should fail. Air hoses should not be disconnected at compressors until lines have been bled.

Cleaning Up

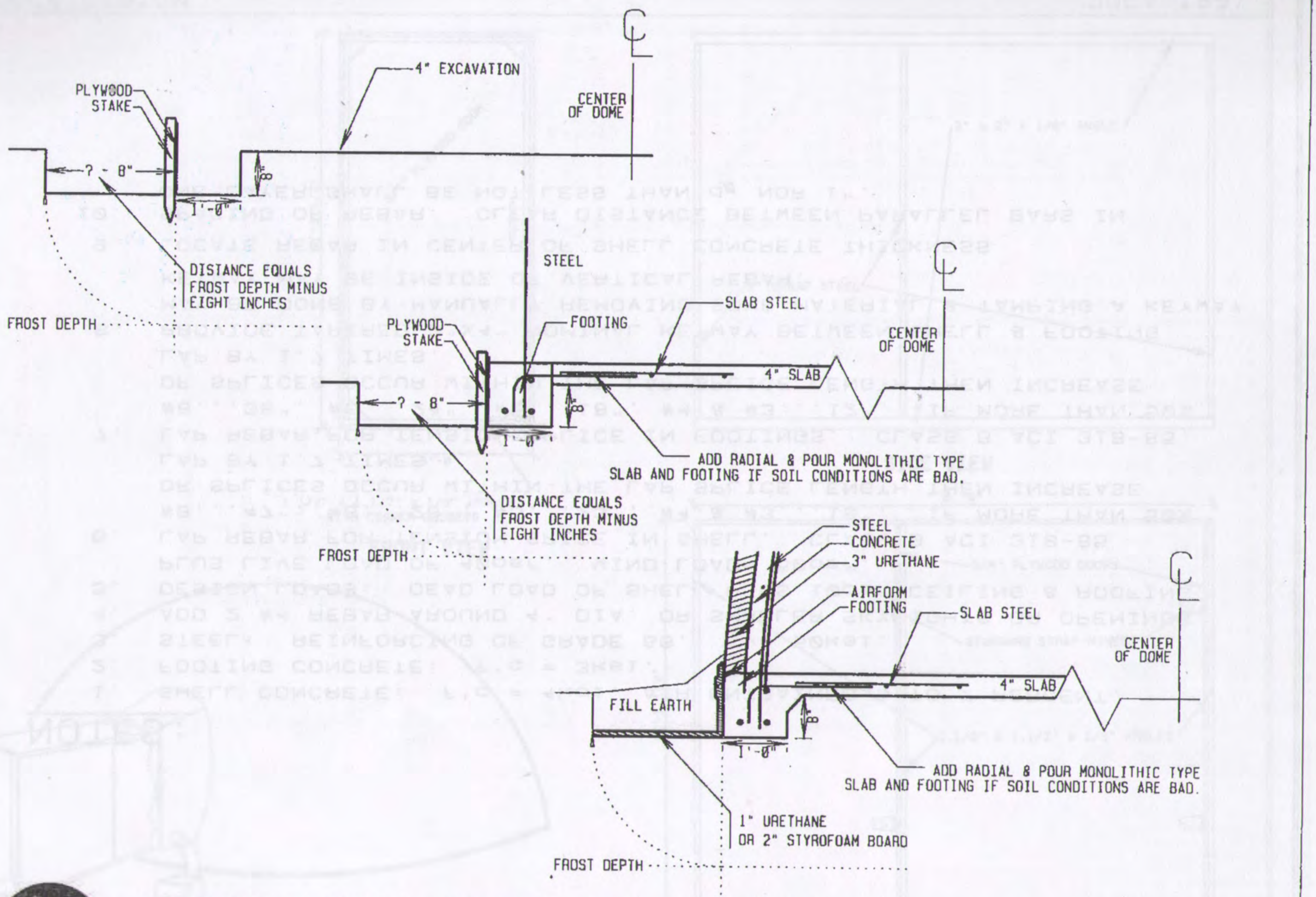
The work area at all times shall be kept clean. At a minimum, site cleanup shall be performed once per week or more often as required.

Addenda

Special addenda to this outlined policy statement may be required from time to time when the scope of a project warrants. Briefings on safety matters by supervisors in these instances will carry the same importance as this written policy though they may be verbal.

Administration Of The Safety Policy

Management and supervisory personnel shall insure that the company's safety program is followed. This is a dynamic document. Where changes are necessary, steps will be taken to implement those changes. Regular and on-going site inspections to insure compliance with the program will be required of the job supervisor.



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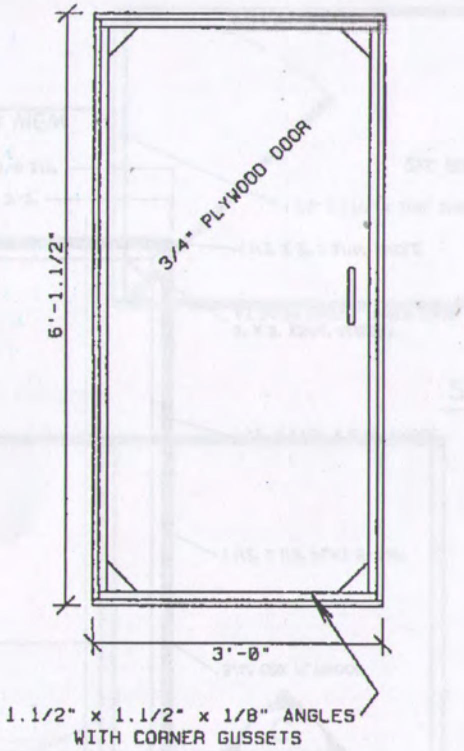
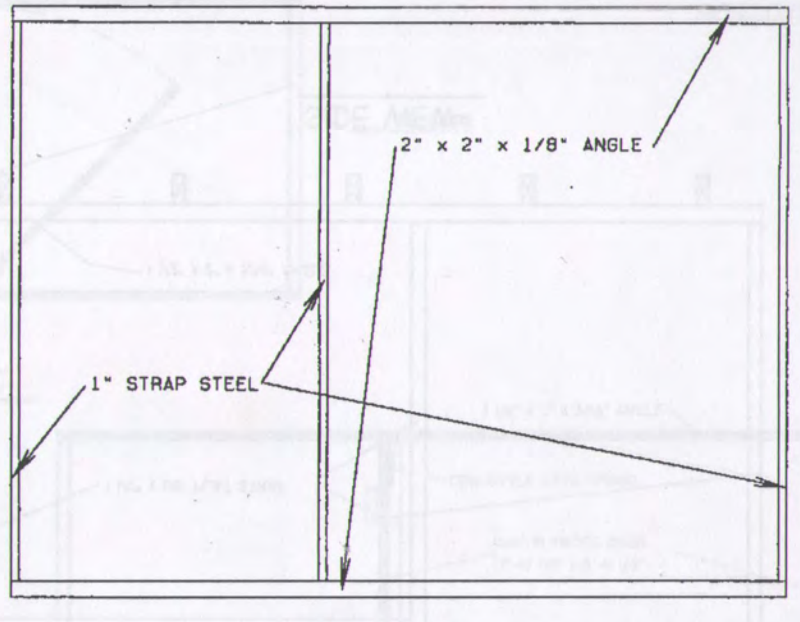
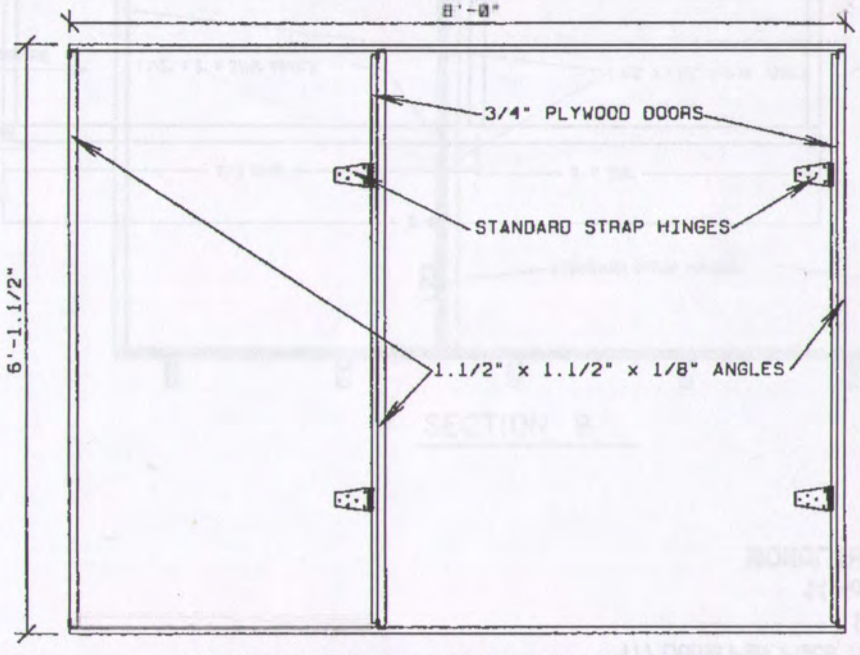


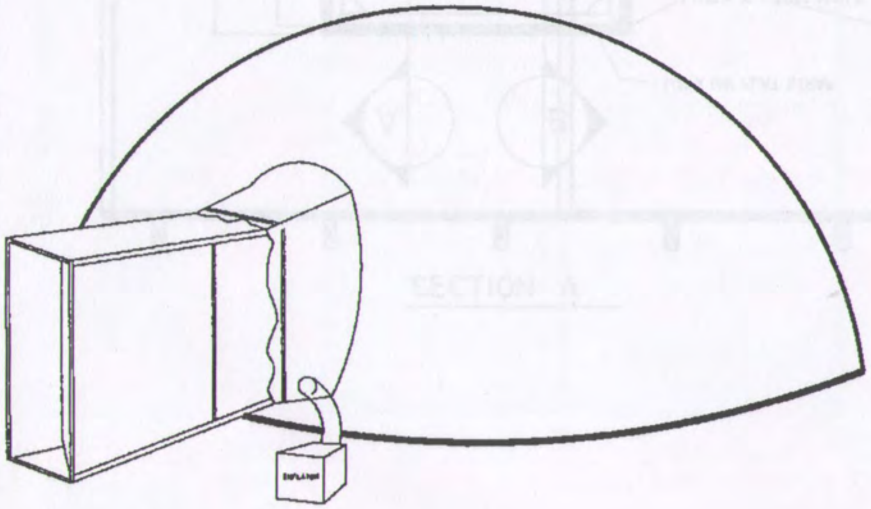
FRONT VIEW



SIDE VIEW



LONGITUDINAL VERTICAL SECTION



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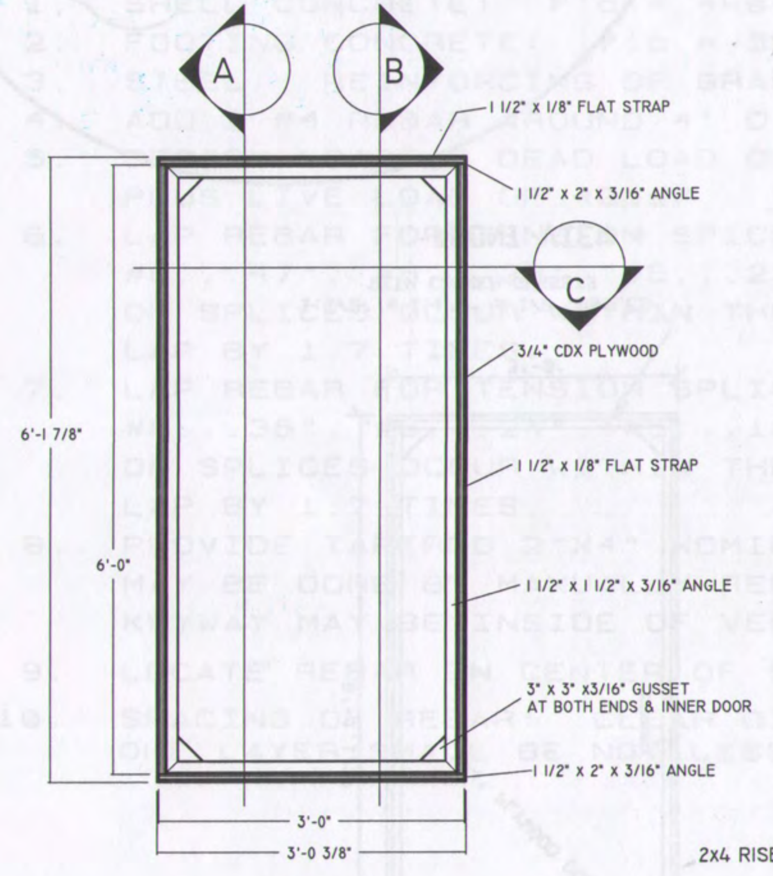
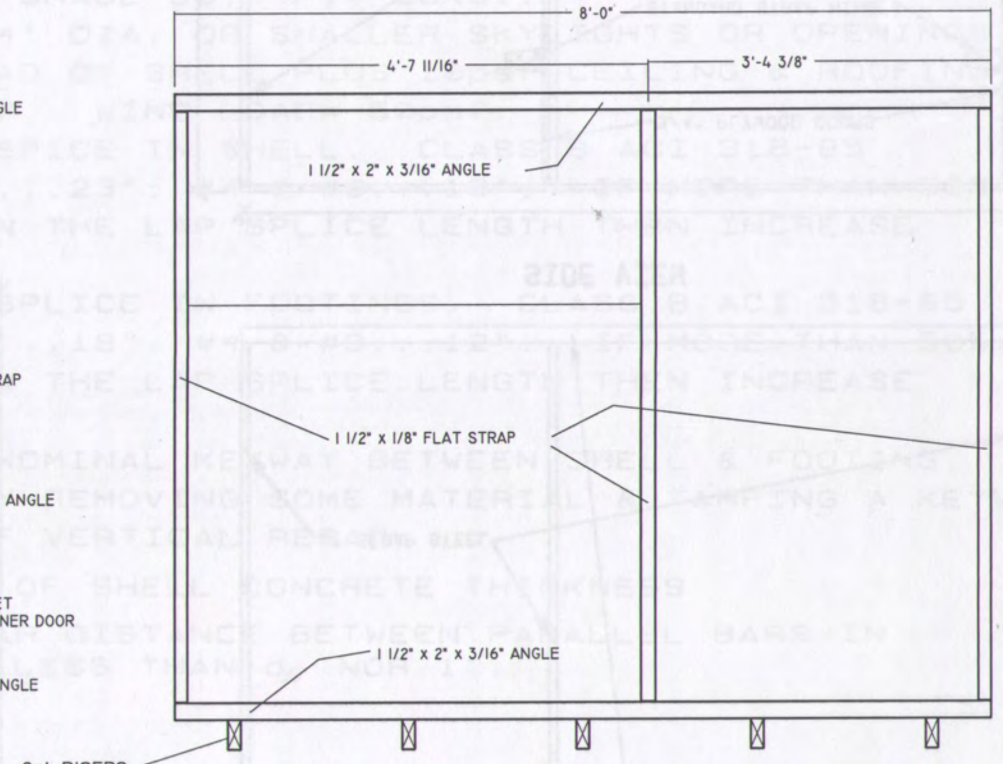
MONOLITHIC AIRLOCK



END VIEW



SIDE VIEW

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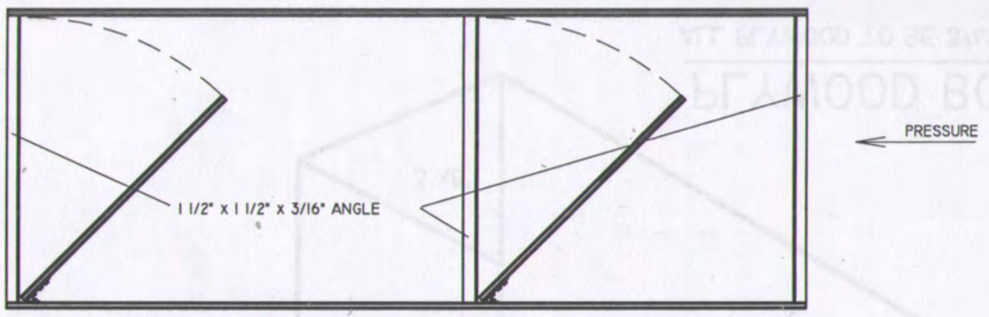
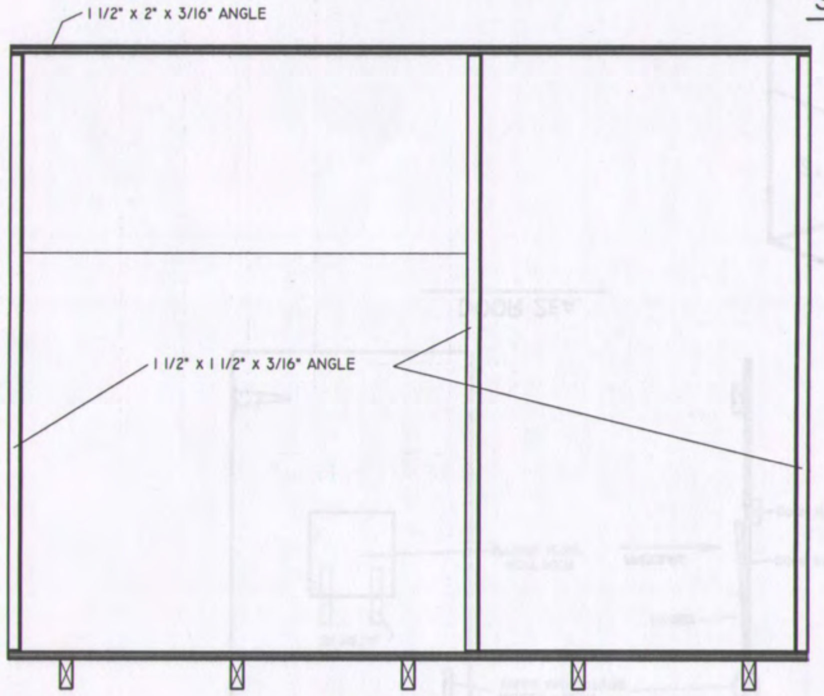
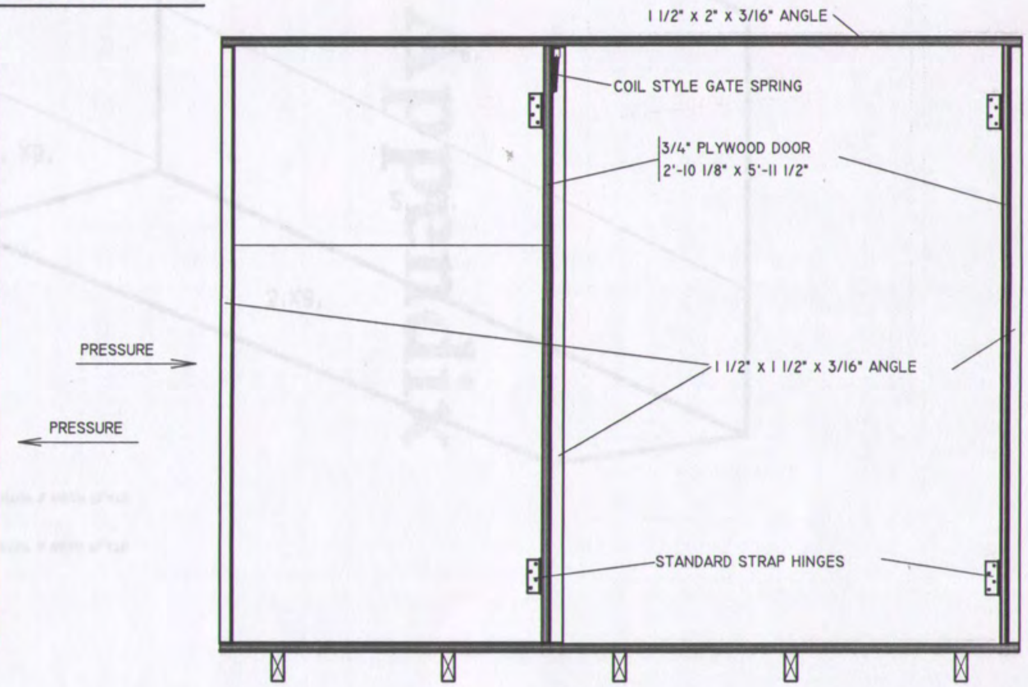
PAGE 2 of 3



SECTION C



SECTION A



SECTION B

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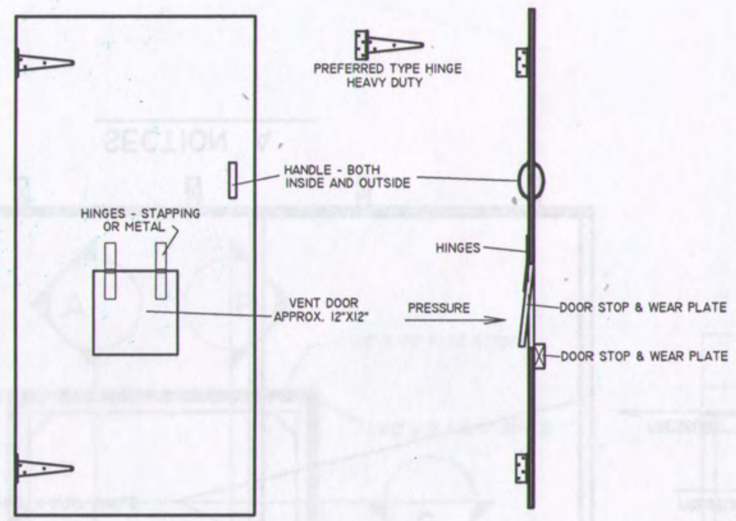
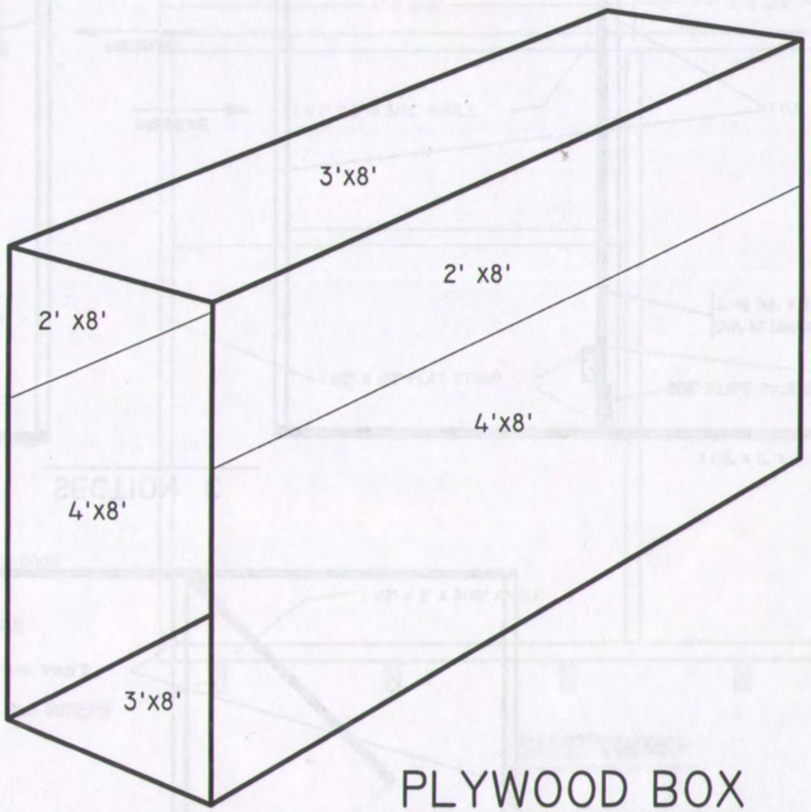
MONOLITHIC AIRLOCK



DOOR 2EA.



PLYWOOD BOX

ALL PLYWOOD TO BE 3/4" CDX

Appendix

Finding a Foam Supplier

One of the best places to start searching for a foam applicator is to contact is to contact **Dan Benedict or Mason Knowles of the Society of the Plastics Industry, in Washington D.C., at (800) 523-6154.** He and his colleagues are most willing to help you find an applicator. Another excellent source is to contact some of the foam manufacturers listed in this table. Ask them for active applicators in your area. (Listing Provided by S.P.I., Inc.)

A Sample Foam Manufacturer / Supplier List:

company	location	phone	contact
Burtin Corporation	Santa Ana, CA	(714) 850-1370	Dennis J. Fabian
Cook Composites & Polymers	Port Washington, WI	(800) 745-5541	Gary Maechtle
Corbond Corporation	Bozeman, MT	(406) 586-4585	Neal E. Ganser
Flexible Products Company	Marietta, GA	(404) 421-3222	Kent Hembree
Foam Enterprises	Minneapolis, MN	(800) 888-3342	James L. Andersen
Foam Supplies, Inc.	St. Louis, MO	(314) 427-7447	David G. Keske
GACO Western	Tukwila, WA	(206) 575-0450	James P. Hazard
Hydro-Seal Coatings Co., Inc.	Fallbrook, CA	(619) 723-8992	Heinz Lapper
Icynene, Inc.	Mississauga, Ontario	(416) 890-7325	Graeme G. Kirkland
IPI, a division of PMC, Inc.	Elkton, MD	(410) 392-4800 ext 216	W. Allen Webster
North Carolina Foam Industries	Mount Airy, NC	(910) 789-9161	Michael A Debone Jr.
Poly Foam Products, Inc.	Spring, TX	(713) 350-8888	Dick Huber
Polymer Development Labs, Inc.	Orange, CA	(714) 921-2300	Louis F. Cenegy
Premium Polymers, Inc.	Austin, TX	(512) 272-5531	Milton Altenberg
Resin Technology Company	Ontario, CA	(909) 947-7224	Bruce Freeman
Roof Mart International, Inc.	Chapman, KS	(913) 922-6544	Larry Garner
Stepan Company	Northfield, IL	(708) 446-7500	Ronald Seimon
SWD Urethane Company	Mesa, AZ	(602) 969-8413	Steven J. Perkins
Utah Foam Products	Salt Lake City, UT	(801) 269-0600	Bruce Wilson
Urethane Contractors Supply Company (UCSC)	Roswell, NM	(505) 623-9726	Lela Wright

Shotcrete Terms

Shotcrete

Shotcrete is a process by which concrete is air placed usually on a vertical or an overhead surface. Shotcrete is generally made from a mixture of sand, cement and water which is pumped usually by a piston pump through a hose to the nozzle. At the nozzle air is injected to break up and actually apply the concrete. Shotcrete is also called wet gunning or wet placed concrete. Most generally the concrete comes from a ready mix truck.

Gunite

Gunite is a term for a patented process by which sand and cement are mixed together and transported down a hose with a large volume of air to the nozzle. At the nozzle water is injected to create the proper moisture to set the concrete. Gunite is also called dry gunning or dry gunned air placed concrete. Generally the sand and cement are mixed on the job site. Gunite takes approximately three times as much air as shotcrete. It will have twice as much rebound.

Rebound

Whenever air placed concrete, either wet or dry process, is sprayed the surface will reflect or bounce back a certain amount. We have found it to be 10% with wet gunning and 20% with dry gunning. This can vary substantially from these numbers depending on the situation.

Concrete Strengths

Normally shotcrete is much stronger than conventional concrete because of several factors. Normally more cement is used in the mix. Also the impaction created by the air tends to drive out the larger air spaces thus providing a somewhat denser product. Usually shotcrete will have a compressive strength of more than 4,000 psi.

Concrete strength depends greatly on the aggregate, the amount of cement and the amount of water.

Aggregate

The best aggregate for shotcrete is a very even gradation from 3/8 to nearly nothing. If any of the sizes are left out that size must be replaced by the cement creating a much harder mixture to pump and work with. Rarely in the United States do we find nice, even graded aggregate. Aggregate that has been crushed is also much harder to work with than river or natural aggregates. The jagged edges of the crushed aggregate tend to hang up in the pumping process. Rarely do we find an even graded aggregate. So generally we have to make the best with what we can find in the locality.

Mix Water

Wherever possible the water cement ratio needs to be held at .4 - .45. This creates an extremely strong, workable concrete. Sometimes additional water must be used to create a pumpable mix. This is done most often when some of the aggregate is off size or cracked. Theoretically the slump test will give you an indication of the water cement ratio. However with 3/8 minus aggregate slump tests are very unreliable.

Slump Test

The slump test is performed by filling an inverted cone with concrete; removing the cone and measuring the distance the concrete slumps from the original height. A slump test is an extremely valid measurement for concrete in the 5, 6 sack range with 3/4 or larger aggregate.

Compressive Strength Tests

Compressive strengths in the conventional concrete industries are performed by breaking cylinders that have been filled and set aside for that purpose. A good correlation between a series of cylinders is about 20%. Unfortunately shotcrete doesn't test very well in cylinders unless they are special shotcrete cylinders which are hard to come by. The most valid system for testing shotcrete seems to be the Windsor Probe or spraying a 2" thickness that is later cubed and tested.

Cubed tests and Windsor Probe tests are generally quite comparable. The Windsor Probe is much easier as it is simply a matter of firing a bolt with a predetermined charge into the concrete and measure the depth of penetration. It is somewhat destructive in that there's a small hole left with a bolt sticking out of it. Cubed tests are totally nondestructive unless they are taken as cores. The major problem with cubed tests is always the question was the concrete cured under exactly the same conditions that is in the facility itself.

Concrete Thickness

Every endeavor is made to make concrete the proper thickness. This thickness is gauged by the amount of embedment on the steel, by stickers that are left as depth gauges and by the experience of the nozzleman. It is further checked and corroborated by the calculations of the volumes needed for the project. In general, however, the thickness is less important than properly embedding all of the reinforcing steel.

Fallouts

Fallouts are a phenomena of the wet concrete overcoming gravity. The wet concrete overcomes the suction and patches of wet concrete fall from the dome. This fallout is of the consistency of mud. It is not particularly dangerous but it doesn't feel great having it splash on you. The fallouts are replaced with the next day's shotcreting. They are neither a hazard nor a structural problem. They are simply a bothersome construction problem.

Equipment Needed to Build a Monolithic Dome

Inflator:

Obviously if we are to make Airformed concrete structures, we must have something to blow air. In our equipment list we are showing an electric fan to inflate the Dome. This fan is very adequate, but you must realize it is dependent on electricity.

If the electricity goes off for any reason damage may occur. If the electricity goes off when the Airform is first inflated, the Airform will just deflate. Once the urethane is in place on the smaller domes, the dome is self supporting. It is not supported well enough to be concreted, but at least it won't fall down. The times of vulnerability are when just part of the foam is applied, and when the first layer of concrete is applied. During that time there is a definite vulnerability to air pressure shut down.

This vulnerability to air pressure shut down can be mitigated by running two fans – one fan with an auxiliary generator, and the other fan by house power. If you decide to use two fans it is terribly important to place a flap over each fan outlet. If either fan shuts off the flap will prevent the air pressure from escaping. This flap can be a simple piece of fabric hung loosely over the outlet of the fan. The fabric will flop down over the fan and keep the air from going back through the fan, if it should shut down.

Lights:

High pressure sodium lights seem to work the best. Any light will work. They need a face guard to protect them. The face guard should be made of tempered glass. The glass should be flat so it can be cleaned regularly with a razor blade scraper. Simple 150 watt spot lights will also work on a limited basis.

Air Compressor:

It is terribly important the air compressor has enough volume. 185 CFM, 100 PSI is the absolute minimum for shotcreting (we prefer 250 CFM). Obviously, where someone else is doing the shotcreting, you should be able to rely on them. These air compressors are available from every reputable supplier. Diesel powered or electric, both work very well.

Urethane Foam Spray Equipment:

The primary supplier of urethane spray equipment in the United States is Gusmer Corporation. They sell all different kinds and sizes. Grayco, Ransburg, others also supply equipment. Our suggestion is if you want equipment you talk with us further. You need more than just the urethane machine. You need additional training which most of the vendors give. You need auxiliary equipment to go with the urethane machine – pressure tanks, etc. If you decide to spray your own urethane we will be glad to work with you.

Concrete Pumping Equipment:

There are many different kinds of concrete pumps that can be used to shotcrete. The most successful are hydraulically driven. If a hose jams, on these pumps, it doesn't bring the system to a deadlock and break something.

We can be helpful on a specific basis if we know what you may want to do. Concrete pumps run from 20 - 50 thousand dollars. The kind we use are Pea-Rock pumps. In other words they are specifically designed for the higher pressures of shotcreting, and they are designed to use 3/8ths of an inch as a maximum aggregate size. In many places they are called grout pumps.

We have developed a series of small peristaltic pumps for the smaller domes. They are marketed under the "Targhee" brand.

Suppliers of Urethane Foam:

Originally we planned on listing suppliers of Urethane Foam and Urethane applicators. Because this list changes from time to time, and is region specific, we suggest that you contact us for those suppliers and applicators in your area. We will keep a list available. We will try to keep the list updated as we locate applicators and/or suppliers.

In general you can find Urethane applicators in your yellow pages under insulation hot/cold. Most applicators will specify Urethane insulation spraying in their ad.

Concrete Application Companies And Equipment Suppliers:

This as with the Urethane Foam is generally region specific. We will endeavor to help you find both suppliers and applicators if you will give us a call. Let us know what you are looking for and in what region. We have found the best source for shotcreters to be in the swimming-pool trade. In metropolitan areas we find shotcreters listed separately in the yellow pages. Also, ask your ready-mix supplier.

Types of Portland Cement

Type I. Normal Portland Cement.

This is a general purpose cement suitable for all uses when the special properties of the other types are not required. It is used in pavement and sidewalk construction, reinforced concrete buildings and bridges, railway structures, tanks and reservoirs, sewers, culverts, water-pipe, masonry units, soil-cement mixtures, and for all uses of cement or concrete not subject to special sulfate hazard or where the heat generated by the hydration of the cement will not cause an objectionable rise in temperature.

Type II. Modified Portland Cement

This cement has a lower heat of hydration than Type I and generates heat at a slower rate. It is intended for use in structures of considerable size where cement of moderate heat of hardening will tent to minimize temperature rise, as in large piers, heavy abutments and heavy retaining walls when the concrete is placed in warm weather. In cold weather when the heat generated is of advantage Type I cement may be preferable for the users. Type II cement is also intended for places where added precaution against sulfate attack is important, as in drainage structures where the sulfate concentrations are higher than normal but are unusually severe.

Type III. High Early Strength Portland Cement.

This cement is used where high strengths are desired at very early periods. It is used where it is desired to remove forms as soon as possible or to put the concrete into service as quickly as possible, in cold weather construction to reduce the period of high strengths desired at early periods can be secured more satisfactorily or more economically than by using richer mixes of Type I cement.

Type IV. Low Heat Portland Cement.

This is a special cement for use where the amount and rate of heat generated must be kept to a minimum. The development of strength is also at a slower rate. It is intended for use only in large masses of concrete such as large gravity dames where temperature rise resulting from the heat generated during hardening is a critical factor.

Type V. Sulfate Resistant Portland Cement.

This is a special cement intended for use only in structures exposed to severe sulfate action, such as in some western states having soils or waters of high alkali content. It has a slower rate of hardening than normal portland cement.

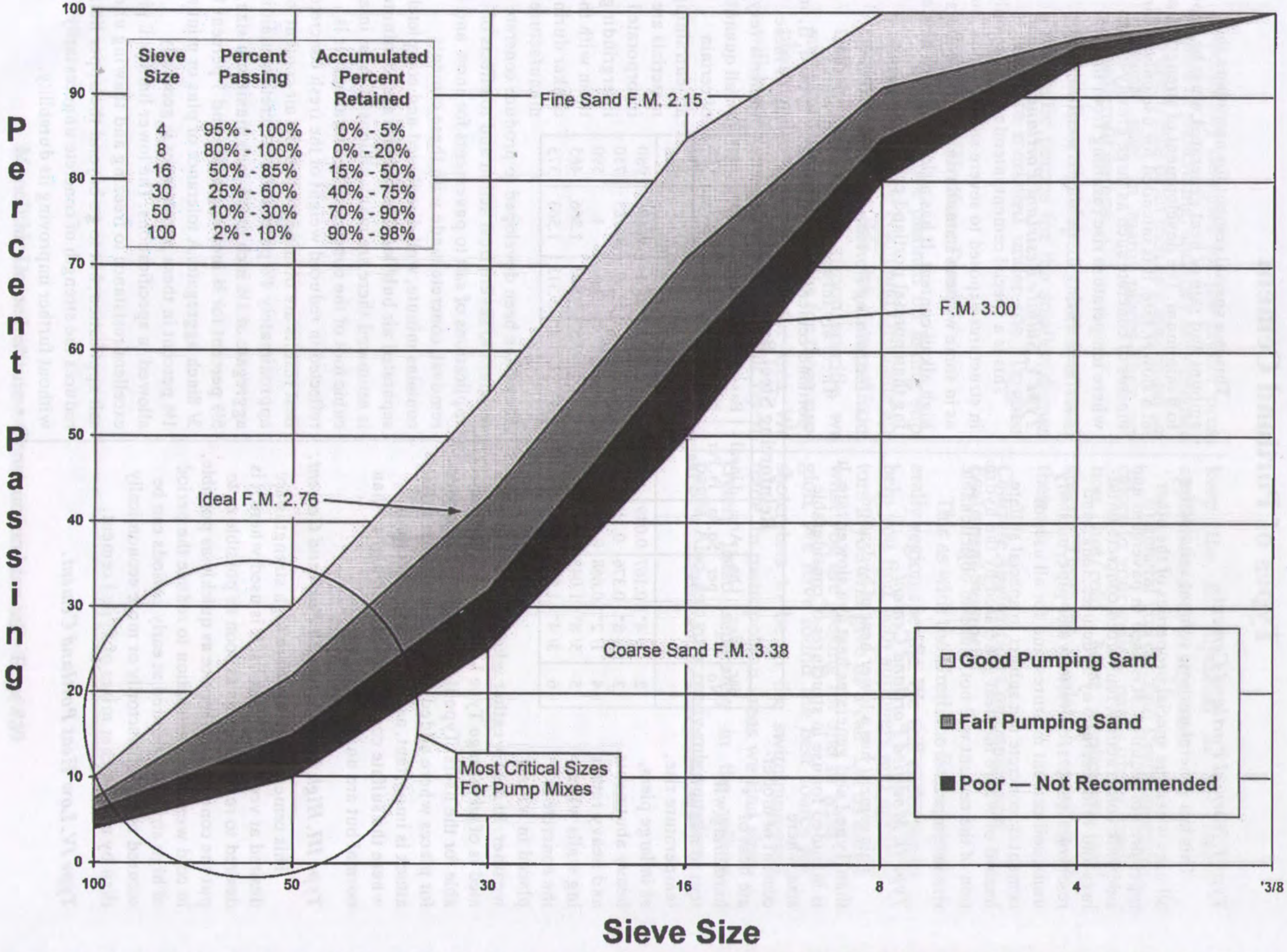
Air Entraining Portland Cement.

There are three types of air-entraining portland cement corresponding to Types I, II, and III. In these cements very small quantities of certain air-entraining materials are incorporated by intergrinding them with the clinker during manufacture. They have been developed to produce concrete resistant to severe frost action and to effects of applications of salt to pavements for snow and ice removal. concrete made with these cements contains minute, well-distributed and completely separated air bubbles. The bubbles are so minute it is estimated there are many billions of them in a cubic foot of the concrete. The entrained air is reflected in reduced weight of the fresh concrete. Best results are obtained when the air content is approximately 4½ percent for concrete containing aggregate of 1½ inch or 2½ inch maximum size, 5½ percent for ¾ inch aggregate and 7 percent for 3/ 8inch aggregate. A tolerance of plus or minus 1½ percent in these percentages is generally allowed in specifications. The lower limit will give excellent resistance to freezing and thawing under salt application, but to go beyond the upper limit reduces the strength of concrete unnecessarily without further improving its durability.

Reinforcing Steel Bars

Bar No	Size	Lbs per Ft.	Area Sq. In.	Lineal Ft. Per Ton	Bar No	Size	Lbs Per Ft.	Area Sq. In	Linea l Ft. Per Ton
2	1/ 4"	0.167	0.049	12000	7	7/ 8"	2.044	0.601	980
3	3/ 8"	0.376	0.11	5320	8	1"	2.67	0.785	750
4	1/ 2"	0.668	0.196	3000	9	1"	3.4	1	590
5	5/ 8"	1.043	0.307	1910	10	1 1/ 8"	4.303	1.266	465
6	3/ 4"	1.502	0.442	1330	11	1 1/ 4"	5.313	1.563	375

Fineness Modulus Chart



ON SITE MIX DESIGNS

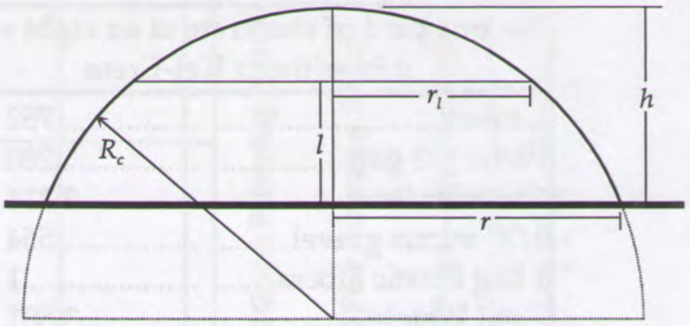
For one yard of shotcrete at an eight sack mix without Kel-Crete	For one yard of shotcrete at a seven sack mix with Kel-Crete
Cement..752 lbs.	Cement..658 lbs.
Water (35 gal)..............................280 lbs.	Water (35 gal)..............................280 lbs.
Concrete Sand..............................2,214 lbs.	Concrete Sand..............................2,275 lbs.
3/8" minus gravel..........................554 lbs.	3/8" minus pea rock.......................576 lbs.
1 Bag Plastic Fibers.......................1 lbs.	Kel-Crete(as needed)......................1 oz.
Total Weight.................................3,801 lbs.	1 Bag Plastic Fibers.......................1 lb.
	Total Weight.................................3,801 lbs.
Add air entrainment of 5% to 8%. Add water reducer per instructions.	No air needed. No water reducer needed.

Two sack mix per batch for approximately one fourth (1/4th) yard of shotcrete at an eight sack mix without Kel-Crete	Two sack mix per batch for approximately 3/10th yard of shotcrete at a 7 sack mix with Kel-Crete
Cement..........................188 lbs. (2 sacks)	Cement..........................188 lbs. (2 sacks)
Water.............................70 lbs. (8.75 gal.)	Water.............................80 lbs. (10 gal)
Concrete Sand...............552 lbs. (8 @5 gal.)	Concrete Sand ....690 lbs. (10 @5 gal.)
3/8" minus gravel.........140 lbs. (2 @5 gal.)	3/8" minus gravel.........140 lbs. (2 @ 5 gal.)
1/3 Bag Plastic Fiber ....1/3 lb.	Kel-Crete (as needed)...........................2 to 3 oz.
Total Weight...........................950 1/3 lbs.	1/3 Bag of Fiber.................................1/3 lb.
	Total Weight...........................1,101 1/3 lbs.

NOTES:

1. The 3/8" pea gravel may be left out. The mix will usually be harder to pump. The concrete will not be as strong, but generally acceptable especially for the last coat or two. The surface will be smoother.
2. Water may need to be adjusted to achieve the proper slump 2" to 6".
3. The Kel-Crete should be added early in the mix with the water or direct.
4. EasySpred should rehydrated by mixing with water for 15 minute minimum. It can be premixed as long as two weeks before using.

SPHERICAL DOME FORMULAS



Spheroid Dome

Circumference of base: $C = 2\pi r$

Floor Area: $F_a = \pi r^2$

Radius of Curvature: $R_c = \frac{r^2+h^2}{2h}$

Surface Area: $S_a = 2\pi h R_c = \pi(h^2+r^2)$

Radius at second level: $r_l = \sqrt{R_c^2 - (R_c - h + l)^2}$

Volume: $V_s = \frac{1}{3}\pi h^2(3R_c - h) = \frac{1}{6}\pi h(3r^2+h^2)$

Skin Tension: $T_s = \frac{P_a R_c}{2}$

Air Pressure: $P_a = 1''$ water column $= 0.0361\,psi = 5.2\,psf$

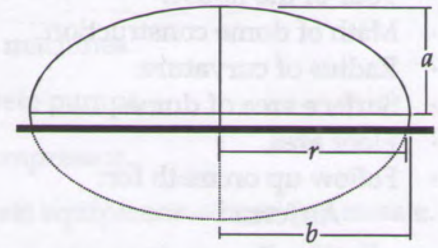
Explanation of terms

- π – is the number Pi (pronounced "pie"). Pi is the distance around the edge of a circle divided by its diameter. For our purposes the number π is a constant of 3.14159.
- d – is the diameter of the base of the dome.
- r – is the radius of the base. It is equal to half the diameter.
- R_c – is the Radius of Curvature. A spheroid dome is a segment of a sphere. Usually the top or cap of a sphere, but it can be any segment including half the sphere (hemisphere) or greater. It is helpful to think of a dome as a sliced off top of a basketball. The shape is always that of the whole basketball no matter where or how it is cut. The radius of curvature is the distance to the center of the sphere.
  Example: 40 foot diameter by 15 foot tall dome. $r = \frac{40}{2} = 20$ feet
  $R_c = \frac{r^2+h^2}{2h} = \frac{20^2+15^2}{2*15} = \frac{20*20+15*15}{30} = \frac{400+225}{30} = \frac{625}{30} = 20.83$ feet
- l – is the distance from the base of the dome to a second level (like a second floor).
- r_l – is the radius of the dome at a second level (l high). This radius is helpful to create a second floor layout or to check clearances for doors and windows. Floor area and circumference at this level is calculated using the same formulas for the whole dome (where r_l is substituted for r).
- C – is the circumference or perimiter of the base of the dome (the distance around the dome).
  Example: 40' x 15' dome – $C = \pi d = 3.14159 * 40 = 125.66$ feet
- F_a – is the area of the floor of the dome.
  Example: 40' x 15' dome – $F_a = \pi r^2 = 3.14159 * 20^2 = 3.14159 * 20 * 20 = 1,256$ ft^2
- S_a – is the surface area of the dome. (This is the equation where R_c is used most often)
  Example: 40' x 15' dome – $S_a = 2\pi h R_c = 2 * 3.14159 * 15 * 20.83 = 1,963$ ft^2

ELLIPSOID DOME FORMULAS

Ellipsoids are difficult to calculate and understand, however, they make very useful dome shapes. Our most common shape is the *oblate ellipsoid.* It looks like a standard spherical dome with a circular base, but it is "squashed" a little. The sides are more vertical and the top is flatter. This makes smaller "house" size domes that have a little more headroom along the dome wall. A *prolate ellipsoid* looks more like a watermelon. It is useful in creating a unique building shape.

Ellipse: (Let *a* be the semi-major axis and *b* be the semi-minor axis.)



Elliptical formula: $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

Eccentricity: $\in = \frac{\sqrt{a^2 - b^2}}{a} = \sqrt{1 - \frac{b^2}{a^2}}$

Oblate Ellipsoid: An *oblate ellipsoid* is formed by the rotation of an ellipse about its minor axis. Let *a* be the semi-major axis and *b* be the semi-minor axis. Let ∈ be the eccentricity of the revolving ellipse.

Minimum Semi-minor to Semi-major axis ratio: 1 : 1.35

Surface area for entire *oblate ellipsoid*: $S_o = \pi a^2 + \frac{\pi b^2}{2\in} \ln\left(\frac{1+\in}{1-\in}\right)$

Volume for entire *oblate ellipsoid*: $V_o = \frac{4}{3}\pi b a^2$

Prolate Ellipsoid: A *prolate ellipsoid* is formed by the rotation of an ellipse about its major axis. Let *a* be the semi-major axis and *b* be the semi-minor axis. Let ∈ be the eccentricity of the revolving ellipse.

Surface area for the entire *prolate ellipsoid*: $S_p = 2\pi b^2 + \frac{2\pi ab \arcsin(\in)}{\in}$

Volume for entire *prolate ellipsoid*: $V_p = \frac{4}{3}\pi a b^2$

Monolithic Training #1

Narration by David B. South

- David's introduction.
- Outside of office.
- Inside of office.
- Now in Oberon house.
- Tour of the house.
- Math of dome construction.
- Radius of curvature.
- Surface area of dome.
- Floor area.
- Follow up on math for:
  - Airform.
  - Foam.
  - Rebar and hangers.
  - Concrete.
- Different densities of foam.
- How much foam to buy.
- How many stickers to buy.
- How much rebar to buy.
- How much concrete to buy.
- Rough pricing totals.
- Other shapes.
- Why curves give strength.
- Low profile domes.
- Elliptical shapes.
- Plan view and side view.
- Caterpillar.
- More math– radius @ the top.
- Concrete.
- 8 sacks cement.
- Concrete is plastic (hydrates).
- Why use 9 bag mix.
- Slump testing.
- Good spraying shotcrete may have different slumps.
- Cylinder testing.
- Other testing.
- Should easily achieve 4000 PSI.
- Gradation of aggregate.
- Concrete sprayed in layers.
- Where to start.
- Where to spray concrete.
- Spray angle is very important.
- Make certain that concrete helps hold itself up.
- Concrete is a cross-linking process.
- Do not lose humidity.
- Do not lose heat.
- Add heat if necessary to building.
- Ordering the concrete– how to order. 4000 PSI concrete in 28 days.
- Washed aggregate may be hard to use if it is washed carelessly.
- Small domes.
- Foam is enough strength.
- But still plaster or spray concrete.
- Foam buildings without concrete can burn.
- Footings must be heavy enough.
- Footings and floors can be poured together.
- Pouring concrete floors to the dome-- no need for expansion joint.
- Dome shells breath slightly.
- Concrete works with rebar, compression and tension.
- Notch in footing keyway.
- Nails in window bucks to hold them securely.
- Put extra steel around openings.
- Scaffold for building domes.
- Anchoring things to the dome shell.
- How to find someone to spray foam.
- Deciding on what foam to use "density."
- Foam sprayer must spray well, even layers.
- Spray foam perpendicular to the wall.
- Depth of foam.
- Must spray on dry Airform –no water.
- Check depth carefully.
- Use fast foams.
- Foam spraying can be tricky for the novice.
- How to find concrete sprayers.
- Swimming pool builders etc...
- Use Wet Gun Shotcrete.
- Big difference in shotcreting pools vs. domes.

Monolithic Training #2

Narration by David South

- Spray concrete to proper thickness.
- Depth gauges (cut off rebar hangars).
- Spray concrete with adequate velocity.
- Spray concrete with even layers, not too thick, avoid fallouts.
- Very small domes, foam can support.
- Foam equipment can be small and portable.
- Concrete can be hand mixed and hand trowelled on to the building.
- Airforms – strong, but can be damaged, how to repair.
- Lighting in the dome while it is under construction.
- High pressure sodium (400 watts) works very well.
- More on equipment:

1. Fan units.
2. Foam machines.
3. Concrete pumps.
4. Air compressor.

- Shotcrete equipment – hose and nozzle.

40 minute section on EcoShells

Monolithic Training #3

Narration by Randy South

- Basics of concrete domes.
- Basics of concrete itself.
- Aggregate, water and cement.
- Concrete and steel working together.
- Imagine building a bridge.
- Concrete under compression-- has to be hard.
- Steel rebar under tension-- has to be strong.
- Reasons for using rebar in concrete.
- Keeping cracks small.
- Moment or sheer connections.
- Concrete must surround or embed rebar.
- Rebar is called deformed bar.
- Ridges on rebar are very important.
- How rebar is classified for strength.
- 60,000 lb tensile strength bar for domes.
- Steps to build dome.
- Mark out footing.
- Put in footing.
- Forms.
- Put in steel in footing.
- Prop up steel from floor of footing.
- Pour concrete in footing.
- Put in keyway.
- Steel tendons make the ring beam.
- Forces on a dome are distributed.
- Concrete has little tensile strength.
- Domes are inherently strong because of shape.
- More on rebar.
- Rebar is called a number according to eighths of inches.
- Back to building an example 50' dome.
- Must have a certain mass to hold building down.
- How to figure how much rebar to buy.
- Must lay bars with overlaps.
- If overlaps in same area use longer laps by 1.7 times.
- Also must have radial dowels out of footing ready.
- How to order concrete for footing.
- What makes strongest concrete.
- Discussion about rocks and pastes.
- Even gradation of sand.
- Concrete companies don't even know these secrets.
- Sand Sieves.
- Fineness Modulas.
- Why not use 8 or 9 sack concrete all of the time.
- Using sand and pea gravel so we can spray.
- Pour footing.
- Attach Airform to footing.
- Measure footing (place Airform carefully).
- Make certain rebar is bent down.
-
- Photographs of dome construction.

  Rebar tendons in footing.

  Anchor bolts can be poured in place.

  Footings can even be sprayed.

  Airform ready for shipping.

  Steel must be bent down so it won't ... tear Airform.

  Can pour floor and footing in one ..... piece.

- Bolt skin down using flat iron bolted to concrete with wedge anchors.
- Bolt skin down using metal clips to regular concrete anchor bolts.
- Caterpillar dome footing.
- Spreading an Airform and airlock.
- Place necessary equipment inside before you spread Airform.
- Do not spread Airforms or inflate domes in high winds.
- Caterpillar dome Airform inside.
- Blown on entry Airforms.
- Hook the air lock to the dome.
- What is the air lock like.
- What kind of fan to use.

Monolithic Training #3, page 2

- Manometer.
- Water column pressure.
- Fan big enough to overcome leaks.
- Squirrel cage fan must be backward inclined blades.
- After building is inflated the volume of air going into the building virtually stops. The fan maintains a head of pressure.
- When spraying foam and sealing leaks watch pressure carefully.
- Do not cut holes into Airform.
- Insert hoses, electrical etc. through holes in airlock tubes.
- Holes in airlock allow you to pass rebar, lumber etc. inside.
- Fans use a slide gate to regulate air flow again watch pressure carefully.
- Photographs.
    - Slide gates.
    - Different fans and motors.
    - How to fasten air locks to air lock tubes.
- How to attach air lock tube-must allow for slack.
- Slide gate-make sure you can lock it into place.
- Video training for the men from Iraq.
- Air lock.
- Manometer.
- Spreading Iraqi skin.
- Bolting skin to the footing using 4 in channel iron clamps and 3/4" rebar.

Monolithic Training #4

Narration by Randy South

- Iraqis spreading skin in Georgia.
- Inflating Airform.
- Attaching air lock to air lock tube.
- Cover floor with plastic.
- Filling and checking manometer.
- Cover rebar inside (protect from foam).
- Spraying foam.
- Mounting window buck.
- Detail bolting skin to footing.
- Detail covering rebar.
- Spray foam 3" thick.
- Seal around base first (watch air pressure).
- Spray foam properly.
  1) No off ratio.
  2) Thin layers to keep from puckering.
  3) Do not spray on water or water vapor.
- Magic of insulation (urethane).
- How we got started building domes.
- Why urethane burns inside a building.
- Why Monolithic Domes can't burn.
- Urethane Sun burns – either leave skin on or paint or shingle.
- We recommend 22 oz. or 28 oz. vinyl.
- Airform material.
- How to tell inside and outside of an Airform.
- Stretch on Airform materials.
- Why leave Airform on building.
- Airforms last for long periods of time.
- Critical that foam is sprayed (on ratio).
- Make certain equipment is functioning properly.
- Again spray bead of foam around base.
- Spray thin layers of foam.
- Hang stickers.
- Spray the rest of the foam.
- Where to put stickers.
- Put one sticker in place.
- Stretch wire for marking sticker lines (compass method).
- Iraq men putting in stickers.
- Stickers can be put in with measuring rod (second method).
- Tying rebar to stickers (horizontal bars to stickers).
- Tying vertical next (to horizontal bars).
- Splices in an area (increase the length of the splice 1.7 times).
- Tools required few and simple.
- Do not use cutting torch unless very careful.
- How to tie with loop ties.
- Hang rebar horizontal first (except at base) at base stand vertical rebar first.
- How to read steel engineering for rebar.
- Certain there is a finger's distance from rebar to foam.
- Tie overlaps securely.
- Recap– tools.
- Tie conduit right onto rebar (where needed).
- Spraying Concrete.
  - Spray at proper angle.
  - Spray domes (different concept).
  - Spray concrete in layers (why it works).
  - Are no cold joints with 9 sack mix.
  - Spray full depth wedge onto footing first.
  - Spray proper angle and distance.
  - Spray with proper velocity of concrete.
- Back to demonstration dome. Use plenty of air 185 CFM minimum.
- Concrete (Shotcrete) spraying operation.
- Spray concrete use up and down stroke.
- Concrete spray hat.
- Use protective suit to keep from burning.

Monolithic Training #4 page 2

- Make certain good concrete before you spray wall.
- Keep nozzle low.
- Keep nozzle close.
- Build up base first.
- Concrete forced out to back of bar.
- Check depth by sticking into wet mud.
- Spraying again.
- Wear protective gear (hat & dust masks).
- After every spray clean off door frames etc...
- Recap.
- Spray concrete at base thick at first.
- Spray close, at proper angle, distance and velocity.
- Pictures of domes under construction.
- Tie steel in a semi spiral to save time and rebar cutting and fitting.
- Domes can accommodate large openings.
- Use redwood or pressure treated lumber.
- Domes in Iraq and other miscellaneous pictures.