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ALTERNATE FORMING SYSTEM FOR SMALL DIAMETER CONCRETE DOMES

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ALTERNATE FORMING SYSTEM OF SMALL DIAMETER CONCRETE DOMES FOR LIVING STRUCTURES

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This project by Christopher Scott Zweifel is accepted in its present form by the Department of Civil and Environmental Engineering of Brigham Young University as satisfying the project requirements for the degree Master of Science.

Arnold Wilson, Committee Chair

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Date

Introduction

Perhaps the most stable geometric shape is the sphere. It therefore follows that half of a dome, anchored to the ground to complete the continuity, is also a very stable structure. This shape puts the structure almost entirely in compression which makes concrete an ideal building material choice. Many domes have been constructed in the United States and throughout the world. However, the cost of the special equipment that is needed to construct a dome is very expensive. On the other hand, the construction of a dome is not a terribly labor intensive project. This works well for our country where labor is very expensive and equipment is readily available. However, the opposite is true in other countries where labor is cheap and machines are inaccessible! This or an equivalent system would allow people to build a dome home with an inexpensive material and their own tools and labor.

My project originated from a desire to develop a forming system for the construction of small diameter concrete dome homes. The objective was to minimize the need for expensive tools and technical expertise. This construction method provides a good opportunity for areas where cheap labor is readily available.

Around the world there are people that live in little hovels subjected to the dangers of high winds and rain. Many of these homes are destroyed each year killing hundreds or thousands of people. If these people were able to build a concrete dome home, the chance of this sort of destruction would be reduced. These homes would also provide a very secure and sealed structure that could be kept cleaner, which would help eliminate a lot of disease.

I would suggest a dome home that is 16 ft in diameter. A 16 ft diameter would be the most feasible for this because it covers about 200 square feet and is 8ft in height at the center. A smaller dome would have such a short center and such a small curvature that most of the structure would be unusable because of its limited height. A dome that is much larger than this becomes unbuildable with this system because of its height and large diameter.

Procedure

The original forming system, as shown in figure 1, was a steel slip form mounted to a vertical pole and mounted solidly in the vertical position. The vertical pole was positioned so that it would be directly in the center of the dome. This pole was approximately 7 ft in height(for a 16 ft diameter dome). The pole serves as the center of the dome which will grow up around it. The pole must be securely fastened to the base for ease of use.

The second step was to find a lever arm to attach to the center pole. It needed to be around 7.5 feet in length. The lever arm needed to be attached to the pole so that it could be rotated completely around the vertical pole. It was able to rotate both horizontally and vertically. The lever arm was stiff enough to avoid bending while the dome was under construction.

The form shape was the next step of the construction procedure. A continuous slip form was originally designed and constructed. The intent was to slip it around the dome in a continuous casting technique. A continuous wrap of #2 wire was placed around the base, and the rest was to be basically unreinforced.

The slip form was constructed of two pieces of 11"x 30"x 1/8" thick steel (see figure 2) that were rolled to the desired curvature.

Due to the circumstances of the dome construction, the slip form did not work smoothly. The concrete would not release from the form. As the concrete was forced between the slip form, it became lodged inside of the form. Nothing could get the concrete out of the forms, including setting a block down to push the concrete out as the form rotated. These problems can be attributed to the following three reasons: first, had the forms been polished, they would have slipped around the concrete. Second, a layer of plastic was placed on the floor to protect the lab, and the plastic would catch on the form and move with it. Third, if the slip form could be vibrated the concrete may slip through the form. With these obstacles removed, the system likely would have worked.

The majority of the idea was good. However, some modification was required. Dr. Wilson and I developed an idea to mount a large wooden form onto the face of the steel slipform that I had already built. The new form would not be continuous casting, but would cover a lot more area at once. The new form would also be able to integrate all of the work that had already been done.

To build this form, a 4'x8' sheet of 1/4" plywood was cut in four strips, each approximately 12" wide. One piece of the plywood was then screwed to the middle of the steel form that was previously built. The other strips were attached on in such a way as to stagger the joints. The final form was 16' in length and 1' high. The long strip was bent around until it approximated the shape that was required. The inside of the form was braced with 2x4's so that it would retain its shape even when lifted off of the ground.(see figure 3)

To make this form the right shape it was first traced out on the ground. By following this somewhat simple layout, a good form was made in a very short amount of time. Care needs to be taken when building the form. Because of my haste, one side of the form was somewhat flatter than the other side which caused some very significant problems later.

In attaching this form to the lever arm, the following suggestion proved very useful. The form was mounted to a moveable jig that would slide in and out a total of about 6 inches.

The reason behind this was that you can move the form around into the position that you would like, then extend the arm until it is flush with the sections of the dome. After the concrete has set, you just loosen the set screw and let the form release back into the center of the dome. This allows the lever arm to rotate freely because it now has a slightly smaller radius. This also makes it much easier to release the form from the concrete.

After attaching the form to the end of the lever arm, the lever arm needed to be attached to the base of the center pole. It should be able to rotate freely at the base. Then a rope was run from the top of the center pole to the end of the lever arm where the form was attached. This was necessary to be able to raise the form around the dome.

When starting the construction of the dome, the form was painted with oil, then chicken wire was placed up against the form.

The concrete was plastered onto the form. A mix that worked well was three parts sand, one part cement, and one-quarter part lime. The trick was to mix well and add just enough water to make it workable. The lime can be deleted, but it really helps in making the concrete more workable and easier to apply onto the form.

The plastering was started from the bottom and worked in an upwards motion to the top of the form. The right amount of water in the mix was found to be critical to a good mixture. If this precious ingredient was mixed in the right proportion, the concrete stood up easily on the form with the wire mesh. If too much water or not enough was used, the mix would either be too runny to stand up or too stiff to work with. An effort was made to keep the layer uniform from the top to the bottom of the form. It was not necessary to make this first layer 100%

smooth. In fact, it should be somewhat rough so that the second layer can bond properly and well.

When doing lifts, it is best to go in a circular-spiral pattern. In this way, you can make a best fit and a closely jointed structure. I started that way and then decided to try "stacking" the lifts or moving the form straight up for two of three lifts. Then, the form was moved over and another row was started.

This seemed like a good method at first, but it was not realized that a slight imperfection in the form, or if the form was a little crooked then the closure error was multiplied. Since the concrete was stopped on either side of the doorway, the closure error was not realized until the concrete crossed over the top of the door. And it was about a six inch gap where the form did not meet both edges of the existing concrete. The gap created quite a difficulty in tieing the formed section together.

The form over the top of the door was moved much higher so that it would touch both sides. Then a form was located over the lower section directly over the door and the concrete placed. This gave the "beam" that was spanning over the door area enough depth and curvature to stand by itself.

There were numerous other discontinuities and gaps that appeared in the dome as it was being constructed. Evidence of these and the relatively simple procedure to fix them can be seen in figures 11 through 13.

Throughout the dome, pieces of wire fabric were placed to reinforce the dome and help hold it all together. It was found that using strips of "chicken wire" that were about 14" tall and 48" long worked the best. When the pieces where larger, they became difficult to work with because of the double curvature of the dome. Smaller pieces were also a problem because they required too much effort and tie-wire to hold all of them together.

As the dome grew and gained double curvature, it became very stiff. It even supported the weight of the person troweling concrete on the upper layers (See figure 15).

Nearing the top, it was easier to shovel the concrete on the outside of the form and trowel it down using a ladder on the inside (See figure 17).

On the top side of the dome, it was also necessary to brace the form so that it did not move around or deflect while placing the concrete on it.

After the entire dome was plastered with the first layer, it looked very patchy (See figures 23 and 24). It was also very strong. I was able to stand on top of the dome when it was only ½" thick.

The entire dome should then be wrapped with another layer of chicken wire and plastered with another ½" of concrete. It will help tie the dome together better if the second wrap of wire was wrapped perpendicular to the first layer.

I was able to successfully complete this project within the desired specifications. It was even tested very briefly by setting a forklift from the lab, which weighed 7,500 pounds, on top. The forklift did cause a failure of the structure.

Suggestions

I would like to give the following advice for anyone trying to build a dome of their own. If the form is the least bit out of round, you will have gaps appear with the rotation of the form. You should be able to trowel over these with a light skimming of concrete. Don't try to fill these gaps with one single pass. Lightly coat the chicken wire with some concrete and let it set. By the time you are ready to put up another lift, you should be able to easily recoat the gap and it will fill in nicely. If it is too bad, it might take three passes to completely fill in. When working higher up on the dome, it was necessary to shore up the form to keep it from sagging. To keep the wire mesh in the right place, it can be tied to the last lift with pieces of tie wire. After the first layer of the dome is complete, it will look like a pretty sad igloo. Don't worry through, when the second layer is applied, it will smooth it all out. To tie the two layers together, wrap it with chicken wire that goes 90 degrees to the first lifts. Be sure to fill all of the gaps together with wire. The whole dome can be covered with wire at once. The second layer of concrete can be applied all at once also. Just spread the concrete on in the same manner as before. Starting from the bottom and working upwards. Work your way around the dome filling in any low spots. It is important to not have too much water in the mix for the second layer because you can get large shrinkage cracks. If the concrete is too thick, try to use a water reducer to make it more workable. Also, thoroughly wet down the first layer to keep it from sucking the moisture out of the second layer. As the form was moved around, small discontinuities started to appear. This in part was credited to the fact that the form was not perfectly symmetrical. Also, as I was starting in a spiral pattern, the joints were staggered where the form ended. This really played havoc because of the inconsistencies in the form. The small gaps and fissures that were created were not a problem because the plaster could easily cover them over. If they were more than one inch or if the concrete would not stand up by itself to cover the holes. I would spread a little on and let it set up before putting a little more on. I then repeated this process until the hole was filled in. As I worked upward, I found that it was best to do so in a spiral pattern. I also tried "stacking" the lifts one on top of the other to make things go easier. The trouble with the lift technique was that any imperfections in the form were multiplied and when the time comes to tie the whole dome together, the gaps and imperfections were very large.

I feel that this project completely fulfilled the objective for which it was made. I created a forming system which can be used any number of times. This form was built with only 1 sheet of plywood, 2 steel poles, a short length of rope, various fittings and connections and a lot of hard work. After the form was built I had only to mix up the concrete in a wheelbarrow and spread it on the form with a trowel. It was very time consuming, I estimate that about 180 man hours were spent on the project, but it is a system that will require very few tools or technical expertise to duplicate.

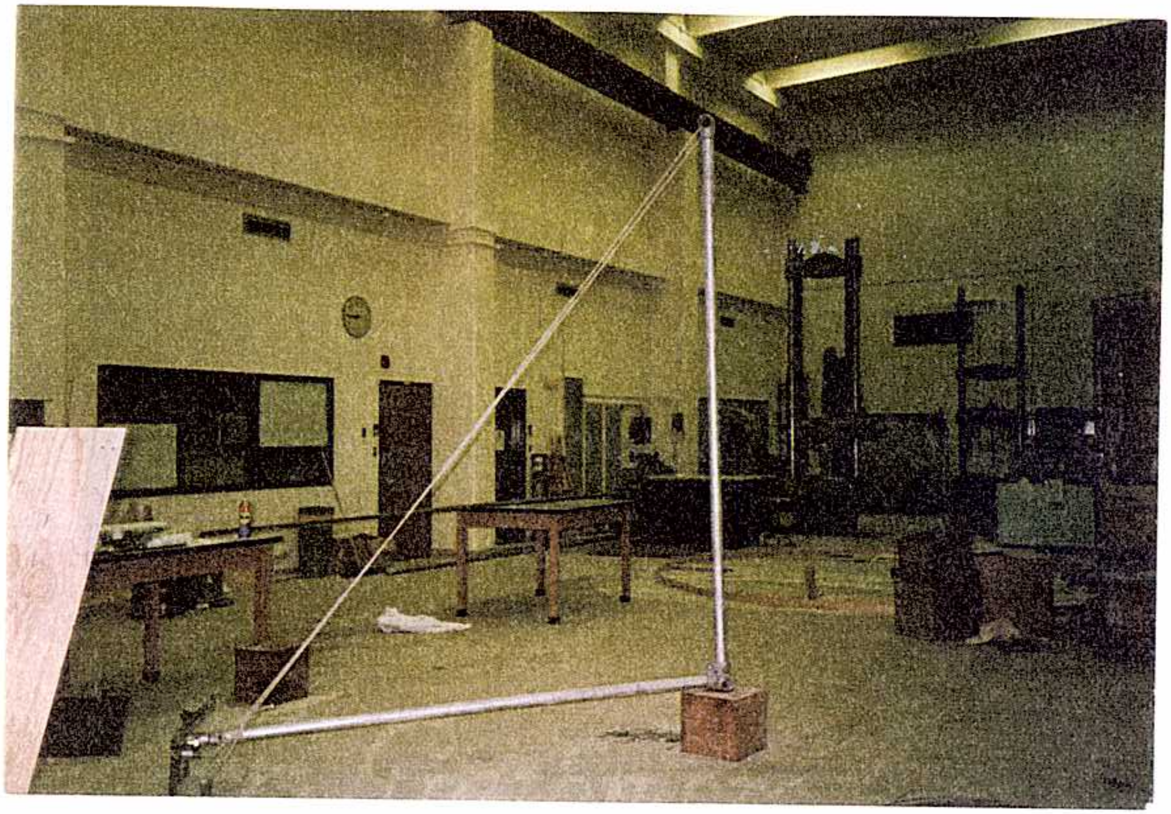

Figure 1. Original framework with slipform

Figure 2. Rolled steel slipform

Figure 3. Moveable form attached to swivel arm

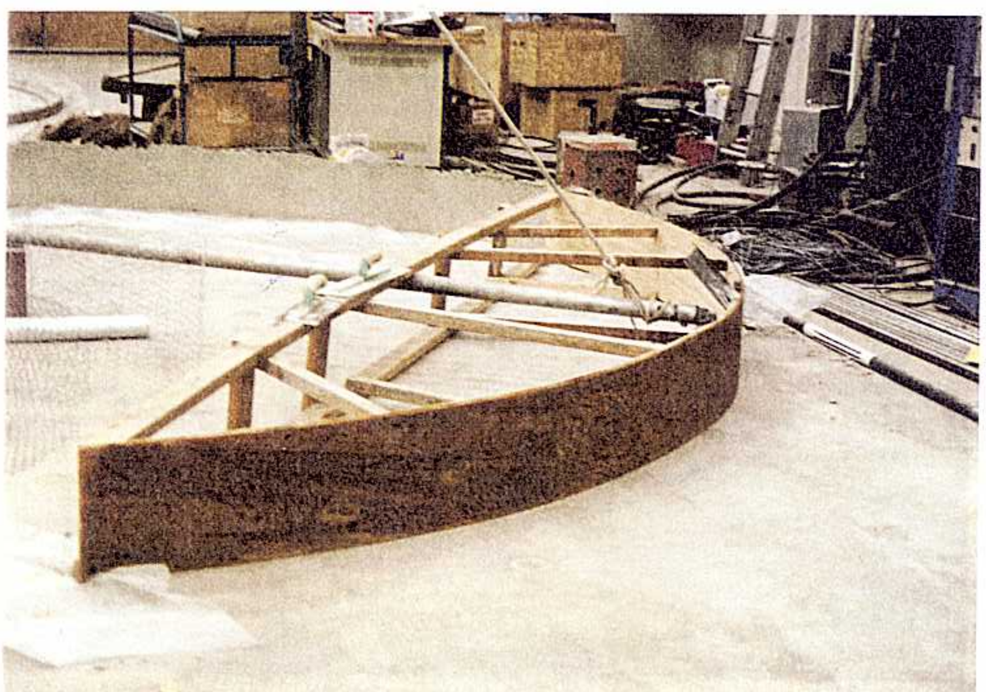

Figure 4. Moveable form with one "lift" standing

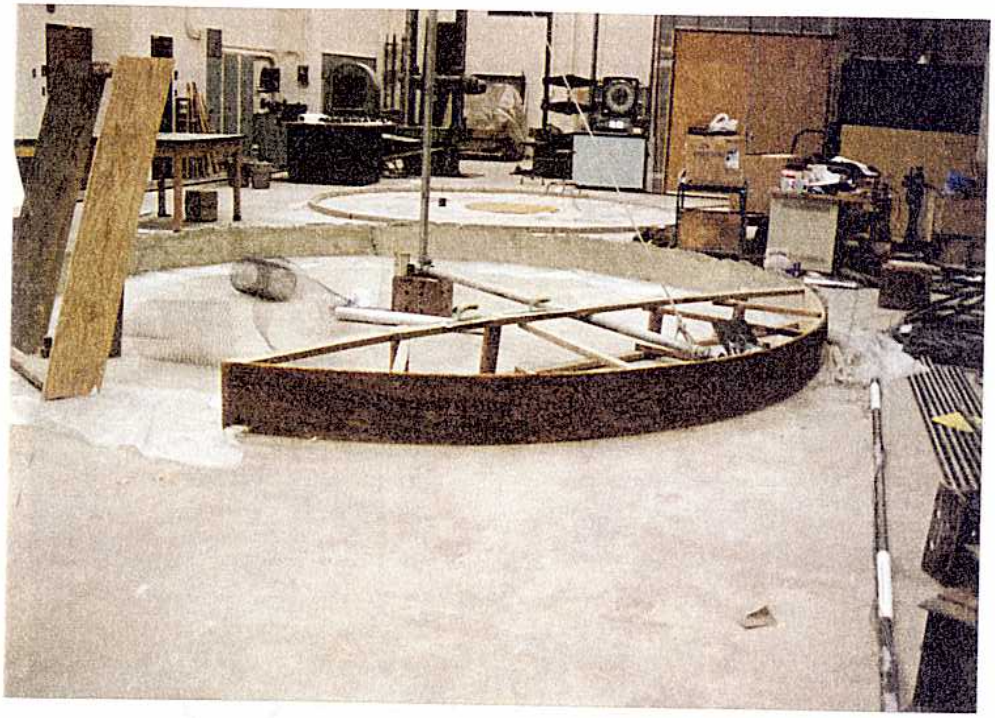

Figure 5. Continuing first lift

Figure 6. First lift completed with wire mesh reinforcing showing

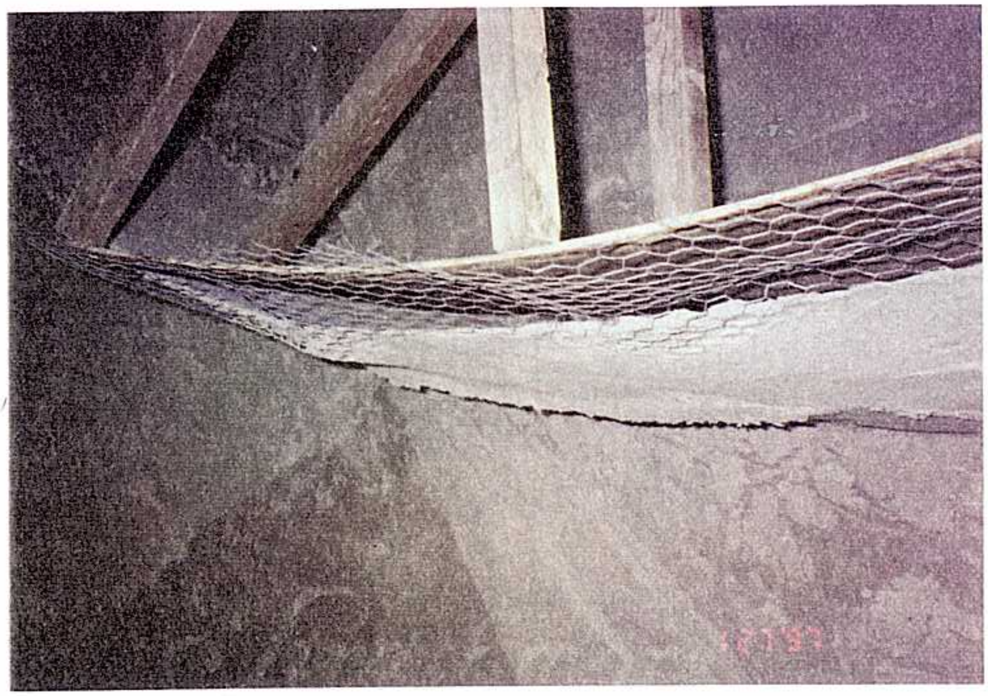

Figure 7. Gap created after releasing collar

Figure 8. You can see the slight discontinuity between layers

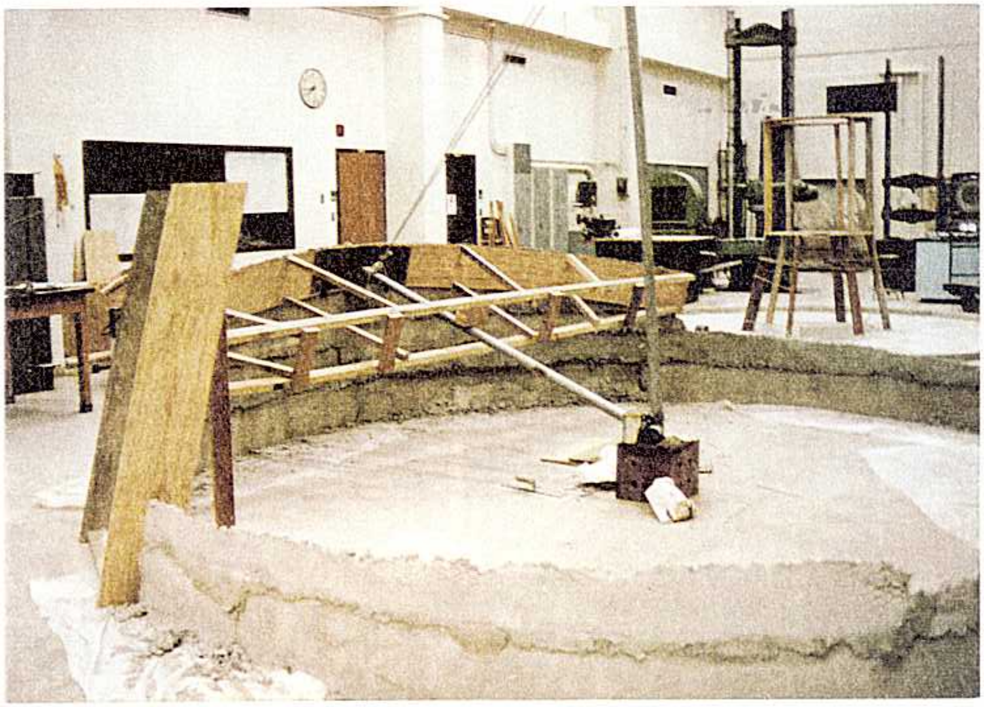

Figure 9. After I completed circular lifts, I tried "stacking" the lifts.

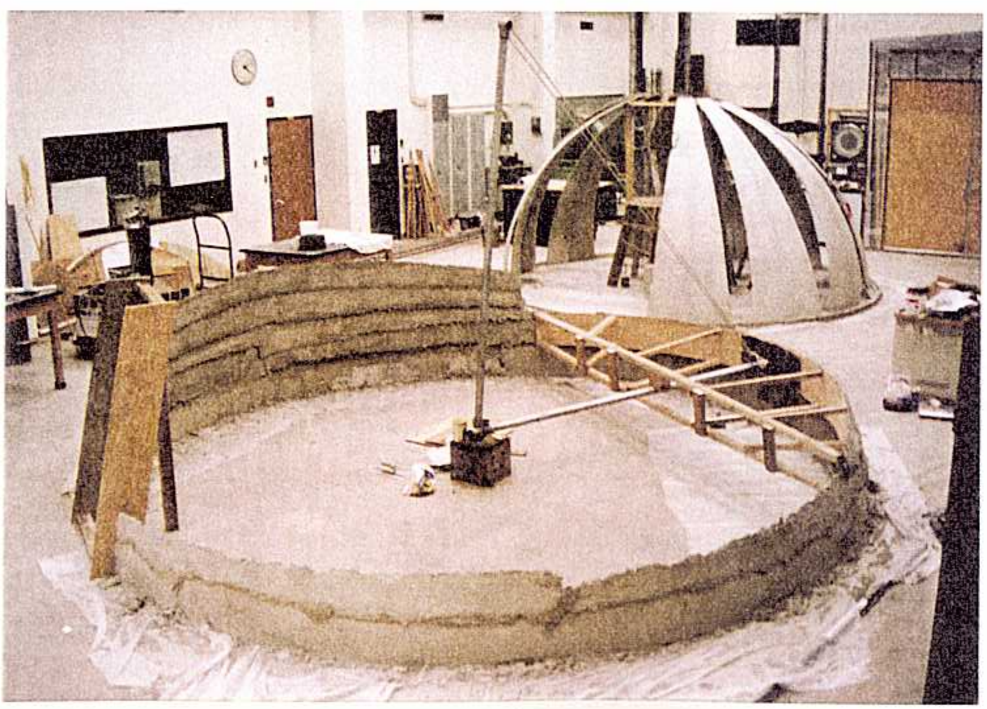

Figure 10. After "stacking" three lifts, I rotated the forms.

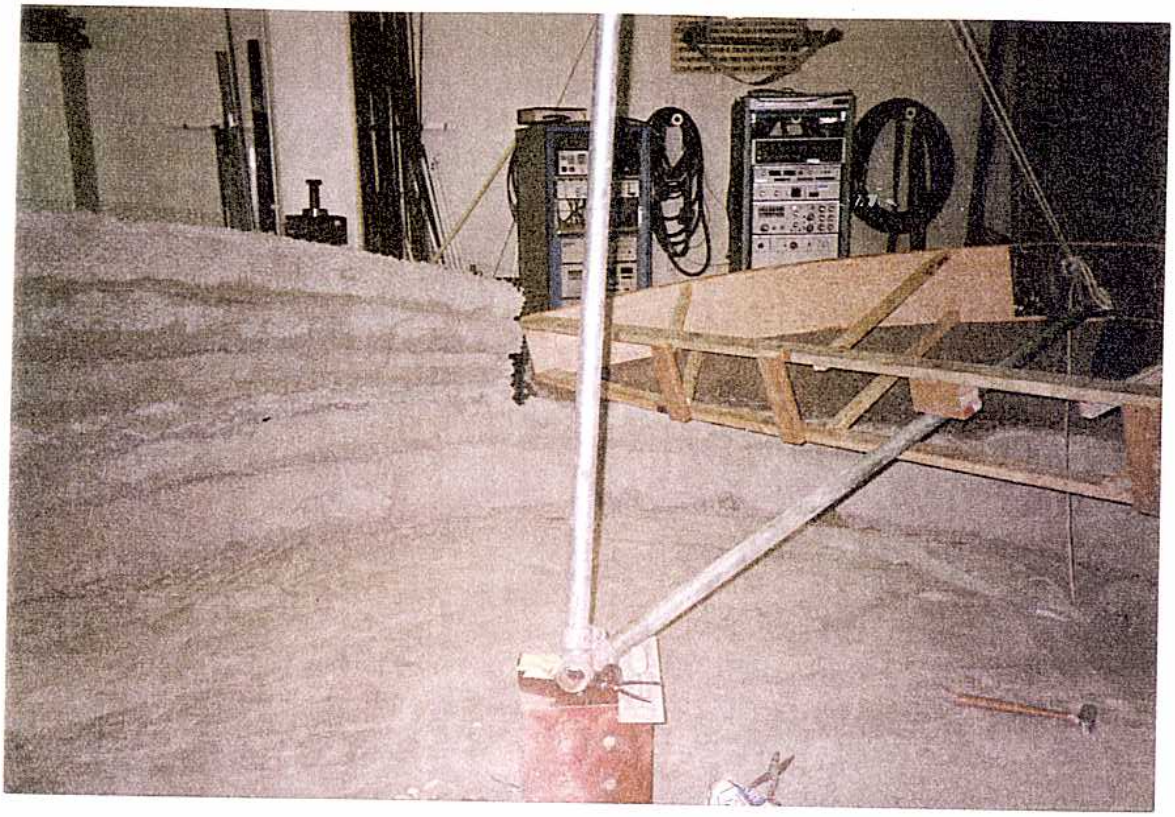

Figure 11. A slight gap is created by moving the form.

Figure 12. The same gap as seen from outside of the dome.

Figure 13. The small gap is easily covered.

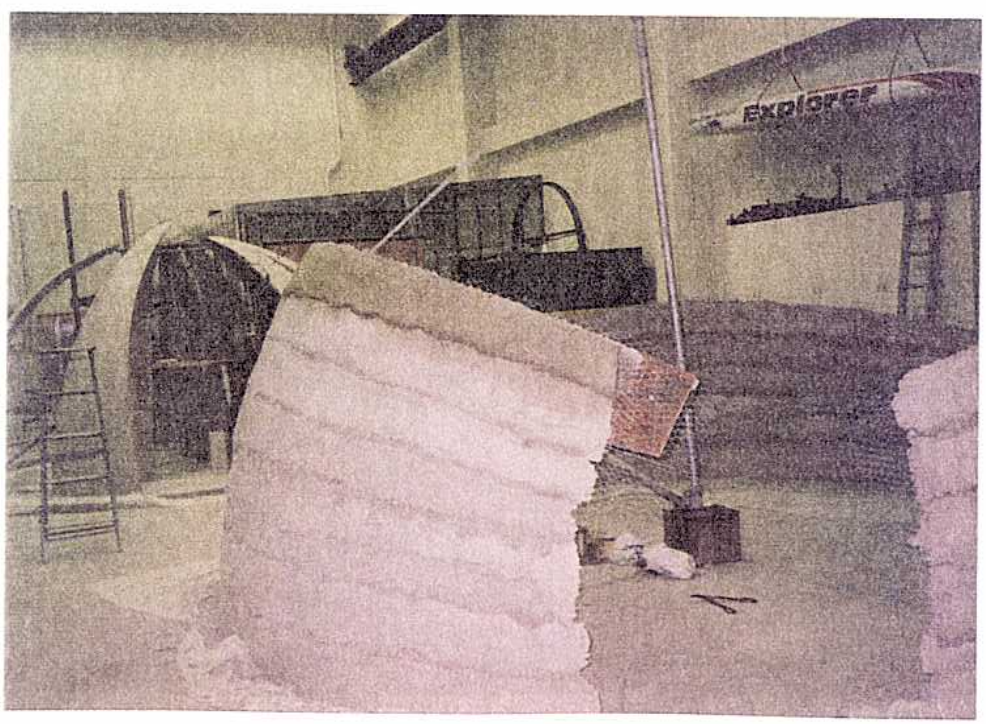

Figure 14. The dome is beginning to take shape with door opening left open.

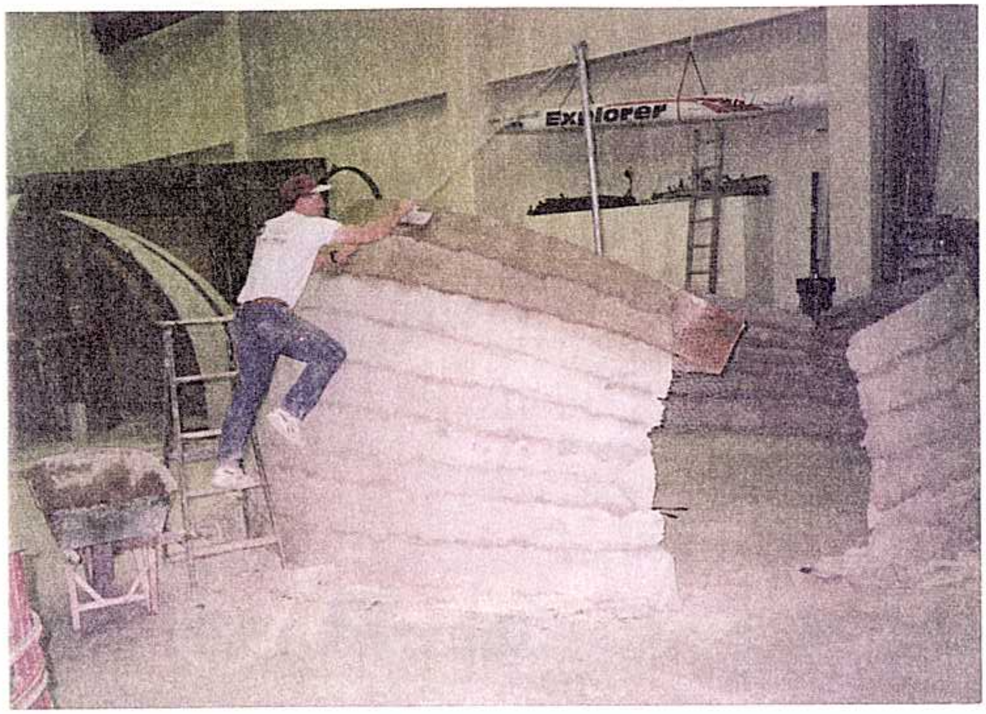

Figure 15. As the dome grows, it is necessary to leave the form in place longer to cure better.

Figure 16. Last lift before crossing over the door opening.

Figure 17. A great view of the back of the dome and how the form is "shored up."

Figure 18. It is now easier to spread out the concrete from inside.

Figure 19. A view from the inside of the dome as it closes.

Figure 20. Last lift on the right side of dome. At this point it is easier to shovel the concrete from the inside.

Figure 21. As the layers are going up, generous portions of wire fabric are overlapped and left to bond the future exterior layer.

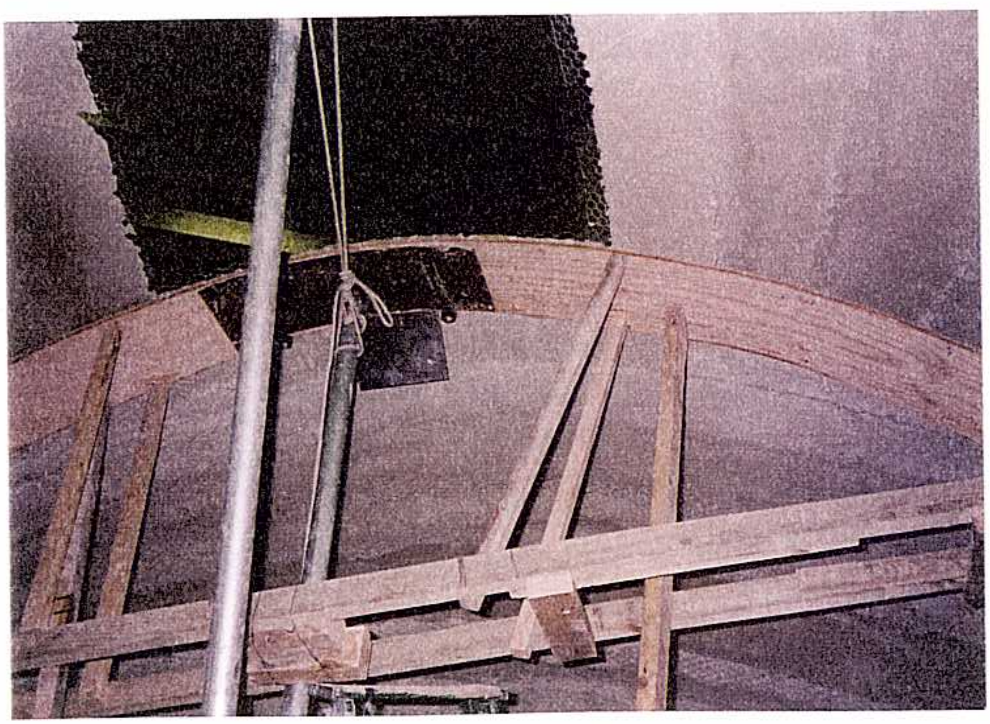

Figure 22. Inside of dome as final layers are being applied

Figure 23. Exterior of finished dome after first layers of concrete. It looks very "igloo" like.

Figure 24. The back of dome shows many patches.

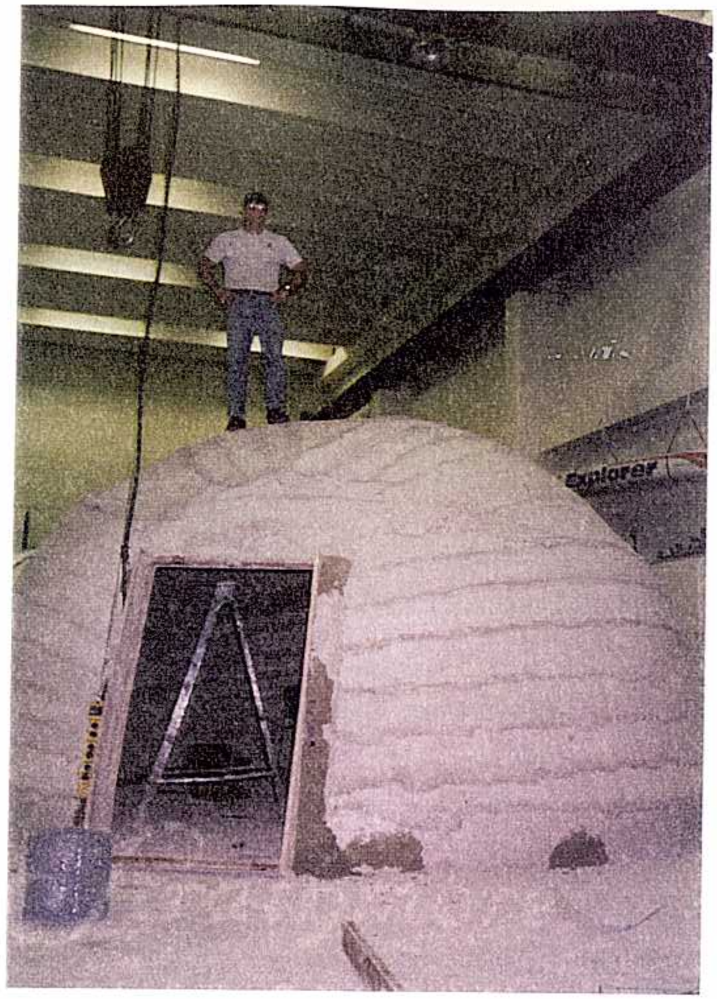

Figure 25. Finished 1/2" thick dome with 190 lb. point load on top.

Figure 26. The skylight in the dome. Wire fabric will be removed later.

Figure 27. Side of dome with outline of future window

Figure 28. Dome with new window in side

Figure 29. Front of dome after partial second layer of concrete has been added.

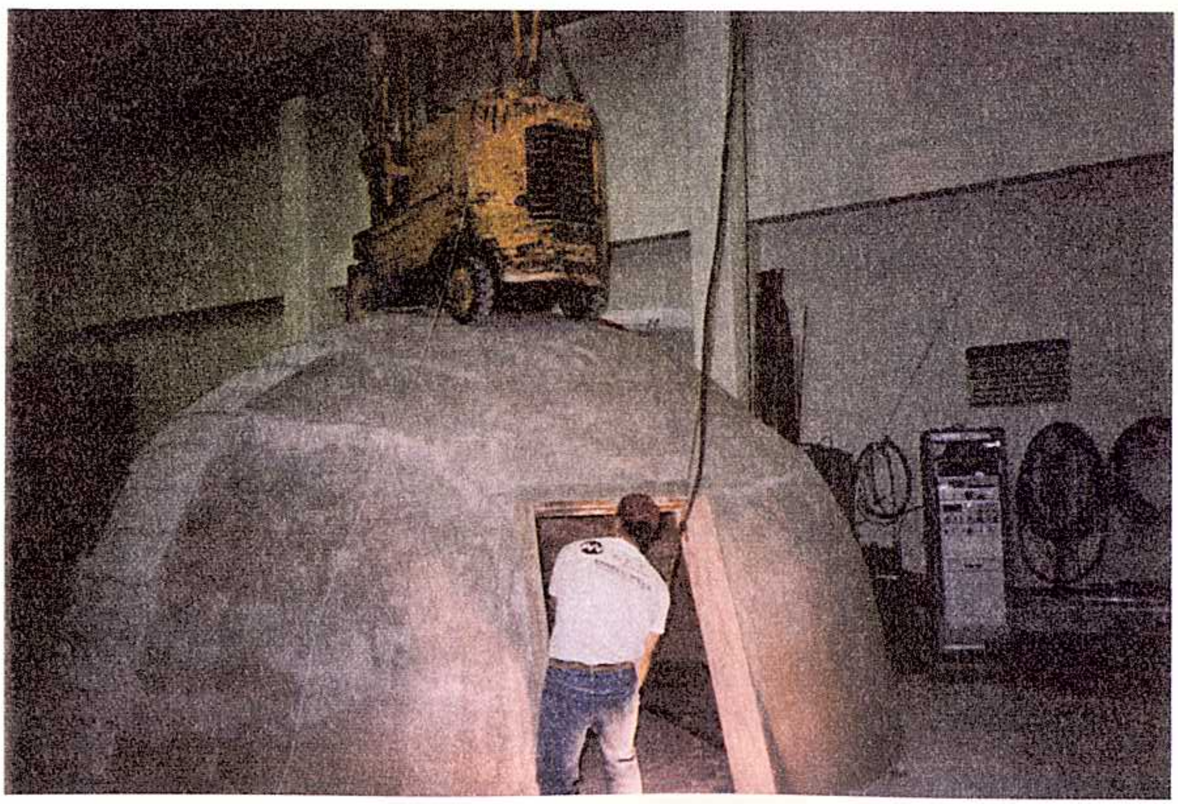

Figure 30. Dome as 7500# forklift is being set on top.