

FABRIC FORMWORK

FOR

CONCRETE

'by

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ABSTRACT

This thesis is an investigation of fabric and concrete as composite building materials. It proposes using fabric as internal and external formwork for concrete. Included in this proposal is a description of the previous research in this field, the range of possible options, the experimentation that was carried out and a suggestion of future possible research that should be done.

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Special thanks to Ed Allen for being an enthusiastic advisor, Sean Wellesley-Miller for the initial concept of fabric formwork and Bobby Roscow and Andy Lippman who were conned into mixing concrete and lifting the panels. No thanks to Dunbar who stepped in everything. And last but not least thanks to my typist, Mala.

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Errata.

"Fabricform" should read "Fabriform"

1. Introduction

This thesis is an investigation of a fabric and concrete composite for the production of building components. It is an attempt to research some of the characteristics and potential forms possible in such a system without entering into an extensive analysis of the properties of the materials. Actual components were fabricated and evaluated in the laboratory during a period of three months. The experiments were performed by one person with limited equipment. Consequently, the size and complexity of the components were restricted.

The problem that this thesis attempts to offer a solution for is the direct proportionality between cost and flexibility in the building industry. More than any other single factor, this ratio is responsible for the minimal architecture that surrounds us. Cost is determined by three factors: material expense, labor time and construction skill. Traditional, small component building systems and industrialized prefabrication can only maintain low cost by repeating building components, joint systems and dimensions which minimizes the labor time and skill required. Building systems which reduce some of the costs and yet retain some degree of flexibility are usually ones which employ:

1. continuity of material
2. lightness of weight
3. efficient forms
4. flexibility of form and the ability to accomodate change
5. inexpensive and readily available materials

A fabric/concrete composite may offer a solution because the materials have many of these characteristics. (see table 1)

1. their strengths are complementary
2. Fabric is easily fabricated, transported, erected, modified, stretched, twisted;
3. concrete is cheap, available, almost fool-proof, fire resistant;
4. to summarize: this composite might be both flexible and cheap, as well as strong

There are two basic kinds of composites possible:

1. fabric as lightweight external formwork with a heavy concrete infill;
2. fabric as internal formwork and lightweight structural system onto which concrete is applied.

This thesis describes experimentation with these two types of formwork, projects a larger realm of possibilities and suggests directions in which further research should proceed.

Table 1:

	Advantages	Disadvantages
FABRIC	<ol style="list-style-type: none"> 1. lightweight 2. flexible 3. continuous surface 4. readily available and usually inexpensive 5. efficient: large spans, two way curves, minimal surface 6. good in tension and shear 7. great variety of types and textures 	<ol style="list-style-type: none"> 1. difficult to make rigid and therefore unable to support itself 2. poor in compression
CONCRETE	<ol style="list-style-type: none"> 1. cheap and usually readily available 2. good in compression 3. continuous surface 4. dense: good thermal and acoustical insulation 5. requires little skill to mix and apply 	<ol style="list-style-type: none"> 1. not good in tension 2. weight: difficult to handle in bulk 3. not elastic: must be kept rigid when curing otherwise will crack 4. messy and caustic

Plastics and foams were not considered in this thesis because of their present expense but they should be kept in mind for future research.

Table 1 Appendix:

	Advantages	Disadvantages
PLASTICS AND FOAM	<ol style="list-style-type: none"> 1. formability: easy to handle, cut, etc. 2. lightweight and strong per unit weight 3. great variety of forms 4. light transmission 5. efficient: large spans double curvature, minimal surface 	<ol style="list-style-type: none"> 1. low stiffness 2. cost per lb. high 3. the insulation value and the structural strength are inversely proportional 4. destruction by ultra-violet light

2. Previous research

Previous research in this area has had very little impact on the building industry at large. One of the earliest attempts at using concrete and fabric together was tried by the California architect Bernard Maybeck in his studio house in Berkeley. To surface the outside walls of his studio, he dipped doubled burlap bags into concrete and nailed the bags onto the bare stud wall in an overlapping manner, giving the exterior of his house a stucco-shingle like appearance (drawing 1).¹ The finish is inexpensive and durable, and a skilled worker was not required to apply it. Unfortunately, this is the only example of its kind discovered in researching this thesis (figure 2.1).

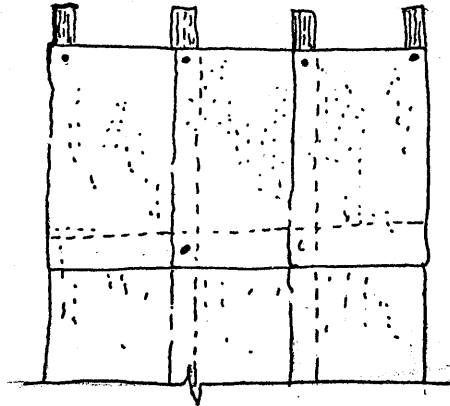


figure 2.1

Two methods that have been successful enough to be marketed are "stack sacks"² and "Fabricform."³ Both are packaged concrete systems. "Stack sacks" are halved gunny sacks sewn into narrow bags and filled with a mixture of cement and sand. The sacks are stacked together, and re-bar is pounded down through the bags; then the whole wall is sprayed with water. Wet concrete may be troweled on later if a smooth wall is desired.

"Fabricform" is one of the several options used to

control erosion offered by Erosion and Soils Technology, Inc., and other companies. Two sheets of duPont Cordura nylon or a similar material are joined loosely together, and the space between them is inflated with concrete. The resulting concrete "mattress" has a quilted appearance (figure 2.2a).

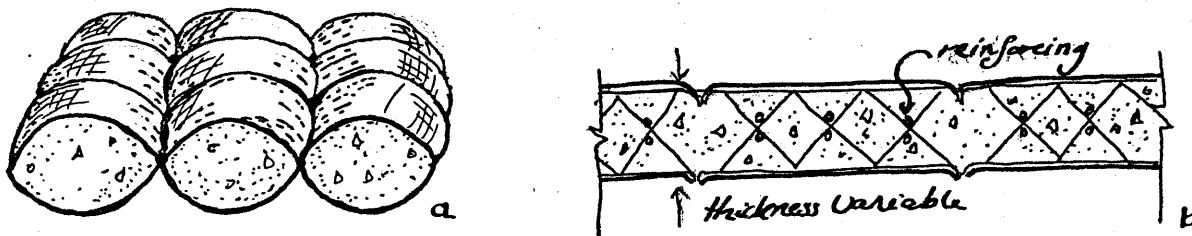


figure 2.2

Flat impermeable "mattresses" can also be obtained by a method of diagonally stitching two sheets of fabric (figure 2.2b). Basically this "Fabricform" system consists of utilizing nylon as a tension form for concrete which is injected under pressure into the nylon form, and the pumping pressures as well as the hydrostatic head force the excess water through the nylon. In this manner the water/cement ratio of the concrete is lowered, and its compressive strength is increased. The advantage of these systems lies in the fact that they enable one to pour concrete without having to build formwork. Since formwork is the major expense of working with concrete, this saves a great deal of time, labor and money.

A more architectural solution is inflated fabric that is coated with concrete. This method has been used for several years to obtain concrete shells. Originally, inflated membranes were used as pneumatic models for calculating the

ideal shell shape while the shells themselves were built using ordinary steel and wood forms. Heinz Isler of Switzerland is one of the proponents of this method.⁴ A more reasonable approach is to inflate a full-scale membrane and cover it with concrete. This method was first attempted by Wallace Neff in 1942 and Noyes and Salvadori in 1954 using a sprayed gunite (pneumatically sprayed concrete).⁵ The high expense of the gunite and the need for scaffolding from which to spray the concrete limited the practicality of this system until Dante Bini developed a less expensive application method.⁶ In his Binishells, all building operations are performed at ground level. An extremely elastic membrane is used on which spring-like and/or deformable reinforcing is placed and followed by a poured layer of ordinary concrete and another elastic membrane. The entire mass is inflated into the desired position; the concrete, being contained within the double membrane, is vibrated and allowed to cure for twelve to fourteen hours. At that time the interior membrane is deflated and can be reused and any openings, which were not provided for by templates set on the ground before pouring, are cut out with a circular saw. One problem that Bini fails to mention but should be considered of the utmost importance is the difficulty of maintaining the stability of the inflated form as the concrete is curing. Any air leak or external temperature change will cause a deformation in the pneumatic membrane which cannot be tolerated by the concrete causing it to crack. Haim Heifetz of Haifa, Israel, seems to have solved this with two devices: a membrane control system and a water column

control system.⁷ The water control system appears to be the most efficient of the two. Built like a small water container with an air pipe from the form fixed to its lower portion, this control system prevents outflow of air as long as the weight of the water column is not exceeded by the air pressure in the form. These pressure control systems are important to note because one of the recurring problems in working with composite concrete and fabric components is making the fabric sufficiently rigid.

The obvious benefits of using pneumatic formwork are: efficiency of shape, materials, and production. The shape is always a minimal surface. The air pressing upwards places the membrane totally in tension. Consequently the concrete shell applied to this membrane and acting downward under its loads will have only compressive stresses. Compression is the most efficient state for concrete; therefore, less concrete needs to be used in these shells, thus reducing the overall weight of the structure and the size of the foundations needed. As with "Fabricform" there is also the great efficiency of not having to build wood and steel formwork. In fact, this system is so quick that Heifetz claims it is possible to erect one of his shells in less than a day, including the removal of the inflated form.

There are several other building systems that should be considered here, even though they do not use a composite of concrete and fabric, because they contributed to some of the ideas tested in this research project. One is a system which extrudes quick-setting concrete into a moving mold, developed by Ed Allen

of M.I.T.⁸ Unfortunately the stringent quality controls needed to maintain a constant flow of concrete prevent it from being practical to use at the present time. However, if these problems could be overcome this would offer a system that requires no built formwork or even an inflated membrane, has a rapidity of construction comparable to pneumatics, and should exceed pneumatics in flexibility of form.

The other systems that need to be mentioned all involve the use of fabric. The most limited of these in terms of variability of form is a system of winding glass filament around a structural frame and then dipping the entire unit in polyester or epoxy resin. This was tried by the University of Michigan on an AID grant with the Hercules Powder Company.⁹ The forms produced were rectangular boxes with openings possible only at the two ends. The winding process severely limits the size and shape of the components, and some kind of internal frame in addition to the filament is required. Decidedly more flexible than this is the process of spraying fabric with polyurethane foam. Winslow Wedin¹⁰ among others has built structures using fabric draped from tensioned wires as a form on which foam is sprayed. The process is quick because again no elaborate mold needs to be constructed first, only wires and fabric hung from a pole.

With all these systems there is the additional advantage that neither concrete nor foam requires a great deal of mixing or application skill though spraying an even coating takes some practice. If one looks at Frei Otto's extensive work with tensile

structures¹¹ a tremendous variety of forms possible with draped and sprayed fabric techniques will be apparent. (figure 2.3)

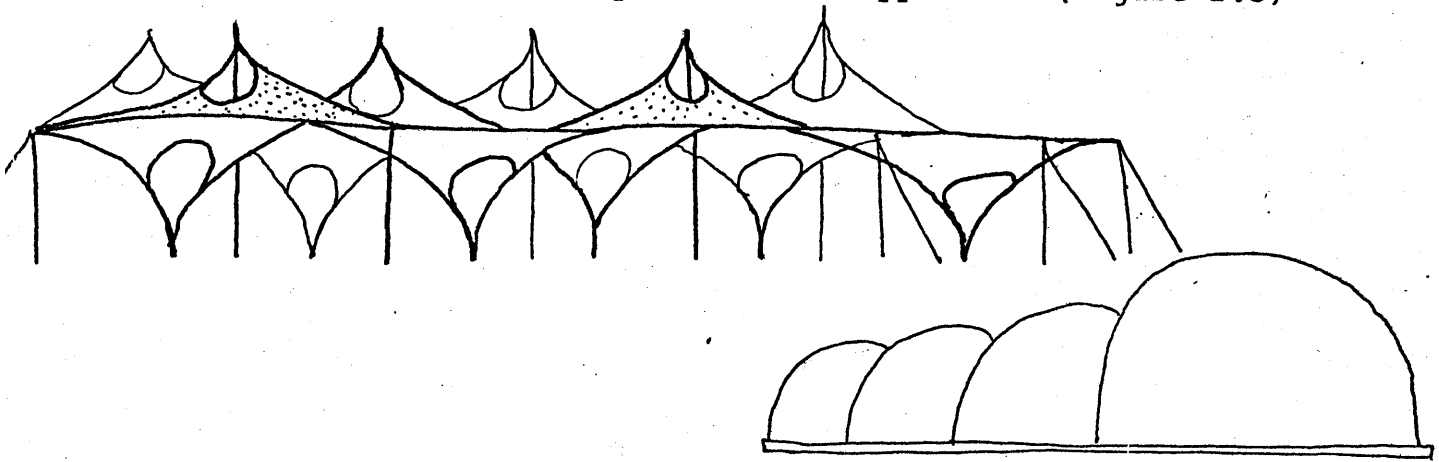


Figure 2.3

Footnotes

Section 2

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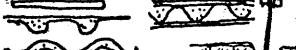
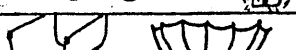
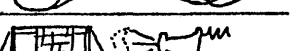
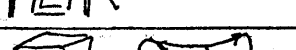






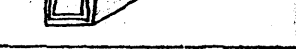
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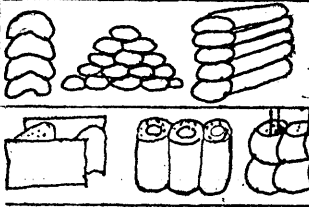
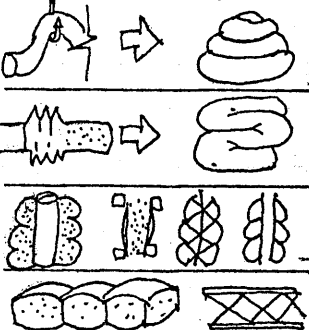
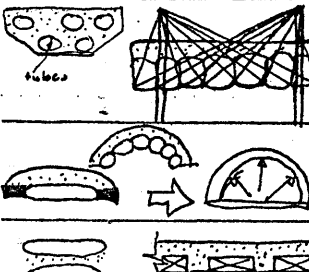
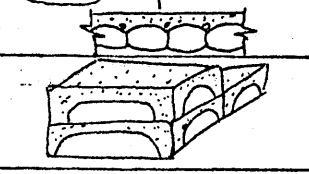


3. Morphology

Chart I delineates the range of possible forms within this building system.



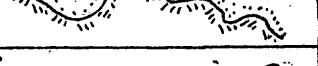
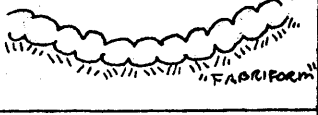
Chart II indicates the process involved in producing these forms.

CHART I

	state of fabric	Fabrication process	Application	Illustrations	Comments
INTERNAL FORMWORK	Hung	dipped and hung	"shingles"		1. need temporary fabric support
		troweled	panels		2. fabric provides partial reinforcing for concrete
		hung or stretched and sprayed	panels		3. efficient structure but concrete in tension; must reverse
		panels	vaults		1. filament needs rigid support
		vaults	tents		2. one directional strength
		tents	small components i.e. beams		3. opening only at ends
	Wound	filament run through concrete and then wound	panels		2. opening only at ends
		wound and then dipped	units		combine compressive strength of concrete and tensile strength of fabric? results may resemble wood
		walls vertical on site	boards		
		columns	beams		
		beams			
					

state of fabric	Fabrication process	Application	Illustrations	Comments
Filled	stacked (dry)	stack sacks ... vertical mattress linear tubes... coiled		1. self supporting compression structure 2. temporary fabric dam
	extruded, (wet) pumped	bagged in tubes..... fabric "mat-tress" vertical : horizon- tal :		
Inflated	FABRIC : CONCRETE : single sided double sided single sided double sided filled "vacuumatic"	sprayed		1. formwork can be removed and reused 2. form could serve as insulation 3. expansion and contraction problems 4. vast variety of shapes
		poured		
		troweled		
		pellets		

EXTERNAL FORMWORK

state of fabric	Fabrication process	Application	Illustrations	Comments
EXTERNAL FORMWORK Earth formed-	poured	vertical retaining walls.		
		vaults.....		
		domes.....		
	pumped horizontal erosion control	"free forms".....		
		"fabricform" ¹ mattress".....		
		inflated nylon ² bags.....		

1 | Erosion and Soils Technology, Inc.
2 |

CHART II

	geometry of parts	materials	fabrication	equipment	application
FULL SCALE CONTINUOUS SURFACE SYSTEMS TESTED	extruded tubes	concrete burlap 3" plastic sewer pipe	long tubes of burlap closed at one end gathered on the pipe, concrete pushed through the pipe with a plunger; fabric fills, expands, some concrete oozes through fabric creating mortar and the concrete pressure moves the apparatus along	sewing machine pipe plunger (a hopper for the concrete fitted to the pipe would speed the operation considerably OR better still a concrete pump)	continuous construction: walls domes floors (on grade only)
	concrete mattresses	concrete burlap (or Cordura nylon) (perhaps steel reinforcing or wires)	doubled fabric stuffed with wet (or perhaps dry) concrete under pressure; vertical or horizontal	concrete pump some way of loosely joining the two sides of fabric can be woven this way	walls floors retaining walls earthworks

	geometry of parts	materials	fabrication	equipment	application
SMALL COMPONENT SYSTEMS TESTED	concrete pillows	concrete burlap (unsized, 7 oz., loose weave)	bags filled with dry concrete mix (1) stacked dry and sprayed with water OR (2) dipped in water, rolled in wet concrete and stacked vertically	sewing machine (scoop and funnel)	walls: free standing or retaining vaults
	rolled components	concrete fiberglass mesh (vinyl or epoxy coating) wire: ungalvanized, 18 gauge burlap	concrete troweled on; piece rolled without a cardboard tube inside (cross section: round or rectangular)	nothing necessary except hands and rubber gloves but could use a trowel or roller to apply the concrete and a concrete mixer	columns beams 2" x 4"s

	geometry of parts	materials	fabrication	equipment	application
PANEL SYSTEMS TESTED	laminated panels : flat corrugated vaults	concrete fiberglass mesh:(vinyl or epoxy coated) reinforcing if necessary: ungalvanized steel wire or reinforcing rods	concrete troweled onto fabric piece by piece then panel covered and either left horizontal or draped on rods (or a form) or hung vertically flat or gathered	flat surface trowel concrete mixer (if possible)	panels for floors, ceilings, walls

	geometry of parts	materials	fabrication	equipment	application
SMALL COMPONENT SYSTEMS UNTESTED	wound tubes	concrete fiberglass filament (coated) a form of some kind	filament wound around a form then dipped in concrete OR filament dipped in concrete and then wound on a form	mandrel tub for concrete	beams columns "boards" (panels)
PANEL SYSTEMS UNTESTED	inflatables	concrete steel elastic membranes	(1)concrete applied to surface of membrane and then membrane inflated OR (2)membrane inflated and then concrete sprayed onto it	<u>air pump</u> pneumatic concrete sprayer concrete mixer	vertical and horizontal panels

FULL SCALE, CONTINUOUS SURFACE SYSTEMS UNTESTED	geometry of parts	materials	fabrication	equipment	application
	filament wound units	see previous reference			entire units
	sprayed tents	concrete fabric: burlap, fiberglass, or other framework (steel, aluminum, ...)	set up tent like structure and then spray with concrete	concrete sprayer	entire tensile shells OR if reversed when cured compression structures
	inflatables	see previous reference			entire units multistory structures space frames the structures for subsequent infill

4. The experiments

4.1 Internal Formwork

Panel Systems

1. The first weeks of work proved fairly discouraging. Three experiments were carried out at this time :

- i. to test the adhesion between concrete and two fabrics selected for their difference in properties (a sized burlap and fine mesh, phenolic-coated fiberglass);
- ii. to test several methods of applying concrete to these fabrics;
- iii. to attempt to make several kinds of building components of the concrete-fabric composite.

Several major problems were encountered. The various hypothesized methods of applying the concrete were not successful.

The first technique tried was that of dipping two by three foot pieces of burlap and fiberglass mesh in wet concrete and hanging them vertically (figure 4.1)

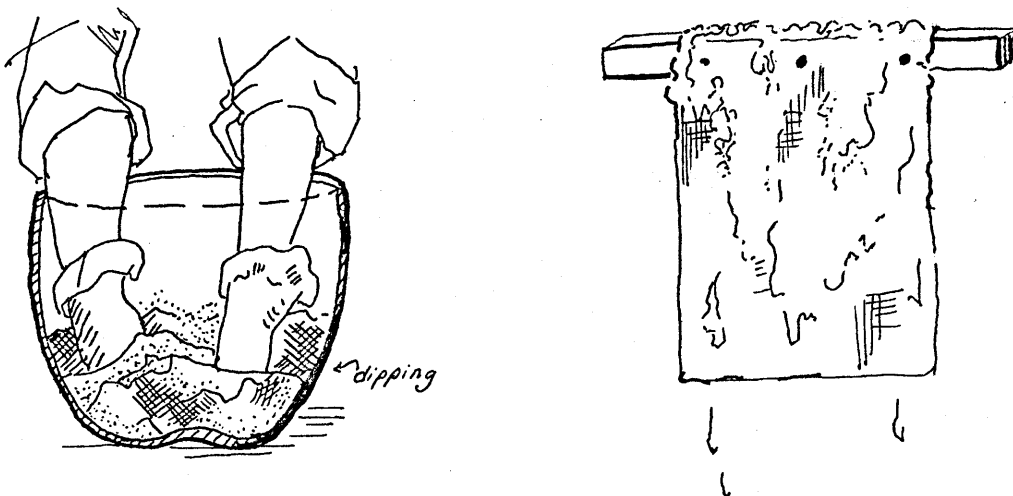


figure 4.1

It was impossible with a single dipping to obtain a coating of any significant thickness and strength. Furthermore, the coating was uneven, and when the pieces were hung a great deal of the concrete that had adhered fell off. This was true even after latex was added to the concrete to increase its stickiness.

The second method was comprised of stretching the fabrics tight and then troweling the concrete on. It was even less successful. It was not possible by manual methods to stretch either the burlap or the phenolic-coated fiberglass mesh tight enough to achieve a flat, rigid troweling surface.

After several attempts failed it became fairly obvious that the materials were more at fault than the methods. In the first series of tests the concrete was definitely too stiff and contained aggregate that was too large and too great in quantity. The concrete consequently did not penetrate the material, and in fact, barely adhered to the surface. The mix for these first pieces consisted of seven pounds portland cement to fourteen pounds mixed aggregate (light) with four and one-half pounds water. When the mix was thinned with an additional five pounds of water, it adhered better to the fabric, although it still contained too much aggregate.

The third test of this series again consisted of dipping flat pieces of fabric into concrete. This time a synthetic latex additive (Dow latex 460) was mixed in, and equal weights of cement and lightweight mortar sand were used. The mix was a soupy consistency and the burlap was damp. The results at first appeared encouraging because far more concrete adhered to the surface of

the fabrics than in the previous tests, although the concrete coating was uneven and some of the concrete fell off the pieces that were hung vertically (photograph 1). But a week later, the concrete on the panels cracked easily and seemed rubbery. Also, on the fiberglass strips the concrete had turned a dark maroon color. This change probably indicated that the phenolic coating on the fiberglass was not thick enough, or was cracked, and that the fiberglass was being attacked by the alkaline salts in the concrete. Moreover, it was subsequently discovered that the latex has a shelf life of only six months. As the latex used in the test was more than a year old, this could explain the weak, rubbery quality of the concrete. The final problem with the materials was with the fabrics themselves. Neither fabric had a wide enough weave or a fuzzy enough texture to hold sufficiently large quantities of concrete or to allow it to penetrate through the fabric.

The kinds of shapes possible with this dipping and hanging process were only briefly explored, due to the difficulties with the materials. Several panels of burlap and fiberglass were made up, with various corrugations and overlappings sewn into them. The manufacture of them was fairly quick and easy on an industrial sewing machine, and they indicated some fairly reasonable possibilities for panels (figure 4.2, photographs 2, 3, 4)

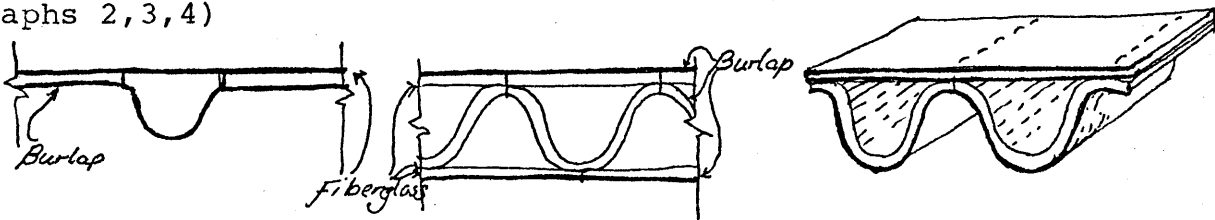


figure 4.2

But due to the difficulties with the materials, a thick coating of concrete was not obtained. Also, with all of the pieces getting any concrete on the interior convolutions of the form would be difficult unless it were sprayed or these portions were filled solid with concrete. Actually, the latter idea suggests a fairly reasonable system that was briefly tested. One piece of fabric (one foot by two feet) was dipped in concrete. The contour portion was then filled with the remaining concrete (photograph 4). Reinforcing could have been placed in here along with the concrete, and the system could work with these thick parts acting as the structural supports and the flat dipped portion in between serving as the infill (figure 4.3) below.

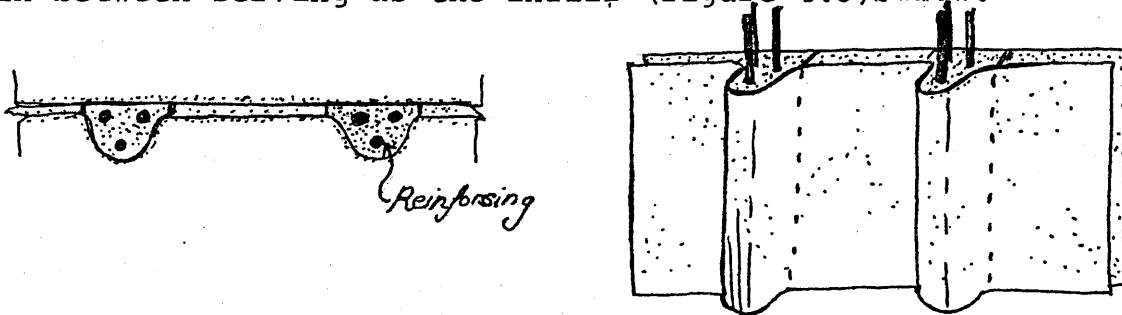


figure 4.3

Despite the general failure of these tests, there were several encouraging indications. The concrete definitely adhered better to the burlap than to the fiberglass, enough so that further research with the burlap appeared promising. Also, it was discovered that by placing four layers of concrete-soaked fabric together (two burlap, two phenolic coated fiberglass), a piece three-eighths of an inch thick could be obtained. This worked especially well if the piece was left to cure in a horizontal position. In this position it was possible to obtain a fairly

even and smooth surface on both sides of the piece.

2. The second series of tests comprised another attempt to obtain a thick coating of concrete on a fabric. This time fresh cement (cement has a shelf life of only six months) without any latex additives and a second-hand burlap of varied weights and weaves were used, as well as a vinyl-coated fiberglass mesh instead of the phenolic-coated one. Unfortunately, the mesh was still finer than desired. Nearly a quarter of an inch of concrete adhered to the surface of all the pieces dipped, even when they were hung vertically. The one exception was the fiberglass, but about an eighth of an inch of concrete did adhere to it, and the fiberglass did not react with the concrete.

Second-hand burlap was chosen for the test because the new burlap used previously appeared to have sizing on it; a glue-like coating on the cloth which seemed to prevent good adhesion between the fibers and the concrete. The weight of the burlap ranged from seven ounces to eighteen ounces depending on the size of the fibers and the weave from very tight to loose. However, this variation did not seem to make a significant difference to the amount of concrete that adhered to the burlap pieces or to the strength of the pieces with the exception being a woven burlap and plastic fibered mesh which was noticeably stiffer when manually broken. Looser weaves did make a difference, allowing the concrete to penetrate through the fabric and, consequently, the coating adhered better to these pieces. It was decided, therefore, to use seven-ounce and eight-ounce burlap in the next composite pieces, because they were the least expensive,

lightest weight and easiest to cut with scissors. Also, these weights were the loosest weaves available. The stiffer plastic and burlap fabric was not used because it could only be obtained in a very close weave so the concrete cracked off of it very easily. (figure 4.4)

3. The third series of experiments continued some of the earlier attempts to obtain thicker, stiffer pieces by using multiple layers of fabric but this time also introduced a corrugated pattern into the pieces. Corrugating a panel increases its effective depth by considerably increasing its moment of inertia. In other words, a panel an eighth of an inch thick when bent into three-inch deep corrugations now has an effective depth of three inches and can resist bending forces far more efficiently, both horizontally as a floor panel and vertically as a bearing wall.

Only the burlap was used because the concrete adhered to it in greater quantities than to the fiberglass. In addition, it was hoped that the burlap might add enough stiffness to the panels by drying and shrinking inside the concrete and in this manner provide some post-tensioning to the concrete. Two-by-three foot pieces of burlap were soaked in water, wrung dry and dipped into concrete, which was then worked into the fabric (figure 4.5).

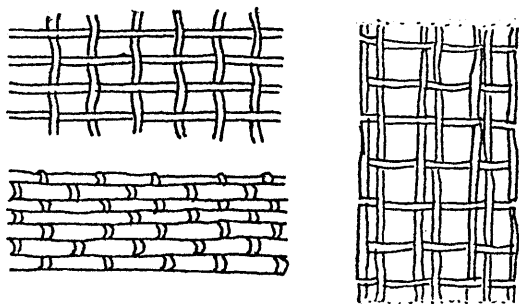


figure 4.4

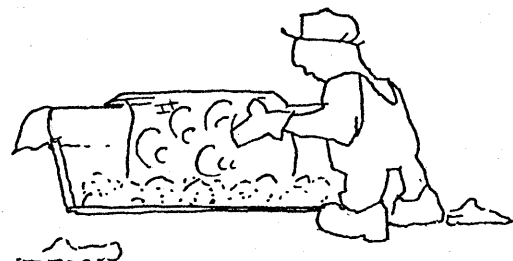


figure 4.5

The pieces were then draped onto a variety of corrugated forms and left in a horizontal position to cure (figure 4.6).

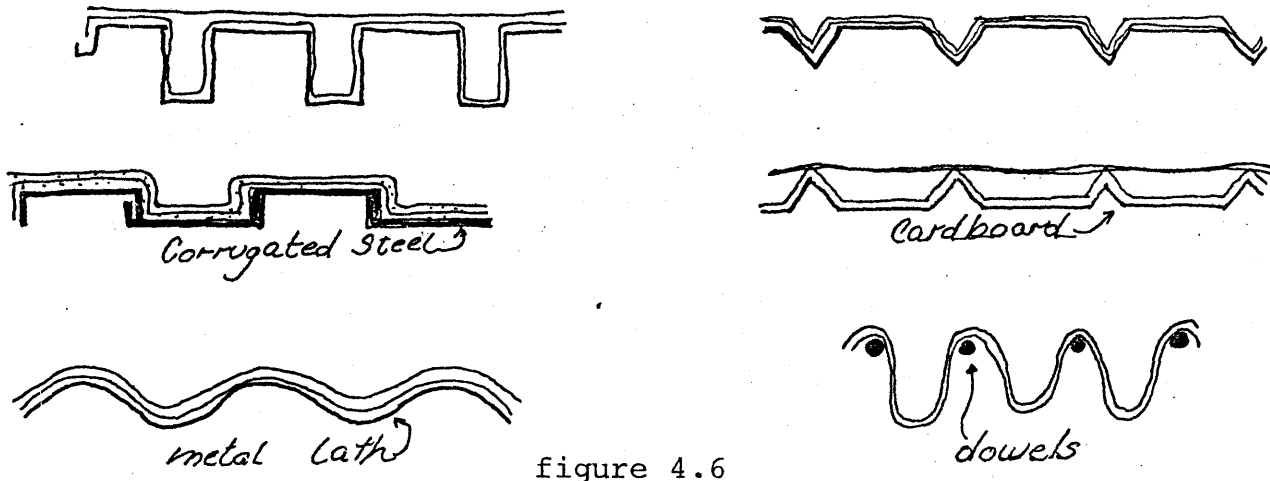


figure 4.6

The concrete stuck quite well to the burlap even when the pieces were lifted onto the corrugated forms. Single pieces were about an eighth of an inch thick throughout; doubled pieces were a quarter of an inch and tripled pieces a half an inch. In several pieces one side of the corrugation was filled with concrete (figure 4.7). The result was a piece similar to the one previously shown in figure 4.3. This could be the way to make floor panels with this system.

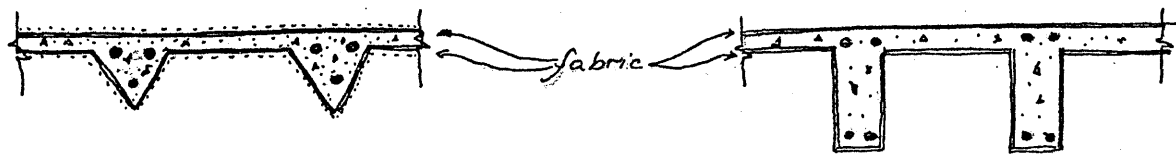


figure 4.7

When these pieces were removed from the forms a week later their corrugated configuration appeared to add considerable stiffness. The pieces were regular in shape, were evenly coated, and had a good finish: stucco-like on the side finished by hand

and glass-smooth on the other side resting on the polyethylene which was covering the form. But the drawback was that in addition to the fabric other formwork had to be used. Cardboard and corrugated steel is inexpensive formwork when compared with building wooden forms and some of the corrugated patterns are ideal for stack molding (stacking several panels on the same form: figure 4.13), but this was not the original intent. From the start of this thesis, it was hoped that it would be possible to find a system that relied on fabric as its only formwork. If other restrains were required in addition to the fabric they should be variable such as cable restrains on an inflatable or the air pressure within an inflated membrane. This kind of flexibility would not be possible with corrugated steel or cardboard forms. Each time a panel's configuration was changed, a new form would have to be built.

One method of obtaining a corrugated panel that is more versatile is to drape the concrete soaked fabric on a series of parallel rods. The rods can be moved closer or further apart and the fabric can be draped differently to obtain varied pieces (figure 4.8).

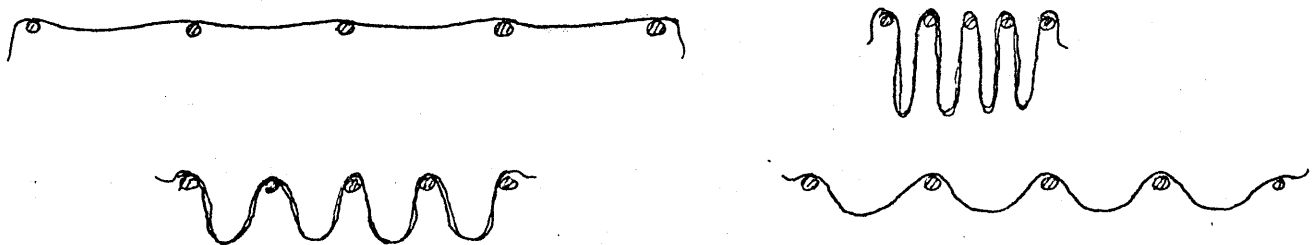


figure 4.8

This was tried in the laboratory using dowels for rods with

encouraging results. A one-foot by one-and-a-half-foot piece was produced which was in every way comparable to the preceding corrugated pieces except that the corrugations were not all the same depth and distance apart as it was difficult to drape the fabric evenly between the poles. Besides no rigid formwork, there is the additional advantage that each hanging loop of concrete-soaked fabric is a cantinary curve, the most efficient tension form that exists. When such a curve is reversed, it is an ideal compression shape, structurally the most efficient state for concrete.

An extension of this idea was to make freely hung, curtain-like panels. Pieces of burlap were again dipped and spread with concrete and then hung vertically, the material bunched together in an irregular corrugated pattern resembling a curtain (photograph 5, figure 4.9a). These small test pieces looked reasonable, but the weight of the concrete on the fabric's upper edge could be a problem with larger pieces. A variety of forms were tried, the stiffest being a corrugated piece with a straight piece draped on either side, making a panel over two inches thick (photograph 6, figure 4.9b). Thick solid panels, beams and columns could also be made using this method by flattening folds of fabric together (figures 4.9c, d).

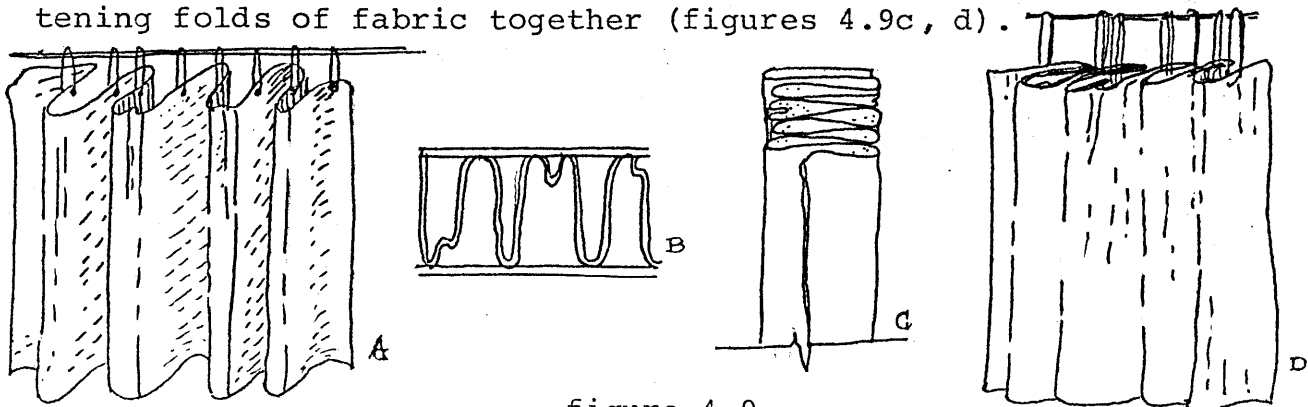


figure 4.9

When the strength of the pieces was "tested" or, in other words, the pieces were handled, stepped on, twisted and bent, their strength varied. The pieces were fairly stiff if stood on vertically or stepped on horizontally especially if they were of this configuration (figure 4.10, photograph 7):

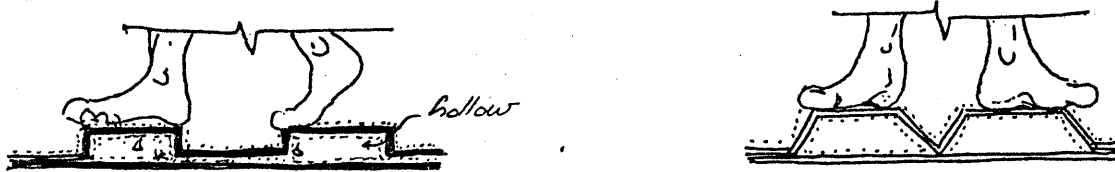


figure 4.10

One piece is corrugated and one piece is flat to prevent the corrugations from spreading, figure 4.10. However, when any of the pieces were bent or twisted particularly in the direction of the corrugations, they broke easily. The concrete cracked off the burlap leaving it intact. This was expected because concrete is not good in tension, but it was disappointing to find that the bond between the concrete and the fabric was not stronger. In the thinner pieces, it was easy to rip the piece in half, a feat which is not possible with burlap alone. It was unclear as to why this occurred. Either the strength of the burlap was severely impaired or attacked by the concrete, or the concrete merely stiffened the burlap, providing a hard edge on which the burlap fibers could be torn. In any case, burlap does not have a high enough modulus of elasticity to provide the needed stiffness and the bond between the concrete and burlap is poor.

4. The next test consisted of a large two-and-a-half-foot by seven-foot panel. The purpose was to explore three problems:

1) to increase the stiffness of the pieces; 2) to test the

possibility of "stack molding" with cardboard forms; 3) to try the system at full scale. Two pieces of eight-ounce burlap (fourty inches by seven feet) and two pieces of vinyl-coated fiberglass mesh of the same dimensions were used. First a piece of polyethylene was spread flat on the floor, and a layer of concrete was laid down and smoothed by hand (figure 4.11).

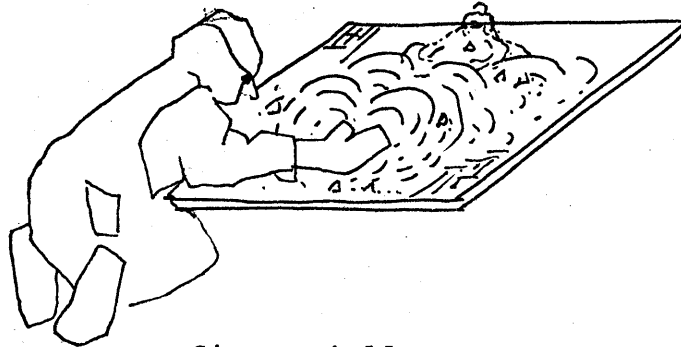


figure 4.11

Then a piece of the fiberglass was laid on top of the concrete, and pressed down so that the concrete was forced through the mesh. Then another layer of concrete was applied, smoothed and followed by a damp piece of burlap and so on until a panel three fourths of an inch thick was completed. The panel consisted of two layers of fiberglass on either side of the burlap with concrete between each layer and the entire piece was wrapped in polyethylene to insure a good cure (figure 4.12, photograph 8). Nearly two hundred pounds of wet concrete were used (about seventy five pounds of cement). When dry it could just be handled by one man (photograph 9).

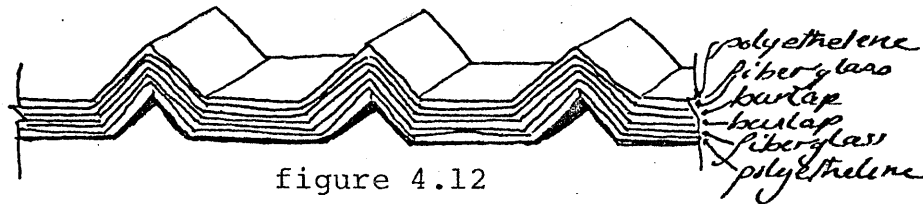


figure 4.12

The fiberglass was intended as stiffening and possible reinforcing

for the panel so it was placed on the outer faces of the piece where the maximum tensile and compressive stresses occur. The wet piece was dragged onto the corrugated cardboard form which collapsed in the process. After a concerted effort, the form was erected again with the panel on it, but it was impractical to "stack mold" with such a form at this time. If each corrugated section had been firmly fixed in place then the form would probably have been successful at least for one panel. But each additional step makes the form more inflexible. The piece was constructed independently of the cardboard form because it was impossible to apply an even layer of concrete otherwise. The resulting panel had a corrugated pattern two inches deep and six inches apart on center (photograph 8, figure 4.13).

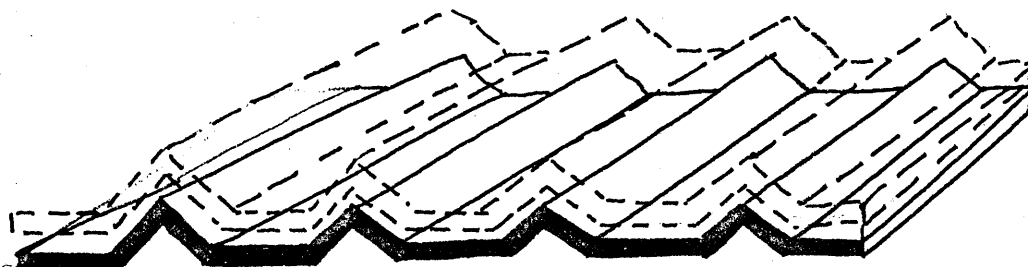


figure 4.13

Several weeks later a rough test of the strength of this panel was made. The piece was placed between two sets of milk cartons with a free span of six feet. It held one 115-pound person without any audible cracking sound but collapsed in the center under the weight of a 205-pound individual (photographs 10, 18, 19). The failure can be attributed to several factors: 1) the panel was not thick enough and was uneven; it averaged about one inch thick but in some places it was less than a half an inch

and in other places more than an inch; 2) the bottom layer of fiberglass was not properly coated with concrete; 3) the fabrics were not flat and straight; in the process of lifting the piece onto the mold the fabrics bunched up especially around the middle of the panel; or 4) perhaps a straightforward failure of the materials occurred; they seem very brittle. It is unclear whether the burlap helped or hindered in this situation. It is very possible that it was not needed here, and, in fact, it may weaken the panels by preventing proper penetration of the concrete across the panel.

5. The final corrugated panel produced for this project was a large six-and-a-half-foot by four-foot piece weighing over four hundred pounds. It was another burlap-and-fiberglass laminated piece, and it was draped horizontally on steel rods. Because no adequate hoisting system was available, the panel was made in place on the rods. A sheet of vinyl with slots welded into it was used for the base layer. The steel rods were pushed into the slots and the whole form was strung between two-by-fours resting on milk cartons (photograph 11). The vinyl was stretched as taut as possible by nailing the steel rods about a foot apart, but once some concrete was poured onto it the vinyl sagged making it difficult to trowel the concrete on in even layers (photographs 12, 13). Thirty nine square feet of the vinyl-coated fiberglass mesh and the same amount of eight-ounce burlap were used to make the laminated panel (figure 4.14). Nearly two and a half bags of cement were used with an equal weight of sand. The mix was soupy.

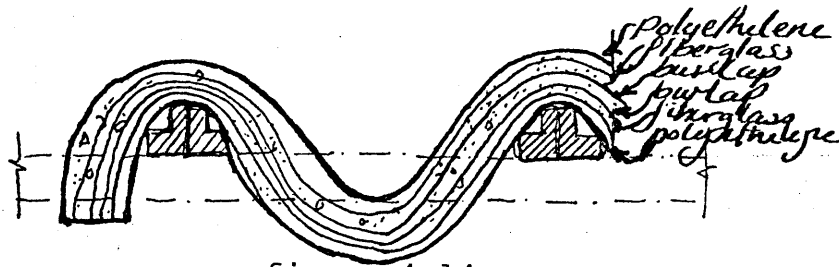


figure 4.14

Once all of the concrete and fabric had been applied, the steel rods were moved closer together so that they were all now nine inches apart on center. This created a finished panel four feet wide instead of the original six-and-a-half-foot wide piece with regular corrugations four-and-one-half-inches deep and nine inches apart on center (photograph 14). The resulting panel had an average depth of one-and-one-fourth inches deep and an effective depth of six-and-one-half inches. It took four men to tilt it up when cured. It was so heavy that no adequate load tests could be run on it in the laboratory and the unevenness of the coating and some surface cracking indicated that if tests were conducted they would not predict accurately how a panel such as this was capable of behaving. The surface cracking was the results of the initial layer of concrete setting before the rods were moved together. Otherwise, the surface of the panel was smooth and regular especially on what had been the underside (photograph 15).

B. Vaults

1. Another group of tests was conducted to explore the possibility of making three dimensional hanging components. Two barrel vaults were made: one upright, draped over a cylindrical form (an oil drum) and the other reversed, hanging from two opposite edges

in a cantinary arch (photographs 16. 17). Both were made in the same way as the previous panel; instead of the earlier dipping method, the concrete was troweled onto them layer by layer, and then they were lifted into place (photograph 13, figure 14.15).

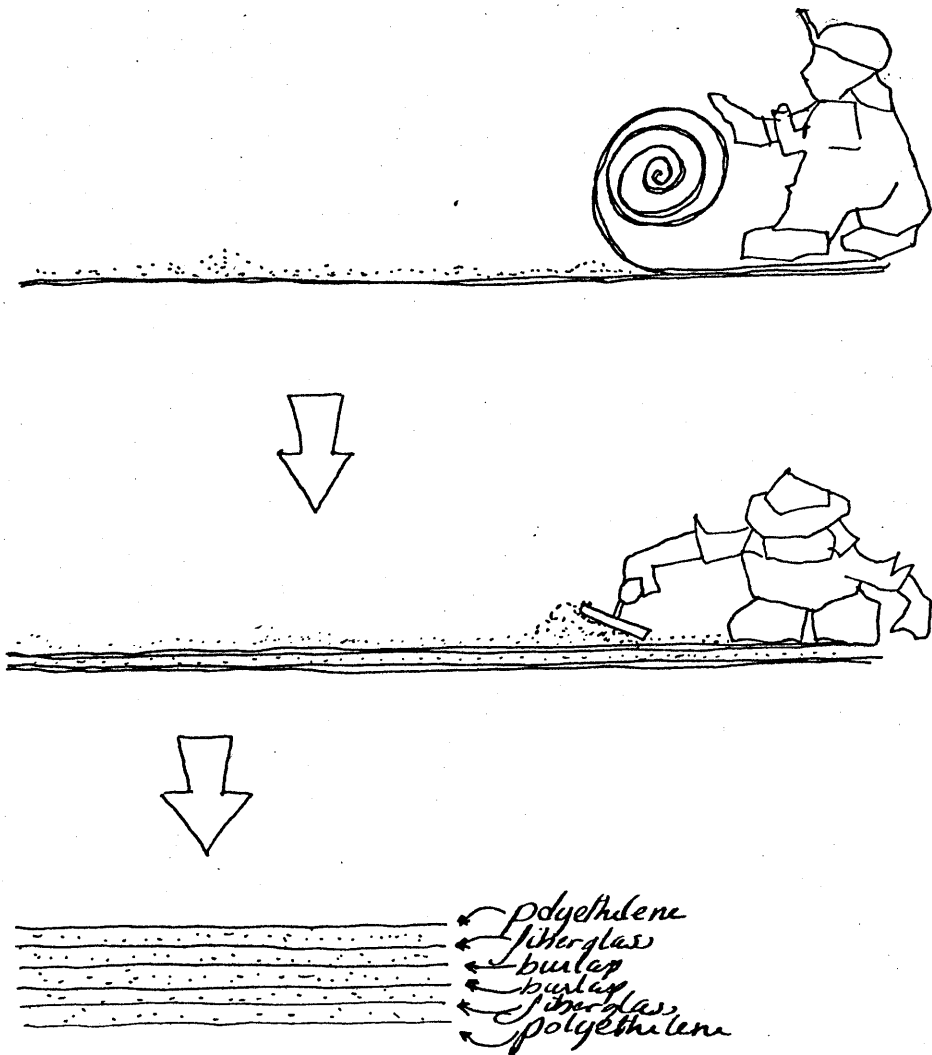


figure 14.15

The only difference was the addition of metal reinforcing: eighteen gauge steel, ungalvanized wire in the smaller vault and one fourth of an inch steel rods in the larger, suspended vault. (The steel reinforcing was not bent correctly so it caused some distortion in the cantinary curve of the arch).

The dimensions of the upright vault were: thirty-five inches by forty-eight inches, with a span of twenty-three inches and a height of seventeen inches. Twenty four square feet of burlap and the same amount of vinyl-coated fiberglass were used.

The larger, hanging vault was forty-five inches by seventy-four inches by thirty inches high and spans more than a yard. Forty-eight square feet of burlap and the same of fiberglass were used. The small vault was on the average three-eighths of an inch thick and the larger averaged three-quarters of an inch (figure 4.16)

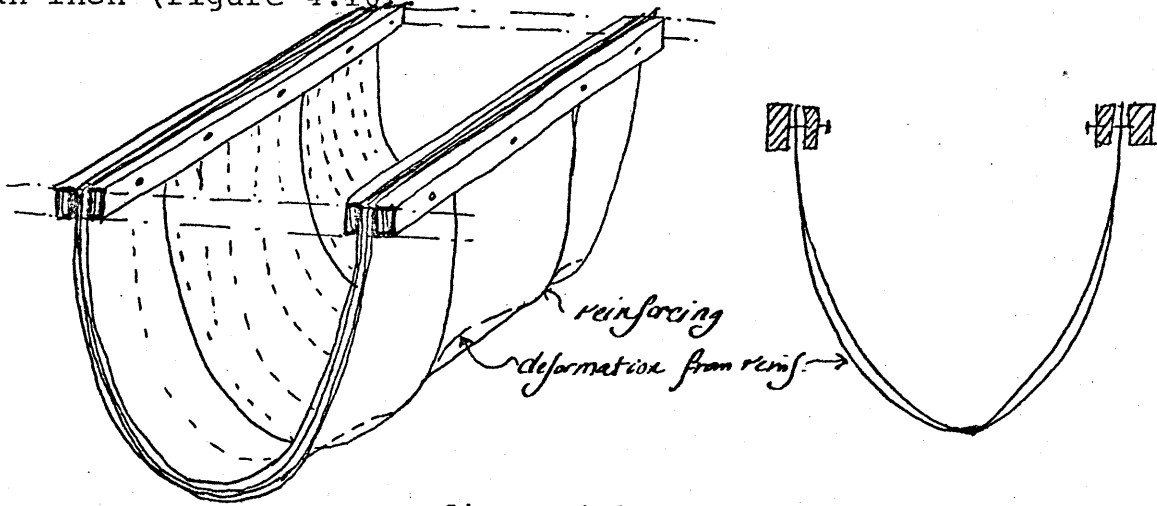


figure 4.16

The results were encouraging. The small vault supported 115 pounds without any sign of cracking (photograph 20), and the larger vault when turned over supported 205 pounds without the least indication of failure (photograph 21). Neither vault was tested to the point of failure because their edges were not fixed and, consequently, failure would have occurred at an earlier point because the vault would spread. But it was clear that these were by far the strongest components made in terms of their strength compared with their weight and the amount of materials

used. This was a fairly obvious conclusion because they were also the most efficient structurally, since all of the concrete was in compression.

It is also important to note that the concrete did not drop off or slide on the fabric when the vaults were lifted in place even though it was fairly wet. This can probably be attributed to: (a) the fuzziness of the burlap which must have held the concrete in place in the interior of the pieces and (b) the polyethylene on the outside which always adheres temporarily to wet concrete.

C. Rolled Components

A variation on this kind of internal fabric formwork was rolled "planks." Strips of burlap and fiberglass were dipped in concrete and rolled into small concrete "boards." It was hoped that these pieces might have some of the properties of wood so that, for example, one could nail into them. The first pieces were rolled into a quarter of an inch by four inch by two foot board-like components, but the method failed because of the faulty concrete, latex and burlap.

Larger samples employing better materials were then produced. Three samples were made: one resembling a "two-by-four" in shape and dimensions; one, a thick column (three and a half inches in diameter) rolled out of seven linear feet of burlap around a thin cardboard tube; and one, a thin-walled tube made from two linear feet of burlap wrapped around a cardboard tube (four inches in diameter) which was intended to be removable (photograph 22, figure 4.17). In all the pieces wire was used for

stiffening instead of fiberglass.

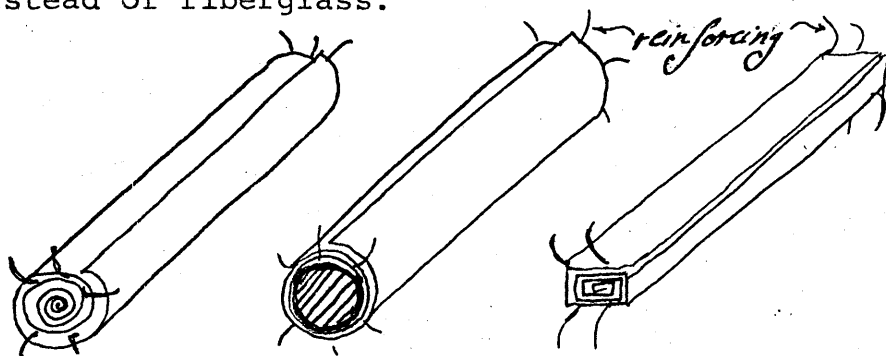


figure 4.17

The behavior of the cured pieces was fair. The "two-by-four" piece broke cleanly in the middle, reinforcing and all, when it was stepped on. The other two pieces seemed stronger. When they were strung between two milk cartons it was possible to sit on them though the cardboard tube in the four-inch diameter piece was carrying most of the load. They proved disappointing, furthermore, in that it was difficult to nail into them, especially the solid two-by-four, and the nail pulled out easily.

D. Small Test pieces.

1. A brief investigation was made into Maybeck's shingle method. Five pieces of burlap were dipped in concrete and nailed vertically overlapping each other on both sides. A considerable amount of concrete adhered to the pieces, and more could have been stuffed inside them. The sample was a half an inch thick. The surface was very tough and it was difficult to bend the pieces. It appeared to be a very reasonable way to surface a structure, though no test was made of its weather resistance (figure 4.18).

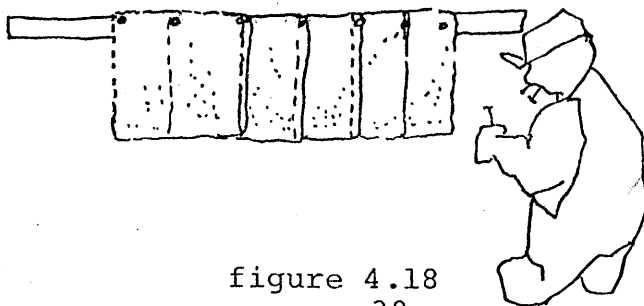


figure 4.18

2. Several other small panels were made to test whether there was any difference in strength between the epoxy coated fiberglass and the vinyl coated fiberglass. The epoxy coated fiberglass was a larger mesh and fiber size, while the vinyl coated fiberglass mesh had smaller but more numerous fibers. Sarabond¹ high bond mortar mix (a latex additive produced by Dow Chemical Company) was also added to some of the pieces to see if it made any difference to the strength of the concrete or made the bond between the concrete and the fabric stronger. The behavior of all the pieces was nearly the same. When placed between two milk cartons and slowly stepped on, all the panels snapped suddenly at about the same place. It seemed to make no difference whether or not the panel contained an internal layer of burlap or what the size of the fiberglass mesh was. With the latex additive the only noticeable change was the dull surface and brown tone that the latex gave to some of the pieces. The bond between the burlap and concrete may have been a little stronger.

4.2 External formwork

The other area of research tested somewhat less extensively is that of external formwork or bagged concrete.

A. Stacked bags.

1. The first method was similar to the previously mentioned "stack sacks" (section 2), only smaller sacks were used (four inches across by two feet long at seven pounds per sack) in an attempt to make a cleaner wall and use less material. Also muslin was used instead of burlap because of the possibility that too much of the dry mix might be washed away when the bags were

sprayed with water. The opposite was found to be true. There was insufficient concrete seepage so that no bond was made between the sacks. However, the water seemed to have penetrated to the center of the bags which was an encouraging sign.

2. A slightly more successful test was tried with the same dry-filled "stack sack" technique but this time using burlap. In filling the bags, a good coating of dry concrete mix filtered through the burlap to the outside of the bags (photograph 23), but in spraying them this coating washed off. Once again the layer of mortar between the bags was not satisfactory. There were also difficulties in keeping the wall from falling down, especially when it was sprayed with considerable force.

3. This method was tried one other time using the same-sized bags, only these were made of a loose-weave seven-ounce burlap and were not filled as full. Three bags were stacked vertically and sprayed with water for approximately one minute. The bags stayed in place much better because they were not as full so they stacked flatter. A thin layer of mortar did form this time between the bags. A more successful method was that of dipping the dry sacks into a bucket of water, waiting until the bubbles stopped rising to the surface, and then rolling the bag in wet (or even dry) concrete and stacking them (photograph 24).

B. Dry filled wall.

Only a brief exploration was made in this area. It was hoped that it would be possible to obtain some of the ready made "fabricform" material from Erosion and Soils Technology, Inc. and set it up vertically filled with a dry concrete mix. The material

never arrived so only one test was made. This test consisted of dry filling a stitched fiberglass-burlap piece and then spraying it with water (photograph 25). The water penetrated to the center of the piece, but the configuration of the fabricform was not the most appropriate shape that could have been chosen. Wherever there was stitching, there was no concrete so the wall could bend. However if a panel were given one of these configurations (see figure 4.19), it might be a reasonable system: the fabricform could be suspended from temporary supports and it could be filled a course at a time (figure 4.20).

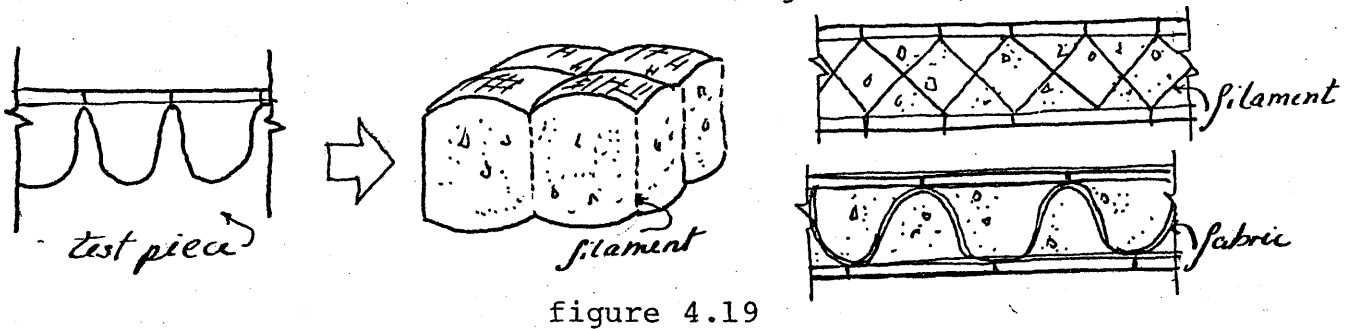


figure 4.19

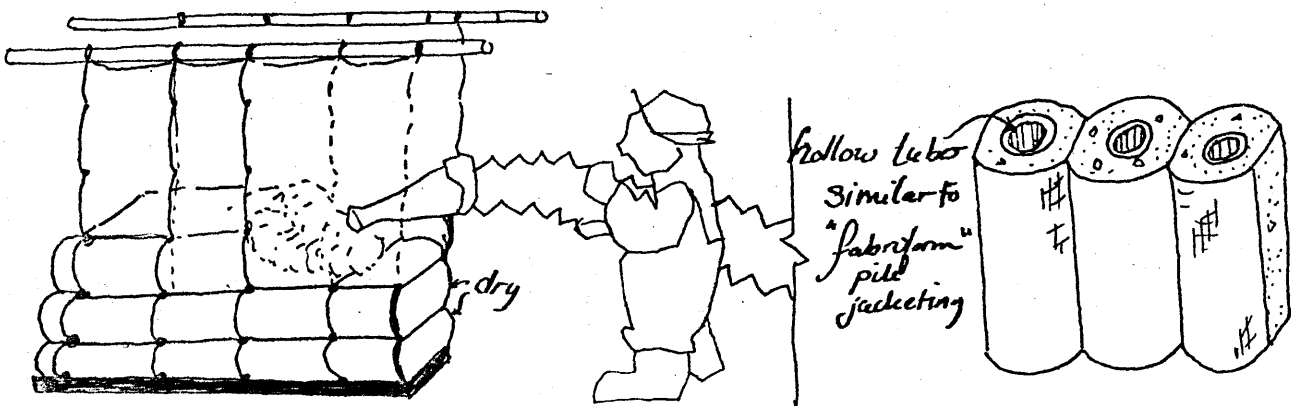


figure 4.20

It should also be noted that the concrete did not seep out through the fabric so the burlap and the fiberglass could be peeled off the concrete after it had dried.

C. Extrusion

The most successful test using external formwork was an extrusion system. The system consisted of forcing wet concrete into a long bag of fabric with a primitive piston inside a tube on which the fabric bag was gathered. The burlap expanded as it was filled with concrete, and the force of the piston pushed the entire apparatus along, extruding the fabric and concrete behind it. Besides eliminating the usual extrusion problems which accompany quick-setting concrete, this system has the added advantage of producing its own mortar. Under the pressure exerted by the piston, enough of the concrete oozed out through the loose weave of the seven-ounce burlap to form an adequate layer of mortar, which also serves as a thin surfacing over the burlap. There was no problem here of the fabric peeling off the concrete. The wall that was constructed measured one and one half feet by two and one half feet by four inches approximately (photograph 26). In a normal building situation one would presumably extrude such a wall either clockwise or counterclockwise as in the various ways Edward Allen suggests in Continuous Construction, (unpublished paper, M.I.T.), instead of doubling back as was done in the test wall. The only anticipated complication is the need to support it from one side, but this could be overcome with bags having somewhat oblong shapes, with reinforcing rods or with other such solutions (figure 4.21).

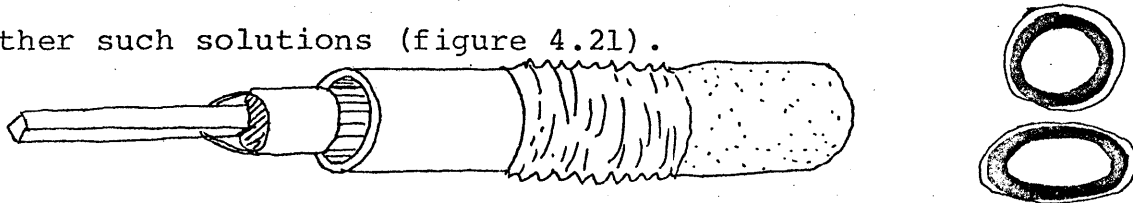


figure 4.21

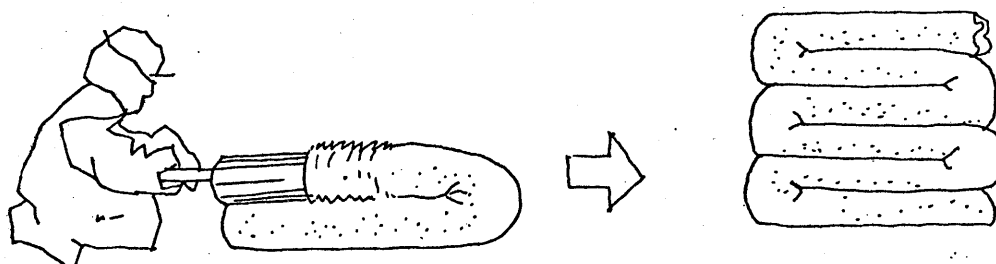


figure 4.21

4.3 Surfacing

It should be evident from the preceding tests that using fabric with concrete can result in a variety of textures and surfaces. As has been seen in all the test pieces, if the concrete is wrapped in an impervious fabric such as polyethylene, the result is a shiny glass-like finish (photograph 14). The opposite of this is a hand finished or troweled surface which is dull and somewhat rough. Some of the pieces were also wrapped in burlap which was removed when the concrete was dry. The burlap left uneven woven patterns on the panels' surfaces. Material could easily be pressed onto the wet surface of the concrete and left there as a surface finish. In this manner any fabric, acoustic fuzz or wood veneer could be added to a concrete building component with the concrete acting as the glueing agent. In the case of pieces such as the one in photograph 25, the final finish could even be the formwork.

4.4 Observations on the behavior of materials.

The behavior of the materials used for this project was disappointing. The final components were made much stiffer than the original pieces, but they were now brittle. They bent very little and failed all at once. This must, to a large extent, be

the fault of the fiberglass which was intended to strengthen the pieces in tension but must not have been strong enough. Furthermore, the bond between the fiberglass and the concrete was poor, and the vinyl-coated mesh was too fine. Both of these factors caused the concrete to chip and crack off certain of the corrugated panels.

Research needs to be done into various fiberglass meshes. A more explicit analysis of the behavior of the system follows in the next section.

The following pages contain a few schematic drawings of other methods which it was hoped would be investigated in this thesis but were not, due to lack of funds and time.

Extrusion.

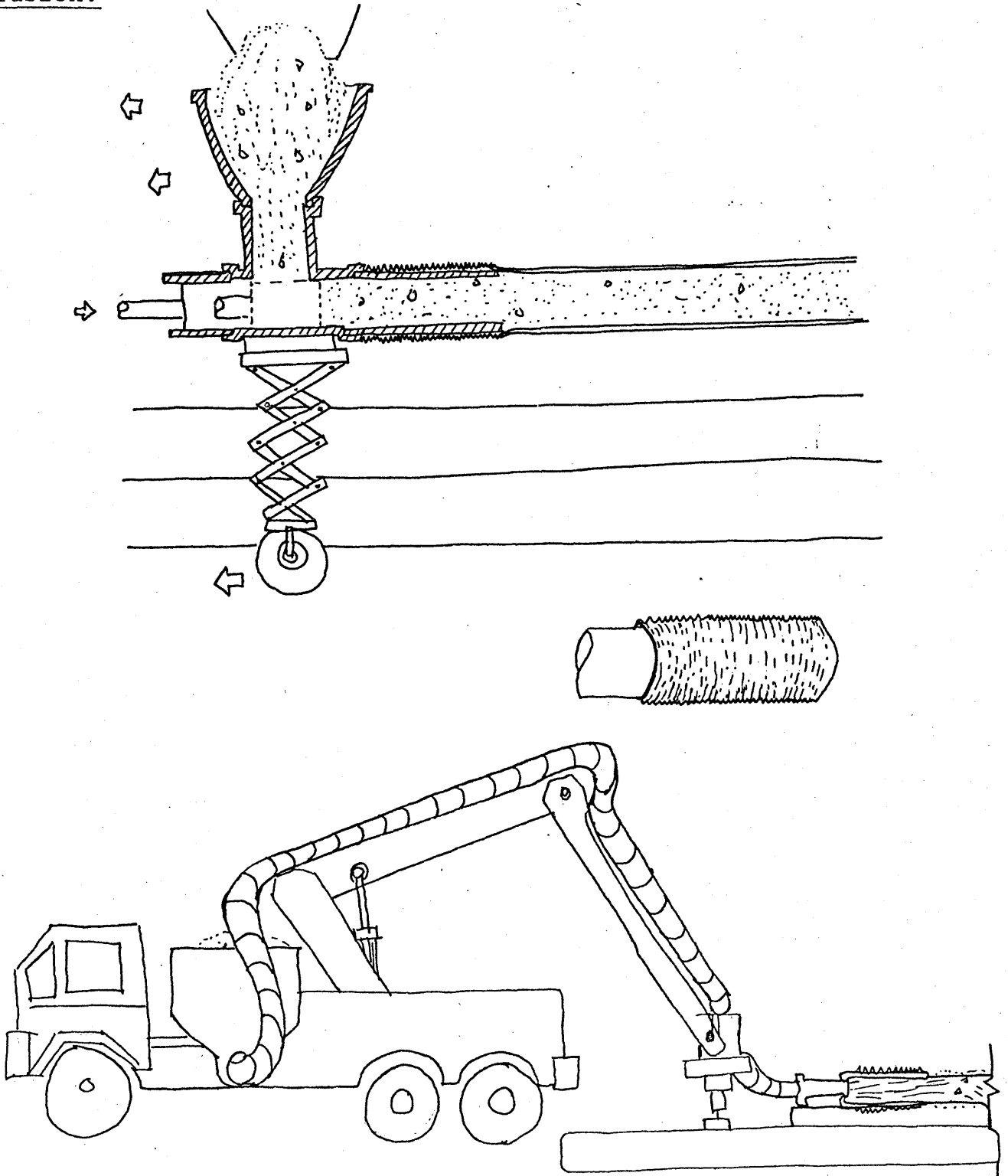


figure 4.22 extruder-sprayer adapted from Ed Allen, Continuous Construction

Methods of application.

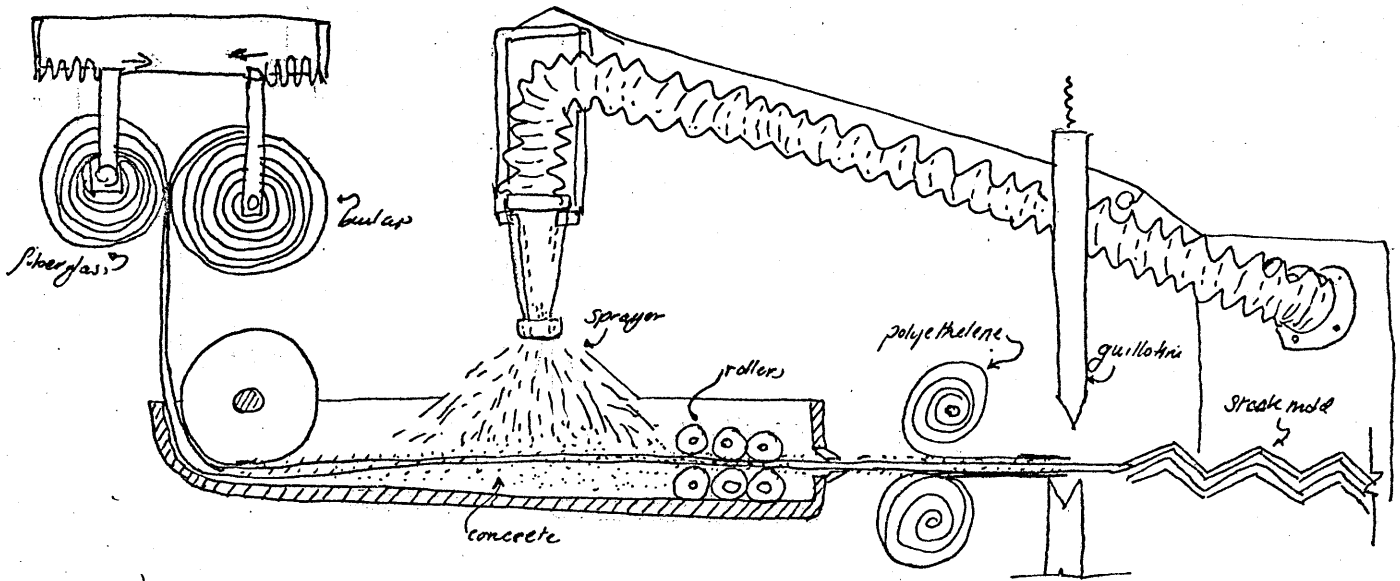
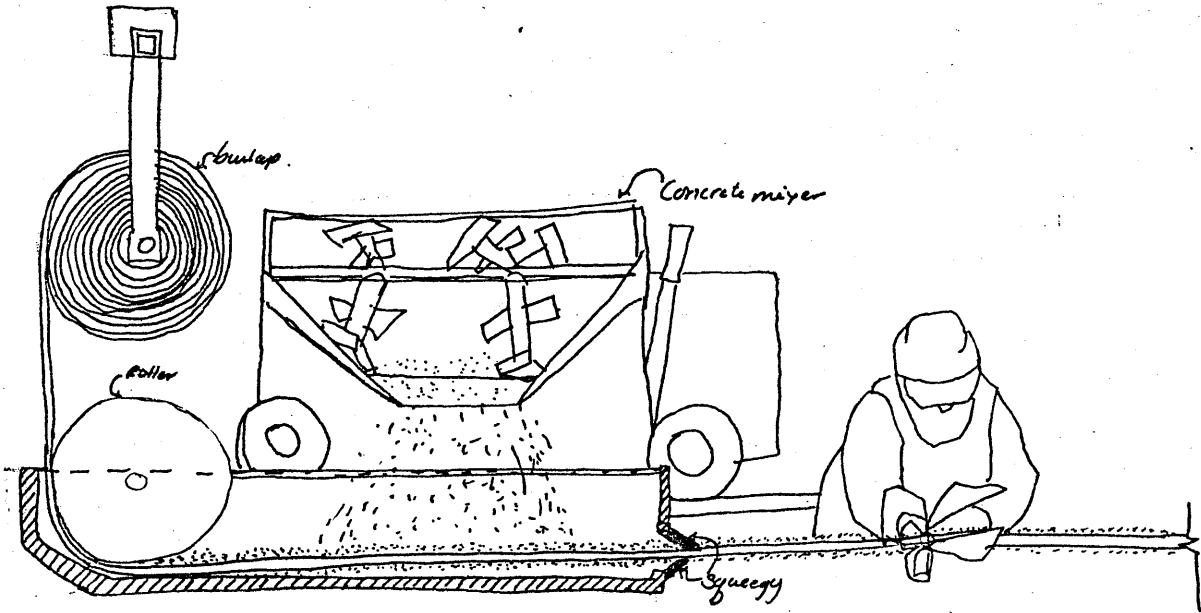
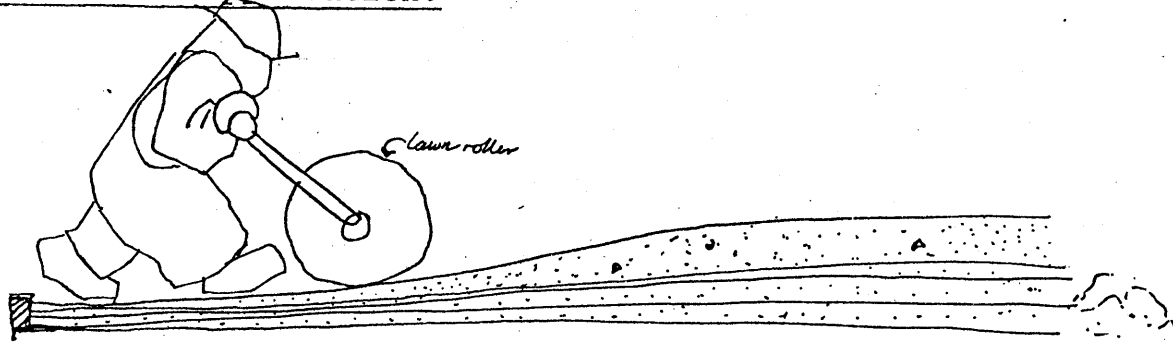
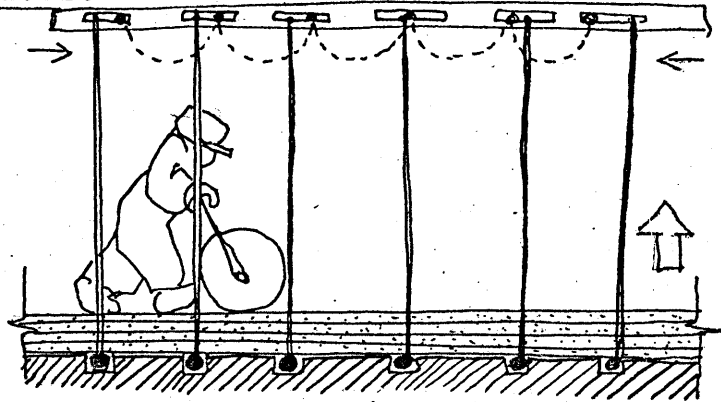
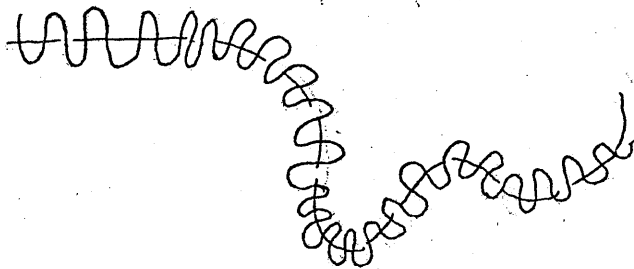
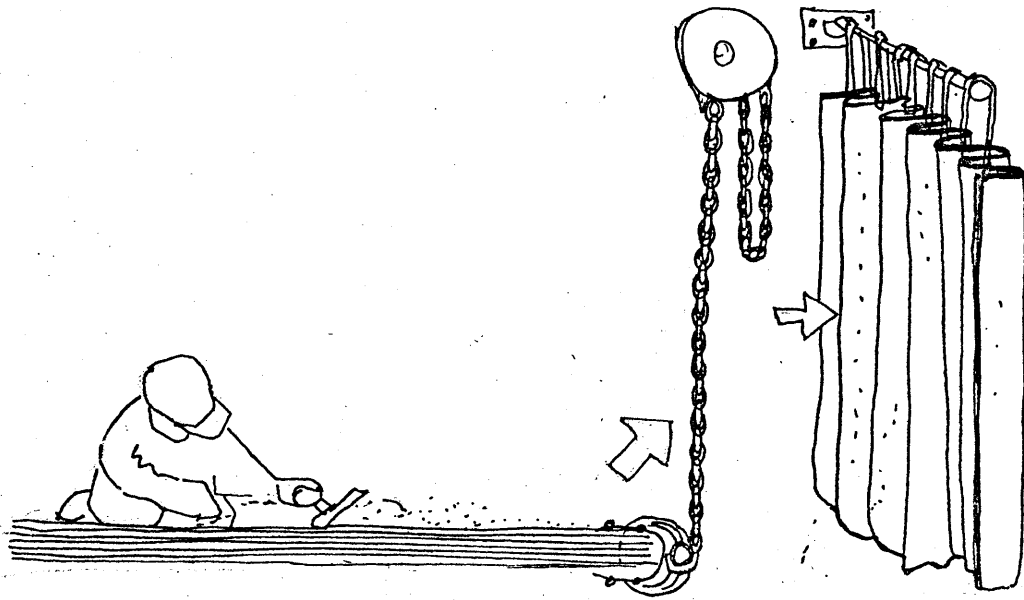


figure 4.23

Draping methods.



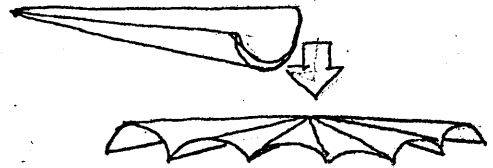
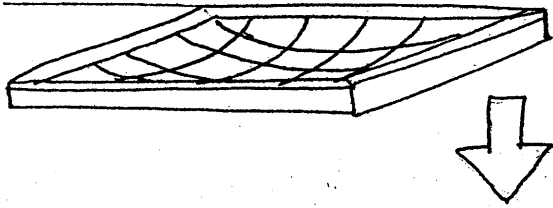
for a draped panel.



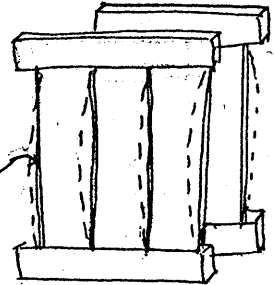
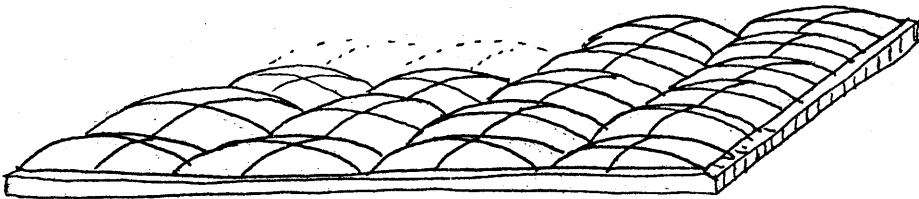
This test was intended to be tried ^{at full scale} in this thesis but won't because of lack of time.

figure 4.24

Miscellaneous.

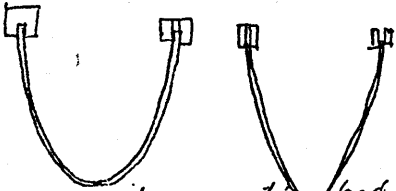


roof panel.



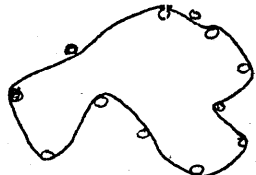
rods

Vertical Stuffed wall

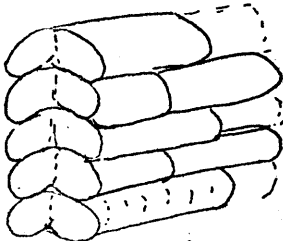
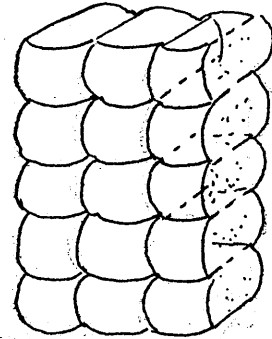
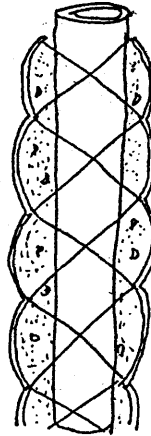
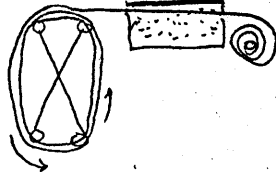


if a specific load is placed on a cable - the load weight will be more efficient.

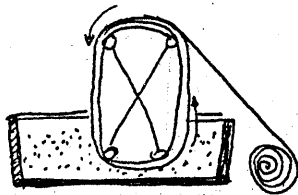
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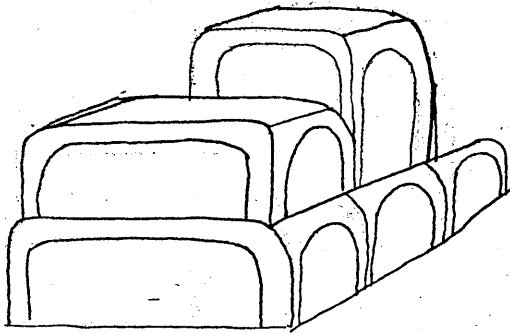
filament winding



Stack ribs



Cables or baffles will do this



Sewing baffles on the inside of a pneumatic membrane will alter its shape; baffles this shape should give a rectangular shape which is good for multi-story building

figure 4.25

TABLE 2

The preceding experiments were limited in scope. The extent of the variations possible can be seen perhaps best in a Zwicky-type morphological analysis.¹

General:

P₁¹, P₁², P₁³, P₁⁴

plane of surface: vertical, horizontal,
curved, corrugated

P₂¹, P₂², P₂³, P₂⁴

fabric coatings or fill: concrete, foam,
concrete and foam, other

Concrete:

P₃¹, P₃²

state of concrete during erection: wet, dry

P₄¹, P₄²

concrete mix: with latex/without latex

P₄³, P₄⁴

soupy/stiff

P₄⁵, P₄⁶, P₄⁷, P₄⁸

regular aggregate/lightweight
aggregate/ sand/other

P₅¹

concrete proportions: cement=aggregate

P₅

cement > aggregate

P₅

cement < aggregate

P₆¹, P₆², P₆³, P₆⁴

means of application of concrete: spray,

P₆⁵

trowel, dip, prefill, roll

P₇¹, P₇², P₇³

curing position: final position: same,
reversed, tilt-up

P₈¹, P₈², P₈³, P₈⁴,

reinforcing: fiberglass mesh, wire, steel

P₈⁵, P₈⁶

re-bar, wire mesh, fiberglass filament, none

Fabric:

P₉¹, P₉²

nature of fabric: structural/non-structural

P₉³, P₉⁴

natural/synthetic

P₉⁵, P₉⁶

porous/impervious

P₉⁷, P₉⁸

permanent/temporary

P₉⁹, P₉¹⁰, P₉¹¹

loose weave/tight weave/no weave

P₁₀¹, P₁₀², P₁₀³, P₁₀⁴,

types of fabric: burlap, muslin, duPont

P₁₀⁵, P₁₀⁶

Cordura nylon, polyethylene, fiberglass, other

P₁₁¹, P₁₁², P₁₁³,

configuration of fabric: flat, rolled,

P₁₁⁴, P₁₁⁵, P₁₁⁶

folded, quilted, bagged, wound, corrugated

P₁₁⁷

P₁₂¹, P₁₂², P₁₂³,

number of layers: one, two, three, four,

P₁₂⁴, P₁₂⁵

more

P₁₃¹ , P₁₃² , P₁₃³

P₁₃⁴ , P₁₃⁵ , P₁₃⁶ , P₁₃⁷

P₁₄¹ , P₁₄² , P₁₄³

means of support: hanging, inflated, concrete filled, precast on floor, earthworks, vacuum, stretched

types of protective coating on the fiberglass: vinyl, epoxy, phenolic

Principal Components produced:

sewn corrugated panels (figures 4.2,4.3)

hanging curtain panels (figure 4.9)

corrugated panel (figures 4.6, 4.7, 4.12, 4.13)
cardboard formwork

corrugated panel (figures 4.8, 4.14)
draped

hanging vault (figure 4.16)

upright vault (figure 4.16)

rolled beams (figure 4.17)

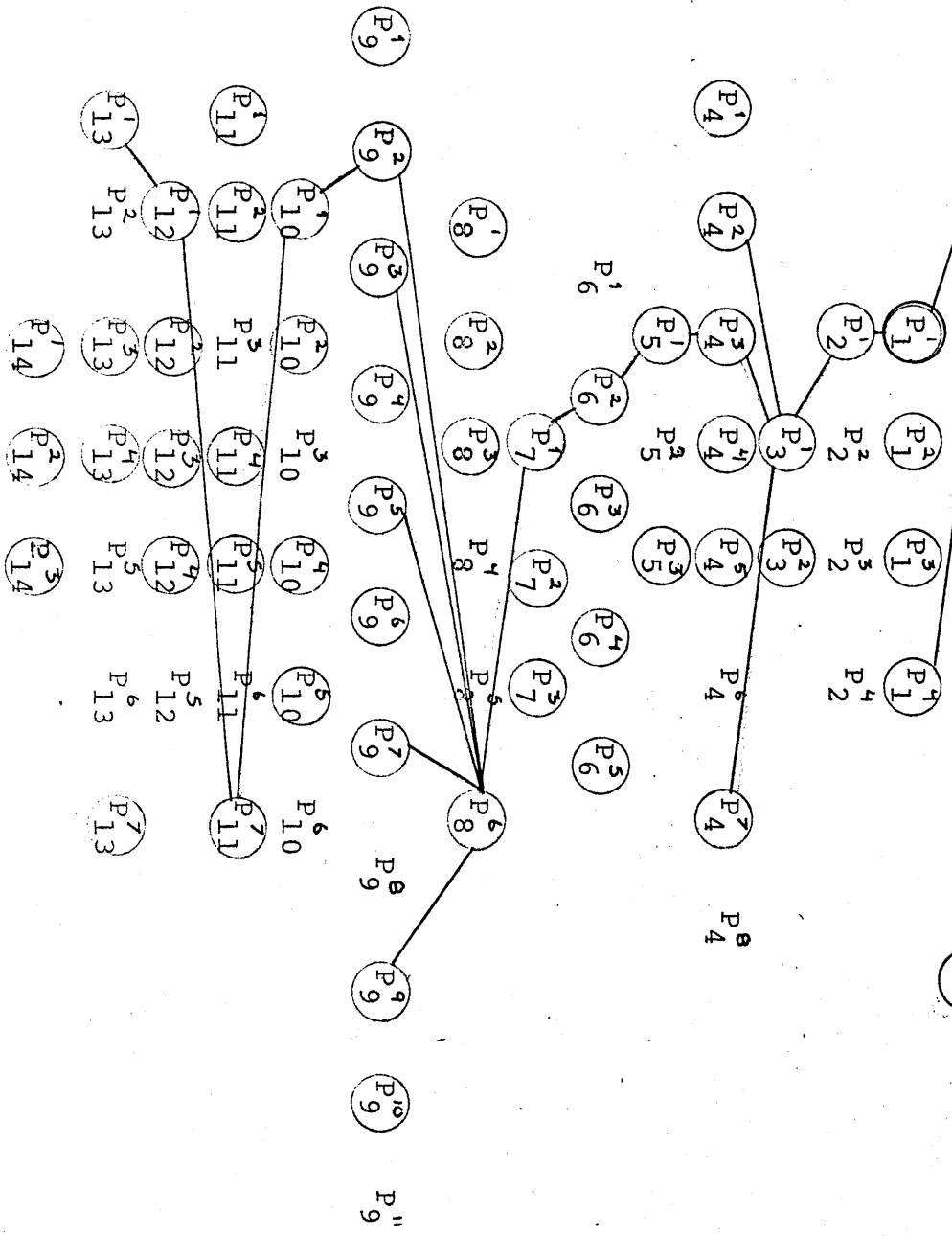
"shingles" (figure 4.18)

"stack sacks" (photographs 23,24)

dry filled walls (figure 4.19)

extruded wall (figure 4.21)

○ The circles represent areas that have been tested to some extent in the project. The path through the chart represents a simple hanging curtain-like wall (photographs 5,6).



Footnotes

1. Sean Wellesley Miller, "Control Aspects of Pneumatic Structures," Proceedings, International Symposium on Pneumatic Structures. Delft. 1972. Vol. 1. pp.SWM 2-3.

5. Conclusions

The conclusions reached after twelve weeks of research and experimentation were that fabric formwork has a number of potential advantages as well as some basic problems.

5.1 Advantages

(a) The fabric formwork is lightweight and flexible. Large pieces can easily be handled by an individual. This quality considerably increases the ease of transporting and erecting the formwork, although once the concrete is applied, the weight becomes a serious problem.

(b) Little tooling or skill is required in handling either the fabric or the concrete. The fabric can be cut with scissors and sewn on a sewing machine if necessary. Concrete requires little mixing skill, and applying the concrete to the fabric as was done in these experiments was uncomplicated though heavy and fairly time-consuming work. With the method suggested in figure 4.23 even this problem should be solved.

(c) All the materials used were inexpensive and readily available. The only exception is the fiberglass which averaged thirteen cents a square foot (see appendix 6 for itemized costs). Though keeping costs down is important, the major considerations are labor and time which account for most of a building's cost. Among the most time-consuming elements are the joint systems. The more varied these are and the more skill they require to assemble, the more steeply the costs rise. The use of large tilt-up panels and hanging pieces in this fabric formwork system or the use of continuous extrusion methods decreases the number of joints needed.

The continuous nature of the materials and the self-adhering quality of the concrete may eliminate the need for complex joints. If inflated formwork is used, there is no need for any joints. Furthermore, the cost of transporting the formwork should practically be negligible because it is so lightweight.

(d) Structural efficiency. Fabric, when suspended or inflated, assumes a minimal surface of uniform tensile stress and the reverse of this is the most efficient and minimal-surfaced compressive shape. This means that this fabric formwork system is an economical way of construction in terms of shape and materials.

(e) New Forms. The variety of possible forms that lie within this system appear to be extensive. The forms that were tested in this project were the most conservative shapes possible so that an easy comparison with conventional systems could be made, but the formwork lends itself naturally to far more organic shapes (see chart I). Simply by draping the fabric in different ways or by moving the poles on which the fabric is hanging closer or further apart one can obtain a great variety of shapes without building new formwork each time.

Rolling, dipping, and hanging concrete-coated fabric eliminates the need for wooden or metal formwork, which at present is one of the most costly and restrictive factors.

Other variations could also be obtained by stretching the fabric on different frames and then spraying it. Or using inflatable formwork, one could vary the form by changing the amount of pressure and the cable restraints. By cutting the fabrics into different sizes and shapes, other forms are also

easily possible.

5.2 Problems

(a) The weight of the concrete limits the size and the variety of the forms possible within this system. There are certain advantages to having the weight since it makes permanent, weather resistant, and durable what would otherwise be a flimsy structure of fabric. But unless the structure is sprayed on an inflated form or extruded in place, all the other methods which involve dipping, hanging, and draping fabrics will need to be restricted in size or will require mechanical hoisting systems. This applies to the proposed concrete-sprayed tension structures similar to Frei Otto's "tents" as well as to the smaller prefabricated tilt-up manufactured for this project. The reason for these restrictions is that, in order to obtain structural efficiency, the draped structures or components must be turned over once they have been cured in order to place the concrete in compression. This method would add a great deal of extra time and labor to use the system, in addition to severely limiting the size of the components. One partial solution may be to use a lightweight concrete, especially a foamed concrete (concrete with aluminum added), which is presently in use in Europe for certain prefabricated structures. Or it may prove more efficient to make the basic structure with an inflated form and drape additional concrete-soaked fabric on this structure. Otherwise it will be necessary to heavily reinforce hanging structures because the concrete will be in tension instead of compression. The one exception are forms that are hung vertically but resting on the ground when cured.

(b) The flexibility of fabric is a problem as well as an advantage in the internal formwork structures. The advantages, as mentioned earlier, are the considerably increased ease by which this type of formwork can be transported and erected. Once in place, however, the fabric poses several problems concerning the application of concrete. Whether the concrete is sprayed or troweled on, the fabric must be taut. Therefore, either the fabric must be lying horizontally on a smooth, flat surface or it must be stretched on a frame. Stretching it is not as difficult as it first appears. There are already excellent examples of simply stretched tension structures using cables and poles, the best example being the work of Frei Otto. There are also optimal ways of stretching fabric so that the number of poles and cables is minimized. A saddle shape is perhaps the best example.



figure 5.1

Straight, vertically hung panels and vaults only need the upper edge supported since the weight of the concrete will keep the fabric taut along the vertical axis. Some buckling will occur since the fabric is not held in the horizontal direction, but for the panels this feature was found to be desirable in some cases because the corrugated effect provides lateral support. Inflatables perhaps present the greatest support problems in that their boundary foundation must be securely fastened to the ground. Usually this requires a poured-in place, slab on grade,

onto which the membrane is anchored by means of an inflated circular hose secured to the slab.

In addition to these requirements, the fabric must also remain rigid while the concrete is curing. The slightest deformation of the fabric will result in the concrete's cracking. As mentioned in section 2 this problem is particularly apparent with inflatables. However, Heifetz may have the problem solved with his water valve. With non-inflated forms one can only hypothesize that the weight of the concrete would prevent pieces from moving except perhaps in high wind conditions.

In the last phase, the fabric must have a high modulus of elasticity if it is to provide a fair measure of stiffening and reinforcing to the final structure. Unfortunately this property is not common to fabric. Only fiberglass and metals have a sufficiently high modulus to provide the needed rigidity. It is possible to use fiberglass and metal in a mesh form. A fiberglass mesh was used in this project because it was easier to handle. While the mesh used definitely increased the stiffening of the panels, it was not adequate in most cases when tensile forces were exerted on the components.

(c) The permanent character of concrete may limit the flexibility of this system. Once in place, concrete, because of its density, is easy to add to but not as easy to subtract from. Bini mentions cutting his concrete shells with a circular saw, but it is unclear how much difficulty would be involved especially if it were an extruded wall. Ideally, a concrete solvent is needed.

(d) Efficient structures are often symmetrical in form. The

minimal surface that fabric assumes when it is inflated or draped is symmetrical because the loads are evenly distributed on its surface. For example, Binishells and Heifetz's shells are usually hemispherical. This seems to be a minimal architectural solution to what should be a flexible system considering that if restrictions are placed on the fabric in the way of cables or supporting framework, variations in the shape of the fabric are immediately produced. So it would seem that Bini and Heifetz use the hemisphere for the sake of simplicity. Obviously the external formwork and multiple panel structures can be varied even more easily.

5.3 Applications in the industry

(a) Using this system as an option for do-it-yourself building may not be feasible. The light weight of the formwork and the little skill needed to use the fabric and the concrete, as well as the potential inexpense of this building method make it ideal for self-help housing. However, the weight of the concrete makes it extremely difficult for individuals to mix or handle it without machinery in any way other than in small quantities. This imposes severe limitations on the size of the building components which reverts to the time and labor problems inherent in traditional, small-component construction. It might be possible to overcome this weight problem by introducing a low degree of mechanization into the system, for example, simple hoists, an inflation system, or a pump and piston extrusion system (refer to figure 4.22). The weight may not be a prohibitive factor in third world countries where manpower is readily available but technical

skill and money are not.

It was hoped that with fabric formwork it would be possible to set up the basic formwork, change it and rearrange it, and then make it permanent, designing your house as you build it. This might be possible only with hanging fabric sprayed in place.

(b) The need for little tooling and the possibility of producing panels without using rigid formwork could make this a very efficient prefabrication system. Rigid forms are one of the most restricting factors in prefabrication because each new form requires considerable time and labor to build, add the reinforcing to, pour the concrete, and wait a week for it to cure. On the other hand, with this fabric formwork system, it might be a continuous process: pieces of fabric run through a bath of concrete, hung and stack-molded (refer to figure 4.23). Panels that were stack-molded would stack well for efficient transport. Prefabricated panels using this method would also save on cost because the pieces, especially the corrugated and hung pieces, would be lighter in weight since they use less material. Another alternative would be to produce thin concrete panels in a factory, transport them to the site where they are lifted together (reinforcing could be added), and then sprayed with further layers of concrete and possibly other materials such as foam for insulation. In addition to spraying, concrete soaked fabric could also be draped on the prefabricated pieces to increase their strength. An example of this is the piece in photograph 7.

(c) A system that requires little skill and possibly considerably

less construction time could facilitate on-site construction. It has the potential of saving on cost without limiting flexibility. The cost of the materials, the amount of time, labor, and skill that is required to use this system are potentially low. And the range of flexibility is high, from inflatables to extrusion to hanging panels and vaults. One of the greatest savings of this system is that there is no need for building on-site formwork -- usually an extremely expensive and time-consuming process.

6. Future Research: Further research into this system should proceed in two divergent directions. On one hand, research should be directed into an extensive analysis of the properties of the materials and their behavior, paralleled by a more complete study of the forms possible with these materials. On the other hand, studies must probe application methods and developing the machinery to be used for the system. Table 3 delineates these areas of future research.

TABLE 3

I. The properties of the materials and their behavior

A. Primary systems

1. Materials (see table 1)

a. fabrics

(1) material composition

(a) fibers : synthetic/natural/composite

(b) weave : directional/density

(2) behavior

(a) strength and reinforcing potential

(b) permeable/impermeable

(c) modulus of elasticity

b. concrete

(1) material composition

(a) regular/lightweight

(b) additives : i.e. latex

(2) behavior

(a) strength

(b) durability

(c) finish

c. reinforcing

(1) woven into fabric

(2) additional : steel

2. Application

a. Fabric formwork

(1) manufacture

(2) erection

b. concrete'

- (1) method of application
- (2) mechanization of the system

B. Secondary systems

1. Compatibility of other materials

a. Infill

- (1) windows
- (2) doors
- (3) cabinets

b. coating for concrete

- (1) weatherproofing
 - a. latex
 - b. membrane (Bini's method)
- (2) acoustical
- (3) aesthetic

2. Compatibility of other systems

a. mechanical systems

- (1) pumping
- (2) heating
- (3) electrical

b. structural systems

- (1) reinforcing
- (2) supporting structure for fabric

c. Analysis of the systems

- (1) weather-ability
- (2) durability
- (3) strength

(4) fireproofing

(5) cost

(6) practicality

II. The Application of the System

A. the building industry

1. on site construction

2. prefabrication

3. self-help

B. Development of machinery

1. application of concrete

2. placing components in place

C. Morphology of form (see Chart I)

Sources for materials.

Fiberglass:

Epoxy-coated:

Eli Sandman (speak to Michael Sandman)

280 Greenwood Ave.

Worcester, Mass.

tele. 757-7781

Vinyl-coated

Central Square Hardware (screening wire)

453 Mass. Ave., Cambridge, Mass.

Burlap:

second-hand:

Harry Stoller and Company

128 Auburn Street

Chelsea, Mass.

tele. 884-2420

Fabricform:

Erosion and Soils Technology, Inc.

tele. (215) MO4-5590; Larry Herver

Cordura nylon:

Textile Fibers Department

E.I. duPont Co.

Wilmington, Delaware

tele. (302) 999-4272; Mr. Ebdon

Latex, Sarabond:

Dow Chemical Corp.

Michigan

tele. (517) 636-3722; Lou Kuhlmann

MATERIALS

portland cement	94 lb. bag	\$2.30
sand	70 lb. bag	\$1.10
burlap (used)	per lb.	\$0.45
fiberglass (vinyl-coated)	per sq. ft.	\$0.13
(epoxy-coated)	per sq. ft.	donated

TOTAL:	concrete	\$57.00
	burlap	\$27.00
	fiberglass (did not use nearly as much of this as burlap)	\$30.00

total cost of the building materials for this project \$114.00
(not including extras)

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Waddell, Joseph J., Concrete Construction Handbook. McGraw-Hill Co., New York: 1968.

3. Many architectural journals were used for ideas. Some of the most helpful were A.D. published in London, and L'Architecture D'Aujourd'hui published in Paris. Listed below is a sample of the findings from them:

A.D. February 1971: Tube Building
Air Supported Dome Kit
Garbage Housing
March 1971: PVC Membrane Roof
Dripped foam house
May 1971: Canopies
January 1972: Parachute House

L'Architecture D'Aujourd'hui

July-August 1954: Cable Structures
June-July 1959: Robert Le Ricolais
October 1960: Expandables



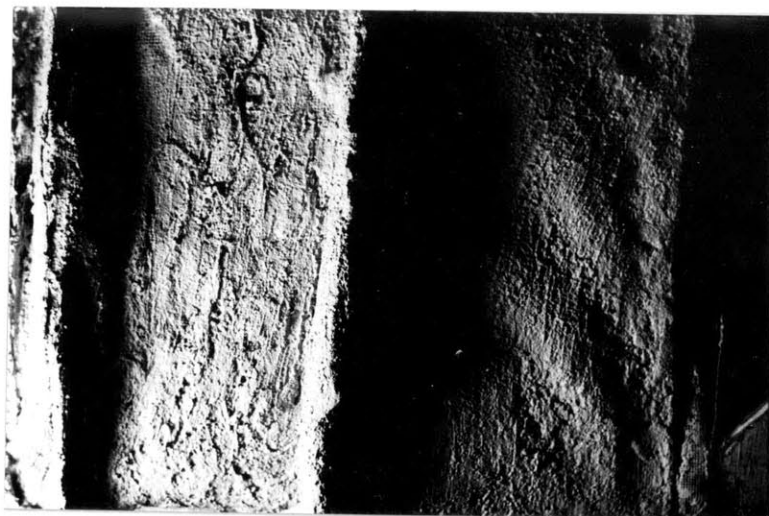
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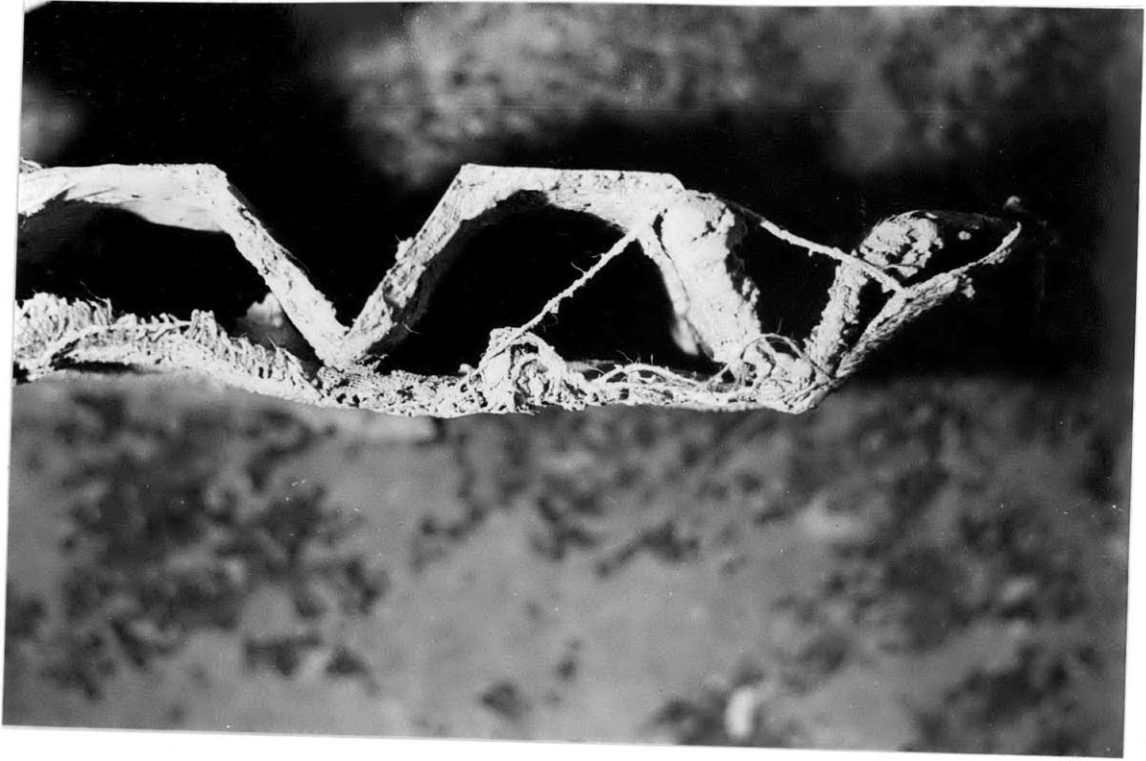
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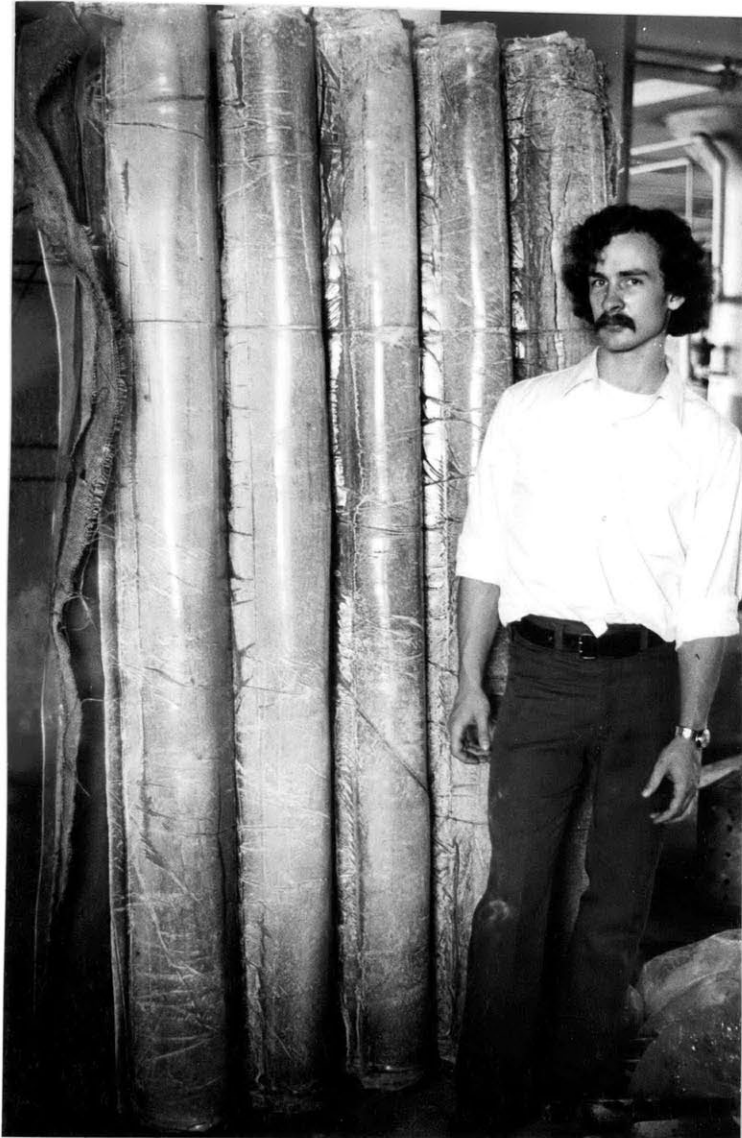


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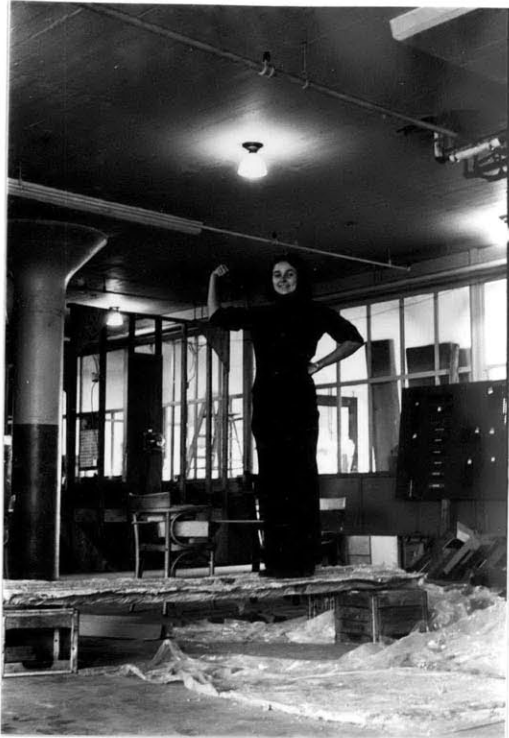
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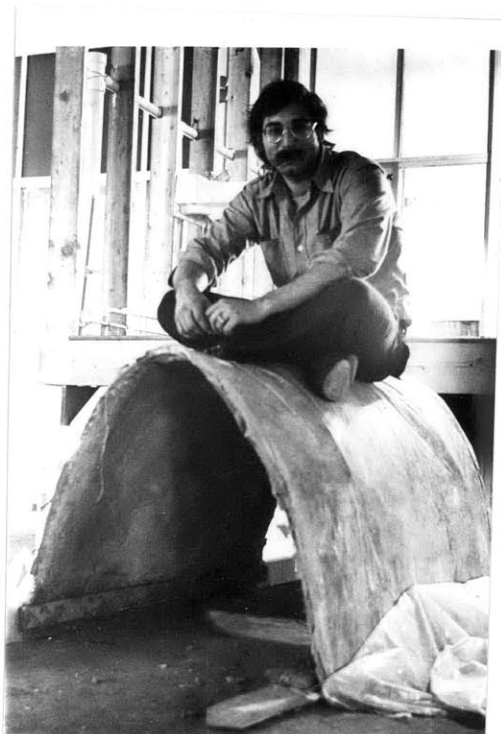
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