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9. ABSTRACT
(HOUSING R & D)
In 1962 the University of Michigan received a USAID grant to explore the potential of foam plastics for solving housing problems in developing nations. A feasibility study completed in 1962 (see PN-AAD-174) established the desirability of investigating the use of foam plastics as structural material. The project was conducted in two phases. The first phase involved experimentation to obtain information on a variety of foam plastics. Several structural systems were established as scale models before two structural concepts were selected for full-scale construction and testing. One concept involved application of spray polyurethane foam on a folding wood lattice armature. The other concept involved production of large structural components made of paper-laminated polyurethane foam board. During the second phase of the project, four prototype structures representing different techniques were built. One consisted of seven umbrella-shaped components made of sprayed polyurethane foam. A second was a two-story structure made of triangulated bents of folded paper-laminated polyurethane foam board. A third consisted of four square umbrella-shaped components made of flexible foam coated with reinforced polyester. The fourth was a room-sized unit in which polyurethane foam board served as the mandrel for filament-wound polyester. The research program also investigated requirements for production and marketing of chemicals and foam plastic products for structures and building components in underdeveloped countries. The major recommendation stemming from the project was

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that AID collaborate with the U.S. plastics industry in sponsoring construction and evaluation of suitable prototype dwelling units in developing countries. Interim reports of the project activities during 1964 and 1965 are available as PN-ADD-177 through PN-AAD-182.

Architectural Research Laboratory
The University of Michigan - Ann Arbor

AID/csd-288
IUD-M

ORA PROJECT 05687

title: STRUCTURAL USES OF FOAM PLASTICS FOR HOUSING IN UNDERDEVELOPED AREAS

sponsor: U. S. DEPARTMENT OF STATE - AGENCY FOR INTERNATIONAL DEVELOPMENT

first interim report: March through June 1963

1. At the beginning of this period the project staff operated under a hardship fund set up by the University in order to maintain continuity of research between the earlier ORA project 05215 and the present ORA project 05687. Until the new research contract was signed on 28 June no commitments could be made for any extensive collaboration between the project and interested plastics producers. Also, since the terms of the hardship fund temporarily restricted expenses to the remuneration of non-academic personnel and the purchase of needed supplies, testing had to be kept to a minimum. As a result the originally planned time schedule had to be set back somewhat, but every effort was made to keep the delay as small as possible.

2. The final report on ORA project 05215 was distributed to all collaborating companies, as well as to agencies and persons who had expressed interest in the project. The distribution list is attached as Appendix A. The response has been very gratifying and requests for additional copies are continually being received. Copies of correspondence resulting from this distribution have already been submitted to AID.

3. Talks describing the project were given by Professor Paraskevopoulos at the foam plastics conference of the National Academy of Sciences in Boston and at the spring conference of the Association of Collegiate Schools of

Architecture in Miami. Travel expenses incurred in making these presentations were borne respectively by the Academy and the University.

4. Priorities as to the course of work to be pursued were established on the basis of what the project staff believed to be the most promising possibilities for immediate application. Although the main project objective is the development of total structural systems for the underdeveloped countries, materials have also been viewed for their potential in resolving partial construction problems, such as better roofing. Thus, two materials were selected for initial structural development: (a) polystyrene foam, whose technology is well advanced, and (b) polyurethane foam produced between paper skins, which offers a fair amount of quality control and unique structural possibilities. Dow Chemical has an interest in the first material, while Union Carbide, Atlas Chemical and Houdry Chemical have an interest in the latter.

5. Dow Chemical has disclosed to the project staff under a priviledged information agreement a simple mechanical device capable of erecting curvilinear structural shapes with polystyrene foam by heat-bending the material in plank form and heat-sealing the joints. The project staff believes that this system has considerable potential for the erection of a large variety of structures and that Dow should be given every encouragement to further such development. It was decided that the Dow system should be tested and the construction problems evaluated through the erection of a full-scale test structure. Dow agreed to contribute the materials, equipment and operating personnel needed for the erection of a structure whose design, detailing and construction sequence would be determined by the project staff. It was further agreed that the structure should be put to actual use in order that the project staff might acquire the desired use data.

6. Webster Golflands, Inc., Ann Arbor, offered to make use of the proposed test structure and to assume the cost of all items not directly pertaining to the objectives of the project. An agreement was signed between Webster Golflands, Inc., and the University with Dow agreeing to assume the aforementioned obligations; a copy of this agreement is attached as Appendix B and a copy of the request from the University to Dow is attached as Appendix C.

7. Erection of the test structure, a dome 45 feet in diameter, was begun early Wednesday morning, 27 June. Twelve hours later the dome shell was

complete. A statement describing its erection is attached as Appendix D. The erection process has also been documented with photographs and a movie. The structure clearly demonstrates the potentials of foam plastics as a structural material and should become a stimulating force for the rest of the plastics industry. Dow's contribution to this particular case-study is estimated conservatively to be approximately $3,200 for construction labor and all other on-site experimentation, plus another $3,000 for both construction materials and other materials.

8. Concurrently the project staff began making preliminary studies to determine how the paper-urethane type of building material could best be used. Models have been built utilizing samples of Union Carbide's material which were contributed to the project by Outdoor Fiber Products, a local manufacturing concern interested in the development of shelters. Both Atlas Chemical and Union Carbide have also offered to contribute materials.

9. At the beginning of this period a series of experiments were also conducted on the incorporation of fillers in foam. Materials such as ground phenolics, clay, and wood shavings have been used for this purpose, and a number of samples tested. The results are described in Appendix E. Although not too encouraging, the information has been found useful as background experience by the project staff for any future evaluation of filled foams.

Appendix A

interim report: March -June 1963
AID-sponsored ORA project 05687

DISTRIBUTION OF FINAL REPORT ON ORA PROJECT 05215:

A Preliminary Investigation of the Potential Uses of Foam Plastics for Housing in Underdeveloped Areas

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1	8-4-63	Mr. Ralph Brozan Delka Research Corporation 275-281 Goffle Road Hawthorne, New Jersey
1	8-5-63	Commanding General ATAC - Detroit Arsenal Center Line, Michigan Attention: John M. Reynar-RCM. 2
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1	5-4-63	Dr. Samuel Steingiser, Chairman SPI Cellular Plastic Division Mobay Chemical Company Penn Lincoln Parkway West Pittsburgh 5, Pennsylvania
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1	2-5-63	Mr. Allen E. Abrahams, Manager Commercial Development Witco Chemical Company, Inc. 122 East 42nd Street New York 17, New York
1	9-4-63	Woodall Industries, Inc. 7565 East McNichols Road Detroit 34, Michigan
1 3	28-3-63 29-7-63	Mr. R. G. Buskin Wyandotte Chemicals Corporation 60 East 42nd Street New York, New York
1	5-4-63	Mr. Stanford Davis, Manager Urethane Division Wyandotte Chemicals Wyandotte, Michigan
1	5-4-63	Mr. Kurt C. Frisch, Director Polymer Research Research Division Wyandotte Chemicals Wyandotte, Michigan
1	8-4-63	Mr. Richard W. Johnston Technical Representative New Products Department Michigan Alkali Division Wyandotte Chemicals Corporation Wyandotte, Michigan

Copies	Date Sent	Recipient
1	5-4-63	Mr. Trix Wyandotte Chemicals Wyandotte, Michigan
1	28-7-63	Mr. Adli S. Yener, Architect 1343 North Woodward Birmingham, Michigan

WEBSTER GOLFLANDS, INC.
Route 1
Ann Arbor, Michigan

June 17, 1963

The Regents of The University of Michigan
The University of Michigan
Ann Arbor, Michigan

Gentlemen:

It has been brought to our attention that your Department of Architecture is conducting research on the structural use of plastics (ORA Project 05687) under sponsorship from the Agency for International Development (AID). It is our understanding that part of this work involves the investigation of new structural ideas, through the erection of full scale structures in collaboration with interested plastics companies.

It is further our understanding that the Dow Chemical Company has expressed willingness to contribute, if requested to do so by the University, the necessary materials, equipment and labor for the erection of an experimental shell-structure consisting of a "styrofoam" dome approximately 45 feet in diameter. The purpose of this experiment is to establish the actual erection cost of such structure in the field as well as to obtain other data for the purposes of project 05687. In this connection, we have been informed that project 05687 is also interested to obtain data from the actual use of this structure.

We would therefore like to request that our corporation be given the use of this experimental "styrofoam" shell for the purpose of housing a temporary golf club facility.

If permission to use this "styrofoam" shell is granted, Webster Golflands Inc. agrees:

1. To offer a site for the erection of the shell structure convenient for our purposes and acceptable to the University.

2. To complete the structure to obtain a workable clubhouse facility in accordance with plans and specifications acceptable to the University and to our corporation.

3. To assume the responsibility of contracting and paying for site preparation, excavations, foundations, floor slab, glazing, mechanical and electrical and plumbing installations, interior partitions, equipment and any other item required by us, except for the erection, cutting and coating of the "styrofoam" shell.

4. To release and hold harmless the University and the Dow Chemical Company from any liability for any damages which may result to our corporation or to any other person from the use of this structure.

5. To secure access to and entry of the structure to staff members from the University and the Dow Chemical Company as required for the purpose of obtaining test data.

6. To maintain the structure for at least two years from the date of its completion, unless it is damaged by the elements, or by factors beyond our control or permission to the contrary is obtained from the University.

The above is subject to the University's agreeing:

1. To make the necessary arrangements with the Dow Chemical Company for the erection of the "styrofoam" shell on our site.

2. To provide the necessary architectural assistance as well as supervision for erection and on-the-job direction when required.

If this proposal is acceptable to the University, conditional upon the willingness of the Dow Chemical Company to contribute the necessary materials, equipment, and labor, for the erection of the "styrofoam" shell, please signify your acceptance by having the attached copy of this letter signed by an authorized official of the University in the place indicated below.

Sincerely,

WEBSTER GOLFLANDS, INC

Accepted by the University:

W. K. Pierpont
Vice President

J. F. Clayton
Vice President

SCAP:JFC:rw:rt

Appendix C (interim report: March through June 1963, ORA project 05687)

June 19, 1963

Dr. D. H. Margon
College Relations
Dow Chemical Company
Midland, Michigan

Dear Dr. Margon:

Professor Paraskevopoulos has informed me of the willingness of your company to contribute materials to the University, and to supply us with the necessary equipment and labor for the erection of an experimental dome in connection with our plastics research program (ORA Project 05687).

This is to submit a request for the following materials, which I understand will be delivered to the erection site by Mr. D. R. Wright via Dow semi-trailer:

1. 18,624 board feet of fire retardant "styrofoam."
2. 30 gallons of red latex paint.
3. 20 gallons of white latex paint.
4. 40 gallons of #560 latex.
5. 20 bags of #4 vermiculite.
6. 3 cases of epoxy resin.
7. 50 yards of 3" fiberglas cloth.
8. 20 yards of 36" fiberglas cloth.
9. 125 feet "ethelfoam" tube 3" O.D. x 3/4" I.D.

With this opportunity we wish to express our sincere appreciation for the willingness of your company to contribute so generously towards the success of our research program.

Sincerely yours,

Robert E. Burroughs

REB:bw

Appendix D

interim report: March - June 1963
AID-sponsored ORA project 05687

ERECTION OF A PLASTIC DOME BY THE DOW "SPIRAL GENERATION" PROCESS

As a case-study under ORA project 05687, sponsored by the Agency for International Development, a styrofoam plastic dome has been erected on a site outside Ann Arbor and is now being used as a temporary clubhouse by Webster Golflands, Inc.

Preparation of the site for erection of the 45-foot diameter dome was started on Monday, 24 June, 1963. One-half day was required for unloading of equipment and assembling of a base ring. The site was leveled and a circular trench 40 inches deep and approximately 2 feet wide was dug prior to erection of the generating equipment. Actual generation of the styrofoam shell took twelve hours to complete. At intervals during the succeeding five days, the exterior of the shell was sealed with epoxy resin, sanded, painted and all cut lines were located. The dome was then lowered into the previously prepared trench.

Between 3 July and 15 July the interior rough carpentry work was accomplished. Structural mullions were installed along with the mechanical service facilities. During the period from 15 July to 25 July the interior of the shell was completed: leaks were sealed, all patched surfaces sanded, all cut edges reinforced, and the styrofoam ventilating monitor at the top of the structure was put in place.

The completed structure is shown in Figure 1.

The "Spiral Generation" Process

This system is based on the use of a specially designed machine which bends, places, and fastens pieces of prefoamed plastic together in a predetermined path to form an integral structure. Although so far the system has been utilized mostly for the generation of structural domes, a variety of shapes can be produced by modifying the layout or locus of points followed by the machine in its generating course.

The only power supply required is a single-phase 110 - 220 volt system. Depending upon the size of the structural shape to be generated, the weight and bulk of the equipment may vary; this, however, should not cause any difficulty in the machine's handling or in its portability.

The machine head is attached to the end of a lightweight structural boom which is secured to a mechanism which controls the machine's path and thus predetermines the shape of the structure. The machine-head end of the boom is supported on the structure as it is being generated and the balance of the boom's weight is taken by the centroid or pivot mechanism. As the generation begins, foamed material is placed in the machine head which then forms it and seals it into a rising structural spiral. The process is continued until the entire structure has been generated.

Materials

Although Styrofoam has been used to generate the structures currently in use use, other foams capable of being heat-sealed could be employed with only slight modification of the generating equipment.

The foam plastic used on the case-study dome was Styrofoam[1] FR. This particular formulation is flame retardant and specially formulated to meet the requirements of ASTM test D 1692-59T for self-extinguishing plastics (see engineering data presented in Table 1).

The advantages of this type of expanded polystyrene are its light weight, its resistance to water penetration and moisture vapor transmission, and its low thermal conductivity. It does not support mold growth and is not attractive to rodents. It can be easily handled and fabricated using standard hand and power woodworking tools. However, conventional methods of fastening, e.g., nailing or screwing, are usually inadequate. Heat-sealing methods or adhesives like epoxy prove to be more durable.

For use in the "Spiral Generation" system, the slab foam is cut into rectangular planks whose width depends on the thickness required for the generated structure. Usually the planks are 4 inches wide, 2 inches thick and 10 feet long (see Figure 2).

---

[1] Styrofoam is a Dow trademark for polystyrene, expanded approximately forty times into a rigid, closed cell foam having a density range of 1.8 to 4.5 pounds per cubic foot.

Since the Styrofoam density can be varied, the thickness of the generated structure can be made less if higher density foam is used; conversely, it must be increased if a lower density foam is used. These variables are dependent upon the specific use requirements of any particular structure.

The Clubhouse Structure

Webster Golflands presented the research project staff with a tentative list of facility requirements for a temporary type clubhouse. These requirements were studied and summarized as follows:

FACILITY	EQUIPMENT	AREA (approximate)
Clubroom	Furniture	650 sq. ft.
Kitchen	Range Dishwasher & sink Hot water heater Cabinet storage Beverage coolers	160 sq. ft.
Toilets		
Men	One WC One urinal One lavatory	40 sq. ft.
Women	Two WC One lavatory	40 sq. ft.
Circulation		400 sq. ft.
Pro shop	Display cases Counter	280 sq. ft.
Conference & Admin.	Furniture	300 sq. ft.
	Total	1870 sq. ft.

Using approximately 1900 sq. ft. as the required floor area, it was determined ($\pi r^2 = A$) that a structural dome would require a radius of 24.59 feet. However, by using part of the space in the upper portion of the dome for the conference and administration area, the radius could be reduced to 22.56 feet. A diameter of 45 feet was therefore established as not only adequate for the required facilities but also being well within the capability of the generating equipment.

Preliminary plans and sketches (see Plates 1 - 5) were developed by the research staff and subsequently discussed with representatives from Dow Chemical

Company. The resulting design proposal showed no unusual technical difficulties and was assumed to be entirely feasible.

Working drawings were then prepared. The required materials were calculated and requested from Dow Chemical.

Clubhouse Construction

On 24 June, three workmen under the supervision of Donald Wright arrived from Dow Chemical Company to begin erection of the case-study dome. All preparatory work such as grading, leveling and trenching had been accomplished by the General Contractor prior to their arrival.

The Dow crew transported all equipment in a single tractor-trailer truck. This equipment was unloaded at the site. First step was assembling the base ring. Pieces of 3" x 3" x 1/4" angle iron, pre-rolled to the diameter of the dome, were bolted together with splice plates to assure continuity. This ring was then placed over the trench and supported on 2" x 4" wood blocks spaced approximately 4 feet apart (see Figure 3).

After the base ring had been positioned, the generating equipment was erected and a starter strip was applied. Generation of the dome required only twelve hours after the equipment had been set up.

Following the generation process, the dome was lowered into the trench by hand. This operation required thirty persons, each supporting a 60-pound load on ropes connected to the base ring (see Figure 4).

After the dome had been lowered and the trench back-filled, all openings were marked, cut, and reinforced with fiberglass and epoxy. Cutting was accomplished with an electric saber saw. Any discernible voids in the vertical joints between the plastic planks were closed by applying a mixture of epoxy resins and ground glass.

Construction of the interior partitions and floor slab were begun while the dome shell was being prepared for exterior painting. Construction of the ventilating monitor was also started.

The dome interior was painted prior to the finish carpentry work. Plumbing and electrical services had been installed before the concrete floor slab was poured.

The completed ventilating monitor was then lifted to the top of the dome and fastened in place with epoxy resin.

Glass for the exterior walls was cut and placed in the mullions. A

flexible polyethylene foam gasket was developed by the project staff for the mullions (see Plate 5).

Preliminary Cost Evaluation

The following calculations are based entirely on data obtained from a single case-study involving the erection of a 45' diameter plastic dome. As in all evaluations, certain variables are present. The most pronounced variable is the current stage of machine development. The amount of hand labor required for the patching of vertical joints has the apparent effect of increasing the unit price when related to the unit price of materials. Another variable present but not of major significance is the possible use of additional coatings.

Table 2 sets forth the number of man-hours required for various operations in the erection of the dome. Finishing involved patching the vertical joints, attaching epoxy strips, and the like.

The hourly rate per worker was computed at $6.40. This rate is based on an hourly rate of $5.00 plus $15.00 per day travel expenses. Applying this rate, a labor cost per operation results as shown in Table 2.

With a projected floor area of 1600 square feet, this yields a total unit labor cost of $1.304 per square foot.

Table 3 provides a cumulative list of materials and their respective prices.

A total materials cost of $2274.50 yields a unit material cost of $1.421 per square foot.

Adding both the unit labor cost and the unit material cost, the total unit cost thus becomes $2.725 a square foot. It should be noted that this figure includes only the dome shell, its coatings and pigmentation, and openings. It does not include the cost of the interior partitions, glass, floor slab or trench.

General Comments

It is apparent that the Dow "Spiral Generation" Process is unique not only in concept but in its versatility. It derives its principal advantages from a well-integrated use of relatively simplified equipment and the economic use of materials. It affords a continuous system of rapid erection and produces a structure which enjoys a high strength to weight ratio.

Its versatility is inherent in the system and the machinery. It is possible to produce structures varying in size with only slight modification of

equipment. The number of workers required would in all probability not be increased when making larger structures, and there would be little if any change required in the basic power supply.

The development of the outside shell, which is highly sophisticated, seems to suffer when conventional building methods are used to complete the interior partitions and enclosing members which are not part of the shell itself. Although this problem does exist, it is not insurmountable. Its solution lies, in part, in re-evaluating the use of conventional materials and their traditional methods of installation.

The actual generation of the shell structure is accomplished in a relatively short time as compared to conventional construction. The large amount of hand labor required in finishing the shell means that the advantage of rapid erection is lost.

There are additional problems which merit further consideration. These problems lie essentially in two categories, one being related to machine development and the other to the complexities inherent in hemispherical shapes.

The systematic problems incurred by the current stage of machine development arise out of the shipment of relatively large volumes of very light-weight materials to the construction site. It would be more advantageous to ship smaller volumes of a more dense material to the site and then expand these supplies at the time of construction. Expansion during generation could be accomplished by modifications which would allow unexpanded material to be introduced directly at the machine head and then be expanded in place. On the other hand, in very large projects where great volumes of foamed material are required, it may become feasible to establish a slab stock plant at the site from which required planks could be obtained and utilized by existing equipment.

Current machine development requires one man to be constantly feeding expanded foam at the machine head while another worker supplies him from a stock pile nearby. These man hours could be substantially reduced by introducing mechanized equipment to do the same tasks. Labor time could also be saved by providing some method as mentioned above; i.e., by feeding the machine with unexpanded foam materials or by supplying a continuous strip of expanded foam.

A continuous system presumably could be achieved by connecting pieces of prefoamed planks prior to introduction at the generating machine.

By referring to Table 2, man-hour requirements related to finishing techniques become evident. Over 80% of the total man hours are utilized for

plugging and sanding vertical joints, painting, and applying interior finishing materials. At present, these operations are accomplished by conventional methods. By using pre-foamed polystyrene in a continuous strip or as a number of strips mechanically sealed, the need to repair vertical joints would virtually be eliminated. Using a plank with twice the present length means that the number of vertical joints could be reduced 50%, thus affording a corresponding reduction in hand labor.

Although the system used for painting is unique, some improvements in distribution would be desirable. Such systems could utilize either an independent spray system or a helical brush rather than the "squeegee" currently being used. These devices may also be incorporated in the generating head which would then provide a continuous process for finish applications. Incorporation of coating equipment would eliminate the need for separate covering and plugging which are the basic causes for the disproportionate amounts of hand labor. Further reductions in sanding and painting could also be achieved by a different choice of coating mediums.

Since completion of the case-study dome, Mr. Wright of Dow Chemical has been experimenting with an asphaltic coating which may be applied by an independent spray and covered with stone chips. It is expected that this new application will be approximately one fourth the cost of the earlier coatings. This coupled with machine refinements reducing hand operations would effectively lower the unit cost to approximately $1.90 per square foot. (This figure is based on elimination of base ring, substitution of asphaltic coating for latex and paint, and 50% of the epoxy used; reduction in labor is assumed to be 50% of the finishing operation in Table 2.)

When such refinements are made the system will be a unique, rapid system for the building of structures of varying magnitude. The system is a revolutionary approach in the building industry.

Table 1. ENGINEERING DATA RELATING TO STYROFOAM FR

	ASTM Test Method	Styrofoam FR
Physical Properties		
Density (lb./cu.ft.) average	-----	1.9
Compressive yield strength (psi) average (at deflection of 5%)	D1621-59T	30.0
Water Resistance Properties		
Water absorption, % by volume	C-272-53	0.25
Water absorption (after submersion under 10 ft. head for 48 hours; lbs./sq.ft. of surface area)	-----	0.08
Water vapor transmission, per-inch	E96-53T (Procedure E)	2.0
Capillarity	-----	none
Thermal Properties		
Burning characteristics	D1692-59T	SE[1] *
Linear thermal coefficient of expansion (in./in./°F.) between 0°F. and 80°F	-----	0.00004
Thermal conductivity (BTU-in./sq.ft.-hr.-°F.)		
mean temp. 70°F., average	-----	0.26
mean temp. 40°F., average	-----	0.24
Heat distortion temperature (maximum for continuous use), °F.	-----	170.0

* Resistance to accidental ignition: From welding sparks, thrown matches, and other small-scale fire sources. ASTM D1692-59T. Self-extinguishing.

Table 2. LABOR COSTS FOR THE SPIRALLY GENERATED DOW PLASTIC DOME

	Man-Hours	Percentage	Labor Cost (@ $6.40/hr.)
Preparation	24	7	$ 153.60
Generation	36	11	230.40
Finishing	266	82	1702.40
Total	326	100	$2086.40

Table 3. MATERIALS COSTS FOR THE SPIRALLY GENERATED DOW PLASTIC DOME

Materials	Cost
12,720 Board Feet Styrofoam FR 2" x 4" x 9' - 11/7¢/bd. ft.	$1488.24
30 Gallons Latex Paint (Red) - $5.00/gallon	150.00
20 Gallons Latex Paint (White) - $5.00/gallon	100.00
40 Gallons Dow No. 560 Latex - $5.18	207.00
20 Bags No. 4 Vermiculite - $3.00/bag	60.00
36 Quarts of Dow DER No. 331 Resin with hardener - $2.66/qt.	95.76
50 Yards 3" wide Glasscloth - $8.00/roll	8.00
20 Yards 36" wide Glasscloth - $ .40/yd.	8.00
125' 3" diameter Ethafoam - $ .06/ft.	7.50
3 x 3 x 1/4 angle iron base ring	150.00
Total Cost	$2274.50

DOW
"SPIRAL-GENERATED"
PLASTIC DOME

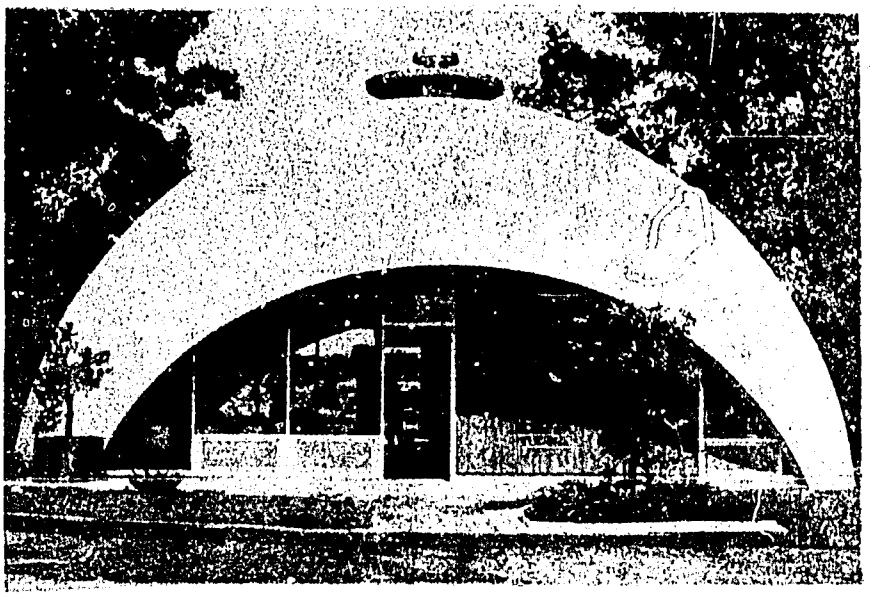


Figure 1

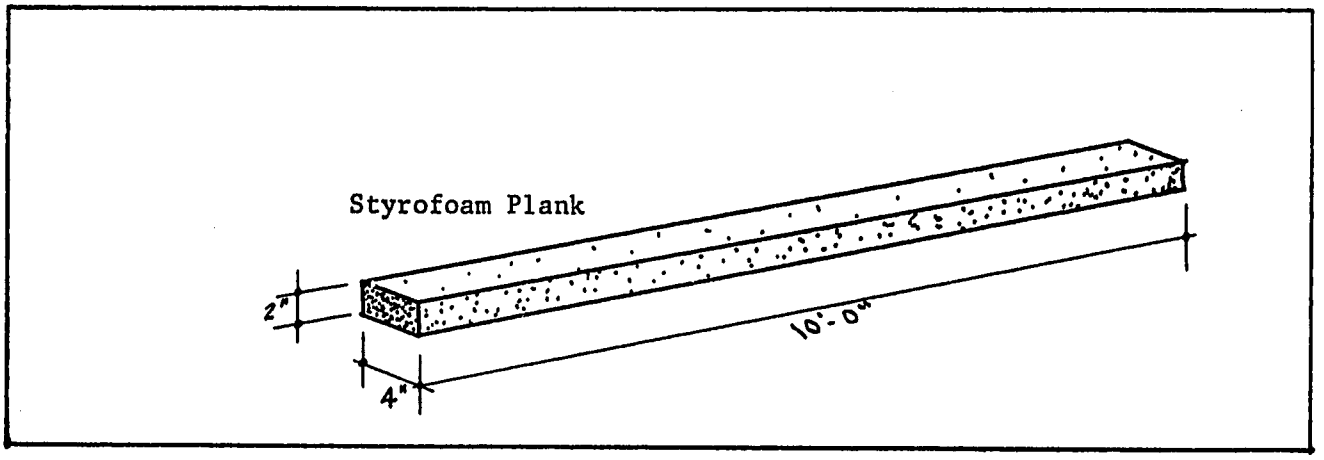


Figure 2

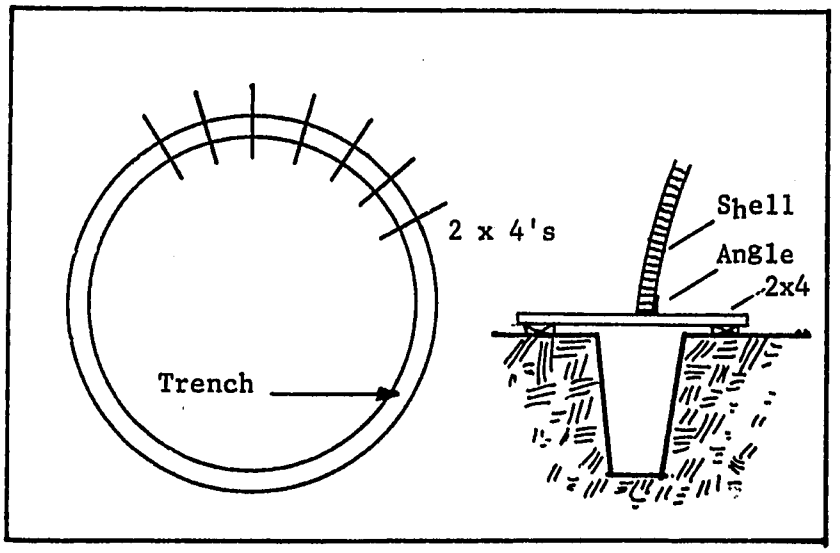


Figure 3

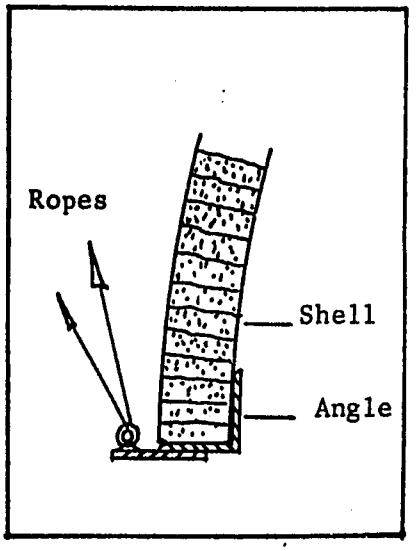


Figure 4

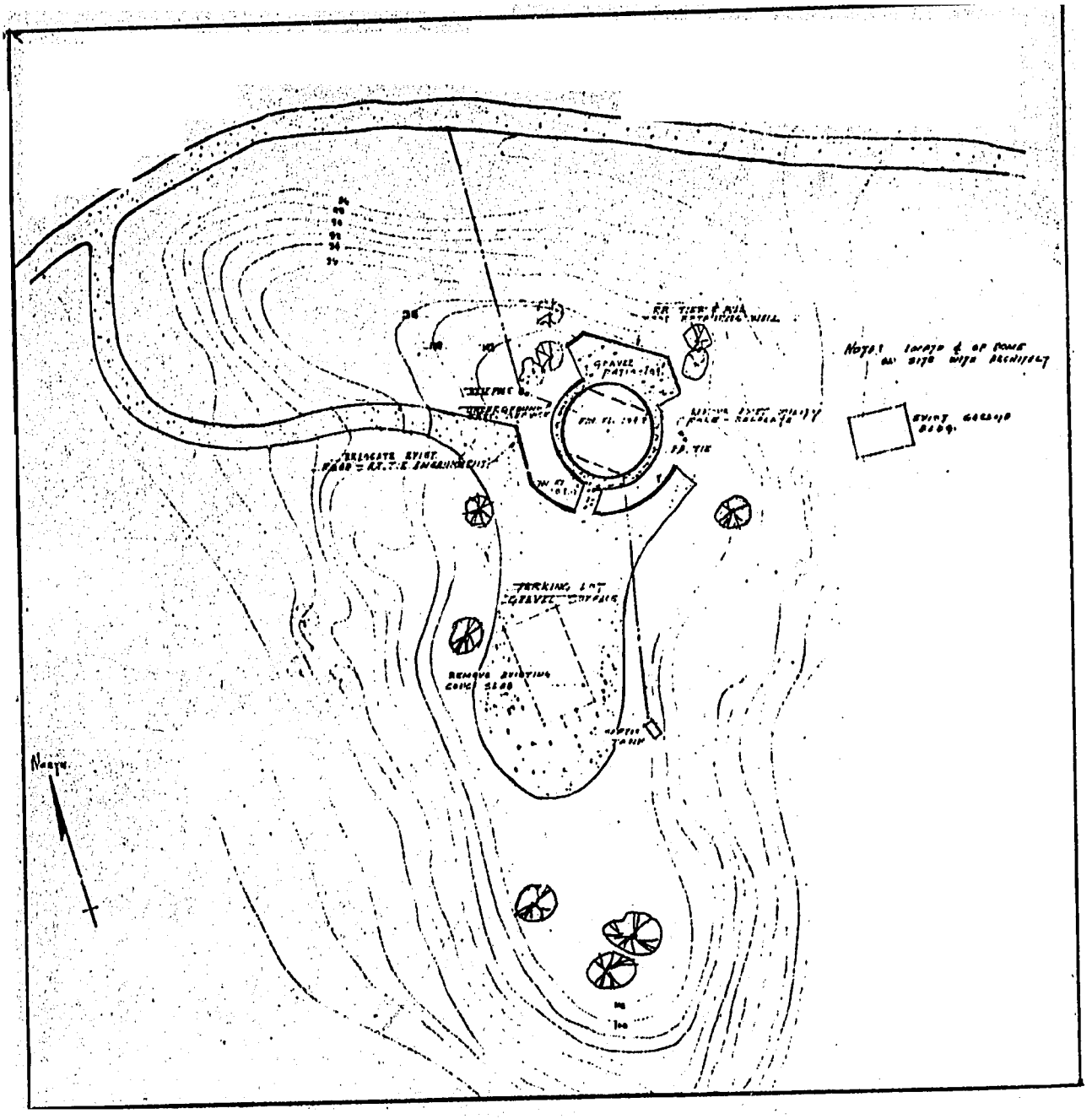


Plate 1

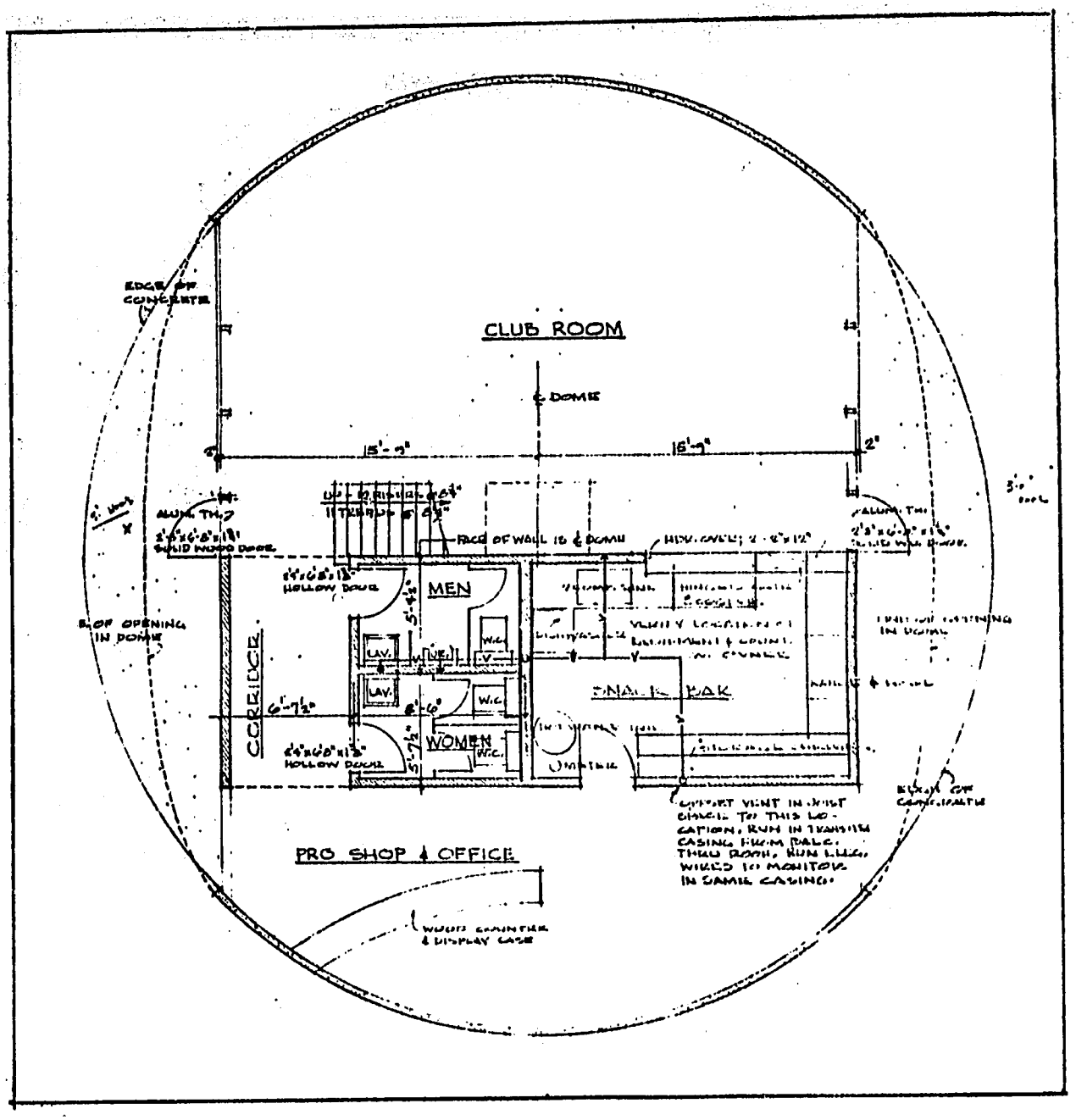
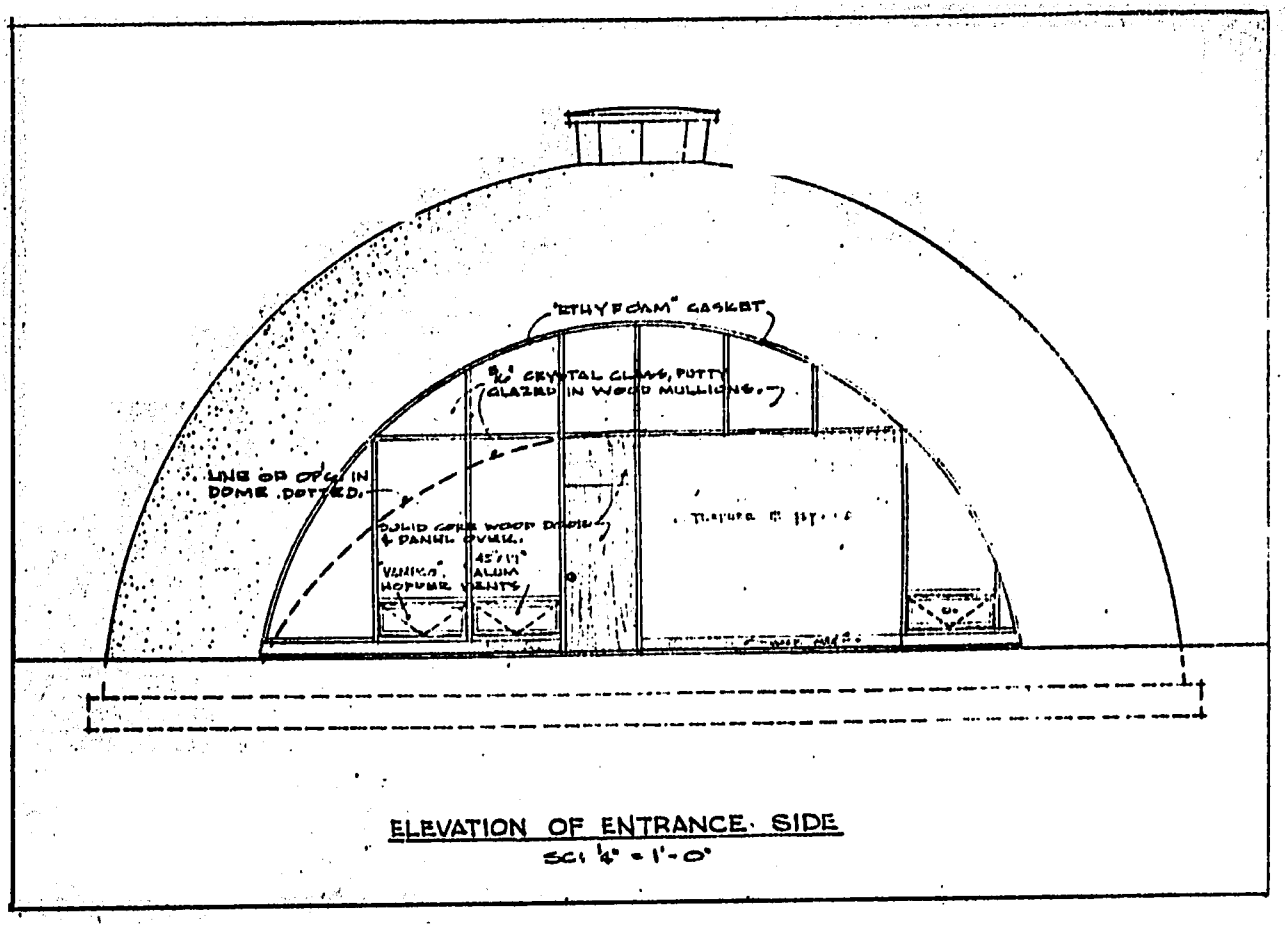
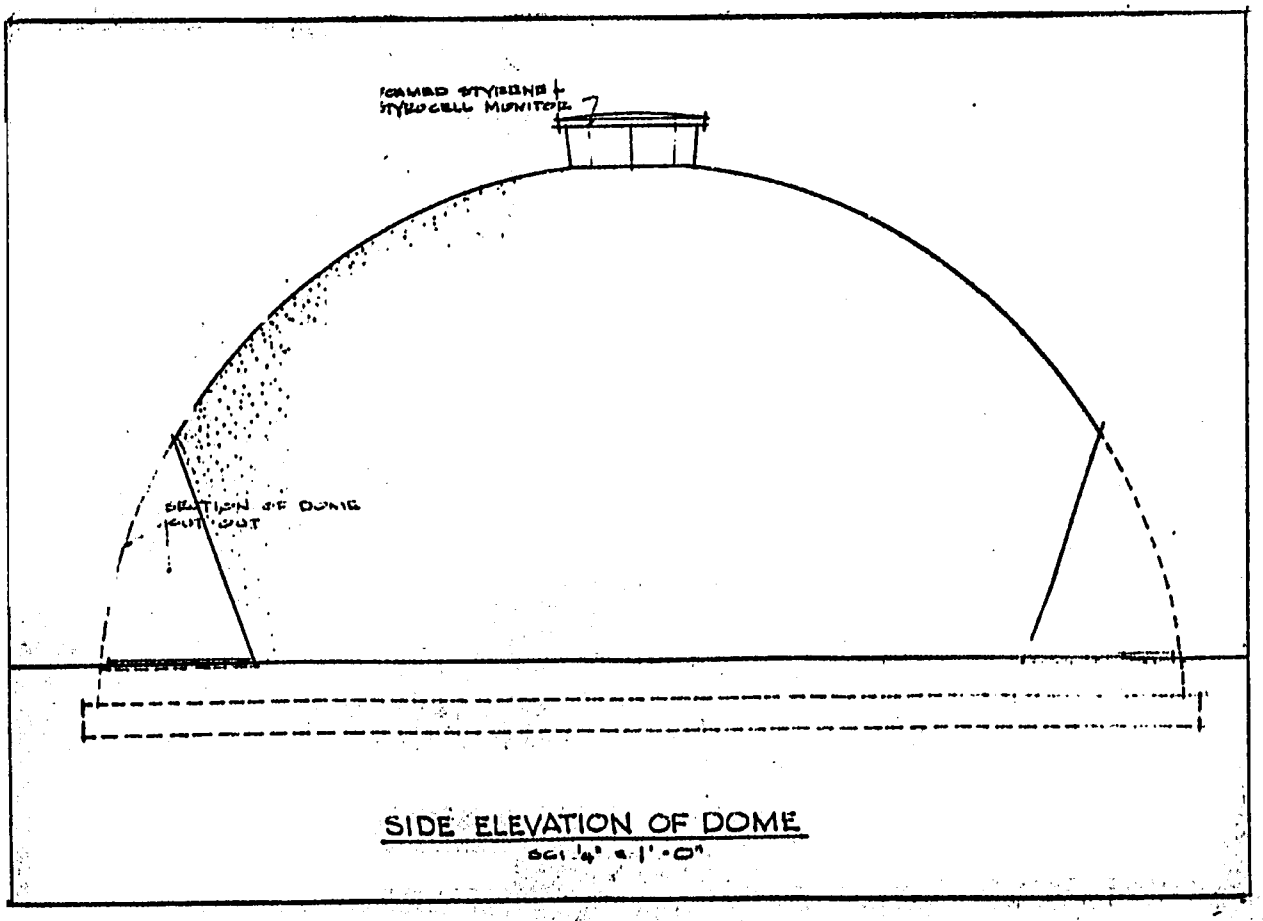

CLUB ROOM
℄ DOME
15'-9"
15'-9"
2"
EDGE OF CONCRETE
FACE OF WALL IS ℄ DOME
MEN
WOMEN
CORRIDOR
LAV.
W.C.
SNACK BAR
PRO SHOP & OFFICE
WOOD COUNTER & DISPLAY CASE
OFFSET VENT IN JOIST SPACE TO THIS LOCATION, RUN IN TRANSITE CASING FROM BALC. THRU ROOM, RUN ELEC. WIRES TO MONITOR IN SAME CASING.

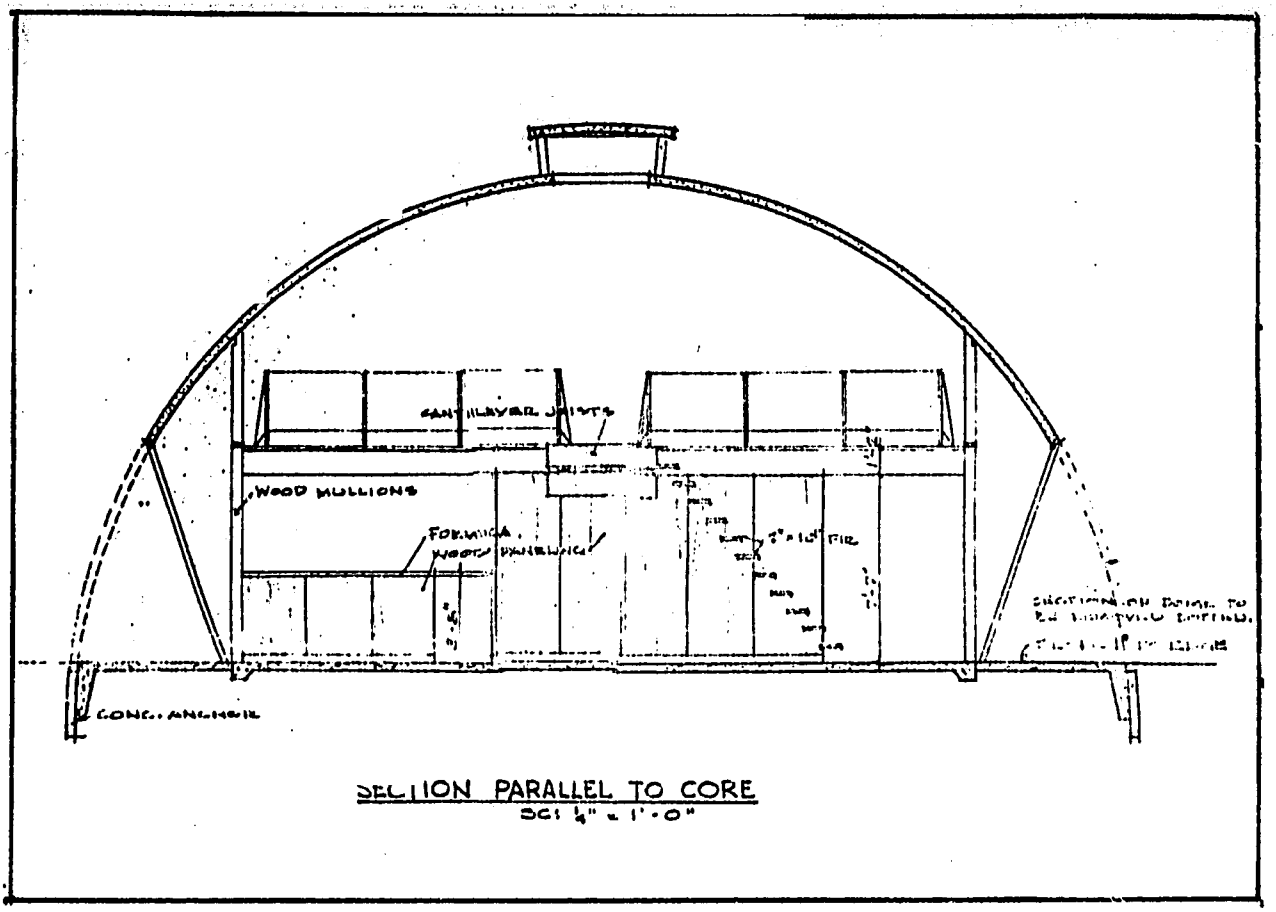
Plate 2



ELEVATION OF ENTRANCE SIDE
SCL ¼" = 1'-0"



SIDE ELEVATION OF DOME
SCL ¼" = 1'-0"


CANTILEVER JOISTS
WOOD MULLIONS
FORMICA
CONC. ANCHOR
SECTION PARALLEL TO CORE
SCL ¼" = 1'-0"

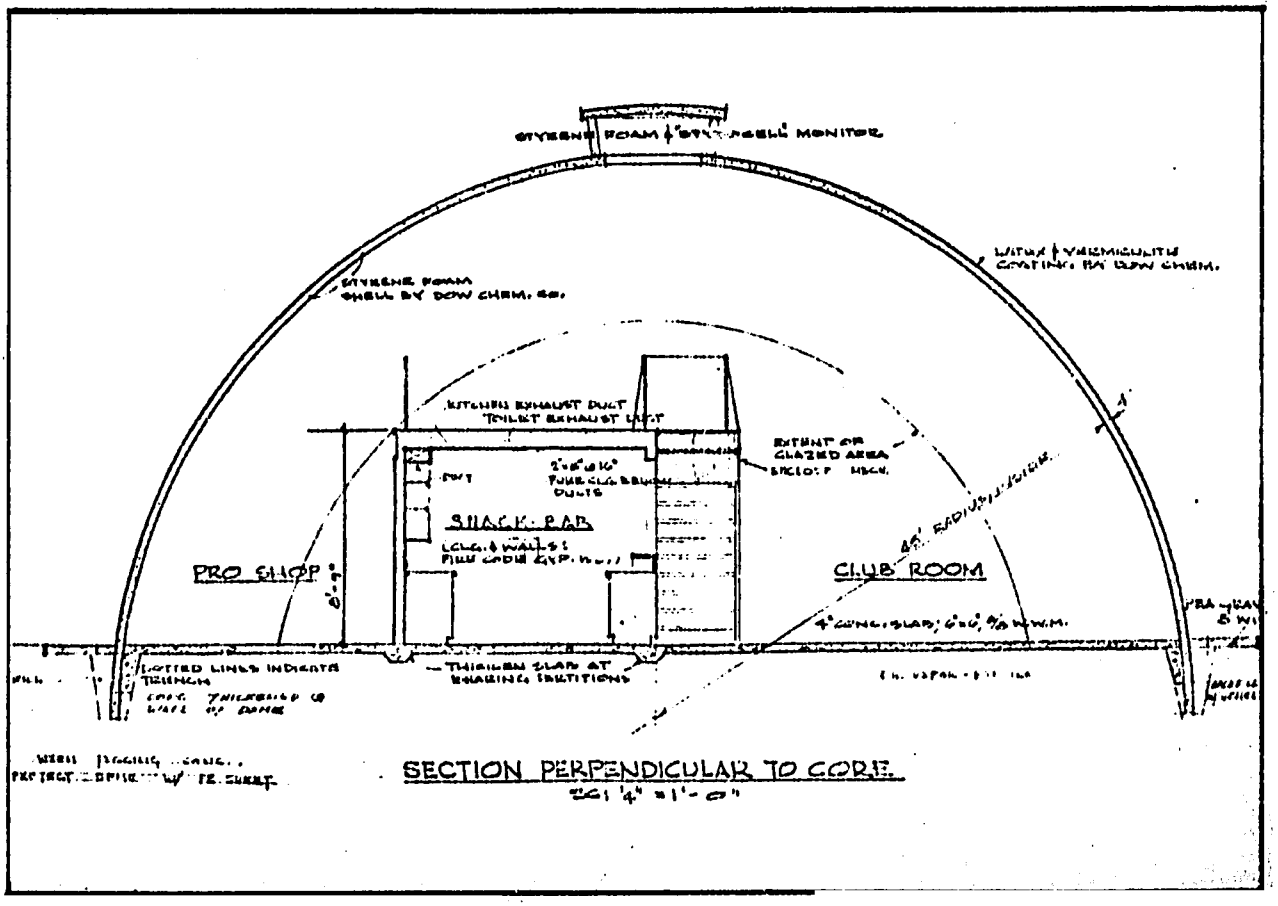

STYRENE FOAM
SHELL BY DOW CHEM. CO.
KITCHEN EXHAUST DUCT
TOILET EXHAUST DUCT
EXTENT OF GLAZED AREA
SHACK BAR
PRO SHOP
CLUB ROOM
DOTTED LINES INDICATE TRENCH
THICKEN SLAB AT BEARING PARTITIONS
SECTION PERPENDICULAR TO CORE
SCL ¼" = 1'-0"

Plate 4

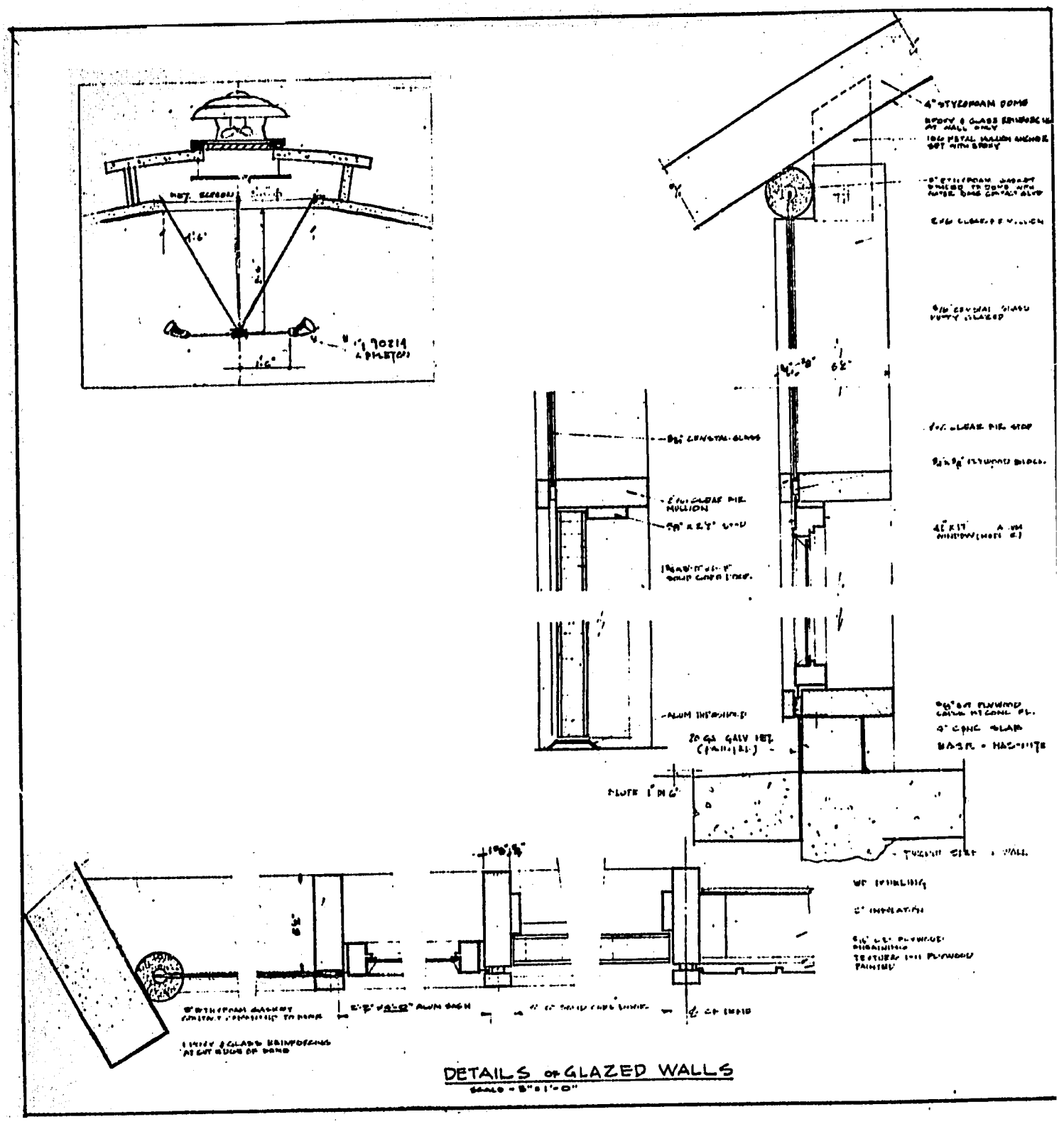


Plate 5

Appendix E

interim report: March - June 1963
AID-sponsored ORA project 05687

EVALUATION OF URETHANE FOAM SYSTEM UTILIZING VARIOUS KINDS OF FILLERS AS DEVELOPED BY DELKA RESEARCH CORPORATION, HAWTHORNE, NEW JERSEY

According to the producer, this system derives its unique properties and cost advantage from its formulation, which is based on the use of an inexpensive oil and other factors as one side of a two-part system. On the other side of the system is a crude isocyanate (MR) partially reacted with a proprietary liquid resin manufactured from polyethylene waste. Advantages claimed for the system: (1) reduced toxicity; (2) lower cost; (3) increased reactivity, such that fillers may be introduced chemically into the system, providing higher density and greater strength at lower cost.

The purpose of the project's investigation of this system was two-fold: first, and primarily, to evaluate the claims made by the manufacturer, and to determine appropriate uses for the material within the scope of the AID-sponsored project; secondly, to gain experience and insight into the uses and limitations of liquid component foams in general.

In evaluating the claims made by the manufacturer for this system, it was the opinion of the project staff that the most significant advantage claimed is the possibility of combining a foam with fillers of various sorts and thus improving its mechanical properties (see pp. 3.13 - 3.15, ORA Research Report for Project 05215). Work with this system was therefore oriented toward an exploration of the effect of fillers on the compressive strength of foam at varying densities. Other factors being equal, the cost of a structure and the compressive strength of the material used are highly correlative, cost being inversely proportional to strength.

Description of System

The material tested is a two-part, CO_2-blown foam system, described as series "22." Part "A" of the system is a dark brown liquid with a slightly

acrid odor. It is water-miscible, and has a density of 1.24 gm/cc. Part "B" is a dark brown liquid with a distinct oily odor. It is not water-miscible, and has a density of .97 gm/cc. The components of the system are mixed one part "A" to one part "B" by weight, with varying proportions of water to achieve a range of foam density from .86 gm/cc (components dried in silica gel; hand mixed) to .04 gm/cc (5% H_2O by weight; undried components; beater mixed). Water in excess of 5% by weight has no appreciable effect on foam density. However, some rupturing of cell walls and collapse of structure was evident even at the 5% level.

Preliminary Investigation

A variety of fillers was added to the basic foam system in order to determine by visual inspection and approximate methods what types of fillers might warrant further study. The performance criteria used at this stage were as follows: (1) there should be as little effect on cell structure (size, uniformity) as possible; (2) friability should not be markedly different from unfilled samples; (3) apparent compressive strength should not be less than that of unfilled samples of equal density; (4) handling characteristics should be such that machine methods would be possible.

As a result of this initial study, two fillers were selected for more sophisticated testing. These consisted of finely divided phenolic powder, and finely divided red clay. (Of these two, the clay had the least apparent effect on rise, cell structure, strength, and consistency.) Because of the sensitivity of MR to water in this system, it was necessary to dry all fillers thoroughly before adding to the liquid components. Throughout the period of investigation, control of moisture was a problem, the principal sources of "accidental" moisture being the atmosphere, the "B" component of the system which varied appreciably from one container to the next, and the fillers used. The presence of unpredictable quantities of water available to the reaction made density control difficult.

Test Procedure

The testing machine used to perform the compression tests was an "INSTRON" with a C-D compression cell of 10,000 lb. capacity. Crosshead speed was set at .2"/min. with chart speed at 1"/min. Full scale readings of 200#, 500#, 1000#, 2000#, 5000#, and 10,000# were available. Height of samples was measured initially, and a rough approximation of deformation can be obtained from the load curves.

Preparation of Samples

Samples were prepared for testing by using a triple beam balance for the weighing of components, a graduated syringe for the addition of water, and an air-driven beater for mixing. The foam was permitted to rise and cure in the cup before cylinders were cut. To cut the cylinders, a hole saw was used in a drill press, which resulted in uniform cylinders with no surface "skin" effect and minimal changes in cross section or density. The ends of the cylinders were squared by machine sanding in a jig. Prior to testing, the dimensions and weights of each cylinder were checked, and the volume and density of each computed (see Attachment A). Cylinders were cut from the top of the rise in each case, and a subsequent check revealed no significant variation in properties between bottom and top of rise.

Description of Test Results

Results of compression testing of the prepared test cylinders will be found in Attachment C. The values tabulated in Attachment A as safe compressive strength are the maximum load sustained per square inch of area within the linear portion of the load test curve (see Figure 1, Attachment B). On the average, this value is approximately 65% of the load sustained at apparent failure. Cycling of samples to this load produces congruent load curves with no evidence of cumulative deformation (see Figure 2, Attachment B).

Interpretation of Test Results

When the value for safe compressive strength is plotted against density for each sample, a direct, exponential relationship of the type $S = A(D)^C$ is observed, where S is the safe compressive strength, A and C are independent variables dependent on the material tested, and D is the density (see p. 4.4 of ORA Research Project 05215 report). This relationship is true of the filled as well as the unfilled samples, although, as would be expected, the constants are changed considerably. The curves computed from the plots are as follows:

Unfilled foams; $S = 1.040(D)^{2.177}$

Phenolic - filled foams; $S = 1.084(D)^{1.923}$

Clay - filled foams; $S = .0147(d)^{3.157}$

It is apparent that the filled urethane foams tested have less capacity to resist compression stress than the unfilled foams of equal density.

(See Attachment C for load test curves comparing filled and unfilled samples.)

It can also be shown that the cost of materials in a cylinder of a given height, designed to support a given load, is higher when filler is used than when filler is not used. Reason: reduction in foam volume with filler is far greater, proportionally, than the increase in stress capacity caused by the increase in density. Even the addition of clay, which does not seem to affect rise to an appreciable degree, produces such a great loss in stress-carrying capacity that it can be considered an uneconomical filler.

Fillers

The use of fillers to increase the stress-carrying capacity and improve the mechanical properties of Delka Research Corporation's urethane foams does not show great promise of success. The preliminary investigations made, and the actual tests performed indicate that such factors as filler particle size and quality, absolute filler density and moisture content have much more effect on foam properties than do any intrinsic characteristics of the filler itself. It is reasonable to assume that other fillers than those tested will have similar effects on mechanical properties, and that in respect to stress-carrying capacity and cost, the effect will be negative. From a structural point of view, the use of fillers should be approached with caution: when pigments and the like are introduced into a urethane foam, it will more than likely be necessary to use a higher density material in order to sustain the structure. In the case of pigments, the oost of the structure will undoubtedly be higher, and it is quite likely that a coating will provide color at less cost than integral pigment.

Toxicity

The experience of the project staff is insufficient to indicate the extent of long-range or cumulative physiological effects of Delka Research Corporation's urethane formulation. During the three-month period of investigation no special precautions were taken to avoid contact with the materials or inhalation of fumes, and no toxic reactions were experienced by any member of the project staff. The materials (particularly the isocyanate component) are slightly staining to the skin. Normal protective clothing, i.e., lab coats and rubber gloves, are advisable to prevent this. The polymerization reaction of the materials is highly exothermic, particularly when water is used as a blowing agent; some provision

for fire extinction should be maintained in the vicinity of experiment.

Evaluation of Cost

The cost of urethane foam is normally compared on a per pound or a per board foot basis at equal density and equal insulating value (K factor). If one is primarily interested in these materials as insulating board, this is a reasonable basis for comparison. However, the assumption of this project has been that structural performance is of more importance than insulating value for most applications. Therefore, in evaluating costs, it has been necessary to compare the cost of materials of equal strength rather than equal density.

On this basis, and using cost data supplied by the manufacturer, Delka Research Corporation urethane foam at a density of 15 lbs./cu.ft. compares favorably with more conventional freon blown foams at a density of 9 lbs./cu.ft. The load capacity of both is in the area of 350 psi. The Delka foam shows a slight cost advantage at this density - $3.75/cu.ft. as opposed to $4.05/cu.ft. for the freon blown urethanes.

Summary of Conclusions

While the development of this particular urethane by Delka Research Corporation is not seen as a major breakthrough in the area of application to structures, nevertheless it offers a slight cost advantage and considerable ease of handling. Although dimensional change was not investigated, the water-blown Delka foams appear to be quite stable, and notably free from "cure shrinkage." The formula is definitely not more amenable to the use of fillers than are other types of urethane foam, but the ease of adjusting density within a rather large range is a significant advantage.

Attachment A: SUMMARY OF RESULTS OF COMPRESSION TESTING OF URETHANE-POLYETHYLENE FOAM SAMPLES PREPARED FROM DELKA RESEARCH CORPORATION COMPONENT SYSTEM.

Sample No.	Height (c)	Volume (cc)	Weight (gm)	Density gm/cc	Density lbs/cu	Safe Compressive Stress (psi)
13	2.45	18.5	10.10	.546	34.0	830
14	2.33	17.6	5.60	.318	19.8	372
15	2.41	18.2	4.42	.243	15.1	208
16	2.40	18.1	3.55	.196	12.2	133
17	2.14	16.2	2.60	.160	10.0	75
18	2.41	18.2	3.00	.165	10.3	93
19	2.22	16.8	1.80	.107	6.8	55
27	2.64	20.0	7.85	.392	24.5	1060
28-2	2.47	18.6	5.15	.276	17.3	504
29	2.56	19.3	5.90	.306	19.1	675
29-2	2.37	17.9	4.42	.246	15.4	410
30	2.53	19.1	4.05	.212	13.2	233
31	2.63	19.8	2.00	.108	6.8	56
32	2.35	17.7	1.20	.068	4.3	34
40	1.60	12.1	4.81	.398	24.8	342
41	2.42	18.3	5.05	.276	17.2	128
42	2.43	17.7	3.70	.209	13.0	51
43	2.50	18.9	3.80	.201	12.5	34
44	2.14	16.2	2.92	.180	11.2	30
45	2.20	16.6	2.48	.149	9.3	17

Attachment B TYPICAL FORM OF LOAD TEST CURVES

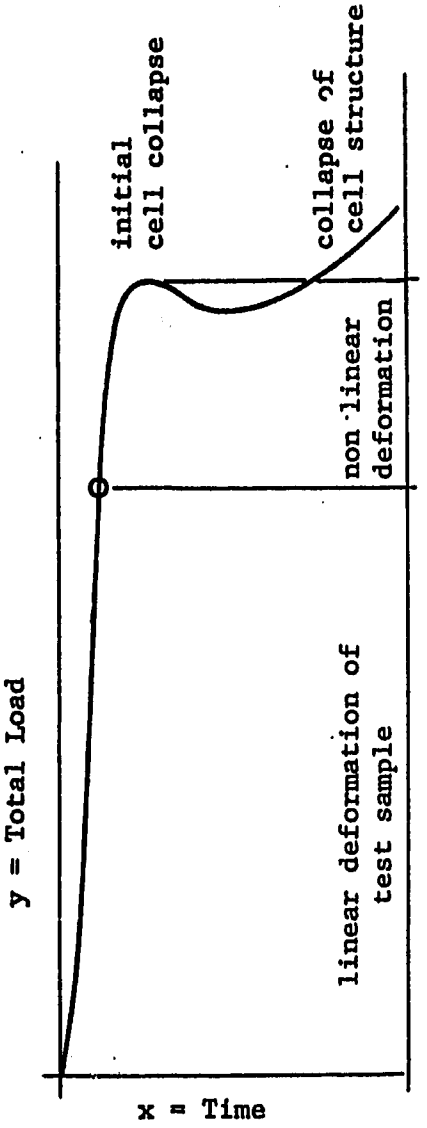


FIGURE 1: Characteristic Loal Test Curve

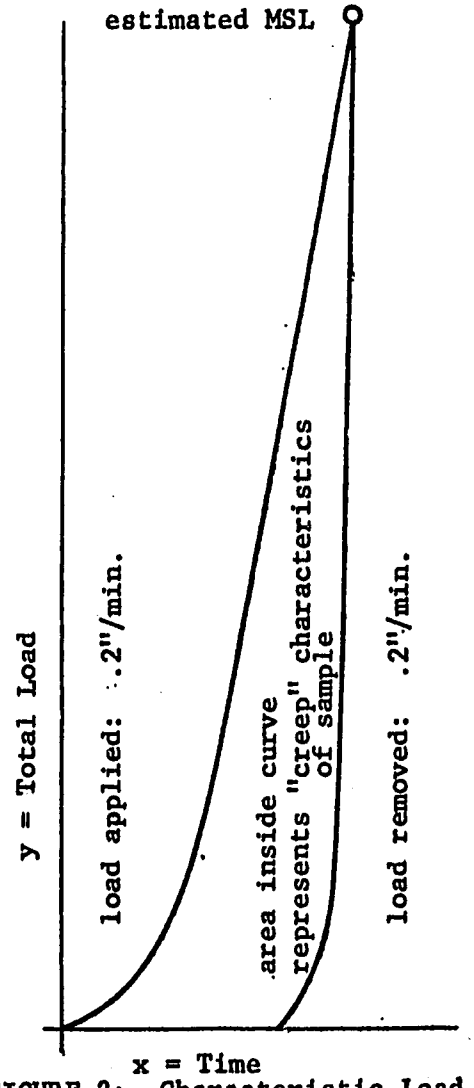


FIGURE 2: Characteristic Load Cycle Curve (three cycles typical)

Attachment C LOAD/TIME CURVES OF TEST SAMPLES
DELKA RESEARCH CORPORATION URETHANE FOAM SYSTEM

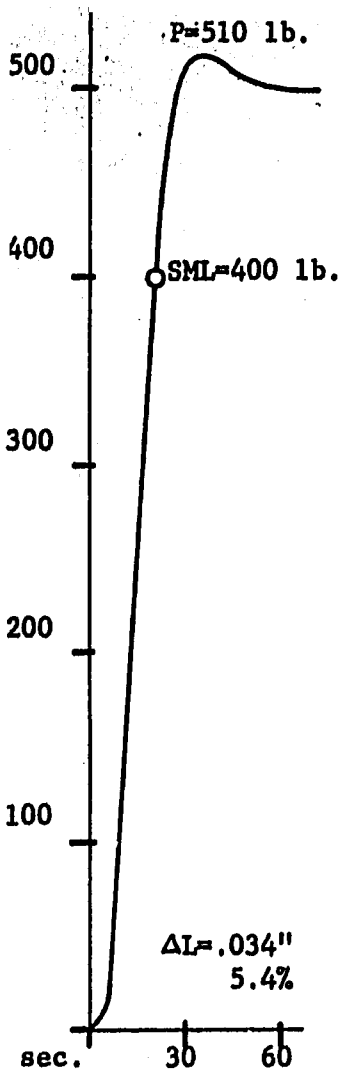
Key: P - total load at apparent failure

SML - safe maximum load (upper limit of linear portion of curve)

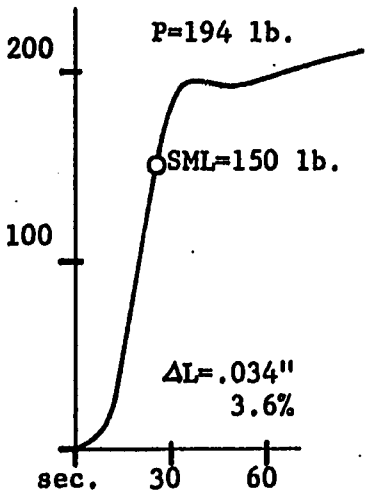
L - approximate deformation at SML

LOAD CURVES: RED CLAY FILLER
May 28, 1963

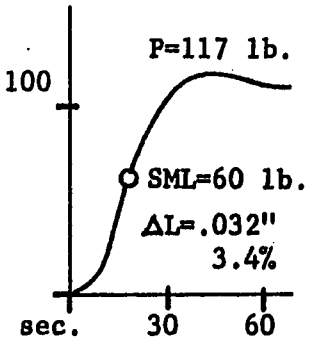
Total Load (pounds) Load Rate: .2"/min.



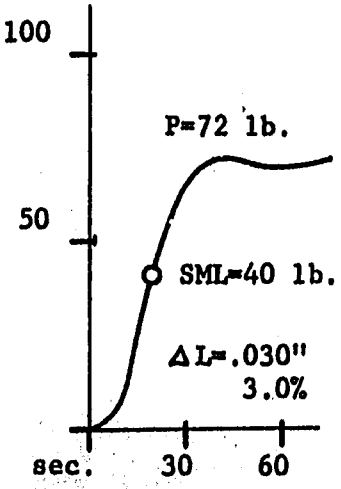
Sample No. 40



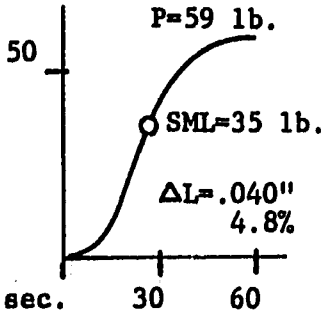
Sample No. 41



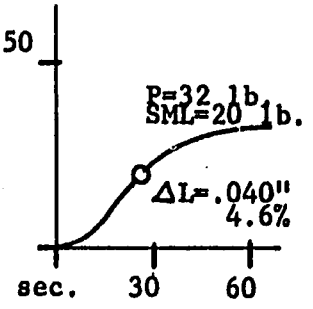
Sample No. 42



Sample No. 43



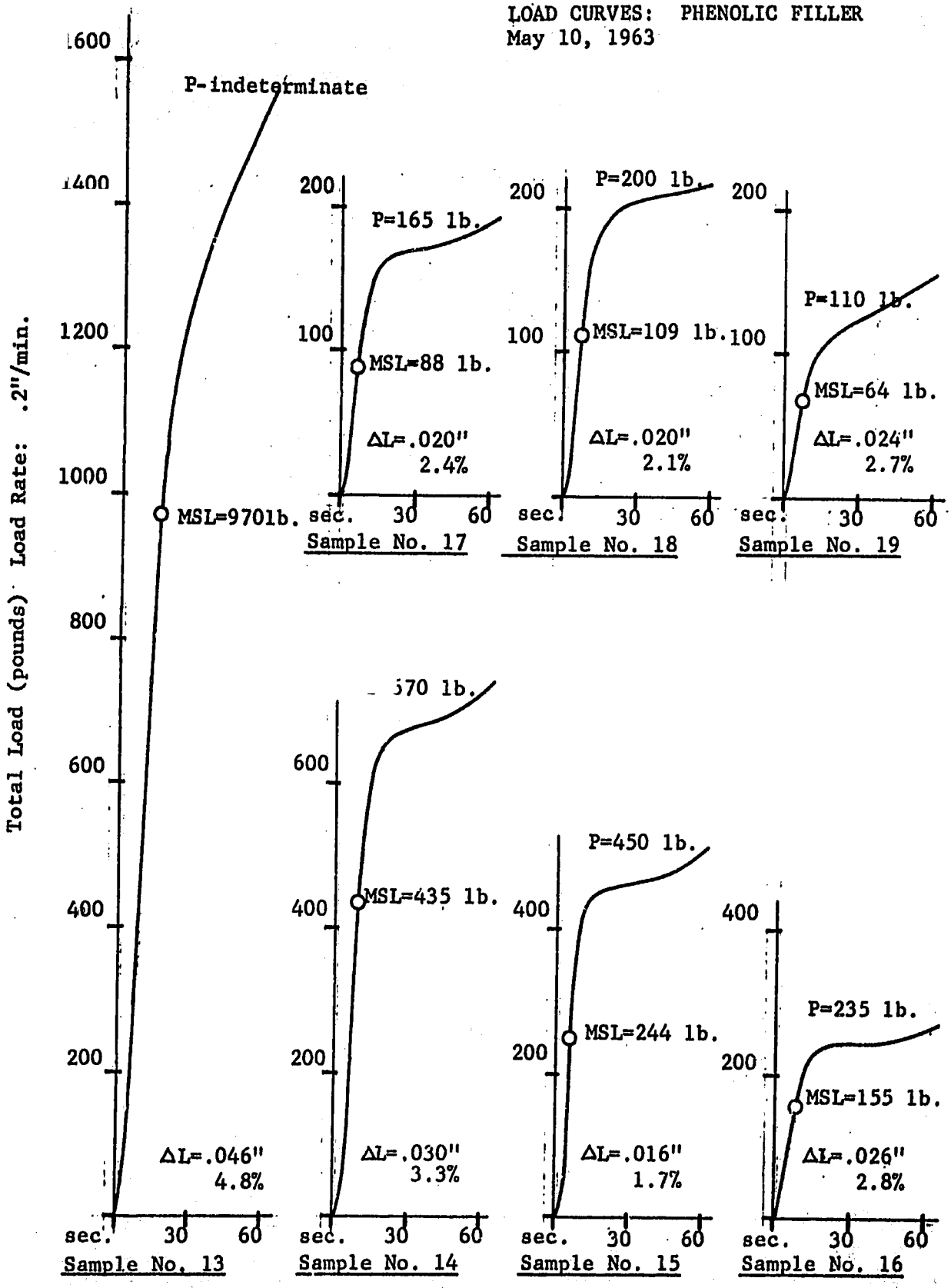
Sample No. 44



Sample No. 45

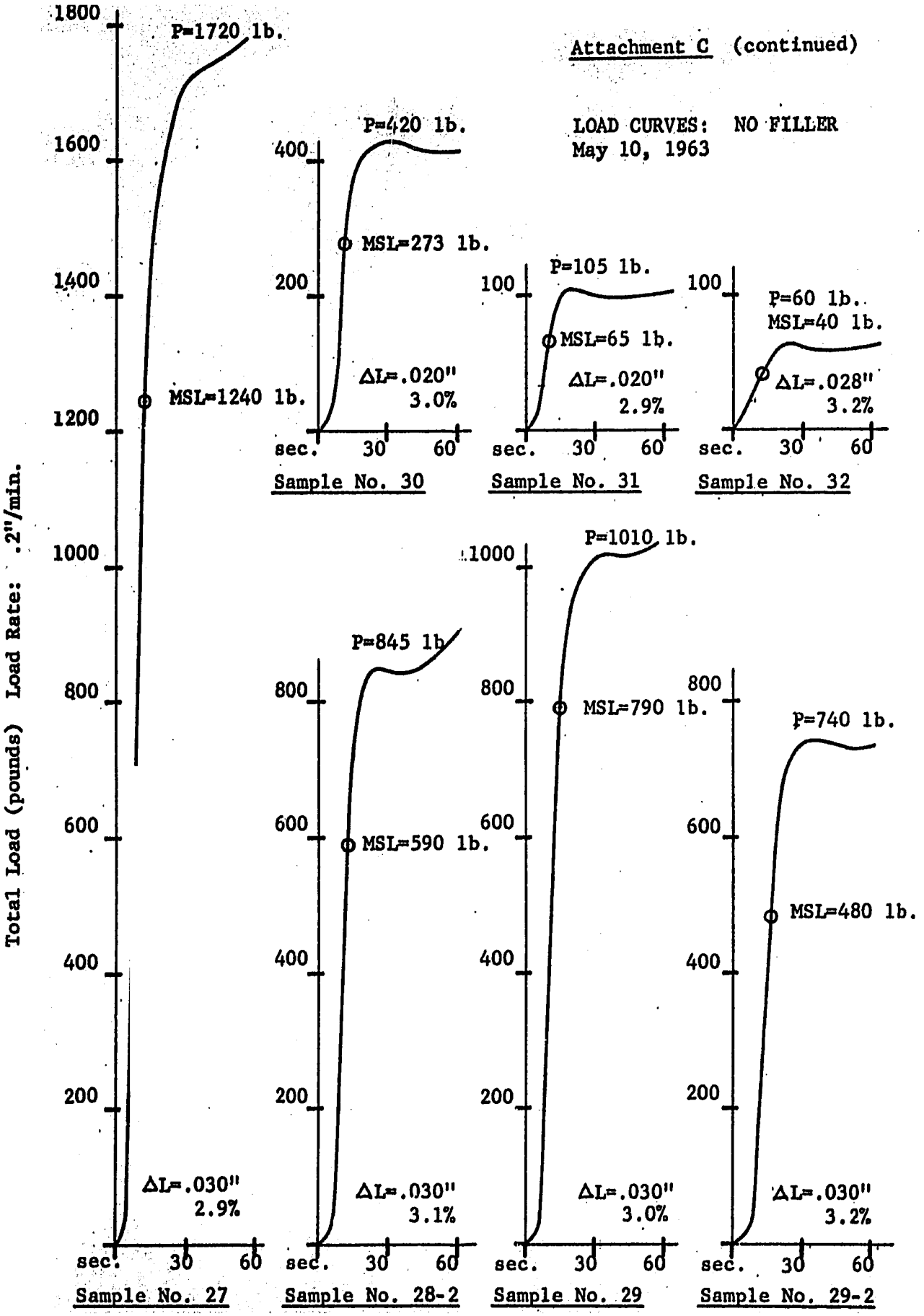
Attachment C (continued)

LOAD CURVES: PHENOLIC FILLER
May 10, 1963



Attachment C (continued)

LOAD CURVES: NO FILLER
May 10, 1963



Attachment D: FORMULATION OF TEST SAMPLES, DELKA RESEARCH CORPORATION URETHANE FOAM SYSTEM.

#13: 20.0 gr. "A", 20 gr. phenolic filler, .2 gr.H_2O,
20.0 gr. "B".

#14: 21.0 gr. "A", 13.3 gr. phenolic filler, .2 gr.H_2O,
20.3 gr. "B".

#15: 20.0 gr."A", 10 gr. phenolic filler, .2 gr.H_2O,
20.0 gr."B".

#16: 21.0 gr."A", 8 gr. phenolic filler, .2 gr.H_2O,
21.3 gr."B".

#17: 20.7 gr."A", 6.8 gr. phenolic filler, 2 gr.H_2O,
20.3 gr."B".

#18: 20.3 gr."A", 5.7 gr. phenolic filler, .2 gr.H_2O,
20.3 gr."B".

#19: 20.0 gr."A", no filler, .2 gr.H_2O,
22.0 gr."B".

#27: 20.0 gr."A", no filler, .0125 gr.H_2O,
20.0 gr."B".

#28-2: 20.0 gr."A", no filler, .025 gr.H_2O,
20.0 gr."B".

#29: 20.0 gr."A", no filler, .05 gr.H_2O (incorrect),
20.0 gr."B".

#29-2: 20.0 gr."A", no filler, .05 gr.H_2O,
20.0 gr."B".

#30: 20.0 gr."A", no filler, .10 gr.H_2O,
20.0 gr."B".

#31: 20.0 gr."A", no filler, .20 gr.H_2O,
20.0 gr."B".

#32: 20.0 gr."A", no filler, .40 gr.H_2O,
20.0 gr."B".

#40: 20.0 gr."A", 50 gr. red clay, no water*,
20.0 gr."B".

#41: 20.0 gr."A", 50 gr. red clay, 0.2 gr.H_2O*,
20.0 gr."B".

#42: 20.0 gr. "A", 50 gr. red clay, 0.4 gr.H_2O*,
20.0 gr. "B".

#43: 20.0 gr."A", 50 gr. red clay, 0.6 gr.H_2O*,
20.0 gr."B".

#44: 20.0 gr."A", 50 gr. red clay, 0.8 gr.H_2O*,
20.0 gr."B".

#45: 20.0 gr."A", 50 gr. red clay, 1.0 gr.H_2O*,
20.0 gr."B".

*Represents H_2O added. Considerable moisture present in clay accounts for low density (.398 gr/cc) of sample to which water was not added.