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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 progra m 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.

AID/csd-288
PN-AAD-179

SOC-4-2
U. of Mich
Monthly Reports

ARCHITECTURAL RESEARCH LABORATORY - THE UNIVERSITY OF MICHIGAN

Quarterly report: to the Agency for International Development
on ORA project 05687
for the period July through September 1964

RESEARCH ON STRUCTURAL SYSTEMS UTILIZING THE FOAM PLASTICS AS A STRUCTURAL MATERIAL FOR HOUSING IN UNDERDEVELOPED AREAS

TCR/ORA
Official File Copy

REVIEW OF WORK PERFORMED

1. Structural research and development involved three of the four systems selected for the production of full-scale demonstration units: (a) the folded plate system, (b) the folding armature system, and (c) the rigidized flexible system.

With regard to the folded plate system, a two-story test structure was erected with components made of paper skin -- polyurethane foam core boards. At the same time a laboratory testing program was begun, and is now under way, to determine the creep characteristics of this material.

As the result of model testing, the folding armature -- polyurethane foam spray structure erected at Wyandotte was altered around the edges to reduce bending stresses. Laboratory research was also conducted to determine the shape of the next full-scale structure, in the interest of further reducing the bending stresses.

A full-scale structural component made of rigidized flexible polyurethane foam was produced and erected for testing purposes. Experiments with an adhesive for the production of wider components were successful and arrangements are being made for the production of such components.

A more detailed description of this work, illustrated through a series of photographs, is attached as Appendix A.

2. The project staff was invited in August by the Hercules Powder Company to make a presentation of the AID-sponsored project to a group of company officials. The objective of this meeting was to determine possible areas of collaboration between the company and the project.

It was agreed that the project should conduct an analysis to determine the feasibility of using the filament winding process for the creation of structural units. This process was demonstrated to the project staff, and design data were obtained in order to facilitate preliminary computations.

The first idea being investigated is the feasibility of creating room-size structural units through this process. Computations are presently under way and a meeting with technical representatives from the company is scheduled for October.

3. As of September 1, Mr. Einhorn has started work to determine the requirements for the industrial production, distribution and marketing of chemicals for plastics in underdeveloped areas. A series of meetings has been arranged with major chemical producers who have offered to furnish some of the required data.

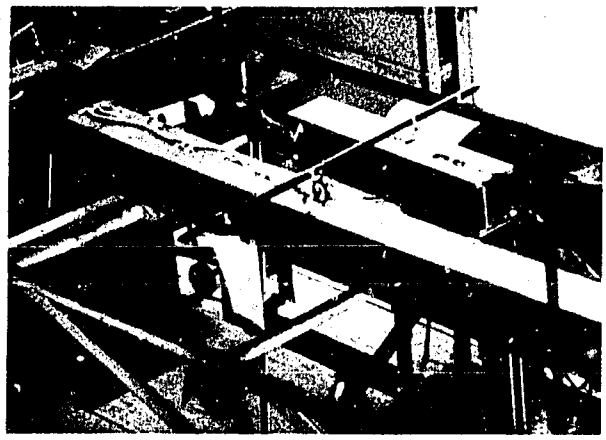
4. A paper on this project was presented at the International Conference on Cellular Plastics held in New York, September 14-18. This paper was submitted in June 1964 and appears in the form of an article in the January 1965 issue of the Journal of Cellular Plastics. A copy of this article has been attached to the interim report to AID covering the period from July 1963 through June 1964.

The project was invited to submit a paper for the next conference of the Counseil International du Bâtiment (CIB), to be held in Copenhagen in August 1965. Papers will be presented by raporteurs designated by the CIB and are required to be brief. A copy of the paper submitted for this conference is attached as Appendix B.

Appendix A

STRUCTURAL DEVELOPMENT WORK

1. TEST STRUCTURE WITH PAPER SKIN -- POLYURETHANE FOAM BOARDS



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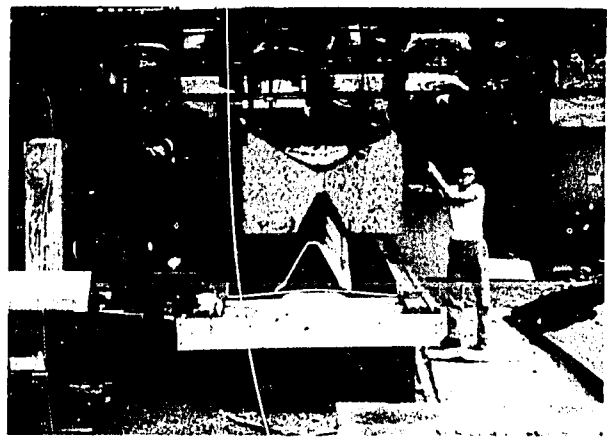

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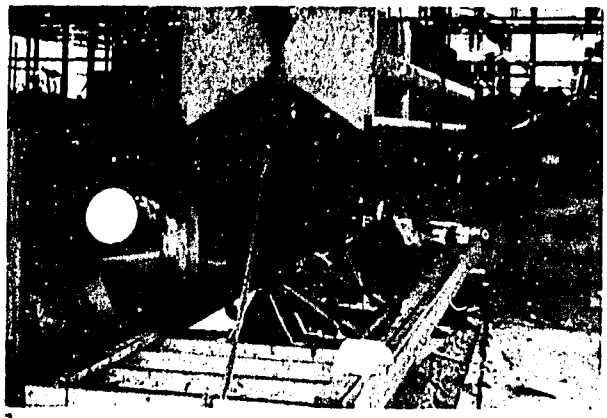

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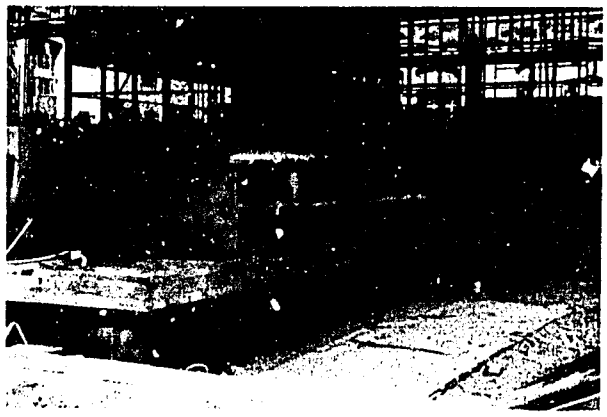

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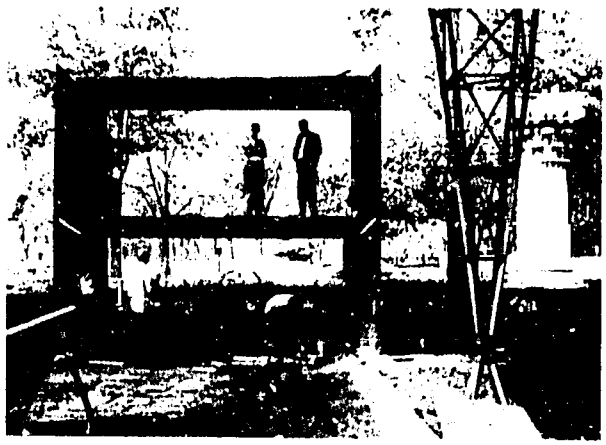


1f

1 TEST STRUCTURE WITH PAPER SKIN -- POLYURETHANE FOAM CORE BOARDS

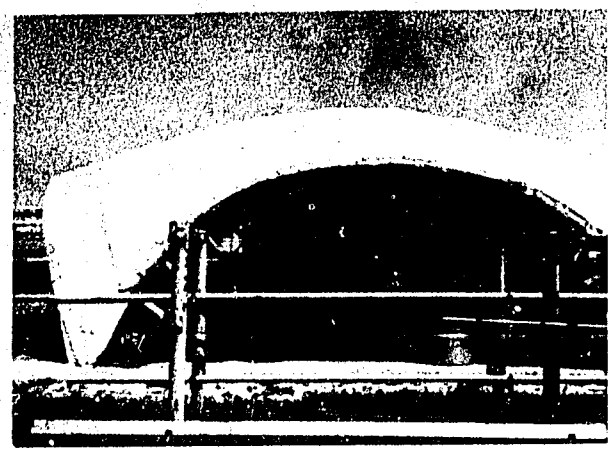
While the structural components for a two-story structure were being assembled, a test program was set up to determine more accurately the creep and other mechanical characteristics of the paper skin -- polyurethane foam boards supplied by Union Carbide Corporation. Strain gages were attached to a box beam designed for this purpose and readings are being taken continuously (Fig 1a). Results are expected to be computed before the summer of 1965.

With regard to the test structure, a field assembly template was designed and constructed for the production of the required structural components (Fig 1b). This was done for the sake of expediency; if found desirable, then equipment would have to be developed to produce the required structural bents through a continuous rolling process attached at the end of the material production system. Actual work showed that the material was easily creased and coated with polyester resin. Structural components were produced with this template by fastening the boards together with glass fiber tape and polyester resin (Figs 1c and 1d).

The cross section of the vertical and horizontal members is identical except for the addition of perpendicular diaphragms in the wall components. The total structure is attached to concrete footings by means of a polyester resin-impregnated glass fiber tape. The same method was used to attach the floor components to the wall members (Fig 1e). The theoretical sheer capacity of the connection, based on model testing, is estimated to be approximately 150 psf distributed over the floor area.

The basic structure (Fig 1f) was erected by the end of September. Arrangements are being made to enclose it as well as to coat the surfaces. Its behavior, through exposure to the elements, will be closely observed.

2. RESEARCH ON THE SHAPE OF THE FOLDING ARMATURE FOR POLYURETHANE FOAM SPRAY



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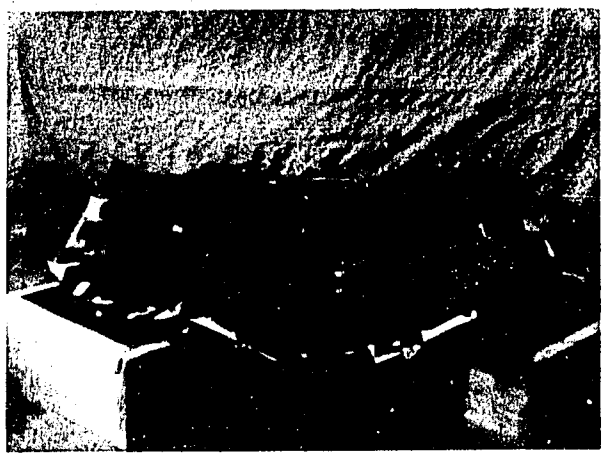

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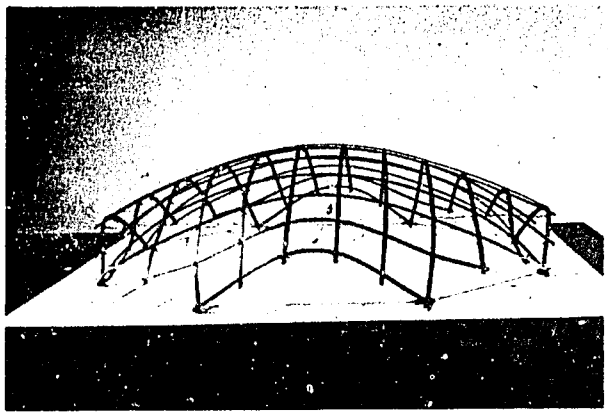

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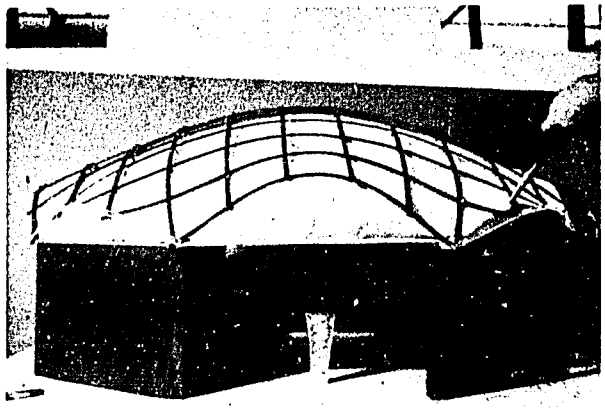

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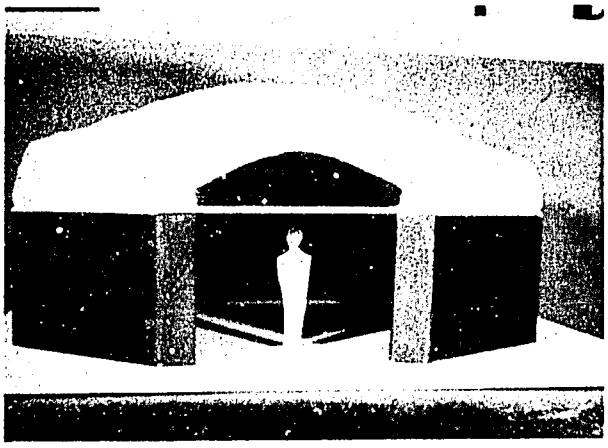

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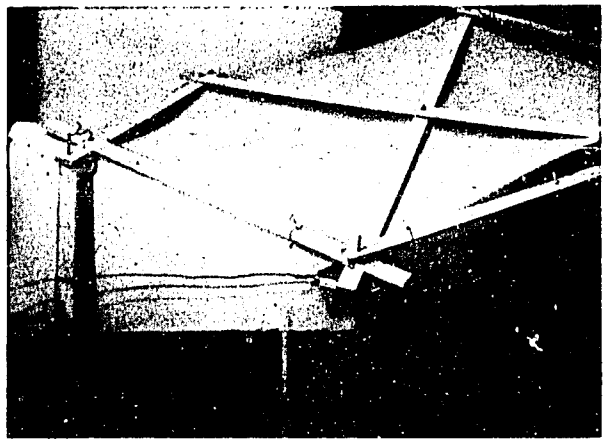


2f

2. RESEARCH ON THE SHAPE OF THE FOLDING ARMATURE FOR POLYURETHANE FOAM SPRAY

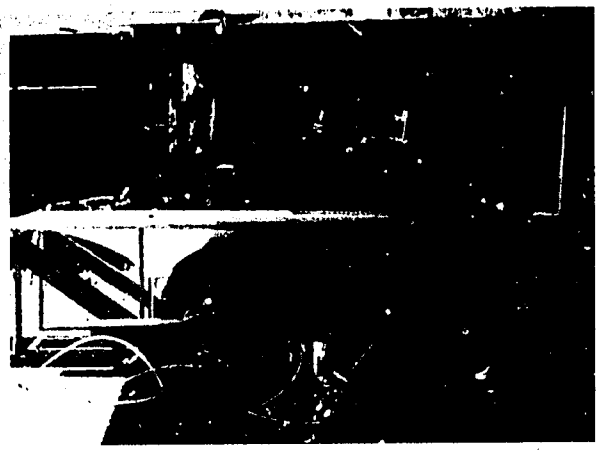
The full-scale experiment with polyurethane foam involving the use of a folding armature structure, conducted in collaboration with Wyandotte Chemicals Company, has demonstrated that bending stress within the structure will have to be reduced to avoid eventual failure due to creep. After conducting a series of model studies, the structure was pulled back into its original shape through tension applied on the four corners, and the edges were reinforced with wood arches (Fig 2a). Bending stresses in the supports, due to dead load conditions, were thus eliminated. The structure will remain under observation through the winter months. Comparative laboratory creep tests have been set up, which include samples from the spray formulation used in this experiment.

As a result of this experiment, a study was conducted to lower the bending stresses by altering the shape of the shell structure. To determine the shape, a rubber sheet was suspended in scale model form from points corresponding to the eventual supports. The anticipated dead load was simulated by uniformly loading the rubber sheet with lead components, and the sheet thus took a shell shape under this load (Fig 2b). Theoretically, this form, if duplicated with polyurethane foam, should not be subject to bending stresses under its own weight.

Exact measurements were taken from the rubber sheet model and the form was duplicated in model scale with a folding armature (Fig 2c). Once the form for the next armature was established, it was decided to conduct two full-scale experiments before proceeding with a demonstration structure. In the first the armature will be retained within the structure, while in the second an attempt will be made to remove it.

To study this second possibility, a skin made of thin flexible polyurethane foam was attached with fasteners on the inside of the model armature and coated with polyurethane foam. Once rigidized, the structure was placed on scale model walls and the armature was removed (Figs 2d and 2e). To study the details involved in this system, a full-scale mock-up was erected (Fig 2f). The next step is to determine the foam formulation to be used for this experiment.

3. STRUCTURAL DEVELOPMENT WITH RIGIDIZED FLEXIBLE POLYURETHANE FOAM



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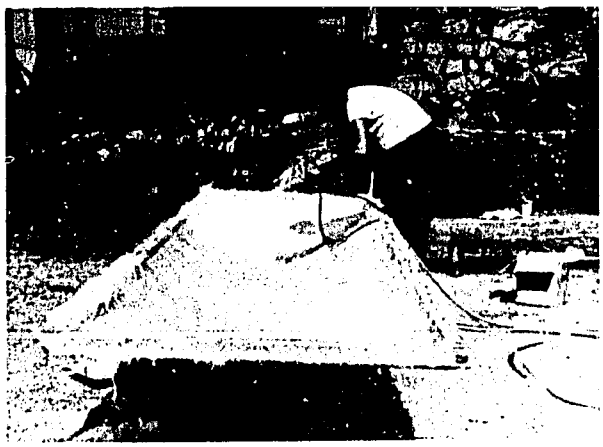

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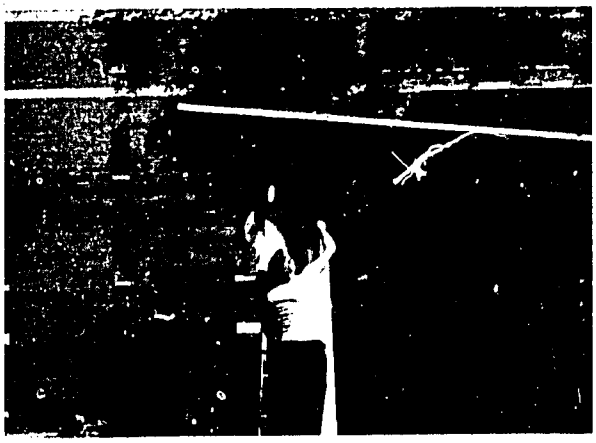

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3. STRUCTURAL DEVELOPMENT WITH RIGIDIZED FLEXIBLE POLYURETHANE FOAM

Experiments were conducted with two identical structural components made of rigidized reticulated flexible polyurethane foam. The objective is the creation of such components by giving a sheet of flexible foam the desired shape, allowing it to rigidize through a pre-impregnation or post-impregnation process and then spraying the surfaces with chopped glass fibers and polyester resin. The possibility of rigidizing flexible membranes opens new avenues for the erection of structures. The system is not necessarily restricted to the method presently being used for experimentation.

Various problems encountered in the spraying of the first component were overcome and the second section was completed without difficulty. A sheet of one-inch thick foam measuring 56 inches x 16 feet was stretched in a simple horizontal wooden frame and two points were pulled down to obtain the desired shape (Fig 3a). The stretched sheet was then impregnated with a moisture-curing urethane resin and rigidized in this position. Once rigidized, the component was removed from the frame and sprayed with chopped glass and polyester resin (Figs 3b, 3c and 3d). It was then attached to the tops of tubular asbestos cement columns (Fig 3e). Water can be drained through the columns (Fig 3f) and collected if desired.

An earlier limitation imposed by the 56-inch width (the maximum width in which the reticulated flexible foam can presently be obtained) has been overcome. This was done through the use of an adhesive whose chemical composition is similar to that of the foam material and which offers the required stretch properties. The results from fastening several sheets of foam together by simply coating their edges are very encouraging. The next step will be an attempt to produce a 12-foot square umbrella-shaped structural component by adhering three sheets of foam.

Appendix B

PAPER SUBMITTED FOR CIB CONFERENCE

FOAM PLASTICS FOR HOUSING IN THE INTEREST OF INTERNATIONAL DEVELOPMENT

by Stephen C. A. Paraskevopoulos, Professor of Architecture, United States

1. Frame of Reference

The program of research on the structural use of plastics now being conducted at the Architectural Research Laboratory of the University of Michigan, has been sponsored by the Agency for International Development (AID), United States Department of State. It is aimed at exploring the feasibility of using plastics, especially foam plastics, for the construction of dwellings in the underdeveloped areas of the world.

The housing problem cannot be divorced from any country's total problem of social and economic development. The available resources of the technologically less advanced countries should be viewed as something more than just mere expedients for an immediate output of needed dwellings. The extent to which any particular material or method of construction might be used should depend on the degree to which they also help to increase the national productivity and to raise the national standard of living.

The often advanced theory that only locally available materials should be considered for housing use to the exclusion of any imported materials must accordingly be viewed with some skepticism. If by importing certain materials (such as may be the case with chemicals needed for the production of plastics) a country can upgrade its local resources or create new ones, then it may be to the advantage of this country to import such materials.

If we think in terms of a worldwide international development rather than merely the assistance contributed by the privileged to the underprivileged nations, then the most advanced technology should be considered for introduction in every country. Even innovations in the developmental stage could be introduced in a cooperative program in which the experience of those being aided will also benefit those who are providing technical assistance.

In short, it is believed that much more can be achieved if housing is not seen as an independent quantity and if the building industry is not treated as an independent factor. Both must be considered together as integral parts of an integrated and developing industrial economy.

2. Plastics and Industrialization

Being a synthetic product, the plastics require industrial facilities for their manufacture and processing. Industrialization will therefore be promoted in any country where markets can be created for the various types of plastics. Many different kinds of products with very precise specifications can be readily produced to meet many different requirements and conditions without any great change-over costs in production. Quality

can also be largely controlled in the laboratory where the attitude traditionally has been always to improve a product through continuous research and experimentation.

The main industrial advantage offered by the plastics lies in their wide variety or possible uses, ranging all the way from tableware and small toys to large structural components. This versatility in turn assures a greater diversification of markets. If production facilities can be created for the building market, potentially the largest, the output should be ample enough to take care of other markets, notably furniture and equipment of all sorts, all of which present equally pressing needs in the newly developing countries.

This diversification of markets makes the plastics rather attractive from the standpoint of capital investment in the underdeveloped countries. Even if the existing housing market is not immediately large enough to absorb an output of building materials commensurate with low unit costs and a reasonable margin of profit, the investment may be justified by producing needed consumer items for which there is already a large market demand. The production and sale of allied products will assist in amortizing a considerabl part of the initial capital investment, and this will eventually make possible the production of building materials at lower unit costs.

3. Basic premises

The foam plastics, besides offering advantages in terms of global logistics, have such virtues as ease of fabrication at low investment cost, light weight, and excellent insulation properties. As their density decreases so also does their cost when measured in volume of material. This fact does not necessarily mean that the lowest density foams will produce the most economic structures, but it does indicate that in order to achieve maximum economy in a structure the density of the materials must be taken into careful consideratio

Economy is a factor that always has to be considered, especially in the case of the underdeveloped nations. It is misleading, however, to compare plastics on a pound or board-foot basis. Much depends on how efficiently their properties are being used, and thus the only meaningful figure is their cost in place.

A decision which formulated the course of our research was that plastics should not be viewed as substitutes for conventional building materials but for their own intrinsic value in building construction. The aim has been to explore such new or improved structural solutions as are made possible through the introduction of these new materials. With each plastic material the objective is to develop a total system (design, production, and marketing) consistent with its inherent properties and to make whatever adjustment may be needed within the system to enable it to cover the widest possible range of specific housing requirements.

4. Approach to Structure

To determine priorities in our structural research, we have approached the problem of structure from three directions: (1) structural analysis, (2) production methods, (3) erection techniques.

Since the foam plastics have very low moduli of elasticity, flexural stiffness will depend primarily on the distribution of the material in the structure; in other words, on the structural geometry. The proper geometry will also lead to the reduction of stresses within the structure. Low stress values are essential not only because of low material strengths, but also because creep seems to depend upon the stress level of the material.

Foam plastic structures which offer the largest potential are those in which stress levels are kept low by the distribution of loads throughout the structure, and where load and stress concentrations are avoided as much as possible. Structural solutions have therefore been sought within the family of "surface structures," especially shells and folded plates, which have such characteristics.

Through further analysis involving the basic families of internal stresses, theoretical solutions can be obtained which will be fairly ideal from a purely structural standpoint. However, these solutions may be far from ideal with regard to application, especially so far as our particular project is concerned.

The possibilities and limitations imposed by efficiency in production methods are major factors also influencing the structural solution. Such factors affect the form of the structure as well as the form in which materials can be used. Finally, the erection technique must be considered, because these plastic materials present some unique possibilities which may affect considerably both the structural form and its cost in place

5. Experimental Structures

The examples that follow illustrate experimental structures in varying degrees of development. With the exception of the first example which is being tested for long-term performance, these structures have been erected primarily in order to obtain information regarding their behavior. This information will be a guide in developing a second generation of experimental structures freed from certain present shortcomings.

a. Polystyrene Foam Structure

This structure -- a dome 45 feet in diameter -- was erected in collaboration with the Dow Chemical Company through their "Spiral Generation" process. The process involves the use of a specially designed machine which bends, places and fastens boards of plastic foam together in a predetermined shape, layer upon layer, into a rising structural spiral.

In erecting this structure a trench, corresponding to the diameter of the dome, was excavated and bridged by 2 x 4-inch wood blocks which supported a base ring. A starter strip of polystyrene foam was attached to the ring and the "Spiral Generation" process

begun (Fig. a1). Foam boards, 4 inches thick, with a density less than 2 pounds per cubic foot, were used, and the dome was erected in less than 12 hours by two men (Fig. a2). It was then lowered into the trench which was backfilled with earth, fully on the outside and partly on the inside. Openings were marked, cut and reinforced around the edges with fiberglass tape and epoxy resin (Fig. a3). A cement floor slab was then poured and its edge anchored to the dome. The surface was coated with a mixture of latex paint and vermiculite. Partitions were installed in the openings (Fig. a4). A flexible polyethylene gasket is used to create the joints between the dome and the glass fenestration.

b. Polyurethane Foam Board Structure

This experiment, involving a two-story test structure measuring 16 x 18 feet in plan, has been conducted in collaboration with Union Carbide Corporation. The material is a panel consisting of a polyurethane foam core, 3/8 inch thick with a density of about 2.5 pounds per cubic foot, and surfaced on both sides with paper skins. It is produced by a continuous process in which the skins, introduced in rolls, go through a machine at a rate that permits the liquid foam components to be evenly distributed between the skins; the components then expand into a rigid foam which adheres tightly to the skins.

The material can be scored and folded, thus lending itself to the making of folded plate structures. From a production standpoint it is desirable to develop structural systems which require merely the adding of equipment to the material production line. With these ends in mind, following an extensive testing procedure (Fig. b1), a triangulated bent was developed (Fig. b2). In the absence of regular production equipment, a templet was constructed (Fig. b3) for the assembly of the bents whose components are held together with polyester impregnated fiberglass tape. The surface was also coated with polyester resin. For the two-story structure (Fig. b4), fiberglass tape and polyester resin were used to assemble the bents, all of which have the same uniform cross-section, and to anchor the complete structure to concrete footings.

c. Spray Polyurethane Foam Structure

An essential element in polyurethane spray application is the form-giving surface against which the foam components are sprayed. For this purpose we devised a lightweight lattice armature, capable of being folded, easily transported to the site, and quickly erected by being pulled into a double-curved shape. A shell, covering a square floor area 22 feet wide, has been erected in collaboration with Wyandotte Chemicals Corporation.

The folding armature was placed on a concrete slab with four anchor plates (Fig. c1). Then, using tension chords, the armature was lifted into place and anchored to the plates (Fig. c2). The entire armature was covered with a stapled-on nylon reinforced paper skin and sprayed with the polyurethane components to a foam thickness of 4 inches with a density of 2.5 pounds per cubic foot (Fig. c3). Stress levels in the structure (Fig. c4) can be controlled by the rise of the center portion and the stiffness of the edge members.

d. Rigidized Flexible Polyurethane Foam Structure

This experiment was intended to explore the possibility of erecting double-curved surfaces by rigidizing flexible foams with resins after they have been stretched to the desired shape. These materials could also be preimpregnated with an atmospheric curing resin in the factory and then transported to the site in a vacuum bag before being stretched in place and allowed to become self-rigidizing.

For the purposes of this experiment a reticulated flexible polyurethane foam produced by the Scott Paper Company was selected. A sheet, 56 inches by 16 feet and one inch thick, was impregnated by a moisture-curing polyurethane resin developed by the Wyandotte Chemicals Company. It was placed in a wooden frame (Fig. d1) and two points were pulled down to produce a structural component (Fig. d2). Once cured, the component was sprayed with chopped glass fibers and polyester resin (Fig. d3) and fastened on top of tubular columns (Fig. d4).

6. Conclusions

These experiments have shown that foam plastics structures are within the realm of technical and economic feasibility. Before any meaningful design data can be developed, however, more research is needed in the chemistry and production of these materials to eliminate present qualitative inconsistencies. Also, more data must be obtained as to their behavior and long-term performance in order to establish a better correlation between materials and structure. If properly stimulated by architects, the chemical industry can greatly contribute to the advancement of building technology through chemistry.

Acknowledgements

This research is being conducted with my colleagues, Harold J. Borkin, J. Sterling Crandall, Robert M. Darvas, James L. Haecker, C. Theodore Larson, and Willard A. Oberdick.

References

1. "The Potential Use of Foam Plastics for Housing in Underdeveloped Areas," Architectural Research Laboratory, The University of Michigan, Ann Arbor, 1963.

2. "Architectural Research in the Use of Foam Plastics," by Stephen C. A. Paraskevopoulos, Journal of Cellular Plastics, Vol. 1, No. 1, January 1965, pp 132-142.