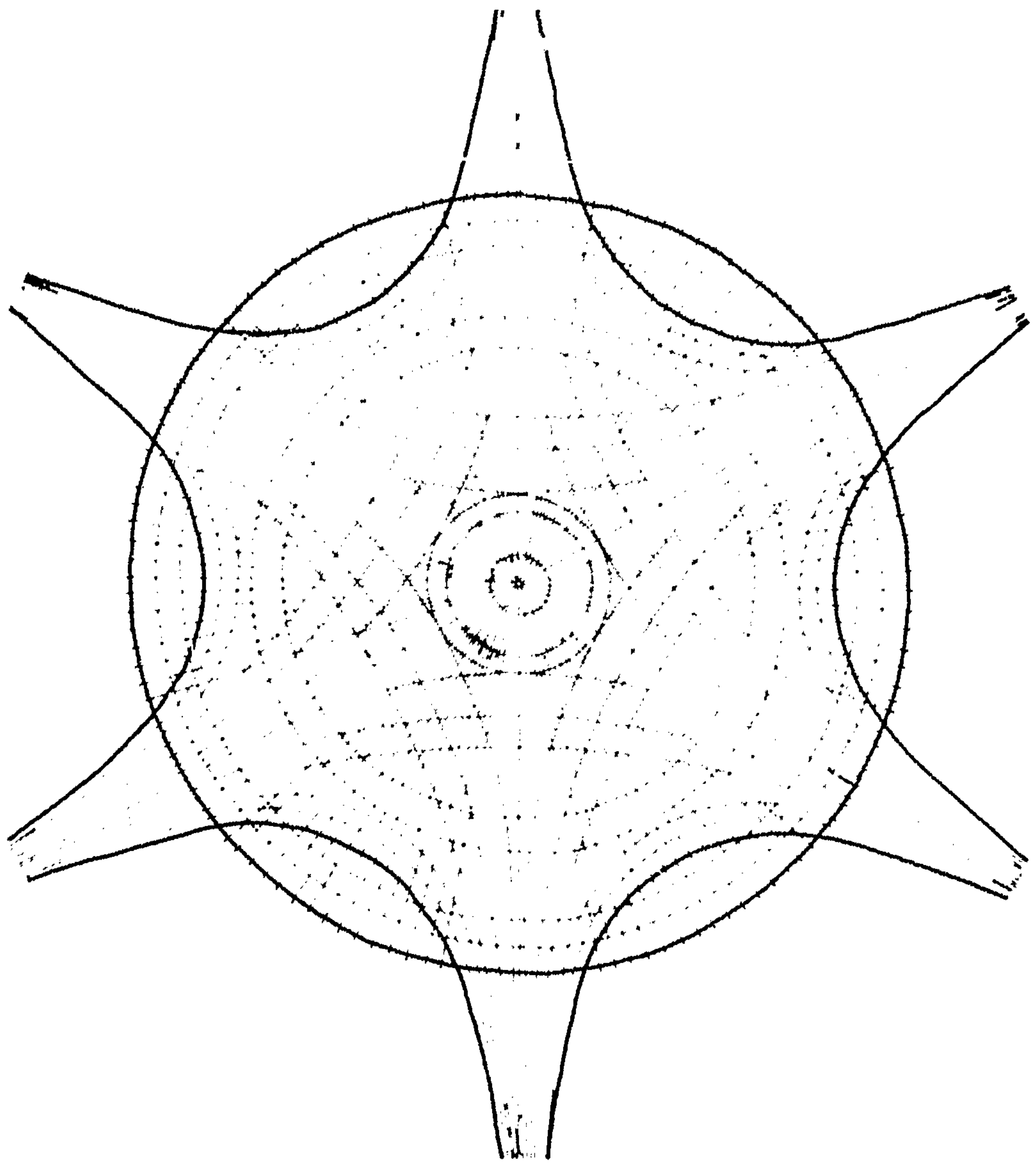
DOCUMENT RESUME

ED 025 917 EF 002 341

By-Evans, Ben H.
Lift-Shape Construction, An EFL Project Report.
Texas A and M Coll., College Station. Architectural Research Group.
Spons Agency-Educational Facilities Labs., Inc., New York, N.Y.
Pub Date 62
Note-28p.
Available from-Publication Department, Texas Engineering Experiment Station, A. & M. College of Texas, College Station, Texas
EDRS Price MF-$0.25 HC-$1.50
Descriptors-Building Design, Cement Industry, Construction (Process), Construction Costs, *Prestressed Concrete, *Structural Building Systems, *Test Construction

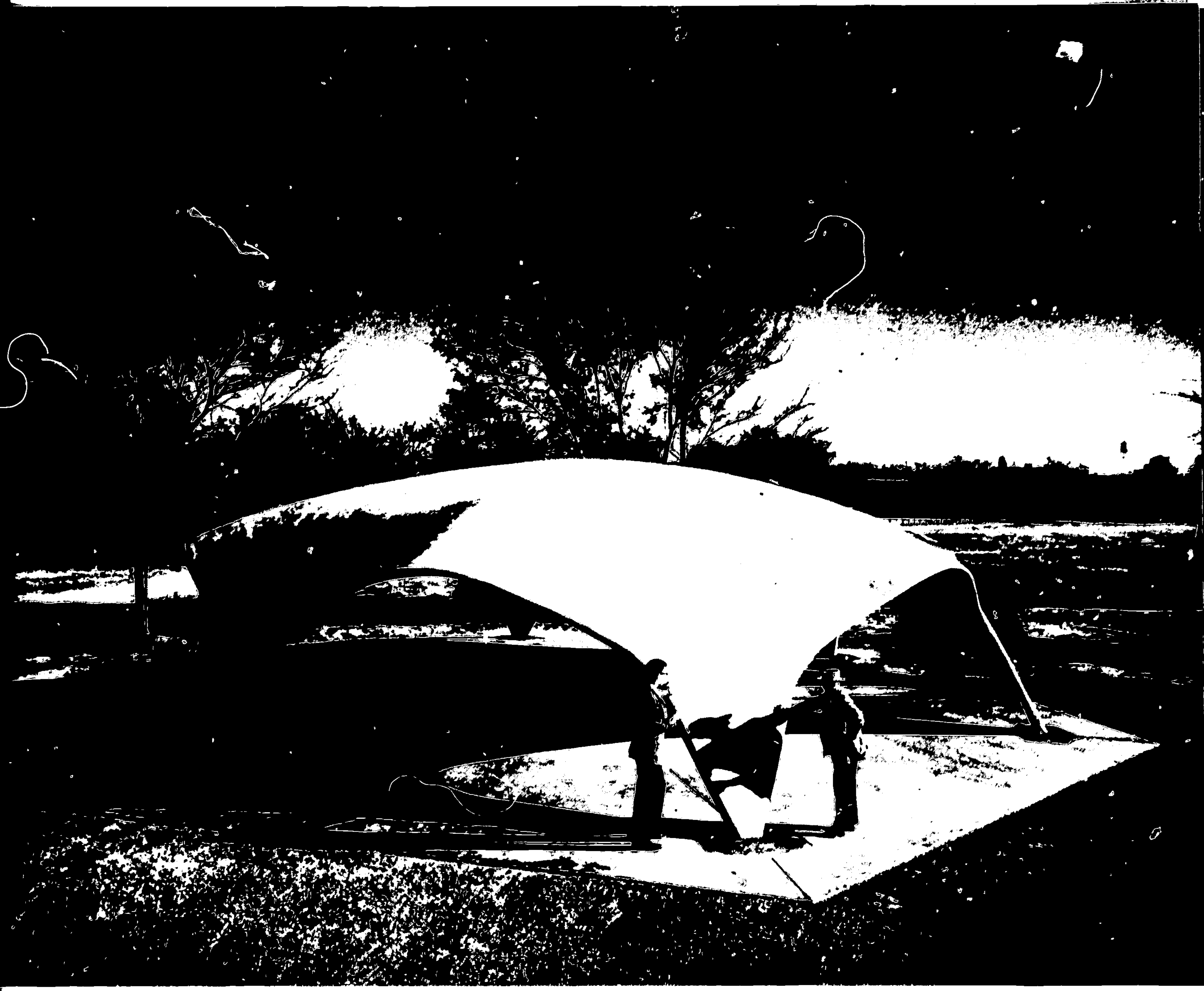
Research development of a construction system is detailed in terms of--(1) design and analysis, (2) construction methods, (3) testing, (4) cost analysis, and (5) architectural potentials. The system described permits construction of usual shapes without the use of conventional concrete formwork. The concrete involves development of a structural steel skeleton in such a way that it can be fabricated on a flat plane, sprung into final position, and coated with concrete or other sprayable materials. Photographs and diagrams illustrate development of both the system and actual construction. (MH)



LIFT - SHAPE CONSTRUCTION

an EFL project report

ARCHITECTURAL RESEARCH GROUP · THE A. & M. COLLEGE OF TEXAS



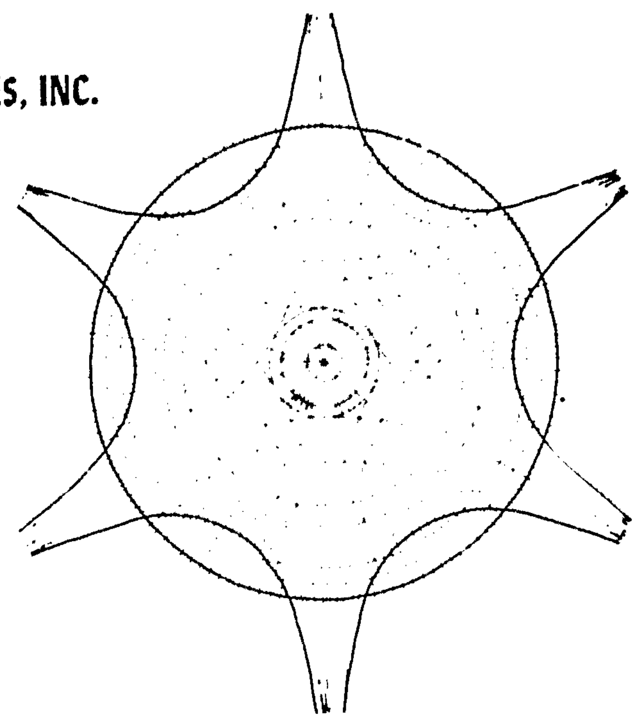
A Research Project conducted by the ARCHITECTURAL RESEARCH GROUP of the Texas Engineering Experiment Station under contract with the Texas A. & M. Research Foundation, College Station, Texas 1962.

LIFT-SHAPE CONSTRUCTION

A Research Report on a New Building Construction Technique
JAMES H. MARSH,III, Inventor of the Lift-Shape Technique

report by
BEN H. EVANS, Coordinator, Architectural Research Group
and JAMES H. MARSH,III, Assistant Professor of Architecture

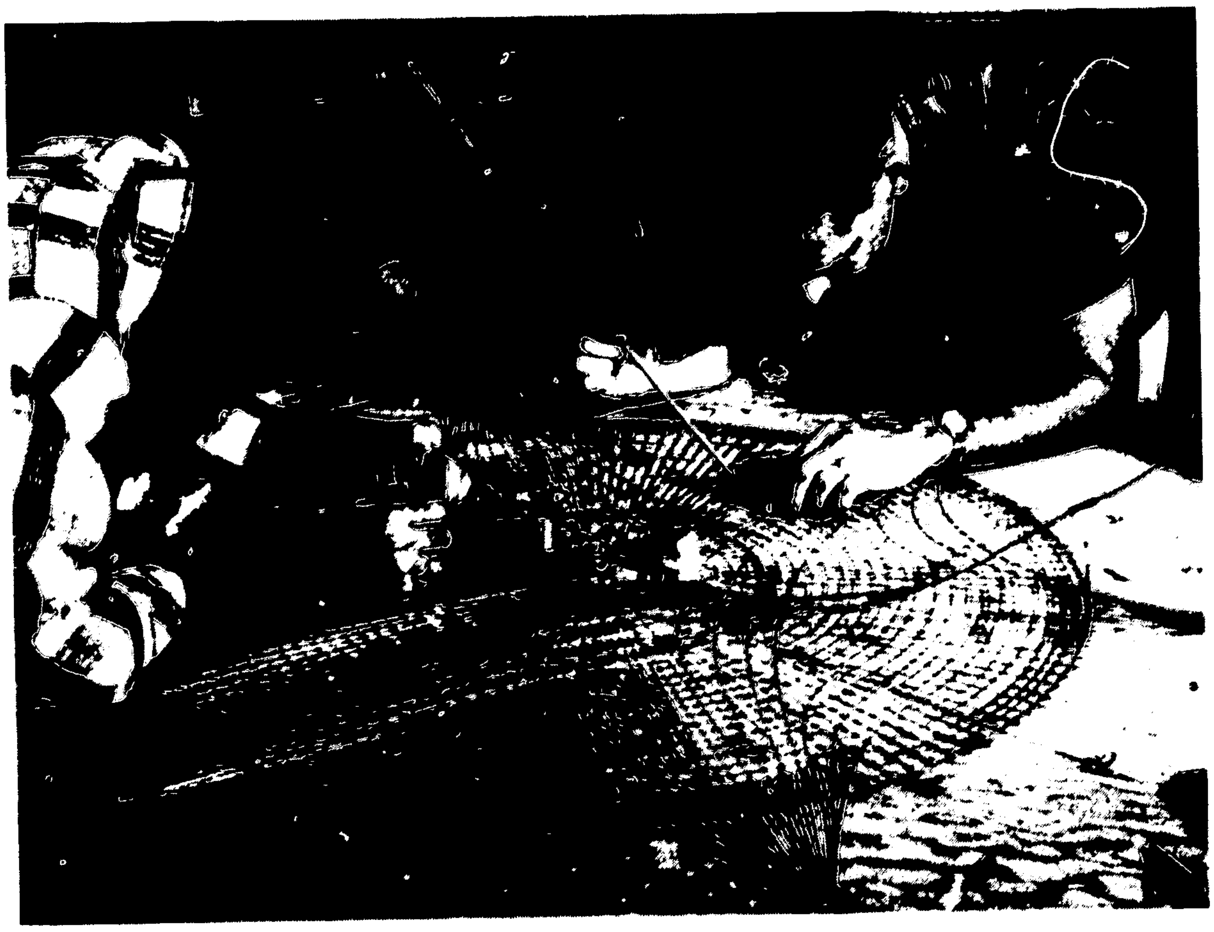
SUPPORTED BY A GRANT FROM EDUCATIONAL FACILITIES LABORATORIES, INC.



Additional Copies Available From:

Publications Department
Texas Engineering Experiment Station
A. & M. College of Texas
College Station, Texas

Library of Congress Catalogue Card Number; 62-62666



CREDITS

CONSULTANTS

William G. Wagner, Research Architect
Matthew A. Nowak, Research Physicist
C. Jack Godwin, Structural Engineer
James E. Harris, Structural Engineer
James E. Antill, Texas Bureau of Lathing & Plastering

TECHNICAL ASSISTANCE

Kenneth A. Bobo, Supervision
E. E. Johnson, Construction
Carl Doerner, Construction

TABLE OF CONTENTS

FOREWORD

Architecture today is seeking, among other things, new and more fluid forms of expression. Architects are continually striving for design criteria which will not limit their creativeness and in recent years there have been numerous instances of significant structures consisting of thin, reinforced concrete shells spanning large areas, and taking on fluid shapes such as never before attempted. There have also been numerous attempts to design and construct "sculptured" buildings, as opposed to "machined" buildings, wherein the designer has almost complete freedom in developing shapes and forms to suit his functional and aesthetic tastes. Unfortunately, however, geometric factors related to materials, methods of construction, and economics, have prevented the degree of fluid form development that seems desirable.

To assist in the solution of some of these problems, the Architectural Research group at the A. & M. College of Texas has been involved in a program of basic research for the past fourteen years, delving into studies of the environment, both physical and aesthetic, and has more recently included studies of construction techniques and materials.

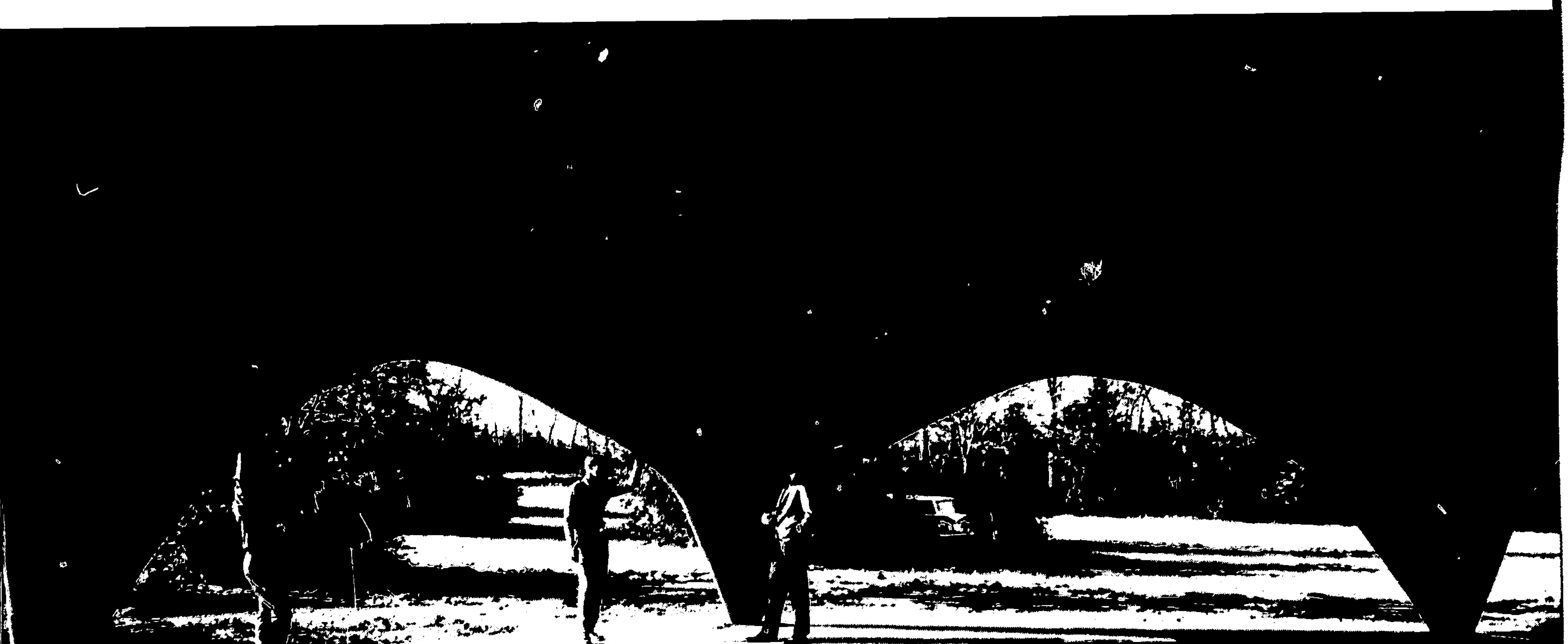
In an effort to solve some of the construction problems inherent with fluid shapes, James H. Marsh, III, Assistant Professor of Structures with the Division of Architecture at the A. & M. College of Texas, conceived a method for constructing unusual shapes without the use of conventional concrete formwork.

The concept involves the development of a structural steel skeleton in such a way that it can be fabricated on a flat plane and then lifted and "sprung" into final position for a spray coating of concrete or other material. Professor Marsh conceived the idea in his back yard workshop and when the potentials of the system seemed significant, he applied for a patent. Marsh's primary objective in getting a patent was to prevent unadvised and indiscriminate use of the system, perhaps resulting in ugly and unsafe buildings. Further development of the basic ideas came about through Professor Marsh's work in the Architectural Research Laboratories with scale models.

The Lift-Shape concept is based primarily on the fact that when forces are applied to the ends of a straight bar the bar will bow and take a parabolic form. This bending condition will occur, of course, so long as the forces do not cause the bar to exceed its yield strength. Combinations of intersecting bars of different lengths fastened together will take curves other than parabolic when forces are applied to the ends of the bars. Thus, the shapes available through various patterns of bars are almost limitless. Predicting what curves any set of bar lengths and patterns will take when sprung into position is both an art and a science. Consequently, a design is conceived intuitively and then further developed and refined through the use of scale models. The finished structural shape will be determined by both the original concept and the natural functions of the bar pattern.

Once the general pattern of the steel layout is derived, the quantity and size of the steel bars and the concrete material necessary can be reasonably determined by existing structural analytical methods. A more detailed resume of the structural analysis of the first large Lift-Shape structure is included in the following chapter on Design and Analysis. Since one of the most fertile areas for the application of new construction techniques is in the field of school construction, Educational Facilities Laboratories, Inc. lent their support to an investigation of the potentials of the Lift-Shape system. Through an E.F.L. grant, the Architectural Research Group, with Professor Marsh, was commissioned to design and build a fifty-foot Lift-Shape structure of thin, reinforced concrete. The project was intended to provide data on the feasibility of the Lift-Shape principle, the financial advantages to be gained, if any, by the construction process, and, the potentials of the system as related to everyday labor practices and materials availabilities. The purpose of this report is to present the results of this project and to suggest how this construction system might be applied to the construction of schools and other types of buildings.

Theo R. Holleman



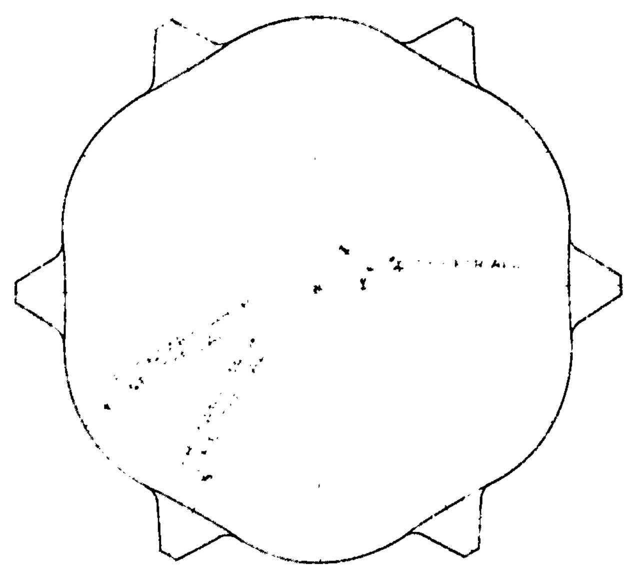
DESIGN AND ANALYSIS

Shape Design

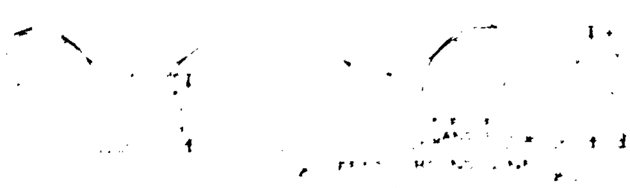
Since this was to be the first Lift-Shape structure of any consequence, considerable thought was given to the development of an appropriate shape. However, the purpose in building the structure was to determine whether or not the construction process was valid, so the selection of a shape was essentially an arbitrary decision. It would have been presumptious, perhaps, to have selected a shape especially difficult to construct. At the same time a shape which would have been simple to construct such as a parabolic vault or a parabolic dome, would not have exploited all the advantages of the Lift-Shape technique. The six-legged paraboloid of revolution finally selected involved numerous double-curved surfaces and was, because of its symmetry, about as inherently stable as any shape that might have been selected.

A second assumption involved the size of the structure. Previous experience with several small Lift-Shape armatures indicated that spans of ten to twenty feet were relatively easy to construct and required no special equipment. On the other hand spans of over a hundred feet seemed beyond the scope of the Lift-Shape process at this stage of its development. Consequently a span of fifty feet was chosen as one which involved some risk, but which seemed within the probable limits of the system.

The shape was developed and refined through the use of small scale models. At this stage of development there was no technique for determining a flat bar pattern to produce a given three dimensional shape except through trial and analysis.



A ROOF PLAN



B ELEVATION - EAST & WEST

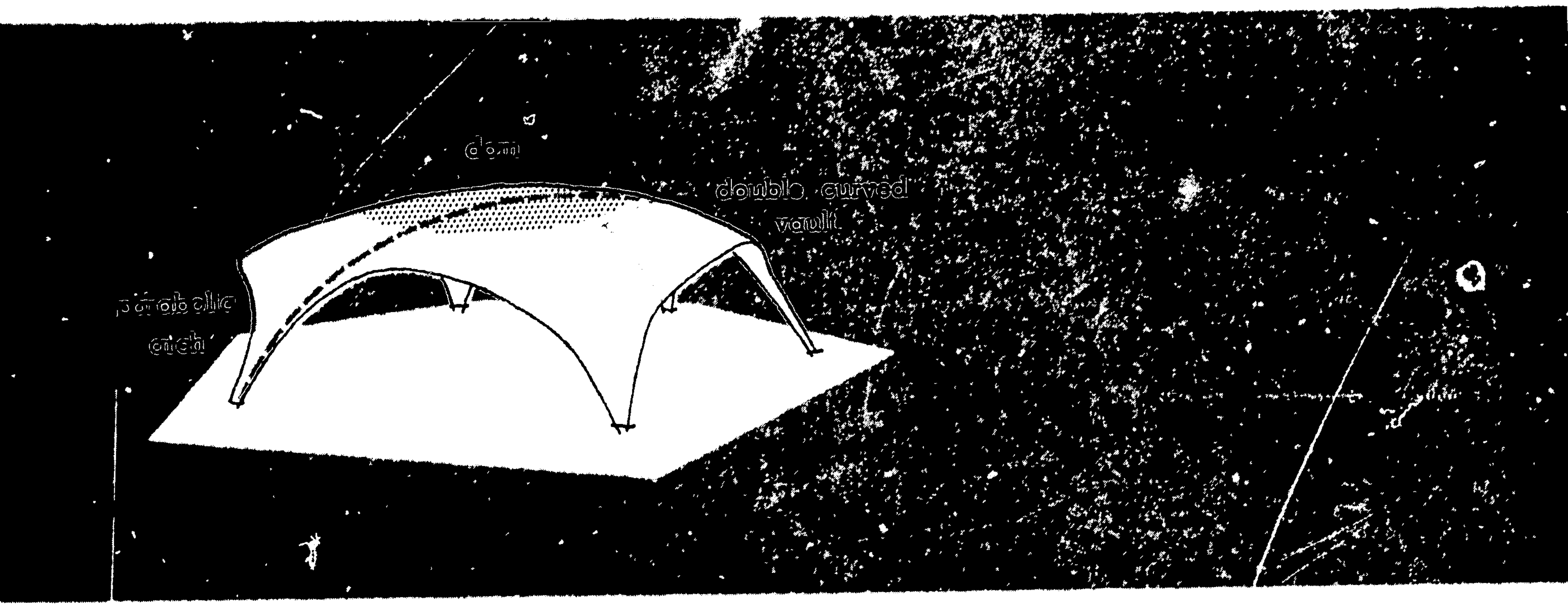
Structural Design

The Lift-Shape process is basically a **technique of construction** and not a new method of structural design. While the Lift-Shape technique involves a logical system of thrust and counterthrust, taking into consideration every advantage of the geometry itself, and while the system has a significant effect on the steel quantity and the layout of the steel pattern, the structural analysis itself is not significantly different than for more conventional methods of designing thin shell concrete.

The structural design of thin-shell concrete is, to say the least, not an exact science. While some of the bolder designers in the engineering field have developed mathematical techniques of analysis for several of the more basic thin shell shapes, even these techniques involve assumptions and data based primarily on previous experiences. As far as could be determined, no shape, or combination of shapes, such as involved in the paraboloid of revolution shape selected for this project, had ever been systematically structurally analyzed. Consequently, the analysis used was essentially a combination of existing systems for several simpler shapes. While the details of that analysis are not of particular importance to this report, it is at least worthwhile to look briefly at the general technique of analysis used.

The uppermost one-third of the structure is essentially a spherical dome and was analyzed with a uniform vertical load according to criteria set forth in "Design of Circular Domes," a bulletin published by the Portland Cement Association.

The "eyebrows" were designed as uniformly loaded double curved vaults based upon a modification of criteria for groined vaults set forth in the Portland Cement Association's bulletin No. 35 on Reinforced Concrete, "Elementary Analysis of Hyperbolic Paraboloid Shells."



The legs, or columns, and transversal arches were designed as parabolic two-hinged arches with a horizontal uniform wind load on one-half of the arch. These sections were analyzed on the basis of the method outlined in "Frames and Arches" by Valerian Leontovich, 1959. The wind force was assumed to be 35 pounds per square foot on an equivalent exposed vertical surface taken at the base of the leg. While this wind loading is somewhat arbitrary, it is based on "New Standard Wind-Load Requirements" by James P. Thompson of the National Bureau of Standards, Washington, D. C., 1957. The 35 psf force is derived from a wind of approximately 61 miles per hour with gusts up to 79 miles per hour and takes into account an additional 1.3 safety factor based on the usual rectangular shape of buildings. Each leg was assumed to carry 2/3 of the total wind force acting perpendicular to it.

To compensate for the bending moment in each leg due to the horizontal wind force it was necessary to place a web of extra steel along each leg. This steel was attached to the steel armature after the essential erection had already taken place. Details of this extra steel can be seen in the accompanying photographs. The combination of armature steel and this extra steel web on the legs provided a thick form for the application of some extra high strength concrete, thus producing a high strength, reinforced concrete "beam" to compensate for the wind load bending moment.

Concrete Mix

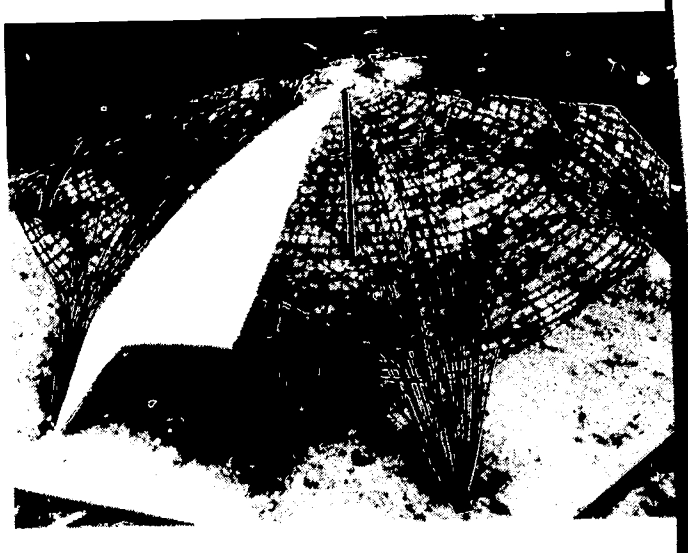
It seemed obvious on first analysis that there were two primary elements to be considered in the structural analysis. First the bending moment due to the wind load and secondly the dead weight of the concrete in the structure. The wind force naturally, was beyond the control of the designer in this instance, but in order to keep the dead weight of the structure to a minimum the decision was made to use a concrete with a lightweight aggregate of expanded volcanic shale called Haydite.

Several trial batches of concrete were put together in the laboratory, using a plaster spray machine, to aid in determining the most suitable concrete mix. After curing of the cylinders containing the experimental mixes the cylinders were tested to failure. The concrete with the most desirable strength-to-weight ratio provided a compressive 28-day strength of 1500 pounds per square inch and weighed 90 pounds per cubic foot. More conventional landrock concrete usually provides a strength of 2000 to 4000 psi and weighs 150 pounds per cubic foot.

The mix selected consisted of one part by volume of Type 1 Portland Cement, one part by volume of Masonry Cement (2/3 standard Portland Cement to 1/3 hydrated lime), six parts by volume of Haydite fines, and 2 quarts of short asbestos fibers per sack of Portland Cement.

Steel Fabrication

After the structural analysis was completed and the amount and placement of steel determined, a wire model to the scale of 3/4" = 1'-0" was constructed for a study of how and where intersecting steel bars should be attached to each other. Experimentation on the model revealed that rigid connections at all bar intersections prevented the steel from developing natural curves as it was sprung from the flat position to the three dimensional position. The model studies showed that only a few fixed joints were necessary and these only to maintain the general relative position of the bars. Consequently, joints of bars around the perimeter of the structure and in the legs were welded together while most of the other bar intersections were only loosely tied with 18 gauge wire. The model studies also indicated that the expanded metal lath covering the entire steel armature would have to be loosely tied also so that it would not restrain the development of the shape during the erection.



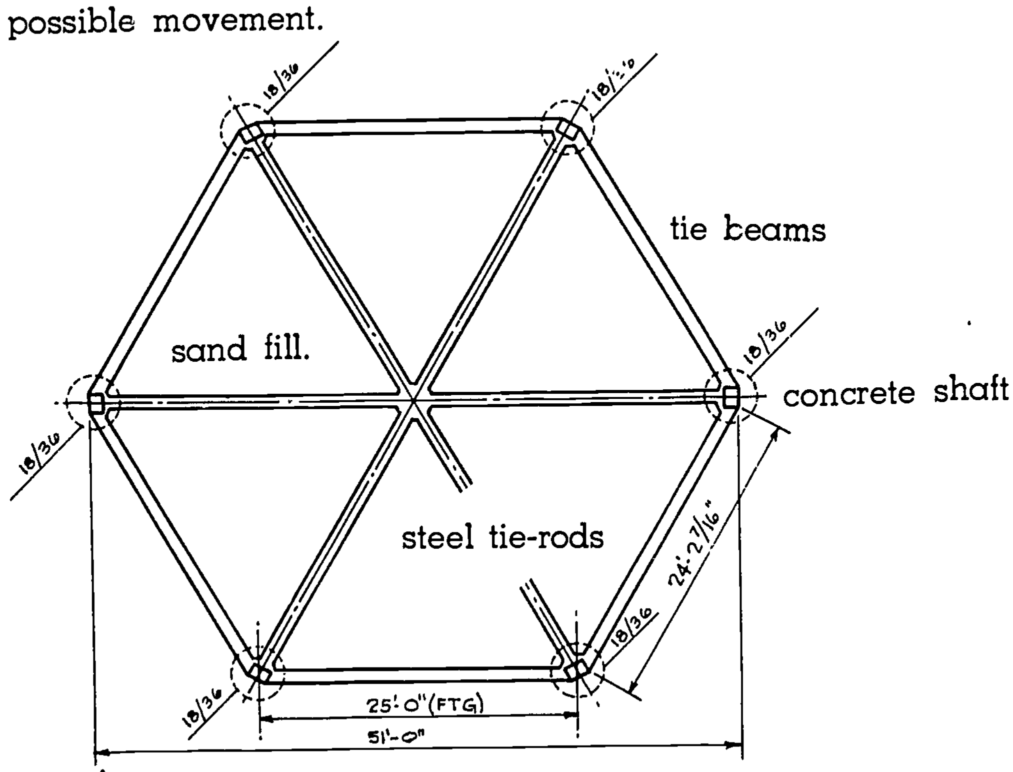
CONSTRUCTION

It will be well to keep in mind the objectives of this project as the actual details of the construction are described. First of all, the primary objective was to determine whether or not a reinforced concrete building could be erected by laying the steel out on a flat plane, lifting it into shape, and then spraying it with concrete. A secondary objective was to determine how far the concept could go in utilizing existing materials, equipment and labor. Although the time necessary for construction, the safety of the method of construction and the economies involved were also points of special interest, all were secondary to the first objective: Will the system work?

The Foundation

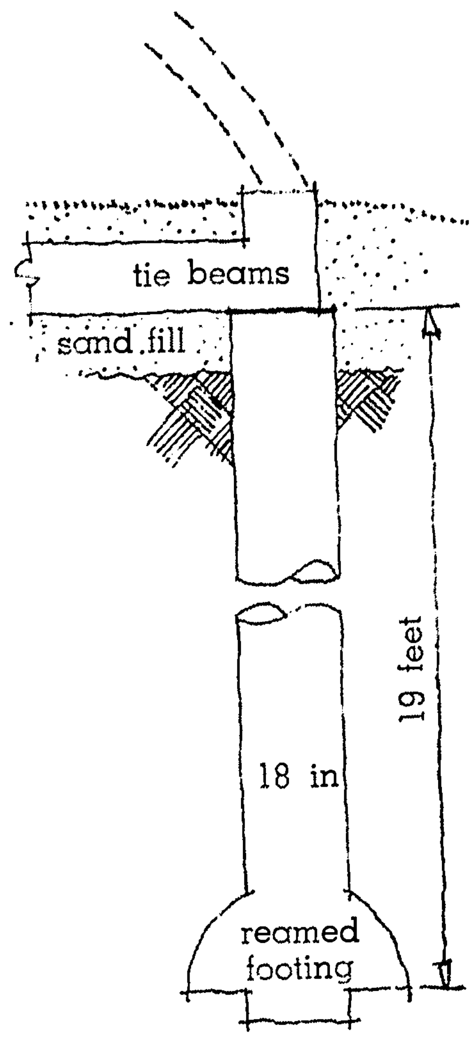
The foundation under the first Lift-Shape Experimental Structure relates only indirectly to the construction process itself, but it will be worthwhile to describe briefly the kind of foundation that was used and why.

First of all, it was necessary to provide a foundation which would maintain a level, unmoving support so that any cracks or deflections which might occur in the Structure after its erection could not be attributed to foundation shifting. Secondly, the construction site, and most of the Central Texas Area, consists of a very erratic and unstable soil. It was necessary then, to take all precautions in designing the foundation against possible movement.



A FOUNDATION PLAN

Under each of the Experimental Structure's six "legs" is a reinforced concrete shaft 18 inches in diameter extending down to 19 feet (to a reasonably stable soil) which terminates in a 36-inch diameter reamed footing. The tops of the six footings are tied together into a reasonably stable unit with steel tie-rods encased in concrete just under the surface of the sand fill. The steel tie-rods are coated with asphalt to prevent bonding so that the concrete acts simply as a cover for the tie-rods which carry any horizontal thrust. Opposing footings are tied to each other through a common center point and adjacent footings tied together by a similar tie around the outer perimeter. These concrete tie beams were formed by trenching in the highly compacted sand fill, which was used to bring the site to a reasonably level state. Thus the foundation was designed to give a support as stable as might be feasible with the particular soil conditions encountered.



36-inch diameter

The Armature

Previous associations had indicated that lathers and plasterers would be the most logical people to construct the steel and concrete shell. Lathers and plasterers are historically acquainted with the process of forming curves from steel, lath, and plaster. It is the lathers and plasterers who construct false vaults in rectangular spaces; who produce drop ceilings of unusual shapes and forms; and who develop the imaginative display work for amusement parks and theaters. The Lift-Shape project also required a contractor with a concrete, or plaster, spray gun, a common tool of most modern lathers and plasterers. Consequently, these prerequisites led to the employment of the Doerner Plastering Company of Houston, Texas, who was contracted on a cost-plus basis, to build the Lift-Shape Experimental Structure.

Working on the smooth, compacted sand floor over the foundation tie beams, two lathers and two apprentices laid out the reinforcing steel pattern for the Lift-Shape armature on a series of 2 x 4 and 2 x 6 planks placed in a random radial pattern. A series of critical measurements were made so that principal points of curvature could accurately be laid out. Surprisingly enough, only a few measurements were needed to provid. the lathers with their basic form. There were three basic layers of steel. The curved bars extending from one leg to another were laid out first, then the straight bars radiating out from the center, and finally on the top, the circular bars.

The lathers used their regular 18 gauge tie wires to fasten all splices and joints together. Unfortunately, the steel bars were delivered to the job site from the steel plant in Houston, 90 miles away, in 20-foot lengths instead of 40-foot lengths as specified. To avoid any delay in construction the 20-foot bars were accepted. This resulted in considerable more handling and tieing of steel than was expected and a considerable amount of extra splice-welding. Since the total layout and splicing, however, required much less time than was anticipated, the welder was not on the construction site when the steel skeleton was finally finished and consequently, the lathers decided to finish their portion of the work by laying out and attaching the galvanized diamond expanded metal lath to the top of the steel skeleton. This proved later to be a costly decision. Up to this point a total of approximately 75 man-hours had been expended on the construction of the shell armature.

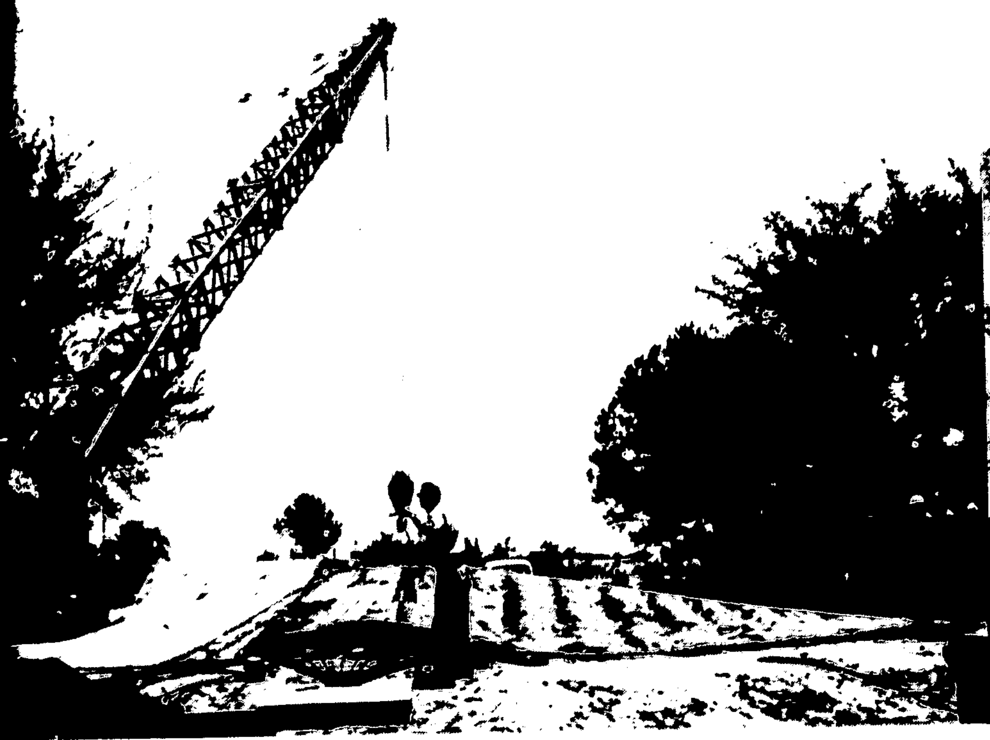
While the majority of intersections of steel bars were loosely tied by the lathers so that the bars might rotate and move during the erection process, it was necessary to weld a number of preselected joints. With the numerous extra splices brought about by the use of the shorter 20-foot bars and because the welder had to weld through the metal lath to splice the bars, his total time on the job was nearly double that anticipated.

In addition, a considerable portion of the welder's time was spent positioning and welding short, steel angles to the ends of the dome legs. These angles were necessary to tie the armature "leg" bars togther and to provide a method for attaching the legs to the foundation. Thus, the first phase of the fabrication of the steel bars and lath was complete and the armature was ready for erection. Total labor expended: approximately 100 man-hours.

The Erection

The erection of the steel armature was to be accomplished through the application of a lifting force at the center of the steel skeleton and pulling forces on each of the six legs. Theoretically, if these forces were applied simultaneously, the flat steel pattern would naturally form the predicted shape. A prefabricated steel "wagon wheel" 3-feet in diameter was placed beneath the steel skeleton at its center point and a metal cable bridle attached to the "wagon wheel" to provide a lifting support for the crane hook.

When the crane boom had been centered over the steel skeleton the lifting ring was attached and the center of the steel skeleton lifted approximately four-feet above the ground. As the lifting force was applied, the bridle attached to the lifting ring slipped causing the entire steel mass to swing off center and assume an asymmetrical position. It became immediately obvious that a larger lifting ring or some other lifting process should have been used and that much more care should have been exercised in applying the lifting force.



With the center of the steel skeleton approximately four-feet above the ground to provide working space, block and tackle chains were attached to the inside of each leg and to bolt supports embedded in each of the concrete tie beams inside and adjacent to each leg. Thus, the steel skeleton was lifted and pulled together by the application of these forces. Unfortunately, the application of the forces was unsymmetrical and several abnormal bends were induced into the skeleton causing it to take a shape slightly different than was anticipated.

At this point, the steel skeleton was in place, the legs had been adjusted and attached to the foundation supports and the armature was essentially completed. An hour and a half had been required for the actual lifting. The crane attached to the lifting ring at the top and center of the armature was still in place and it was apparent that the armature would not support itself without the crane's lift. The next two hours were spent securing the frame with guy wires and adjustable bracing to prevent any further movement that might occur due to unusual wind loads. After the braces and supports were in place the crane was detached and removed. At this point approximately 135 man-hours had been expended.

Since the armature did not form the precise desired shape, due to the unsymmetrical lifting procedures, some bending and re-shaping was necessary. This required two laborers a day and a half. A few bars had to be braced by welding some extra pieces of steel in place and adjustments were made in the heights of critical points on the armature.

Wind Bracing

As discussed in the preceding chapter, the greatest structural problem with this particular armature was compensating for the bending moment in the legs due to possible severe wind loading. Thus, the extra steel bracing for the legs had to be welded in place after the armature was in its raised position. It would not have been feasible to put this steel in place when the armature was flat on the ground and then lift it all together. It was a relatively simple matter, however, to weld the bars in place after the armature was in the raised position. After attaching the wind bracing steel and the steel lath to the area around the legs, a final check was made on elevations for critical points on the armature and the dome was ready for the plasterers. A total of approximately 250 man-hours had been expended.

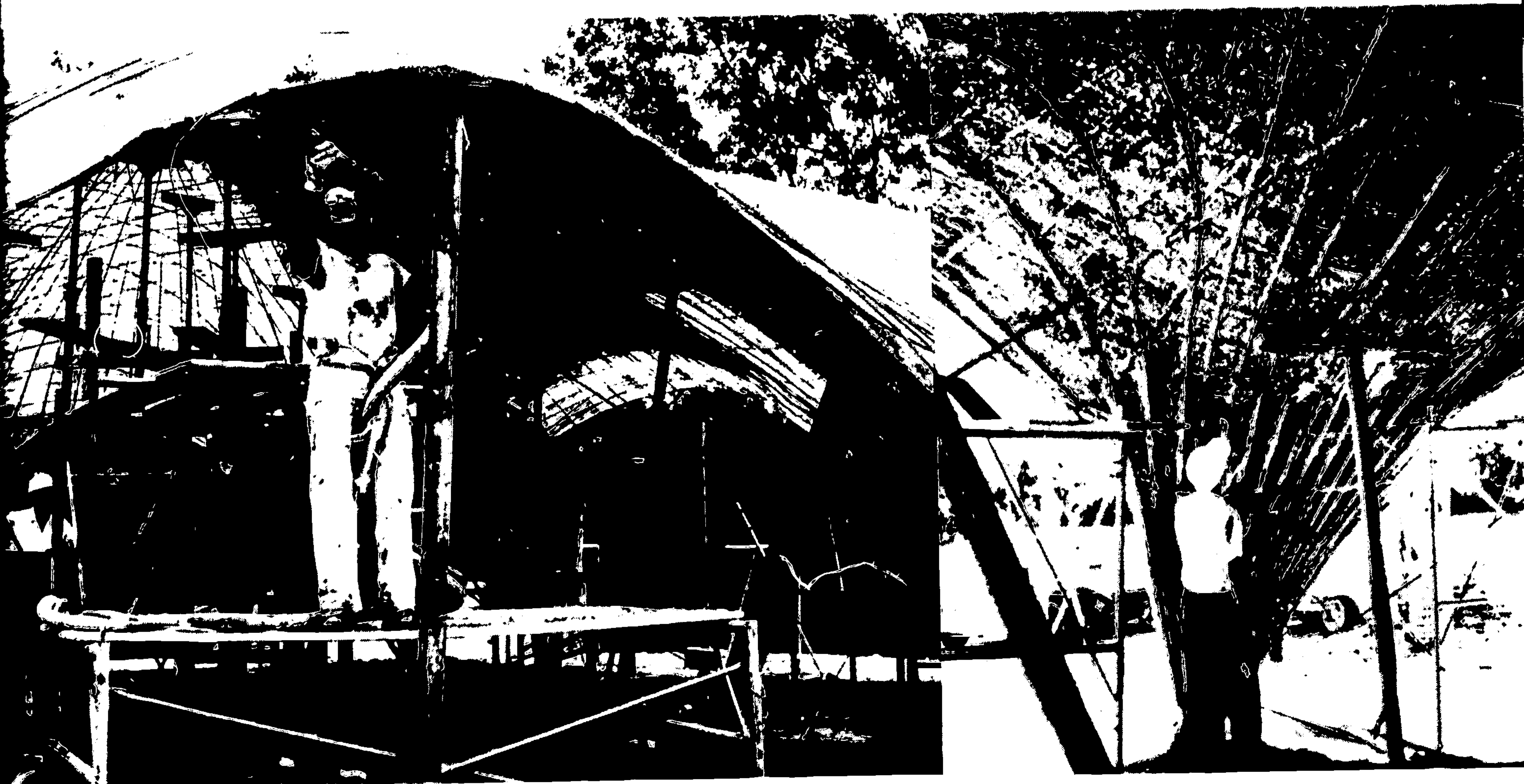
Concrete Work

The application of concrete to the steel armature was a process with several unknown factors involved. First of all, there seemed to be a minimum amount of information available as to the problems of application for the particular concrete materials to be used as described in Chapter 11. Secondly, there was a question as to what type of spray gun should be used with this particular batch mixture. And thirdly, there were questions about how much concrete could be applied at one time and how many coats would be required to build up the desired thickness. For the most part, the answers to these questions were left to the Contractor.

Weighing carefully the pros and cons concerning the spray machine, the Contractor selected a small plaster spray machine operated on the rotor stator worm gear principle. The concrete was mixed in an attached 6-cubic foot rotary blade mixing machine and was then discharged directly into the hopper of the spray machine. The mix was then transported to the structure through a length of rubber hose an inch and a half in diameter. At the spray end of the hose, air was introduced at approximately 15 pounds per square inch of pressure, the air hose and compressor being an integral part of the plaster machine. The purpose of the compressed air was to project the concrete mix and control the spray pattern—the higher the air pressure the finer the spray pattern and the lower the air pressure the denser the spray pattern. The air pressure was controlled by the plasterer at the hose nozzle. The capacity of the machine for spraying was approximately one and a half cubic feet of concrete mix per minute.

This type of "wet-mix" spray machine was selected because it would allow careful control over the water-cement ratio of the concrete, and because less air pressure is needed to spray the wet mix. Thus, the sprayed concrete would not be as likely to blow through the metal lath as with the high pressures usually inherent with concrete spray machines where the cement mix and water are mixed at the nozzle.

The labor force supplied by the plastering contractor for the entire job consisted of 3 men: a plasterer, an apprentice, and a laborer. They worked an average of 8 hours per day for two weeks excluding the weekend. As the application of the concrete material got underway, the plasterer soon found that the inherent "sharpness" of the Haydite aggregate was causing considerable wear on the moving parts of his spray machine. After much experimentation and replacement of several parts he increased the water, cement, and asbestos fibers content of the mixture so as to make the mixture more workable. This provided a smoother, wetter mixture but required that the concrete be applied in a much thinner layer than was planned. Samples of the actual concrete mixture as used were tested and showed an average 28-day strength of 2400 pounds per square inch in compression. This was well over the strength requirements specified by the structural analysis.



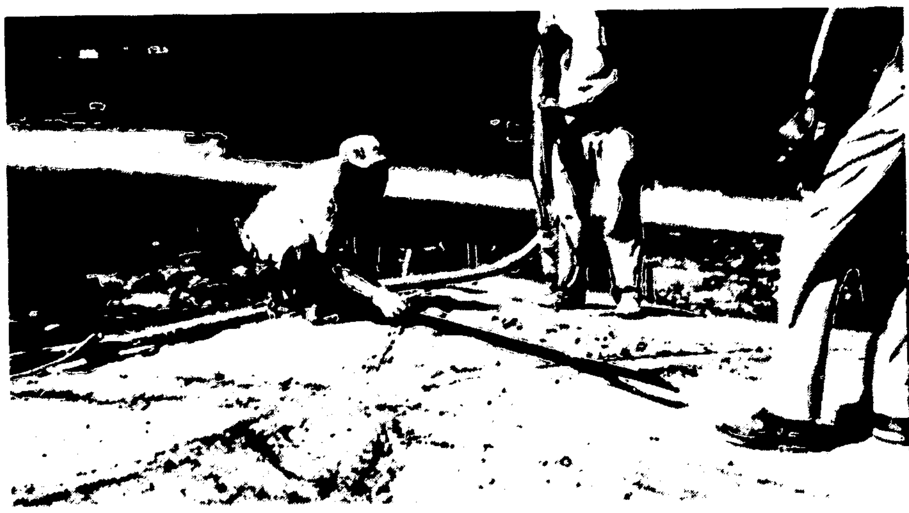
The first coat of concrete was rather thin and intended primarily to fill the voids in the metal lath, thus providing a backing for the application of succeeding coats of concrete. The plasterers worked from day to day spraying onto the underside of the armature in a continuous rotating pattern. Not until the underside concrete work was complete, except for the finish coat, did the plasterers take their equipment to the top side of the armature.

To provide a smooth curve to work to on the top of the structure, the plasterers embedded a length of flexible, thin, soft, wood in wet concrete around the edges and across the top of the armature. This detail can be seen in the accompanying photographs. After the concrete hardened, the wood was removed and the remaining ridge of hardened concrete provided a screed to which further concrete applications could be molded.

To get the concrete mix to the top of the dome it was pumped there using the spray machine without the hose nozzle itself. As the concrete was pumped in a steady stream onto the surface by one man, another man spread the mixture around with a long straight float. As the mixture began to harden it was sculptured to its finished shape by the plasterer and his apprentice using hand tools.

The final surface of the entire structure, underside and topside, was a mixture of sand, cement, and an X-59 admixture (to provide greater workability and to reduce shrinkage cracks) applied in a 1/4" layer and hand rubbed to a sand-smooth finish. Approximately 4 hours after application of the final concrete coat, curing operations were begun. The outer surface was kept moist for a period of five days through the use of a water sprinkler placed on top of the structure. The inside, or underneath surface, was wetted intermittently with a water hose and spray nozzle.

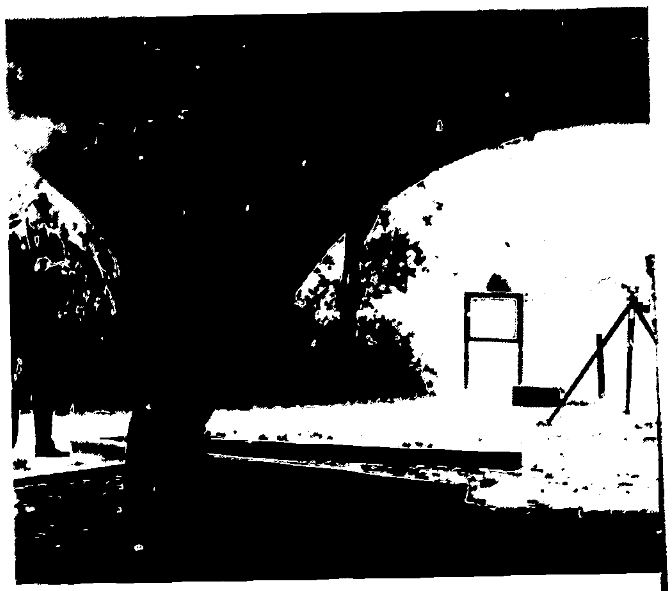
The layout and fabrication of the steel armature, the erection, the final welding and adjusting, the application of all concrete and the completion of the entire shell required approximately 700 man-hours of labor. This is about the equivalent of 4 men working 4 weeks.




TESTING

Although this research project has been concerned primarily with a concept for a new construction process, some evaluation of the actual finished structure is necessary and desirable. The structural design process differed only slightly from currently accepted methods for structural analysis of unusual concrete shapes so if there was a failure of the structure after completion it would most likely be due to error in construction rather than in the structural analysis itself. There could be something within the construction process which might prevent the structure from developing its intended strength so it would, therefore, seem desirable to determine whether or not the finished structure would carry the load for which it was designed.

Determination of whether or not the structure would carry the load for which it was designed was a relatively simple matter. The design live load, over and above the weight of the structure itself, was approximately 20 pounds per square foot. The testing operation consisted of placing sand bags on the top surface of the dome until a load of 20 psf was developed.



However, to determine whether or not any effects on the structure were produced by the test loading and the degree of the effects, if there were any, a series of measurements were made. These studies consisted of before-and-after measurements on the deflection of the dome at some 25 points, first with a loading of 10 pounds per square foot, then with a loading of 15 pounds, and finally with a loading of 20 pounds per square foot.

The maximum deflection after 4 hours of sustained load at 20 pounds per square foot over the entire surface of the dome was 3/16 of one-inch in the center area. Deflections at the "eye-brows" were negligible and at other points unmeasurable for normal field equipment.

Another test on the Structure was performed by nature and is perhaps the most significant in terms of the actual loading that might be normally expected. In September of 1961, just about three weeks after completion of the concrete work on the shell, the center of Hurricane Carla passed approximately 50 miles west of the construction site at College Station producing heavy wind loads for a period of two days. U. S. Weather Bureau records from nearby Easterwood Airport show that the maximum recorded wind speed for the period was 67 miles per hour. Whether or not the wind force at the site of the Experimental Structure was as great as that measured at the Airport is open to question. In any case, however, the wind loading must have been very significant.

Careful periodic examinations indicate that no cracking or significant shrinking occurred during or after construction and loading. A few scattered very tiny surface cracks can be seen on the underside of the dome if a careful examination is made. However, these are believed to be in the surface coat only and their extent or frequency did not change after loading.

The conclusion to be reached after the testing by both man and nature is this: since no cracking or damage of any kind occurred due to the test loads and since the deflections measured were for all practical purposes insignificant, the construction process can be said to produce a quality of finished product as good or better than conventional methods of construction.

COST ANALYSIS

As indicated previously, the Experimental Structure was constructed under a cost-plus contract with the Doerner Plastering Company of Houston. The cost-plus contract required that the contractor maintain a careful accounting of the costs for all labor, equipment and materials involved so that proper evaluation might be given to the economy achieved. All actual costs involved in the construction of the Lift-Shape shell itself are itemized below. These figures do not, of course, include the cost of design, engineering and the considerable amount of advance planning done by both the Architectural Research Group and the contractors.

Construction Costs		
LABOR		$1,911.61
Layout and Erection	$ 809.38	
Concrete Work	1,002.23	
Supervision	100.00	
MATERIALS		1,486.31
Steel	$ 409.18	
Lath and Wire	155.80	
Concrete and Sand	769.73	
Miscellaneous	151.60	
EQUIPMENT RENTAL		133.66
INDIRECT COSTS		1,229.48
Taxes and Insurance	$ 226.59	
Travel	349.16	
Overhead and Profit	653.73	
	TOTAL COSTS	$4,761.06

Although there is no simple, satisfactory method for comparing the costs of this building to others, a cost based on the usable square footage of covered space will serve as a beginning point for comparisons. The total area of floor space maintaining at least a ceiling height of 5'-6" is approximately 1,500 square feet. Thus, the cost of the shell alone, neglecting foundation costs, etc., is approximately $3.18 per square foot of usable covered space. Or, the costs might be expressed in terms of the surface area of the concrete shell itself. The area of the shell, not counting the surface of the "legs," is approximately 1,675 sq. ft. Thus the cost per square foot of shell is $2.85.

Comparative Estimates

To provide a basis for comparing these actual cost figures to the cost of constructing the same building by more conventional methods, a number of contractors experienced in thin-shell construction were asked to submit bids on the cost of constructing the shell with conventional formwork.

Robert E. McKee, General Contractor, Inc., of Dallas, Texas was one such organization to supply this information. Their cost figures are listed below. Their proposed formwork would consist of "2 x 6 purlins templated to the shape of the shell and over these would be applied 1 x 4 strips on approximately 6-inch centers, and then applied over the 1 x 4 strips would be quarter-inch plywood or masonite which would be the contact surface." In addition to providing an estimate of costs for the conventional system for constructing the proposed shell, McKee, Inc. also provided an estimated cost for construction using the Lift-Shape method.

CONVENTIONAL SYSTEM	(McKee Bid)
Formwork	$2,715.29
Concrete work	607.00
Steel reinforcing	644.00
Miscellaneous	454.25
Taxes and Insurance	366.98
Overhead and Supervision	750.00
	$5,537.52

Another complimentary bid on the costs for constructing the Experimental Structure by more conventional methods was provided by Gene Murphree, General Contractor, of Houston, Texas. The general scheme proposed was basically the same as that proposed by Robert E. McKee, Inc., of Dallas.

CONVENTIONAL SYSTEM	(Murphree Bid)
Formwork	$2,737.00
Concrete work	1,499.00
Steel reinforcing	640.00
Miscellaneous	1,045.00
Taxes and Insurance	409.00
Overhead and Supervision	700.00
	$7,030.00

The basic differences in these two complimentary bids based on conventional construction methods seems to be in the unit cost of labor, the amount of labor necessary for the concrete pouring and finishing, and in miscellaneous anticipated expenses.

McKee's figures indicate that the conventional system of construction would cost slightly over 23% more than the Lift-Shape method, by his own estimate of costs. This appears to be based on reasonably accurate estimates since the actual cost of the Experimental Structure ($4,761.06) was within $271.23 of the McKee estimate ($4,489.83).

In any case it seems safe to say that the Lift-Shape system of construction for this particular building offers a savings of 23% or more over the conventional system of construction. There are other factors to be considered, of course. If the formwork necessary ror the conventional system were to be reused on several successive structures, it is highly possible that the final costs might be less than for the same number of structures by the Lift-Shape method. Also, the conventional forming system requires no special equipment other than normal carpentry tools, whereas the Lift-Shape system requires a plaster spray machine, a tool not readily obtainable in all locations, particularly small towns.

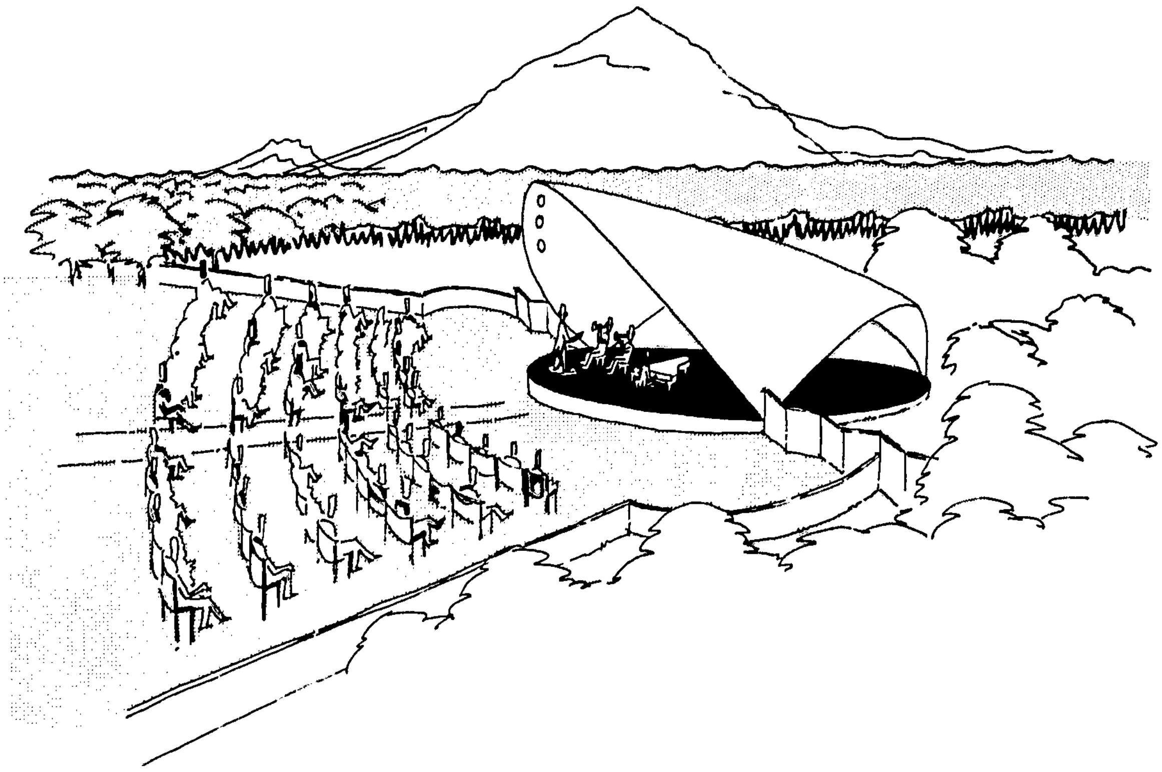
Nevertheless, the Lift-Shape system offers advantages in that it requires a fewer number of skilled craftsmen, and those primarily of one trade, it provides a smooth sand finished surface as opposed to the rather rough surface provided with conventional formwork, and the problems of cracking and settling associated with the removal of conventional forms is eliminated. It seems entirely reasonable also, that the costs inherent in the Lift-Shape system will be reduced as the procedures and methods of development become more common.

ARCHITECTURAL POTENTIALS

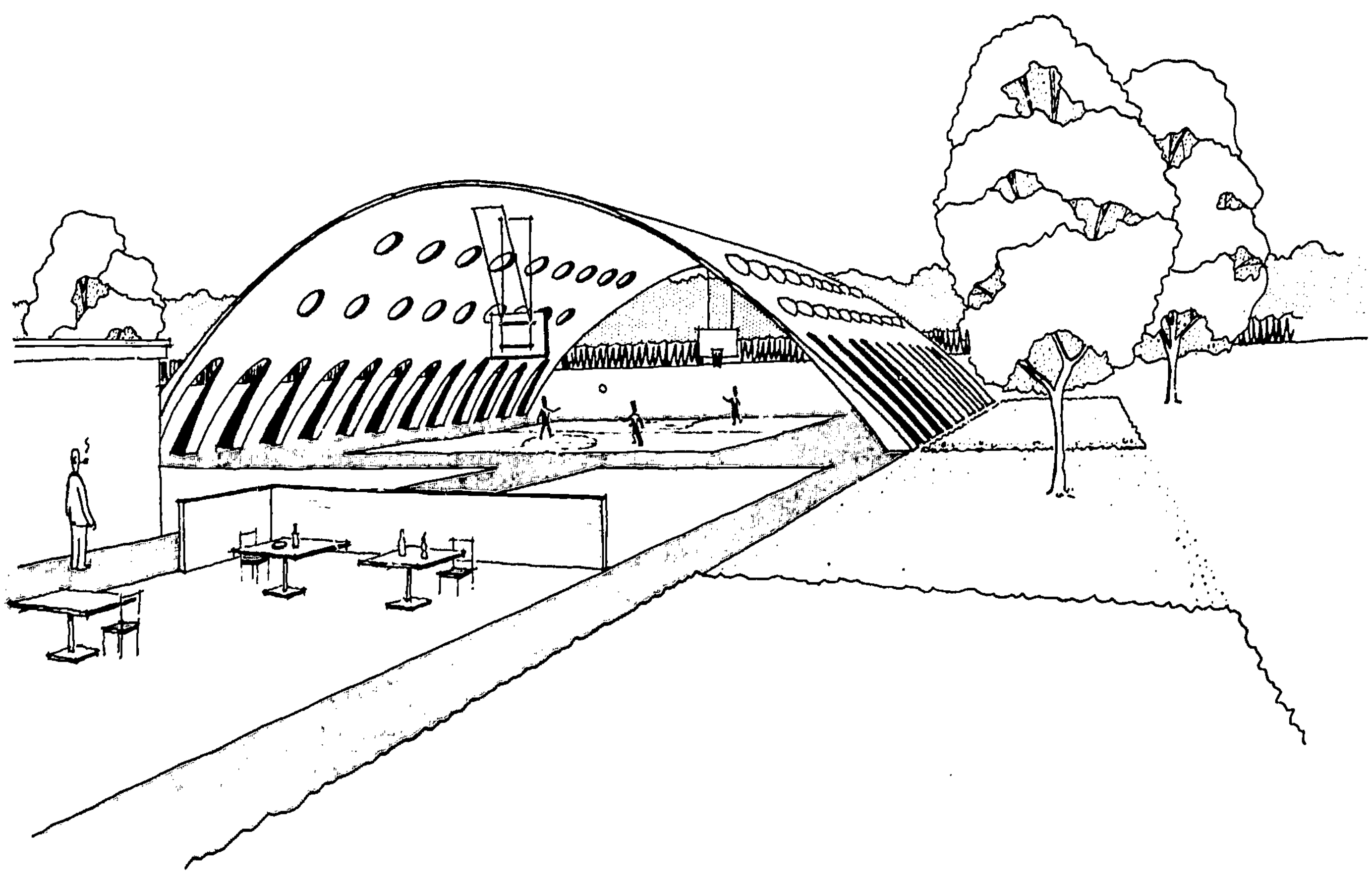
There seems to be no end to the shapes that can feasibly be developed through the Lift-Shape process. Naturally, the research program described in this report has not solved all of the problems to be associated with this erection method. However, this should not prevent immediate consideration of the system for various kinds of building types. Until a number of actual buildings are constructed, involving integration of the problems of construction of walls, glass, doors, plumbing, air conditioning and so forth, the questions concerning how these things can be done will go unsolved.

Even without a complete answer to these problems, however, there are still many areas in which the Lift-Shape process can be put to immediate use. Any shelter which requires no walls, or a minimum of walls, and which might be classified as a semi-shelter, could well use the Lift-Shape method now with spans up to 80 or 100 feet.

Here, for instance is an outdoor school theater and band shell which might serve during the off-season for skating, bingo, or other such games. Such a shape could be easily and economically constructed providing the permanence and maintenance-free service necessary for this kind of public building.



A parabolic vault might well be used as a semi-outdoor physical education facility, housing a basketball court or a swimming pool.



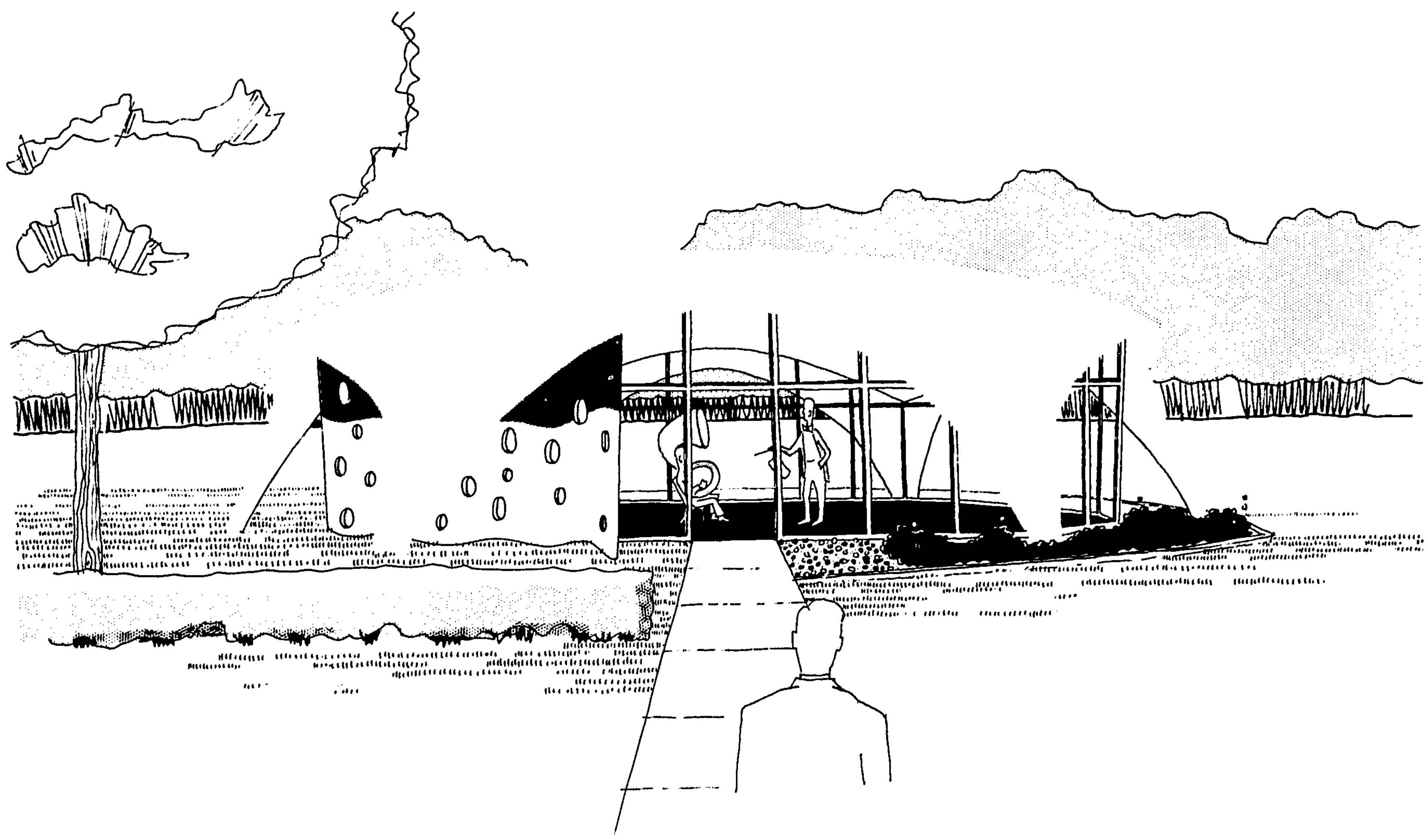
The Lift-Shape Experimental Structure might even be adapted to use as a classroom, bandroom, or administrative office. Such problems as acoustics, insulation, the aesthetic problems of relating curvi-linear walls, waterproofing, and expansion and contraction, are yet to be studied, but there is no reason to believe that these problems can't be solved, based on experience already recorded with thin-shell buildings.

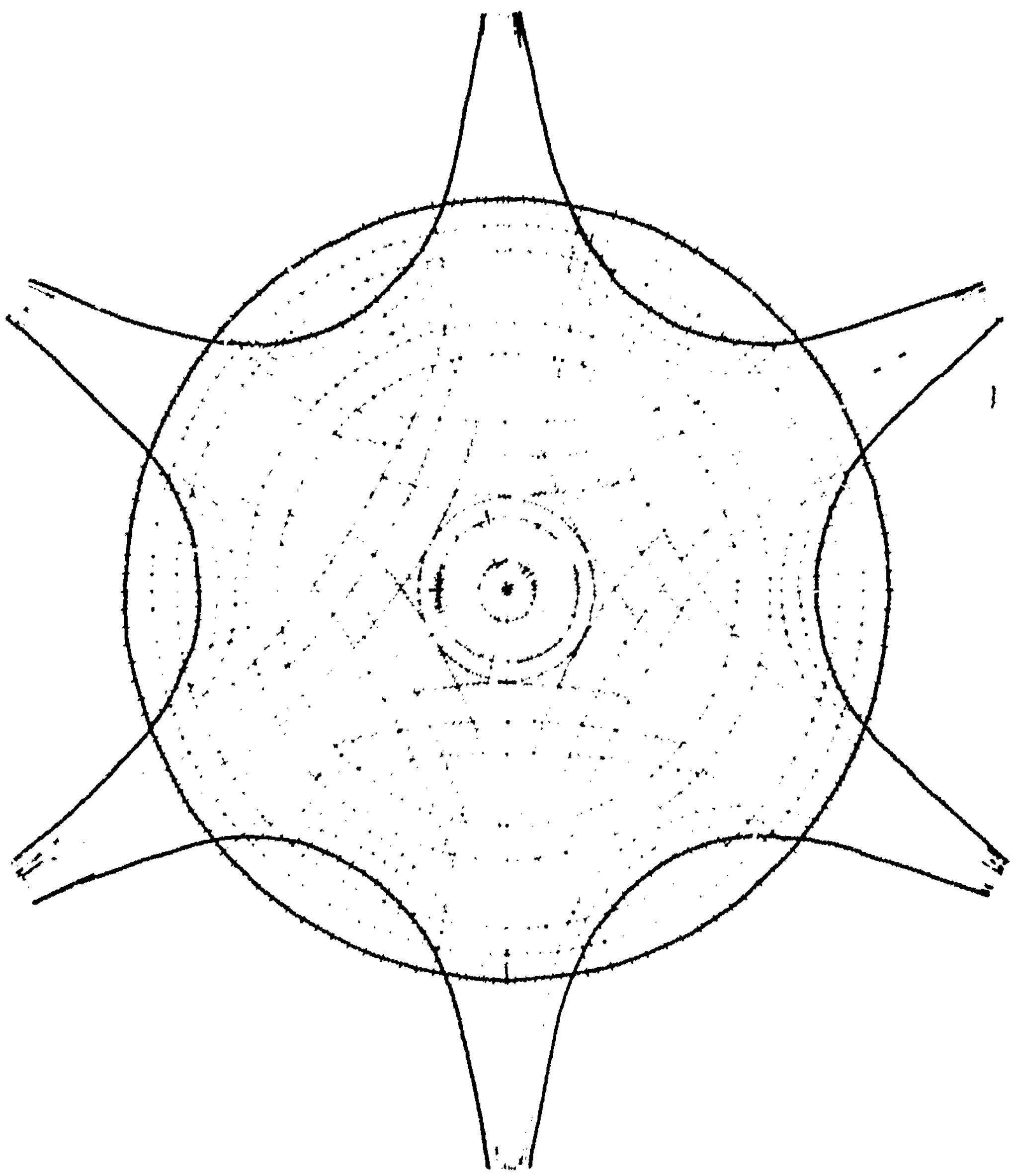
The construction industry should be working towards a construction technique which eliminates many of the evils today considered necessary, such as; waste of materials and labor; the use of numerous trades on the job and the often delicate problem of determining which trade is to do which job; the use of multitudes of different kinds of equipment; and particularly the fantastic amount of transportation necessary to get raw materials from their natural state to the manufacturer and then to the building site. The Lift-Shape technique with its related spray-on covering can help considerably towards the elimination of some of these problems.

Conceivably, a building could be constructed using the Lift-Shape process with all materials consisting of steel and concrete. Lightweight steel studs with metal lath could be easily attached to a Lift-Shape skeleton for walls. The whole building might then be sprayed with concrete in one operation. Different surface textures could be achieved through the use of various concrete aggregates. Chipped marble, pea-gravel, sawdust and a host of other materials can be mixed with concrete and sprayed as readily as sand and cement. Thus, a very large percentage of the building could be constructed by one crew, the lathers and plasterers.

However, even elementary structural analysis points up the fact that concrete, even concrete made with lightweight aggregates, is not necessarily the ideal material for this type of construction. The primary basis for structural analysis of a reinforced concrete shell is to provide strength to support the tremendous dead weight of the concrete of the structure itself. If the weight of the concrete could be eliminated without sacrifice in structural properties, the structural design loading could be reduced considerably. This would mean a significant reduction not only in the amount and strength necessary for the covering material, but also in the amount of steel necessary for the armature. As the world of plastics becomes larger and more flexible each day, it is entirely within the realm of possibility that some plastic material, or combination of materials, may suit the Lift-Shape armature much better than concrete. As a matter of fact, there appear to be plastic materials available now that may readily solve the problems of thin membrane coverings for large spans. If there are such materials available, or if there will be in the near future, the whole concept of building construction may be significantly changed.

It is the intention of the authors to continue this study of the Lift-Shape erection process with a detailed investigation of the possibilities for the use of plastic materials with the steel erection frame. These studies will be of a twofold nature; first, finding one or more lightweight materials for the covering; and, second, determining feasible criteria for developing necessary strengths in the armature itself. The study may also involve the use of materials other than mild steel for the armature, such as high strength steel or aluminum bars or perhaps even bamboo. The construction industry has done great things in the development of new materials, but the most significant advances will come about with new thoughts for new construction techniques.





The Texas A. & M. College System
M. T. Harrington, Chancellor

The A. & M. College of Texas
Earl Rudder, President

School of Engineering
Fred J. Benson, Dean

Division of Architecture
Theo R. Holleman, Head

The Texas A. & M. Research Foundation
Archie Kahan, Executive Director