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USE OF GLASS REINFORCED CONCRETE (GRC) AS A SUBSTRATE FOR PHOTOVOLTAIC MODULES

Final Report

In Reference To:

JPL Contract No. 955281

Prepared For:

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

12 March 1980

MB-R-80/05

PREPARED BY

MBAssociates

Bollinger Canyon Road, San Ramon, California 94583

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ABSTRACT

MBAssociates (MBA), under contract to Jet Propulsion Laboratories (JPL) developed a substrate for flat plate photovoltaic solar panel arrays using a glass fiber reinforced concrete (GRC) material. The installed cost of this GRC panel (designed, developed and fabricated by MBA) is 30% less than the JPL cost goal of the Near Term Low-Cost Flat Plate Photovoltaic Solar Array Program. The 4' x 8' panel is fabricated from readily available inexpensive materials, weighs a nominal 190 lbs., has exceptionally good strength and durability properties (rigid and resists weathering), is amenable to mass production and is easily installed on simple mountings. Solar cells are encapsulated in ethylene/vinyl acetate (EVA) with Tedlar backing and Korad cover film. The laminates are attached to the GRC substrate with acrylic transfer tape and edge sealed with a silicone RTV adhesive.

1.0 SUMMARY

1.1 Introduction

MBAssociates' (MBA) approach to the use of Glass Fiber Reinforced Concrete (GRC) for cost reductions in flat plate photovoltaic solar array systems was to employ GRC as both an encapsulation substrate and part of the array structure.

GRC was selected as a possible structural material on the basis of its combined structural rigidity, flexibility of configuration, resistance to natural elements and weathering and the availability of relatively low cost ingredients. The use of this material in forming a large single piece combined substrate and array structure permits the simplification of structural supports and minimizes on-site labor costs for the field installation. It also eliminates the need for relatively expensive framing materials that are presently used with glass substrates and/or superstrates.

MBA used Bechtel Corporation's study report (Reference 1-1) to select an effective panel size. This study indicated that a 4 ft x 8 ft panel would be the least costly (Figure 1.1). Thus, this size substrate was chosen for the design of a panel using the GRC material.

GRC is a homogeneously reinforced concrete consisting of cement, sand, water and alkali resistant glass fibers (1" - 2" in length) as the reinforcing medium. The combination of the concrete's compressive strength properties and the glass fiber's flexual, tensile and impact strength characteristics produces a material exhibiting synergistically improved properties.

Reference 1-1 Bechtel Corporation, Engineering Study of the Module/Array Interface for Large Terrestrial Photovoltaic Arrays, ERDA/JPL-No. 954698-77/1, June 1977.

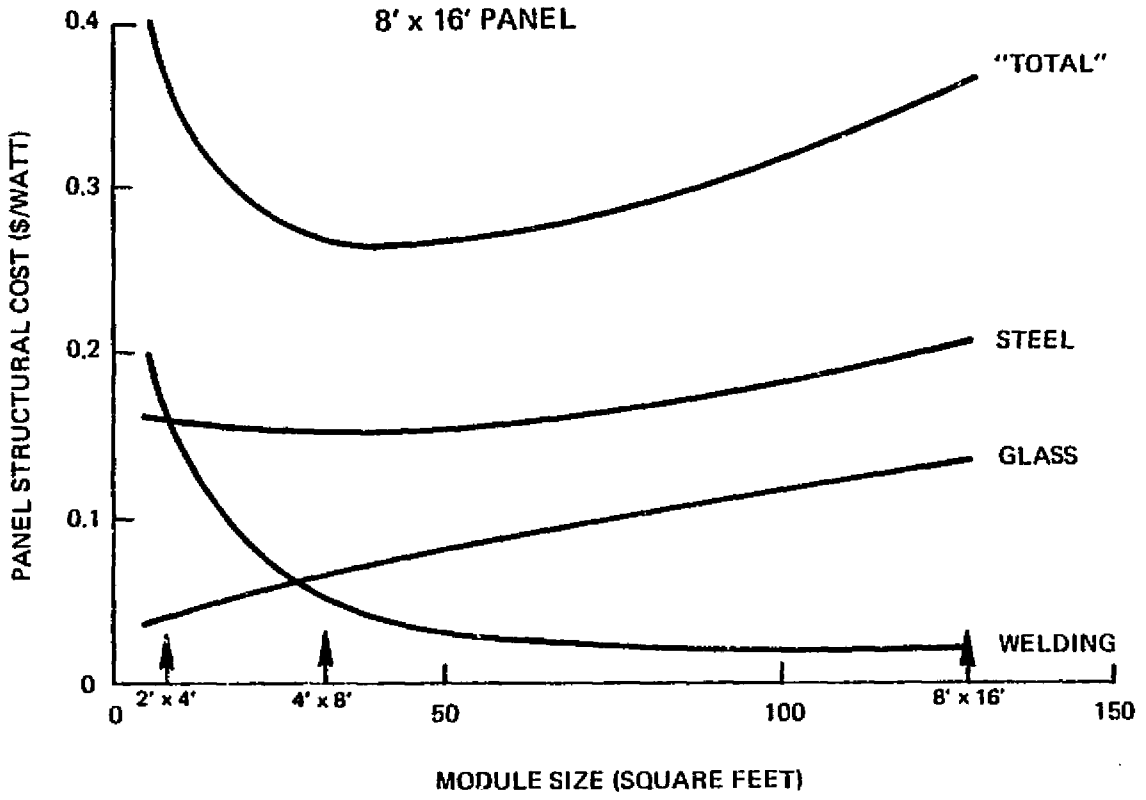


FIGURE 1.1-1
ESTIMATED PANEL STRUCTURAL COST VS. MODULE SIZE

In another JPL funded study (Reference 1-2), the material costs for a 15" x 45" substrate were estimated to be $.13 - $.14/ft^2 for wood products based on the criteria of 1/4" maximum deflection (at center) under a uniform loading of 50 psf load. "The wood products substrate" material costs, combined with the steel costs of the Bechtel study indicated a total material cost of $1.75/ft^2 for presently used array structures. Using preliminary structural design concepts, MBA estimated that the material costs for a GRC Substrate could be $.39/ft^2 which would be a considerable cost reduction. These costs are in 1975 dollars.

When glass fibers were first used in cement, in an attempt to reinforce its strength, the test samples were initially strong but the strength diminished as the samples aged because of the highly alkaline environment, provided by the cement, attacked the surfaces of the glass fibers.

In 1971 scientists in England, at Pilkington, Bros. Ltd. and the Building Research Establishment, announced joint development of an alkali resistant glass fiber. In the United States Owens Corning also developed an alkali resistant fiber at approximately the same time. The two firms have worked out a technology exchange and are both continuing research on the glass fibers. This development has made possible the glass reinforced concrete (GRC).

Industrial applications of GRC includes a roof of a large pavilion as early as 1977. Other projects located in the United States which have utilized glass fiber reinforced concrete are:

Project	Architect
South Central Bell Telephone Charlotte, Tennessee	Sverdrup and Parcel
University of Tennessee Arts and Architecture Building	McCartney, Bullock & Holsapple
Redstone Arsenal Redstone, Alabama	Warren, Knight & Davis

Reference 1-2 Cuddihy, Edward, Encapsulation Material Trends Relative to 1986 Cost Goals, Jet Propulsion Laboratory Report No. 51-1-61, 13 April 1978.

Project	Architect
Quaker Oats Warehouse St. Joseph, Missouri	A. M. Kinney
RCA Alaskcom Office Building Anchorage, Alaska	M. Troy Jenkins
Calista Sheraton Hotel Anchorage, Alaska	CCC/Hellmuth, Obata & Kassabaum
U. S. Post Office Ketchikan, Alaska	Grahm Associates
Maryland Education Center Hagerstown, Maryland	Nes, Campbell & Associates
South Central Bell Telephone Birmingham, Alabama	Warren, Knight & Davis
Nashville, House Nashville, Tennessee	Hart, Krivatsy & Stubee

1.2 Objectives

The overall objective is to provide proven technology and hardware that will be capable of achieving reductions in the cost of flat plate photovoltaic modules early in the 1979 - 1981 time-frame.

To achieve the overall objective, the following goals were set:

- Determine the characterization of GRC through varying ingredients and strength testing.

- Select the best GRC ingredient combination and curing methods to achieve a material with:
  - Low cost ingredients
  - Good early strength
  - High final strength
  - Workability amenable to mass production
  - Good dimensional stability
  - Weathering resistance to environmental elements
  - A life expectancy of 20 years or more
- Design a substrate structure with the following features and restraints:
  - Readily mass produced
  - 4ft. x 8ft. in size
  - 4 point suspended
  - Maximum deflection of 1/4" under a uniform load of 50 psf
  - Economical for field assembly and installation
- Propose a manufacturing facility to produce substrates at a 15 megawatt per year rate using technology that would be transferable to industry.

1.3 Results

A GRC combination using a sand/cement ratio of .66 to 1.0 with 1½" long alkaline resistance glass fibers (5% by weight) was developed and chosen as the best mix to produce a mortar that was easily sprayed; had good slump characteristics; had sufficient early strength that the castings could be removed from the molds within 12 - 18 hours; and was one of the most economical since it contained a large proportion of sand, an inexpensive ingredient.

The amounts of each ingredient used per 100 lbs. of mortar were: 17 lbs. of water, 47 lbs. of Portland Type 1 cement, 31 lbs. #30 silica sand, 5 lbs. of glass fiber, 42.3 ml of Pozzolith 300R admixture.

The 28 day strength test results for 1/4" test plates of this GRC combination were:

(LOP) Limit of proportionality = 730 psi

(Mod) Modulus at .25" deflection = 1537 psi

These results were obtained from flexural test procedures and formulas as described in section 2.2 and cannot be compared with normal ASTM tensile strength measurements.

The substrate design selected had the following features. A 1/4 inch thick, 4 ft x 8 ft, glass reinforced photovoltaic array solar panel incorporating:

- A smooth, dense, hard, flat surface.
- Two (2) trapezoidal stiffening ribs serving also as structural support points.
- Strategic placement of ribs, with imbedded support tubes (standard PVC tubing), minimizing bending moments and resulting stresses produced by installation and wind loads.
- A structural design amenable to mass production which also minimizes the labor required for installation.
- A four (4) point support system requiring only:
  - Four (4) wooden posts (6" x 6") pressure treated fir each serving two (2) separate panels.
  - Four (4) simple post brackets of (6" x 6") standard square structural steel tubing, each serving two (2) separate panels.

- Two (2) support bars (standard one (1) inch, schedule 40, galvanized pipe) with No. 7 reinforcing steel bars inserted in the pipe ends as bracket connectors (4, 20.5" long).

Photographs of a 1/4" scale model are shown in Figures 1.3-1 and 1.3-2. A full size panel submitted to uniform loading at 50 psf had maximum deflections of .10 and .20 inches, respectively, when the loading was applied to the top (cell surface) and bottom (rib section).

Manufacturing cost data submitted to JPL's computerized cost program "SAMICS" resulted in a peak watt cost of $6.56 for the GRC panel in 1980 dollars. This is the complete cost of a flat plate photovoltaic panel ready for installation including manufacturing costs. However, the greatest amount of savings would be realized in installation costs since the GRC panel is self supporting and does not require expensive metal framing. Definitive information on installation costs of other types of panels has not been obtained but a reportedly cost effective metal support frame for photovoltaic panels was displayed at JPL's Progress Integration Meeting, December 1979 with a represented cost of $12.80/m^2 excluding tooling costs. An MBA estimated cost summary for an installed panel indicates a cost 30% below JPL's cost goal. This estimated cost summary comparison does not include cells or encapsulation labor. The detailed cost data is presented in section 7.2.

1.4 Conclusions

It was concluded that a substrate, as designed and produced by MBA, using the GRC ingredient combination developed would satisfy all strength and installation requirements and be extremely effective in reducing the cost of flat plate photovoltaic arrays. It was estimated to cost 30% less installed than JPL's cost goals. The greatest cost reducing impact of this substrate design lies in the elimination of the metal framing and its related installation costs.

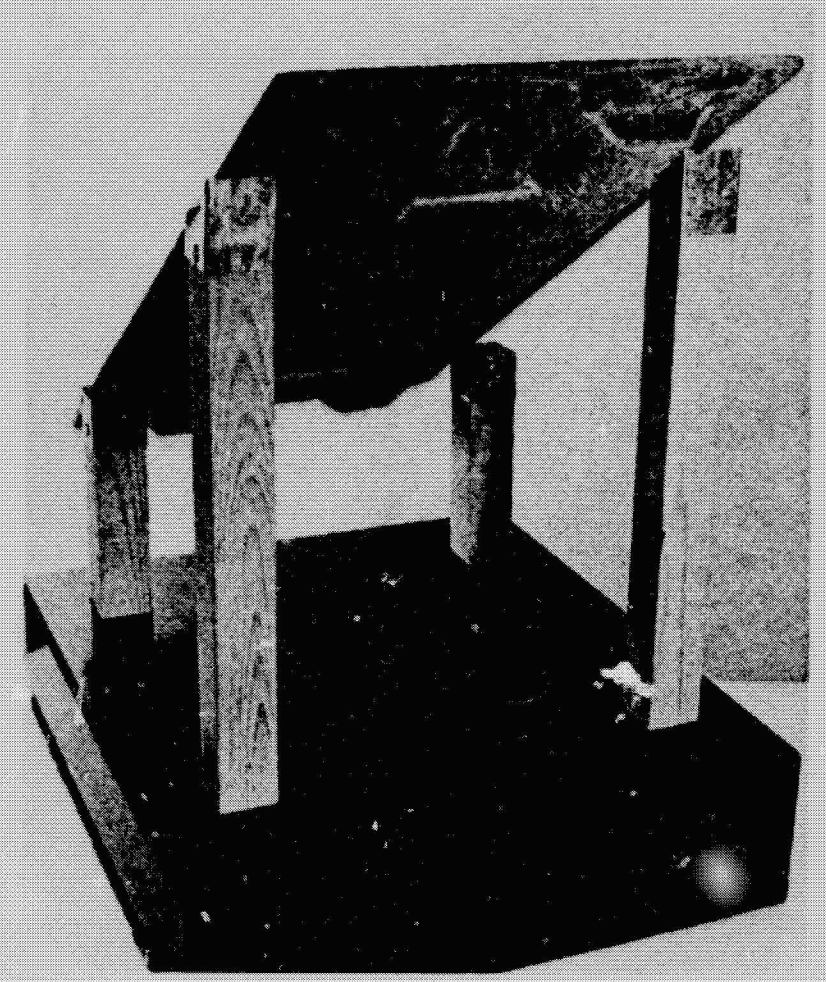


FIGURE 1.3-1
MODEL OF INSTALLED GRC PANEL – BOTTOM VIEW

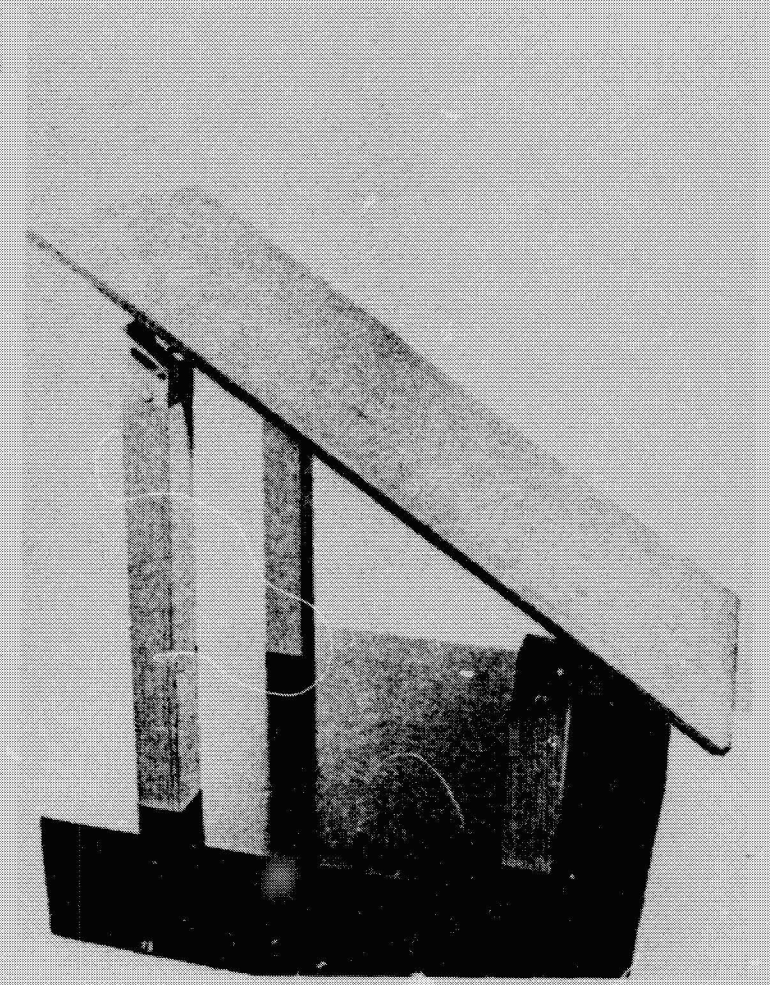


FIGURE 1.3-2
MODEL OF INSTALLED GRC PANEL – TOP VIEW

2.0 GRC CHARACTERIZATION

2.1 Background

There is considerable published information on GRC that can be obtained from the various references. A list of references are included in the appendix. Much of the early investigation, testing and research has been performed at Building Research Institute and Pilkington Brothers Limited, both in England. The reported physical properties are as presented in Table 2.1.

Since GRC offers the combination of structural rigidity, flexibility of configuration, long term stability and durability when exposed to atmospheric conditions, and low material costs; it was considered, by MBA, to be the most promising material for the cost reduction of flat plate photovoltaic substrates. The use of such material would allow for elimination of the glass or other substrates that require rigid support framing of relatively more expensive materials such as steel or aluminum.

GRC is basically a cement and sand mortar with imbedded glass fibers. Various combinations of ingredients were tested to develop a combination that would best suit the application for photovoltaic solar cell substrates. The ingredient combination desired was one that could be readily sprayed, inexpensive, have good curing qualities which would provide sufficient one day strength that it could be removed from the mold, have good slumping characteristics so it could be sprayed on a variety of surface configurations and have sufficient final strength and durability characteristics to withstand the installation handling, wind loads and long exposure to natural elements.

2.2 Test Procedures

A single variable technique was used to separately identify the various effects upon the strength characteristics of GRC by varying the constituents of the mortar used. The test plates were nominally 12" x 24" and of varying thicknesses from 1/4" to 1/2". At least two test plates were used for each test point. Plates were fabricated in molds

TABLE 2.1

PHYSICAL PROPERTIES

GLASS FIBER REINFORCED CONCRETE

Ultimate flexural strength	3,000 - 4,500 psi
Ultimate tensile strength	1,000 - 1,600 psi
Compressive strength	7,000 - 12,000 psi
Impact strength (Charpy)	70-140 inch - lbs./in^2
Youngs Modulus	1.5×10^6 psi - 3×10^6 psi
Density	105 lbs./ft.^{3} - 130 lbs./ft.^{3}
Modulus of Rupture	3,000 - 4,600 psi
Thermal Conductivity	7.0 BTU in/ft^2 Hr $^\circ$ F.
Coefficient of Thermal Expansion	6×10^{-6} - $9 \times 10^{-6}/^\circ F$

made of high density overlay plywood. The molds were coated with a chemical release agent to allow removal of the plate from the mold after curing. Plates were spray cast in approximately 1/8" layers. Each layer was vibrated and rolled to remove the entrapped air and increase the density of the GRC. All plates, except one group, were placed in plastic bags to cure until they were tested. The plates not placed in plastic bags (group B-1) were cured with the use of a curing compound which was sprayed on the molded GRC. Plastic bags were used to keep the moisture (needed for adequate curing) from evaporating. If bagging or curing compounds were not used, water would have to be added regularly to keep the specimens moist. Curing compound seals the surface inhibiting evaporation.

The first group of mixes, with varying amounts of ingredients, was tested at the intervals of curing of 1, 7, 28 and 56 days. A second group of mixes was tested after the curing period of 28 days.

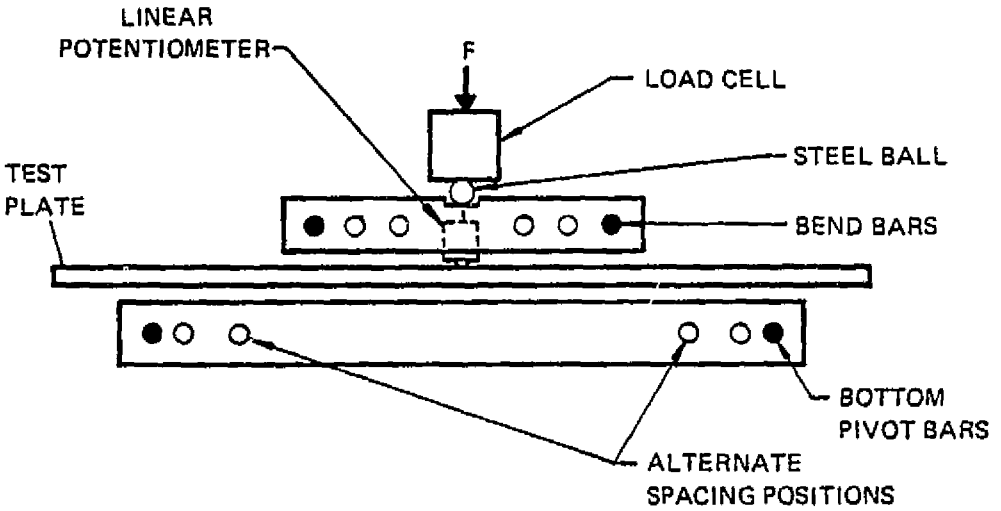
The test procedure was designed so that the results could be used to evaluate the relative performance of the various GRC compositions. The procedure was not intended to produce results to be compared with GRC properties derived from other physical test properties. The testing consisted of measuring the force and deflection in a 4 point bending apparatus. A schematic of the bend test fixture is shown in Figure 2.2-1. The loading was applied at a constant rate. The force and deflection were measured with a load cell and a potentiometer respectively and results plotted simultaneously with an XY recorder.

The bending stress was calculated at the limit of proportionality and at .25" deflection. See Figure 2.2-2 which is a typical force deflection bending graph as plotted by the XY recorder. Stress calculations were determined by the use of the following formula:

$$F_b = PL/bd^2$$

where:

P = Load applied (lbs.)
F_b = Bending stress (lbs./sq.in.)
L = Support span (inches)
b = Width (inches)
d = Thickness (inches)



SPACING OF BEND BARS

1/4" PLATE	4" SPACING ON LOAD 12" SPACING ON BOTTOM PIVOTS
3/8" PLATE	6" SPACING ON LOAD 18" SPACING ON BOTTOM PIVOTS
1/2" PLATE	7" SPACING ON LOAD 21" SPACING ON BOTTOM PIVOTS

FIGURE 2.2-1
BEND TEST FIXTURE SCHEMATIC

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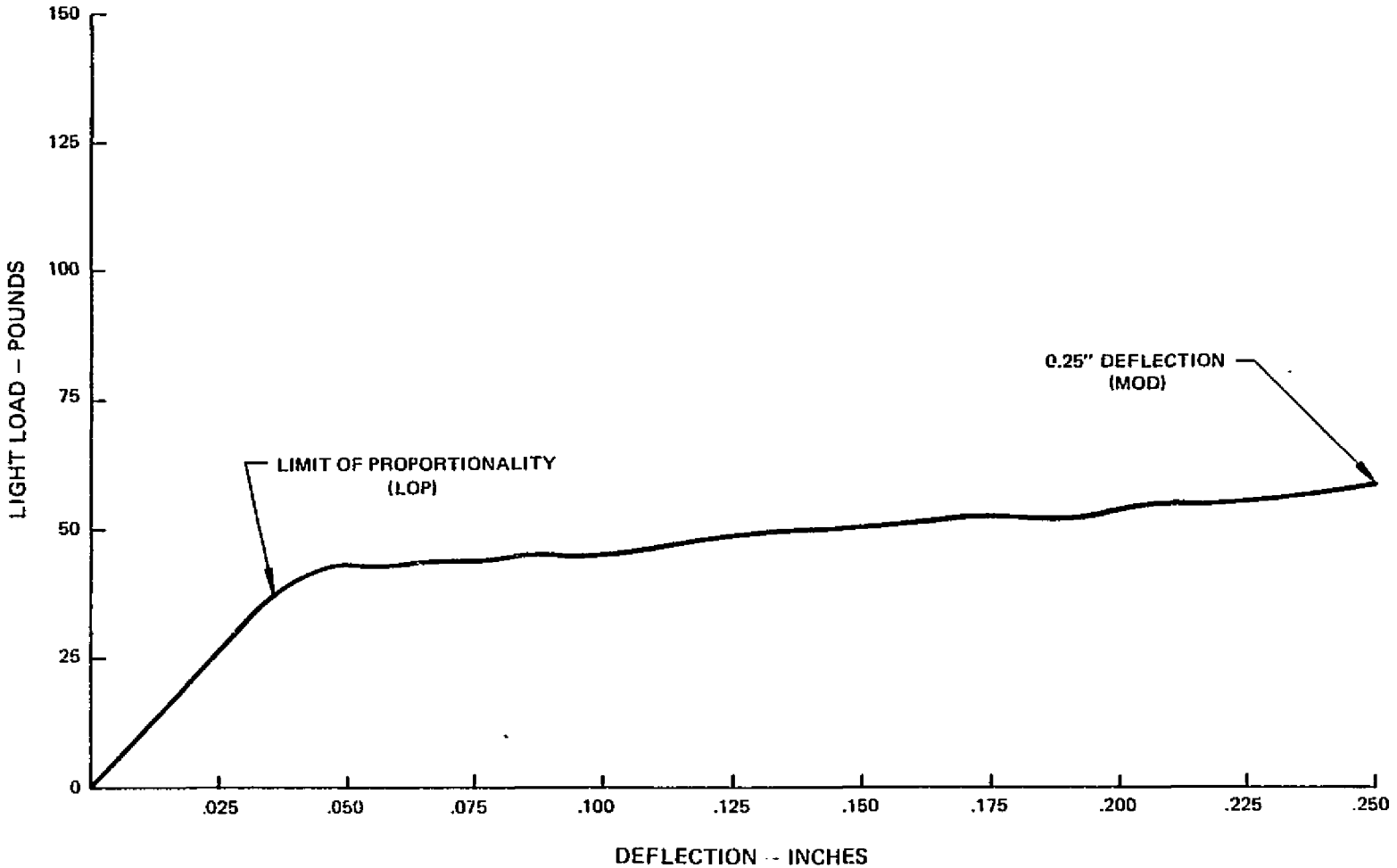

FIGURE 2.2-2
TYPICAL FORCE/DEFLECTION GRAPH

2.3 Test Equipment

A 6 ton hydraulic press was adapted for the strength test. A linear potentiometer was mounted at the bend center line of the test plate to measure the amount of deflection and a load cell at the center of the bend fixture to measure the force applied. These were both connected to an XY recorder which plotted the stress/strain graph. In order to provide adequate control over the rather small loads applied with such a large capacity press, it was necessary to use a motorized gear combination to apply the load to the "inching control" mechanism of the press. This equipment is shown in Figures 2.3-1 and 2.3-2.

2.4 Test Results of the First Group of Ingredient Combinations

The results obtained from testing the first group of ingredient combinations are shown in the Table 2.4. The values presented are the average values. Also included in this table are the ingredients used in each mix and the amount. All combinations were tested after being cured in plastic bags for the curing time intervals except the B-1 which was cured in open air after being sprayed with a curing compound. The bending stress at the limit of proportionality was higher in all cases for the baseline composition of 1/4" in thickness cured in plastic bags (B) than for the baseline composition cured in air with the curing compound (B-1).

A special admixture was used in all mixes (Pozzolith 300-R) which reduces water content and in general improves workability, slump characteristics, strength characteristics, reduces permeability and cracking tendencies and improves durability. A pamphlet on Pozzolith 300-R is included in the appendix.

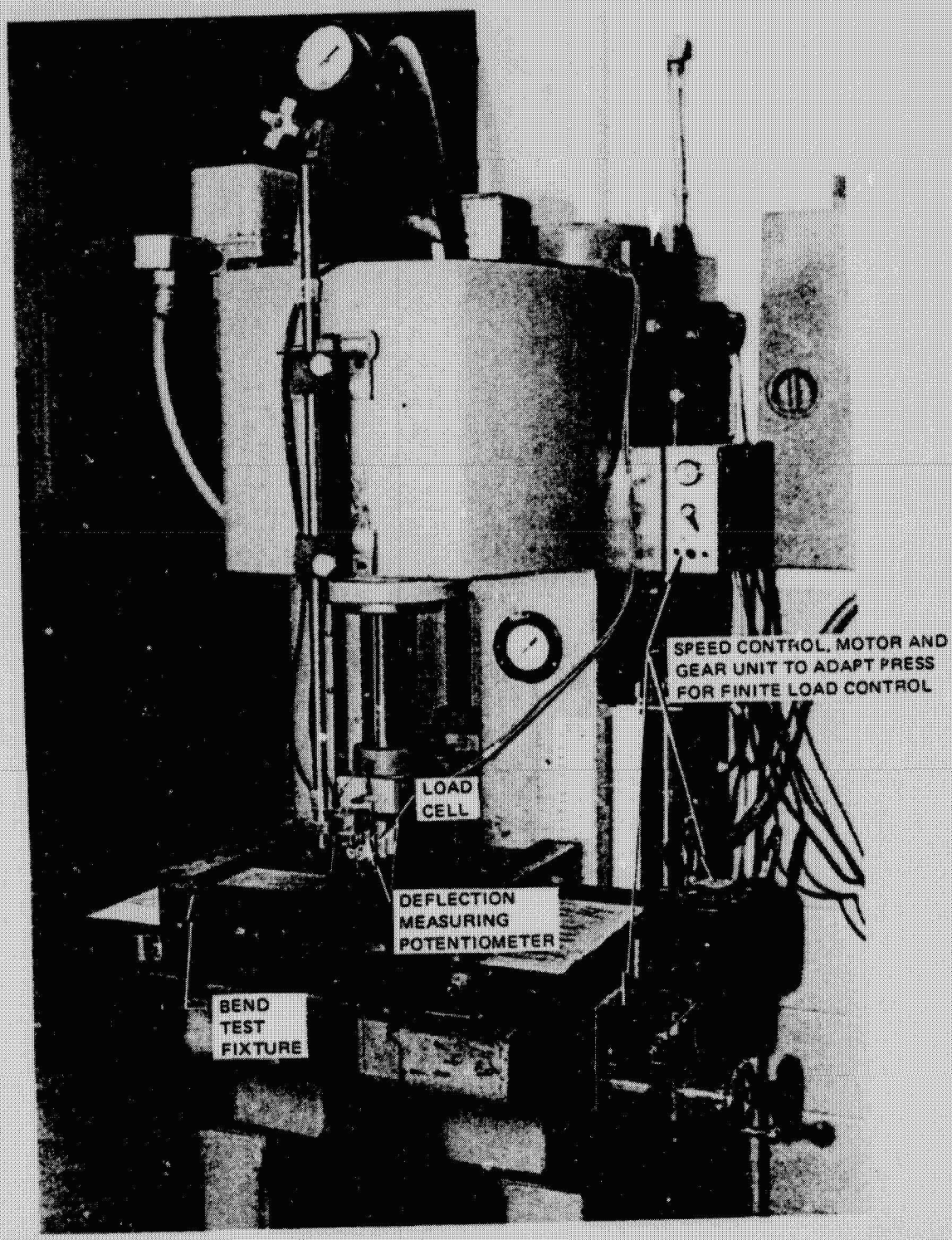

FIGURE 2.3-1
FOUR POINT BEND TEST EQUIPMENT

MBA

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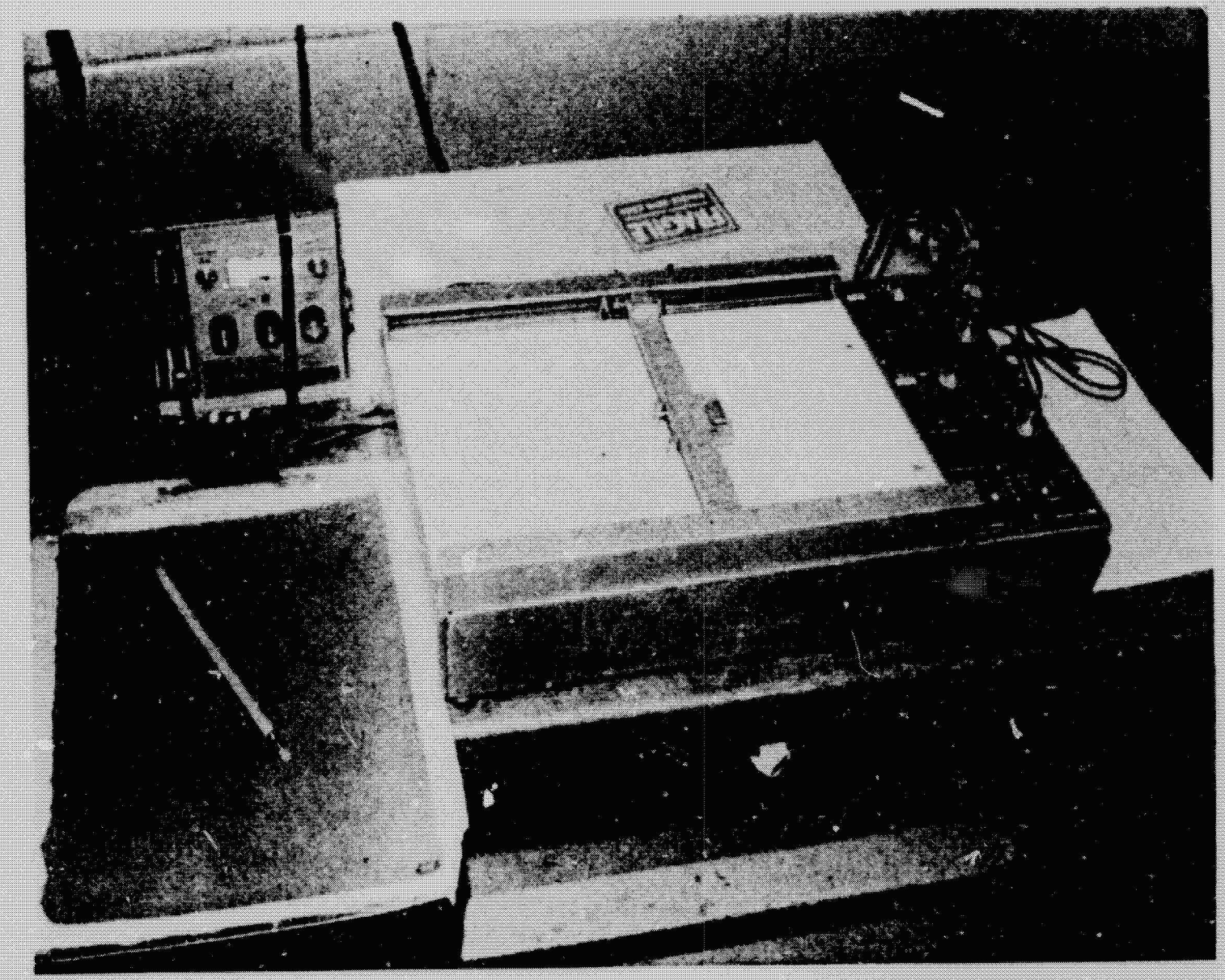


FIGURE 2.3-2
X-Y RECORDER

TABLE 2.4

AVERAGE BENDING STRENGTH VALUES

FIRST GROUP OF MIXES

CURING TIME	STRENGTH VALUE psi	MIX A			MIX B		SPECIMEN SIZE AND COMPOSITION B-1		C		D		MIX E		MIX F		MIX G		MIX H	
		1/4"	3/8"	1/2"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"	1/4"	3/8"
1 DAY	LOP	375	162	375	597	703	480	672	587	489	706	583	468	561	515	296	522	[illegible]	466	466
	MOD	822	667	605	893	874	792	1249	950	659	1178	893	886	725	755	264	1007	592	765	784
7 DAY	LOP	823	551	584																
	MOD	1466	942	1086																
28 DAY	LOP	1244	591	1039	890	860	602	786	656	656	959	846	731	946	776	657	767	661	796	894
	MOD	1703	1061	1856	1586	1365	1184	1299	1228	1229	1986	1286	1702	1648	1424	1113	1495	1081	1533	1678
56 DAY	LOP	737	654	910	905	904	655	534	815	815	834	783	1322	910	727	655	896	501	742	658
	MOD	1542	1030	1465	1593	1542	1198	870	1339	1339	1566	1358	2094	1692	1635	1213	1659	838	1372	1533
INGREDIENTS AND AMOUNTS																				
Cement		Portland Type II			Portland Type I		Portland Type I		Portland Type V		Portland Type III		Portland Pozzolan		Yosmite Type I		Yosmite Type I		Yosmite Type I	
Amounts		72 lbs.			72 lbs.		72 lbs.		72 lbs.		72 lbs.		72 lbs.		64.5 lbs.		72 lbs.		72 lbs.	
#10 Sand		30 lbs.			30 lbs.		30 lbs.		30 lbs.		30 lbs.		30 lbs.		30 lbs.		30 lbs.		30 lbs.	
Water		24 lbs.			24 lbs.		24 lbs.		24 lbs.		24 lbs.		24 lbs.		24 lbs.		21.5 lbs.		21.5 lbs.	
Curing Agent							Sprayed coating													
Pozzolith 300 R		64 ml			64 ml		64 ml		64 ml		64 ml		64 ml		65 ml		64 ml		127 ml	
Air Entraining Darex																	16 ml			
Pozzolan Lassenite															7.5 lbs.					
Mix Type		Low Alkali			Baseline		Baseline		Sulfate Resistant		High Early Strength		Portland Pozzolan		Pozzolan Additive		Air Entrained		Plastic	

The low alkali composition, Type A, had a bending stress at the limit of proportionality lower than the comparable baseline composition after one day, but greater after the 28 day, and then again lower after the 56 day curing time. Thus, the low alkali composition did not appreciably increase the strength after it was fully cured. The bending stress at the limit of proportionality for the sulfate resistant composition, (Mix C), was less than the bending stress of the baseline composition. The bending stress at the .25" deflection for the sulfate resistant composition for the one day curing time was slightly greater than the baseline composition but somewhat less for the 28 day curing time and again less for the 56 day curing time. Thus it did not enhance the overall strength characteristics and would have to be relatively better than the baseline's composition, in long term performance, before it could be considered for use.

The bending stress results for the high early strength composition, (Mix D), were not significantly different from those of the baseline composition; therefore, there appears to be no advantage in using the high strength composition for fabrication.

The bending stress results for the Portland Pozzolan cement composition, (Mix E), and the Pozzolan additive composition, (Mix F), were similar to the bending stress results for the baseline composition. With the possible long term gain of these two compositions and the possiblity to retard the degradation of the glass fibers may make them desirable compositions and thus warranted further testing.

The bending stress for (Mix C) with the "DAREX" additive, air entrained, (Mix G) was lower than the baseline composition in all cases. A pamphlet on "DAREX is included in the appendix.

Plasticized composition's bending stress, (Mix H), was not significantly different than the baseline composition. The use of a plasticized composition does not appear to be warranted in production as it is more difficult to use.

2.5 Test Results of Second Group of Ingredient Combinations

In an attempt to improve upon the strength and workability characteristics of the GRC and to re-verify some of the results obtained during the first tests, six different combinations were tested, along with the original baseline composition as a comparison. These compositions and their results are shown in Table 2.5.

The .50/1.00 sand/pozzolan cement (Mix J), performed comparably to the baseline composition strength wise; however, the composition exhibited stickiness. This resulted in an increase in the time required for spray casting and compaction.

The .66/1.00 sand/pozzolan cement (Mix L), produced bending stresses also less than the baseline composition. In addition, it had excessive stickiness which made it unsuitable for spray casting.

The .50/1.00 sand/cement (Mix M), performed comparably to the baseline composition in all strength tests and exhibited the same or comparable spray casting and compaction properties.

The .66/1.00 sand/cement (Mix N), was greater than the baseline composition in bending stress characteristics while the spray casting and compaction characteristics were very comparable to the baseline composition.

The 1.0/1.0 sand/cement (Mix P), composition's strength performance was greater than the baseline composition's strength performance; however, the high sand content produced a harsh mixture. This harshness resulted in spray casting and compaction characteristics which were less satisfactory than the baseline compositions.

Thus the .66/1.00 sand/cement ratio composition, (Mix N), exhibited superior strength and workability characteristics over those of the other compositions. It also is less costly since it contains more of the cheaper ingredient, sand. The increased sand content also reduces shrinkage. Thus, this composition, (Mix N), was selected for use in the fabrication of the flat plate photovoltaic substrates because of its demonstrated suitability for spray casting and its superior strength, economical and stability characteristics.

TABLE 2.5-1

AVERAGE BENDING STRENGTH VALUES

SECOND GROUP OF MIXES

28 Day Tests		MIX B-2	MIX J	MIX K	MIX L	MIX M	MIX N	MIX P
LOP (psi)	1/4"	642	691	696	569	660	730	748
	3/8"	548	613	546	477	345	727	704
	1/2"	561	678	604	224	596	552	706
MOD (psi) @ .25	1/4"	1291	1333	1333	1164	1489	1537	1428
	3/8"	1329	1409	1103	1046	1199	1415	1550
	1/2"	1264	1233	1139	785	1505	1587	1634

H_2O (lbs)	24	29	30	32	22	21	21
Cement Portland(lbs)	68 Type I	43 Type II	38 Type II	32 Type II	66 Type I	60 Type I	50 Type I
Sand #30 (lbs)	29	27	27	25	33	40	50
300-R (ml)	61	59	96	96	59	54	75
Airoy Pozzolan (lbs)		22	25	32			
Sand/Cement	.43/1.0				.50/1.0	.66/1.0	1.0/1.0
Pozzolan/Cement		.50/1.00	.66/1.00	1.0/1.0			

3.0 SUBSTRATE DESIGN

3.1 Original Concepts

Original concepts for this substrate panel were based on the published physical properties of GRC, a very small allowable deflection, and extreme corner support points. The original concept is shown in Figures 3.1-1, 3.1-2 and 3.1-3. By changing the design to position the support points at positions inside the edges of the panel, an intermediate design was conceived. This concept is shown in Figures 3.1-4 and 3.1-5. These new positions reduced the stress moments on the panel.

3.2 Structural Testing

Several structural design concepts were then sprayed cast and strength tested to determine their ease of manufacture and strength characteristics. Some of these test specimens are shown in Figure 3.2-1.

The first three specimens cast and tested were a longitudinal section and a cross section of the panel. These are shown in Figures 3.2-2, 3.2-3 and 3.2-4. Cardboard forms were used to form the rib structure; however, these were found difficult to use and maintain control of the thickness of the various sections. GRC forms were then used for the various structures and found to be a great improvement.

Some tubular rib structures were spray cast but were found to be difficult to compact to obtain the necessary density and uniformity. Two are shown in Figure 3.2-5. It is believed that forms needed to manufacture this type of structure under automated conditions would be complicated and expensive. The compaction at the bottom of the tubular structure would also be difficult to obtain without a complicated fixture.

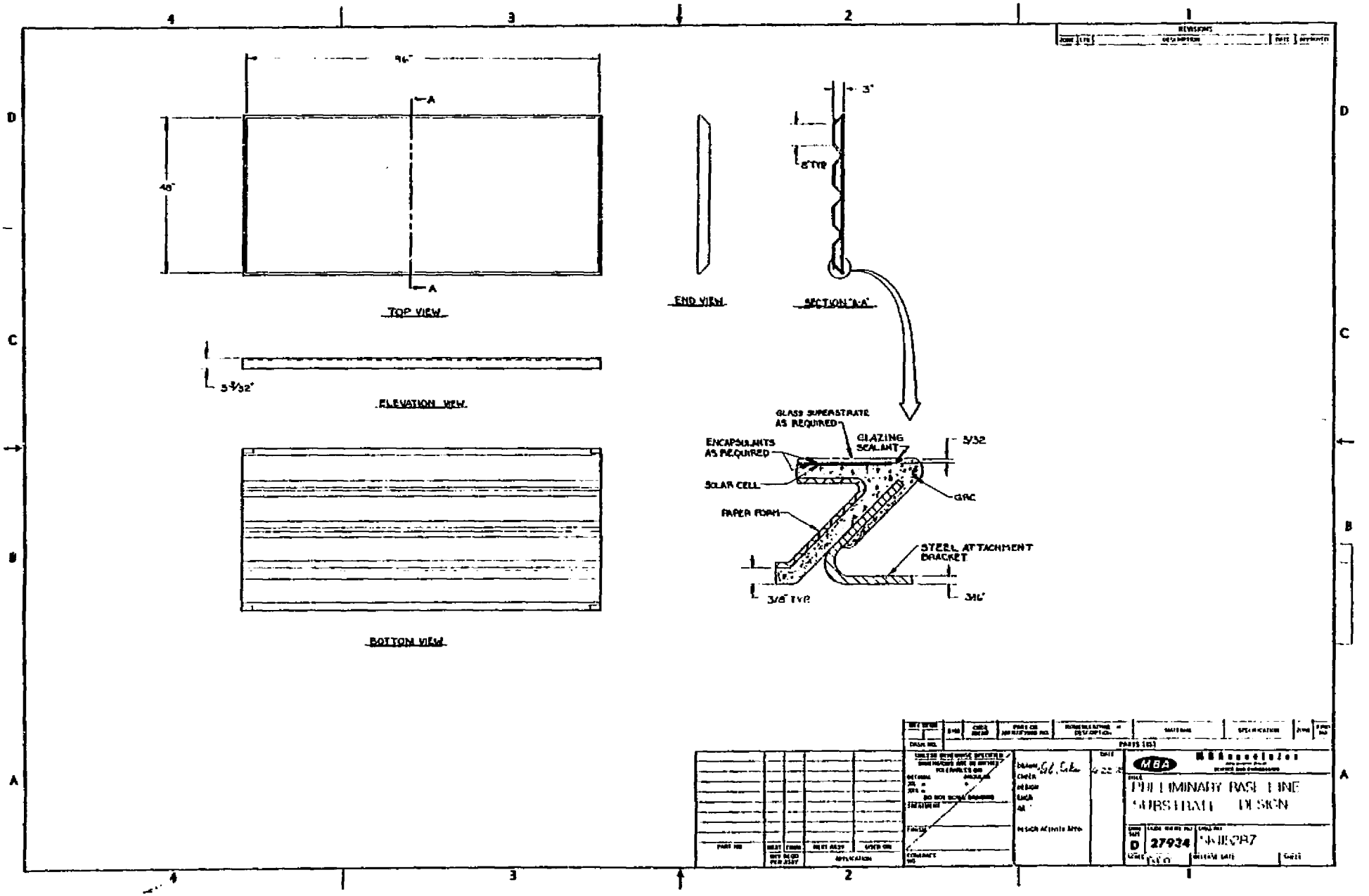


FIGURE 3.1-1
PRELIMINARY BASELINE SUBSTRATE DESIGN

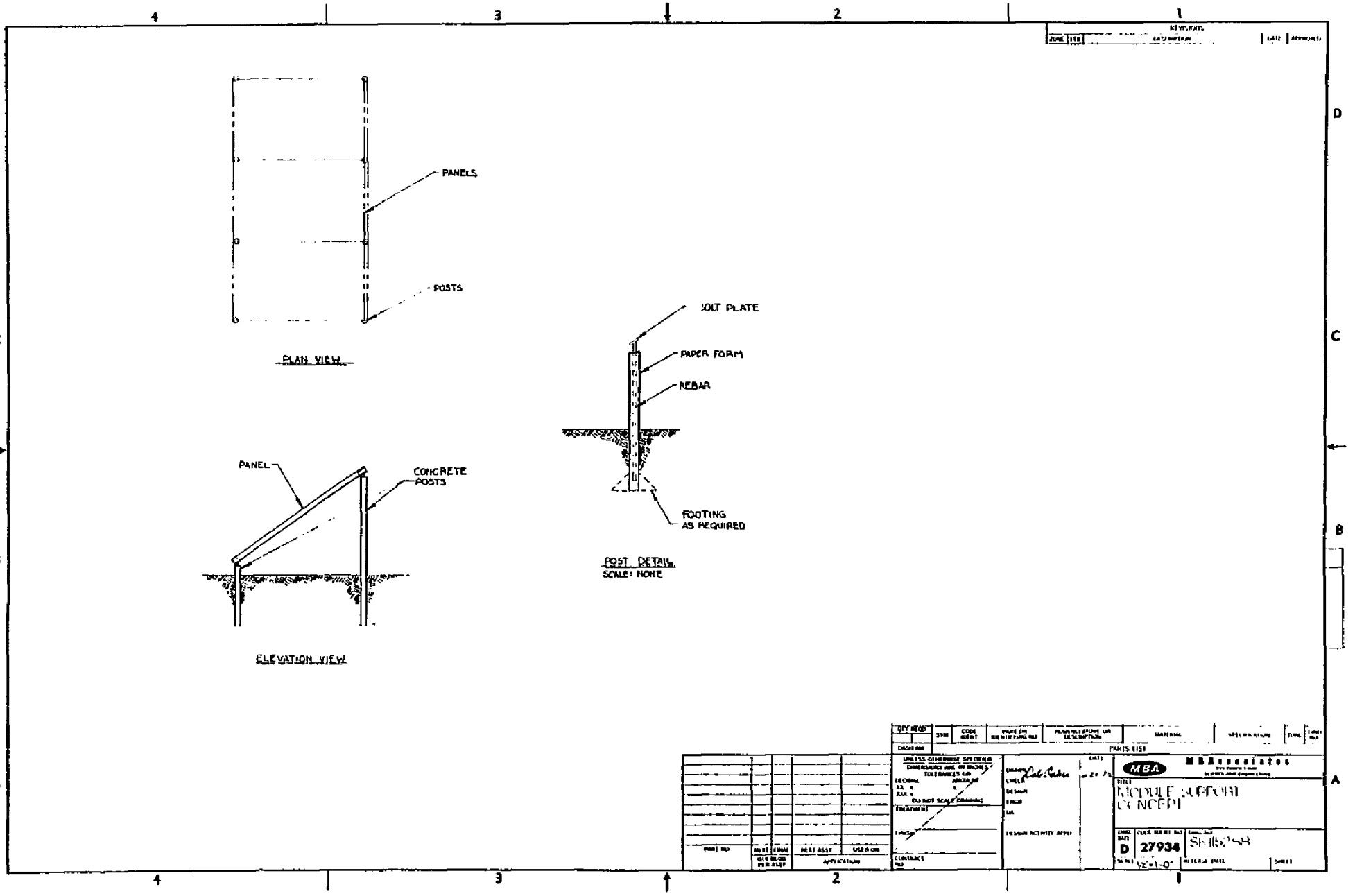
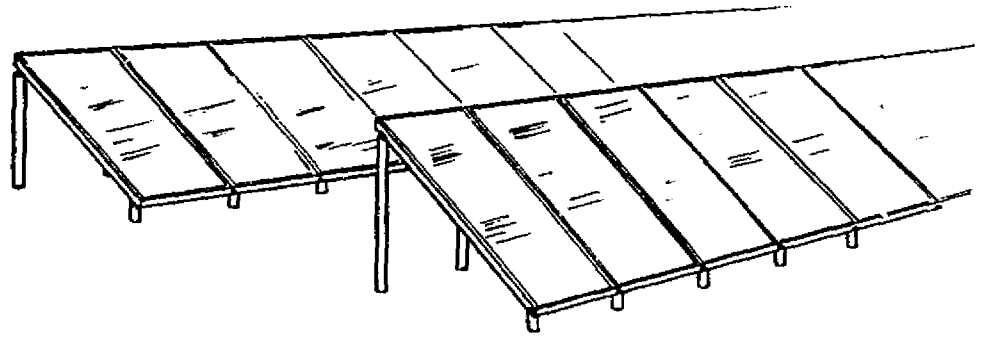


FIGURE 3.1-2
MODULAR SUPPORT CONCEPT (Sheet 1 of 2)



REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE	FIND NO.
DASH NO.								

PARTS LIST

PART NO.	NEXT	FINAL	NEXT ASSY	USED ON
	QTY REQD PER ASSY		APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMAL .XX ± .XXX ± ANGULAR ± DO NOT SCALE DRAWING

TREATMENT

FINISH

CONTRACT NO.

		DATE
DRAWN	[illegible]	6-23-76
CHECK		
DESIGN		
ENGR		
QA		
DESIGN ACTIVITY APPD		

MBA Associates

TITLE MODULE SUPPORT CONCEPT

DWG SIZE	CODE IDENT NO.	DWG NO.
C	27934	SK115296

SCALE NONE | RELEASE DATE | SHEET

FIGURE 3.1-3
MODULAR SUPPORT CONCEPT (Sheet 2 of 2)

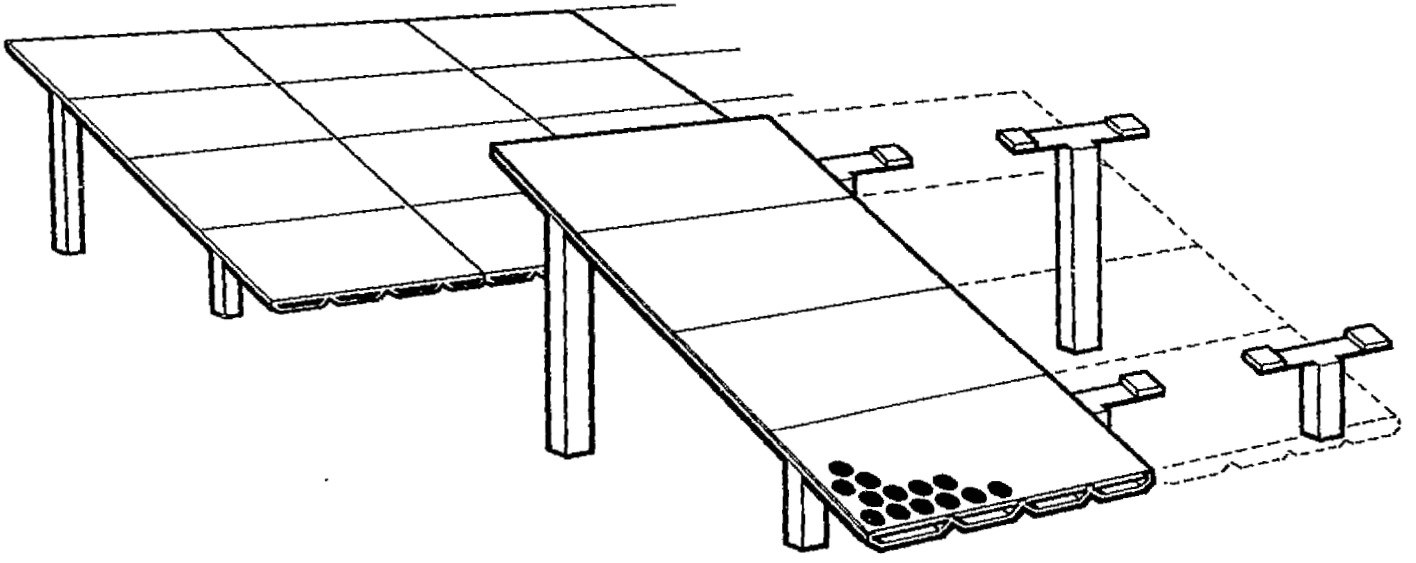


FIGURE 3.1-4
A POSSIBLE FIELD ARRAY CONCEPT INDICATING POSTS AND BRACKETS

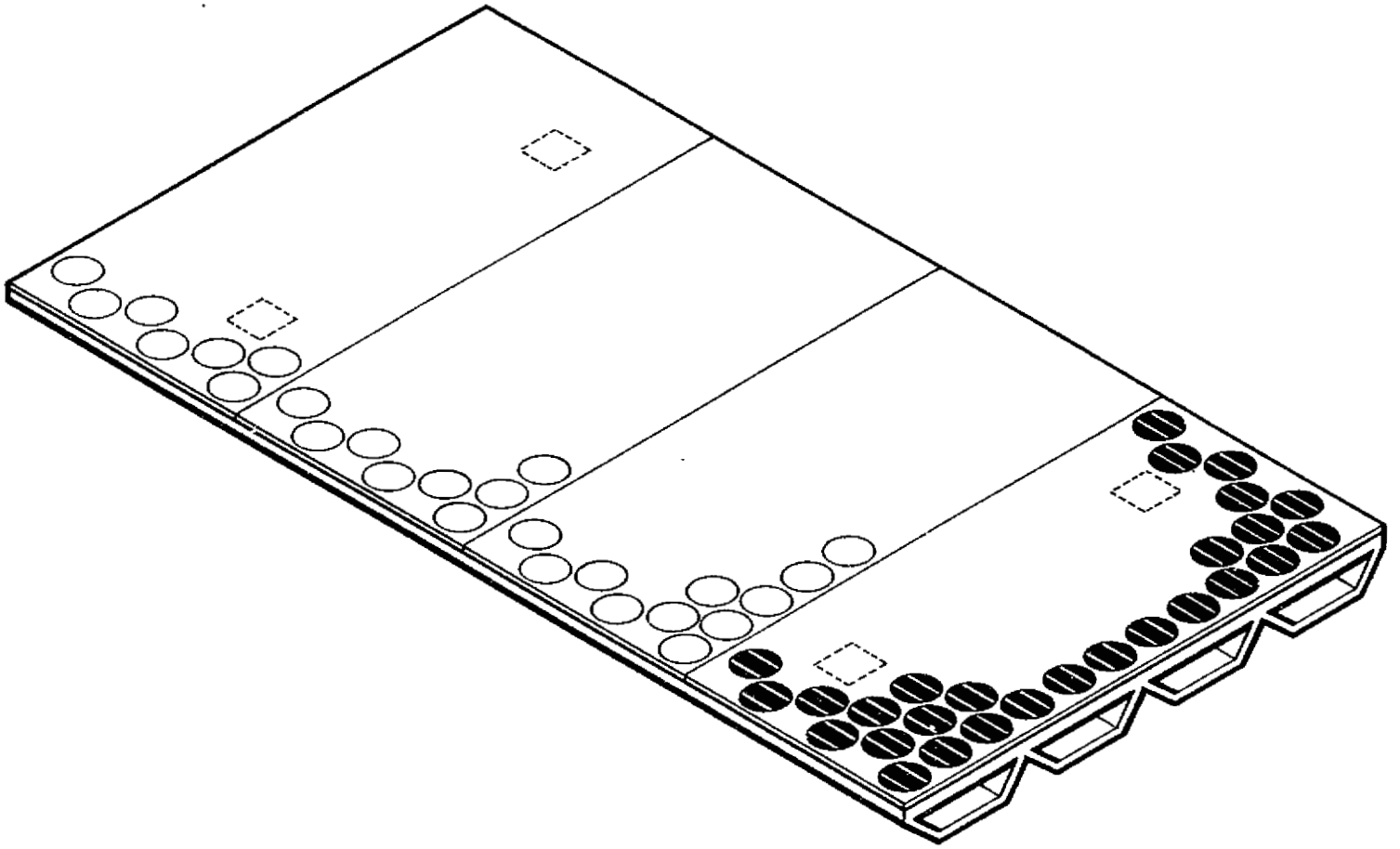


FIGURE 3.1-5
A POSSIBLE 4' X 8' GRC PANEL WITH FOUR 2' X 4' FLAT PLATE PHOTOVOLTAIC MODULES EACH WITH 66 FOUR-INCH DIAMETER CELLS. THIS PANEL TO BE FOUR POINT SUPPORTED ON BRACKETS IMBEDDED IN REINFORCED CONCRETE POSTS.

FIGURE 3.2-1
TEST SPECIMENS FOR STRUCTURAL DESIGN AND GRC CHARACTERISTICS
1) FORMS FOR THE FLAT PLATE GRC CHARACTERIZATION TESTS
2) GRC CHARACTERIZATION TEST PLATES

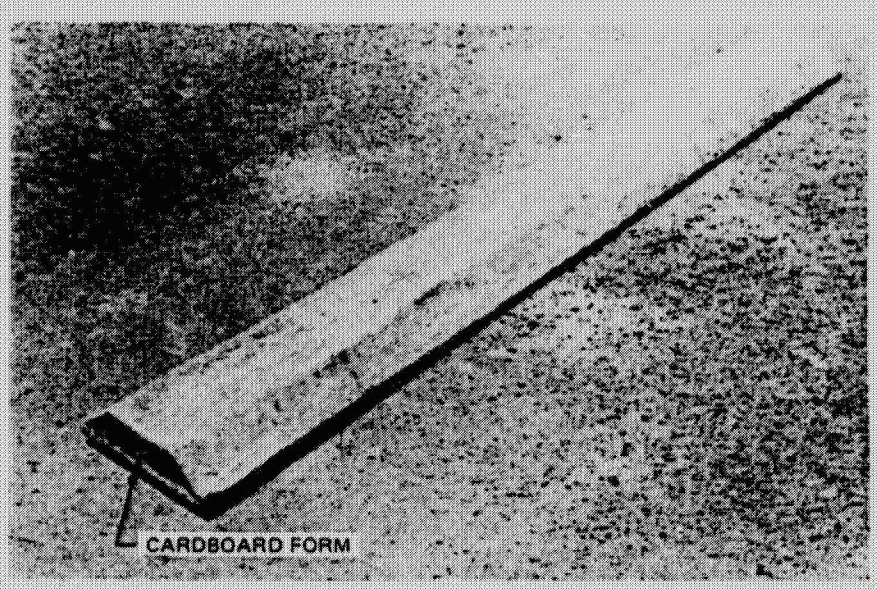


FIGURE 3.2-2
FULL LENGTH (8') RIB SECTION OF GRC PANEL
MADE WITH CARDBOARD FORM

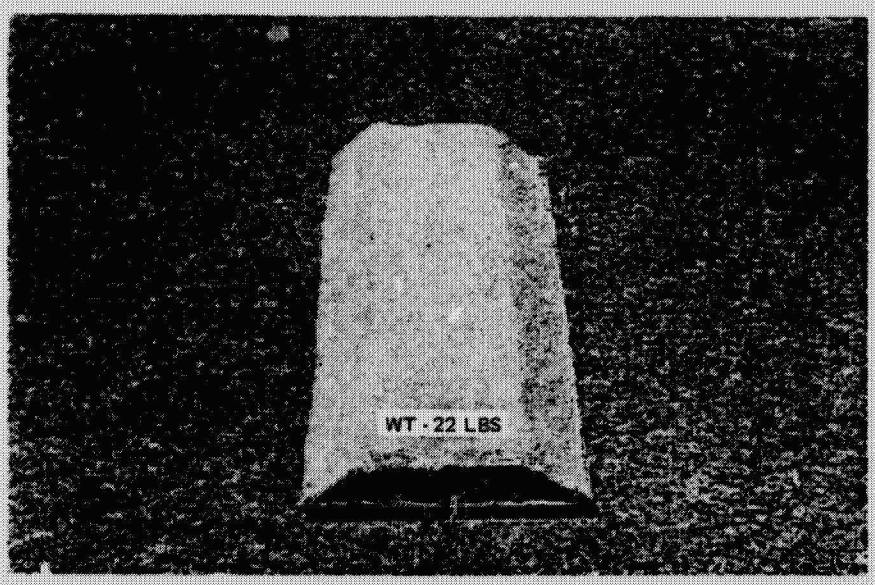


FIGURE 3.2-3
1' X 2' SECTION OF A RIB STRUCTURE FOR
CONCENTRATED LOAD TESTING

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1879-16715

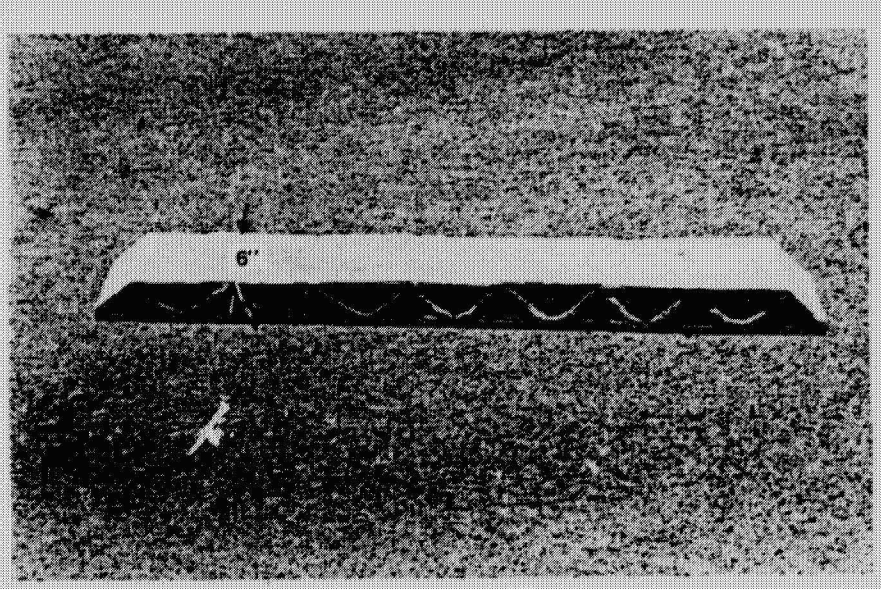

FIGURE 3.2-4
FULL LENGTH CROSS SECTION (48") OF GRC PANEL
AT LOAD POSITION 20" FROM END OF PANEL
FABRICATED WITH CARDBOARD FORMS

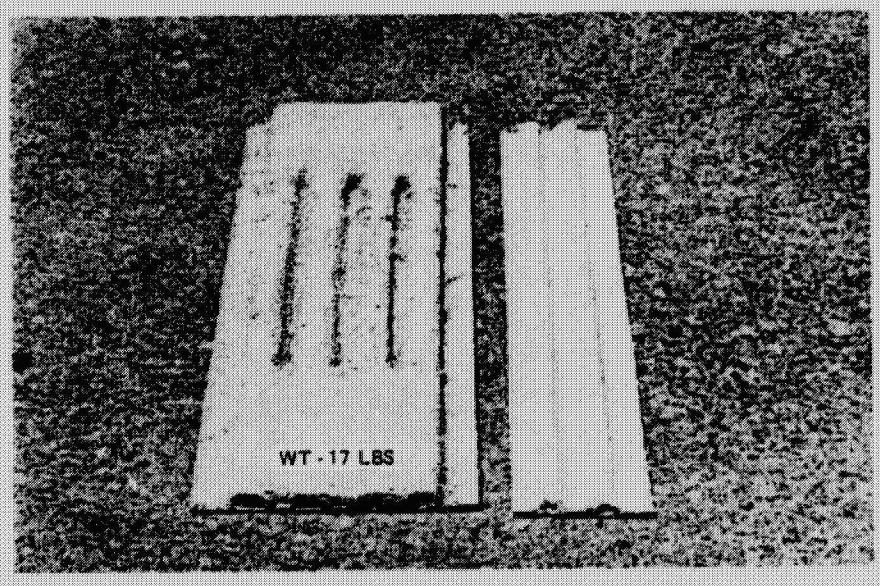

FIGURE 3.2-5
BEAM STRUCTURES WITH TUBULAR INSERTS

The final structural design evolved from a four rib (trapezoidal shape) to a three rib, all with GRC tie support plates and then to a final two rib with a pipe-tube, tie-bar support. These are shown in Figures 3.2-6, 3.2-7, 3.2-8 and 3.2-9. Bend tests on those structures shown in Figures 3.2-6, 3.2-7 and 3.2-8 revealed that the GRC connections were not strong enough to withstand the design forces. Also pull tests on these structures proved that the section joints were weak areas in this design. A full length longitudinal rib section was tested under uniform loading (Figure 3.2-10) and found to have more than adequate strength.

The pipe tie-bar support concept was designed to eliminate the need for higher strength bonding between section of GRC. This is shown in Figure 3.2-9. The concentrated load bending test proved that it was strong enough to go ahead with a full size plate structure of this design. The data collected from these tests are presented in Tables 3.2-1, 3.2-2 and 3.2-3. Photographs of the hand spraying method and a full size panel sprayed with this method are shown in Figures 3.2-11 and 3.2-12. The panel was found to be of variable "thickness and a decision was made to mechanize the spraying operation before fabricating more full size panels.

3.3 Selected Substrate Design

The final substrate design selected for production is shown in the panel substrate drawing, #115729, Figure 3.3-1.

The novelty features of this design are:

- A 1/4" thick 4 ft x 8 ft panel: with a smooth, hard, dense, flat surface that is weather resistant and long lasting.
- Contains two trapezoidal stiffening ribs serving also as structural support points.
- Ribs strategically placed and imbedded with support tubes (standard PVC tubing) minimizing bending moments and resulting stresses produced by installation and wind loads.

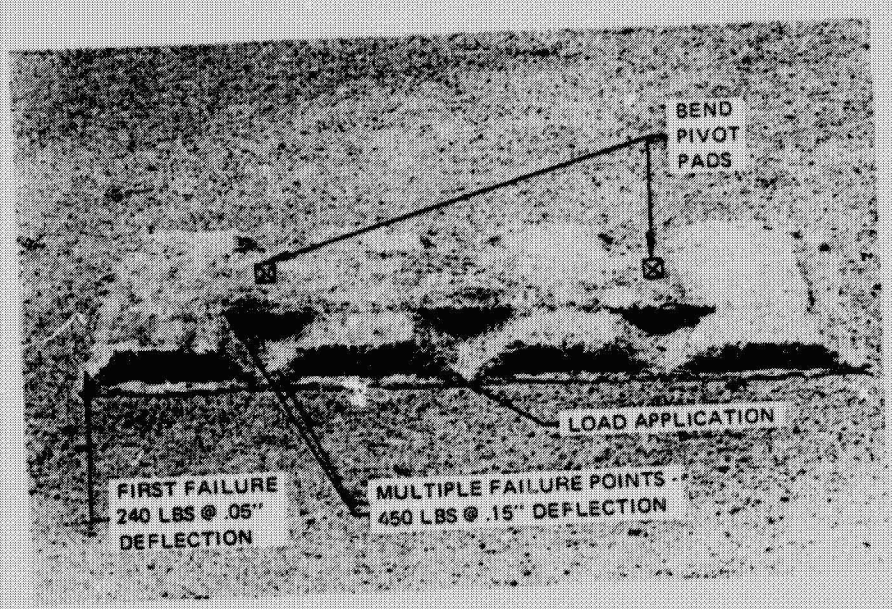

FIGURE 3.2-6
FOUR RIB STRUCTURE CROSS SECTION

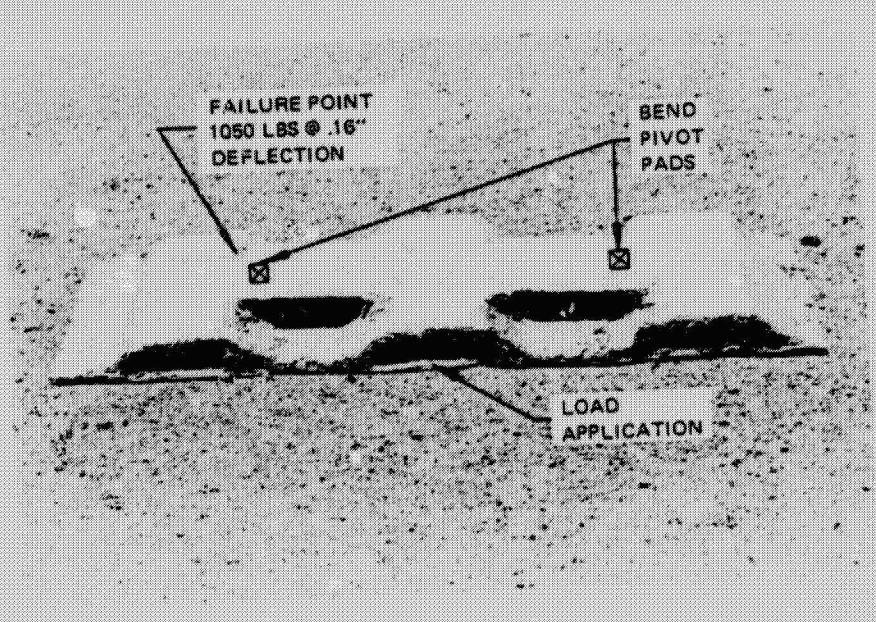

FIGURE 3.2-7
THREE RIB STRUCTURE CROSS SECTION

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1879-16718

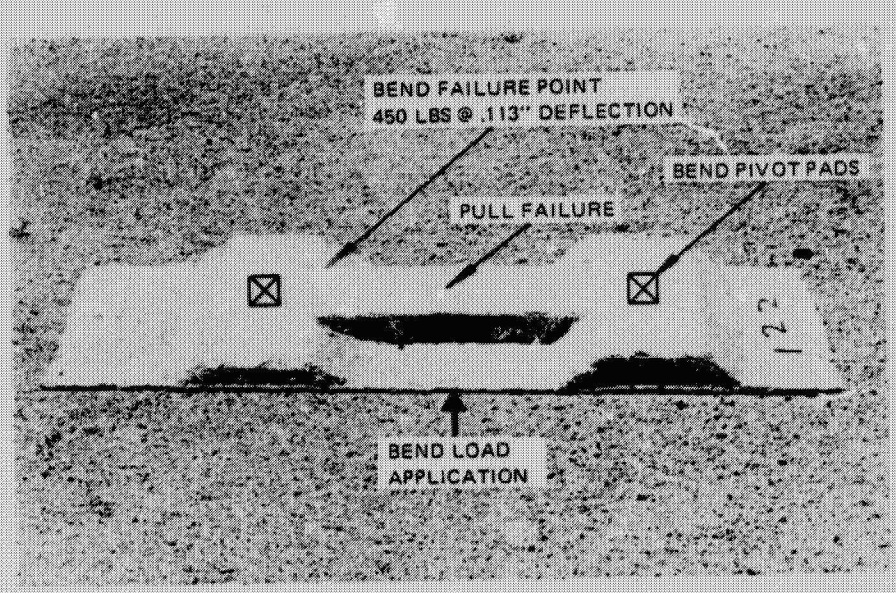

FIGURE 3.2-8
2 RIB STRUCTURE CROSS SECTION

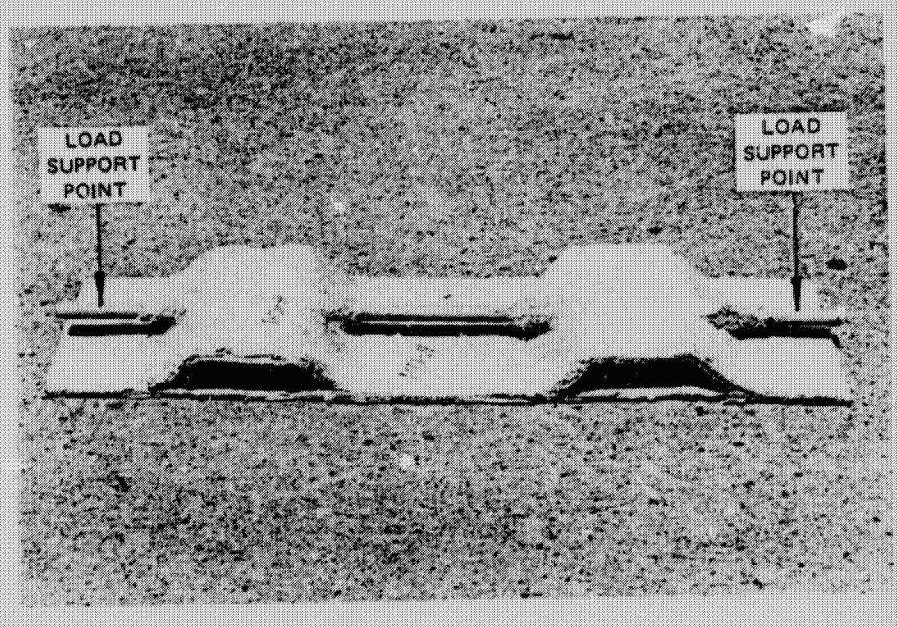

FIGURE 3.2-9
2 RIB STRUCTURE CROSS SECTION WITH
PIPE SUPPORT BAR INSTEAD OF GRC STRIP

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1879-16717

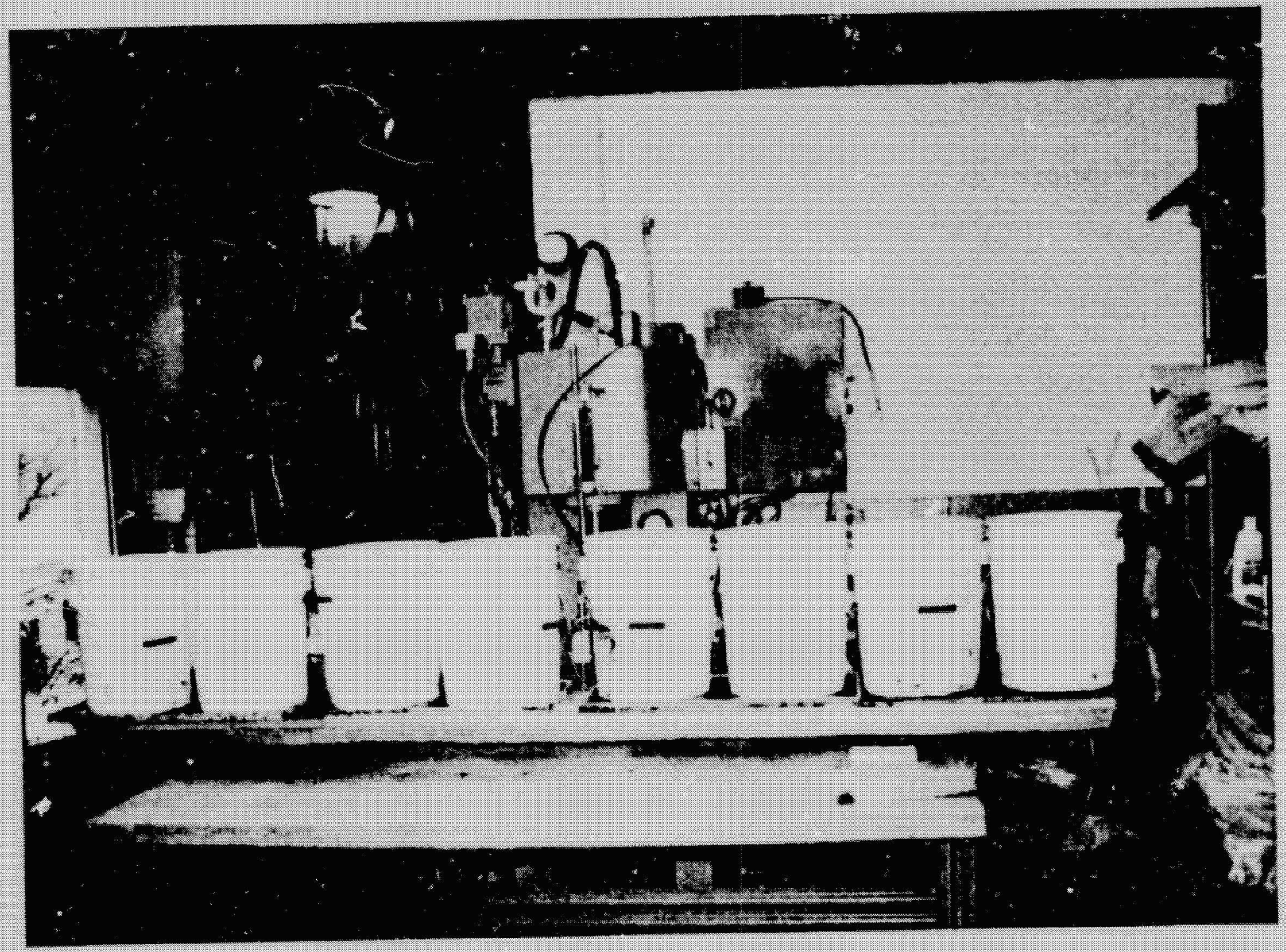

FIGURE 3.2-10
UNIFORM LOAD TESTING OF A LONGITUDINAL RIB SECTION

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1879-16722

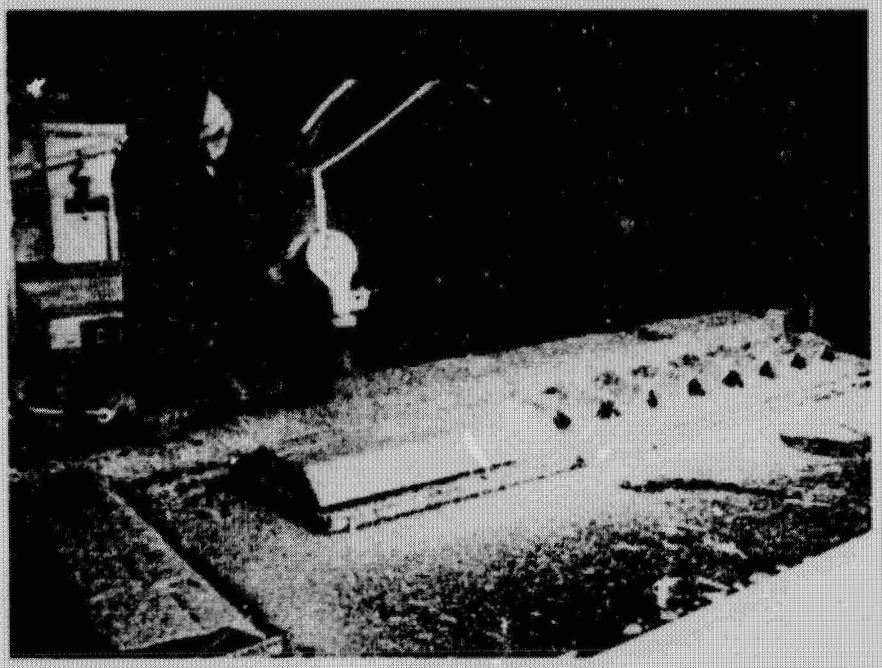


FIGURE 3.2-11
GRC HAND SPRAYING OPERATION

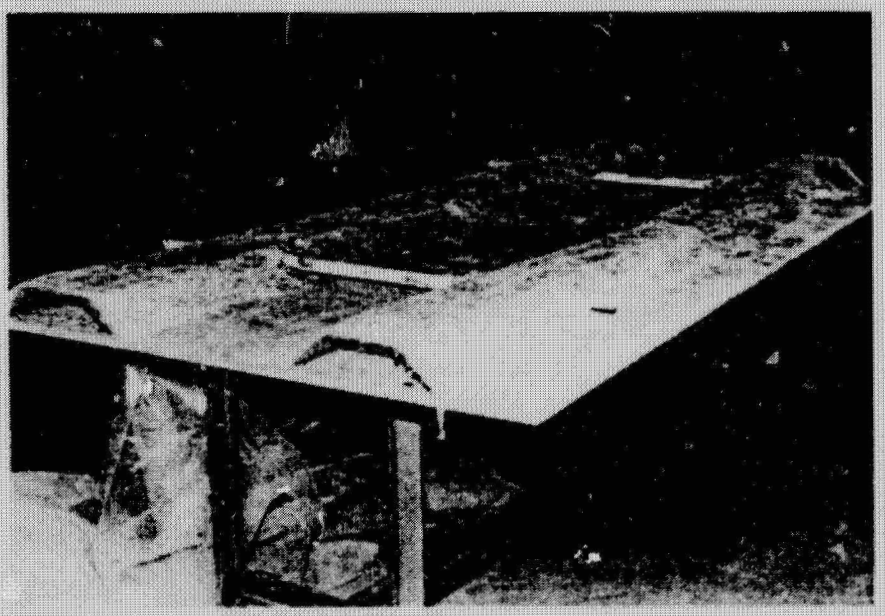


FIGURE 3.2-12
FIRST FULL SIZE GRC SOLAR ARRAY PANEL

TABLE 3.2-1

CONCENTRATED LOADING RIB STRUCTURE

Form	Figure	Load (lbs)	Deflection (inches)
Trapezoidal Section (Cardboard Form)	3.2-3	1750	.110
Trapezoidal Section (GRC Form)	(not shown)	1400	.235
Triangular Cross Section	(not shown)	1250	.230
4 Tube Structure	3.2-5	950	.070
2 Tube Structure	3.2-5	750	.130
4 Rib Cross Section (GRC Tie Plate)	3.2-6	240	.050
3 Rib Cross Section (GRC Tie Plate)	3.2-7	1050	.160
2 Rib Cross Section (GRC Tie Plate)	3.2-8	450	.113

TABLE 3.2-2

TENSION OR PULL TESTS

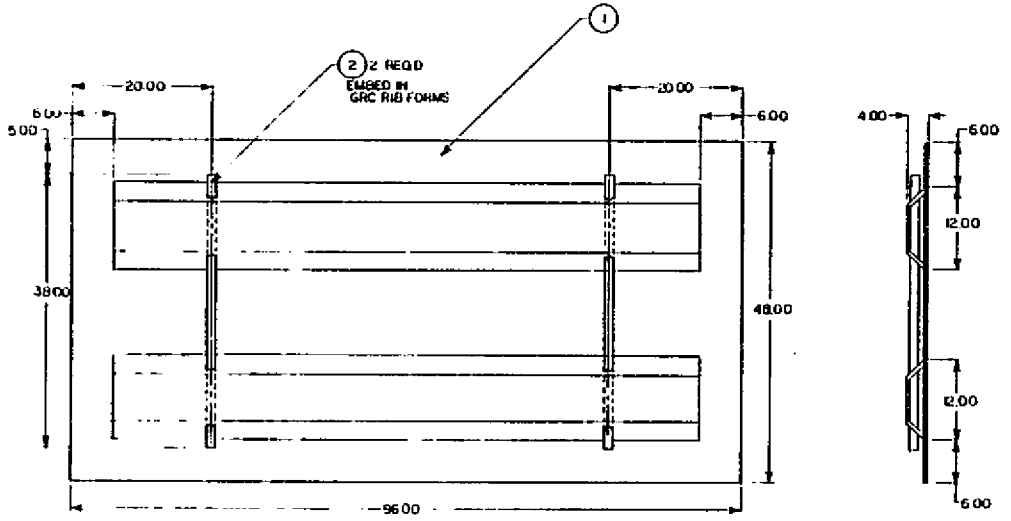
(GRC TIE PLATES)

Form	Figure	Load (lbs) (To Failure)
4 Rib Cross Section	3.2-6	250
3 Rib Cross Section (Thick Sections)	3.2-7	200
3 Rib Cross Section (Normal Thickness)	3.2-7	80
2 Rib Cross Section (Normal Thickness)	3.2-8	50

TABLE 3.2-3

UNIFORM WATER LOADING

Form	Figure	Load (lbs/sq.ft.)	Deflection (inches)
4 Rib Cross Section (GRC Tie Plate)	3.2-6	14	.010
		31	.020
		46	.030
3 Rib Cross Section (GRC Tie Plate)	3.2-7	14	.015
		31	.040
		46	.080
2 Rib Cross Section (GRC Tie Plate)	3.2-8	14	.020
		31	.060
		46	.090
8 ft. Rib Structure	3.2-2	23	.025
		46	.050
2 Rib Cross Section ½" Pipe Tie Bar	3.2-9	14	.020
		31	.060
		46	.090
		92	.180


2 2 REQ'D
EMBED IN
GRC RIB FORMS
1
20.00
20.00
6.00
5.00
6.00
38.00
48.00
96.00
4.00
6.00
12.00
12.00
6.00

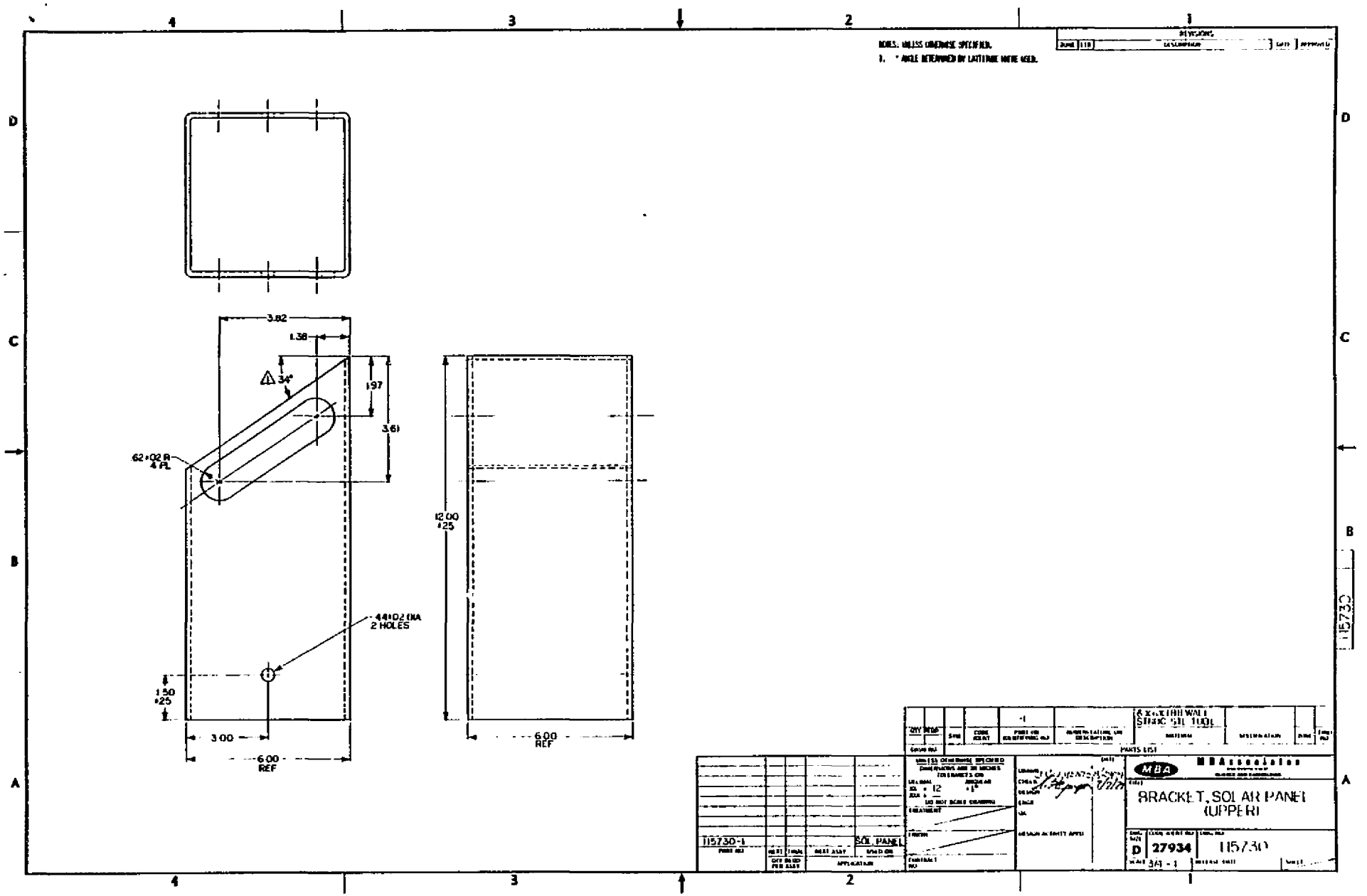
NOTES: UNLESS OTHERWISE SPECIFIED
1. MATERIAL: FIBER GLASS REINFORCED CONCRETE, GRC
NOMINAL .25 THICK.
2. MATERIAL: 3/4 PVC TUBE LC 200 E.
REVISIONS
2 -2 TUBE
1 -1 PANEL
PARTS LIST
115729-300
SOL PANEL
MBA
PANEL , SUBSTRATE
D 27934 115729
115729

FIGURE 3.3-1

- A structural design amenable to mass production which also minimizes the labor required for installation.
- A 4 point support system requiring only:
  - 4 wooden posts, each serving two separate panels.
  - 4 simple post brackets, each serving two separate panels.
  - 2 support bars of standard 1" schedule 40 galvanized pipe with four (4) No. 7 reinforcing steel bars, 20.5" long, inserted in the pipe ends as bracket connectors.

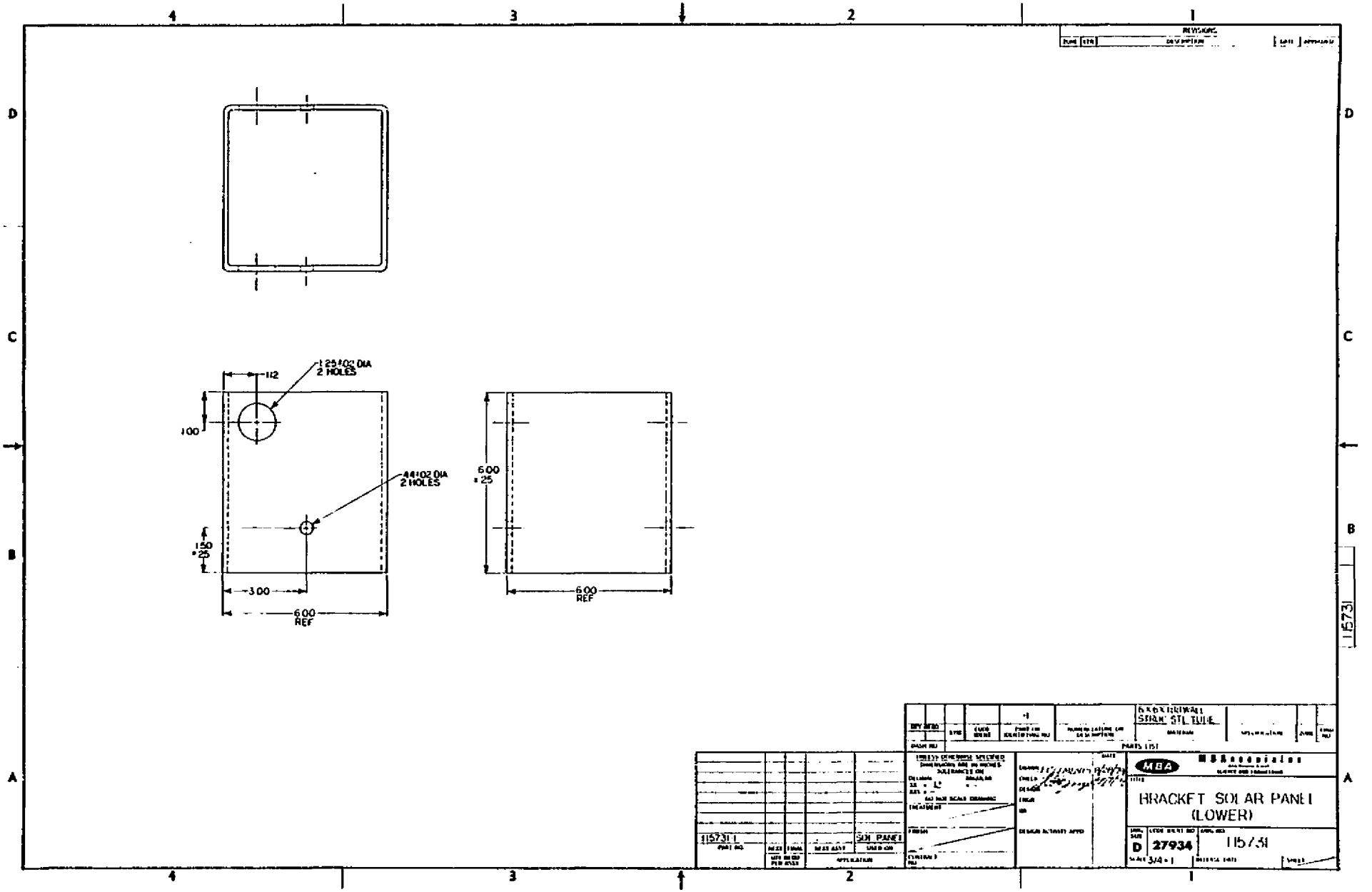
It is believed that this overall design is a novel approach to reduce the cost of substrates for solar array panels and could be considered as new technology. It was presented as such.

Drawings of the post brackets, drawing numbers 115730 and 115731 are shown in Figures 3.3-2 and 3.3-3 respectively.



3.82
1.38
34°
1.97
3.61
.62±.02 R
4 PL
.44±.02 DIA
2 HOLES
1.50
±.25
3.00
6.00
REF
12.00
±.25
6.00
REF
115730-1
SOL. PANEL
BRACKET, SOLAR PANEL
(UPPER)
D
27934
115730

FIGURE 3.3-2



1.25±.02 DIA
2 HOLES
.112
1.00
.44±.02 DIA
2 HOLES
1.50
±.25
3.00
6.00
REF
6.00
±.25
6.00
REF
115731
STRUC STL TUBE
PARTS LIST
MBA
BRACKET SOLAR PANEL
(LOWER)
D
27934
115731
SOL PANEL
115731-1

FIGURE 3.3-3

3.4 Stress Analysis

In the original concept a 15" x 45" panel was chosen as a baseline design, in Reference 1-1, with deflection under the 50 psf load limited to 1/4". Calculations were made using the published GRC physical properties. The equations used describing deflections under uniform loading for edge supported rectangular flat panels (Reference 3-1)* are:

$$J = \text{maximum stress (at the center)}$$

$$= \frac{\beta q b^2}{t^2} \quad \text{psi}$$

$$y = \text{deflection at the center}$$

$$= \frac{\alpha q b^4}{E\ t^2} \quad \text{in.}$$

where:

q = uniform loading, psi

t = thickness, inches

E = modulus of elasticity, psi

b = width

a = length

and β and α are constants dependent on the ratio a/b.

---

*Reference 3-1 Roark, R. J., et al, Formulas for Stress and Strain, 4th Edition, McGraw Hill, 1975.

Following the data of Reference 1-2 thru this analysis for a promising wood product material, for example, chipboard, for which

$$t = 0.266$$

$$E = 3.75 \cdot 10^5 \text{ psi}$$

$$a/b = 3$$

$$\beta = 0.7134$$

$$\alpha = .1355$$

yields:

$$\sigma = 788 \text{ psi}$$

$$y = 0.25 \text{ inches as expected}$$

$$\sigma = \text{Strain} = \frac{788}{3.75 \cdot 10^5} = 0.00210$$

Then considering a similar panel of GRC configured to meet the 1/4" deflection criterion. For this case:

$$t = 0.184''$$

$$E = 1.5 \cdot 10^6 \text{ psi}$$

$$\sigma = 1647 \text{ psi}$$

$$\frac{\sigma}{E} = 0.0011$$

With this low stress level for GRC it was selected to be the material for the substrate panel design. Additional stress calculations were made on the various conceptional designs and for handling and operational stresses. These calculations are included in the appendix. The results indicated the design and material to be well within the load requirements. The results are summarized as follows:

SUBSTRATE ANALYSIS
3/8"

LOADING

Dead Load = 6.8 lbs./Ft^2
Wind Load = 50.0 lbs./Ft^2

LONGITUDINAL SECTION PROPERTIES

$I = 10.4\ in^4$

C = 1.3 in from face

$A = 7.55\ in^2$

TRANSVERSE SECTION PROPERTIES

$I = 7.8\ in^4$

C = 1.5 in from face

$A = 4.5\ in^2$

LONGITUDINAL HANDLING STRESS (12 Hrs. - 16 Hrs.)

V_{max} = 16 ft. lbs.

M_{max} = 10 ft. lbs.

F_v = V/A = 16/7.55

= 2.12 psi shear

$F_{b1.3}$ = Mc/I = 10 x 12 x 1.3/10.4

= 15 psi bending

$F_{b1.7}$ = Mc/I = 10 x 12 x 1.7/10.4

= 19.6 psi bending

TRANSVERSE HANDLING STRESS (12 Hrs. - 16 Hrs.)

V_{max} = 28 lbs.

M_{max} = 14 ft. lbs.

F_v = V/A = 28/4.5

= 6.22 psi shear

F_b = Mc/I = 14 x 12 x 1.5/7.80

= 32.2 psi bending

SUPPORT HANDLING STRESS (12 Hrs. - 16 Hrs.)

GRC Tie Bar System

F_v = V/A = 56/2.25

= 24.9 psi shear

Pipe Support System

F_v = 56/3/8 x 2 x 1.25

= 59.7

LONGITUDINAL OPERATIONAL STRESS

V_{max} = 135 lbs.

M_{max} = 80 ft. lbs.

F_v = V/A = 135/7.55

$F_{b\ 1.3}$ = Mc/I = 30 x 12 x 1.3/10.4 = 120 psi

$F_{b\ 1.7}$ = Mc/I = 30 x 12 x 1.7/10.4 = 157 psi

LONGITUDINAL RADIUS OF CURVATURE

$$r = EI/M = \frac{1.5 \times 10^6\ (10.4)}{80 \times 12}$$

= 16,250 in

TRANSVERSE OPERATIONAL STRESS

V_{max} = 228 lbs.

M_{max} = 114 ft. lbs.

F_v = V/A = 228/4.5

= 50.7 psi shear

F_b = Mc/I = 114 x 12 x 1.5/7.8

= 263 psi bending

SUPPORT OPERATIONAL STRESS

F_v = V/A 456/2.25

= 202.7 psi shear

TRANSVERSE RAIDUS OF CURVATURE

r = EI/M = 1.5×10^6 (7.8)/114 x 12

= 8553 in

SUPPORT OPERATIONAL STRESS

GRC Tie Bar System

F_v = V/A 456/2.25

= 202.7 psi shear

Pipe Support System

F_v = 456/3/8 x 2 x 1.25

= 486.4 psi

Both the handling and operational stresses are well within the allowable elastic limits of GRC with a minimum safety factor of 3-4 (based upon estimated 20 yr. properties).

Since the GRC characterization substantiated the assumed GRC properties, the section thickness was reduced to 0.25 in and still provided a safety factor of 2-3.

SUBSTRATE ANALYSIS

1/4"

LOADING DEAD = 4.43 WIND = 50 lbs/ft^2

LONGITUDINAL SECTION PROPERTIES

$I = 7.56\ in^4$ C = 1.3 in-comp C = 1.7 in-ten $A = 4.91\ in^2$

TRANSVERSE SECTION PROPERTIES

$I = 5.69\ in^4$ C = 1.5 in $A = 3\ in^2$

LONGITUDINAL HANDLING STRESS

V_{max} = 11 lbs M_{max} = 7 ft-lbs.

F_v = 2.24 psi shear F_b 1.3 = 19.2 F_b 1.7 = 25.1

TRANSVERSE HANDLING STRESS

V_{max} = 18 lbs M_{max} = 9 ft-lbs.

F_v = 6.0 psi shear F_b = 28.47 psi

AT SUPPORTS

GRC Tie Bar System

F_v = 35.4/1.5 = 23.6 psi

Pipe Support System

F_v = 35.4/.625 = 56.6 psi

LONGITUDINAL OPERATIONAL STRESS

V_{max} = 127 lbs. M_{max} = 76 ft-lbs

F_v = 25.87 psi $F_{b\ 1.3}$ = 156.83 psi $F_{b\ 1.7}$ = 205.10 psi

TRANSVERSE OPERATIONAL STRESS

V_{max} = 218 lbs M_{max} = 109 ft-lbs

F_v = 72.67 psi F_b = 344.82 psi

AT SUPPORTS

GRC Tie Bar System

F_v = 145.33 psi

Pipe Support System

F_v = 348.80 psi

3.5 Fabrication of Substrate Panels

In fabricating the substrate panels, a spray machine was used which consists of a concrete mixer, vibrating hopper, concrete or slurry pump and a spray gun which also chops the glass fiber. These are shown in Figures 3.5-1 and 3.5-2. Figure 3.5-3 is a schematic of the glass chopper and spray gun. The gun chops the fiber into desired lengths from a glass fiber roving. The roving is a twisted multi-strand continuous filament glass fiber. The glass composition is an alkali resistant type.

The concentric spray gun consists mainly of three parts. The inner section is the main tube and chopped fiber glass inlet tube. Air is supplied to the main tube creating a venturi action that pulls in the chopped fibers and blows it into the slurry. The slurry is pumped through an annulus surrounding the main tube. A cap with serrations covers the annulus and helps break up the slurry which is atomized with air. The glass chopper consists of a rotating wheel with blades that contacts against a backing roller which pulls the glass roving into the gun as it cuts the fibers. The cutting blades are spaced to obtain the desired length fibers.

The first experimental panel was sprayed by hand but was found to be non-uniform in thickness. It was then decided to mechanize the spray gun in order to achieve better uniformity.

The mechanization consisted of mounting the spray gun on a carrier attached to a tram rail structure. The movements of the spray head were controlled horizontally in both longitudinal and transverse directions by variable speed motors operating cable and belt drives sequenced by limit switches. (See Figure 3.5-4). The production sequence used was to spray the flat sheet portion of the panel with two 1/8" layers of GRC, with each layer rolled and vibrated to produce the fiber compaction and density desired. This operation is shown in Figure 3.5-5. Rib forms were made of GRC the day before and are shown in Figure 3.5-6. These were placed on the freshly sprayed flat sheet portion of the panel along with their imbedded PVC tubes and sprayed with two 1/8" layers of GRC, each layer rolled to obtain the compaction desired. (See Figure 3.5-7).

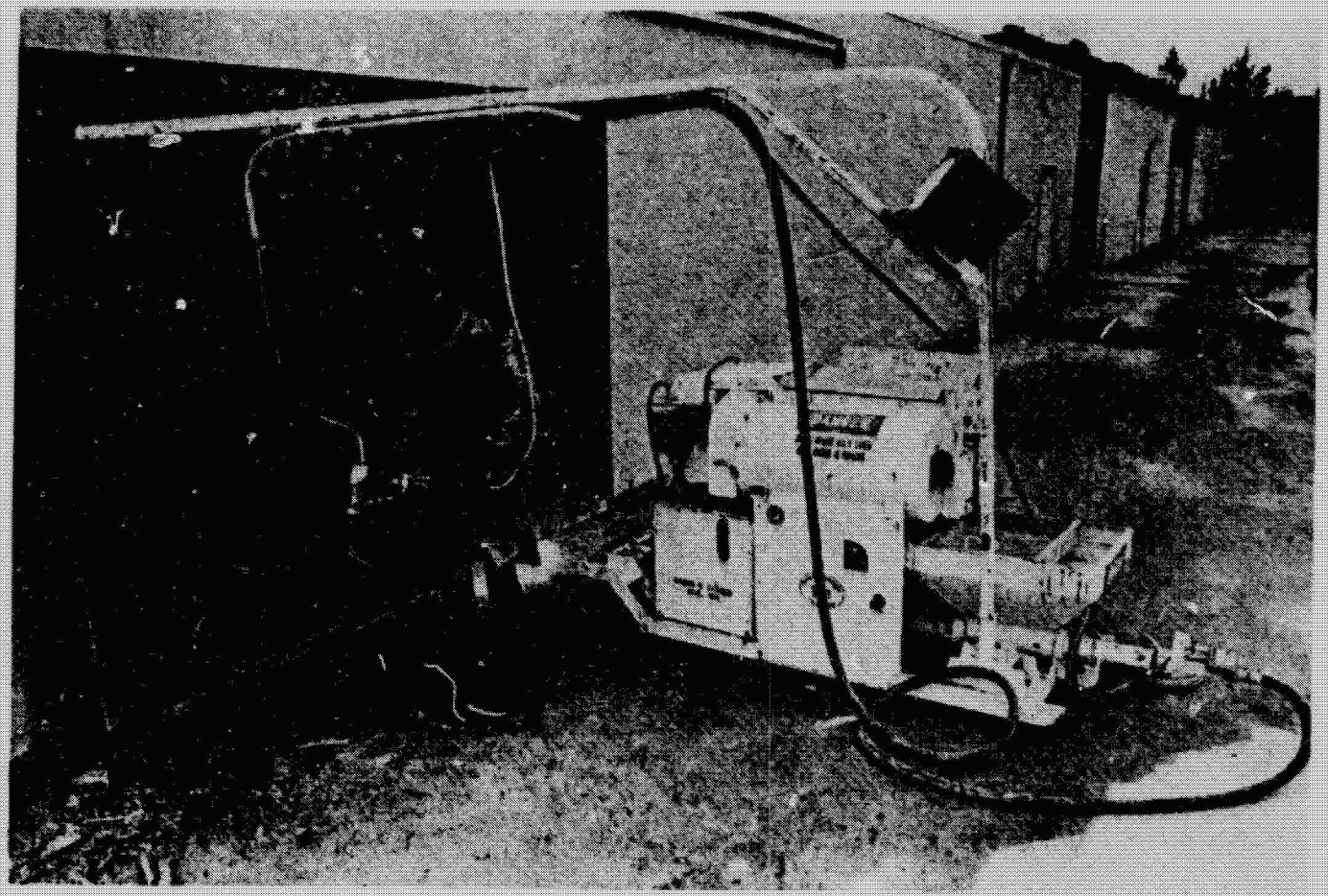


FIGURE 3.5-1
GRC MIXER, PUMP AND OPERATOR WITH SPRAY NOZZLE

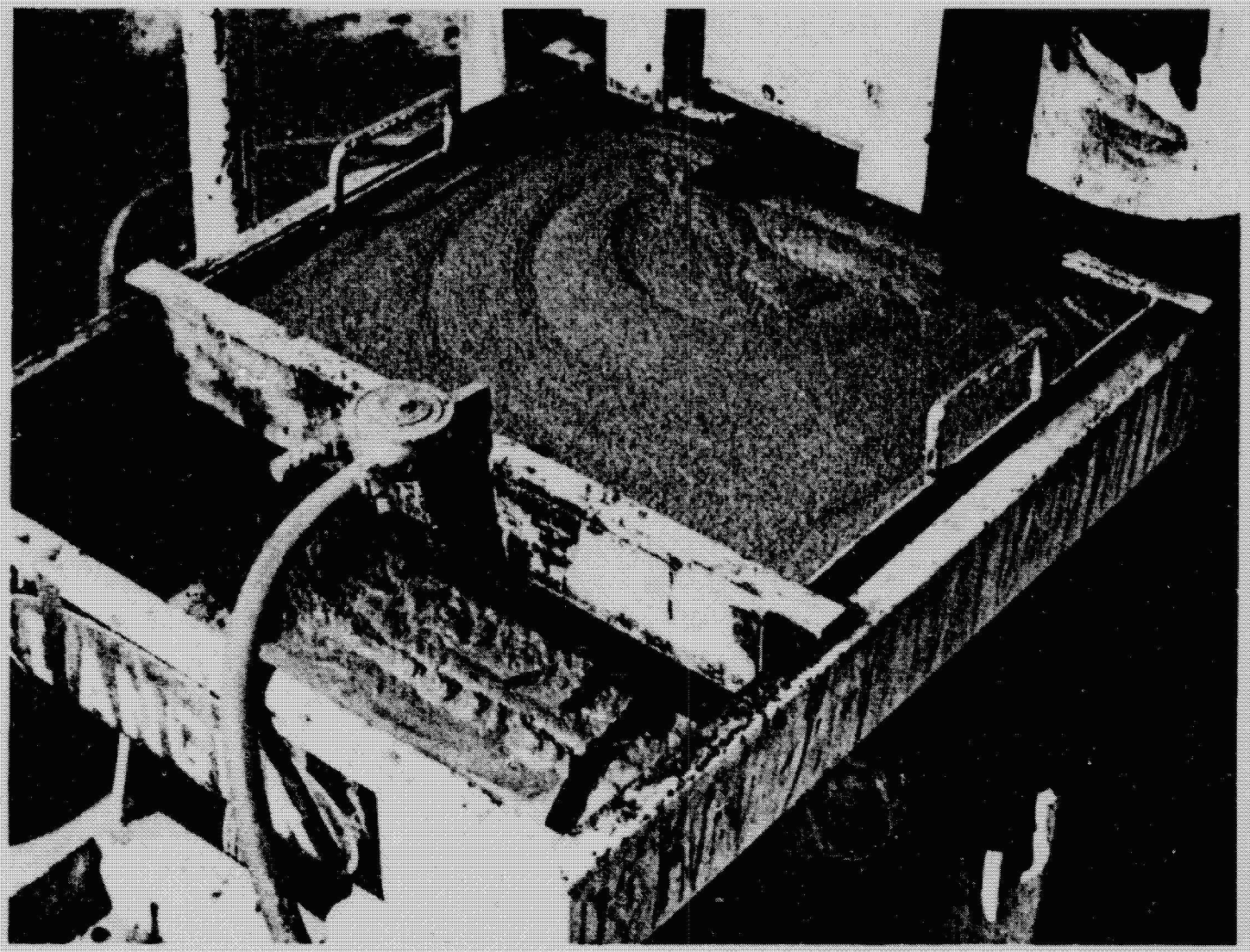


FIGURE 3.5-2
GRC SLURRY IN VIBRATING SCREEN ON PUMP

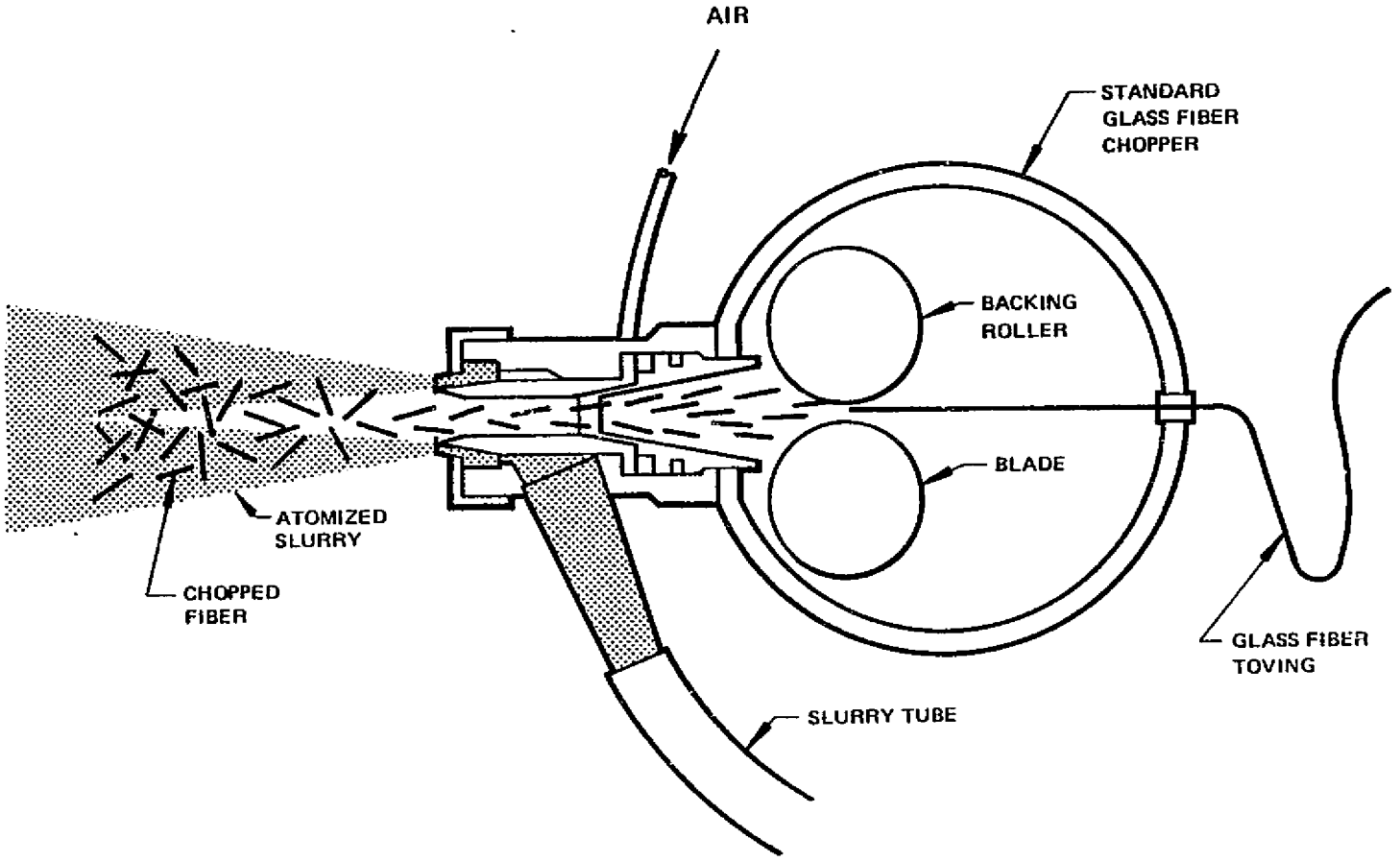


FIGURE 3.5-3
GRC SPRAY GUN SCHEMATIC

FIGURE 3.5-4
MECHANIZED SPRAYING OF PANEL FORM WITH GRC

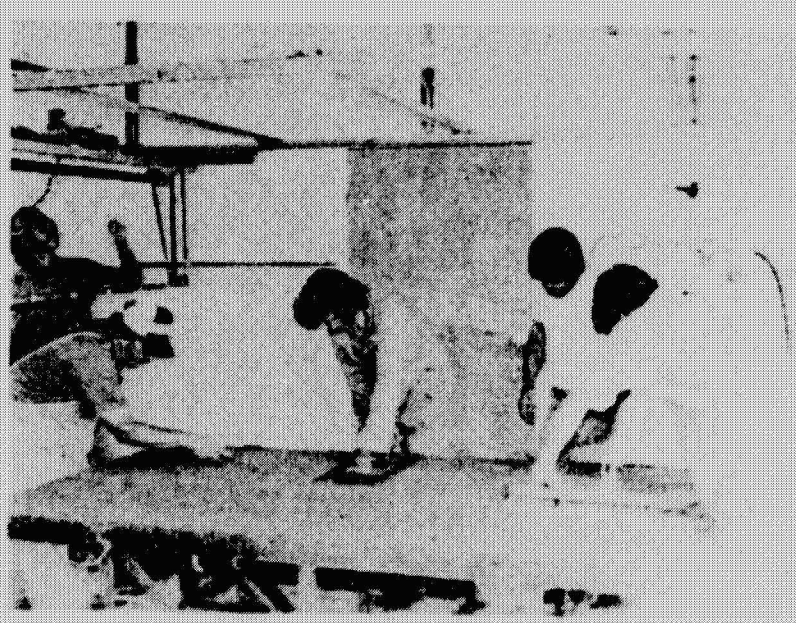


FIGURE 3.5-5
COMPACTING FLAT SHEET

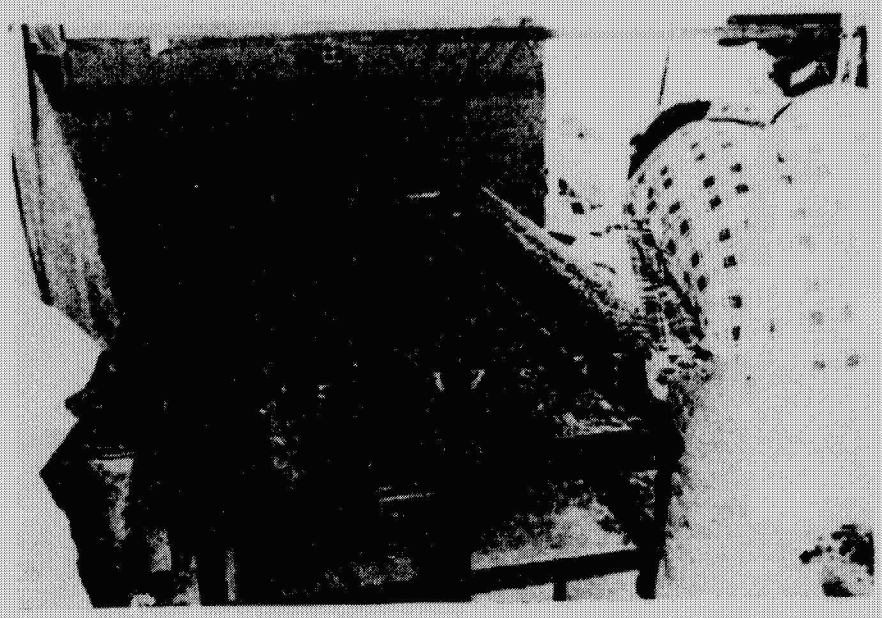


FIGURE 3.5-6
SPRAYED RIB FORMS

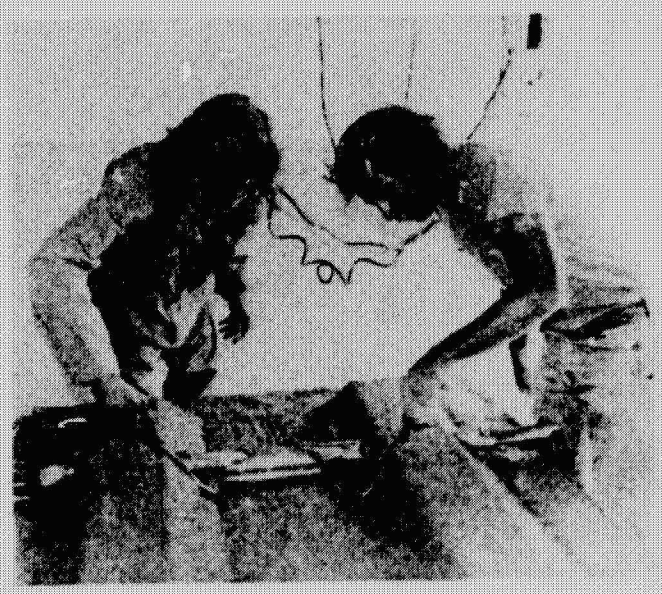


FIGURE 3.5-7
ROLLING SPRAYED RIBS

Fifteen full size panels were fabricated and 12 shipped to JPL for further testing. One was tested at MBA under uniform loading using water as the load medium. This was accomplished by using a frame lined with flexible plastic sheeting to contain the water. The load applied was 50 psf. The panel was supported at the designated support points using specified support hardware, except for the posts and brackets. (See Figure 3.5-8, which is a photograph of the panel under test).

The maximum deflection occurred with the load applied to the bottom or rib side and amounted to .51 inches including the deflection attributed to the mounting segments which amounted to .32". The deflection was .19" when loading the cell on the top side including the .10" attributed to the mounting segments. Thus the approximate deflection or bending of the GRC panel under a 50 psf uniform load was .20 and .10 inches, bottom loading and top loading respectively, which are well within design expectations. In addition, the loading in each case was increased to an overload of 50%, the limit of the fixture used, and no failures of any kind were observed.

3.6 Field Installation

Of the several mounting and installation concepts considered, the most cost effective that met the design criteria was selected. The material required and the procedure recommended for installation are as follows:

Materials Required:

	Quantities For Single Panel	Quantities For Additional Panel
6" x 6" Pressured Treated Fir Posts 8' -10' long*	2	1
6" x 6" " " " " 4' - 6' long*	2	1
Brackets - Upper	2	1
" - Lower	2	1

* Lengths determined by soil conditions and post embedment to resist overturning moment of 1200 ft-lbs.

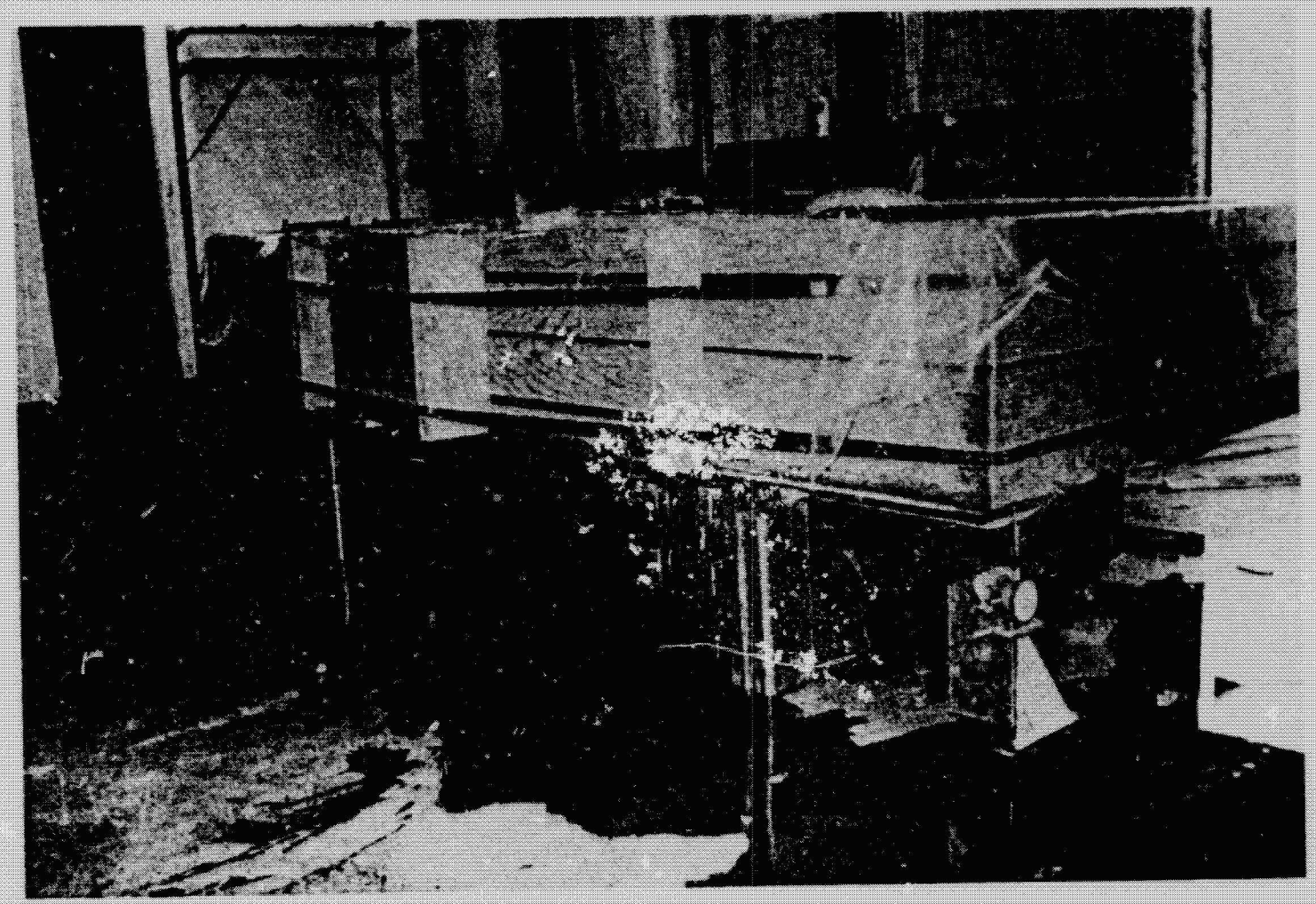


FIGURE 3.5-8
PANEL TESTING WITH UNIFORM LOADING

Materials Required: (continued)

	Quantities For Single Panel	Quantities For Additional Panel
Bolts - 1/2" x 7" with Nuts & Washers	4	2
Support Pipes 1" Schedule 40 water Pipe 40" long	2	2
Support Pins #7 Reinforcing Bar 20.5" long	4	4

Procedure For Installation:

- Attach lower brackets to front (short) posts.
- Embed all four (4) posts as per diagram (Figure 3.6-1).
- Attach upper brackets to rear posts in a position to produce the desired angle of inclination.
- Insert support pipes in PVC encasement tubes.
- Insert support pins in support pipes.
- Suspend panel vertically, from upper support pipe, aligning lower support pins with lower bracket holes. (Figure 3.6-2).
- Move pins into the bracket holes.
- Slacken panel suspension to allow panel to pivot on lower support pins lowering panel to align upper support pins with upper bracket slots. (Figure 3.6-3).
- Move upper support pins into bracket slots. (Figure 3.6-4).

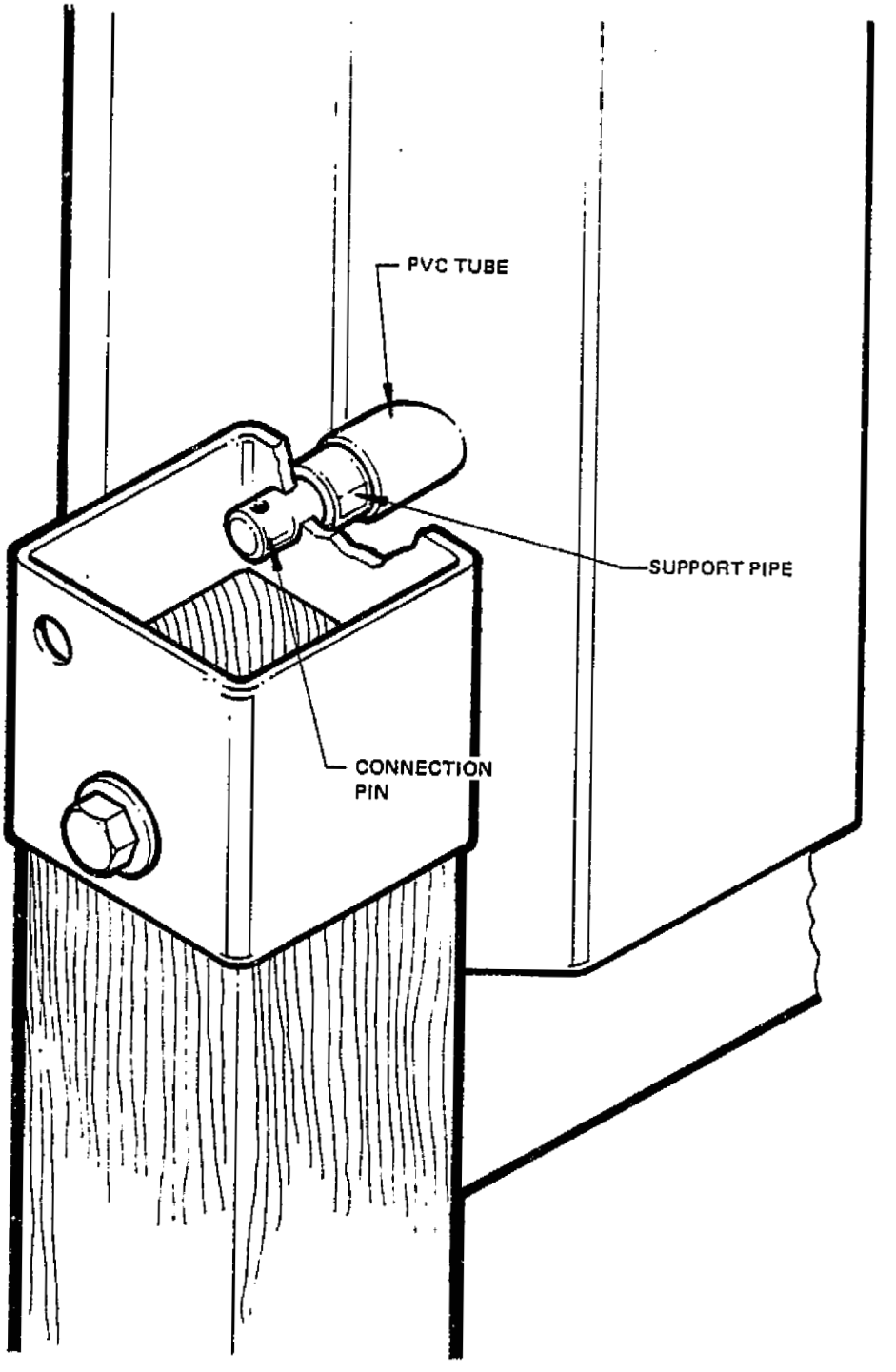


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FIGURE 3.6-2
SUPPORT PIN IN POSITION
BOTTOM BRACKET

MBA

2709-16787

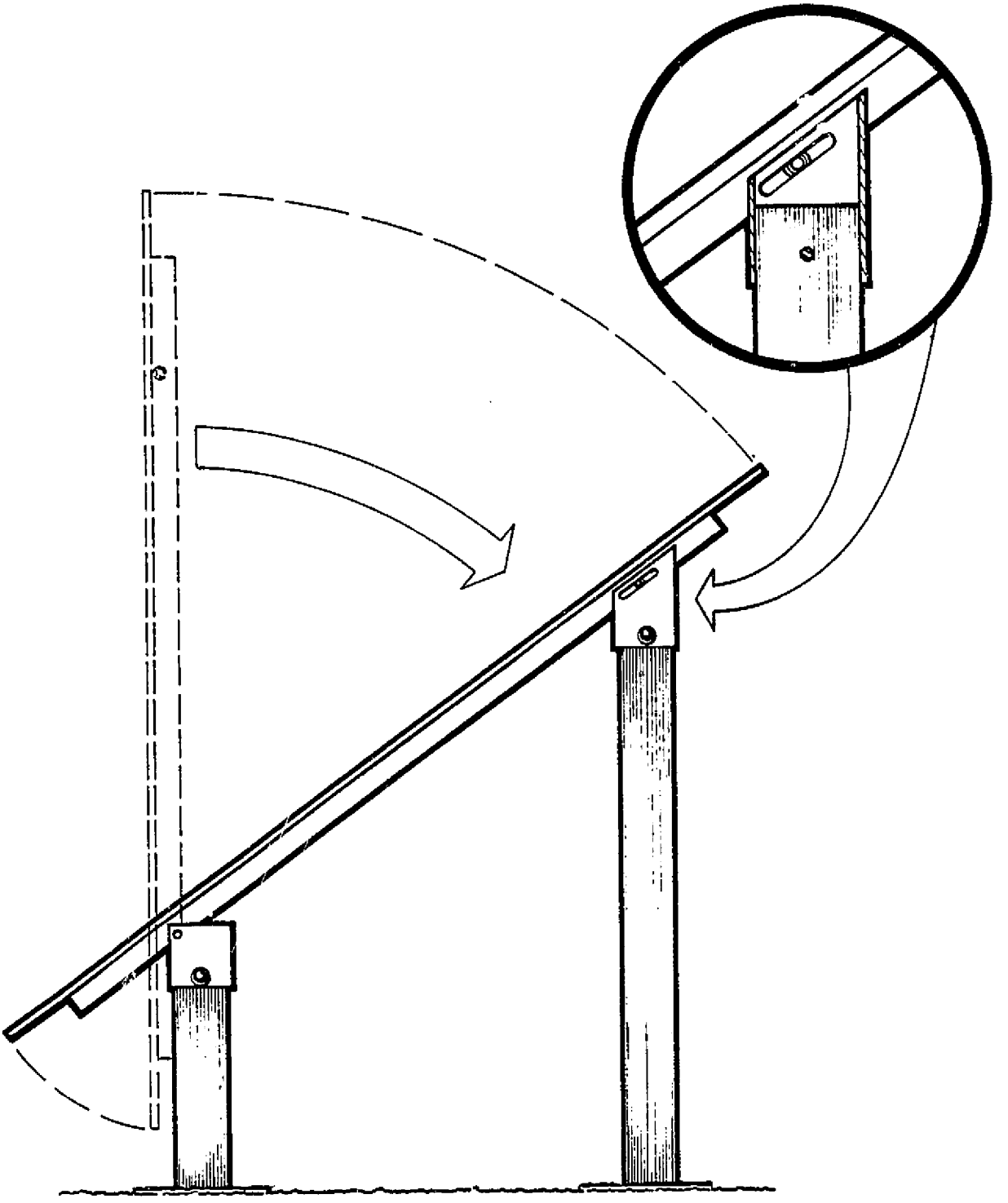

FIGURE 3.6-3
CONNECTION SEQUENCE

MBA

2699-16784

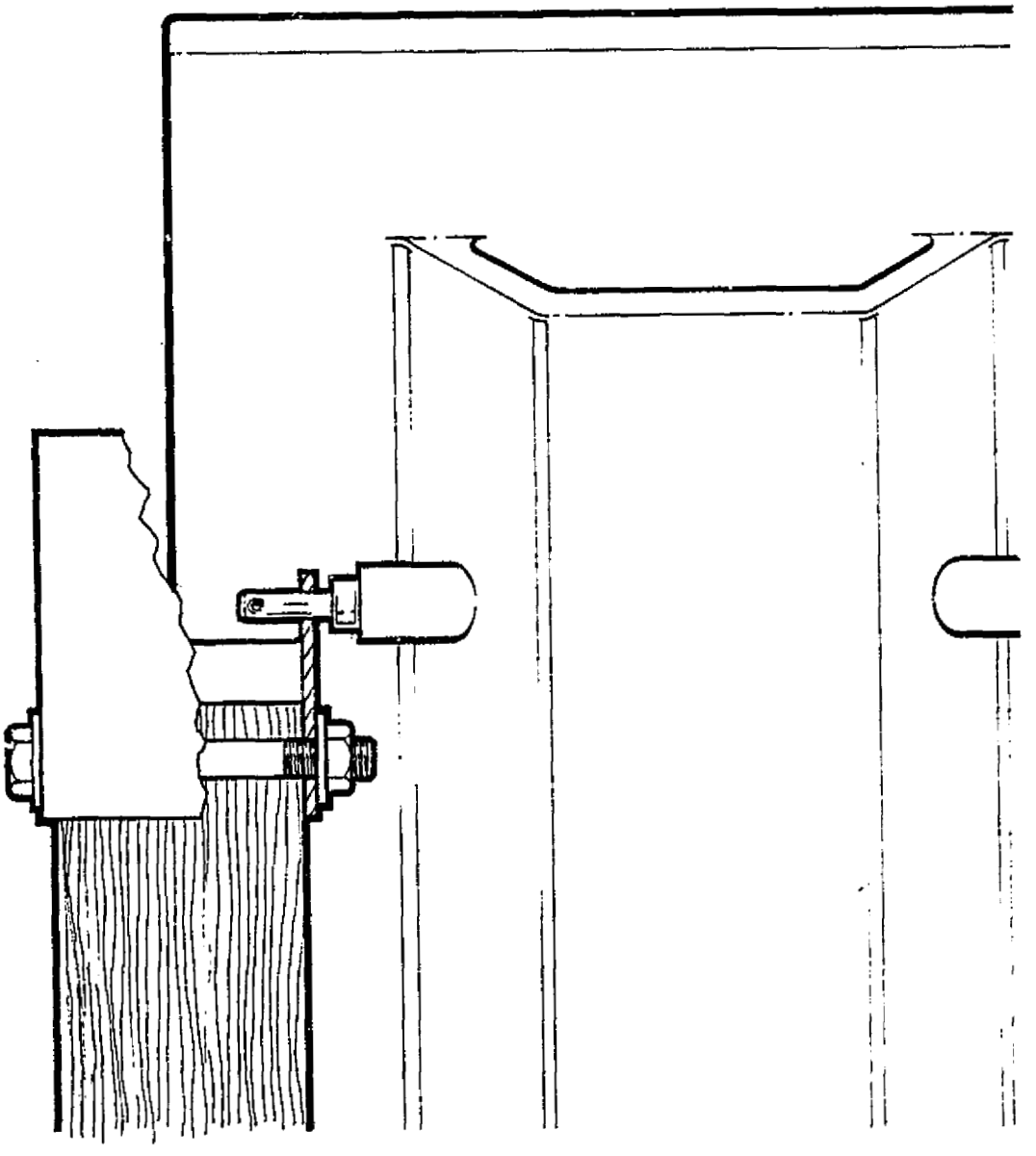

FIGURE 3.6-4
PIN SECURED IN POSITION
TOP BRACKET

MBA
2699-16785

4.0 ENCAPSULATION

Experimental investigations were made in order to determine the possibility of encapsulating the photovoltaic cells directly to the glass reinforced concrete. Preliminary results indicated it would not be feasible to encapsulate directly to the GRC.

Encapsulating with EVA required a vacuum chamber in order to remove all air from the pottant. Applying a vacuum to the top surface of the GRC plate could not be done with reasonable success with available equipment, and held, during the heat cycle. Also, it was not practical to consider the possibility of using a vacuum chamber of sufficient size to contain the full 4' x 8' substrate panel. Thus, it was decided to encapsulate 1' x 4' laminates and attach the laminates to the substrate with an adhesive.

The laminates were composed as follows:

Tedlar/cloth scrim/white EVA/glass scrim/cells/clear EVA/ Korad cover film.

The encapsulation cycle used was to apply a 27-inch mercury vacuum for 30 minutes: heat to 150°F for 30 minutes; heat rapidly to 300°F; allow to cool normally under vacuum for 20 minutes; release vacuum and cool with fan 10 minutes; remove from vacuum chamber; a total of one and one-half hours vacuum heat cycle.

The vacuum chamber and heat lamps used for the encapsulation are shown in Figures 4.0-1 and 4.0-2.

The laminates were attached to the GRC Substrate with an acrylic transfer tape and edge sealed with an RTV adhesive.

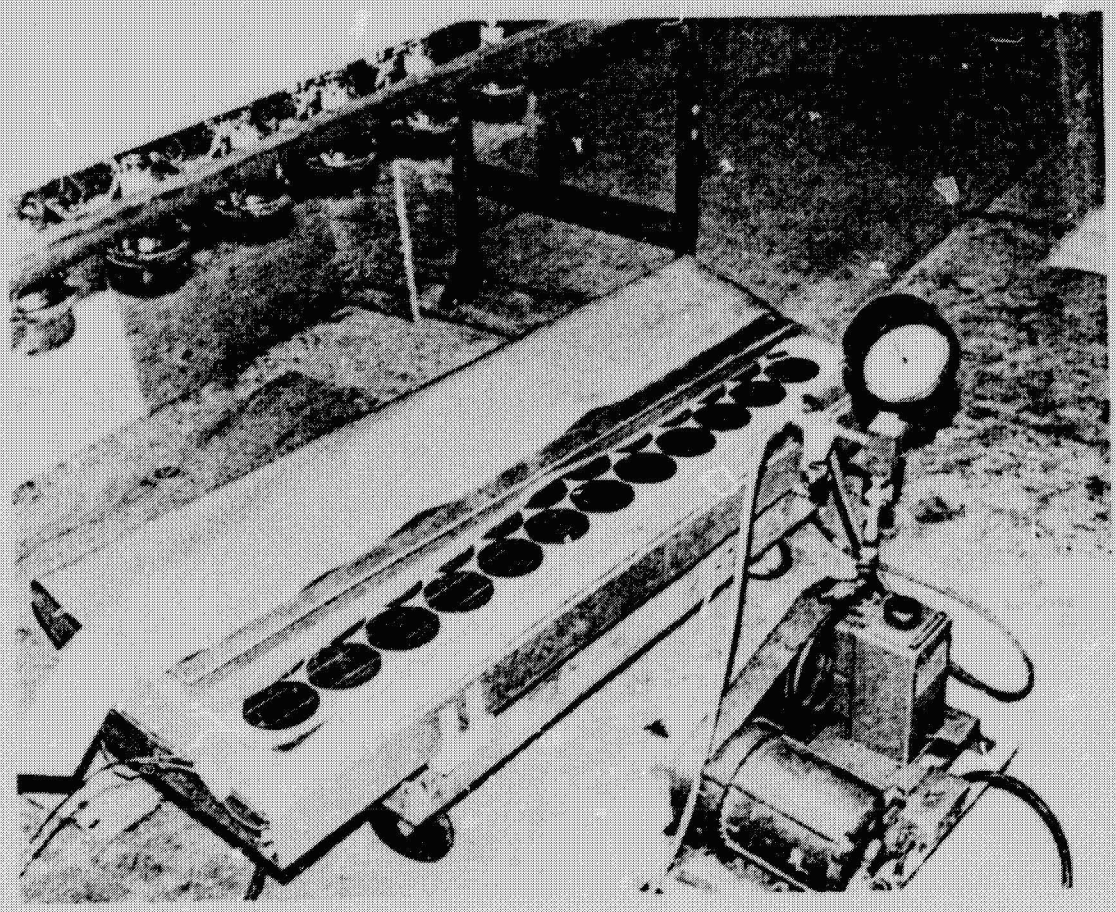

FIGURE 4.0-1
VACUUM CHAMBER AND HEAT LAMPS WITH LAMINATE

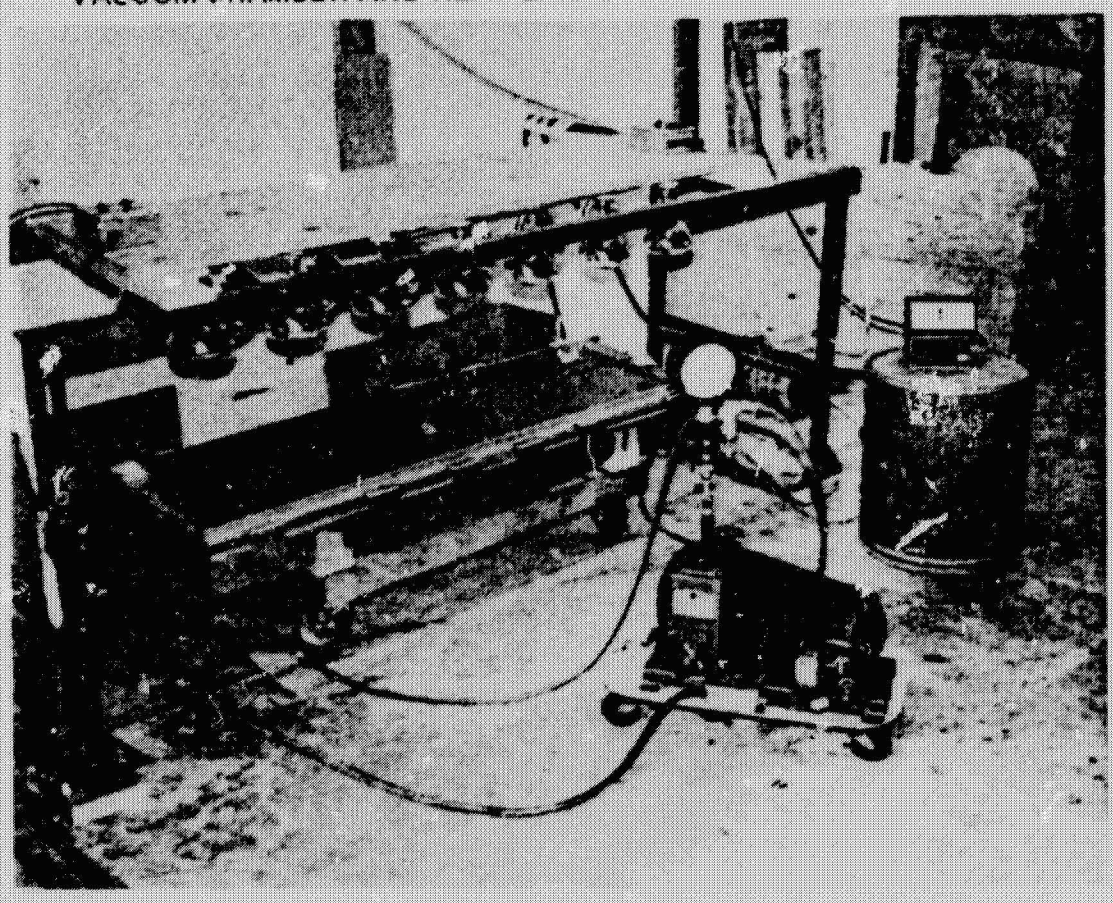

FIGURE 4.0-2
VACUUM CHAMBER AND HEAT LAMPS

5.0 ATTACHING LAMINATES TO GRC PANEL

5.1 Adhesive Tests

Several tests were made with different adhesives to determine the best one to use to attach the laminates to the GRC panel structure. They were as follows:

- Dow Chemical clear sealant "Sylgard" #184 silicone
- National Adhesive's "Plymaster" #87-1059 acrylic transfer tape
- GE Silicone #534-044A
- GE RTV #157
- GE Silpruf SCS 2020
- 3M - 1M8R Seven Minute Epoxy
- 3M - 34B9R Ninety Minut[illegible]xy
- 3M "ISOTAC #Y-9473" Pressure Sensitive Tape

Test samples were made of these materials on GRC samples and submitted to heat cycling tests. All failed the tests except the GE Silicone 534-044A, the 3M-1M8R Seven Minute Epoxy and the National Adhesive's "Plymaster" 87-1059.

Based on these results and the method of application, or ease of application, a decision was made to use the National Adhesive's "Plymaster" to attach the laminates to the GRC panel. An edge sealant of GE 157 RTV was applied to all edges of each laminate.

A photograph of a completed panel is shown in Figure 5.1-1.

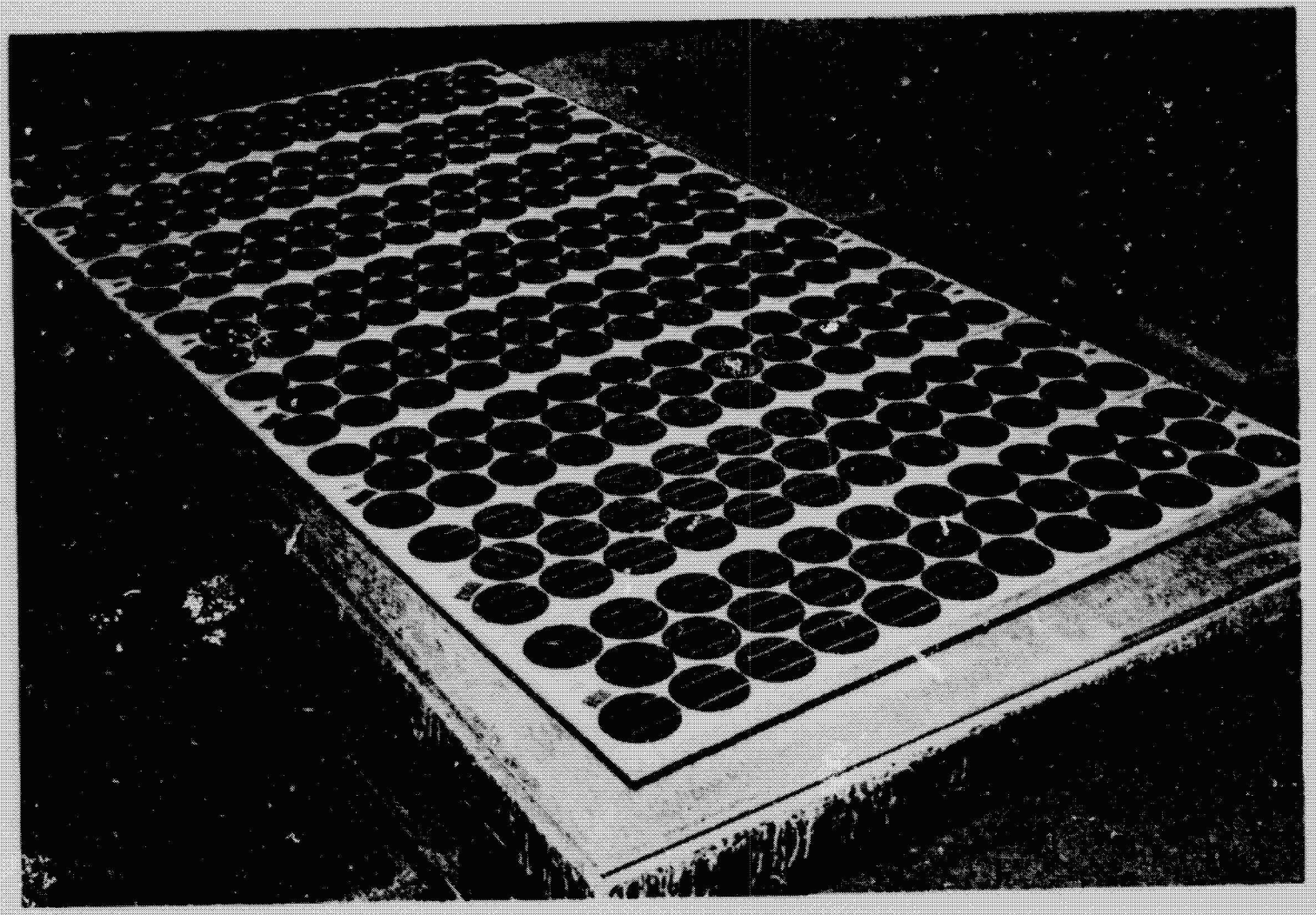

FIGURE 5.1-1
COMPLETED PANEL WITH CELLS

6.0 HI-POT TESTS

It was reported that some concern was being expressed regarding the conductivity properties of the GRC material and that Hi-Pot tests should be conducted in order to determine the proper lamination to use to minimize any current leakage that might be found.

Several Hi-Pot test samples were made using various laminations. Some were encapsulated directly to the GRC. In the first test, only three passed the JPL requirement of 50 micro amp leakage at 3KV. One of these had been encapsulated directly to GRC. The other two were both encapsulated as laminates and attached to the GRC with the acrylic transfer tape. One with no backing exhibited 45 micro amp leakage and the other with a Tedlar backing exhibited zero micro amp leakage. All samples were thermo cycled. After thermo cycling for 50 cycles, all exhibited less micro amp leakage except for the one with the Tedlar backing and transfer tape adhesive which had zero leakage before cycling. The samples were then soaked in water for 12 hours and allowed to room dry for 48 hours. All failed the micro amp test at only 1.5KV except the one sample with the Tedlar backing which had been placed on GRC treated with a moisture resistant. The moisture resistant treatment of the GRC was by the application of SEALCRETE. A copy of the SEALCRETE specifications and characteristics can be found in the appendix.

The Tedlar backed laminate on moisture resistant treated GRC was immersed in water for 24 hours and Hi-Pot tested immediately after removal and drying the surface with paper towels. The result was zero micro amp leakage at 3KV.

7.0 SUBSTRATE MANUFACTURING

A proposed manufacturing facility for producing GRC substrates at a yearly rate of 15 megawatts would have to produce approximately 50,000 substrates a year, based on a substrate panel producing 300 watts. This amounts to 4,166 substrate panels a month or approximately 200 substrate panels a day.

7.1 Manufacturing Process

The number of stations, men per station and equipment required are shown in the work flow sketch and equipment list in Figure 7.1-1. Roller conveyors transport the substrate molds through the spray casting, finishing and indoor storage operations.

At Station No. 1, two men clean the molds (make minor repairs, if needed) and apply mold release agent. Rate of output is one mold each 6 minutes.

At Station No. 2, one man positions mold under spray head and operates the semi-automatic mechanized equipment. One-half minute is allocated for positioning mold and two and one-half minutes for spraying the glass fiber and mortar. This produces a layer approximately 1/8-inch thick. The spray head would be similar to that shown in Figure 7.1-2.

At Station No. 3, two men vibrate and roll the sprayed GRC to compact the glass fiber and remove entrapped air. These molds are then routed back to Station No. 2 for a second layer. After the second layer has been applied and compacted, the molds are routed on to Station No. 4. The mold sequence arriving at Stations No. 2 and No. 3 is: 1-2-3-1-4-2-5-3-6-4-7-5-8-6-9-7-10, etc. Thus, total cycle time would be 6 minutes (2 times 3 minutes).

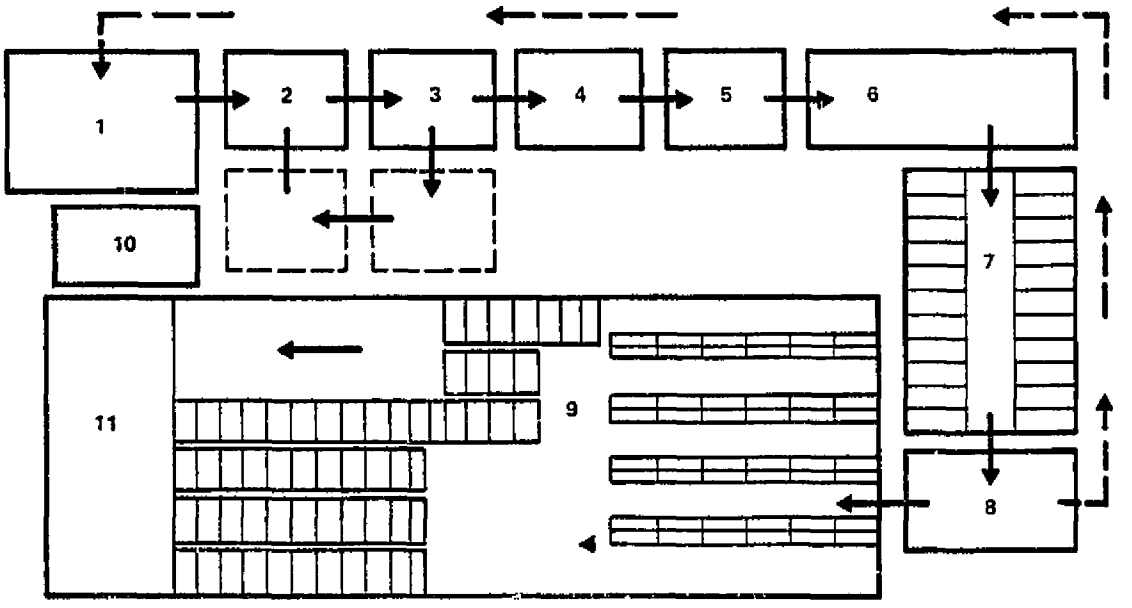

FIGURE 7.1-1
MANUFACTURING PROCESS WORK FLOW AND EQUIPMENT

Station	Men	Equip. Description & Oper.	Cost Equip. $	Area Sq. Ft.
1	2	Hand Tools - Prepare Forms	-	400
2	1	Spray Gun & Chopper & Carrier	3,000	200
3	2	Vibrator & Roller	800	200
4	1	Position Rib Forms	400	300
5	2	2 Spray Guns, Choppers & Carrier Vibrator & Roller	6,000 800	200 200
6	2	Hand Finishing	-	600
7	1	Stacking Machine & Racks Indoor	19,000	4,000
8	2	Demolding & Bagging	1,000	1,000
9	2	(2) Fork Lifts & Storage Racks Outdoor Storage	35,000	(50,000)
10	2	Hoppers & Mixers (Mortar)	30,000	500
11	2	(2) Fork Lifts - Shipping & Receiving	30,000	1,000
12	-	Conveyors (Not Shown)	10,000	incl.
TOTAL	19 men		$136,000	8,600

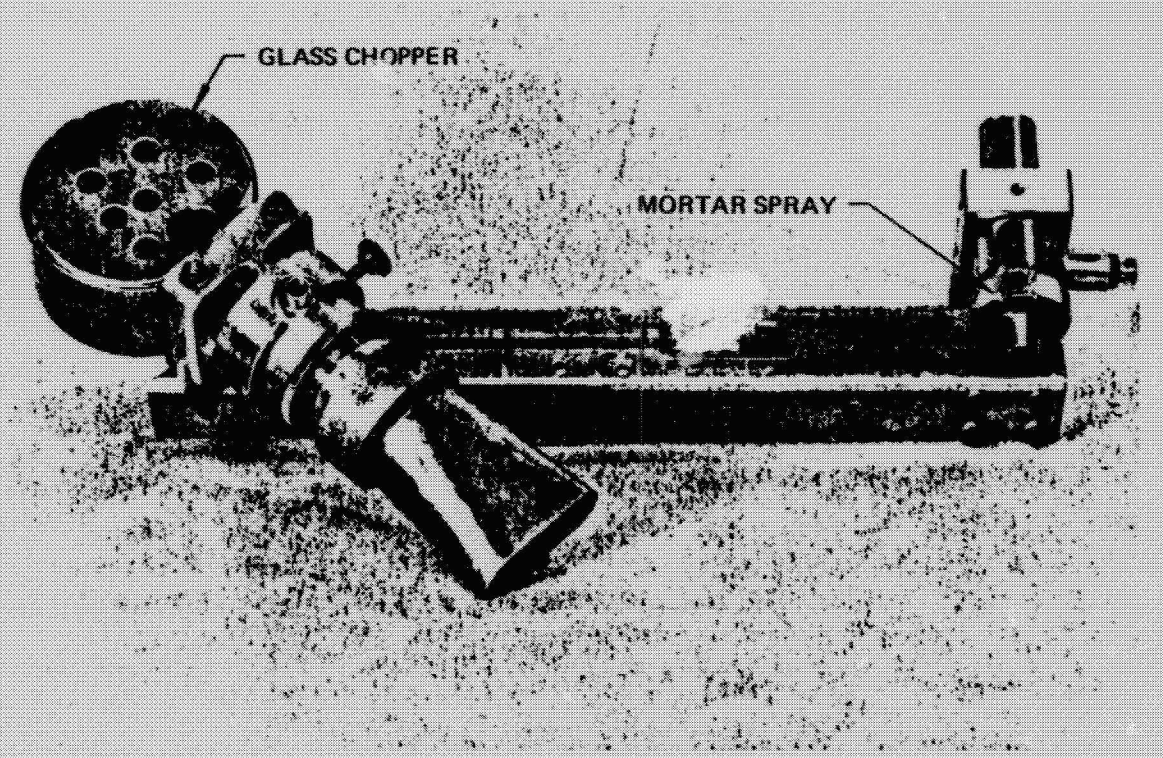

FIGURE 7.1-2
A DOWNLAND GRC SPRAY HEAD

At Station No. 4, one man positions cardboard forms, inserts PVC tubes and routes the molds on to Station No. 5. (Allotted time, 6 minutes). Mold sequence is straight numerical.

At Station No. 5, two men using two semi-automatic mechanized spray heads spray the GRC over the rib forms in two layers compacting each layer. Cycle time, 6 minutes, which is composed of two 1-minute spray cycles and two 2-minute compacting cycles. The molds are then transported on to Station No. 6.

At Station No. 6, two men surface finish the sprayed mold by troweling, trimming and spraying with "Sealcrete."

At Station No. 7, the indoor storage, one man operating a stacking machine places completed mold in storage rack and removes one of the molds that has been in the storage rack for 24 hours. This 24 hour mold is routed on to Station No. 8.

At Station No. 8, two men remove substrate from the mold, turn (to place rib side down) and apply "Sealcrete" to flat surface. They reroute the empty molds back to the Station No. 1. Eighteen to twenty-four minutes later after spraying the "Sealcrete," the treated surface is flushed with water; the substrate is turned rib side up, wrapped in plastic and placed on plywood sheet. These are routed on to Station No. 9.

At Station No. 9, the outdoor storage, two men using forklifts move the wrapped or bagged substrates on the plywood sheets to storage racks. At the same time, one of the substrates is placed in a rack, one is removed from the rack that has been in the rack for seven days. These are stacked in the yard area. Plywood sheets remain with the substrates during yard storage and shipment to destination. They are returned for reuse with an estimated 50 percent recovery.

7.2 Cost Estimates

GRC PANEL

Material = Glass Fiber Reinforced Concrete

Mortar = .66/1.00 Sand/Cement ratio

Glass Fiber = 5% mortar wt.

Panel Design wt = 185 lbs + 20 lbs overspray

= 205 lbs gross wt

Matl./380 lbs batch	wt/lb mortar
H_2O - 67 lbs	.1764 lbs
Cement - 188 lbs	.4947 lbs
Sand - 125 lbs	.3289 lbs
300R - 169 ml	.0012 ml
Glass Fiber - 19 lbs	.0500 lbs

MATERIAL COSTS

Ingredient	Per Unit	Per lb. Bag Lots	Per lb. Bulk	Per lb. Mortar
Cement	(94 lb) 5.39	.0573	(Ton) .04	.0198
Sand 30 mesh	(100 lbs) 3.40	.034	(Ton) .01	.0033
Water	.028(x7.9gal/ft^3 ÷ 62.4)		.0036	.0008
300R (1.25gm/ml	4.50/gal (3785 ml/gal)	.0012/ml (x169 ÷ 380)		.0005
Glass Fiber	1.65/lb	1.65	1.25	.0625
PVC Tubing (2x38" ÷ 12=6.33 ÷ 205x.30)	35.44/100ft	.3544/ft	.30/ft	.0093

(1980 $) $.0962 x 205 lbs = $19.73/panel = $.62/ft^2 = 6.67/M^2

ENCAPSULATION MATERIALS

	$/Sq.Ft.
Tedlar (1 mil)	.04
EVA (2-1/3 layers)	.09
Glass Scrim (.02/sq.ft.)	.02
Korad clear (56 sq.ft./lb. $3.50/lb.)	.06
Edge Sealant RTV GE 157	.22
Totals	$ .43/sq/ft = $4.63/M^2

MANUFACTURING LABOR COST ESTIMATES (MBA)

Direct Labor, 19 Line + 2 QC	=	21
1/3 Lunch & Relief	=	7
1 Supervisor or Foreman	=	1
Number per shift		29

3 shifts x 29 = 87

$25.00/hr. incl. overhead = 87 x 25 = $2,349.00

Times 8 hr. shift = $18,792

Panels required at 300 watts/panel for 15 megawatts/year

50,000/yr. ÷ 12 = 4166 month ÷ 22 = 189/day

Production capacity 10/hr x 8 x 3 shifts = 240

x .90(mfg. eff.) x .95(5% scrap loss) = 205/day produced

$18.792 ÷ 205 = $91.67 ÷ 32 = $2.86/sq.ft. = $30.77/M^2

PROCESSING MATERIALS

Description	$ Cost Per Unit	$ Cost Per Panel
Plastic storage bags 5'x10' (7 day storage)	.50/panel	.50
Wood storage-base ¼" plywood (Part of shipping package-returnable and reusable). Estimate 50% returned	5.00/panel	3.33
Panel Forms		
3/4" Finnboard	25.00/form	
1" Angle	3.00/form	
	28.00/form	
(Life 50 molds) Maintenance .24		.24
Rib Forms (cardboard)	2.00/form	2.00
Mold Release Agent	4.00/gal	.04
Sealcrete	7.50/gal	.80
	Total =	$6.64/panel
		$.2075/ft^2
		2.23/M^2

ESTIMATE INSTALLATION COST
GRC PANEL

Material Required:	Cost Per Unit	Array Cost/ Panel
2 posts 6"x6" pressure treated Fir, 8' long ea.	6.00	12.00
2 posts 6"x6" pressure treated Fir, 4' long ea.	3.00	6.00
4 bolts 3/8" x 7" & Nuts	.15/bolt	.30
2 upper brackets	1.42	2.84
Material: 6x6 steel tubing, 1' long	(1.00)	(2.00)
Labor: 1/20 hr. each	(.42)	(.84)
2 lower brackets	.71	1.42
Material: 6x6 steel tubing, 6" long	(.50)	(1.00)
Labor: 1/60 hr. each	(.21)	(.42)
2 - 1" sched. 40 water pipe 40" long (2 ea.)	1.75	3.50
4 - 12" #7 Reinforcing steel	.50 each	2.00
1/4 cu. yds. 4 posts	40.00/cu.yd	5.00
		33.06 = $11.11/M^2

Installation Costs for Labor & Machines:

Labor:		
Hole boring $0.50/hole (50/hr)	.50/hole	1.00
Concrete $4.00/post Placing posts $1.00/post (20/hr)	1.25/post	2.50
Installation of brackets Placing and drilling holes (20/hr) and bolting - 4 men, (1 transit + 3 others)	5.00/ bracket	10.00
Hanging panel 2 men and truck = $50.00 + 1 helper $20.00/hr.	3.50/panel	3.50
		$17.00 = 5.72/M^2

TOTAL INSTALLATION COST PER PANEL

$16.83/M^2

TOTAL COST PER SQ. FT. PANEL

1980 Dollars

	$/sq.ft. panel	$/sq.M
Encap. Matl.	.43	4.63
GRC "	.62	6.67
GRC Labor	2.86	30.77
GRC Proc. Matl.	.21	2.26
GRC Inst. Matls.	1.03	11.08
Panel Inst. Cost (Labor & Machines)	.53	5.78
	5.68/sq.ft.	$61.07/sq.M

Note: These do not include cells, encapsulation labor or factory investment costs.

7.3 Cost Comparisons

Using JPL's 1975 baseline values: $.50/watt or $54 - 46 (cells and encapsulation labor) = $8/M^2$ for panel and $54/M^2$ for installation and a conversion factor of 1.4 to obtain 1980 values, results in the following:

Item	MBA's GRC Substrate	JPL's 1980 Values
Panel	$42/M^2$	$11/M^2$
Installation	19/M^2	76/M^2
TOTAL	$61/$M^2$	$87/$M^2$

87 - 61 = 26 or 30% less

8.0 NEW TECHNOLOGY

An improved design of a photovoltaic solar panel fabricated from a recently developed glass fiber reinforced concrete material was reported to NASA's New Technology Representative September 17, 1979 as a possible "New Technology". This design was first disclosed in Quarterly Report No. 2 dated July 2, 1979 (paragraph 2.2.3, page 14, Figures 11 and 12) prepared by MBAssociates under DOE/JPL Contract No. 955281-79/05. It was also mentioned in Quarterly Report No. 3 dated October 5, 1979 (paragraph 2.5 and 4.0, pages 9 and 19, Figures 9 through 16).

8.1 Novelty Features of New design

A 1/4" thick 4 ft x 8 ft Glass Reinforced Concrete Photovoltaic Solar Panel incorporating:

- A smooth, dense, flat, hard surface suitable as a solar cell substrate.
- Two (2) Trapezoidal stiffening ribs serving also as structural support points.
- Strategic placement of ribs, with imbedded support tubes (standard PVC tubing), minimizing bending moments and resulting stresses produced by installation and wind loads.
- A Structural design amenable to mass production requiring minimal labor for installation.
- A Four (4) point support system requiring:
  - Four (4) wooden posts (6" x 6") each serving two (2) separate panels.
  - Four (4) simple post brackets of (6" x 6") standard, square structural steel tubing, each serving two (2) separate panels.

- Two (2) support bars of standard one (1) inch, schedule 40 galvanized pipe with No. 7 reinforcing steel bars inserted in the pipe ends as bracket connectors.

8.2 Inovator

James L. Eirls, Project Engineer, MEAssociates.

APPENDIX A

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   September 1975 209-216

9. The Role of the Interface in Glass Fibre Reinforced Cement
   A. J. Majumdar
   Cement and Concrete Research Vol. 4, No. 2
   March 1974 247-268

10. Glass Fibre Reinforced Cement
    A. J. Majumdar and R. W. Nurse
    Materials Science and Engineering Vol. 15, 1974 107-127

11. Flexural Fatique of Glass Fibre Reinforced Cement
    A. P. Hibbert and F. J. Grimer
    Journal of Materials Science Vol. 10, No. 12, December 1975 2124- 2133

12. Properties of Glass Fibre Cement - The Effect of Fibre Length and Content. M. A. Ali, A. J. Majumdar and B. Singh
    Journal of Materials Science Vol. 10, 1975 1732 - 1740

APPENDIX B

POZZOLITH 300-R

MASTER BUILDERS

POZZOLITH* 300-R

ADMIXTURE FOR IMPROVING CONCRETE

Meets and Exceeds Requirements of ASTM C 494 for Type B and Type D Admixture

POZZOLITH 300-R is a ready-to-use liquid admixture for making better, more uniform and predictable high quality concrete. It reduces the water content of concrete of a given consistency while retarding the setting time to facilitate placing and finishing.

benefits: POZZOLITH 300-R admixture aids in the production of concrete with these special qualities:

- MODERATE TO EXTENDED RETARDATION depending on dosage used
- SUPERIOR FINISHING CHARACTERISTICS FOR FLATWORK
- BETTER APPEARANCE OF FORMED SURFACES
- Plus ALL THE BASIC BENEFITS OF POZZOLITH 300-N
  - Increased strength — compressive, flexural and bond of concrete to steel
  - Greater economy in a mix designed for a given strength, slump and air content
  - Minimum cracking
  - Reduced permeability — Improved watertightness
  - Easier placement — Economy in placement
  - Greater durability

where to use: POZZOLITH 300-R admixture is recommended for use in all types of concrete where retardation of set and improved performance are required or desired.

POZZOLITH 300-R admixture improves pumped concrete, shotcrete and conventionally placed concrete; it improves plain, reinforced, precast, prestressed, lightweight or standard weight concrete.

POZZOLITH 300-R can be used with air-entraining cements and with air-entraining admixtures approved under AASHTO, ASTM and CRD Specifications when air-entrained concrete is specified or desired.

When used in conjunction with another admixture, each admixture must be dispensed separately into the mix.

Master Builders approved air-entraining admixtures are recommended for use with POZZOLITH 300-R admixture when air-entrained concrete is specified or desired.

It can be used in white or colored concrete and in architectural concrete.

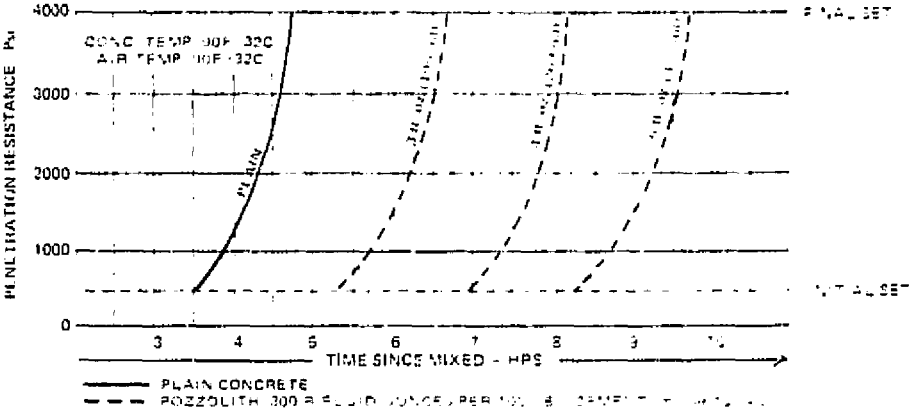
*, U.S. Pat. Off.

dosage: Use 4 : 1 fluid ounces (260 : 65 ml per 100 kg) of POZZOLITH 300-R per 100 pounds of cement.

rate of hardening: Setting times given below are comparative for a specific set of materials and conditions and are offered only as a guide.

Since setting time is also influenced by the chemical and physical composition of the basic ingredients of the concrete, temperature of the concrete and climatic conditions. Trial mixes should be made with job materials to determine the dosage required for a given degree of retardation.

COMPARATIVE RATE OF HARDENING AT VARIABLE DOSAGES



temperature: The temperature of the concrete mix and the surrounding temperature (forms, earth, reinforcement, air, etc.) affect the rate of hardening of the concrete. At higher temperatures concrete hardens more rapidly and may impose problems on placing and finishing of concrete. By varying the dosage of POZZOLITH 300-R, concrete with more desirable rate of hardening characteristics can be obtained. For retardation requirements which exceed the 5 fluid ounce (325 ml per 100 kg) dosage, consult your local Master Builders fieldman before proceeding.

compressive strength: In comparison with plain concrete, concrete containing POZZOLITH 300-R admixture develops higher early and higher ultimate strengths. Exceeds the strength requirements of ASTM C 494, AASHTO M-194 and CRD-C 87 specifications for admixtures.

packaging: POZZOLITH 300-R admixture is supplied in 55 U.S. gallon (208 litres) drums.

caution: If POZZOLITH 300-R admixture has frozen, thaw at 35F (2C) or above and completely reconstitute by mild mechanical agitation. Do not use pressured air for agitation.

For additional information on POZZOLITH 300-R or on its use in developing a concrete mix with special performance characteristics, contact Master Builders, Cleveland, Ohio 44118 or Master Builders local field representative.

MASTER BUILDERS
DIVISION OF MARTIN MARIETTA CORPORATION
CLEVELAND, OHIO 44118 • TORONTO, ONTARIO M6M 3E4

Products for Improving Concrete

APPENDIX C

SEALCRETE

General Information
on
SEALCRETE

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1.0 General Description

1.1 SEALCRETE is a scientific penetrating preservative which waterproofs and seals concrete, masonry, concrete block, stucco, precast concrete, sand blasted concrete, terrazzo, and concrete plaster. SEALCRETE is an odorless, non-toxic, and non-flammable liquid compound. SEALCRETE is completely safe to use.

2.0 Characteristics

2.1 SEALCRETE reacts with the alkali and moisture in the concrete products to form a gel within the material. This gel engulfs all the particles and binds them into one solid mass. The results are a higher density, an increase in strength, and a permanent water-sealed material.

2.2 SEALCRETE reacts to water regardless of volume. SEALCRETE utilizes the water to create additional chemical binding substance. The chemical reaction continues until every particle in the concrete is completely sealed.

2.3 The application of SEALCRETE is very simple and completely safe. Use SEALCRETE as it comes out of the container never mix it with any other solutions. A hudson sprayer or equivalent has been found to be the most economical and convenient way of application. Cement blocks and sandblasted surfaces require three or four applications because of the excessive porosity.

3.0 Concrete

3.1 SEALCRETE cures concrete uniformly by utilizing the water in the concrete to set up a gel within allowing the concrete to cure without shrinkage and cracking. The application is simple, just spray the concrete with SEALCRETE after the concrete has been troweled. One gallon will cover 100 square feet.

3.2 SEALCRETE provides an alkali free surface for painting, thereby increasing the paint life.

3.3 SEALCRETE provides a moisture free and alkali free surface for adhesives (mastics) used in the installation of tiles, linoleums, terrazzos, etc.

3.4 SEALCRETE moisture seals and preserves basement walls, new or old, on the exposed and the dirt side below grade Only one side of the wall needs to be treated. In countries outside the U.S.A. where cements are below standard, SEALCRETE has been found over and over to be the most effective product for sealing the concrete internally.

3.5 SEALCRETE cleans old and new concrete by forcing all

materials foreign to concrete to the surface. SEALCRETE penetrates progressively through the concrete, binding all the aggregates into one solid mass and forcing all dirt, grease, oils and other impurities to the surface. Once SEALCRETE has sealed the concrete , contaminates such as oils, greases, brake fluids, and acids may be rinsed off with water without staining the surface.

3.6 SEALCRETE will prevent alkali-leaching on old or new concrete. This is accomplished with applications of SEALCRETE. SEALCRETE will penetrate, seal the concrete, and force the loose alkali to the surface where it may be rinsed off or cleaned with a mop.

3.7 SEALCRETE internally seals and waterproofs concrete blocks, concrete slabs, precast concrete, tilt ups, and concrete walls. SEALCRETE will also prevent wall sweating and moisture from passing from one floor to another in multiple story buildings. SEALCRETE is excellent for treating subterranean garages where water is passing through due to capillary action and hydrostatic water pressure.

3.8 SEALCRETE will prevent deterioration and abrasive dusting on new or old concrete where there is excessive dusting, applications with SEALCRETE will seal and prevent future deterioration.

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3.9 SEALCRETE increases the density on old or new concrete and increases the resistance to hydrostatic pressures. Results of tests show that the percentage of hydrostatic resistance is increased in direct proportion to the voids existing in the concrete prior to the application of SEALCRETE.

3.10 Tensile Strength Increases: Laboratory tests show that concrete treated with SEALCRETE had a definite increase in tensile strength from 20% to as much as 40% on very low density concrete.

3.11 Patching of old concrete: SEALCRETE provides an excellent surface for patching concrete with epoxies or with cement. When patching with compounds other than cement, saturate the affected area with SEALCRETE and allow SEALCRETE to penetrate the concrete. when the excess alkali is exposed to the surface rinse a way with water. The area is now ready to be patched. This also applies to surfaces where caulking materials are to be used.

3.12 When patching with cement, apply SEALCRETE in the affected area, than the patching cement. After the patch has been applied. spray or flush the patch with SEALCRETE. SEALCRETE will prevent shrinkage and cracking and will provide a perfect and effective bond between the concrete and the patch.

4.0 SEALCRETE will clean and seal concrete, terrazzo, and stucco by expelling the foreign materials to the surface where they can be flushed off with water. SEALCRETE WILL NOT CHANGE OR DISCOLOR THE SURFACE OF THE CONCRETE, STUCCO OR TERRAZZO.

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4.1 Oil, grease or acid conditions. No preliminary cleaning is necessary before SEALCRETE is applied. Flush area with SEALCRETE. After SEALCRETE has penetrated, the area will feel sticky, tacky or slippery, depending on the amount of grease. This means that SEALCRETE has penetrated the surface and expelled the contaminates to the surface. Flush area with water. A stiff broom will help float oils and grease from the surface. Deep oil and grease stains will not be entirely removed at the time of application but will gradually disappear. The concrete should be flushed with water whenever convenient as this will accelrate the cleaning of the concrete, quarry tile, etc.

4.2 Meat processing, packing and dairy buildings. SEALCRETE is completely effective in these applications because of its ability to penetrate fats, greases, oils, and latic acid, all of which are deleterious to concrete. SEALCRETE progressively expels these materials to the surface and seals the concrete so that it may thereafter be kept clean by flushing off with water.
The SEALCRETE formula has been approved for application in this industry by the U.S. Dept. of Agriculture ref. document YLY dated December 6, 1960.

5.0 Stucco

5.1 SEALCRETE is excellent for use with stucco, it waterproofs, seals against contaminants, and prevents deterioration. Tests were performed by making containers out of very porous first coating stucco, then applying SEALCRETE. The treated and untreated containers were filled with water. The containers treated with SEALCRETE did not leak or sweat when sprayed with nitrogen. The untreated containers permitted water to pass freely,In addition, the untreated containers exhibited hairline cracks when exposed to water and nitrogen.

5.2 Curing of stucco. SEALCRETE is excellent and effective in curing stucco due to its characteristic of accelerating the setting and delaying the curing period. This is due primarily to the fact that SEALCRETE utilizes the moisture in the stucco to form a gel within the stucco, eliminating the escaping of moisture. The reactions are permanent.

5.3 Application. Spray SEALCRETE on the stucco after troweling and the surface water **has** disappeared. SEALCRETE will stop all surface dusting and prevent hairline cracking and in addition it will seal the stucco. Spray stucco with three application of SEALCRETE at the rate of one hundred (100) square feet per gallon.

5.4 Increase in tensile strength. SEALCRETE has been found to be very effective in old or new stucco by increasing the density and filling in the voids, thereby increasing the tensile strength of stucco. Tests indicate an increase as much as 40%.

5.5 Patching. Apply SEALCRETE in the affected area, then patch. Apply SEALCRETE after patching, this will prevent cracking due to shrinkage.

5.6 Chemical Laboratory and Battery manufacturing plants. Acid conditions, flush area to be treated with SEALCRETE immediately after troweling to prevent penetration of acids and staining of the concrete. SEALCRETE prevents the deterioration of the concrete and eliminates frequent costly repairs.

5.7 Wineries. SEALCRETE will penetrate into the concrete surfaces and expel all materials foreign to concrete, thereby preventing spores from algae, stains and the penetration of acids.

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6.0 Summation. SEALCRETE will increase the density and tensile strength of concrete, old or new, and will prevent cracking due to shrinkage and capillary action of water. The ideal time to apply SEALCRETE is when concrete or stucco is placed. SEALCRETE will cure, waterproof, and prevent deterioration of concrete. It will also provide an alkali free surface for painting and floor covering. It will prevent penetration of foreign materials, and retard the formation of algae and bacteria.

SEALCRETE will in no way damage filters, pumps, or fixtures.

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APPENDIX D

DAREX - CONCRETE ADMIXTURES

DAREX · CONCRETE ADMIXTURES

DESCRIPTION:

DAREX AEA® admixture is an aqueous solution of a complex mixture of organic acid salts. It contains a catalyst for more rapid and complete hydration of portland cement. DAREX AEA is specially formulated for use as an air entraining admixture for concrete and is manufactured under rigid control which provides uniform, predictable performance. It is supplied ready-to-use and does not require premixing with water. One gallon weighs approximately 8.5 lbs.

USES:

DAREX AEA is used in ready-mix, block, and concrete products plants. It is also used as a gauge water addition on the job at batching plants, job-site mixers, highway pavers . . . wherever concrete is mixed.

Because DAREX AEA plasticizes or "fattens" the mix, it is particularly effective with slag, lightweight, or manufactured aggregates which tend to produce harsh concrete. It also makes possible the use of natural sand deficient in fines.

AIR ENTRAINING ACTION:

Air is entrained by the development of a semimicroscopic bubble system — introduced into the mix by agitation and stabilized by DAREX AEA in the mortar phase of the concrete.

Air Content is Controlled. Because excessive entrained air may be detrimental to strengths, DAREX AEA is designed to limit the maximum amount of air entrained despite an inadvertent overdose. DAREX AEA is not supersensitive. Small variations in addition rate are not critical and do not materially affect the amount of air entrained.

Workability is Improved. Millions of tiny air bubbles entrained with DAREX AEA act as flexible ball bearings, lubricating and plasticizing the concrete mix. This permits a substantial reduction in mixing water with no loss in slump. Placeability is improved . . . bleeding, green shrinkage and segregation are minimized.

Durability is Increased. DAREX AEA concrete is extremely durable, particularly when subjected to freezing and thawing. It has a remarkable resistance to frost and deicing salts as well as to sulfate, sea and alkaline waters.

COMPATIBILITY WITH OTHER ADMIXTURES:

DAREX AEA is compatible in concrete with all known water reducing admixtures and water reducing retarders, such as WRDA with HYCOL™, WRDA® and DARATARD®. By combining the separate effects of air entrainment with the dispersion of a water reducing admixture, the water requirement of concrete may be reduced up to 20% — with proportional increases in strength and outstanding improvement in durability. DAREX AEA is also compatible with concrete mixes containing calcium chloride. EACH ADMIXTURE SHOULD BE ADDED SEPARATELY TO THE MIX.

ADDITION RATES:

There is no standard addition rate for DAREX AEA. The amount to be used will depend upon the amount of air required under job conditions, usually in the range of 4 to 8%. Typical factors which might influence the amount of air entrained are: temperature, cement, sand gradation, and use of extra fine materials such as fly ash. Typical DAREX AEA addition rates range from ¾ to 3 fluid ounces per 100 lbs. of cement.

The air entraining efficiency of DAREX AEA becomes even greater when used with water reducing and set retarding agents. This may allow a reduction of up to two-thirds in the amount of DAREX AEA required for the specified air content.

MIX ADJUSTMENT:

Entrained air results in increased yields with a consequent decrease in the cement content of the placed concrete. This condition calls for a mix adjustment, usually accomplished by reducing the fine aggregate content. This is in addition to the reduction in water content brought about by the increase in plasticity.

DISPENSING EQUIPMENT:

A complete line of automatic DAREX AEA dispensers is available. Accurate and simple, these dispensers are easily adapted to existing facilities on paving mixers and in batching plants.

PACKAGING:

DAREX AEA is available in bulk, delivered in metered tank trucks, and 55-gallon drums. DAREX AEA contains no flammable ingredients. IT FREEZES AT ABOUT 30°F, BUT ITS AIR ENTRAINING PROPERTIES ARE COMPLETELY RESTORED BY THAWING AND THOROUGH AGITATION.

ARCHITECTS' SPECIFICATION FOR CONCRETE AIR ENTRAINING ADMIXTURE:

Concrete shall be air entrained concrete, containing 4 to 8% entrained air. The air contents in the concrete shall be determined by the pressure method (ASTM Designation C 231) or gravimetric method (ASTM Designation C 138). The air entraining admixture shall be a purified hydrocarbon type with a cement catalyst, such as DAREX AEA, as manufactured by the Construction Products Division of W. R. Grace & Co., or equal. The air entraining admixture shall be added at the concrete mixer or batching plant at approximately ¾ to 3 fluid ounces per 100 lbs. of cement, or in such quantities as to give the specified air contents.

W. R. Grace & Co. 3p CONCRETE MATERIALS

CONSTRUCTION PRODUCTS DIVISION, W. R. GRACE & CO.

We hope the information given here will be helpful. It is based on our best knowledge, and we believe it to be true and accurate. Please read all statements, recommendations or suggestions herein in conjunction with our conditions of sale which apply to all goods supplied by us. We assume no responsibility for the use of these statements, recommendations or suggestions, nor do we intend them as a recommendation for any use which would infringe any patent or copyright.

GRACE

HEADQUARTERS: 62 WHITTEMORE AVE., CAMBRIDGE, MASS. 02140

Form CMD-431-2G A

1077 Printed in U.S.A.

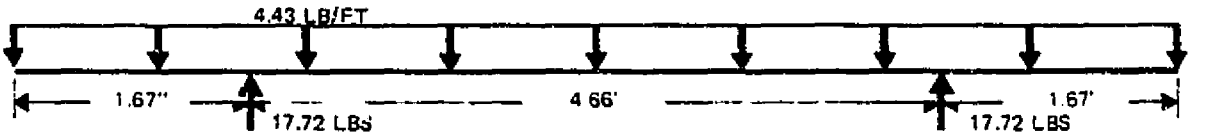
APPENDIX E

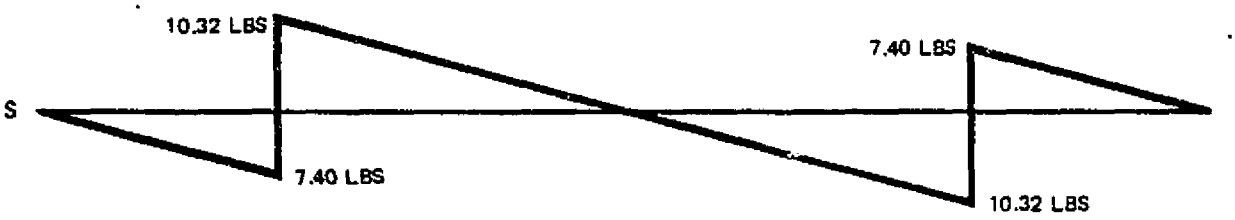
CALCULATIONS

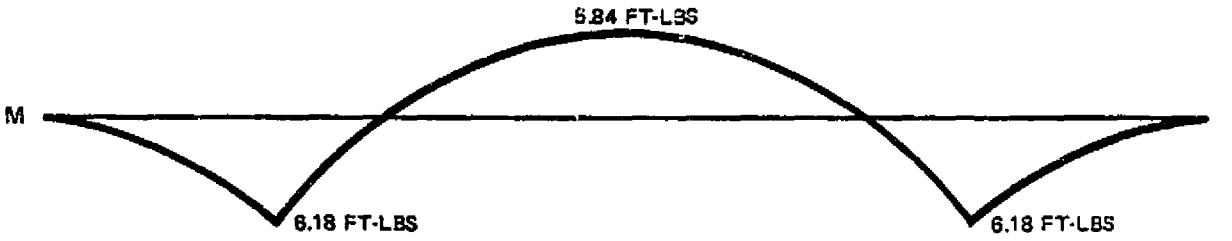
LOAD ANALYSIS HANDLING

1/4" THICK SUBSTRATE
DL = 4.43 LBS/FT^2
LL = 0

LONGITUDINAL







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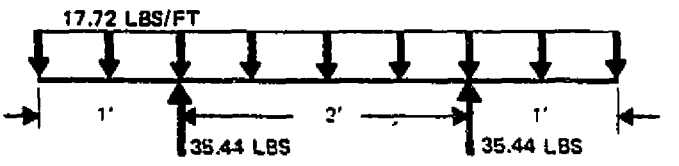
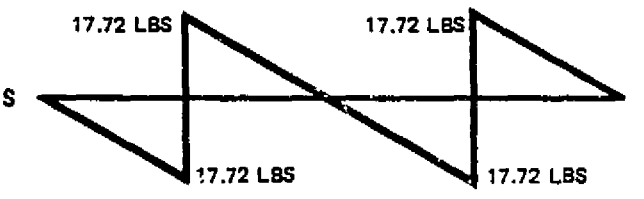
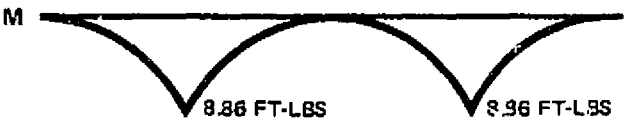






MBA

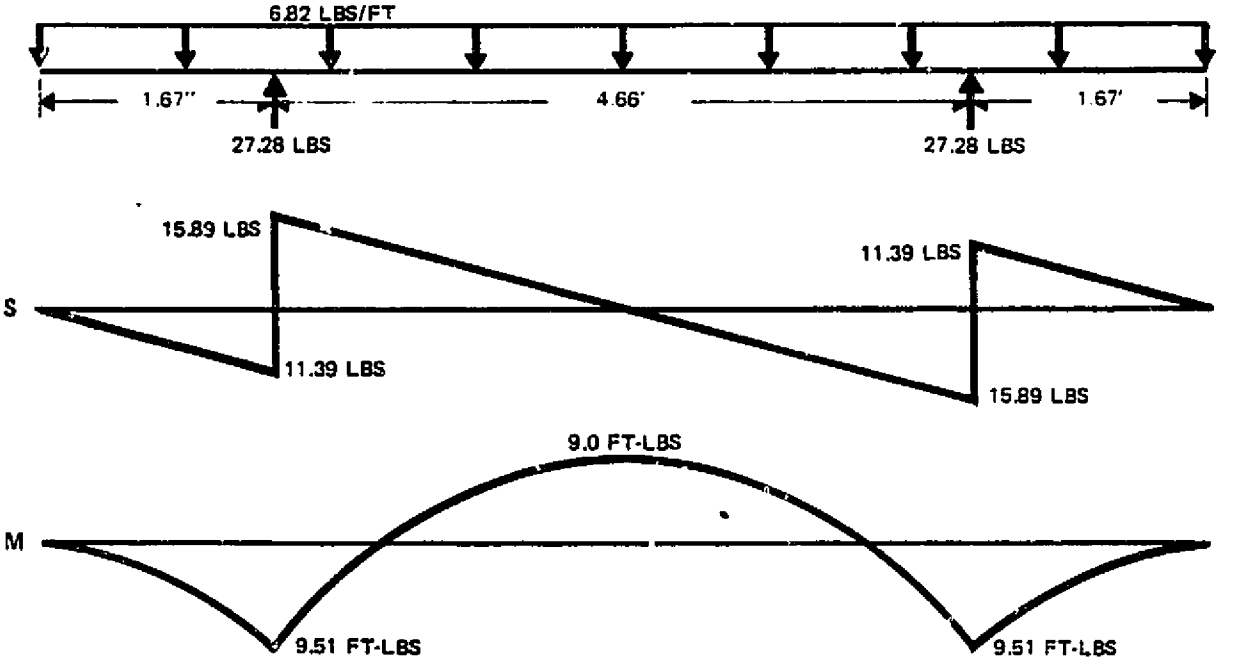
C-2

0650-16973

LOAD ANALYSIS HANDLING

3/8" THICK SUBSTRATE
DL = 6.82 LBS/FT^2
LL = 0

LONGITUDINAL



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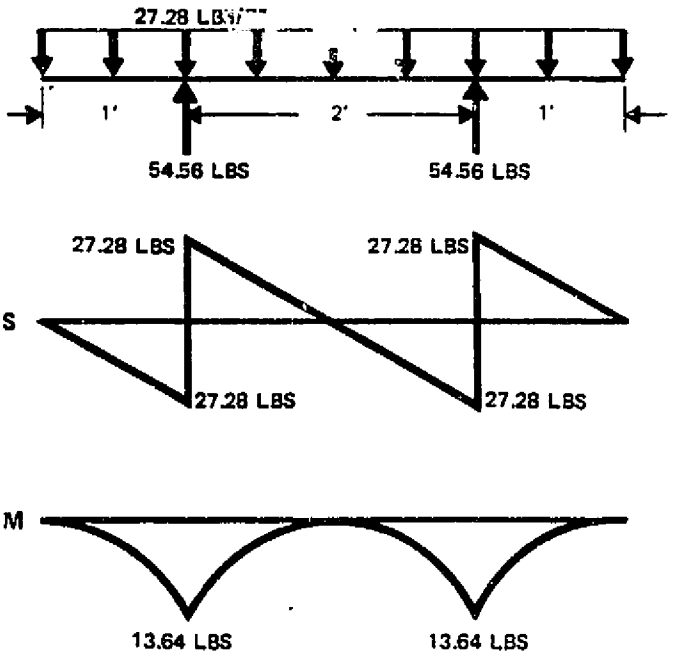

MBA

0650-16974

LOAD ANALYSIS OPERATIONAL

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DL = 4.43 LBS/FT^2
LL = 50 LBS/FT^2

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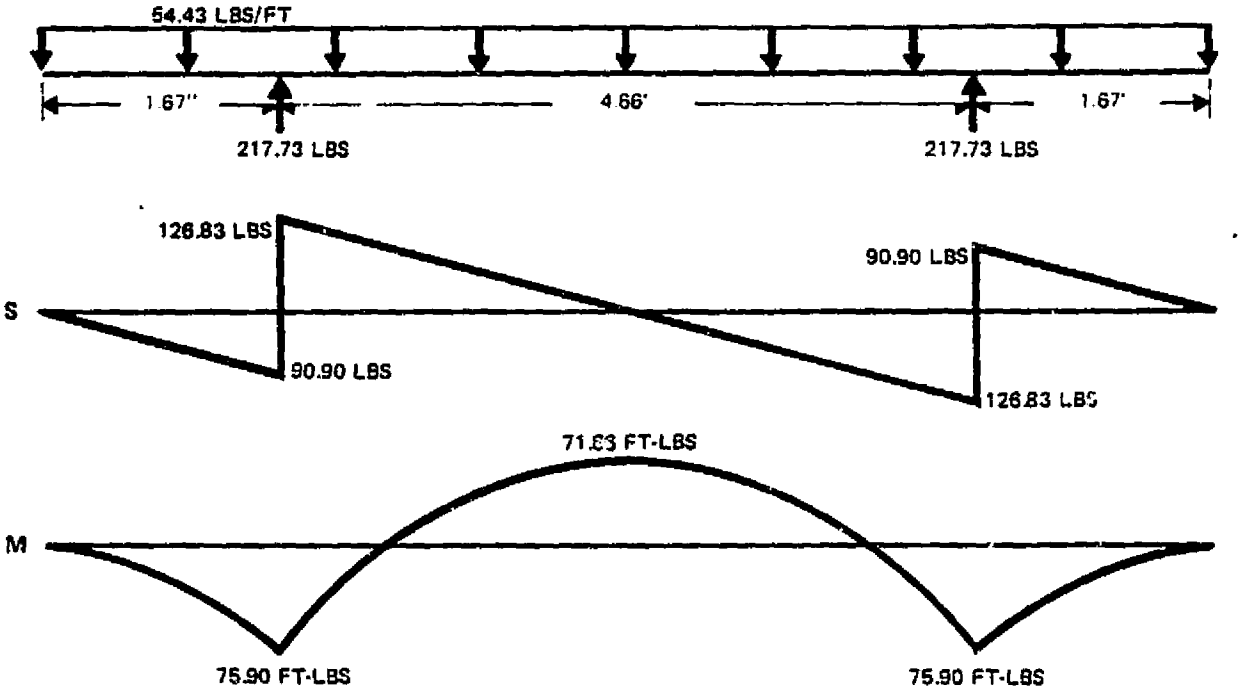

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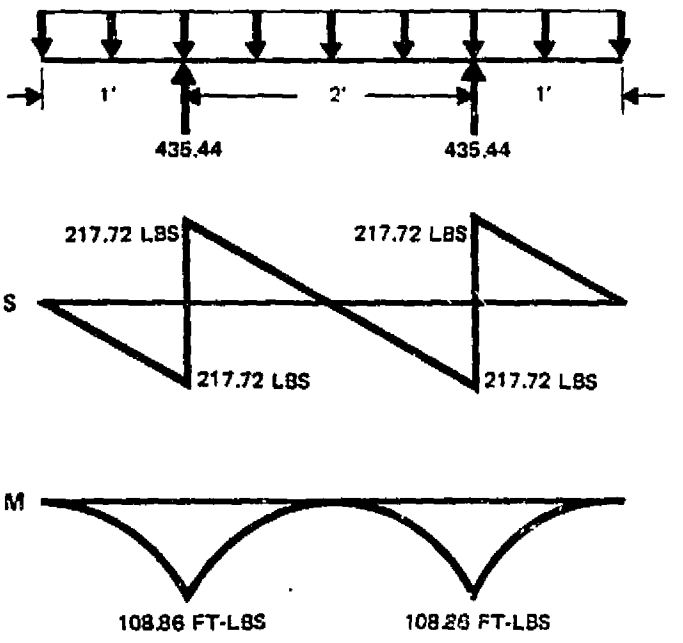


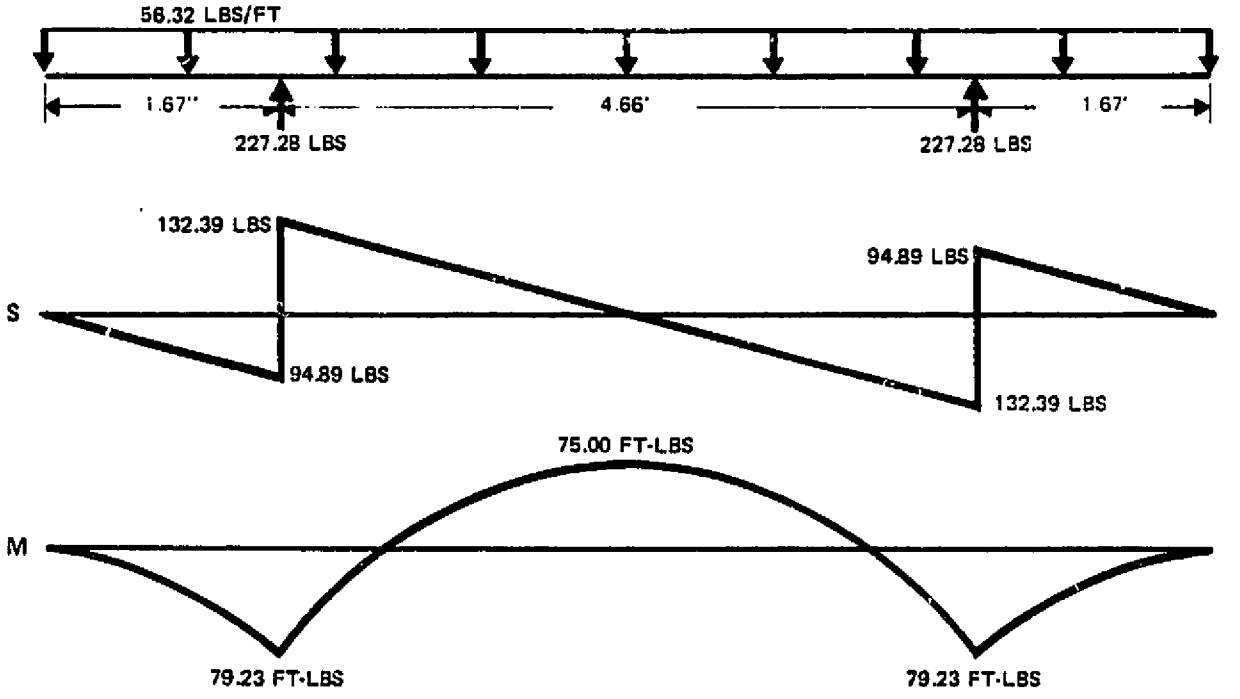
MBA

0650-16975

LOAD ANALYSIS OPERATIONAL

3/8" THICK SUBSTRATE
DL = 6.82 LBS/FT^2
LL = 50 LBS/FT^2

LONGITUDINAL



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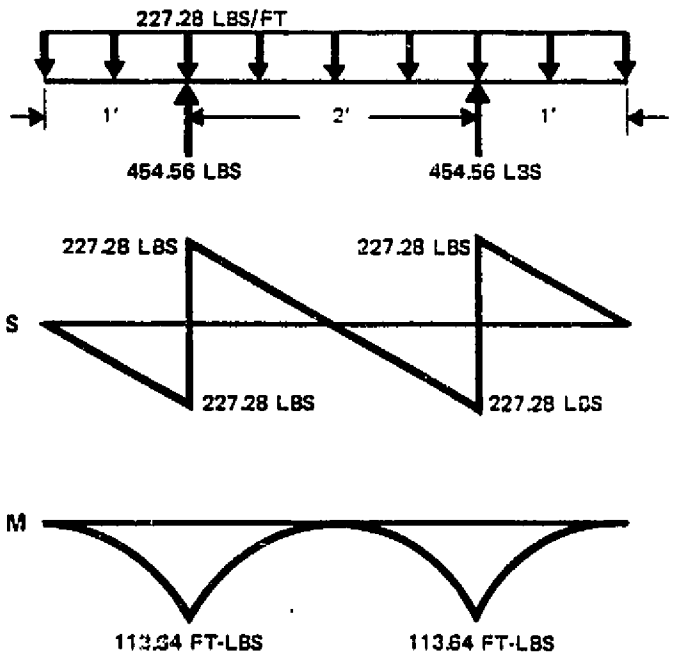
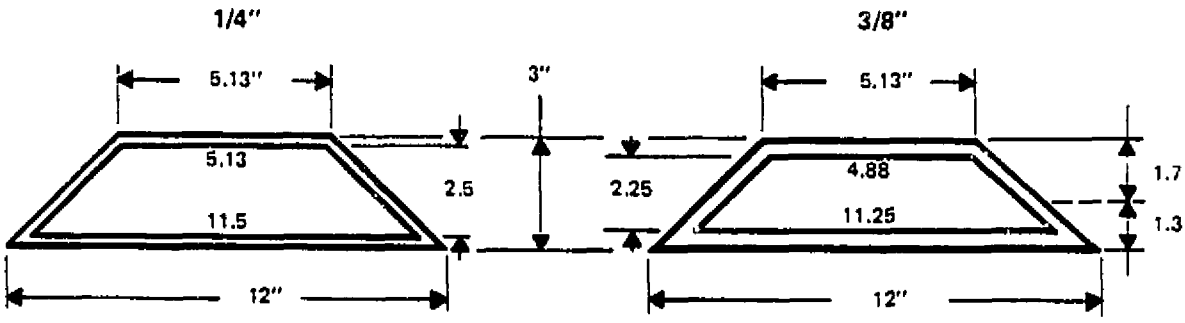


MBA

0650-16976

SECTION ANALYSIS – LONGITUDINAL



1/4"

$$I = \frac{3^3(12^2 + 4\ (12)(5.13) + 5.13)}{36\ (12 + 5.13)} - \frac{2.5^3(11.5^2 + 4\ (11.5)(5.13) + 5.13)}{36\ (11.5 + 5.13)}$$

$$I = 17.31 - 9.75 = \underline{\underline{7.56}}\ in^4$$

$$C = \frac{3\ (2 \times 12 + 5.13)}{3\ (12 + 5.13)} = \underline{1.70"}$$

$$A = \frac{3(12 + 5.13) - 2.5\ (11.5 + 5.13)}{2} = \underline{4.91}\ in^2$$

$$A_{wt.} = \frac{4.91 \times 12}{1728} \times 130\ lbs/ft^3 = \underline{\underline{4.43}}\ lbs$$

3/8"

$$I = \frac{3^3(12^2 + 4(12)(5.13)\quad 5.13)}{36(12 + 5.13)} - \frac{2.25^3(11.25^2 + 4(11.25)(4.88) + 4.88)}{36\ (11.25 + 4.88)}$$

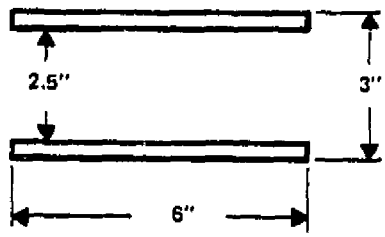
$$I = 17.31 - 6.39 = \underline{\underline{10.42}}\ in^4$$

$$C = \frac{3\ (2 \times 12 + 5.13)}{3\ (12 + 5.13)} = \underline{\underline{1.70"}}$$

$$A = \frac{3\ (12 + 5.13) - 2.25\ (11.25 + 4.88)}{2} = \underline{7.55}\ in^2$$

$$A_{wt.} = \frac{7.55 \times 12 \times 130\ lbs/ft^3}{1728} = \underline{\underline{6.32}}\ lbs$$

SECTION ANALYSIS – TRANSVERSE



1/4"

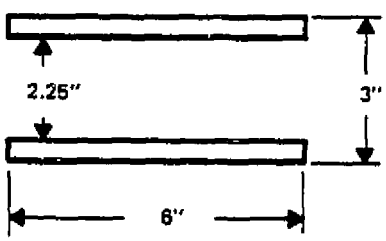
$$I = \frac{6\ (3^3 - 2.5^3)}{12}$$

$$I = \underline{\underline{5.69}}\ in^4$$

$$C = 3/2 = 1.5$$

$$A = 6\ (3 - 2.5)$$

$$A = \underline{\underline{3.0}}\ in^2$$



3/8"

$$I = \frac{6\ (3^2 - 2.25^2)}{12}$$

$$I = \underline{\underline{7.80}}\ in^4$$

$$C = 3/2 = 1.5$$

$$A = 6\ (3-2.25)$$

$$A = \underline{\underline{4.5}}\ in^2$$

STRESS ANALYSIS - HANDLING

1/4" SUBSTRATE

LONGITUDINAL

$F_v = 11/4.91$

$F_v = 2.24$ psi

$$F_{b\ comp} = \frac{7 \text{ ft-lbs} \times 12 \text{ in} \times 1.3 \text{ in}}{7.56 \text{ in}^4}$$

$F_{b\ comp} = 14.44$ psi

$$F_{b\ ten} = \frac{7 \text{ ft-lbs} \times 12 \text{ in} \times 1.7 \text{ in}}{7.56 \text{ in}^4}$$

$F_{b\ ten} = 18.89$ psi

$M_{max} = 7$ ft-lbs

$V_{max} = 11$ lbs

$I = 7.56 \text{ in}^4$

$C_{comp} = 1.3$ in

$C_{ten} = 1.7$ in

TRANSVERSE

$F_v = 18$ ft-lbs/3.0

$F_v = 6$ psi

$$F_b = \frac{9 \text{ ft-lbs} \times 12 \text{ in} \times 1.5 \text{ in}}{5.96 \text{ in}^4}$$

$F_b = 28.47$ psi

$M_{max} = 9$ ft-lbs

$V_{max} = 18$ lbs

$I = 5.69 \text{ in}^4$

$C = 1.5$ in

AT SUPPORTS

$F_v = 36 \text{ lbs}/3 \text{ in}^2$

$F_v = 12$ psi

STRESS ANALYSIS - HANDLING

3/8" SUBSTRATE

LONGITUDINAL

$F_v = 16 \text{ lbs}/7.55 \text{ in}^2$

$F_v = 2.12 \text{ psi}$

$$F_{b\ comp} = \frac{10 \text{ ft-lbs} \times 12 \text{ in} \times 1.3 \text{ in}}{10.42 \text{ in}^4}$$

$F_{b\ comp} = 14.95 \text{ psi}$

$$F_{b\ ten} = \frac{10 \text{ ft-lbs} \times 12 \text{ in} \times 1.7 \text{ in}}{10.42 \text{ in}^4}$$

$F_{b\ ten} = 19.58 \text{ psi}$

$M_{max} = 10 \text{ ft-lbs}$

$V_{max} = 16 \text{ lbs}$

$I = 10.42 \text{ in}^4$

$C_{comp} = 1.3 \text{ in}$

$C_{ten} = 1.7 \text{ in}$

TRANSVERSE

$F_v = 28 \text{ lbs}/4.5 \text{ in}^2$

$F_v = 6.22 \text{ psi}$

$$F_b = \frac{14 \text{ ft-lbs} \times 12 \text{ in} \times 1.7 \text{ in}}{7.80 \text{ in}^4}$$

$F_b = 32.30 \text{ psi}$

$M_{max} = 14 \text{ ft-lbs}$

$V_{max} = 28 \text{ lbs}$

$I = 7.80 \text{ in}^4$

$C = 1.5 \text{ in}$

AT SUPPORTS

$F_v = 56 \text{ lbs}/4.5 \text{ in}^2 = 12.44 \text{ psi}$

STRESS ANALYSIS - OPERATIONAL

1/4" SUBSTRATE

LONGITUDINAL

$F_v = V/A$

$F_b = Mc/I$

$F_v = 127 \text{ lbs}/4.9 \text{ in}^2$

$F_v = 25.87 \text{ psi}$

$M_{max} = 76 \text{ ft-lbs}$

$V_{max} = 127 \text{ lbs}$

$I = 7.56 \text{ in}^4$

$C_{comp} = 1.3 \text{ in}$

$C_{ten} = 1.7 \text{ in}$

$$F_{b\ comp} = \frac{76 \text{ ft-lbs} \times 12 \text{ in} \times 1.3 \text{ in}}{7.56 \text{ in}^4} = 156.83 \text{ psi}$$

$$F_{b\ ten} = \frac{76 \text{ ft-lbs} \times 12 \text{ in} \times 1.7 \text{ in}}{7.56 \text{ in}^4} = 205.10 \text{ psi}$$

TRANSVERSE

$F_v = 218 \text{ lbs}/3.0 \text{ in}^2$

$F_v = 72.67 \text{ psi}$

$$F_b = \frac{109 \text{ ft-lbs} \times 12 \times 1.5}{5.69 \text{ in}^4}$$

$F_b = 344.82 \text{ psi}$

$M_{max} = 109 \text{ ft-lbs}$

$V_{max} = 218 \text{ lbs}$

$I = 5.69 \text{ in}^4$

$C = 1.5 \text{ in}$

AT SUPPORTS

$F_v = 436/3$

$F_v = 145.33 \text{ psi}$

STRESS ANALYSIS - OPERATIONAL

3/8" SUBSTRATE

LONGITUDINAL

$F_v = V/A$

$F_b = Mc/I$

$F_v = 135 \text{ lbs}/7.55 \text{ in}^2$

$F_v = 17.88 \text{ psi}$

$M_{max} = 80 \text{ ft-lbs}$

$V_{max} = 135 \text{ lbs}$

$I = 10.42 \text{ in}^4$

$C_{comp} = 1.3 \text{ in}$

$C_{ten} = 1.7 \text{ in}$

$$F_{b\ comp} = \frac{80 \text{ ft-lbs} \times 12 \text{ in} \times 1.3 \text{ in}}{10.42 \text{ in}^4} = 119.77 \text{ psi}$$

$$F_{b\ ten} = \frac{80 \text{ ft-lbs} \times 12 \times 1.7 \text{ in}}{10.42 \text{ in}^4} = 156.62 \text{ psi}$$

TRANSVERSE

$F_v = 228 \text{ lbs}/4.5 \text{ in}$

$F_v = 50.67 \text{ psi}$

$$F_b = \frac{114 \text{ ft-lbs} \times 12 \times 1.5}{7.8 \text{ in}^4}$$

$F_b = 263.10 \text{ psi}$

$M_{max} = 114 \text{ ft-lbs}$

$V_{max} = 228 \text{ ft-lbs}$

$I = 7.80 \text{ in}^4$

$C = 1.5 \text{ in}$

AT SUPPORTS

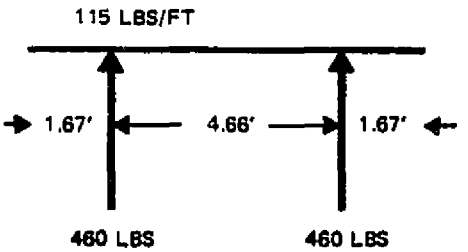
$F_v = 455/4.5 = 101.10 \text{ psi}$

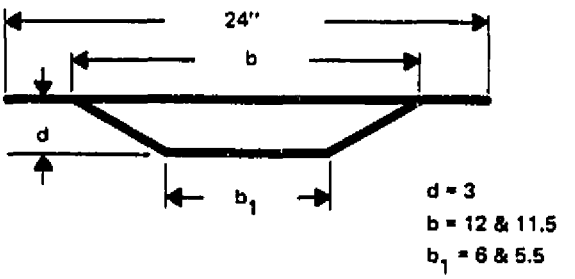
TWO RIB PANEL **3/8" MATERIAL**

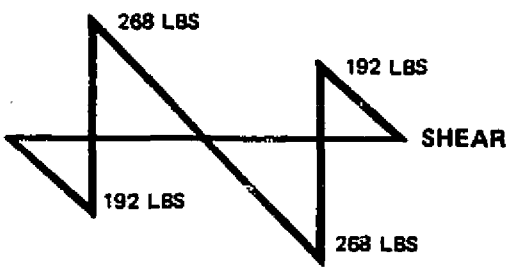
LOAD ON PANEL = 1600 LBS

PANEL WEIGHT = 240 LBS

1/2 PANEL





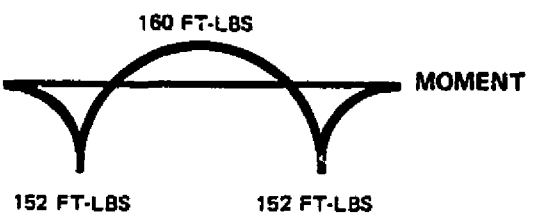


$1.67 \div 4 \times 460 = \underline{\underline{192}}$

$460 - 192 = \underline{\underline{268}}$

$192 \times \frac{1.67}{2} = \underline{\underline{160}}$

$268 \times \frac{2.33}{2} - 160 = \underline{\underline{152}}$



$$I = \frac{d^3(b^2 + 4b \times b_1 + b_1^2)}{36b + b_1}$$

$C_{comp} = 1.3"$

$C_{ten} = 1.7"$

$A_1 = .25 \times 24 = 6$

$A_2 = 2(.25 \times 4.25) = 2.12$

$A_3 = .25 \times 5.75 = 1.43$

$A_{total} = 9.55$

$I = 8.90 \text{ in}^4$

(-15% for irregularities in casting)

$I = 7.56 \text{ in}^4$

$F_v = 268 \div 9.55 = 28 \text{ psi}$

$F_{b\ comp} = 152 \times 12 \times 1.3 \div 7.56 = 313.65 \text{ psi}$

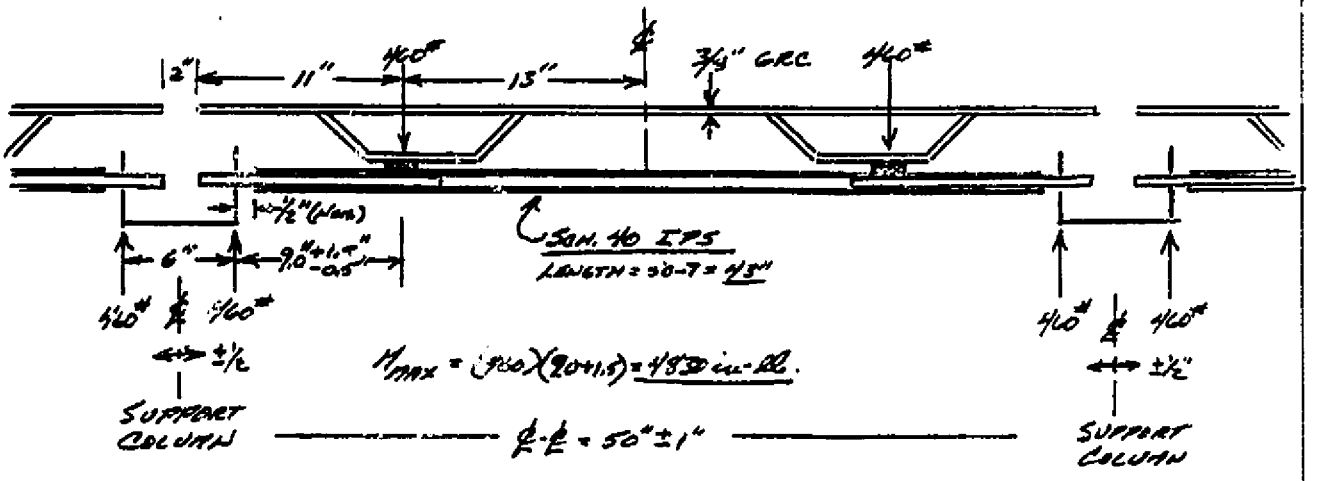
$F_{b\ comp} = 152 \times 12 \times 1.7 \div 7.56 = 410.16 \text{ psi}$

BENDING STRESS IN TRANSVERSE SUPPORT BEAMS

WIND LOAD – 50#/FT² @ 4'-0" x 8'-0" = 1600#

GRAVITY LOAD – 240# MAX (200# MIN.)

SUPPORT REACTION (EQUALLY DIVIDED) = ½(1600+240) = 460# ← DESIGN.



$M_{MAX} = (460)(9.0+1.5) = 4830$ in-lb.

NOMINAL PIPE SIZE	1/2" IPS	3/4" IPS	1" IPS	SQ. TUBE	
d_o = in	.840	1.050	1.315	1.250	1.000
d_i = in	.622	.824	1.049	1.000	.750
Δt = in	.109	.113	.133	0.125	.125
$I_{xx} = \frac{\pi}{64} d_o^4 (1-(\frac{d_i}{d_o})^4)$ = in⁴	.017092	.037036	.087543	0.12012	.056966
$(I_{xx}/c) = \frac{\pi}{32} d_o^3 (1-(\frac{d_i}{d_o})^4)$ = in³	.040695	.070545	.13284	0.1929	.11393
$S = M/(I_{xx}/c)$ = PSI	118,690	68,470	36,365	25,132	42,395
	TOO HIGH	TOO HIGH	OK	BEST	(?)
WT/FT	.8510	1.131	1.679	1.9136	1.4884

BENDING MOMENT AT ℄ OF GRC PLATE

$V = \frac{13}{24} = 0.54167$ $\quad C_o = (2V-1) = 0.08333$ $\quad I = \frac{1}{12}(96)(\frac{3}{8})^3 = 0.42188$ in⁴

$M_{MAX} = \frac{1}{2} P_c L^2 (C_o) = \frac{1}{2}(\frac{50}{144})(96)(24)^2(.08333) = 800$ in-lb.

$S_{MAX} = \frac{M_{MAX}\, c}{I} = \frac{800\,(3/16)}{0.42188} = 355$ PSI OK

ORIGINAL PAGE IS
OF POOR QUALITY