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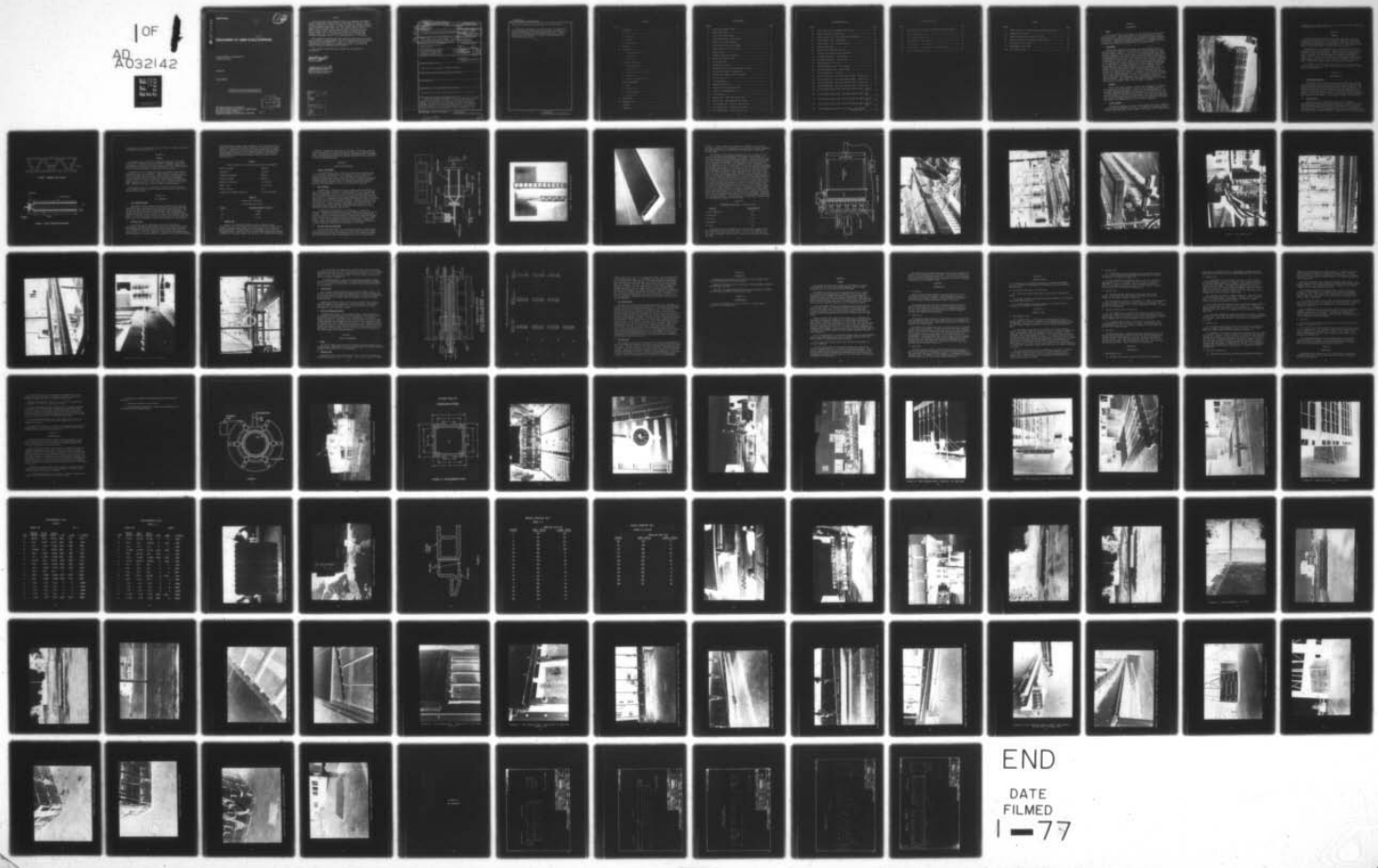

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DEVELOPMENT OF LARGE SCALE Plastic EXTRUSIONS

AMOCO CHEMICALS CORPORATION
SEYMOUR INDIANA

APRIL 1976

FINAL REPORT

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NOTICE

This final report was prepared jointly by the Equipment Development Branch, Aeronautical Systems Division, AFSC, Propellant Division, Amoco Chemicals Corporation, Seymour, Indiana, the Materials Engineering Branch, Air Force Materials Laboratory, Air Force Systems Command under Contract Number F33657-70-C-0884. This effort was sponsored by the Adverse Weather Aerial Delivery Systems Program Office, Aeronautical Systems Division under Project 1244, Task 01, Advanced Air Cargo Handling, Polymer Pallet. Mr. J. L. Weingarten was the project monitor with technical assistance from Mr. L. E. Fielding and Mr. E. J. Morrisey.

This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

JOSEPH L. WEINGARTEN
Project Monitor

ALBERT OLEVITCH, Chief
Materials Engineering Branch
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report details the development of an extrusion process and refers to a pallet for background. Utilizing a 3 1/2 inch extruder, structural shapes 2 1/4 inches thick by 101 inches wide by 9 feet in length were extruded. The material used was Amoco 6004 polypropylene with 30 percent by weight fiberglass from a blend with Fiberfill G-63/70. The structural shape was developed for use as a HCU-6/E (463L) Air Cargo Pallet. The extrusions were equipped with side rails to complete construction of A/C

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pallets and are undergoing evaluation tests as A/C cargo pallets.

A significant advancement in the state-of-the-art of large scale polymer extrusions was accomplished in this program. Development effort to date has effectively shown that large scale extrusions of thermoplastics can be achieved. While feasibility has been proved, economic utilization of this technology will require further improvements to speed the extrusion process.

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SECTION I

INTRODUCTION

1. SCOPE

This report details a new process for the fabrication of large scale polymer extrusions. The present process is semi-continuous with further work required for a faster extrusion. It is intended to provide sufficient information to recreate the original machine setup or to continue research in this area. Advanced work areas and possible uses of hardware that could be manufactured using this technique will be described as well.

2. BACKGROUND

The Air Force operates a world-wide air cargo system basically revolving around a pallet 88 x 108 inches with a load capacity of 10,000 pounds as shown in Figure 1. The aircraft and terminal systems use roller conveyors requiring a flat bottom capable of withstanding the roller loads. The present pallet is constructed in accordance with specification MIL-P-27443E(USAF) and is made from an end-grain balsa wood core with an aluminum facing bonded on both top and bottom. Several factors resulted in the start of this program; balsa wood is imported and therefore continuing supplies are not guaranteed; a bonding problem also existed between the balsa wood and aluminum skin resulting in delamination in some instances from cold working the pallet over roller conveyors; a lower cost pallet. For example, in FY 69 approximately 26,000 pallets were delivered to the Air Force, at the same time the attrition rate was 28,000 units with an average cost of $302.00 per pallet. An example of this high loss rate is found in the following message from the Air Force Chief of Staff, 13 Dec 68: "Loss of 463L pallets and nets to the Air Force inventory continues at an unacceptable rate. The replacement cost is approximately one million dollars a month." While efforts were undertaken to control losses, a need also existed to develop a lower cost and longer life pallet.

3. APPROACH

In late 1968, Amoco Chemicals proposed the development of a plastic core section for the 463L pallet. Initial efforts centered on a cast-extrusion process as described in Section III. During development of the technique, considerable problems were encountered. In view of this, a new extrusion method was developed for production as described in Section IV. This new technique resulted in extruded panels, 101 inches wide, which were then secured to aluminum cargo tie down rails and are presently undergoing evaluation. The evaluation results can be found in Appendix A.

4. DESIGN FACTORS

The primary objectives to be met in this project were (a) to fabricate a core section approximately 81 x 101 x 2 1/4 inches when attached to the aluminum frame would have a total weight of 310 pounds, (b) be cost effective

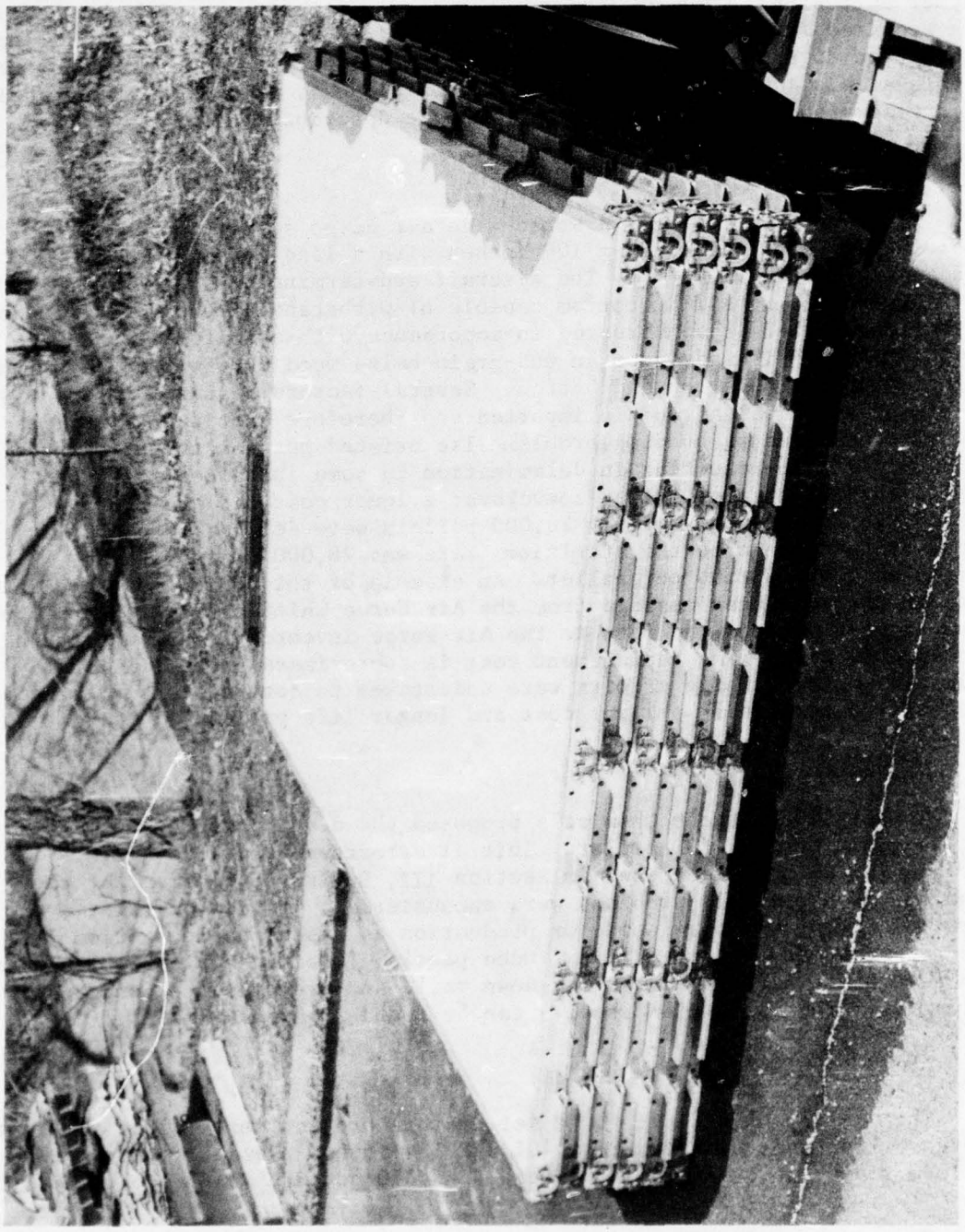

Figure 1 - Ten thousand pound AF Pallet

in relation to the current pallet, and (c) be able to traverse rollers with a 10,000 pound load secured to it.

SECTION II

SUMMARY

Development effort to date has effectively shown that large scale extrusions of thermoplastics can be achieved. Equipment is basically off-the-shelf and actual setup of a system is relatively simple. While feasibility has been proven, economic utilization of this technology will require further improvements to speed the extrusion process.

Potential use of this system should not be limited to flat plates as fabricated during this development. Large diameter pipe could also be extruded and very effectively used. Figure 17 shows a configuration for a die to fabricate this type of pipe with structural reinforcement. Another potential exists in the world of construction and shipping containers. An 8 x 8 ft cross section with a 20 ft length to make a intermodel shipping container as shown in Figure 18 or possibly a room in a home. Conceivably an entire shell of a home could be extruded.

The system could be used today where necessary; however, detailed efforts should be made to further develop the process to achieve a high speed production process.

SECTION III

CAST EXTRUSION

1. CAST EXTRUSION SETUP

The method used was similar to injection molding a part, but on a very large scale. A mold was fabricated to make a section 11-inch wide and 96-inch long using a Warren truss design as shown in Figure 2. The process consisted of forcing the molten plastic into a heated mold. An extruder was utilized to heat the plastic above its melting point and provide the necessary force to cause it to flow into the mold as shown in Figure 3. After the mold was filled, the process was shut down until the mold cooled, was disassembled, finished panel removed, and reassembled.

2. MATERIAL USED

The polymer used for fabrication of the core consisted of polypropylene containing approximately 30 percent by weight glass fibers. The polypropylene used was Amoco grade 6004 and glass super concentrate was Fiberfill Division, Dart Industries Grade G-63/70, properties are given in Table I of the 30% composition. The glass was incorporated into the polypropylene to improve rigidity, strength, and lower thermal expansion.

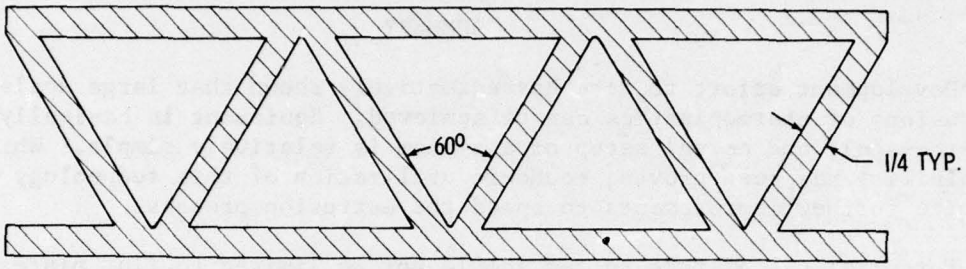

FIGURE 2 WARREN TRUSS DESIGN

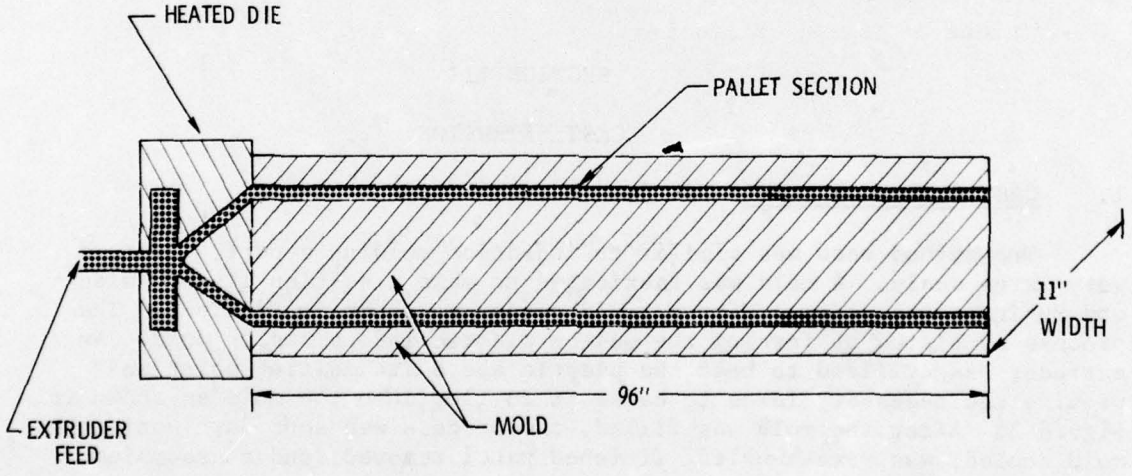

FIGURE 3 INITIAL FABRICATION METHOD

in relation to the current pallet, and (c) be able to traverse rollers with a 10,000 pound load secured to it.

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The polypropylene and glass super concentrate were dry blended prior to being fed to the extruder by drum tumbling for 10 minutes in 125 pound batches. To confirm the selection of 30 percent glass filler, bending and roller indentation tests were conducted on three panels made with varying amounts of glass filler as shown in Table II. The 30 percent filler proved to have the best capability and was utilized for the remaining effort.

TABLE I

Typical Properties of 30 Percent Glass-filled Polypropylene

Tensile Strength	8000 psi
Elongation	2 percent
Compressive Strength	7000 psi
Flexural Strength	9000 psi
Modulus of Elasticity	7×10^{-5} psi
Impact, Izod	2.5 ft lb/in
Specific Gravity	1.13
Coefficient of Thermal Expansion	2.0×10^{-5} in/in^{o}F

TABLE II

Bending Test to Failure

22-Inch Panel 90^{o} to Ribs

% Glass	Breaking Strength (Pounds)
22	11,080
30	13,850
35	11,500

3. INITIAL RUN

The use of a large mold resulted in severe limitations and difficulties. Due to the length of the mold, and lack of fluidity of the polymer, extremely high pressures were encountered at the extruder end. These pressures also caused movement of the triangle cores to shift in unsupported areas. This shift of core section added an additional problem in removal of the finished panel from the mold. The cooling of the polymer

resulted in a shrink fit around the core sections. In one case, the core section had warped to such an extent that it could not be removed from the panel. Time and effort involved in cooling, disassembling and reassembling, along with reheating the mold after each part was made resulted in a need to find an alternative method.

SECTION IV

LARGE SCALE EXTRUSION

1. PROCESS REQUIREMENT

Sufficient material flow could not be achieved in the initial cast extrusion effort, and obviously a full length die, with a width of 101 inches would not be practical. The second phase was directed at re-examining conventional techniques with the intent to develop a new process. Necessary material flow could not be achieved using present single head extruders methods; therefore, means of providing rapid and sufficient material flow uniformally to the die cross section was required.

2. BASIC PROCESS

A conventional solution to achieving a higher flow rate would be to use a larger extruder; although, a problem would still arise on achieving flow to outside edges of the die, requiring extensive flow channels. One possible solution would be the use of a series of extruders interconnected to one die; but, this method would require complicated temperature and flow rate control. A combination of one extruder and simulated series of extruders appeared to provide the best possible solution. Between the extruder and die (Figure 4), a series of heated accumulators were positioned across the rear of the die. The extruder was used to pump the polymer into the accumulators until filled and then a hydraulic ram would pump the molten material from the accumulator into the die.

To determine the feasibility of this approach, a 22-inch wide (Figure 5) extrusion was fabricated with one accumulator between the die and extruder. Trail runs resulted in two changes, both in die configuration. Both were related to cooling the material. The die was originally designed with a thermal barrier; this hot/cool zone produced a weld line as shown in Figure 6, which was subsequently found to be a weak point. Removing the thermal barrier and lengthening the die from 16 to 18 inches, resulted in a gradual temperature gradient and elimination of weld lines.

3. MACHINE SETUP AND OPERATION

The following description is of the final tooling to extrude a panel 101 inches wide by 2 1/4 inches thick. The process at the present time is semi-continuous, requiring a intermittent cycle of five minutes to produce two inches of pallet. Overall, approximately 140 feet of extrusion were

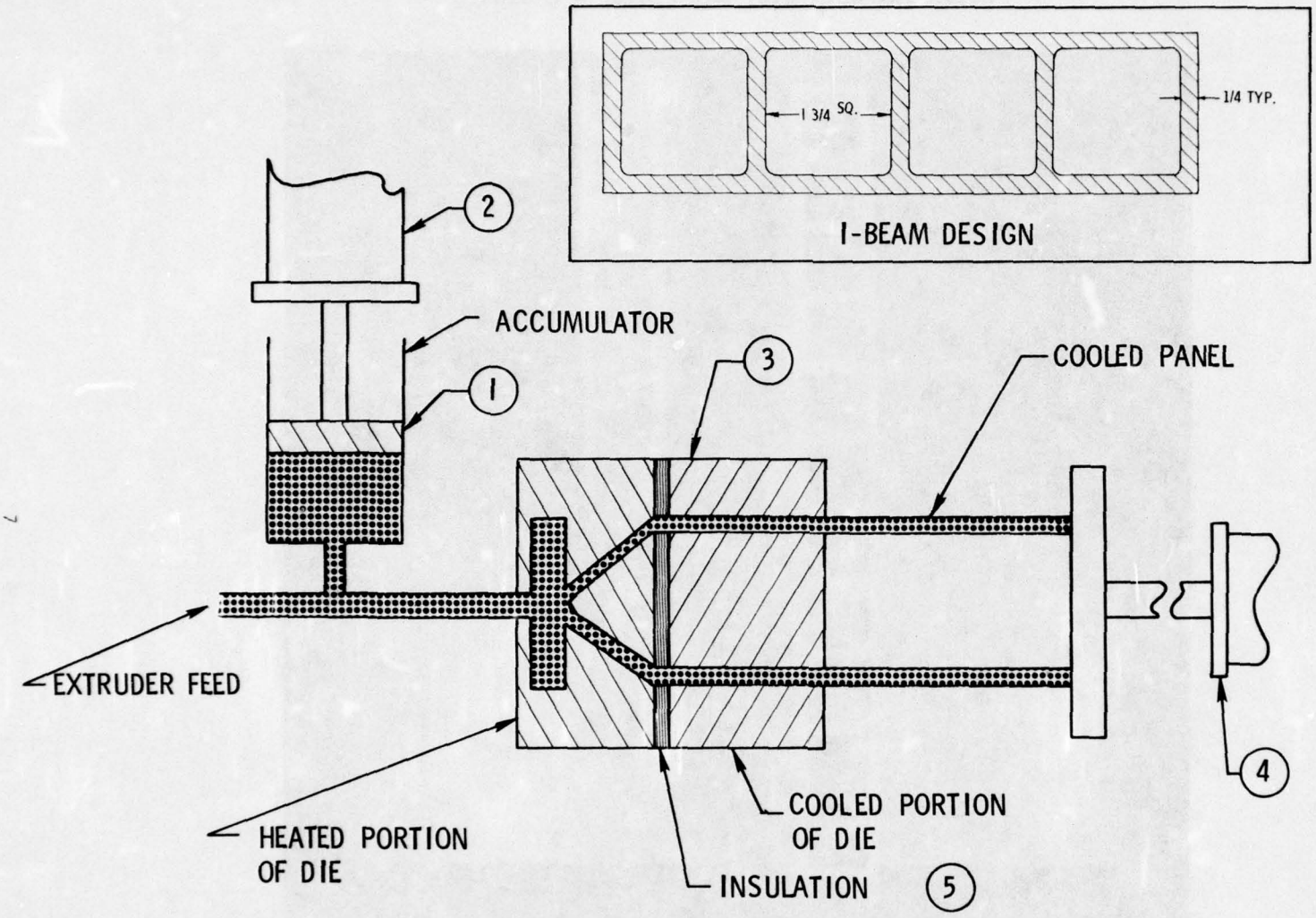


FIGURE 4 FABRICATION PROCESS 22 INCH PANEL

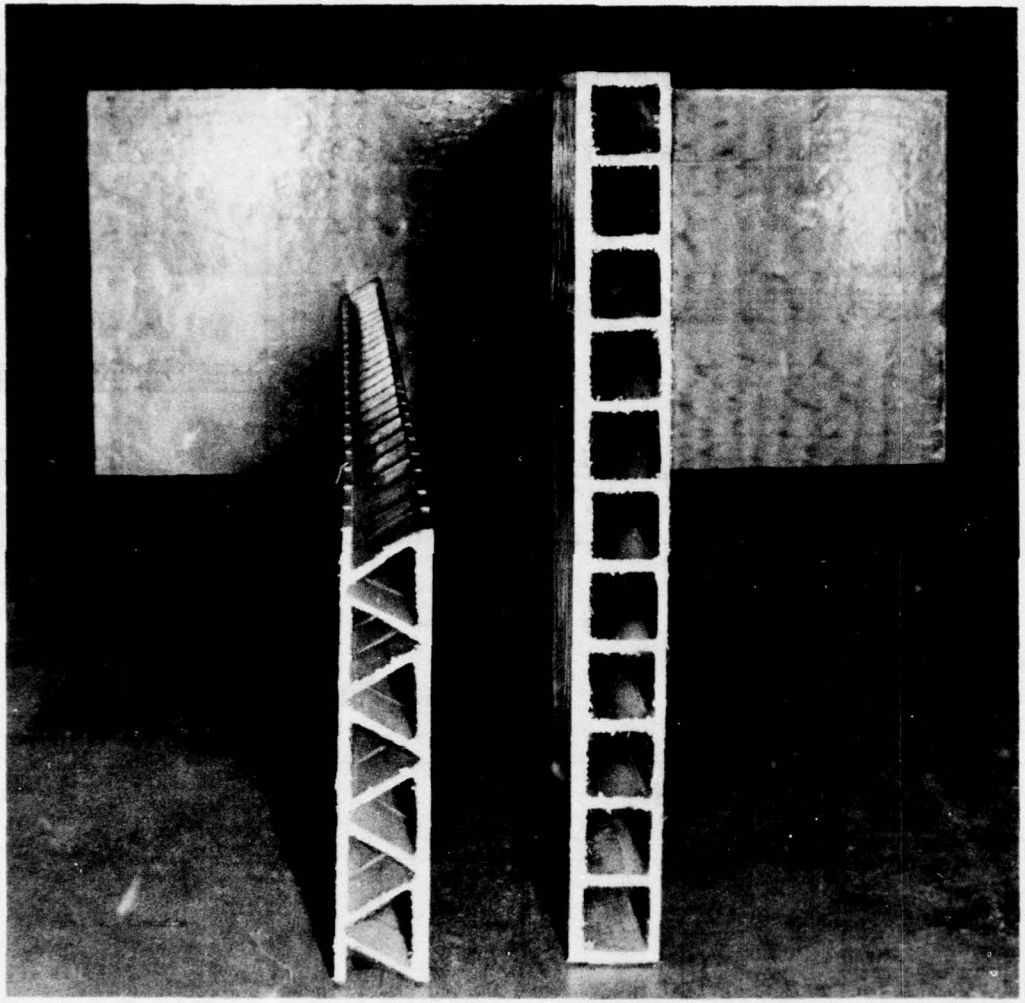


Figure 5 - Twenty-Two Inch Wide Extrusion

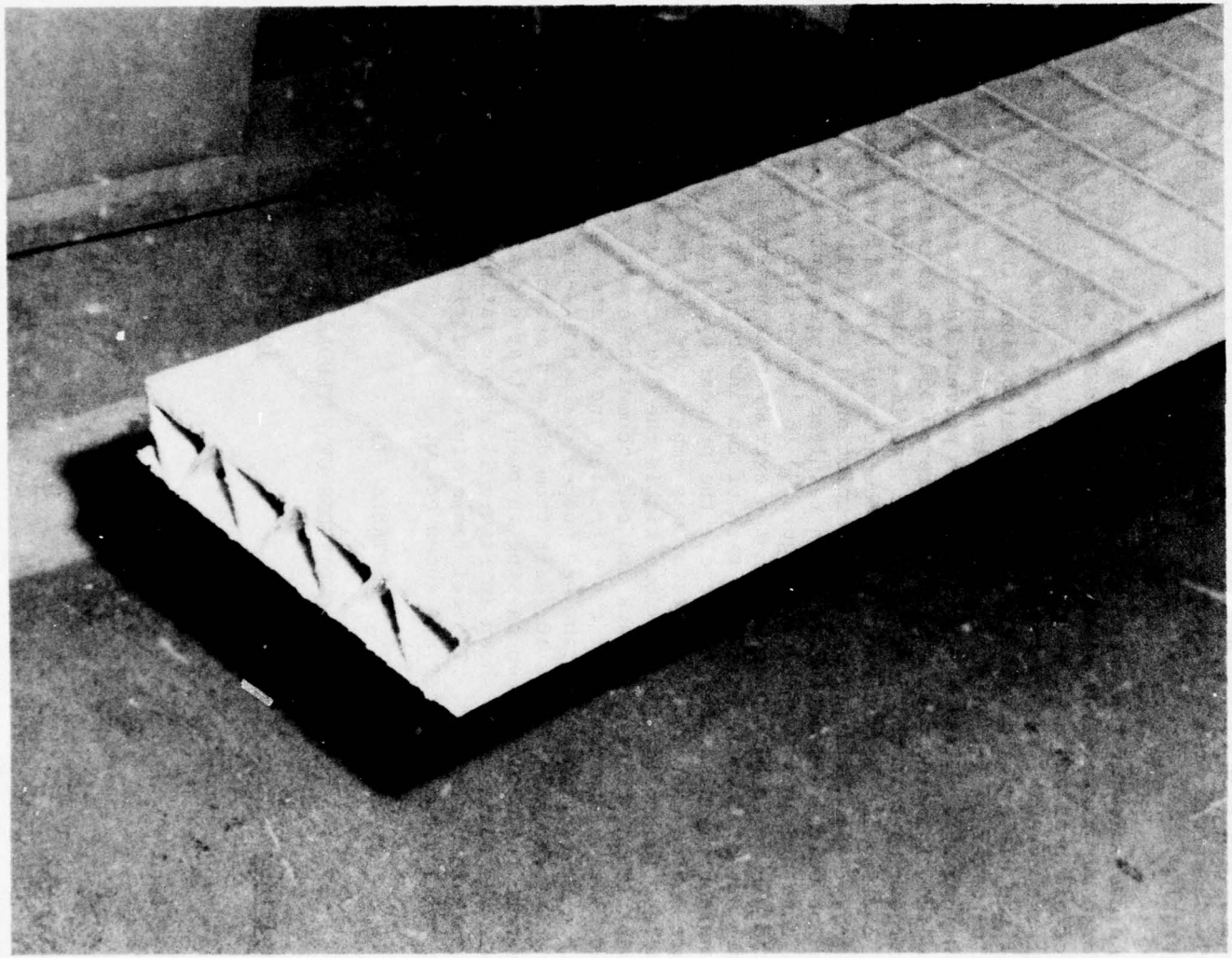


Figure 6 - Hot-Cold Weld Line in Truss Design

produced. No new equipment was developed to accomplish this extrusion technique. Addition of the hydraulic and accumulator cyclinders represented the only departure from a conventional extrusion setup, excluding die configuration.

An over-view of the extrusion hardware is shown in Figure 7. The extruder used was an Atena Standard, 3 1/2 diameter screw, 16tol L/D, with hot oil heat and a 40 horsepower drive motor. This extruder was used to melt the material and pump it through channels around both sides to the rear of the die and accumulators, through heated lines (Figure 8) with an inside diameter of 1 1/4-inch. The accumulators 5-inch in diameter by 10-inch long were filled at 250 psi and to prevent the material from pushing the end item from the die, a back pressure of 350 psi is maintained against the extruded part in the die. This also provides time within the die for better cooling of the extruded item. The accumulator fill sequence was units 1-5, 2-4 and finally 3. Upon completion of the fill cycle, a limit switch on unit 3 was activated which resulted in pressurization of the 5-inch bore hydraulic cylinders (Figure 9) to 1500 psi to pump the material into the die. The back pressure on the extrudent is reversed to pull the end item out of the die at a flow rate of two inches in 15 seconds. The limit switch was also used to recycle the process by shuting down the high pressure source when the accumulator was empty. During the next 4 hours 45 minutes, the molten plastic cools within the die under pressure as the extrusion is now being held back and the accumulators are refilled repeating the cycle. The design of the extrusion incorporated 50 core sections. To each core section, a coolant was pumped through 1/4-inch tubing from a 4-inch pipe shown in Figure 10; exit from die was accomplished in the same manner with the coolant then passing through a heat exchanger. Cooling at the exit was achieved as shown in Figure 11 incorporating water passed over outer surface of the die. Typical temperature conditions at various points in the tooling and extruder are shown below.

TABLE III

TEMPERATURE CONDITIONS OF EXTRUDER & DIE

Position	Temperature ^{o}F
Extruder Hopper End	400
Extruder Head	450
Fill Lines	475
Accumulators	475
Die Entry	490

The push/pull unit was clamped to the extruded part (Figures 12-15) by screwing bolts into the polymer panel. The hydraulic equipment used was a 6-inch bore cylinder with a travel of 8 feet. The limit switch on the center accumulator was also used to control the push/pull cycle during operation.

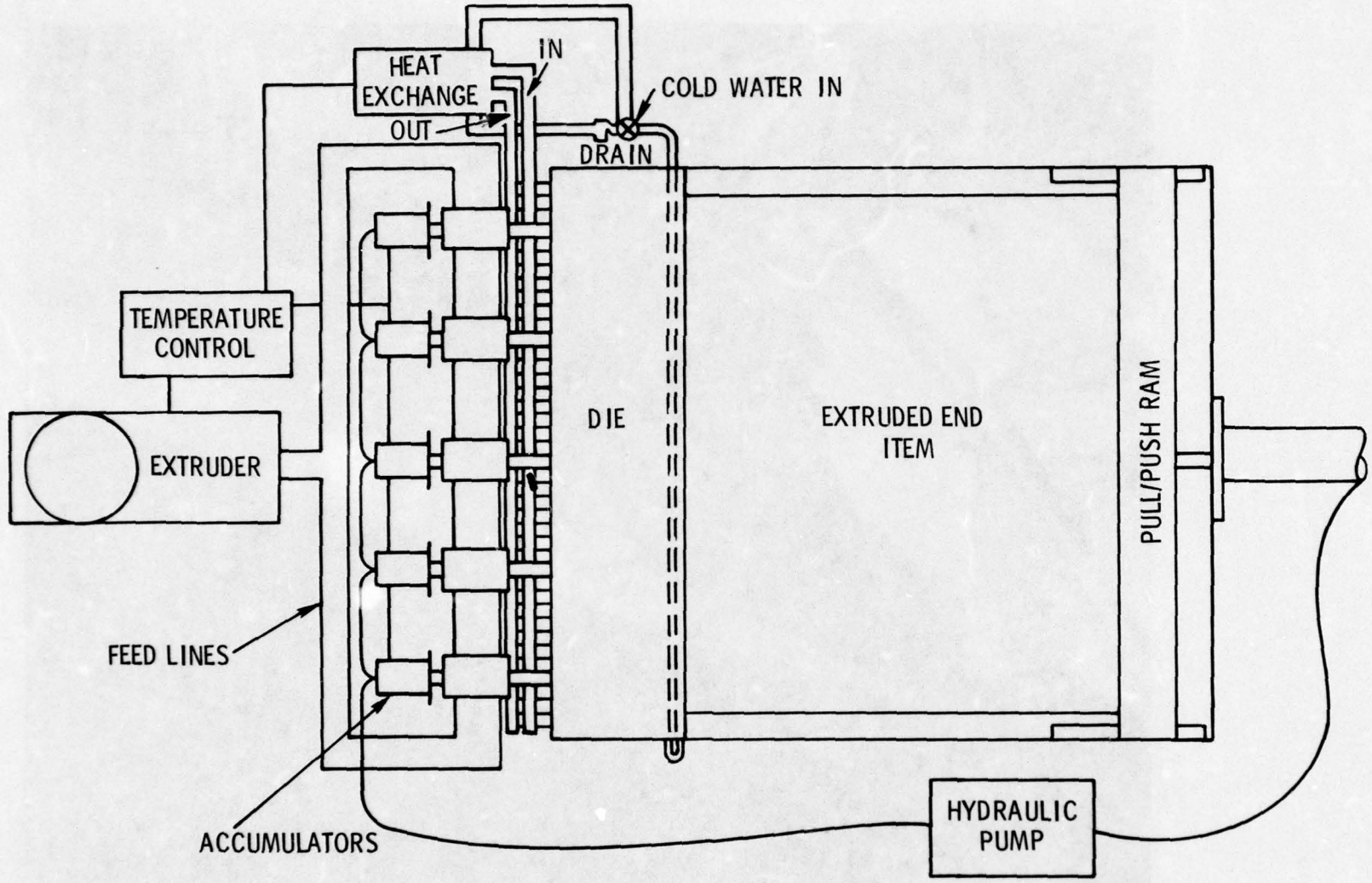


FIGURE 7 ACTUAL TEST SET UP

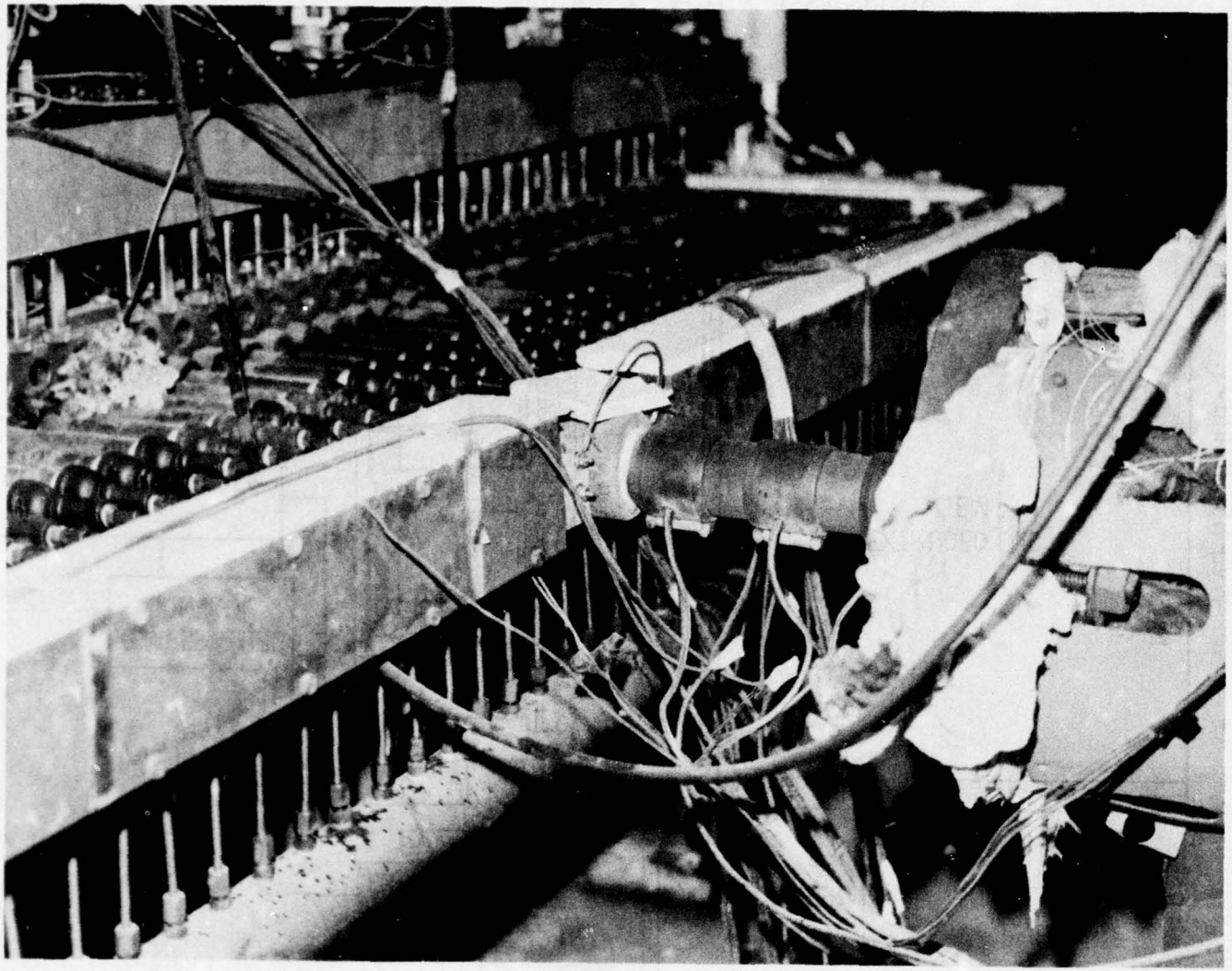


Figure 8 - Extruder Nozzle

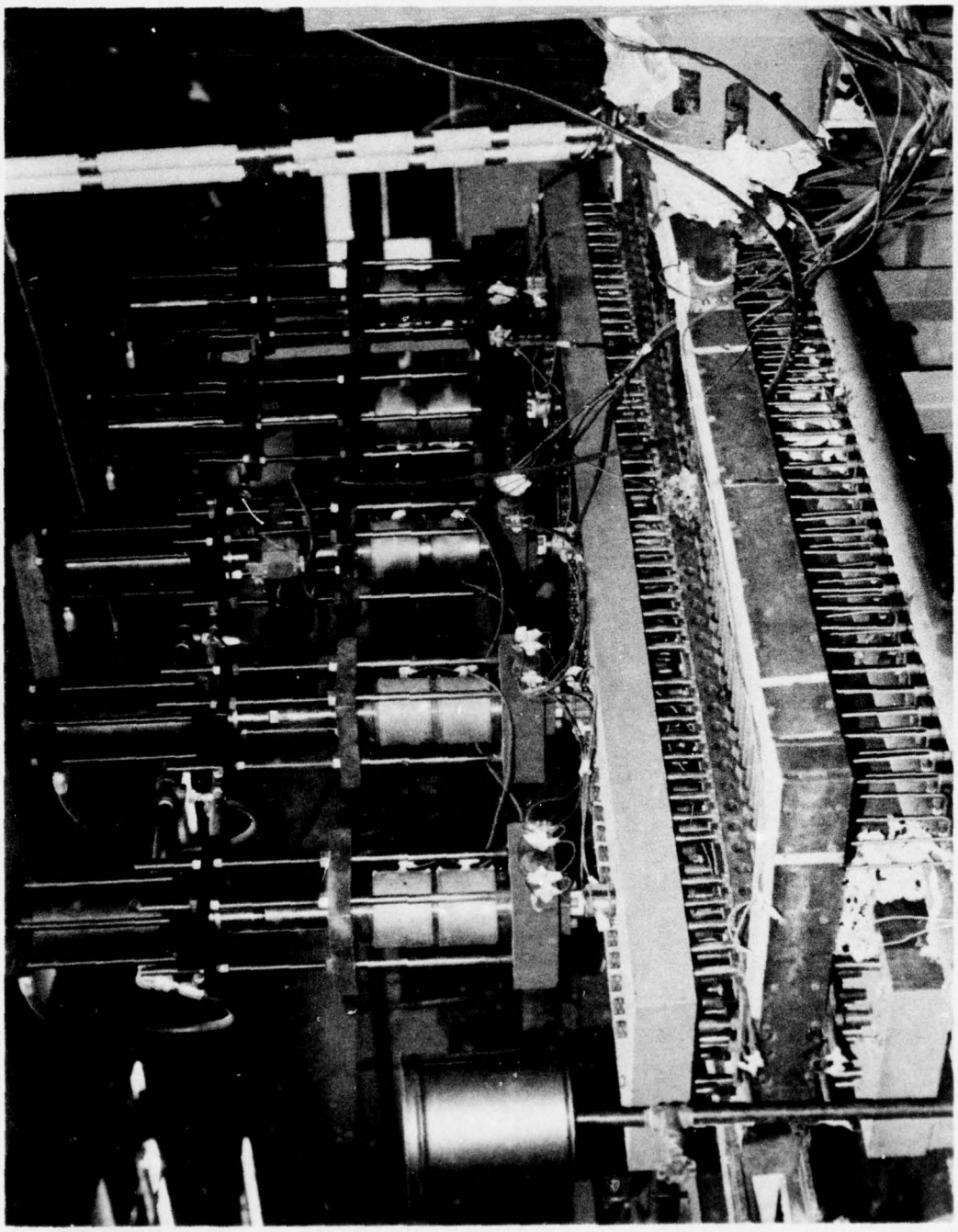


Figure 9 - Extruder Nozzle and Accumulators

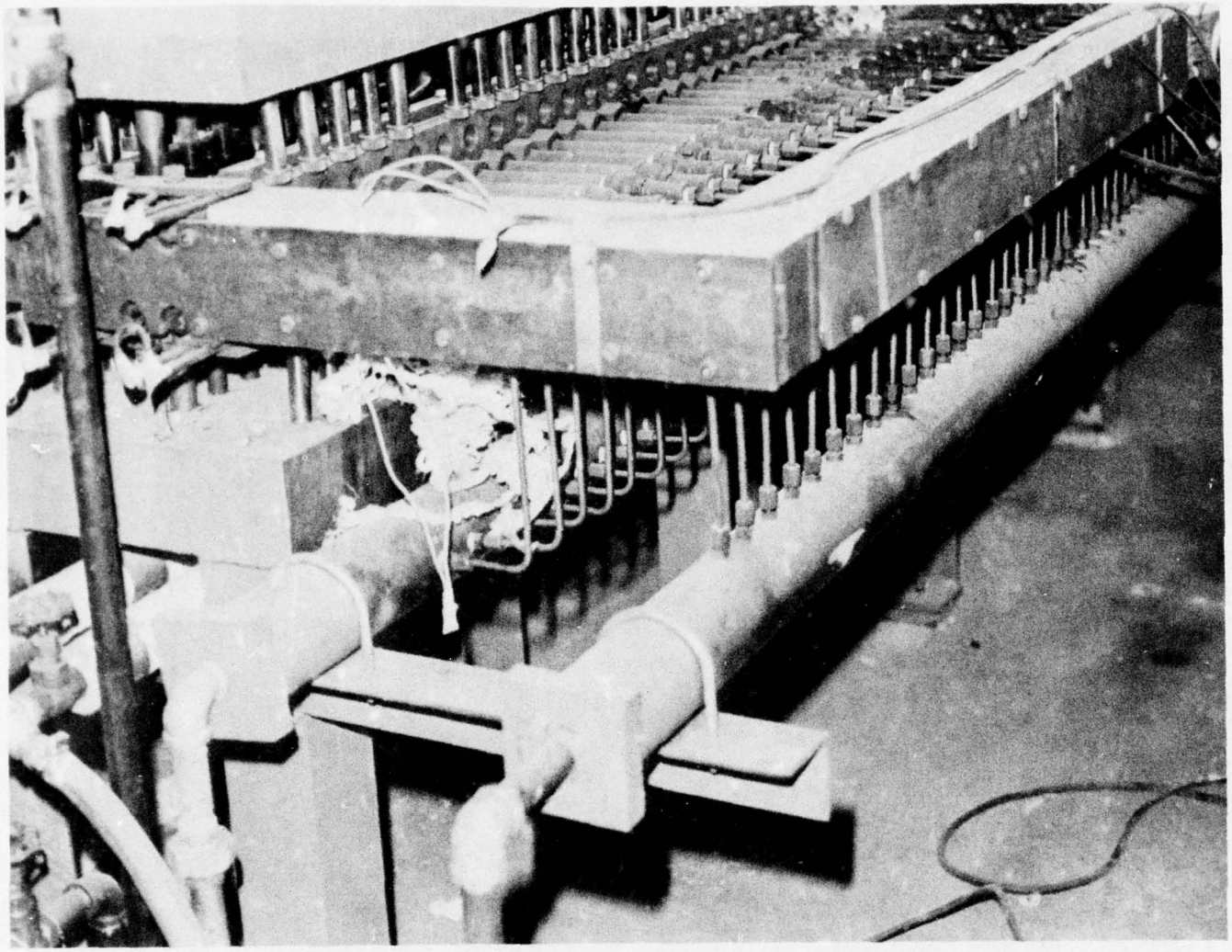


Figure 10 - Coolant Distribution System

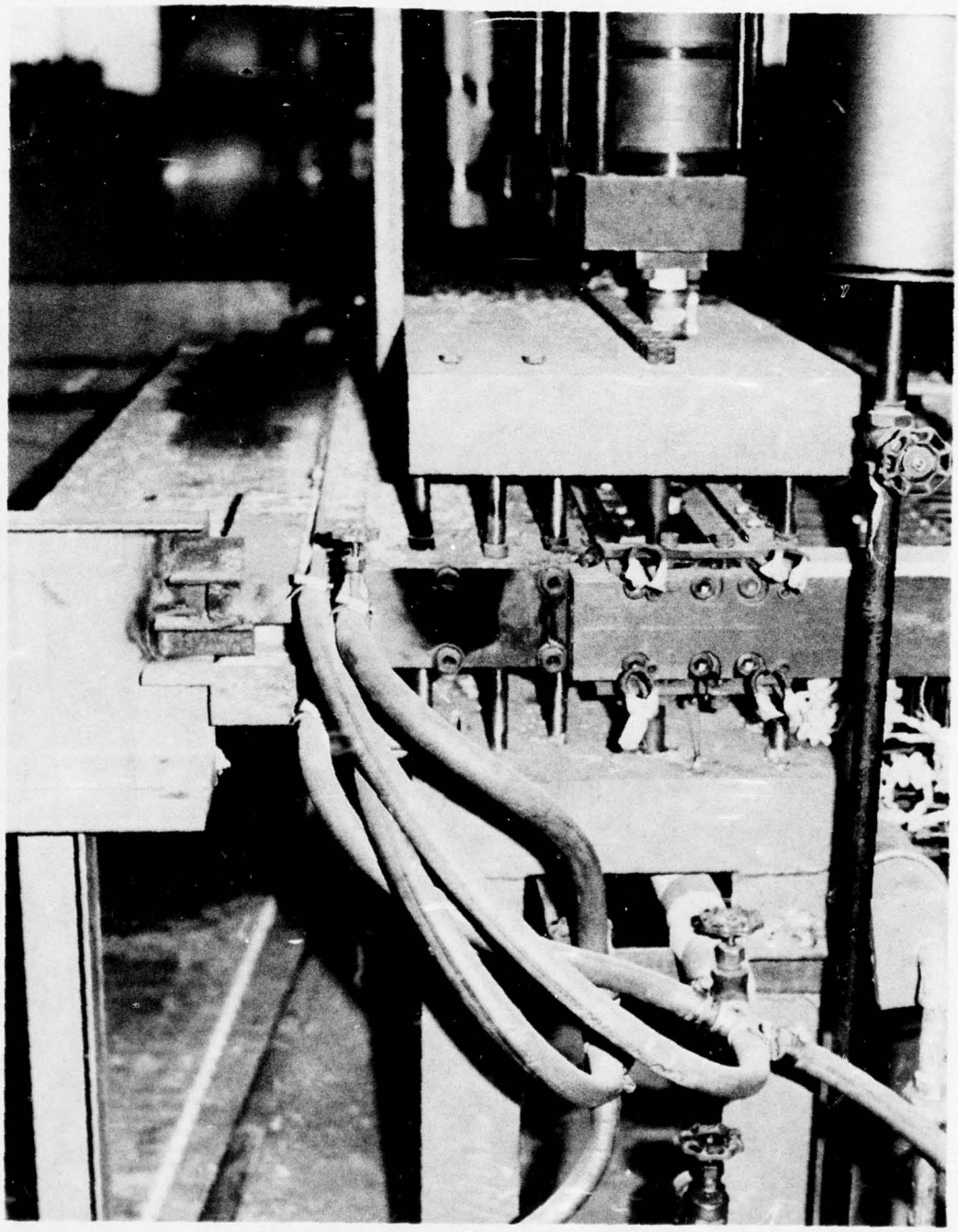


Figure 11 - Dye Cooling Lines

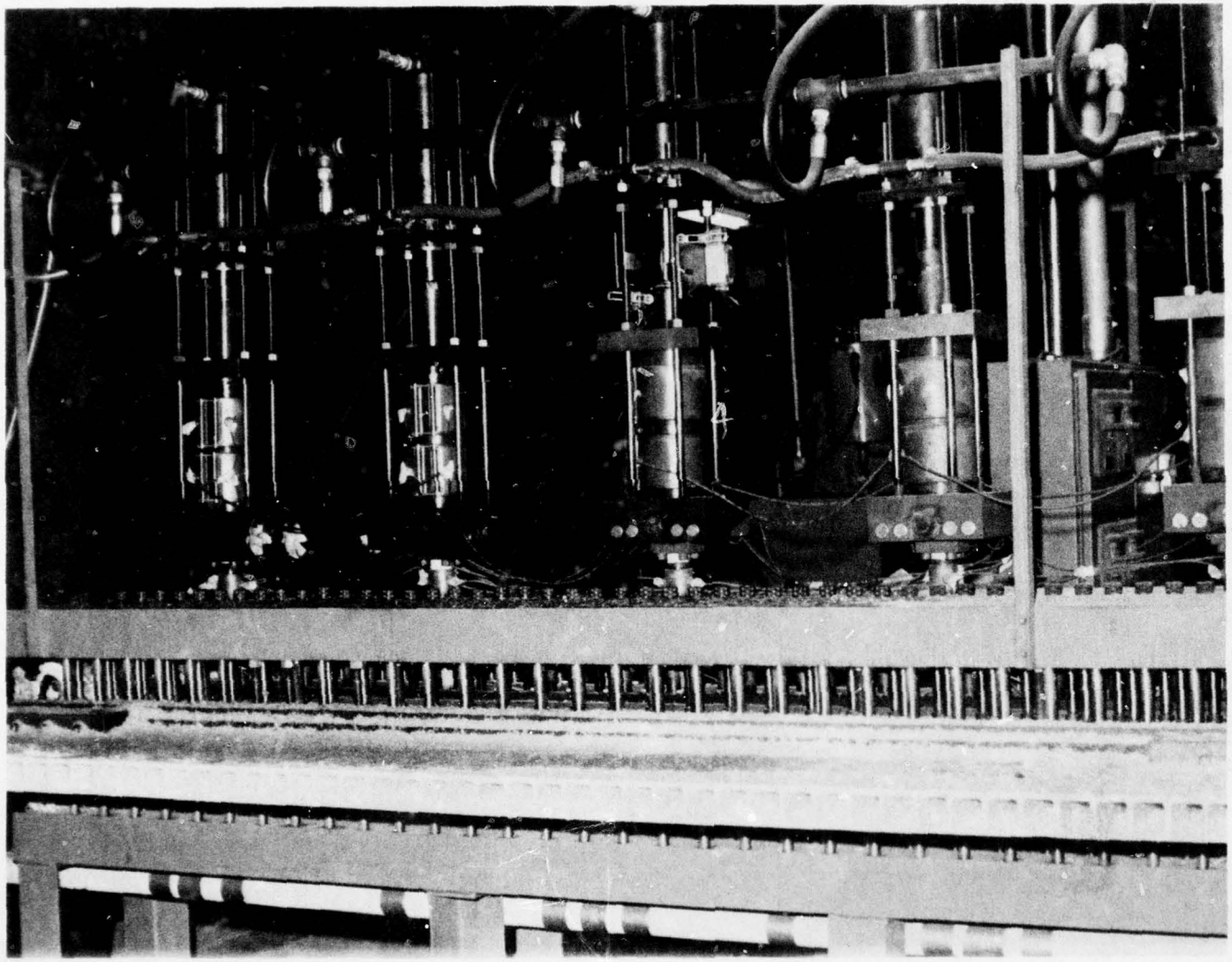


Figure 12 - Extruded Part from Die

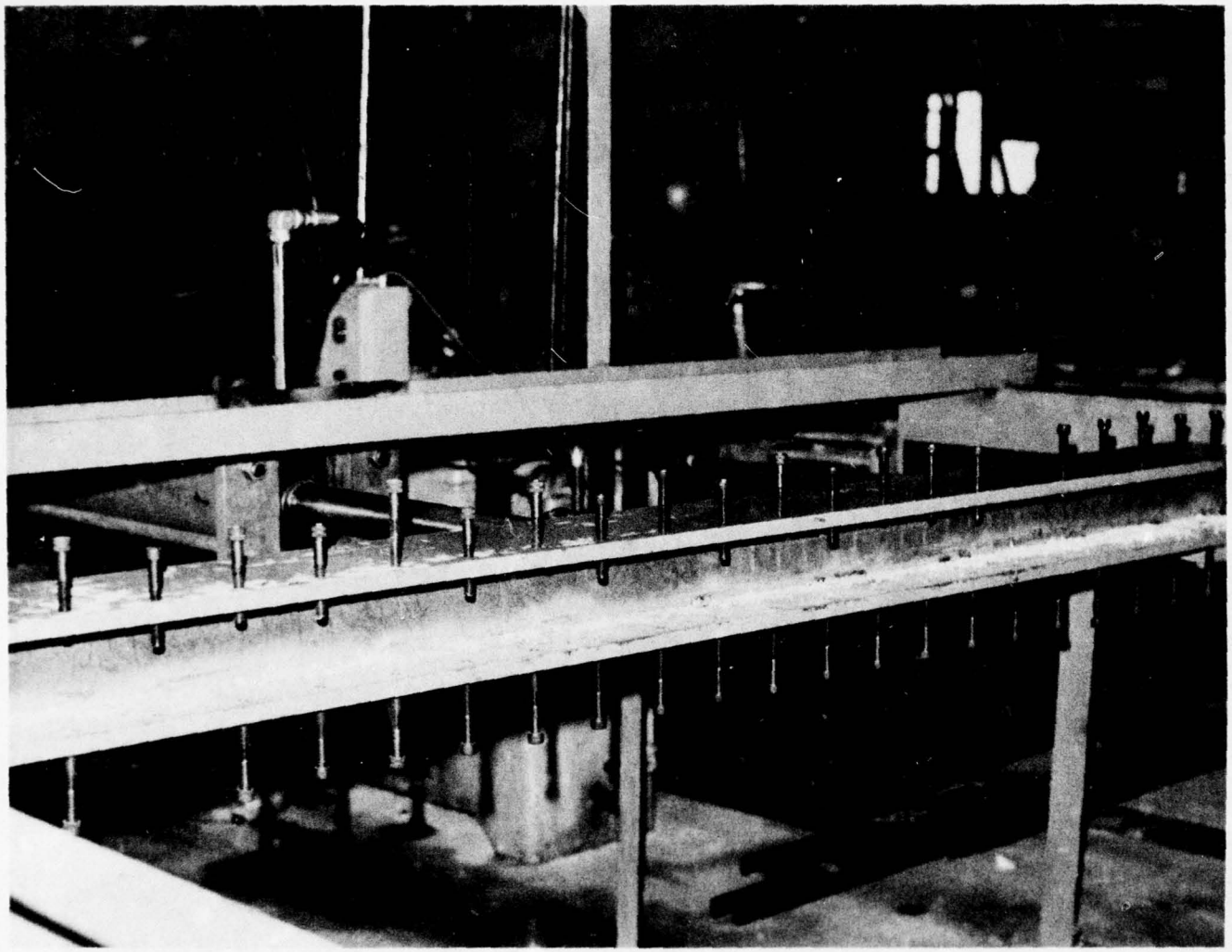


Figure 13 - Push/Pull Unit Shaving End That Mates with Part

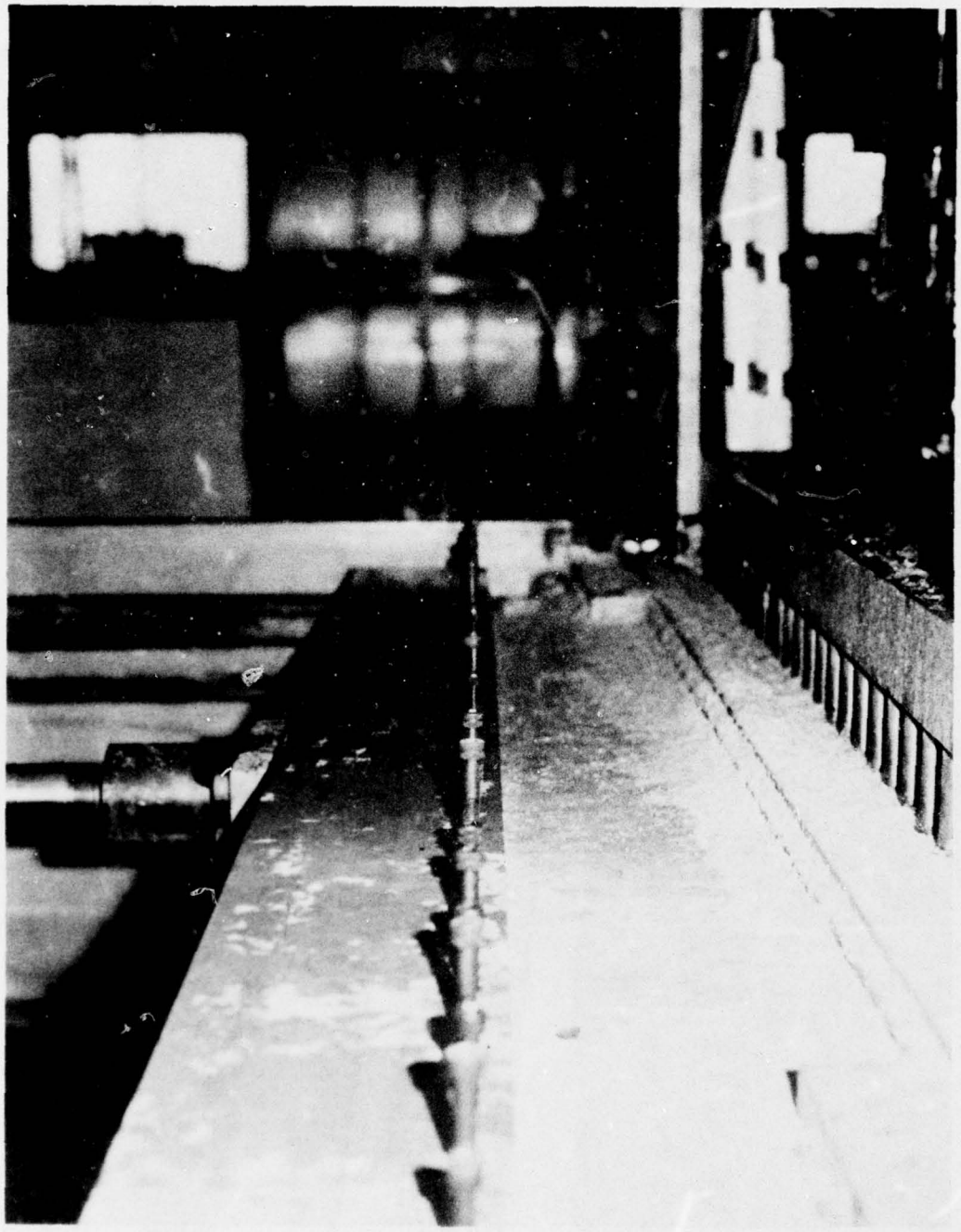


Figure 14 - Push/Pull Unit Mated to Extruded Part

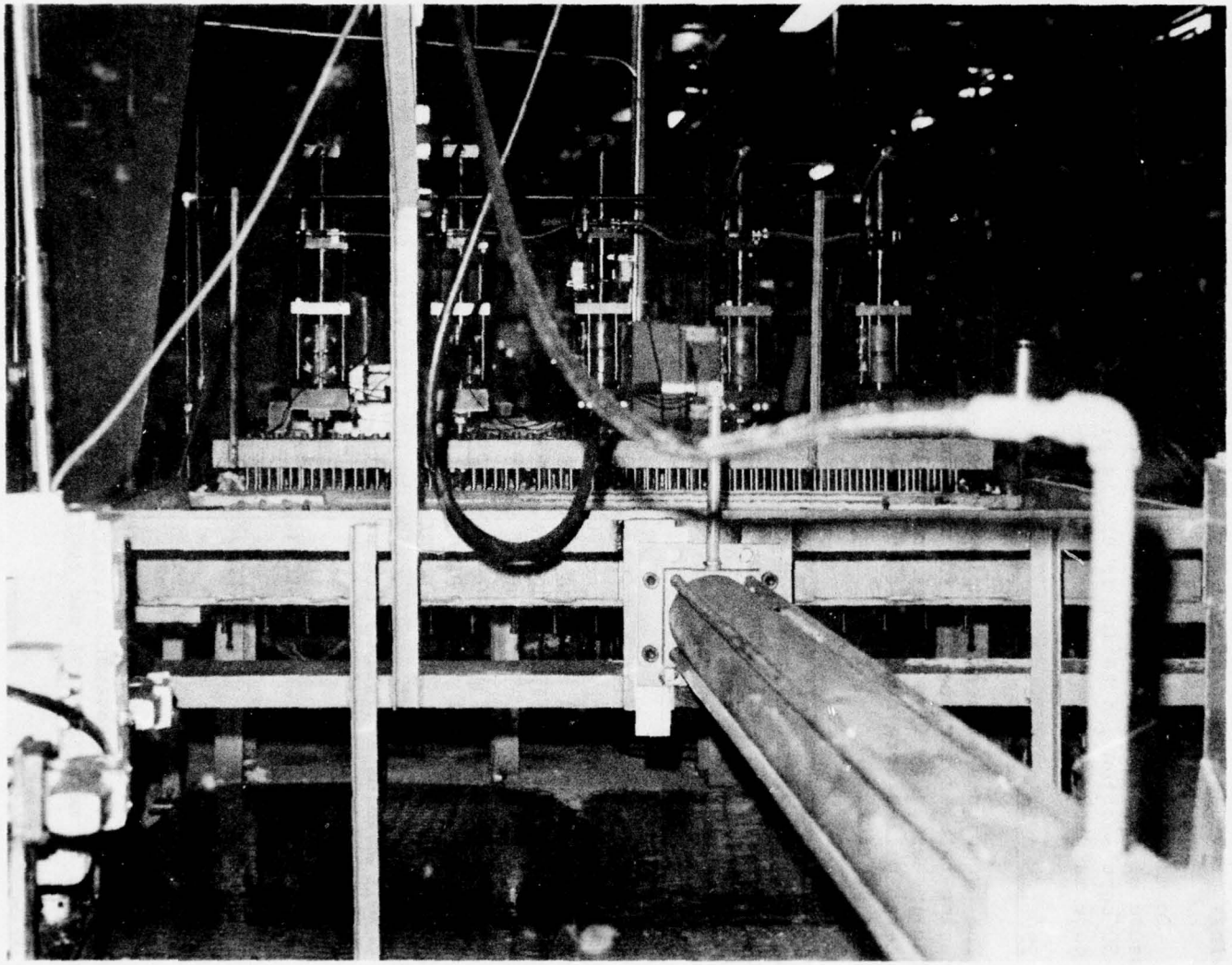


Figure 15 - Push/Pull Unit Shaving End with Cylinder

The die was based on conventional techniques with five entry points. In essence each entry area acted as a separate extruder and with the material being molten and under pressure, complete fusion was possible at the heated rear of the die. The die cross-section is shown in Figure 16 with detail drawings provided in Appendix E.

To maintain pressures within the die and prevent bulging, a clamp pressure of 1375 tons was provided. To achieve cooling only at the end of the 50 core sections, a teflon insert is placed within the rear section of the core mandrel.

4. PROBLEM AREA

The techniques presently employed are relatively simple; however, the extrusion rate is far too slow for economical use. Current extrusion rate is two inches every five minutes and would require 3 1/2 hours to manufacture one cargo pallet core section, then, re-establish the setup to produce another section.

Attempts were made to speed up the process through a higher material flow rate; however, this resulted in a blistered surface. In essence, speed, or lack of it will have to be of prime concern in the further development of this extrusion technique.

5. QUALITY OF EXTRUDED PALLETS

To evaluate the quality of the extruded pallets, tensile properties were measured in both the machine (L) and transverse (+) directions in the surface (S) and web (W) sections of the configuration. The data are reported in Table IV. The higher values in the machine direction specimens clearly indicates some alignment of the fibers as would be expected. This is observed both in the surface and web positions. The transverse strengths are about 60 percent of the machine direction strengths. Modulus data are similar; the modulus in the transverse direction is essentially that of the base polymer. The short gage section in the transverse web specimens did not permit modulus and strain measurements.

SECTION V

PROCESS IMPROVEMENT

1. SPEED

The lack of speed within the current technique precludes production use of this system. Improvement revolves around two factors to provide sufficient quantities of materials and die configuration.

2. MATERIAL FLOW

Within the current cycle the total fill time is 4 hours 45 minutes and intermittent injection time is 15 seconds. It is obvious that a 3 1/2-inch

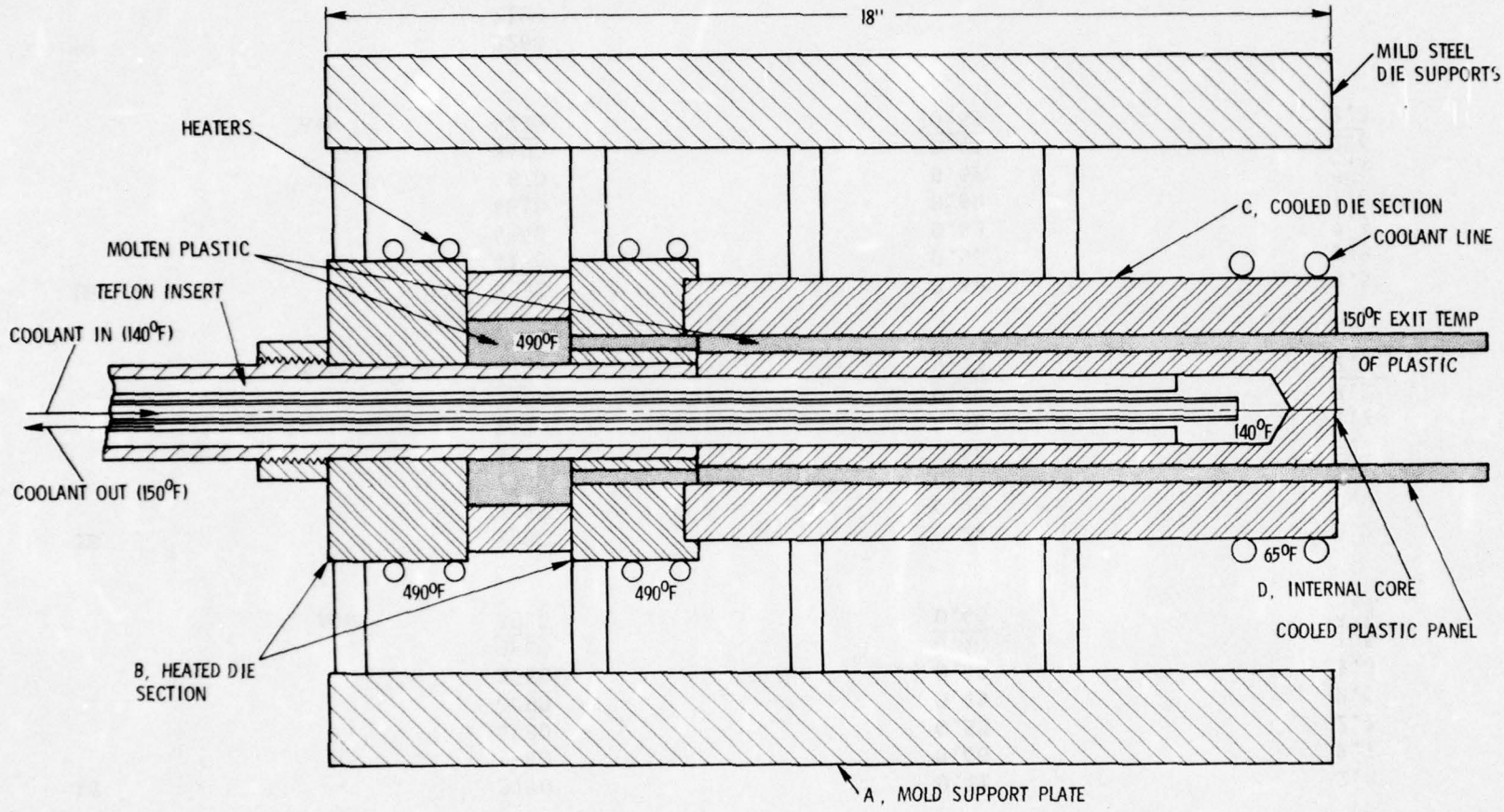


FIGURE 16 DIE CROSS SECTION

FLOW OF MATERIAL - 1-1/2 LBS/MIN
81" LONG EXTRUSION WEIGHT APPROX. 270 LBS.

TABLE IV. TENSILE PROPERTIES OF SPECIMENS CUT FFROM PALLETS

		Ultimate Tensile Strength, Psi	Modulus of Elasticity 10^6 psi	Strain to Failure %
LS		3770	0.41	2.8
		3640	0.46	2.7
		4380	0.58	2.7
		4290	0.49	2.5
		3640	0.43	1.8
		3800	0.40	1.5
	Ave	3920	0.46	2.3
TS		2380	0.26	2.2
		2280	0.29	3.0
		2530	0.35	1.4
		2570	0.38	1.7
		2420	0.36	1.7
		2560	0.38	2.1
	Ave	2450	0.33	2.0
LW		4350	0.69	3.5
		4170	0.56	1.8
		4140	0.43	2.5
		4610	0.60	1.6
		4620	0.62	2.1
		3400	0.41	2.6
	Ave	4210	0.55	2.3
TW		2260		
		2180		
		2310		
		2660		
		2590		
		2340		
	Ave	2390		

extruder with a flow rate of 1 1/2 pounds per minute could be replaced with a higher capacity extruder. It is possible that more than one extrusion press could be used on the same die. In the fabrication of these pallets the six accumulators could have been individually fed by its own extruder. Under this premise, fill cycle time could have been reduced to less than one minute. However, the real problem is not in flow rate or amount of material pumped into the die. Higher flow rates were attempted which resulted in blistering of the panel surface. Blistering can be caused if the material is removed from the die too rapidly. With the current 18-inch die, the material remains within the die for 45 minutes. Therefore, a speed-up in material flow would also require modifications to the current die configuration. Temperature control of the extrudent would have to be closely maintained.

3. DIE CONFIGURATION

Build-up of die pressures would preclude any large scale extension of the die; however, through inward tapering of core face plates and additional cooling the effective length could be achieved. A review of Figure 16 will show the method used for cooling during initial runs. Basically, the material is maintained at 490° for the first six inches of die and then a gradual cooling is achieved by placement of cooling strips at the end of the die and through internal cooling to the core section. This results in an material exit temperature of 150°F. During the first 15 minutes the material is maintained at 490°F and therefore this time could be reduced without any adverse effect. If we assume a flow rate of two inches every minute, the material would exit the die in six minutes versus 30 minutes under present configuration after the first stage. To maintain the same cooling rate would require 60 inches of effect length. This could be achieved by tapering the core section to allow for shrinkage and prevent frictional forces from holding the material in the die. Cooling would also have to be more rapid and uniformly controlled in the first stages of the die. Core cooling should be accomplished through a two stage system with a higher temperature established at the start of the taper and a lower temperature than presently used at the die exit.

4. PUSH/PULL BAR

The extended die length and resultant force build-up could eliminate the need for holding the extrusion in the die during the lower pressure material fill cycle. The pull sequence would still be required during the shot cycle to provide a uniform void across the rear of the die for the molten material to fill. However, in the present hydraulic setup, the need to cut off the end item and reclamp the puller is another time consuming step. Utilization of puller units similar to those used in the pultrusion technique would result in another time improvement and help make the system continuous.

SECTION VI

CONCLUSIONS

Techniques were developed to successfully extrude a shaped cross-section 101-inch wide and 2 1/4-inch thick.

Large scale extrusions can be fabricated utilizing standard equipment with multiple entry dies.

Feasibility has been demonstrated but practical production capability does not exist due mainly to slow extrusion rate.

SECTION VII

RECOMMENDATIONS

To continue development of this technique to increase speed of extrusion to an economic level.

APPENDIX A

SUMMARY

The program described in this report was undertaken to evaluate the feasibility of the HCU-54/E polymer logistics pallet through engineering testing in accordance with MIL-P-27442E.

Environmental testing on a small scale mock-up (2-1/2' x 2-1/2') was conducted by ASD engineering to determine if the polymer center-aluminum side rail configuration would have any adverse expansion/contraction characteristics. The mock-up underwent both high and low temperature immersions at 140°F and -65F° for a period of 48 hours each. Data from these tests indicated that the expansion/contraction characteristics would not prohibit operational use in extreme environments.

Static and dynamic testing on the HCU-54/E polymer pallet was conducted in four parts: (1) traveling 10,000 feet of roller-conveyor with a 10,000 pound load; (2) lift test with a 10,000 pound load utilizing a forklift; (3) side rail strength comparison test with the existing standard aluminum-balsa pallet; and (4) load test with 18,000 pounds.

Results of these tests ranged from satisfactory to unsatisfactory. The pallet completed the 10,000 foot of roller-conveyor testing with no major damage. Permanent deformations of 5/8-inch and 7/8-inch were measured after the pallet completed the forklift test. Data from the side rail tests indicated the HCU-54/E was 50 to 80 percent as strong as the standard aluminum-balsa pallet, with one vertical loading surpassing the existing pallet strength. Failure at one of the side rail mitered corners, resulting from a riveted support failing in shear, terminated the load test prematurely.

Due to the performance of the HCU-54/E polymer pallet in the evaluative tests, it was concluded that the pallet could not feasibly replace the existing HCU-6/E aluminum-balsa logistics pallet.

In all tests, the polymer pallet center proved to be suitable in wear and ruggedness.

The main disadvantage of the HCU-54/E pallet was the addition of existing aluminum side rails. In light of the HCU-54/E failure, the concept of a polymer pallet should not be discarded, but developed. Areas for development include improving attaching techniques for the rails or polymer rails extruded with the center in a one piece panel, and lowering the weight of the end product.

The addition of the standard 463L aluminum side rails increased the weight of the finished pallet considerably. The excessive weight was a result of crude attaching techniques (i.e., steel bolts, nuts, plating, and aluminum rods) implemented by the contractor to secure the standard aluminum rails to the polymer center.

SECTION I

INTRODUCTION

A. Preliminary

Early extrusions produced panels in various widths (12, 22 and 101 inches) for use as test samples. These samples were used for evaluation of the plastic extrusion properties through concentrated load testing with varying percentages of glass fiber filler.

The acceptable mixture of 30 percent glass fiber was determined during these concentrated load tests. The incorporation of this amount of glass fiber into the polypropylene, although adding weight and cost, was considered a necessity due to the improved rigidity, strength, and lowered thermal expansion.

B. Construction

The logistic polymer pallets are constructed of a one piece polymer panel approximately 101 x 81 x 2-1/4 inches thick, with a standard set of aluminum side rail extrusions, manufactured by Brooks and Perkins, Inc., bolted to the polymer center.

The method of attaching pallet side rails proved to be a far greater problem than first realized. In order to attain a comparable strength rating of the existing aluminum-balsa logistics pallet, heavy extraneous material had to be used. In October 1971, strength comparison tests of the preliminary rail attachment method on two pre-prototypes were accomplished. It was determined that, at that time, the rail attachment method was not sufficiently as strong at the standard logistics pallet. Modifications were performed to the attachment techniques, and the finished full size (108 x 88 x 21/4 inches) pallets were delivered to Wright-Patterson AFB, Ohio (Figure 1).

C. Test Units

Ten full size pallets were received from the contractor in Jan 72. Four of these pallets were shipped to the Tactical Airlift Command at Pope AFB, North Carolina, for service testing. The remaining six pallets underwent static and dynamic tests at Wright-Patterson AFB by Aeronautical Systems Division and Air Force Flight Dynamics Laboratory.

SECTION II

PURPOSE OF TEST

A. To determine the operational suitability of the HCU-54/E polymer air cargo pallet as a replacement for the HCU-6/E balsa wood/aluminum sandwich pallet.

B. The specific objectives of the test were:

(1) Verify the strength capability and durability of the HCU-54/E pallet.

(2) Through strength comparisons, determine feasibility of replacing the standard HCU-6/E pallet.

(3) Provide adequate engineering analysis to be used in future development of a polymer air cargo pallet.

SECTION III

METHOD OF TEST

A. Environmental Tests

(1) A square (21/2' x 21/2') mock-up of the actual full size polymer pallet was tested in accordance with MIL-STD-810B, Environmental Test Methods. All tests were conducted by the Combined Environments Group, Air Force Flight Dynamics Laboratory, located at Wright-Patterson AFB, Ohio.

(2) The mock-up was marked off in segments by scribing reference lines on the polymer center and aluminum side rails, as shown in Figure 19. Linear measurements around the periphery, as well as thickness in five locations, were taken preceding the soak, at the halfway point (24 hours), and after the soak was completed (48 hours). A calibrated mechinist's rule and dividers were used to attain all measurements. The results, an increase or decrease in measurements, would determine the expansion/contraction characteristics of the aluminum side rail - polymer center interface. These characteristics would outline the probability of a pallet expanding or contracting a significant amount which would result in induced stress and clearance.

(3) The pallet was subjected to a temperature of 140^{o}F for 48 hours in accordance with Method 501, Procedure II (High Temperature Soak). After a brief cooling period (5 days), the pallet was subjected to a temperature of -65^{o}F for 48 hours in accordance with Method 502, Procedure I (Low Temperature Soak).

B. Conveyor Test

(1) An HCU-54/E pallet was uniformly loaded with 10,000 pounds of 8 x 16 x 8 inch concrete building blocks while supported on conveyors, for a distance of 10,000 feet (Figure 20).

(2) To accomplish the 10,000 foot criteria, 50 ft of cargo floor space inside a C-141 test aircraft was used. The pallet was moved 200 times for and aft. At random, a force indicator, as shown in Figure 21, was used to measure the amount of force needed to overcome the inertial force and to sustain rolling motion.

C. Forklift Test

(1) Since the average operational load is well below 10,000 pounds, a 6,000 pound load was uniformly distributed over the top surface of the pallet, as shown in Figure 22.

(2) The pallet was lifted by the forklift to a height of approximately two feet, as shown in Figure 23, the then lowered to the ground. This procedure was repeated ten times. Forklift tines were 72 inches x 8 inches, spaced on 42-inch centers.

D. Ultimate Strength Rail Attachment Test

(1) For comparison with previous test results on an HCU-6/E pallet, the HCU-54/E polymer pallet side rails were loaded along both the 108 and 88-inch sides. Loads were applied in the vertical and horizontal direction. These configurations can be seen in Figures 24, 25, 26 and 27.

(2) Two pallets were utilized. Each pallet was anchored to the floor jig similar to that in the actual aircraft. Load application was accomplished by five oil dyne hydraulic cylinders for the 88-inch side and six for the 108-inch side.

E. Load Test

(1) While supporting a uniformly distributed 18,000 pound load, the HCU-54/E pallet was slowly raised from the floor with an overhead crane by means of four cables attached to the four tie down rings adjacent to the four corners. The pallet was raised off the floor, held in that position for one minute, and then returned to the floor. This procedure was repeated ten times. Figure 28 shows this configuration.

SECTION IV

REST RESULTS

A. Environmental Test

(1) The small scale mock-up endured the high and low temperature

soaks with no deterimental effects. Measurements indicated some very small variations after the 24 and 48 hours intervals (Tables V and VI).

B. Conveyor Test

(1) The HCU-54/E pallet traversed 10,000 feet of roller conveyor with no major damage, as shown in Figure 29. Minor damage in the form of a "mashed" edge, Figure 30, was evident in the location where the rollers cross the pallet. This damage was apparently due to a non copolaner low area between the edge of the polymer center and the inner edge of the side rail. (Section detail is shown in Figure 31.) The side rail low area is utilized for smooth lap joint construction in the aluminum skin, balsa core pallet construction.

(2) Measured force data is listed in Table VII. There was little variation in forces within each category. Average values for the test were: (1) 258.12 pounds to begin rolling, and (2) 80.03 pounds to continue rolling at an average of 25 fpm.

(3) At one particular location in the aircraft, approximately Fus Sta 1140, the pallet came into contact with the guide rails. Scrape and abrasion marks on the guide rail are shown in Figure 32. The damage was determined to be the result of tolerance build-up between the pallet and guide rail.

(4) Excessive bumping and vibration was noted as the pallet traveled fore and aft. This problem was again attributed to the height differential of the polymer center and inner edge of the side rail as described in (1) above.

C. Forklift Test

(1) The 6,000 pound load was raised off the ground ten consecutive times to a height of approximately two feet, Figure 33. After eight lifts, the pallet showed noticeable deflection, Figure 34.

(2) Permanent deformation was observed and measured after the pallet was unloaded. Figures 35 and 36 illustrate the deflection obtained when viewed form the 88-inch and 108-inch sides, respectively. With the top up, the amount of deflection obtained was 5/8-inch, as shown in Figure 37. The pallet was overturned (bottom up) to measure the depth of the bow from the side rail plane. At approximately the center of the pallet, a 7/8-inch depth was measured, Figures 38, 39, and 40. Since unacceptable deformation was experienced at 6,000 pounds, no 10,000 pound load was accomplished.

D. Side Rail Strength Test

(1) Horizontal loading along the 88-inch side produced structural

failure at 24,255 pounds for the polymer pallet. A breaking strength of 28,638 pounds was determined by loading the 108-inch side. Previous tests conducted on a standard aluminum-balsa pallet resulted in breaking strengths of 34,210 pounds and 53,313 pounds for the 88-inch and 108-inch sides, respectively.

(2) The steel bolts pulled through the aluminum plate located in the second polymer extrusion cavity during the horizontal 88-inch side loading, Figures 41 and 42. The aluminum rods failed in tension in the 108-inch configuration as shown in Figures 43 and 44.

(3) Vertical loading of the polymer pallet resulted in breaking strengths of 18,865 pounds for the 88-inch side, and 24,255 pounds for the 108-inch side. These results were compared with the aluminum-balsa pallet results of 16,311 pounds and 29,512 pounds for the 88-inch and 108-inch sides, respectively

(4) As shown in Figures 45, 46, and 47, the failure along the 108-inch side resulted primrily from the aluminum rods failing in shear. Again the steel bolts pulled through the aluminum plate along the 88-inch side Figures 48, 49 and 50.

(5) No damage was done to the polymer center during the horizontal loadings. On the vertical 88-inch side loading, the polymer center cracked three-quarters of the length. This failure could possibly be from the variation in wall thickness along this side. No damage was noted on the 108-inch side vertical loading.

E. Load Test

(1) The pallet deflected quite severely when lifted from the ground as shown in Figures 51 and 52.

(2) Several rivets from different corners, Figure 53, failed in shear after the second lift. Rail separation, Figure 54, was noted after five on the eighth lift, the pallet side rail failed at one corner. This failure was diagnosed as being a direct result of rivet failures at the mitered corner, Figure 55.

(3) Permanent deformation of the polymer section was not noted after the pallet was unloaded. This may not indicate an acceptable condition because the 18,000 pound load probably flattened the pallet when it was repositioned on the flat floor, Figure 56.

SECTION V

CONCLUSIONS

The polymer center-aluminum side rail interface has no detrimental expansion/contraction characteristics which would prohibit operation in extreme environments.

The HCU-54/E polymer pallet surpassed the 10,000 feet of roller conveyor virtually unscathed. No damage was observed which would warrant failure of the test and rejection of the pallet.

Permanent deformation of 5/8 to 7/8 of an inch was measured after the forklift test. This is considered a failure.

Side rail strengths compared favorably with the existing aluminum-balsa pallet, but still remained generally weaker, primarily in the horizontal loading configuration. The polymer pallet was 54 and 70 percent as strong as the existing pallet in horizontal loading for the 108 and 88-inch sides, and 83 and 100 percent as strong as the existing pallet in vertical loading for the 108 and 88-inch sides.

The pallet did not complete all of the required ten lifts of the load test due to failure of the side rail mitered corner. This is considered a failure.

In light of the evaluative tests, it is concluded that the HCU-54/E polymer pallet could not feasibly replace the existing aluminum-balsa HCU-6/E logistic pallet in its present state.

SECTION VI

RECOMMENDATIONS

Although the HCU-54/E polymer pallet proved satisfactory in only two of five evaluative tests, the concept of a polymer pallet should not be discarded. Data obtained from this development project will aid future development of a polymer pallet.

In all tests, the polymer center proved to be suitable in wear and ruggedness, especially in the roller conveyor test where the pallet traversed 10,000 feet with no damage. The disadvantage of the HCU-54/E pallet was the addition of the aluminum side rails. The "off-the-shelf" aluminum rails were not designed for the polymer pallet and, due to the extruding techniques, the pallet could not efficiently be designed to fit the aluminum rails. As a consequence, heavy, extraneous, and expensive attaching hardware was required to attach the side rails in an awkward method. Test results substantiate the inefficiency the side rails provide to the pallet.

To produce a feasible polymer pallet capable of competing with the standard aluminum-balsa pallet, more work remains to be done. Areas requiring further work include improving:

a. Techniques used to attach the rails or further consideration of polymer rails extruded along with the polymer center.

b. Resiliency in bending by experimenting with various filler materials.

c. Lowering the weight of the end item.

d. Quality assurance provisions to assure pallet dimensions and tolerances are within specification.

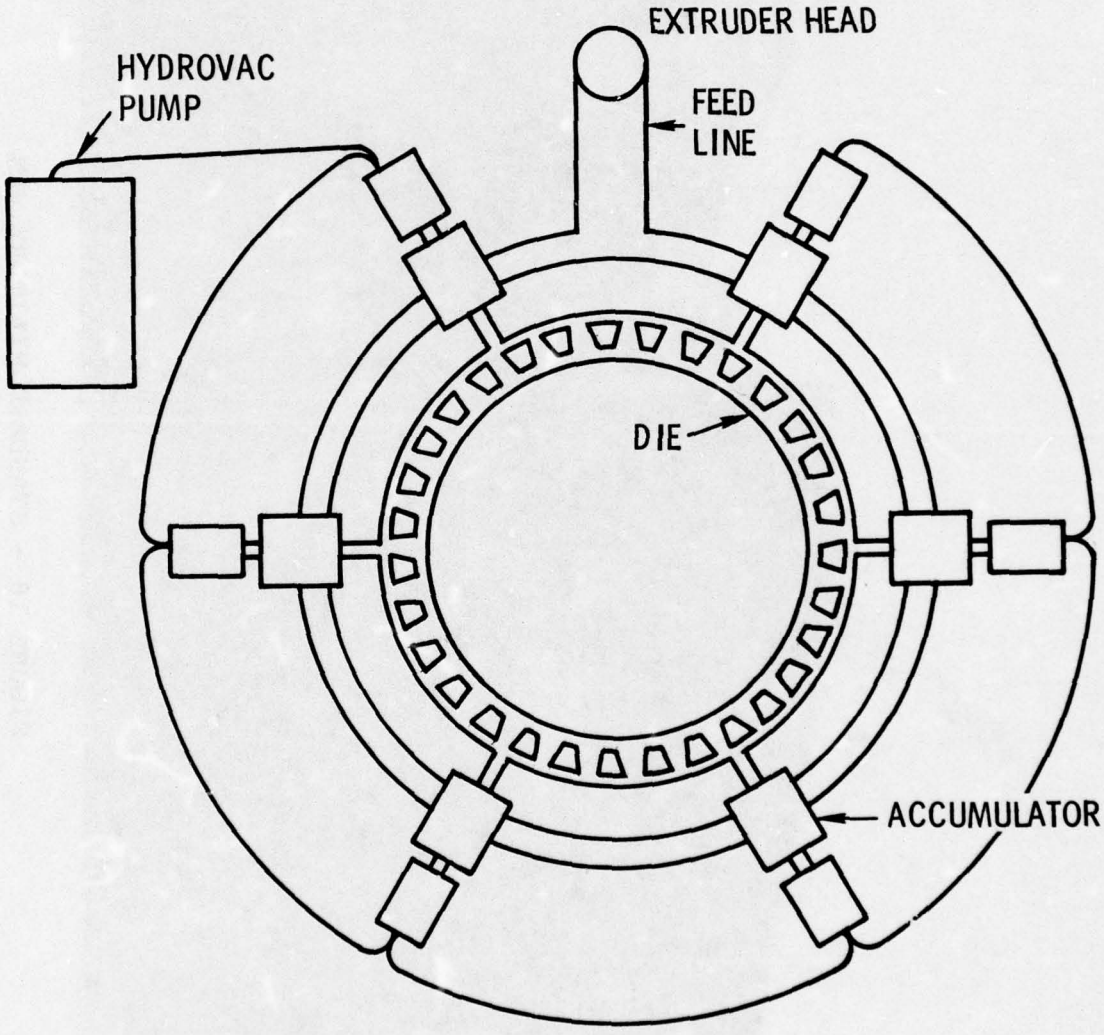


FIGURE 17

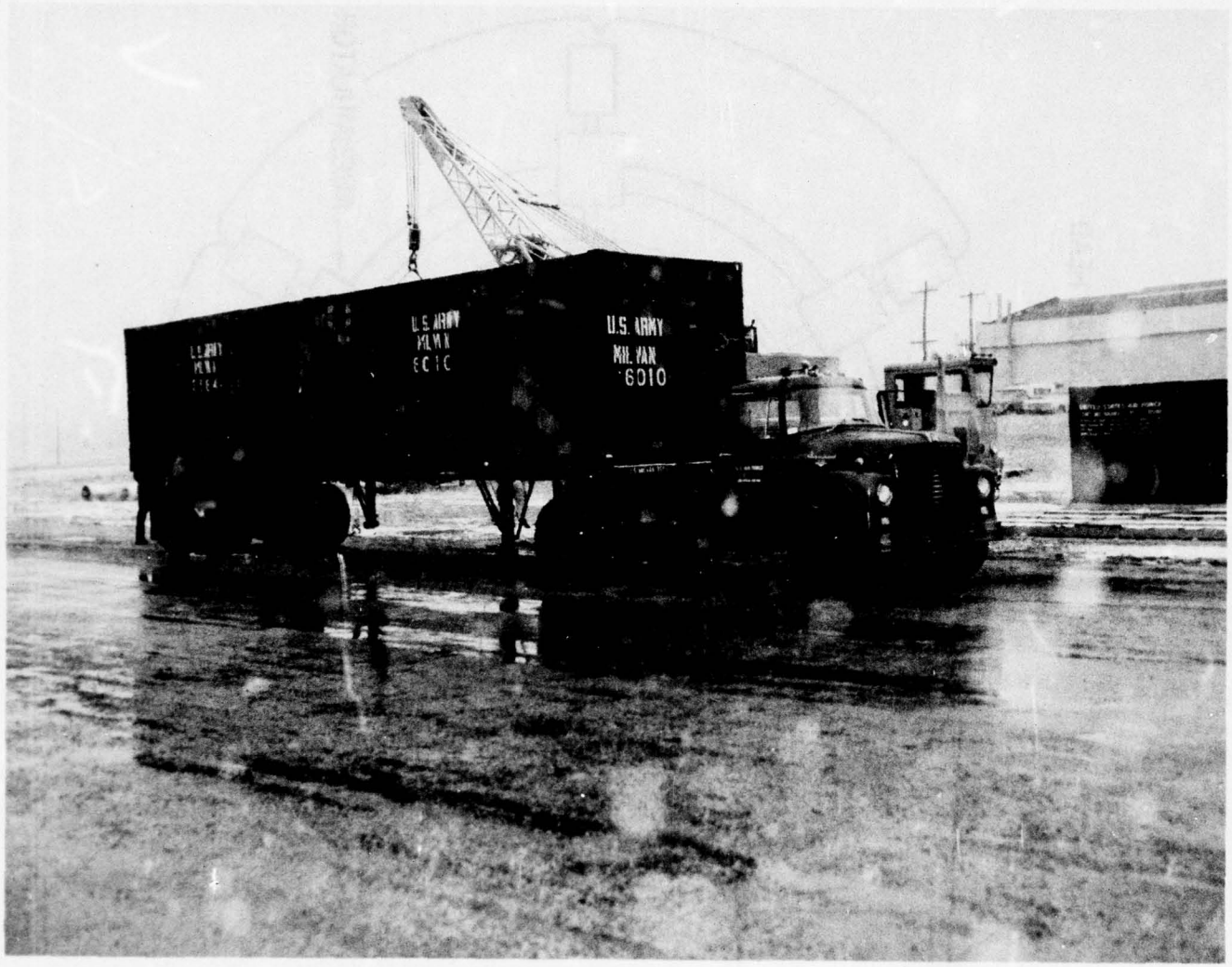


FIGURE 18 - STANDARD MILITARY VAN

HCU-54/E MOCK-UP

DIMENSIONAL PATTERN

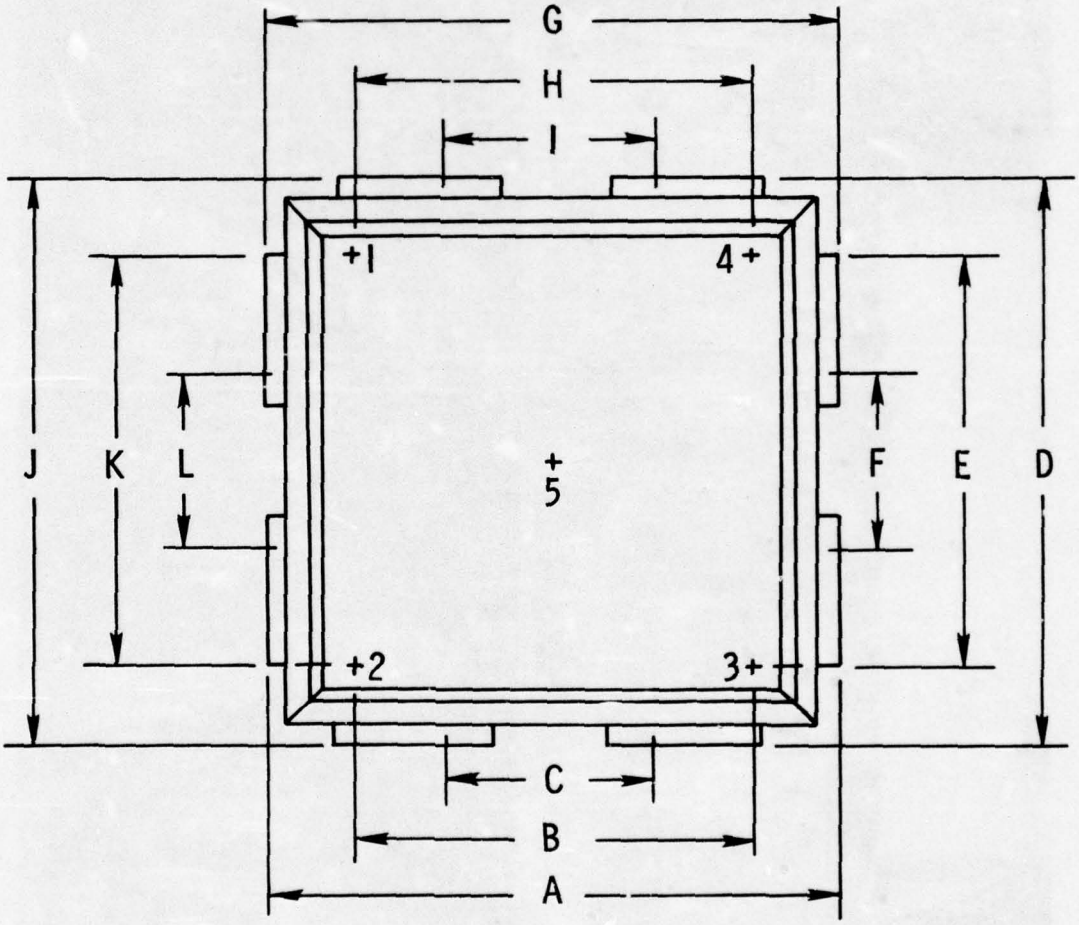


FIGURE 19 ENVIRONMENTAL TESTS

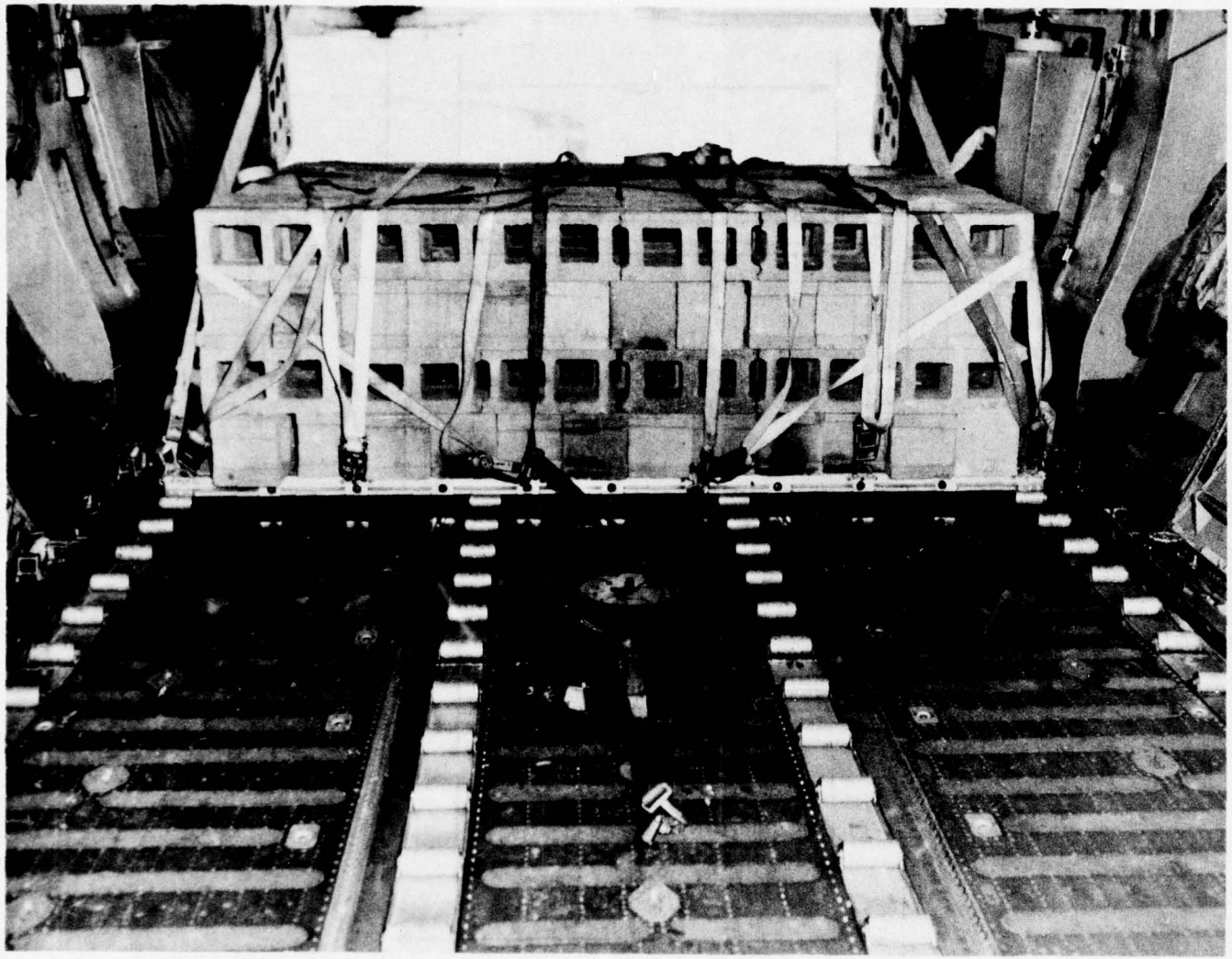


FIGURE 20 - CONVEYOR TEST - 10000 POUND LOAD

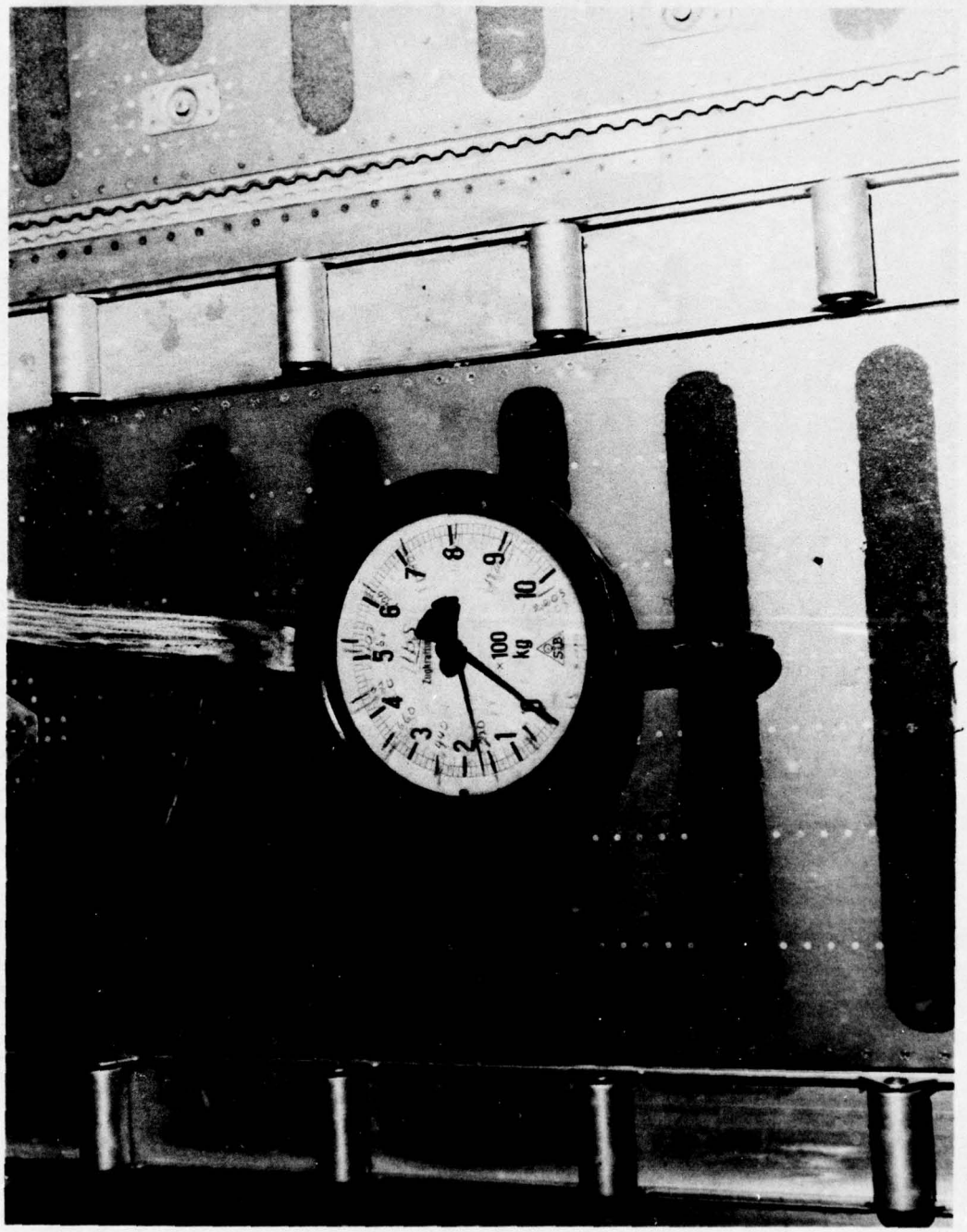


FIGURE 21 - FORCE INDICATOR

FIGURE 22 - FORKLIFT TEST 6000 POUND LOAD AT REST

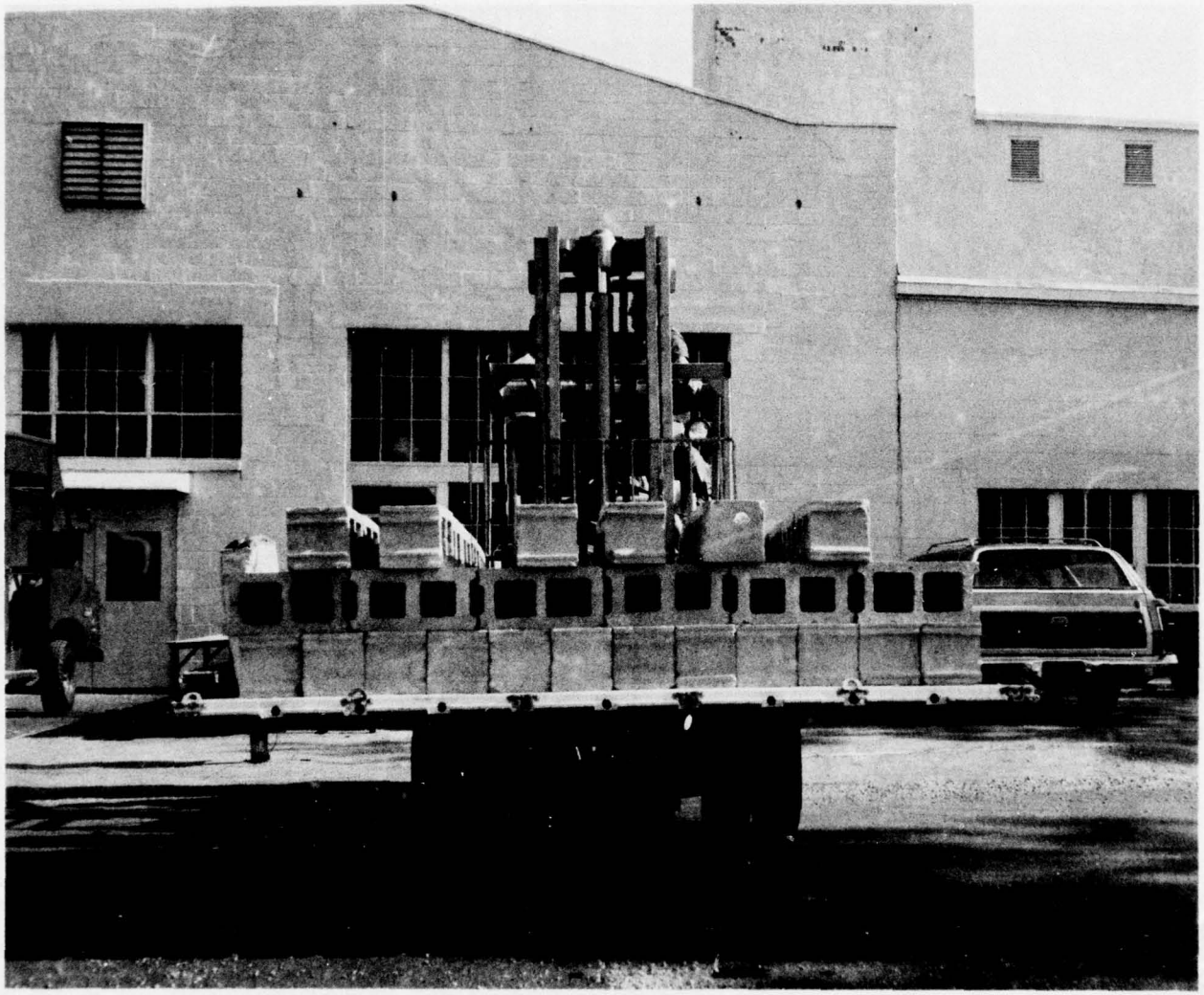


FIGURE 23 - FORKLIFT TEST - 6000 POUND LOAD OFF GROUND

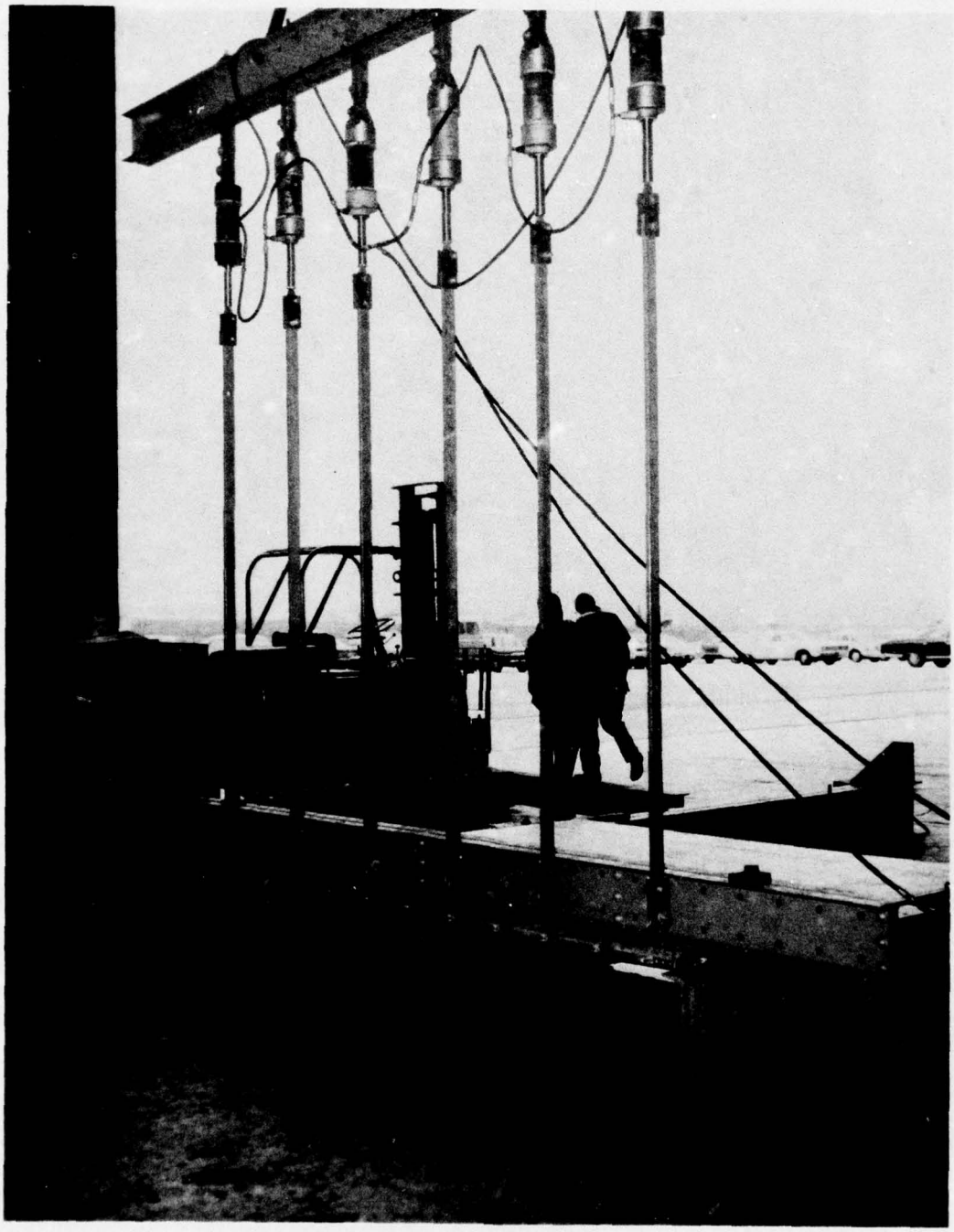


FIGURE 24 - RAIL STRENGTH TEST - VERTICAL, 108 INCH EDGE

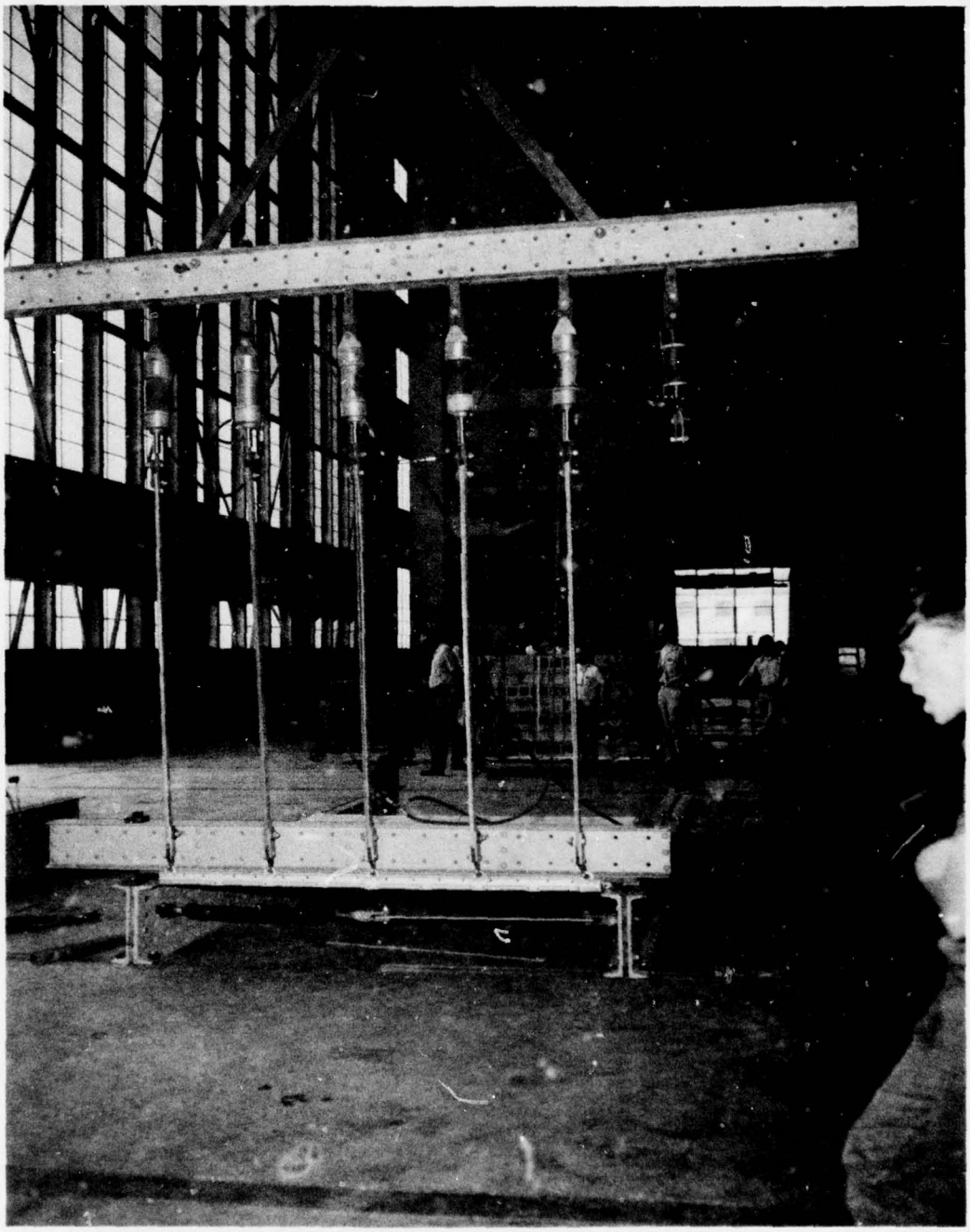


FIGURE 25 - RAIL STRENGTH TEST - VERTICAL, 88 INCH EDGE

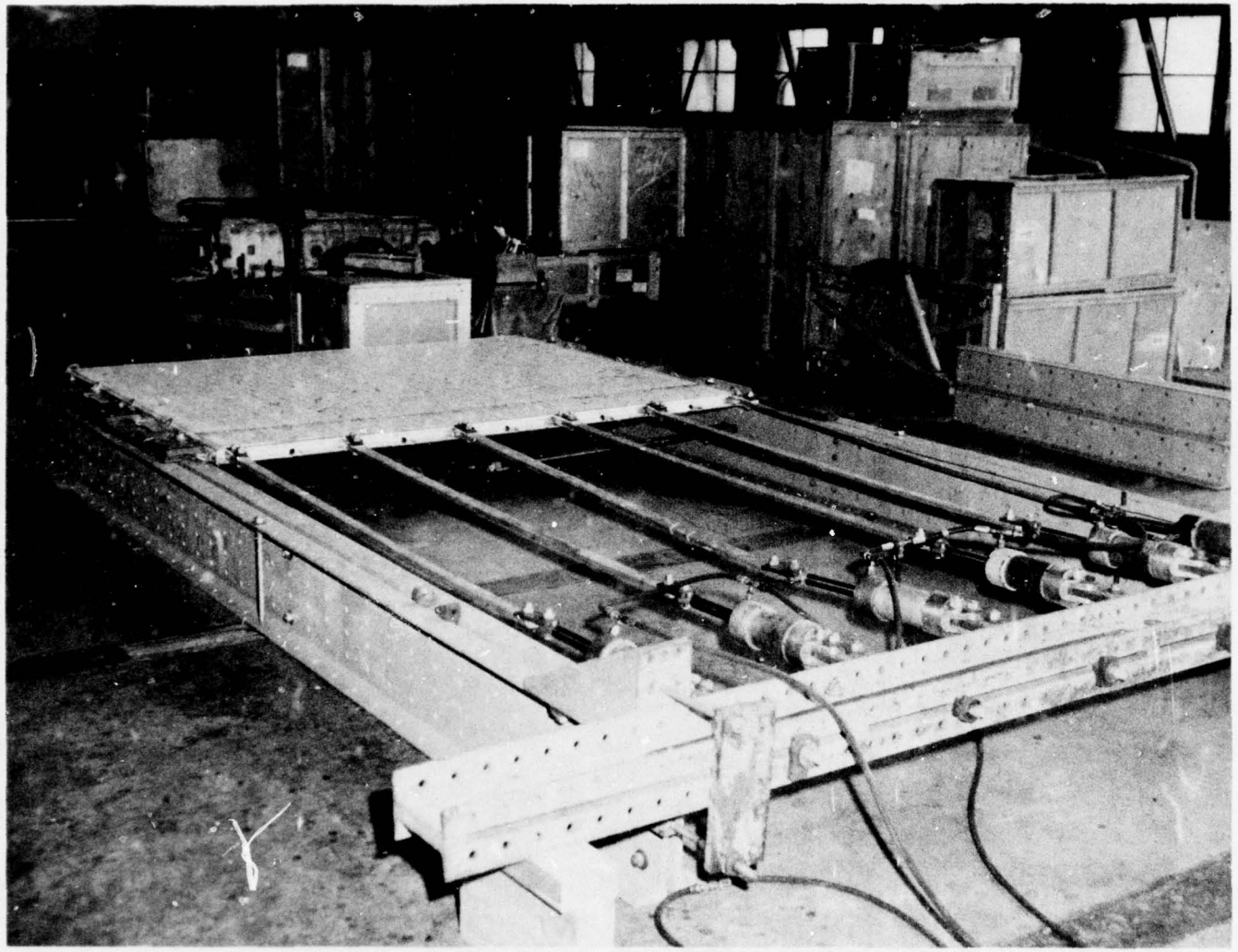


FIGURE 26 - RAIL STRENGTH TEST - HORIZONTAL, 108 INCH

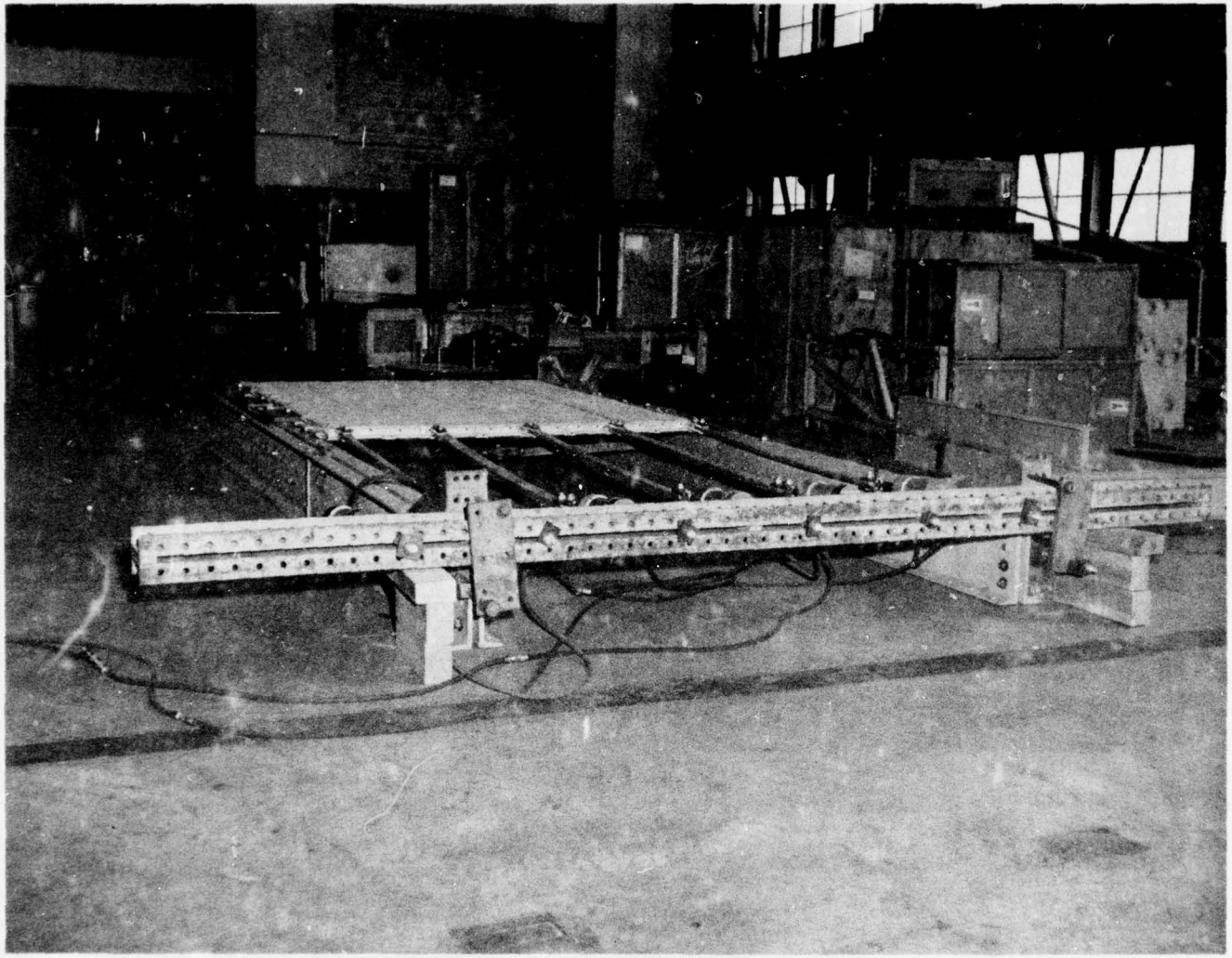


FIGURE 27 - RAIL STRENGTH TEST - HORIZONTAL, 88 INCH EDGE

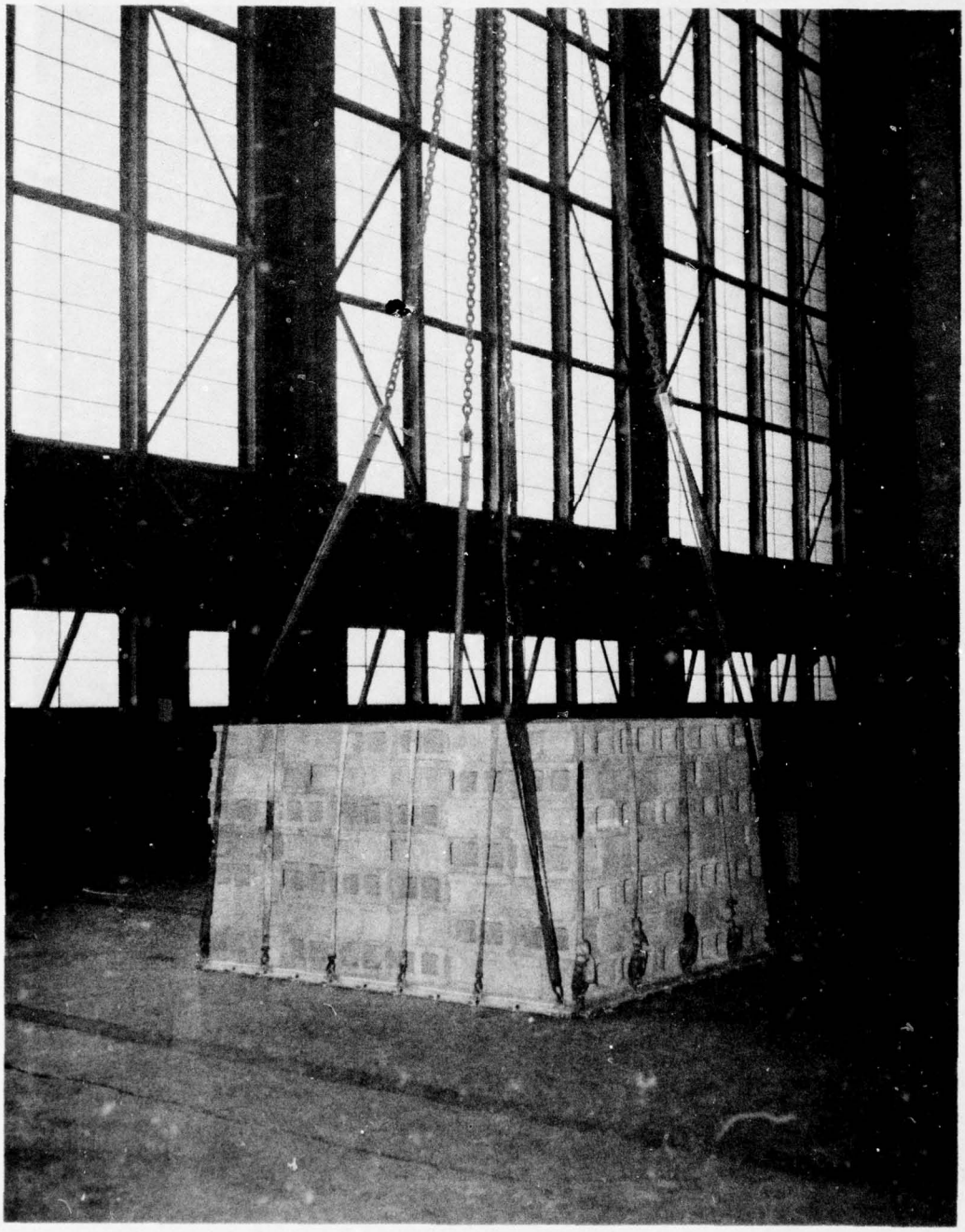


FIGURE 28 - CORNER SLING TEST - 18,000 POUNDS

ENVIRONMENTAL TESTS

TABLE V

Method 502 -65° F

STA	INITIAL MESMT	24 hr MESMT	48 hr MESMT	Δ 24	Δ 48	Δ (Theor)
A	28.312	28.25	28.187	.0625	.125	.0713
B	20.0	19.937	19.937	.0625	.0625	.0540
C	12.0	11.984	11.968	.0156	.0312	.0204
D	29.0625	29.0	28.937	.0625	.125	.0713
E	20.0	19.968	19.968	.0652	.0625	.0539
F	12.0	11.968	11.968	.0625	.0625	.0204
G	28.312	28.25	28.125	.0625	.0927	.0713
H	20.0	19.937	19.906	.0625	.0937	.0540
I	12.0	11.984	11.968	.0156	.0312	.0204
J	29.0	29.0	29.0	0	0	.0713
K	20.0	19.906	19.906	.0937	.0937	.0540
L	18.0	17.968	17.968	.0312	.0312	.0204
1	2.25	2.25	2.25	0	0	.00607
2	2.25	2.25	2.25	0	0	.00607
3	2.25	2.25	2.25	0	0	.00607
4	2.25	2.25	2.25	0	0	.00607
5	2.375	2.312	2.312	.0625	.0625	.00607

ENVIRONMENTAL TESTS

TABLE VI

Method 501 $+140^{0}$ F

STA	INITIAL MESMT	24 hr MESMT	48 hr MESMT	Δ24	Δ48	Δ (Theor)
A	28.312	28.3125	28.3125	0	0	.0356
B	20.0	20.0	20.0156	0	.0156	.0270
C	12.0	12.0	12.0	0	0	.0102
D	29.0625	29.0937	29.156	.0312	.0937	.0356
E	20.0	20.0312	20.0	.0312	0	.0270
F	12.0	12.0156	12.0156	.0156	.0156	.0102
G	28.312	28.3125	28.3437	0	.0156	.0356
H	20.0	20.0	20.0	0	0	.0270
I	12.0	12.0	12.0	0	0	.0102
J	29.0	29.0	29.0	0	0	.0356
K	20.0	20.0	20.0312	0	.0312	.0270
L	18.0	18.0	18.0	0	0	.0102
1	2.25	2.25	2.25	0	0	.00315
2	2.25	2.25	2.25	0	0	.00315
3	2.25	2.25	2.25	0	0	.00315
4	2.3125	2.375	2.375	.0625	.0625	.00315
5	2.3125	2.375	2.3125	.0625	0	.00315

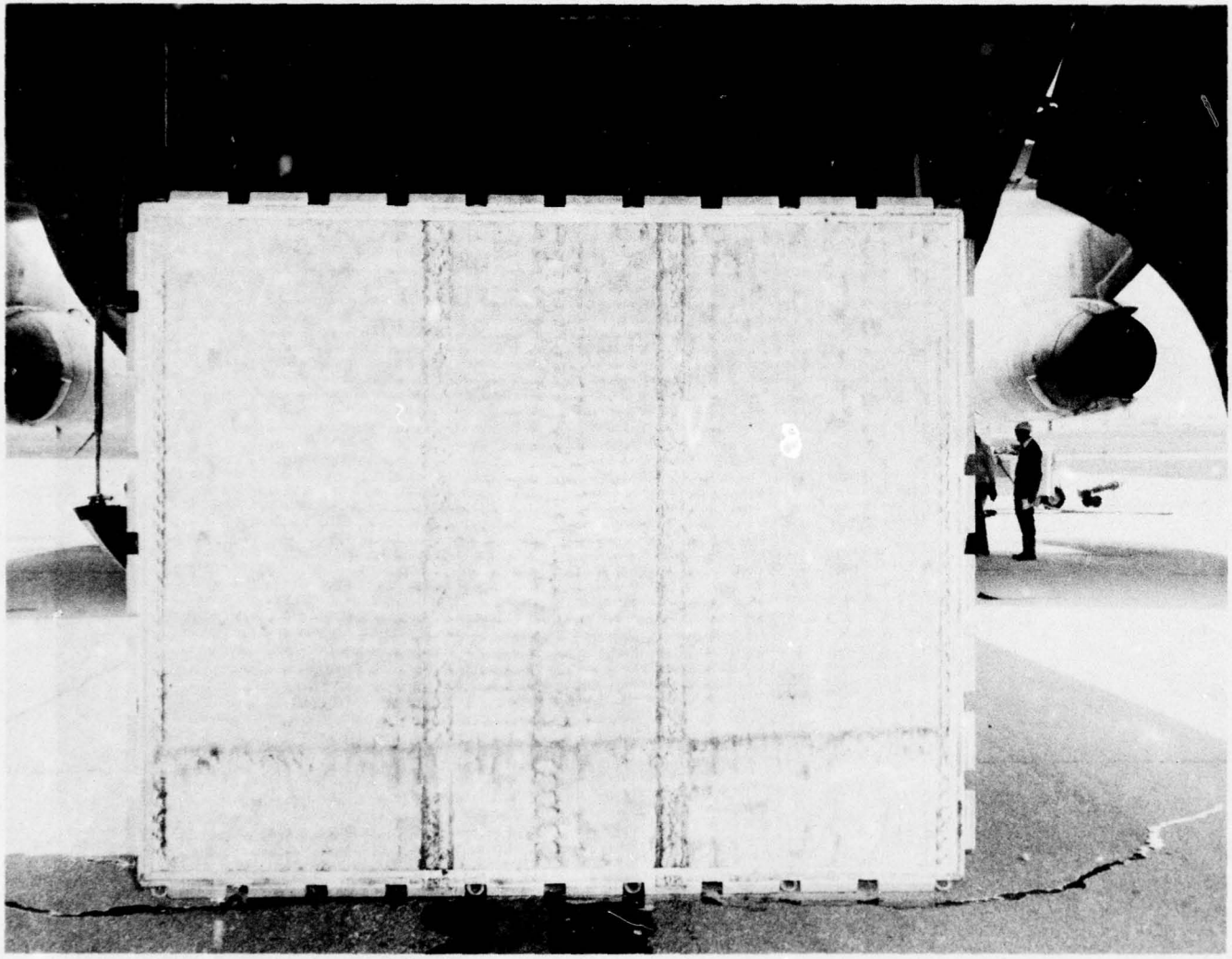


FIGURE 29 - ROLLER CONVEYOR TEST - SIDE IN CONTACT WITH ROLLERS

FIGURE 30 - ROLLER CONVEYOR TEST - MASHED EDGE

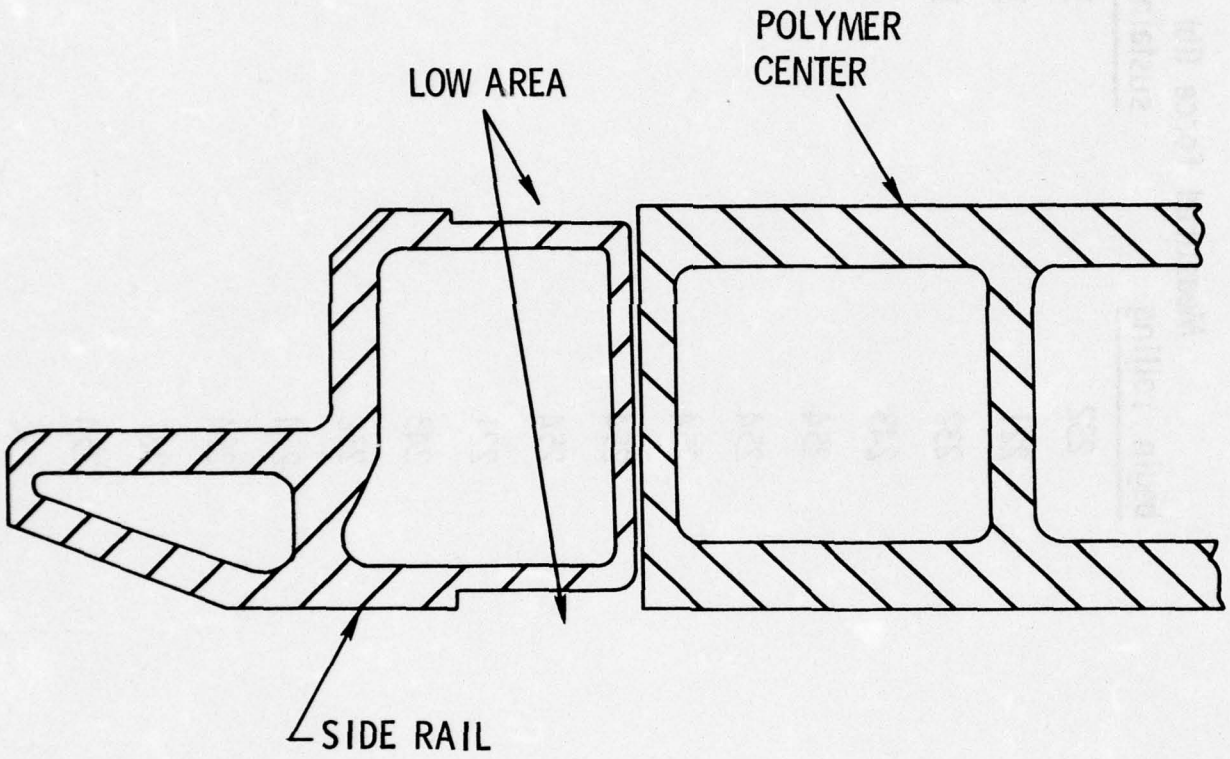


FIGURE 31

ROLLER CONVEYOR TEST

TABLE V I I

Interval	Measured Force (lb) begin rolling	sustain rolling
1	232	110
7	221	132
11	232	132
15	243	121
19	254	104
23	254	77
29	254	77
35	254	143
41	254	66
45	221	77
51	243	66
59	232	55
65	254	71
71	254	66
83	287	66
89	254	55
95	254	66
101	287	71

ROLLER CONVEYOR TEST

TABLE VII (cont'd)

Interval	Measured Force (lb)	
	begin rolling	sustain rolling
109	276	77
115	287	77
121	265	75
127	276	66
135	287	77
145	254	66
155	254	71
165	287	71
175	254	71
185	265	77
195	265	66
200	272	66

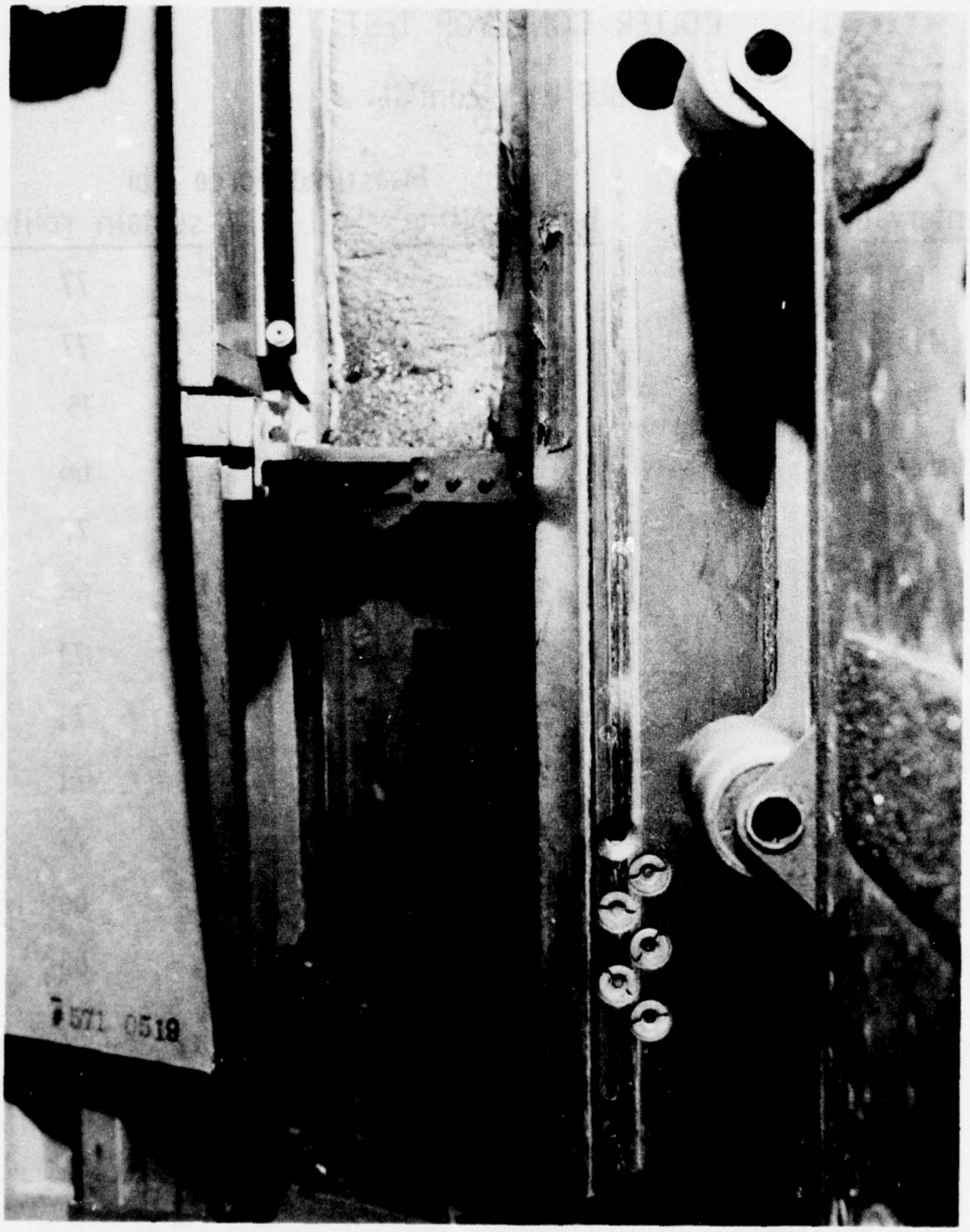


FIGURE 32 - GUIDE RAIL ABRASION

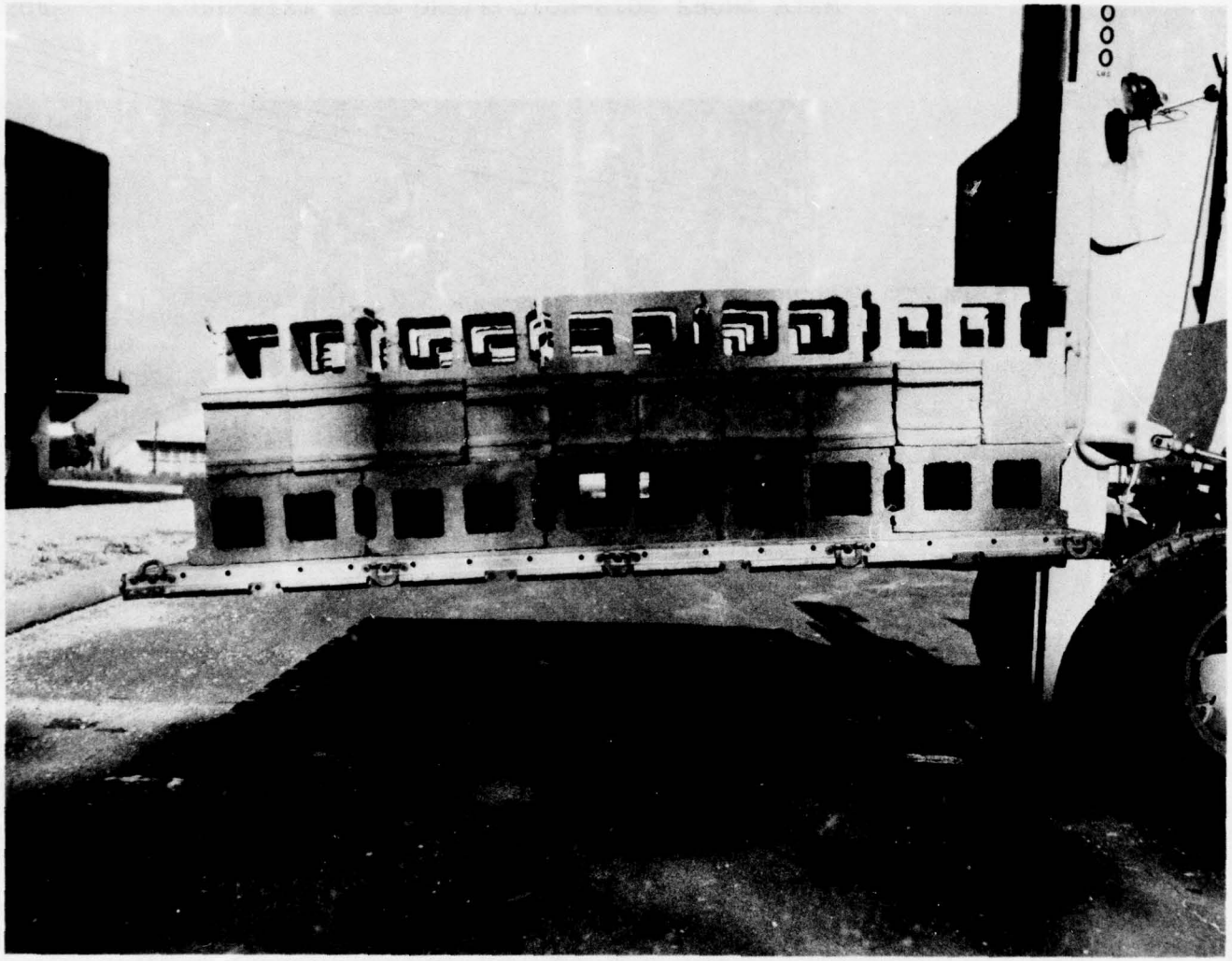


FIGURE 33 - FORK-LIFT TEST DEFLECTION-SIDE VIEW

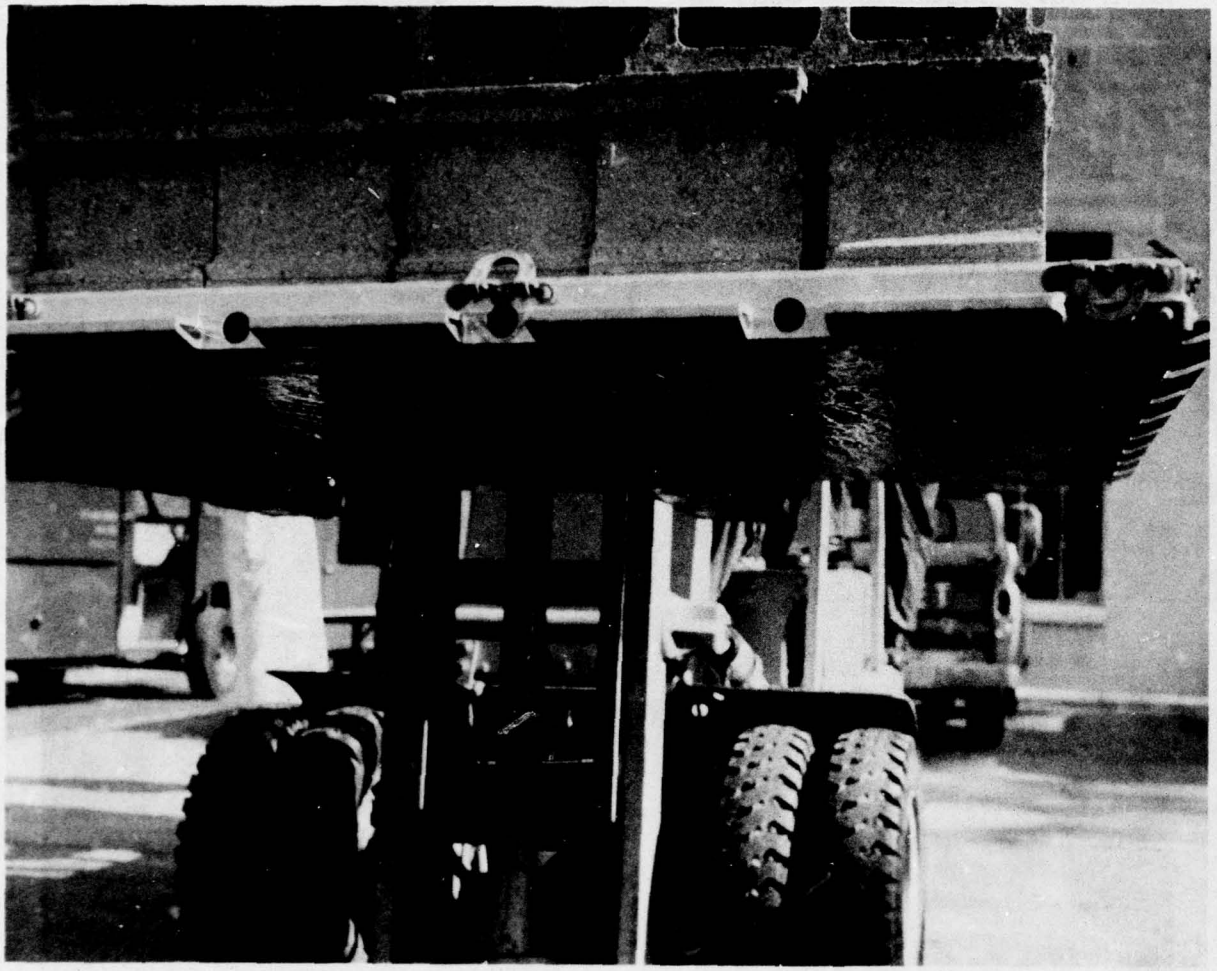


FIGURE 34 - FORK-LIFT TEST DEFLECTION-SIDE FRONT VIEW

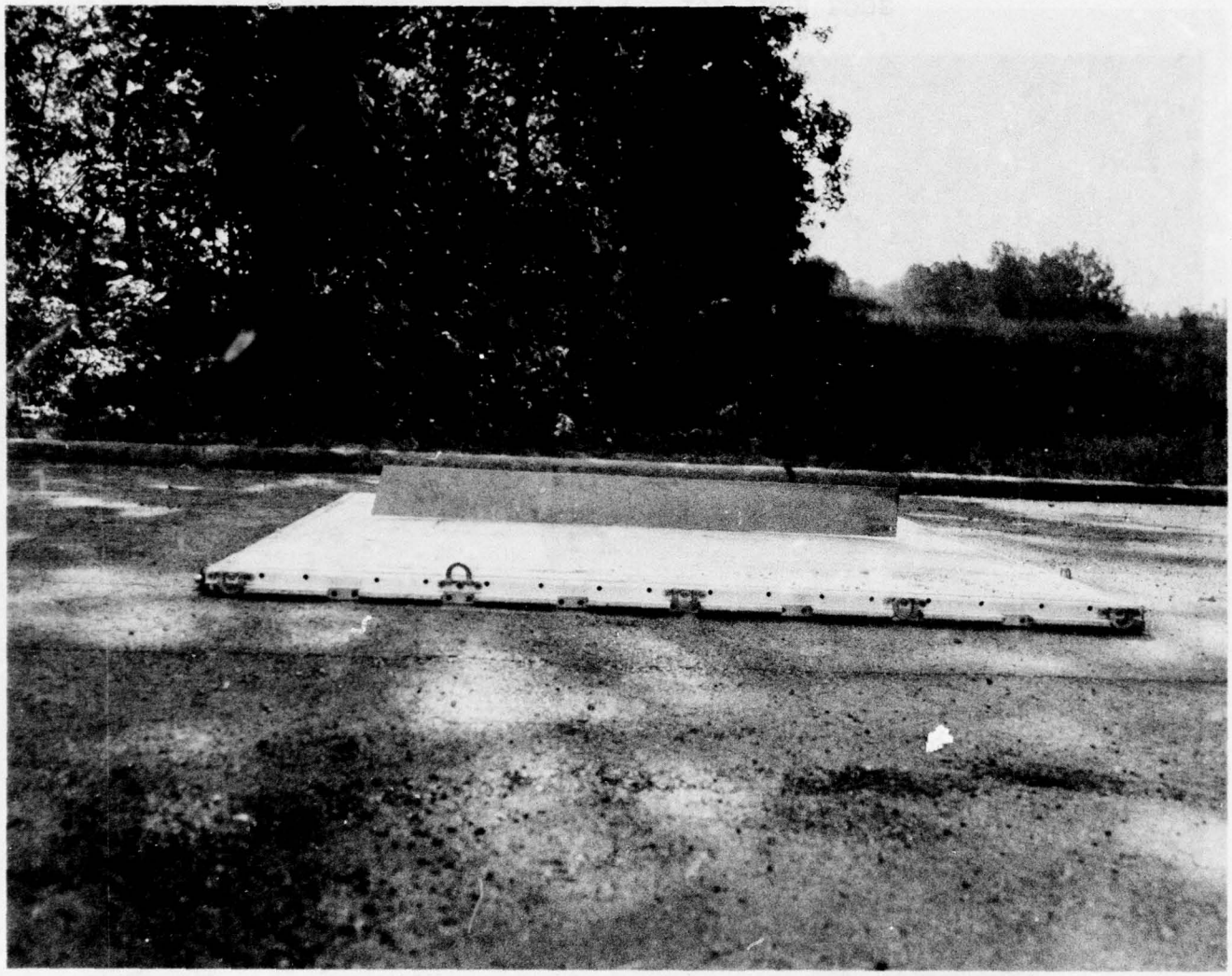


FIGURE 35 - PERMANENT DEFORMATION - 88 INCH EDGE

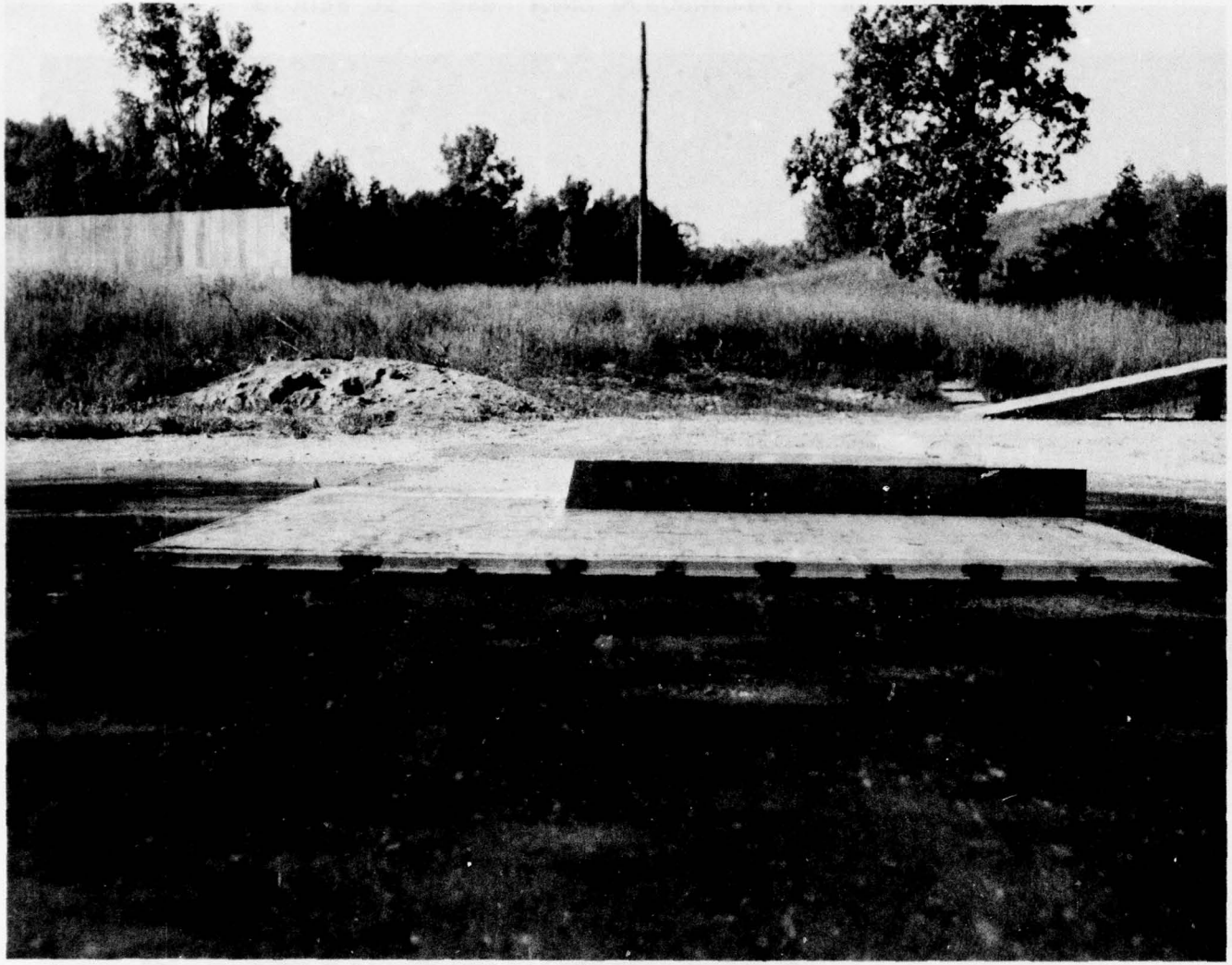


FIGURE 36 - PERMANENT DEFORMATION - 108 INCH EDGE

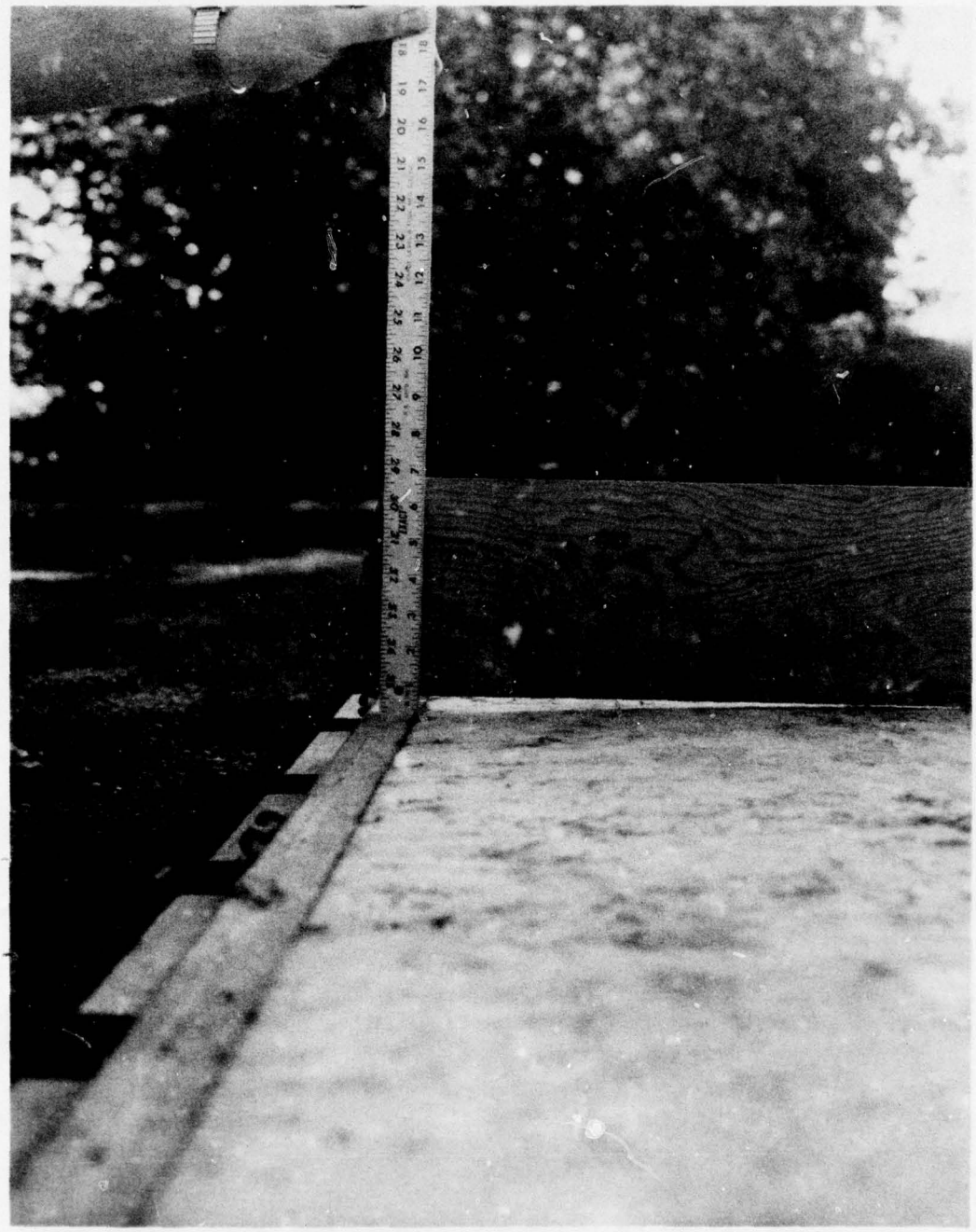


FIGURE 37 - EDGE DEFORMATION - 5/8 INCH

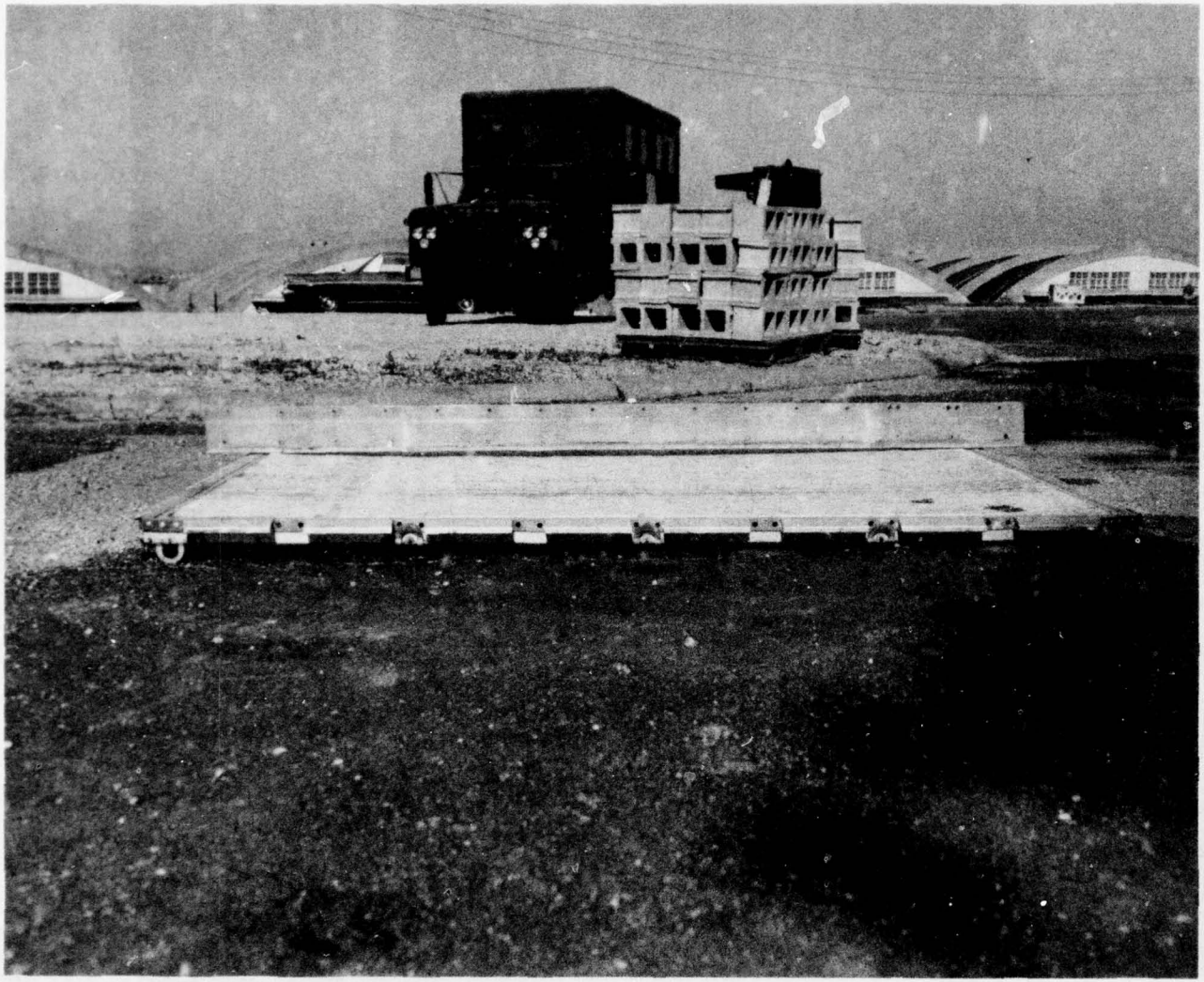


FIGURE 38 - CENTER DEFORMATION FROM 88 INCH EDGE

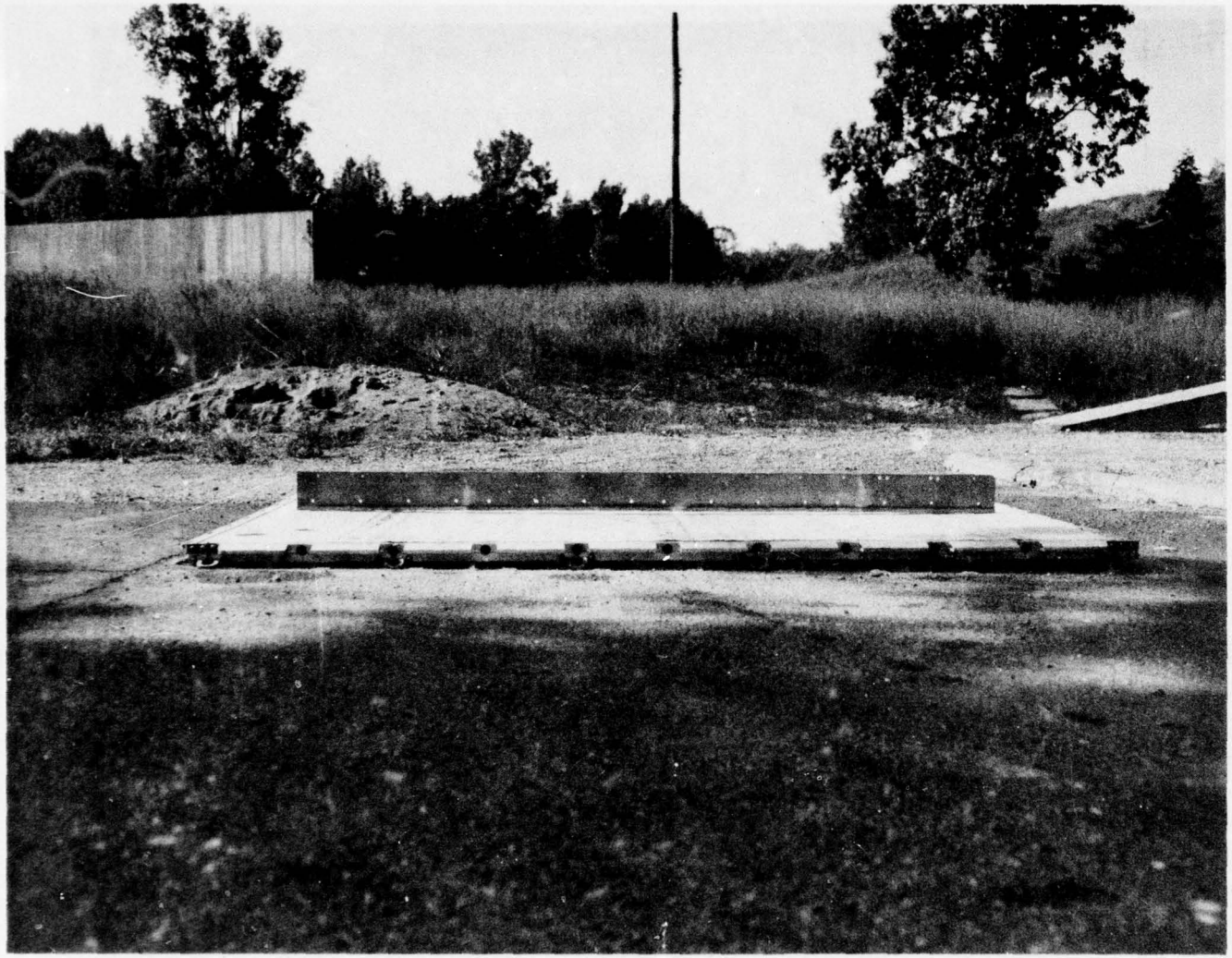


FIGURE 39 - CENTER DEFORMATION FROM 108 INCH EDGE

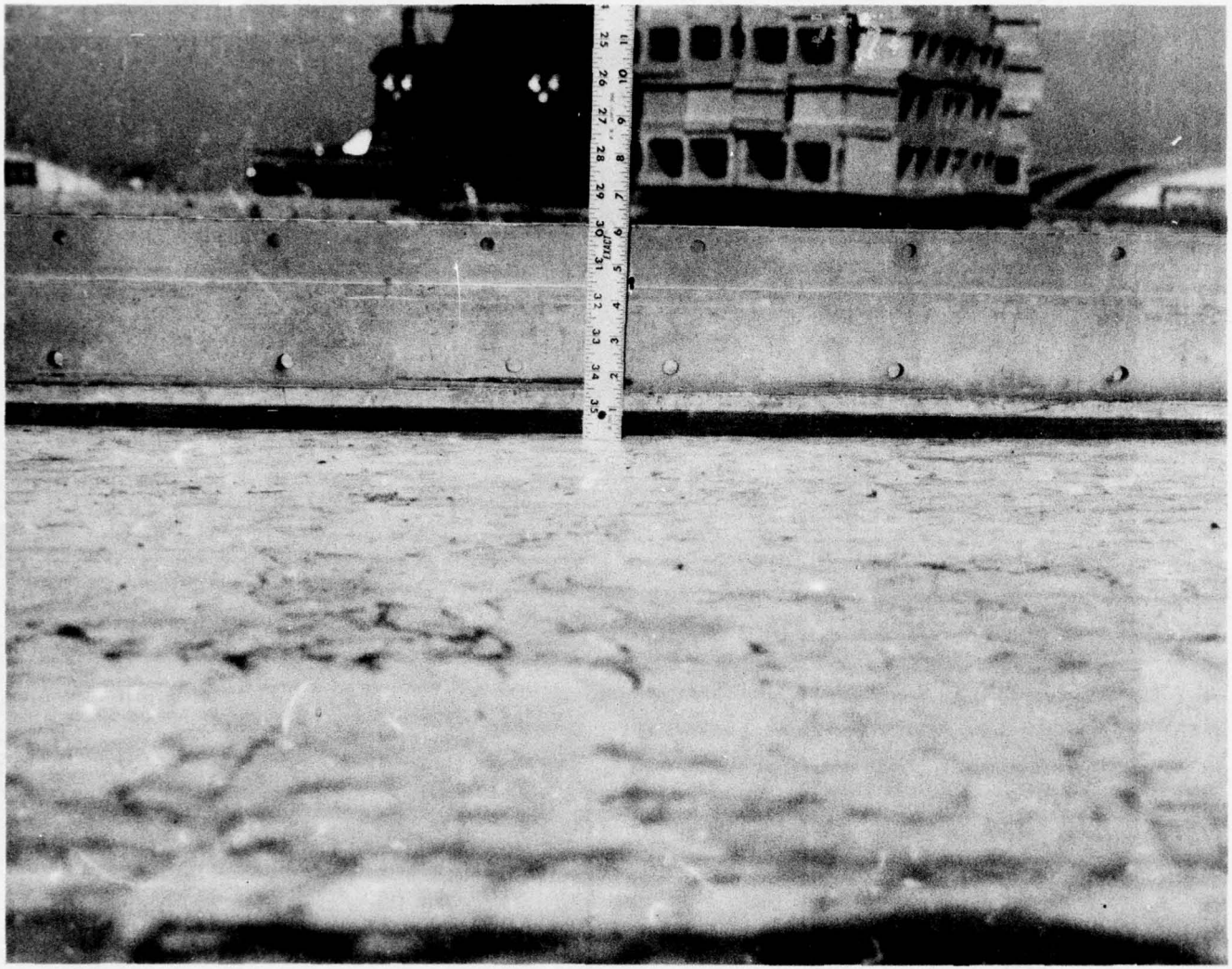


FIGURE 40 - CENTER DEFORMATION - 7/8 INCH

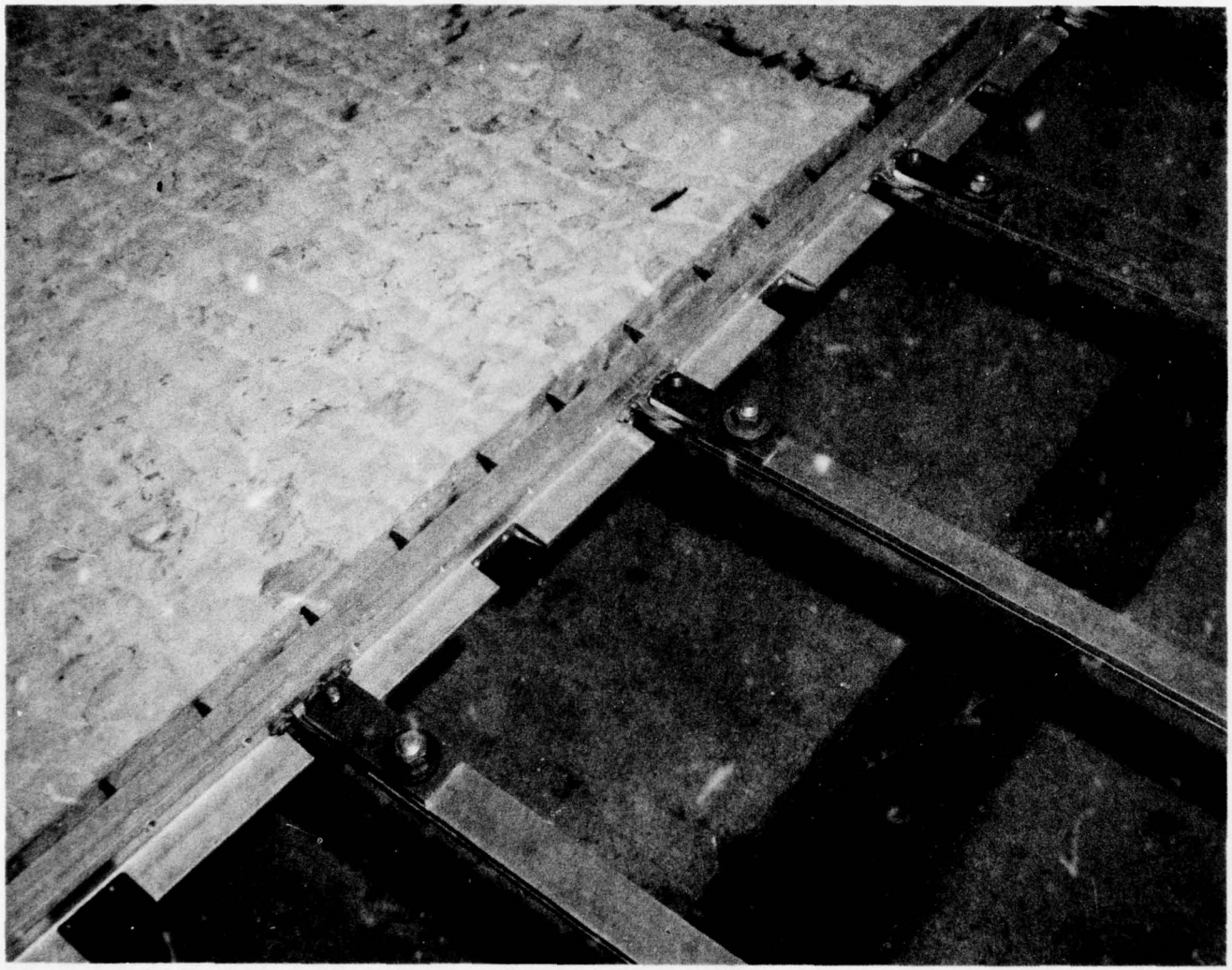


FIGURE 41 - RAIL STRENGTH TEST - BOLT PULLOUT 88 INCH EDGE - CLOSEUP VIEW

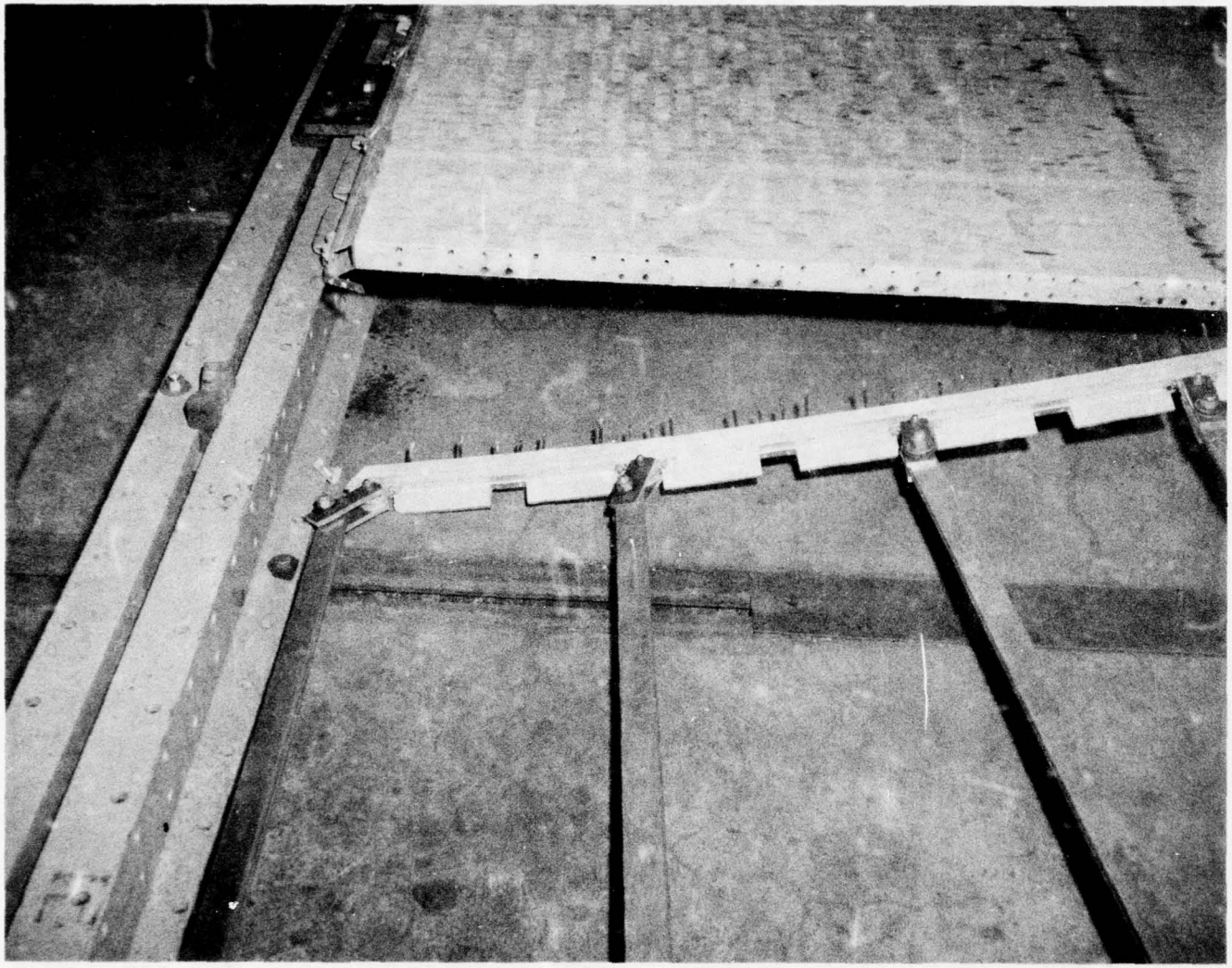


FIGURE 42 - RAIL STRENGTH TEST - BOLT PULLOUT 88 INCH EDGE - OVERALL VIEW

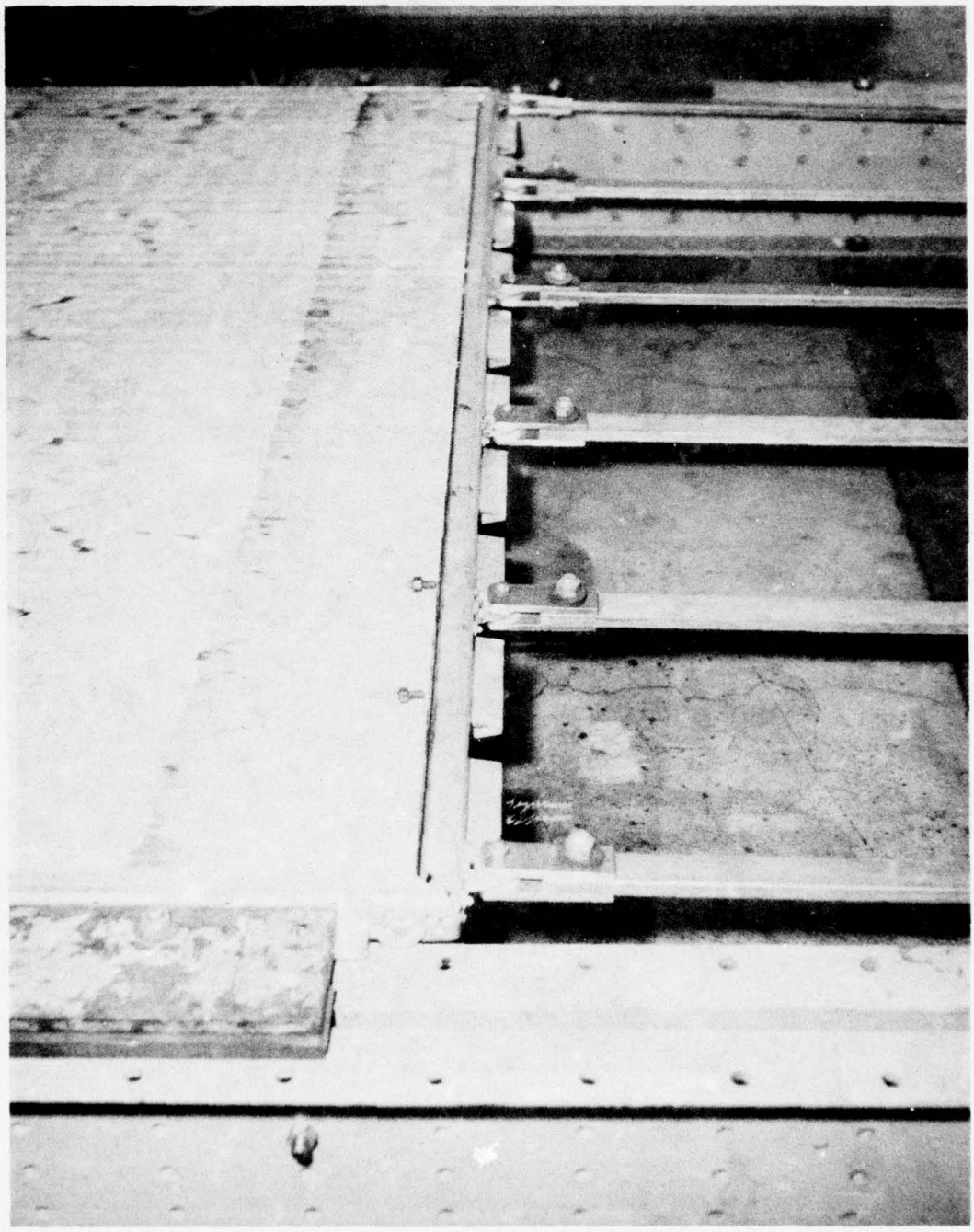


FIGURE 43 - RAIL STRENGTH TEST - ROD FAILURE 108 INCH EDGE OVERALL VIEW

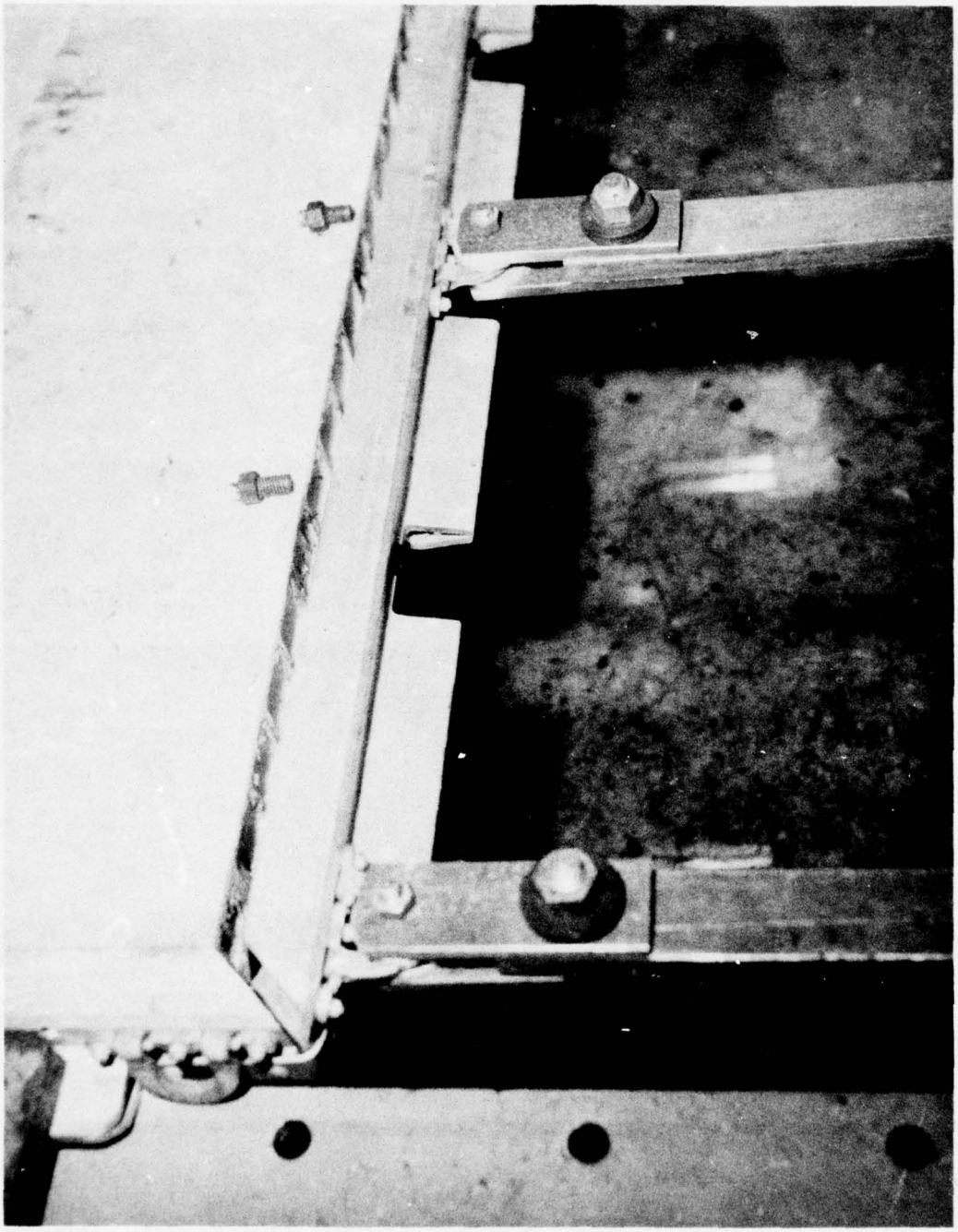


FIGURE 44 - RAIL STRENGTH TEST - ROD FAILURE 108 INCH EDGE OVERALL VIEW

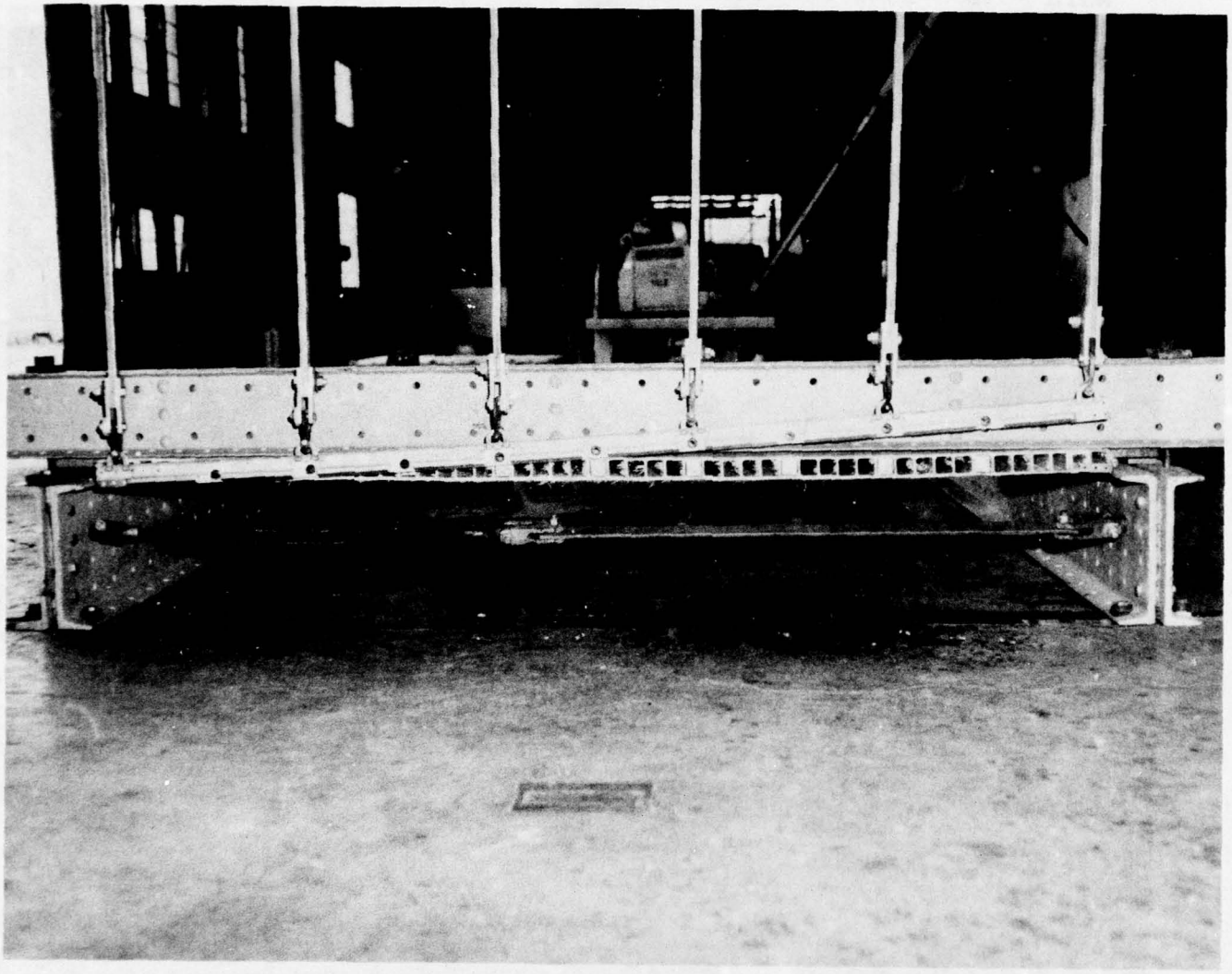


FIGURE 45 - RAIL STRENGTH VERTICAL TEST - ROD FAILURE 108 INCH EDGE - OVERALL VIEW

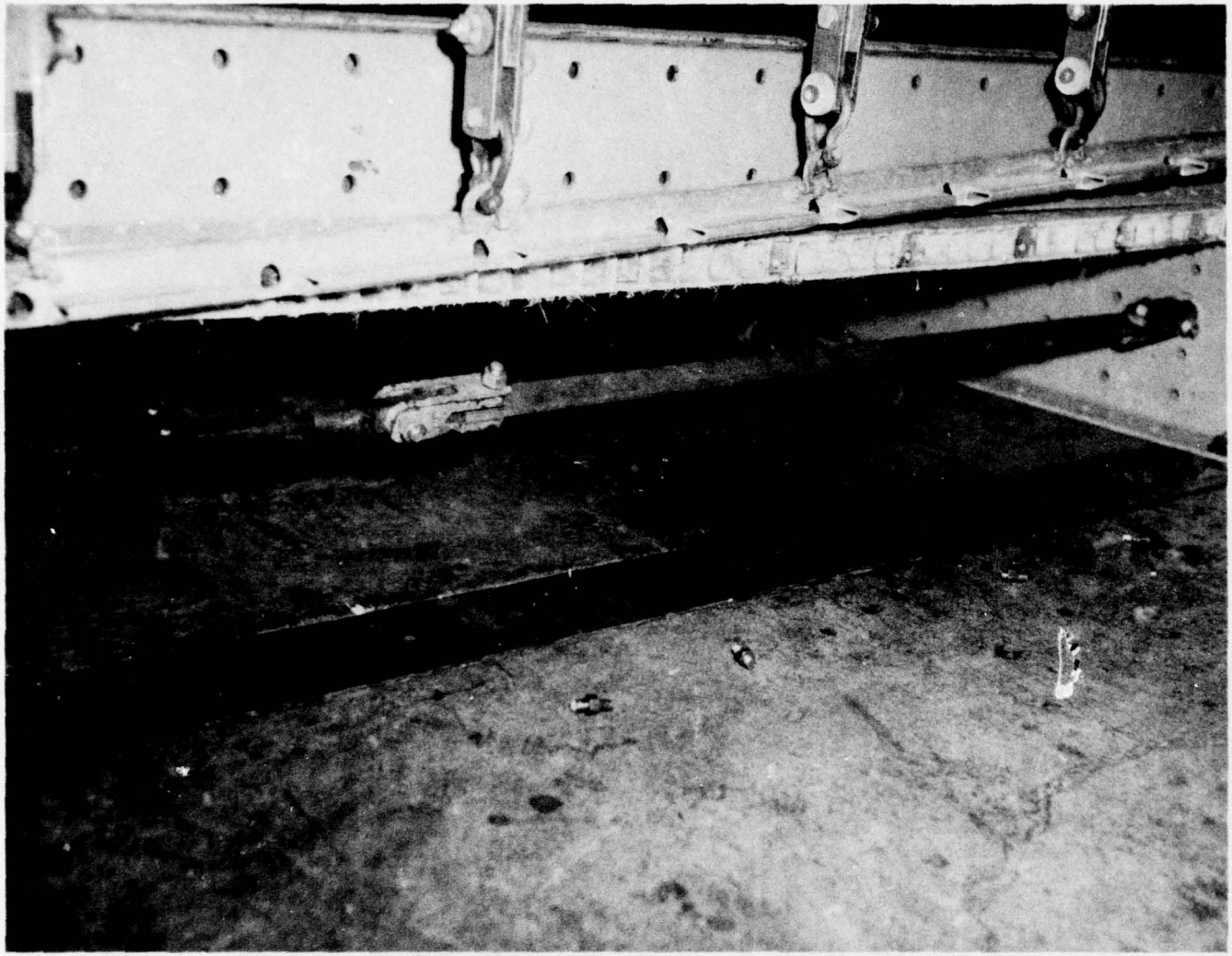


FIGURE 46 - RAIL STRENGTH VERTICAL TEST - ROD FAILURE 108 INCH - SIDE VIEW

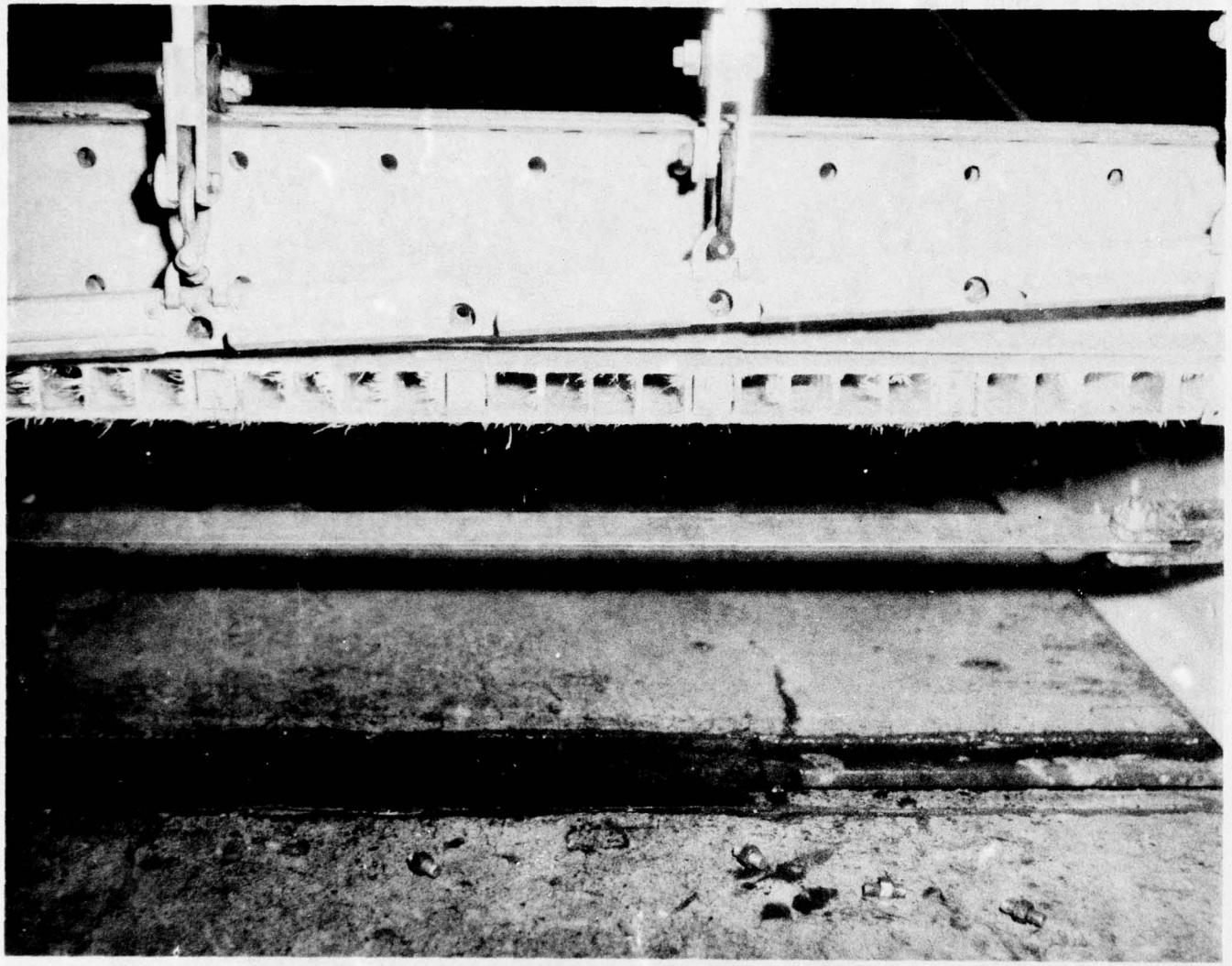


FIGURE 47 - RAIL STRENGTH VERTICAL TEST - ROD FAILURE 108 INCH EDGE - CLOSEUP VIEW

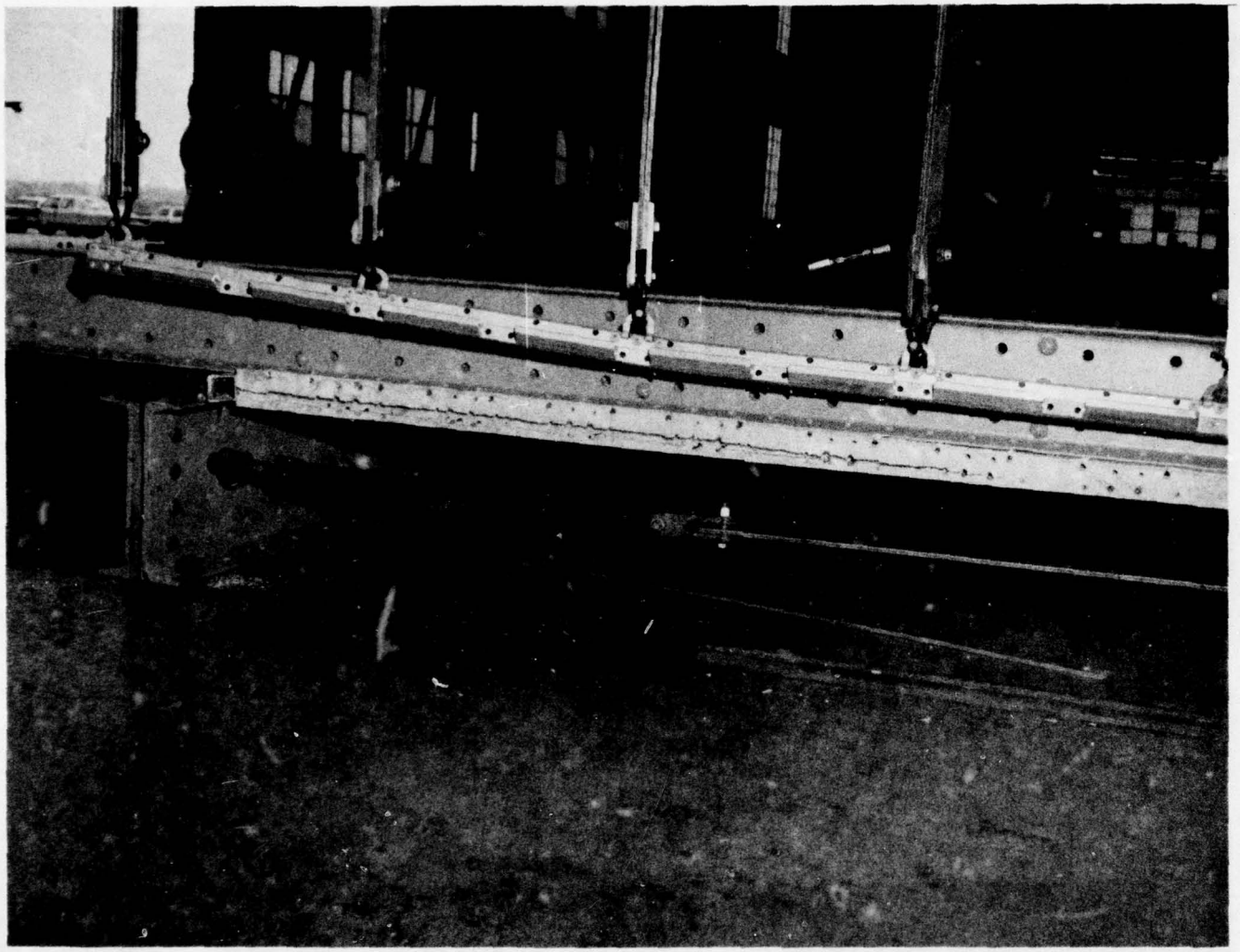


FIGURE 48 - RAIL STRENGTH VERTICAL TEST - BOLT PULLOUT 88 INCH EDGE - OVERALL VIEW

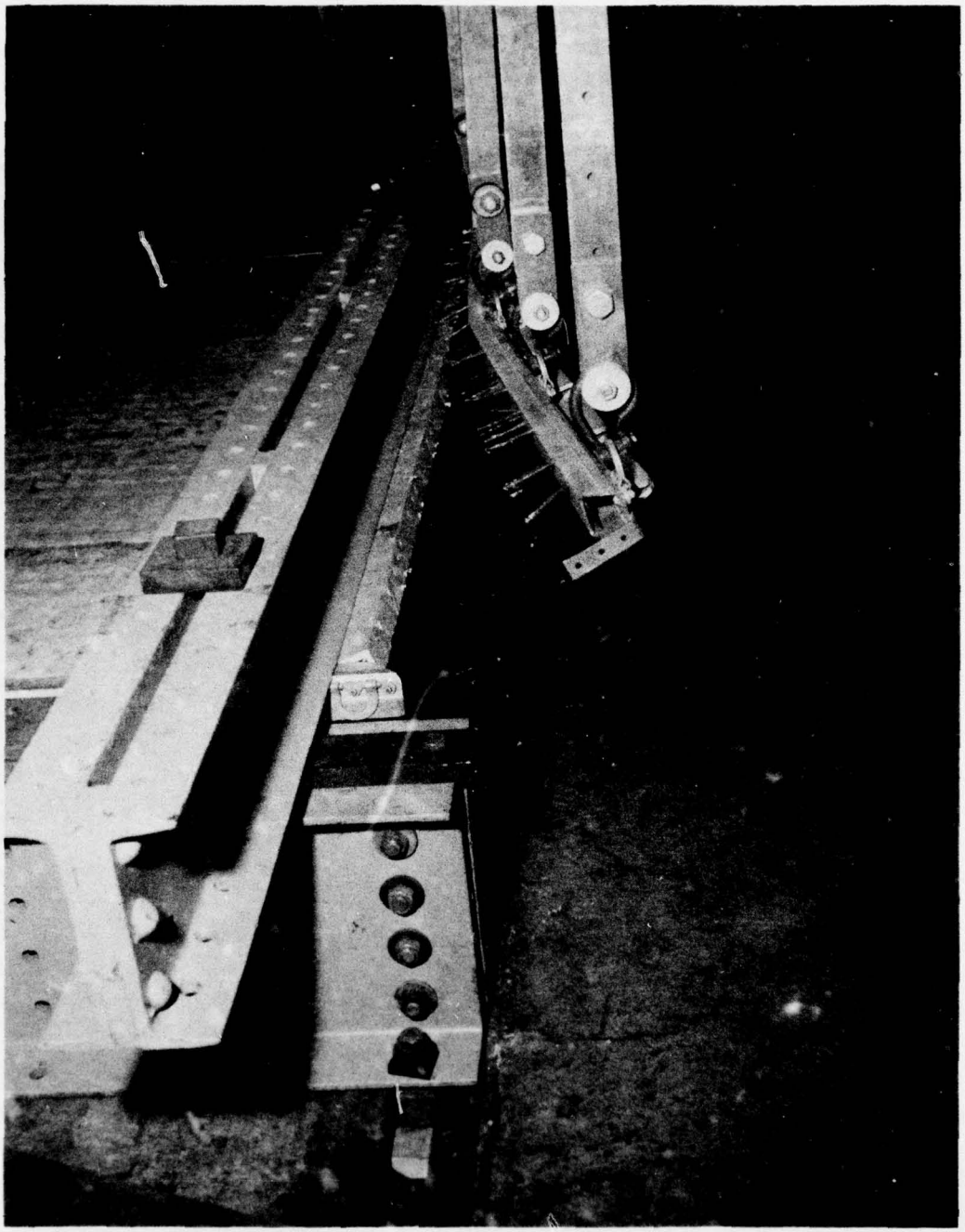


FIGURE 49 - RAIL STRENGTH VERTICAL TEST - BOLT PULLOUT - 88 INCH EDGE - DOWNWARD VIEW

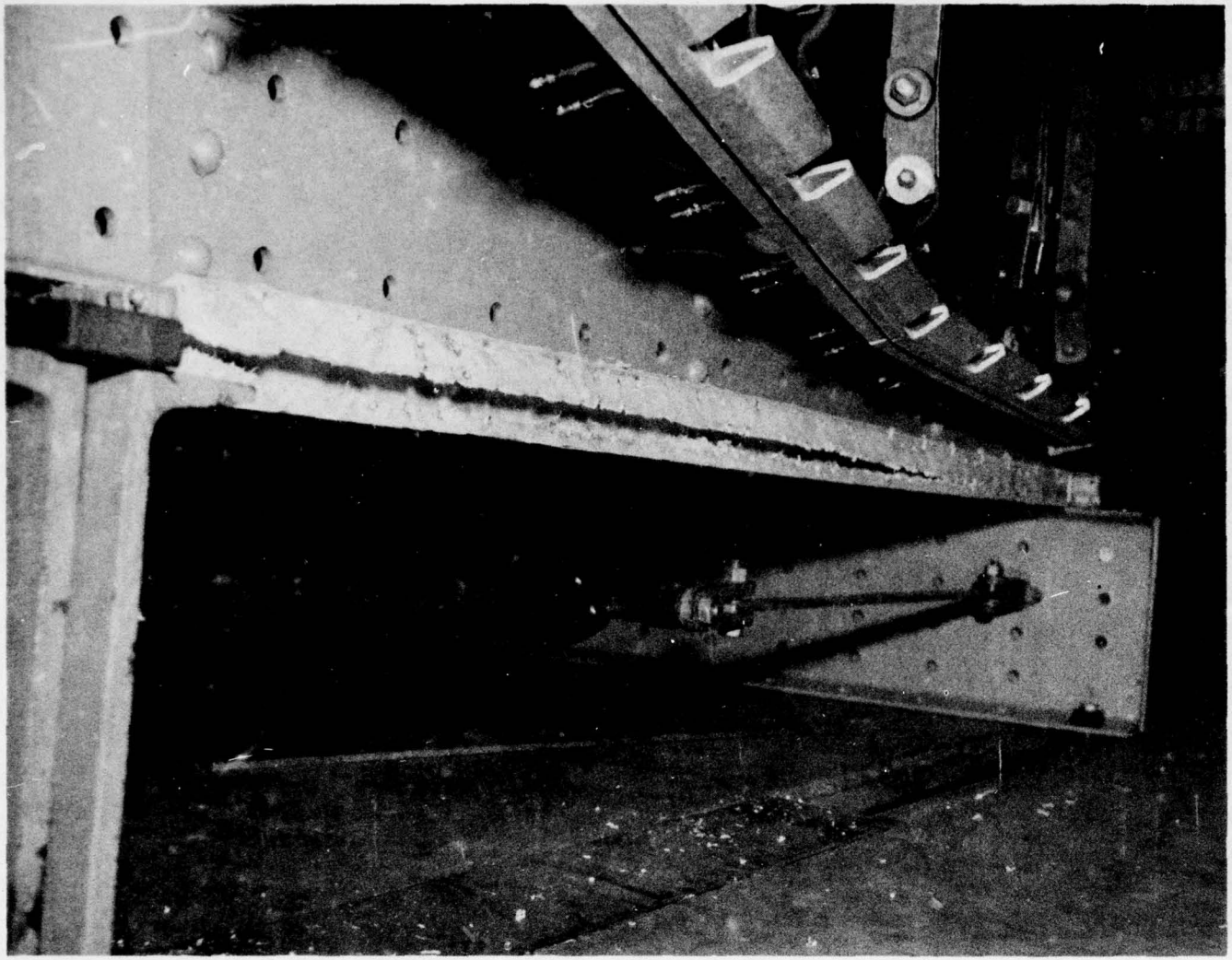


FIGURE 50 - RAIL STRENGTH VERTICAL - BOLT PULLOUT - 88 INCH EDGE- UPWARD VIEW

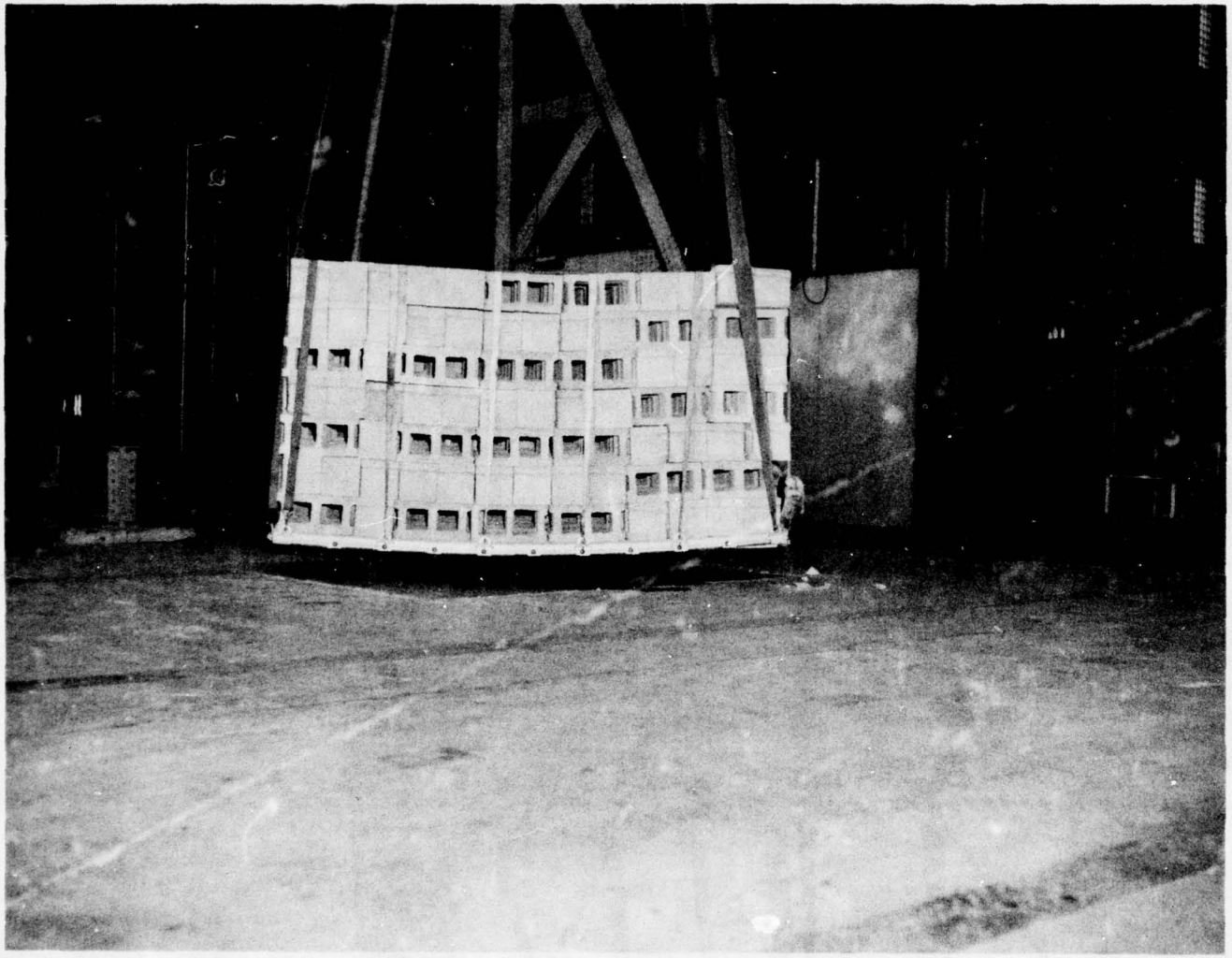


FIGURE 51 - SLING LOAD DEFLECTION - #1

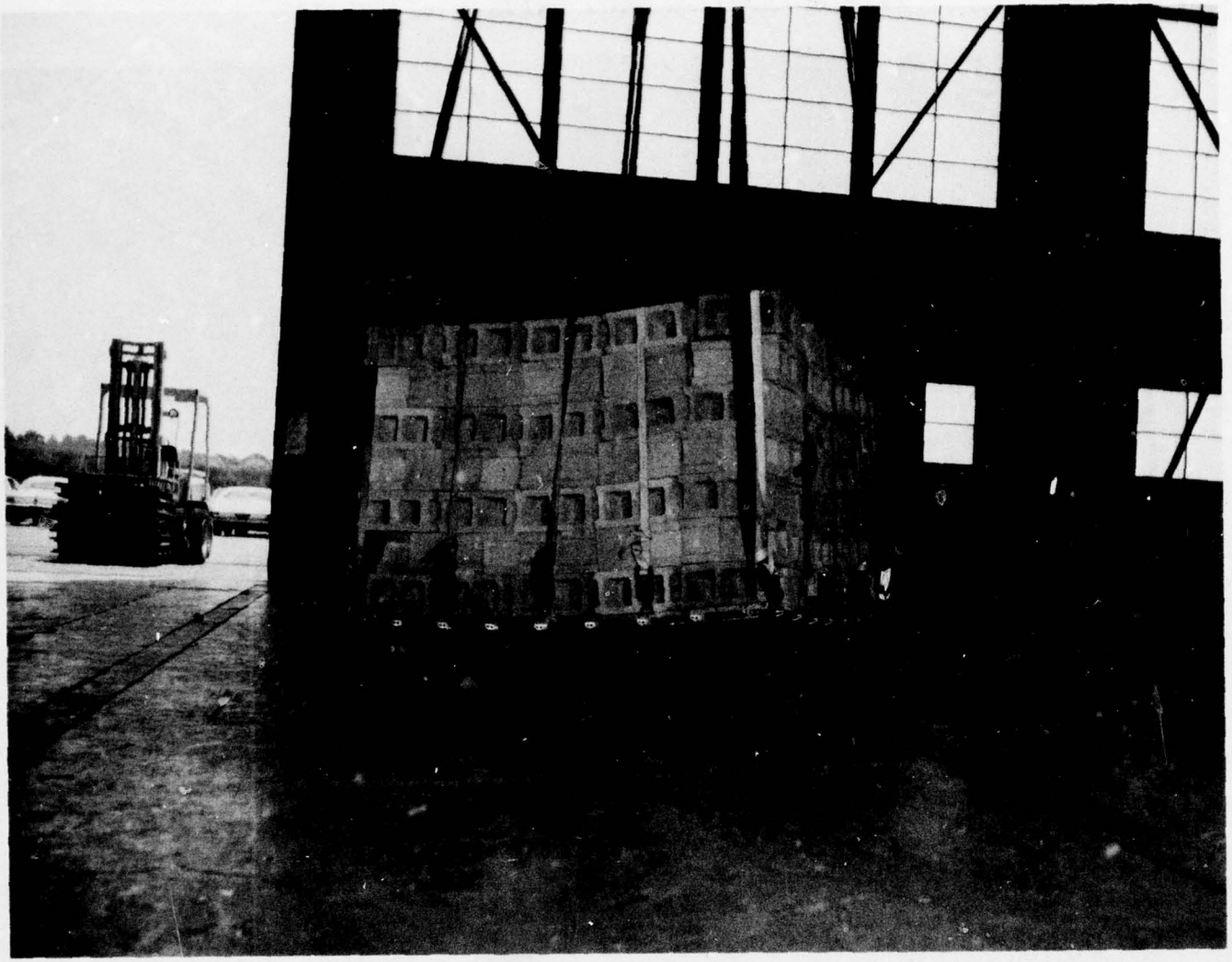


FIGURE 52 - SLING LOAD DEFLECTION - #2

FIGURE 53 - SLING LOAD TEST - RIVET FAILURE

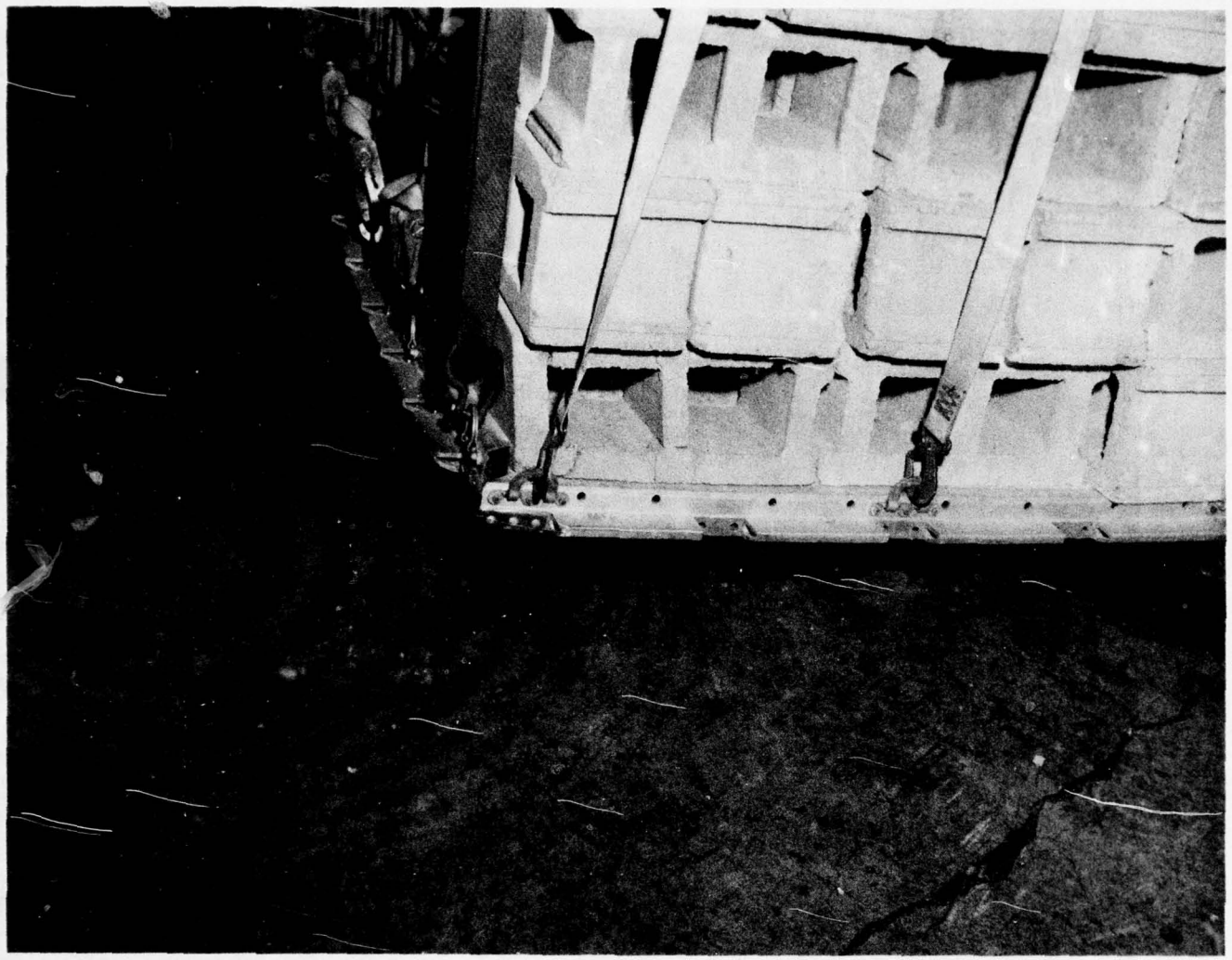


FIGURE 54 - SLING LOAD TEST - RAIL FAILURE

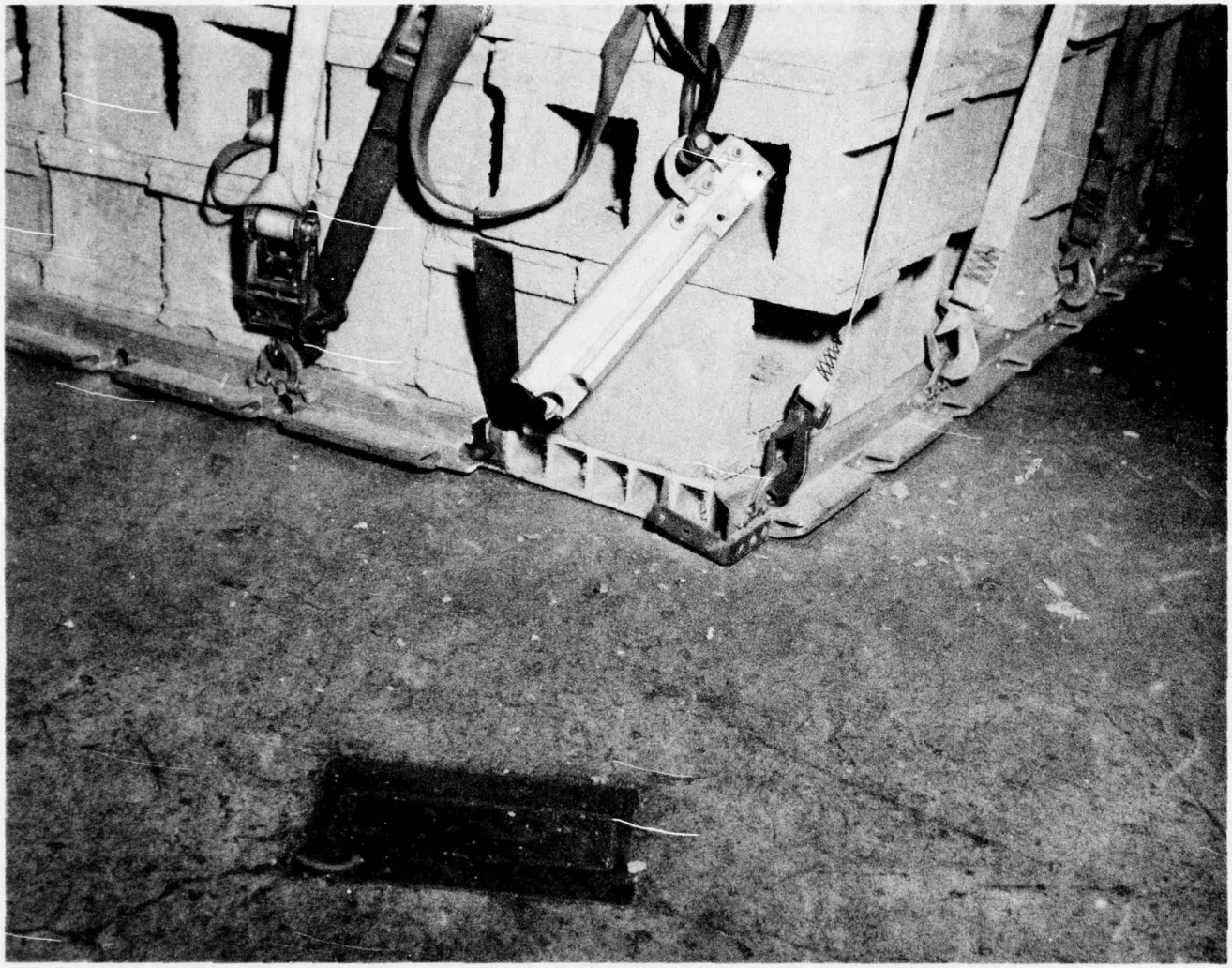


FIGURE 55 - SLING LOAD TEST - RIVET FAILURE AT MITERED CORNER

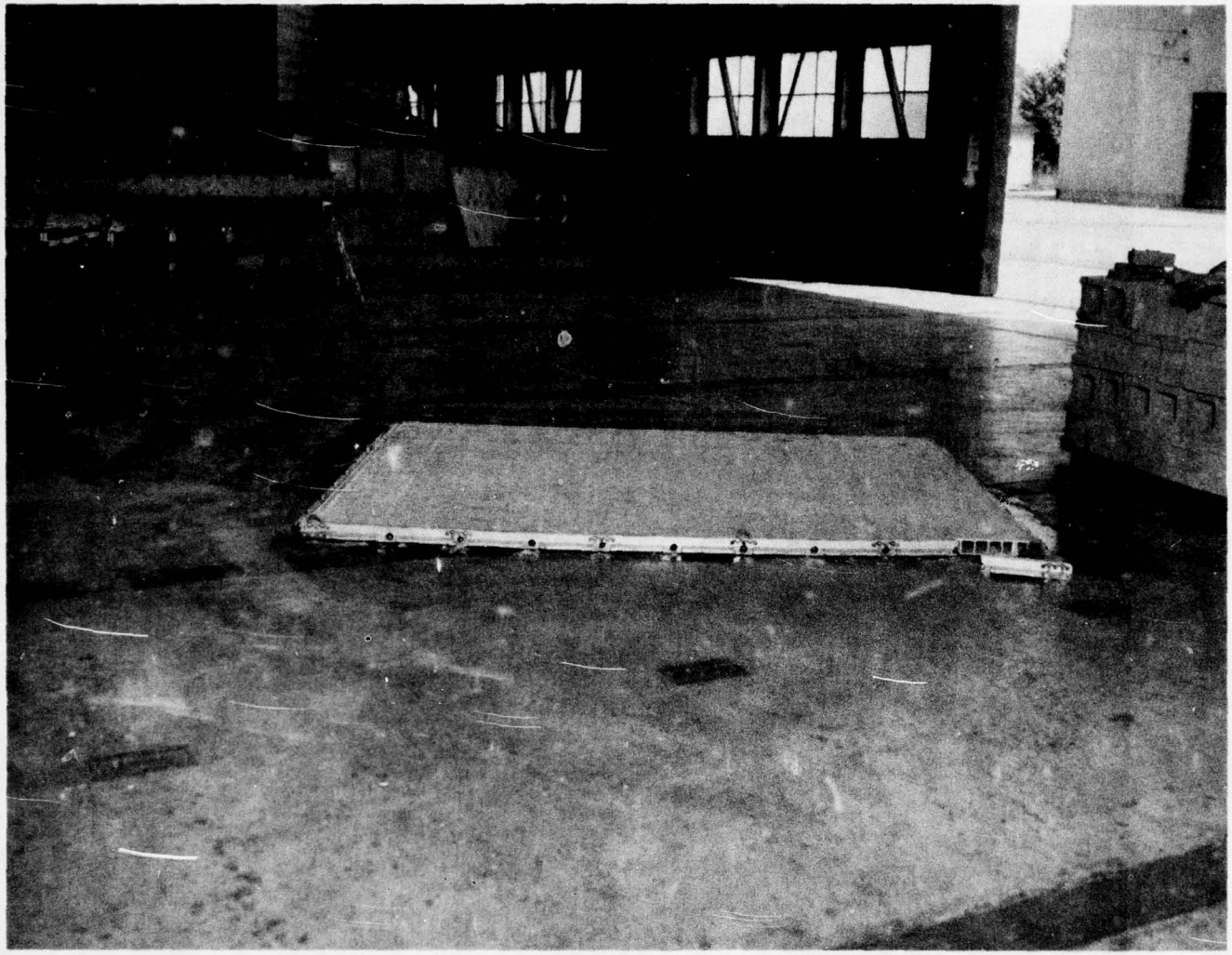
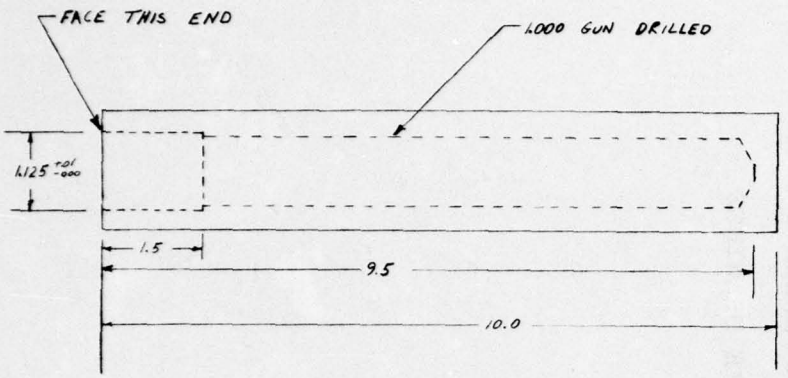
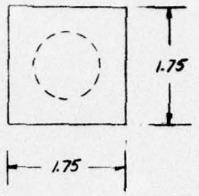


FIGURE 56 - PALLET AFTER SLING LOAD TEST

APPENDIX B

DIE DRAWINGS





MAT'L. - 1 3/4 CRS SQUARE

ITEM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SIZE, DESCRIPTION & SPECIFICATION	QTY REQD
		LIST OF MATERIAL OR PARTS LIST		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS .X ± .XX ± .XXX ±
ANGLES ±
FRACTIONS ±
SURFACE ROUGHNESS PER MIL STD-10
DO NOT SCALE THIS DRAWING
RELEASE
DATE

DRAWN
DESIGNED
CHECKED
APPD

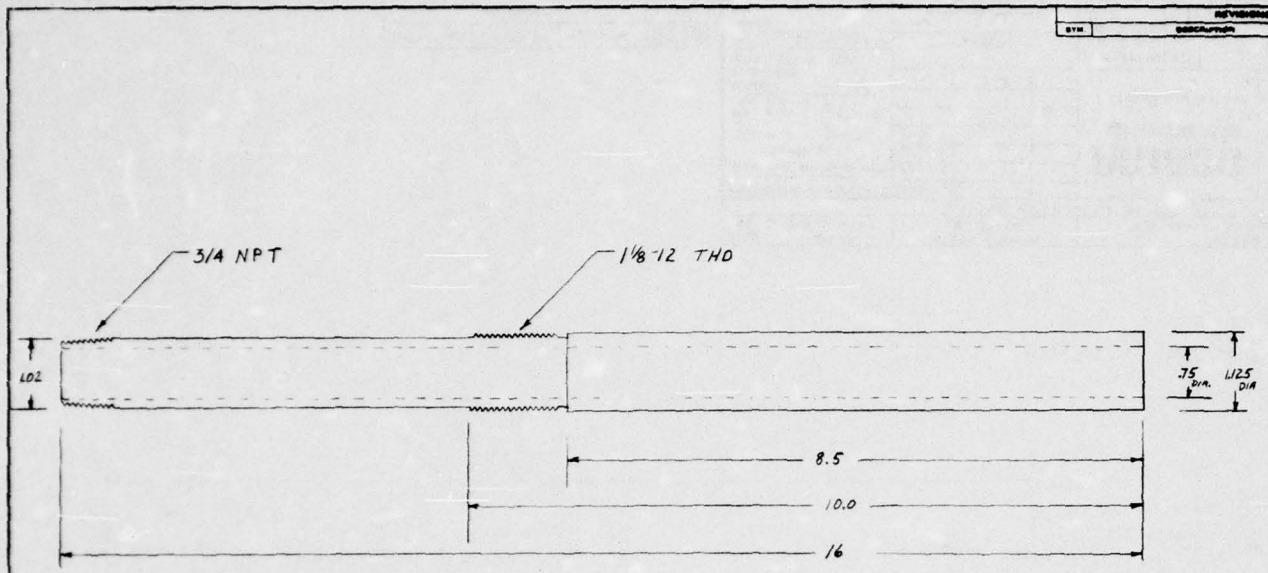
APPROVED
APPROVED

AMOCO chemicals
Propellants Division

SQUARE DIE INSERTS

CODE IDENT NO. 12963 | SIZE C | 21995
SCALE | WEIGHT | SHEET

PART NUMBER	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION			QTY REQD	



MAT'L. 1 1/8 O.D. x 3/4 I.D.
MECH. STEEL TUBING

ITEM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SIZE, DESCRIPTION & SPECIFICATION	QTY REQD

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS: .X ± .05, .XX ± .02, .XXX ± .01
ANGLES ±
FRACTIONS ±
SURFACE ROUGHNESS PER MIL STD-10
DO NOT SCALE THIS DRAWING
RELEASE DATE

DRAWN	J.C.B.	
DESIGNED		
CHECKED		
APPD		

APPROVED
APPROVED

AMOCO chemicals
Propellants Division

TUBULAR DIE INSERTS

PART NUMBER	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION			QTY REQD	

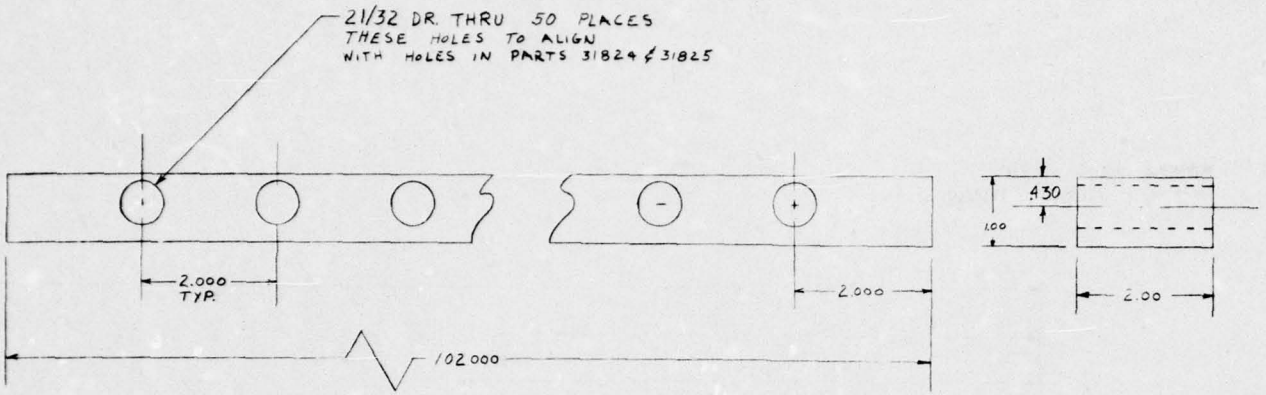
CODE IDENT NO.	SIZE	
12963	C	21996

SCALE	WEIGHT	SHEET

1244-01

79

REVISIONS			
SYM	DESCRIPTION	DATE	APPD



MAT'L. 1X2 .RS BAR

ITEM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SIZE, DESCRIPTION & SPECIFICATION	QTY REQD
		LIST OF MATERIAL OR PARTS LIST		

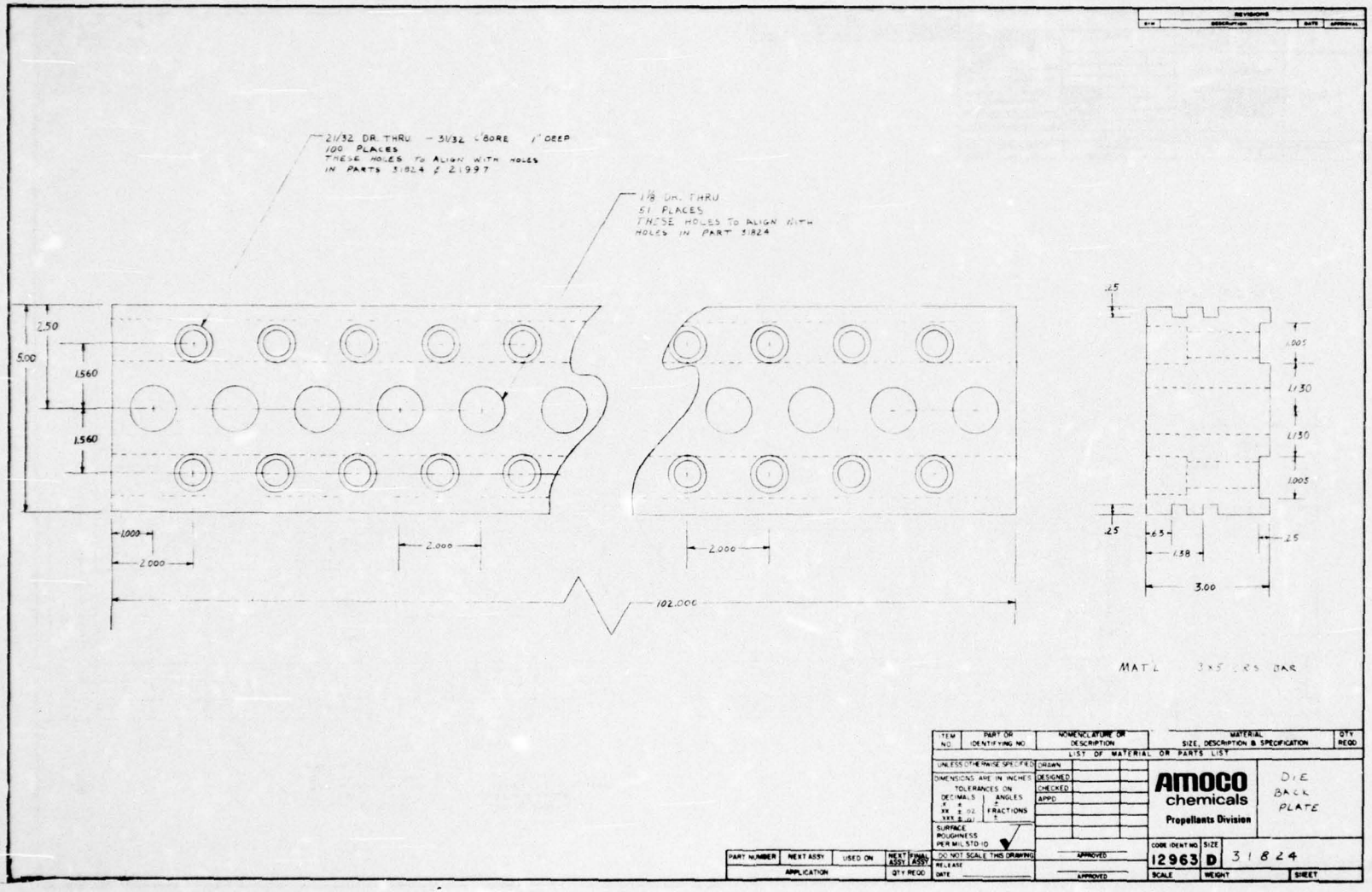
UNLESS OTHERWISE SPECIFIED	DRAWN		
DIMENSIONS ARE IN INCHES	DESIGNED		
TOLERANCES ON DECIMALS .X ± .1, .XX ± .02, .XXX ± .01; ANGLES ± ; FRACTIONS ±	CHECKED		
	APPD		
SURFACE ROUGHNESS PER MIL STD-10 ✓			
DO NOT SCALE THIS DRAWING	APPROVED		
RELEASE DATE	APPROVED		

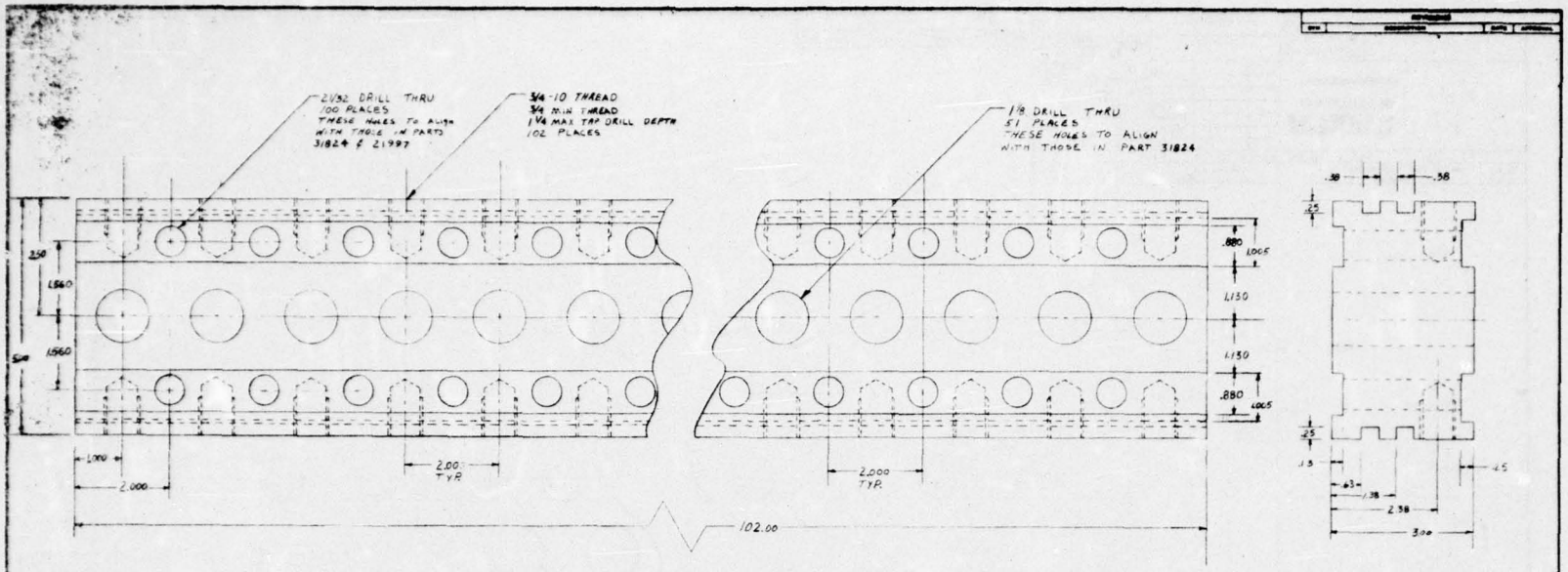
AMOCO chemicals
Propellants Division

DIE SPACER BARS

PART NUMBER	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION			QTY REQD	

CODE IDENT NO.	SIZE	
12963	C	21997
SCALE	WEIGHT	SHEET


21/32 DR. THRU - 31/32 C'BORE 1" DEEP
100 PLACES
THESE HOLES TO ALIGN WITH HOLES
IN PARTS 31824 & 21997
1/8 DR. THRU
51 PLACES
THESE HOLES TO ALIGN WITH
HOLES IN PART 31824
2.50
5.00
1.560
1.560
1.000
2.000
2.000
2.000
102.000
.25
1.005
1.130
1.130
1.005
.25
.63
1.38
.25
3.00
MATL 3 X 5 X 8 5 BAR
ITEM NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
MATERIAL SIZE, DESCRIPTION & SPECIFICATION
QTY REQD
LIST OF MATERIAL OR PARTS LIST
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS ANGLES FRACTIONS
SURFACE ROUGHNESS PER MIL STD 10
DO NOT SCALE THIS DRAWING
RELEASE
DATE
DRAWN
DESIGNED
CHECKED
APPD
APPROVED
APPROVED
AMOCO chemicals
Propellants Division
DIE BACK PLATE
CODE IDENT NO 12963
SIZE D
31824
SCALE
WEIGHT
SHEET
PART NUMBER
NEXT ASSY
USED ON
NEXT ASSY
FINISH ASSY
APPLICATION
QTY REQD



MAT'L - 3X5 CRS BAR

ITEM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SIZE, DESCRIPTION & SPECIFICATION	QTY REQD
		LIST OF MATERIAL ON PARTS LIST		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS: X ± , XX ± .02, XXX ± .01
ANGLES ±
FRACTIONS ±
SURFACE ROUGHNESS PER MIL STD-10
DO NOT SCALE THIS DRAWING

DRAWN
DESIGNED
CHECKED
APPROVED
APPROVED

AMOCO CHEMICALS
Prophylene Division

DIE PLATE

DATE RELEASED: 12963 | SIZE: D | 31825

SCALE | SHEET

PART NUMBER	NEXT ASSY APPLICATION	USED ON	NEXT ASSY QTY REQD	FINAL ASSY QTY REQD

RELEASE DATE

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