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A Study of Rigid Polyurethane Foam. Volume II Final Report

Budd Co, Fort Washington, Pa Technical Center

Prepared for

National Highway Traffic Safety Administration, Washington, D C

Mar 77

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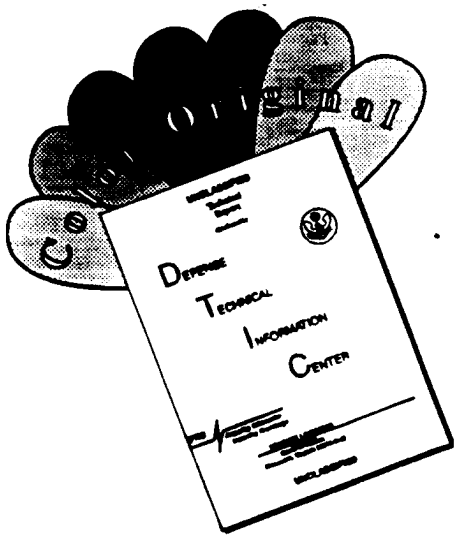

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1 - AD NUMBER: D423278
5 - CORPORATE AUTHOR: BUDD CO FORT WASHINGTON PA TECHNICAL CENTER
6 - UNCLASSIFIED TITLE: A STUDY OF RIGID POLYURETHANE FOAM. VOLUME II-FINAL REPORT.
9 - DESCRIPTIVE NOTE: FINAL REPORT., JUN 75 - SEP 76,
10 - PERSONAL AUTHORS: GRASSO,V. A. ;
11 - REPORT DATE: MAR , 1977
12 - PAGINATION: 270P
14 - REPORT NUMBER: TCR-0334
15 - CONTRACT NUMBER: DOT-HS-5-01261
18 - MONITOR ACRONYM: DOT
19 - MONITOR SERIES: HS-802299
20 - REPORT CLASSIFICATION: UNCLASSIFIED
21 - SUPPLEMENTARY NOTE: (SEE ALSO VOL. I, PL-26796).
22 - LIMITATIONS (ALPHA): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED. AVAILABILITY: NATIONAL TECHNICAL INFORMATION SERVICE. SPRINGFIELD, VA. 22161. PB-266-085.
33 - LIMITATION CODES: 1 24

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PB 266 085
DOT HS-802 299

A STUDY OF RIGID POLYURETHANE FOAM
Volume II-Final Report

Contract No. DOT-HS-5-01261
March 1977
Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS-802 299		

4. Title and Subtitle	5. Report Date
A Study of Rigid Polyurethane Foam Volume II - Final Report	April 1977
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s) V. A. Grasso	TCR - 0334
9. Performing Organization Name and Address The Budd Company Technical Center 300 Commerce Drive Fort Washington, PA 19034	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-HS-5-01261
	13. Type of Report and Period Covered Final Report 6/75 - 9/76
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Admin.	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This study has evaluated the applicability of rigid polyurethane foams to automobile structures for high speed crash energy management through evaluation of energy attenuation characteristics, pertinent material properties, availability, fire hazards, production process, repairability and disposability.

Impact tests were made on elements to assess the effect various environments and conditions have on the energy absorbing characteristics of foam encased in a metallic structure.

While loose shredded foam burns readily, sample tests indicate that foam surfaces exposed by rupturing the metallic shell in which the foam was encapsulated did not indicate any unusual burning hazard when it was soaked with gasoline and ignited. Full scale burning tests should be run to obtain the total effect of flammability and toxicity of decomposition gases of the foam in conjunction with by products of combustion from other materials incorporated in typical automobile structures and trim.

In production, foam filling will require special fixturing to avoid distortion during filling and/or paint oven curing. Costs of representative structural components will increase by 35% to 65% depending on the component. As a general conclusion, the use of rigid urethane foam is feasible and can be used in automotive application when certain guidelines are followed.

17. Key Words	18. Distribution Statement
Polyurethane Foam Crash Energy Management Urethane Foam Degradation Flammability Toxicity	Document is available through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		PC A13 - A01

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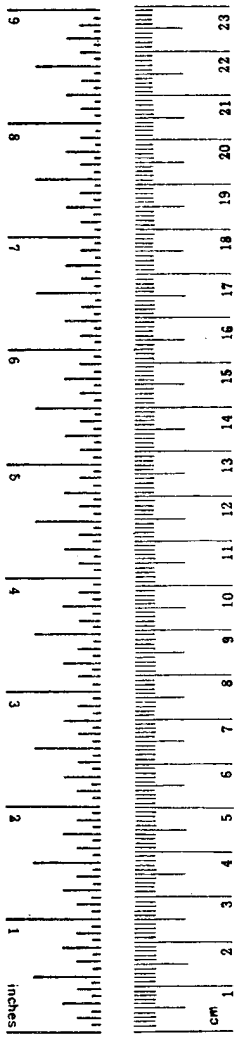
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

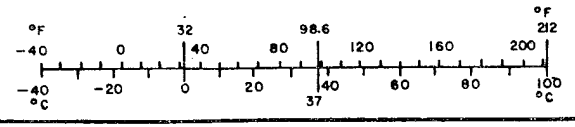
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

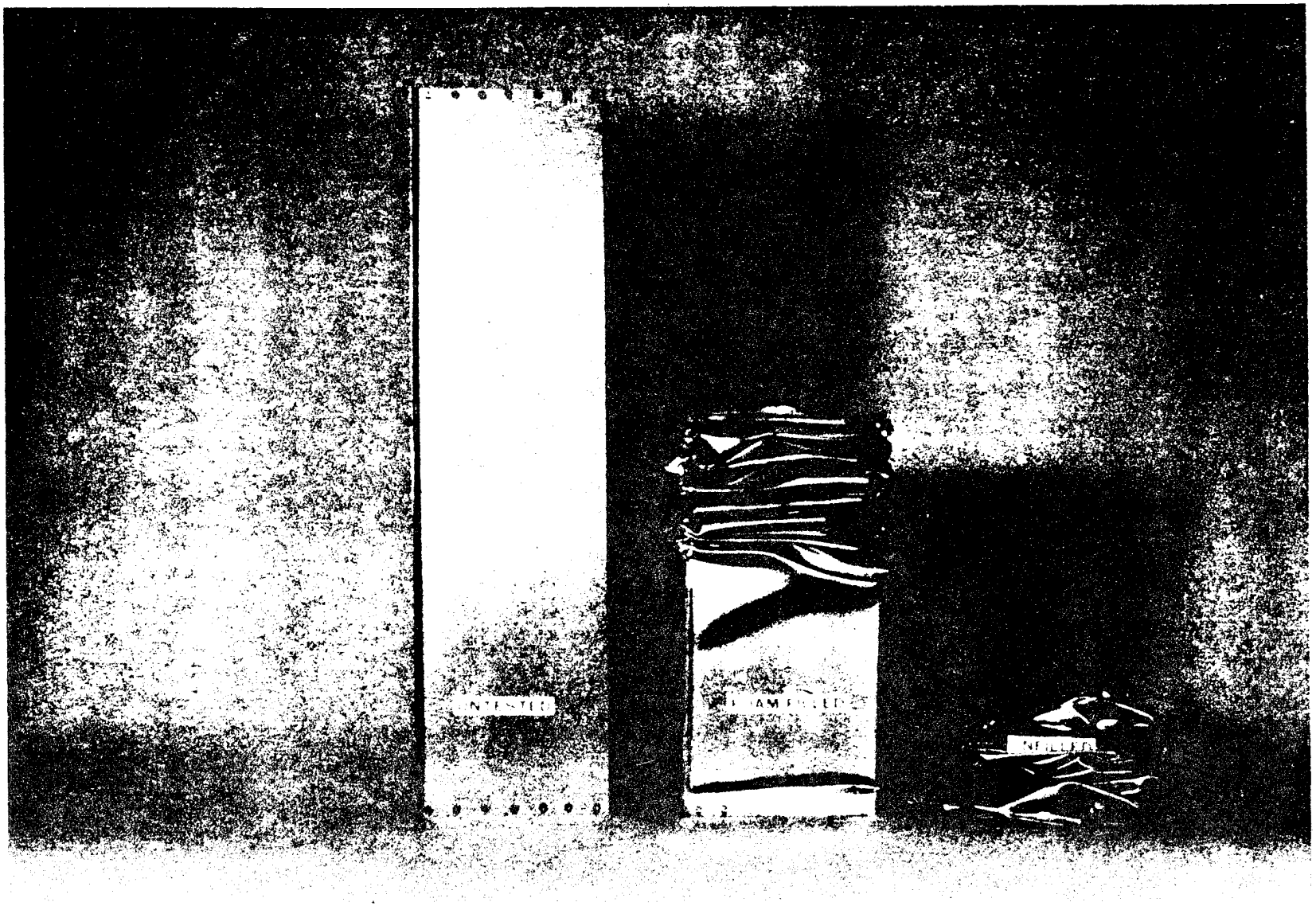
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The engineering assistance and contributions of Budd Company personnel, Mr. H. Jahnle and Mr. M. Pavlick, in this program are gratefully acknowledged.

In addition, the helpful suggestions and comments of NHTSA personnel, Mr. G. Bell and Mr. J. Tomassoni, pertaining to this program are gratefully acknowledged.



Failure Modes of Foam Filled
and Unfilled Specimens

Same Energy Level

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Glossary of Terms

1. Blowing Agent - A substance used as the source of the expanding gas in foam formation. Blowing agents for urethane foams include CO_2 formed by reaction between water and isocyanate, volatile liquid fluorocarbons, and methylene chloride.

2. Catalyst - A chemical (tertiary amine or metal salt, especially tin) used in very small quantities to regulate the rate of urethane polymer growth and gas evolution (in the case of CO_2-blown foams) in such a manner that the gas is sufficiently entrapped.

3. Closed Cell Foam - A cellular plastic in which there is a predominance of non-interconnecting cells.

4. Compressive Strength - The maximum compressive stress which a material is capable of sustaining, based on original cross-section area. This maximum stress may or may not be the compressive stress carried by the specimen at the time of rupture. Compressive strength is expressed in lb/in^2 usually at 10% deflection or at the yield point (ASTM D 1621-64).

5. Cream Time (Maximum Handling Time) - The limiting time between the initiation of mixing prior to pouring into the cavity and the initiation of foaming indicated by a milky appearance of the foaming mass.

6. Dimensional Stability - Change in dimensions of a specimen on exposure to various environments. It can be expressed as a percent volume change, or a linear change in dimensions. The later is preferable, since most rigid foams are not isotropic and exhibit different amounts of change in each axis.

7. Dry Heat Aging - Measures the effect on tensile and compression load properties of aging at specified elevated temperatures at ambient relative humidity. Current tests are run at 104°C (284°F) for 16 hours (ASTM D 1564-64T).

8. Flammability - Has different meanings depending on the test method used. In general, it is a measure of the fire hazard of the material.

9. Free Blow (Free rise, Open blow) - A foam which is allowed to rise without any constraint or restriction.

10. Friability - Surface crumbling characteristics. A friable material crumbles easily.

11. Frothing - A modification of the foam-in-place method of installing rigid urethane foam, in which the mixture is dispensed partially pre-expanded, like aerosol cream. Frothing requires special equipment and an extra blowing agent for immediate pre-expansion; final expansion then occurs as the chemical reaction goes to completion. The main advantage over conventional foaming-in-place is that less pressure is exerted on the forms.

12. Humid Aging - The effect elevated humid heat has on the compression load and other foam properties. Current practice is to subject polyester polyurethane foams to 104°C (220°F) for 3 hours and polyether urethane foams to 121°C (250°F) for 5 hours, each at 100% relative humidity (ASTM D 1564-64T).

13. LD_{50} - Lethal concentration of gases killing 50% of animals.

14. MDI - Diphenyl methane diisocyanate

15. Open Cell Foam - A cellular plastic in which there is a predominance of interconnected cells.

16. Packing (Overpack, Overfill) - The addition of more material to a mold or cavity than is theoretically necessary. Overpacking is used to ensure complete filling of the mold, to create uniform foam properties and to control density. Depending on the application molds may be overpacked from 5% to 10% or more.

17. Peak Dynamic Crush - Maximum crush distance taken from computer analysis when final velocity equals zero, (V_F=0).

18. Polyesters - Polyols made by direct esterification of polybasic acids with polyhydric alcohols, and used in making one basic type of polyurethane foam.

19. Polyethers - Polyols, usually propylene oxide adducts of polyhydric alcohols, used in making the other basic type of polyurethane foam.

20. Polyols - Organic compounds containing two or more hydroxyl (-OH) groups which are not part of an organic acid group (-COOH), used in making urethane foams.

21. Polyurethane - The product of the chemical reaction between a polyol and isocyanate.

22. Pyrolysis - Burning of substance in the absence of air.

23. Thermal Expansion - The rate of linear change with changing temperature. Varies considerably between different materials giving rise to stresses in sandwich constructions subject to temperature fluctuations.

24. TDI - Tolulene diisocyanate

25. Threshold Limit Value - refers to airborne concentrations of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect; expressed as time-weighed concentrations for a 7 or 8-hour week day and 40 hour work week.

1.0 INTRODUCTION

The "Crashworthiness of Subcompact Car Program" sponsored by Department of Transportation developed structural design modifications for frontal and side impacts. Foam enclosed in sheet metal for improved crash energy management was a unique approach and was incorporated in the baseline configuration of the 1974 Pinto. Excellent crashworthiness results achieved using this unique approach deemed it necessary to conduct a detailed evaluation of rigid polyurethane foam as applied to automobile structures.

Presented in this report is information developed in the rigid polyurethane study sponsored by the National Highway Traffic and Safety Administration. The aim of this study was to obtain the detailed information necessary to evaluate the short and long term applicability of lightweight rigid polyurethane foam as applied to automobile structures for high speed crash energy management. A definite conclusion was then to be made as to whether or not rigid polyurethane foam is feasible for use in automobile structures and then present a preliminary set of performance specifications which could be used in future rule making action. To determine this feasibility the program was conducted in the following phases:

1. Literature Survey

The main focus was on, but not limited to, the flammability, energy absorption, ease of usage and the effect of degradation on foam properties.

2. Suitability

Emphasis was on, but not limited to, the following:

a. Material Availability
b. Effect of degradation on physical properties important to crash energy management.
c. Flammability and Toxicity
d. Automobile Assembly Process
e. Storage and Transportation
f. Repairability
g. Disposability

3. Test Program

A program was designed to obtain any data which was missing, incomplete or needed to be validated. See Table 1 on page 3 for Test Program Outline.

4. Feasibility Study

Manufacturing processes necessary to mass produce a sub-compact car with the required modifications using "The Crash-worthiness of Sub-Compact Car Program" as a basis is discussed.

5. Specifications

Preliminary specifications concerning the use of rigid polyurethane foam for use in automobile structures was made for use in future rule making actions.

TABLE 1

TEST PROGRAM OUTLINE

A. Specimen Fabrication and Foaming Procedure

1. Low Carbon Steel and Aluminum Alloy Shells

a. Resistance Spot Welded
b. Pop Riveted
c. Static Test
d. Material Properties (tensile specimens)

2. Foaming Procedure

a. Foaming Pressure, Fixture Requirements

1. Venting
2. Oozing
3. Skin temperature
4. Distortion
5. Packing
6. Density Variations
7. Static Test

b. Anistropy, Rise Direction
c. Foam to Metal Adhesion
d. Foam Properties

3. Repeatability

B. Mechanical Defects

1. Voids

C. Damage and Repair

D. Vibration Damage

E. Low and Elevated Temperature Effects

1. Metal Shells Without Foam Filling
2. Foam Filled Shells at -20° F, and 300° F
3. Thermal Cycling, 300° F
4. Directional Heating, 300° F

F. Effect of Solvent - 28 days @72°F

1. Motor Oil
2. Gasoline
3. Glycol/Water 50/50
4. Car Wash Detergent
5. Water/Salt
6. Water

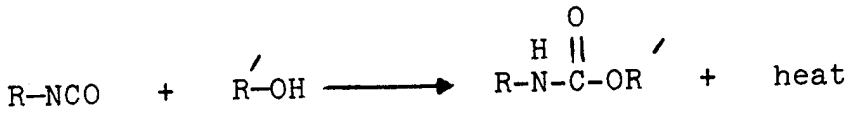
G. Flammability and Explosive Characteristics

1. One Hour at 1500-1700°F
2. Flammability on Damaged Structures
3. Sustained fire

2.0 LITERATURE SURVEY

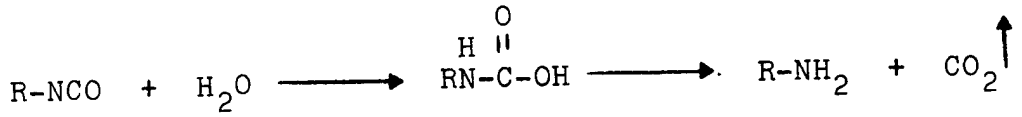
2.1 Chemistry of Urethane Foam Process

The reactive ingredients of a polyurethane foam usually include an isocyanate and a hydroxyl-terminated resin. In addition, flexible foam systems and a few rigid foam systems include water as a source of gas for blowing. The reaction with a hydroxyl compound produces a urethane:

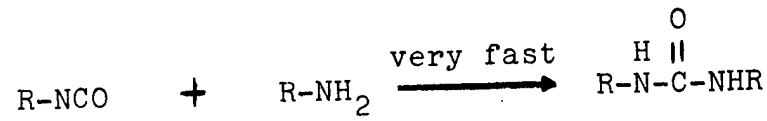


R–NCO	+	R′–OH	⟶	R–N(H)–C(=O)–OR′	+	heat
polyisocyanate		polyhydroxyl compound		a urethane		

The reaction with water produces a urea, by way of an amine intermediate, and carbon dioxide (CO_2):

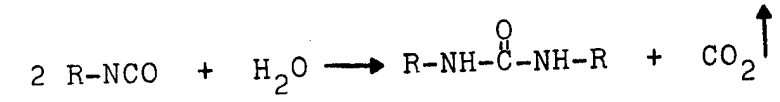


R–NCO	+	H_2O	⟶	RN(H)–C(=O)–OH	⟶	$R–NH_2$	+	CO_2 ↑
isocyanate				carbamic acid		amine		



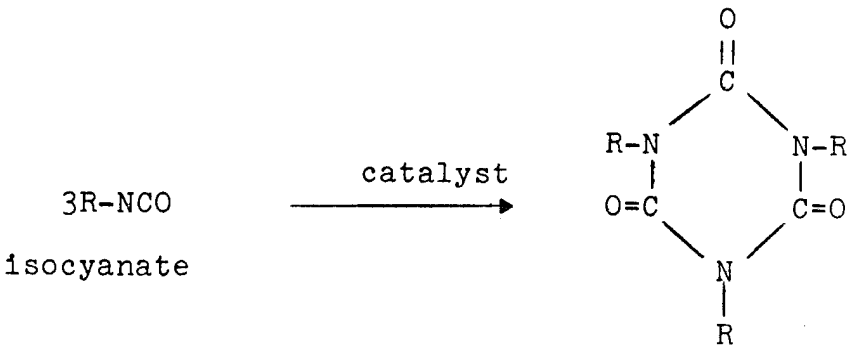
R–NCO	+	$R–NH_2$	very fast ⟶	R–N(H)–C(=O)–NHR
isocyanate		amine		disubstituted urea

The overall reaction can be represented as follows:



2 R–NCO	+	H_2O	⟶	R–NH–C(=O)–NH–R	+	CO_2 ↑
isocyanate				disubstituted urea		

The isocyanate may also react with the urea and with the urethane to give a biuret and an allophanate respectively. These compounds are relatively unstable. Another crosslinking reaction involves the formation of trimers, which may be considered trisubstituted isocyanurates. This reaction takes place in the presence of various catalysts at elevated temperatures:



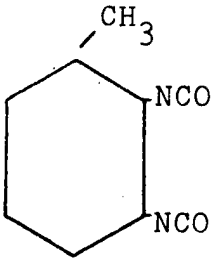
isocyanurate (trimer)

Trimers are very resistant to both heat and hydrolysis. Heat resistant, rigid isocyanurate foams have been prepared by trimerization of isocyanate-terminated prepolymers.

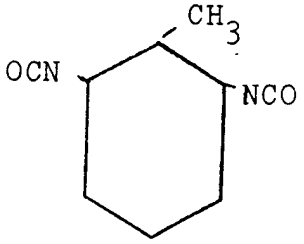
2.1.1 Chemicals Used in Foam Manufacture

2.1.1.1 Isocyanates (Ref. 1)

(a) TDI - tolylene diisocyanate 80/20 mixture 2,4 and 2,6 isomers



2,4 TDI



2,6 TDI

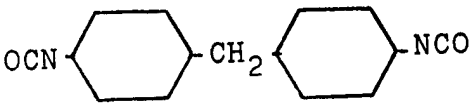
(b) Crude TDI - undistilled product

70% TDI and 30% polymeric Isocyanate

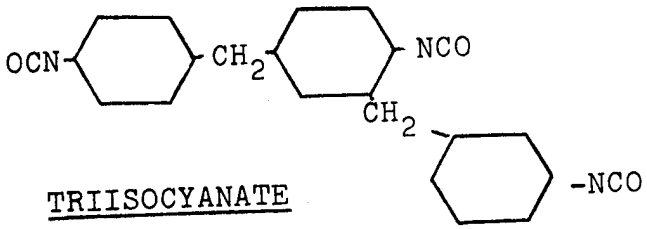
(c) Crude MDI

55% diisocyanate 25% triisocyanate and

20% polymeric isocyanates



MDI



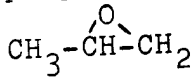
TRIISOCYANATE

(d) MDI (Polymeric Isocyanates)

MDI offers more improved thermal and dimensional stability and flame resistance than TDI. They are excellent char formers and are the most heat stable of all chemicals used in rigid foam formation.

2.1.1.2 Polyols (Ref. 2)

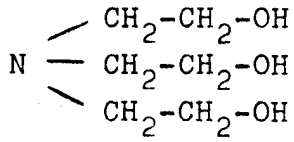
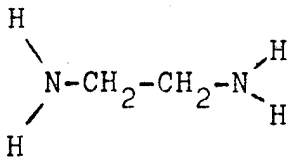
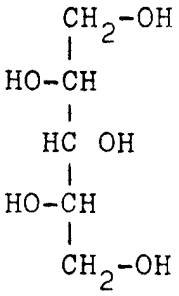
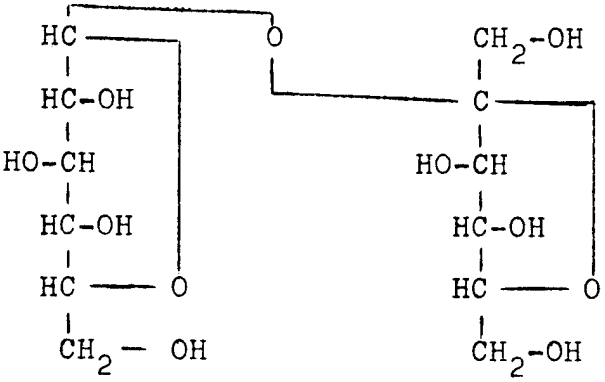
The polyols have the greatest effect on the foam properties. Polyethers have higher serviceable temperature properties. Rigid polyols are produced from propylene oxide



and initiators such as the following:

TABLE 2

INITIATORS—RIGID POLYOLS

Initiator	Functionality
 Triethanolamine	3
 Ethylenediamine	4
 Sorbitol	6
 Sucrose	8

Polyols made with halogenated aromatic initiators are being evaluated for increased flame retardance.

2.1.1.3 Catalyst - Tertiary Amines in conjunction with Organotin (Ref. 3)

(a) Affect the compressive strength and modulus of low density foams.

(b) Higher concentration causes greater activity thus increasing cell length in direction of foam rise, with accompanying decrease in strength perpendicular to foam rise.

2.1.1.4 Silicone Surfactant

Controls foaming to produce open-celled or closed-celled foam.

2.1.1.5 Fluorocarbon - (Freon)

Blowing agent, determines density of foam.

2.1.1.6 Water

Adds stiffness (urea linkage) to foam. Addition of Freon and decrease in water results in soft foam formation.

2.2 Isocyanurate

Isocyanurate foams are characterized by their dimensional stability, even at elevated temperatures, and their inherent high-temperature resistance, with service temperatures 50 to 75°F higher than those of ordinary rigid foams, up to a maximum of 300°F. The thermal properties result from the trimer ring formed during the trimerization of the isocyanurate, which also gives the polymer its inherent flame resistance properties. In conventional urethane foams it is necessary to add flame retardants (based on phosphorus or chlorine compounds) which can have other, undesirable effects on the foam properties.

The dimensional stability of an isocyanurate foam is shown in Table 3 on page 10.

TABLE 3 (Ref. 9)

PHYSICAL PROPERTIES OF A TYPICAL RIGID ISOCYANURATE FOAM

Density, lbs./ft.^{3}	4.5
Thermal Conductivity "K" Factor BTU/hr./sq.ft./in./F.	0.14
Compression Strength, psi	
(a) At temperature prior to heat aging	
75°F.	81
300°F.	84
350°F.	68
400°F.	56
450°F.	48
(b) After heat aging 24 hours and tested at the following temperatures	
300°F.	88
400°F.	82
450°F.	54
(c) After humid aging 7 days at 150°F. (95-100% R.H.)	81
Dimensional Stability, % Volume Change	
(a) After heat aging 24 hours at	
300°F.	0
350°F.	0
400°F.	-2
450°F.	-5
(b) After humid aging 7 days at 158°F.	0

The major problem presently with an isocyanurate foam is its friability. Friability is the condition of foam being easily crumbled, pulverized or reduced to powder. If modified with a polyol the friability will be reduced, but dimensional stability or serviceable temperature may not be as good. Work is being done in this area to correct the friability condition.

Einhorn et.al. at the Flammability Center, University of Utah, conducted an experimental program on the flammability and toxicological effects of isocyanurate foam. The results are as follows:

The isocyanurate foam, fluorinated-copolymer-coated foam, and the intumescent-coated foam were found to have excellent flammability and insulation characteristics, although smoke development was substantial. The LD-50 values for Sprague-Dawley rats, based on a two-week survival, were approximately 2.0 gm/ft^3 for all three materials. Examination indicated an absence of any significant cause of death except carbon monoxide poisoning.

The gases given off by an isocyanurate foam are given in Table 4.

TABLE 4 (Ref. 18)

TENTATIVE IDENTIFICATION OF PYROLYSIS PRODUCTS OF ISOCYANURATE FOAM

Compound	Pyrolysis temp, °C
C Cl_3F (blowing agent)	>100
2,4,6-Trimethyl (diethylaminomethyl) phenol (Catalyst)	>100
Water	>250
Acetonitrile	>250
Acrylonitrile	500 <trace, >500 Detection
Benzene	500 <trace, >500 Detection
Pyrolidone	500 <trace, >500 Detection
Pyridine	500 <trace, >500 Detection
Phenylisocyanurate	>500
Toluene	>500
Styrene	>500
Cumene	>500
Aniline	>500
Tolunitrile	>500
p-toluidine	

2.3 Information Lacking from Literature Survey

Review of data indicated information is lacking or inadequate in the following areas.

1. Properties of foam after cycling -20°F to ambient and ambient to 300°F.

2. Fatigue properties of foam.

3. Effect long term exposure at operating temperature (250 - 300°F) has on foam properties.

4. Effect vibration has on foam properties.

5. Foam systems (other than isocyanurate) with serviceable temperatures greater than 225°F.

6. Energy absorption of foam filled structures under different environmental conditions.

2.4 General Statements and Graphs Concerning Foam Properties

1. Compression strength, tensile strength, flexural strength, shear strength, impact strength, thermal conductivity, water absorpiton and modulus of elasticity are dependent to a greater degree on foam density.

2. Foams with a density lower than 1.5 lb./ft.^{3} are not particularly dimensionally stable.

3. The compressive strength perpendicular to rise is approximately half of that parallel to rise in the low density foams.

4. Polyether rigid foams have higher strengths than polyesters.

5. In low density foams (less than 4 lb./ft^3), the stress required to crush the foam is about the same as yield point stress. In the plateau, strain increased with little or no stress.

6. Use of frothing processes will produce a more isotropic foam and exert less mold pressure.

7. The blowing agent has a pronounced effect on foam densities and is probably the most important single factor affecting the physical and mechanical properties.

8. Isocyanurate foams have higher serviceable temperatures and better flame spread and smoke obscuration properties than do urethanes.

9. The comparession strength of low density foam drops off drastically after 200°F. (Ref. 4)

10. Humid heat aging tends to decrease compressive strength subsequently measured at room temperature. (Ref. 4)

11. Dry heat aging (polymeric isocyanate cure systems) usually increases compressive strength. (Ref. 4)

12. Heat improves the cure and stress relaxation of foam. (Ref. 4)

13. Lack of dimensional stability at low temperature is shown by shrinkage - pressure gradient between atmosphere and interior of cells (blowing agent) exceeds strength of cell structure. (Ref. 4)

14. Foam density is a critical variable on cold aging. Minimum perpendicular compressive strength should be 11 - 17 psi for low temperature use. (Ref. 4)

15. Prolonged exposure to high temperature constitutes dry heat aging and results in permanent changes. (Ref. 4)

16. At lower densities the coefficients of expansion perpendicular to foam rise may become 2 to 6 times those parallel to foam rise, that is, 1.6×10^{-4} perpendicular to 0.2×10^{-4} for parallel. The trend is to expand in direction perpendicular to which foam cells were elongated during foaming. (Ref. 4)

17. Compressive test results are the most reliable and easiest to obtain of all mechanical properties. (Ref. 5)

18. Shear strengths (2 - 3 lb/ft^3) of rigid foams are usually 40 - 60% of compressive strength. (Ref. 5)

19. Modulus and strengths of rigid foams are only slightly rate sensitive in compressive loading (up to 177 in./in./min.). Sensitivity increases as test temperature is raised to glass transition temperature. (Ref. 7)

20. Heat Distortion temperature is usually ball park figure for maximum temperature for foam use. (Ref. 6)

21. Dimensional Stability (Ref. 9)

    Instability results from

    (a) Normal expansion of polymer due to temperature change by coefficient of thermal expansion.

    (b) Dimensional changes due to differences in gas pressure between cells and atmosphere.

(1) At low densities, difference in gas pressures can be of the order of magnitude of compressive strength of foam.

(2) At sub-zero temperature, F-11 (blowing agent) partly condenses making its partial pressure about 2 lbs./in.^{2} in comparison to 14.7 lbs./in.^{2} atmosphere pressure. Pressure difference would tend to collapse the foam.

(3) At higher temperatures the internal pressure in excess of atmospheric tends to make foam expand. Even though the pressure difference isn't as great as sub-zero — the softening effect of temperature can result in expansion.

22. High humidity tends to plasticize the foam causing decrease in strength. Foam retains original strength after moisture is removed. Some results of polymeric isocyanate cured foam (2 lb./ft.^{3}) to Humidity and Thermal Aging are shown below. (Ref. 9)

(a) Aging one week @ 160°F/100% RH dried one week over desiccant — no significant change in compression strength.

(b) Another source using 2 lb./ft.^{3} foam aged at the same condition gave these results: (Ref. 5)

(1) Lost 6% strength after one week.
(2) Lost 12% strength after two weeks.
(3) Lost 25% strength after three weeks.

(c) Thermal aging two weeks @ 275°F. properties increased after 9 months as follows: R.T. Strength - 10 to 15%, 275°F. Properties - 5 to 10% overall.

23. Mold Pressure (2 lb./ft.^{3} foam density) (Ref. 12)

(a) Pour systems can obtain mold pressures to 5 psi. This depends also on mold configuration, the narrower the void the greater the mold pressure. Polymeric isocyanates contribute to higher mold pressure.

(b) Froth System (Ref. 12)

Pressure exerted in an exact fill is <1 psi.
5% overfill increases pressure 20%.
12% overfill - double free rise pressure.
15% overfill - triple free rise pressure.

(c) Typical Urethane Foaming Pressures (Ref. 13)

Packing Factor	Pressure (psi)
1.2	0.5 to 1.5
1.5	4. to 6
2.1	10 to 13
2.5	19 to 23
3.0	36 to 41

$$\text{Packing factor} = \frac{\text{part density}}{1.1 \times (\text{free rise density})}$$

24. Effect of Foam Adhesion to Substrate (Ref. 15)

(a) Aluminum

(1) Mechanical preparation - initial bond good, strengths deteriorate after period of months or years.

(2) Zinc vinyl chromate (wash primer) should be used on aluminum for best initial bond strength and resistance to environment.

(3) Freon blown foams in combination with polyurethane attack most grades of aluminum.

(b) Steels

(1) Solvent wash and rust removal give fair strengths.

(2) Phosphate coatings give good strength.

(3) Sand blasting gives good strength.

(4) Ultimate preparation is phosphate coating primed with red lead or resinous coating.

(c) Thin skinned metal panels have tendency to buckle when entire area of facings are not bonded to urethane foam core. (Ref. 16)

(d) As long as adhesion is maintained between foam and substrate, dimensional changes due to aging and differences in expansion coefficients are almost nonexistant under such conditions. (Ref. 16)

25. Effect of Vibration and Fatigue on Foam Sandwich Construction. Dynamic test made by Bayer and MBB on their plastic

sports car with fiberglass sandwich chassis showed the following without failure:(Ref. 17)

(a) Six million load cycles (high amplitude tension cycle tests)

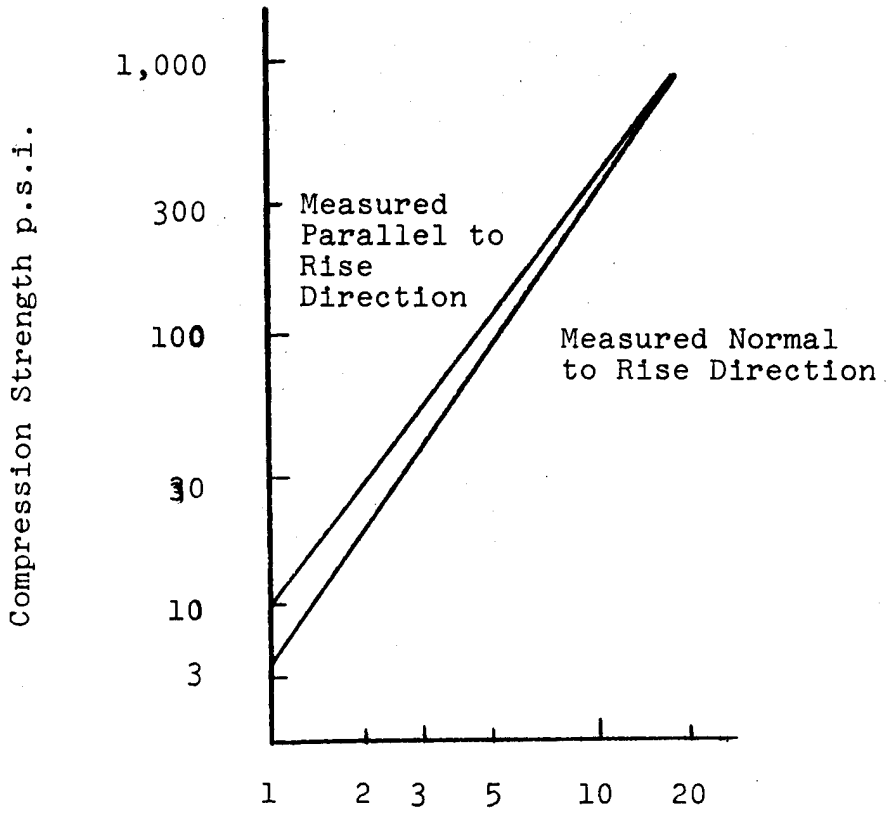
(b) Vibration on VW "washboard" test track.

(c) Seven years continuous driving.

26. In practice it is the visco-elastic nature of the foam which is important. When a sandwich panel is heated, the foam is restrained from expanding more than the facings: the internal stresses in the foam due to the restraining action of the faces diminish with time and eventually disappear. The net effect of these various factors in the foam tends to accomodate itself to the new environment and follows the behavior of the facings. (Ref. 10)

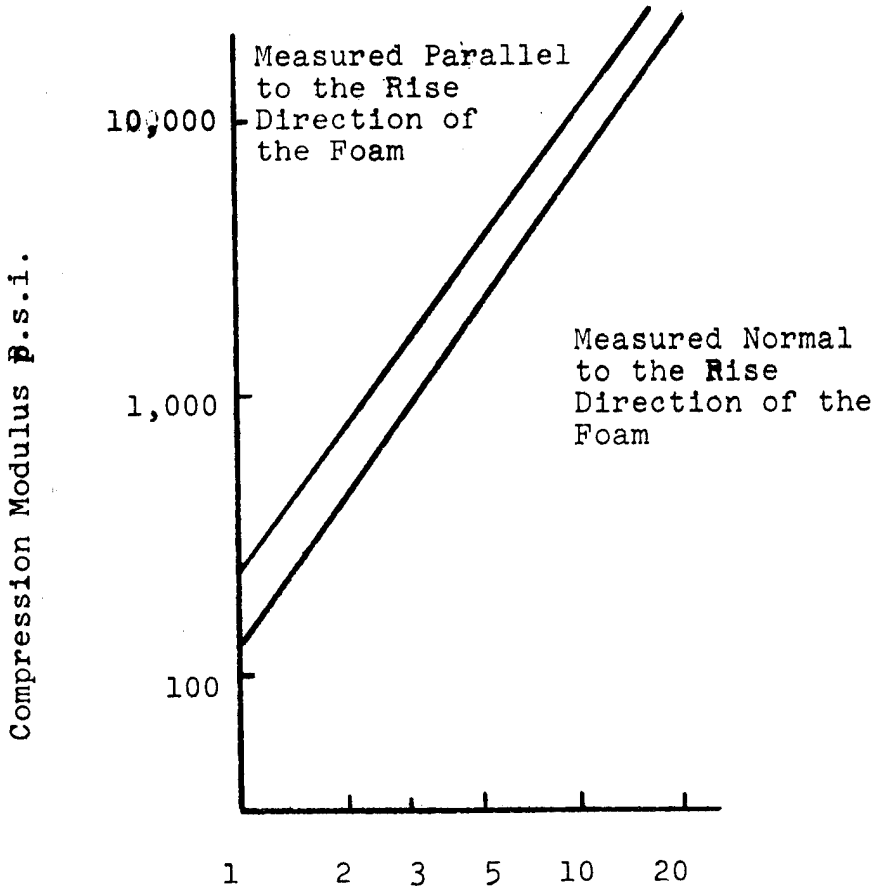
Materials normally expand and contract reversibly as they are heated and cooled. Each material attempts to do so at its own characteristic rate, and thus cause stresses within the composite structure. Assemblies must therefore be designed to keep such stresses low enough that excessive distortion and/or mechanical failure will not occur in service. (Ref. 11)

The graphs and tables on pages 17 thru 28 depict general properties of rigid urethane foams taken from the literature search.



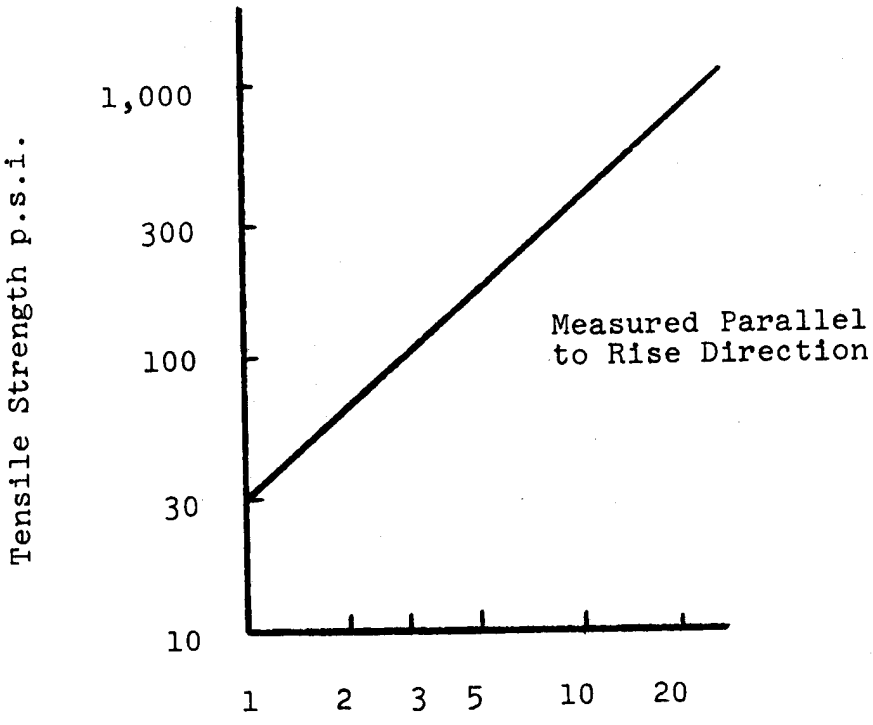
Compression strength v. density

Figure 1 (Ref. 10)



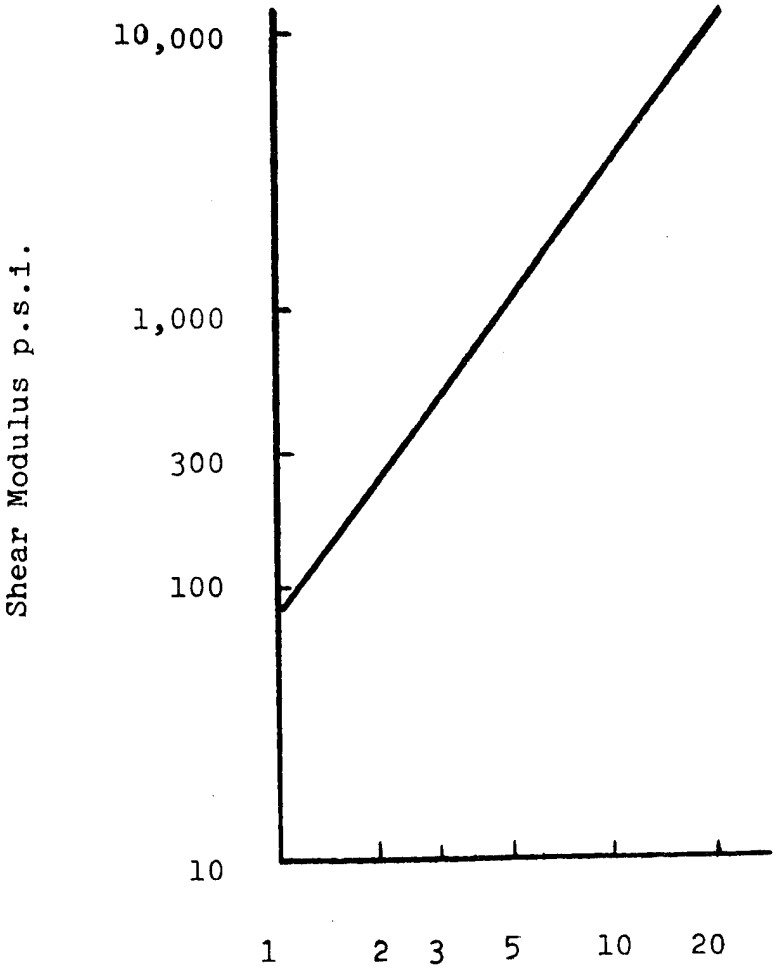
Compression modulus v. density

Figure 2 (Ref. 10)



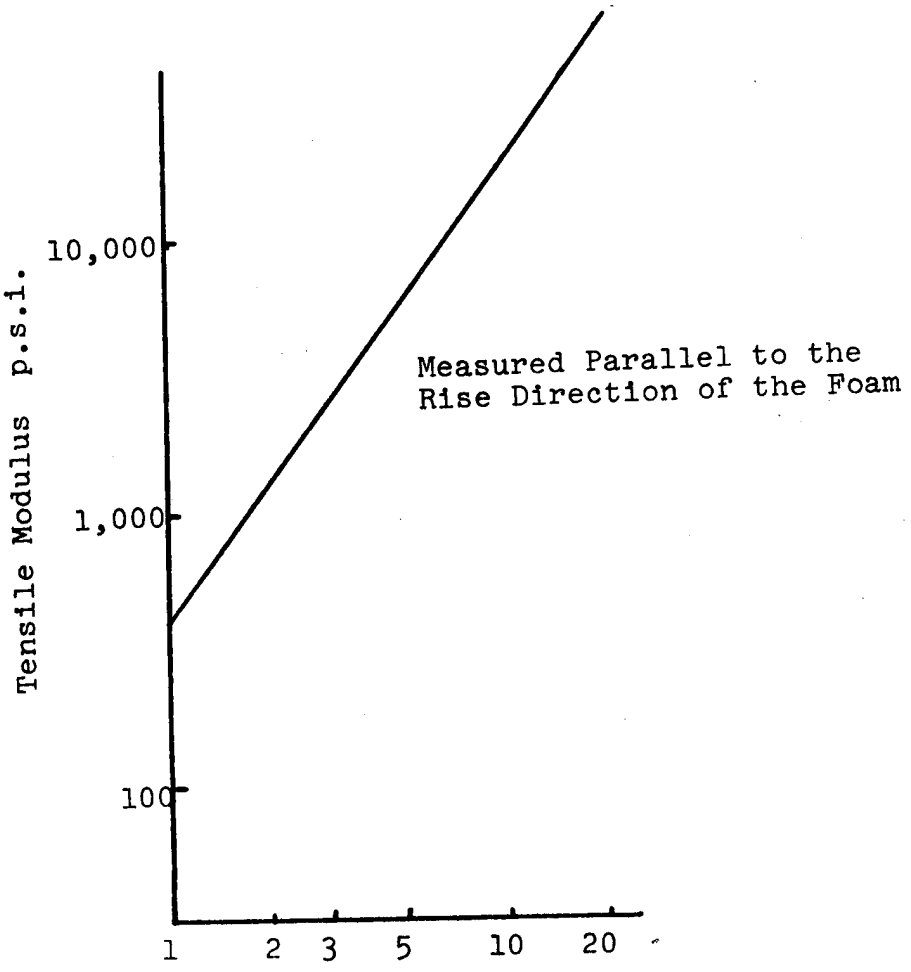
Tensile strength v. density

Figure 3 (Ref. 10)



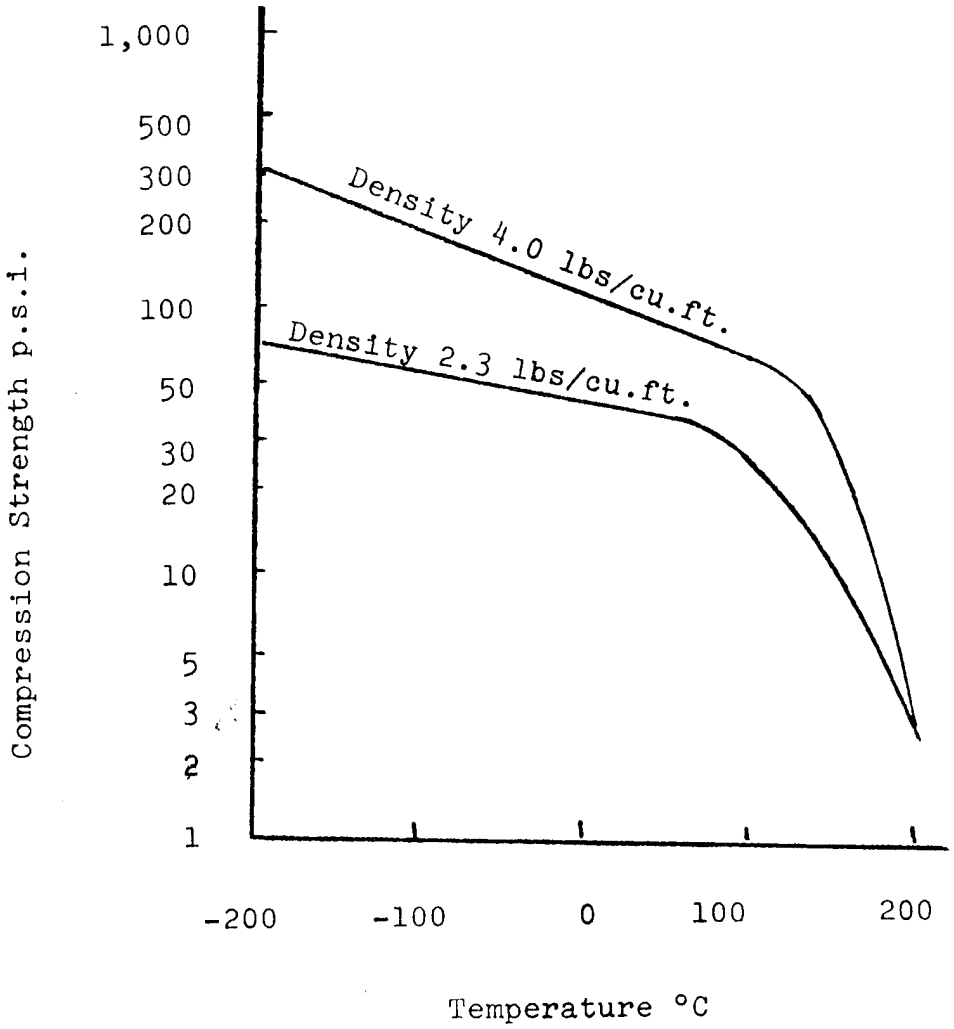
Shear Modulus v. density

Figure 4 (Ref. 10)



Tensile Modulus vs. Density

Figure 5 (Ref. 10)



Change of compression strength with temperature

Figure 6 (Ref. 10)

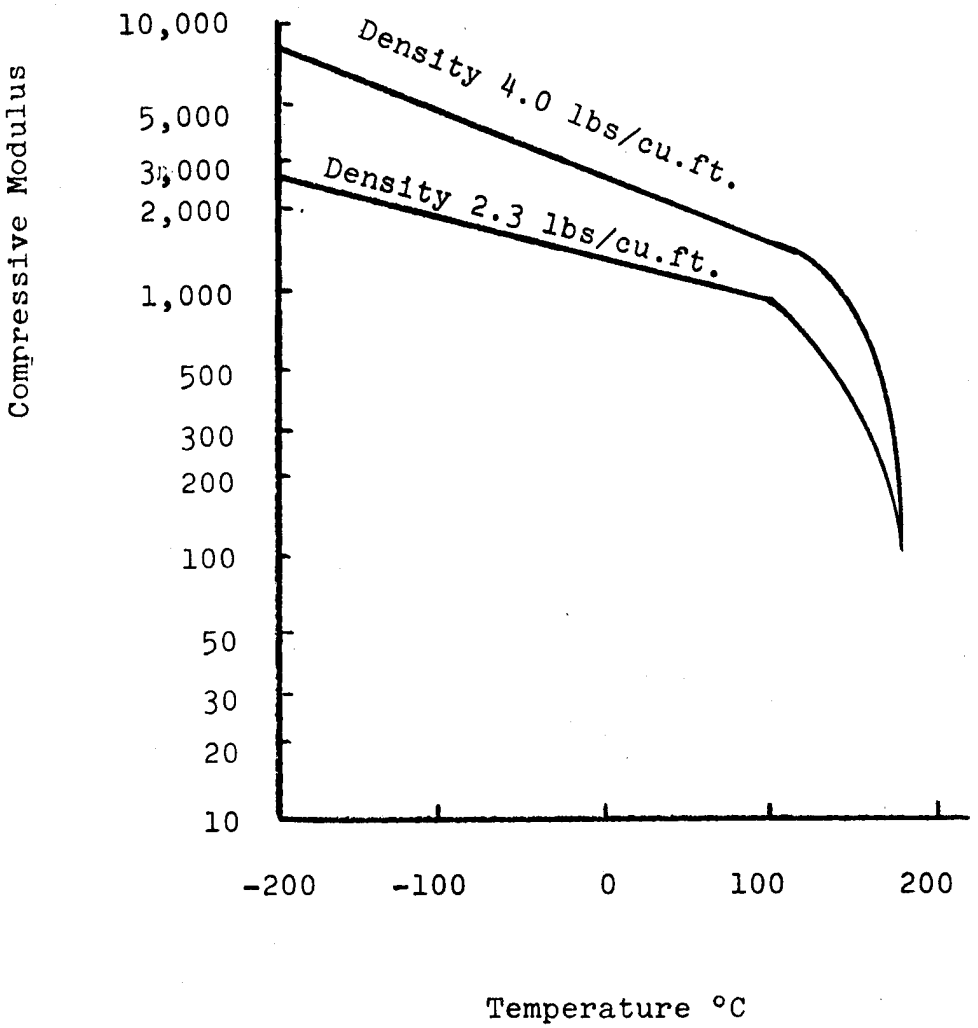
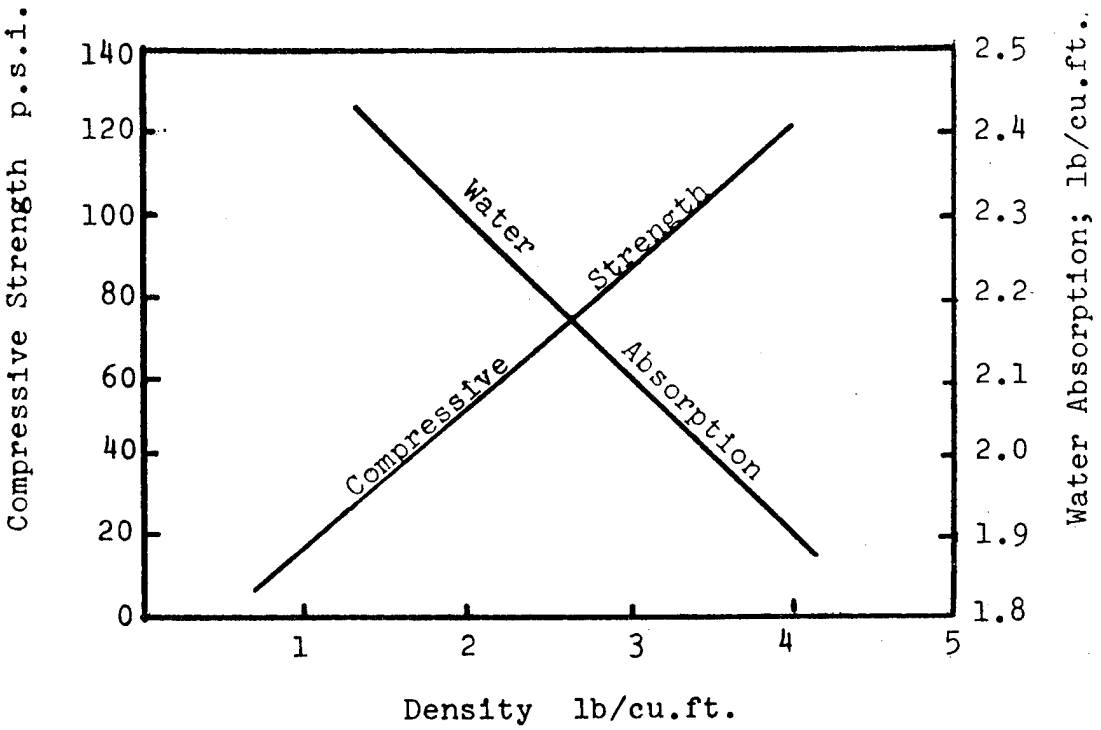
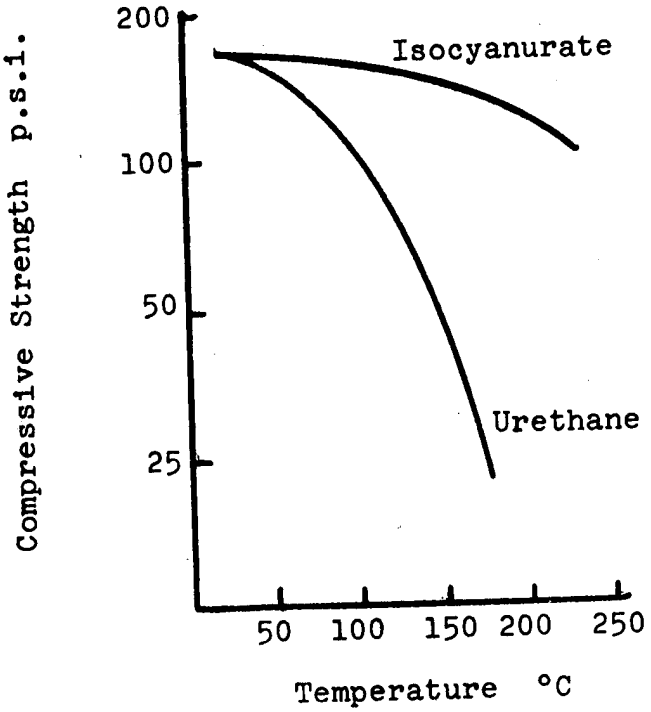


Figure 7 (Ref. 10)



Variation of Compressive Strength and Water Absorption with Density of Rigid Polyurethane Foam

Figure 8 (Ref. [illegible])



Compressive strength versus temperature for polyisocyanurate (6.6-lb/ft^3 density) and polyurethane (6.5-lb/ft^3 density) foams.

Figure 9 (Ref. 19)

TABLE 5 (Ref. 50)

TYPICAL PROPERTIES OF RIGID POLYETHER AND POLYESTER URETHANE FOAMS

Density (lb/cu.ft.) ASTM D1622	1.5 - 2.0
Tensile Strength (psi) ASTM D1623	30 - 40
Compression Strength at Yield (psi) ASTM D1621	
Parallel to foam rise	20 - 45
Perpendicular to foam rise	10 - 25
Compression at yield (per cent)	5 - 10
Closed Cells (per cent) ASTM D1940	92 - 98
Dimensional Stability (per cent vol. change)	
at 70°C, 100% RH, 2 weeks	7 - 15
at 100°C, 2 weeks	5 - 10
at -40°C, 2 weeks	0 - 2

TABLE 6 (Ref. 50)

COMPRESSIVE STRENGTH VARIATION WITH DENSITY
FOR RIGID URETHANE FOAMS

Density lb/cu.ft.	Compressive Strength* Polyether Types	Polyester Types
2	30 - 40	25 - 40
3	65 - 70	40 - 50
6	210 - 200	120 - 160
9	400	240 - 280
12	560	400 - 440

* at yield, parallel to foam rise

TABLE 7 (Ref. 51)

TYPICAL MECHANICAL PROPERTIES OF RIGID URETHANE FOAMS

Density lb/cu ft	Tensile Modulus ∥ psi	Tensile Modulus + psi	Tensile Strength ∥ psi	Tensile Strength + psi	Compression Modulus ∥ psi	Compression Modulus + psi	Compression Strength ∥ psi	Compression Strength + psi
2	1,250	500	65	36	780	430	25	20
4	4,100	1,600	140	80	2,400	1,400	80	70
6	8,300	3,400	200	130	4,700	2,800	160	140
8	15,600	6,000	300	170	7,500	4,500	250	230
10	20,000	9,500	375	210	10,700	6,600	460	350
12	27,300	13,700	450	260	14,400	9,000	580	480
14	35,600	18,200	530	300	18,500	11.700	620	600
16	44,800	23,000	620	350	23,000	14,600	770	750

∥ Measured parallel to foam rise + Measured perpendicular to foam rise

The foams were prepared in boxes 7 in x 7 in cross section and they were about 12 in high. These figures give some indication of how the strength depends on density.

2.5 Energy Absorption Data

The literature survey had not revealed any information directly pertinent to the attentuation of large crushing forces by laterally restrained foam structural elements. Information on unrestrained foams does point out the range of properties available and the effects of environment. Several of these references are reviewed below.

Elevated temperature tests of a large number of unrestrained foam samples indicated that the 275°F compression properties were slightly greater than 50% of the 75°F properties. The foam density was 21 pcf. Variation in average compressive strength at room temperature within six foam batches ranged from 615 psi to 701 psi. Individual test results had a total variation of 565 to 715 psi. Voids artificially produced in 1" high, 1" diameter specimens had little effect on crush strength. The foam used was a carbon dioxide blown isocyanate - polyester urethane. (Ref. 20)

Elevated temperature properties of polyester and polyether foams at the same hydroxyl numbers (similar cross link density) packed to 15 pcf density indicated a strength loss of 30 to 40% at 250°F compared to the 75°F strength. Weight loses were 7 to 11% after 28 days aging at 347°F. (Ref. 21)

The anisotropy of compressive properties with foam rise direction has been mentioned in several papers but no specific information was reported. In one paper, tests showed little effect of rise direction(Ref. 22).

Strain rate effects on rigid polyurethane foams were considered negligible by one investigator. Tests at strain rates from 20 inches/min. to 13,000 inches/min. resulted in a 15% increase in compressive strength. (Ref. 24)

Shrinkage of rigid urethane foams occurs with a decrease in relative humidity and with diffusion loss of carbon dioxide blowing gas. Expansion occurs during heating and the coefficient of expansion may be as great as 41×10^{-6} in/in/°F at 300°F. (Ref. 24)

Tests on foam filled glass reinforced polyester, 2035-T4 aluminum alloy and low carbon steel cylinders performed under contract DOT-HS-4-00929 indicated that the crushing force was dependent on foam density. The foam filled metal cylinders crushed in a different mode than the unfilled cylinders. Heating of foam filled cylinders (foam density 2 lb/ft^3) to 250°F resulted in considerable swelling and softening of the foam. (Ref. 53)

Based on the preceding brief summary, a considerable amount of testing of foam filled metallic structures was required to determine crush properties under environments, especially elevated temperatures, which will be encountered in automobile use.

2.6 Toxicity

Preliminary studies by the Flammability Group, University of Utah, and Stauffer Chemical group on wood, show that smoke produced under applied heat by some typical rigid urethane foams is of lower toxicity than wood smoke. The levels of carbon monoxide and hydrogen cyanide produced and the effect of their smoke on exposed rats was the principal consideration. These tests however, do not consider ignition, flame spread and other factors which are important in real fires.

TABLE 8

The following table summarizes the toxicological findings (with foams not containing TMP+) from:

Stauffer tests in the NBS Smoke Chamber

Exp. No.	Polyol	FR	Toxic Effects Rat Exposure
74-199	Amine Aromatic	16% FYROL 6	None (no deaths)
74-210	Pentaerythritol	16% FYROL 6	None (no deaths)
74-212	Glycerine	16% FYROL 6	None (no deaths)
74-197	Sucrose	16% FYROL 6	None (no deaths)

Conditions: NBS smoke chamber operated at 5.0 watts/cm^2. Sample heated for 10 minutes. Rats exposed during this period and for an additional 15 minutes (25 minutes in chamber, total.) Carbon monoxide and hydrogen cyanide levels in all cases below that required for minimal effects.

* Data from Stauffer Report November 4, 1976
\+ Trimethylolpropane

Polyurethane foam does not produce more hydrogen cyanide than do many other natural and synthetic consumer products as shown in Table 9.

TABLE 9

DETERMINATION OF HYDROGEN CYANIDE
IN PYROLYSIS PRODUCTS
(Ref. 55)

Material	Hydrogen Cyanide (Micrograms/Gm Sample) Air	Nitrogen
Paper	1100	182
Cotton	93 130	85
Wool	6500	5900
Nylon	780	280
Polyurethane Foam	1200	134

The data shown in this table suggests a mechanism of HCN generation from nitrogen-containing polymers. The existance of oxygen seems to be a necessary condition for HCN generation due to nitrogen fixation since less cyanide is produced in atmosphere consisting solely of nitrogen.

Nitrogen fixation is the process that converts free nitrogen into nitrogen compounds.

Heat, to a certain extent, can reverse the isocyanate - urethane reaction to release free isocyanate, but reference here is to temperatures above 210°F. The concentration of isocyanate vapor evolved when urethane foam is heated is insufficient to produce physiologic effects other than irritation. The work of Mitchell, et.al., of the Bureau of Mines confirms the fact that before excessive concentrations of isocyanate vapor develop, the concentration of carbon monoxide from burnable materials would be deadly. It is considered that urethanes do not intensify the hazard of other noxious vapors when involved in a fire. (Ref. 54)

The quantity and toxicity of thermal decomposition products of urethanes have come under much study. Review of all reference articles prompts the conclusion that the thermal

decomposition products would consist mainly of carbon monoxide, benzene, toluene, propene, carbon dioxide, alkenes and water vapor.

Quantitatively, the major decomposition products from urethanes subjected to temperatures up to 3100°F have been defined in Table 10 on page 33.

From the life safety point of view, an often quoted set of conditions hazardous to life in a real fire is:

1. Heat
2. Oxygen depletion
3. Build-up of Carbon Monoxide
4. Presence of Smoke
5. Presence of noxious or toxic gases
6. Fear

To date, the first three have been accepted as primary hazards though the latter three are under continued intensive investigation.

When one considers the issue of smoke and toxic gas evolution, it must be remembered that checking the density of the smoke in a test chamber will not tell you if a hazardous gas is also present. It must also be remembered that carbon monoxide, present in almost all fires to varying degrees, is also a very toxic gas, so that when one talks of poisonous gas evolution from burning materials, one must not forget to think about carbon monoxide. Too much scare talk on hydrogen cyanide poisoning goes on, without due consideration being given the total fire circumstance, the presence of carbon monoxide, oxygen depletion and all the other factors, which together mean a hazard to human life.

A study performed by Bott, et. al., showed the temperatures at which various gases are evolved from heated plastics. (Ref. 56)

The plastics used in this work were a urea-formaldehyde foam, nylon wool, acrylonitrile, and two types of polyurethane foams. The polyurethanes type A and B had been produced from a diphenyl diisocyanate and a polyethyleneoxide alcohol and contained differing degrees of cross linkages, type B being more highly crosslinked and contained a higher mole fraction of isocyanate than type A.

The results of the findings are in Tables 11 and 12 on pages 34 and 35.

TABLE 10

MAJOR THERMAL DECOMPOSITION PRODUCTS FROM POLYURETHANE FOAM PRODUCTS (TEMP. UP TO 3100°F)

Contaminant	Range, ppm	No. Samples
MDI*	0 - 0.160	62
Carbon Monoxide	25 - 400	14
Benzene	1.0 - 48	11
Toluene	1.0 - 48	11
Oxides Nitrogen	0.5 - 13	10
Hydrogen Cyanide	1.- - 8	11

* diphenylmethane - 4:4' diisocyanate

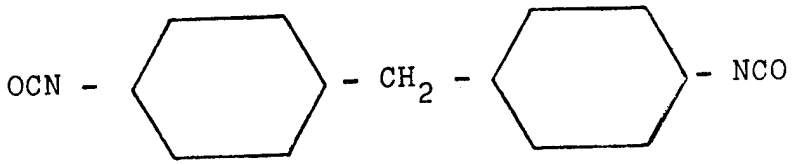


TABLE 11 (Ref. 56)

BOTT ET.AL.: EVOLUTION OF TOXIC GASES FROM HEATED PLASTICS

Temperatures at which the various gases are evolved.

Plastic Material	Temperatures at which gas is evolved in air, °C				Temperature at which gas is evolved in nitrogen, °C			
	HCN	CO	NH_3	Oxides of nitrogen	HCN	CO	NH_3	Oxides of nitrogen
Polyurethane A	325	300	450	600	450	425	430	
Polyurethane B	400	300	450	750	550	400	600	
Urea-formaldehyde	200	250	200	520	275	250	150	210
Nylon	350	350	350	600	350	300	300	650
Acrylonitrile	250	400	360	480	250	400	200	500

TABLE 12 (Ref. 56)

CONCENTRATIONS OF GASES EVOLVED
AT 500°C IN AIR AND NITROGEN

Plastic Material	Concentration of gas evolved in air, ppm				Concentration of gas evolved in nitrogen, ppm			
	HCN	CO	NH_3	Oxides of nitrogen	HCN	CO	NH_3	Oxides of nitrogen
Polyurethane A	700	25000	2000	trace	30	300	250	-
Polyurethane B	200	5000	500	-	20	500	250	-
Urea-formaldehyde	1000	3000	1800	5	800	600	1500	2
Nylon	200	1200	20000	-	80	600	10000	-
Acrylonitrile	3000	400	7000	25	1000	400	7000	20

A laboratory experiment conducted at the University of Utah's Flammability Center showed that some by-products of pyrolysis can cause severe toxicological effects involving the central nervous system resulting in rapid death of test animals.

The toxic pyrolytic by-product has been identified as an alkyl bicyclic phosphorous ester.

It must be noted that this foam formulation was a special atypical case involving a trimethylolpropane polyol (TMP) and flame retardant (phosphorous containing Fyrol 6.) This effect was not observed in any foam systems which did not contain both TMP and a phosphorous flame retardant like Fyrol 6(R) (Ref. 57)

2.7 Flammability

Available data obtained from fire tests in buildings and having a direct bearing on the life hazards to persons from inhaling the volatile combustion or thermal decomposition products of plastic, wooden, or other cellulosic materials under fire conditions are relatively meager. There is, however, a considerable amount of information in technical literature on the volatile products evolved by these materials when burned or subjected to elevated temperature under various experimental procedures conducted on a laboratory scale.

According to the published conclusions of several authors, the principal inhalation hazards in many fires in dwellings and other buildings result from the presence of carbon monoxide or from an oxygen deficiency. Other toxic combustion or thermal decomposition products of plastic, wooden, or other cellulosic building materials may also be present, but in lower concentrations than carbon monoxide. Carbon monoxide, carbon dioxide, or atmospheres deficient in oxygen have no distinctive odors which give warning of their presence when breathed, but many of the other toxic combustion or thermal decomposition products are irritants and cause persons to make efforts to escape or use appropriate protective breathing apparatus. It is recognized that the combustion and thermal decomposition products of plastic materials may present a hazard to life under fire conditions, but in the opinion of these authors the chief hazards in this connection are due to the presence of carbon monoxide or atmospheres lacking in oxygen, which is likewise the case where wooden or other cellulosic building materials are involved in fires.

The available data indicate that plastic, wooden, or other cellulosic materials under certain fire conditions may

(R) Stauffer Chemical

produce toxic gases or vapors in concentrations dangerous to persons when inhaled, depending on the nature of the material or combinations of materials, the amount involved, the conditions of burning or heating (including oxygen excess or deficiency), and the circumstances of the specific situation. Any close distinctions in the life hazards presented by the various building materials in this connection, however, or a classification of the comparative hazards of the materials with respect to their combustion and thermal decomposition products is difficult on the basis of the present data because of wide differences in the test procedures and conditions by which the data were obtained (Ref. 55).

2.7.1 Effect of Environmental Aging on Flammability (Ref. 4)

1. Serious if it produces cell rupture so that susceptibility to combustion is increased by both the loss of fluorocarbon and the failure of the cell membranes which serve as "fire walls" between the adjacent cells.

2. Thermal hydrolytic degradation of the foam polymer makes the polymer more combustible, leaching out of flame-retardant additives is an example. Difficult to determine because of reproducibility in foam manufacture and testing combinations.

3. Adequate vapor barriers reduce the change due to gass diffusion, leaching out would probably never occur in actual service.

4. Conventional flame retarders act as plasticizer, thus decreasing the strength of foam.

5. Reactive flame retardants leave the level of mechanical data uninfluenced.

6. Fire retarders like (TCEP) tricholoroethylphosphate show deterioration in self extinguishing properties at elevated temperatures.

2.7.2 Flammability Tests (Ref. 27)

1. This is a comparative test using a 1-inch by 18-inch strip suspended vertically and ignited by a Bunsen burner. It determines the rate of burning of a 12-inch gage length or states that the specimen cannot be ignited. No provision is made for

measuring smoke or gas emissions. This test is typical of those which cannot be correlated with the behavior of large quantities of film or sheeting exposed to an active fire in a room or other enclosure.

2. Flammability of self-supporting plastics (ASTM D 635).

Samples 5 inches long by 1/2 inch wide are held horizontally and ignited (if possible) with a Bunsen burner if they do not ignite; self-extinguishing if a specified, limited length (1 inch) is burned; and burning if the entire measured length (3 inches) is burned; the rate of burning is also reported. This test is useful for comparing ease of ignition and burning rates, particularly where the test conditions simulate the physical configuration and thermal environment of an actual application for a self-supporting plastic.

3. Flammability of plastic sheeting and cellular plastics (ASTM D 1692).

This method covers a small scale laboratory screening procedure for comparing the relative flammability of plastic sheeting and cellular plastics. It is not suggested as a method for fire hazard classification. The test procedure is similar to that of ASTM D 635. Extrapolation of laboratory tests to actual use conditions is not warranted because of sensitivity to density and thickness (in the case of foamed materials) and the intensity of the igniting flame.

4. Measuring the density of smoke from the burning or decomposition of plastics (ASTM D 2843).

This method covers a laboratory procedure for measuring and observing the relative amounts of smoke produced by the burning or decomposition of plastic under controlled conditions. Measurements are made, under controlled standardized conditions, in terms of the loss of light transmission through a collected volume of smoke. Both the flame and the smoke can be observed during the test. The test is performed in the so-called XP-2 Smoke Density Chamber by burning a 1 by 1 by 1/4 inch specimen in a flame generated by a propane burner. The test is used primarily for building-code acceptance tests of plastic light-transmitted materials. It is also used as a laboratory method for obtaining relative ratings of smoke generation from various plastic materials.

5. National Bureau of Standard smoke chamber.

This system, developed by NBS, represents one of several approaches to small-scale testing for smoke generation. It

differs from the XP-2 chamber in that it uses a 3-inch-square sample and radiant flux (sometimes combined with a pilot light) for ignition. The effect of smoke is determined in a vertical rather than a horizontal path. Both tests rely on optical obscuration as the only measure of smoke density which places an unjustified reliance on the comparability of particle size and degree of agglomeration of smoke generated in a small test chamber with the conditions of a real fire.

6. Flammability of plastics using the oxygen index method (ASTM D 2863).

This laboratory procedure determines the relative flammability of plastics by measuring the minimum oxygen concentration that will just support combustion, in a slowly rising mixture of oxygen and nitrogen. It can be applied only to physically self-supporting plastic test specimens. Burning is vertical from the upper end of the candle-like plastic rod or strip. Test results are said to be highly reproducible and the procedure has found ready acceptance since its introduction in 1970. There is no provision for measuring burning rate or smoke generation in the standard test but modifications to do both can be added. As in the case of most small-scale tests, the sample, once ignited, is heated only by its own flame and the influence ofheating from external fire sources is not considered, though it can contribute substantially to smoke generation.

7. Surface burning characteristics of building materials (ASTM E 84).

This well-known test was mentioned earlier. It was originally established around 1950 as a test for the surface burning characteristics of building materials that are self-supporting either in themselves or by the manner in which they are applied. The procedure is specified in many building codes for conventional building materials and has been used to qualify plastics for use in building construction. In addition to determining the relative flame spread of materials, it also defines evaluation of heat contribution and smoke, including products of combustion. The design of the 25-foot tunnel used for the test results in the best correlation with flame spread of materials along ceilings in hallways since the test specimens are mounted on the roof of the tunnel. This causes complications in the testing of thermoplastic materials due to their tendency to sag and flow when heated. The test chamber simulates actual fire conditions by having a continuous, controlled gas flame at its fire end to induce burning of the specimen. Nevertheless, attempts to correlate E 84 test results with full-scale tests have met with mixed results.

8. Fire tests of building construction and materials (ASTM E 119).

"Fire Resistance" is what most people comprehend as difficulty of ignition and propagation. In the language of the fire and building fraternity "fire resistance" means the number of hours (one-half to four) that a building element (walls, ceiling, floor) will stand up against the ASTM E 119 test. Because of the popular conception of "fire endurance". In this test the specimen is of large area and is used as a partition in a room-sized furnance. Gas fire of controlled and increasing intensity is applied to one side. On the hot side, temperature rises to 1000°F at five minutes, 1300°F at one hour, and 2000°F at four hours. The criterion for rating is that the temperature on the far side of the specimen shall not exceed 250°F above ambient (which is maximum of 90°F). None of today's plastics for building have fire endurance in this sense; all are consumed with access to air at the lowest E 119 temperature.

2.8 Ease of Usage (Ref. 28)

Urethane Systems are normally supplied as 2 or 3 liquid chemical components. The "A" component is the isocyanate, the "B" component usually contains the following: polyol, tertiary amine catalyst, tin catalyst, fluorocarbon, water, silicone surfactant and fire retardant, the "C" component used for isocyanurate systems is usually the catalyst.

The range of equipment available to dispense urethane foam systems varies from small, off the shelf units with flow rates less than 1/2 lb./min. up to custom built, multi-head machines with flow rates in excess of 100 lb./min. per head. The size of foam machine or the machine capacity is expressed as flow rate in pounds per minute and the capacity required is a function of mold or cavity volume, desired foam density, cream or reaction time and chemical component ratio. The equipment type naturally is dependent on the particular application.

Flowrate is calculated as follows:

$$\text{Flowrate (lbs./min.)} = \frac{\text{Mold Volume (cu.ft.)} \times \text{Foam Density (lb./cu.ft.)}}{\text{Cream Time (min.)}}$$

Example:

Mold Volume	=	6.0 cu./ft.
Molded Density	=	2.0 lb./cu.ft.
Cream Time (20 sec.)	=	1/3 min.

Mix ratio "A"/"B"
100/100

The flowrate of machine to fill this cavity would then be:

$$\text{Flowrate} = \frac{6.0 \times 2.0}{1/3} = 36 \text{ lbs/min}$$

This is true of a foam system which has a mixing ratio of 100 parts "A" to 100 parts "B".

Equipment suppliers always specify machine output at 100/100 A/B ratio which gives the highest total flowrate for any given machine design. The total output of a machine stated to have a flowrate of 36 lbs/min means that the equipment will deliver 18 lbs. of each of the two major components.

If the A/B component mixing ratio is other than 100/100, the total output will be reduced.

Example:

Mold Volume	=	6.0 cu/ft
Mold Density	=	2.0 lbs/min
Cream Time (20 sec	=	1/3 min
Ratio of "A"/"B" 120/100		
Flowrate required	=	36 lbs./min

$$\text{Machine Capacity Required} = \frac{36 \times 120}{120 \times 100} \times 2 = 39.2 \text{ lbs/min}$$

This means that a piece of equipment would need the minimum of 40 lb/min flowrate to fill the 6 cu ft cavity.

It can be seen by these examples that in order to get maximum flow rate from a machine the foam systems should be formulated to a 100/100 mixing ratio.

3.0 SUITABILITY

3.1 Foam Evaluation for Use in this Program

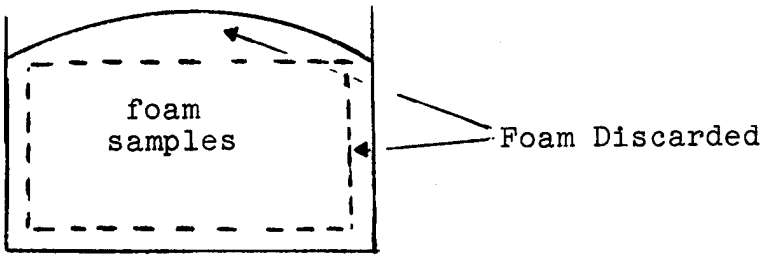
Foam systems selected for evaluation were classified as follows and all nominally 2 lb/ft^3 density.

1. Standard formulation polyether (fire modified)
2. High Strength Polyether (fire modified)
3. Standard, Class I
   Flame spread 25
   Smoke obscuration <450 when tested in accordance to ASTM E-84.
4. Isocyanurate (Trimer)
5. Oil Absorbant Foam

Preliminary tests for screening were made for compressive strengths at elevated temperatures and for dimensional stability.

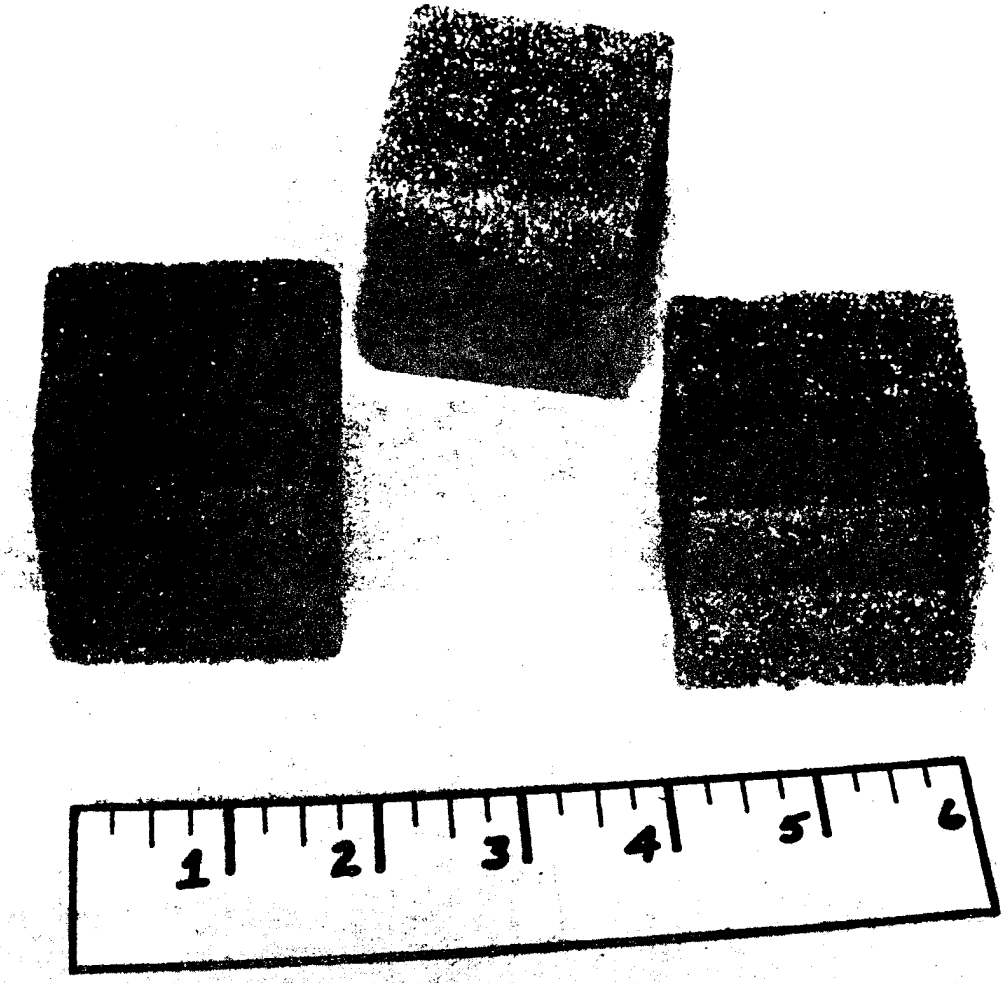
3.1.1 Density

The foam ingredients were weighed and mixed per manufacturer's instructions. Mixing was achieved by means of an electric drill using a jiffy stirrer. This stirrer provides vigorous mixing without aeration or splashing. The mixed foams were then poured into cardboard boxes and allowed to rise without confinement. After 24 hours, samples, 2" x 2" x 2", were cut from the foamed boxes. See Photograph A-1, page 44. The outer 1/2 inch of foam from the foamed boxes was discarded. See sketch below.



The 2" x 2" x 2" cubes were weighed and then the density calculated.

Table 13, on page 45, shows the foams evaluated in this program and a density comparison of the vendor's data with the tested data.



COMPRESSION SAMPLES 2x2x2"

TABLE 13

Sample No.	Foam Designation	Type	Vendor's Data	Test Data	Supplier
1	XR-1050	Class I +	2-2.5	2.02	General Latex Co.
2	R-244	Std.	1.5-1.7	1.6	Stepan Chemical Co.
3	NB-237936 A	Std.	1.8	2.09	Mobay Chemical Co.
4	NB-245217	Hi Temp.	2.2	2.27	Mobay Chemical Co.
5	R0379A/R0380B	Std.	1.8	2.2	Witco Chemical Co.
6	NB-247005	Trimer	1.9	2.6	Mobay Chemical Co.
7	XF-2361	Oil Resistant	2.5	3.8	3M Company
8	7544	Class I	2.5	2.6	Olin Chemical Co.
9	NB-247005*A/B	Trimer	1.88	1.9	Mobay Chemical Co.

\+ Flame Spead less than 25, Smoke Obscuration less than 450 per ASTM E-84

* Foam Block supplied by Mobay Chemical Company

3.1.2 Volume Change (After 24 Hours at 250° F)

Four (4) specimens each of the evaluated foams were measured and then placed in an oven for 24 hours @250°F. The specimens were then remeasured and the % volume change noted. Below is the average % volume changes.

TABLE 14

Sample No.	Foam	Vinitial in^3	Vfinal in^3	% Vol. Change	Comments
1	XR-1050	8	10.55	32	Blocks were badly distorted.
2	R-244	8	9.9	24	Blocks were badly distorted.
3	NB-237936A	8	8.3	3.7	
4	NB-245217	8	8.1	1.2	
5	R-0379A/R-0380 B	8	8.58	7.3	
6	NB-247005 A/B	8	8.05	.6	
7	XF-2361	8	8.07	.8	
8	7544	8	8.26	3.25	
9	NB-247005 A/B (supplied by vendor)	8	8.08	1.0	

The data above clearly shows that the systems exhibit different stability when exposed to a heat source in the free state.

These specimens were then compression tested at 72°F to determine the effect a 250°F exposure had on their compressive strengths.

3.1.3 Compression Strength

Foam exposed 24 hours at 250°F and tested at 72°F.

TABLE 15

Foam	Comp. Str.(psi) Parallel: Prior to Exp.	Comp. Str.(psi) Parallel: After Exp. 250°F for 24 hours	Comp. Str. (psi) Perpendicular: Prior to Exp.	Comp. Str. (psi) Perpendicular: After Exp. 250°F for 24 hours	Density (lbs/ft^3)
XR-1050	31	21.2	15	16	2.02
R-244	24	18.5	13	17.5	1.6
NB-237936A	39	47.5	25	29	2.1
NB-245217	45	52.0	23	36	2.3
R-0379A/R-0380B	36	35	25	27	2.2
NB-247005 A/B	46	43	30	35	2.6
XF-2361	31	26.2	24	21.5	3.8
7544	61	57.5	27	35.5	2.6
NB-247005 A/B (Block supplied by vendor)	31	26	14	22	1.9

NOTE: All specimens tested at 72°F.

Data shows that the compressive strength of foam systems NB-237936A and NB-245217 increased after exposure to 250°F. This increase in strength may be attributed to additional cross linking of these foam systems.

3.1.4 Compressive Strength of Foam at Various Temperatures

Foam samples 2" x 2" x 2" were conditioned two hours before testing at 72°F, 200°F, 250°F, and 300°F. Samples were tested parallel and perpendicular to foam rise. Test results are plotted in Figures 10 and 11 on pages 48 and 49.

It can be seen that NB-237936A, NB-245217 and NB-247005A/B foam systems exhibit the least decrease in strength when tested at 250°F. NB-245217 actually had greater compressive strength at 200°F than at 72°F.

In low density foams the compressive strength is nearly proportional to the density. In order to obtain a comparative compressive strength per unit of weight the compressive strengths of the tested foams were proportioned to a 2 lb/ft^3 density.

Figure 12 on page 50 depicts these values.

Test data shows that there is a considerable drop off in values at 250°F and 300°F in some of the systems tested, but many of the systems still maintained good compressive strengths at these temperatures. Data from literature show compressive strengths at 300°F to be very poor for systems of comparable densities. See Figure 6 on page 22.

3.1.5 Foam Selection

Evaluation tests show that the compressive values of the foam systems at test temperature did vary, but not drastically. Foam system NB-237936A, standard urethane system, was selected for subsequent testing in this program based on the following overall properties.

1. Good thermal stability
2. Good compression strengths from 72°F thru 300°F
3. Nominal 2 lb/ft^3 density
4. Combustibility Modified (ASTM-1692)
5. Ease of usage - reproducible properties
6. In-service use and commercially available
7. Lower cost than trimer or Class I systems.

See Figure 13 on page 51. This selection does not mean that the evaluated systems having comparable compressive test values would not perform as well under the same test conditions, but funding and time, however, does not offer the luxury of testing each and every foam system. The standard urethane system is approximately 10 cents a pound cheaper than Class I systems tested.

3.1.5.1 Vendor's data pertaining to the foam system selected for use on subsequent tests in this program is shown below.

Mobay Chemical Corp.
System NB-237936A - Standard
(Combustibility Modified)

Formulation

Polyol	- 85 pbw	
Fyrol 6	- 15 pbw (fire retardant)	
Catalyst	- 2.75 pbw	Free rise density
Sufactant	- 1.5 pbw	1.8 lbs/ft^3
Freon	- 36 pbw	

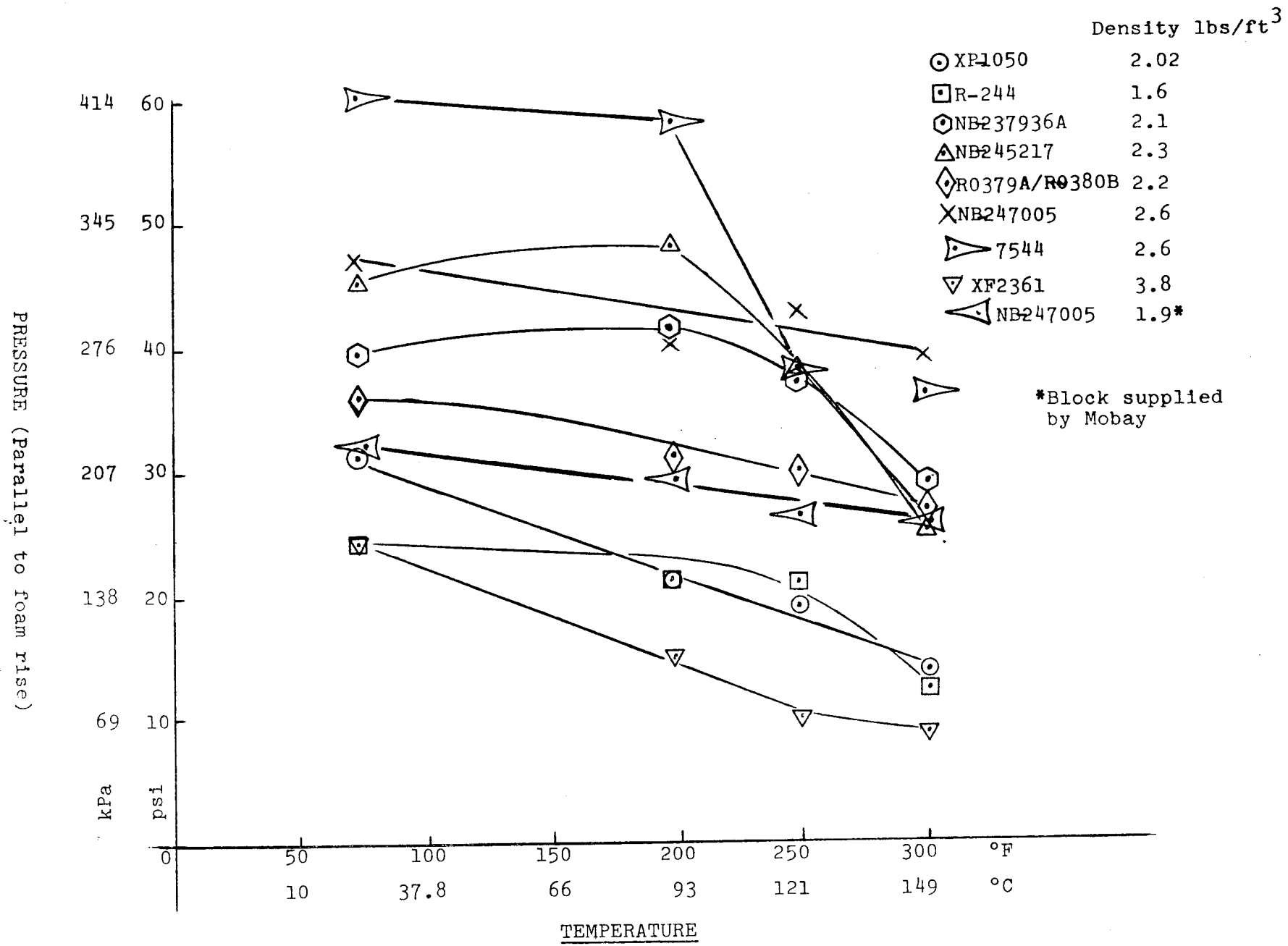

Density lbs/ft3
XP1050 2.02
R-244 1.6
NB237936A 2.1
NB245217 2.3
R0379A/R0380B 2.2
NB247005 2.6
7544 2.6
XF2361 3.8
NB247005 1.9*
*Block supplied by Mobay
PRESSURE (Parallel to foam rise)
kPa
psi
414 60
345 50
276 40
207 30
138 20
69 10
0
50 100 150 200 250 300 °F
10 37.8 66 93 121 149 °C
TEMPERATURE

Figure 10

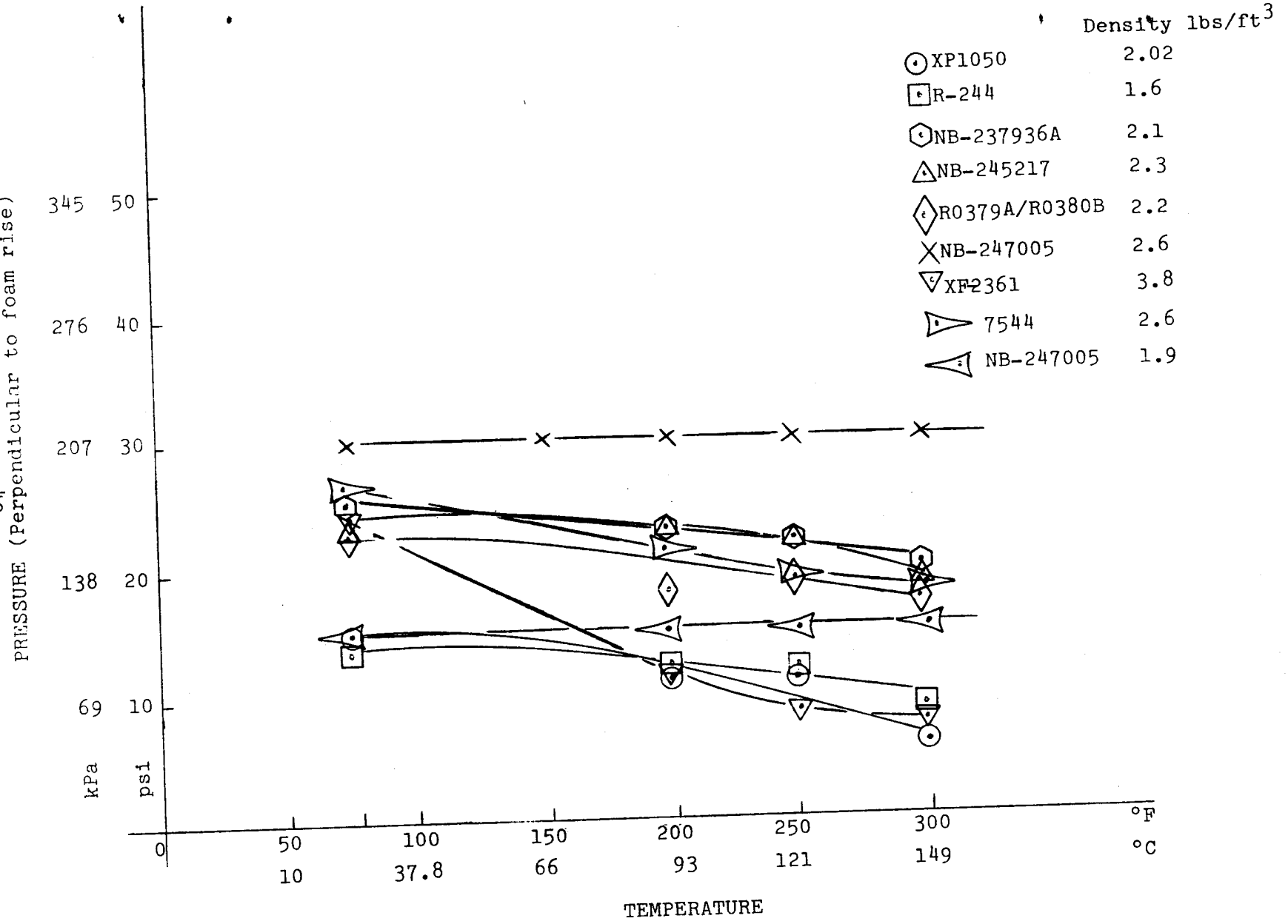

Density lbs/ft3
XP1050 2.02
R-244 1.6
NB-237936A 2.1
NB-245217 2.3
R0379A/R0380B 2.2
NB-247005 2.6
XF2361 3.8
7544 2.6
NB-247005 1.9
PRESSURE (Perpendicular to foam rise)
345 50
276 40
207 30
138 20
69 10
kPa psi
0
50 100 150 200 250 300 °F
10 37.8 66 93 121 149 °C
TEMPERATURE

Figure 11

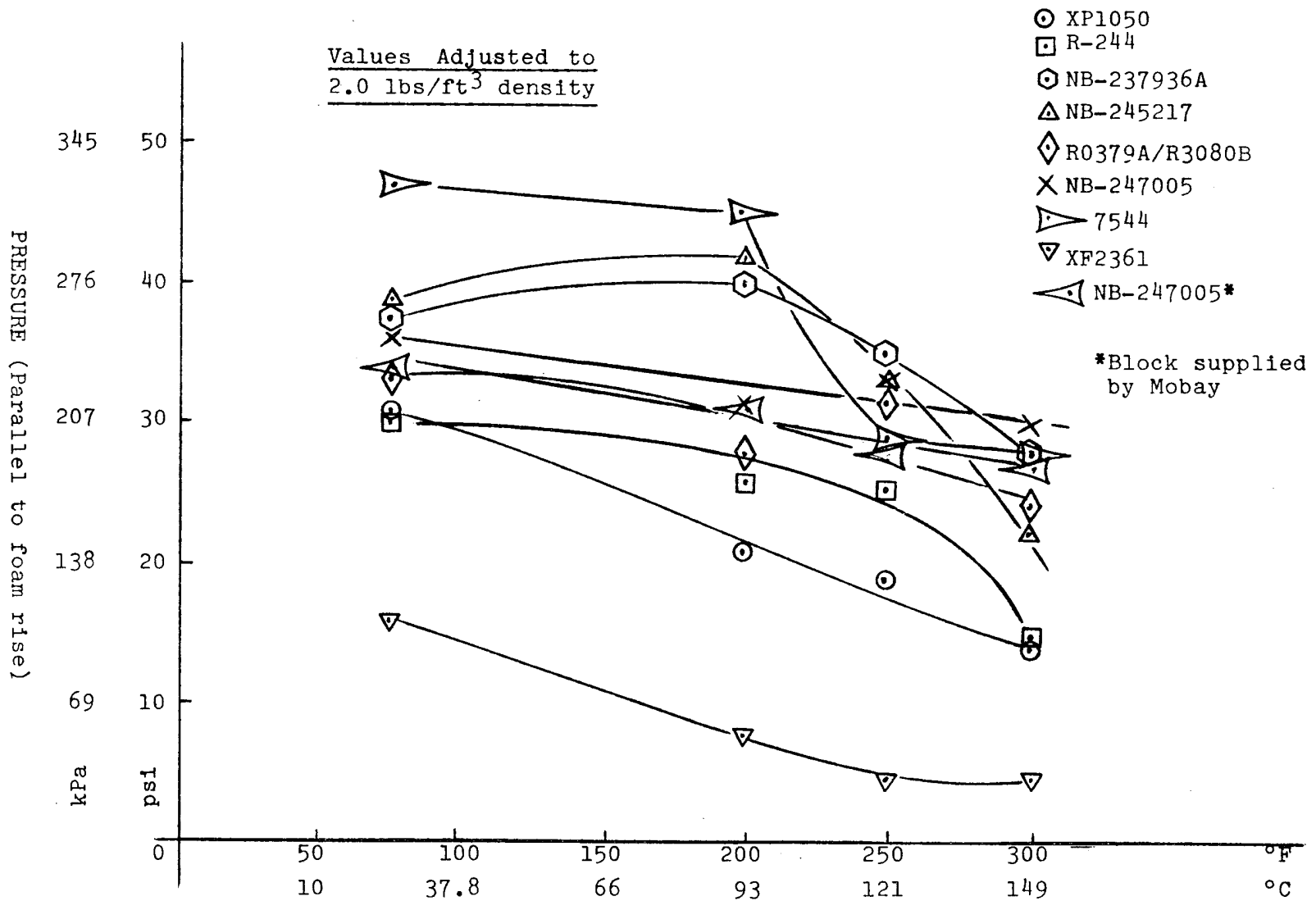

Values Adjusted to
2.0 lbs/ft3 density
XP1050
R-244
NB-237936A
NB-245217
R0379A/R3080B
NB-247005
7544
XF2361
NB-247005*
*Block supplied by Mobay
PRESSURE (Parallel to foam rise)
345
276
207
138
69
0
kPa
50
40
30
20
10
psi
50
100
150
200
250
300
°F
10
37.8
66
93
121
149
°C
TEMPERATURE

Figure 12

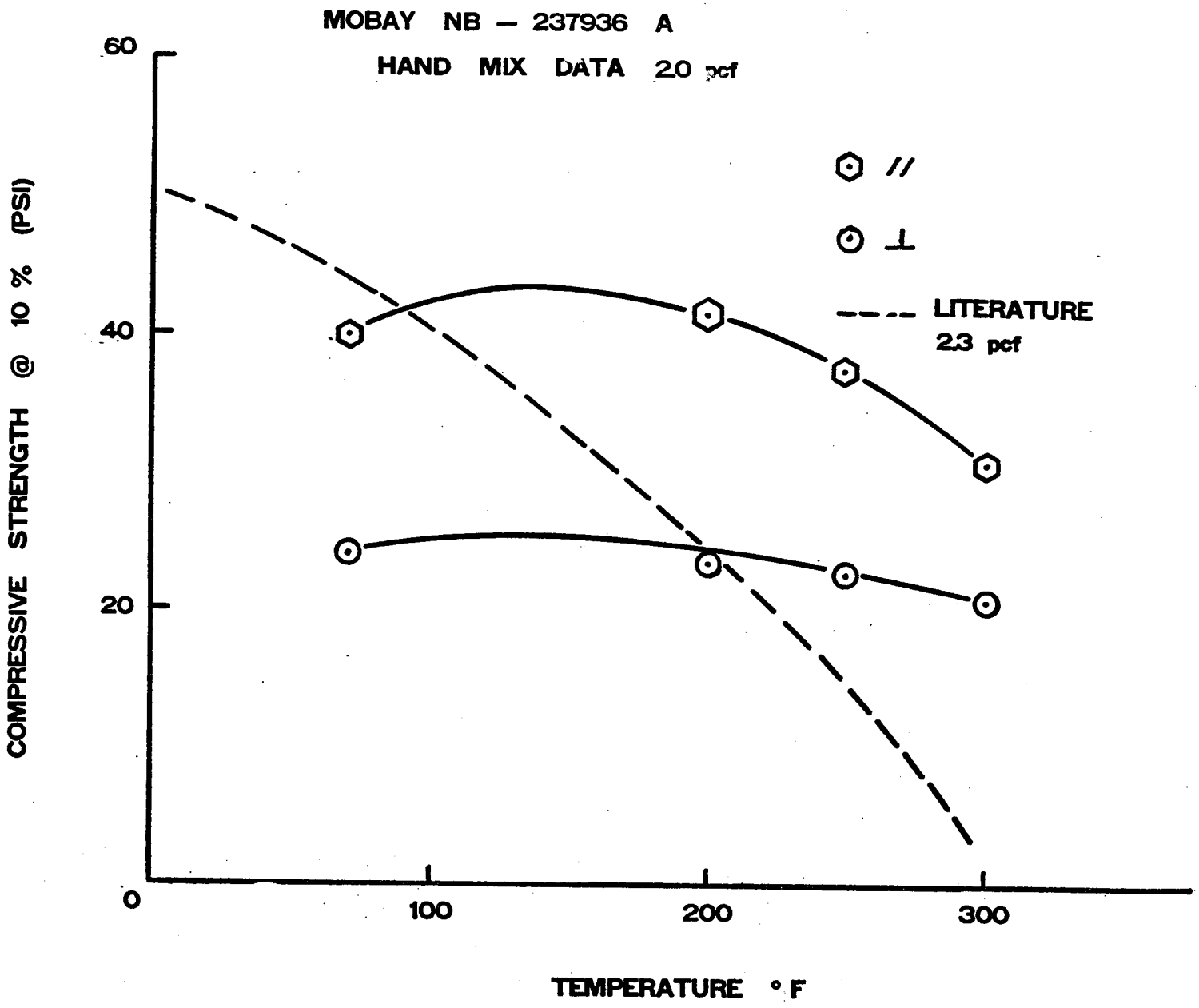

MOBAY NB — 237936 A
HAND MIX DATA 20 pcf
60
40
20
0
100
200
300
//
⊥
LITERATURE
2.3 pcf
COMPRESSIVE STRENGTH @ 10 % (PSI)
TEMPERATURE °F

Figure 13

Ratio - Resin 100 pbw
Isocyanate 88 pbw

Hand Mix Reaction Time

Mix Time - 10 sec
Cream Time - 16 sec.
Gel Time - 42 sec.
Tack Time - 51 sec.
Rise Time - 90 sec.

Compression at Yield (psi)

Test Temp.	Parallel	Perpendicular	Modulus Paral.	Modulus Perp.
160°F	42.5	13.5	728	291
120°F	47.8	14.5	998	265
70°F	48.5	14.8	934	239
20°F	52.5	16.0	1140	300
-20°F	55.3	14.8	1136	286

3.1.6 Compression Strength, NB-237936A Foam System

Comparison of Hand Mix versus Machine Mix of NB-237936A

Foam system, NB-237936A, dispensed from the Canon C7 foam machine was tested after an 18 hour cure at 72°F, and also tested after a 72°hour cure at 72°F. Hand mixed specimens were made and tested after a 72 hour cure at 72°F for comparative purposes. See Table 16 below.

TABLE 16

Results

Sample	Cure @72°F Tested @72°F	Compressive Strength Paral.psi	Perp. psi	Density lbs/ft^3
Machine Dispensed	18 hrs.	32.6	13	1.93
Machine Dispensed	72 hours	36.25	13	1.92
Hand Mix*	72 hours	38.7	16.7	2.05

* Jiffy Stirrer @ 2000 rpm for 10 seconds

Test results indicate that the foam obtains approximately 90% of it's compressive strength in the parallel to foam rise

direction after 18 hours. Hand mixed specimen densities are always slightly higher than machine mix due to Freon loss in the weighing and mixing operations done in an open environment while the machine dispensed foam is a closed system.

The machine mixed specimen and the hand mixed specimen, adjusted to a 2 lb/ft^3 density, were 37.8 psi in the parallel to foam rise direction.

3.1.7 Composite (Foam and container - 6" x 6" x 8")

Preliminary tests were made to determine the following:

1. The distortion of specimen due to foam expansion in the free rise condition and the "packed" condition to obtain pressures exerted by the foam, and thus determine the fixturing which would be required to prevent distortion.

2. The distortion of the specimen due to the expansion of foam after exposure to 250°F for 24 hours.

3. Dimensional change, if any of the specimen fixtured during the foaming process, and changes after the foam had cured and removed from fixture.

3.1.7.1 Specimen Fabrication for Preliminary Testing

Specimens were made from 1010 steel (.022 -.024 in. thick). Spot welds were placed 1-1/2 inches apart. The inside dimensions were 6" x 6" x 7". The top had a 1-1/2 inch diameter hole for pouring of the foam. See Specimen No. 5, photograph A-2 on page 57.

3.1.7.2 Distortion of Specimen due to foam Expansion (Free Rise and "Packed")

Dimensions were taken at the specimen centers prior to foaming and then after foaming without fixturing. The specimen (free rise) expanded an average of 0.04 inches at the centers. The same test was repeated but the foam was confined and overfilled (packed) to insure a complete fill. The "packing" produced greater pressures than free rise and thus greater specimen distortion. The specimen expanded an average of 0.10 inches at the centers.

These tests show that fixturing is required to prevent part distortion during the foaming of light gage metallic structures.

3.1.7.3 Distortion of foam filled Specimens (not fixtured) after Exposure to 250°F for 24 Hours.

Dimensions were taken at the centers of the foam filled specimens prior to being placed in the oven at 250°F for 24 hours.

Data on Table 17 shows that the foams expand and cause specimen expansion in all cases after exposure with the exception of the XF2361 system. This system is predominantly an open celled system which can explain the lack of expansion. Readings were also taken on the specimen after 72 hours to determine if this was a permanent change. The dimensions remained the same showing that the change was permanent. This test shows fixturing is required if the foamed specimen is subjected to subsequent processes which involve exposure to heat.

TABLE 17

Specimen Dimensional Change After Exposure to 250°F for 24 hours.

Specimen No.	Foam	Dimension Change (in.) at 0°	at 180°
2	R0379A/R0380B	+.125	+.123
7	NB-237936A	+.80	+.120
8	NB-237936A	+.110	+.130
9	R-244T	+.150	+.235
10	XP-1050	+.150	+.160
11	NB-245217	+.100	+.055
12	XF2361	+.003	-.003

3.1.7.4 Dimensional changes of specimen after foaming and removal from Fixture.

Dimensions were taken at the specimen centers prior to foaming. The specimen was then fixtured and foamed. The specimen was then removed from the fixture (one hour to insure complete stabilization). The change was only a few thousandths of an inch and for all purposes negligible. This test shows that if the foamed specimen is allowed to remain in the fixture for a prescribed period of time (until the foam becomes stable) additional specimen expansion is negligible.

3.1.7.5 Weight Change of foam filled Specimen after Exposure to 250°F for 24 Hours.

The weights of the foam filled specimens were recorded prior to placing in an oven at 250°F for 24 hours. The weights were then taken after the specimens were removed and cooled to room temperature. Table 18 on page 55 shows that there is a minute weight loss in all foam systems except XF2361 system (slight increase in weight). Since this is primarily an open celled system, the minute weight increase can be attributed to the absorption of moisture.

The negligible weight loss of the other foam systems indicates very little if any foam decomposition due to cells rupturing and loss of Freon 11 at this test temperature.

TABLE 18

Weight Change of Foam After Exposure to 250°F for 24 Hours.

Specimen No.	Foam	Wt. Before Exposure Grams	Wt. After Exposure Grams	Difference Grams
7	NB-237936A	1085	1084.5	- .5
8	NB-237936A	1095	1094.4	- .6
9	R-244-T	1056.5	1054.2	- 2.3
10	XP-1050	1068	1067.8	- .2
11	NB-245217	1128.5	1128.0	- .5
12	XF2361	1200	1202.5	+ 2.5

3.1.7.6 Static Crush of Unfilled and Foam Filled Specimens (6 x 6 x 8 in) at 72°F and at 250°F.

Data shows that the average static crush force of the unfilled specimens was the same when tested at 72°F and at 250°F (1200 lbs). See Table 19 below for results.

See photograph A-2, page 57 for Specimen No. 5 (unfilled) before test and photograph A-3, page 58 after static testing at 72°F for crushing mode.

See photograph A-6 on page 61 for Specimen No. 6, tested at 250°F for crushing mode.

TABLE 19

Specimen No.	Description	Test Temp.	Avg. Static Crush Force lbs.	"Packed" Foam Density lbs/ft^3
5	Unfilled Specimen	72°F	1,200	
6	Unfilled Specimen	250°F	1,200	
3	Foam Filled NB-237936A	72°F	2,800	2.4
4	Foam Filled NB-237936A	250°F	2,400	2.4

Tested on Instron: Cross Head Speed 2"/min.
Chart Speed 20"/min.

3.1.7.7 Average Static Crush Force of Foam Filled Specimens After Exposure to 250°F for 24 hours and Tested at Ambient, 72°F. See Table 20 for results.

Results show that the average static crush force for foam system NB-237936A after 250°F exposure, Specimen Nos. 7 and 8, Table 20, was comparable to the average static crush force of the unexposed foam filled specimen (No. 3) as shown in Table 19 on page 55. This indicates that there is no degradation in foam compressive properties after a short time exposure at 250°F and tested at 72°F.

TABLE 20

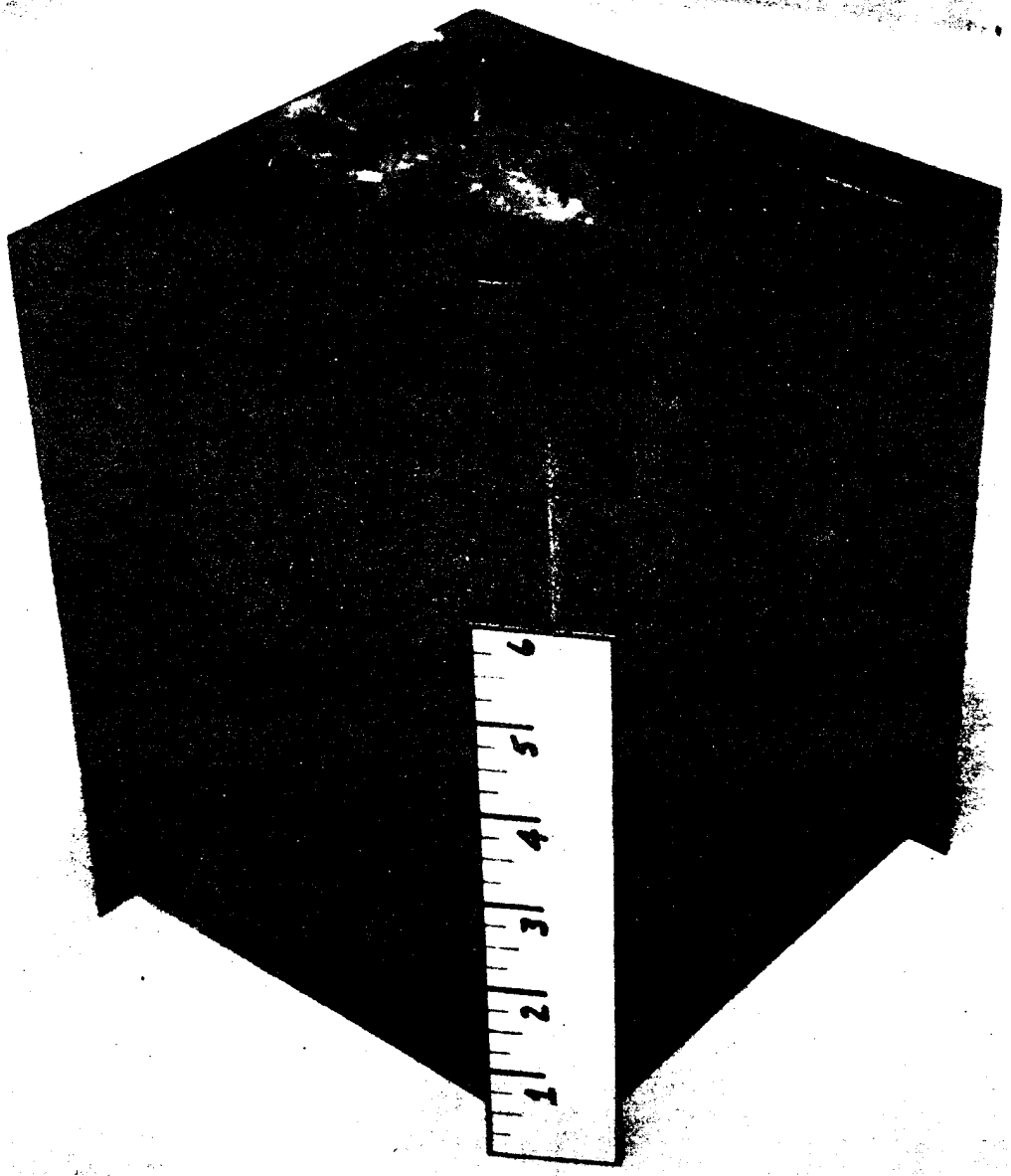
Crush Strength of Composite after Exposure to 250°F for 24 hours and tested at 72°F
Specimen: 6" X 6" X 8", 1010 Steel (.022 - .024)

Static Test

Specimen No.	Foam	Avg. Crush Force lbs.	Pack Density lbs./ft^3	Average Crush Force Contributed by Foam (lbs.)
2	R0379A/R0380B	2200	2.6	1000 lbs. (28 psi)
7	NB-237936 A	2700	2.58	1500 lbs. (41.7 psi)
8	NB-237936 A	3100	2.6	1900 lbs. (52.7 psi)
9	R-244-T	2500	2.1	1300 lbs. (36 psi)
10	XP-1050	2300	2.3	1100 lbs. (30.6 psi)
11	NB-245217	2600	3.2	1400 lbs. (38.9 psi)
12	XF-2361	2200	5.7	1000 lbs. (28 psi)

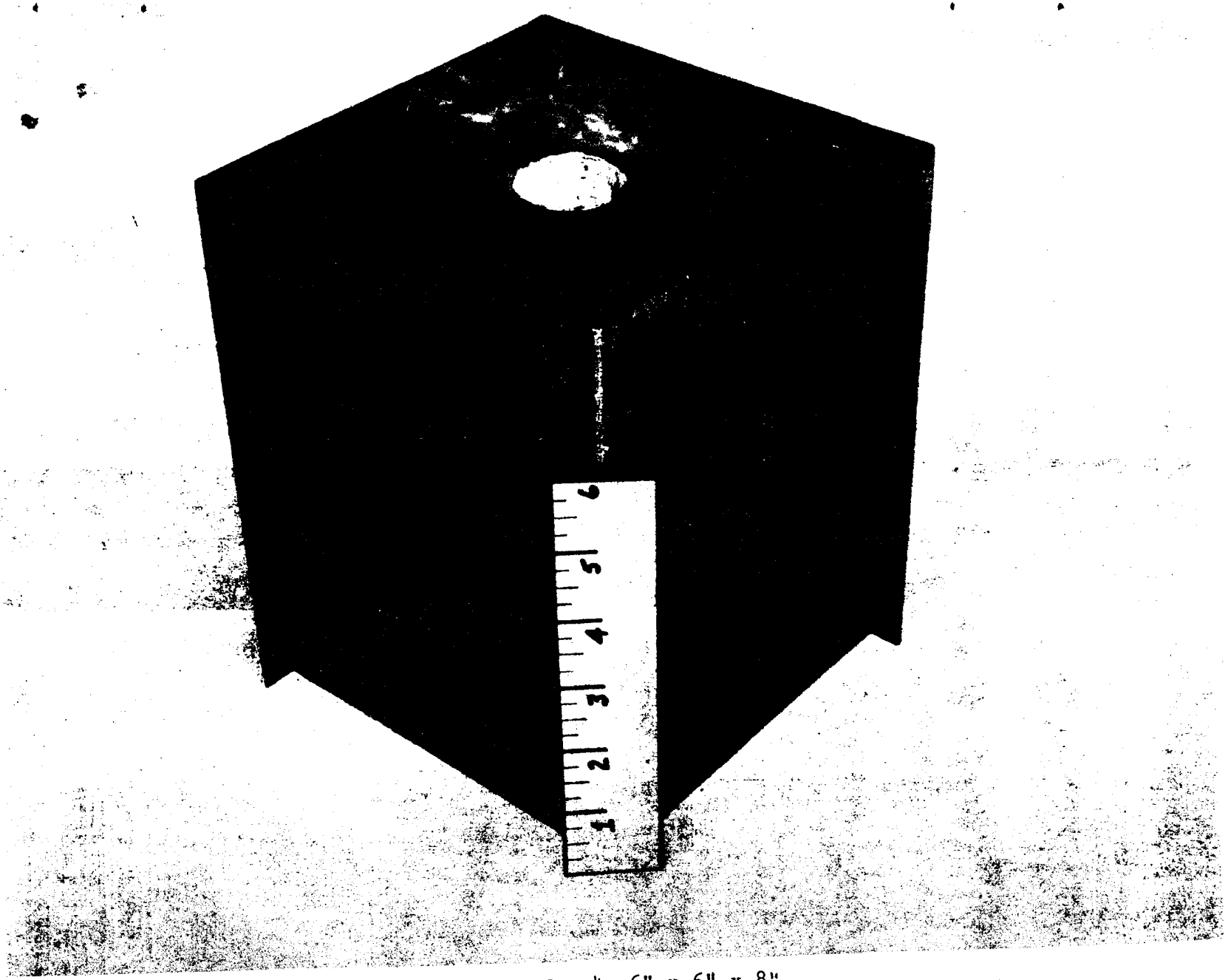
Specimen Nos. 5 and 6 were made and tested to obtain background data for the unfilled steel specimen at 72°F and 250°F. Data shows that the average crush strength is the same (1200 lbs.) at the test temperatures. See Table 19 on page 55 for test results.

Specimen No. 3 was foam filled and static tested at 72°F. Specimen No. 4 was foam filled and static tested at 250°F. A decrease (approximately 14%) resulted in the average crush strength at 250°F when compared to 72°F. See Photograph A-5, page 60, for failure mode at 250°F. Since the metal structure had the same static crush strength at 72°F and 250°F this decrease can only be attributed to the decrease in foam compressive strength at 250°F. See Figure 10 on page 48 for compressive strength of NB-237936A foam system at 250°F.



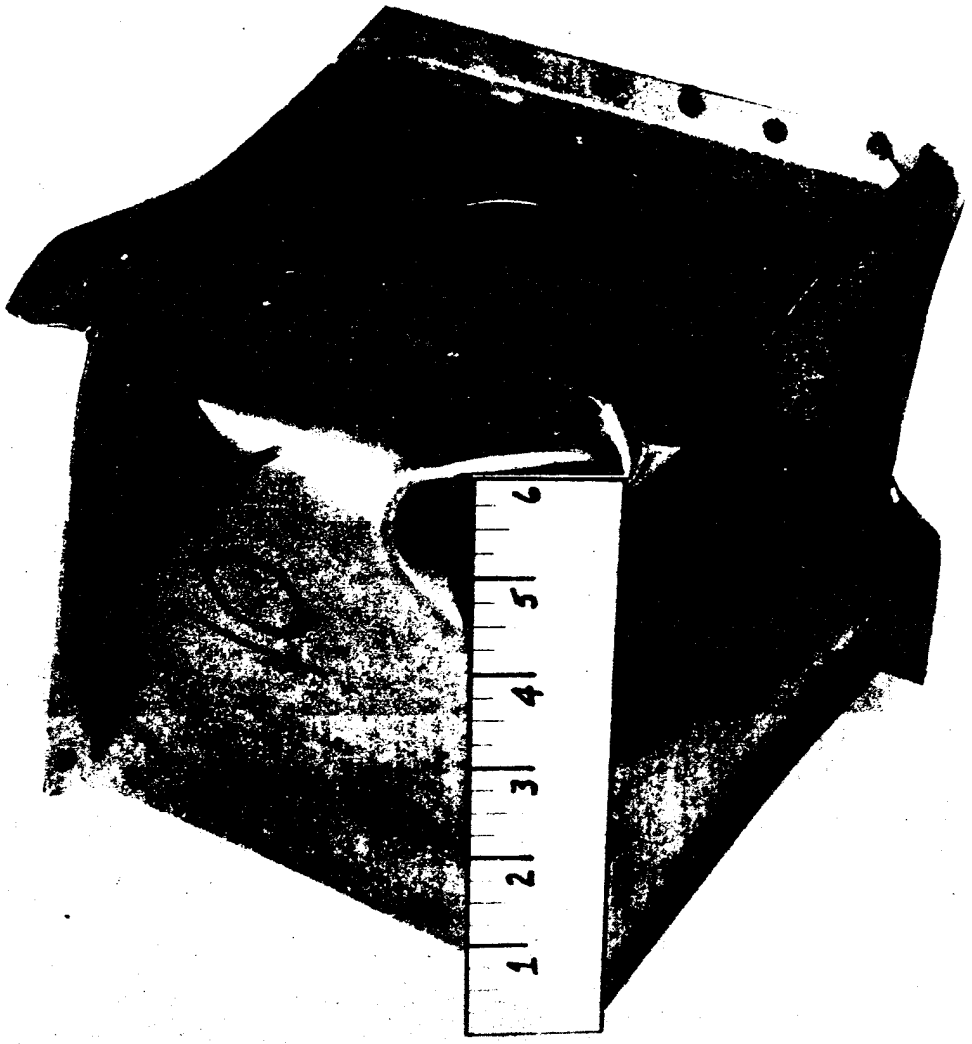
Specimen No. 5, 6" x 6" x 8"
Prior to Test

Specimen No. 5
After Static Test



Specimen No. 4, 6" x 6" x 8"
Prior to Test

Specimen No. 4
After Static Test @250°F



Specimen No. 6
After Static Test @250°F

3.2 Material Availability

There is no global shortage of raw materials for urethane foam. Cost would be the prime factor if raw materials would come from sources other than petroleum or natural gas.

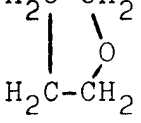
The inadequate capacity to produce raw materials from feedstock due to lack of refinery capacity and basic petrochemical production could present a bigger problem than feedstock availability. Raw materials for plastic production can be obtained from coal, oil shale and vegetable by-products. Figure 14, page 63, shows how a barrel of crude oil is consumed.

3.2.1 Material Availability (Other than petroleum and natural gas)

3.2.1.1 Coal

1. The United States has more than one half the world's known coal reserve or more than 3 trillion tons. Five percent or 150 billion tons is considered recoverable by present technology. This represents a 300 year supply at the present rate of 500 million tons/year. Coal predominately contains aromatic (ring) compounds, while petroleum predominantly contains aliphatic (straight chain) compounds.(Ref.40)

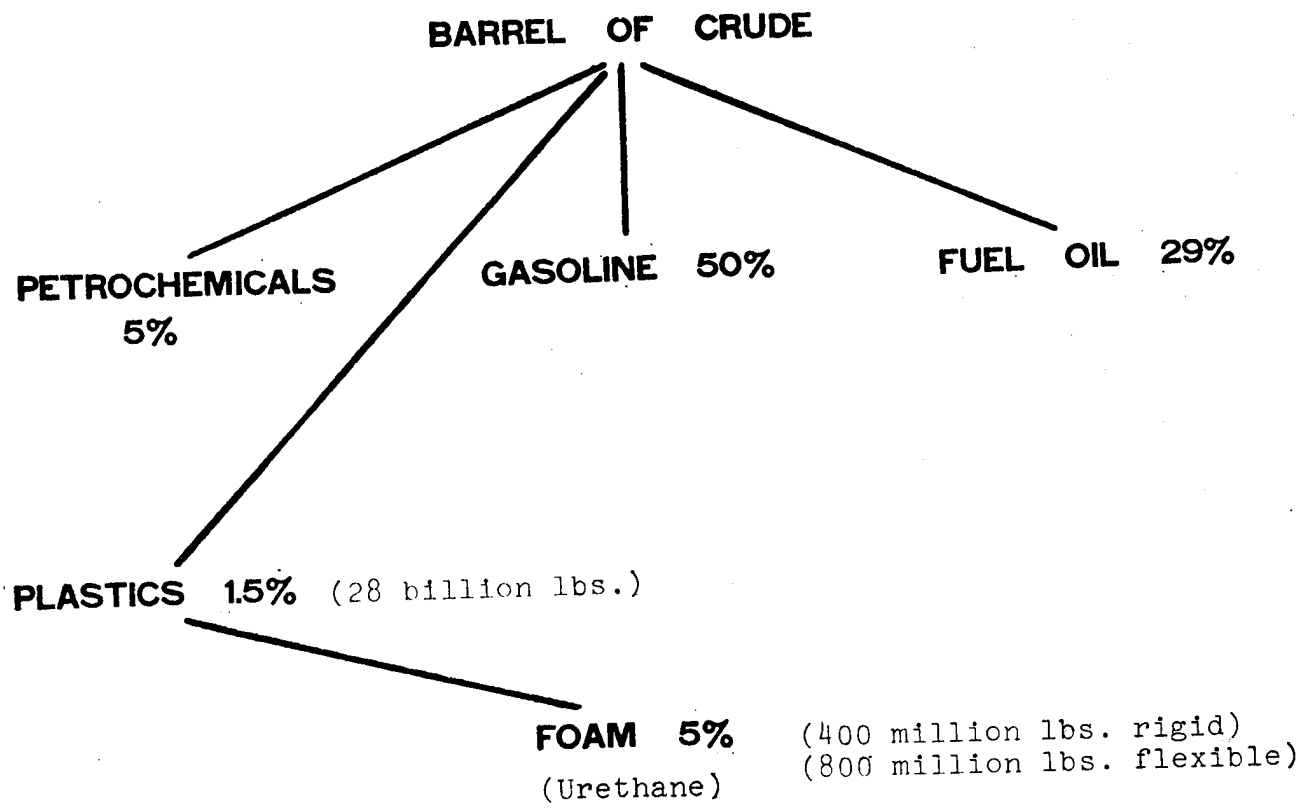
2. Eighty-three (83) percent of the presently mined coal goes to coke production and electric power generation.(Ref.34)

3. All chemicals required for automotive use are directly available from coal or coal by-products except tetrahydrofuran  and ethyl alcohol (C_2H_5OH). (Ref.34)

4. Carbonization of destructive distillation of coal yields, coke, coal tar, light oil, ammonia, sulfate and coal gas. Figure 15 on page 64 shows the products derived from destructive distillation of coal. (Ref. 34)

5. If coal carbonization processes were used exclusively for the plastics industry, roughly $3 \cdot 10^{10}$kg (30 million tons) would be needed annually. (Ref. 34)

CRUDE OIL USAGE



Jet fuels, kerosene, residual oils and lubricants account for the remaining percentage of Crude Oil usage.

Figure 14

Destructive Distillation of Coal

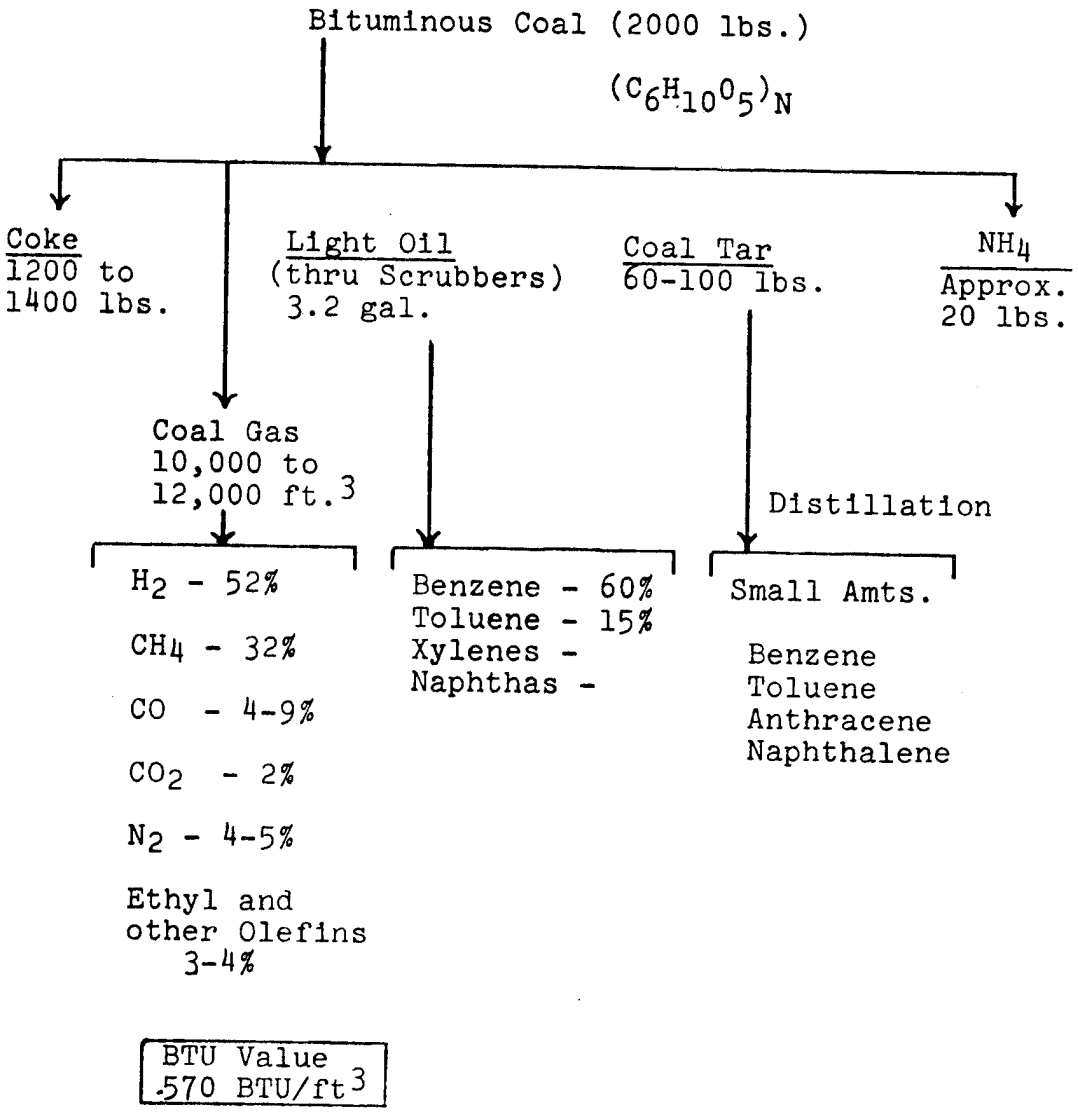


Figure 15

Ninety percent of benzene and toluene from coal is derived from the scrubbing of coke-oven gas. In addition to benzene and toluene, there are approximately 200,000 chemicals derived from coal. (Ref. 33)

3.2.1.2 Oil Shale

Deposits in United States yield about 0.1 m^3 (30 gallons) oil per 1000 kg (1.1 ton) of shale. The 80% inorganic material must be returned to the earth as landfill. (Ref. 34)

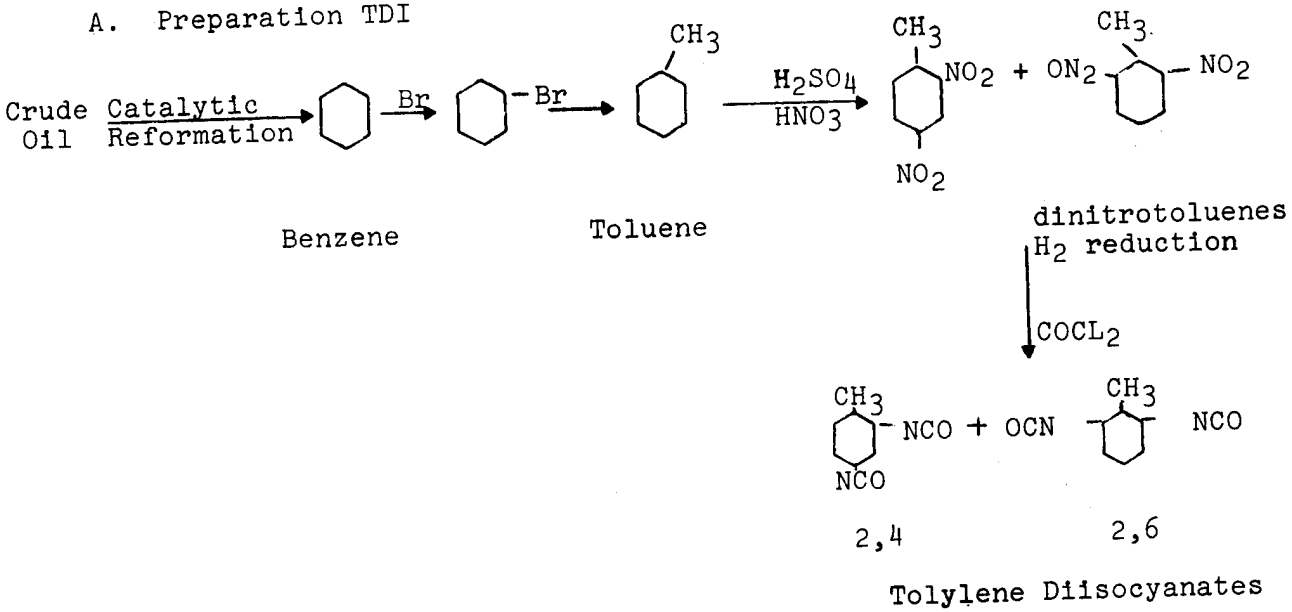
3.2.1.3 Agriculture

Agriculture by-products can be used for ethyl alcohol and furfural. Ethylene can be made from ethyl alcohol. Wheat, corn, sorghum are primary sources of alcohol. (Ref. 34)

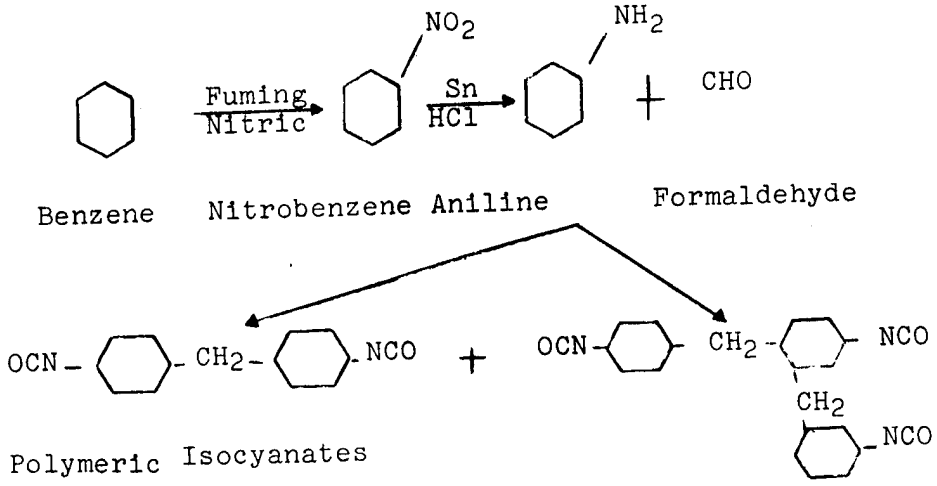
3.2.2 Raw Materials used for Polyurethanes

1. Tolylene diisocyanate (TDI)
2. Polymeric Isocyanates (MDI)
3. Ethylene Oxide
4. Propylene Oxide
5. Initiators (Sucrose, Sorbitol)

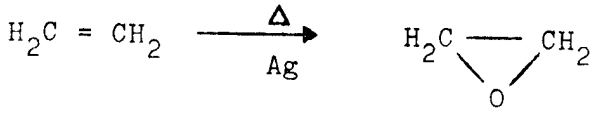
A. Preparation TDI



B. Preparation, Polymeric Isocyanates

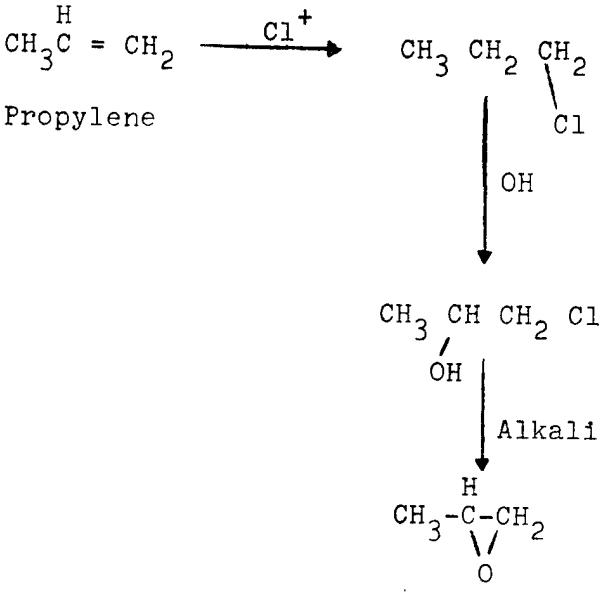


C. Preparation of Ethylene Oxide



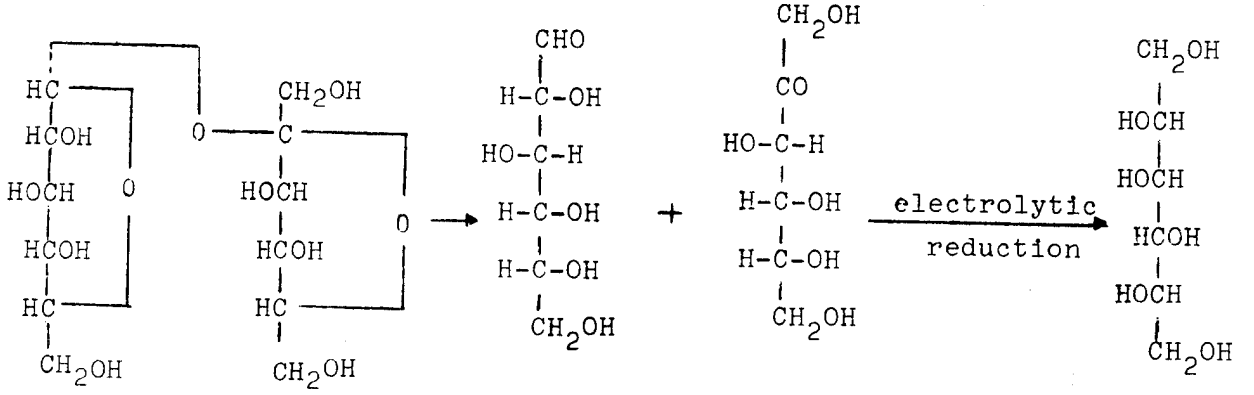
ethylene ethylene oxide

D. Preparation of Propylene Oxide



E. Preparation of Initiators (Sorbitol, Sucrose)

The source of these initiators are from agriculture products (sugar cane, sugar beets and maple sugar.) Sucrose comes directly from these products. The sucrose is then hydrolyzed by acids or enzymes to give one molecule each of glucose and fructose. Glucose is transformed into Sorbitol by electrolytic reduction.



Sucrose d-glucose(+) d-fructose(-) d-sorbitol

3.2.3 Conclusion

There is no global shortage of energy supply. Cost would be a prime factor if petrochemicals were to be made from other sources than crude oil. The raw material costs could be three to four times that of petroleum. It is improbable that coal will be able to compete with gas or oil as a low cost source of feedstock for petrochemicals for many years to come.

A bigger problem than feedstock availability is the inadequate capacity to produce the raw material feedstock due to lack of refinery capacity and petrochemical production due to the deteriorating profit picture. This means even if there is a plentiful feedstock supply there still could be a shortage of raw materials for the plastic industry.

3.3 Factors Involving Physical Properties Important to Crash Energy Management

3.3.1 Sheet Metal Specimen Selection and Fabrication

The data from the literature survey indicated that testing of foam filled metallic structures is necessary to define the effects of manufacturing processes and service environments on crash energy management.

A test specimen was then designed in order to obtain the desired data. A specimen as shown in Figure 16 and Photograph A-7, pages 68 and 69 was selected as the test element. This selection was made as it is a typical cross section of the Fender, No. 1027-2003, taken from Minicar's Drawing No. 1027-2014. See Figure 17, page 70 for section taken from Drawing No. 1027-2014.

Resistance spot welding was selected as the joining process in lieu of pop rivets and arc welding as it is a lower cost joining process and is better adapted to present automotive manufacturing procedures. Materials to be used were 1010 low carbon steel .022 to .024 inches thick, and 5182-0 aluminum alloy .032 inches thick as specified by contract.

Test specimens 6 in. x 8 in. x 30 in. unfilled of the following construction were statically tested.

1. Spot Welded 1010 Steel, .022 to .024 inch thick
2. Riveted 1010 Steel, .022 to .024 inch thick
3. Spot Welded 5182-0 Aluminum, .032 inch thick
4. Riveted 5182-0 Aluminum, .032 inch thick

These tests were made to determine the force required to crush the specimen greater than 50% of its original length. This data is to be used for the 30 mph dynamic tests to obtain specimen crush base line data. See Table 21 and Figure 18, pages 71 and 72 for static test results.

STANDARD TEST SPECIMEN

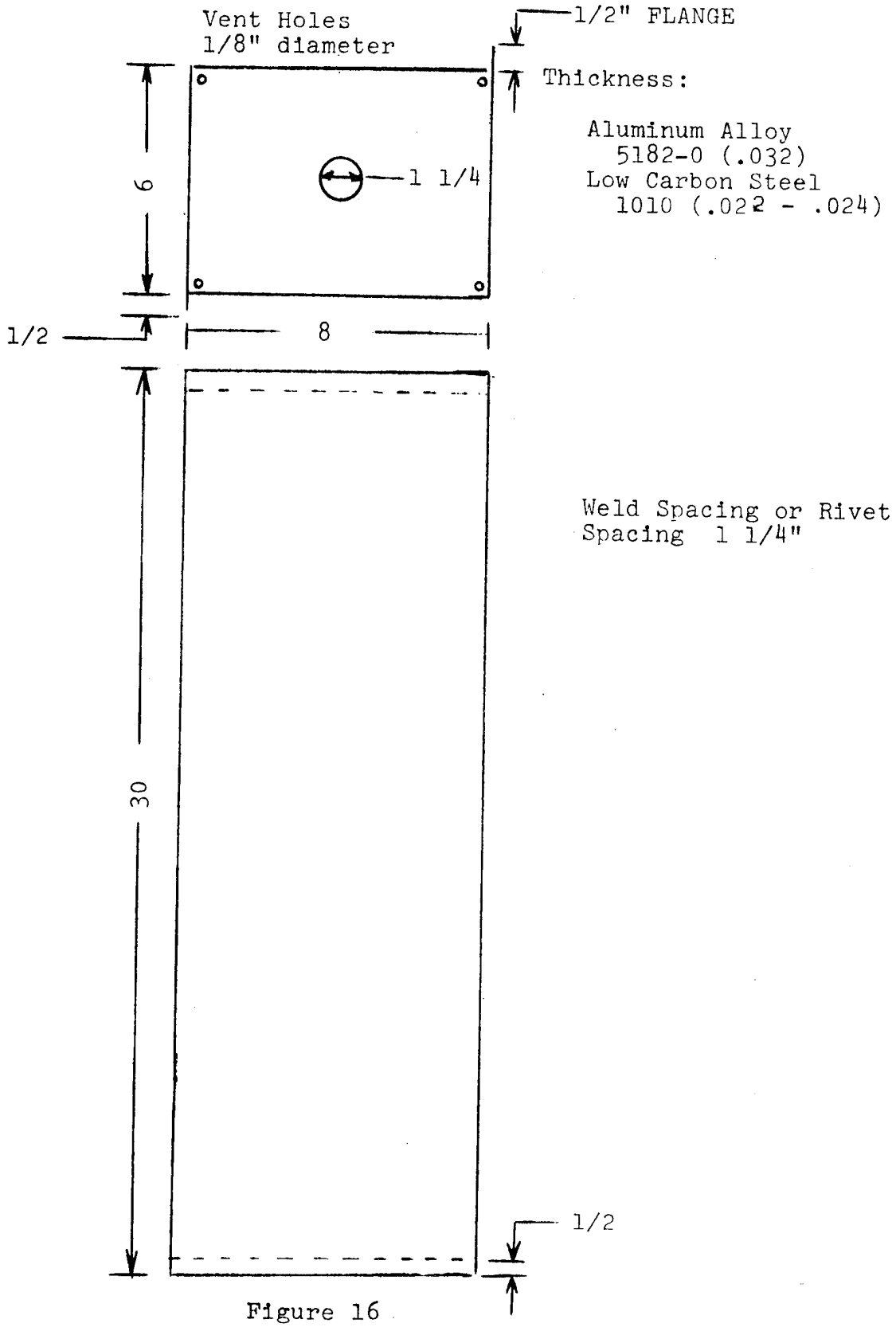
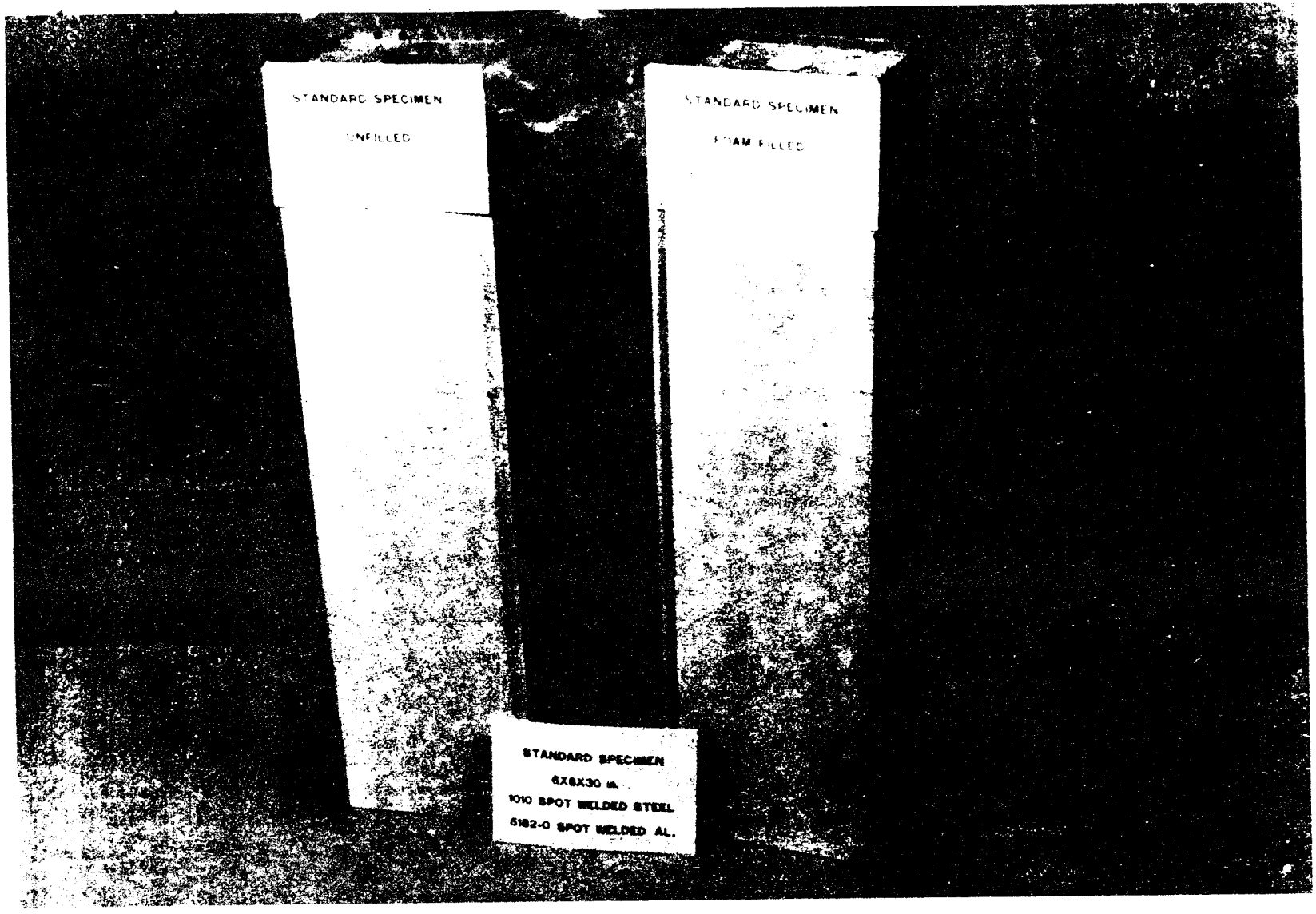


Figure 16



Standard Specimen
6" x 8" x 30"

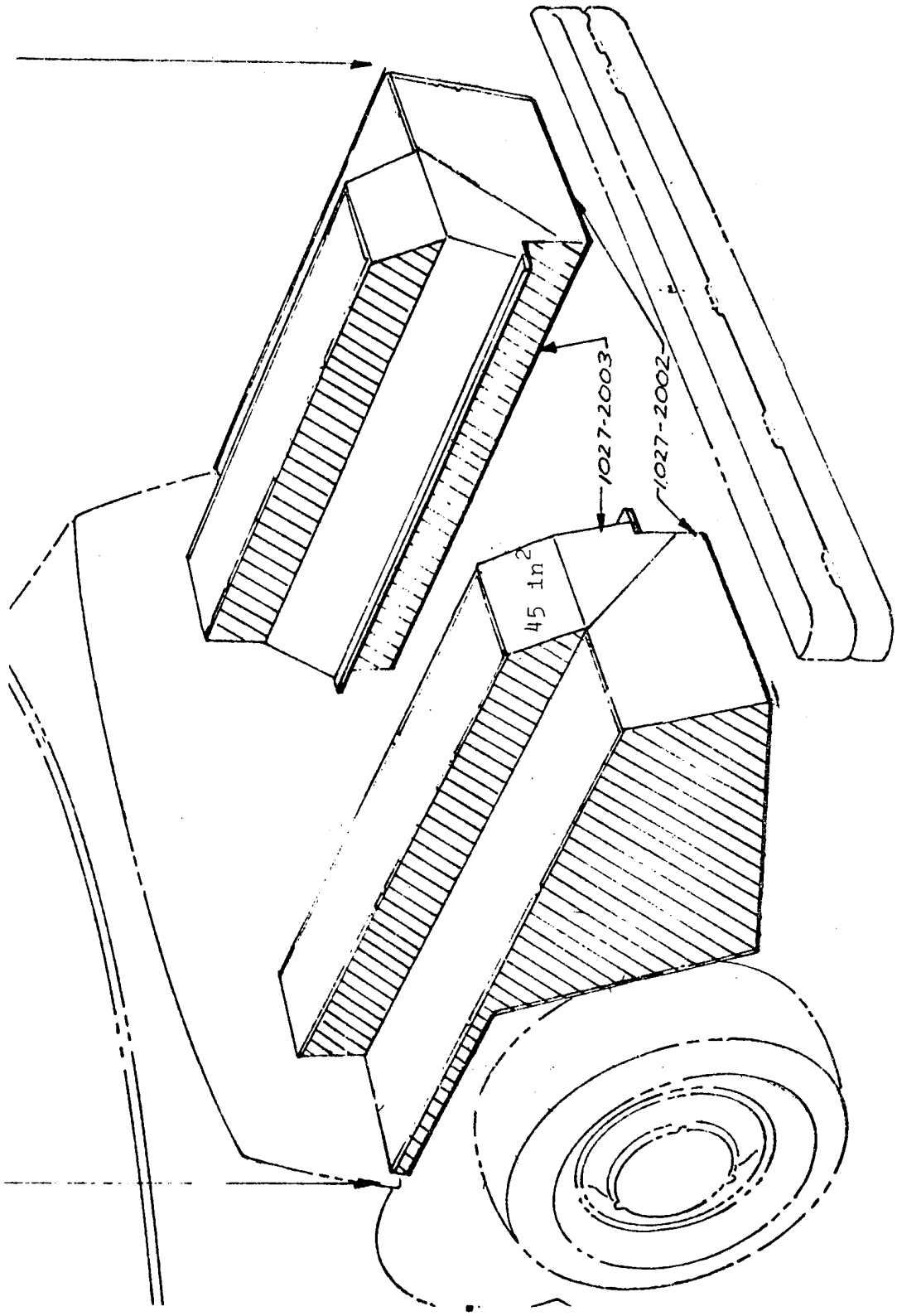


Figure 17

TABLE 21

Static Crush Data
Unfilled Specimens

Sample	Type	Avg. Crush Force (lbs.)
1 SS	Spot Welded Steel	1700
2 SR	Steel Riveted	2109
3 AR	Aluminum Riveted	1855
4 AS	Spot Welded Aluminum	2018

Dynamic tests were made using the same specimen type for comparison. See Table 22, page 73 for results.

Static Crush testing, two inches/minute, indicated an average crush force of approximately 2000 lbs. Based on this data it was calculated that an 88 pound weight with an impact velocity of 30 mph would give approximately 15 inches of crush for an unfilled metal specimen.

It can be seen by the data that the dynamic test crush forces are higher than the static test crush forces. See Table 22, page 73 . See Photograph A-8, page 74 for failure modes. Photograph A-9 on page 75 shows the static and dynamic failure modes of the unfilled specimen.

3.3.1.1 Standard Specimen - Foam Filled Used as Control

In order to compare the effects, if any, on the crush characteristics of the dynamically tested (30 mph) conditioned specimens, a control specimen was required. The following parameters were incorporated for the foam filled control specimen.

1. Foam formulation and density
2. Fill procedure
3. Shell properties
   a. Material (type, designation)
   b. Geometry (length, width, height, thickness)
   c. Fabrication (rivet, welding, spacing)
4. Conditions of Test
   a. Temperature
   b. Impact Speed

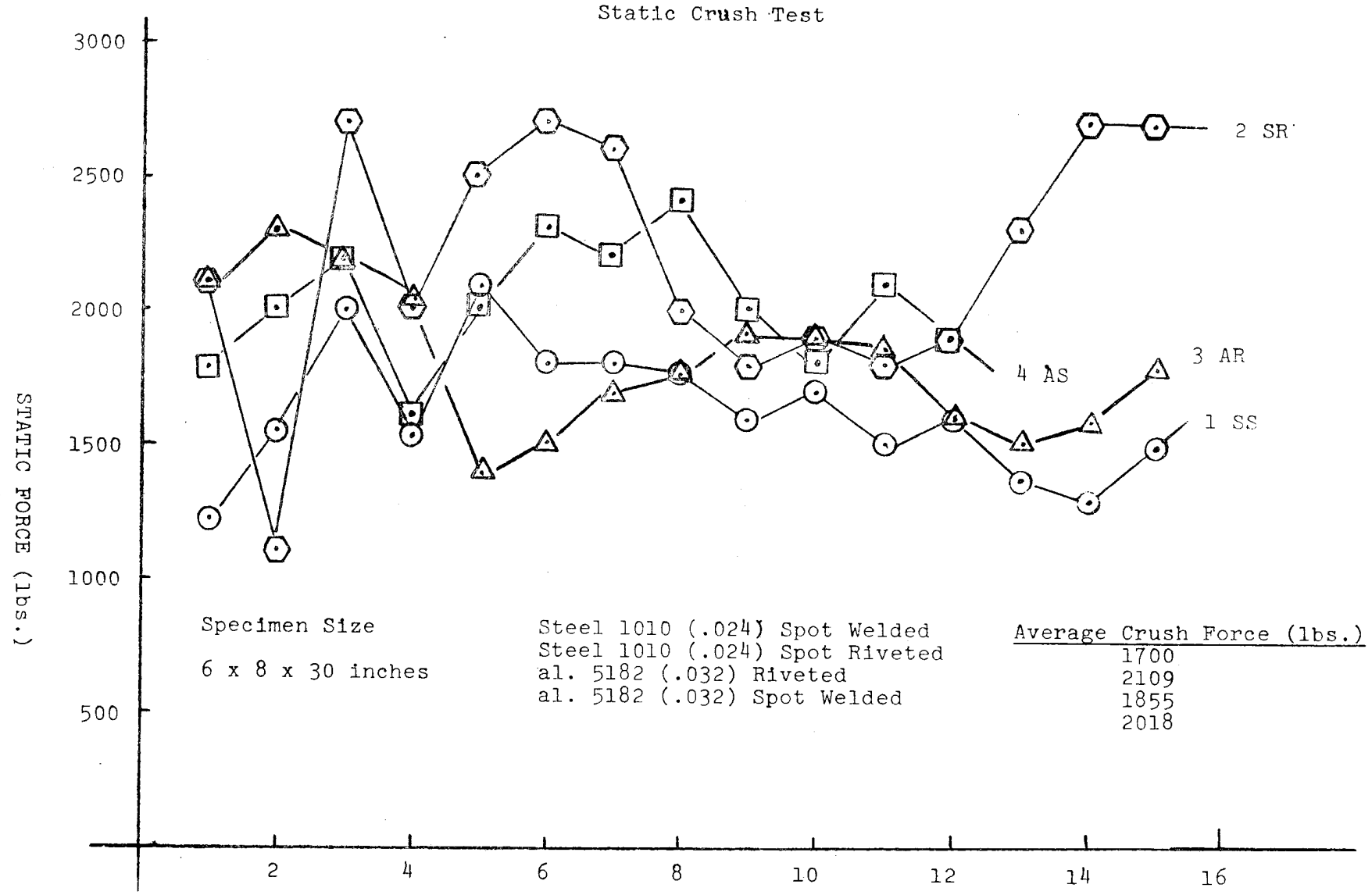

Static Crush Test
3000
2500
2000
1500
1000
500
STATIC FORCE (lbs.)
2 SR
3 AR
4 AS
1 SS
Specimen Size
6 x 8 x 30 inches
Steel 1010 (.024) Spot Welded
Steel 1010 (.024) Spot Riveted
al. 5182 (.032) Riveted
al. 5182 (.032) Spot Welded
Average Crush Force (lbs.)
1700
2109
1855
2018
2
4
6
8
10
12
14
16
CRUSH (inches)

Figure 18

TABLE 22

DYNAMIC TESTING - UNFILLED SPECIMENS

$KE = 1/2\frac{w}{g} V^2$

$w = 88.2$ lbs
$g = 32.2$ ft/sec^2
$V = 44$ ft/sec.

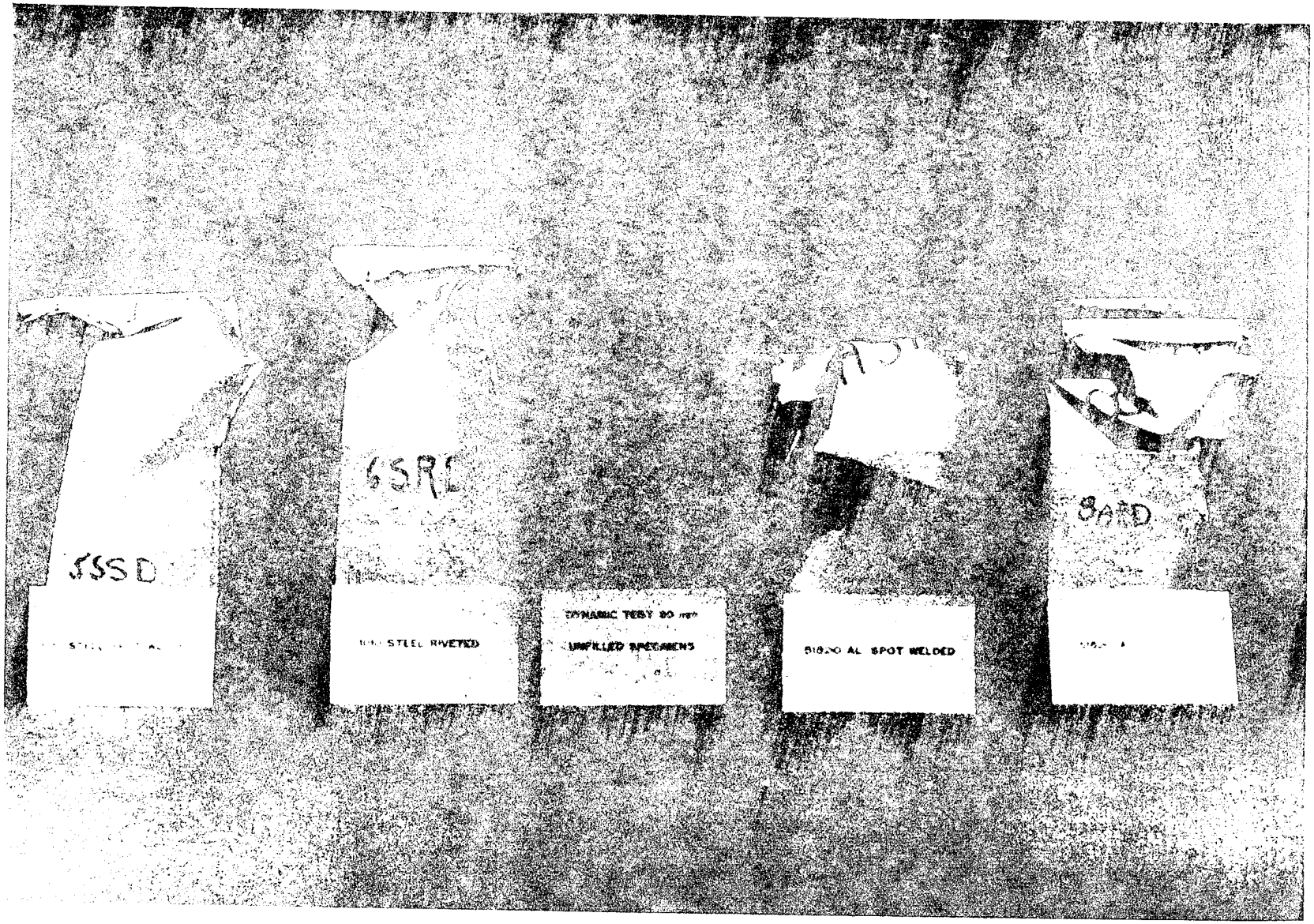
$KE = \frac{88.2 \times (44)^2}{2(32.2)} = 2651.5$ ft-lbs

$= 31818$ in-lbs

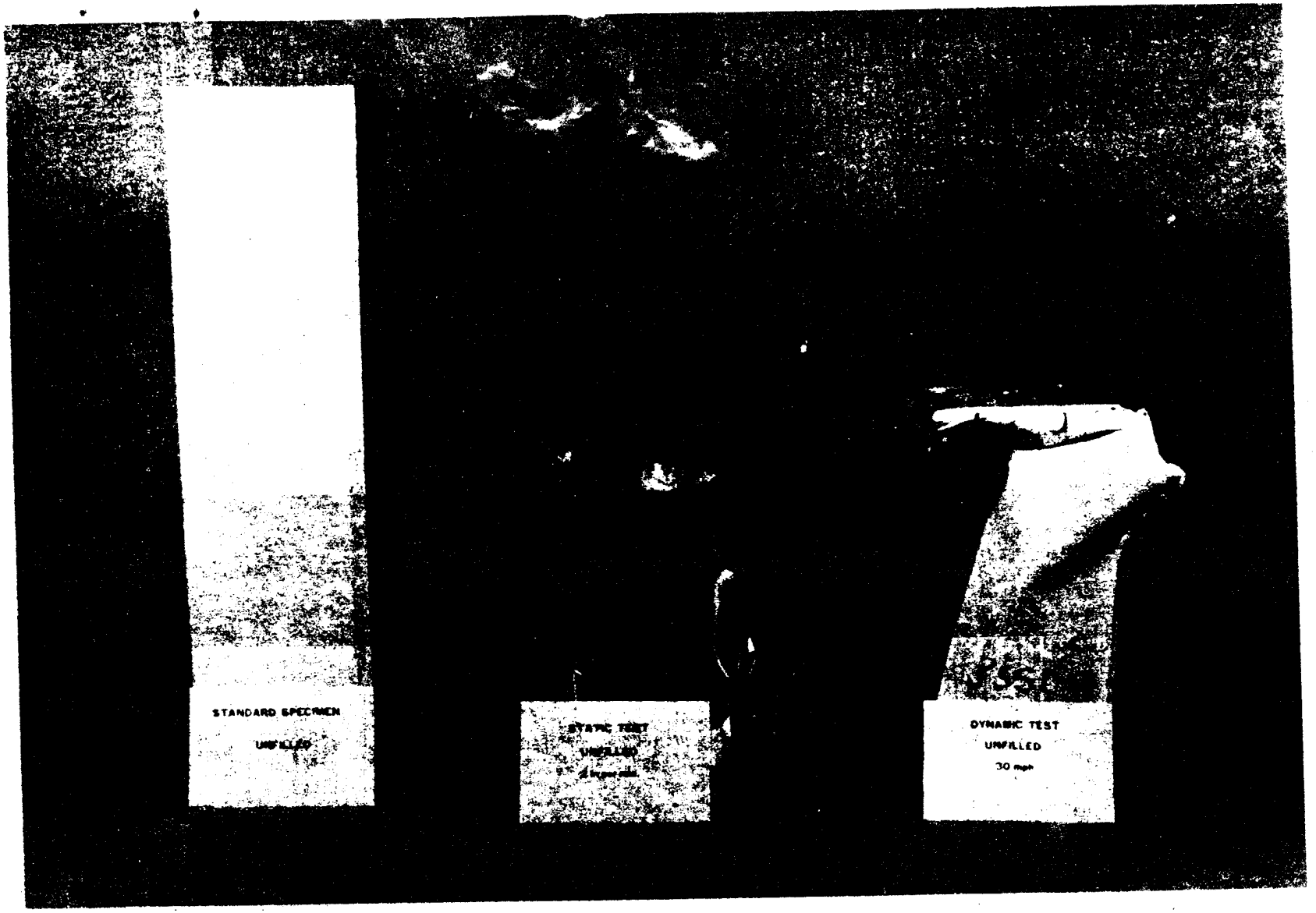
Specimen	Post Test Crush(inches)	Average Crush Force (lbs) Dynamic	Static
Steel Spot Welded	13.125	2424	1700
Steel Riveted	10.78	2952	2109
Aluminum Spot Welded	15.06	2113	2018
Aluminum Riveted	13.84	2299	1855

Steel - 1010, .022-.024 thick

Aluminum - 5182-0, .032 thick



Crushed Dynamic Test Specimens
6" x 8" x 30"



Standard Specimen Static and
Dynamic Tested Specimens

3.3.1.2 Foam "Breakup" NB-237936 A System

When the foam was machine dispensed into the 6" x 8" x 30" specimen the foam had good rise until it reached the 18 - 20 inch mark. The foam then behaved erratically, it continued to rise, but splitting and folding outward until it filled the container. This phenomena is known as "breakup". The foam first introduced from the mix head reaches its get point while the last form introduced is still rising causing the "breakup". See Photograph A-10, page 77.

It wasn't known what effect this phenomena would have on the crush characteristics of a foam filled metallic specimen. An attempt was made to eliminate the foam "breakup" by altering the foam system and changing the shot size. This was to be done in the following manner.

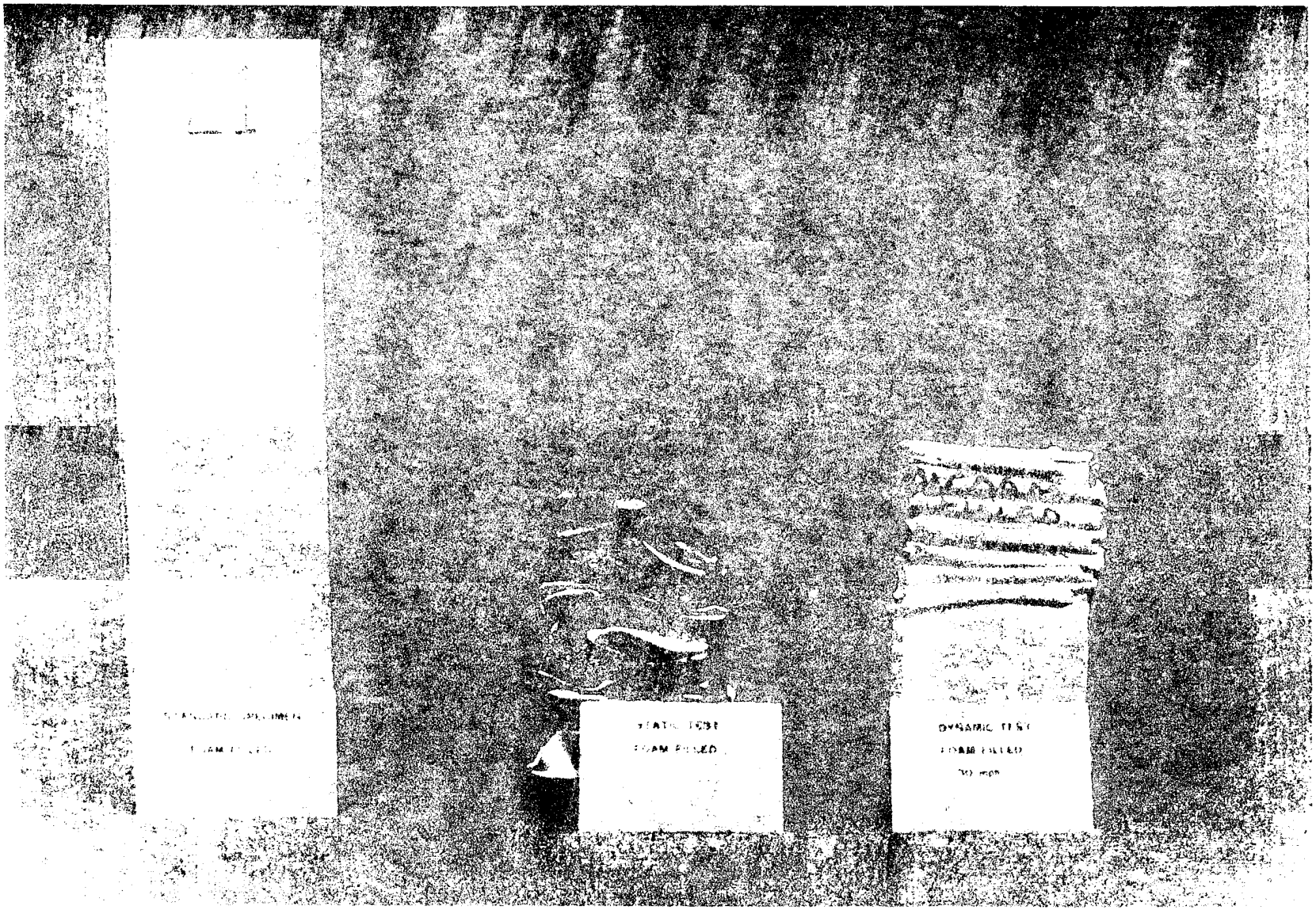
1. Frothing the NB-237936 A system with 5% Freon 12.
2. Altering the catalyst system by making it less reactive.
3. Pouring the foam into a specimen at a 45° angle or less.
4. Pouring two shots in lieu of one with same quantity of foam.

In spite of these efforts the foam "broke up" in all cases regardless of the shot size or fill angle.

Testing of foam filled specimens statically was then performed to determine the loads required to crush the specimens at least 50% of its original length. This data is to be used to determine the drop weight required in the dynamic test.

Static crush data for foam filled specimens are in Table 23, page 79 . Photograph A-11 page 78 , shows the static and dynamic failure modes of foam filled specimens.

Foam "Break up"



Failure Mode, "Static vs.
Dynamic" Foam Filled Specimens

TABLE 23

Static Crush Data

Sample	Type	Average crush Force (lbs.)	Packed Density lbs/ft^3
Specimen 1 6 x 8 x 24	Foam Filled 1010 Steel	4285	3.02
Specimen 2	Foam Filled 1010 Steel	3866	2.54
Specimen 3 6 x 8 x 27	Foam Filled 1010 Steel	3451	2.87
Specimen 6 6 x 8 x 15	Foam Filled 1010 Steel	3953	2.57
Specimen A 6 x 8 x 15	Foam Filled 1010 Steel	3150	2.3
Specimen ISS 6 x 8 x 30	Unfilled 1010 Steel	1700	Unfilled

Dynamic tests were then made to determine the effect the foam "break up" had on the crush characteristics of the foamed specimen. The following specimens were made and tested dynamically.

Specimen No.		
5	NB-237936 A-2 Slow Catalyst	One Pour - Vertical
9	NB-237936 A Froth, 5% Freon 12	One Pour - Vertical
10	NB-237936 A Froth, 10% Freon 12	One Pour - Vertical
11	Froth Gen. Latex XR-338 Commercial	One Pour - Vertical
12	NB-237936 A	One Pour - Vertical
13	NB-237936 A	One Pour - Vertical
14	NB-237936 A	Two Pours - Vertical
15	NB-237936 A	Two Pours - Vertical
16	NB-237936 A	One Pour - @ 45°
17	NB-237936 A	One Pour - @ 45°

The specimen and procedure for each test was as follows for all specimens which were tested unless otherwise noted.

1. Specimens

6 in. x 8 in. x 30 in. .022 - .024 thick, 1010 spot welded steel. Primed with red oxide primer.

2. Test Conditions (Dynamic) and Procedure

The specimens to be tested were fixtured on a steel plate which in turn is supported by three load cells. The specimens were struck by a weight having an impact velocity of 30 mph. The drop weight (228 lbs.) was sufficient to produce greater than 50% crush. A continuous plot of crush force vs time was obtained for each specimen. Final crushed lengths of the specimens were recorded. High speed (1000 frames/second) motion pictures and a computer analysis were obtained on representative tests to allow detailed study of the crushing modes.

Computer analyses on representative specimens were made to obtain curves for.

Deceleration/Time, Deceleration/Displacement, Velocity/Time, Velocity/Displacement, Displacement/Time, Force/Time and Force/Displacement curves. The other tested specimens were measured for average crush forces. Data was filtered at 1000 and 300 Hz.

Table 24 on page 82 is a tabulation of the average crush forces taken by Post Test measurements and the crush forces taken by Peak Crush from the Velocity/Displacement curve when $V_F = 0$.

The crush results from the dynamic test show that the "breakup" didn't appear to affect the crush mode and crush distance of the one shot, vertical pour specimen. This specimen failed in a preferred manner and thus was selected for establishing a standard control specimen.

Photograph A-12 on page 84 illustrates the different modes of failure of the tested specimens. The two pour system shows a failure in the center where the second pour and first pour joined. Testing of NB-237936 A foam system show that the compressive values of foam are of a less value at the top of foam rise, than at the bottom. The two pour results in a weak area at the foam interface of the first and second pours, thus accounting for the failure at the center.

Movies show that the foamed structures store some of the impact energy as the drop weight rebounds approximately six inches after impacting the specimen.

TABLE 24

Average Crush Force (lbs)

$KE = KE = \frac{wV^2}{2a}$

w = 228 lbs

V = 44 ft/sec

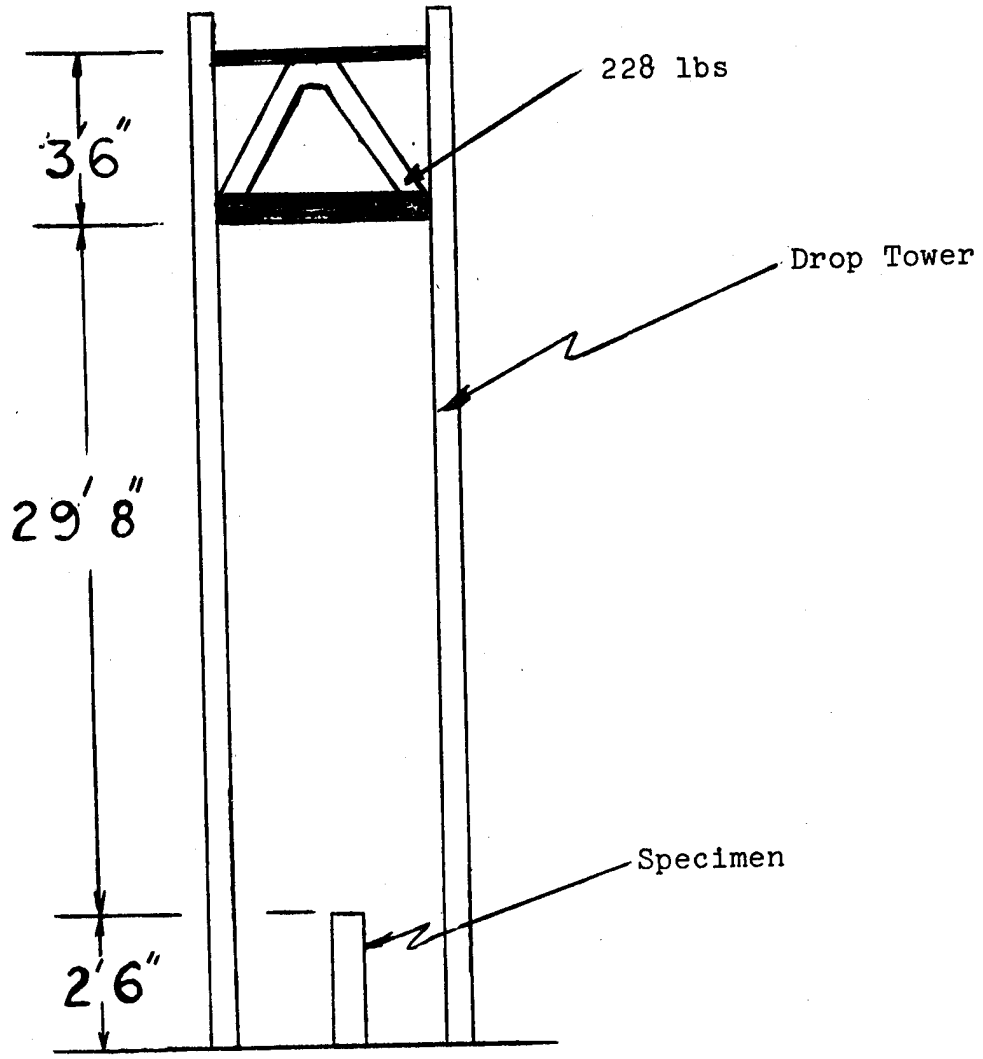
a = 32.2 ft/sec^2

$KE = \frac{228 \times 1936}{2(32.2)} =$ 6854 ft-lbs

82,250 in-lbs

Specimen	Type	Inches Crush: Peak Dynamic Crush Computer Program $V_F = 0$	Inches Crush: Post Test Measured Crush	Peak Dynamic Average Crush Force (lbs)	Post Test Average Crush Force (lbs)
5	Slow Cat.	15.42	14.63	5334	5622
9	Froth 5%	---	15.9		5172
10	Froth 10%	---	18.6		4422
11	Froth XP-338	16.77	15.69	4904	5242
12	1 Pour Vert.	---	---		
13	1 Pour Vert.	15.42	15.31	5334	5372
13a	1 Pour Vert.		15.30		5376
13b	1 Pour Vert.		15.06		5462
14	2 Pour Vert.	15.36	14.88	5355	5528
15	2 Pour Vert.	---	14.83		5660
16	1 Pour 45°	16.42	13.63	5009	6034
17	1 Pour 45°	---	13.44		6120

Calculated V_F

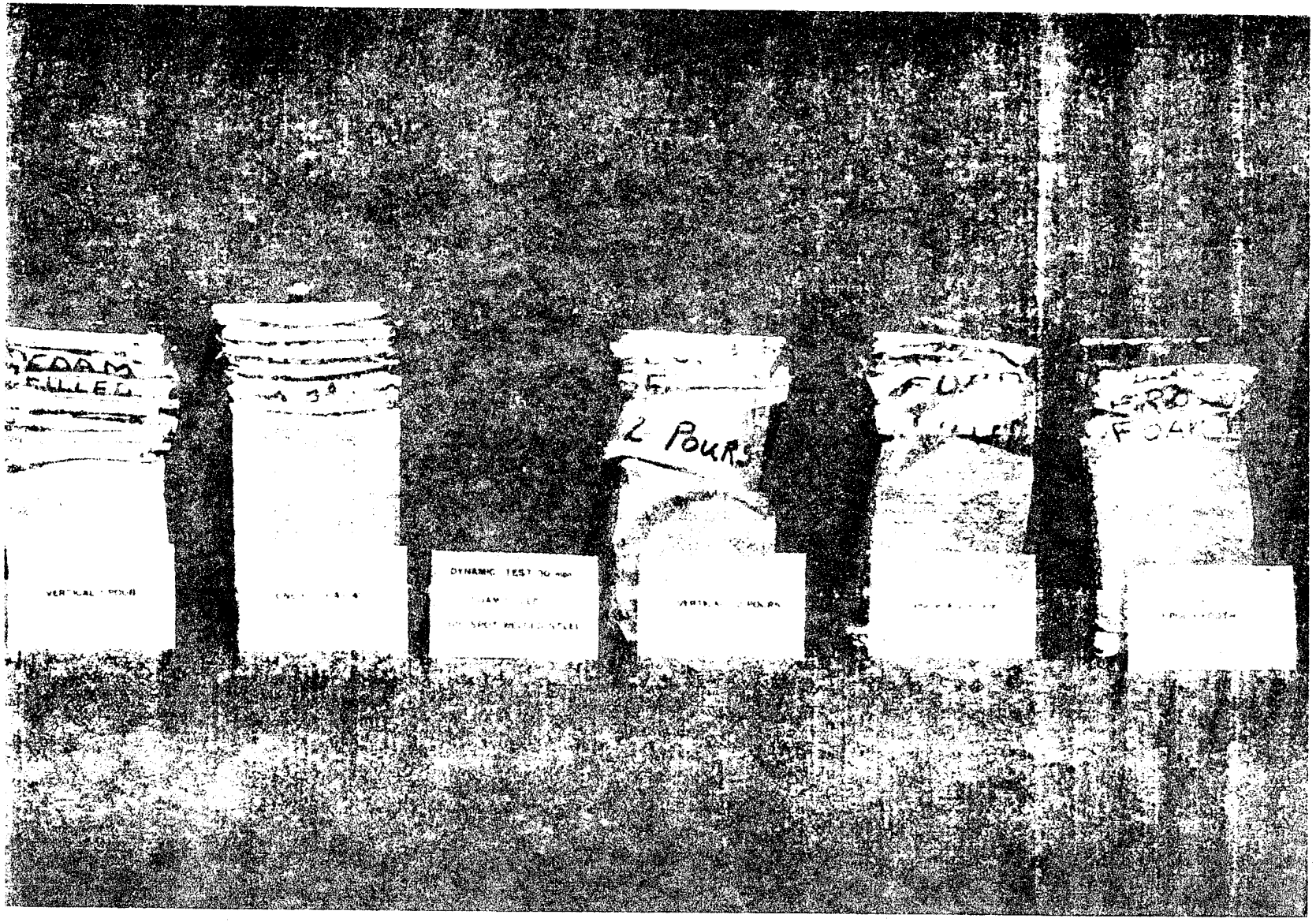


$V_F^2 = V_I^2 + 2as$ $\quad V_I^2 = 0$

$V_F = \sqrt{0+2(32.2 \times 29.67)}$ $\quad a = 32.2 \text{ ft/sec}^2$, $s = 29'8''$ inches

$V_F = 43.7$ ft/sec.

Figure 19



Failure Mode of Different Foam Systems

3.3.1.3 Compressive Strength of Foam Taken from Foamed Specimen

Foam samples, 3 x 2 x 2 inches, were machined from specimens foamed in the vertical position and at a 45° angle. These specimens were filled under the exact same conditions as the ones dynamically tested in Table 24, page 82.

This test was performed to determine the variation of the compressive strength of the foam at the beginning and end of rise due to the foam "breakup" mentioned previously.

Data in Table 25 shows that the compressive strengths are similar in both specimens, i.e., less at the top of foam rise than at start of foam rise.

TABLE 25

Specimen	Comp. Str. psi foam rise		Comp. Str. psi fpam rise	
Foamed	Start of Foam Rise	Top of Foam Rise	Start of Foam Rise	Top of Foam Rise
Vertical Specimen No. 39	37.5	27	29	13
Foamed at 45° Specimen No. 40	42	31.5	31	24

3.3.1.4 Preparation of Specimen for Control

1. Steel specimen walls were primed with red oxide paint. Tests show that the foam has good adhesion properties and that cohesive failures resulted in all tested specimens. That is, failure of foam not of adhesion.

2. Specimens were fixtured in vertical position.

3. Specimens were spot welded.

4. One shot (13 sec), 963 grams ± 10 grams of NB-237936A foam was dispensed by Canon C7 foam dispenser into the specimen.

5. Specimen was removed from the fixture after 15 minutes.

6. The specimen cured a minimum of 72 hours at ambient temperature prior to test. Table 26 , page 86, gives the results of the standard specimen.

TABLE 26

Standard Specimen Crush Test

Specimen No.	Post Test Measured trush (inches)	Peak Dynamic Crush From Computer Program $V_F - 0$
19	15	15.795
20	13.7	-
21	13.5	
22	13.7	15.55
23	13.2	-
24	13.4	-
25	13.4	14.60
13	15.31	15.42
13a	15.30	-
13b	15.06	-
	14.16 Avg.	15.34 Avg.

The failures all started at the top of the pour in preferred crush type pattern. A slight crease was noticed at the base on some specimens. See Photograph A-13 on page 88 for crush mode and specimen consistency.

The differences in the post test measurements in Table 26 can only be explained due to scatter or the variations in the following as all other conditions were constant:

1. Variation in material strength of 1010 steel. Tests show that the yield strength varied from 31,192 to 35,779 psi.

2. Variation in the compressive strength of the foam system.

Tests show that in this foam system there is a difference in the compressive strength at the start of foam rise (35.5 to 41 psi) and at the top of foam

rise (24.5 to 29 psi).

3. The effect buckling, creasing, and bulging of specimen below the crush area has on the measured crush distance.

Based on the consistancy of the failure mode and crush data, these specimens will be considered as the standard specimen and used as the comparative basis for crush distance and mode of failure of the conditioned specimens. All specimens which underwent testing in this program were foamed and tested under the same conditions as the control unless otherwise noted.

3.3.1.4.1 Explanation of Peak Dynamic Crush Discrepancy

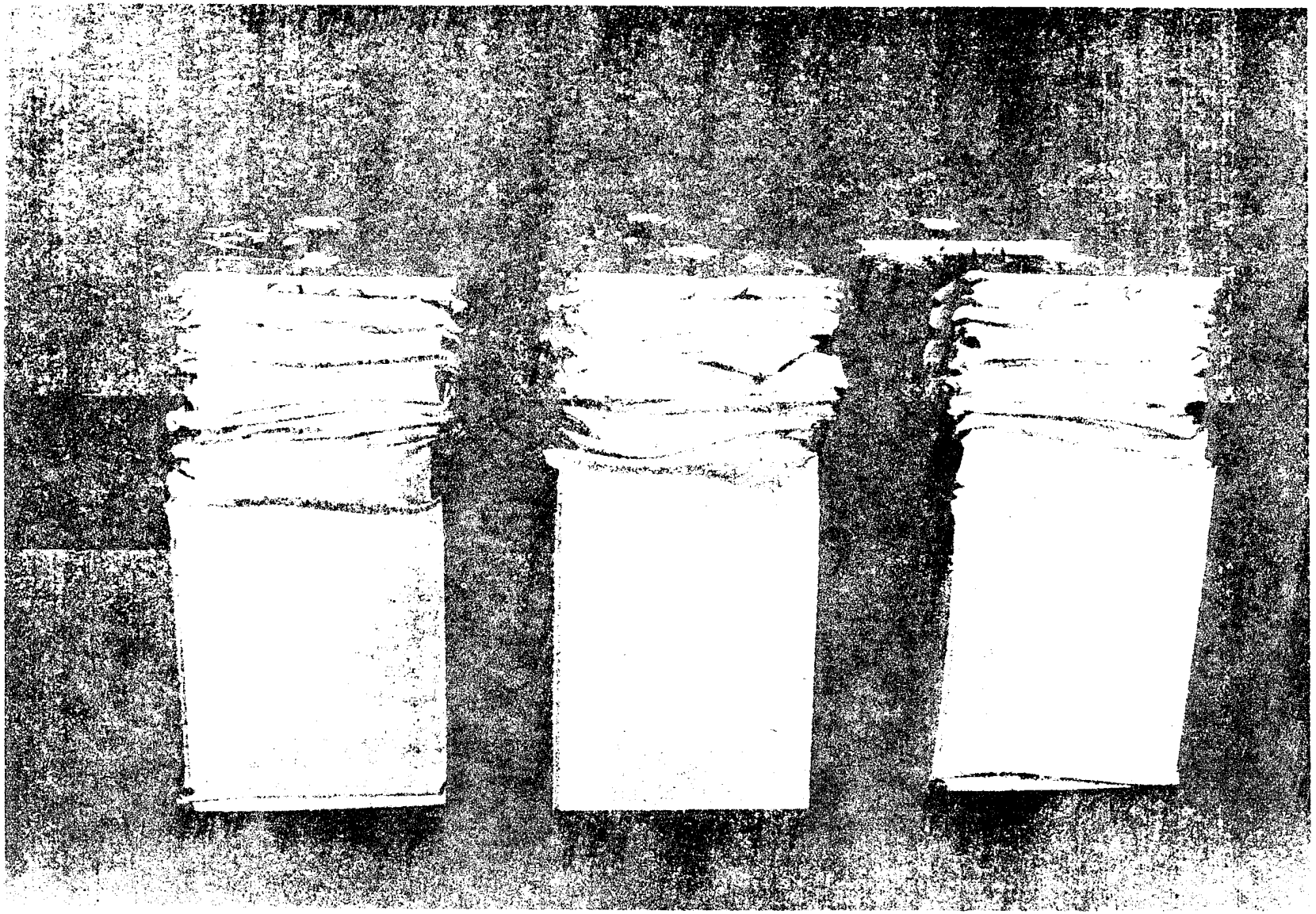
Four Specimens Nos. 29, 68, 77 and 79 had higher post static crush measurements than the peak dynamic crush taken from the program analysis when the final velocity ($V_F = 0$). High speed movies show that the specimens have some spring back after the drop weight rebounded(1 1/2 to 2 inches) except in the extreme temperature tests, -20°F (<1 inch) and @ 300°F (>2 1/2 inches). This indicates that there is some error that is introduced into the computer program. This error can only be explained by accuracy of the input data. The accuracy of the input data depends on the following:

1. Chart speed variation;
2. Resolution of the graphics tablet;
3. The human factor.

Slight variations in the chart speed when recording the accelerometer data creates a difference in the time scale from test to test.

A resolution of one-hundredth of an inch (0.01 in) is the highest degree of accuracy obtainable when digitizing data using the graphics tablet. This limitation can cause neighboring data points to be indistinguishable. The pulser wires of the graphics tablet defines a grid that runs horizontally and vertically, thus any rotation of the chart paper from the horizontal axis will induce a slight error when digitizing the data. The final source of error is due to the placing of the digitizer when using the graphics tablet and is completely dependent on the operator.

These three sources of variation defined above are independent of one another and, therefore, may be additive. Hence a slight variation in chart speed, plus close data points and below par digitizing of the operator can create a sufficient difference between the actual data and computer input and give an erratic peak dynamic crush. The error introduced based on post measured specimens, movies and results from computer analysis may be approximately 10%.



Failure Consistency of Standard
Foam Specimen

3.3.1.5 Material Strength - 1010 steel and 5182-0 Aluminum per ASTM-E8-69 used for test specimens.

TABLE 27

Specimen	Condition	Yield* (0.2% offset) psi	Ultimate Tensile Strength psi	Elongation (%) in 2"
1010 steel	As received	32,721	45,565	37.5
1010 steel	7 days at 300°F, 8 hrs. on-16 hrs. off	35,721	44,867	41
1010 steel	14 days at 300°F, 8 hrs. on-16 hrs. off	34,500	43,333	40
5182-0 alum.	As Received	19,137	40,337	20

* Average - three specimens

Test results indicate that the yield strengths of 1010 steel when exposed to 300°F for seven and fourteen days, eight hours on and sixteen hours off did not decrease from the ambient test data.

These tests were made to determine if the exposure of the 1010 steel to 300°F temperatures for short and long terms affected the material strength thus affecting the crush mode and crush distance of the foamed specimen. Since the values did not change, any change in the failure mode would not be due to the sheet metal but attributed solely to the conditioned foam.

3.3.2 Temperature effect on crush properties

3.3.2.1 High Temperature - @300°F

Thermocouple leads were soldered to the side of the specimen, and attached to potentiometer. Specimens were conditioned at 300°F for six hours prior to test.

The specimen was removed from the oven, placed on the drop tower base plate and tested immediately. A 20 second time lapse occurred until impacting occurred. The sheet metal temperature dropped from 300°F to 275°F at impact.

The foam temperature was taken by means of a four inch probe, inserted into the center. The temperature of the core was 298°F at test. Results of tested specimen are as follows.

Specimen No.	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_p = 0 (inches)
57	13.75	16.01
58	16.8 (split open)	19.43
59	13.1	17.77
	Avg. 14.55	Avg. 17.74

Specimen Nos. 57 and 59 failed in similar manners. Crushing started initially at the top, then at the bottom and then bulging in the center. Specimen No. 58 started crushing at the top and then the spot welded seam split thus causing a peeling action. Hi-speed movies show an approximate 3 inch spring back of these specimens.

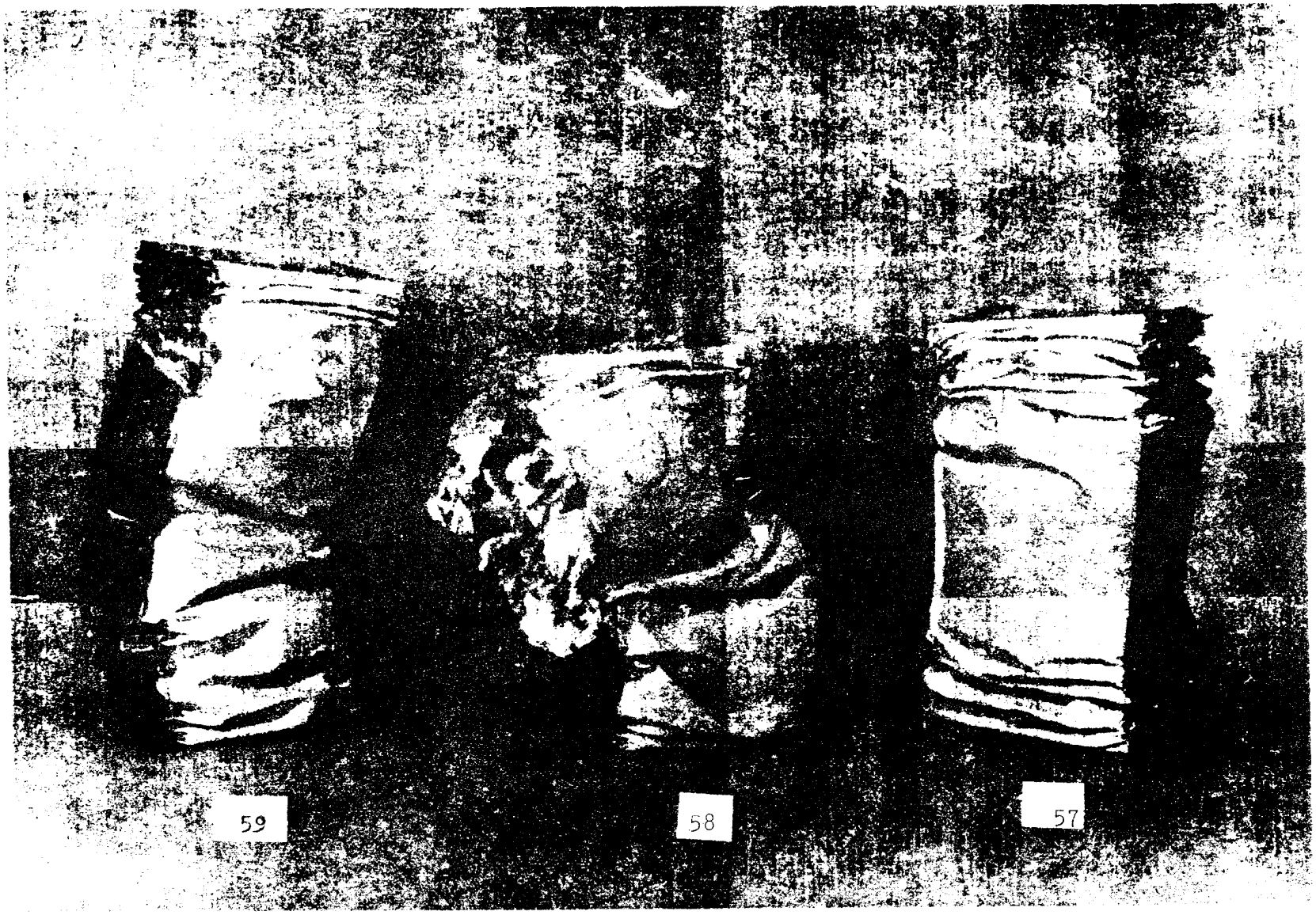
See Photograph A-14 on page 91 for failure modes of the tested specimens.

3.3.2.2 Short time exposure at 300°F, eight hours on, sixteen off for seven days. Specimen Nos. 71 and 72.

Specimens were weighed and had center dimensions taken prior to conditioning.

The specimens were then placed in an oven for eight hours. At the end of eight hours the oven was turned off, doors opened and the specimen allowed to cool off in the oven. The same procedure was used for seven days.

The specimen expanded .65 inches (average) at the centers on the eight inch side and .56 inches at the center on the six inch side. Results of the dynamic test are as follows:



Failure Mode of Specimen at 300°F

Specimen No.	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_F = 0 (inches)
71	13.1	14.25
72	12.93	-

See Photograph A-15 on page 93 for crush mode.

Short time exposure of the foamed specimen at 300°F showed a lesser crush distance of the specimen than the standard when tested under the same conditions. The foam may have completely cured (additional cross linking) which increased its' compressive strength. Previous test on the unconfined foam indicated that the compressive strength increases in this foam system when exposed to higher temperatures for a short period of time.

3.3.2.3 Long Time Exposure at 300°F, 8 hours on, 16 hours off for 28 days, Specimen Nos. 73 and 74.

The specimens were conditioned for 28 days in the same manner as the short term exposure 300°F specimens.

The specimens expanded .84 inches (average) at center of the 8 inch side and .8 inches (average) at the center of the 6 inch side. Results of dynamic test are as follows:

Specimen No.	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_F = 0 (inches)
73	21.4	24.1
74	21.2	

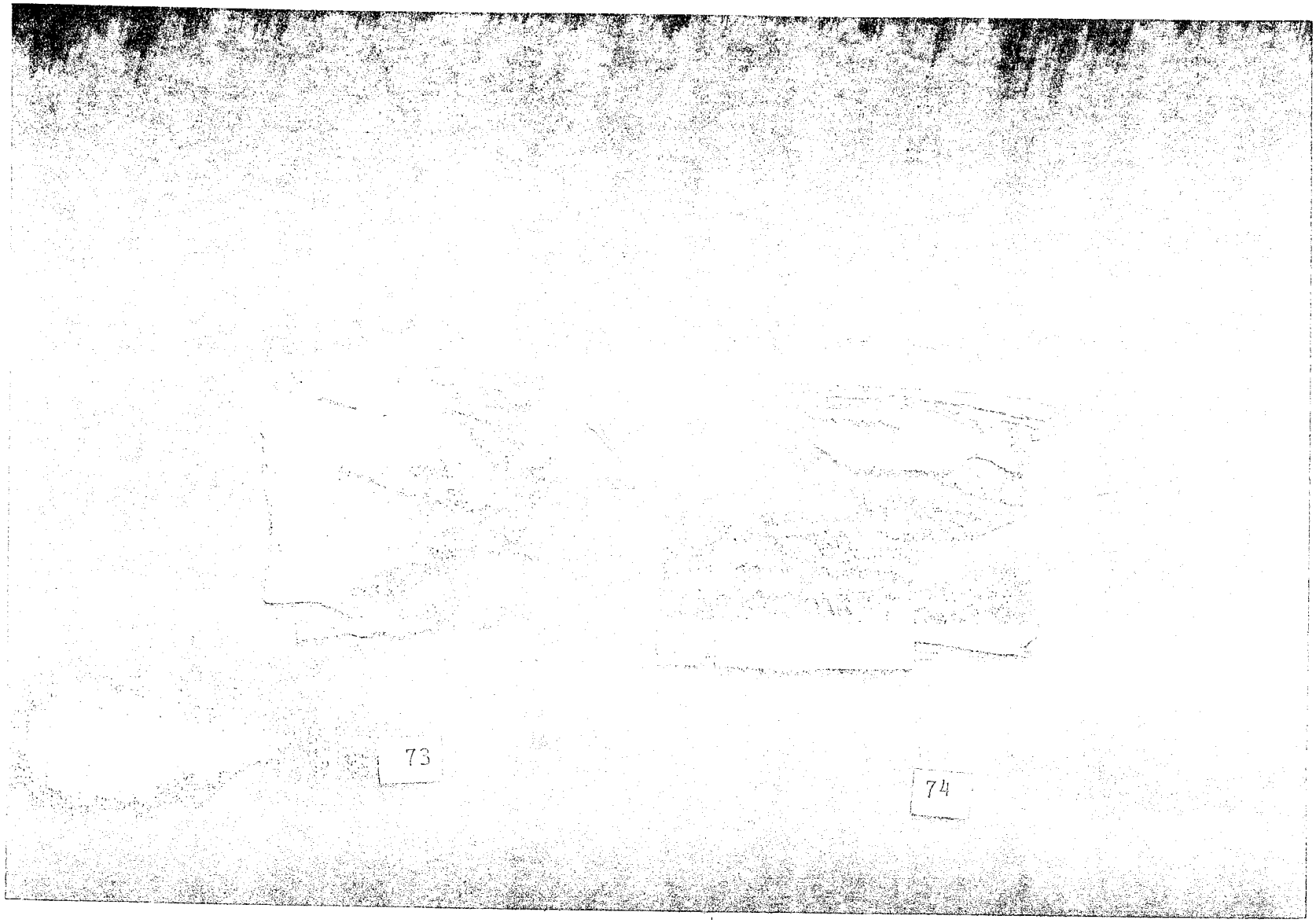
The seams opened up completely, the foam was discolored and powdery showing foam degradation. See Photograph A-16, page 94.

3.3.2.4 Short and long time exposure, one surface at 300°F, top surface at ambient, 8 hours on, 16 hours off. Specimen Nos. 64, 65, 66 and 67.

Specimens were measured at their centers prior to exposure. The specimens were then placed on a 300°F heated platen.

Temperatures were taken at the top surface every 4 hours, the core temperature was taken by a 4 inch probe inserted into the foam through the pour hole every four hours.

Failure Mode of Specimen After
Exposure at 300°F for 7 days



Failure Mode of Specimen After
Exposure at 300°F for 28 days

The platen remained heated for eight hours and off for sixteen hours.

Specimens 64 and 65 were removed for test after seven days.

Specimens 66 and 67 were removed for test after a 28 day exposure.

The top surface temperature never reached higher than 105°F. The core temperature varied from 160 - 170°F over an eight hour period.

Dimensional Change
300° One Side, Ambient Top Side

Specimen	6 inch Side Avg.	8 inch Side Avg.
7 days (Nos. 64 & 65)	+ .042	+ .202
28 days (Nos. 66 & 67)	+ .065	+ .199

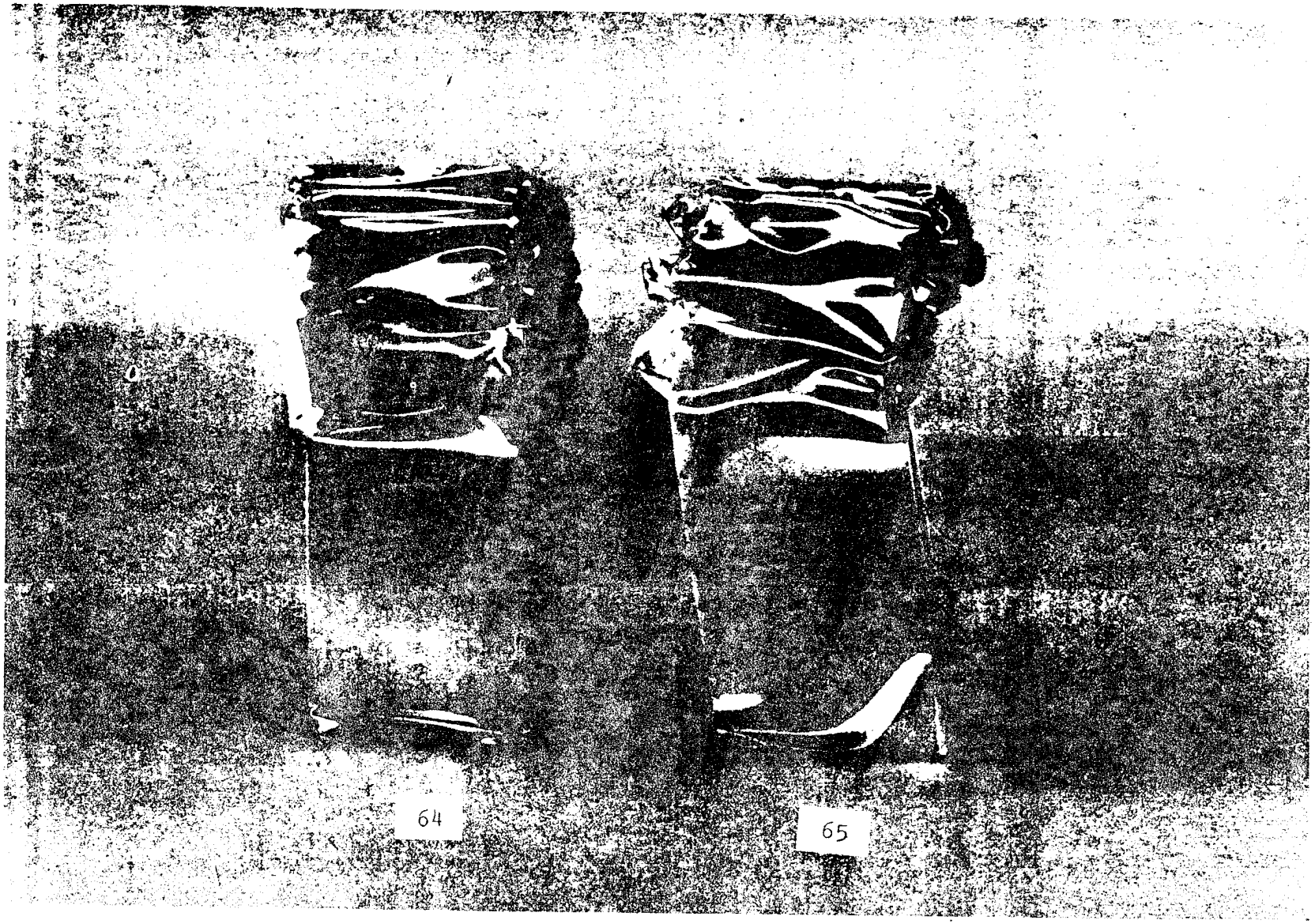
Dynamic Test crush results are shown below:

300°F One Side, Ambient Top Side
7 and 28 Day Test (Tested @72°F)

Specimen No.	Condition	Post Test Measured Crush (inches)	Peak Dynamic Crush Computer Program V_F = 0 (inches)
64	7 days	13.94	14.90
65	7 days	14.3	
66	28 days	14.25	
67	28 days	14.80	17.2

Measured crush results indicate very little differences for the short and long term exposure for post test crush but significant for peak crush for long exposure.

See Photographs A-17 and A-18 on pages 96 and 97 for modes of failure.



Failure Mode of Specimen After
Exposure at 300°F One Side, 7 days

Failure Mode of Specimen After
Exposure at 300°F One Side, 28 days

Table 28 shows the summary of the High Temperature dynamic crush tests. Figure 20 on page 99 shows the Crush Ratio Comparisons in bar chart form.

TABLE 28

Summary High Temperature (300°F)

Specimen Nos.	Condition	Post Test Measured Crush (inches)	Average Peak Dynamic Crush Computer Program $V_F = 0$ (inches)
19 - 25	Control	14.1 (Avg.) (13.2 to 15.3)	15.34 (Avg.) (14.6 to 15.8)
57, 58, 59	Tested at 300°F	14.55 (Avg.) (13.1 to 16.8)	17.75 (Avg.) (16.0 to 19.4)
71, 72	7 days @ 300°F 8 hrs. on, 16 Hrs. off (Tested at 72°F)	13.0	14.25
73, 74	28 days at 300°F 8 Hrs. on, 16 Hrs. off (Tested at 72°F)	21.3	24.1
64, 65	7 days - 300°F one side; 8 Hrs. on, 16 hrs. off (Tested at 72°F)	14.12	14.9
66, 67	28 days - 300°F one side, 8 hrs. on, 16 hrs. off (Tested at 72°F)	14.5	17.2

Test data shows that short term exposure at high temperature (Specimens 71 and 72) had less crush distance than the standard control specimen. The compressive strength of the foam (not composite) NB-237936 A increased in both the parallel to foam rise and perpendicular to foam rise direction when exposed to high temperatures for short periods of time. This increase in foam compressive strength may be attributed to additional curing of the foam thus resulting in a higher strength material. This increase in compressive strength of the foam may account for a higher strength specimen thus a decrease in dynamic crush distance.

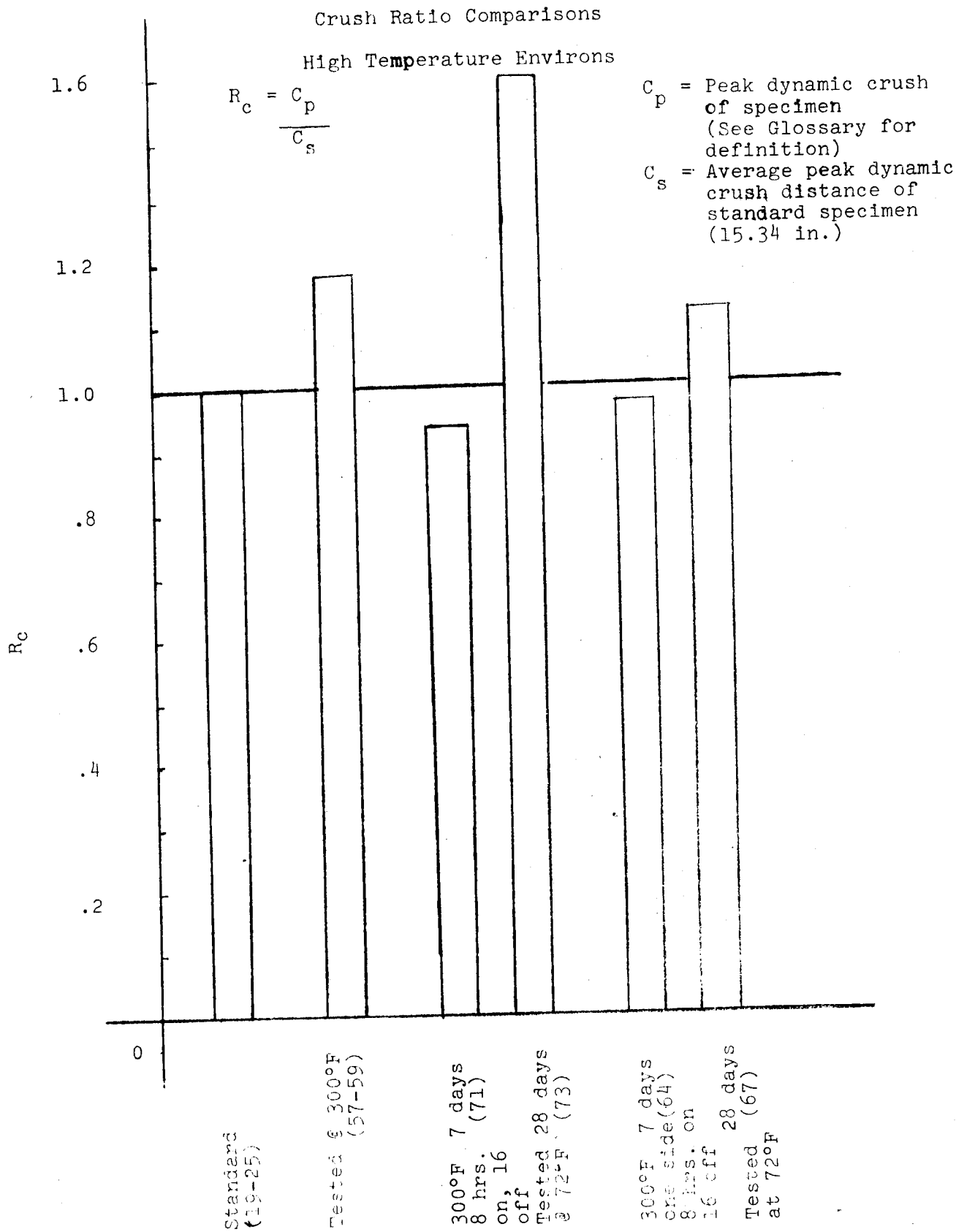

Crush Ratio Comparisons
High Temperature Environs
$R_c = \frac{C_p}{C_s}$
C_p = Peak dynamic crush of specimen (See Glossary for definition)
C_s = Average peak dynamic crush distance of standard specimen (15.34 in.)
R_c
1.6
1.2
1.0
.8
.6
.4
.2
0
Standard (19-25)
Tested @ 300°F (57-59)
300°F 7 days 8 hrs. on, 16 off Tested @ 72°F (73)
300°F 7 days one side(64) 8 hrs. on 16 off 28 days Tested at 72°F (67)

Figure 20

Long term exposure (Specimen Nos. 73 and 74) at high temperatures appears to degrade the urethane foam thus decreasing the foam compressive strength and its stabilizing effect on the metal specimen causing an increase in dynamic crush distance.

Examination of the foam after the long exposure to heat shows that it was brownish and powdery denoting thermal degradation.

3.3.2.5 Low Temperature (-20°F)

Specimens were conditioned at -20°F for six hours prior to test. They were tested immediately after removal from the dry ice. Dynamic crush tests are as follows:

Specimen No.	Post Test Measured Crush (inches)	Peak Dynamic Crush From Computer Program V = 0 (inches)
68	14.88	14.11
69	14.66	
70	14.97	
	Avg. 14.84	Avg. 14.11

Specimens failed in a manner similar to the unconditioned standard control specimen.

See Photograph A-19 on page 102 for failure mode.

3.3.2.6 Low temperature short and long term exposure, 7 and 28 days

Specimens were weighed and dimensions taken at centers prior to conditioning.

Specimens were then placed in freezer, dry ice was added to the freezer to get temperature to -20°F.

Specimens were removed from freezer after 8 hours and allowed to stand at room temperature for 16 hours. This procedure was repeated for 7 and 28 days.

There was a slight decrease at centers after exposure showing a minute amount of foam shrinkage.

Table 29, Summary of Low Temperature dynamic crush results, indicates that the long term exposure seems to effect the crush distance to a slight degree. The failure mode does differ from the control in that the seams of both the short and long term exposure opened more.

See Photographs A-20 and A-21 on pages 103 and 104 for failure mode.

Figure 21 on page 105 shows the crush ratio comparisons in bar chart form.

TABLE 29

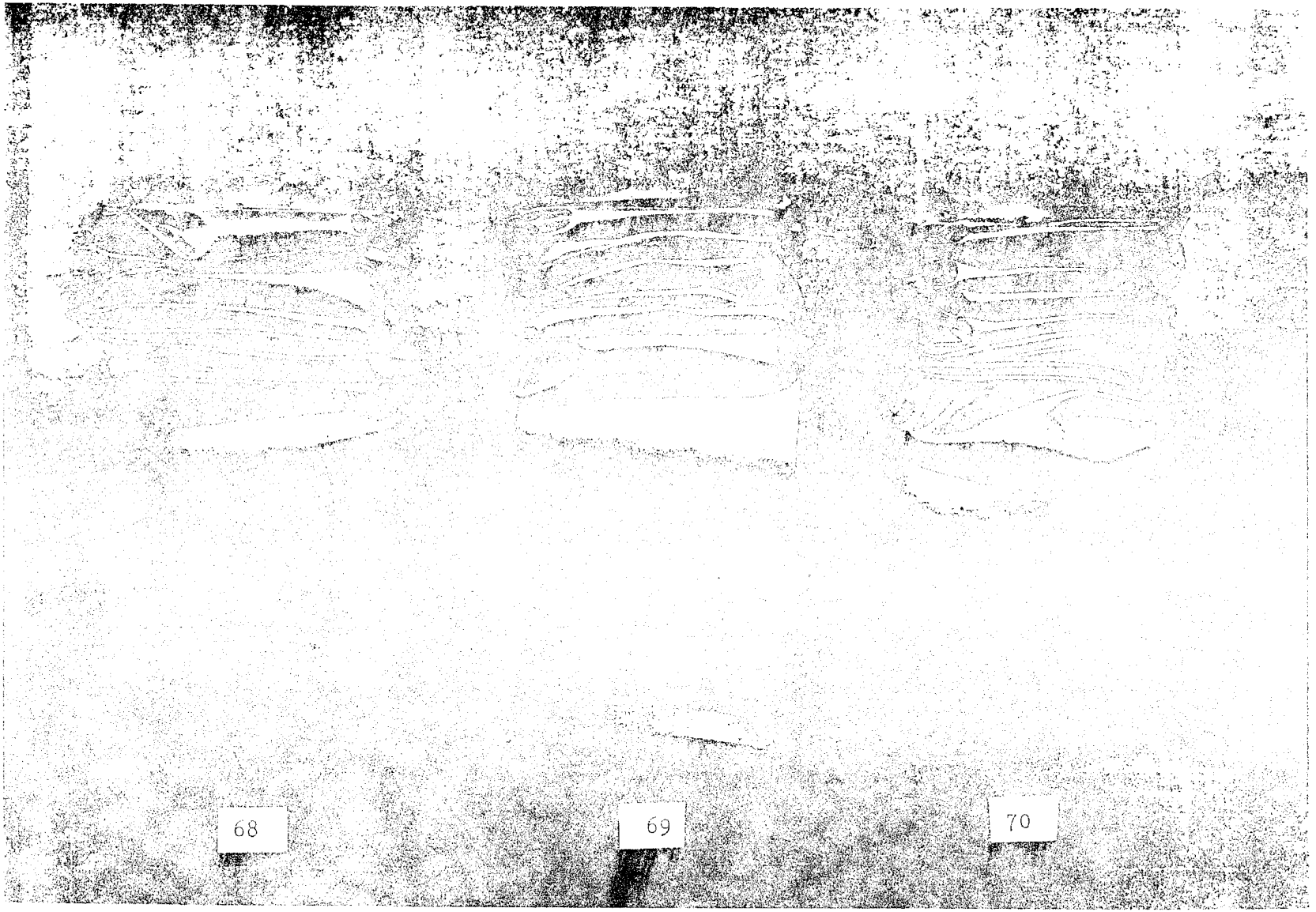
Summary Low Temperature (-20°F)

Specimen No.	Condition	Post Test Measured Crush (inches)	Peak Dynamic Crush Computer Program $V_F = 0$ (inches)
19 - 25	Control	14.1 (Avg.) (13.2 to 15.3)	15.34 (Avg.) (14.6 to 15.8)
68, 69, 70	At -20°F	14.84 (Avg.) (14.66 to 14.97)	14.11*
79, 80	7 days at -20°F: 8 Hrs. on, 16 off	13.75	13.3
81, 82	28 days at -20°F: 8 Hrs. on, 16 off	14.7	16.0

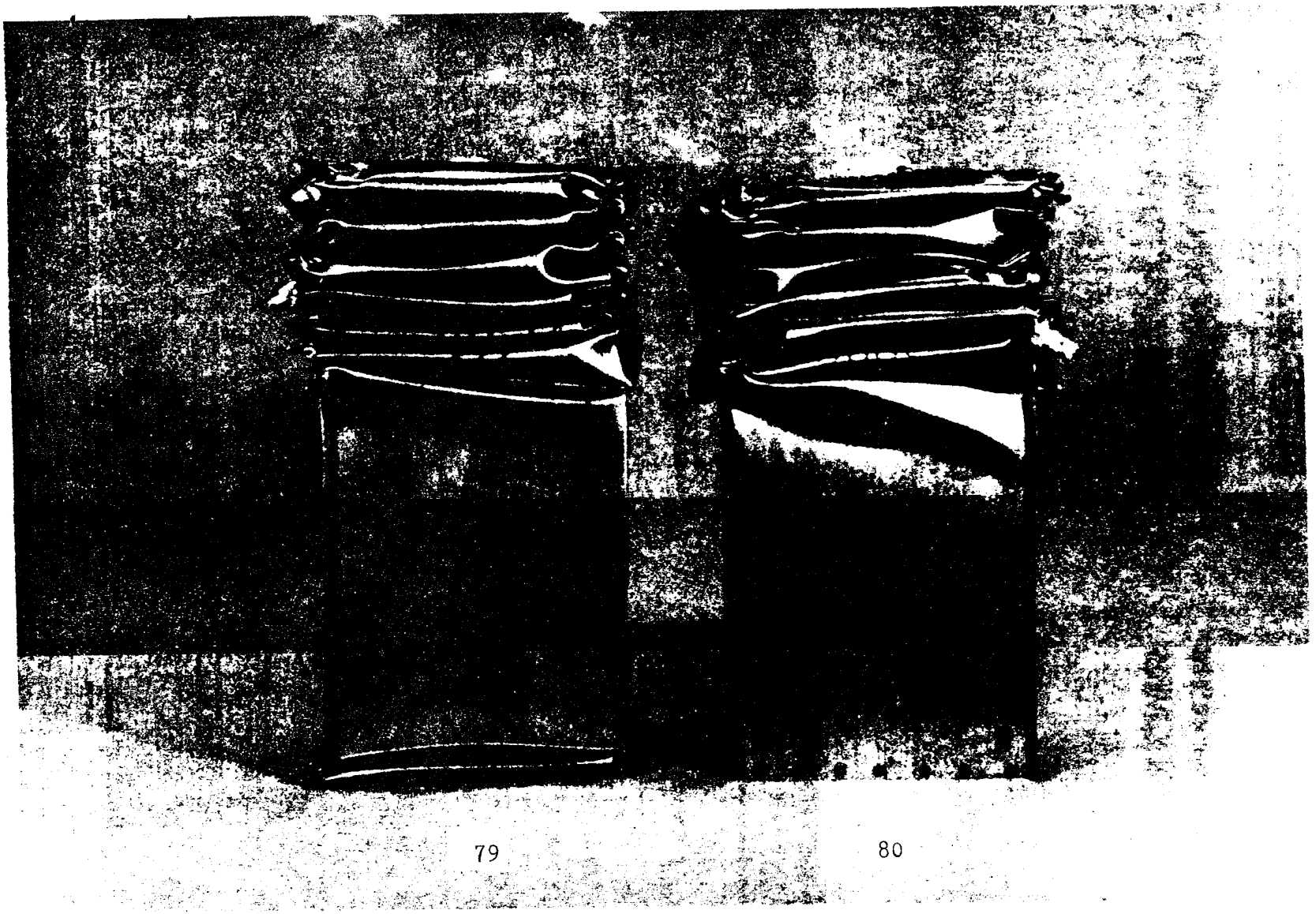
* High Speed movies show an approximate one inch spring back of specimen, showing that this number is in error. See Paragraph 3.3.1.4.1 for explanation.

3.3.3 Solvent Effect

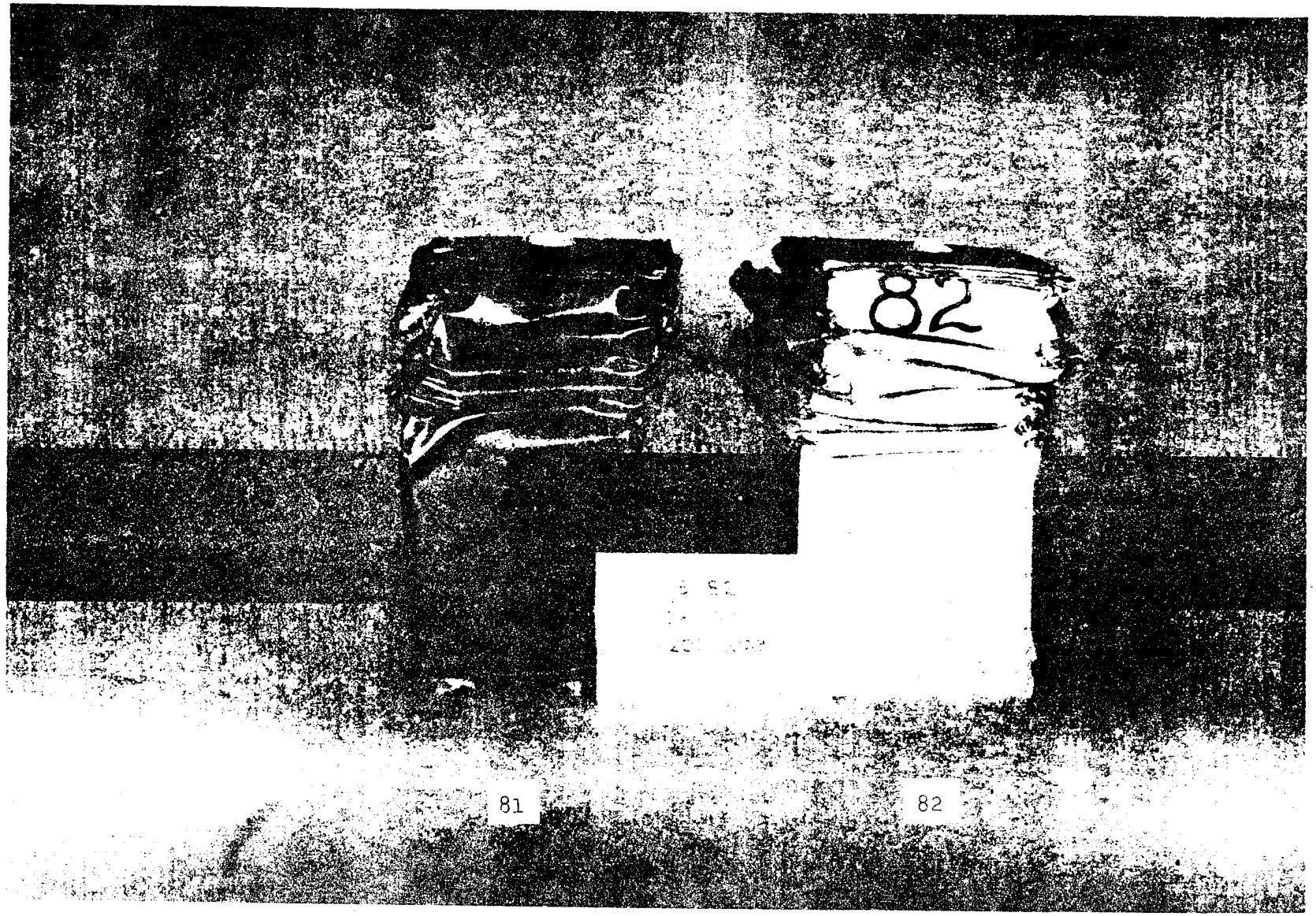
Literature shows solvent resistance of the urethane foam to be very good on the exposed foam as shown by Table 31 on page 108.



Failure Mode of Specimen at
-20°F



Failure Mode of Specimen After
Exposure to -20°F for 7 days



Failure Mode of Specimen After
Exposure to -20°F for 28 days

Crush Ratio Comparisons
Low Temperature Environs

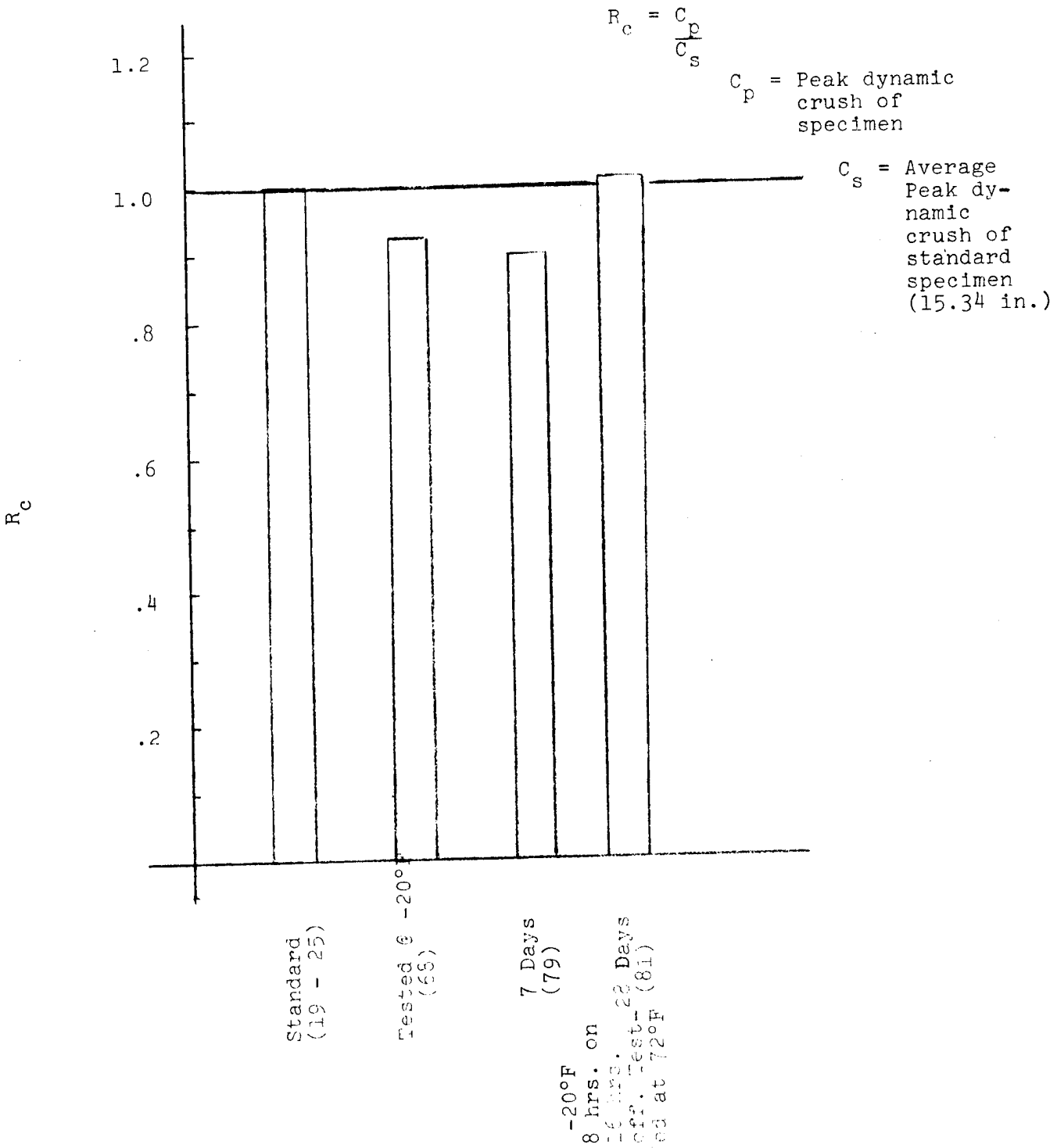


Figure 21

A test was conducted on the foamed specimens, totally immersed in solvents that may be encountered by an automotive structure to determine their effect on the crush characteristics after a 28 day exposure. The test was conducted at ambient temperature. The solvents used in this test were:

1. Salt water (5% Solution)
2. Motor Oil
3. Ethylene Glycol (50/50 with water)
4. Car Wash Detergent
5. Water
6. Gasoline

The weights and dimension were taken of the specimens prior to and after immersion.

There was no detectable increase in weight or measurable change of the container size after the 28 day exposure. The crush results are as follows:

TABLE 30

Summary of Solvent Test

Specimen No.	Condition	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program $V_F = 0$ (inches)
19 - 25	Control	14.1 (Avg.) (13.2 to 15.3)	15.34 (Avg.) (14.6 to 15.8)
1S, 2S	28 days oil	14.6 (14.4 to 14.9)	
5S, 6S	28 days 50/50 water/glycol	14.1 (14.0 to 14.2)	15.8
9S, 10S	28 days detergent	14.25 (14.0 to 14.5)	
13S, 14S	5% salt	14.0 (13.7 to 14.4)	
17S, 18S	Water	14.1 (13.6 to 14.6)	
19S, 20S	Gasoline	14.6 (14.1 to 15.1)	

All failures were similiar to the standard specimen. The measured crush distance did not vary significantly from the standard specimen. See photograph A-22 on page 109 for failure modes and consistency of crush distances.

TABLE 31

Chemical Resistance of Polyurethane Foam
When Immersed in Reagent
for Thirty Days
(Ref. 65)

Active Materials		At 75°F.	At 125°F.
Motor Oil		E	E
Gasoline		G	-
Turpentine		E	-
Kerosene		G	G
Benzene		E	-
Toluene		E	-
Methylene Chloride		F	-
Ethyl Alcohol		G	G
Methyl Alcohol		G	G
Carbon Tetrachloride		E	E
Methyl Ethyl Ketone		P	-
Acetone		P	-
Perchloroethylene		E	E
Water		E	G
Sulfuric Acid	(concentrated)	S	S
Sulfuric Acid	(10%)	G	G
Hydrochloric Acid	(concentrated)	S	S
Hydrochloric Acid	(10%)	G	G
Ammonium Hydroxide	(concentrated)	G	-
Ammonium Hydroxide	(10%)	G	G
Sodium Hydroxide	(concentrated)	E	E
Sodium Hydroxide	(10%)	E	G

Key

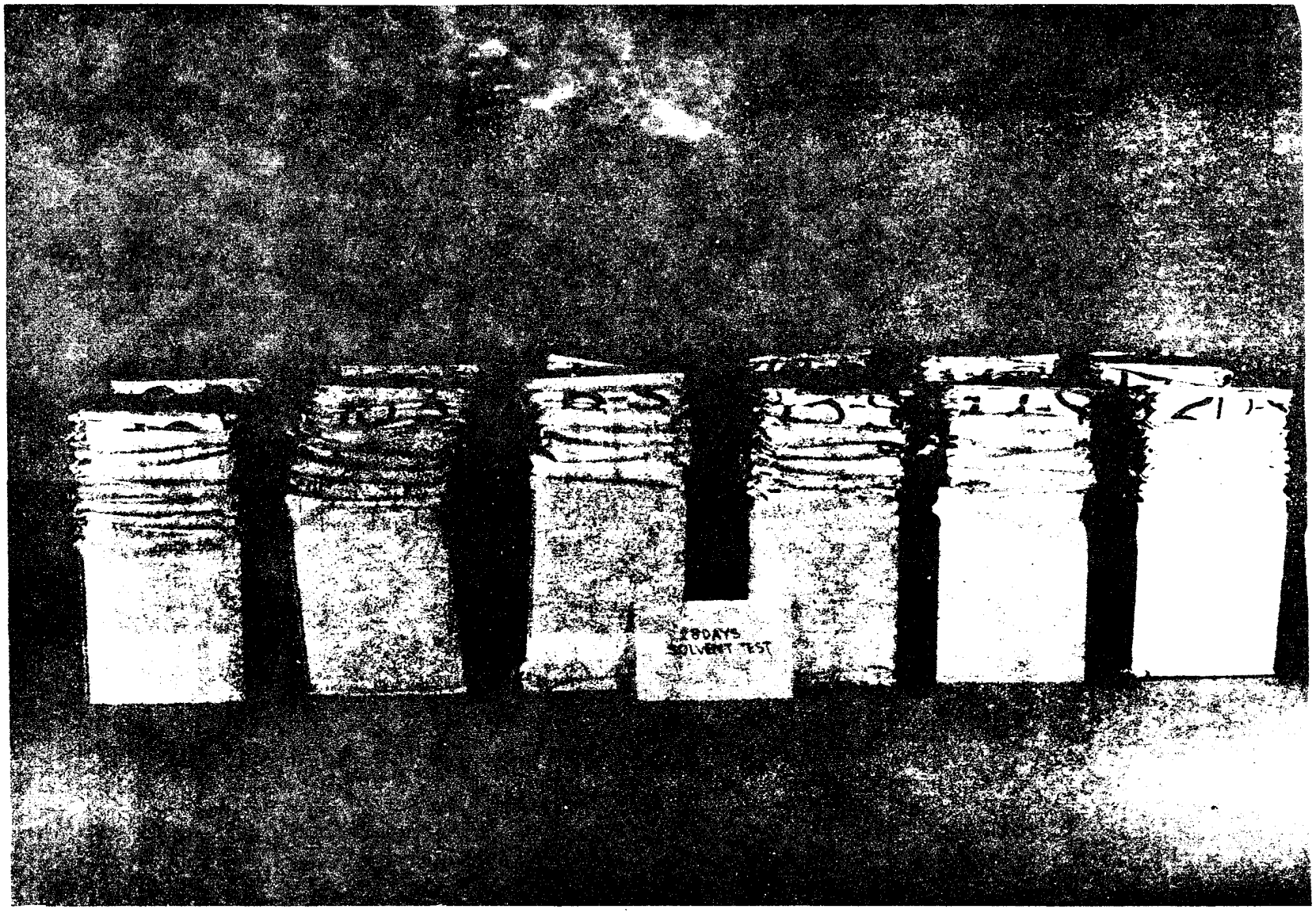
E - excellent resistance

G - good resistance

F - fair resistance

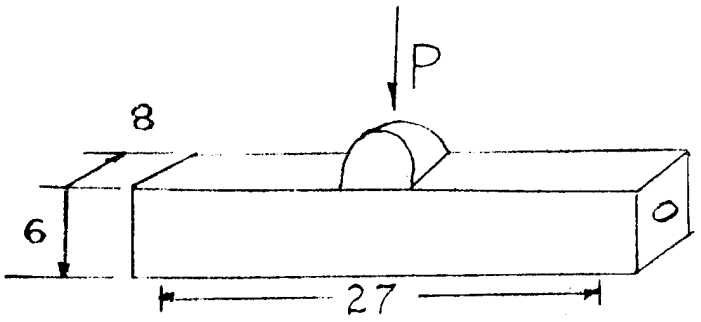
P - poor resistance

S - severe attack, not recommended for use



Failure Mode of Specimens After
Exposure to Solvents, 28 days

3.3.4 Vibration. Primed and unprimed specimens



3.3.4.1 Static Test

Since the requirements of a foam filled structure in normal automobile operation is unknown, a static test was required as performed below for load deflection and thus provide a basis for selecting stress levels in the vibration tests.

Two standard specimens, one filled and one unfilled, were tested as shown. A strain gage was mounted on the tensile side at the beam mid-point to measure longitudinal strains. Deformation of the top surface of the beam was continuously monitored with an LDT (linear voltage differential transformer) and the deflection of the bottom surface of the beam at mid-point was measured with a heighth gage at 100 pound load increments.

Deformation of the upper and bottom beam surfaces are shown in Figures 22 and 23 on pages 111 and 112. Strains and bottom surface deflections are listed in Tables 32 and 33 on page 113. See Photograph A-23 on page 114 for Static Test set up.

The load was applied in a universal testing machine through a centering block. The area of contact at the beam top surface was 5 1/4" x 8" or 42 square inches. The difference in maximum load at collapse was 1220 pounds. Dividing this difference by 42 square inches indicates that the foam increased the crushing stress by a factor of 2.24 times that without foam.

DEFORMATION OF FOAM FILLED BEAM

STATIC TEST

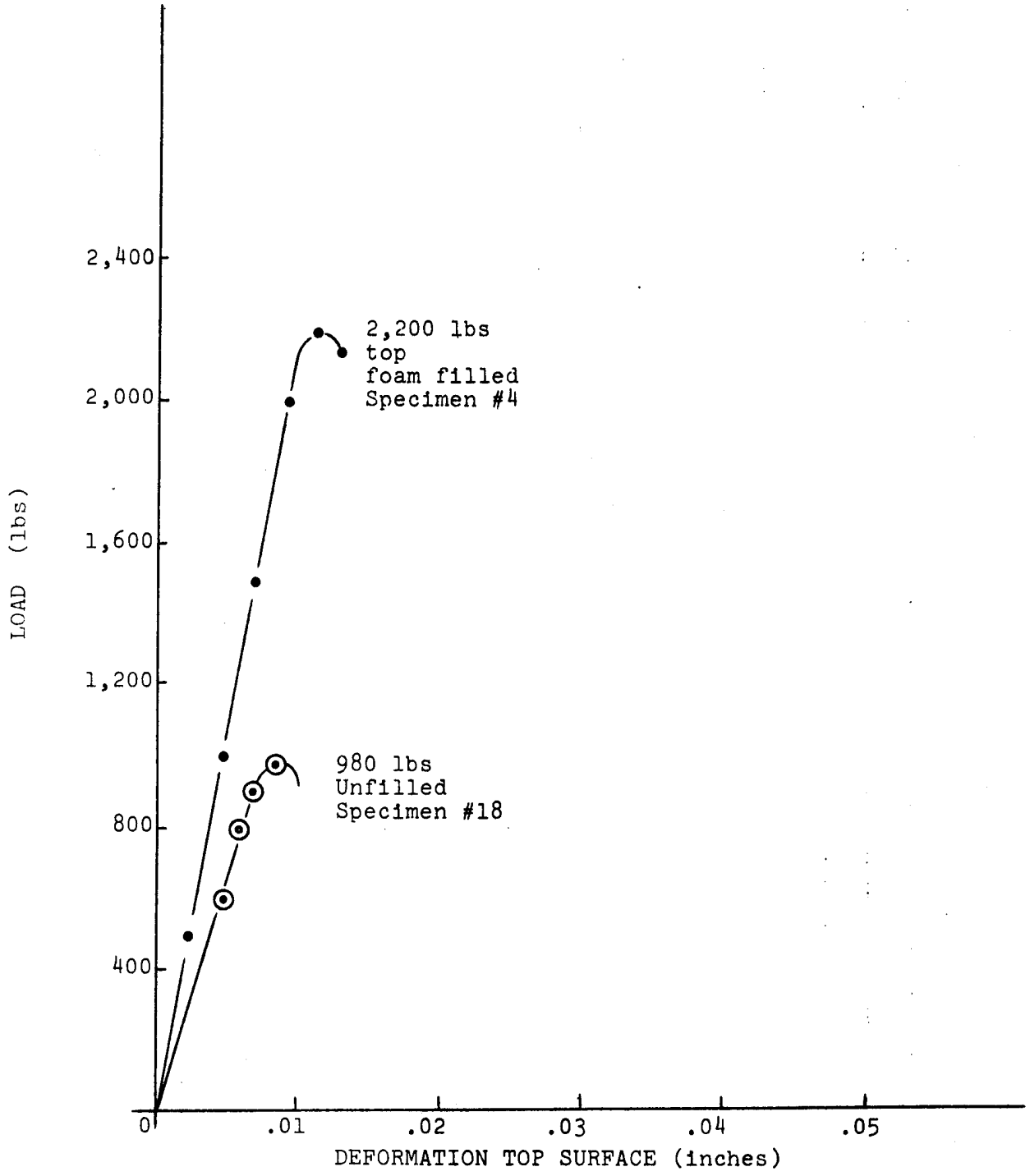


Figure 22

DEFORMATION OF FOAM FILLED BEAM

STATIC TEST

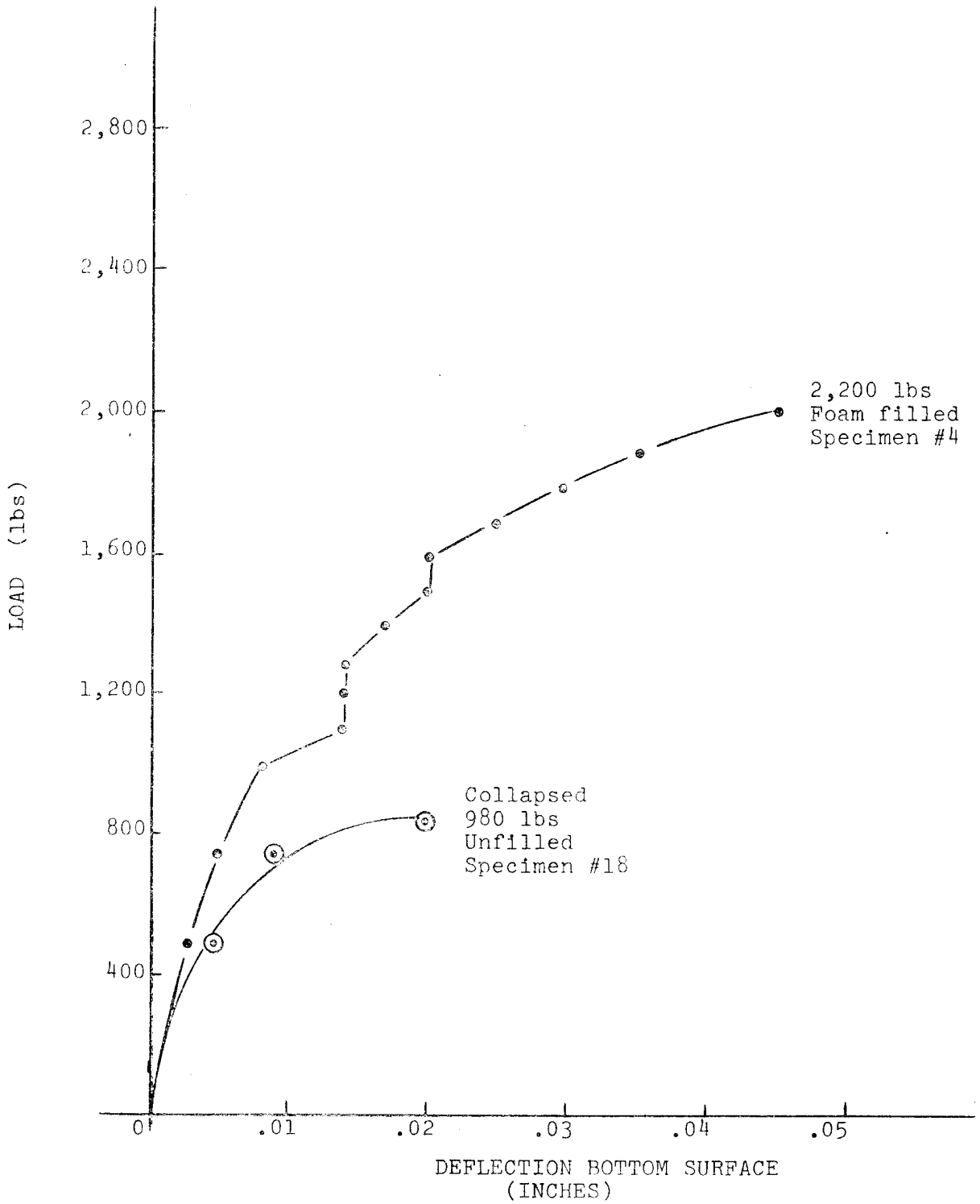


FIGURE 23

TABLE 32

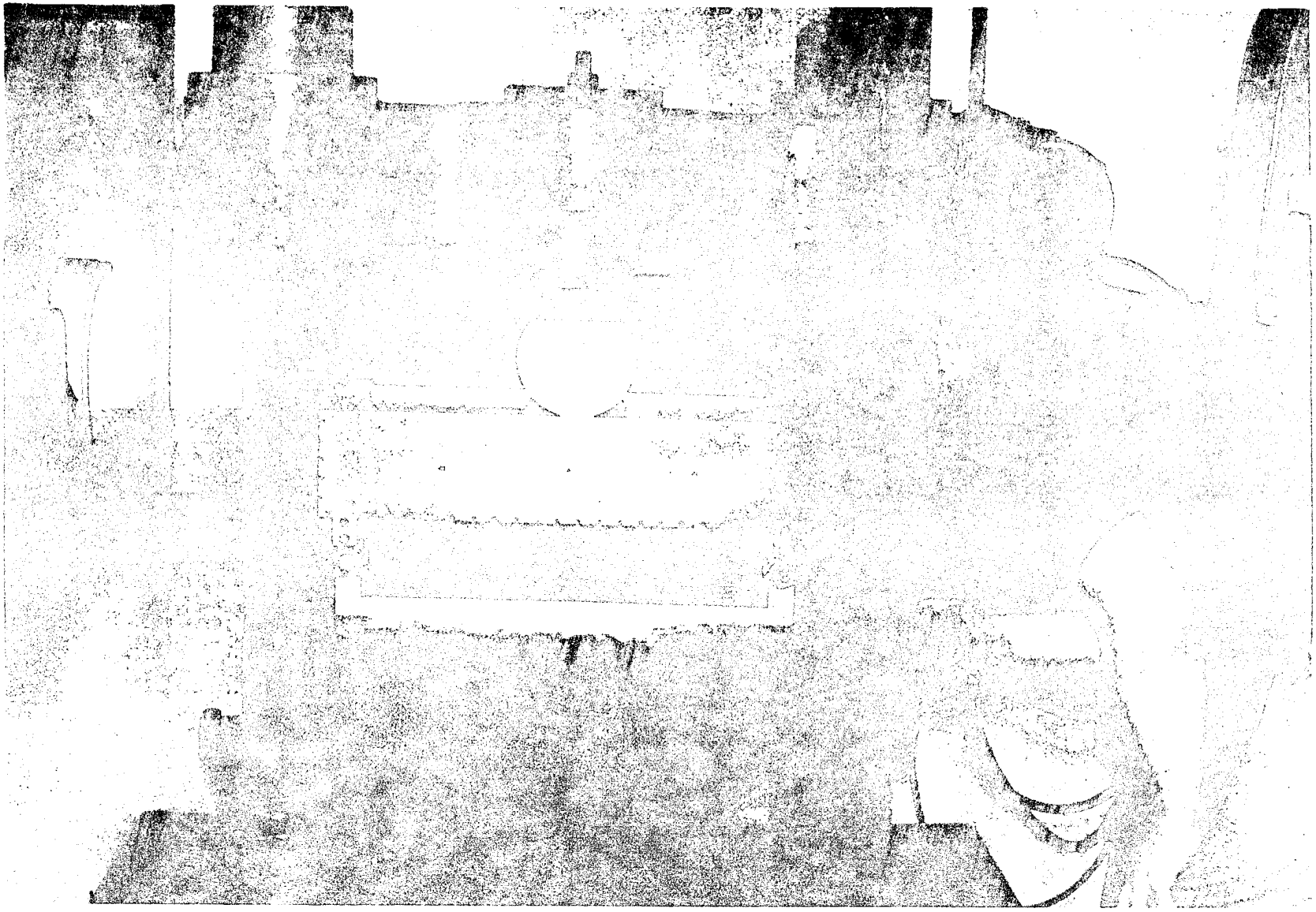
Sample No. 4 - Foam Filled Beam

Load lbs.	Strain $in. \times 10^{-6}$	Skin Stress psi	Bottom Surface Deflection inches
500	51	1530	0.003
750	83	2490	0.005
1000		3300	0.008
1100	110 124	3720	0.015
1200	132	3960	0.015
1300	143	4290	0.015
1400	155	4650	0.017
1500	166	4980	0.020
1600	178	5340	0.020
1700	190	5700	0.025
1800	200	6000	0.030
1900	218	6540	0.035
2000	231	6930	0.045
2100	Collapsed - top surface		0
Load Removed			

TABLE 33

Sample No. 18 - Unfilled

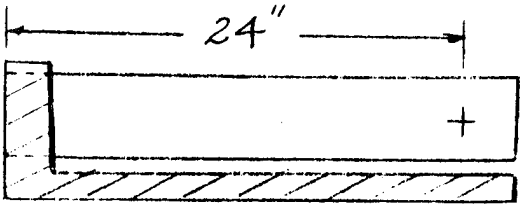
Load lbs.	Strain $in. \times 10^{-6}$	Skin Stress psi	Bottom Surface Deflection inches
500	66	1980	.0.004
750	81	2430	0.009
840	85	2550	0.020
980	Collapsed - top surface		



Static Test Set-Up for
Vibration Loads

3.3.4.2 Dynamic Test of Vibrated Specimens

The standard foamed steel containers were mounted in a fixture as shown below.



The foamed beams were excited by two methods: an electromagnetic shaker or an air driven eccentric motor. Specimen 33 was excited with the electromagnetic shaker at 60 cycles per second. This resonant frequency was determined by scanning from 0 to 5000 cycles per second. Maximum deflection 24" from the end mounting was 0.220" (± 0.110") at 60 cycles per second. The beam was excited for 3.6 hours at resonance or 777,600 cycles.

Specimens 34 and 36 were then mounted in the same fixture in turn and excited. The deflections and vibrating characteristics of Specimen 33 could not be duplicated. The reasons are still unknown. All specimens were made under the same conditions.

An air driven eccentric motor then was used to excite Specimens 34, 35, 36 and 37. Specimens 34 and 36 were vibrated at 20 cycles per second for a total of 500,000 cycles at a total deflection of 0.120" (± 0.060") 24" from the mounting. Specimens 35 and 37 were vibrated at 20 cycles per second for a total of 500,000 cycles at a total deflection of 0.200" (± 0.100"). Deflections were measured with a telescopic vernier and scribe marks on the beam at its centerline. It was noted that local skin sheet deformations occurred throughout the beams which were synchronized with the total beam frequency but did not represent total beam deflections. There was no indication of temperature rise.

The deflections induced in the above 5 samples are of comparable magnitude as those expected in the structural elements of commercial vehicles. Experience with European vehicles and American vehicles has indicated total deflections midway between the front and rear wheels are in the order of 0.020" to 0.040" static and up to 0.125" under dynamic loading. Dynamic crush test results are as follows.

Specimen No.	Conditions	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_F = 0 (inches)
33	Standard (Primed)	13.7	
34	Standard (Primed)	13.8	14.1
35	Standard (Primed)	14.4	
36	Silicone Grease	13.6	17.9
37	Silicone Grease	13.9	

Data shows a significant difference in the peak dynamic crush of the primed and silicone greased vibrated specimens. Post test measured crush didn't show any drastic change in the crush distance of the specimens tested. See Photographs A-24 and A-25 on pages 117 and 118 for failure mode.

Crush Summary of Vibrated Specimens is shown in Table 34.

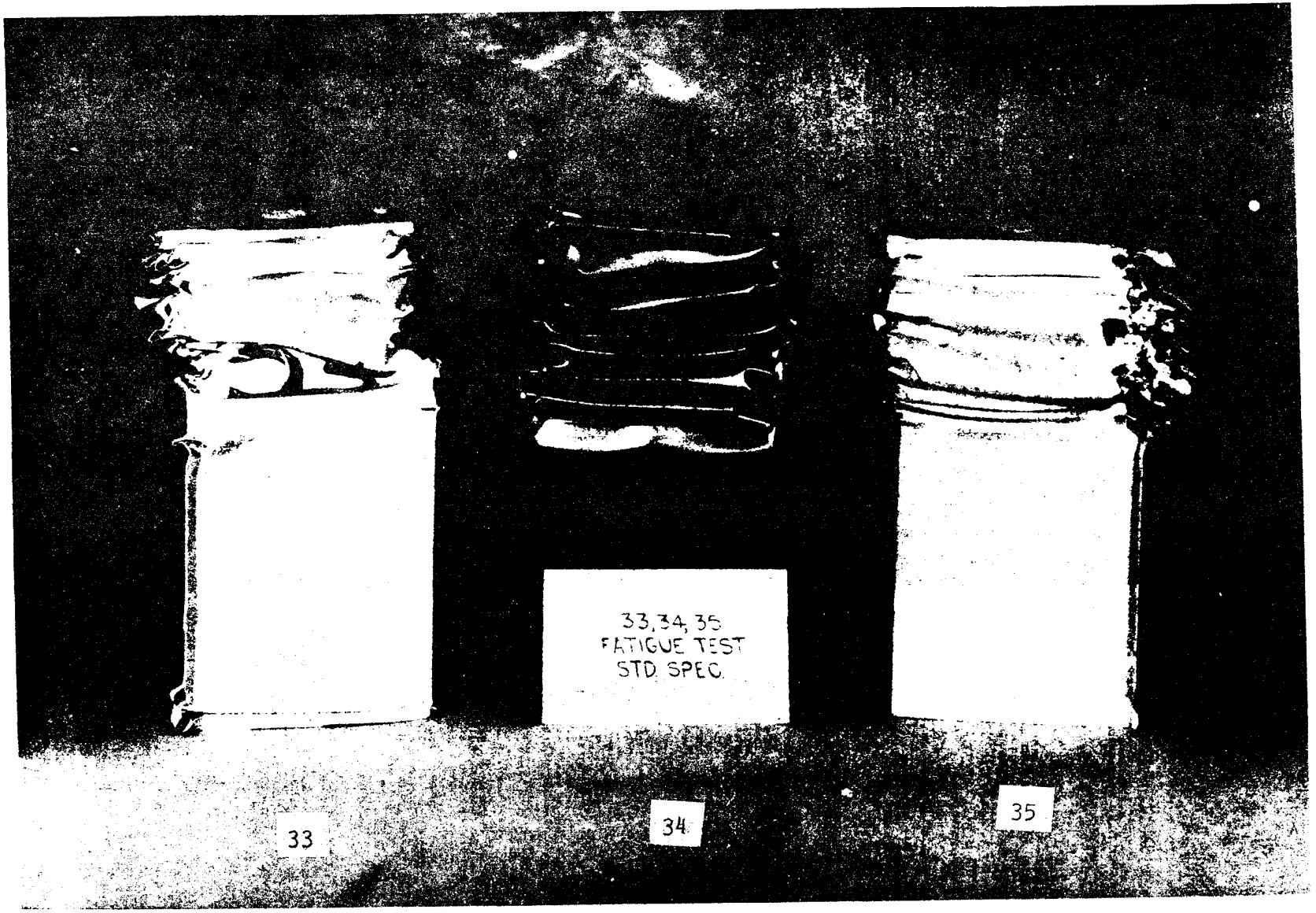
TABLE 34

Crush Summary of Vibration Specimen

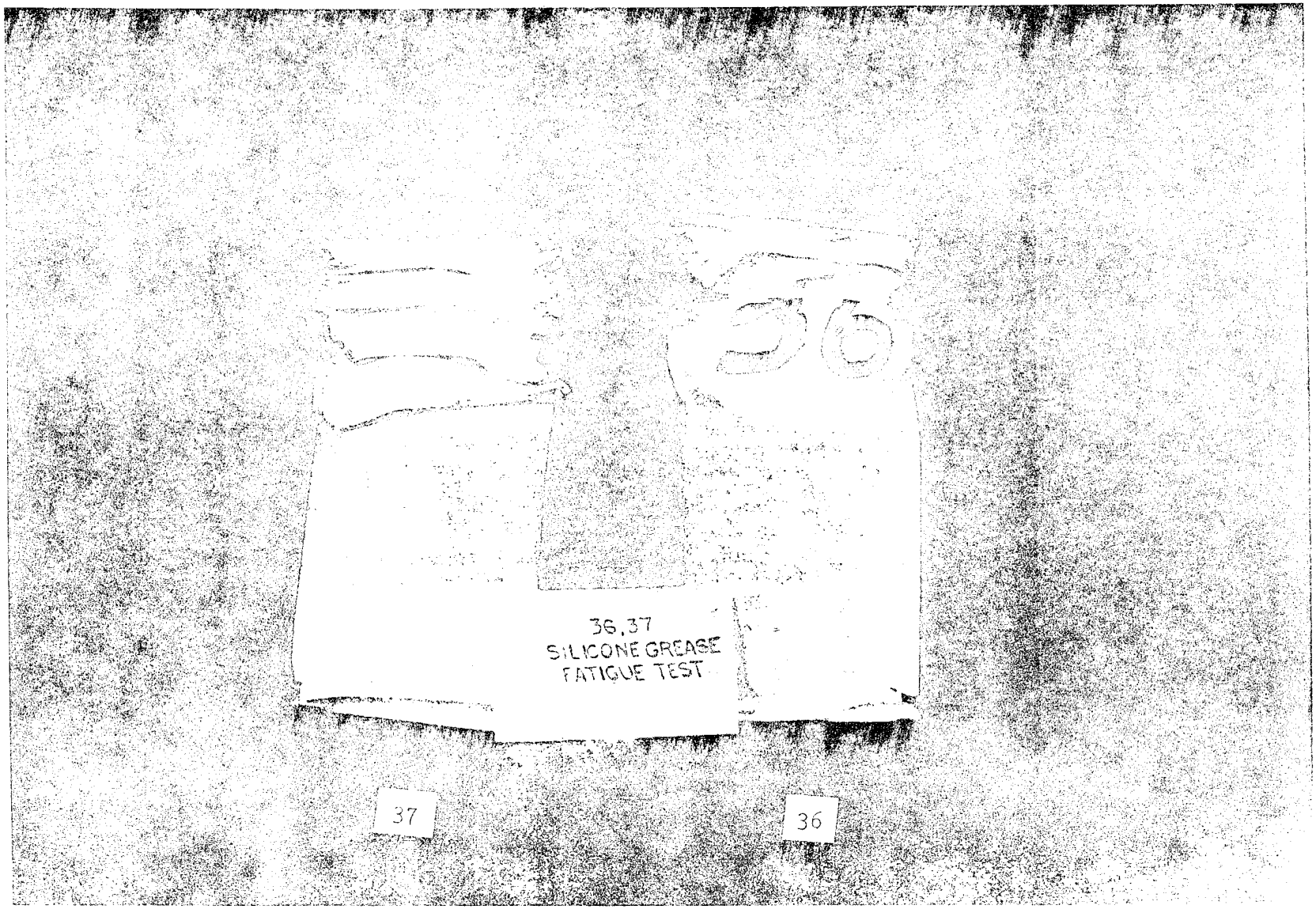
Specimen No.	Condition	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_F = 0 (inches)
33, 34, 35	Vibrated Primed	13.97 (Avg.) (13.6 to 14.4)	14.1
36, 37	Silicone Grease Vibrated	13.75	17.9
19 - 25	Standard Control	14.1 (Avg.) (13.2 to 15.3)	17.9 (14.6 to 15.8)

3.3.4.3 Vibration of Foam Inserted into Metallic Shell

Foam, NV-237936A, was molded, inserted into the standard specimen and then vibrated for $2.16X10^6$ cycles. The frequency was varied from 15 to 55 hz. The maximum deflection varied from .13 to .01 inches. The load level was kept at 3 g's. The specimen was then cross sectioned. The foam showed no signs of powdering or crumbling due to the vibration.



Failure Mode of Fatigue
Specimen (Primed)



Failure Mode of Fatigue
Specimen (Silicone Grease)

3.3.5 Effect of Voids

Voids were machined into foamed specimens to determine the effect they would have on crush charactdristics if voids were introduced during the foaming application in production.

Specimens were foamed in the same manner as the standard specimen with the exception that the lid was silicone greased and clamped for removal in order to machine the voids. The lids were then spot welded after the voids were machined. The voids were made as shown in Figure 24, page 120, and Photograph A-26, page 121. They were made 5 inches deep for one set and 10 inches deep for the second set. See Table 35 for void dimensions and crush results. See Figure 25 on page 122 for Crush Ratio Comparison in bar chart form.

TABLE 35

Crush Results, Voids

Specimen No. and Void	Post Test Measured Crush Distance	Peak Dynamic Crush from Computer Program $V_p = 0$ (inches)
46 (1/2" x 6" x 10" deep, center)	14.5	15.4
47 (1/2" x 6" x 10" deep, side)	13.75	16.65
48 (1 1/4" x 6" x 10" deep, center)	15	18.15
49 (1 1/4" x 6" x 10" deep, side)	17	18.34
75 (1 1/4" x 6" x 5" deep, center)	13.56	15.0
76 (1 1/4" x 6" x 5" deep, side)	14.125	14.6
77 (1/2" x 6" x 5" deep, center)	13.875	13.8
78 (1/2" x 6" x 5" deep, side)	14.81	15.45
Control	14.1 (Avg.) (13.2 to 15.3)	15.34 (Avg.) (14.6 to 15.8)

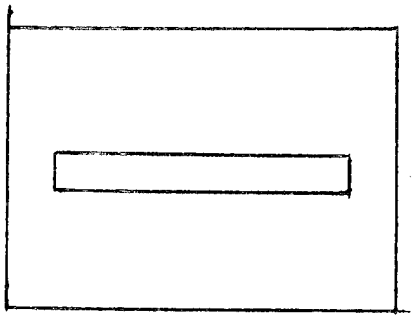
The void depth in the foam has a significant effect on the crush distance of the 1 1/4" x 6" void as shown by the peak dynamic crush in Table 35.

See Photographs A-27, A-28, A-29 and A-30 on pages 123, 124, 125, and 126 for failure modes.

VOIDS & LOCATION

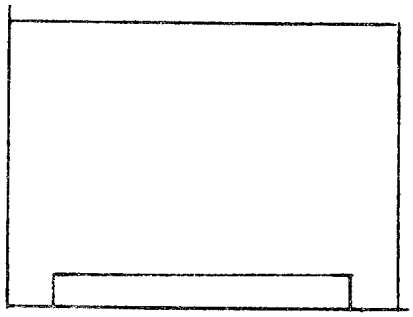
Specimen Size 6 x 8 x 30 inches

6.2% Area Reduction Center



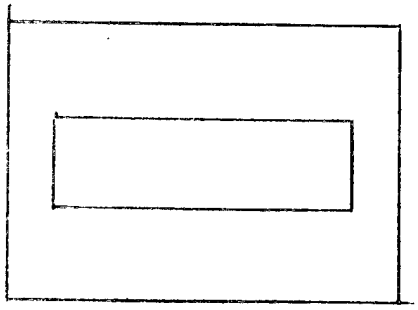
1/2 x 6
5 and 10 inches deep

6.2% Area Reduction Side



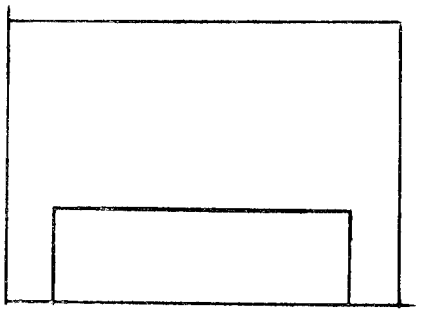
1/2 x 6
5 and 10 inches deep

14% Area Reduction Center



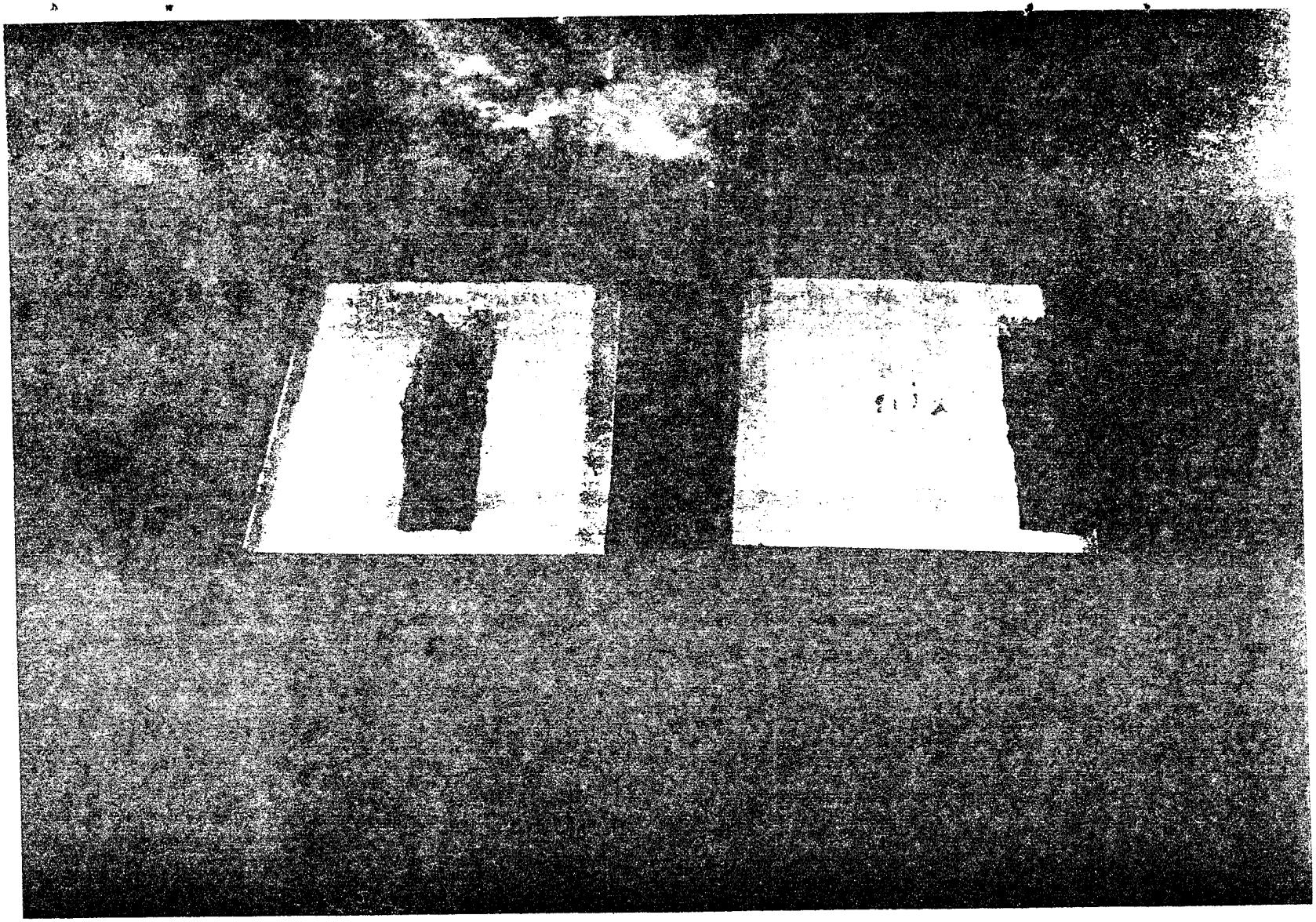
1 1/4 x 6
5 and 10 inches deep

14% Area Reduction Side



1 1/4 x 6
5 and 10 inches deep

Figure 24



1¼ X 6 Inches

Machined Voids

Crush Ratio Comparisons
Void Effects

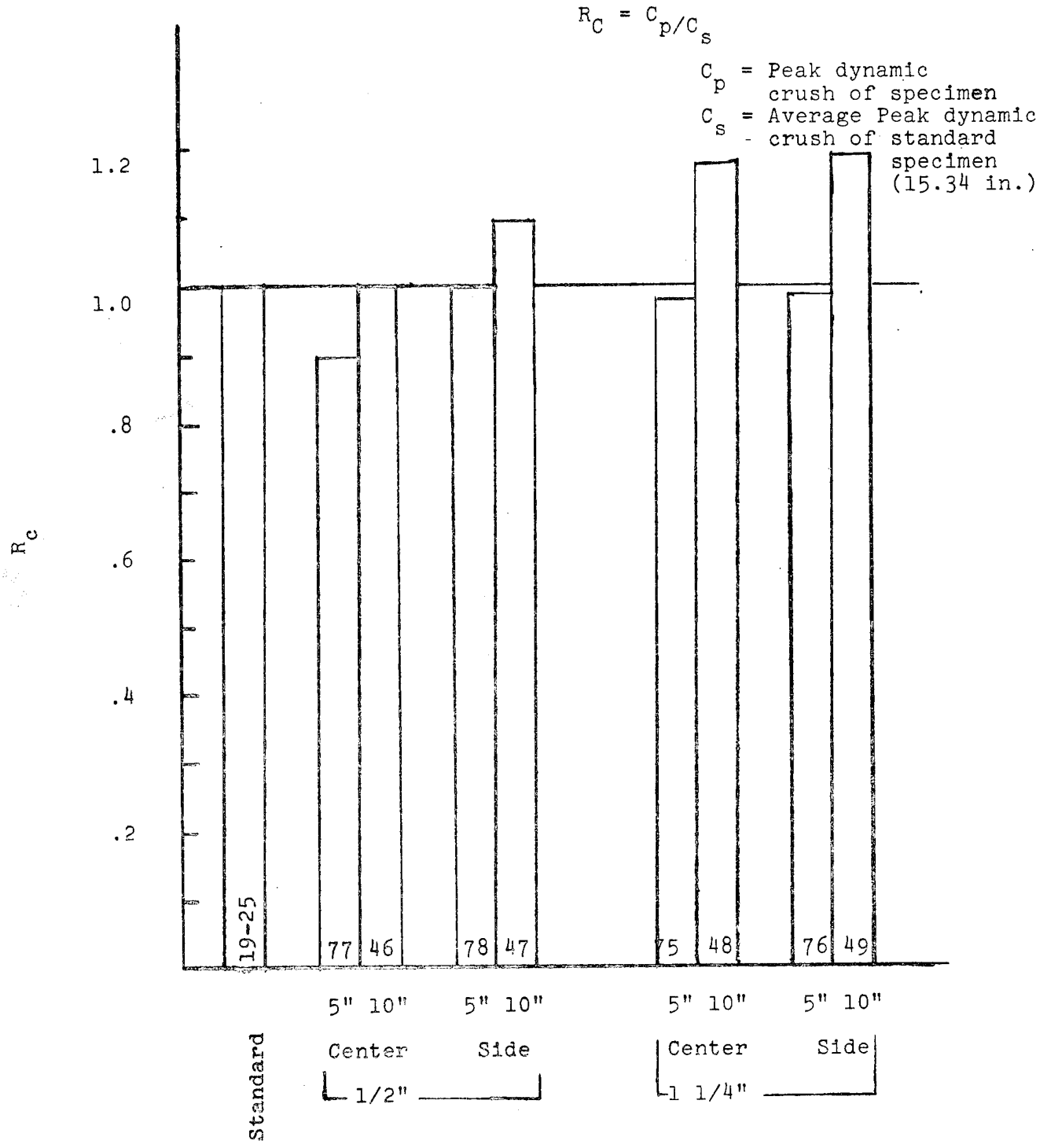
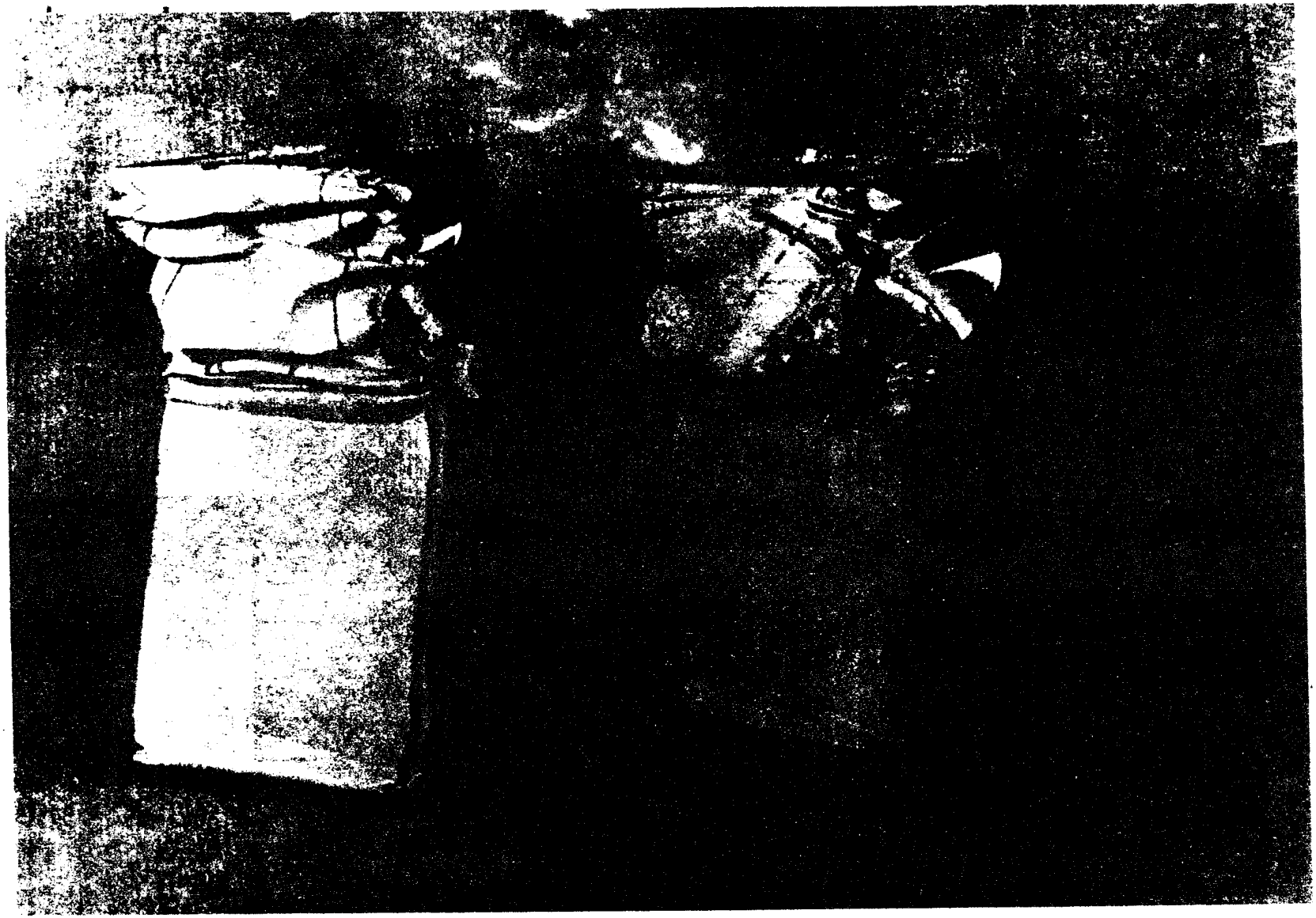


Figure 25



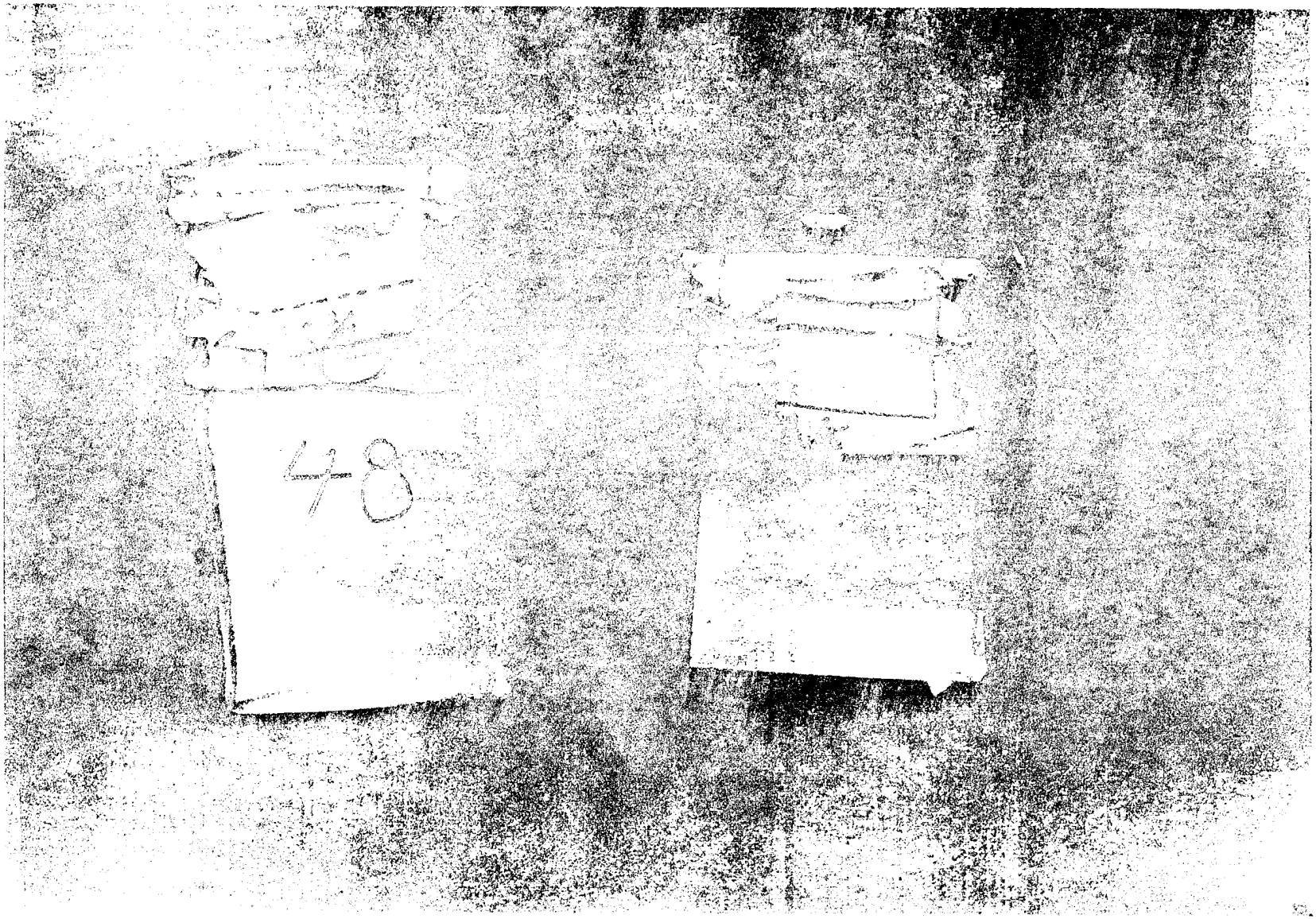
47

46

Side Void

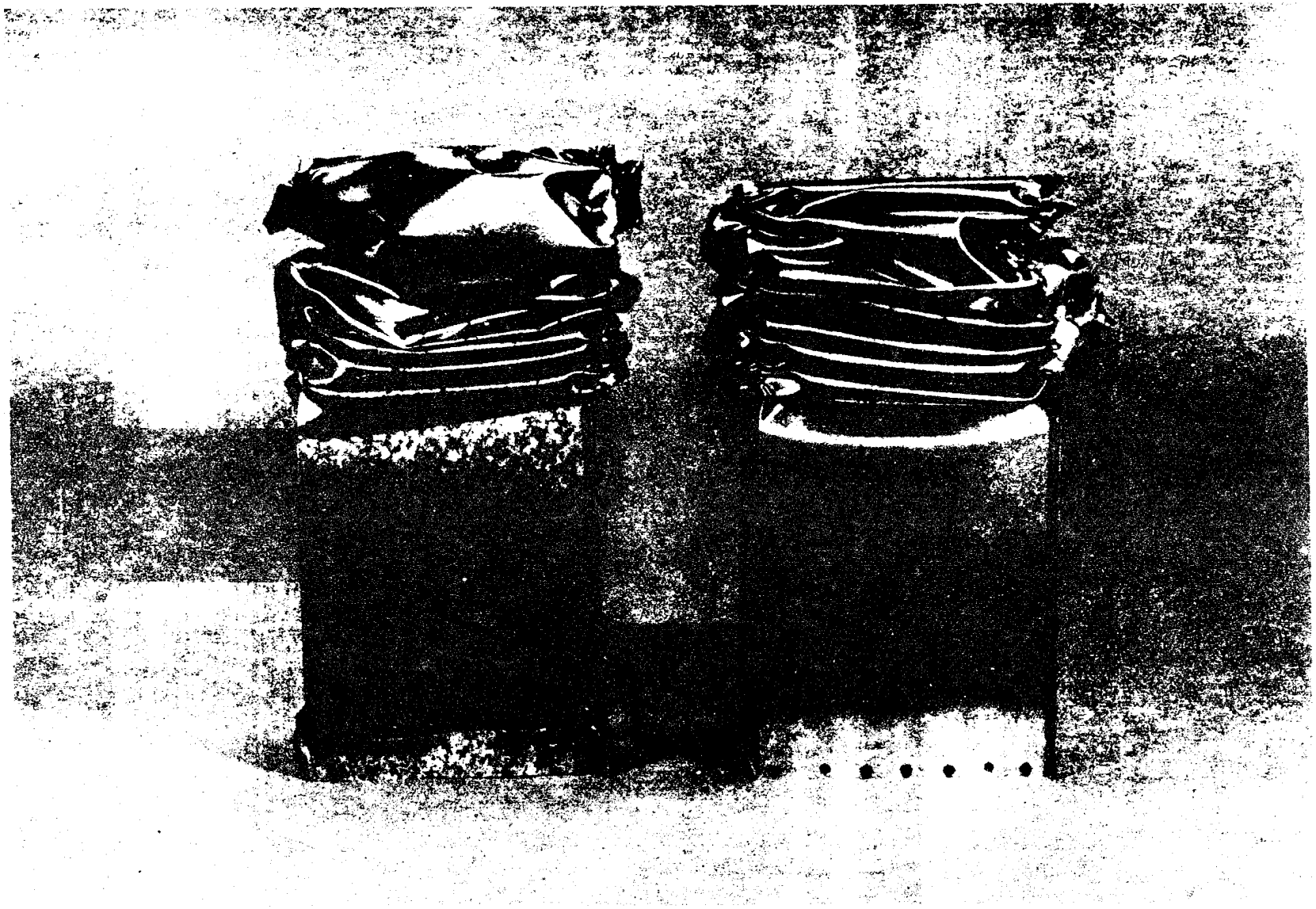
Failure Mode
1/2" x 6" x 10" Voids

Center Void



48 49

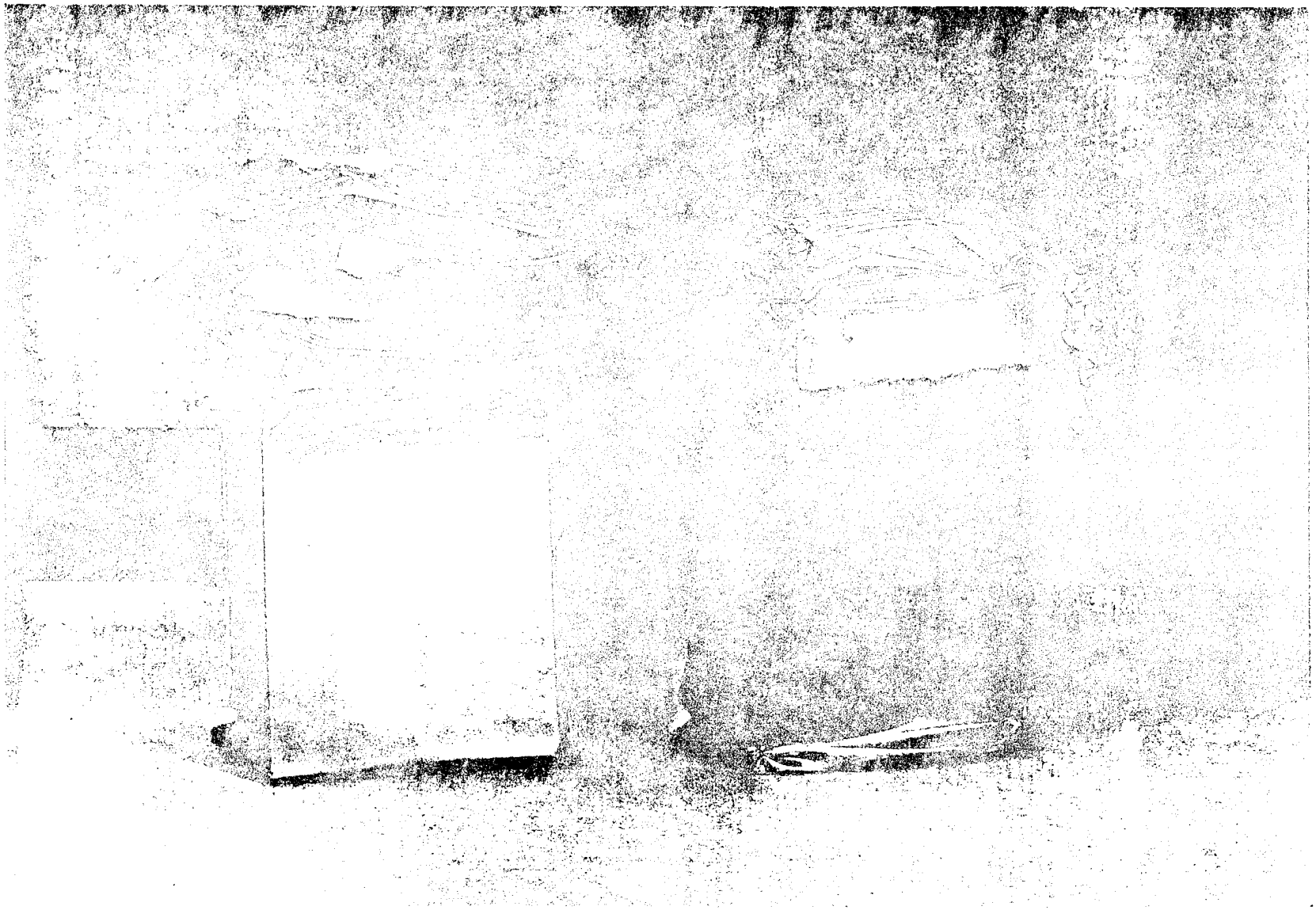
Failure Mode
Center Void 1 1/4" x 6" x 10" Voids Side Void



75 76

Failure Mode

Center Void 1 1/4" x 6" x 5" Voids Side Void



79 78

Failure Mode
Center Void 1/2" x 6" x 5" Voids Side Void

3.3.6 Effect of Foam Adhesion on Crush Properties

Silicone grease was rubbed on the walls of specimens 29 and 30 prior to foaming. Molded urethane blocks were foamed in the same manner and trimmed to fit into the metal specimens to determine the crush characteristics of a specimen where the foam was not adhered to the specimen wall. See results below in Table 36. See Figure 26, page 129, for the Ratio Comparison for the Effect of Adhesion in bar chart form.

TABLE 36

Specimen No.		Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program $V_F = 0$ (inches)
29	Silicone	13.6	13.58
30	Grease	13.6	13.80
83	Molded and inserted loosely into specimen	15.6	16.7
84		15.5	
85		14.94	
36	Silicone Grease	13.6	17.9
37	Vibrated		
19 - 25	Control	14.1 (Avg.)	15.34 (Avg.)
		(13.2 to 15.3)	(14.6 to 15.8)

The peak dynamic crush for the molded, inserted foam was greater than the silicone grease specimen. The difference is probably due to the exacting fit of the silicone greased specimen as the foam was poured in place; while the molded foam had clearance for insertion.

The failure modes of the silicone grease specimens and molded foams were similar. See Photographs A-31 and A-32 on pages 130 and 131 for failure modes.

3.3.7 Riveted Structure

Specimens were fabricated as in Figure 16, page 68, using rivets in lieu of spot welding in order to compare the crush characteristics of a spot welded structure versus a riveted structure.

TABLE 37

Specimen No.	Post Test Measured Crush (inches)	Peak Crush from Computer Program $V_p = 0$ (inches)
42 Riveted Steel	13.5	14.72
43 Riveted Steel	13.6	
44 Riveted Aluminum	15.2	
45 Riveted Aluminum	14.1	15.3

The riveted structures, steel and aluminum failed in a similar manner to the spot welded structure, and had similar crush distances as the spot welded specimen with the exception that the riveted seams had opened more.

See Photograph A-33 on page 132 for failure modes.

See Figure 27, page 133, for Crush Ratio Comparisons of the Riveted Specimens in bar chart form.

Crush Ratio Comparisons

Effect of Adhesion

$R_c = C_p/C_s$

C_p = Peak Dynamic crush of specimen

C_s = Avg. Peak dynamic crush of standard specimen (15.34 in.)

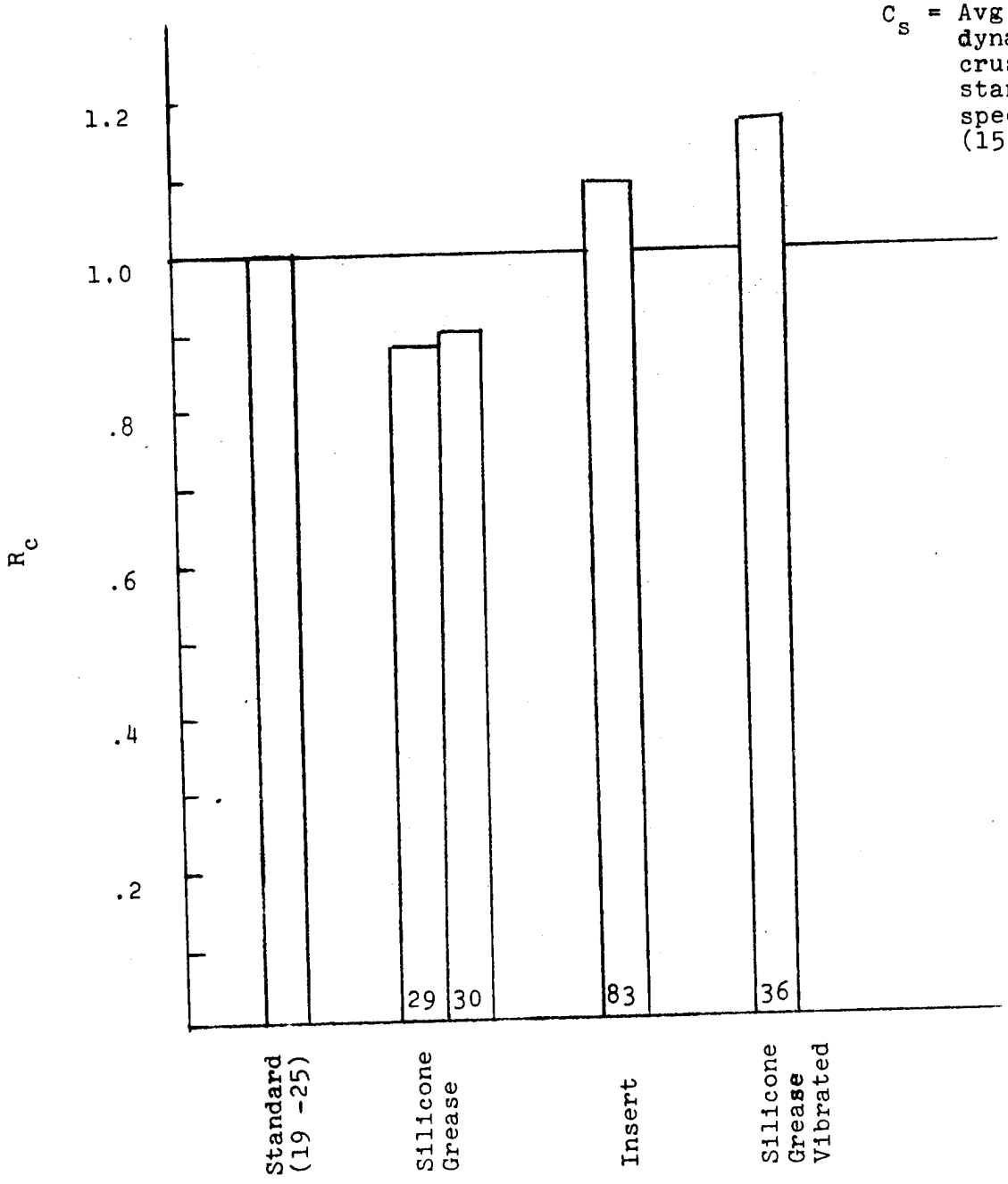
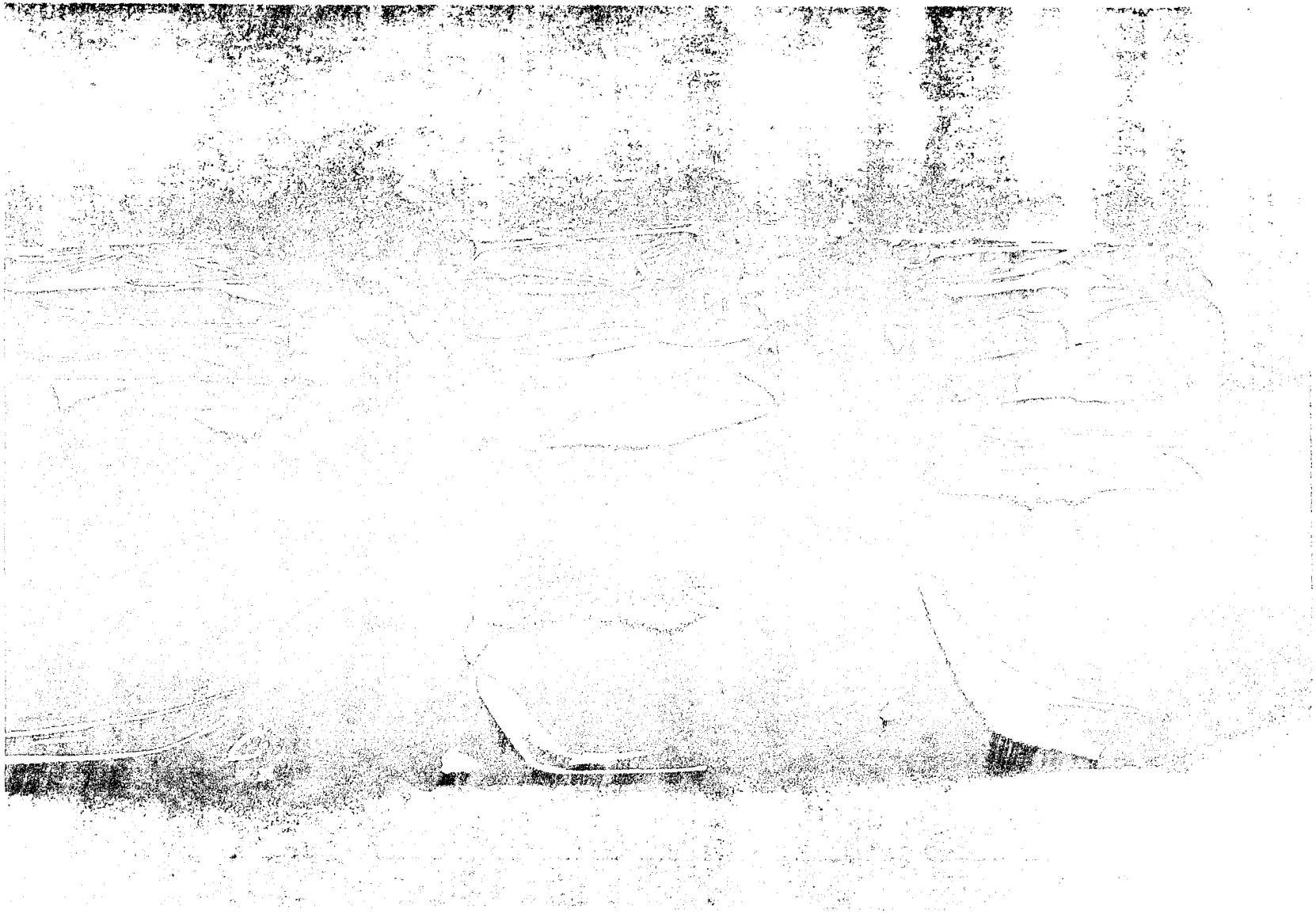
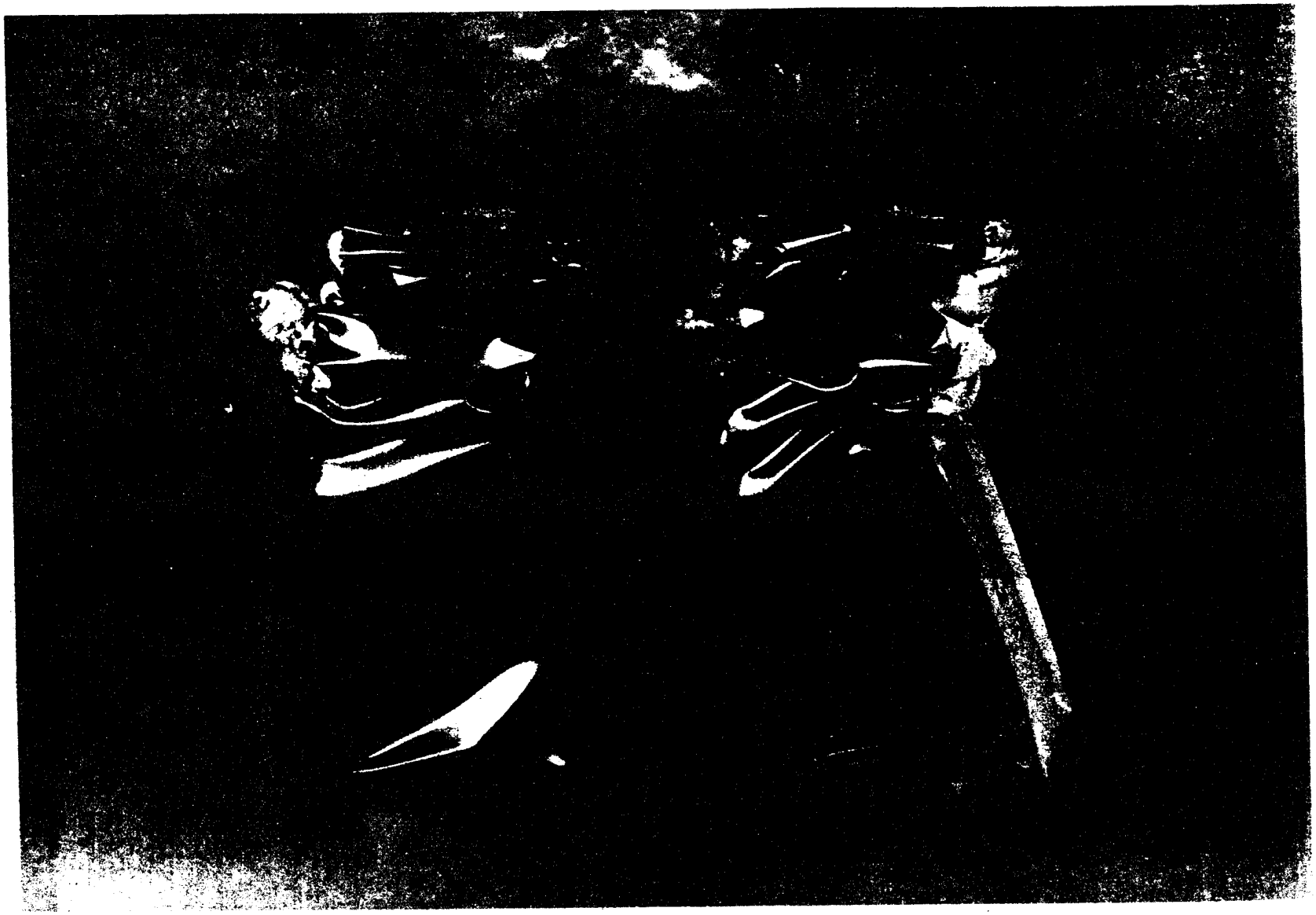


Figure 26



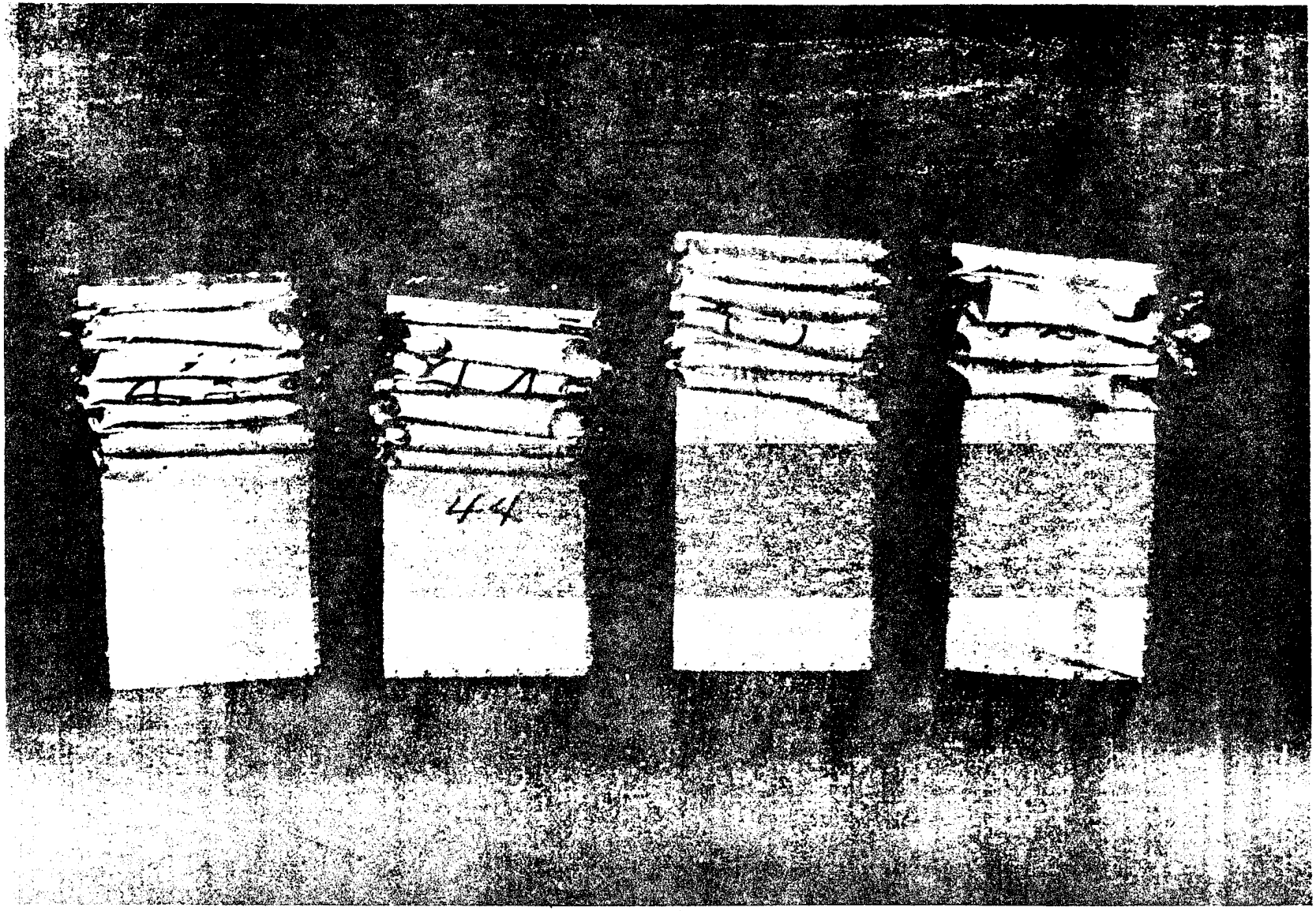
83 84 85

Failure Mode
Molded Foam Inserted into Specimen



30 29

Failure Mode
Silicone Greased Specimen



45 44 43 42

Nos. 45, 44 Failure Mode Nos. 43, 42

Riveted Structures

Crush Ratio Comparisons
Effect of Rivets

$R_c = C_p/C_s$

C_p = Peak dynamic crush of specimen

C_s = Avg. Peak dynamic crush of standard specimen (15.34)

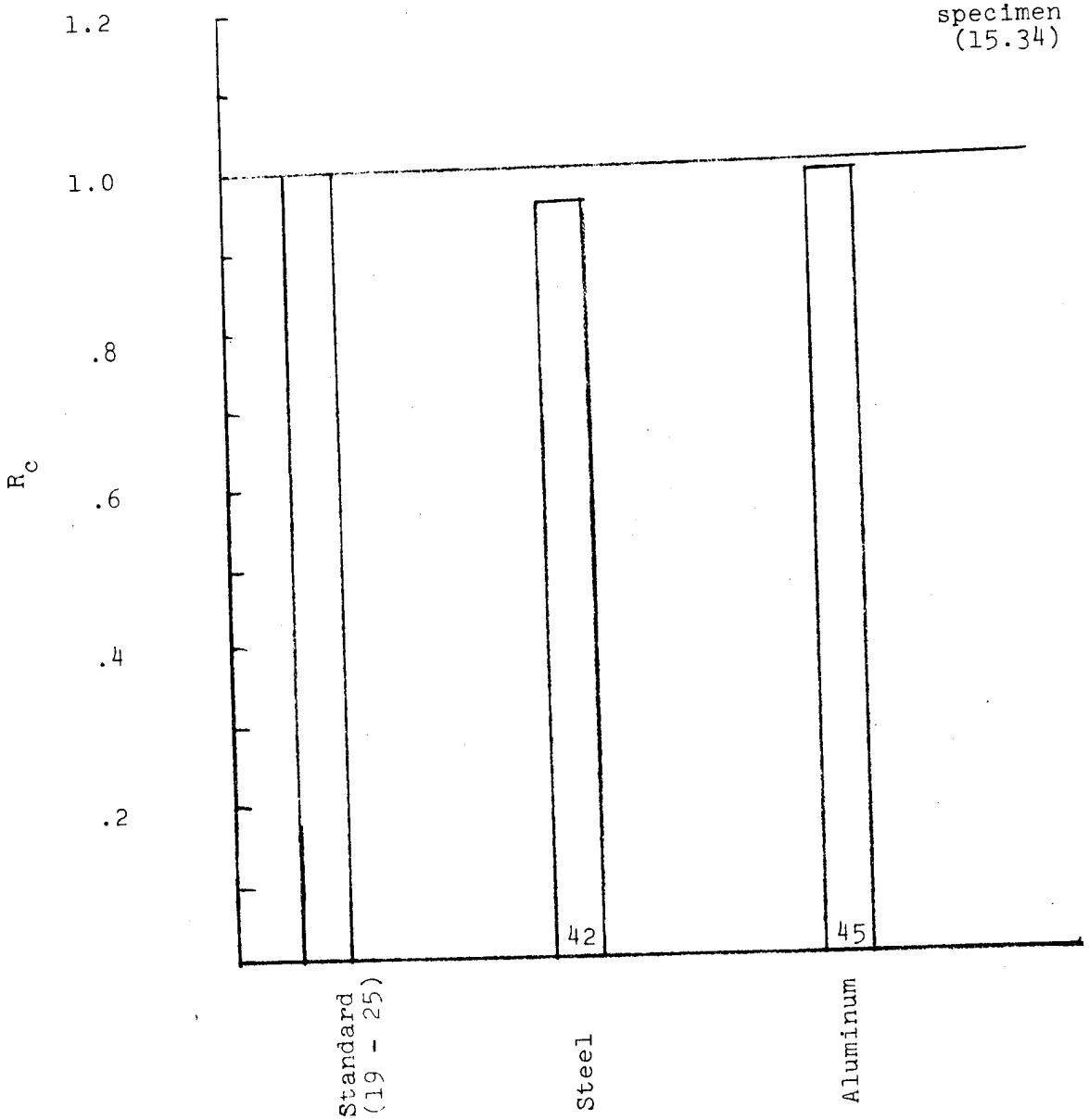


Figure 27

3.3.8 Repair (Low energy damage)

Two types of damage to the foamed specimen were investigated. These were:

1) longitudinal damage, that is along the axis of the member where the damage progressed from the impacted end and,

2) side impacts in which the damage is distributed along the specimen.

The specimens were examined after damage, repaired and then dynamically tested to determine the effect repairability had on the crush characteristics of the specimen. Specimens were impacted at 10 mph.

3.3.8.1 Longitudinal Damage (10 mph)

Specimens were fabricated in the same manner as the standard specimen. The calculations for drop weight and drop distance is on page 136.

The test specimen was positioned on the base plate, the drop weight, 177.2 lbs, was raised 40 inches above the test specimen, and then dropped.

The three damaged specimens all exhibited similar failures and crush distances (1 1/2 inches.) See Photograph A-34 on page 135.

3.3.8.2 Longitudinal Repair

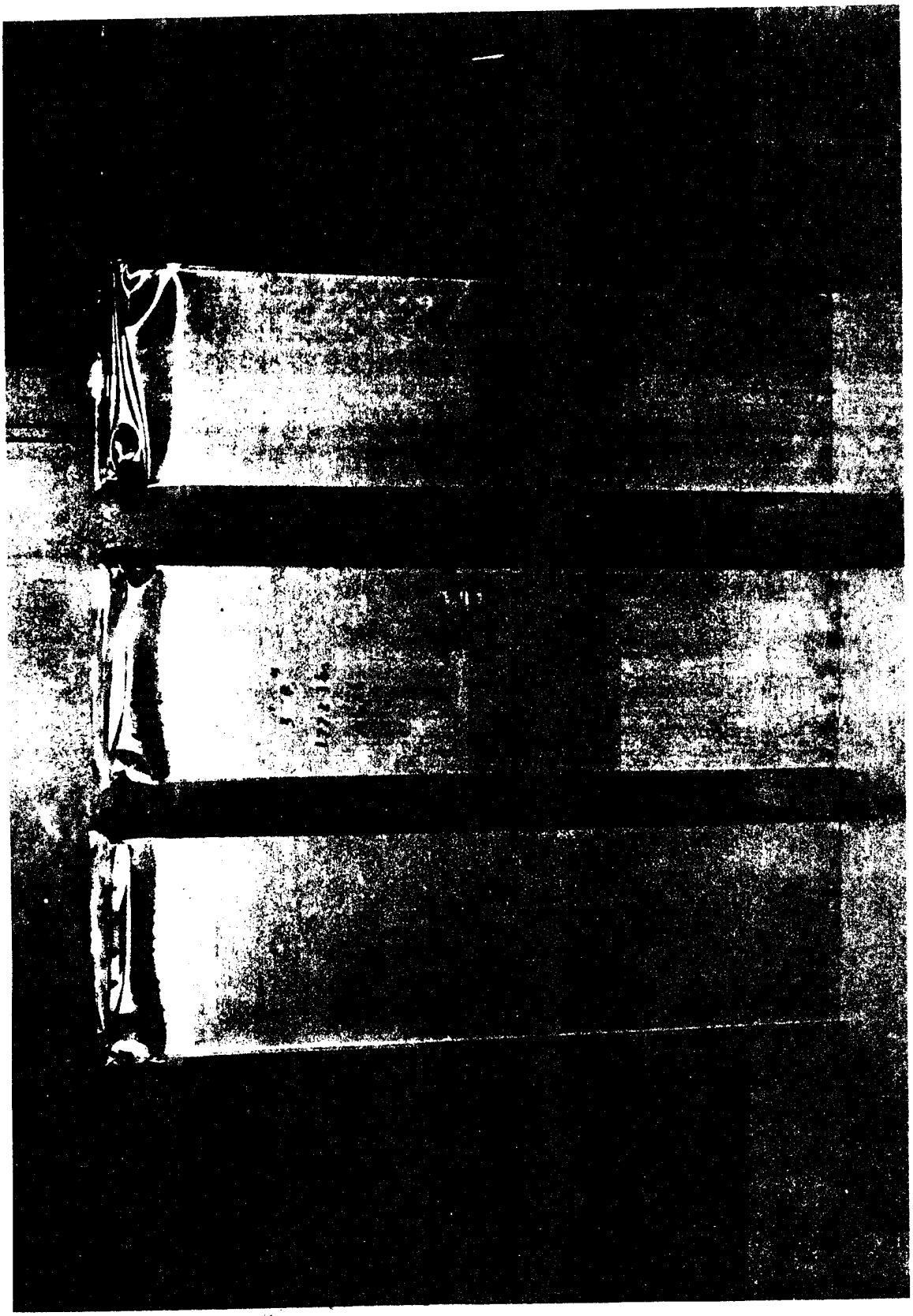
six inches of the damaged container was removed. A new section, of the same material, was fabricated to obtain the original container height.

Adhesive was placed in the areas as shown in Figure 28, page 138, and then riveted to the container walls. The new section was then filled with foam. Photograph A-35 on page 139 shows the original specimen, the damaged specimen, the repair parts, the damaged area removed and the repaired specimen.

Test results, peak dynamic crush, show that the repaired specimen crushed a little more than the standard control specimen. See Photograph A-36, page 140, for failure mode.

The test results are as follows:

Specimen No.	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program $V_F = 0$ (inches)
50	13.8	16.1
51	12.75	



10 mph
Frontal Damage

Tools and material that may be required for repair other than the standard tooling which may be available in a repair shop would be a rivet gun, epoxy adhesive and foam. Foam is available in kits and may be purchased from varied suppliers.

3.3.8.2.1 Calculations for Drop Weight and Drop Distance for Low Energy Impact (10 mph)

Specimens were damaged by arbitrarily selecting a car weight of 2835 pounds impacting a foam filled structure at 10 mph.

The calculations for the drop weight and drop distance for the impacting energy on the test specimen are as follows:

Calculated Drop Distance for 10 mph impact with a 177.2 pound drop weight.

$VF^2 = VI^2 + 2as$

$216 = 0 + 2\ (32.2)\ s$

$3.35\ ft = s$

$VI^2 = o$

$a = 32.2\ ft/sec^2$

$VF = 10\ mph$
$(14.7\ ft/sec)$

177.2 lbs

KE for Specimen @ 10 mph

$KE = 1/2\ MV^2$

$KE = \frac{177.2 \times 216}{2(32.2)}$

Specimen

$KE = 594$ ft-lbs
7132 in-lbs

KE for 2835 lb. car @ 10 mph

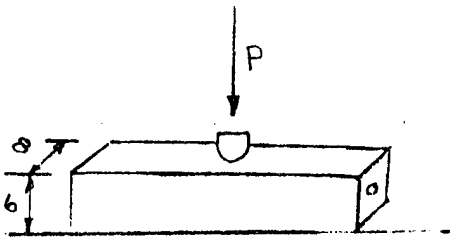
$KE = \frac{2835 \times 216}{2(32.2)}$

$KE = 9509$ ft-lbs

$= 114{,}108$ in-lbs

3.3.9 10 mph Side Impact

The test specimen was positioned on the base plate of the drop tower as shown on the following page.

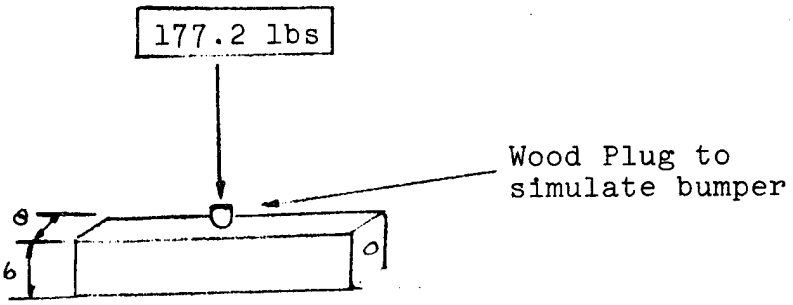


Two specimens were crushed in this manner. The damage was so extensive that the specimens could not be repaired. See Photograph A-37 on page 141 and Figure 29 on page 142.

Three specimens were then damaged by a 5 mph side impact for repair and test.

3.3.10 Procedure - 5 mph side impact

The 177.2 lb. weight was raised 10 inches above the specimen and then dropped. See sketch below for test set-up.



Three specimens were damaged in this manner. See Photograph A-38 on page 143 . Two specimens, 53 and 54 were repaired and then tested dynamically at 30 mph as all the previous specimens were.

Specimen 52 was tested without repair. See Photograph A-39 on page 145. Damage caused by a 5 mph side impact is shown in Figure 30 on page 144 . See Table 58 on page 146 for crush data.

3.3.11 Repair Procedure for 5 mph Side Impact (Epoxy and Metal Patch)

1. A metal skin was fabricated from 1010 Steel (.022" - .024" thick) to cover the damaged area. Holes were drilled at 1 1/4 inch spacings.

FRONTAL REPAIR

10 mph

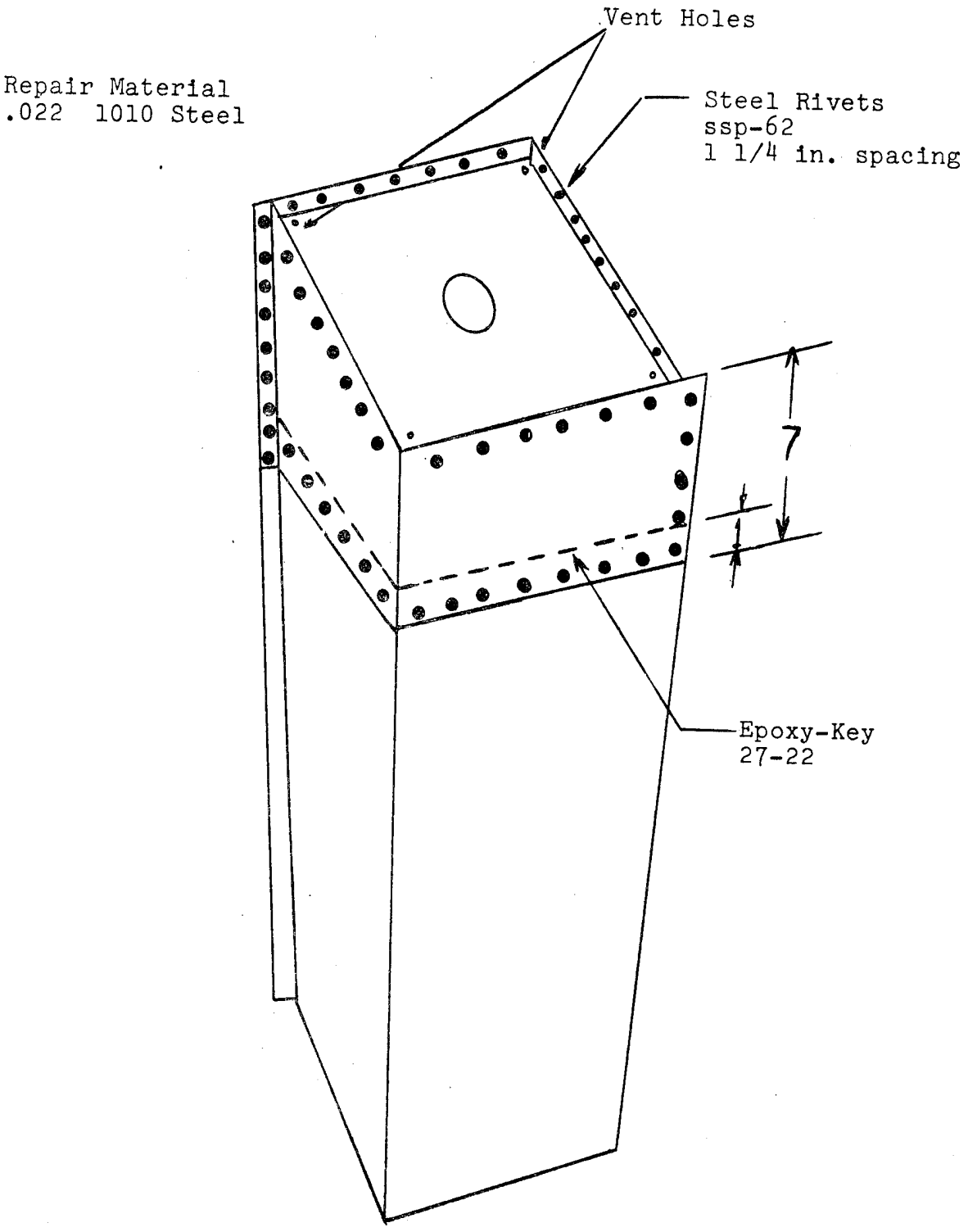
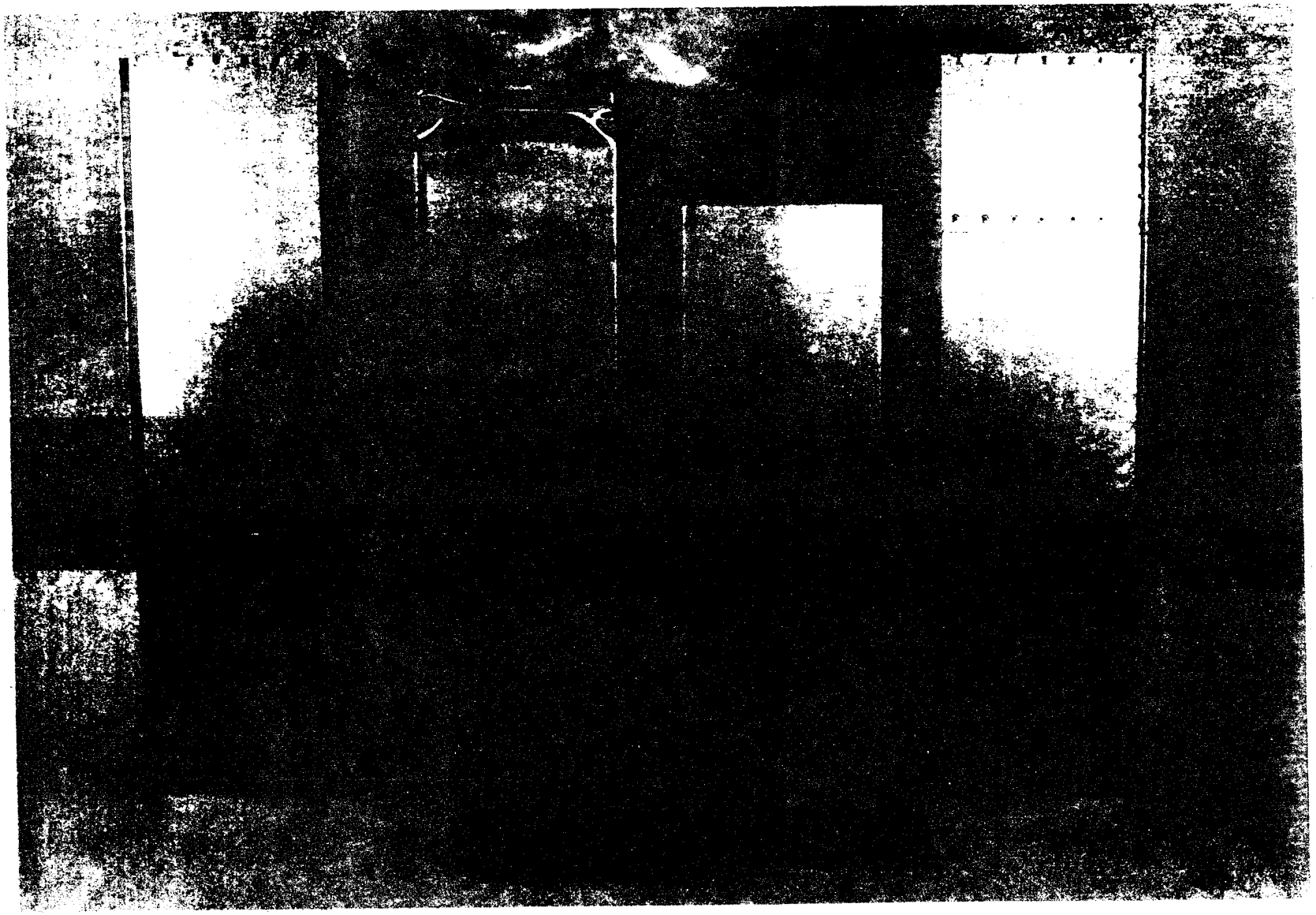
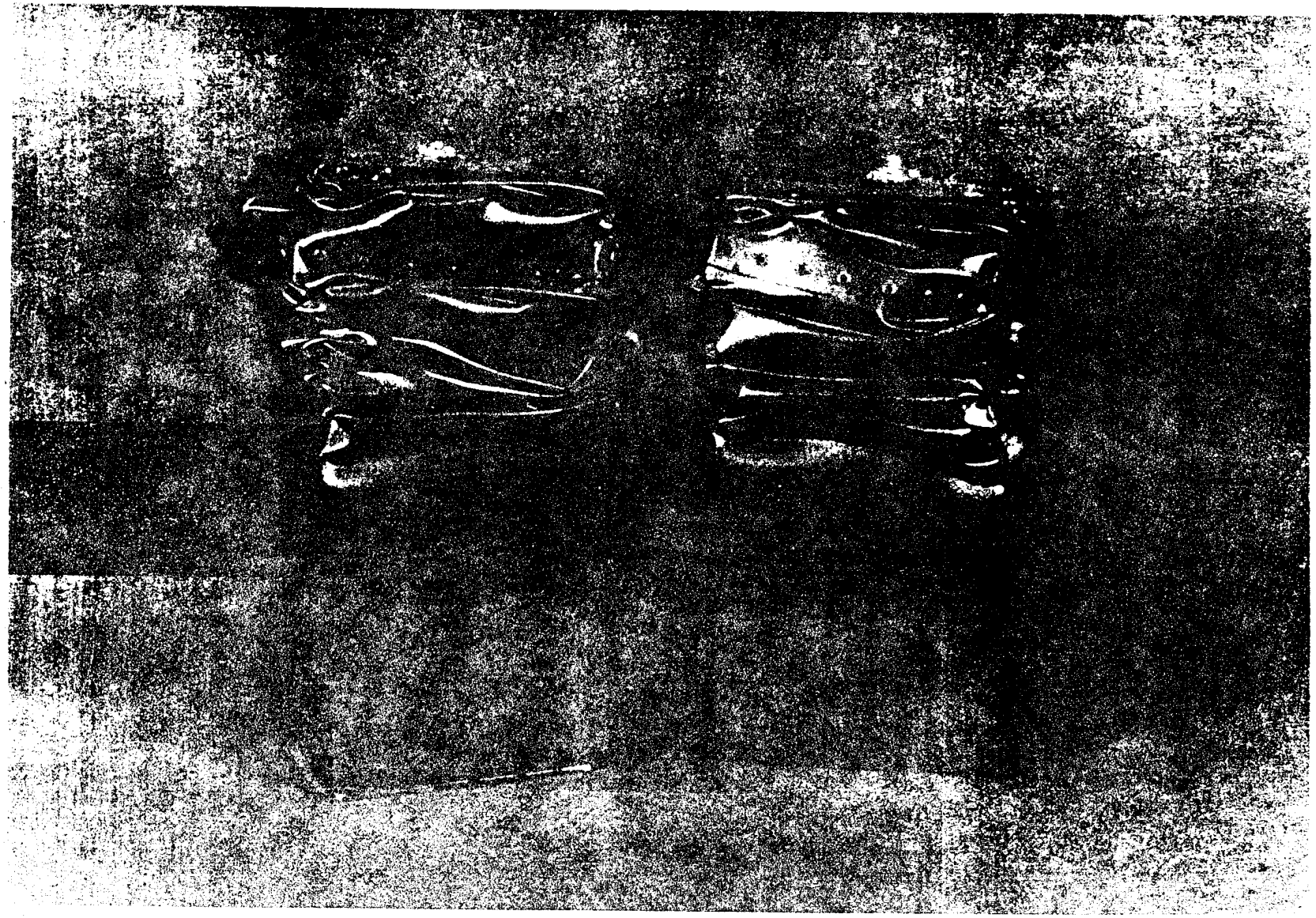


FIGURE 28



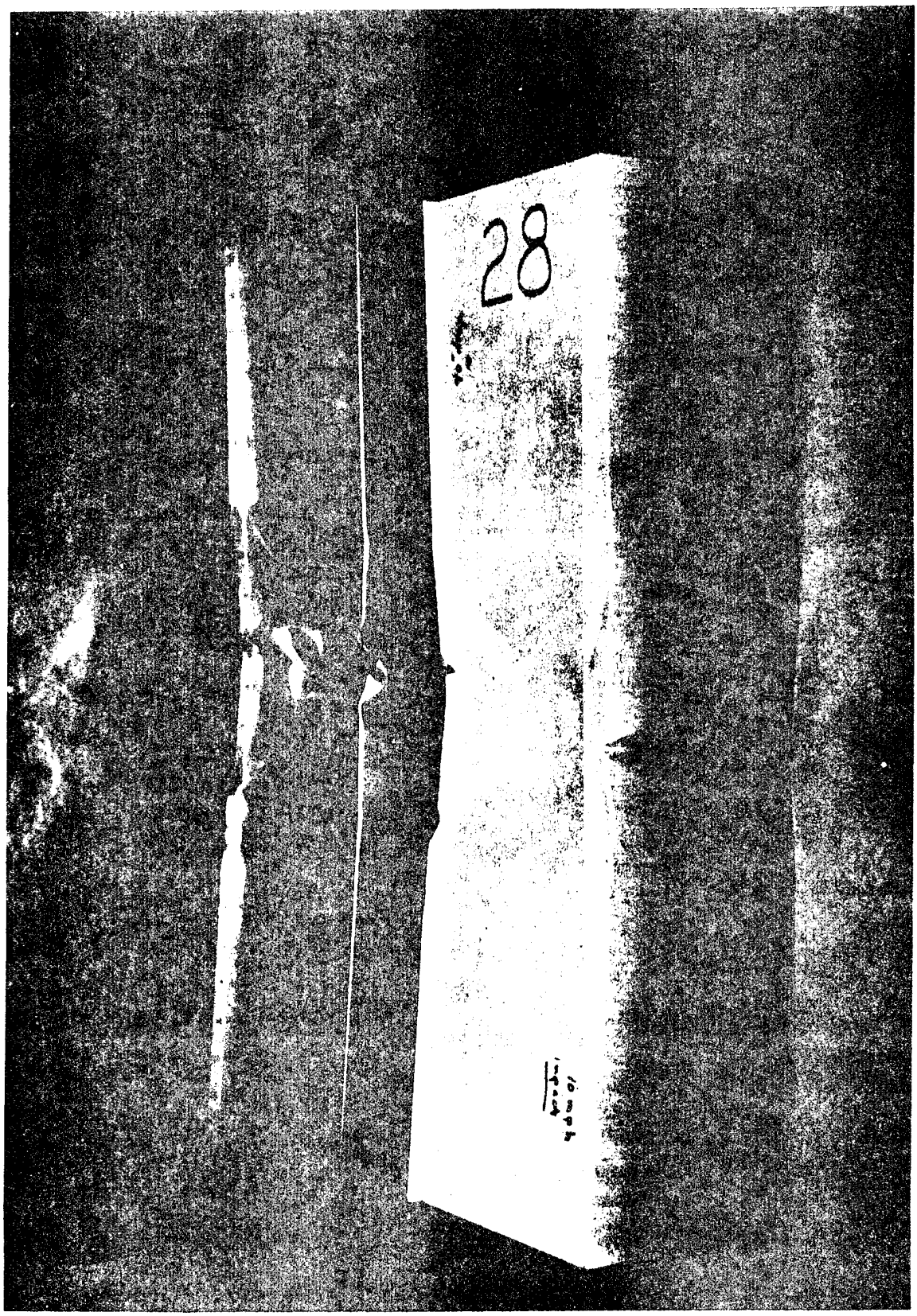
Original Specimen | Damaged Specimen | Specimen with damaged area removed | Repaired Specimen

10 mph
Frontal Repair



50 51

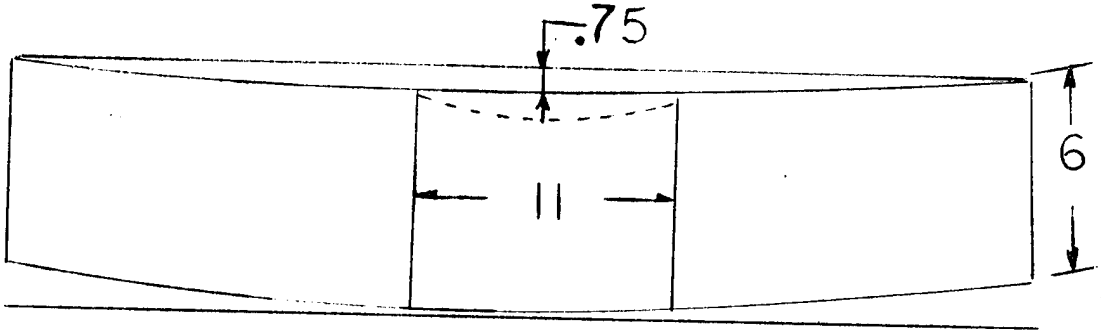
Failure Mode
10 mph Frontal Repair

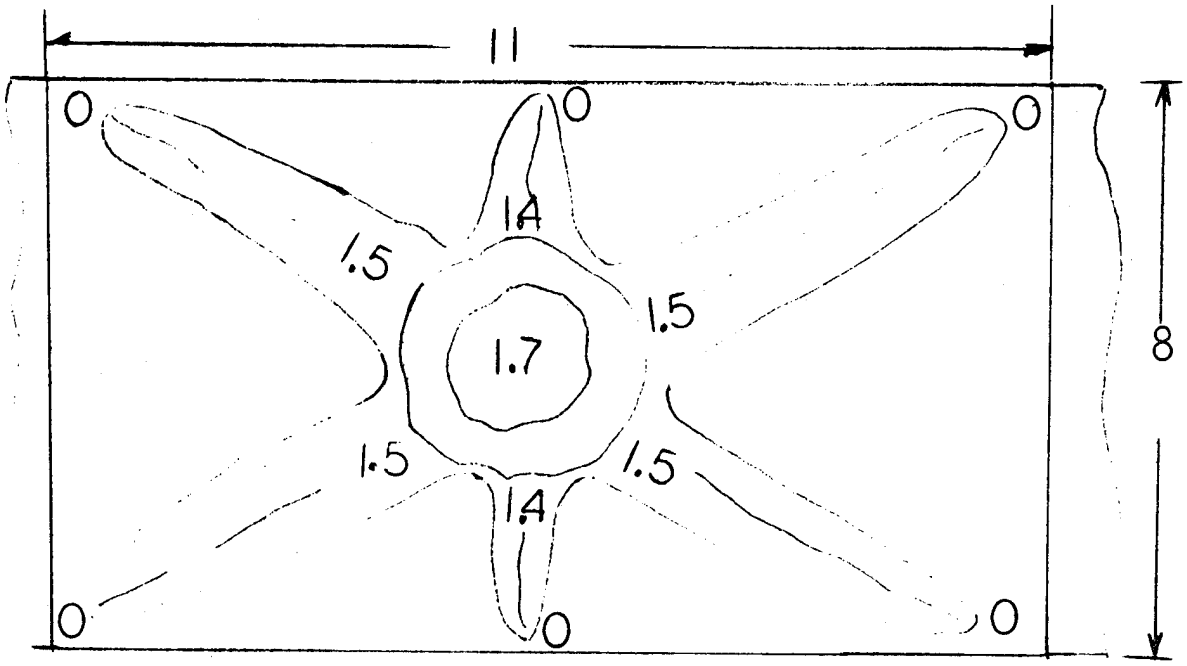


10 mph Side Impact Damage

DEPTH OF DAMAGE (inches) 10 mph

SIDE IMPACT

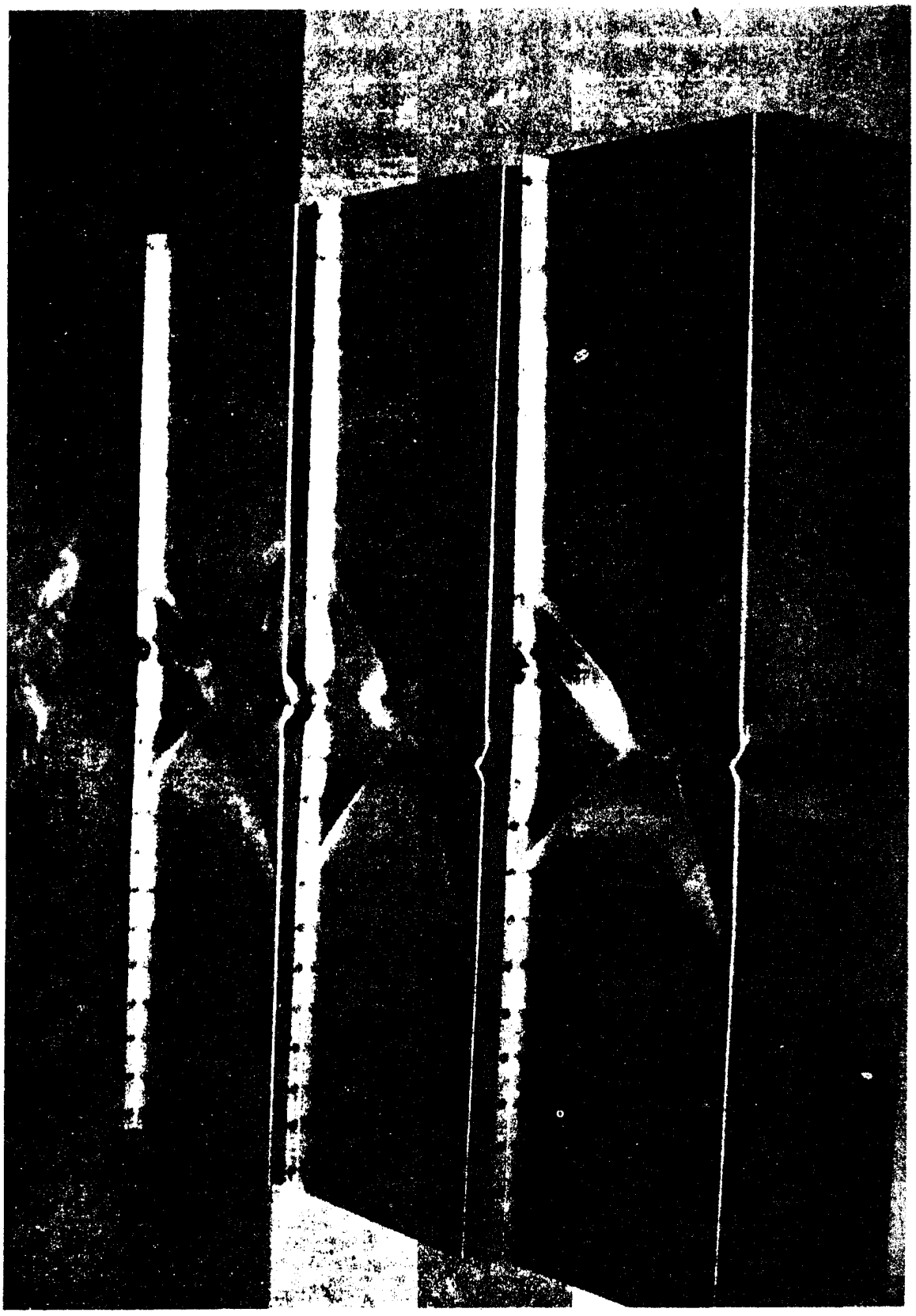




TOP VIEW

DEPTH OF DAMAGE

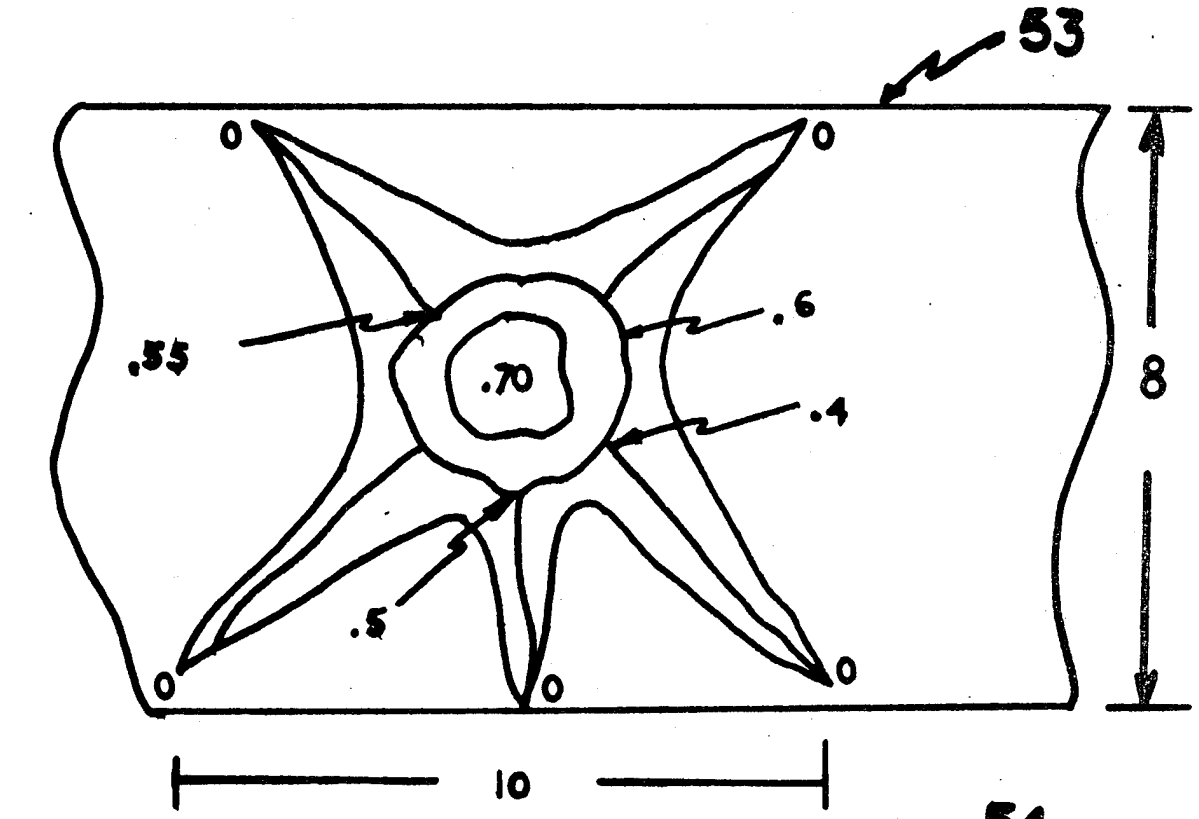
Figure 29



5 mph Side Impact Damage

DAMAGE CAUSED BY 5 mph

Depth of Side Impact, Damage (inches)



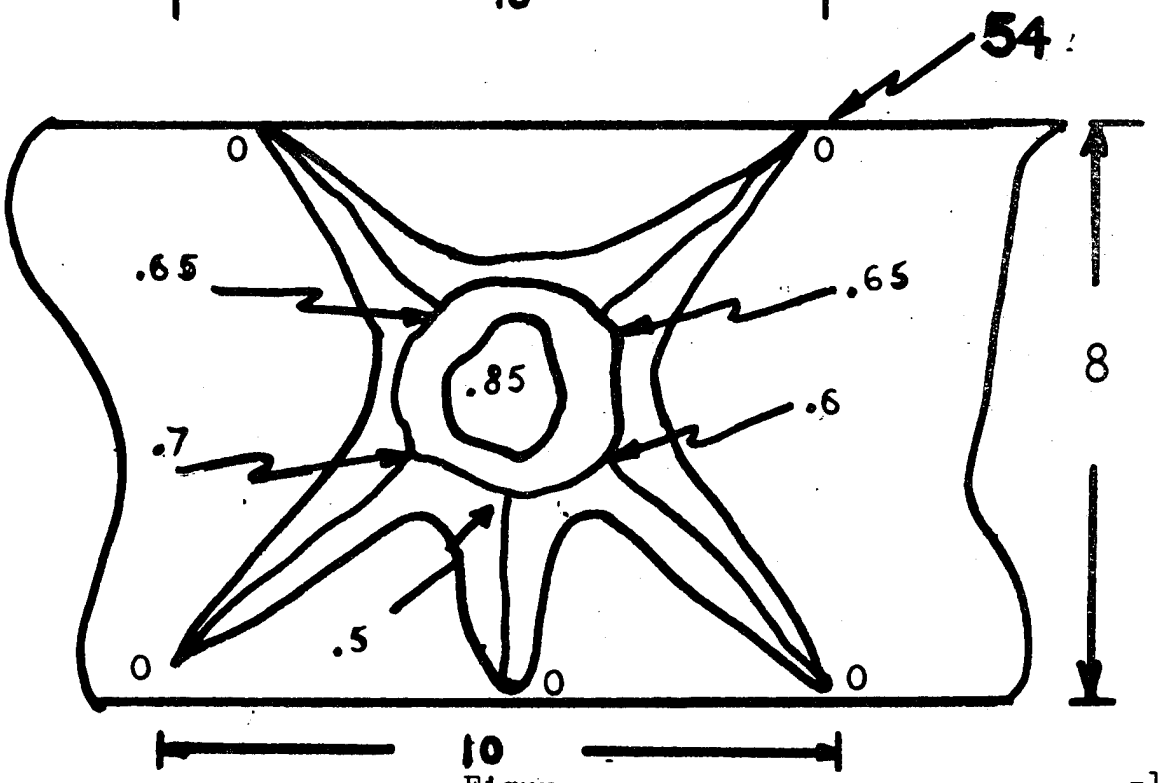


Figure 38

52

Failure Mode - 5 mph
Side Impact, No Repair

2. The damage area and underside of patch were abraded using a scotch brite pad.

3. The abraded areas were then solvent wiped using methylene chloride.

4. Key Epoxy 27 - 22 was then used to fill the depressed area and then spread on the underside of patch.

5. The patch was then positioned and riveted to the damaged specimen and allowed to cure.

See Photograph A-40 on page 147 and Figure 31 on page 148 for repair.

See Photograph A-41 on page 149 for failure mode.

3.3.12 Repair Procedure for 5 mph Side Impact (Epoxy Repair)

1. The damaged area was abraded using a scotch brite pad.

2. The abraded area was then solvent wiped using methylene chloride.

3. Key Epoxy 51 - 189 A/B was then spread in the damaged areas.

4. After curing (minimum of 24 hours) the excess epoxy was ground off.

See Photograph A-42 on page 151 for repair. See Photograph A-43, page 152 for failure mode.

TABLE 38

Repair Crush Data

Specimen No.	Repair	Post Test Measured Crush (inches)	Peak Dynamic Crush from Computer Program V_F =) (inches)	Wt.lbs. After Repair
52	No Repair	18	19.8	
53	Epoxy and Metal Patch	11.9	12.18	12.2
54	Epoxy Fill	15.2	16.3	9.3

5 mph Side Impact Repair
Epoxy and Metal Patch

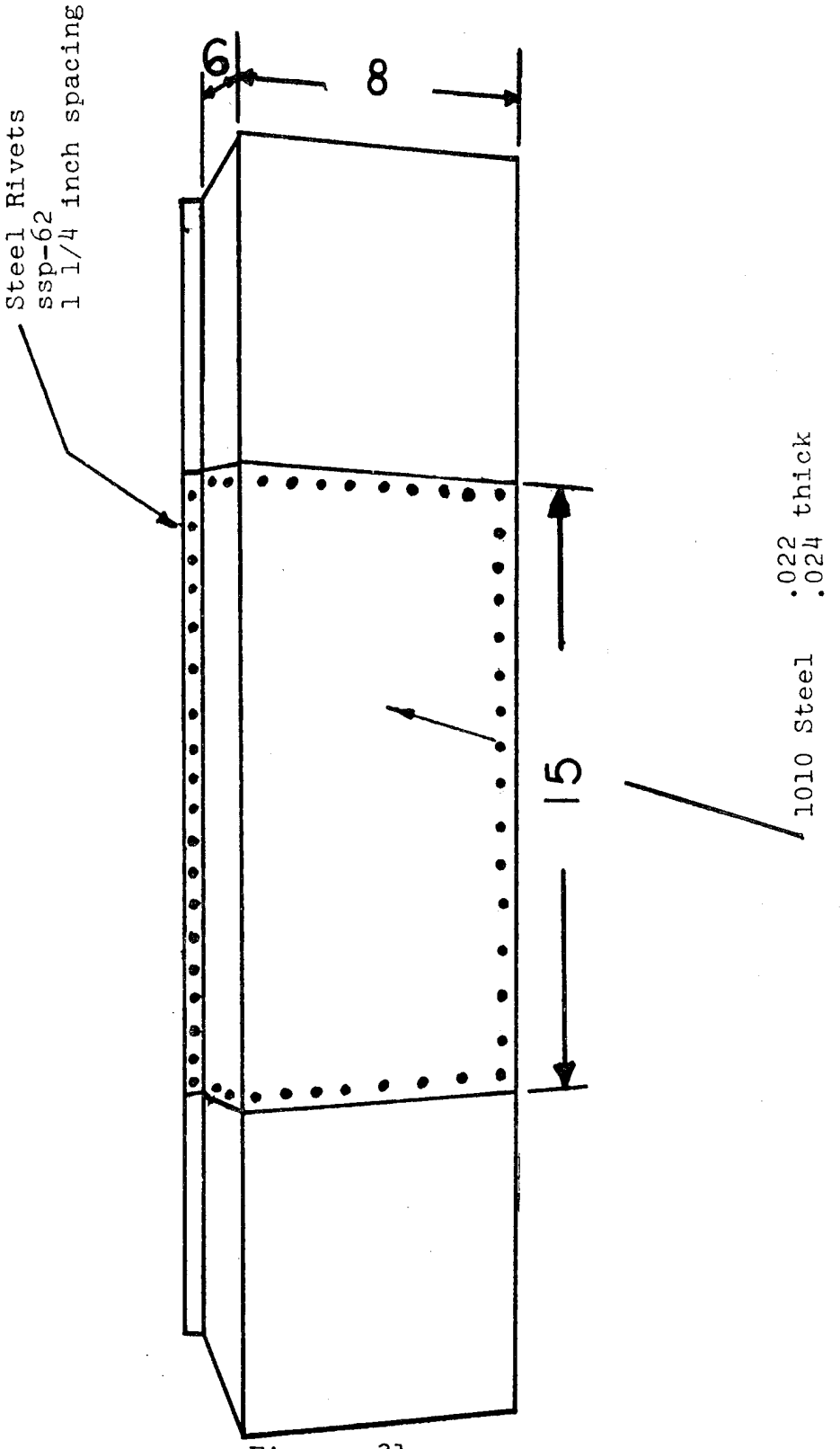
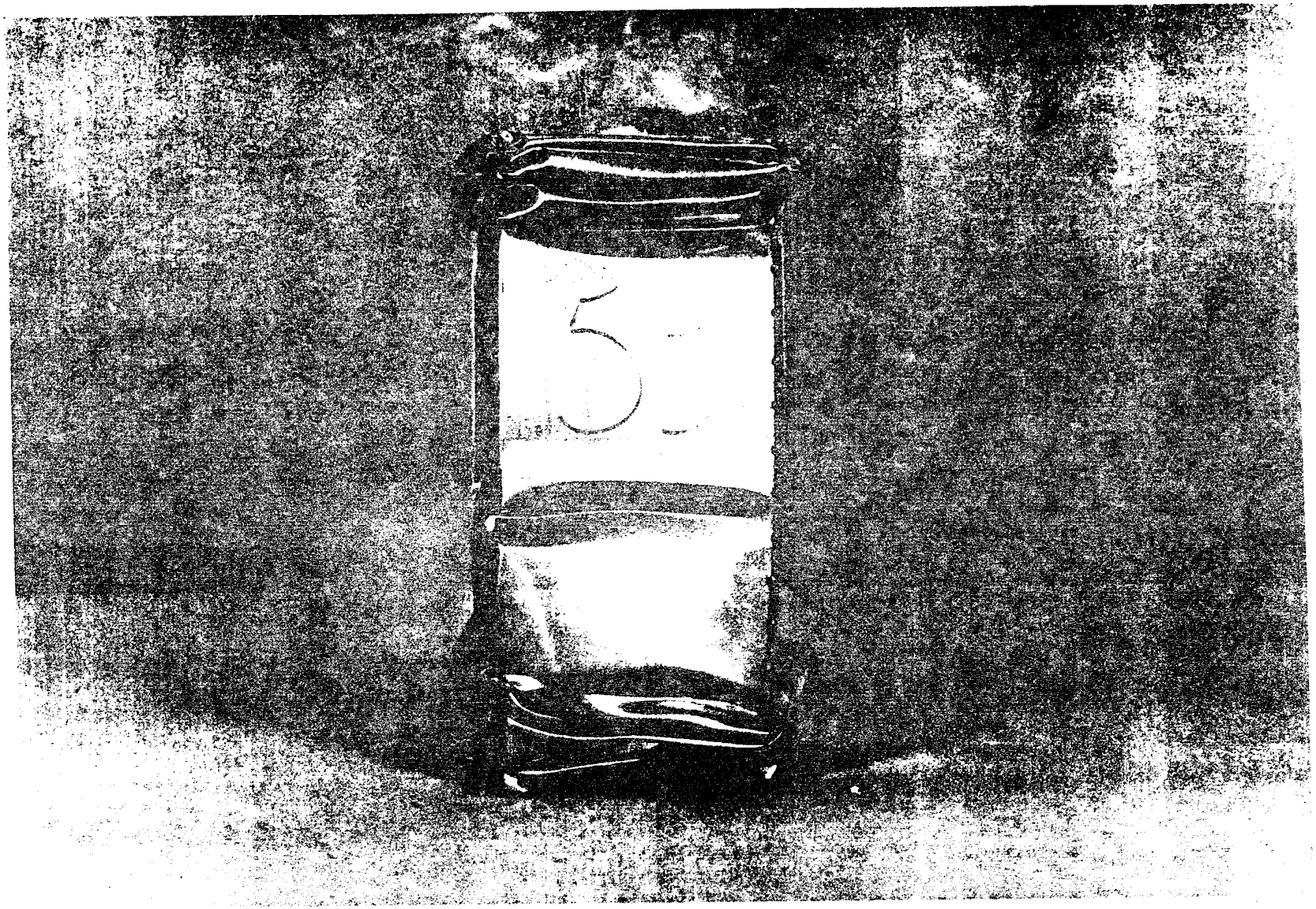

SIDE REPAIR
5 mph.
Steel Rivets
ssp-62
1 1/4 inch spacing
6
8
15
1010 Steel .022 .024 thick

Figure 31



Failure Mode
Epoxy and Metal Patch Repair

Failure occurred as follows:

Specimen 52 - Creasing or folding of specimen occurred at the creases formed in the metal when 5 mph impact was incurred.

Specimen 53 - Failure occurred normally up to patched area. The reinforced area did not crush and cut through the reinforced area below.

Specimen 54 - Specimen initially failed normally, bending then occured below the epoxy patch.

3.3.13 Comparative Burning Test - Rigid Foam Used in This Program and Flexible Foam Used in car Interior

3.3.13.1 Purpose

To determine the burn characteristics of a rigid foam (fire retarded) and a flexible foam used in car interior. The test was performed on a solid block and then shredded material of the same weight.

3.3.13.2 Procedure

Blocks of the same weight, five grams (approximately 2" x 2" x 2" cube) were cut from the rigid foam, and from the interior seat of a 1972 Chrysler, New Yorker.

3.3.13.3 Block-Test Procedure

A match was held at the corner of each specimen. The rigid foam with the fire modifier did not burn, even after five matches were used to try to ignite the sample.

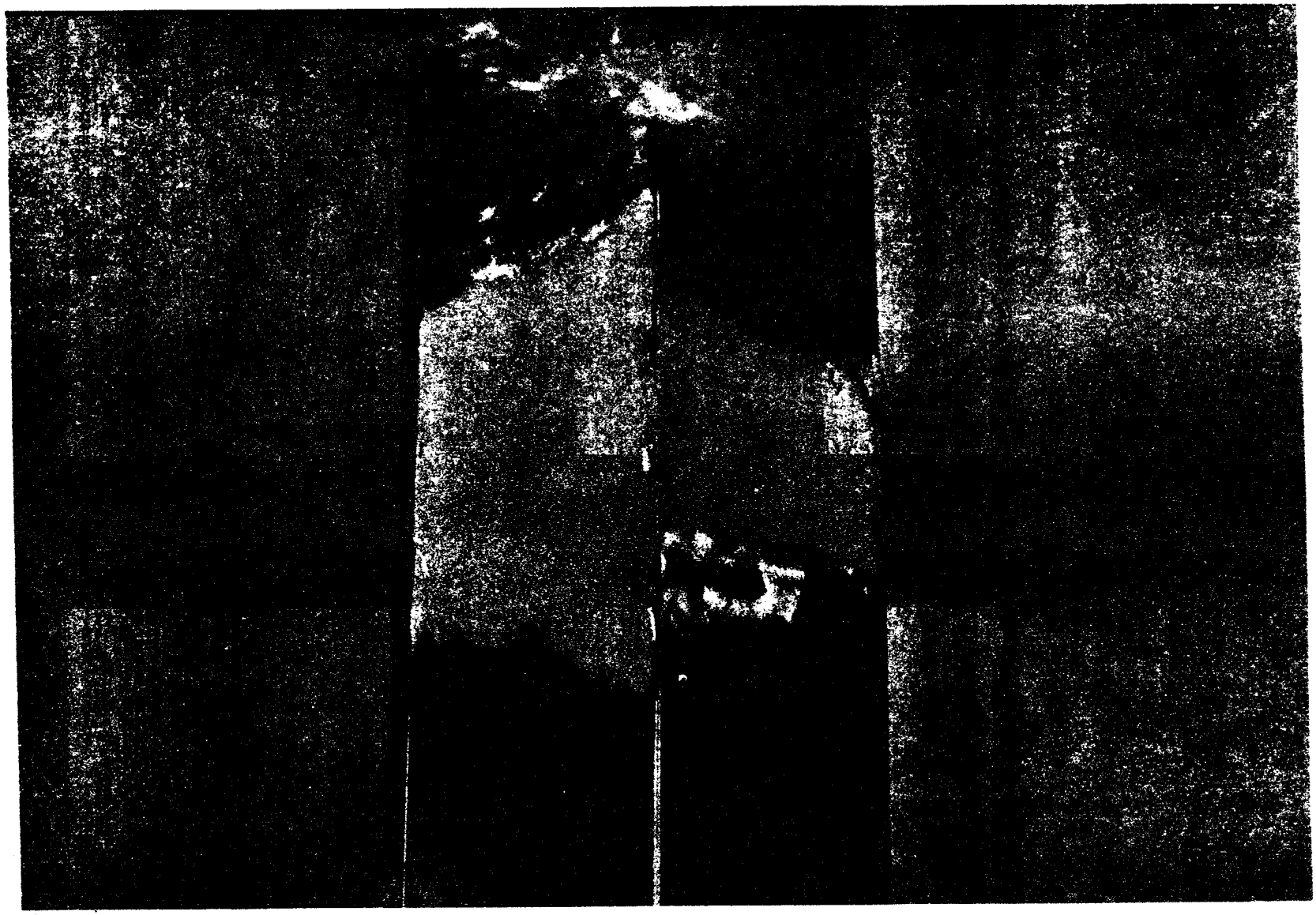
The flexible foam burnt slowly, with little or no smoke. It burnt to completion in three minutes leaving a brownish liquid residue.

3.3.13.4 Shredded Material Test

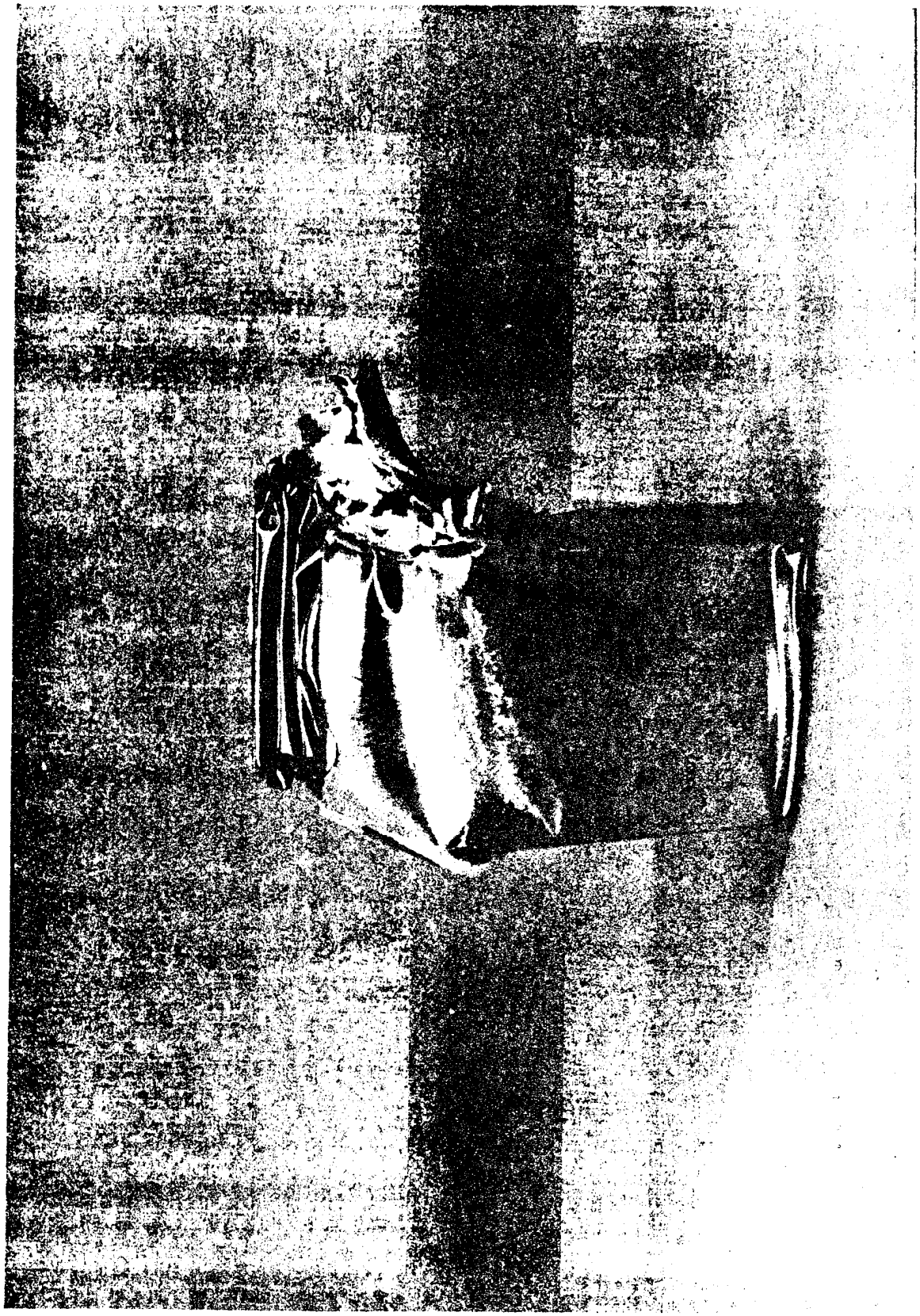
The same quantity of material was cut (flexible foam) and broken (rigid foam) into pieces roughly .5 x .5 x .5 inches. The pieces were ignited as before.

The flexible foam burnt with little smoke, and left the same brownish liquid residue. The foam was totally consumed in 50 seconds.

Whereas the rigid foam did not burn as a solid block, the smaller pieces burnt and spread rapidly to the other pieces, with crackling noises and an abundance of smoke.



Epoxy Patch Repair



Failure Mode Epoxy Patch

There was no melting, but charred remains were left of the broken pieces. Total burn time was also 50 seconds.

The exposure of large surface areas seem to encourage flame spread of the rigid foam even if the material is fire retarded due to its high surface to volume ratio.

3.3.14 High Heat Exposure of Foam Enclosed in Steel Specimen

Four specimens were conditioned for foam degradation after an exposure to a 300°F temperature for a period of seven days and 28 days.

After three days at 300°F, the controls of the oven went awry and temperatures soared to 1000°F. This occurred at 2:00 A.M. The smoke was so dense that it obscured the security photo cells which in turn set off the burglar alarm.

The steel specimens were bulged at the center, the foam was completely charred, there was no evidence of burning, just smoking due to thermal decomposition.

The area smelled similar to that of a burnt out electric motor (phenolic odor).

This test, though accidental, has significance in that the foam does not burn or explode in an enclosed container when exposed to an extremely high heat source, but gives off very dense fumes due to decomposition products.

3.3.15 Torch Flame Test

3.3.15.1 Purpose

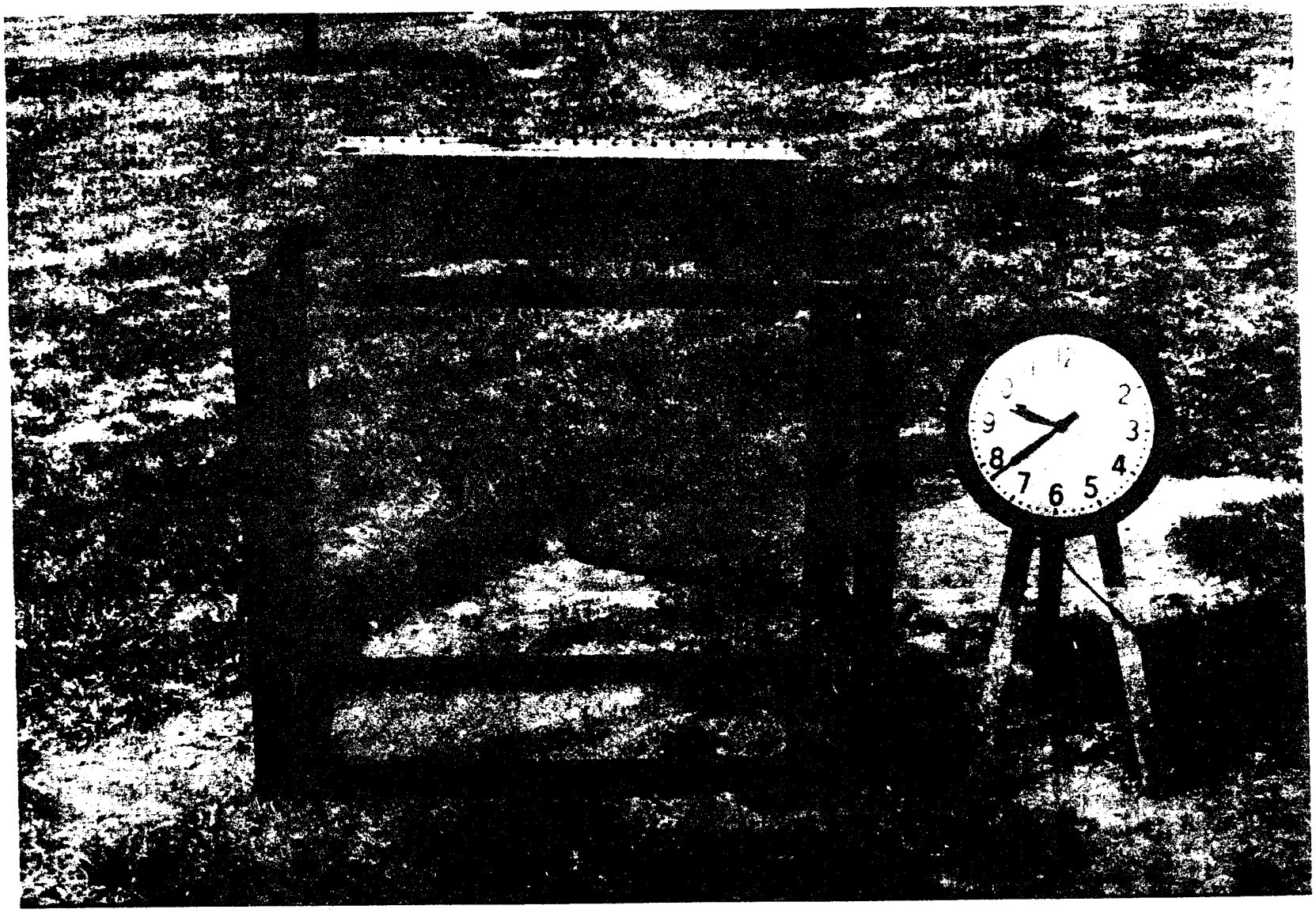
To determine the effect a flame would have on an undamaged foam filled specimen. The flame temperature was 1650 - 1800°F. These are the flame temperatures that are encountered in real fire situations.

3.3.15.2 Procedure

Thermocouple wires were welded to the top and bottom of the foamed specimen. Dimensions and weight were taken on the test specimens. The flame height was adjusted to an approximate 1700°F temperature measured by thermocouple and potentiometer. The specimen was then positioned as shown on Photograph A-44, page 155. Movies (16 mm) were taken of the test events, time of event happenings was taken by incorporation of clock in the movies.

3.3.15.3 Results

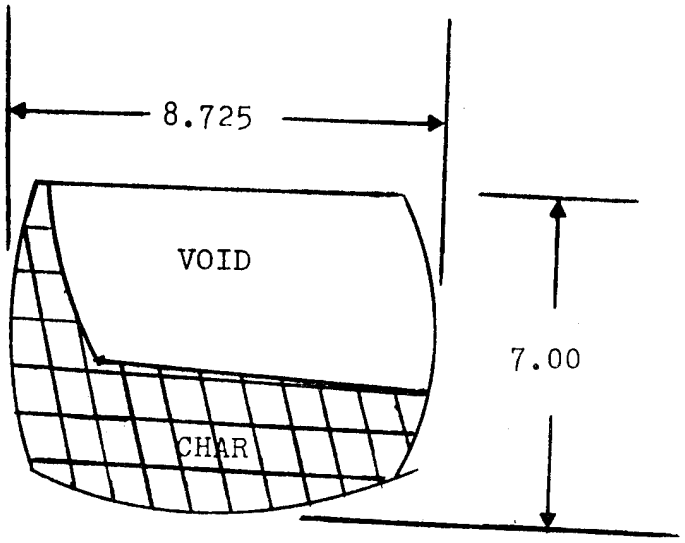
Within a few minutes the specimen bulged, a smell such as that from a burnt out motor was noted. A steady stream of smoke was coming out of the bottom vent hole. A small amount of black substance dripped out of the bottom vent hole at the beginning of the test. No more was noted during the test. The test was stopped after 45 minutes of exposure. The temperature on the top side was 250°F after 45 minutes. The temperature on the bottom was 900°F. The specimen was sectioned through the center to determine the condition of the foam. The cross section through the center is shown on Figure 32, page 156 . Photograph A-45 on page 157 shows cross section of the cut specimen.



Torch-Test Set-Up

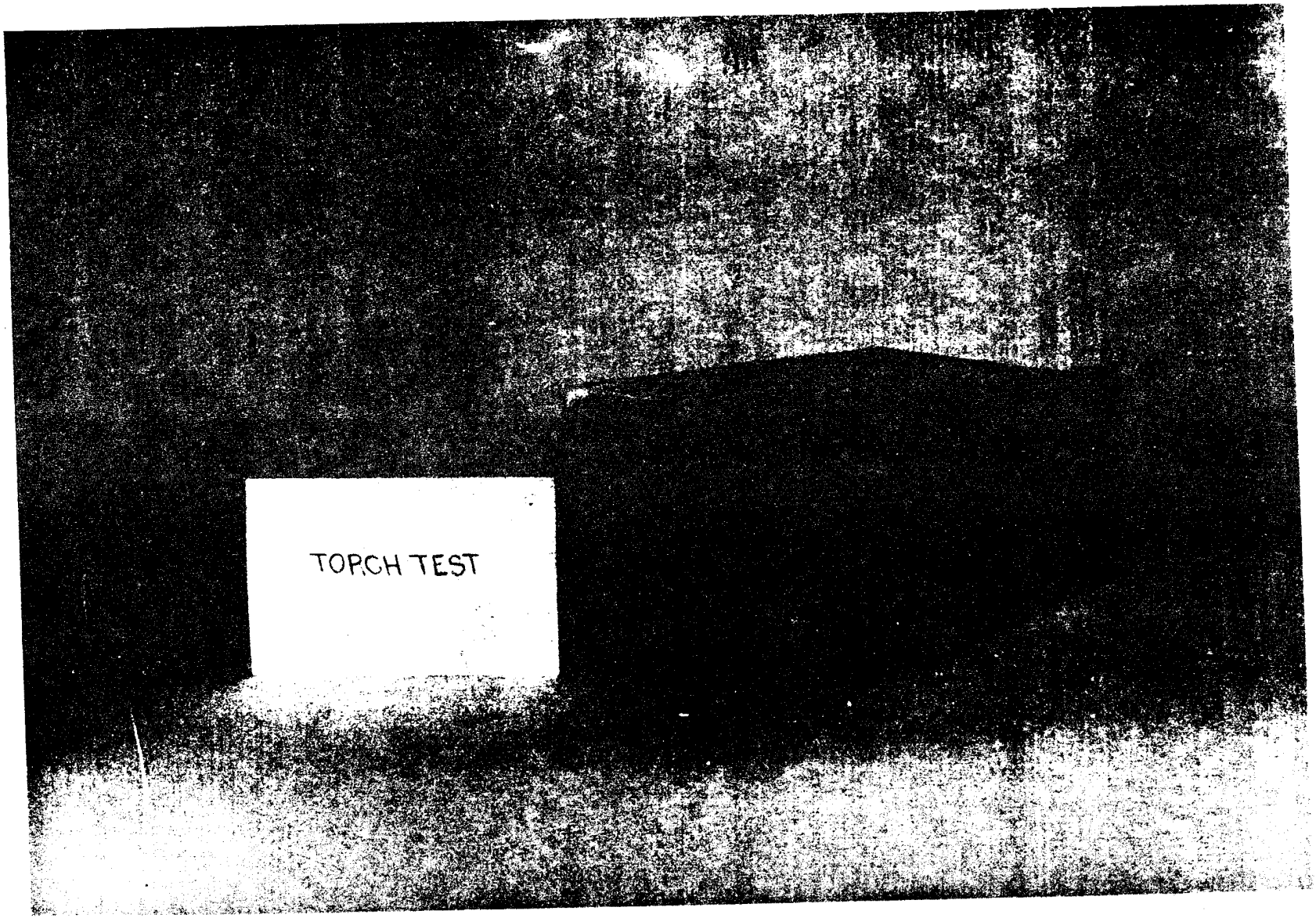
CROSS SECTION - FLAME TEST SPECIMEN

CUT THROUGH CENTER



Dimensions at Center (inches)			Weight (lbs)		
Before	After	Change	Before	After	Loss
7.977	8.725	+ .748	8.4	7.7	.7
6.035	7.000	+ .9965			

Figure 32



Cross Section of Specimen
From Torch Test

3.3.16 Burning Oil Test

3.3.16.1 Purpose

To determine the effect an oil fire would have on an undamaged foam filled specimen. This test was run to simulate an oil fire that may occur, if a carburator backfire were intense enough to ignite the oil on engine block and in turn what the effect would be on the hood if it were a foam filled structure.

3.3.16.2 Procedure

Thermocouple wires were welded to the top and bottom of the foamed specimen. Dimensions were recorded at centers and the specimen weights were recorded. One pint of motor oil 10 - 30 weight was placed in a stainless steel pan 10" x 14" and suspended 10 inches below the specimen. The container was positioned and the thermocouple leads attached to a potentiometer.

The oil was ignited by means of an oxy-acetylene torch. Movies were taken of the test.

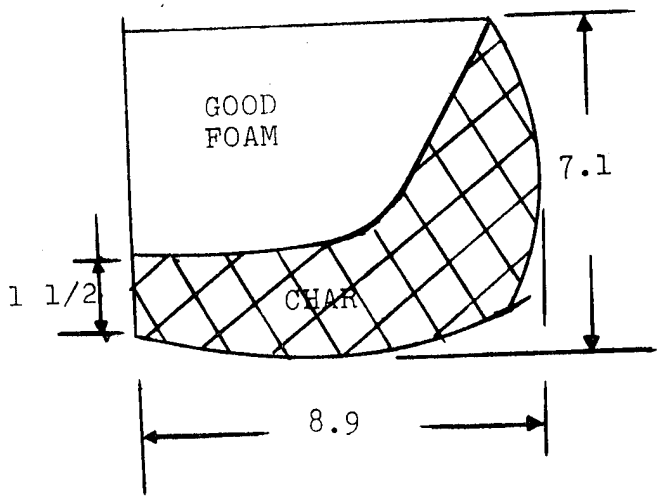
3.3.16.3 Results

Smoke evolved immediately. There was a greater abundance of smoke noted in this test than in the Torch Flame Tests. A greater area of the specimen was engulfed in flame than the torch test. The oil burnt itself out in 5 minutes. There was an occasional small flashing flame observed which came out of the vent holes.

The temperature at the top of specimen was 250 - 300°F in the center and 210°F at the extreme ends at conclusion of the test. The temperature at the bottom was 550°F. The specimen was sectioned through the center. See Figure 33 on page 159 for cross section of cut specimen.

CROSS SECTION - OIL TEST

CUT THROUGH CENTER



Dimensions at Center (inches)		
Before	After	Change
7.963	8.900	+ .937
6.068	7.100	+ 1.032

Weight (lbs)		
Before	After	Loss
8.4	8	.4

Figure 33

3.3.17 Burn Test (Gas Spill)

3.3.17.1 Purpose

To determine the burning characteristic of foam filled specimens which were previously dynamically tested at 30 mph. Specimen No. 22 had minimal seam opening and was tested previously for standard container data. Specimen No. 58 had both seams completely open with the foam exposed. This specimen was tested previously for 300°F properties. See Specimen No. 58. Photograph A-14 on page 91.

3.3.17.2 Procedure

The two specimens were placed in a shallow steel pan. One pint of gasoline was then poured over each specimen, saturating the specimen and the exposed foam, and then ignited. The weights of the specimen were taken prior to test.

3.3.17.3 Results

The only burning noted on previously tested Specimen No. 22 other than the gasoline was the foam at the pour hole. Specimen No. 58 with the foam completely exposed, burnt slowly with a small amount of smoke until the gasoline was depleted. The exposed foam burnt and formed a char layer approximately 5/8 to 3/4 inch deep. See Photograph A-46 on page 161 for tested specimens.

Specimen No. 22		Specimen No. 58	
Weight Before Test	8.3 lbs.	Weight Before Test	8.3 lbs.
Weight After Test	8.3 lbs.	Weight After Test	8.1 lbs.
Weight Loss	0	Weight Loss	.2 lbs.

3.3.18 Decomposition Gases from NB-237936 A Foam

Test results for gases that are evolved from the foam used in this program was performed by United States Testing Company, Inc., Hoboken, NJ, per Bureau of Ships Specification Identification No. 58-1016-1 "Procedures and Analytical Methods for Determining Toxic Gases Produced by Synthetic Materials."

The test report results are as follows. The complete Test Report is in Appendix C.

22 58

Gas Spill Specimens
After Burn Test

The gases detected from the decomposition of NB-237936A foam as reported by U.S. Testing Company, Incorporated, are shown in Table 41 on page 164. The only detectable gases were carbon monoxide and carbon dioxide.

Test Results show that carbon monoxide gas is likely to be the primary toxic hazard from the decomposition of NB-237936A foam. Other toxic gases. if present, were in less concentration than the detectable ranges of the Drager tubes. See Table 39 for sensitivity range of tubes.

It may be assumed from this test that if other toxic gases were in sufficient concentration to be detected in the lethal range the lethal concentration of carbon monoxide would in all probability have been reached prior to their detection.

TABLE 39 (Ref. 58)

GAS	SENSITIVITY RANGE (ppm) Lower	Upper
Chlorine	.2	3
Hydrogen Chloride	1	10
Phosgene	0.25	15
Aldehydes as formaldehyde	2	40
Ammonia	5	70
Carbon monoxide	5	150
Carbon Dioxide	100	1500
Oxides of Nitrogen as NO_2	0.5	10
Hydrogen Cyanide	2	30

Table 40, page 163, shows toxicity limits of gases given off by plastics.

TABLE 40 (Ref. 58)

Toxicity Data

Gas	*M.A.C. (P.P.M.)	Immediate Danger to Life (p.p.m.)
CO (carbon monoxide)	50	5,000
CO_2 (carbon dioxide	5,000	100,000
H_2O (water)	-	-
HCl (hydrogen chloride	5	1,000 - 2,000
HCN (hydrogen cyanide)	10	200-300
$NO+NO_2$ (nitrous oxides)	5 (NO_2)	200-700 (NO_2)
HF (hydrogen fluoride)	3	50-250
SO_2 (sulfur dioxide)	5	400-500
Formaldehyde	5-10	50-100
Phenol	5	

* Maximum atmospheric concentration for an 8 hour exposure

\+ Aircraft Engineer, November, 1972

TABLE 41

Detected Gases from Foam Decomposition

Composition of Atmosphere (in parts per million)

Samples	1	2	3	4	Average
Chlorine	0	0	0	0	0
Hydrogen Chloride	0	0	0	0	0
Phosgene	0	0	0	0	0
Aldehydes as HCHO	0	0	0	0	0
Ammonia	0	0	0	0	0
Carbon Monoxide	5	5	5	5	5
Carbon Dioxide	50	50	25	25	38
Oxides of Nitrogen as NO_2	0	0	0	0	0
Cyanides as HCN	0	0	0	0	0
Oxygen	208,000	208,000	208,000	208,000	208,000
Nitrogen	791,920	791,920	791,945	791,945	791,933
Combustibles as Natural Gas	25*	25*	25*	25*	25*

* Detection limit, sample values lower

3.3.19 Disposal of Urethane Foams

Polyurethane foam being a thermosetting material, cannot be recycled in the usual sense of the word, which implies remelting and usually blending with virgin material to produce a plastic with essentially the same properties as the original.

Considerable consideration is being given recently to the conversion of scrap polyurethane foams to polyols and diamines. Polyols are the basic chemicals used in the manufacture of foams and the diamines are intermediates used for isocyanate formation. These conversion techniques will be discussed in more detail later.

Other important methods of disposal of plastics are landfill, incineration and pyrolysis. Composting is used to some extent, but is not very effective due to the fact that most plastics are not really biodegradable.

Landfill may be carried out as open dumping, this is not an acceptable method; or by sanitary landfill, wherein the waste is deposited in depressed areas and then covered with a layer of soil. Plastics are particularly desireable in sanitary landfills since they do not biodegrade to any appreciable extent with resultant shifting of land masses.

Since there is a limit to the amount of land that can be devoted to sanitary landfill, it is generally considered more desirable ecologically to use either incineration or pyrolysis.

Incineration is the burning in the presence of oxygen. There are no useful recoverable products by incineration with the exception of energy. Toxic gases are known to be emitted during incineration. Since plastics have a high heat content, incineration of wastes with a high proportion of plastics can provide a considerable amount of energy recoverable as steam.

Probably the optimum way of disposing of plastics waste, including urethane foam, is by pyrolysis which is burning in the absence of oxygen. Pyrolysis results in a number of useable by-products, such as oils, waxes and gas for heating.

Incineration is not recommended as a method of foam disposal. Carbonyl fluoride, nitrous oxides and certain cyanide gases are formed during combustion. It is estimated that 700 cubic feet of air is required to dilute the combustion products of one cubic foot of foam to a Threshhold Limit Value (TLV) of 10 p.p.m. for Cyanide. (Ref. 59)

Methods are under study that hydrolyze 80-90% of foam. Methyl chloride, is the solvent used in this process, and the basic chemicals of the foam are nearly entirely recoverable. Currently there are three methods available for reclaiming foam by breaking the foam down into its original chemical precursors. These processes. discussed below, were developed by The Ford Motor Company, General Motor Company and The Upjohn Company.

1. Ford Motor Company Process (Ref. 60)

Polyurethane foam is reacted with superheated water. Upon reaction for 15 minutes with super heated water at 200°C, the low density scrap foam is converted to a liquid more dense than water. A 65-85% theoretical yield of toluene diamines and a 90% yield of liquid polypropylene oxide are isolatable from the liquid. After reaction at 200°C for 15 minutes the low-density foam-water systems are converted to two-phase liquid systems. Upon vacuum distillation, the aqueous phases yield toluene diamines. The yields of diamines vary considerably with the source of the material. Headrest material yielded diamines up to 25% by weight while dirt and oil saturated scrap foam collected from auto shredder sites, yielded toluene diamines 7-12% by weight. The latter were contaminated with dirt and oil.

2. General Motor Company Process (Ref. 61)

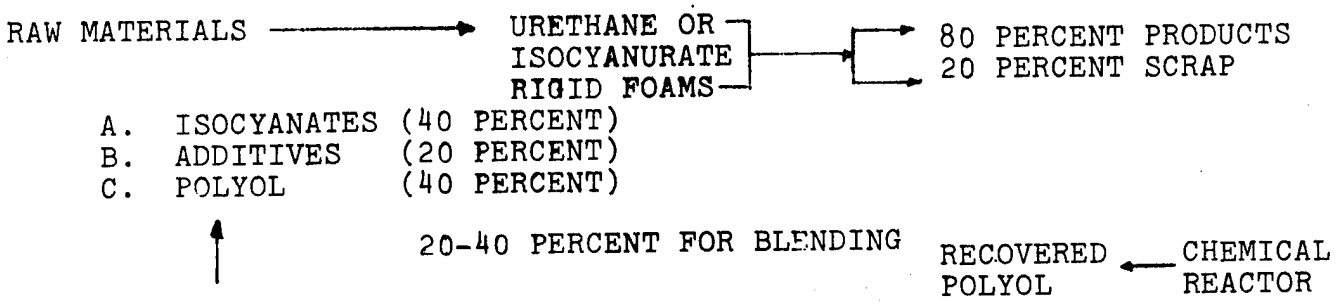
This process utilizes a combination of thermal and hydrolytic degradation and is aimed at reclaiming the polyol without complex purification. Superheated steam at one atmosphere and 600°F provides heat and water vapor for degradation of both the urea and urethane linkages in the foam. Because there are no chemicals or liquid water in equilibrium with the vapor, the polyol produced is reasonably dry and free of contaminants. The steam is under little pressure so there is no danger of explosion and since the reaction occurs in the absence of oxygen, there is no danger of oxidation. The materials obtained by this process can be re-used in making foam.

3. Upjohn Process (Ref. 62)

This process consists simply of feeding cut-up or pulverized foam continuously through a hopper or screw type solids feeder into a heated reactor container from 90-95% of an aliphatic diol and from 5-10% by weight of an dialkanolamine. The reaction is conducted at 185-210°C under slight nitrogen purge. It is in essence an ester interchange reaction.

The product is a homogeneous, very dark viscous liquid which should be drummed at 50°C. This product should be put through a cartridge type filter to remove any foreign particles that may have been introduced with the scrap foam. The reaction is virtually quantitative, encountering only a 6 to 8% loss in total weight. This weight loss is partly due to freon originally present in the foam. Below is the rough recycle scheme for the recovery of components from urethane foam.

ROUGH RECYCLE SCHEME FOR URETHANE AND OTHER ISOCYANATE-BASED RIGID FOAMS



Nippon Soflon, Tokyo, is building a 1.3 million lb/yr. plant to recycle rigid urethane foam. Nippon Soflon is the largest rigid urethane foam manufacturer in Japan. The 1.3 million-pounds/year capacity of the recycling plant is based on one shift per day operations.

The company licensed technology for the plant from Kosei Upjohn Company, a joint venture between Mitsubishi Chemical Industries, Limited and The Upjohn Company.

This process could offer significant dollar savings if manufacture handles 600,000 pounds or more of foam scrap.

4.0 FEASIBILITY STUDY

The feasibility of mass producing sub-compact vehicle body structures which incorporate rigid foam systems was studied. The 1976 Ford-Pinto design and related manufacturing processes served as the baseline for this study. Crash energy management is the primary reason for incorporating rigid foam systems within body structure assemblies. Therefore, crash energy management considerations were given highest priority when reviewing the detail design of the Pinto hood, fender and door assemblies. Rigid foam that is not restrained in any way has a tendency to crumble into small pieces during crash impact. This prevents the foam from absorbing maximum impact energy. However, rigid foam that is contained performs quite well as an energy absorber. Testing has demonstrated that foam filled containers of light gauge sheet metal can provide a means for efficient crash energy management. Incorporating foam filled cavities within body structure assemblies appears to be an excellent application of the energy absorbing qualities of rigid foam. The feasibility of this application with respect to Pinto body components and current production techniques is discussed below.

Standard production designs of the 1976 Pinto fender, hood and door assembly were obtained for review. The Pinto fender assembly is a sheet metal stamping with a rearward stiffner added. The fender assembly by itself is quite flexible and depends on an inner splash panel and the mating vehicle structure for support and additional stiffness when installed. The current fender design could be modified for foaming. The modification would require an additional sheet metal stamping that would be welded to both the inner splash panel and external fender shape. The welded assembly would provide a cavity that could be foam filled. The foamed cavity cross-sectional area would be made as large as possible in order to maximize the energy absorbing capacity. The rearward fender area would be made flat to seat against the fire wall. This interface between fender and firewall would be designed to maintain integrity during vehicle frontal impact and provide the required foam base area support to insure proper foam crush. The rearward portion of the cavity would be designed without exposed holes or seams. This would prevent the foam from leaking out of the cavity when initially poured and before foam rise. The foam could be injected through the head light opening or some other provision.

The Pinto hood assembly is of a conventional design. The basic construction consists of a stamped sheet metal outer panel with a web type stiffener added. Two hinges attach the hood to the vehicle firewall and a hood latch provides frontal attachment. The hood assembly as designed is basically an engine

compartment cover. As such the amount of energy absorbed by the hood assembly during frontal impact would be negligible. The current hood design is not readily compatible with foaming for the purpose of crash energy management. Foam could be added to the stiffeners to increase component stiffness, but in terms of impact energy absorption, the design would require extensive modification. The modification would require a sizeable increase in hood cross-sectional area. The existing outer panel together with a full inner panel would form the cavity to be foam filled. The hood rearward portion along with the firewall interface would be designed to provide the necessary support to the foam base area. As mentioned before, the foam base area must be adequately supported to insure proper foam crush during frontal impact. Additional provisions would also be required to insure that the hood would crush longitudinally during frontal impact and not buckle upward.

The Pinto door assembly consists of two sheet metal stamped panels. The inner and outer panels are joined together by spot welding. The door is quite stiff as a component. The door is attached to the vehicle structure in the conventional way using two hinges and a door latch. The present door design is more compatible with foaming as compared to fender and hood. A basic modification for foaming would be the addition of a baffle. The baffle joined with inner and outer door panels form a cavity which can be foam filled. The window and mechanism will have to be designed to accommodate the foam process. The overall dimensions would not change significantly. Although in an actual application, the fender area and hood would be designed to absorb the energy generated during frontal impact for a given speed, the door could provide additional support to the firewall. A foam filled door would tend to maintain firewall integrity by transferring a portion of the load to the vehicle's rear quarter-panel. This is definitely a benefit to the overall crash energy management system of the vehicle.

It must be kept in mind that the ideas discussed above, concerning body component modifications for foaming, are very preliminary in nature. These ideas indicate concept feasibility to some extent. However, these ideas must be developed and tested on full scale models before actual feasibility can be established. It is difficult to determine by this preliminary study the optimum sheet metal gauges required for a given foam cross-sectional area. This can only be done by extensive testing and design.

4.1 Pinto Assembly Process

A tour of the Ford-Pinto assembly plant in Metuchen, N.J., provided an opportunity for reviewing current manufacturing processes and techniques. In addition, preliminary ideas concerning the impact of incorporating rigid foam systems with

external body components were generated. The tour was complete in that the areas of interest including the storage of body components to final assembly operations were viewed.

The Pinto assembly procedure begins with the sheet metal floor pan stampings being removed from their wooden shipping crates and loaded into the first locating fixture. Various brackets are spot welded to the floor pan during this first assembly line operation. The floor pan is then released from the fixture and moved to the next location. As the floor pan assembly continues down the assembly line, various body and structural components are added progressively until the unitized body structure assembly emerges, complete with hood, doors and trunk lid. At this process stage, all welding operations have been completed and the entire structure is cleaned for the first time. The cleaning process submerges the entire body structure assembly in a cleaning solution. The cleaning solution enhanced by agitation, thoroughly removes all oil films and particles from the body surfaces. The assembly is then dried and ready for priming. The primer is applied by submerging the entire body structure assembly, including doors, hood and trunk lid, in a phosphate primer electro-coat system. The body assembly is then dried in an oven bake cycle set at 350°F. The body assembly emerges clean, dry and primed.

Current manufacturing processes do not maintain body surface conditions compatible with foaming prior to the priming stage. Prior to this stage the body surfaces are unpainted, coated with oils, dirty and gritty. Ideally, the foam should be applied to a primed surface that is clean and dry. Under these conditions, maximum adhesion between foam and mating surface is developed during foam rise and cure. Although the body surfaces are ideal for foaming after the Pinto priming stage, there are several problems at this level of assembly. One major problem area is the type of fixturing that may be required to maintain body shape during foam cure. Fixturing of body components such as hoods, fenders and doors while part of the vehicle assembly would be much more complex than fixturing these same components at the component level. Also, if body components were foamed prior to final painting and baking, the oven bake temperatures could cause the foam to expand resulting in permanent distortion. Based on these considerations it is felt

that a more appropriate flow of operations with greater flexibility be used for the mechanically attached body components that will be foam filled. It is suggested, therefore, that the foaming of hood, fender, and door assemblies be done on the component level. If the foaming was done at the assembly plant, these components could follow the current process routine up to the point where they would be added to the body structure assembly. Then departing from normal routine, they would be cleaned in the dip process as components and then dried. These components could then be primed in the electro-coat priming process and dried in the oven bake cycle. These components could then proceed to final painting and drying. After the final paint is dry, these components could be placed in appropriate fixtures and foamed as components. The type of fixture required would depend on the specific component design. The number of fixtures required for each component type depends on the total time the component must remain in the fixture after foam injection and on the required production rate. The foamed components could then be added to the body structure assembly as it emerges from its normal painting stage. From here on, the assembly line procedure would remain basically unchanged.

The need for fixturing results from the fact that as urethane foam cures, it exerts a pressure on the surface tending to restrain foam expansion. These pressures can be as high as 5 psi. This level of pressure is significant with respect to light gauge sheet metal structures with large surface areas. When dimensions and appearance of a flexible component to be foam filled are critical, then the component shape must be confined to these required dimensions during the period the foam is exerting pressure on its surroundings. This time period includes injection time, rise time and time to cure to an acceptable level of dimensional stability. The actual time a component must remain in a fixture depends on the foam chemistry and shot size. It should be noted that this time period determines the number of fixtures required for any given production rate. As an example, consider these conditions.

Current Pinto Production Rate = 380 Pintos/shift* 48 Pintos/hr.

Typical Fixture Load Time = 0.5 min.

Typical Time for Foam Injection, Rise and Cure = 5.0 min.

Typical Fixture Unload Time = 0.5 min.

Total Fixture Occupation Time = 6.0 min.

Units per Fixture per Hour = 60 ÷ 6 = 10 units

Number of Fixtures required = 48 ÷ 10 = 5 fixtures

*Metuchen, N.J. plant

This example shows that if a particular foam chemistry and shot size required five minutes to stablize dimensionally within the fixture and an additional minute is required for loading and unloading the fixture, then five fixtures for each foamed component type are required to meet the current Pinto production rate of 380 Pintos per shift. It should be noted that if fixturing is required for the hood, left and right front fenders and both doors, then a total of 25 fixtures could be required to meet current production rates.

Incorporating the capability to foam body components within a production assembly line not only effects the sequence of operations but effects the actual layout of the line itself considerably. The fixturing, especially if 25 fixtures are required, will take up a sizeable amount of floor space in addition to the foam dispensing machines. An alternate solution would be to clean, prime and foam components at a convenient location other than within the assembly line. This alternate location could also provide parts dealers with replacement foamed body components. To determine the optium foaming location with respect to cost and logistics would require additional study which is not within the scope of this program.

Perhaps at a future date, foam chemistry can be altered to effect a reduction in the pressure that foam exerts on its container during foam cure without effecting ultimate performance. A significant reduction in the pressures that are generated could reduce or possibly eliminate the need for fixturing.

4.2 Storage and Transportation

Current practices of storage and transportation of Pinto body components were viewed at the Ford-Pinto assembly plant in Metuchen, N.J., during a plant tour. The external body components are constructed from sheet metal stampings with inner and outer panels. The sheet metal body components are

manufactured by various stamping suppliers and then shipped to the assembly plant. The body components are shipped unpainted in open wooden crates. Although the sheet metal surfaces are unpainted at this stage, a light coating of oil on all surfaces prevents corrosion. External body components such as hoods, fenders, doors, etc., are crated with a definite space between each component to prevent external surface finish damage. The component spacing within the crate is held to a minimum in order to maximize packaging efficiency. The basic shape of the Pinto hood, for example, allowed these components to be nested close to each other within the crates resulting in a high packaging efficiency. Front fenders, because of their particular shape, did not permit close nesting and resulted in a rather low packaging efficiency. The crated body components are delivered to the assembly plant in tractor-trailer rigs. The trailers are enclosed, giving the body components protection from the elements during shipment. When delivered, the body components as well as all parts are stored within the assembly plant itself. Current inventory practices at the Ford-Pinto plant represented three days equivalent production. The production rate per shift was 380 vehicles. At the time of the plant tour it was learned that two shifts per day was typical. Therefore, minimum inventory can be approximated by 3 days of production X 380 vehicles per shift X 2 shifts per day. The result represents a minimum of 2,280 components of each type in storage at any given time. Fork-lift trucks are used to transport the crated body components from the storage area to their respective assembly line locations.

The actual change in bulk shipment size and storage area requirements with respect to foamed body components including fender, door and hood assemblies should be minimal. The present Pinto fender shape, as mentioned before, does not permit close nesting within shipping crates and results in a rather low packaging efficiency. Incorporating an integral foamed cavity within the current fender shape would not greatly effect its present packaging efficiency and therefore, would have a minimal effect on fender bulk shipment size and storage area requirements. The current Pinto door design could also be modified to incorporate foamed cavities within the door assembly without increasing the overall dimensions significantly. This would result in minimal effect on door bulk shipment size and storage area requirements. The hood assembly as presently designed does not lend itself readily to foaming. Incorporating rigid foam within a hood assembly, for the purpose of crash energy management, would require a significant increase in hood cross section thickness. As an alternate to hood modification, auto designers would probably choose to incorporate additional foam within the engine compartment or fender assemblies. Since

it is anticipated that the actual change to bulk shipment size and storage area requirements with respect to foamed body components should be minimal, the added costs should also be minimal.

Current practices of corrosion protection of unpainted sheet metal body components begins with the steel producers. As the sheet metal leaves the rolling mills in raw stock form it is coated with a corrosion preventative oil prior to coiling for delivery. The sheet metal is delivered as raw stock to the metal stamping suppliers in the form of large coils of various widths. The sheet metal is then cut to length and formed to shape by various dies. The formed body components retain most of their original coating of oil. Occasionally, forming operations require that the sheet metal and/or die be lubricated to minimize tool wear and ensure easy part removal from the die. Therefore, some formed body components gain additional coatings of oils and lubricants which tend to prevent corrosion. Current manufacturing practice does not remove these oils and films from the sheet metal surfaces until these components are cleaned prior to the priming stage. Since it is highly desirable to add foam to primed surfaces, it is recommended that the body components be foamed some time after priming, thereby eliminating any effects of currently used protective oils on the foams. Further discussion concerning the point at which foam should be added to the components is included as part of the feasibility study section.

The stamping supplier that supplies the assembly plant with unpainted body components for assembly line use also provides the replacement parts. However, replacement parts follow a slightly different process routine. Replacement parts are primed as components in a spraying process. The components that are used on the assembly line are primed on the assembly line as part of the entire vehicle assembly in an electro-coat dip process. Replacement parts could be foamed after spray priming. The storage of foamed replacement components could be handled in the same manner as unfoamed body components. The exact location at which replacement parts would be foamed is included as part of the feasibility study section.

4.3 Cost Comparison

A cost estimate on a per vehicle basis was made, comparing conventional structural components with foamed structural components. The 1975 Pinto hood and fender assembly served as the conventional baseline. The foamed hood and fender assemblies defined in the "Crashworthiness of Subcompact Car Program" served as examples of foamed structural components. The cost comparison addressed three basic areas; sheet metal cost difference, foam material cost and the cost associated with additional operations and processes required for foaming.

The sheet metal material cost for conventional and foamed components should be approximately the same. Conventional shapes usually require sheet metal blanks that are considerably larger than the final shape. The extra material on the edges is required for hold-down purposes during deep draw and forming operations. This excess material is finally trimmed and scrapped. Foamed assemblies because of their compartment like shapes could cut down on the scrappage considerably but will require additional sheet metal parts to complete the cavities. The net result in terms of sheet metal cost would tend to even out. The estimated cost of the foam material required for foamed hood and fender assemblies was based on a foam density of 2 lbs/ft^3 with a 10% overpack. The raw material cost was estimated at 50¢/lb. The volume estimates made for the hood and fender pair were 6.3 ft^3 and 7.4 ft^3 respectively. The resulting foam material cost is $7.00 for the hood and $8.00 for the front fender pair. These costs must then be added to the estimated manufacturing costs.

The manufacturing costs for the 1975 Pinto hood and fender pair are $12.50 and $40.00 respectively. These values were taken from a vehicle cost breakdown and are used for relative comparison purposes only.* These manufacturing costs include sheet metal material cost, direct labor and proportionate overhead. The costs associated with additional operations and processes required for foamed components are expressed as percent increases with respect to the manufacturing costs of the 1975 Pinto hood and fender pair. Neglecting foam cost, the estimated percent increase in manufacturing costs for foamed hood and fender pair are 10% and 15% respectively. These percent increase estimates are based primarily on the number of additional manufacturing operations required for foamed structural components. Additional welding operations will be required to assemble the foam compartments. Operations such as fixture loading and unloading as well as foam dispensing will be required. These operations will require additional assembly line workers. The estimated increases reflect primarily the relative cost of these additional operations.

The cost comparison estimate is summarized in Table 42, page 177. The estimates show that a foamed hood could cost 66% more than the 1975 Pinto hood and that a pair of foamed front fenders cost 35% more than the 1975 Pinto fenders. It should be noted that these cost difference estimates are rough and are strictly a first cut approach. However, these estimates do assume that the tooling required for foaming and fixturing is high production type. The initial investment for tooling capable of producing foamed components at a rate compatible with 300,000

* Study performed by Pioneer Inc. for DOT.

TABLE 42

COST COMPARISON
CONVENTIONAL VS. FOAMED COMPONENTS

	1975 Pinto Hood Assembly	Foamed Hood Assembly	1975 Pinto Fender Assembly (Pair)	Foamed Fender Assembly (Pair)
Foam Raw Material Cost, (50¢/lb)	-	$ 7.00	-	$ 8.00
Manufacturing Cost, (Sheet Metal, Direct Labor, Burden)	$ 12.50	$12.50 + 10%	$ 40.00	$40.00 + 15%
Total Manufacturing Cost	$ 12.50	$20.75	$ 40.00	$54.00
% Cost Difference	Base	+ 66%	Base	+ 35%

vehicles per year could be on the order of 2 to 4 million dollars.

4.4 Hazards of Raw Material Related to Assembly Process (Ref. 48)

4.4.1 A-Component - Isocyanate

These are highly reactive organic substances. Their physiological effects result from reaction with body fluids, protein and other active hydrogen compounds.

The greatest practical hazard in the use of isocyanates arises from inhalation of their vapors. Tolulene Diisocyanate (TDI) presents a greater hazard than Diphenylmethane Diisocyanate (MDI) or polymeric isocyanates. At 77°F the vapor pressure of TDI is reported to be 0.07 mm Hg, while that of the polymeric isocyanate is reported to be .00016 mm Hg. This means that TDI at room temperature will generate approximately 438 times as much isocyanate vapor as liquid polymeric isocyanate at the same temperature.

Threshold limit values (TLV's) have been established and published by Department of Labor.

TLV of MDI -0.02 ppm set by OSHA (Occupational Safety and Health Administration)

TLV of TDI - 0.005 ppm set by NIOSH (National Institute of Safety and Health)

These limits are for a time-weighted average of an eight hour work day with a maximum acceptable concentration of 0.02 ppm for any 20 minute period. TDI odor cannot be detected until about 0.3 ppm. This means that if the operator can smell TDI, the TLV has been exceeded and a hazardous condition does exist. For this reason, monitoring equipment is required.

4.4.1.1 Effects of Inhalation of Isocyanate Vapors

1. Short exposure to humans at or near ceiling value cause progressive disabling illness characterized by breathlessness, chest discomfort and reduced pulmonary function.

2. Massive exposure to high concentrations has caused within minutes irritation of the trachea and larynx and severe coughing spasms. Massive exposure may also lead to bronchitis, bronchial spasm and/or pulmonary edema.

3. A small percentage (0.5 to 1.5 percent) of the population can become truly sensitized to isocyanates. These sensitized individuals when exposed to minute concentrations of isocyanate considerably below the ceiling level may lead to asthmatic attacks and respiratory distress.

4.4.1.2 Fire and Explosion Hazards

TDI and Polymeric isocyanates are classified as Class III B combustible materials by National Fire Protective Agency (NFPA) and are not considered serious fire hazards.

Isocyanates will burn in the presence of an existing fire or high heat source. Isocyanates decompose rapidly above 525°F and should not be exposed to temperatures in this range. Isocyanates generate irritating and hazardous isocyanate vapors and toxic fumes, including carbon monoxide, oxides of nitrogen and traces of hydrogen cyanide under fire conditions. The relative volatility of isocyanates used in preparation of polyurethanes and related materials minimize potential explosion hazards. No explosive limits are known for MDI (polymeric isocyanates). However, under fire conditions, in which high concentrations of isocyanate vapor could be generated, explosive limits could possibly be attained and explosions could result.

4.4.1.3 Isocyanate Spills

If a major isocyanate spill occurs, the spill should be covered with sawdust, vermiculite, fuller's earth or other absorbant material in quantities to absorb all of the liquid isocyanate. It should then be neutralized with a dilute aqueous ammonia/glycerine (or ethylene glycol) solution. The neutralized material (solid-polyurea-urethane) is innocuous and can be disposed of by standard methods.

Isocyanate waste should be converted to harmless solids by reactions with water in open containers before disposal and should never be poured into or washed down drains.

4.4.2 B-Component

The usual B-component blend contains the following.

1. Polyol
2. Tertiary Amine Catalyst

3. Tin Catalyst (Rigid spray and flexible slab molding formulations)

4. Fluorocarbon and other blowing agents

5. Water

6. Silicone Surfactant

7. Fire-retardant additive

The overall toxicity will be determined by the toxicities of each of the components.

4.4.2.1 Polyol

Most polyols are based on propylene oxide which is present at a level of 80 percent or more. Other polyols are derived from tetrahydrofuran or adipic acid and diethylene glycol. Experience has shown us that these materials are relatively innocuous and present essentially no physiological hazard in normal handling. Since their vapor pressure is low, there is no significant hazard from vapor inhalation at ordinary temperatures; however, precautions afforded any organic liquid should be exercised at all times while handling these materials.

However, there is a class of polyols called amino polyols which contain basic nitrogen as well as propylene oxide polymer in the molecule. In most of them, the nitrogen content is sufficiently low so that their toxicity does not differ significantly from regular polyols. However, a polyol such as Quadrol (4 mole propylene oxide adduct of ethylenediamine) will exhibit toxicity effects more like tertiary amine catalysts discussed later. One should always keep in mind when handling amino polyols that they are extremely reactive with isocyanates and the two should be mixed only in very small quantities. A number of explosions have resulted from the accidental mixing of TDI and an amino polyol which had inadvertantly been substituted for an ordinary polyol.

4.4.2.2 Tertiary Amine Catalyst

Catalyst are normally used at only a 1-1.5 weight percent level in the B-component, and as a result, the hazard is greatly reduced. Nevertheless, they are alkaline materials whose vapors are irritating to the eyes and respiratory system.

The more volatile tertiary amines such as N-ethylmorpholine produce a temporary fogging of the eyes in which the victims see a blue halo or haze. Needless to say, this is not a popular occurrence, and there has been a trend towards the use of less volatile amines such as dimethylamino-ethylmorpholine or 3,2'-dimethylamino diethyl ether among others which

are relatively free of this problem. Above all, it should be remembered that chronic exposure to tertiary amines often causes liver and kidney damage to experimental animals, and the operator should make a conscious effort to keep these materials confined. If he has occasion to work with the pure amines, he should avoid all skin and eye contact and keep the area well ventilated with an exhaust fan.

It should be pointed out that while N-methylmorpholine has a flash point at 72°F and N-ethylmorpholine has a flash point of 96°F, most of the nonvolatile amines now being used have flash points above 200°F and present no significant fire hazard. Furthermore, one to two percent N-ethylmorpholine dissolved in a B-component blend does not significantly increase the fire hazard of that blend.

It can be seen that the manufacturer has the option of selecting the safer tertiary amines with which to work. To this end, he should make a point of keeping up with the advancing technology in this area and buy the safest products which will do the job adequately for him.

4.4.2.3 Tin Catalyst

Various organo-tin catalysts are used in the manufacture of flexible urethane foams and in rigid foam spray systems. In the undiluted form, these materials will penetrate the skin and may cause sensitization. Eye contact should always be avoided. Generally, they are used at sufficiently low levels in the B-component so as to represent a minimum hazard. However, when handling, the operator should wear goggles and protective clothing.

4.4.2.4 Fluorocarbon Blowing Agents

Flurocarbon-11 and -12 exhibit very high vapor pressures and they are often used at levels as high as 30 percent or more in the B-component. Therefore, the operator must be exposed to relatively high vapor concentrations of these materials, especially in pouring open molds or in frothing. Fortunately, the TLV for these fluorocarbons is 1000 ppm. As a practical matter, one should not normally find this value exceeded except in cases of considerable neglect. (About the only material with which we work which has a higher TLV is carbon dioxide, which is 5000 ppm).

By means of a simple calculation, one learns that he need evaporate only 0.29 pounds of fluorocarbon-11 into a room 10' X 10' X 8' with no ventilation to reach this concentration, and this is not very much material. However, if a fan were used, exhausting air at the rate of 850 cu.ft. per minute, one could evaporate about one pound of fluorocarbon into the air every 3½ minutes without exceeding

this concentration, and with proper exhaust design, much more. It is important to exhaust downward away from the breathing area of the operator as this is the direction of flow of these heavy vapors. The minimum fan requirement to accomplish this job should be 18 inches in diameter, turning at 1000 rpm and driven by 1/15 horsepower explosion-proof motor.

By means of a material balance on the foaming operation, one can readily determine the amount of fluorocarbon lost into the air and judge the need for an exhaust fan.

These fluorocarbons are not without real hazard to the operator who is careless. At some level above 1000 ppm they begin to have a narcotic effect. There have been instances of workers who have become seriously ill entering fluorocarbon storage tanks filled with fluorocarbon vapor. Obviously, this should not be done.

Open flames or high temperature readily break down these materials, releasing hydrochloric and hydrofluoric acid and other decomposition products (the hydrogen can come from other molecules present if it is not in the fluorocarbon molecule). Space heaters and internal combustion engines (fork lifts and floor sweepers) are often badly corroded by these acid gases. So far as smoking is concerned, Du Pont feels the taste of the decomposition products will discourage further puffs before any real harm is done to the smoker.

Often the operator will come in contact with these blowing agents, especially when opening drums (cool to 70°F to avoid spewing), setting up for frothing, or when adding additional fluorocarbon to the system to make up for evaporation loss or to lower the density of the foam. It will be well to remember that these materials are excellent solvents for grease, and prolonged skin contact will leave a dry, sensitive skin which may be easily irritated. Contact with fluorocarbon-12 can cause frost bite. The answer is to wear neoprene gloves where prolonged contact is made. One final note of caution — avoid eye contact.

4.4.2.5 Water

Water does not contribute to the toxicity hazard of urethane foam systems. Its reaction product, carbon dioxide, has a TLV of 5000 ppm and by itself does not normally present a hazard. However, the rapid evolution of carbon dioxide such as occurs in the production of open-celled, flexible urethane foam will entrain the other more toxic ingredients making the need for an effective exhaust system very important for the operator's safety.

4.4.2.6 Silicone Surfactant

As a general statement, the silicone surfactants are

generally inert and since they are present at such a minor concentration in the B-component (one to two percent), they do not contribute significantly to the toxicity hazard of the B-component.

When handling silicone surfactants, care should be exercised to keep them out of the eyes because they may cause transitory irritation. However, toxicity studies have shown that they are not skin sensitizers.

4.4.2.7 Fire-Retardant Additives

While there are many fire-retardant additives in use, most are either organic phosphonates or phosphates containing halogens as well. As a class, organic phosphates are rather toxic materials and vapors of the more volatile ones should be avoided as well as direct skin or eye contact.

As a practical matter, one can choose relatively non-volatile fire-retardant additives which offer a minimum hazard when handled properly. However, because these materials are often present in the B-component blend, direct skin and eye contact with it should be avoided as well.

4.5 Effect of Polyurethane Dust

4.5.1 Physiological Effect (Ref. 63)

A statement issued in 1971, by the Environmental Health Committee of the Society of Plastics Industry, composed of 22 medical directors, toxicologists and industrial hygienists revealed that "Preliminary results of a recent toxicological study in animals suggested unexpected possible adverse health effects from inhaling polyurethane dust." Other studies and work experience with polyurethane have not indicated such effects in man.

Emphysema was induced experimentally in rats by massive exposure to finely-ground dust.

Animal exposure studies made with polyester fiberglas plant dust and freshly generated polyurethane foam dust. Rats and hamsters were exposed to threshold levels of each for 30 days and held for lifetime observation. Centribular emphysema was seen in several of rats exposed to polyester fiberglas dust, significantly higher incidences were seen with the polyurethane dust. Squamaus cell carcinomas of bronchiogenic origin were seen in the polyurethane studies.

Polyurethane dust is also classified as a "nuisance" dust which can cause mechanical irritation of the eyes and mucous lining of the nose and throat.

Good industrial hygiene practices should be followed to avoid exposure to all levels of dust including polyurethane.

Industry is actively undertaking further studies for safe manufacturing and use of polyurethanes.

4.5.2 Fire and Explosive Hazards of Dust

A dust explosion results from the rapid combustion of finely divided solids in air which generate pressure from the sudden evolution of heat and volume of gaseous deomposition products from the burning dust. In general, any finely divided combustible solid is capable of producing a dust explosion under certain conditions.

Urethane dust explosions have been experimentally-produced using 200 mesh polyurethane dust. Minimum airborne concentrations of 25-30 grams of dust per cubic meter are required before an explosion can occur. Some experiments show that 100-200 grams per cubic meter as the lowest critical concentration.

The probability of a dust explosion during normal operations of a fabricating plant are negligible as the dust concentration is considerably below the critical level and the dust formed is too coarse to remain airborne for long and settles rapidly.

Settled dust could present a potential hazard in that a disturbance could generate a dust cloud of sufficient concentration to be explosive. (Ref. 64)

Second potential hazard of settled dust lies in its ease of ignition and train-firing properties. Experiments have shown that accumulated dust can be ignited by small flames and the flame front readily propagates.

4.5.3 Recommendations to reduce potential health, explosion and fire hazards. (Ref. 48)

1. Power tools should have dust-collecting devices and be grounded.

2. All dust should be vacuumed not blown at frequent intervals.

3. Eye and respiratory protection should be worn when operations generating dust are made.

4. Filters in dust must be cleaned and replaced at frequent intervals.

5. Persons involved who are exposed to dust and display symptoms of allergy; or irritation should be removed from job and examined by physician as soon as possible.

5.0 DISCUSSION AND CONCLUSIONS

The applicability of rigid polyurethane foam to automotive structures has been evaluated on the basis of available literature, discussions with foam material suppliers, automotive production personnel and results of Budd Tests. It must be noted that dynamic testing of foam filled specimens was done in small lots, and that the conclusions in this report are based on these tests. The conclusions that are drawn in this program are outlined in the general categories of material availability, energy attenuation characteristics, fire hazards, repairability, process and production implications, cost and disposability.

5.1 Material Availability

There is no global shortage of raw material for polyurethane foam. Feedstocks are available from sources such as coal, oil shale and agricultural products. Cost could be a prime factor if feedstocks would have to come from sources other than petroleum or natural gas.

5.2 Energy Attenuation

Foam filled structural elements internally primed and with foam properly encapsulated, are effective in absorbing energy. The amount of energy absorbed does not vary significantly as a function of processing and environment even though the failure mode of the metal encapsulating containers may vary. See photograph A-12 on page 84 In this sense, the material seems to show an insensitivity to minor variations in process. These minor variations may not be critical to crash energy absorption and may be considered in structural design as minimum or maximum conditions. For example: A foamed structural component to be used in a vehicle should be given an effectiveness tolerance on crushability (force and deformation of $\pm$ 15% based on results herein). Extremes of environment and exposure do degrade the performance of the material but these extremes are not likely to be encountered in normal automotive practice. Adequate quality control is needed to prevent the inclusion of large voids since performance is downgraded when such voids occur. Encapsulated foam is not perfectly elastic in dynamic impact loading and some spring back can be expected following dynamic crash. Specimens within the same test group demonstrated consistency with regard to failure mode and crush distance. See photograph A-13 on page 88 .

5.3 Fire Hazard

Foam encapsulated in a steel structure and subjected to intense heat creates smoke due to thermal decomposition but does not burn or explode. Exposed foam used in this program when subjected to open flame does not exhibit any unusual burning. When the flame source is removed, the fire extinguishes itself leaving

the exposed foam surface in a charred condition. This foam when shredded and exposed to a flame source burns with a crackling sound and smokes in contrast to a large block which self-extinguishes when the flame source is removed. Flame retardants decrease foam flammability but in general increase smoke generation and increase cost. The hazard for foam (encapsulated) may not be the flammability aspect but the smoke and gases produced as a result of intense heat. Studies show that smoke from typical urethane foams are of lower toxicity than wood smoke. The principal inhalation hazards, as in fires in dwellings, may be more a function of the presence of carbon monoxide or oxygen deficiency. To evaluate the overall effect of the decomposition gases produced, the burning characteristics of an entire vehicle must be considered since the heat contribution can come from several sources within the vehicle. It is believed that full scale tests need to be performed in a car or cars of foam construction, varying the environment conditions and collecting the gases to determine the time required for the gases to evolve and the lethal limits of these gases for the exposed period of time.

5.4 Repairability

For the test specimens evaluated, ease of repair varies with the type of failure. For longitudinal damage, that is, along the axis of the member where the damage progressed from the impacted end, specimens were readily repaired without effecting energy absorption capability. For side impacts in which the damage is distributed along the specimen, the repair is very difficult. Extrapolating this experience to full scale automotive structures with all the constraints and potential crash conditions, repair to primary structure will be difficult at best. It would appear that some replaceable, sacrificial structural assembly should be provided for crash pulses below some pre-determined energy level.

5.5 Process and Production Implications

Current foams exert pressure in the foaming process. Inherent in the design of foam encapsulation is the need for light walled sections. This combination tends toward structural deformation unless suitable fixturing is provided. Also, exposure of the foam to heat following the foaming process causes the foam to expand, resulting in permanent structural distortion and necessitates fixturing. For these reasons, fixturing is required in the foaming process and any following process or processes in which elevated temperatures are encountered. This suggests that the sequence of foaming and paint oven operations should be carefully weighed to minimize fixturing and structural distortion. To obtain a preferred crush pattern, i.e. a progressive type failure starting from the point of impact,

foaming should be done parallel or 45° to the impacted direction. Foam should have a 35 psi compressive strength in the foam rise direction.

Dynamic testing of foams with lower compressive strengths (20 psi parallel to foam rise) did not show a significant difference in crush distance, but did show a non-preferred type failure mode. There was almost as much crush at the base of the specimen as at the point of impact. The reason for citing this example is that the foam evaluated in this study has a 20 psi compressive strength perpendicular to foam rise and indicates the type of failure and crush that could be expected if foam rise were parallel to the direction of impact.

5.6 Cost

Preliminary cost estimates based upon selected foam filled elements (Minicar's Concept, Contract No. DOT-H-113-3-746) show that the costs may be from 35 to 65% higher than comparable structural elements on the 1975 Pinto. This additional cost does not reflect the cost of the foaming equipment or the additional floor space.

5.7 Disposability

Disposal of foam by recycling to obtain its starting components appears to be a viable solution if the quantity of scrap is sufficient. A pilot plant is now operating in Japan which uses this method.

5.8 General Conclusions

The widespread use of rigid polyurethane foam in automotive structure appears feasible. The economic feasibility still needs to be established.

6.0 RECOMMENDATIONS

The feasibility of using lightweight rigid polyurethane foam for crash energy management is established. There are still some areas which need further clarification. The recommendations listed below reflect these needs.

1. Full scale cars should be burned to obtain the total effect of gases evolved and the burning characteristics. This real life situation would help to establish the time in which the gases are released and the extent to which concentration would be harmful or lethal.

2. The search should be continued for foams which would eliminate or minimize the need for fixturing during filling operations or any subsequent operation exposed to elevated temperatures. Foam companies should be encouraged to develop systems in this regard.

3. Studies should be made to determine minimum metal encapsulation that would, without fixturing, sustain foaming pressures and still have acceptable structural deformation. This would include metal thickness as well as geometrical variations within the constraints of strength and durability of the vehicle.

4. Techniques and production test equipment should be determined for locating foam voids or defects which would be detrimental to crash energy attenuation.

5. Further work should be done in the cost analysis of foam filled structures which are specifically designed to reflect the best features of the foam filled construction.

7.0 SPECIFICATIONS

The following specifications are to be followed to obtain preferred crush performance, i.e., progressive type failure, based on the encapsulated foam test elements used in this study. Other than preferred crush may be satisfactory and perform adequately as an energy absorption system when incorporated in an assembled structure. These specifications apply only to the findings of this study.

7.1 Foam Material, Minimum Requirements

1. Free rise density 1.8 to 2.0 lbs/ft^3
2. Fire modified per ASTM-1692
3. MDI (polymeric Isocyanate) system
4. Compressive strength parallel to foam rise

   @ 72°F - 35 psi
   @ 250°F - 80% of 72°F value

7.1.1 Provisions for the Quality Control of Foam Raw Materials to Insure Consistency of Foam Performance such as the following should be performed.

1. Viscosity
   a. Polyol
   b. Isocyanate
2. Specific Gravity
   a. Polyol
   b. Isocyanate
3. Cream Time
4. Rise Time
5. Density

7.2 Structure

1. Substrates must be primed per automotive specifications.
2. Provisions for the Quality Control of the structure joints to insure foam containment.

   a. Weld penetration
   b. Weld spacing

7.3 Fixturing

1. Required during foam filling to prevent distortion and stress on joints due to foam expansion.
2. Required during the paint cycle if painting is to be done after foaming to prevent distortion due to foam expansion.

7.4 Foam Application

1. Foaming is to be done parallel or 45°F to foam rise to obtain maximum compressive strength of foam in the crush direction to obtain a progressive preferred crush pattern.
2. One pour is to be used to fill cavity to avoid any weak areas in the foamed structure.
3. Structure is to be 90°F during foaming operation.

7.5 Large Void Detection

Provisions to be made for large void detection.

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APPENDIX A

Crushed Specimen
Summary Chart

The Crushed Specimen Summary Chart includes all the specimens (6"X8"X30") tested statically and dynamically in this program.

Four specimens, Nos. 29, 68, 77 and 79 had higher post static crush measurements than the peak dynamic crush taken from the program analysis when final velocity ($V_F=0$). High speed movies show that the specimens have some spring back after the drop weight rebounds (approx. 1 to 2 inches) except in the extreme temperature tests, -20°F (<1 inch) and 300°F (>2½ inches). This indicates that there is an error that is introduced in the computer program.

This error can only be explained by the accuracy of the input data. The accuracy of the input data depends on the following.

1. Chart speed variation
2. Resolution of the graphics tablet
3. The human factor

These three sources of variation are independent of one another and, therefore, may be additive causing a discrepancy in the peak dynamic crush. See paragraph 3.3.1.4.1 on Page 87.

A Crush Ratio Comparison bar chart of the Dynamic tests, Figure A-1, is included in this appendix.

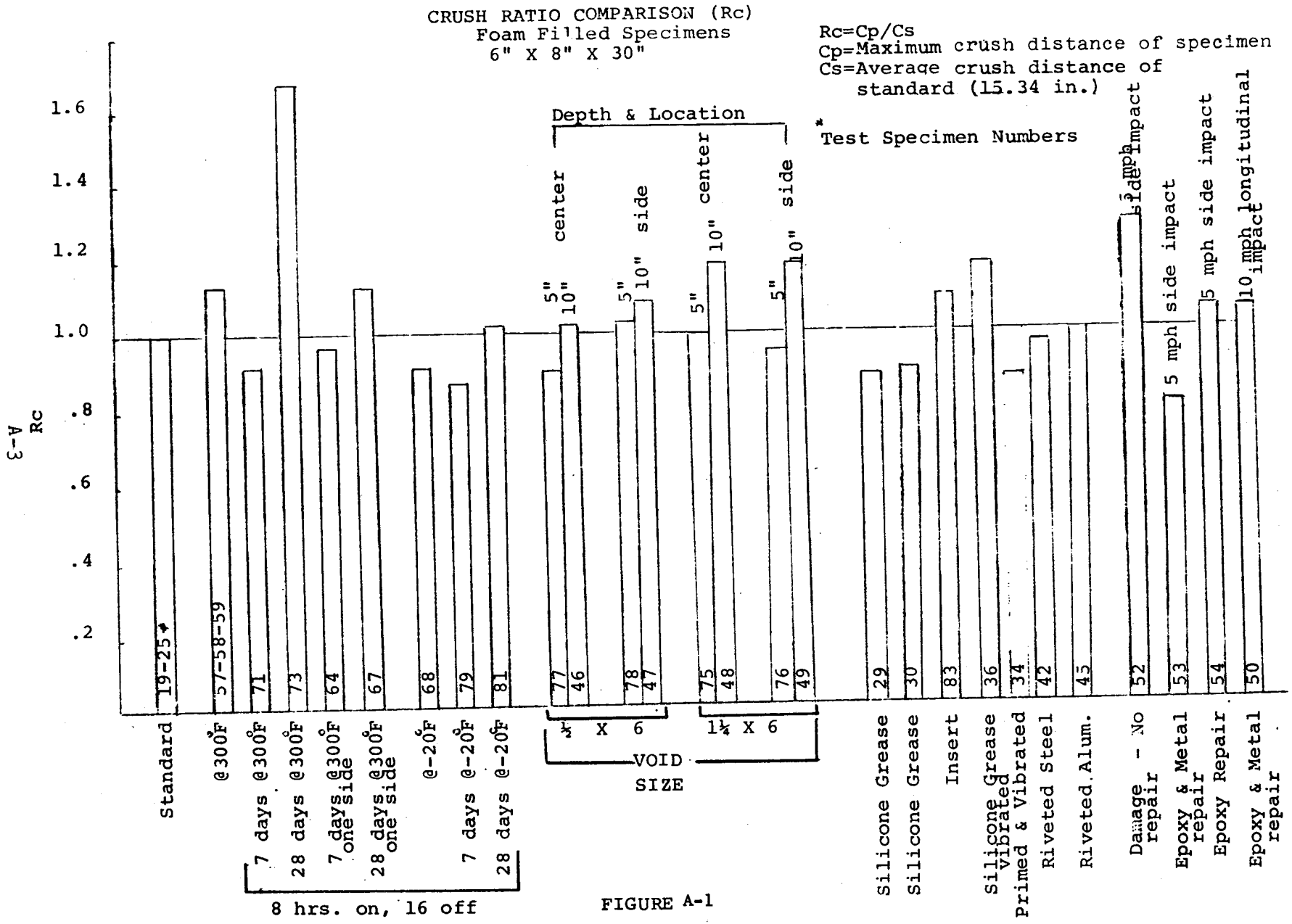

CRUSH RATIO COMPARISON (Rc)
Foam Filled Specimens
6" X 8" X 30"
Rc=Cp/Cs
Cp=Maximum crush distance of specimen
Cs=Average crush distance of standard (15.34 in.)
Depth & Location
* Test Specimen Numbers
Rc
1.6
1.4
1.2
1.0
.8
.6
.4
.2
A-3
19-25*
57-58-59
71
73
64
67
68
79
81
77
46
78
47
75
48
76
49
29
30
83
36
34
42
45
52
53
54
50
Standard
@300F
7 days @300F
28 days @300F
7 days @300F one side
28 days @300F one side
@-20F
7 days @-20F
28 days @-20F
8 hrs. on, 16 off
5" center
10" center
5" side
10" side
1/2" X 6
1 1/2" X 6
VOID SIZE
Silicone Grease
Silicone Grease
Insert
Silicone Grease vibrated
Primed & Vibrated
Riveted Steel
Riveted Alum.
Damage - No repair
Epoxy & Metal repair
Epoxy Repair
Epoxy & Metal repair
5 mph side impact
5 mph side impact
10 mph longitudinal impact

FIGURE A-1

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
1SS	Spot Welded St.,No Foam	Static	12		1700		1.All specimens are 6 x 8 x 30" unless spec'd.
2SR	Riveted St., No Foam	Static	12		2109		2.Mat'l. is steel. 1010, .024 thick unless specified.
3AR	Riveted Al., No Foam	Static	12		1855		3.Specimens are spot welded unless specified.
4AS	Spot Welded Al.,No Foam	Static	12		2018		4.Foam is NB237936-A unless specified.
5SSD	Spot Welded St.,No Foam	30 mph dynamic	13-1/8		2424		
6SRD	Riveted St., No Foam	30 mph dynamic	10.78		2952		
7ASD	Spot Welded Al.,No Foam	30 mph dynamic	15.06		2113		
8ARD	Riveted Al., No Foam	30 mph dynamic	13.84		2299		
1.	6 x 8 x 24 Foam Filled	Static	16		4285		
2.	6 x 8 x 30	Static	19		3866		
3.	6 x 8 x 27	Static	18.0		3451		

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
4.	6 x 8 x 30	Static Fatigue Test					Loads to be used for Fatigue Test
5.	Slow Catalyst syst. NB-237936A	Dynamic 30 mph	14.63	15.42	5622	5334	Compressive strength, 20 psi parallel to foam rise
6.	6 x 8 x 15 Foam Filled	Static	8.5		3900		
7.	6 x 8 x 15 Foam Filled	not tested					Samples made to determine fill characteristics
8.	"	" "					
9.	NB-237936A 5% Freon 12 (Froth syst.)	30 mph Dynamic	15.9		5173		
10.	NB-237936A 10% Freon 12 Froth System	30 mph Dynamic	18.6		4422		
11.	XP 338 Gen'l. Latex Foam	30 mph Dynamic	15.69	16.77	5242	4904	
12.	One pour Vertical	30 mph Dynamic					The lid was not welded and specimen banana peeled.
13.	One pour Vertical	30 mph Dynamic	15.31	15.42	5372	5334	
13. a.	"	"	15.30		5376		
13. b.	"	"	15.06		5462		

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
14.	2 pour vertical	30 mph Dynamic	14.88	15.36	5528	5355	
15.	"	"	14.53		5660		
16.	one pour @ 45°	"	13.63	16.42	6034	5009	
17.	"	"	13.44		6120		
18.	6 x 8 x 30 No Foam	Fatigue Test,Static					Static tested for Fatigue Test
19.	one pour vertical	30 mph Dynamic	15	15.8	5483	5205	
20.	"	"	13.7		6004		Specimen Nos. 19 thru 25 used for control. 963 grams ±10 g of NB-237936 A Foam
21.	"	"	13.5		6092		
22.	"	"	13.7	15.55	6004	5289	
23.	"	"	13.2		6231		
24.	"	"	13.4		6138		
25.	"	"	13.4	14.6	6138	5634	
26.	"	10 mph side impact damage too severe for repair.					
27.	"						
28.	"						

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
29.	Silicone grease put on walls to prevent adhesion	30mph Dynamic	13.6	13.58	6047	6056	
30.		"	13.6	13.80	6047	5960	
31.	Al.one pour, primer	"	13.6	15.57	6047	5282	
32.	Al.two pour, primer	"	16.3	17.33	5046	4746	
33.	Primed vibrated	"	13.7	14.1	6004	5833	
34.	"	"	13.8		5960		
35.	"	"	14.4		5712		
36.	Silicone grease, vib'd.	"	13.6	17.9	6048	4595	
37.	"	"	13.9		5917		
38.	Al.one pour primer	"	Not measurable specimen broken	15.31		5372	
39.	Std.specimen vertical foamed at 45° angle		Specimens sectioned and cut into 2 x 2 x 2 blocks for Compression Tests				
40.							
41.							
42.	Riveted St.		13.5	14.72	6092	5588	
43.	"		13.6		6047		

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
44.	Riveted Al.	30 mph Dynamic	15.2		5411		
45.	"	"	14.8		5557		
46.	1/2 x 6 x 10 Center void	"	14.5	15.44	5672	5327	
47.	1/2 x 6 x 10 Side void	"	13.75	16.65	5982	6070	
48.	1-1/4 x 6 x 10 Center void	"	15	18.15	5483	4531	
49.	1-1/4 x 6 x 10 Side void	"	17	18.34	4838	4485	
50.	10 mph frontal impact repair	"	13.8	16.1	5960	7457	
51.	"	"	12.75		6450		
52.	5 mph side impact No repair	"	18	19.8	4569	5216	
53.	5 mph side impact epoxy & metal patch	"	11.875	12.176	6926	6755	
54.	5 mph side impact epoxy patch	"	15.2	16.326	5411	5038	
55.	10mph frontal spares Not repaired or tested						
56.	"						

CRUSHED SPECIMENT SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
57.	at 300° F	30 mph Dynamic	13.75	16.05	59.82	5125	
58.	"	"	16.8	19.43	4896	4233	Badly split
59.	"	"	13.1	17.77	6278	4628	" "
60.	Specimens were being conditioned at 300° F						
61.	Oven went awry						
62.	Samples were destroyed by intense heat						
63.							
64.	300° F one side, 8 hrs. on, 16 off for 7 days	30mph Dynamic	13.94	14.9	5900	5520	
65.	"	"	14.3		5751		
66.	300° F one side 8hrs.on,16 off for 28 days	"	14.25		5772		
67.	"	"	14.80	17.2	5557	4782	
68.	@ -20° F	"	14.88	14.1	5527	5833	
69.	"	"	14.66		5610		
70.	"	"	14.97		5494		
71.	300°F total exposure,8 hrs.on, 16 off for 7 days	"	13.1	14.25	6278	7018	
72.	"	"	12.93		6361		

CRUSHED SPECIMENT SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
73.	300°F total exposure,8 hrs.on 16 off for 28 days	30mph Dynamic	21.4	24.1	3843	4115	
74.	"	"	21.2		3879		
75.	1-1/4 x 6 x 5 Center void	"	13.56	15.	6065	5483	
76.	1-1/4 x 6 x 5 Side void	"	14.125	14.6	5823	6476	
77.	1/2 x 6 x 5 Center void	"	13.875	13.8	5927	5960	
78.	1/2 x 6 x 5 Side void	"	14.81	15.45	5554	5323	
79.	-20° F total exposure,8hrs. on 16hrs.off for 7days	"	13.69	13.3	6008	6184	
80.	"	"	13.81		5960		
81.	-20° F total exposure 8hrs.on, 16 off for 28days	"	14.8	16.0	5557	5141	
82.	"	"	14.6		5633		
83.	Molded foam inserted into specimen shell	"	15.6	16.66	5272	4937	
84.	"	"	15.5		5306		
85.	"	"	14.94		5505		

CRUSHED SPECIMEN SUMMARY CHART

Specimen No.	Description	Test	Post Test Measured Crush (Inches)	Peak Dynamic Crush(Inches) Computer Prog. VF = 0	Post Test Avg.Crush Force(lbs)	Computer Prog. Avg.Crush Force (lbs) VF = 0	Comments
86.	Specimen was used for Torch Test						
87.	Specimen was used for Burning Oil Test						
1S	28 days in oil total immersion	30mph Dynamic	14.9		5520		
2S	"	"	14.4		5712		
5S	28days in 50/50 water/glycal total immersion	"	14.2	15.8	5792	5206	
6S	"	"	14.0		5875		
9S	28days in car wash detergent total immersion	"	14.0		5875		
10S	"	"	14.5		5672		
13S	28days in 5% salt, total immersion	"	14.4		5712		
14S	"	"	13.7		6004		
17S	28days in water Total immersion	"	14.6		5634		
18S	"	"	13.6		6048		
19S	28days in gaso-line,total immers.	"	14.1		5833		
20S	"	"	15.1		5447		

APPENDIX B

Computer Program

Data

Computer analyses were performed on representative specimens to obtain the following curves:

1. Deceleration/Time
2. Deceleration/Displacement
3. Velocity/Time
4. Velocity/Displacement
5. Displacement/Time
6. Force/Time
7. Force Displacment

The equipment, technique and procedure for generation of these curves follows:

A. Equipment: Tektronix 4954 Graphic Tablet and 4014-1 Graphic Computer Terminal were used with a Data General Eclipse S/200 Computer.

B. Technique: The Tektronix equipment digitized the load cell and accelerometer data and then transmitted the digitized data to the Eclipse S/200 Computer. The computer program ACCEL" was used by the Eclipse S/200 to generate time vs. velocity and time vs. displacement curves, with the initial velocity of 30 mph. Finally, the computer program "FORCOM" used the output from "ACCEL" and the digitized load cell data to generate a force vs. displacement curve.

C. Computer Programs: The program "ACCEL" integrates the digitized accelerometer data (operator selects 1 trace of 2 recorded) twice numerically using the initial velocity as the starting point.

The program "FORCOM" combines digitized load cell data (direct summation from 3 load cells) and the output from "ACCEL."

This program was run on the following specimens:

Specimen No.	Description
5	NB-237936A Slow Catalyst
11	General Latex Froth System XP-338
13	One Pour Vertical Primed
14	2 Pour Vertical Primed
16	One Pour @ 45° Primed
19	One Pour Vertical Primed - for Standard Specimen
22	One Pour Vertical Primed - for Standard Specimen
25	One Pour Vertical Primed - for Standard Specimen
29 and 30	One Pour Vertical Silicone grease
31	Al, one pour Primed
32	Al, 2 pours Primed
34	Primed, Vibrated, Tested 30 mph
36	Silicone Grease, Vibrated tested at 30 mph
38	Al, one pour, no primer
42	Riveted Steel
46	Void, 1/2 x 6 x 10, center
47	Void, 1/2 x 6 x 10, side
48	Void, 1 1/4 x 6 x 10, center

Continued

Specimen No.	Description
49	Void, 1 1/4 x 6 x 10, side
50	10 mph frontal impact, repaired and tested
52	5 mph side impact
53	5 mph side impact epoxy and metal patch
54	5 mph side impact epoxy patch
57 58 59	Tested at 300°F
64	300°F one side 8 hours on, 16 off 7 days
67	300°F one side 8 hours on, 16 off 28 days
68	At -20°F
71	300°F total exposure 8 hours on, 16 off 7 days
73	300°F total exposure 8 hours on, 16 off 28 days
75	Void, 1 1/4 x 6 x 5, center
76	Void, 1 1/4 x 6 x 5, side
77	Void, 1/2 x 6 x 5, center
78	Void, 1/2 x 6 x 5, side
79	-20°F, 8 hours on, 16 off 7 days
81	-20°F, 8 hours on, 16 off 28 days

Continued

Specimen No.	Description
83	Molded foam inserted loosely into specimen
6S	28 days in 50/50 glyol/water

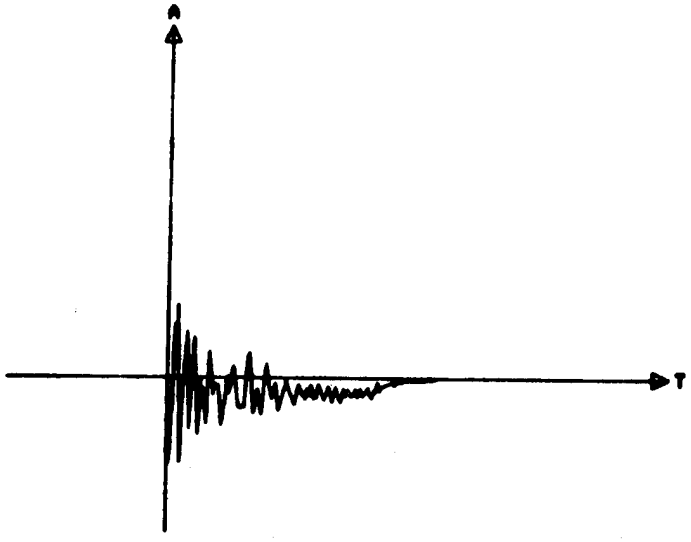
A typical computer run (Specimen No. 25) with accelerometer, load cell traces, and curves generated from this data are included. The Force/Deflection curves of all the programmed specimens are also included.

```
R
TYPE ACCPRINT

   DOT FOAM STUDY SPECIMAN NO 25

        INITIAL VELOCITY  -- INPUT  0.440000E  2 -- CALCULATED 0.558353E  2

   DOT FOAM STUDY SPECIMAN NO 25

          TIME              ACCELERATION          VELOCITY          DISPLACEMENT
    0.000000E  0      0.000000E  0      0.440000E  2      0.000000E  0
    0.692700E -3     -0.517213E  4      0.422086E  2      0.298584E -1
    0.133920E -2     -0.270053E  4      0.396638E  2      0.563236E -1
    0.168560E -2     -0.139232E  4      0.389549E  2      0.699404E -1
    0.177790E -2      0.142035E  4      0.389562E  2      0.735360E -1
    0.219360E -2      0.333595E  4      0.399448E  2      0.899356E -1
    0.279390E -2      0.555990E  3      0.411130E  2      0.114265E  0
    0.295550E -2      0.449466E  4      0.415211E  2      0.120942E  0
    0.371750E -2     -0.513475E  4      0.412772E  2      0.152488E  0
    0.471040E -2     -0.364430E  3      0.385471E  2      0.192117E  0
    0.565710E -2      0.280332E  4      0.397016E  2      0.229156E  0
    0.648830E -2     -0.312103E  4      0.395695E  2      0.262101E  0
    0.785060E -2      0.248094E  4      0.391335E  2      0.315709E  0
    0.912060E -2     -0.345276E  4      0.385164E  2      0.365017E  0
    0.972090E -2     -0.373800E  2      0.374689E  2      0.387824E  0
    0.100903E -1     -0.178011E  4      0.371332E  2      0.401603E  0
    0.108292E -1     -0.668120E  3      0.362287E  2      0.428707E  0
    0.114988E -1     -0.279398E  4      0.350696E  2      0.452577E  0
    0.123070E -1      0.160257E  4      0.345881E  2      0.480726E  0
    0.134384E -1     -0.104657E  4      0.349026E  2      0.520037E  0
    0.137386E -1     -0.392470E  3      0.346866E  2      0.530482E  0
    0.150778E -1     -0.513940E  3      0.340797E  2      0.576528E  0
    0.158397E -1     -0.292013E  4      0.327715E  2      0.601995E  0
    0.169481E -1     -0.148576E  4      0.303298E  2      0.636966E  0
    0.176408E -1      0.513900E  2      0.298330E  2      0.657803E  0
    0.181026E -1     -0.990510E  3      0.296161E  2      0.671530E  0
    0.187722E -1     -0.186900E  2      0.292782E  2      0.691248E  0
    0.193263E -1      0.724190E  3      0.294737E  2      0.707525E  0
    0.203885E -1     -0.107928E  4      0.292851E  2      0.738732E  0
    0.207810E -1     -0.174273E  4      0.287313E  2      0.750118E  0
    0.216815E -1     -0.180814E  4      0.271325E  2      0.775270E  0
    0.226282E -1     -0.177544E  4      0.254362E  2      0.800154E  0
    0.235287E -1      0.130354E  4      0.252237E  2      0.822963E  0
    0.241060E -1      0.152781E  4      0.260410E  2      0.837761E  0
    0.252143E -1     -0.220061E  4      0.256682E  2      0.866416E  0
    0.263457E -1     -0.719520E  3      0.240163E  2      0.894522E  0
    0.271077E -1     -0.157920E  4      0.231405E  2      0.912489E  0
    0.275002E -1     -0.224266E  4      0.223904E  2      0.921424E  0
    0.289087E -1      0.873700E  3      0.214263E  2      0.952282E  0
    0.297169E -1     -0.406480E  3      0.216151E  2      0.969675E  0
    0.305019E -1     -0.126617E  4      0.209586E  2      0.986385E  0
    0.316102E -1     -0.345749E  3      0.200654E  2      0.100912E  1
    0.324877E -1     -0.200438E  4      0.190343E  2      0.102627E  1
    0.347043E -1     -0.172870E  3      0.166212E  2      0.106579E  1
    0.352123E -1     -0.602710E  3      0.164242E  2      0.107418E  1
    0.370595E -1     -0.162125E  4      0.143702E  2      0.110263E  1
    0.383294E -1     -0.373780E  3      0.131034E  2      0.112007E  1
    0.394147E -1     -0.105592E  4      0.123276E  2      0.113387E  1
    0.399457E -1     -0.878370E  3      0.118140E  2      0.114028E  1
    0.402228E -1     -0.130354E  4      0.115117E  2      0.114351E  1
    0.407539E -1     -0.612060E  3      0.110031E  2      0.114949E  1
    0.414697E -1     -0.109330E  4      0.103927E  2      0.115715E  1
    0.420238E -1     -0.397140E  3      0.997978E  1      0.116279E  1
    0.427627E -1     -0.130354E  4      0.935146E  1      0.116993E  1
    0.432014E -1     -0.845670E  3      0.888003E  1      0.117393E  1
    0.435247E -1     -0.117740E  4      0.855300E  1      0.117675E  1
    0.441019E -1     -0.387790E  3      0.810129E  1      0.118156E  1
    0.457644E -1     -0.135961E  4      0.664876E  1      0.119382E  1
    0.470806E -1     -0.490580E  3      0.543115E  1      0.120177E  1
    0.480272E -1     -0.144838E  4      0.451344E  1      0.120648E  1
    0.491355E -1     -0.532630E  3      0.341566E  1      0.121087E  1
    0.496204E -1     -0.100920E  4      0.304185E  1      0.121244E  1
    0.505902E -1     -0.144838E  4      0.185017E  1      0.121481E  1
    0.513984E -1     -0.668120E  3      0.994890E  0      0.121596E  1
    0.518833E -1     -0.114469E  4      0.555374E  0      0.121633E  1
    0.524882E -1     -0.840247E  3      0.000000E  0      0.121642E  1
R
```

Acceleration vs. Time Taken from
Accelerometer Trace

Specimen No. 25

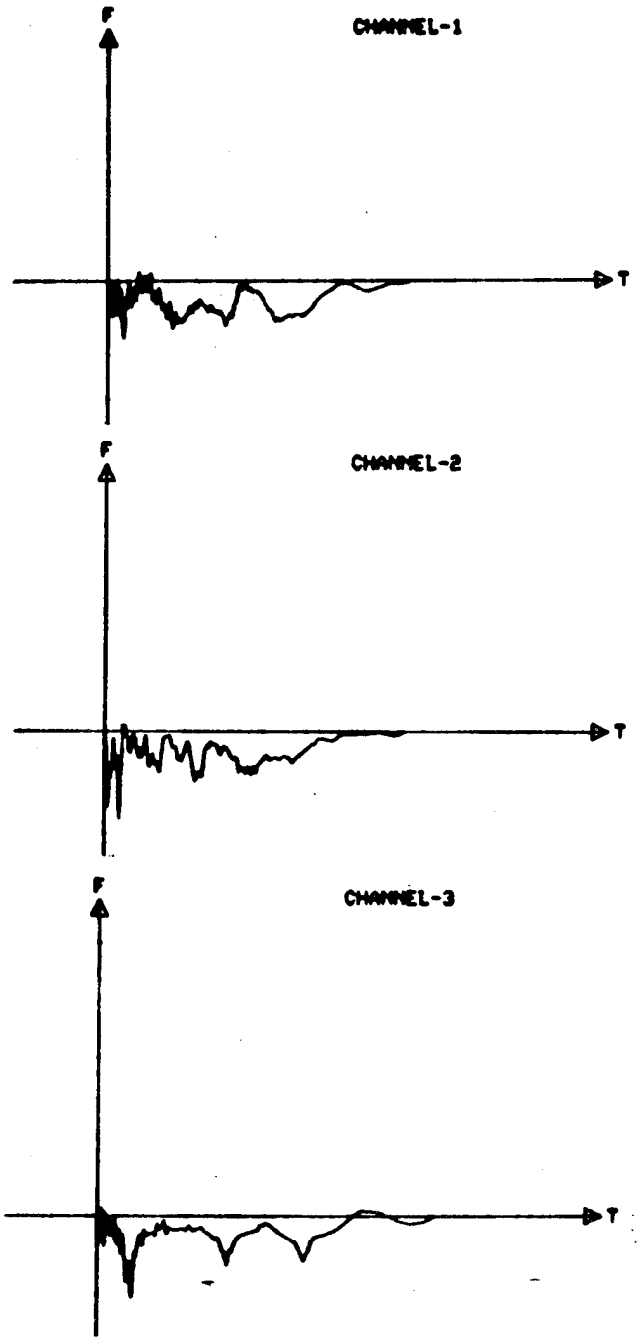
(Used as input to ACCEL Program)



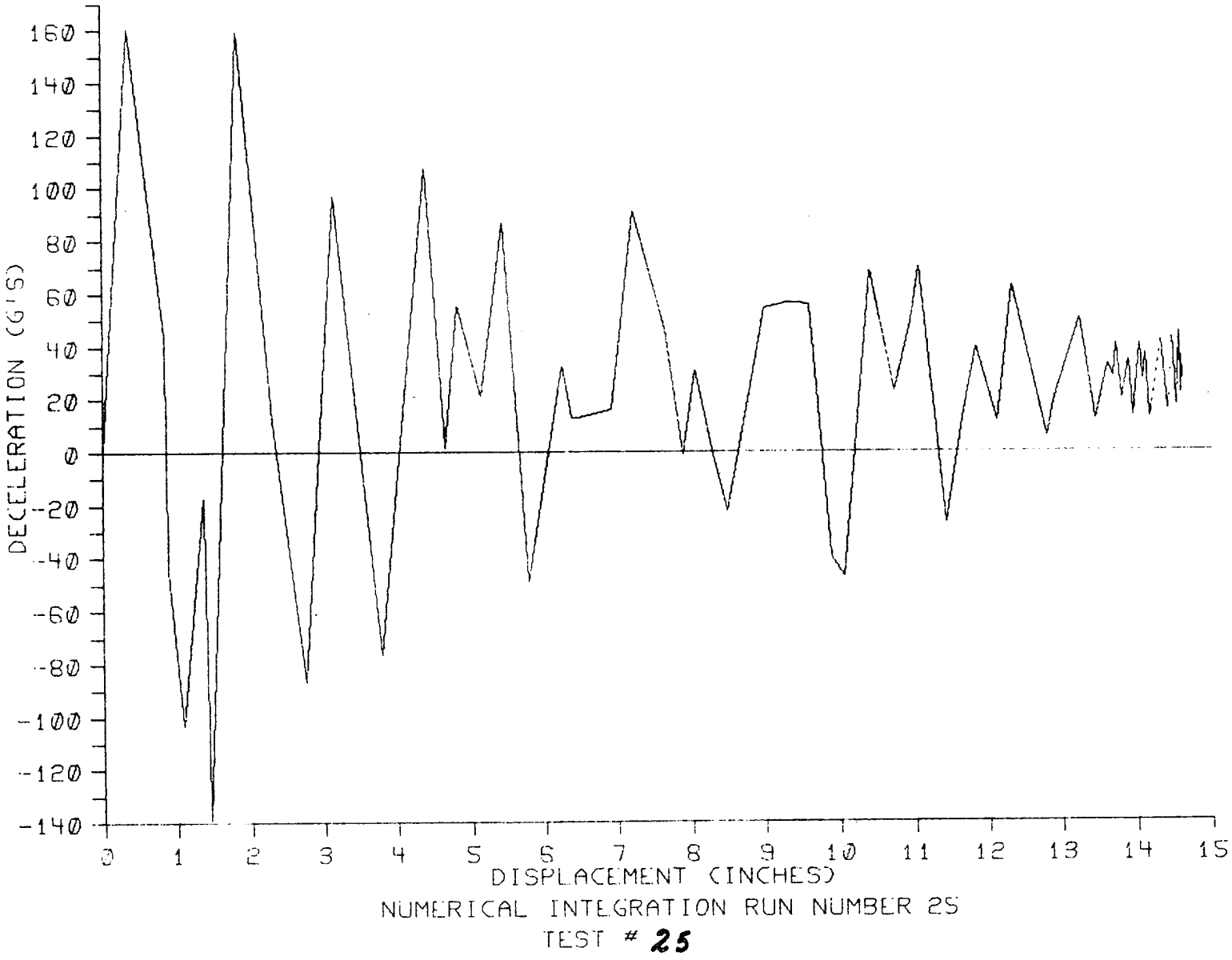
Force vs. Time - Data from Load Cell Traces

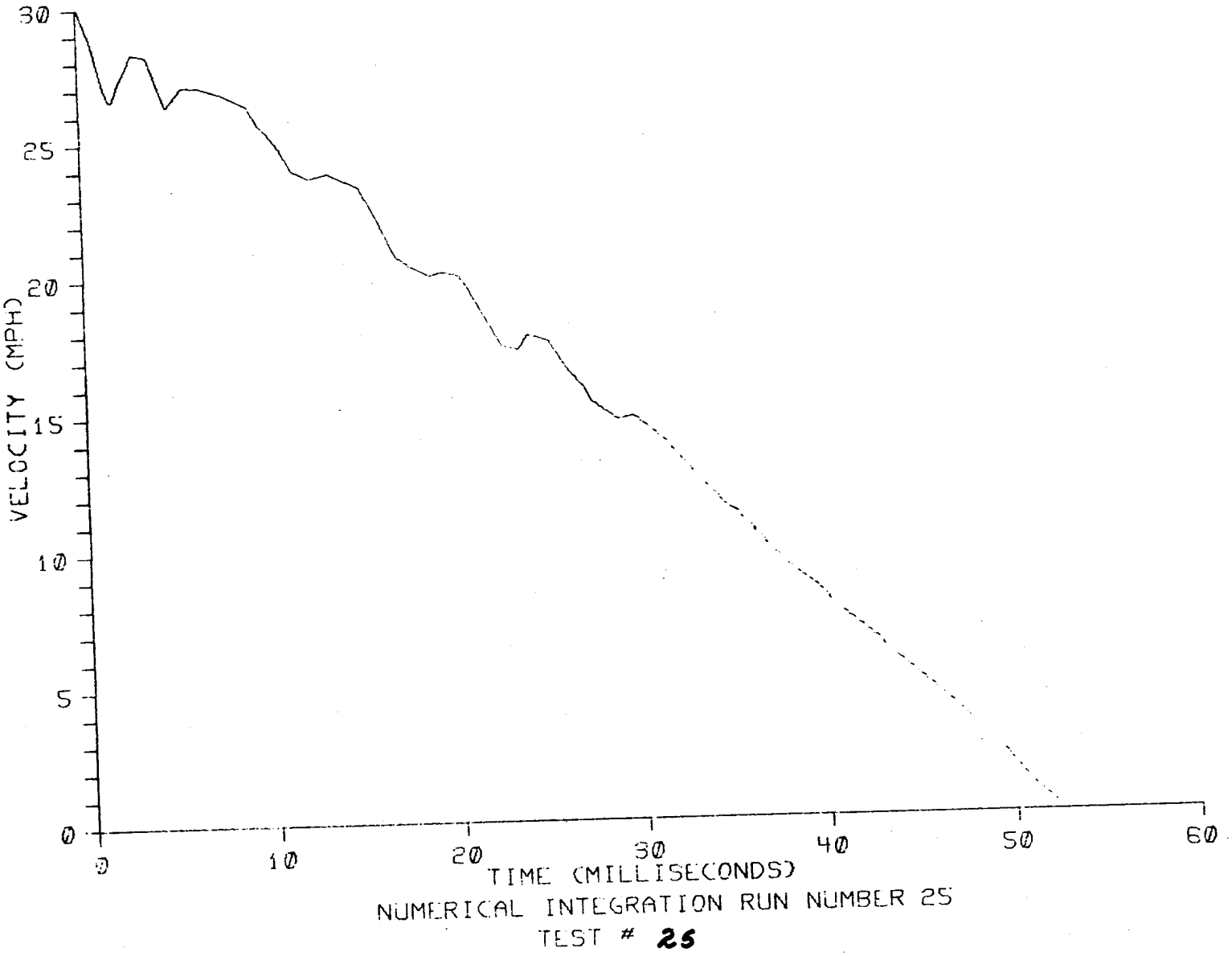
Specimen No. 25

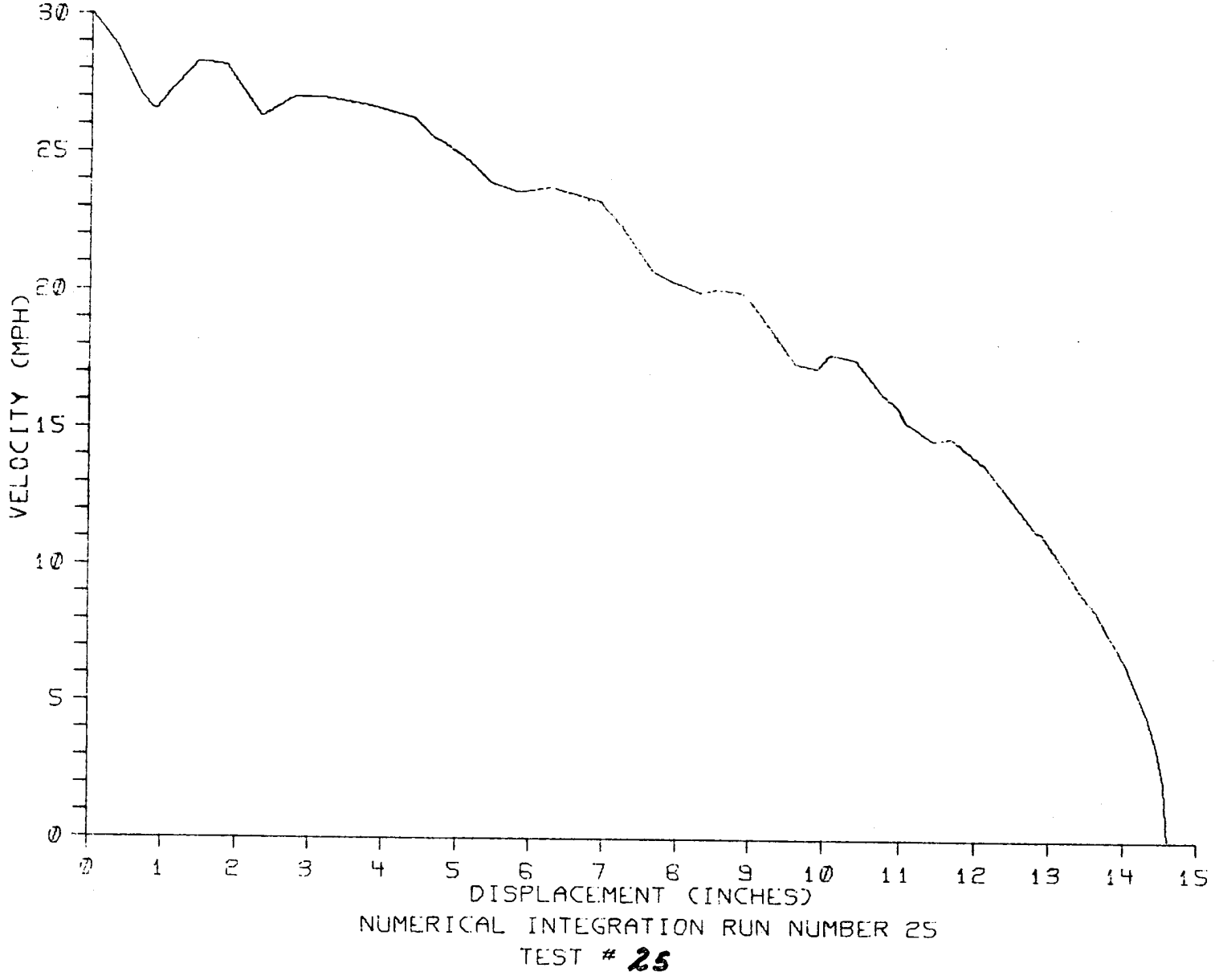
(Used as input to FORCOM Program)

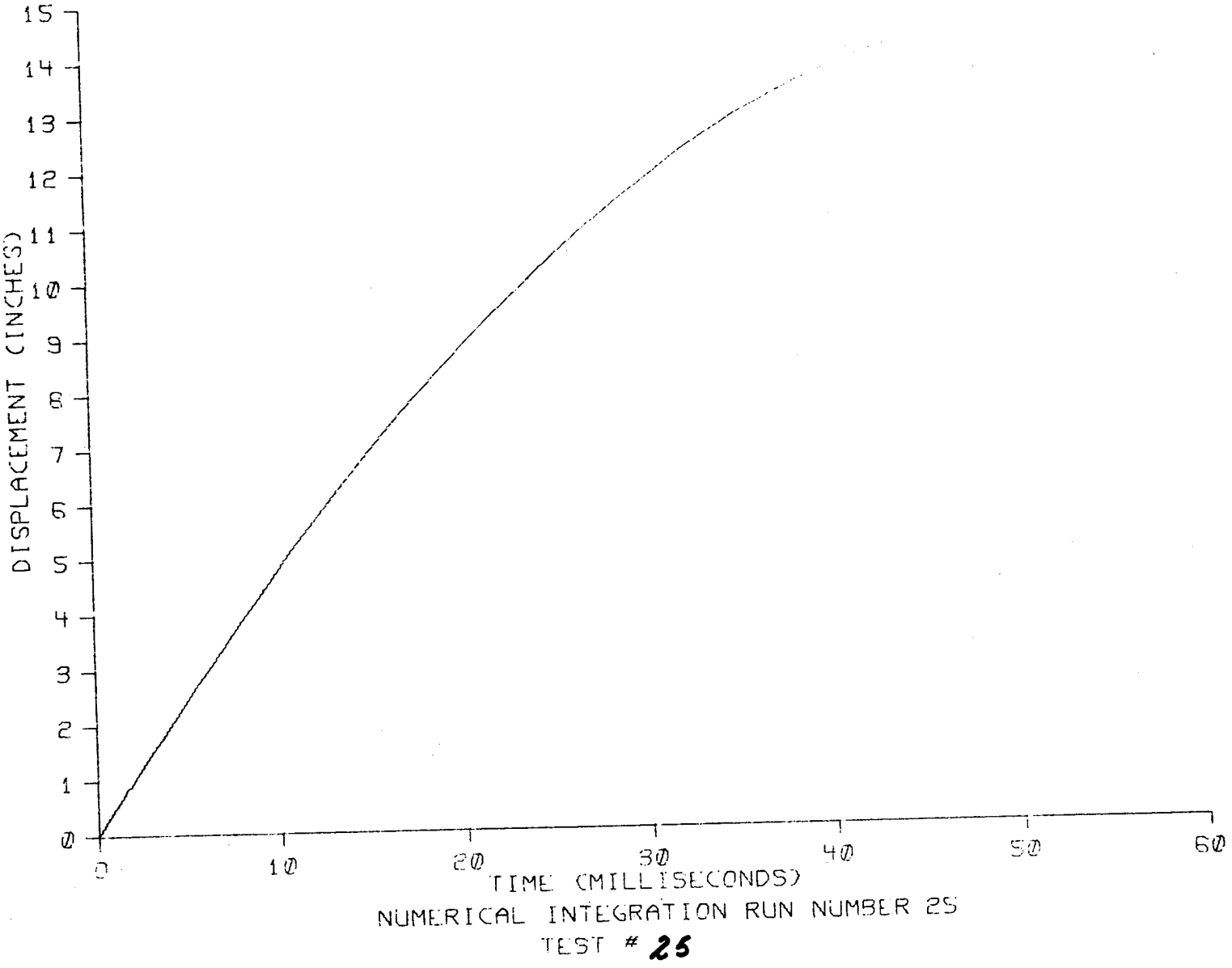


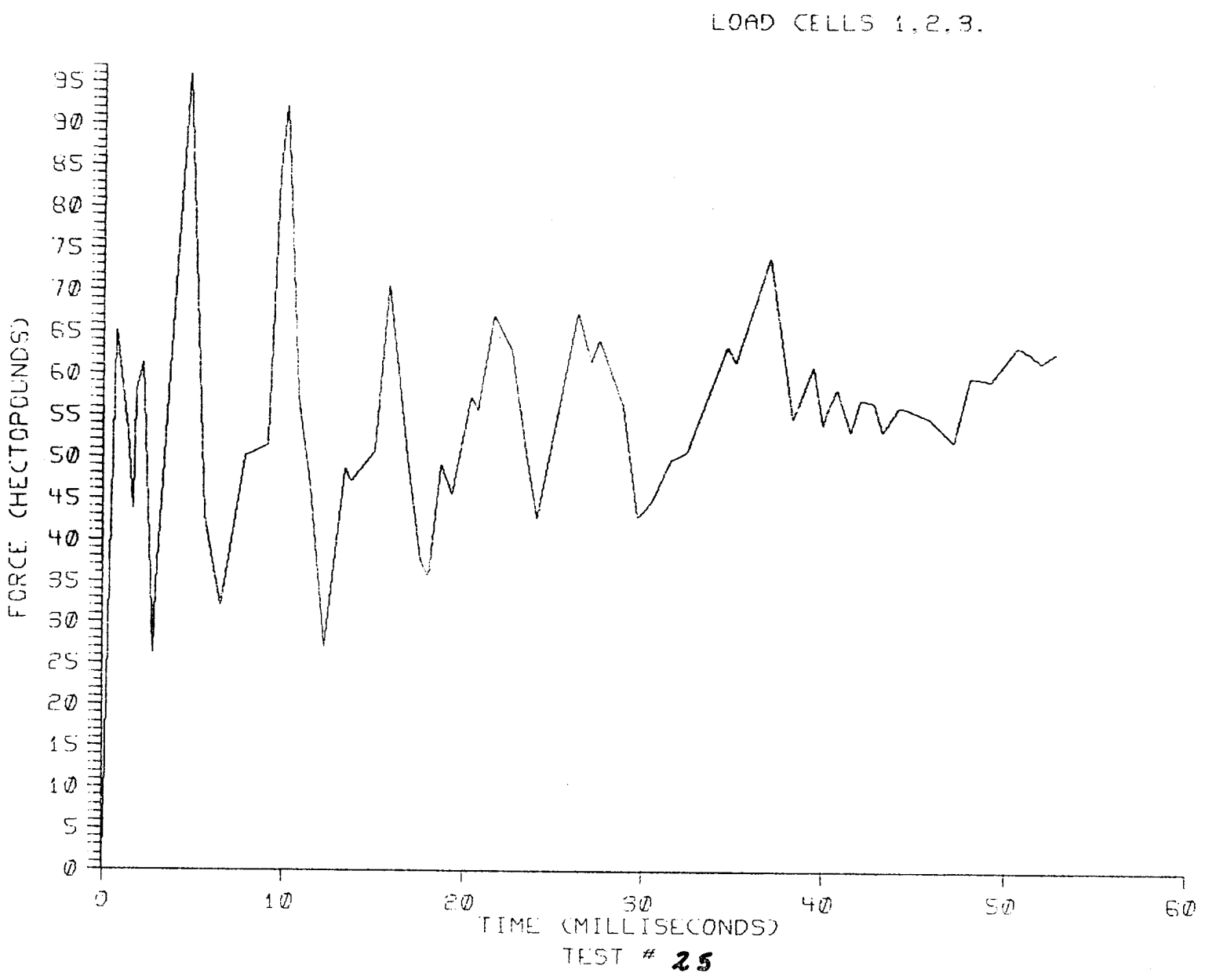
60
50
BER 25
DECELERATION (G'S)
150
140
120
100
80
60
40
20
0
-20
-40

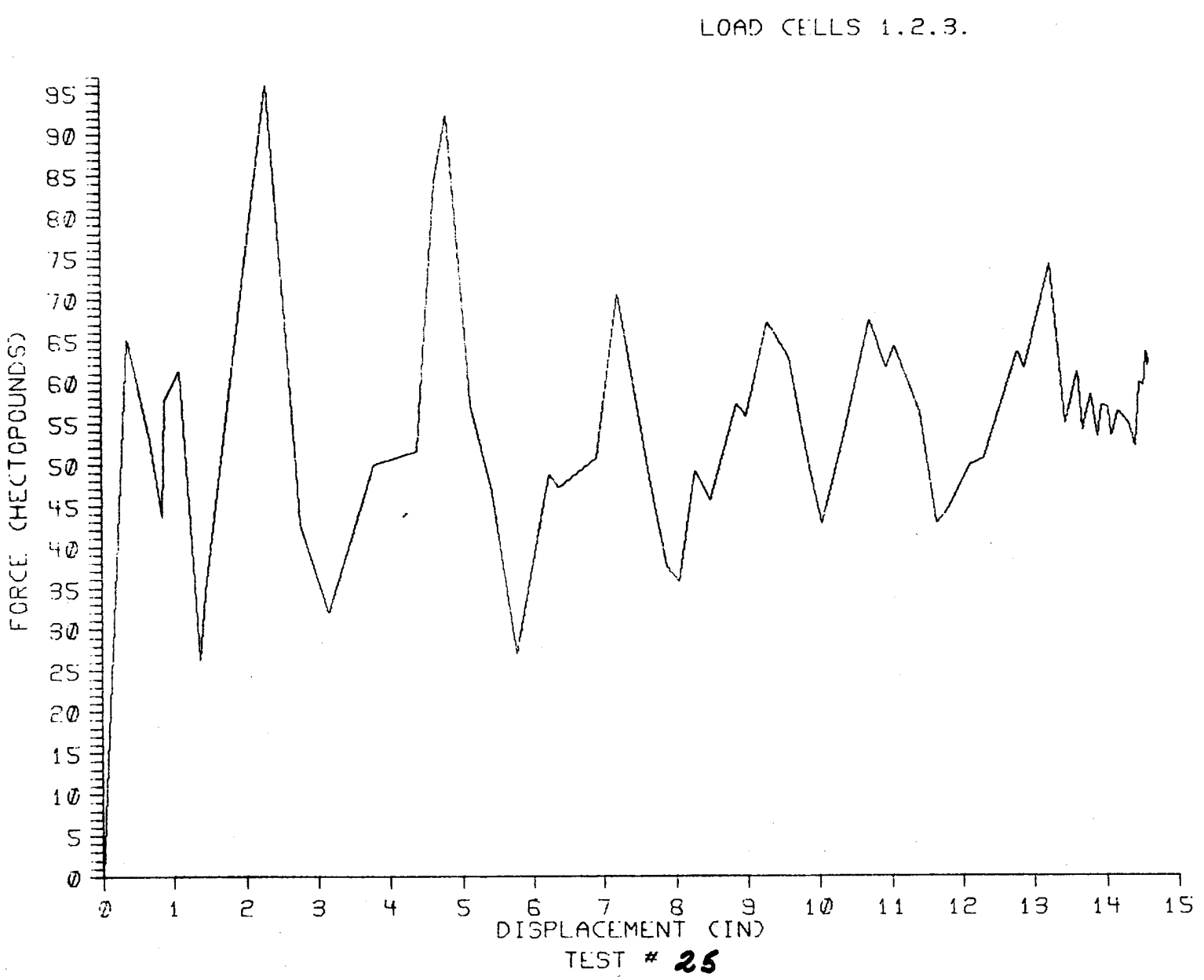

160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
DECELERATION (G'S)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
DISPLACEMENT (INCHES)
NUMERICAL INTEGRATION RUN NUMBER 25
TEST # 25

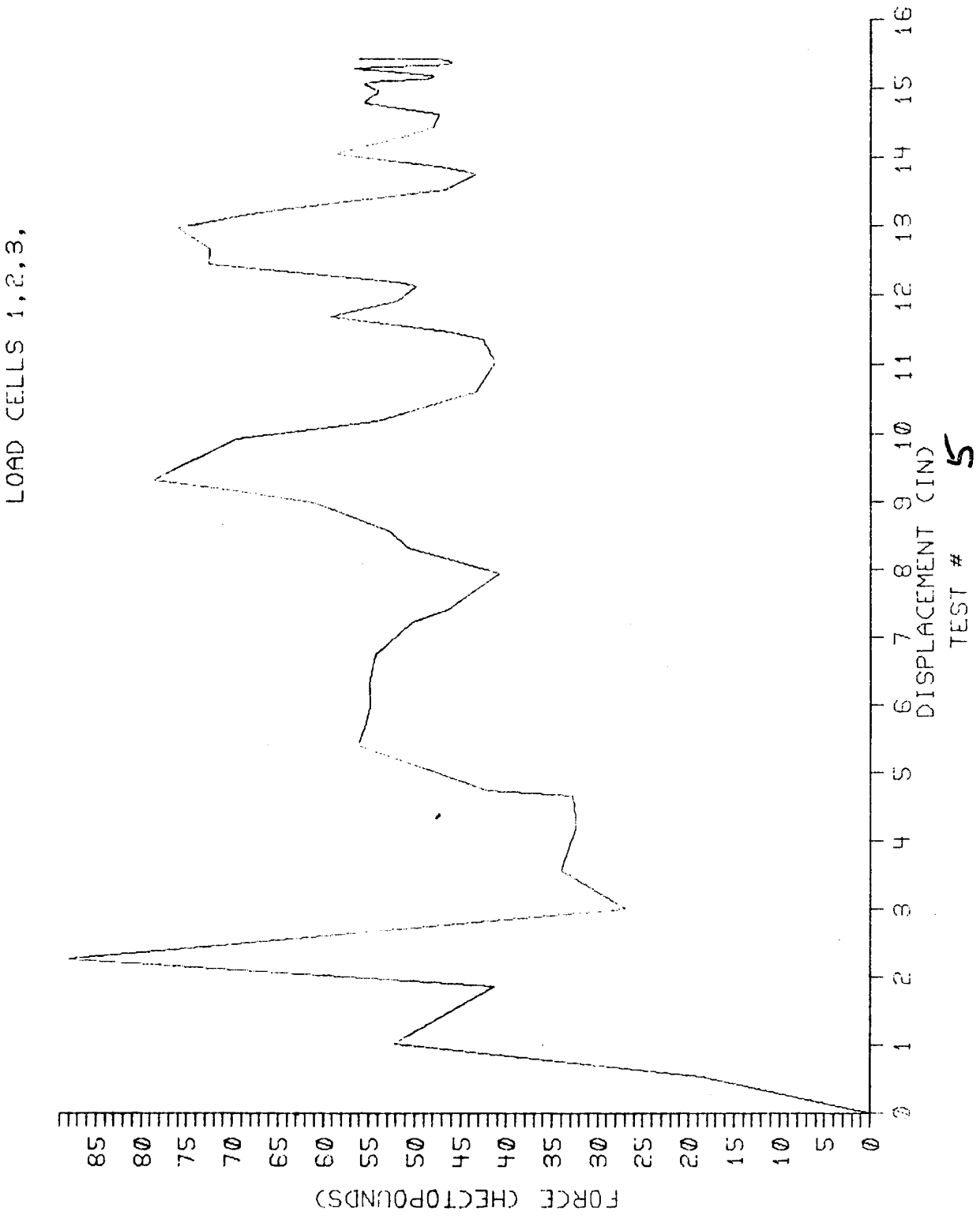

30
25
20
15
10
5
0
VELOCITY (MPH)
0
10
20
30
40
50
60
TIME (MILLISECONDS)
NUMERICAL INTEGRATION RUN NUMBER 25
TEST # 25


30
25
20
15
10
5
0
VELOCITY (MPH)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (INCHES)
NUMERICAL INTEGRATION RUN NUMBER 25
TEST # 25


15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
DISPLACEMENT (INCHES)
0
10
20
30
40
50
60
TIME (MILLISECONDS)
NUMERICAL INTEGRATION RUN NUMBER 25
TEST # 25


LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
TIME (MILLISECONDS)
TEST # 25


LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST # 25


LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
85
80
75
70
65
60
55
50
45
40
35
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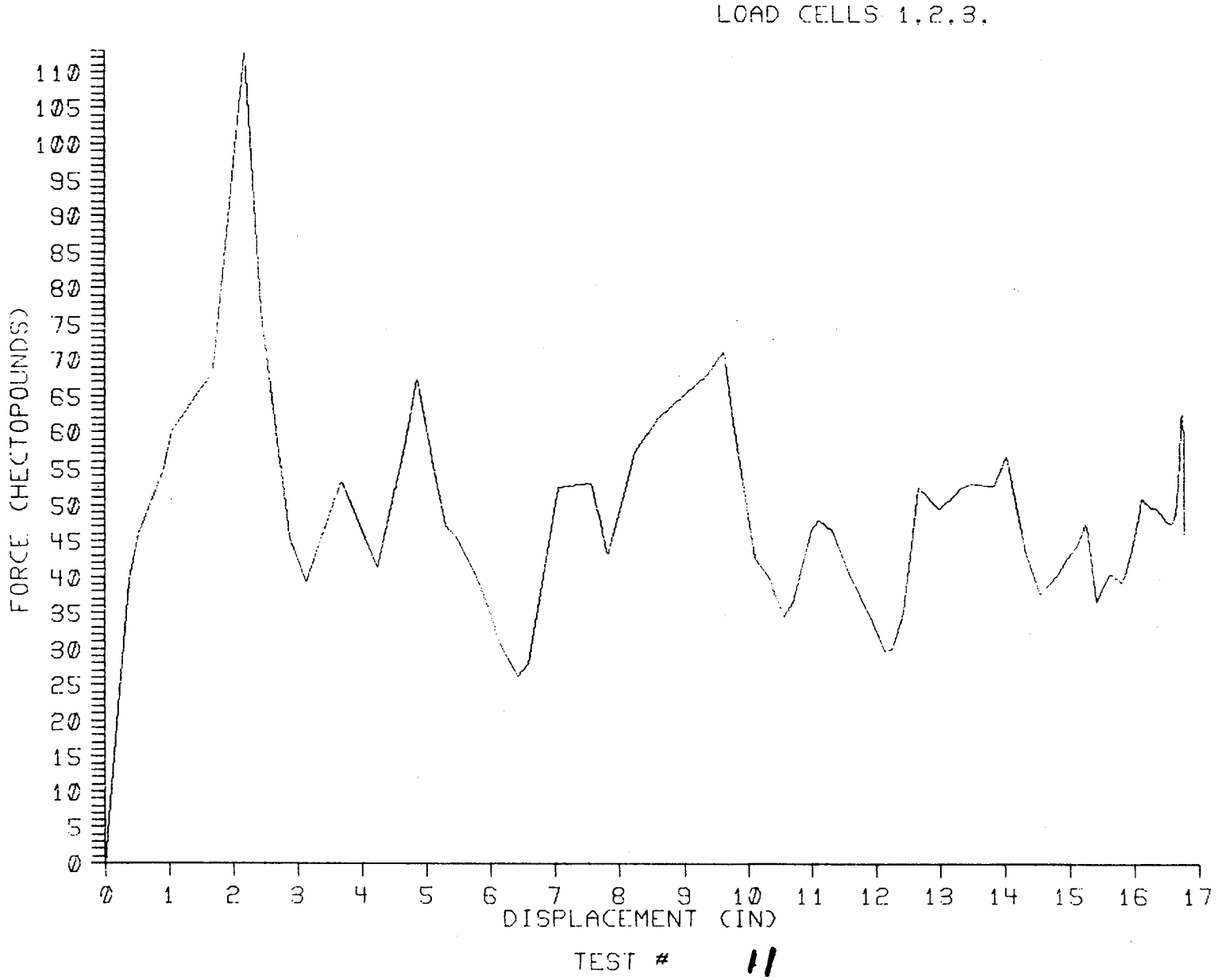
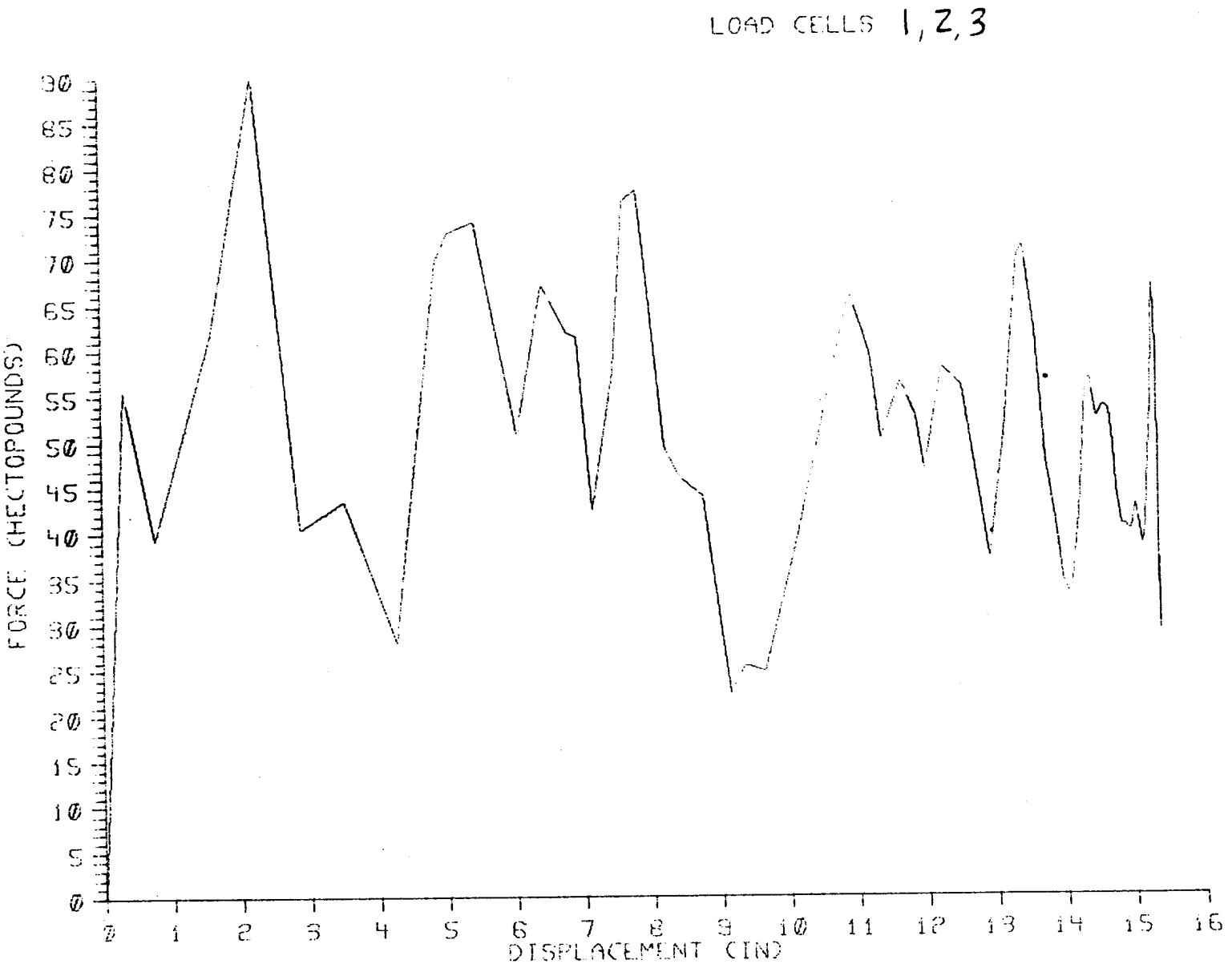
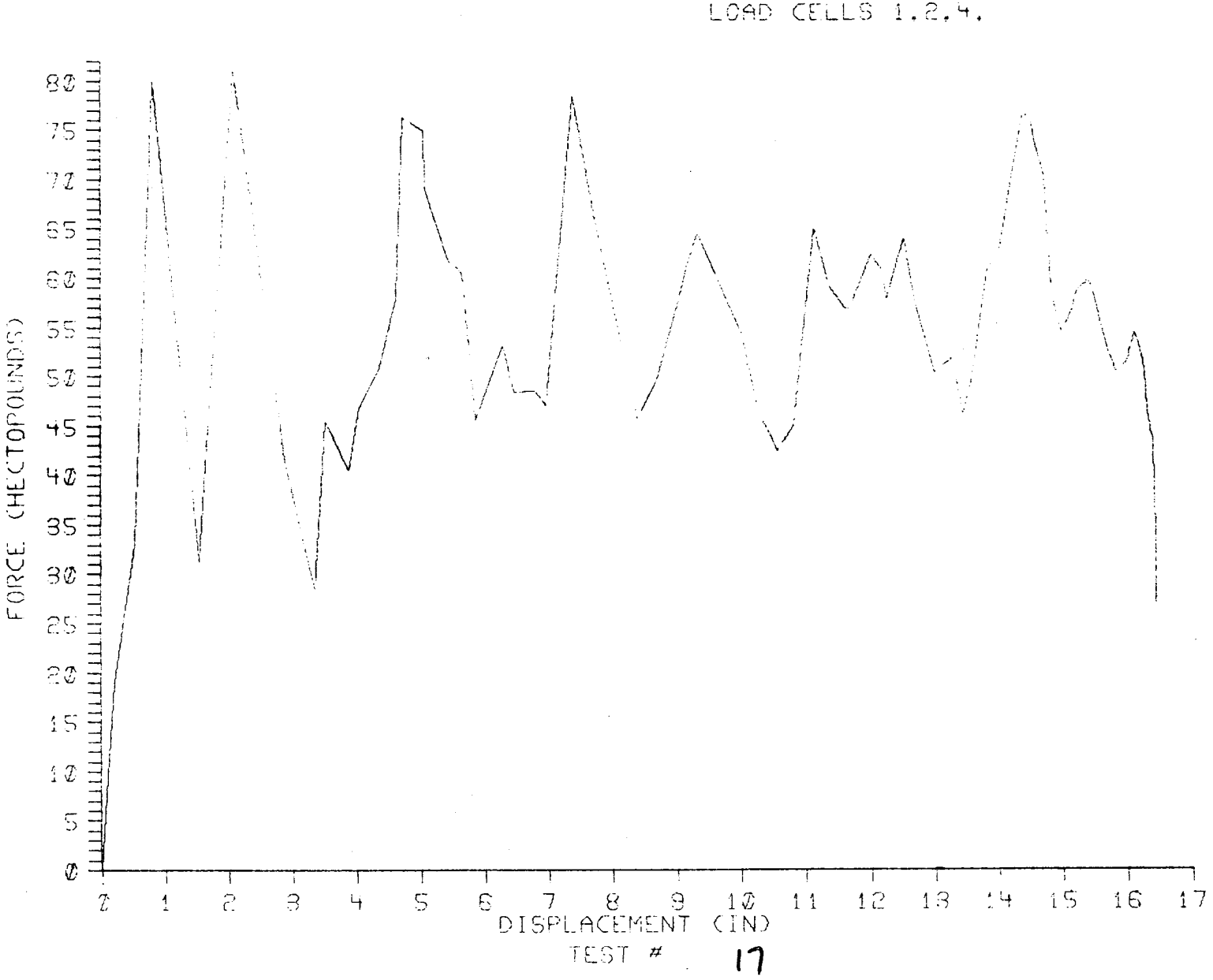
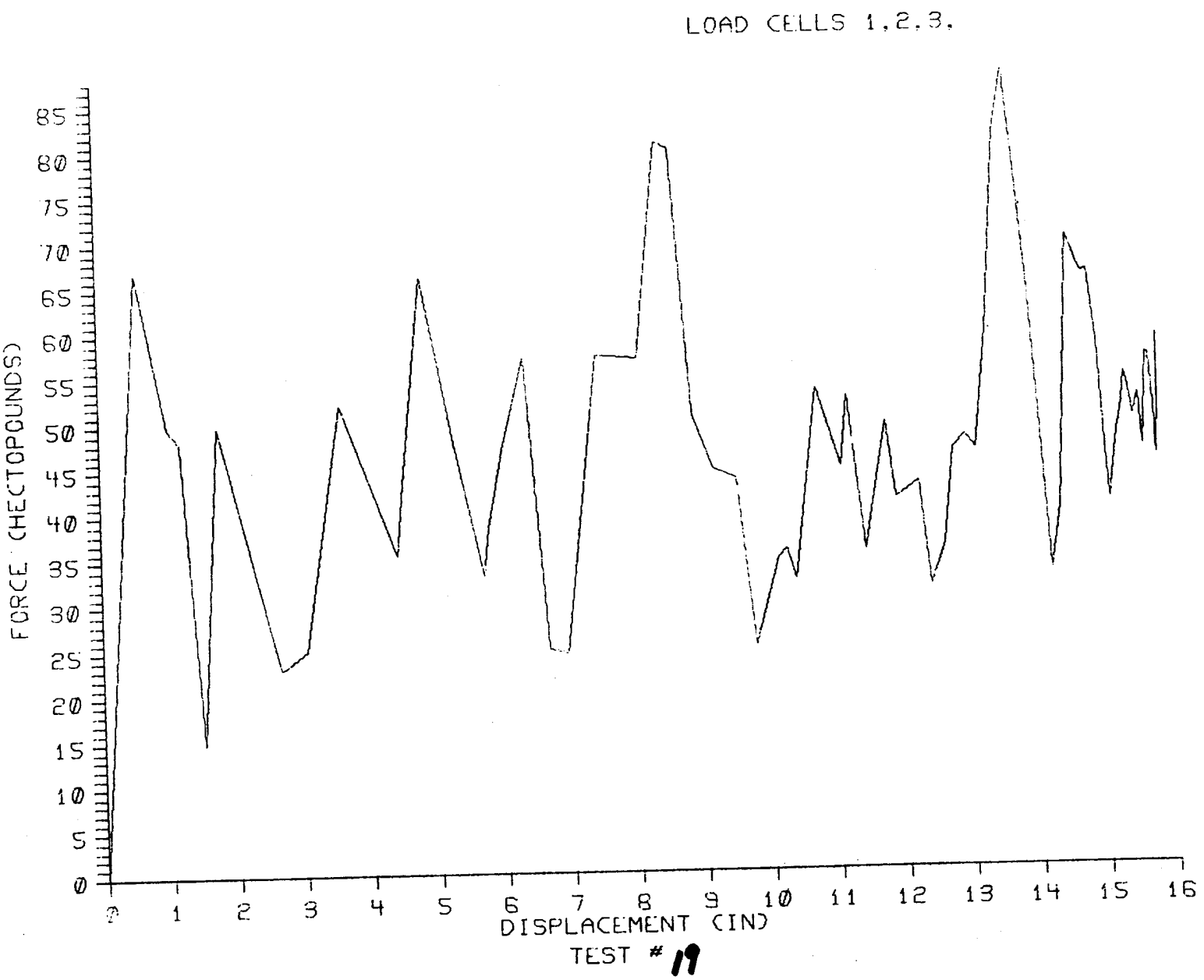
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
DISPLACEMENT (IN)
TEST # 5

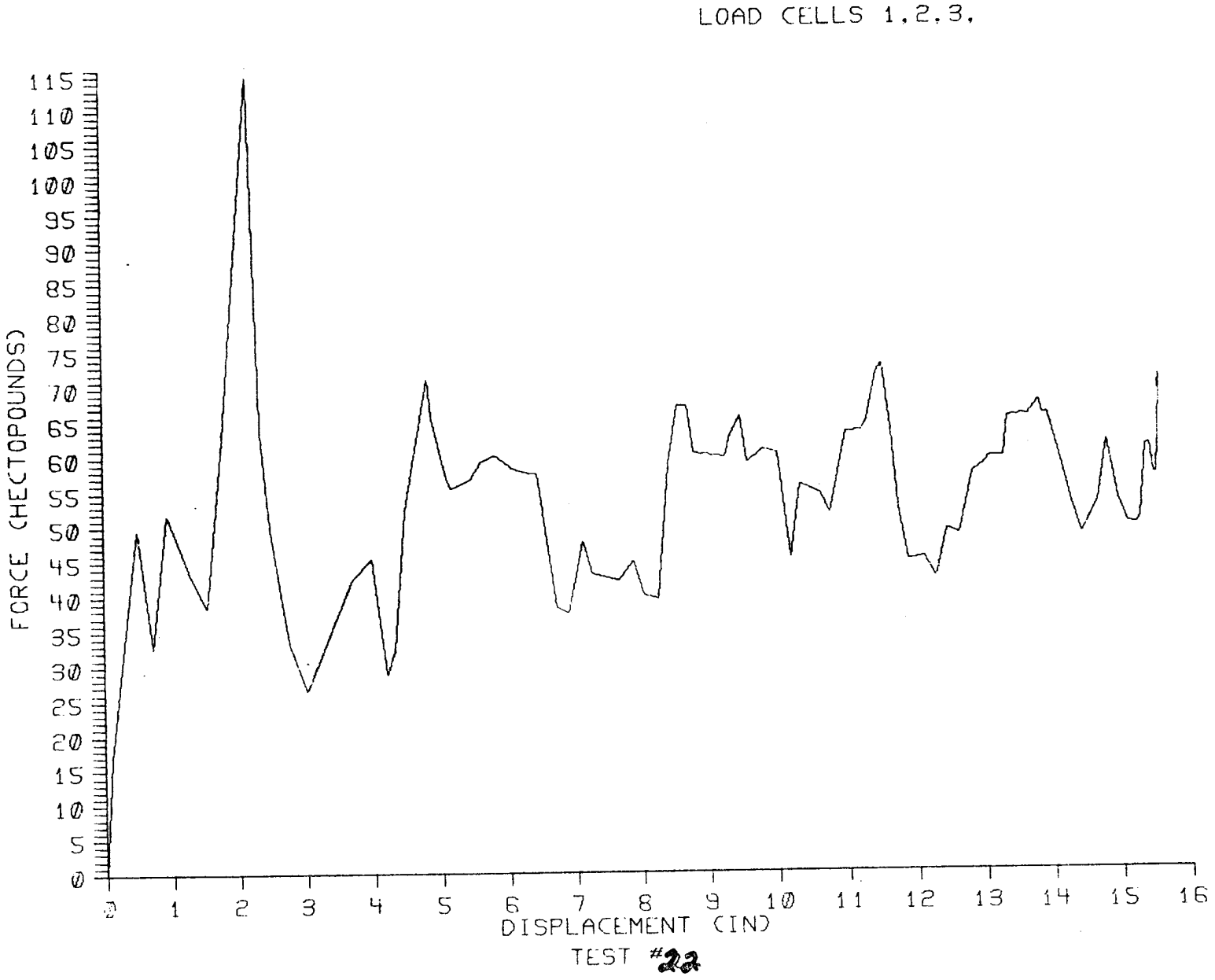

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST # 11

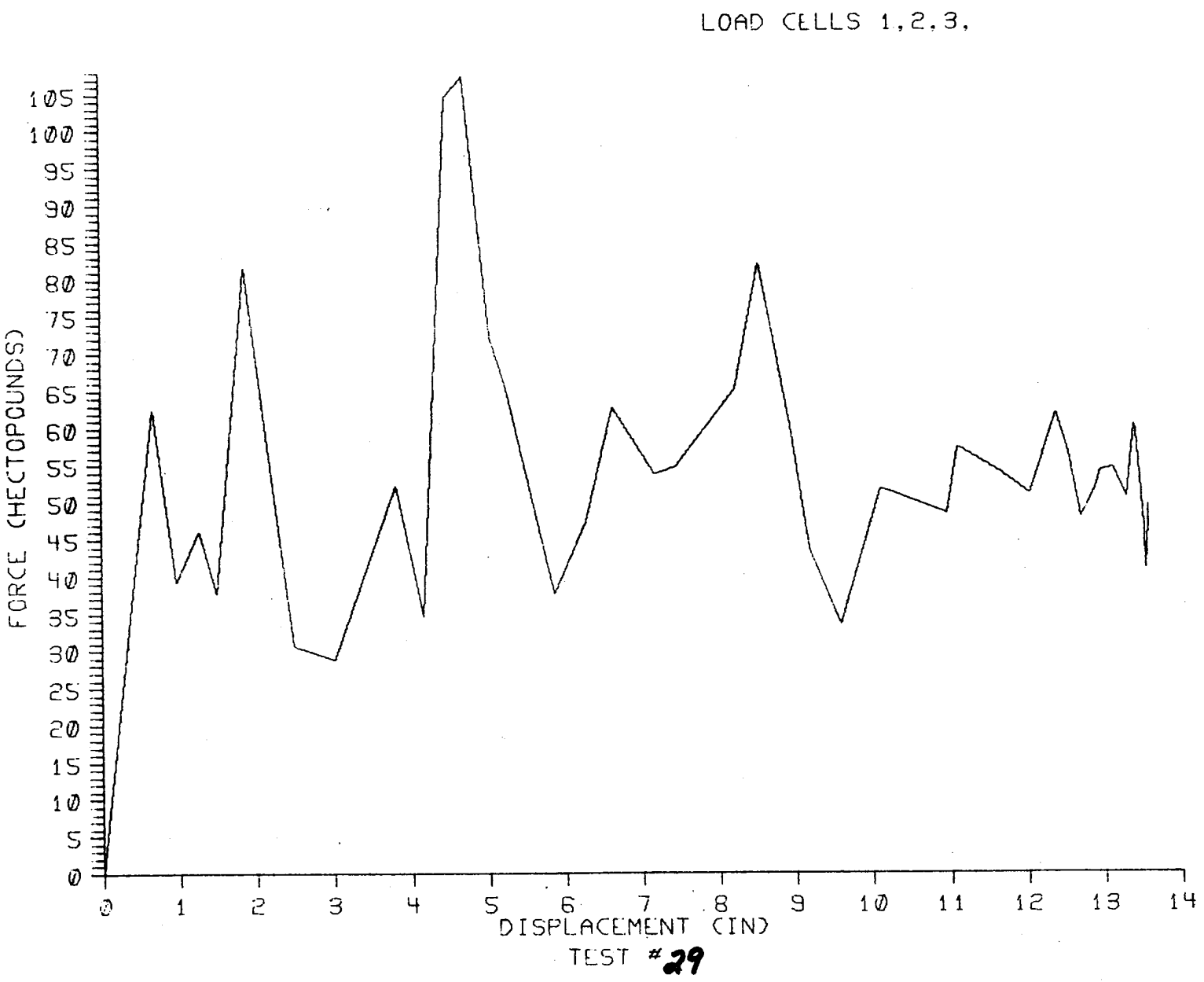
FORCE (HECTOPOUNDS)
DISPLACEMENT (IND)
No. 13

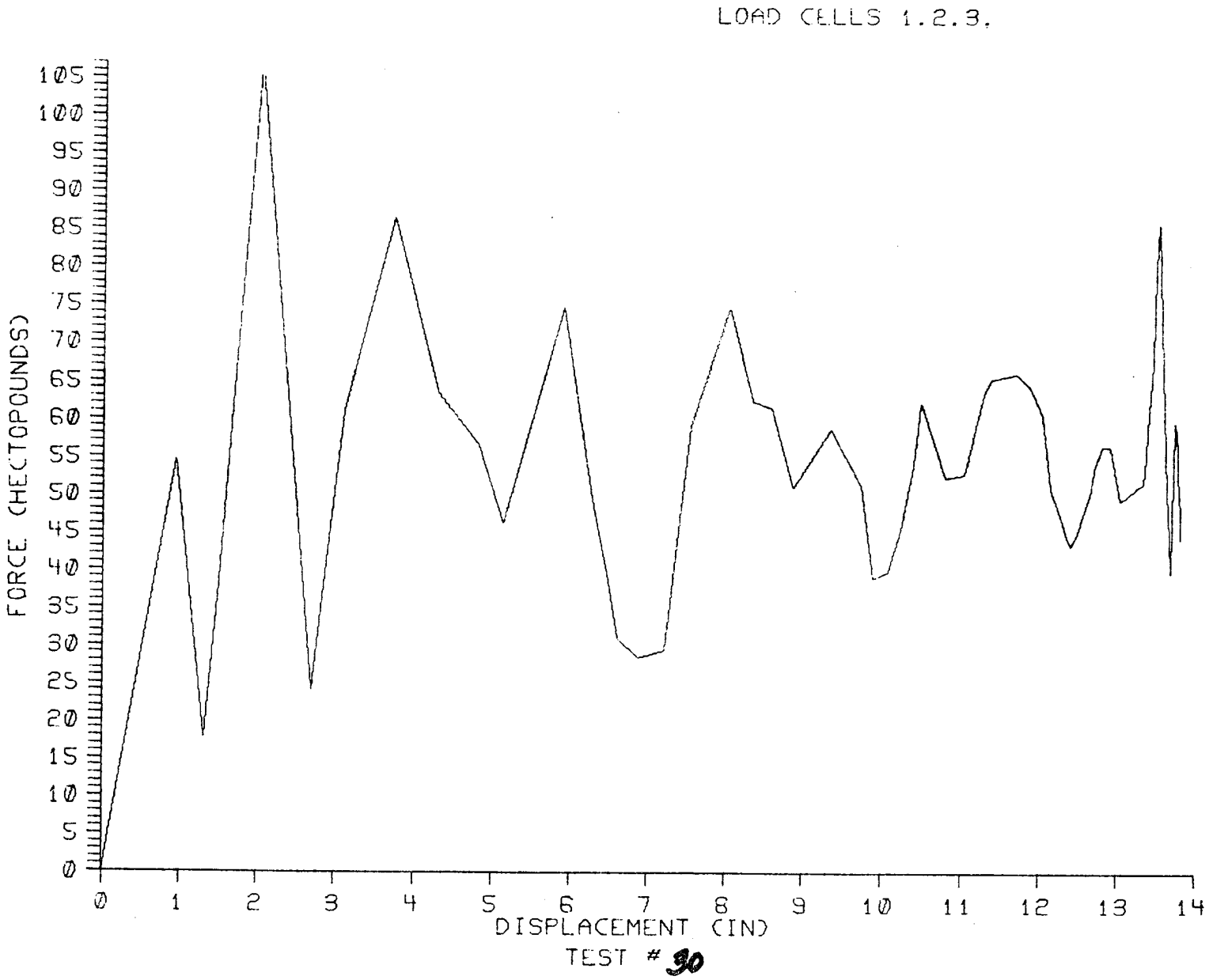

LOAD CELLS 1, 2, 3
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
DISPLACEMENT (IN)

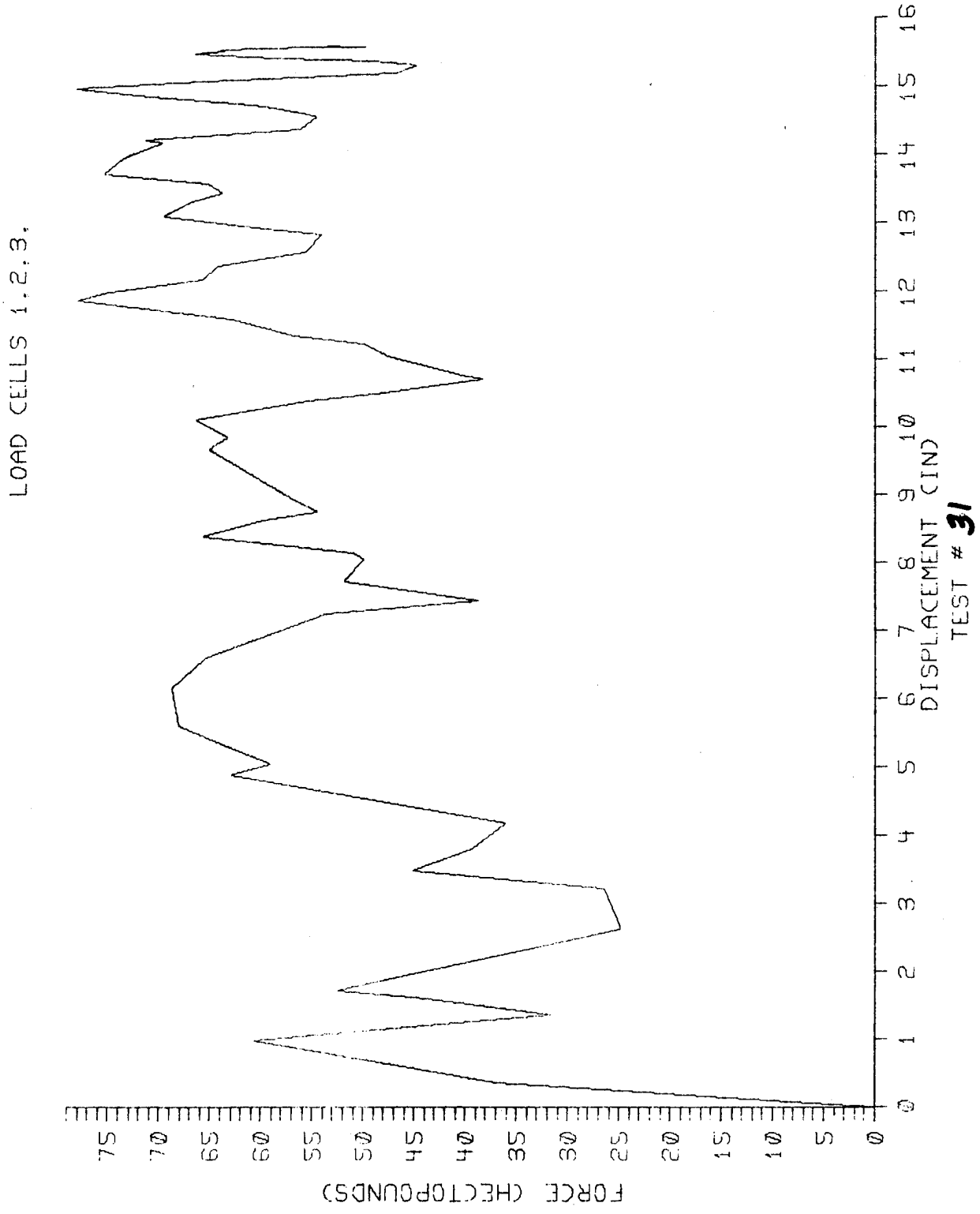

LOAD CELLS 1.2.4.
FORCE (HECTOPOUNDS)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST # 17

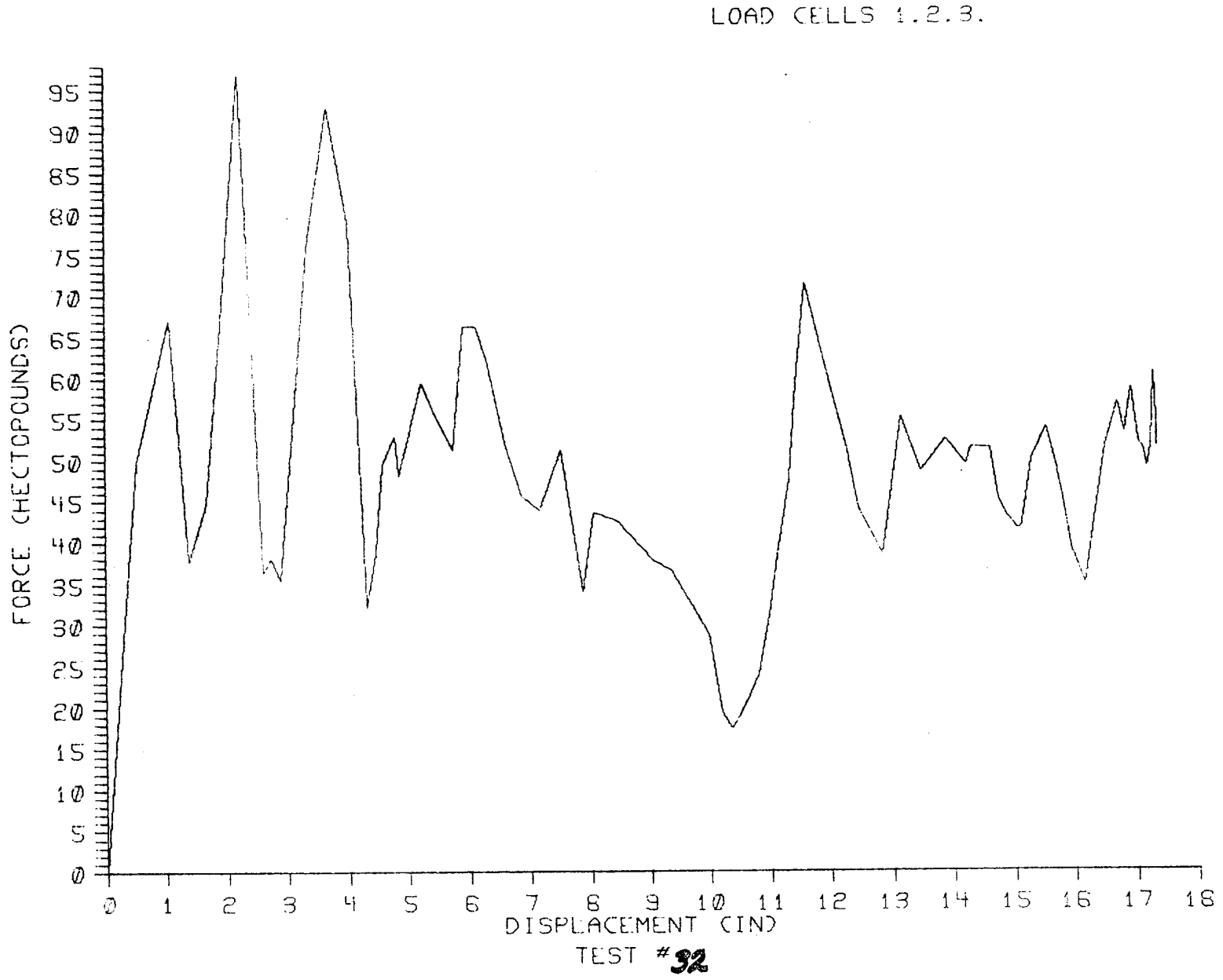

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
DISPLACEMENT (IN)
TEST # 19

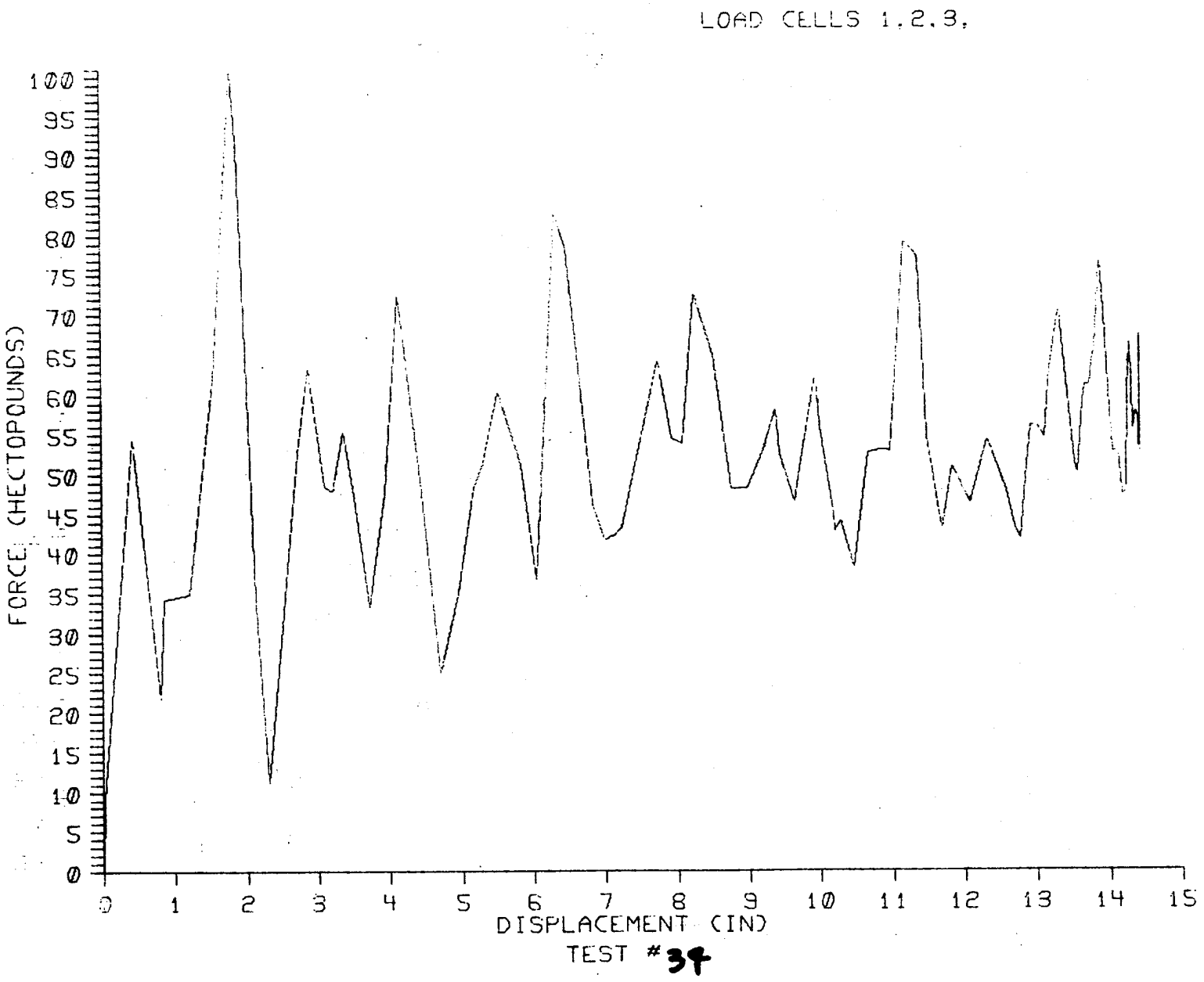

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DISPLACEMENT (IN)
TEST #22

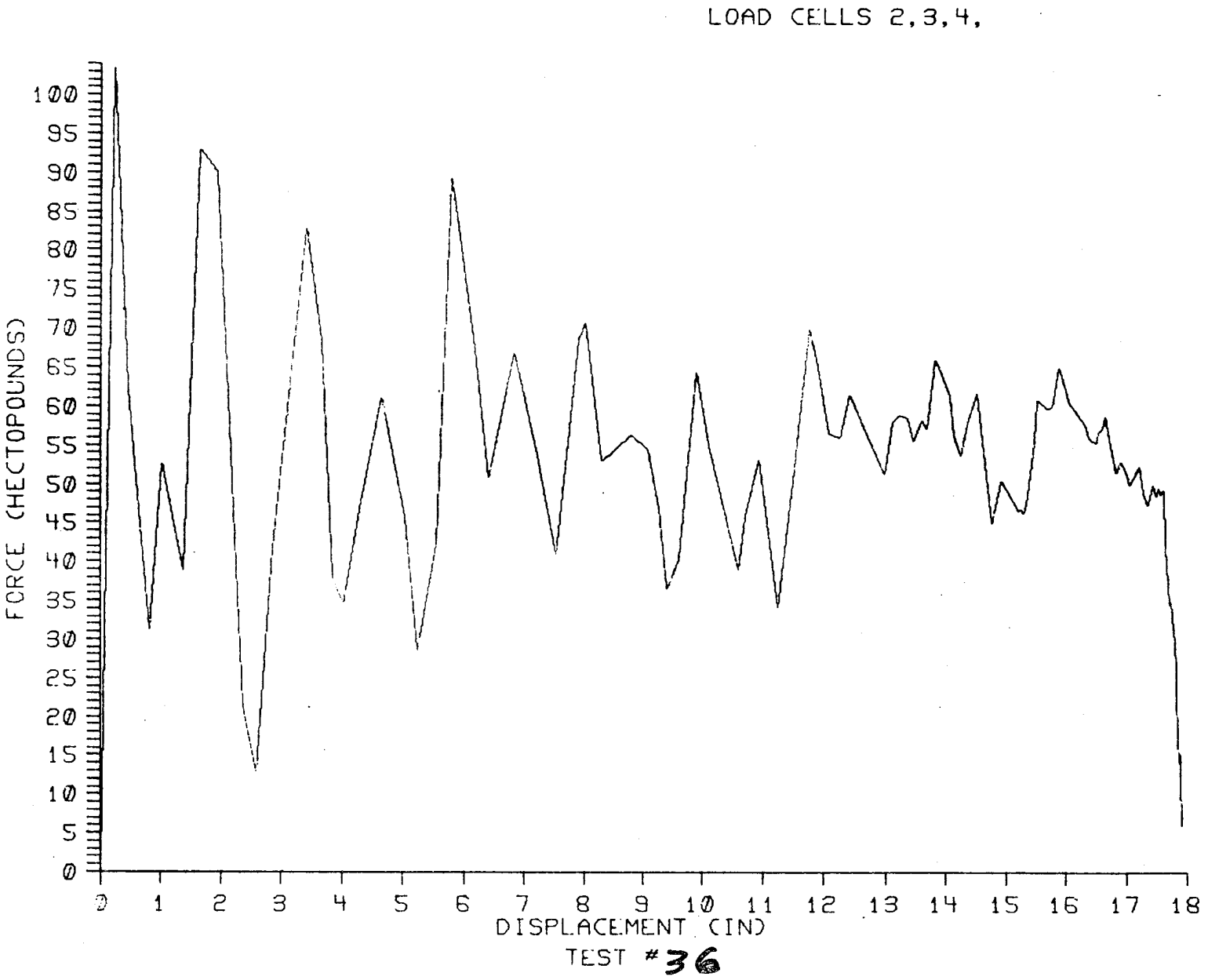

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DISPLACEMENT (IN)
TEST #29

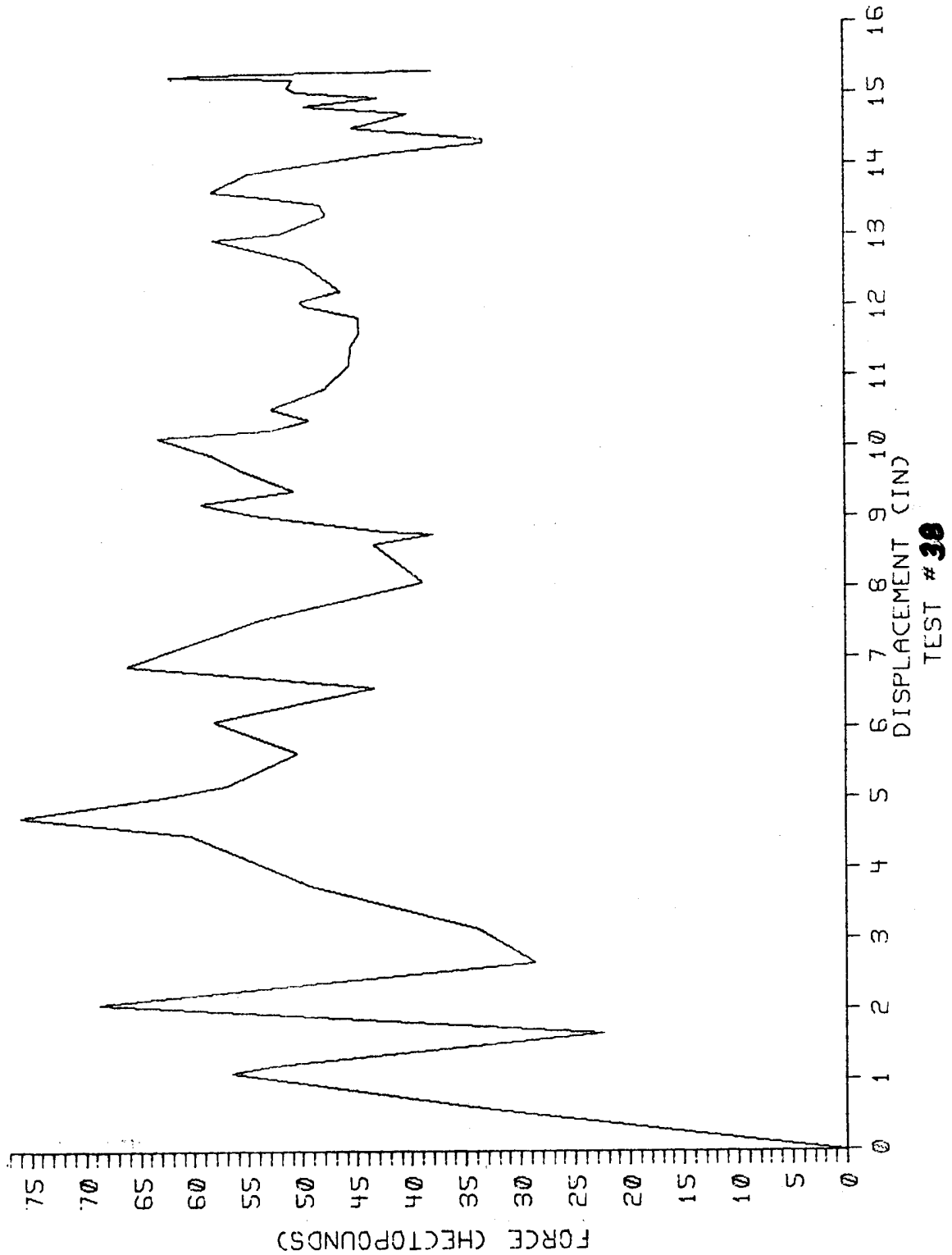

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
DISPLACEMENT (IN)
TEST # 30

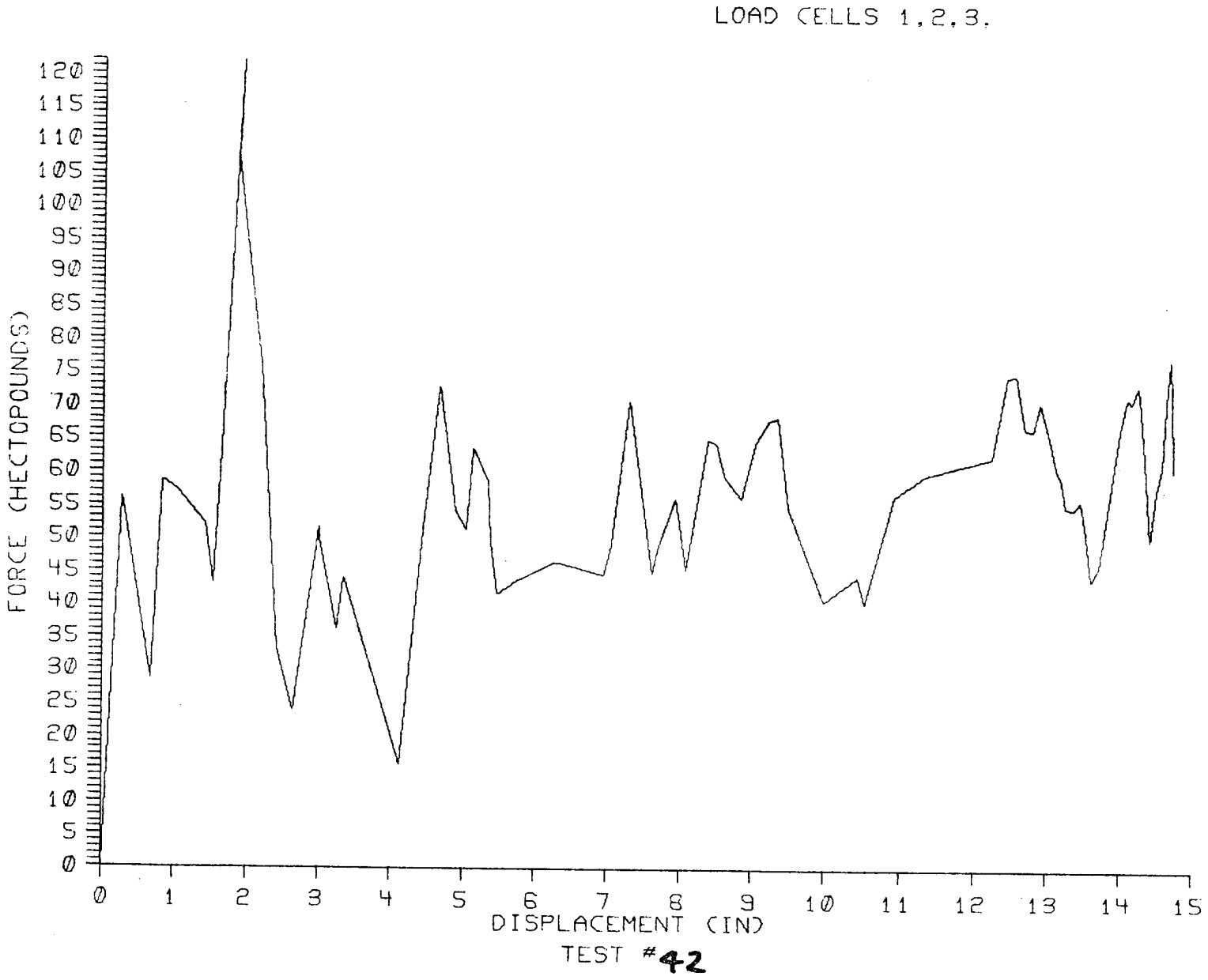

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DISPLACEMENT (IN)
TEST # 31

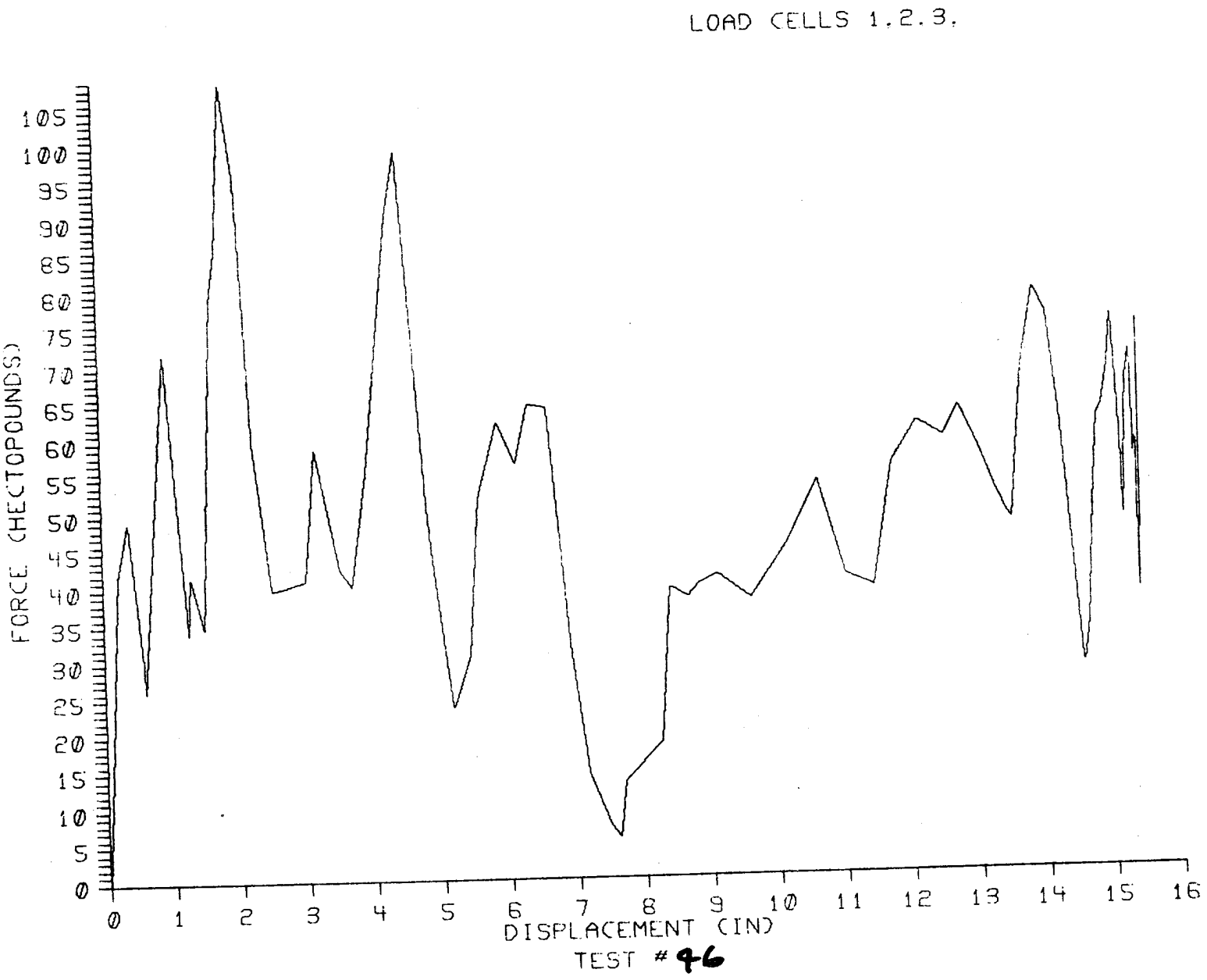

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
DISPLACEMENT (IN)
TEST #32

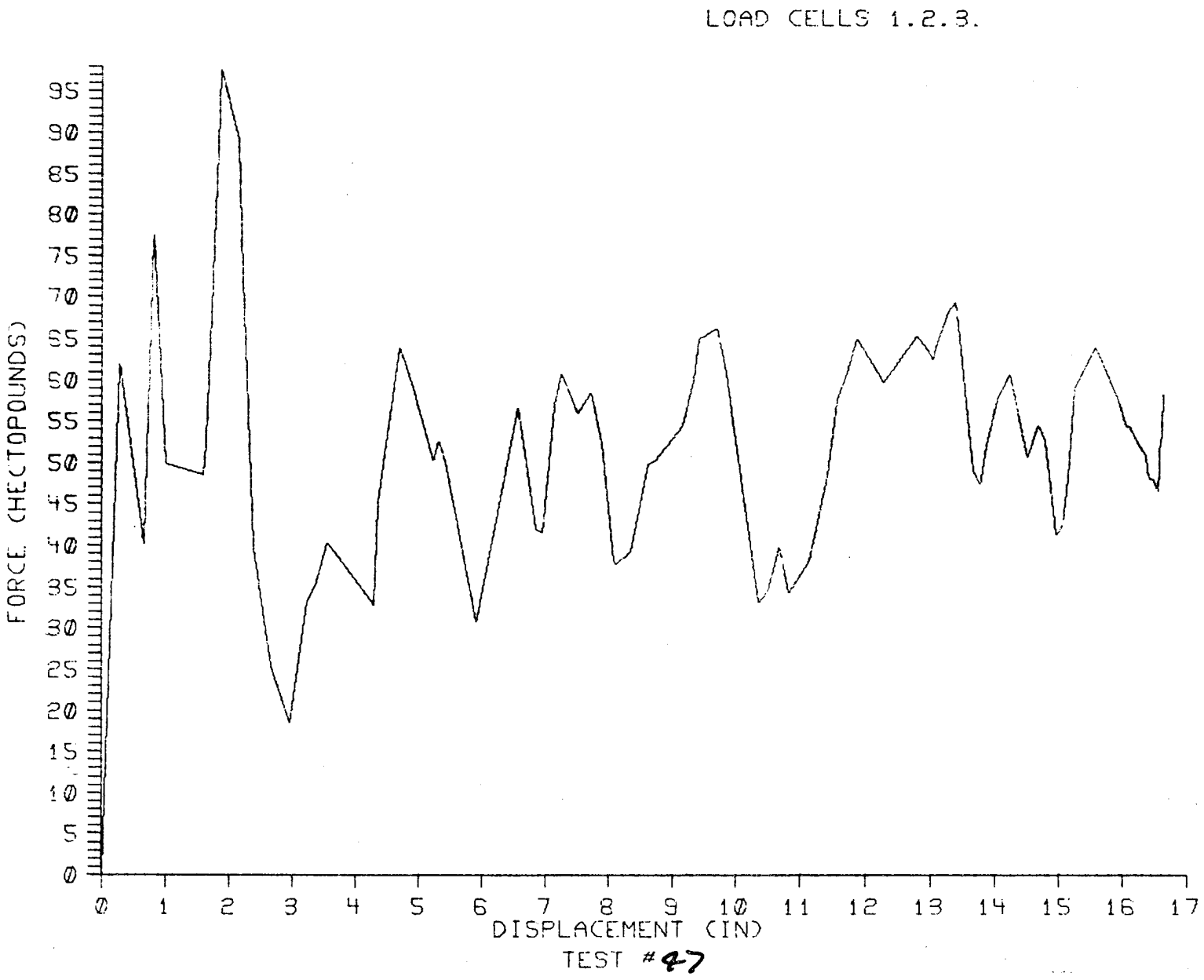

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST #34

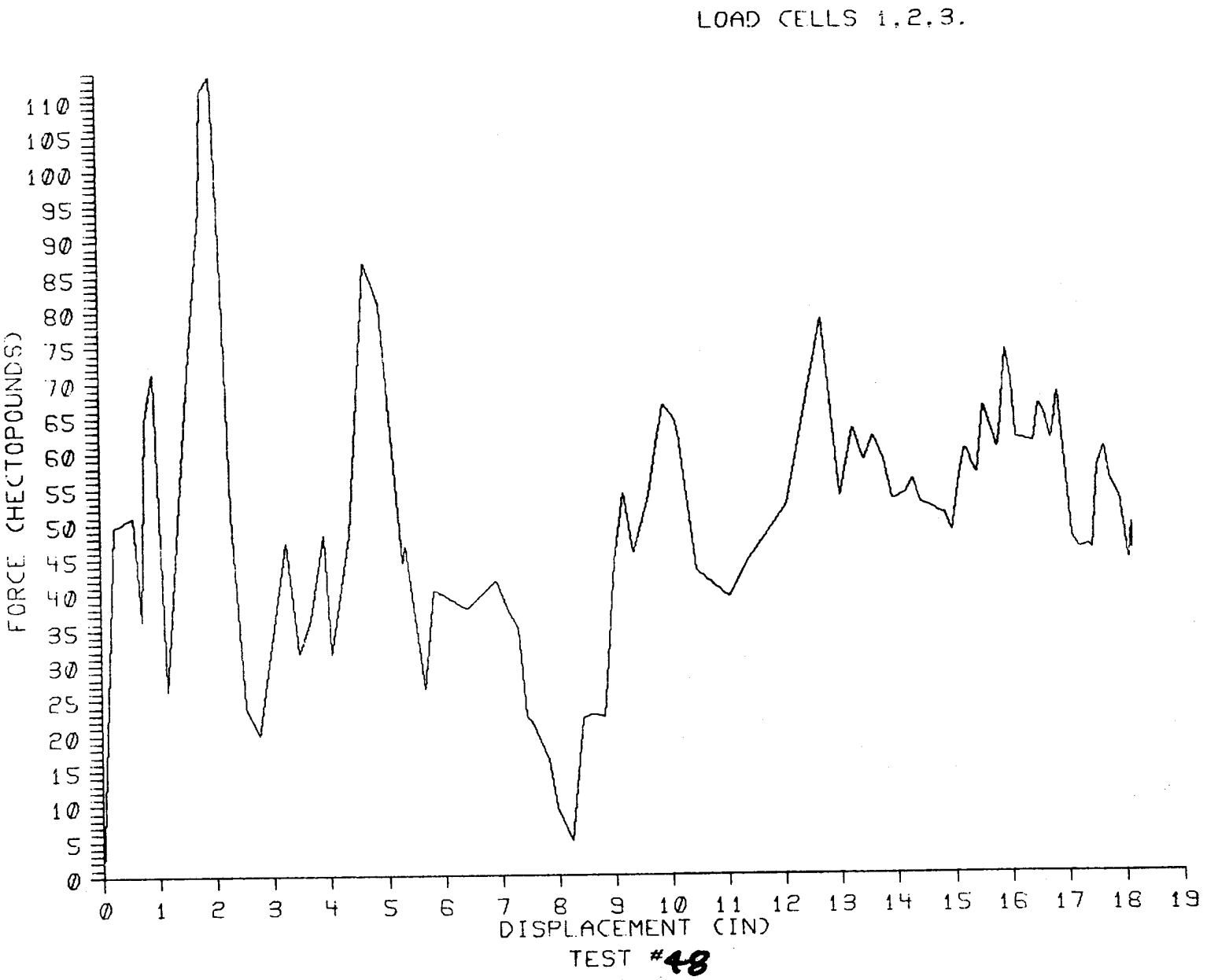

LOAD CELLS 2,3,4,
FORCE (HECTOPOUNDS)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
DISPLACEMENT (IN)
TEST #36

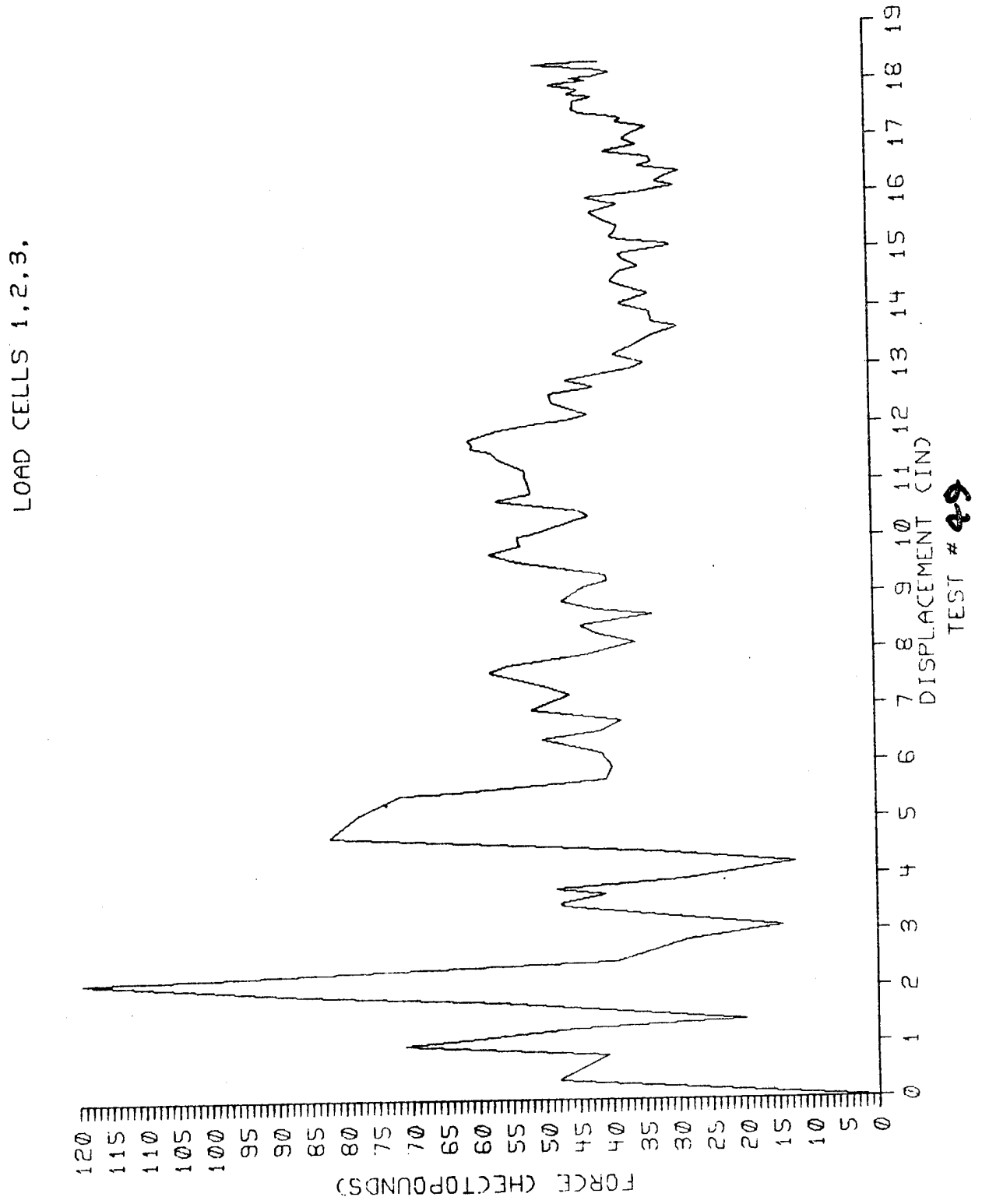

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
DISPLACEMENT (IN)
TEST #38

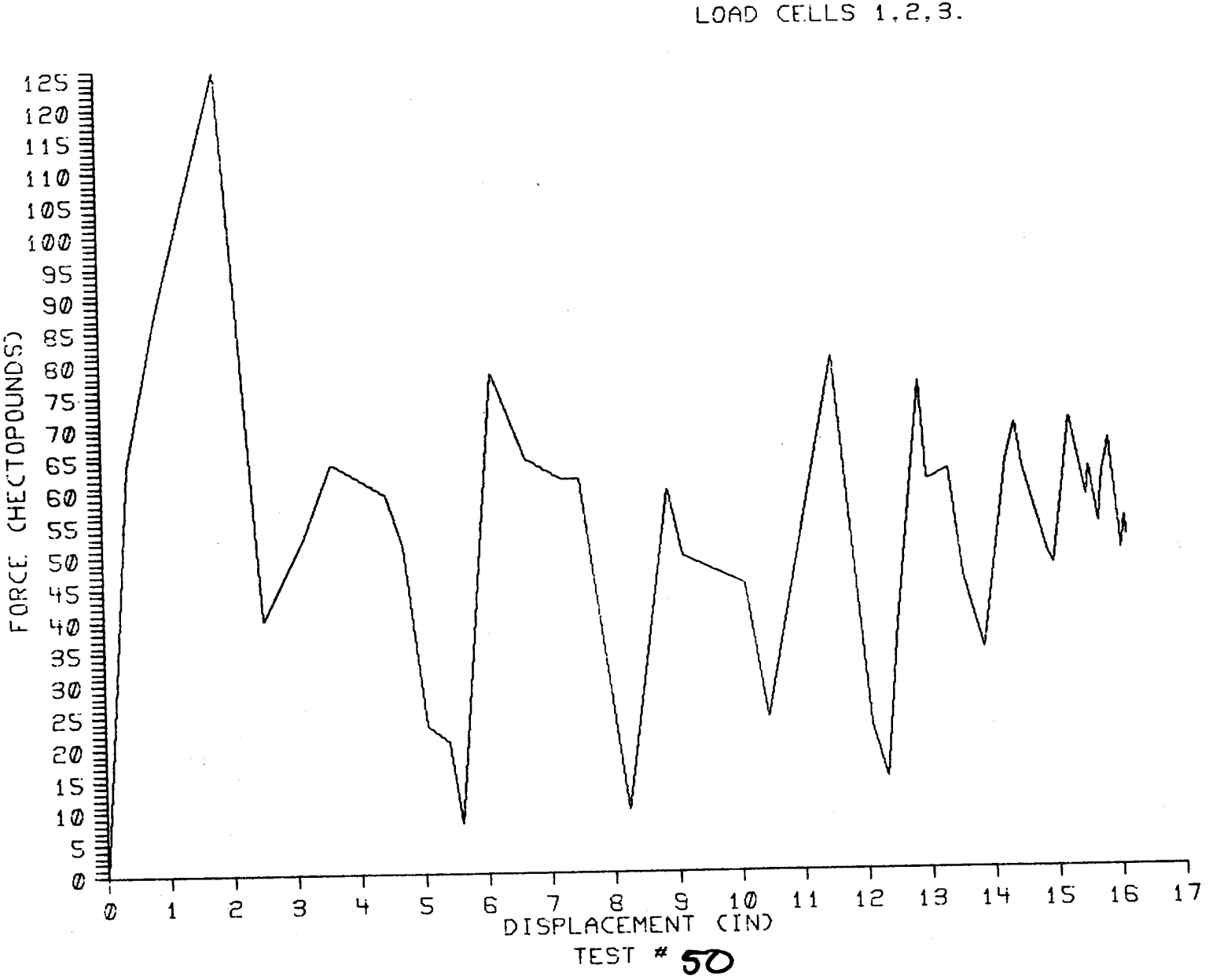

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST #42

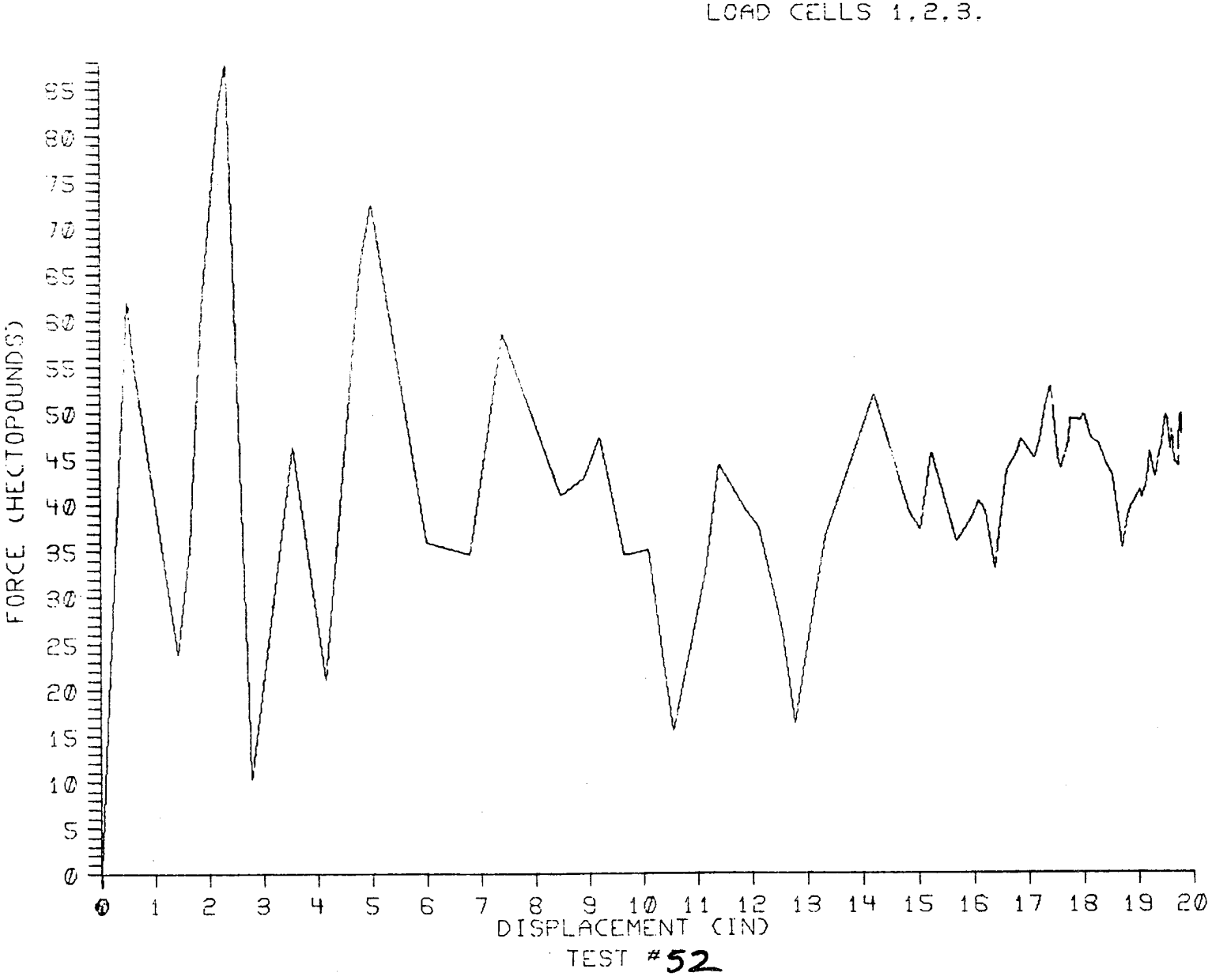

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DISPLACEMENT (IN)
TEST # 96

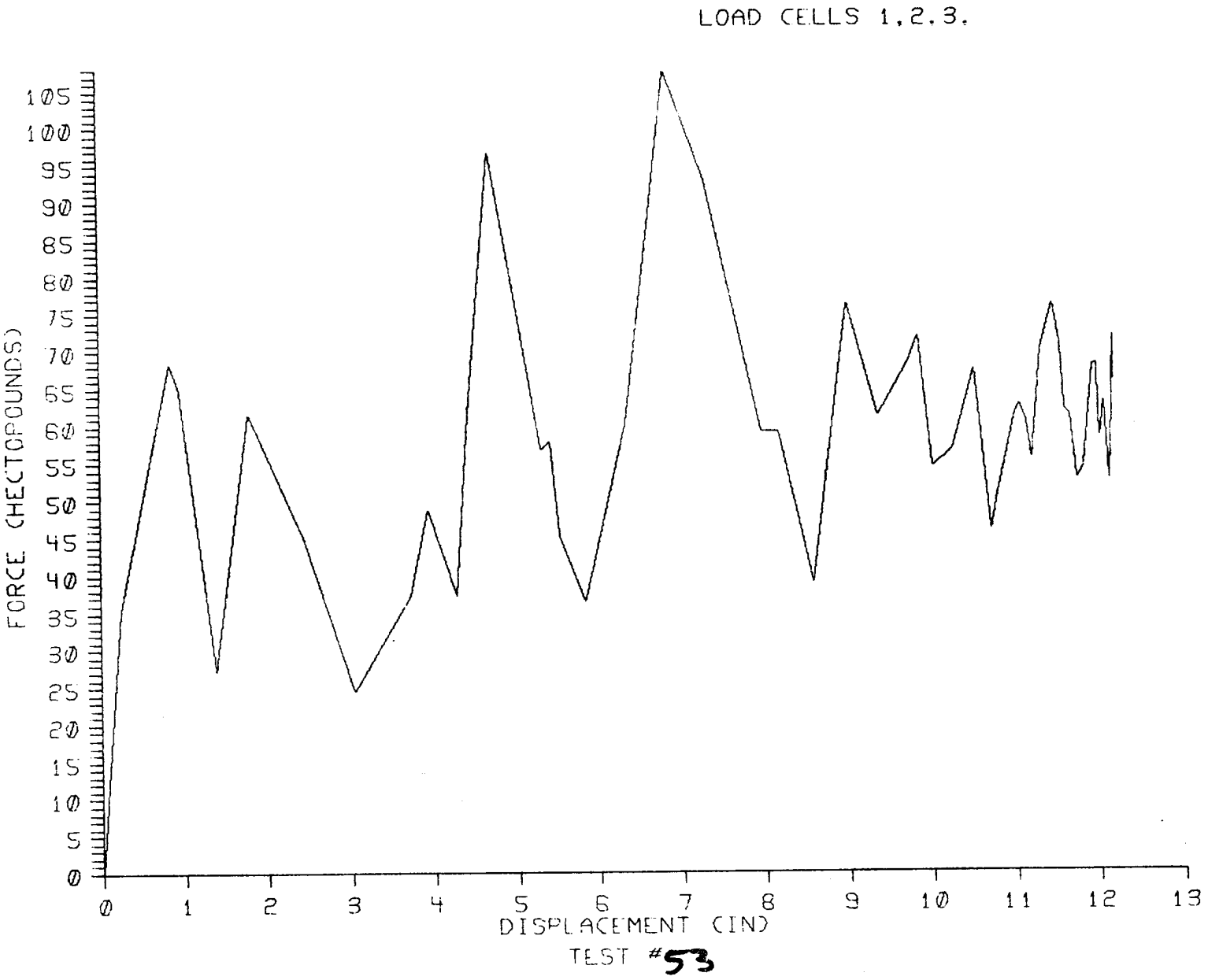

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST #87

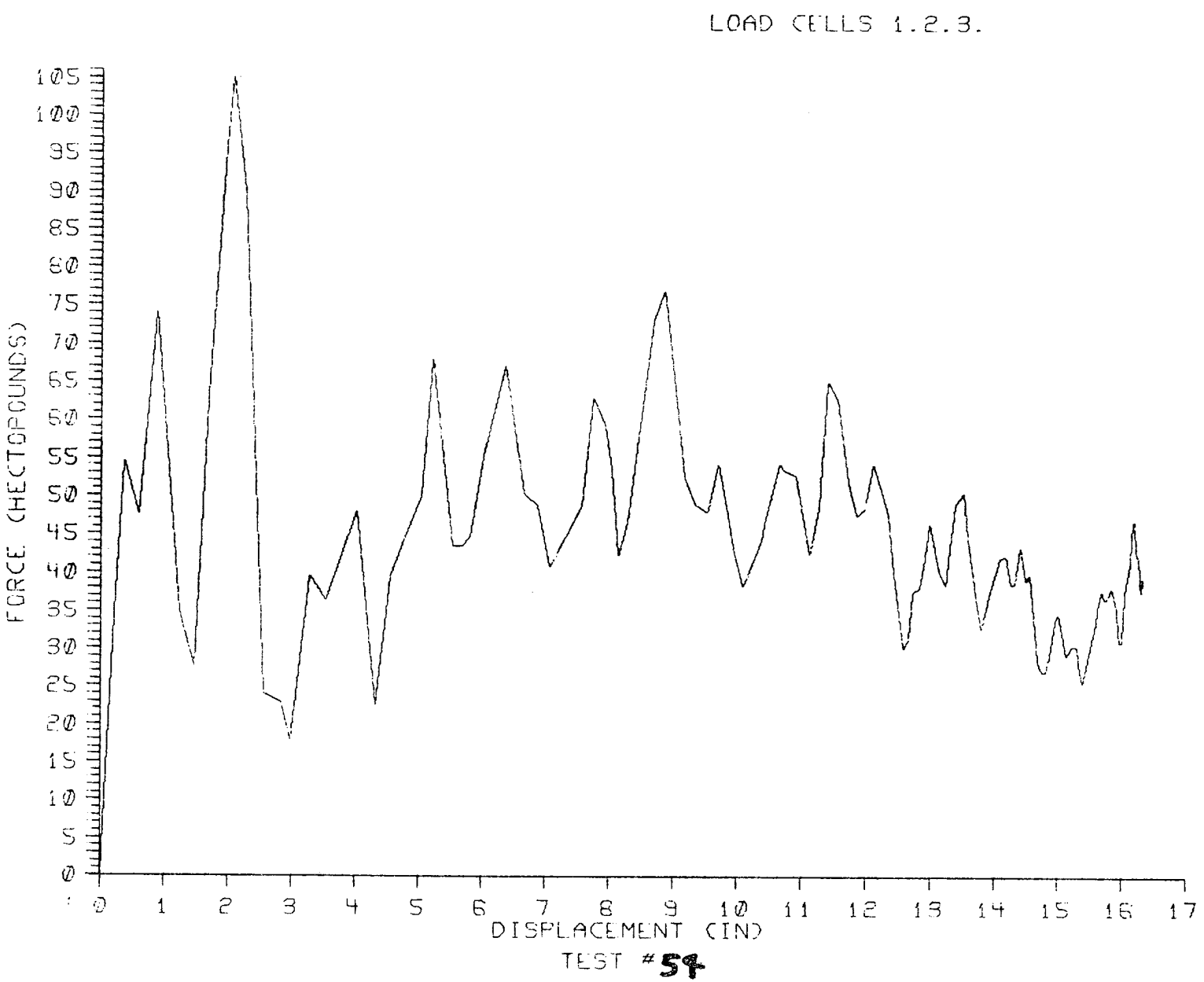

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
DISPLACEMENT (IN)
TEST #48

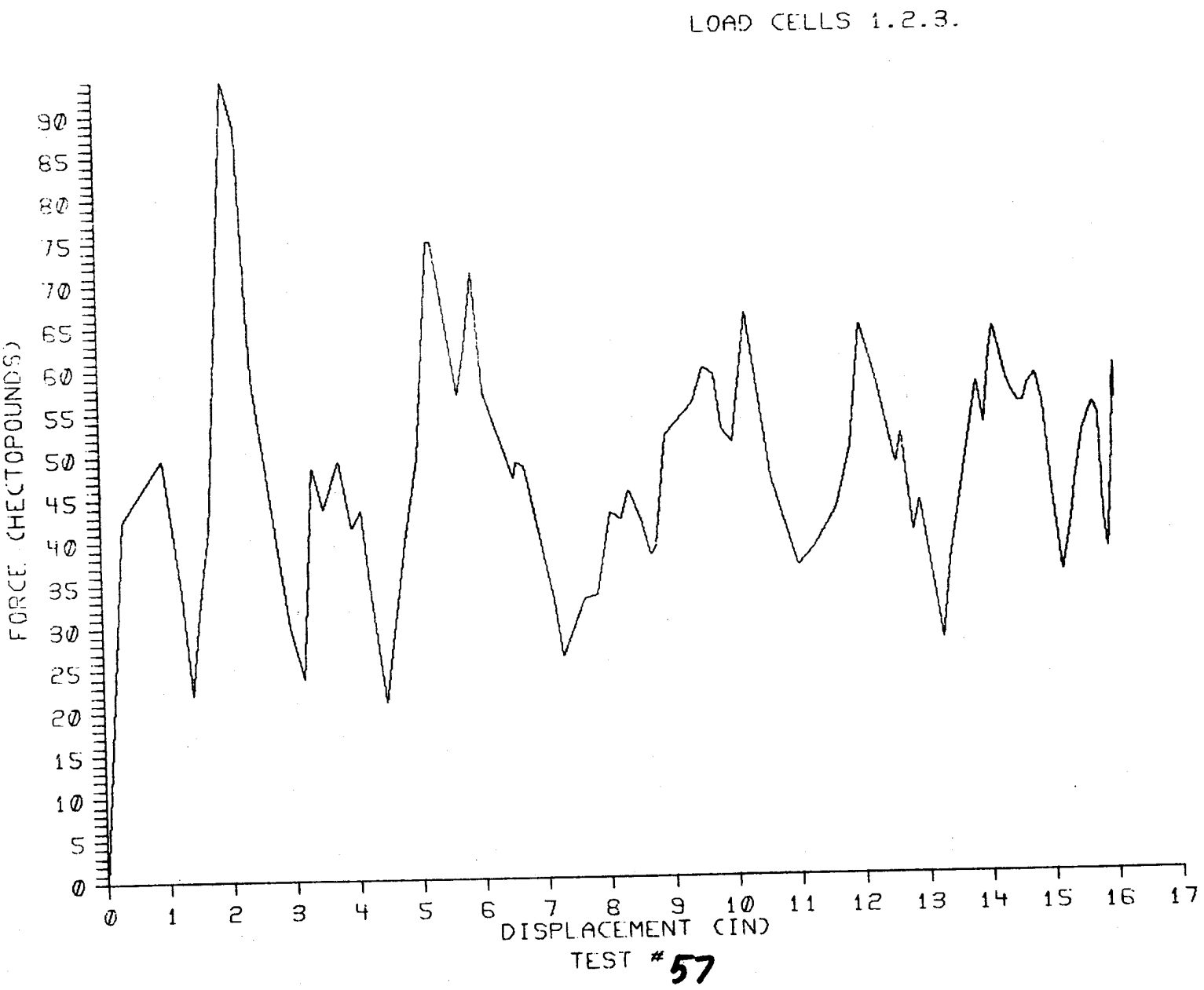

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
DISPLACEMENT (IN)
TEST # 49

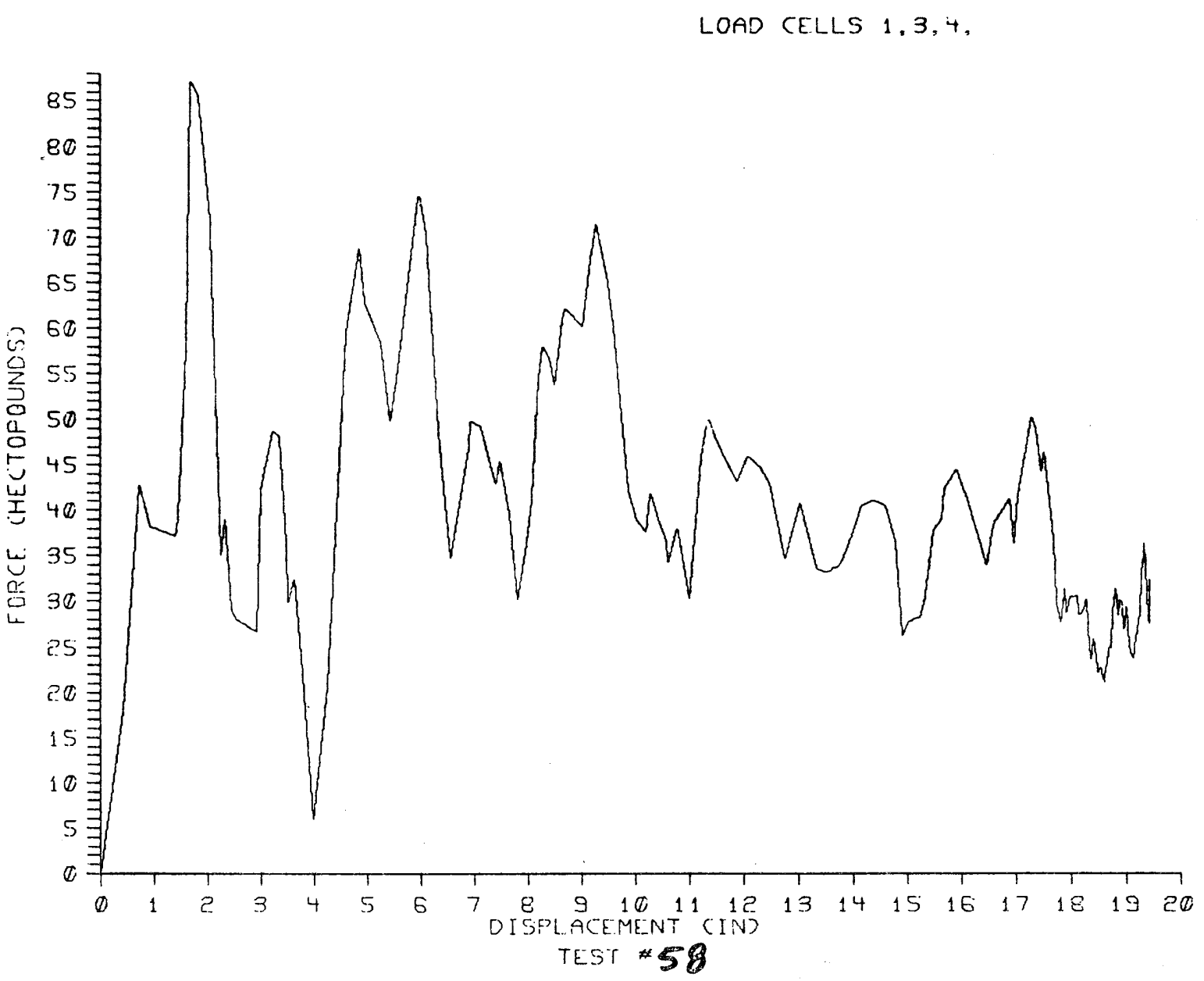

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST # 50

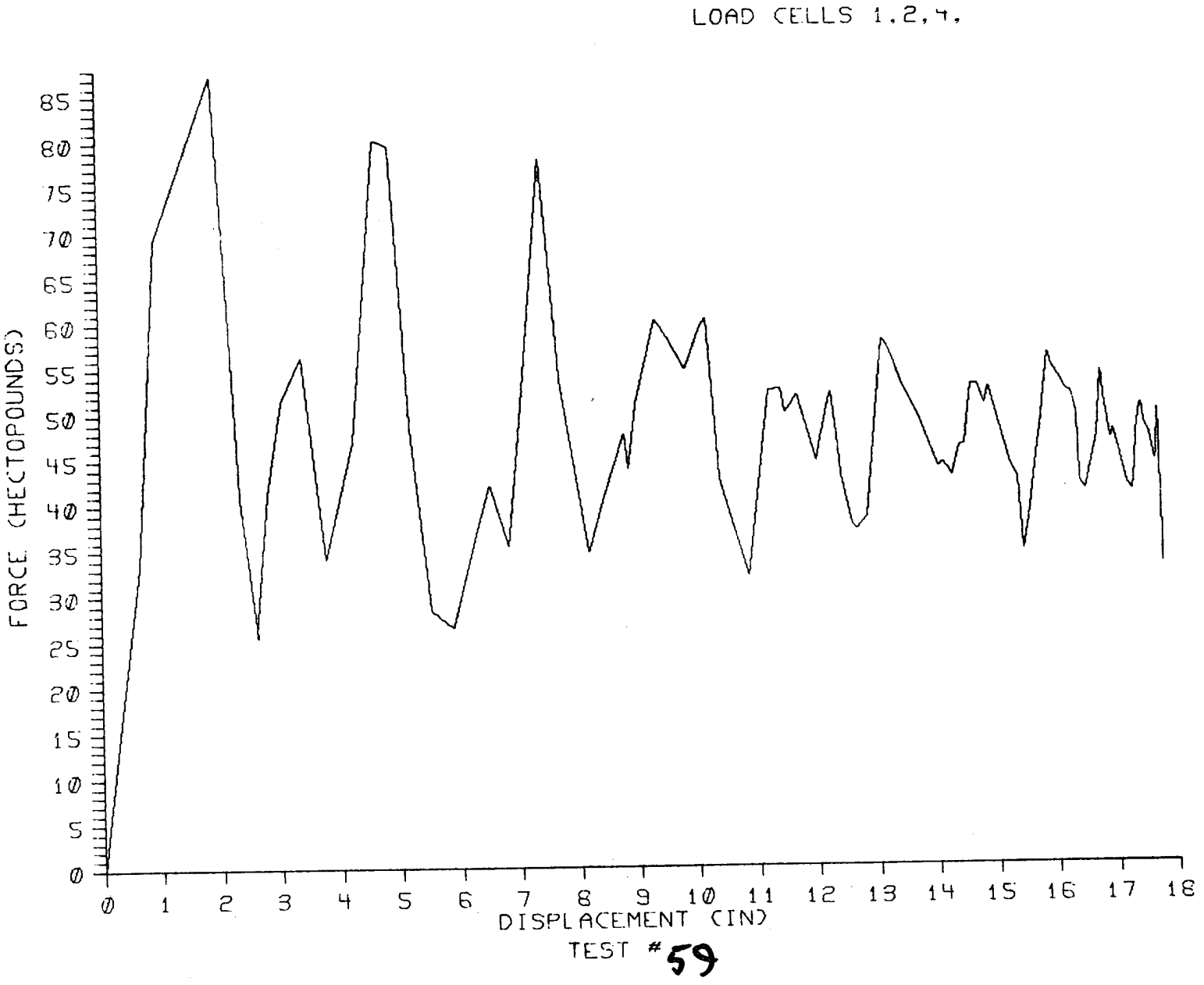

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
DISPLACEMENT (IN)
TEST #52

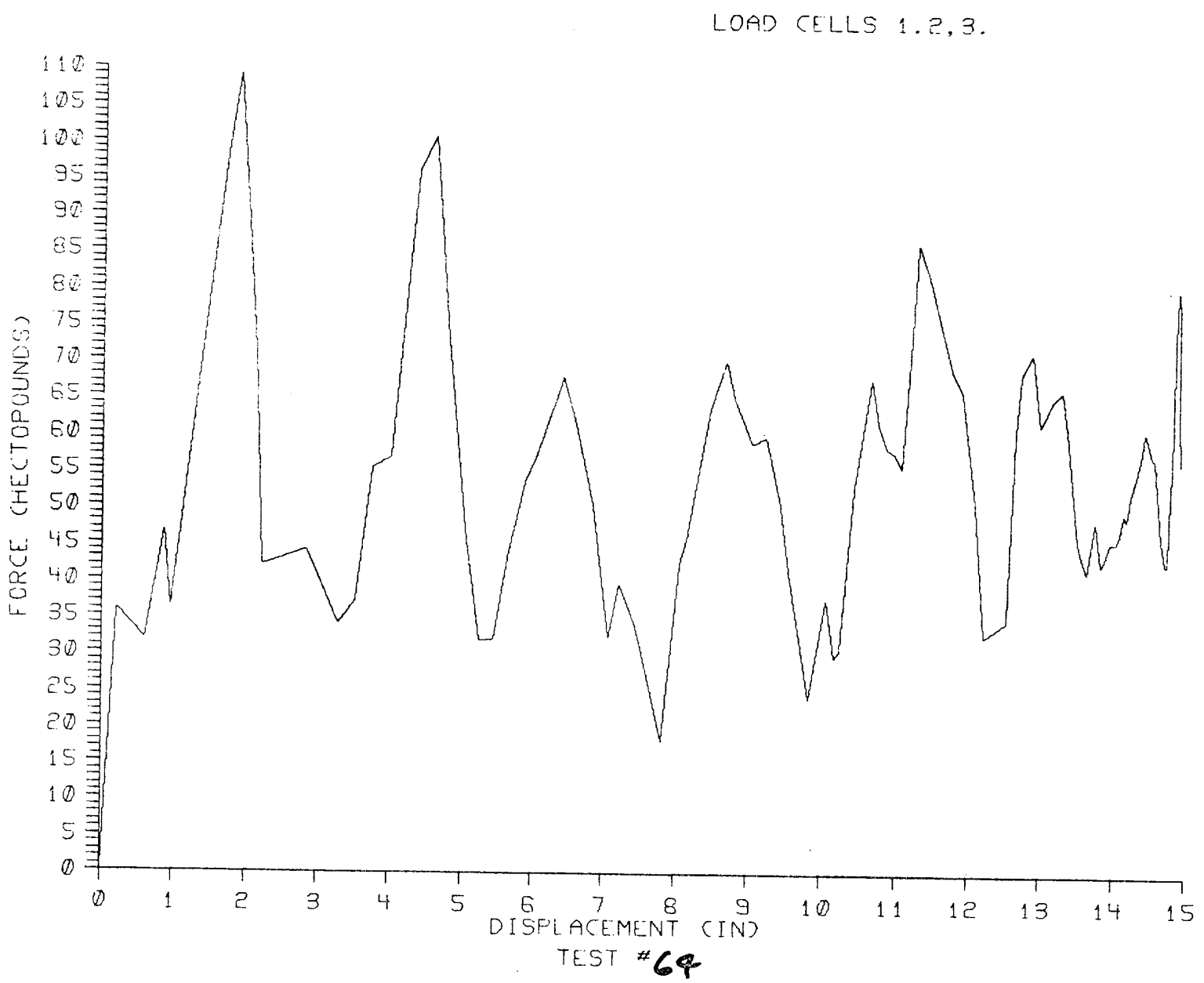

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DISPLACEMENT (IN)
TEST #53

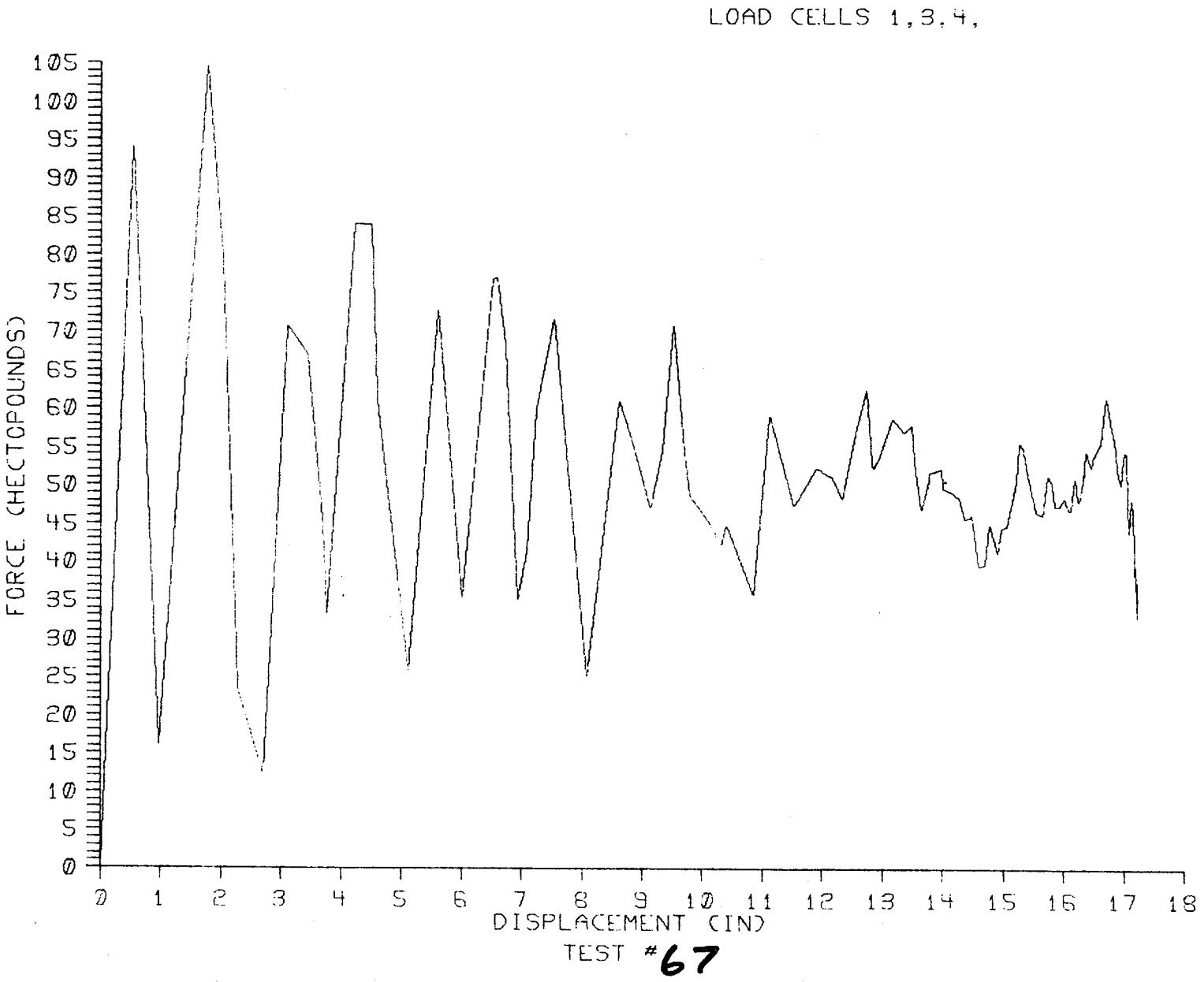

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST #54

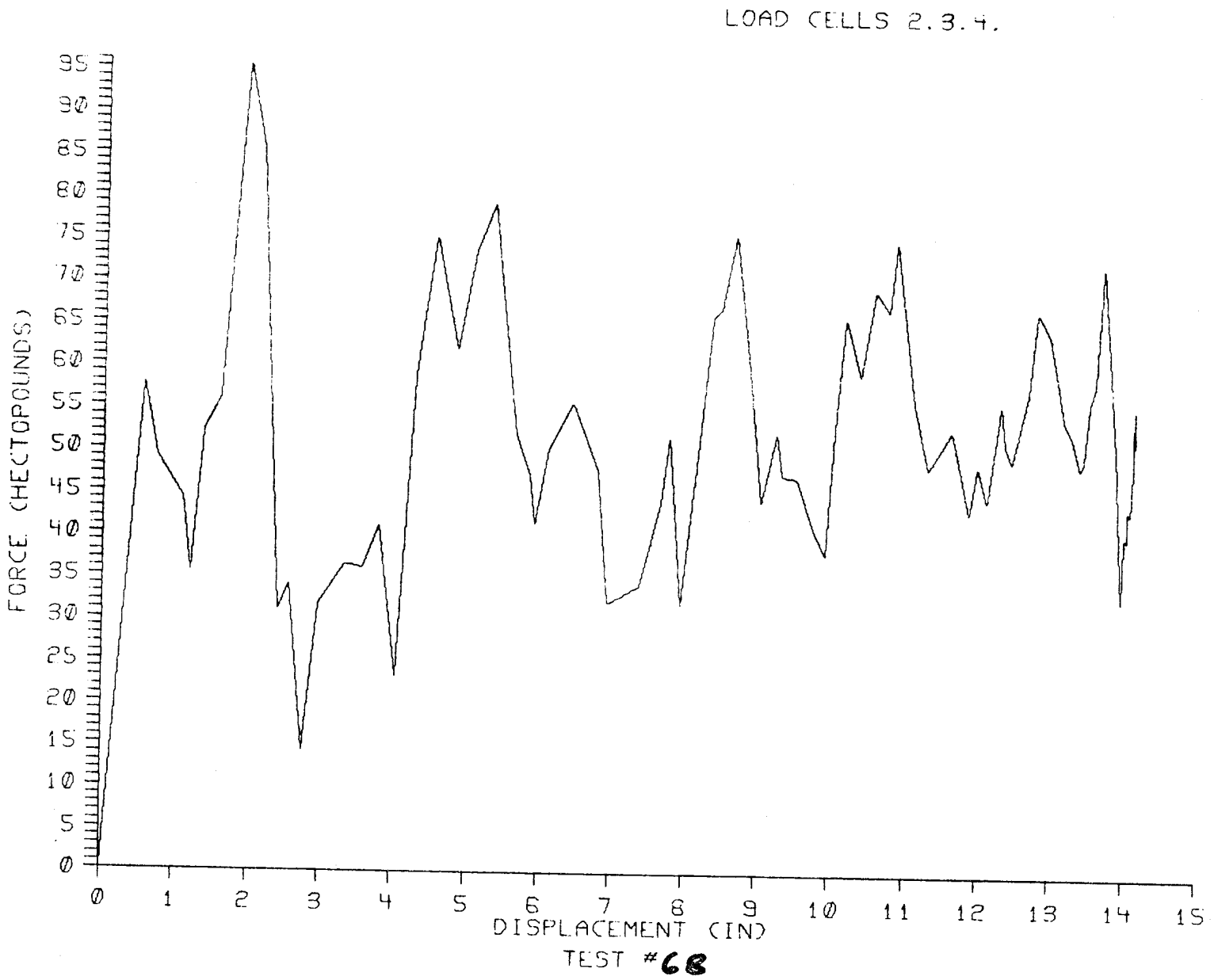

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST # 57

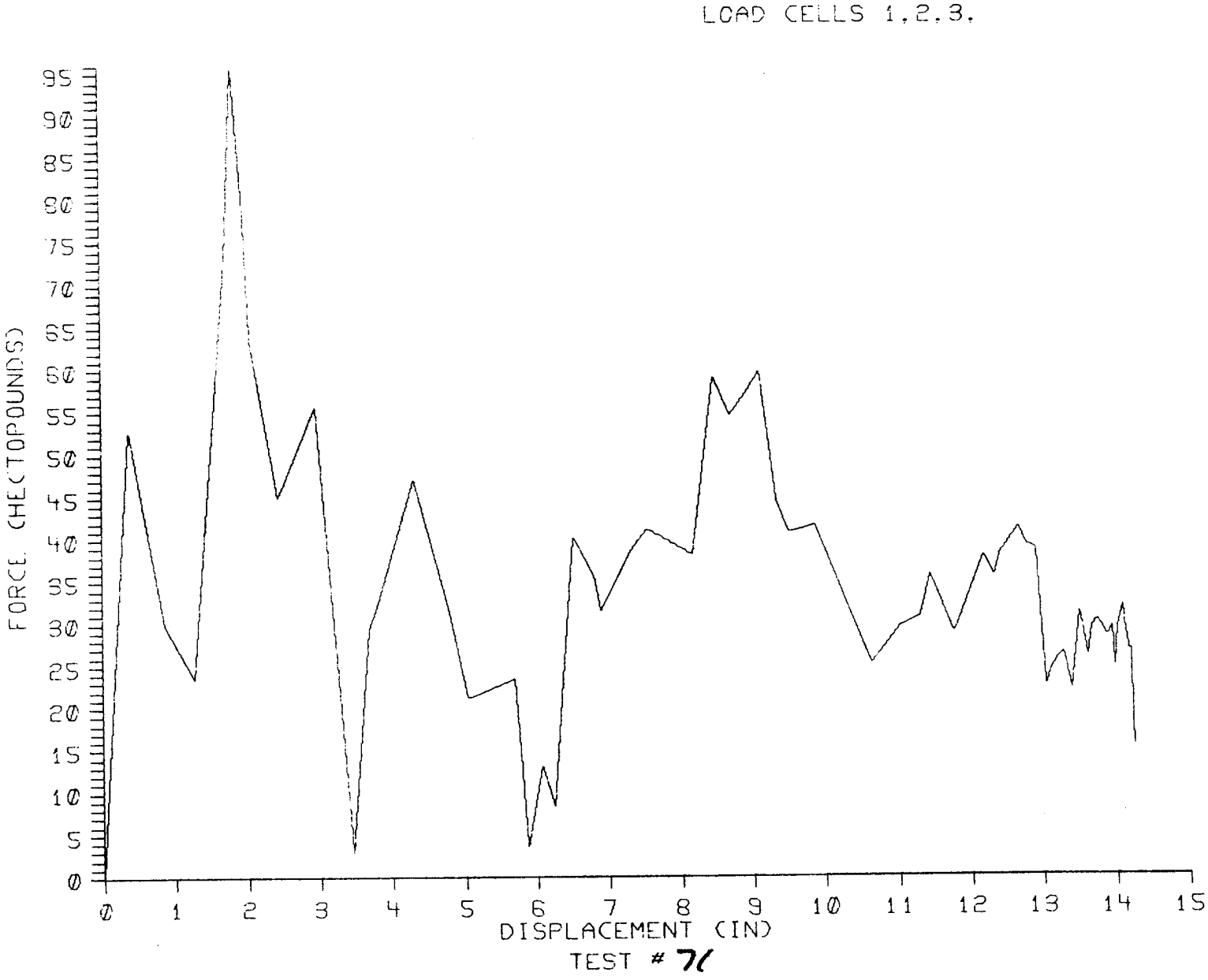

LOAD CELLS 1,3,4,
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
DISPLACEMENT (IN)
TEST #58

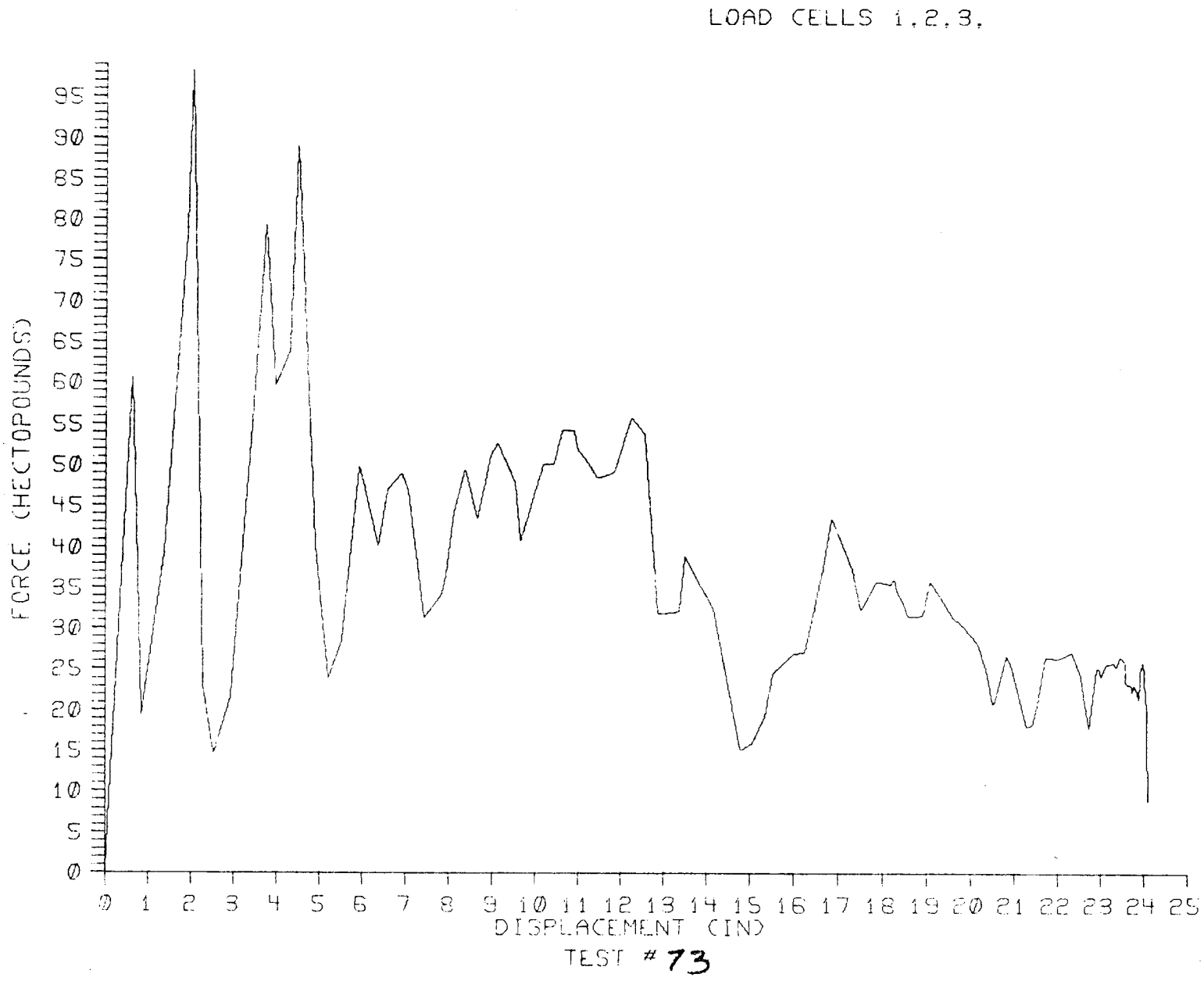

LOAD CELLS 1,2,4.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
DISPLACEMENT (IN)
TEST #59

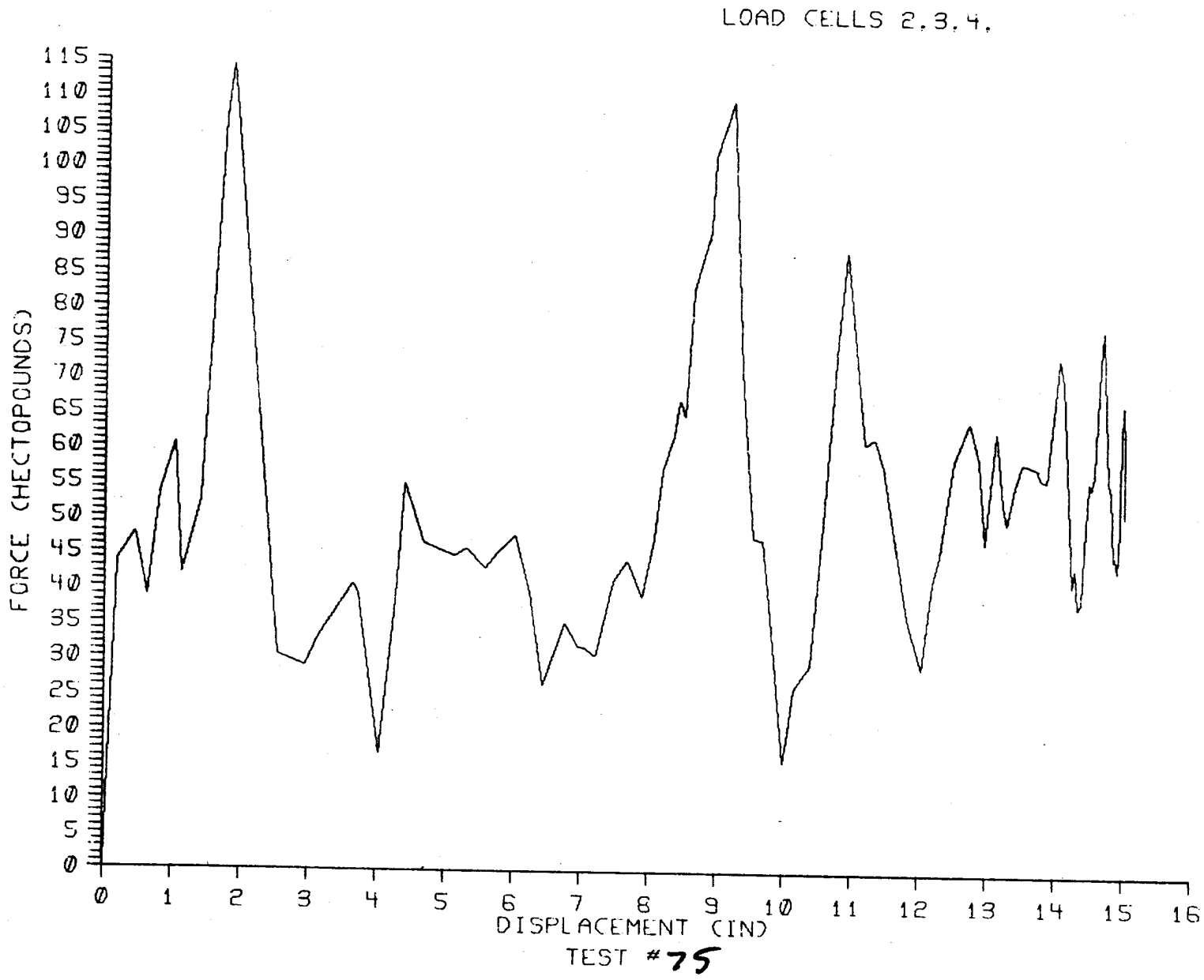

LOAD CELLS 1.2,3.
FORCE (HECTOPOUNDS)
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST #69

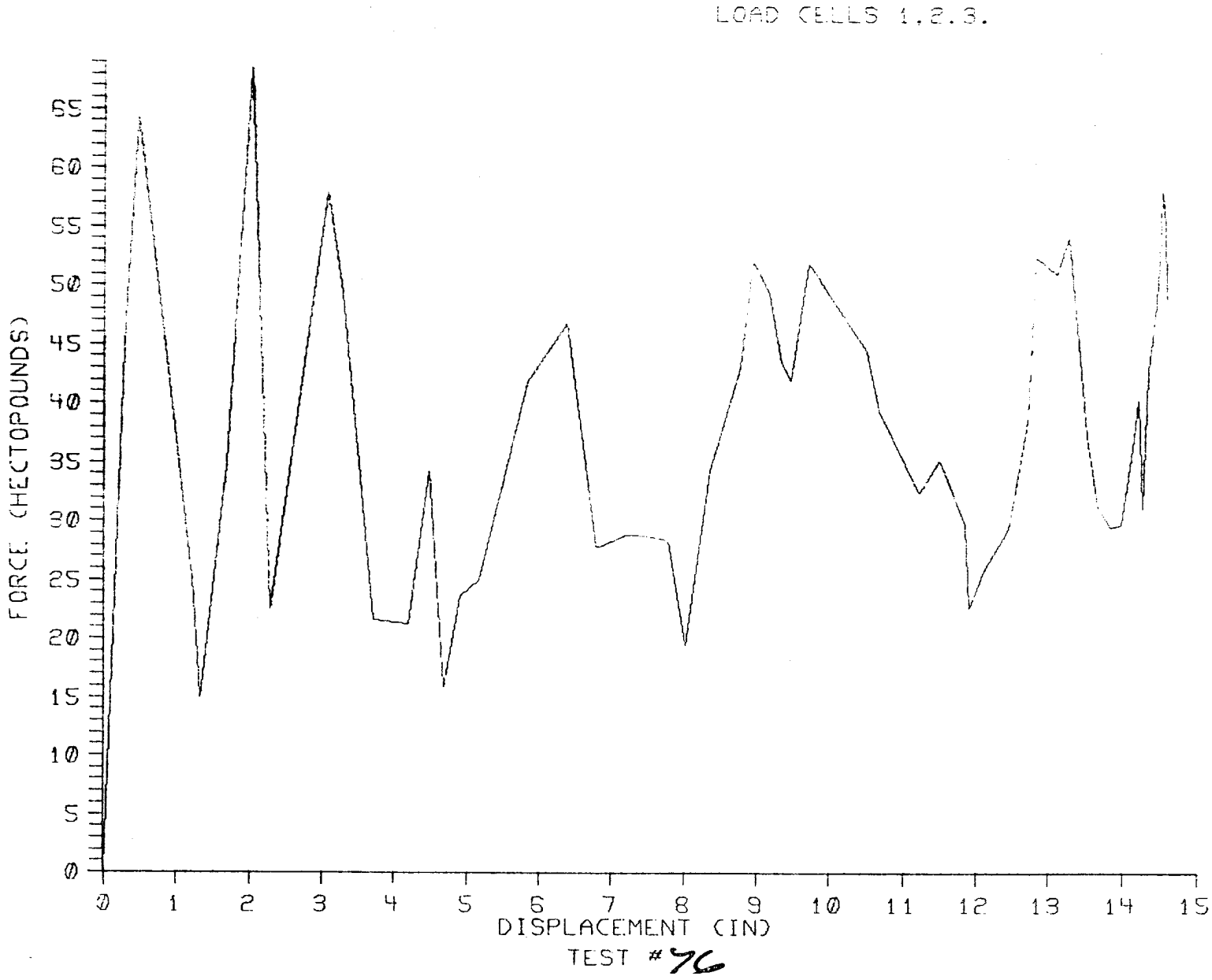

LOAD CELLS 1,3,4,
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
DISPLACEMENT (IN)
TEST #67

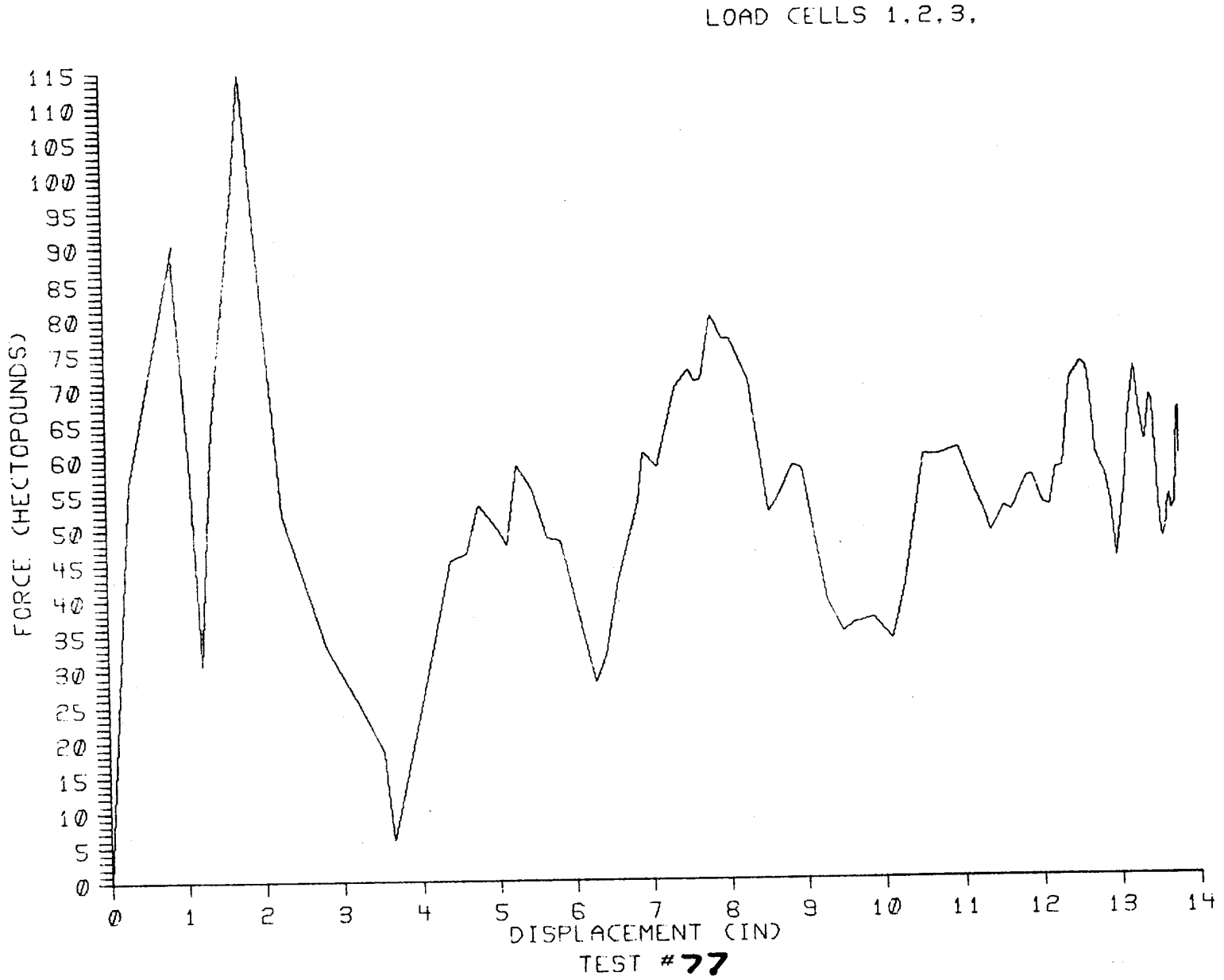

LOAD CELLS 2.3.4.
FORCE (HECTOPOUNDS)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST #68

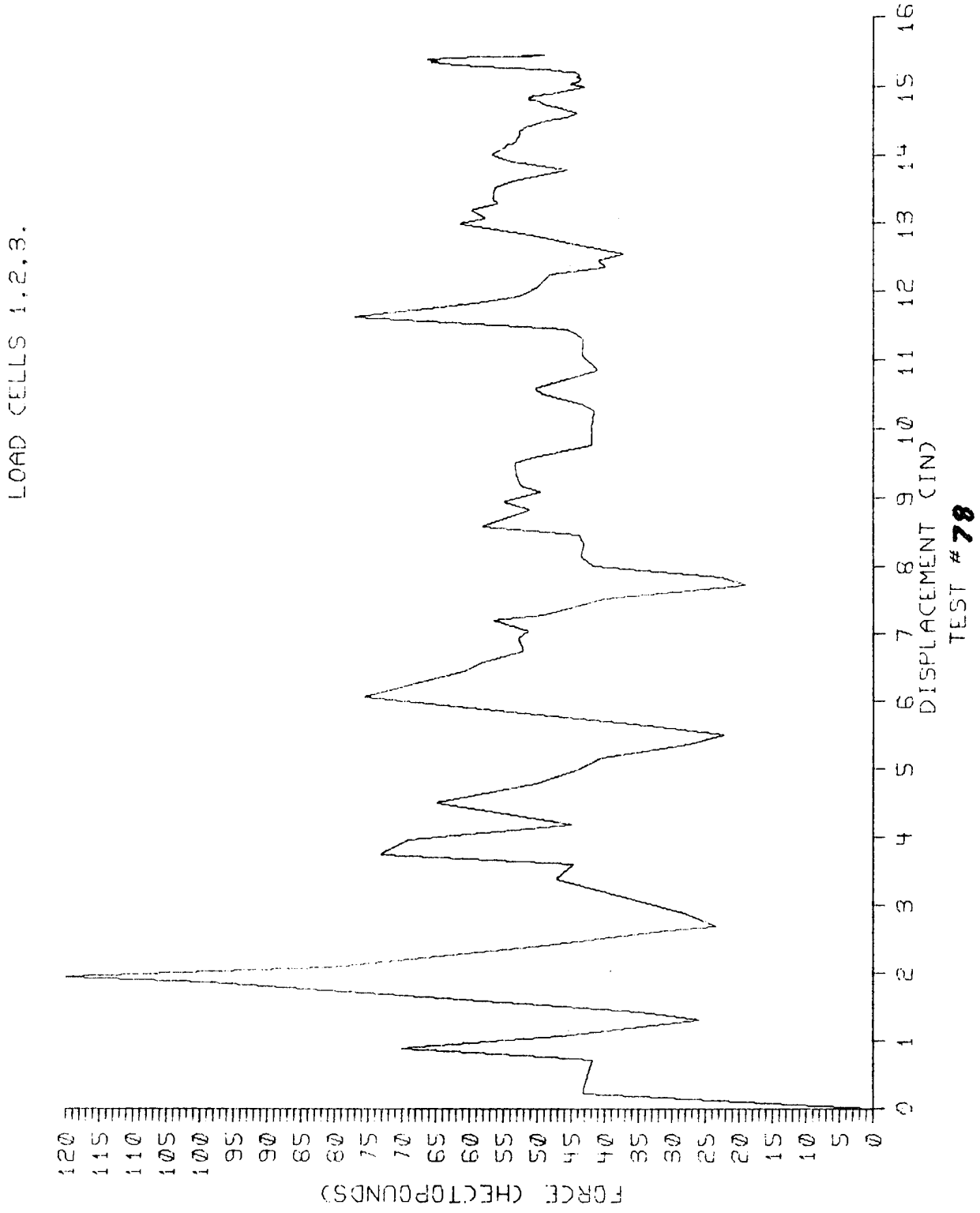

LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST # 7(

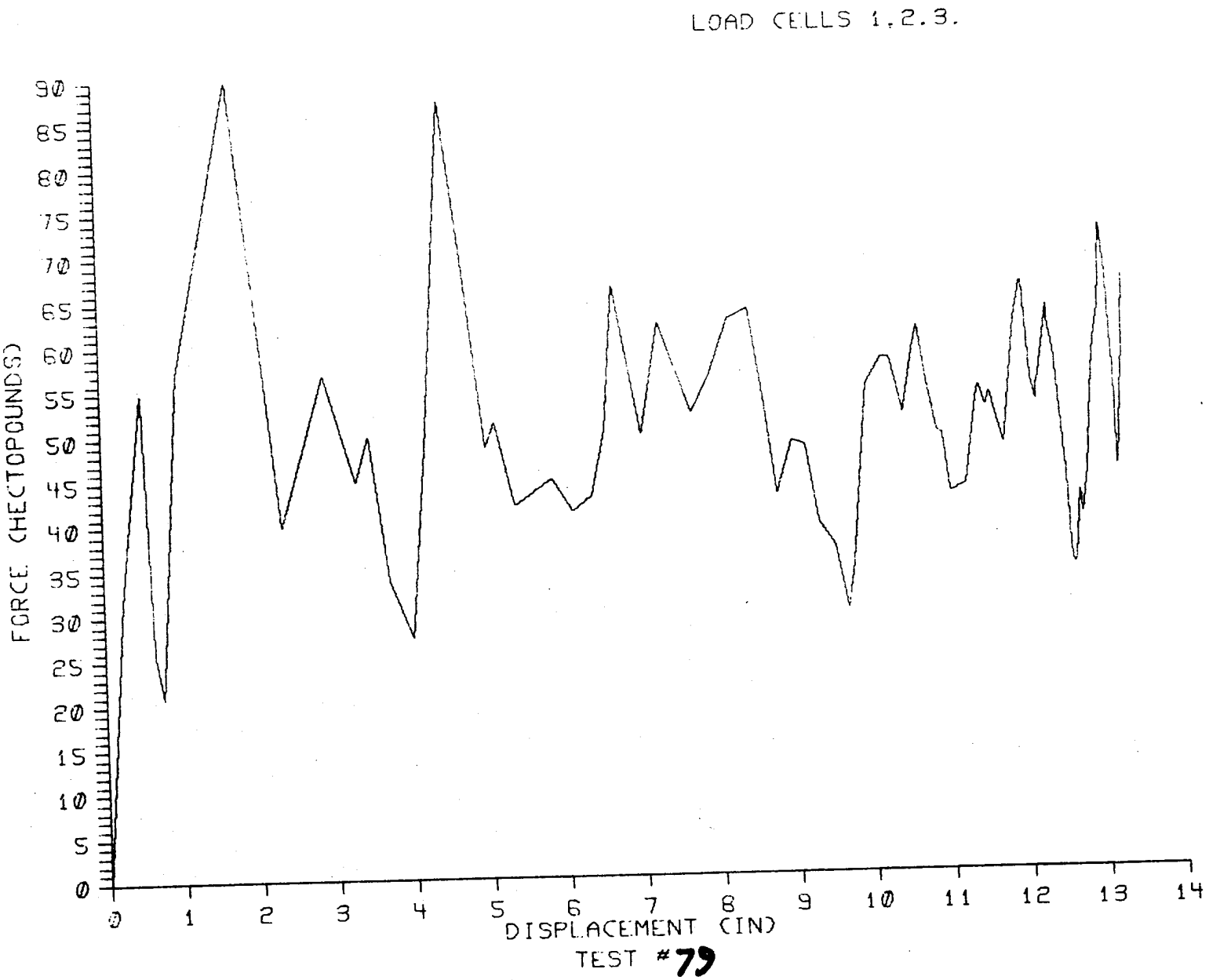

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
DISPLACEMENT (IN)
TEST #73

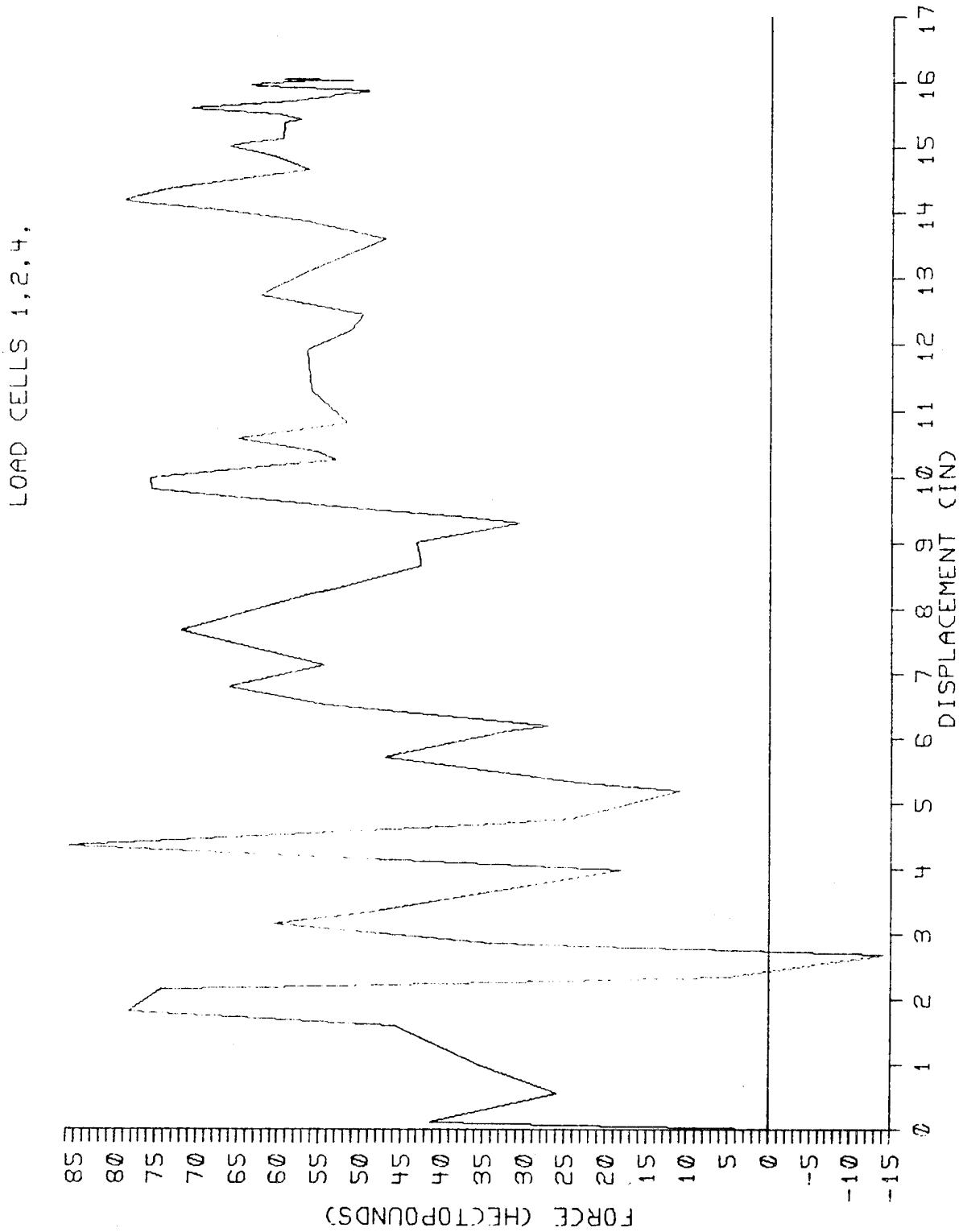

LOAD CELLS 2.3.4.
FORCE (HECTOPOUNDS)
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DISPLACEMENT (IN)
TEST #75

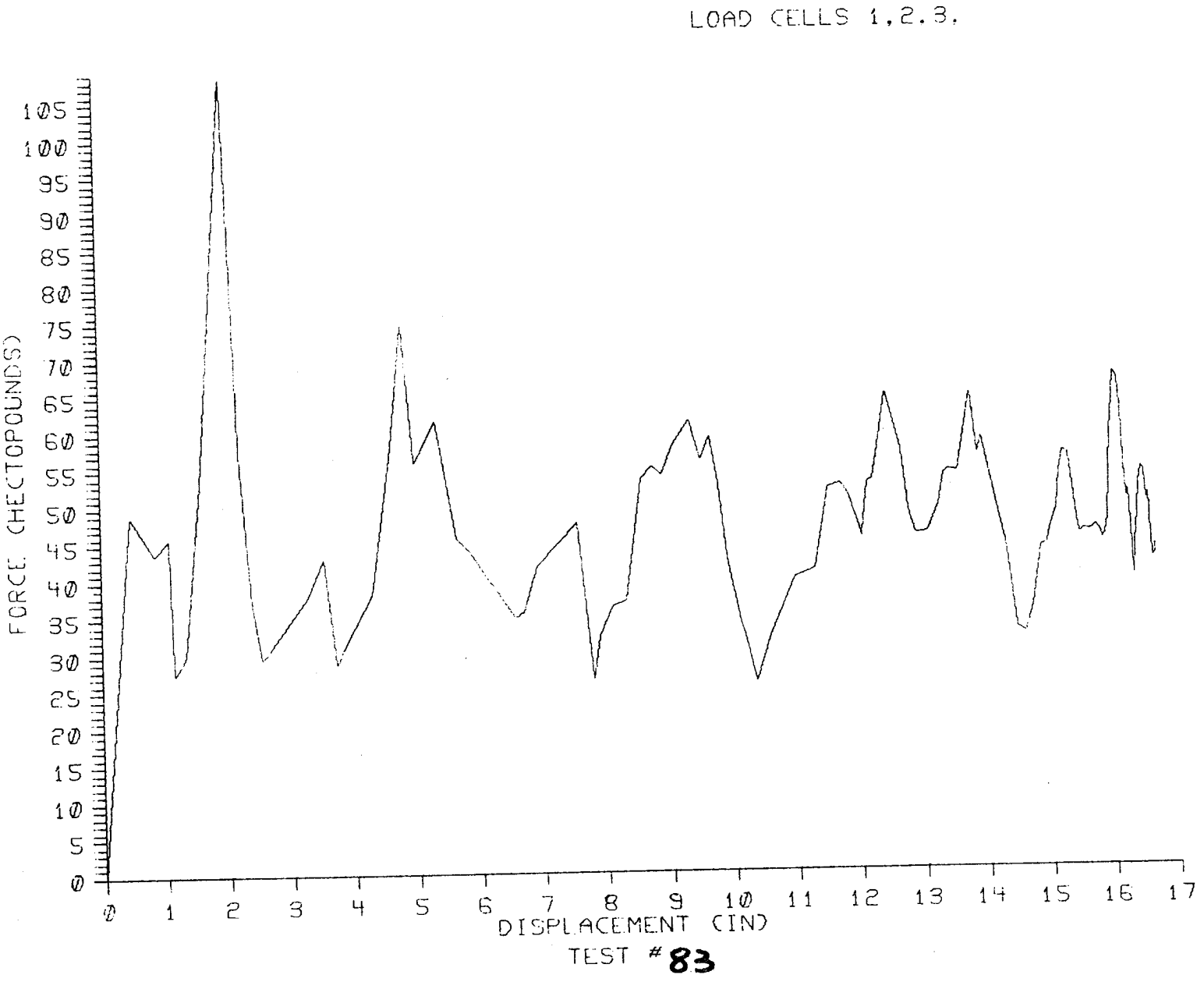

LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
DISPLACEMENT (IN)
TEST #76

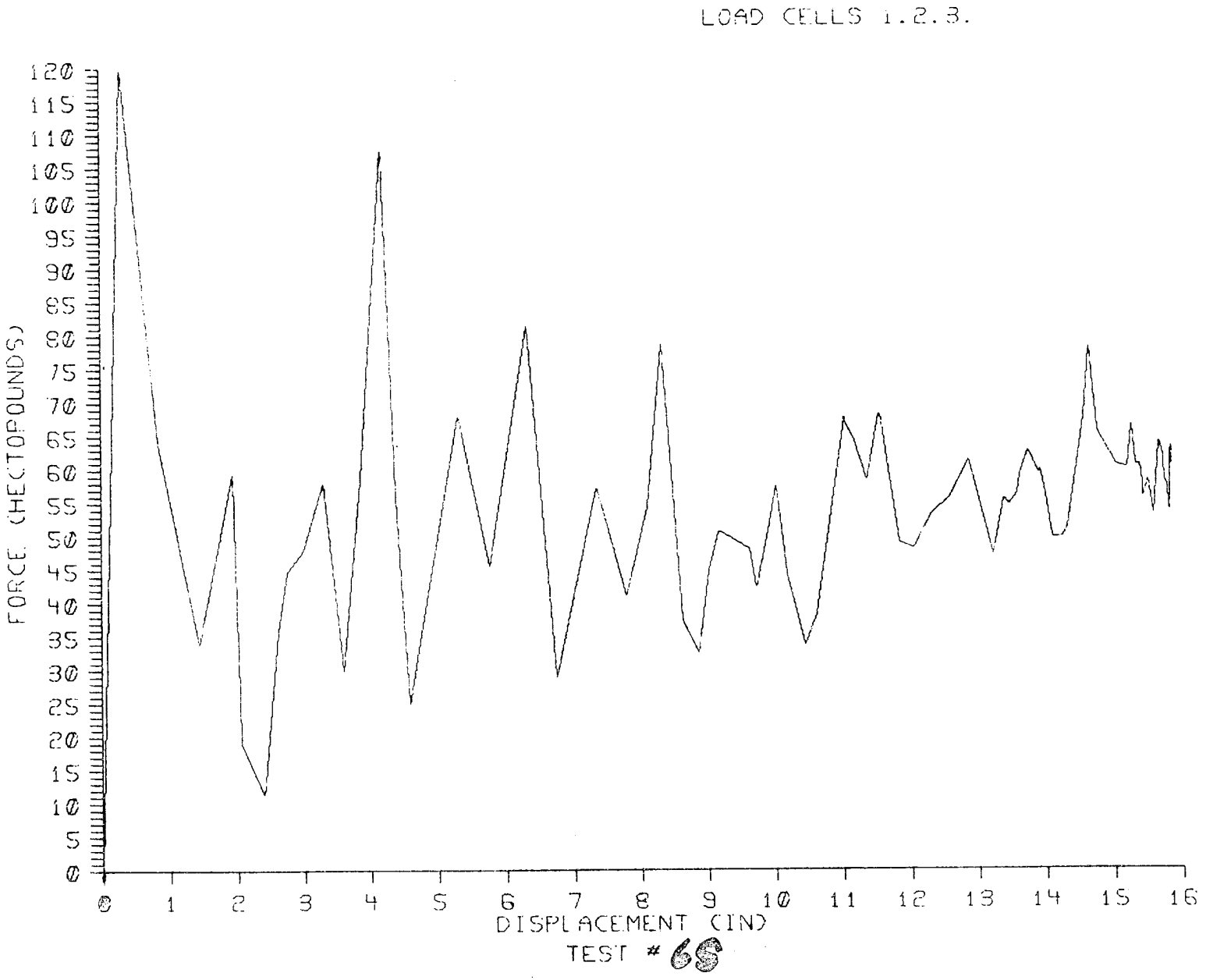

LOAD CELLS 1,2,3,
FORCE (HECTOPOUNDS)
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
DISPLACEMENT (IN)
TEST #77


LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
DISPLACEMENT (IN)
TEST #78


LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DISPLACEMENT (IN)
TEST #79


LOAD CELLS 1,2,4.
FORCE (HECTOPOUNDS)
85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 -10 -15
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST # 81


LOAD CELLS 1,2,3.
FORCE (HECTOPOUNDS)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISPLACEMENT (IN)
TEST #83


LOAD CELLS 1.2.3.
FORCE (HECTOPOUNDS)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DISPLACEMENT (IN)
TEST # 65

APPENDIX C

TEST FOR DECOMPOSITION GASES OF FOAM

NB-237936A System

Test Report Submitted by U.S. Testing Company, Inc. on October 1, 1976

1.0 PURPOSE

The general purpose of the test was to develop data to evaluate synthetic materials when they are subjected to high temperature heating. The test results are to evaluate the potential hazard from toxic gases produced should the material be burned or thermally decomposed in an enclosed area. The data developed include the determination of:

1. Ignition Time
2. Burning Time
3. Composition of the Atmosphere Produced
4. Weight Loss of Material
5. Flash - Ignition Temperature
6. Self-Ignition Temperature

2.0 PROCEDURE

The equipment used to burn or thermally decompose the sample material is similar to the equipment formally employed at the Materials Laboratory of the New York Naval Shipyard and by the Bureau of Mines Central Experiment Station at Pittsburgh for determining the flame resistance of thermosetting plastics. Also as reported in U.S. Testing Company Report #83413, for the Bureau of Ships, U.S. Navy and referenced in Military Specification MIL-M-14g.

The equipment consists of a specimen support, heating coil and spark generators mounted in an essentially gas tight chamber, equipped with facilities for sampling the test atmospheres produced. In brief, the tests are conducted by placing a stick or sticks of the materials to be tested (sample size - 5" x ½" X ½") in the center of a heating coil which is situated in the air tight chamber.

The heating coil is activated and the number of seconds it takes, from the time the coil is activated until the sample begins to burn, is recorded as the ignition time. After the stick has burned for 30 seconds, the heating coil is deactivated, the number of seconds it takes for the sample to stop burning (from the time of deactivation) is recorded as the burning time. When the sample has stopped burning, the atmosphere produced is mixed by an internal circulating fan. A manifold circulating pump is then activated and the atmosphere within the chamber is withdrawn into gas analyzing apparatus. A sample of the atmosphere was also withdrawn for subsequent analysis employing a mass spectrometer.

3.0 DISCUSSION OF RESULTS

Test results indicate that carbon monoxide gas is likely to be the primary toxic hazard from the thermal decomposition of NB-237936A Foam.

Other toxic gases, if present, were in less concentration than the detectable range of the Drager tubes.

It may be assumed that if other toxic gas were involved in sufficient concentration to be detected in the lethal range, the lethal concentration of carbon monoxide would in all probability have been reached prior to their detection.

TABLE C-1

Flash Ignition and Self-Ignition

4.0 RESULTS:

	1	2	3	4	Average
Original Weight, gms.	0.55	0.55	0.56	0.55	0.55
Residual Weight, gms.	0.21	0.20	0.20	0.21	0.205
Loss in Weight	0.34	0.35	0.36	0.34	0.35
Temperature of Coil °C	Equilibrium Temperature 550°C				
Ignition Time, secs.	31.6	31.3	32.7	31.8	31.9
Burning Time, secs.	All samples self extinguish prior to deactivation				
Flash Ingition °c		225°		225°	225°
Self Ignition °C				575°C	
Temperature of Chamber °C	28°	28°	28°	28°	28°
Beilstein Test	Negative				
Smoke	Light amount black smoke				
Flame	4" - 5"				
Ash	Faint trace black.				

TABLE C-2

Detected Gases from Foam Decomposition

Composition of Atmosphere (in parts per million)					
No. of Samples	1	2	3	4	Average
Chlorine	0	0	0	0	0
Hydrogen Chloride	0	0	0	0	0
Phosgene	0	0	0	0	0
Aldehydes as HCHO	0	0	0	0	0
Ammonia	0	0	0	0	0
Carbon Monoxide	5	5	5	5	5
Carbon Dioxide	50	50	25	25	38
Oxides of Nitrogen as NO_2	0	0	0	0	0
Cyanides as HCN	0	0	0	0	0
Oxygen	208,000	208,000	208,000	208,000	208,000
Nitrogen	791,920	791,920	791,945	791,945	791,933
Combustibles as Natural Gas	25*	25*	25*	25*	25*

* Detection limit, sample values lower.

TABLE C-3

Mass Spectrometer Results

Nitrogen	78 + %
Oxygen	20.8 %
Argon	0.94%
Carbon Dioxide	0.054%

The sample was scanned from mass 2 thru mass 150, with no other constituents detected. The detection limits for constituents between mass 2 and mass 150 are all approximately 10 parts per million.

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