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16. ABSTRACT
This report describes three investigations of materials and components used or intended for use in highway energy absorbing barriers.

Part I: Preliminary Development of a Vermiculite Concrete Crash Cushion .
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Vermiculite concrete, steam curing, lightweight aggregate, crash cushions, helicells, compression tests, polyethylene, tensile strength, exposure

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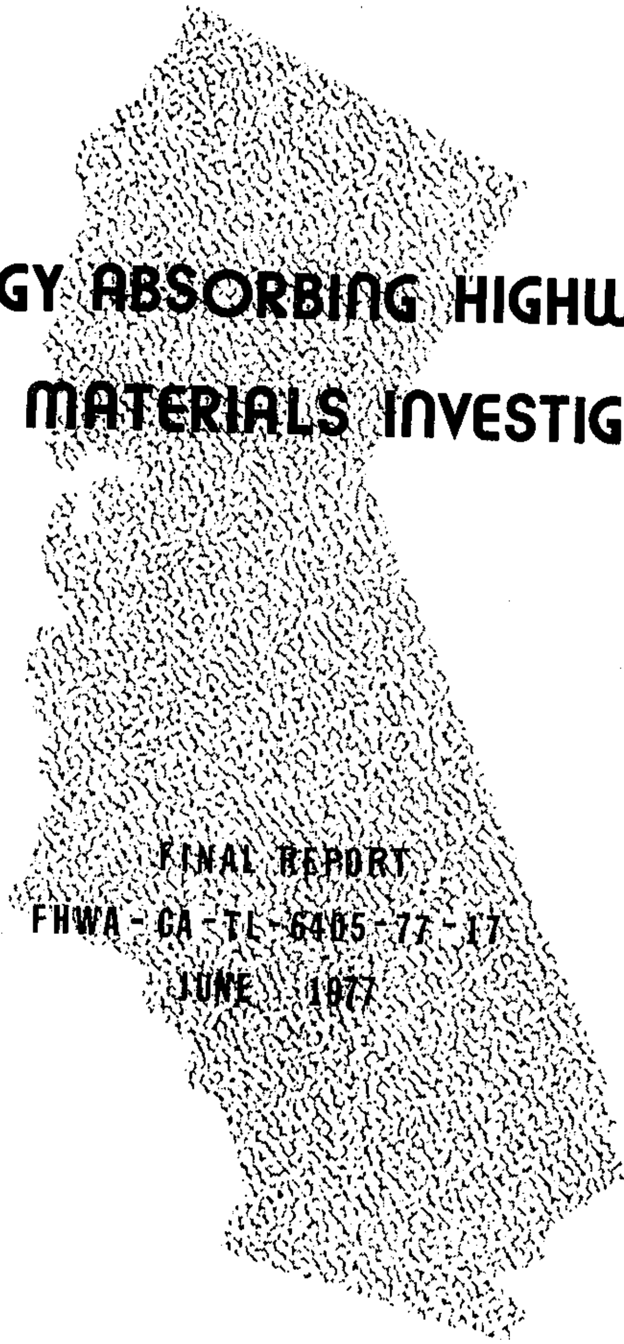
TRANSPORTATION LABORATORY
RESEARCH REPORT

ENERGY ABSORBING HIGHWAY BARRIER MATERIALS INVESTIGATION



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PART II: Evaluation of Vermiculite Concrete Helicells
Vermiculite concrete cells used as the energy absorbing elements of crash cushions were exposed to various temperature and humidity conditions,

(continued)

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Vermiculite concrete, steam curing, lightweight aggregate, crash cushions, helicells, compression tests, polyethylene, tensile strength, exposure.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

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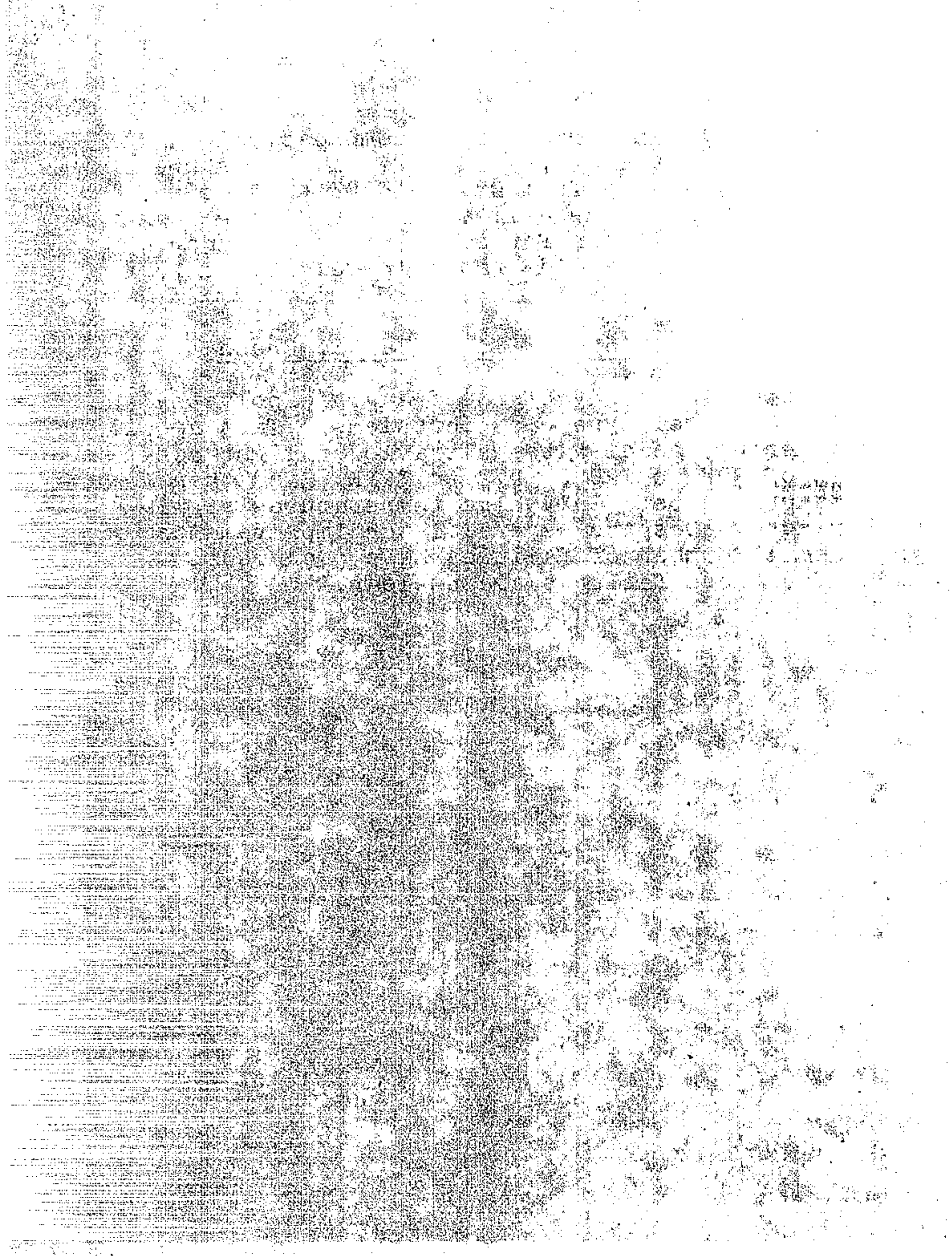
and then were subjected to static and drop weight compressive strength tests. It was concluded the cells had effective moisture proof coverings. Temperatures varying from 0° to 150°F (255 to 339K) did not affect the strength of the cells. Curves of deflection vs energy consumed were similar for both static and drop weight compression tests. There was a wide range in weights of individual cells.

PART III: Strength Investigations of Sand-Filled Plastic Crash Cushion Barrels

Failures in the field prompted the study of the frangible polyethylene material used in sand filled barrel type crash cushions. Test specimens were exposed to weathering, accelerated ultraviolet light conditions, and temperatures of 30° to 120°F (272 to 322K), and then subjected to tensile strength tests. Only high temperatures significantly lowered the strength. Despite several later improvements in the barrel design, a small number of failures have occurred in the field. The reasons for these failures are unclear.



STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

June 1977

FHWA No. D-4-69
TL No. 636405

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

ENERGY ABSORBING HIGHWAY BARRIER
MATERIAL INVESTIGATIONS

Study made by . . . . Structural Materials Branch

Under the Supervision of . . . . E. F. Nordlin, P.E.

Principal Investigator . . . . J. R. Stoker, P.E.

Co-Principal Investigator . . . . . . R. L. Stoughton, P.E.

Co-Investigator . . . . D. M. Parks, P.E.

Report Prepared by . . . . R. L. Stoughton, P.E. and
D. M. Parks, P.E.

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

RLS/DMP:lb

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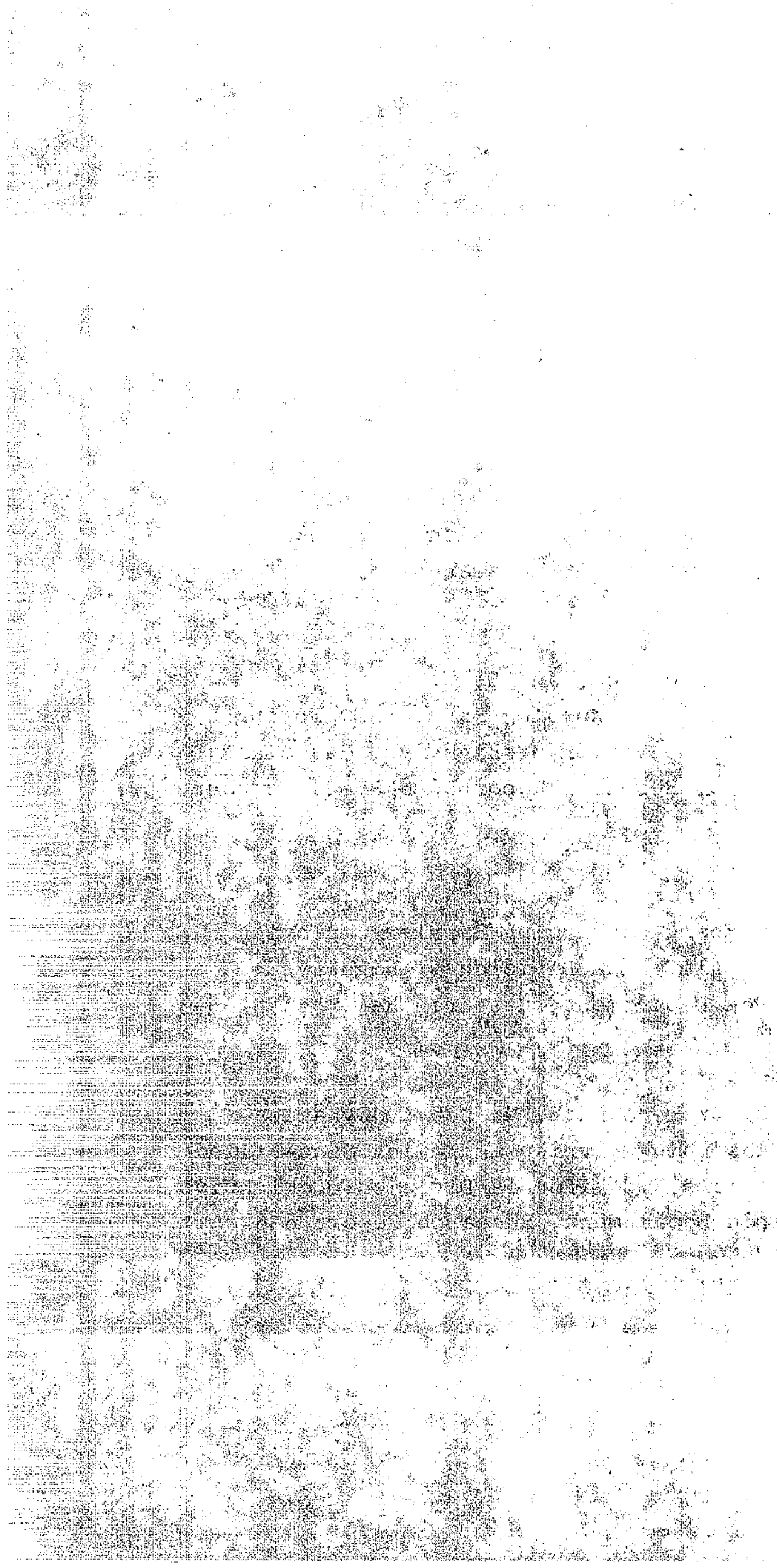
This research was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, and represents the final report for Item D-4-69 of Work Program HPR-1(12), Part 2, Research, titled, "Energy Absorbing Highway Barrier Designs". Other reports published under Item D-4-69 were as follows:

1. Nordlin, E. F., W. H. Ames, L. G. Kubel, and W. Chow; "Evaluation of a Telemetry System for Use in Vehicle-Barrier Impact Tests," California Division of Highways, Materials and Research Department, Research Report No. 636405-1, July 1969.

2. Nordlin, E. F., J. H. Woodstrom, and R. N. Doty; "Dynamic Tests of an Energy Absorbing Barrier Employing Steel Drums," California Division of Highways, Materials and Research Department, Research Report 636405-2, October 1970.

3. Nordlin, E. F., J. H. Woodstrom, and R. N. Doty; "Dynamic Tests of an Energy Absorbing Barrier Employing Water-Filled Cells," California Division of Highways, Materials and Research Department, Research Report 636405-3, November 1970.

4. Nordlin, E. F., J. R. Stoker and R. N. Doty; "Dynamic Tests of an Energy Absorbing Barrier Employing Sand-Filled Frangible Plastic Barrels," California Division of Highways, Materials and Research Department, Research Report 636405-4, July 1971.



The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Appreciation is due the following employees of the Transportation Laboratory for their assistance in conducting this research:

Part I. Bob Doty prepared the initial research proposal. Orvis Box, Lee Staus and Lee Wilson conducted the mix design tests and helped build the module forms. Valuable assistance was received from Dave Wong and Don Smith in the former Concrete Branch of the Lab.

Part II. Roger Pelkey coordinated and conducted many of the tests, analyzed test data, and wrote the initial draft of the first half of the report. James Keesling and Lee Staus helped conduct and photograph the tests, and reduced the data. The staff of the machine shop built the drop tower test apparatus with their usual excellent skill and precision.

Part III. Vince Martin developed the test procedure and conducted the tests. Lee Staus helped analyze the data and wrote the initial draft of the first half of the report.

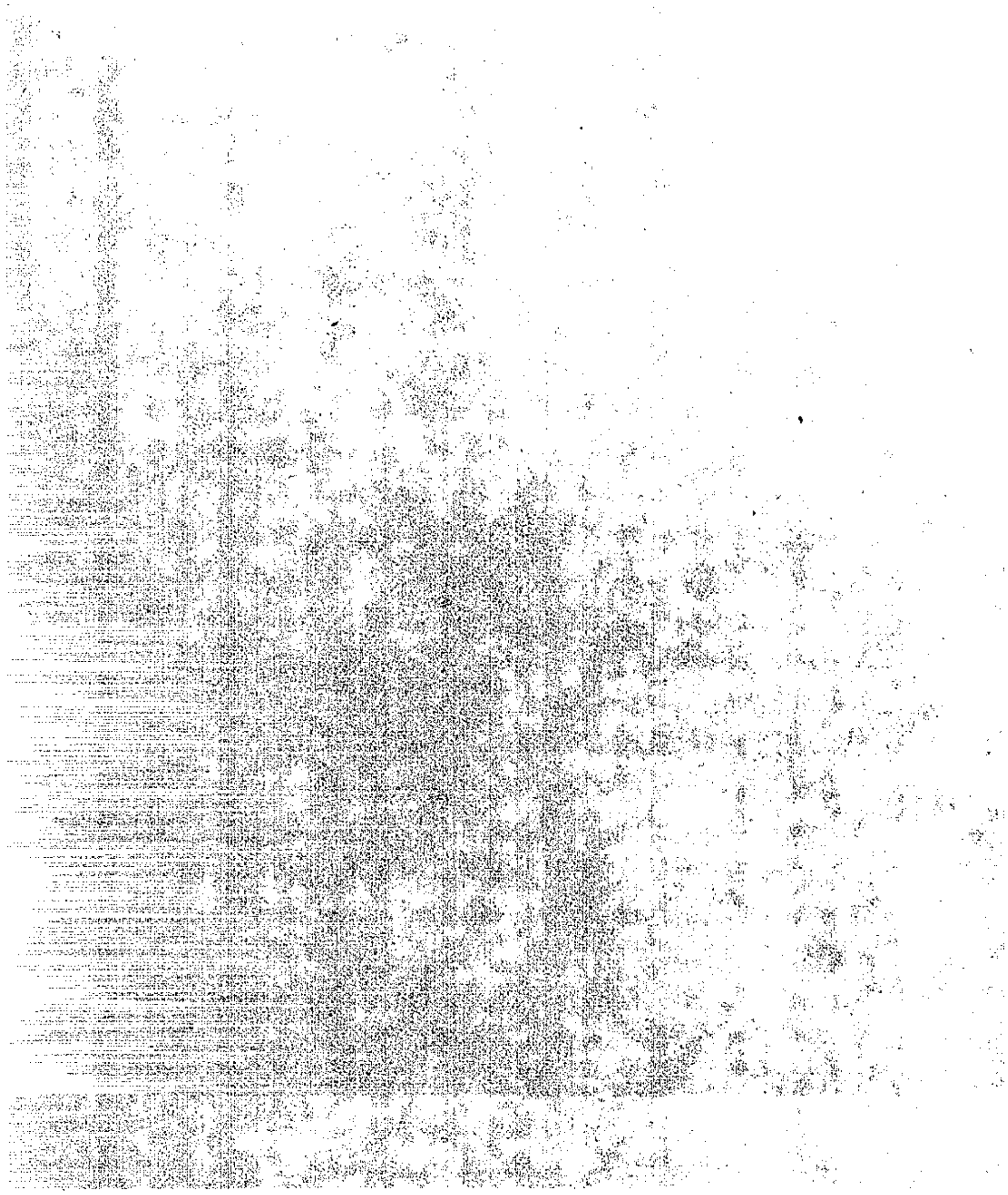
This report was reproduced by Larry Stevens.

The cooperation and assistance of industry representatives is also appreciated:

Part I Ron Hodges, Zonolite Construction Products Division, W. R. Grace & Co. was especially helpful in the early stages of the project.

Part II. Grant Walker, Dynamic Research & Manufacturing Co.

Part III. Fred H. Gades, Gades Sales Co.; Robert A. Mileti, Fibco, Inc; and Bruce O. Young, Energy Absorption Systems, Inc.



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*1 lb = 0.454 kg
1 mph = 0.447 m/s
1° = 0.0175 rad

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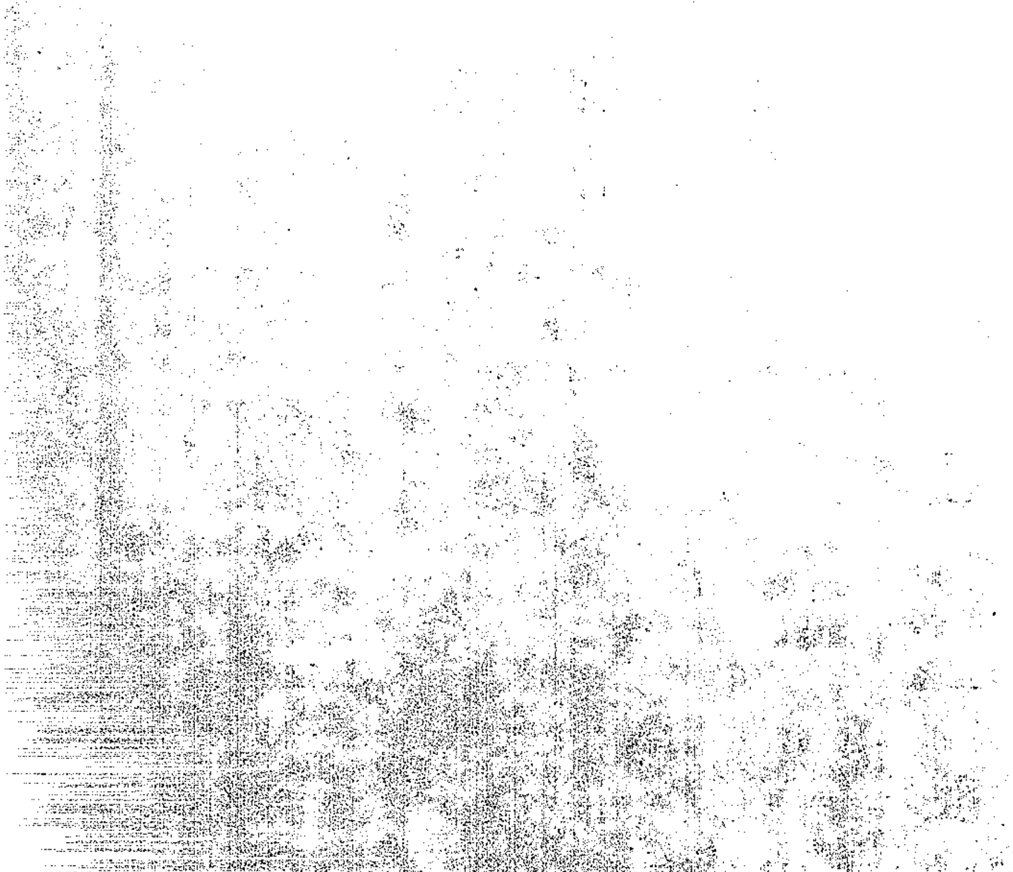
PART TWO: EVALUATION OF VERMICULITE CONCRETE HELICELLS



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PART ONE: PRELIMINARY DEVELOPMENT OF A VERMICULITE CONCRETE CRASH CUSHION

I. INTRODUCTION

This project was initiated in 1971 after successful crash tests conducted by the Texas Transportation Institute (1) on vermiculite concrete crash cushions indicated that vermiculite concrete was an effective energy absorbing material. The concept of a crash cushion made with a lightweight, low-strength concrete seemed promising because of its predicted low first cost and the aesthetic flexibility of a material that could be formed.

The vermiculite concrete used in this study was composed of portland cement, water, an air-entraining agent and vermiculite aggregate. Vermiculite aggregate is formed from mica by a thermal expansion process.

Investigations were begun to determine the feasibility of using the "New Jersey" safety shape contour for the sides of a vermiculite crash cushion. The side panel system used on the crash cushions at TTI (1) could then be eliminated. It was anticipated that the contoured sides would improve the appearance of the crash cushion and provide a better redirective capability.

At first, this project concentrated on developing a vermiculite concrete crash cushion for use in gore areas on elevated bridge structures to replace hazardous concrete wedge shaped blocks which served as terminals at the intersection of converging bridge rails. But a greater need for a vermiculite crash cushion evolved when California began using the Concrete Barrier Type 25. This barrier is a 32 inch (813 mm) high concrete parapet incorporating the "New Jersey" safety shape traffic face contour and is the current standard bridge barrier rail. This type of barrier railing was to be used on all projects not requiring a pedestrian walkway on the bridge deck. The approach barrier was originally intended to have the Type 25 shape also, and be flared back away from the traveled way. However, it was soon recognized that this approach barrier was a very rigid obstacle, particularly if impacted headon at the upstream end.

A terminal section that could be cast from vermiculite concrete and contoured to blend with the Type 25 approach barrier was proposed. It was hoped that this would be an economical solution which would provide optimum safety and aesthetics at the end of the approach barrier.

The developmental phases of the project were to include the following:

- Low speed vehicle load tests of the traffic face of a contoured block of vermiculite concrete,
- Design of a reliable vermiculite concrete mix,
- Fabrication and static compression testing of quarter scale and full size precast barrier modules,
- Construction of a full scale vermiculite crash cushion, and
- A series of headon and side angle vehicle impact tests into a full scale crash cushion.

The crash cushion was to be assembled from a series of two or three types of modules with different stiffnesses that could be used in tandem to form a barrier with a graduated stiffness. Standard size precast barrier modules would be used to facilitate on-site restoration of the crash cushion after a collision.

Midway through the project, work was discontinued. This was due mainly to difficulties in developing a reliable vermiculite concrete mix design with a consistent compressive strength range. It was also realized that the problems of durability and weatherability had not been solved yet for this type of concrete. These problems of attaining a reliable mix design are discussed in the report.

Also described are the results of the following work:

- Low speed vehicle load tests,
- Experience with steam curing vermiculite concrete,
- Discussion of a vermiculite crash cushion concept,
- Fabrication and static compression testing of two full-size precast barrier modules.

II. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

Conclusions

A vermiculite concrete mix design with a reliable compressive strength between 40 and 60 psi (276 and 414 kPa) could not be attained. This narrow strength range was needed to develop a crash cushion dependent on a material with a predictable low crushing strength. Compression test results from many samples were mostly erratic and inconsistent even though samples were batched using the same procedures and cured at 70°F (294 K) or in a fog room environment. Attempts to develop a reliable mix that could be steam cured and oven dried were also unsuccessful.

Aggregate segregation in the concrete mixer was not a problem when a stabilized vermiculite aggregate containing an air-entrainment additive was used. Aggregate segregation occurred only when a liquid air-entraining agent was added to the mix. A timed mixing sequence was needed to optimize the air-entrainment, in order to lower the concrete strength (using stabilized aggregate). This also increased the workability of the mix.

Vermiculite concrete compressive strengths were sensitive to aggregate gradation, moisture content of the samples, and the amount of damage to samples that occurred during stripping and test preparation operations.

Two full size steam cured precast barrier modules absorbed 42.2 and 32.1 foot-kips (56.9 and 43.4 kJ) of energy when crushed statically.

A safety-shaped block of lightly reinforced, low strength vermiculite concrete supported the mass of a 4900 lb (2222 kg) passenger car driven onto the sloping face at speeds of approximately 5 mph (2.2 m/s).

Recommendations

Vermiculite concrete in bulk form is not recommended for use as a material for crash cushions due to its sensitive strength and mixing properties. However, the concept of a crash cushion composed of crushable precast modular units need not be discarded. Perhaps the strength characteristics of portland cement concrete using other forms of lightweight aggregate could be controlled more easily. A considerable developmental effort would be required, however, to test alternate low strength materials in bulk form for crash cushions.

Implementation

There are no results from this investigation that can be implemented.

III. TECHNICAL DISCUSSION

A. Preliminary Vehicle Tests of a Vermiculite Concrete Block Cast With a New Jersey Safety Shape Contour

1. Objective

The objective of this phase was to conduct a series of low speed vehicular impacts to evaluate the strength of a block of vermiculite concrete formed with a safety-shape "New Jersey" profile. If the blocks were sufficiently strong, this same profile could possibly be used on the sides of a vermiculite concrete crash cushion in place of a fender panel system to provide a redirective capability.

2. Test Block Design and Construction

The vermiculite concrete block, Figure 1, was 1.67 ft (509 mm) high, 1 ft (305 mm) thick and 8 ft (2.4 m) long. It was cast with a safety shape profile against an existing concrete bridge barrier parapet at the test site.

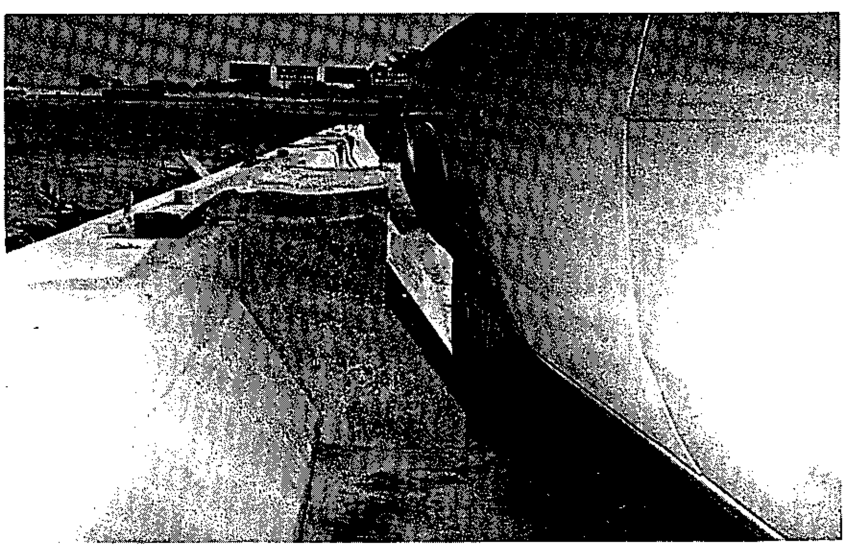


Figure 1 - Vermiculite Concrete Test Block

A layer of 2x2-14x14 (51x51 mm-2x2 mm) welded wire fabric was placed with a 1 inch (25 mm) cover next to the front face of the test block.

The mix design used for the test block was similar to that used by Texas Transportation Institute (TTI) for test barrier 505V-C (1). TTI used a special fast setting portland cement, which permitted form removal in two hours, instead of Type III portland cement. Vermiculite concrete batches of 6, 6, and 4 cubic feet (0.17, 0.17, and 0.11 cubic metre) were proportioned from the following masses for a 1 cubic yard (0.76 cubic metre) batch: 150 lbs (68 kg) vermiculite aggregate, 305 lbs (138 kg) of Type III portland cement, 645 lbs (293 kg) of water, and 6 pints (2.84 l) of liquid Vinsol Resin air-entraining agent.

Water and the liquid air-entraining agent were placed into a 9-cubic foot (0.25 cubic metre) plaster mixer with rubber coated rotating paddles and mixed at about 36 revolutions per minute (rpm) for one minute. Then the Type III cement and the vermiculite aggregate were added and mixed at the same speed for two minutes.

Before the concrete was placed, epoxy was applied to the face of the concrete bridge parapet to bond it to the vermiculite concrete block. The forms were tapped lightly with a hammer to consolidate the vermiculite concrete during the placing operation. Samples taken during the pour were also tapped lightly, but were not rodded. After the test block was poured excess water began seeping out the bottom of the forms.

3. Static Compression Test Results

The following table presents the compressive strength results of cylinder samples and cores for the vermiculite concrete test block:

TABLE 1***

No. of Samples	Sample Size, In.	Age, Days	Average Compressive Strength, psi
1*	6 x 12	7	10
1**	6 x 12	18	35
1**	6 x 12	21	35
2**	6 x 12	25	38
2*	6 x 12	28	26
2**	6 x 12	28	40
2 cores	2 x 4	21	60
2 cores	2 x 4	25	78
7 cores	2 x 4	28	55

*Samples taken from 4 cubic ft. (0.11 cubic metre) batches

**Samples taken from 6 cubic ft. (0.17 cubic metre) batches

***1 in. = 25.4 mm

1 psi = 6.89 kPa

All the 6 x 12 inch (153 x 305 mm) cylinder samples were cured outside near the test block installation in metal containers for four days, then stored at room temperature, about 70°F (294 K). After 18 days, the 6 x 12 inch (153 x 305 mm) samples that had not been tested were stripped and placed outside to simulate a field cure. The cores were taken the day before they were tested. All 2 x 4 inch (51 x 102 mm) cores were drilled from the top of the vermiculite concrete test block. Water was used during the coring operation.

Variations in the compressive strengths of the cylinders and cores might be attributable to any of several causes such as: batch size, sample size, curing methods, damage to samples sustained during stripping operation (vermiculite concrete stuck to the sides of many of the sample containers), uneven bearing surfaces for compressive tests, use of low load range on laboratory testing machines, wet samples, etc. The interior portions of all cylinders and cores were somewhat damp. The samples failed in a plane between the damp and dry portions of the vermiculite concrete.

4. Vehicular Impact Tests

a. Test 1: 4900 lb./5 mph/6.5° (2222 kg/2.2 m/s/0.11 rad). The test vehicle, a 1969 Dodge Polara sedan, was placed about one car length back from the block. The driver approached the test block at about 5 mph (2.2 m/s) holding the steering wheel lightly and ran up the sloping face of the block and off the end. There was some minor scuffing on the front quarter panel of the vehicle when it dropped off the end of the block.

The vermiculite concrete test block was abraded slightly to a depth of about 1/16 inch (2 mm), and a fine layer of powder was left on the surface, Figure 2.

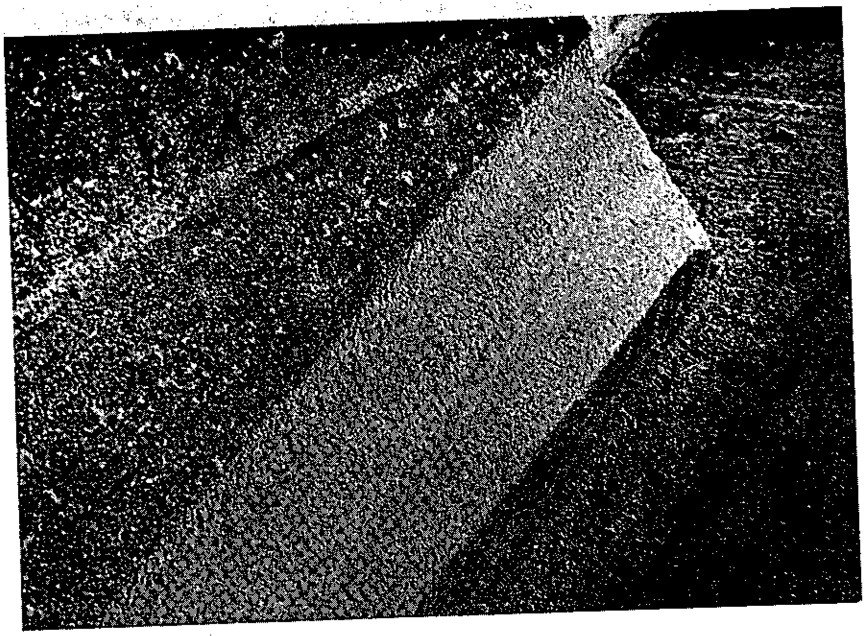


Figure 2 - Damage to Vermiculite Concrete Block From 6.5° (0.11 rad) Impact.

b. <u>Test 2: 4900 lb./5 mph/12° (2222 kg/2.2 m/s/0.21 rad)</u>. The test vehicle approached the block in the same manner as in the first test except the approach angle was increased to about 12° (0.21 rad). The vehicle rode about 10 inches (254 mm) up onto the sloping face and dropped off the end of the block. The front quarter panel of the vehicle sustained some additional light scuffing damage. The vermiculite concrete test block was abraded to a depth of about 1/8 inch (3 mm) from tire scuffing and its downstream top edge was damaged as the test vehicle rode off the end, Figure 3.

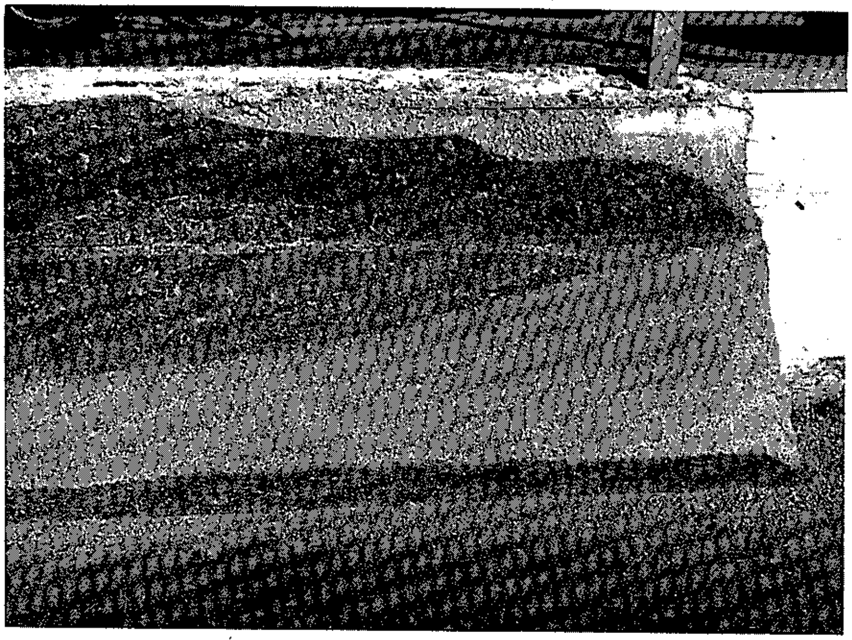


Figure 3 - Damage to Vermiculite Concrete Block From 12° (0.21 rad) Impact.

c. Test 3: 4900 lb./5 mph/25° (2222 kg/2.2 m/s/0.44 rad). The test vehicle approached the block as before at an angle of about 25° (0.44 rad). The left front wheel was forced to the left and rode up to the top of the block. There was no damage to the vehicle. The sloping face of the block was slightly abraded. The full length of the top front edge of the vermiculite block was damaged to a depth of about 1.5 inches (38 mm), Figure 4. The exposed vermiculite concrete was still damp, while the outside surface appeared dry.

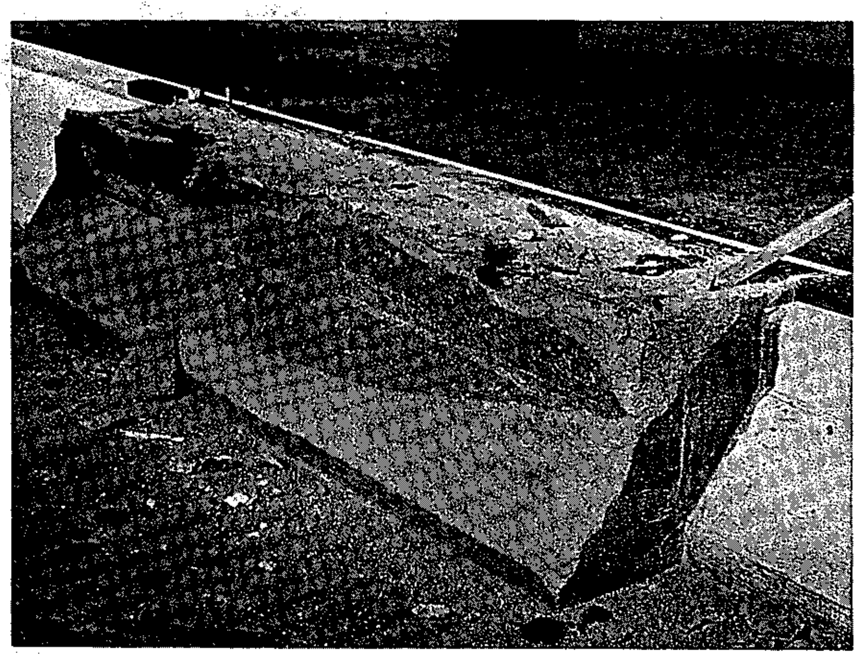


Figure 4 - Damage to Vermiculite Concrete Block From 25° (0.44 rad) Impact.

5. Discussion of Results

Results of the preliminary low speed impact tests indicated that lightly reinforced low strength vermiculite concrete cast with a New Jersey safety shape could withstand the weight of a full size automobile. These tests justified the potential use of a New Jersey contour for the sides of a vermiculite concrete crash cushion. It was realized, however, that vermiculite concrete might behave somewhat differently when impacted at higher speeds with the less rigid backing of a crash cushion.

Fabrication of the vermiculite concrete block also provided experience with the mixing, placing, sampling and curing peculiarities of this type of concrete. Due to the inconsistent compressive strength results, additional work was begun to refine the mix design before continuing with the development of a crash cushion.

B. Vermiculite Concrete Mix Design Experience

1. Objectives

The second phase of the project was divided into two parts. The first part dealt with developing a more refined vermiculite concrete mix design with a more reliable ultimate strength between 40 and 60 psi (276 and 414 kPa). In part two the mix design experience from part one was used to determine the feasibility of steam curing vermiculite concrete so that standard size precast barrier modules could be quickly and easily built and stockpiled.

2. Trial Mix Designs

During the project five series of trial mix designs were tested. Variations investigated in Series I included changing from Type II modified to Type III portland cement, using a stabilized vermiculite aggregate which contained an air-entraining additive versus adding a liquid air-entraining agent to the mix, changing the quantity of cement per batch, and using a different mixer. The liquid air-entraining agent used in the stabilized aggregate was a Vinsol resin type conforming to ASTM Designation: C260. The stabilized vermiculite aggregate contained the equivalent of about 6 pints (2.84 l) of air-entraining agent per cubic yard. The vermiculite aggregate had a dry density between 5 and 9 lbs. per cubic foot (80 and 144 kg per cubic metre) with a particle size of about 1/8 inch (3 mm).

The following batch weights for the Series I mix designs are for 2 cubic foot (0.06 cubic metre) batches except F1-1.5 and A1-1.5 which were 1.5 cubic foot (0.04 cubic metre) batches. The reference mix is the same design used for the vermiculite concrete test block except that Type II modified portland cement was used instead of Type III portland cement in all but one batch.

Series I Trial Mix Designs *

Mix Design	Change or % Change from Reference Batch	Water (lbs)	Added Air-Entraining Agent (oz.)	Type II Cement (lbs)	Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Refer.	No change	47.8	7.1	22.6	11.1	38.5
A2-2	Type III Cement	47.8	7.1	22.6**	11.1	41.0
A4-2	Stabilized Aggregate	47.8	0	22.6	11.1	35.5
B1-2	+8% cement	47.8	7.1	24.1	11.1	40.6
C1-2	-7% cement	47.8	7.1	21.1	11.1	40.2
D1-2	-13% cement	47.8	7.1	19.6	11.1	39.0
E1-2	+13% cement	47.8	7.1	25.5	11.1	40.6
F1-1.5	Stabilized Aggregate	35.9	0	14.7	8.3	34.9
A1-1.5	Different Mixer	35.9	5.3	17.0	8.3	43.0

*1 lb = 0.454 kg; 1 oz. = 0.028 kg; 1 pcf = 16.0 kg/m^3.

**Type III portland cement.

The second series of trial mix designs measured the effects of varying the water cement ratio. Type III high-early-strength cement and stabilized vermiculite aggregate were used for all batches, based on the experience in the first series of mix designs. The mix designs and wet unit weights were as follows for two cubic foot (0.06 cubic metre) batches: (The decreases in the amounts of water and cement were based on the reference mix used for the vermiculite concrete test block.)

Series II Trial Mix Designs*

Mix Design	% Change From Reference Batch	Water (lbs)	Type III Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Reference Design (not mixed)	0% H_2O 0% Cement	47.8	22.6	11.1	-
Z-I-1	-10% H_2O 0% Cement	43.0	22.6	11.1	34.3
Z-II-1	-20% H_2O 0% Cement	38.2	22.6	11.1	33.3
Z-III-1	-10% H_2O -10% Cement	43.0	20.3	11.1	32.0
Z-IV-1	-10% H_2O -20% Cement	43.0	18.1	11.1	30.0

*1 lb = 0.454 kg; 1 pcf = 16.0 kg/m^3.

The number following the Roman numerals I, II, III, etc., of the mix designs represents the batch number.

The third series of mix designs was planned to investigate a fast setting calcium aluminate cement that was supposed to set initially in one hour and gain full strength in 24 hours. Also, a more complete set of test samples was desired for the Z-I design used in the second series, as well as a mix with the Type III cement content increased above that in the Z-I design. All the following batches were two cubic feet (0.06 cubic metre).

Series III Trial Mix Designs*

Mix Design	% Change From Reference Batch	Water (lbs)	Calcium Aluminate Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Reference Design (not mixed)	0% H_2O 0% Cement	47.8	22.6	11.1	-
F-I-1	-10% H_2O +10% Cement	43.0	24.9	11.1	39.6
F-II-1	-10% H_2O -10% Cement	43.0	20.3	11.1	36.9
F-III-1	0% H_2O 0% Cement	47.8	22.6	11.1	37.6
F-IV-1	-10% H_2O +10% Cement	43.0	24.9**	11.1	38.5
Z-I-2	-10% H_2O 0% Cement	43.0	22.6**	11.1	35.1

*1 lb = 0.454 kg; 1 pcf = 16.0 kg/m^3.

**Type III portland cement.

Vermiculite concrete samples were steam cured during the fourth series of trial mix designs. Also, two full size precast barrier modules were fabricated and steam cured during this period. Further explanation of the design, construction, and steam curing procedures of these modules appears in subsequent sections of this report. Mix designs Z-I-3 and Z-I-4 were two cubic foot batches (0.06 cubic metre); the remaining batches were each five cubic feet (0.14 cubic metre).

Series II Trial Mix Designs*

Mix Design	% Change From Reference Batch	Water (lbs)	Type III Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Reference Design (not mixed)	0% H_2O 0% Cement	47.8	22.6	11.1	-
Z-I-1	-10% H_2O 0% Cement	43.0	22.6	11.1	34.3
Z-II-1	-20% H_2O 0% Cement	38.2	22.6	11.1	33.3
Z-III-1	-10% H_2O -10% Cement	43.0	20.3	11.1	32.0
Z-IV-1	-10% H_2O -20% Cement	43.0	18.1	11.1	30.0

*1 lb = 0.454 kg; 1 pcf = 16.0 kg/m^3.

The number following the Roman numerals I, II, III, etc., of the mix designs represents the batch number.

The third series of mix designs was planned to investigate a fast setting calcium aluminate cement that was supposed to set initially in one hour and gain full strength in 24 hours. Also, a more complete set of test samples was desired for the Z-I design used in the second series, as well as a mix with the Type III cement content increased above that in the Z-I design. All the following batches were two cubic feet (0.06 cubic metre).

Series III Trial Mix Designs*

Mix Design	% Change From Reference Batch	Water (lbs)	Calcium Aluminate Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Reference Design (not mixed)	0% H_2O 0% Cement	47.8	22.6	11.1	-
F-I-1	-10% H_2O +10% Cement	43.0	24.9	11.1	39.6
F-II-1	-10% H_2O -10% Cement	43.0	20.3	11.1	36.9
F-III-1	0% H_2O 0% Cement	47.8	22.6	11.1	37.6
F-IV-1	-10% H_2O +10% Cement	43.0	24.9**	11.1	38.5
Z-I-2	-10% H_2O 0% Cement	43.0	22.6**	11.1	35.1

*1 lb = 0.454 kg; 1 pcf = 16.0 kg/m^3.
**Type III portland cement.

Vermiculite concrete samples were steam cured during the fourth series of trial mix designs. Also, two full size precast barrier modules were fabricated and steam cured during this period. Further explanation of the design, construction, and steam curing procedures of these modules appears in subsequent sections of this report. Mix designs Z-I-3 and Z-I-4 were two cubic foot batches (0.06 cubic metre); the remaining batches were each five cubic feet (0.14 cubic metre).

Series IV Trial Mix Designs*

Mix Design	Water (lbs)	Type III Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Wet Unit Weight (pcf)
Z-I-3	43.0	22.6	11.1	40.3
Z-I-4	43.0	22.6	11.1	37.9
Z-I-5	107.5	56.5	27.8	40.6
Z-I-6	107.5	56.5	27.8	39.7
Z-I-7	107.5	56.5	27.8	42.7
Z-I-8	107.5	56.5	27.8	41.7

*1 lb = 0.454 kg; 1 pcf = 16. kg/m^3.

Static compression test results for the Series IV steam cured test cylinders were twice as strong as anticipated. The fifth series of mix designs was initiated to decrease the strength of the original mix to accommodate steam curing, if possible. All of the following 0.4 cubic foot (0.01 cubic metre) batches were mixed under laboratory conditions:

Series V Trial Mix Designs*

Mix Design	% Change From Reference Batch	Water (lbs)	Type III Cement (lbs)	Stabilized Vermiculite Aggregate (lbs)	Water Cement Ratio (lbs/lb)
Z-I-9	Reference	8.6	4.5	2.2	1.91
Z-IV-2	-20% Cement	8.6	3.6	2.2	2.39
1-F-2	-53% Cement	8.6	2.1	2.2	4.10
2-Control	+26% H_2O + 4% Cement +27% Agg.	10.8	4.7	2.8	2.30
2-Z-4	+26% H_2O +27% Agg.	10.8	4.5	2.8	2.40
2-F-4	+26% H_2O +13% Cement +27% Agg.	10.8	5.1	2.8	2.12
3-W-1	+26% H_2O - 9% Cement +27% Agg.	10.8	4.1	2.8	2.63
3-W-2	+36% H_2O -16% Cement +27% Agg.	10.8	3.8	2.8	2.84
3-W-3	+26% H_2O -22% Cement +27% Agg.	10.8	3.5	2.8	3.09
3-W-4	+26% H_2O - 7% Cement +27% Agg.	10.8	4.2	2.8	2.57
3-W-5	+26% H_2O - 2% Cement +27% Agg.	10.8	4.4	2.8	2.45
3-W-6	+26% H_2O + 2% Cement +27% Agg.	10.8	4.6	2.8	2.35

*1 lb = 0.454 kg

Agg. = aggregate

3. Mixing and Sampling Procedures

All trial mix design batches for Series I through IV except for mix A1-1.5 of Series I were mixed with a 9 cubic foot (0.25 cubic metre) plaster mixer with rubber edged blades that thoroughly scraped the bottom and ends of the cylindrical drum mixer. A 2 cubic foot (0.06 cubic metre) Lancaster Countercurrent pan mixer Type SKG, Model 294 was used for mix A1-1.5. All Series V batches were mixed with a 0.4 cubic foot (0.01 cubic metre) Hobart Mixer at speeds between 100 and 200 rpm. Use of the plaster mixer was recommended by vermiculite industry representatives, as were some of the other techniques.

Materials were added in a predetermined order and mixed for a specified time. In Series I the water and the liquid air-entraining agent (Vinsol resin type) were mixed for one minute, the cement added and mixed for one minute, and finally the vermiculite aggregate was added and mixed for four minutes. Mixing speed was 36 rpm.

Immediately after mixing, the cement and water paste separated from the vermiculite aggregate used with the liquid air-entraining agent and sank to the bottom of the mixer. Separation did not occur when a smaller sized stabilized vermiculite aggregate was used which contained an air-entraining additive. Stabilized aggregate was used for all mix designs after Series I.

Samples were taken immediately after the vermiculite concrete was mixed. Two types of sample containers were used. One was a 3 x 6 inch (76 x 152 mm) cylindrical waxed fiberboard can with a metal bottom (normally used for mortar samples). It was sealed with a piece of clear plastic and a rubber band. The other container was a polystyrene box with four 3 x 6 inch (76 x 152 mm) cylindrical holes and a polystyrene lid. ASTM C495-69, "Compressive Strength of Lightweight Insulating Concrete" specifies four 3 x 6 inch (76 x 152 mm) samples when testing this type of lightweight concrete. A few 6 x 12 inch (152 x 305 mm) cylindrical samples were taken during Series IV. Samples were not rodded but were tapped lightly to minimize separation of the water and cement from the aggregate.

The bottom portion of all the samples from the Series I mix designs with unstabilized aggregate crumbled when the sample containers were stripped prior to compressive strength testing. Nail holes were punched (6 to 8 per can) in the bottom of some of the containers used for the Series II and III samples to permit drainage of excess water. Some drainage of water had been observed at the base of the forms when the vermiculite concrete test block was cast.

The vermiculite concrete also showed a tendency to stick to the sides of the sample containers. The polystyrene box appeared to produce less damaged samples, especially after a hot wire cutter was used to slice the polystyrene away from the samples.

4. Static Compression Test Results and Curing Procedures

The charts at the end of this subsection of the report are the results of compressive strength tests for the 3 x 6 inch (76 x 152 mm) vermiculite concrete cylinder samples for four of the five series of trial mix designs. As explained earlier, all the samples for Series I crumbled when they were stripped and could not be tested. Results for the fifth series were divided into three parts to facilitate reporting.

Curing methods are explained at the end of each chart. Most of the sample cylinders for Series IV and V were steam cured. At the time of this work there were no established procedures for steam curing vermiculite concrete. Attempts were made to follow the steam curing procedures for precast concrete members as outlined in the California Standard Specifications. The time periods pertinent to the steam curing cycle (2) are defined as follows: delay period - time between adding water to the mixture and first application of the steam; temperature rise period - time during which the temperature of the curing chamber is uniformly varied to a maximum; maximum sustained temperature period - period during which the curing chamber is at a constant maximum temperature.

Two steam curing chambers were used, each being 5.5 ft. (1.7 m) long, 3.7 ft. (1.1 m) wide and 5.5 ft. (1.7 m) high. Steam was supplied by a Type 72 boiler manufactured by the Mercoid Corporation, Chicago, Illinois, with a maximum operation pressure of 100 psi (689 kPa). The temperature within the curing chambers was regulated by a system of valves that could be adjusted to control the amount of steam entering each chamber. Thermocouples monitored the temperature in the chambers during some of the curing cycles.

Before testing, the bearing surfaces of the samples were ground plane. Samples were placed between two pieces of corrugated cardboard and tested with a Tinius-Olsen testing machine with a 120,000 lb. (53.4 kN) capacity. A continuous load was applied to each sample at a constant rate so that the maximum load was reached in about 50 seconds. The failure plane for most of the samples was about 45° (0.79 rad).

Series II Compressive Strength Results [1]

Mix Design	Number of Samples Tested*	Curing Method**	Average Compressive Strength, psi, of Samples at Age, Days 3	7	28
Z- I -1	1,1	A	-	25	51
Z- I -1	1,1	B	-	44	56
Z- I -1	1,1	C	-	23	45
Z- I -1	1,1	D	-	41	50
Z- II-1	1,1,1	A	29	26	51
Z- II-1	1,1	B	-	42	58
Z- II-1	1,1,1	C	20	23	35
Z- II-1	1,1	D	-	40	48
Z-III-1	1,1	A	15	23	-
Z-III-1	1,1	B	-	30	42
Z-III-1	1,1,1	C	11	16	35
Z-III-1	1	D	-	-	44
Z- IV-1	1,1	A	8	-	19
Z- IV-1	1,1	B	-	26	28
Z- IV-1	1,1	C	-	13	23
Z- IV-1	1,1	D	-	18	32

* 1,1 = one sample tested for each compressive strength entry
All samples 3 x 6 inch (76 x 152 mm) cylinders

** A = Samples cured at 70°F in fiberboard containers with perforated bottoms to permit drainage of excess water.

B = Samples cured at 70°F in polystyrene containers with perforated bottoms to permit drainage of excess water.

C = Samples cured at 70°F in fiberboard containers.

D = Samples cured at 70°F in polystyrene containers.

1. 1 psi = 6.89kPa ; K = (°F + 460)/1.8

Series III Compressive Strength Results [1]

Mix Design	Number of Samples Tested*	Curing Method**	Average Compressive Strengths, psi, of Samples at Age, Days 1	3	7	28
F- I -1	3,4,4,4	A	38	53	22	69
F- I -1	4,4,4,4	B	15	25	30	34
F- I -1	4	C	-	-	-	35
F- I -1	4	D	-	-	-	27
F- II-1	3,4,4,3	A	21	22	22	29
F- II-1	4,4,4,4	B	13	10	20	35
F- II-1	4	C	-	-	-	28
F- II-1	4	D	-	-	-	13
F-III-1	3,3,4,2	A	13	20	23	22
F-III-1	4,4,4,4	B	8	8	10	21
F-III-1	4	C	-	-	-	18
F-III-1	4	D	-	-	-	9
F- IV-1	4,3,4	A	-	22	35	65
F- IV-1	4,4,4	B	-	34	57	83
F- IV-1	3	C	-	-	-	68
F- IV-1	4	D	-	-	-	76
Z- I -2	3,3,4	A	-	17	23	53
Z- I -2	4,4,4	B	-	23	36	62
Z- I -2	3	C	-	-	-	40
Z- I -2	4	D	-	-	-	56

* All samples 3 x 6 inch (76 x 152 mm) cylinders

** See curing methods for Series II

1. 1 psi = 6.89kPa

Series IV Compressive Strength Results [1]

Mix Design	Number of Samples Tested*	Steam Curing Method**	Average Compressive Strength, psi, of Samples at Age, Days: 1	2	7	10	14	28	7mo.
Z- I -3	8	E	55	-	-	-	-	-	-
Z- I -3	2	E	57••	-	-	-	-	-	-
Z- I -4	8	F	41	-	-	-	-	-	-
Z- I -4	2	F	48••	-	-	-	-	-	-
Z- I -3	2	G	-	-	-	-	-	-	92••
Z- I -4	2	G	-	-	-	-	-	-	138••
Z- I -5	4,3	H	33	-	-	-	-	55	-
Z- I -6	4,3	H	33	-	-	-	-	57	-
Z- I -7	4,4	I	29	-	49	-	-	-	-
Z- I -7	4,4	I	64•	-	-	-	109•	-	-
Z- I -7	4	J	-	-	-	-	-	93	-
Z- I -8	4,8,4	I	-	-	123•	86	105	-	-
Z- I -8	8	J	-	-	-	-	-	133	-
Z- I -8	4,4,4	G	36	78•	-	-	94	-	-

* 3 x 6 inch (76 x 152 mm) sample cylinders cured in polystyrene containers unless otherwise noted.

**

Curing Method	Delay Period	Temperature Rise Period	Maximum Sustained Temperature Period
E	4 hrs	3 hrs @ 20°F/hr	16.75 hrs @ 150°F
F	4 hrs	1.5 hrs @ 40°F/hr	16.5 hrs @ 150°F
H steam cabinet malfunctioned during cycle	4 hrs	2 hrs @ 40°F/hr	16 hrs @ 150°F
I	4 hrs	3 hrs @ 30°F/hr	16 hrs @ 150°F

G = Samples cured in fogroom at 73°F and 100% relative humidity.

J = Samples cured at 70°F for 24 hrs. then stripped and placed in fogroom at 73°F and 100% relative humidity.

• Samples dried at 140°F and cooled before testing.

•• 6 x 12 inch samples taken in metal cylinder cans.

1. 1 psi = 6.89kPa ; K = (°F +460)/1.8

Series VA Compressive Strength Results[1]

Mix Design	Number of Samples Tested*	Curing Method**	Average Compressive Strength, psi, of Samples at Age, Days 2	4	7	10	21
1- F -2	2,3,4	K	15	-	12	16	-
Z- IV-2	3,3,3	K	42	-	27	41	-
Z- I -9	2,4,4	K	102	-	75	91	-
2- Z -4	4,4,4	L	-	68	46	-	93
2- CON	4,4,4	L	-	106	61	-	69
2- F -4	1,4,4	L	-	168	136	-	248

* 3 x 6 inch (76 x 152 mm) sample cylinders cured in polystyrene containers.

**

Curing Method	Delay Period	Temperature Rise Period	Maximum Sustained Temperature Period
K	4 hrs	4 hrs @ 20°F/hr	16 hrs @ 150°F

L = Steam cabinet malfunctioned ; 4 hr delay period ;

Steam curing cycle 24 hrs at the following temperatures:

70°F to 150°F for 1 hr

3 hrs at 150°F

6 hrs at 145°F

145°F to 110°F for 1 hr

9 hrs at 100°F

100°F to 130°F for 1 hr

130°F to 80°F for 3 hrs

1. 1 psi = 6.89kPa ; K = (°F + 460)/1.8

Series VB Compressive Strength Results[1.]

Mix Design	Number of Samples*	Curing Method**	Average Compressive Strength, psi, of Samples at Age, Days 2	3	4	5	8	14	15	26	27
3-W-3	4,4,4	M	-	20	-	-	-	25	-	27	-
3-W-3	4,4,4	M	-	-	14	-	-	-	17	-	18
3-W-2.	1,4,4	M	-	125	-	-	-	127	-	126	-
3-W-2.	1,4,4	M	-	-	86	-	-	-	88	-	87
3-W-2.	4,8,4	M	53	-	-	101	85	-	-	-	-
3-W-1	4,4,4	M	-	53	-	-	-	32	-	50	-
3-W-1	4,4,4	M	-	-	37	-	-	-	22	-	34

* 3 x 6 inch (76 x 152 mm) sample cylinders cured in polystyrene containers.

** Curing Method M: 4 hour delay period; temperature rise period 1 hour at 35°F/hr.; maximum average sustained temperature period 39.5 hrs. at 140°F.

. The bottom of the bag of stabilized vermiculite aggregate (much finer gradation) was used and 0.9 lbs. of water was added to the mix design as shown for Series V.

1. 1 psi = 6.89 kPa; K = (°F+460)/1.8

Series VC Compressive Strength Results[1.]

Mix Design	Number of Samples Tested*	Curing Method**	Average Compressive Strength, psi, of Samples at Age, Days: 2	5	7	8	14	20	28
3-W-4	4	N	75	-	-	-	-	-	-
3-W-5	4	N	72	-	-	-	-	-	-
3-W-6	4	N	97	-	-	-	-	-	-
3-W-4	4,4	O	23	-	-	-	-	52·	-
3-W-5	4	O	38	-	-	-	-	-	-
3-W-6	4	O	41	-	-	-	-	-	-
3-W-4	4,4,8	O	33	-	-	66·	54·	-	-
3-W-6	4,4,4,4,4,4	O	37,64·	-	49	67·	59·	-	93
3-W-6	4,4,4,4	O	35	-	123·	-	104	-	133
3-W-6	4,4	G	78	-	-	-	94	-	-
3-W-2	4,4,4	O	53	101·	-	85·	-	-	-
3-W-4	4,4,4	O	57	118·	-	101·	-	-	-

* 3 x 6 inch (76 x 152 mm) sample cylinders cured in polystyrene containers.

**Curing Method	Delay Period	Temperature Rise Period	Maximum Sustained Temperature Period
O	4 hrs.	2.5 hrs. @30°F/hr.	4 hrs. @150°F

Curing Method N: Steam cabinet malfunction: 20 hr. delay period @ about 70°F followed by 24 hrs. @150°F.

Curing Method G : Samples cured in fogroom at 73°F and 100% relative humidity.

·Samples oven dried @ 140°F and cooled before testing.

1. 1 psi = 6.89 kPa; K = (°F + 460)/1.8

5. Discussion of Results

A great deal of information was gained during the first three trial mix design series. Stabilized vermiculite aggregate containing a vinsol resin type air-entraining additive substantially reduced segregation between the vermiculite aggregate and the cement-water paste. Segregation had occurred when a liquid air-entraining agent was used and caused the Series I samples to crumble and fall apart when stripped. A predetermined timed mixing procedure was necessary to guarantee consistant workability between batches. The whipping action of the mixer was required to generate air bubbles. A high-early-strength Type III portland cement facilitated early stripping of samples. Type II modified portland cement and a 24 hour setting calcium aluminate cement were not as successful.

The low strength vermiculite concrete mixes were difficult to sample. Samples stripped from polystyrene containers with a hot wire cutter were considerably less damaged than those stripped from fiberboard or metal sample containers.

Compressive strength results based on a limited number of samples for Series II indicated that mix design Z-I-1 and Z-II-1 with 28 day compressive strengths between 35 and 58 psi (241 and 400 kPa) came closest to the desired design strength range of 40 to 60 psi (276 to 414 kPa). However, mix Z-II-1 seemed too dry and was hard to mix. The compressive strength ranges for mixes Z-III-1 and Z-IV-1 were too low. Samples from the first series of mix designs were not tested because they were damaged while being stripped.

The same Z-I-1 mix design from Series II, mix Z-I-2, was used for comparison in Series III with mixes F-I-1, F-II-1, and F-III-1 all containing calcium aluminate cement and mix F-IV-1 containing 10% more Type III cement than Z-I-2. Compressive strengths for batches F-I-1, F-II-1, and F-III-1 were all low. The strengths for these batches were probably low because the recommended water-cement ratio for calcium aluminate cement as indicated on the cement bag had been exceeded. The 28 day compressive strengths for the F-IV-1 batch exceeded 60 psi (414 kPa) and the mix also seemed too dry. The 28 day compressive strength range of 40 to 56 psi (276 to 386 kPa) for mix Z-I-2 compared closely to the range of 45 to 56 psi (310 to 386 kPa) for batch Z-I-1 in Series II.

Compressive strength results for Series IV and V mix designs were quite erratic and inconclusive. During this phase of the research project work had begun on a vermiculite concrete crash cushion. A conceptual barrier design is discussed in the next section of the report. In order to facilitate construction of a full scale barrier composed of precast modules steam curing was initiated for Series IV and V.
Since very little information was available at the time on steam curing vermiculite concrete, the California Standard Specifications for steam curing precast concrete members were closely followed. These specifications incorporated the following major provisions: a 4 hour presteaming period, a maximum rate for application of steam within the steam chamber not exceeding 40°F (275 K) per hour, and a maximum curing temperature not exceeding 150°F (344 K). A maximum sustained temperature period was not specified. Therefore, a 16 hour maximum sustained temperature period was selected for the first trial batches.

The 24 hour compressive strengths of 41 to 57 psi (282 to 393 kPa) for the preliminary steam cured batches Z-I-3 and Z-I-4 in Series IV were consistent with the 28 day strengths for batches Z-I-1 and Z-I-2 in Series II and III which were conventionally cured. It should be noted that all the Z-I batches contain the same mix design; the number following the Roman numeral I represents a batch number. About seven months later, however, compressive strengths for some fog room cured samples from batches Z-I-3 and Z-I-4 were 60% to 140% stronger than the 24 hour steam cured samples. These higher strengths indicated that the steam curing cycle was too short.

Before these seven month old samples were tested, however, the first full size precast barrier module was cast using batches Z-I-5 and Z-I-6. (Barrier modules are discussed in the following section.) The 24 hour strengths for these batches were somewhat lower than those for the Z-I-3 and Z-I-4 batches and additional 28 day compression tests verified that the steam curing cycle was too short. Since the steam cabinets malfunctioned during the steaming cycle for the Z-I-5 and Z-I-6 batches, steam cabinet temperature exceeded 150°F (344 K) sometime during the cycle, two additional batches Z-I-7 and 8 were mixed and steam cured to verify the need for a longer hydration period.

Even though somewhat erratic, compression test results for batches Z-I-7 and Z-I-8 indicated that the Z-I mix design might have contained too much cement for the desired strength range or possibly that the total steaming period was too short. Samples were also oven dried at 140°F (339 K) and tested for these batches. The oven dried samples were about twice as strong as the undried samples.

Compressive strength results for Series V were divided into three parts. Mix designs 1-F-2 and Z-IV-2 (same as Z-IV-1 in Series II) with lower cement contents were compared with Z-I-9 and again steam cured for 16 hours. Strength results were more consistent for batches 1-F-2 and Z-IV-2 than for Z-I-9. These atory conditions. All previous batches had been mixed outside with a plaster mixer. These outside batches were much larger and might have been affected by weather conditions at the time of mixing. Some of the Series III batches were mixed during the winter at 45°F (286 K).

The proportions for the remaining three batch designs in Series VA and all the batches in Series VB and VC were increased somewhat to allow more samples to be made for each batch.

Compressive strength test results for batches 2-Z-4, 2-con, and 2-F-4 were inconsistent, possibly due to an erratic steam curing cycle. See Chart VA for a detailed explanation. Prior to Series VA, the steam curing cycle had not been continuously monitored by using thermocouples and a recorder. The curing period for these batches was increased from 16 hours to 24 hours.

Cement contents were lowered and the steam period was increased to about 40 hours for batches 3-W-1 through 3-W-6 shown on charts for Series VB and VC.

Strength results for batch 3-W-3, even though consistent in a range of 14 to 27 psi (96 to 186 kPa), were too low. The strength range of 22 to 53 psi (152 to 365 kPa) for batch 3-W-1 was also low.

While mixing batches 3-W-2 the bottom of the bag of vermiculite aggregate (fine-gradation) was inadvertently used and more water was added to make the batch as workable as the previous batches. Strengths for 3-W-2 batches varied between batches and were considerably higher than those for batch 3-W-3. However, the compressive strength results for batches 3-W-3, 3-W-2 and 3-W-1 did not vary appreciably with sample age. This indicated a more complete cure due to the longer steaming period.

Series VC mix designs were planned to further refine a vermiculite concrete mix that could be steam cured and produce a consistent compressive strength range. Compressive strength results for these batches were again somewhat erratic. Some samples were stripped and tested while others were dried before being tested.

The steam boiler failed to operate properly when the first three batches in Series VC were ready to be steam cured. The steam boiler was not repaired until the following day; hence, the samples were presteamed for 20 hours before being steam cured for 24 hours. The two day compressive strengths of 72 to 97 psi (496 to 668 kPa) for these batches were also high.

Additional 3-W-4, 5 and 6 batches along with a 3-W-2 batch were mixed and steam cured for 40 hours. Again the compressive strength results varied over a wide range from 33 psi (228 kPa) to as much as 130 psi (916 kPa). At this point it was decided to discontinue considering vermiculite concrete for use in an energy absorbing barrier due to its mixing peculiarities and difficulties in attaining consistent compressive strength results.

In summary, numerous vermiculite concrete design mixes were batched and cured over a wide variety of conditions. Due to the strict mixing requirements for consistently workable batches, the sampling and testing difficulties encountered with these low tensile strength mixes and the wide range of compressive strengths for the same batch designs cured under similar conditions, vermiculite concrete should not be considered for use in bulk form for energy absorbing barriers.

While the trial mix design series were being conducted and at a point during the research project when preliminary strength tests looked somewhat favorable, two full size precast vermiculite concrete barrier modules were cast, steam cured and statically crushed. The design and testing of these modules along with a conceptual full scale barrier design are discussed in the following sections of this report.

C. Vermiculite Concrete Barrier Experience

1. Objectives and Completed Work

During the mix design phase of the research program vermiculite concrete energy absorbing barriers composed of a series of precast barrier modules with varying stiffnessess were proposed. Precast modules were specified to minimize restoration work after a barrier collision. Each precast module was to be cast with contoured sides similar to the profile of the New Jersey type concrete median barrier. It was hoped these contoured sides, while aesthetically improving the barrier, would provide a satisfactory redirective capability in place of side panels.

Prior to any full scale crash tests, full size and quarter scale modules for an energy absorbing barrier were to be built and statically crushed to develop strength relationships and reliable forming and casting techniques. If reasonable correlations were established between the models and the full size modules, additional models would be tested, as required, to determine module dimensions. Full size modules were to be used for this additional testing if the model technique was unsatisfactory. Barrier dimensions would be based on the energy required to crush the modules statically after the static to dynamic energy ratio developed at the Texas Transportation Institute (1) was applied.

When efforts to develop an acceptable vermiculite mix design failed and further work on a vermiculite crash cushion was discontinued, many of the tasks concerning the design of the barrier and testing of the modules had not been completed.

Initial fabrication of the quarter scale modules resulted in very fragile specimens. Wooden forms could not be easily stripped without the vermiculite concrete sticking to them. Consequently, the model studies were abandoned and some full size modules were built.

The remainder of this report deals with the vermiculite concrete barrier concepts that were developed. Two full size precast modules that were built and statically crushed are described. Forms for a weaker barrier module were built but were never used.

2. Vermiculite Concrete Barrier Concepts

This project was initiated to develop a vermiculite concrete crash cushion to be used to protect motorists from concrete gore noses on structures and structural supports in the median area or at gore locations. At the time this research began, the three types of energy attenuators then approved for use were the Texas Steel Drum Barrier, the Hi-Dro Cushion Attenuator, and the Fitch Inertial Barrier. They all lacked aesthetic qualities that would allow them to blend in with the concrete parapet type bridge rails being used in California. It was hoped a moldable cushioning material such as vermiculite concrete would provide the flexibility to cast smooth attractive transitions that would fit naturally with any bridge rail configuration.

The vermiculite crash cushion concept, Figure 5, developed during this project was intended to provide protection at the terminal end of a concrete bridge barrier rail adopted for use on projects that did not require a pedestrian walkway on the bridge deck. This Type 25 bridge rail was a 32 inch (813 mm) high concrete parapet with the New Jersey safety shape contoured traffic face.

Complete details for a full size crash cushion were not developed at this time because the crushing properties of the full size barrier modules were not known. The precast modules were to be incorporated into a prototype full scale barrier after satisfactory completion of a series of laboratory static compression tests.

During the development of a suitable precast module it was realized that a barrier design with a limited number of standardized units would allow stockpiling of units in maintenance yards and would facilitate barrier repair efforts. Repair by casting in place vermiculite concrete probably would not be too practical due to the time required to gain sufficient concrete strength.

Rectangular and circular voids of various sizes and arrangements were considered during the stages of developing a precast modular unit. A New Jersey contoured safety shape was used for the sides of the units in place of a system of fender panels to provide an effective redirective capability.

The following sections of this report discuss the details of developing the precast barrier modules. No attempt was made to specifically adhere to the void arrangements shown in the conceptual crash cushion sketch, Figure 5.

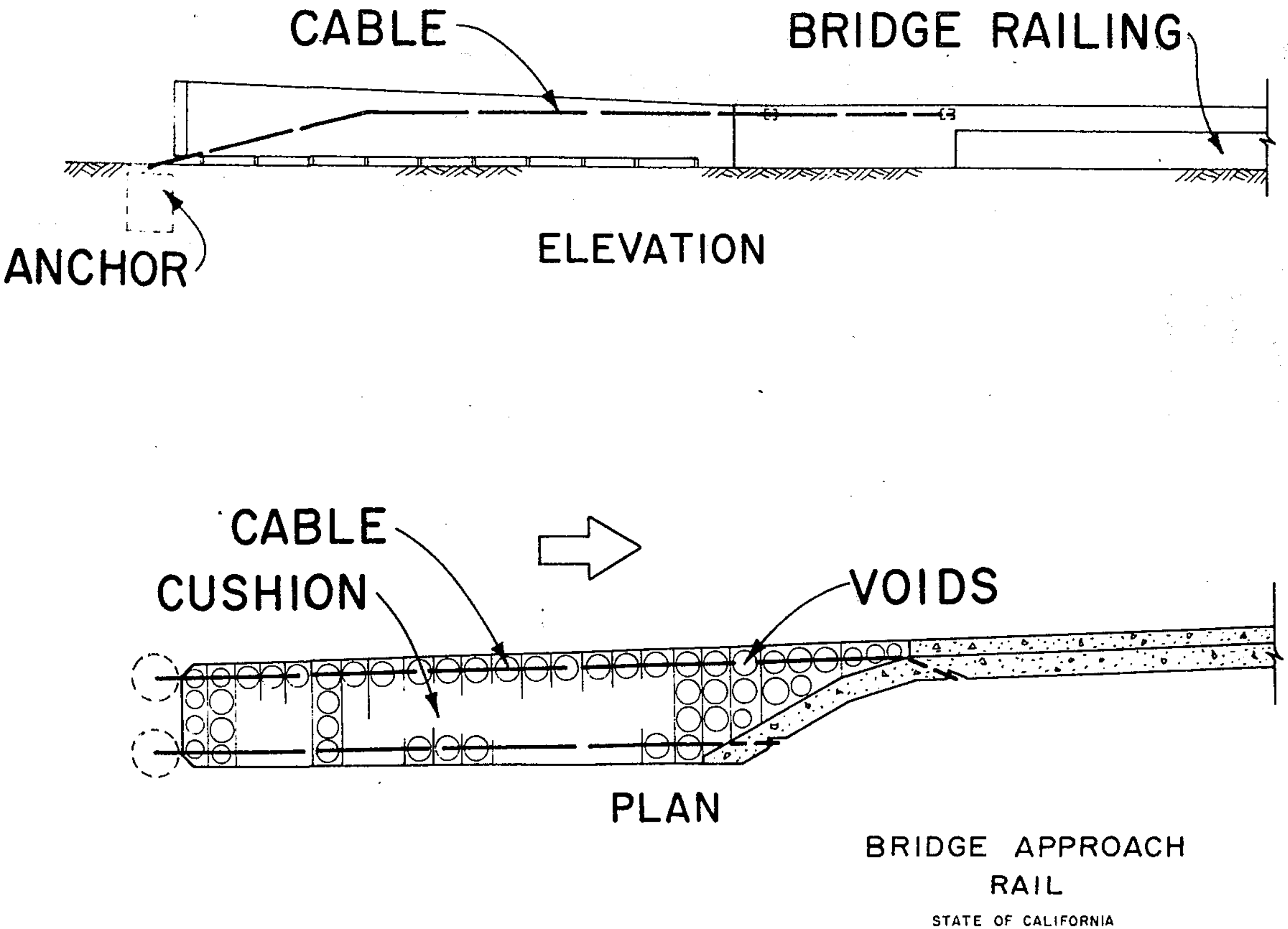


Figure 5 - Concept of a Vermiculite Concrete Crash Cushion

3. Full Size Precast Barrier Modules

a. Design and Construction. Two full size barrier modules with contoured sides similar to a New Jersey safety-shaped median barrier were fabricated with slightly different void configurations formed with 10 inch (254 mm) diameter sonotubes. Some changes in design were implemented for the second module based on the static compression test results of the first module. These first two modules would have been placed in the back rows of a vermiculite concrete crash cushion. Forms were built for a softer, more crushable full size module for use in the front rows of a cushion, but none were cast because at that time the project was being discontinued.

The exterior physical dimensions for the precast barrier modules are shown in Figure 6.

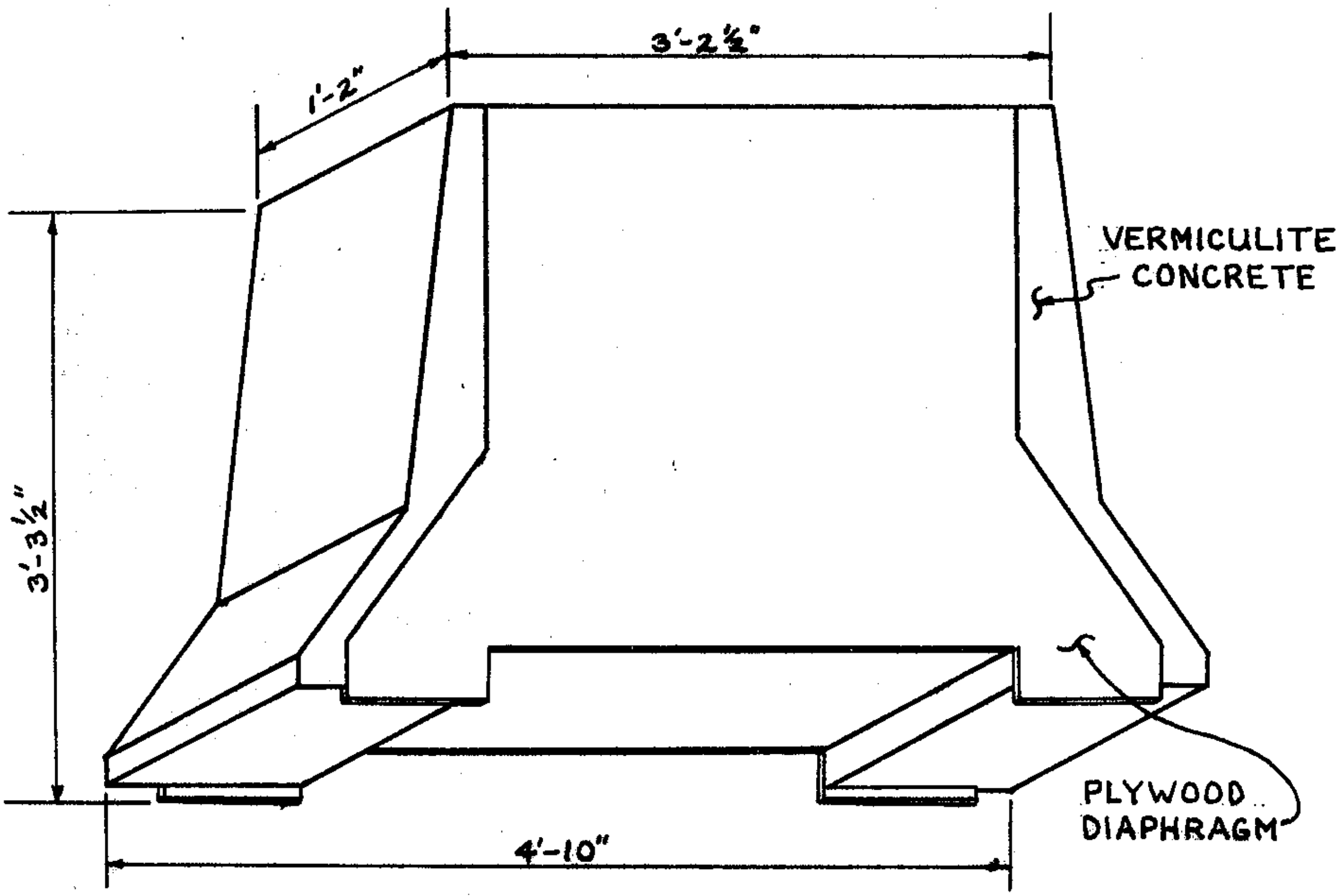


Figure 6 - Full Size Module Dimmensions

Note: 1 in. = 24.5 mm
1 ft. = 0.305 m

Three 10 inch (254 mm) diameter sonotubes, placed vertically, formed the voids for the module. Two smaller 6 inch (152 mm) diameter voids formed with lightweight cardboard were placed inside parallel to the bottom sloping surface of the module. Welded wire fabric, 2 x 2 - 14 x 14 (51 x 51 mm - 2 x 2 mm), stapled to the inside face of the two plywood diaphragms reinforced the sloping sides of the module.

The 1/4 inch (6 mm) thick plywood diaphragms elevated the module 1 inch (25 mm) off the ground to minimize intrusion of runoff water, to decrease the frictional resistance of the barrier during a headon collision and to distribute the forces during a frontal collision.

The module is shown in Figure 7 after being cast from batches Z-I-5 and Z-I-6 and steam cured.

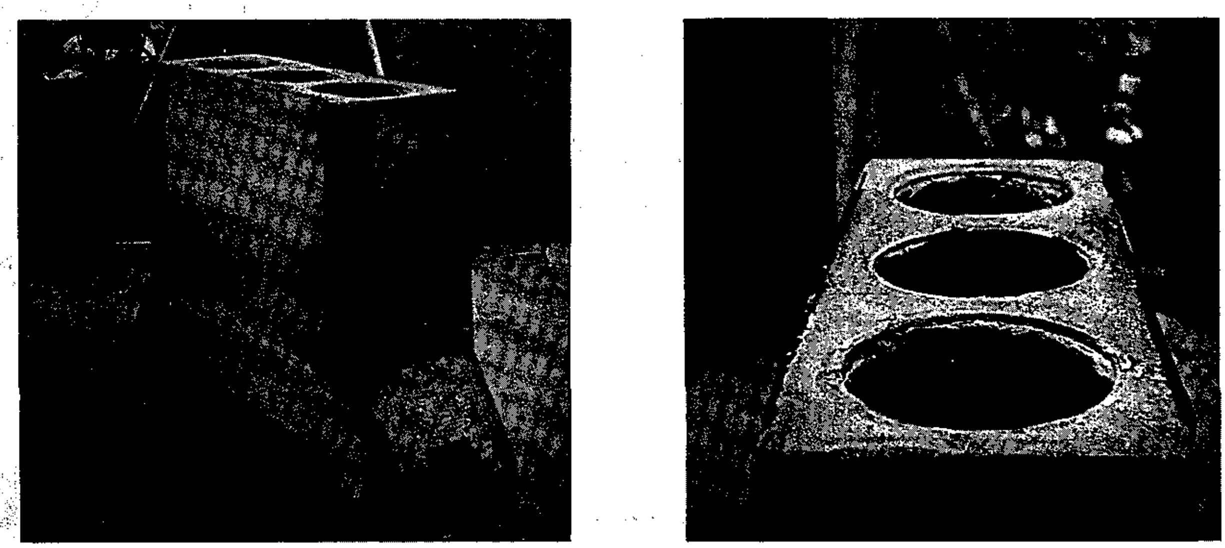


Figure 7 - First Full Size Precast Barrier Module

Some separation occurred between the vermiculite and the plywood diaphragms at the top edges of the barrier. This problem was corrected in the second module by bolting the diaphragms to the sonotube void forms.

The second full size module was built with the same outside dimensions as the first module. In addition to the three primary 10 inch (254 mm) diameter voids, two irregularly shaped voids conforming to the side slopes of the module were used in place of the two 6 inch (152 mm) diameter voids. There was no vermiculite concrete wall between the sonotube voids for the second design. The sonotubes were bolted together. The plywood diaphragms were increased in thickness to 1/2 inch (13 mm) and were also bolted to the sonotube void forms. Plastic spacers used with the bolts maintained clearance between the diaphragms and the sonotubes. The same welded wire fabric used in the first module was used to reinforce the sides of the second full size module. Both modules were cast upside down to attain a better surface finish. Figures 8 through 12 show some components of the forms, the connection details, the void arrangement, and the finish of the second barrier module.

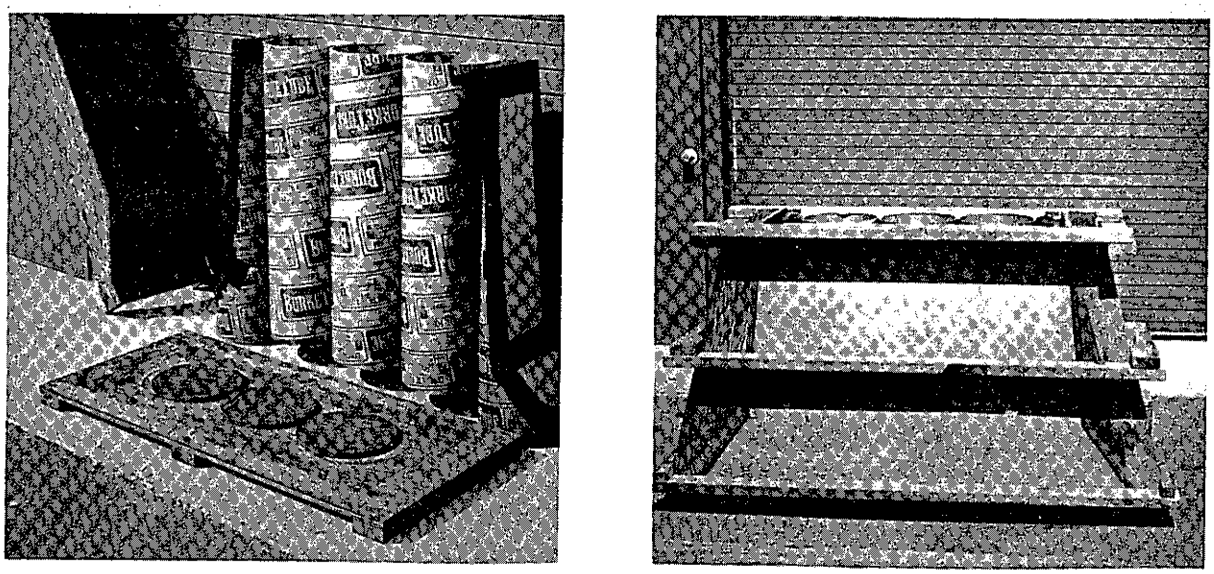


Figure 8 - Forms for Second Full Size Barrier Module

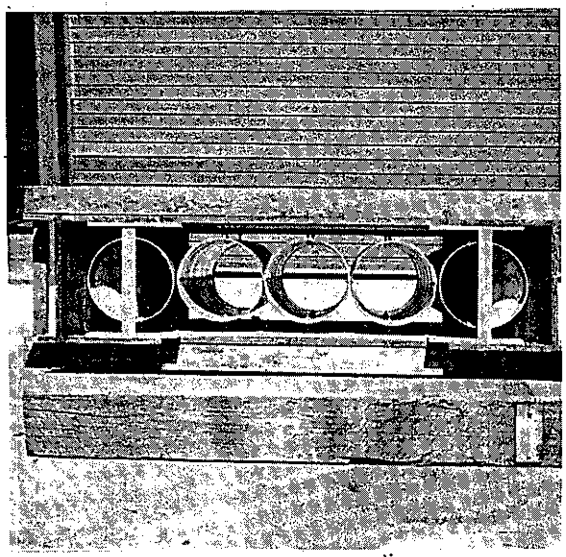


Figure 9 - View Showing Bottom Side of Module

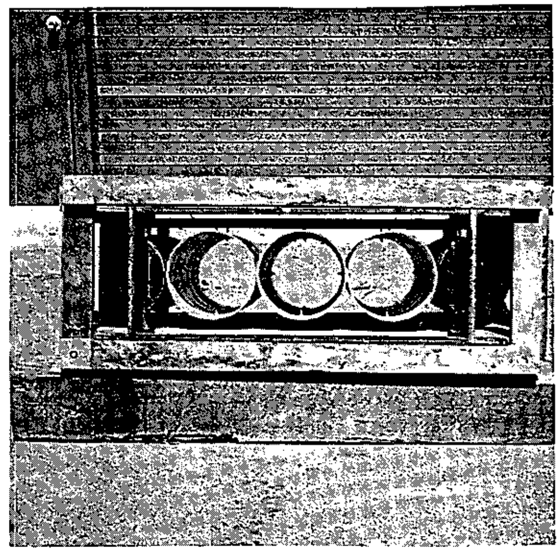


Figure 10 - View Looking at Top of Barrier Module

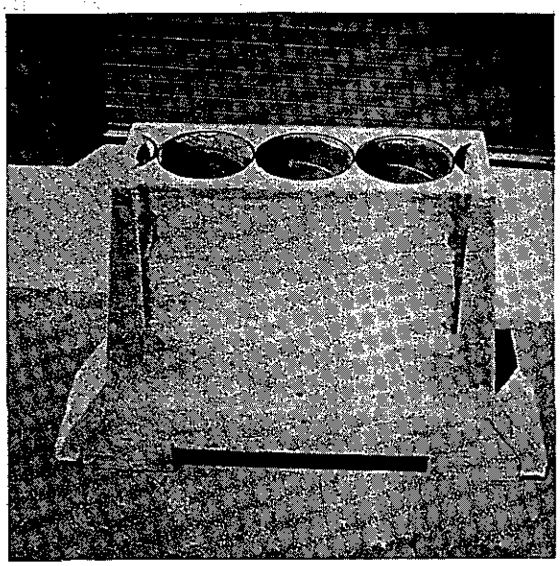


Figure 11 - Completed Barrier Module

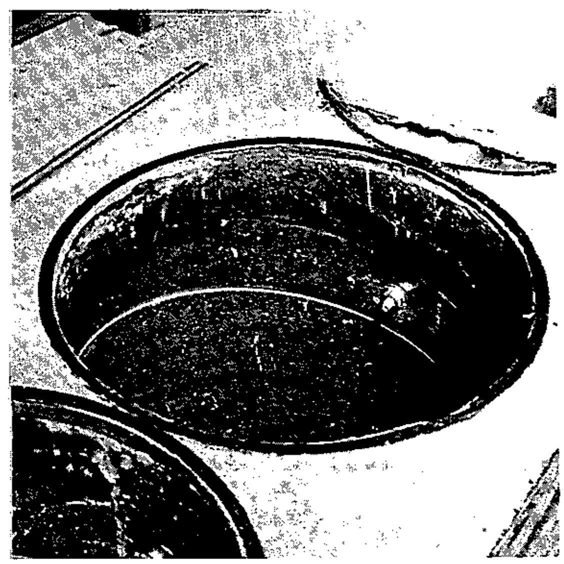


Figure 12 - Closeup View of Top of Barrier Module

Forms were fabricated for a softer full size barrier module with larger voids than the two previous module designs. Sixteen inch diameter sonotubes were bolted together to form the interior voids. The centerline width of this module was increased from 14 to 20 inches (0.36 to 0.51 m) to accommodate the larger void size. The welded wire fabric and other dimensions were essentially the same as those used for the first two modules. Figures 13 through 15 show some of the form work and details for this module. This module was never cast because the project was discontinued.

Figure 13 - Sonotube Void forms

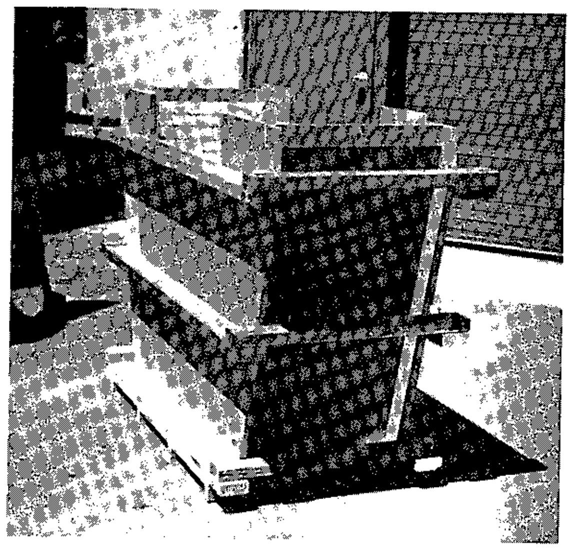


Figure 14 - Module Forms - Upside Down

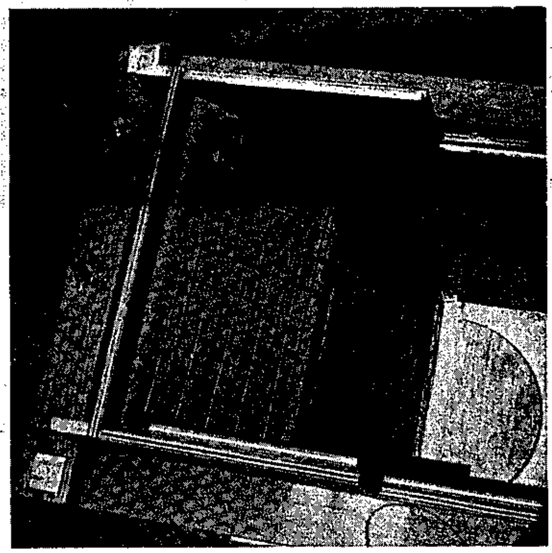


Figure 15 - View of Bottom looking Inside Module Before Placement of Sonotube Void Forms

b. <u>Static Compression Test Results</u>. Both full size modules were statically crushed at a rate of 9 inches (229 mm) per minute by a one million pound (4.45 MN) capacity testing machine, Figure 16.

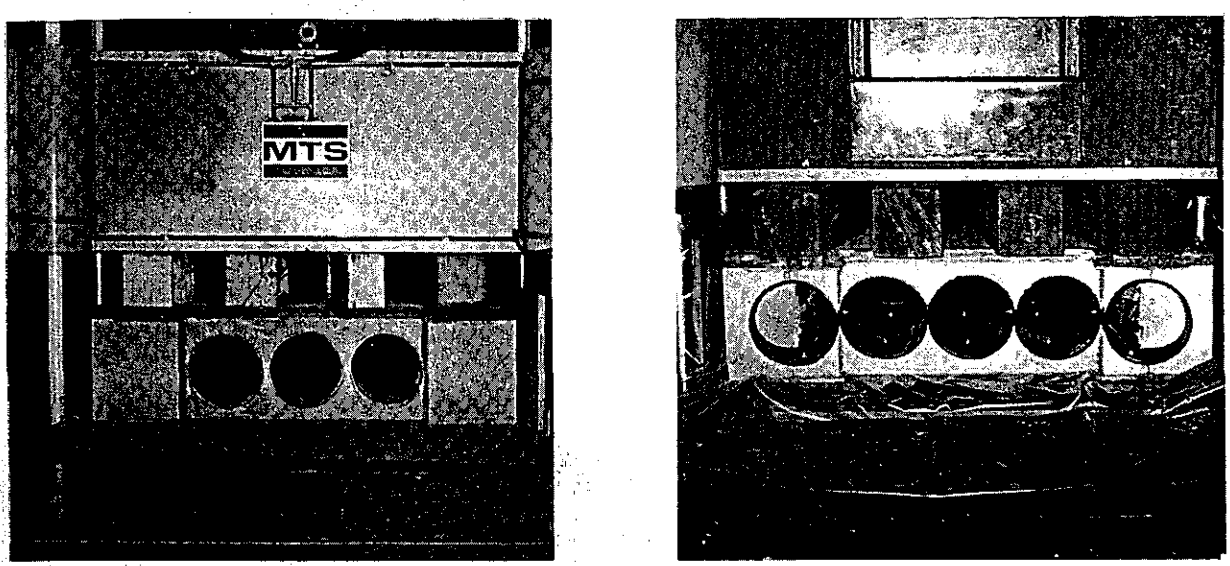
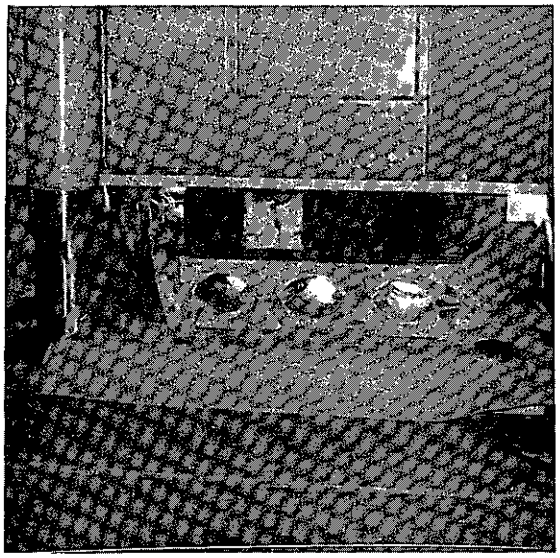
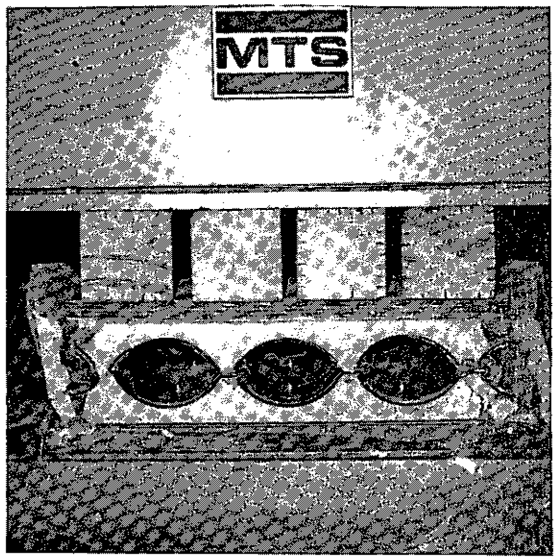


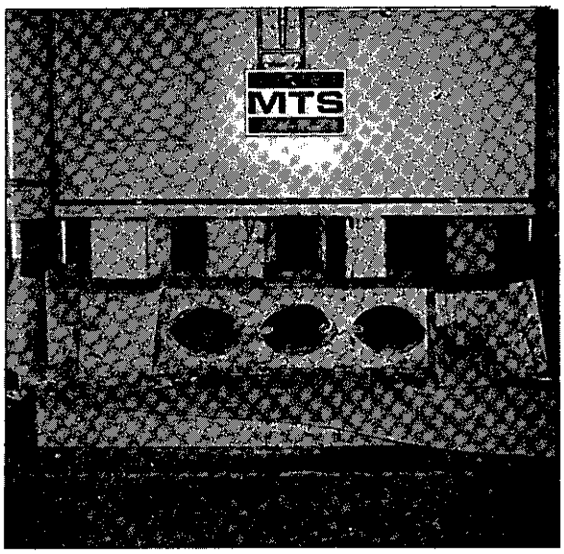
Figure 16 - The First and Second Modules Prior to Compression Tests

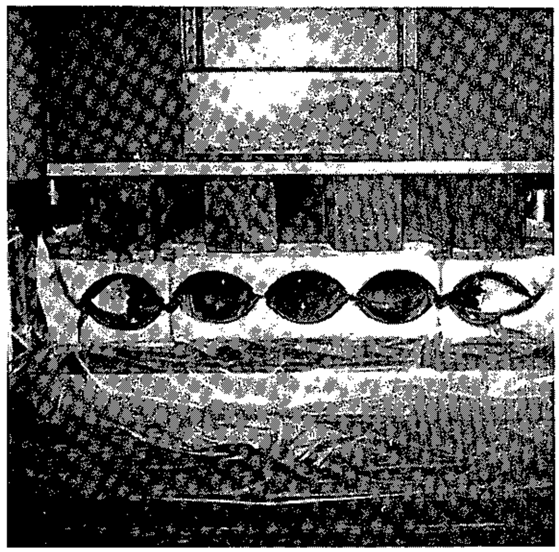
Figure 17 shows the failure modes of the modules during their static compression tests.





Views of Tops of the Modules





Views of Bottoms of Modules

First Module Design

Second Module Design

Figure 17 - Views of Partially Crushed (about 30%) Full Size Modules

Load deflection curves for both modules are presented in Figure 18. At the time the modules were tested, their vermiculite concrete compressive strengths were 56 and 86 psi (386 and 593 kPa) respectively.

Based on areas under the load deflection curves in Figure 17, the static energy absorbed by each module assuming a crush of 8.5 inches (216 mm) was as follows:

First Module Design = 41,210 foot - pounds (55.9 kJ)
Second Module Design = 32,100 foot-pounds (43.5 kJ)

The static energy absorbed by the second module came closest to the anticipated design energy of about 30,000 ft-lbs (40.7 kJ). This module would have been used in the back rows of a crash cushion. More crushable modules, capable of absorbing about 15,000 ft-lbs (20.3 kJ) of static energy, were to be used for the front half of the barrier.

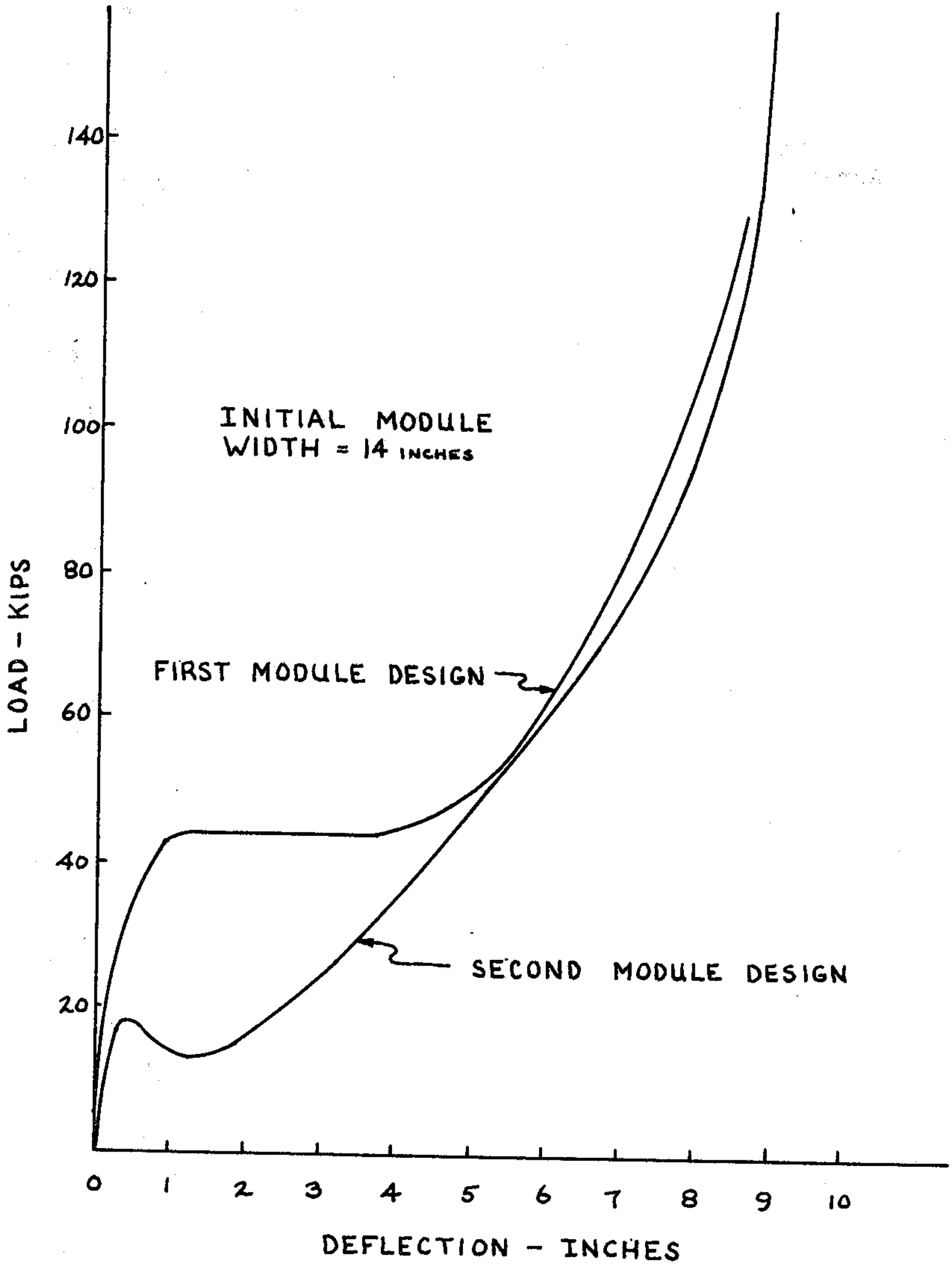


Figure 18 - Load Deflection Curves for Full Size Barrier Modules

Note: 1 kip = 4.45 kN
1 in. = 25.4 mm

IV. REFERENCES

1. Hirsch, T. J., et al, "Test and Evaluation of Vehicle Arresting, Energy Absorbing, and Impact Attenuation Systems," Texas Transportation Institute, Contract No. CPR-11-5851, November 30, 1971.

2. Brown, H. E., "An Investigation of the Delay Period and Related Factors in Steam Cured Concrete," Virginia Council of Highway Investigation and Research, April 1965.

PART TWO: EVALUATION OF VERMICULITE CONCRETE HELICELLS

I. INTRODUCTION

A. Background

Energy absorbing vermiculite concrete cells, termed helicells in this report, were developed by Dynamics Research and Manufacturing Inc. (DRM) of Sacramento, California. The cells were originally intended for use as block-outs in metal beam guardrail. Later they were incorporated into the design of two crash cushions, the Hi-Dri attenuator and the Guardrail Energy Absorbing Terminal (G.R.E.A.T.), as the principal energy absorbing elements.

The attenuators are marketed by Energy Absorption Systems, Inc. (EAS) of Sacramento, California. Development and vehicle impact testing of the attenuators was done jointly by DRM and EAS.

Reports on the development of the helicell applications described above are contained in references 1 to 4. FHWA has approved the use of Hi-Dri and GREAT attenuators on federal aid highways. Staff members of the Transportation Laboratory and other Caltrans engineers witnessed numerous developmental vehicle impact tests on the crash cushions before recommending their use on California highways. At this time a small number of the two attenuators have been installed in California with a number of others planned for future projects.

The Hi-Dri and GREAT attenuators appear to be effective designs. No vehicle impact tests on these designs were conducted or are planned by Caltrans. However, it was decided to do a limited study of the properties of the individual helicells. The results of that study are contained in the Appendix. It was concluded that the helicells might have energy absorbing characteristics dependent on the ambient temperature and the density of the helicells. Hence, a more detailed investigation was conducted. This report describes the results of that investigation.

B. Objectives

This study was designed to:

- Determine the static compressive strength and force-deflection characteristics of helicells.

- Determine the energy-deflection relationships of helicells subjected to drop tests.

- Determine the effects of humidity on the static strength of helicells.

- Determine the effects of hot and cold temperatures on helicells subjected to static strength tests and drop tests.

The results of this study were to be used to:

- Determine whether exposure of helicells to extremes of temperature and humidity changes their effectiveness.

- Provide information needed to estimate the number of helicells needed for installation sites having various design parameters.

- Establish standard tests that can be used for the quality control of helicells.

II. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

Conclusions

Based on laboratory tests vermiculite concrete helicells used as energy absorbing elements in highway crash cushions:

A. Are not sensitive to temperatures from 0° to 150°F (255 to 339 K) when subjected to static load compression tests.

B. Are not affected in static load compression tests by experiencing first a number of temperature cycles from 0° to 150°F (255 to 339 K).

C. Have waterproof coverings of aluminum foil and asphalt which are effective in preventing moisture absorption by the cells in high humidity environments.

D. Show a large decrease in strength if the aluminum foil and asphalt covering are removed and the helicells are then placed in a high humidity environment. This results in a large amount of water being absorbed in the helicells.

E. Exhibit a fairly well defined band of load vs. deflection curves plotted from static load compression test data.

F. Have deflection vs. energy consumed curves that are fairly similar for both static and dynamic (drop weight) compression tests, and agree with average values plotted from vehicle impact tests.

G. Have close dimensional tolerances but widely varying weights.

Recommendations and Implementation

A. The manufacturer should be encouraged to maintain strong quality control procedures.

B. User agencies should verify that quality control procedures are being adequately maintained.

III. TECHNICAL DISCUSSION

A. Description of Helicells

Helicells used in Hi-Dri attenuators are cylinders of molded vermiculite concrete having a hollow core (Figure 1). They have dimensions of approximately 7 inches (178 mm), outside diameter, 2 1/2 inches (63.5 mm), inside diameter, and 11 1/2 inches (292 mm), length and a mass of about 5.5 to 6.5 lbs. (2.5 to 3.0 kg).

The manufacturing process for the helicells is as follows:

1. Aluminum foil wrap of a constant width is cut to a standard length, pleated transversely at intervals, then rolled into a cylindrical shell.

2. The spiral reinforcing cage is constructed in two steps.

   a. Galvanized wire, 16 ga. (1.6 mm), is wrapped automatically around a revolving steel mandrel. A variable speed motor turns the steel drum to control the spacing of the wire wrap.

   b. Two lengths of galvanized wire are manually spot welded longitudinally across the spiral reinforcing cage.

3. The aluminum foil cylinder is opened slightly at its pleats and placed over the reinforced wire cage on the mandrel. The pleats are then closed tightly around the wire cage. The completed reinforced aluminum foil cylinders are stacked on pallets.

Although the wire cages are intended to have a specific spiral wire spacing, this spacing is sometimes disturbed when vermiculite concrete is placed inside the wire cages. Removal of the aluminum foil wrap on some test samples disclosed skewed and overlapping wires.

4. A vermiculite concrete mix is placed inside the reinforced aluminum foil cylinders. The mix is composed of vermiculite aggregate, portland cement, water, and plaster. (Liquid asphalt was included in the mix originally but is no longer used. It was included in samples 1 to 60 and X-1 to X-5 described in this report.) A 2-1/2-inch (63.5 mm) diameter hole is punched longitudinally through the cells while the vermiculite concrete is still wet. This hole allows the vermiculite cylinder to dry faster when the cells are placed into drying ovens. The reinforced vermiculite cells are stacked on pallets.

5. After casting, the vermiculite cells are allowed to dry approximately 6 to 7 hours before they are placed into drying ovens. The suppliers of the vermiculite aggregate contend the vermiculite concrete is more stable and performs more uniformly when 80% of the moisture is removed.

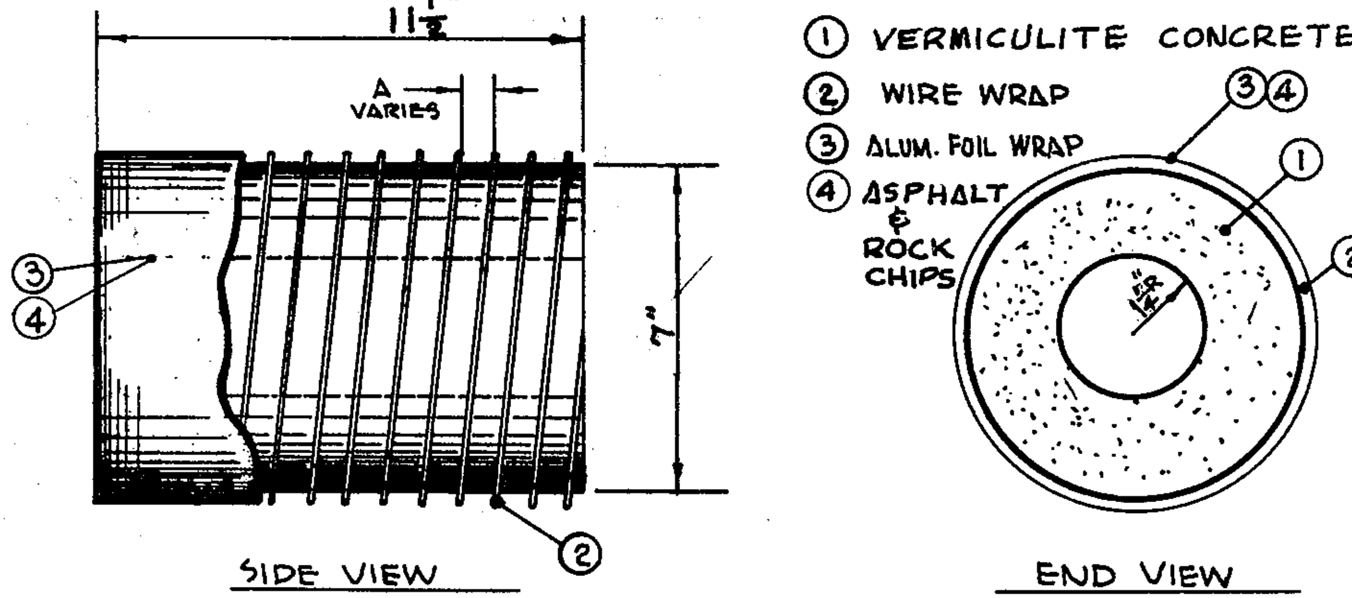
6. Two pallets of cells are stacked in each of two drying ovens. The cells are dried for 24 hours, then they are taken out of the ovens and cooled.

7. Next, the ends of each cell are capped. The ends are dipped into a hot asphalt mix, then forced into a mandrel, shaped like the ends of the cylinders, containing a circular aluminum foil cap. The aluminum foil cap adheres to the cell by sticking to the liquid asphalt mix.

8. Finally, the capped cells are again rolled in the liquid asphalt mix, excluding the ends, and then rolled in a bin of aggregate chips. This fine aggregate protects the asphalt coating on the cells.

In the Hi-Dri attenuator, helicells are grouped into cartridges (Figure 2). Each cartridge consists of up to 12 helicells glued to three plywood retainer panels. The helicells mounted on the retainer panels are placed in waterproofed cardboard cartons. The cartons are then taped closed, painted, and labeled. Handling straps are stapled to each cartridge to aid both the workmen in shipping the cartridges and those who assemble the Hi-Dri attenuator at the construction site. Eight to ten of these packaged cartridges are inserted in the structural framework of the Hi-Dri attenuator (Figure 3). The GREAT attenuator has similar cartridges, but the helicells are shorter.

Eighty six helicells for Hi-Dri attenuators were obtained from the manufacturer for test evaluation in the Fall of 1973. These samples were selected from the manufacturer's stock and are assumed to be representative of standard production helicells. The samples were labeled, weighed, and measured. Sample masses varied from a minimum of 5.25 lbs. (2.38 kg) to a maximum of 7.23 lbs. (3.28 kg). Sample heights and diameters were very consistant at 0.96± .01 ft. (293±3 mm) and 0.60± .01 ft. (152±3 mm) respectively. The GREAT attenuator had not been developed at the time the above samples were taken.



1 in = 25.4 mm

HI-DRI HELICELL

FIGURE 1

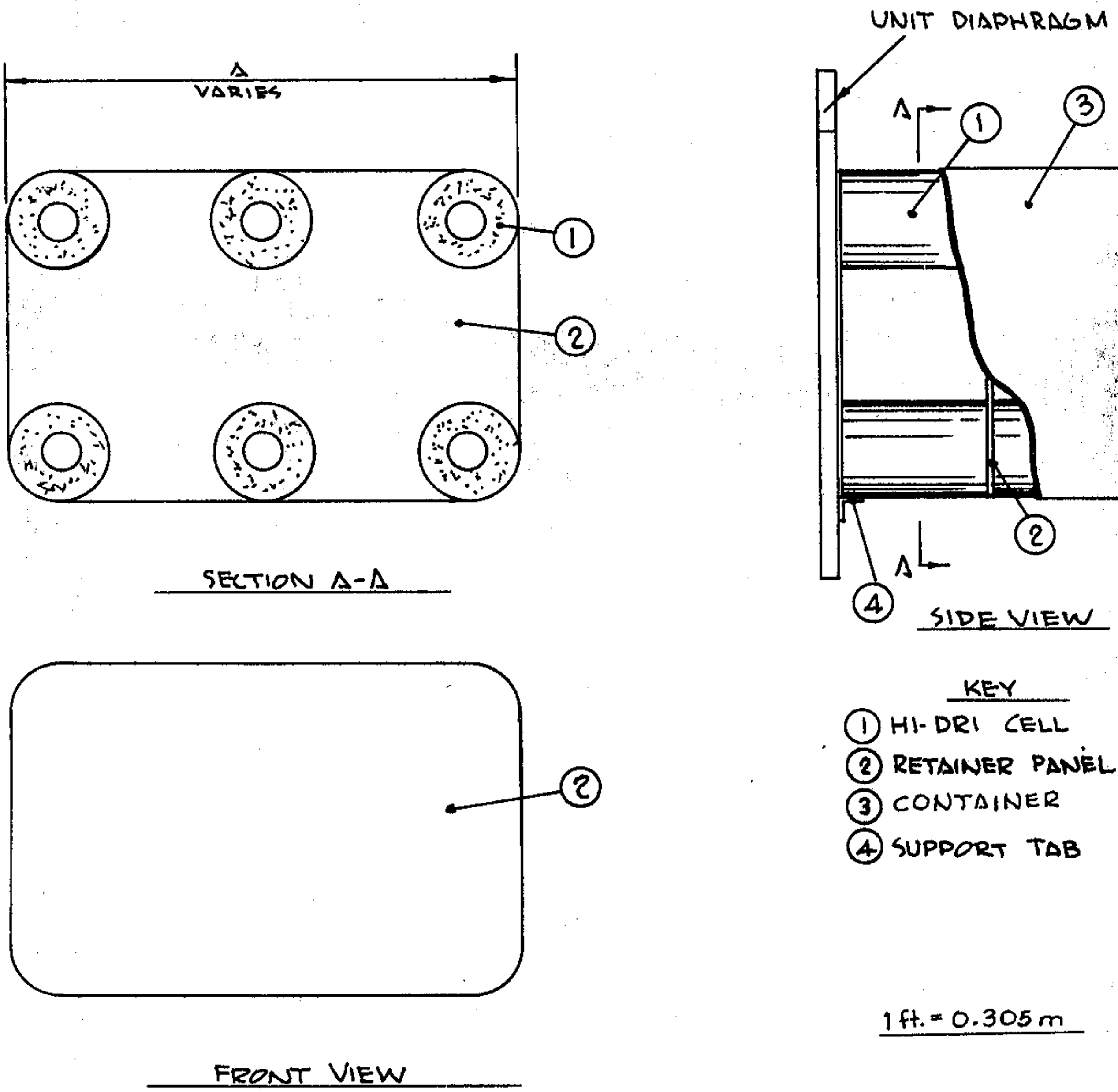
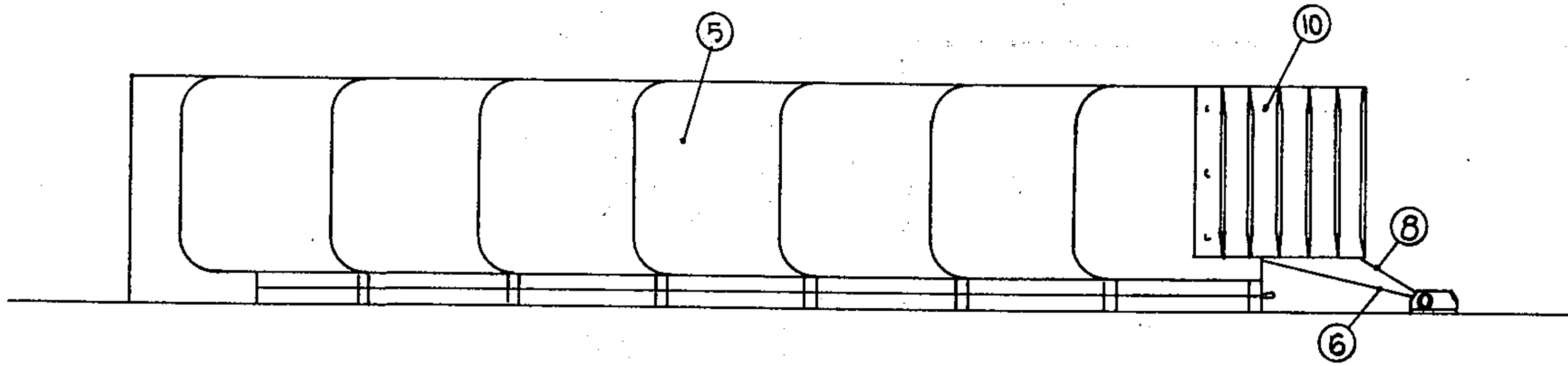
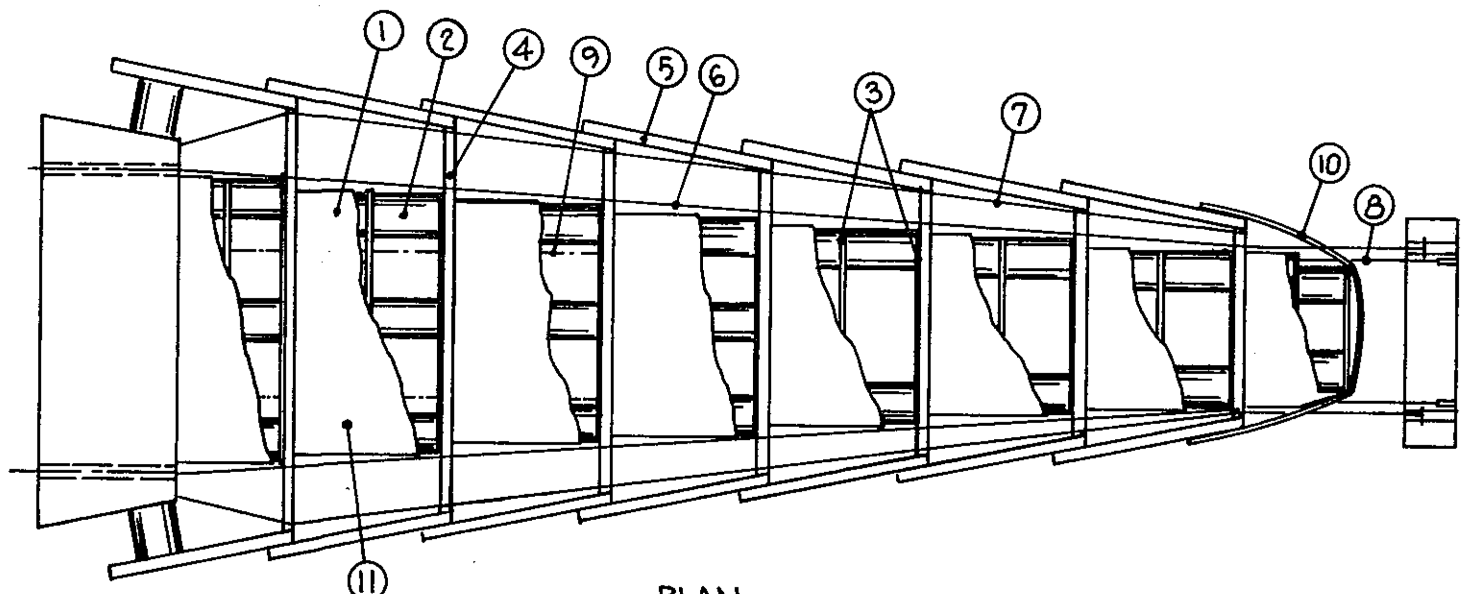


FIGURE 2

CARTRIDGE



ELEVATION



PLAN

KEY

① HI-DRI CELL CARTRIDGE
② HI-DRI CELL
③ RETAINER PANELS
④ DIAPHRAGMS
⑤ FENDER PANELS
⑥ RESTRAINING CABLES
⑦ PULL-OUT CABLES
⑧ SECONDARY CABLES
⑨ SLIDE STRAPS
⑩ SAFETY-FLEX BELT
⑪ CONTAINER

FIGURE 3
IMPACT ATTENUATOR WITH HELICELL CARTRIDGES

B. Test Description

To achieve the objectives of this study, the following five phases of testing were established. The test results for each of the five phases is included in Section II.C, Test Results of this report.

1. Static Load Compression Tests

Six tests were conducted to determine the static compressive strength and force-deflection characteristics of standard helicells. These tests were performed on randomly selected helicells at the standard laboratory ambient temperature of 73°F (296 K).

A 60 kip (267 kN) Baldwin Testing Machine was used with 12 in. (305 mm) diameter compression discs and a fixed head. The rate of load was 2 in. (51 mm)/min. (load scale setting of 15), and the indicator dial setting was 12 kips (53.4 kN). Load readings were taken for each 0.05 ft. (15 mm) of sample deflection up to a maximum deflection of 0.6 ft. (183 mm). Deflection readings were taken at loads of 500 and 1000 lbs. (2.22 and 4.45 kN) and at each 100 lb. (445 N) load increment thereafter.

2. Fog Room Tests

Twelve tests were conducted to determine the effects of humidity on the static compressive strength of helicells. Randomly selected helicells were conditioned in a fog room at a controlled temperature of 73°F (296 K) and a relative humidity of 100%. Two samples each were conditioned for periods of 1, 3, 7, 14 and 28 days; and two additional samples were conditioned for 28 days with the sealed aluminum foil coverings removed. Following the conditioning, each sample was measured, weighed and subjected to static compression testing following the procedure outlined in Section III. B. 1, Static Load Compression Tests.

3. Temperature Sensitivity Tests

Nine tests were conducted to determine the effects of hot and cold temperatures on the static compressive strength of helicells.

Three samples each were conditioned for a period of three days at temperatures of 0°F (255 K), 75°F (297 K), and 150°F (339 K). The 0°F (255 K) samples were conditioned in a cold room at a constant temperature of 0°F±2°F (255±256 K). The 75°F (297 K) samples were conditioned in a Lab Line Controlled Environmental Chamber at 75°F (297 K) and 50% relative humidity. The 150°F (339 K) samples were conditioned in a Blue-M air circulating oven set at 150°F (339 K). Following the conditioning, each sample was measured, weighed and subjected to static compression testing following the procedure outlined in Section III.B.1. Static Load Compression Tests.

4. Temperature Cycle Tests

Three tests were conducted to determine the effects of cyclic temperature exposure on the static compressive strength of helicells.

Randomly selected helicells were subjected to 20 alternating 2 hour exposure cycles at 0°F (255 K) and 150°F (339 K). The 150°F (339 K) exposure was in a Blue-M air circulating oven. The 0°F (255 K) exposure was in a Missimers Cold Box with a Leeds and Northrup Speedomax Recorder. Following the 20 cycles of exposure, the samples were returned to room temperature, 73°F (296 K), measured, weighed, and subjected to static compression tests following the procedure outlined in Section III.B.1., Static Load Compression Tests.

5. Dynamic Load Compression Tests

Thirty-four tests were conducted to determine the energy-deflection relationship of helicells subjected to dynamic impact by a falling weight. The samples were divided into three test temperature ranges 0°F (255 K), 75°F (297 K) and 150°F (339 K).

The apparatus used for the dynamic tests consisted of a 30 ft. (9.1 m) tower, an electric hoist, and a manually released free falling mass (Figure 4). Three masses were used, i.e.: 119 lb. (54 kg), 247 lb. (112 kg), and 366 lb. (166 kg), at varying heights of 4.2 ft. (1.3 m) to 29.5 ft. (9.0 m), to achieve the desired impact for different values of kinetic energy. The drop heights were measured from the top of the sample to the bottom of the weight. With a test sample centered on the impact platen, the weight was raised to the desired height by the electric hoist, then manually released to free fall and impact the test specimen. It was difficult to release the weight at precise heights because the height marks had to be viewed from the ground. The drop weight velocity and sample deflection were calculated from high speed cinematography obtained with a Photosonics 1-B camera operating at a speed of 300($\pm$) frames per second. One thousand timing pips per second were simultaneously exposed on the film using an Adtrol Timing Pulse Generator. Data reduction was accomplished on a Vanguard Motion Analyzer. Still photos and final deflection measurements completed the data collection.

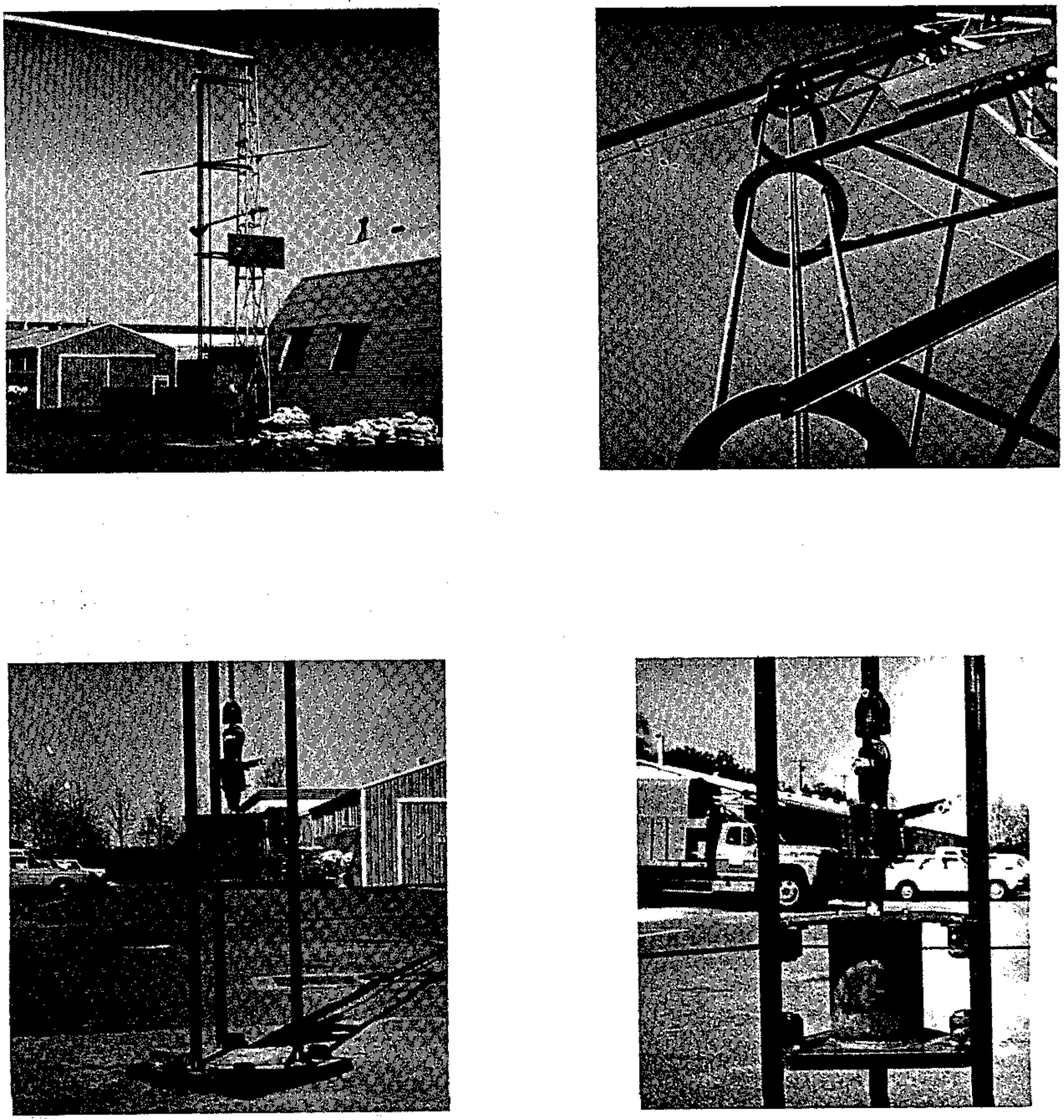


Figure 4 - Dynamic Test Apparatus

C. Test Results

1. Static Load Compression Tests

Six randomly selected helicells were subjected to static load compression testing as outlined in Section III.B.1. of this report. Table 1 tabulates the physical properties of the samples.

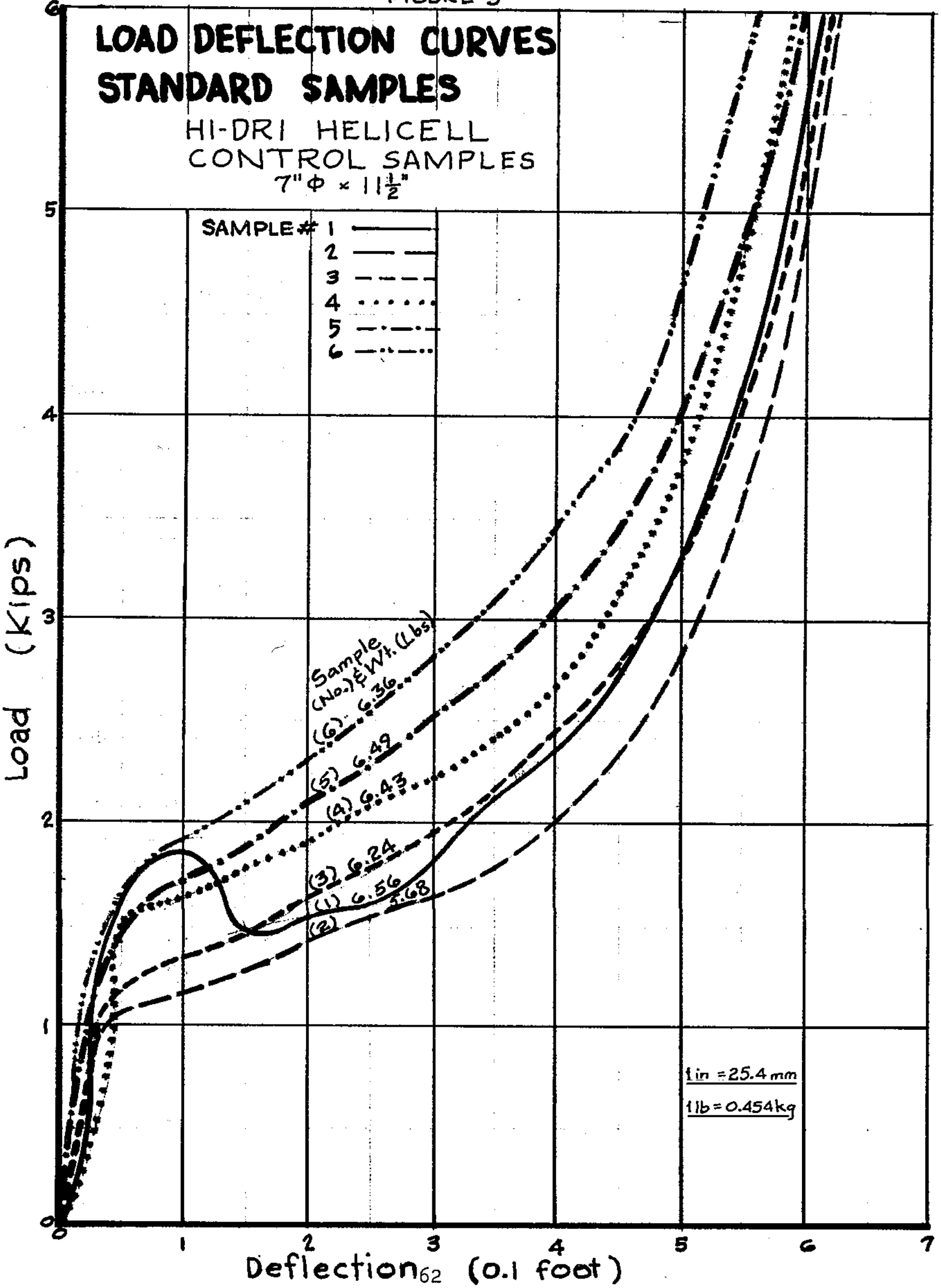
Table 1*

Sample No.	Weight (lb.)	Height (ft.)	Diameter (ft.)
1	6.56	0.96	0.61
2	5.68	0.96	0.60
3	6.24	0.96	0.60
4	6.43	0.96	0.60
5	6.49	0.96	0.61
6	6.36	0.96	0.60

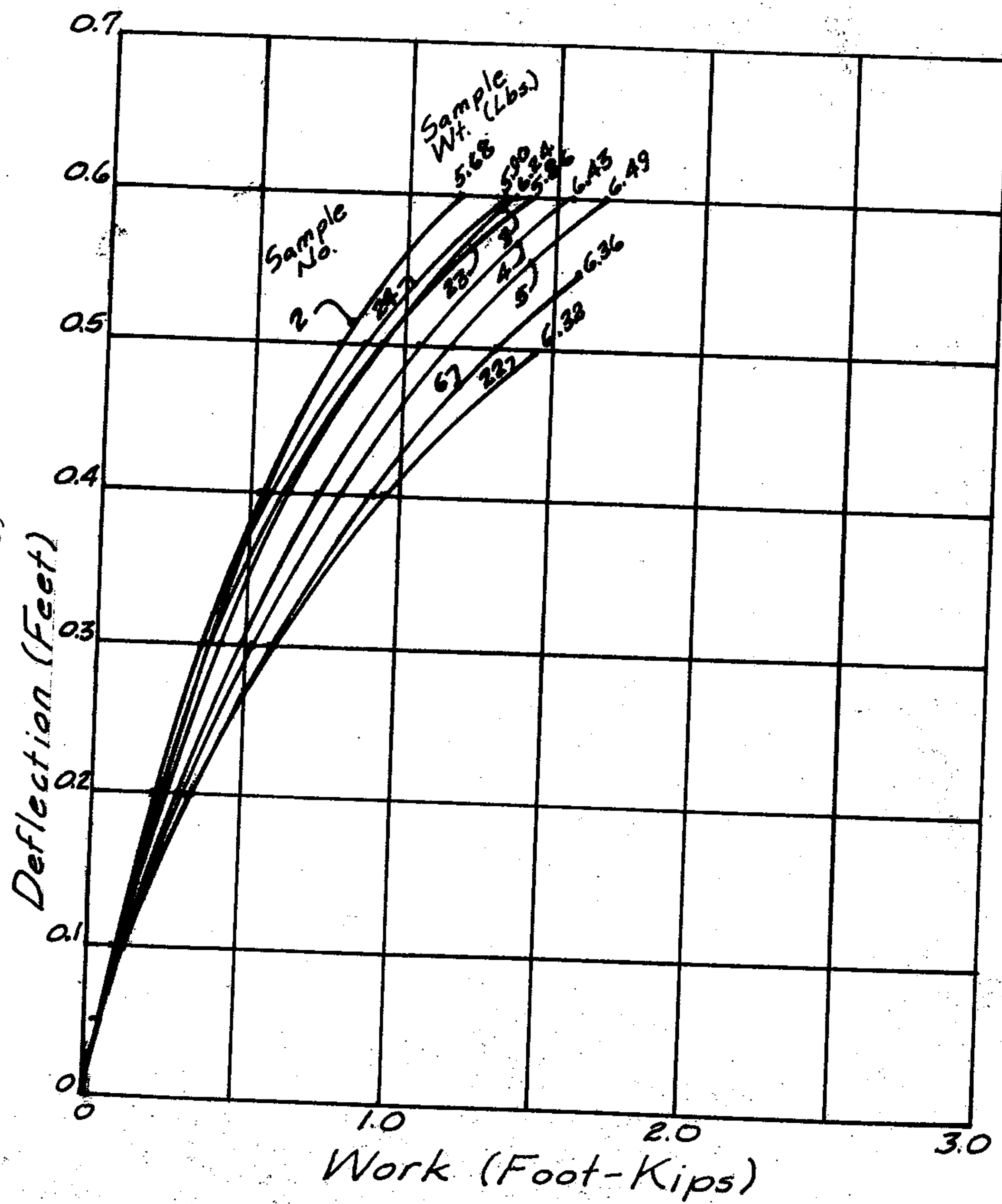
*1 lb. = 0.454 kg
1 ft. = 305 mm

Figure 5 contains the load vs. deflection curve for each sample. Figure 6 contains the deflection vs. energy absorbed curves. Sample 1 was excluded because of its erratic load vs. deflection curve. Samples 22-24 from the temperature sensitivity test series were included because they were tested at 75°F (297 k). Figure 7 shows the samples after the static compression tests were completed. All samples were compressed 0.6 ft. (183 mm).

FIGURE 5



LOAD DEFLECTION CURVES
STANDARD SAMPLES
HI-DRI HELICELL
CONTROL SAMPLES
7" Φ × 11½"
SAMPLE # 1
2
3
4
5
6
Sample (No.) & Wt. (Lbs)
(6) 6.36
(5) 6.49
(4) 6.43
(3) 6.24
(1) 6.56
(2) 5.68
1in = 25.4 mm
1lb = 0.454kg
Load (Kips)
Deflection (0.1 foot)
0
1
2
3
4
5
6
7



Work Done to Compress Hi-Dri Helicells Statically at 75°F

Figure 6

Helicells 7" Φ × 11½"

1 in = 25.4 mm

1 ft = 0.305 m

1 lb = 0.454 kg

1 ft-kip = 1.36 kJ

°K = (°F + 460) ÷ 1.8

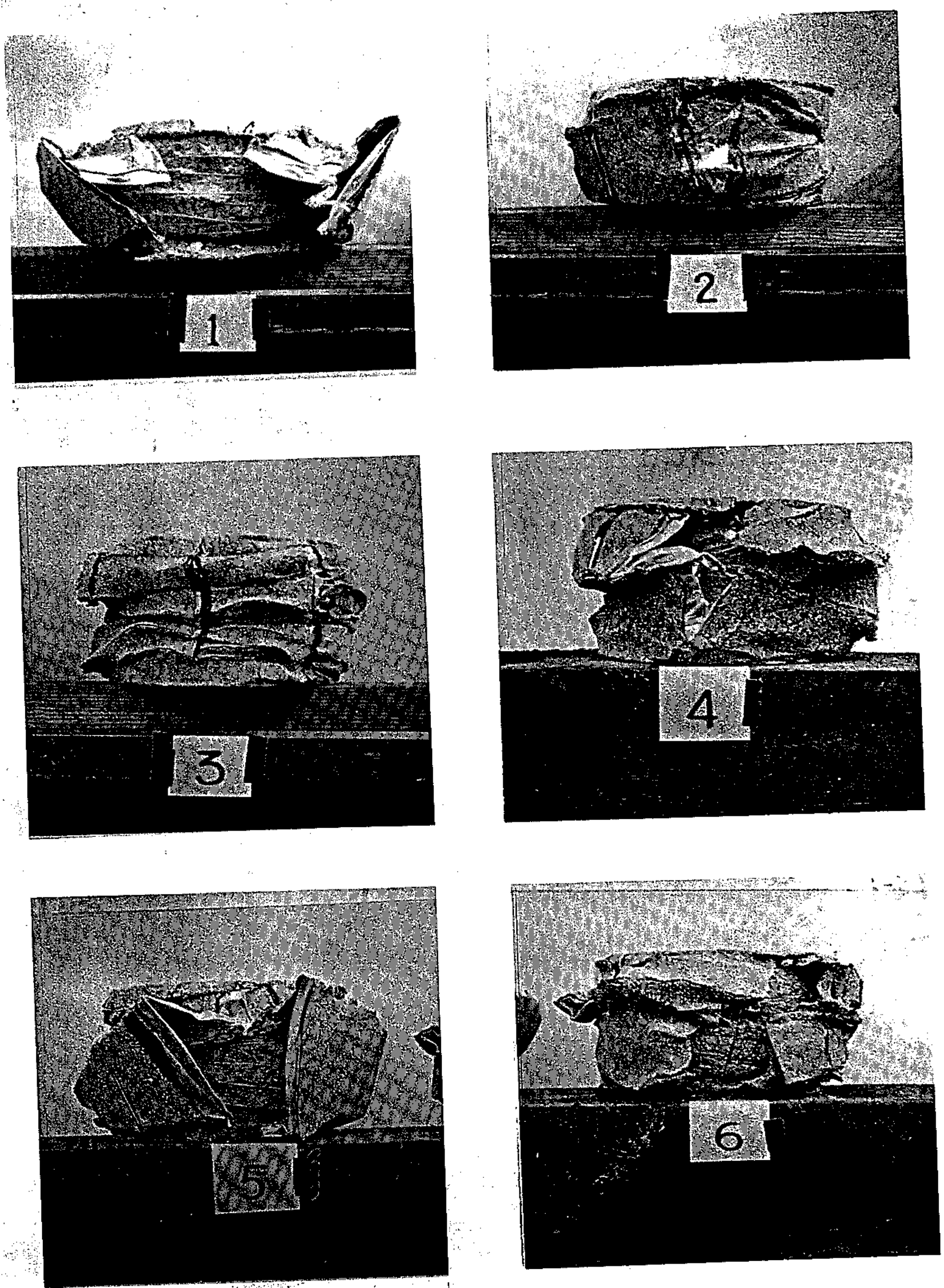


Figure 7 - Helicell Control Samples - Compression Tests

2. Fog Room Tests

Twelve randomly selected helicells were conditioned and tested as outlined in Section III.B.2. of this report. Table 2 tabulates the physical properties of the samples.

Table 2**

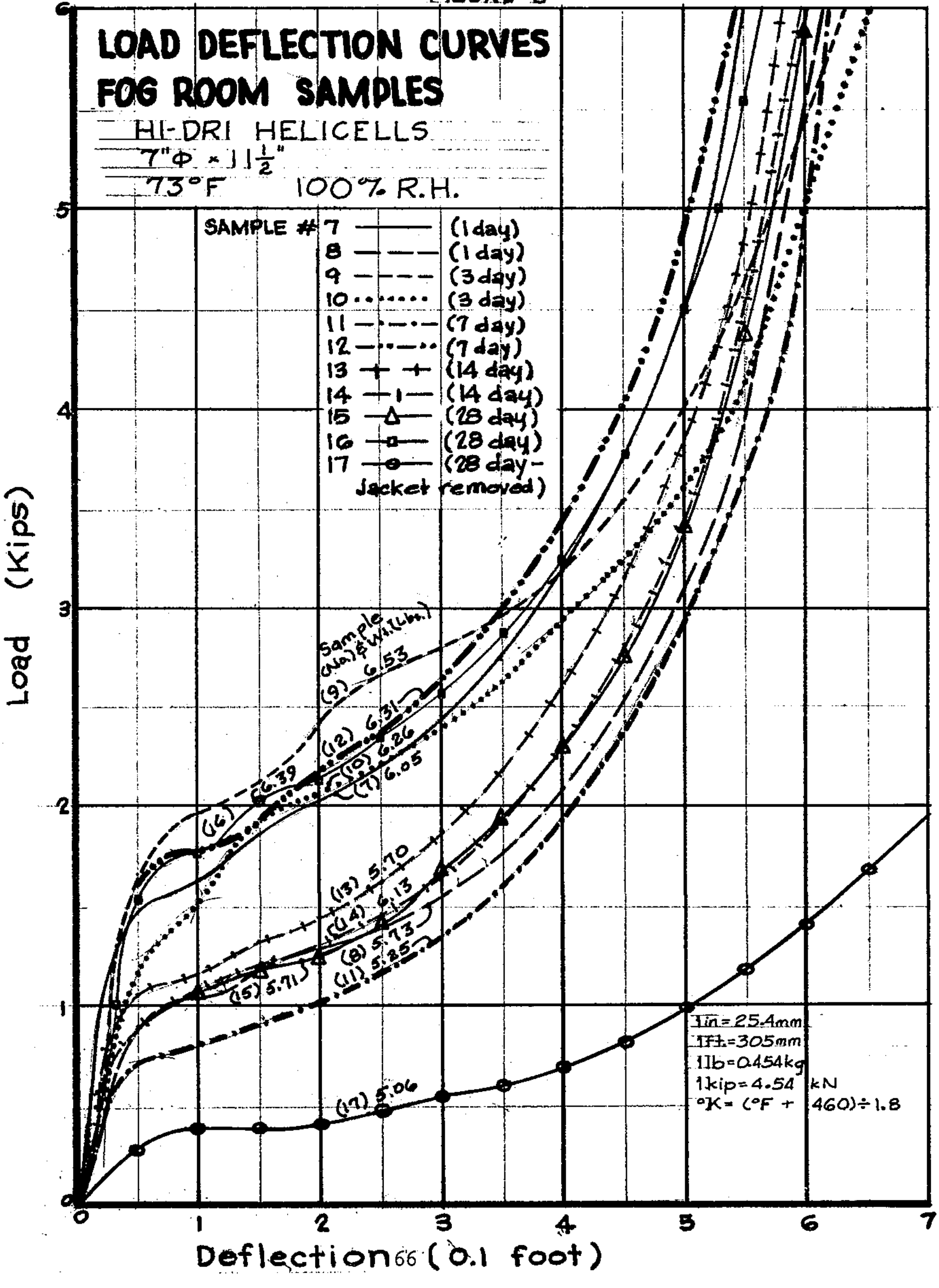
Sample No.	Days in Fog Rm.	Weight (lb.) Dry	Wet	Height (ft.)	Diameter (ft.)
7	1	6.05	6.07	0.97	0.60
8	1	5.73	5.75	0.96	0.60
9	3	6.53	6.56	0.96	0.61
10	3	6.26	6.28	0.96	0.60
11	7	5.25	5.27	0.95	0.60
12	7	6.31	6.34	0.97	0.60
13	14	5.70	5.73	0.95	0.60
14	14	6.13	6.16	0.96	0.59
15	28	5.71	6.51	0.95	0.60
16	28	6.39	6.41	0.97	0.60
17	28*	5.06	14.65	-	-
18	28*	4.36	12.09	-	-

*Samples 17 and 18 were stripped of their protective aluminum foil covering before placement in the fog room.

**1 lb. = 0.454 kg; 1 ft. = 305 mm

Figure 8 contains the load vs. deflection curve for each of the samples. Figures 9 and 10 show the samples after the static compression tests.

FIGURE 8


LOAD DEFLECTION CURVES
FOG ROOM SAMPLES
HI-DRI HELICELLS
7"Φ × 11½"
73°F 100% R.H.
SAMPLE #
7 (1 day)
8 (1 day)
9 (3 day)
10 (3 day)
11 (7 day)
12 (7 day)
13 (14 day)
14 (14 day)
15 (28 day)
16 (28 day)
17 (28 day - Jacket removed)
Load (Kips)
Deflection (0.1 foot)
1in = 25.4mm
1Ft = 305mm
1lb = 0.454kg
1kip = 4.54 kN
°K = (°F + 460) ÷ 1.8

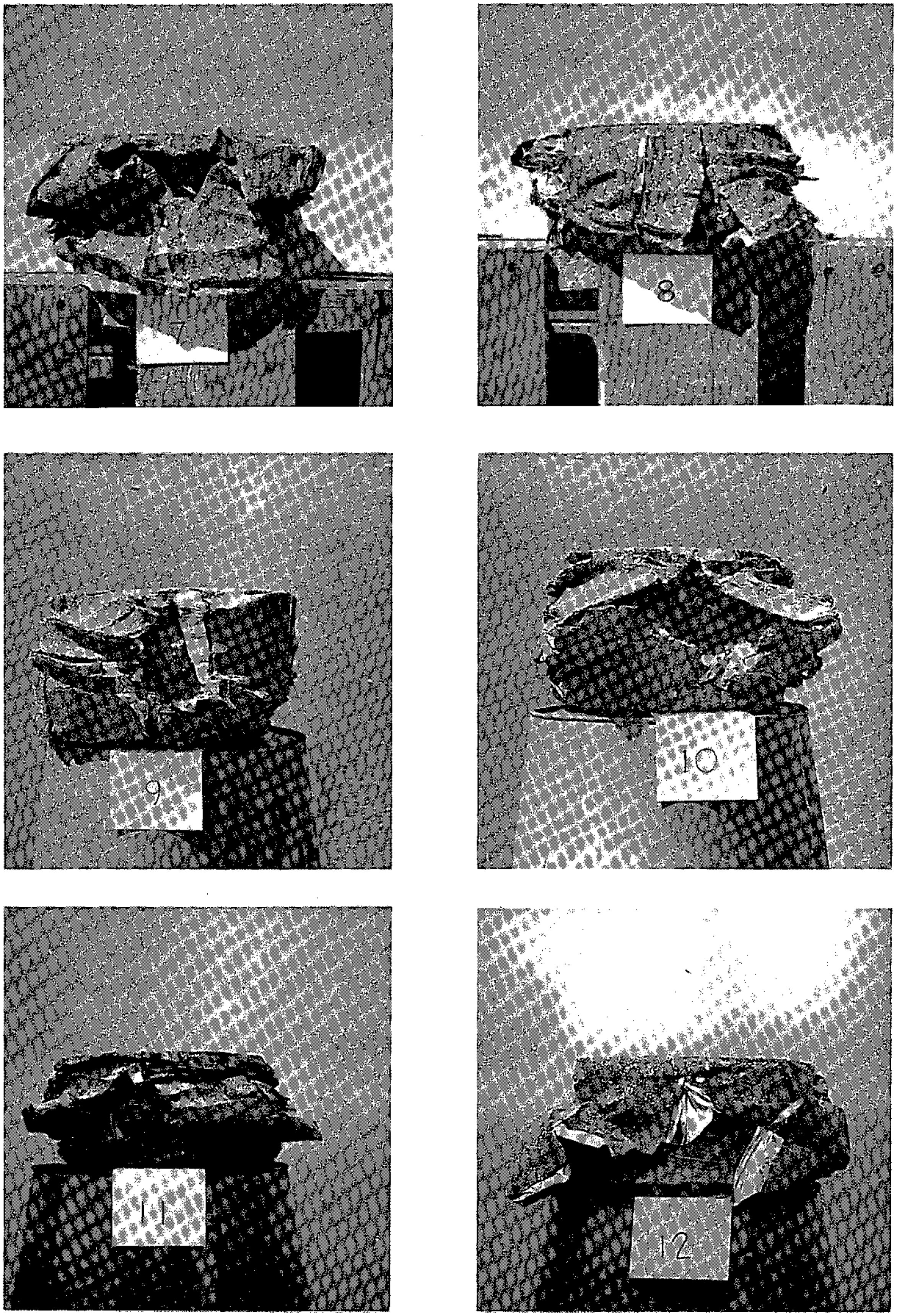


Figure 9 - Fog Room Test Samples (73°F, 100% Relative Humidity)

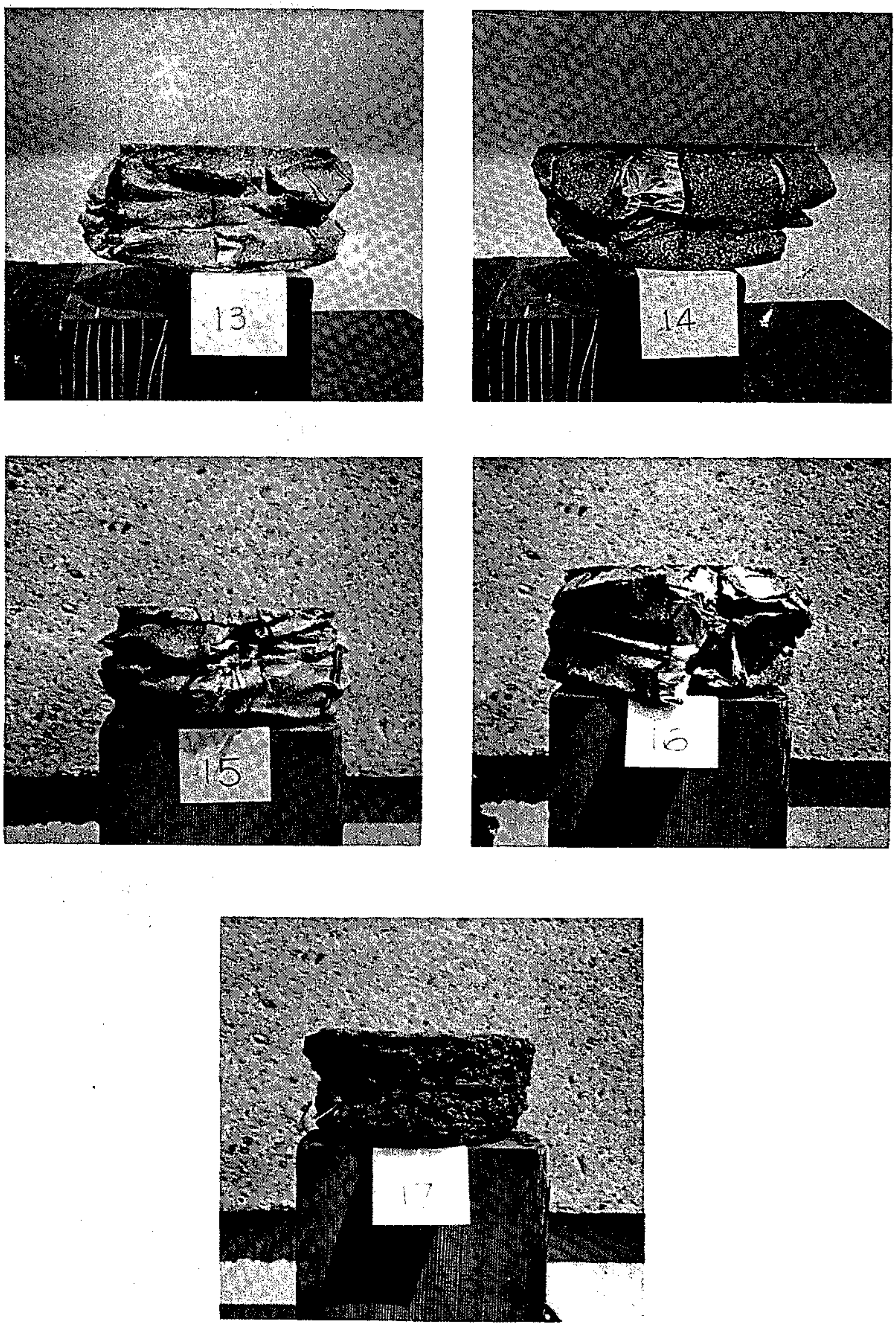


Figure 10 - Fog Room Test Samples (73°F, 100% Relative Humidity)

3. Temperature Sensitivity Tests

Nine randomly selected helicells were conditioned and tested as outlined in Section III.B.3. of this report. Table 3 tabulates the physical properties of the samples. There was no significant change in these properties after the conditioning period.

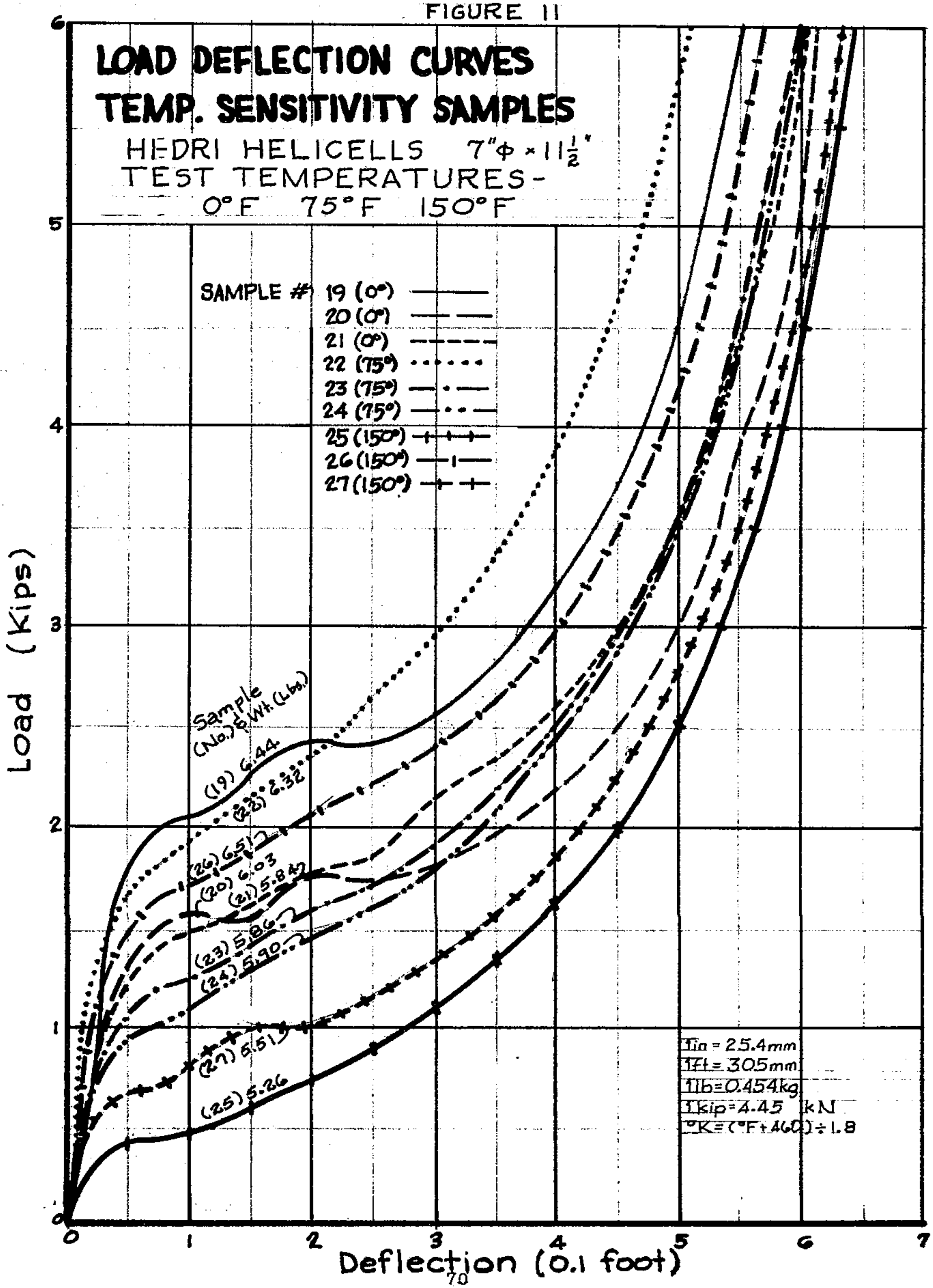
Table 3*

Sample No.	Conditioning Temperature (Degrees F.)	Weight (lb.)	Height (ft.)	Diameter (ft.)
19	0°	6.44	0.96	0.61
20	0°	6.03	0.96	0.59
21	0°	5.84	0.96	0.60
22	75°	6.32	0.96	0.60
23	75°	5.85	0.96	0.60
24	75°	5.90	0.97	0.60
25	150°	5.26	0.95	0.60
26	150°	6.51	0.96	0.60
27	150°	5.51	0.96	0.60

*Degrees K = (°F +460)/1.8
1 lb. = 0.454 kg
1 ft. = 305 mm

Figure 11 contains the load vs deflection curve for each of the samples. Figure 6 contains the deflection vs energy absorbed curves for samples 22, 23, and 24. Figures 12 and 13 show the samples after the static compression tests.

FIGURE 11


LOAD DEFLECTION CURVES
TEMP. SENSITIVITY SAMPLES
HEDRI HELICELLS 7"φ × 11½"
TEST TEMPERATURES -
0°F 75°F 150°F
SAMPLE # 19 (0°)
20 (0°)
21 (0°)
22 (75°)
23 (75°)
24 (75°)
25 (150°)
26 (150°)
27 (150°)
Sample (No.) & Wt. (Lbs.)
(19) 6.44
(22) 6.32
(26) 6.51
(20) 6.03
(21) 5.84
(23) 5.86
(24) 5.90
(27) 5.51
(25) 5.26
1in = 25.4mm
1ft = 305mm
1lb = 0.454kg
1kip = 4.45 kN
°K = (°F + 460) ÷ 1.8
Load (Kips)
Deflection (0.1 foot)
0
1
2
3
4
5
6
7

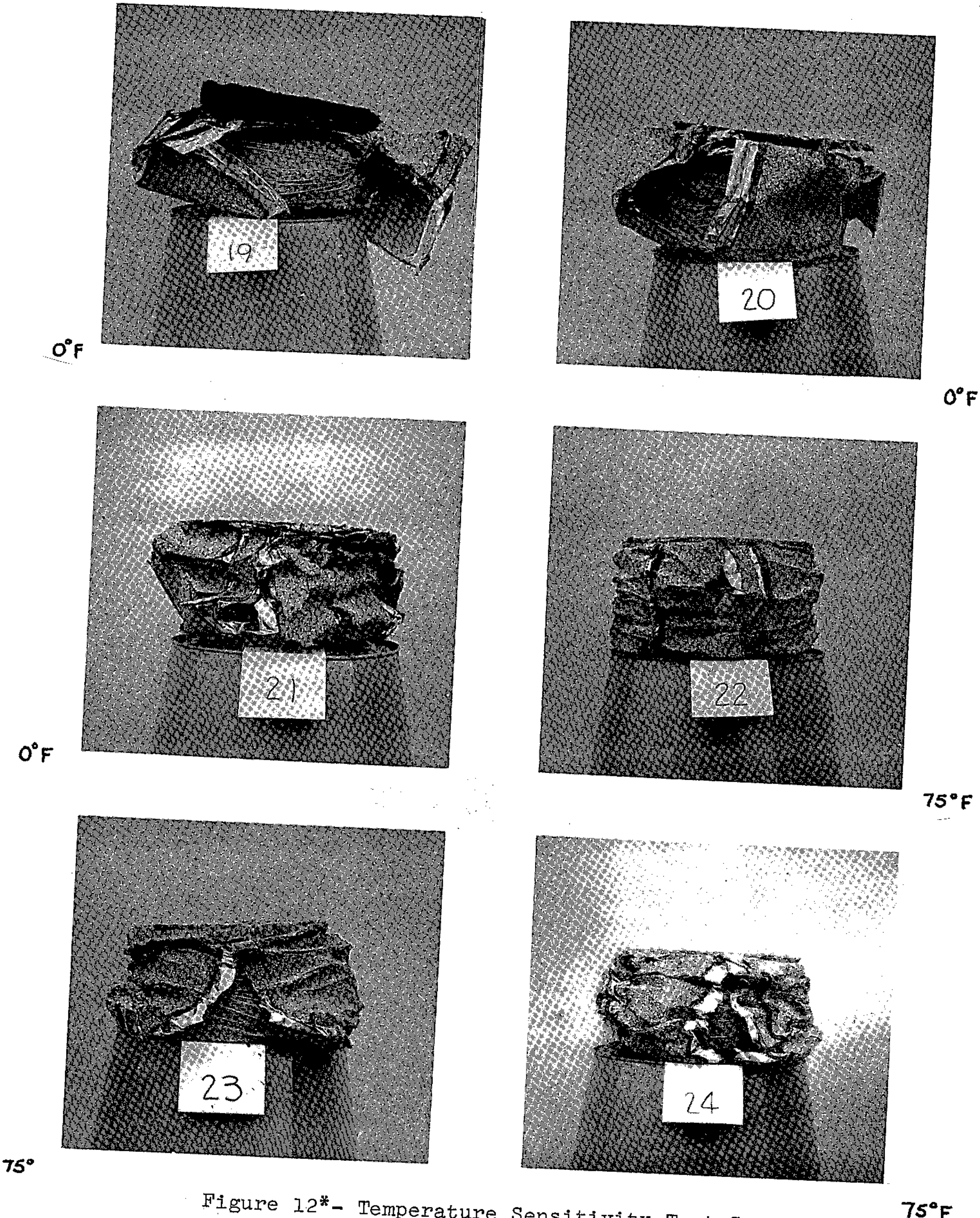


Figure 12*- Temperature Sensitivity Test Samples

*Degrees K = (°F+460)/1.8

150°F

150°F

150°F

Figure 13*- Temperature Sensitivity Test Samples

*Degrees K = (°F+460)/1.8

4. Temperature Cycle Tests

Three randomly selected helicells were conditioned and tested as outlined in Section III.B.4. of this report. Table 4 tabulates the physical properties of these samples. There was no significant change in these properties after the conditioning period.

Table 4*

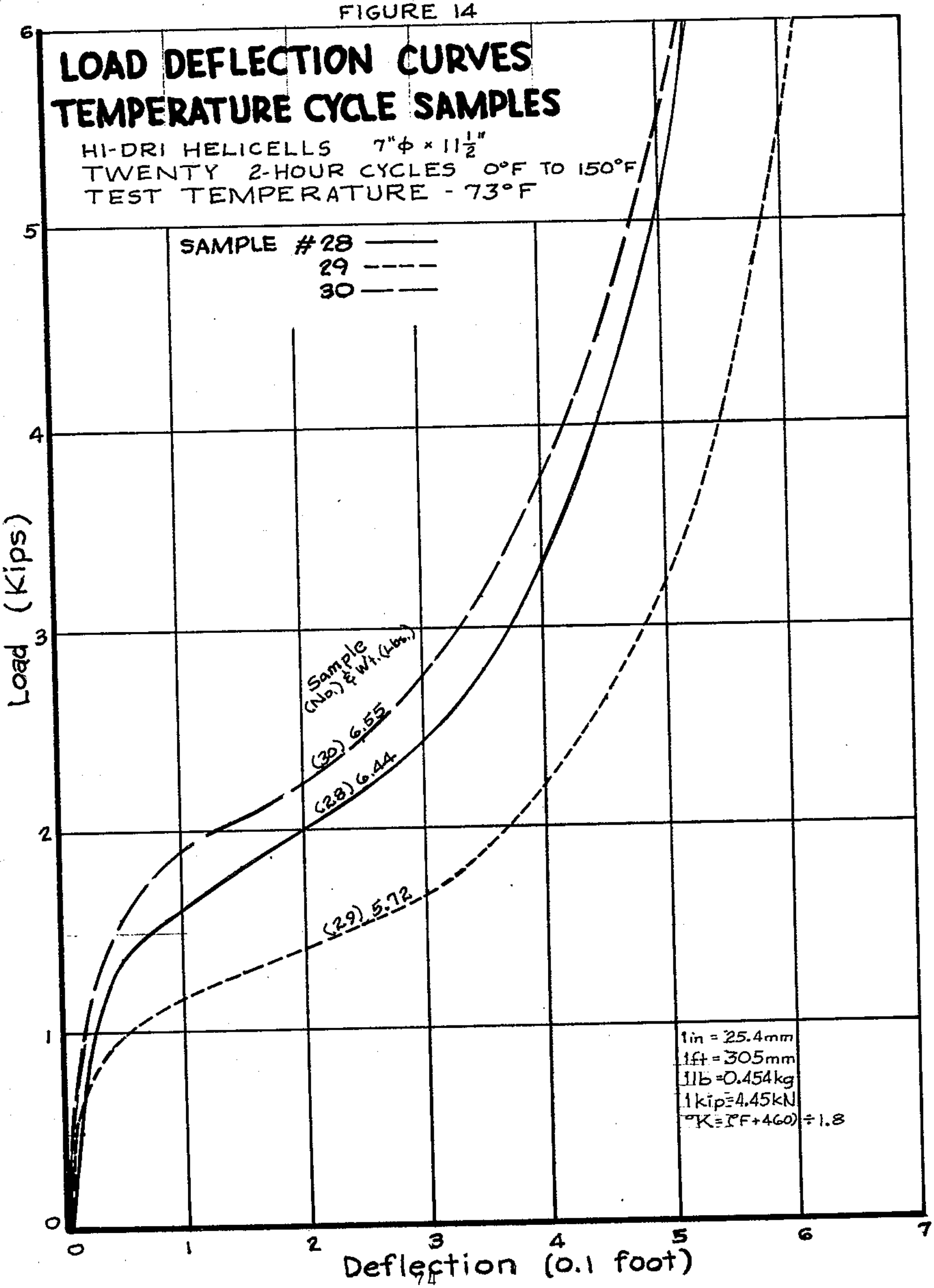
Sample No.	Weight (lb.)	Height (ft.)	Diameter (ft.)
28	6.44	0.95	0.60
29	5.72	0.96	0.59
30	6.55	0.96	0.61

*1 lb. = 0.454 kg
1 ft. = 305 mm

Figure 14 contains the load vs. deflection curve for each of these samples.

Figure 15 shows the samples after the static compression tests.

FIGURE 14



LOAD DEFLECTION CURVES
TEMPERATURE CYCLE SAMPLES
HI-DRI HELICELLS 7"φ × 11½"
TWENTY 2-HOUR CYCLES 0°F TO 150°F
TEST TEMPERATURE - 73°F
SAMPLE #28
29
30
Sample (No.) & Wt. (Lbs.)
(30) 6.55
(28) 6.44
(29) 5.72
1in = 25.4mm
1ft = 305mm
1lb = 0.454kg
1kip = 4.45kN
°K = (°F+460) ÷ 1.8
Load (Kips)
Deflection (0.1 foot)
0
1
2
3
4
5
6
7

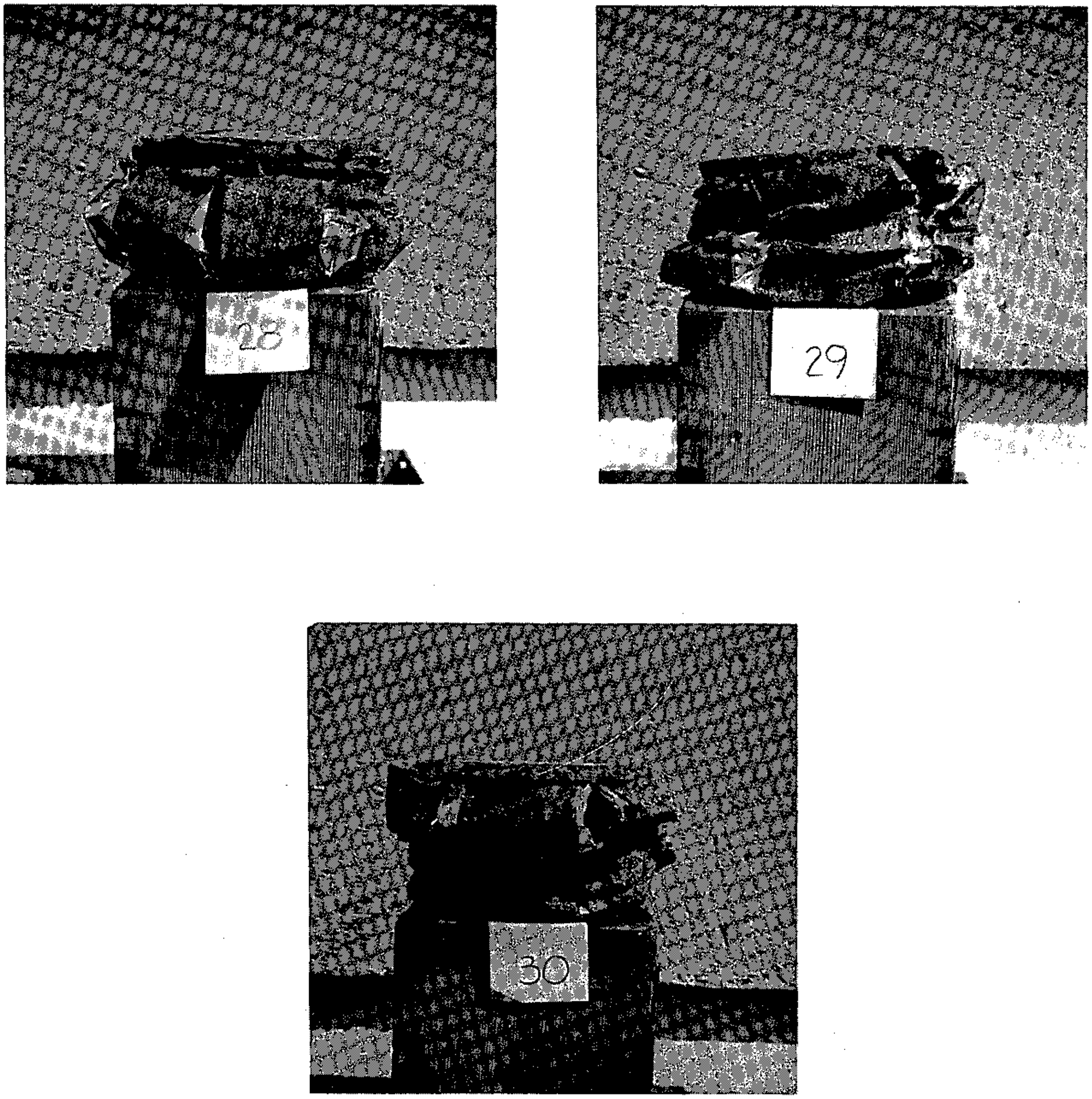


Figure 15 - Temperature Cycle Test Samples
Temperature Cycle 0°F to 150°F
Twenty 2 hr. cycles
Test Temperature 73°F

5. Dynamic Load Compression Tests

Thirty-five helicells were subjected to dynamic testing as outlined in Section III.B.5. of this report. Six samples were selected at random (37 thru 42), conditioned at 75°F (297 K) and tested. Twenty-four samples were classified by sample weight into three test temperature ranges, 6 at 0°F (255 K), 6 at 150°F (339 K) and 12 at 75°F (297 K). The six samples in the 0°F (255 K) temperature range (31 thru 36) had masses of 6.35 ± .05 lb. (2.88±0.02 kg). The six samples in the 150°F (339 K) temperature range (55 thru 60) had masses of 6.20 ± .05 lb. (2.81 ±0.02 kg). In the 75°F (297 K) temperature range the samples were divided by mass into a high and low range. The six samples in the low mass range (43 thru 48) had masses of 5.77 ± .05 lb. (2.62±0.02 kg). The six samples in the high mass range (49 thru 54) had masses of 6.45 ± .05 lb. (2.93±0.02 kg). Samples X-1 through X-5 were added later to obtain more test data using the heavier drop weights; they were tested at 75°F (297 K).

Table 5 tabulates the physical properties of all the dynamic test samples. There was no significant change in these properties after the conditioning. Table 6 gives the test conditions for each sample, and test data which was obtained from an analysis of high speed film.

Figure 16 shows the initial deflection of the helicells vs. the kinetic energy of the drop weights at the instant of contact with the samples. Also plotted are the envelopes of deflection vs. work values from static tests for comparison.

Table 5

DYNAMIC TEST SAMPLES

Sample No.	Test Temp. (Degrees - F)	Weight (lb.)	Height (Ft.)	Dia. (Ft.)
31	0	6.30	0.96	0.60
32	0	6.32	0.97	0.60
33	0	6.34	0.96	0.60
34	0	6.35	0.96	0.60
35	0	6.36	0.96	0.60
36	0	6.38	0.96	0.60
37	75	6.04	0.96	0.61
38	75	6.35	0.96	0.60
39	75	6.61	0.97	0.61
40	75	5.43	0.96	0.60
41	75	6.14	0.97	0.61
42	75	6.69	0.97	0.61
43	75	5.72	0.96	0.60
44	75	5.72	0.96	0.60
45	75	5.74	0.96	0.59
46	75	5.74	0.96	0.60
47	75	5.81	0.94	0.60
48	75	5.82	0.96	0.60
49	75	6.41	0.97	0.60
50	75	6.41	0.96	0.60
51	75	6.45	0.96	0.60
52	75	6.45	0.96	0.60
53	75	6.48	0.96	0.60
54	75	6.50	0.96	0.60
55	150	6.11	0.97	0.60
56	150	6.12	0.96	0.06
57	150	6.15	0.96	0.60
58	150	6.15	0.96	0.60

Table 5 (con't.)

Sample No.	Test Temp. (Degrees - F)	Weight (lb.)	Height (Ft.)	Dia. (Ft.)
59	150	6.26	0.96	0.60
60	150	6.26	0.97	0.60
X-1	75	5.16	0.95	0.60
X-2	75	5.92	0.96	0.60
X-3	75	6.54	0.96	0.60
X-4 & 5	75	5.94	0.96	0.59
		5.97	0.96	0.60

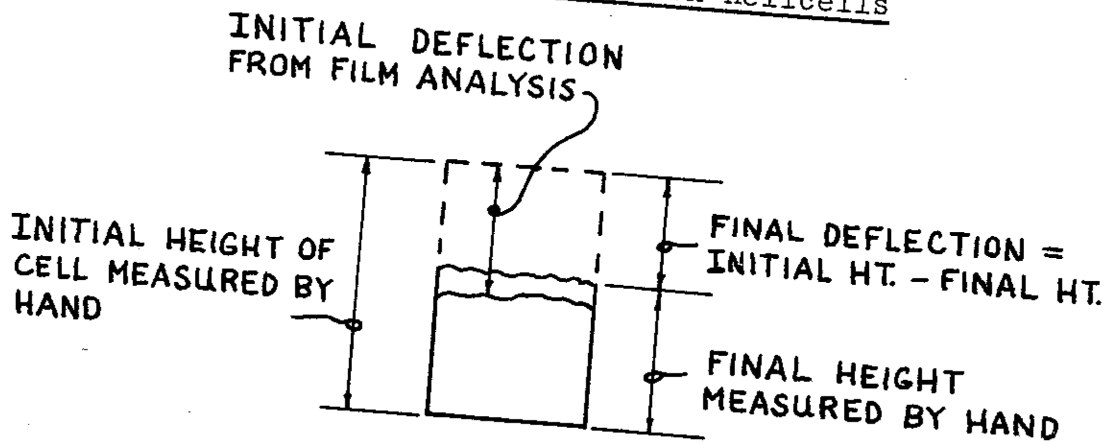
*Degrees K = (°F + 460)/1.8

1 lb. = 0.454 kg

1 ft = 305 mm

Table 6

Results of Dynamic Tests on Helicells



HELICELL DEFLECTION QUANTITIES

Sample No.	Drop Ht. (Ft)	Drop Wt. (Lbs)	Drop Wt. Impact Velocity (Fps)	Kinetic Energy of Drop Wt. (Ft-Lbs)	Initial Deflection of Helicell (Ft)	Final Deflection of Helicell (Ft)	Drop Weight Rebound Ht. (Ft)	Final Ht. of Helicell (Ft)
31	25.2	119	36.3	2440	0.66	0.59	1.00	0.37
32	21.0	119	33.5	2079	0.62	0.42	0.60	0.55
33	16.8	119	31.1	1793	0.46	0.31	0.45	0.65
34	12.6	119	25.6	1216	0.46	0.31	0.45	0.65
35	8.4	119	21.8	878	0.36	0.23	0.50	0.73
36	4.2	119	15.0	418	0.21	0.13	0.10	0.83
37	10	119	25.0	1156	0.47	0.42	0.35	0.54
38	10	119	22.4	928	0.39	0.31	0.30	0.65
39	20	119	32.3	1930	0.56	0.45	0.72	0.52

Table 6 (con't.)

Sample No.	Drop Ht. (Ft)	Drop Wt. (Lbs)	Drop Wt. Impact Velocity (Fps)	Kinetic Energy of Drop Wt. (Ft-Lbs)	Initial Deflection of Helicell (Ft)	Final Deflection of Helicell (Ft)	Drop Weight Rebound Ht. (Ft)	Final Ht. of Helicell (Ft)
40	20	119	32.7	1978	0.69	0.68	1.17	0.28
41	30	119	38.7	2771	0.67	0.77	1.19	0.20
42	30	119	38.1	2685	0.60	0.54	1.26	0.43
43	4.2	119	15.0	418	0.31	0.24	0.40	0.72
44	25.5	119	36.3	2440	0.68	0.56	1.50	0.40
45	12.6	119	25.6	1216	0.56	0.43	0.55	0.53
46	21.0	119	33.5	2079	0.61	0.62	0.85	0.34
47	20.0	246.75	33.5	4311	0.74	0.77	1.10	0.17
48	29.5	365.75	36.3	7499	0.86	0.91	1.30	0.05
49	4.2	119	15.0	418	0.27	0.78	0.50	0.19
50	12.6	119	25.6	1216	0.46	0.29	0.45	0.67
51	21.0	119	33.5	2079	0.51	0.43	0.75	0.53
52	25.2	119	36.3	2440	0.56	0.48	0.90	0.48
53	29.3	246.75	39.6	6021	0.86	0.84	1.10	0.12
54	29.5	365.75	36.3	7499	0.86	0.91	1.00	0.05
55	4.2	119	15.0	418	0.32	0.23	0.15	0.74
56	8.4	119	21.8	878	0.51	0.40	0.35	0.56
57	12.6	119	25.6	1216	0.51	0.39	0.60	0.57
58	16.8	119	31.1	1793	0.66	0.49	0.90	0.47
59	21.8	119	33.5	2079	0.68	0.55	1.02	0.41
60	25.2	119	36.3	2440	0.77	0.76	1.00	0.21

Table 6 (con't.)

Sample No.	Drop Ht. (Ft)	Drop Wt. (Lbs)	Drop Wt. Impact Velocity (Fps)	Kinetic Energy of Drop Wt. (Ft-Lbs)	Initial Deflection of Helicell (Ft)	Final Deflection of Helicell (Ft)	Drop Weight Rebound Ht. (Ft)	Final Ht. of Helicell (Ft)
X-1	15.0	246.75	29.1	3240	0.80	0.85	1.8	0.10
X-2	30.0	246.75	39.6	6010	0.86	0.84	1.3	0.12
X-3	25.0	246.75	36.3	5050	0.76	0.76	1.2	0.20
X-4* & X-5	30.0	365.75	39.6	8910	1.72	1.67	1.2	0.25

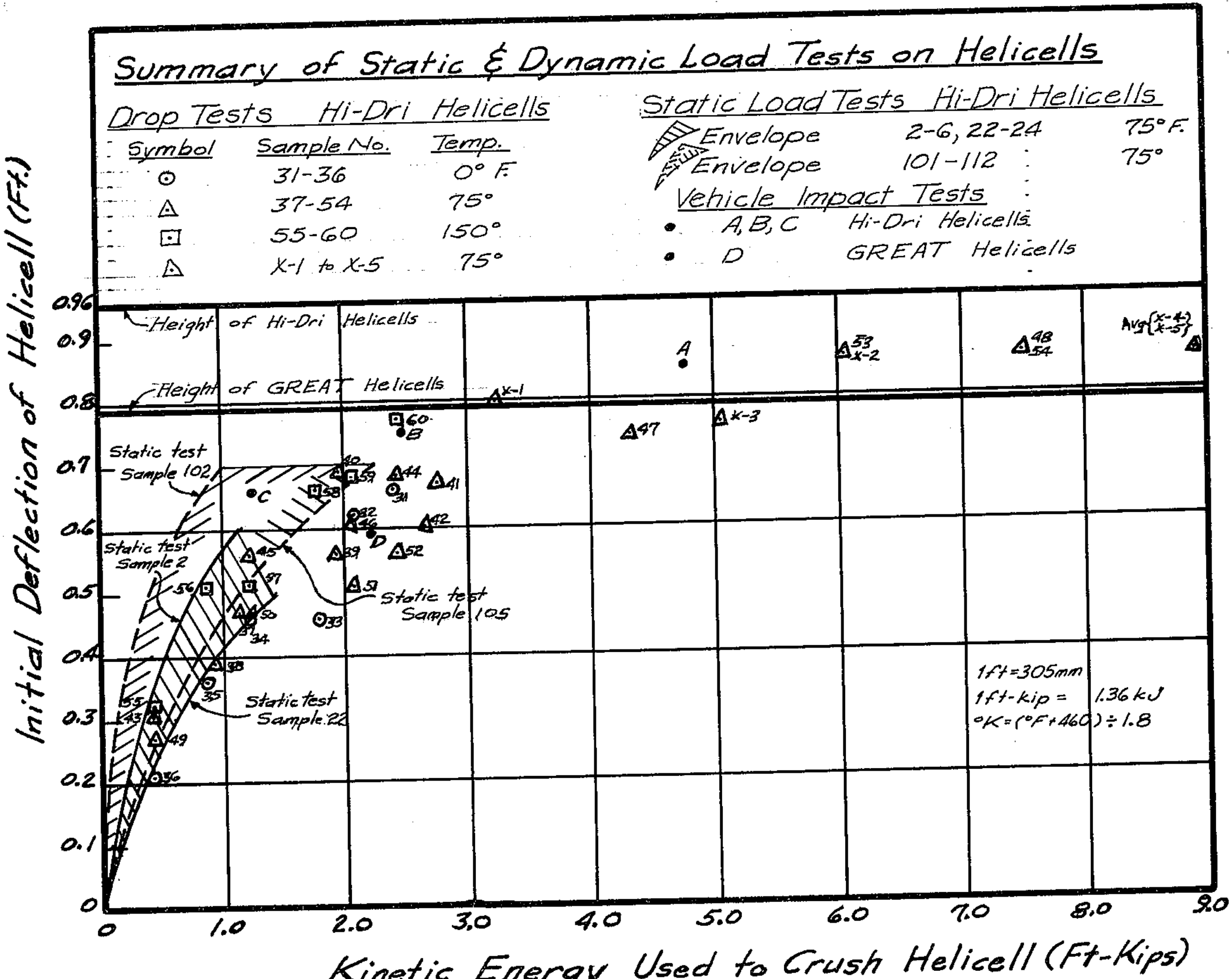
*X-4 and X-5 were stacked for the drop test.

1 ft. = 305 mm

1 lb. = 0.454 kg

1 fps = 0.305 m/s

1 ft-lb = 1.36 J



Summary of Static & Dynamic Load Tests on Helicells
Drop Tests Hi-Dri Helicells
Symbol Sample No. Temp.
31-36 0° F
37-54 75°
55-60 150°
X-1 to X-5 75°
Static Load Tests Hi-Dri Helicells
Envelope 2-6, 22-24 75° F.
Envelope 101-112 75°
Vehicle Impact Tests
A, B, C Hi-Dri Helicells
D GREAT Helicells
Height of Hi-Dri Helicells
Height of GREAT Helicells
Static test Sample 102
Static test Sample 2
Static test Sample 105
Static test Sample 22
Avg{X-4, X-5}
1ft=305mm
1ft-kip = 1.36 kJ
°K=(°F+460)÷1.8
Initial Deflection of Helicell (Ft.)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.96
0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0
Kinetic Energy Used to Crush Helicell (Ft-Kips)

Figure 16

D. Later Test Results

1. General

Following the test program above, the manufacturer modified the mix design of the cells to omit the asphalt. It had originally been included to provide weather resistance and with the thought that it might help the cell material "flow" during impact. A number of factors combined to promote the change. The cells and cartridges had several layers of weather protection which minimized that need for the asphalt. The manufacturer also concluded after testing that the asphalt was not necessary for the proper functioning of the cell. It was about this time when the petroleum shortage in the country limited sources and raised the costs of the needed material. Hence, the asphalt was omitted.

To update this study, it was decided to obtain samples of helicells without the asphalt. Also, by this time, the design of GREAT attenuators using shorter helicells had been completed. Therefore, samples of helicells for both the Hi-Dri and GREAT attenuators were taken.

The Hi-Dri helicell samples were taken from the top three layers of helicells on one pallet. All these 75 helicells were weighed; the five lowest weight and five highest weight helicells were taken for testing. Two other helicells which had unusually high weights were also taken. A pallet of 75 GREAT helicells were also weighed and the six lightest and six heaviest ones were taken. Table 7 lists the physical properties of the samples. The 24 samples were tested as outlined in Section III.B.1. for static load compression test at 73°F (296 K).

Table 7

Physical Properties of Helicells Tested in 1975

Sample No.	Weight (Lbs.)	Height (Ft.)	Diameter (Ft.)
101	6.84	0.97	0.60
102	4.97	0.96	0.60
103	8.95	0.97	0.60
104	6.52	0.97	0.60
105	7.52	0.96	0.60
106	6.45	0.97	0.60
107	6.61	0.96	0.60
108	4.82	0.96	0.60
109	6.83	0.96	0.60
110	4.88	0.95	0.60
111	5.04	0.95	0.60
112	4.97	0.95	0.59
201	5.66	0.81	0.60
202	3.85	0.79	0.60
203	5.59	0.81	0.60
204	5.70	0.81	0.60
205	5.69	0.80	0.60
206	5.58	0.81	0.60
207	4.22	0.80	0.60
208	4.20	0.80	0.60
209	4.20	0.80	0.59
210	4.10	0.80	0.60
211	5.62	0.81	0.60
212	4.05	0.80	0.59

Note: Samples 101-112 were for Hi Dri attenuators;
Samples 201-212 were for GREAT attenuators.

1 lb. = 0.454 kg
1 ft. = 305 mm

2. Results

Figures 17 and 18 contain the curves of load vs deflection for the samples. Sample 207 was not included because of an error in recording the data during the test. The areas under these curves were computed to obtain the curves of deflection vs. work shown in Figures 19 and 20. Only enough curves were drawn to show an envelope of maximum and minimum values.

Figure 17

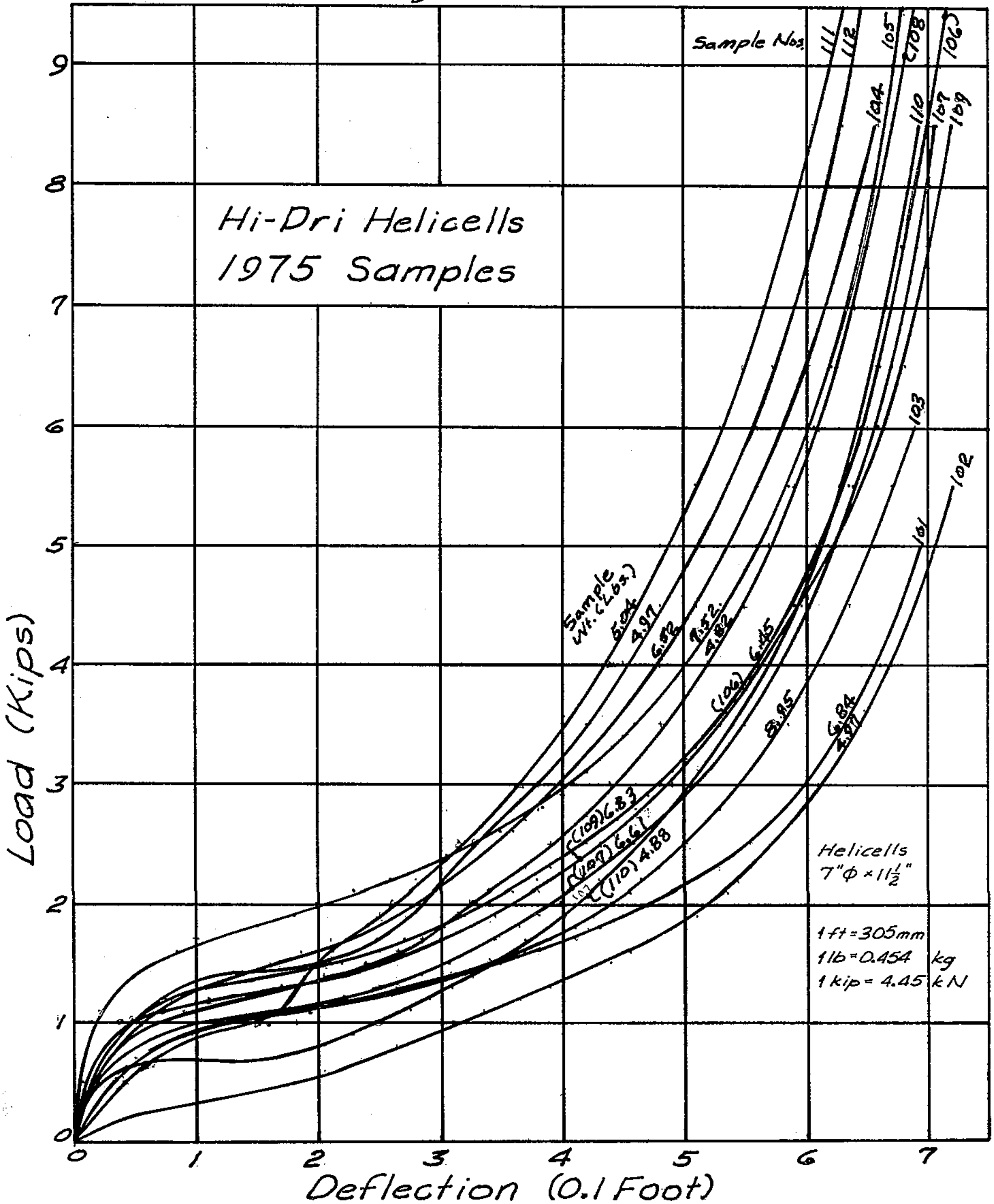
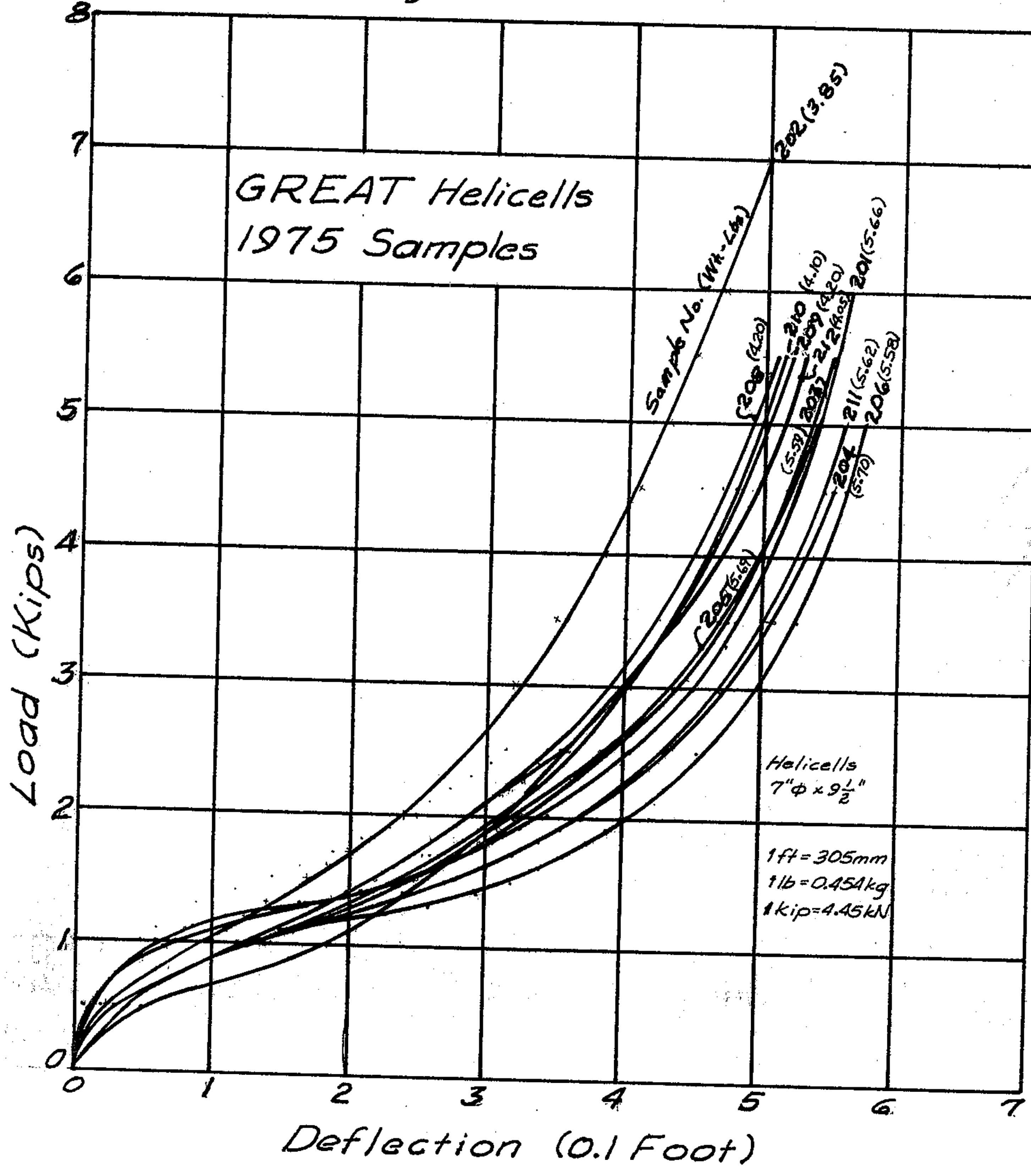
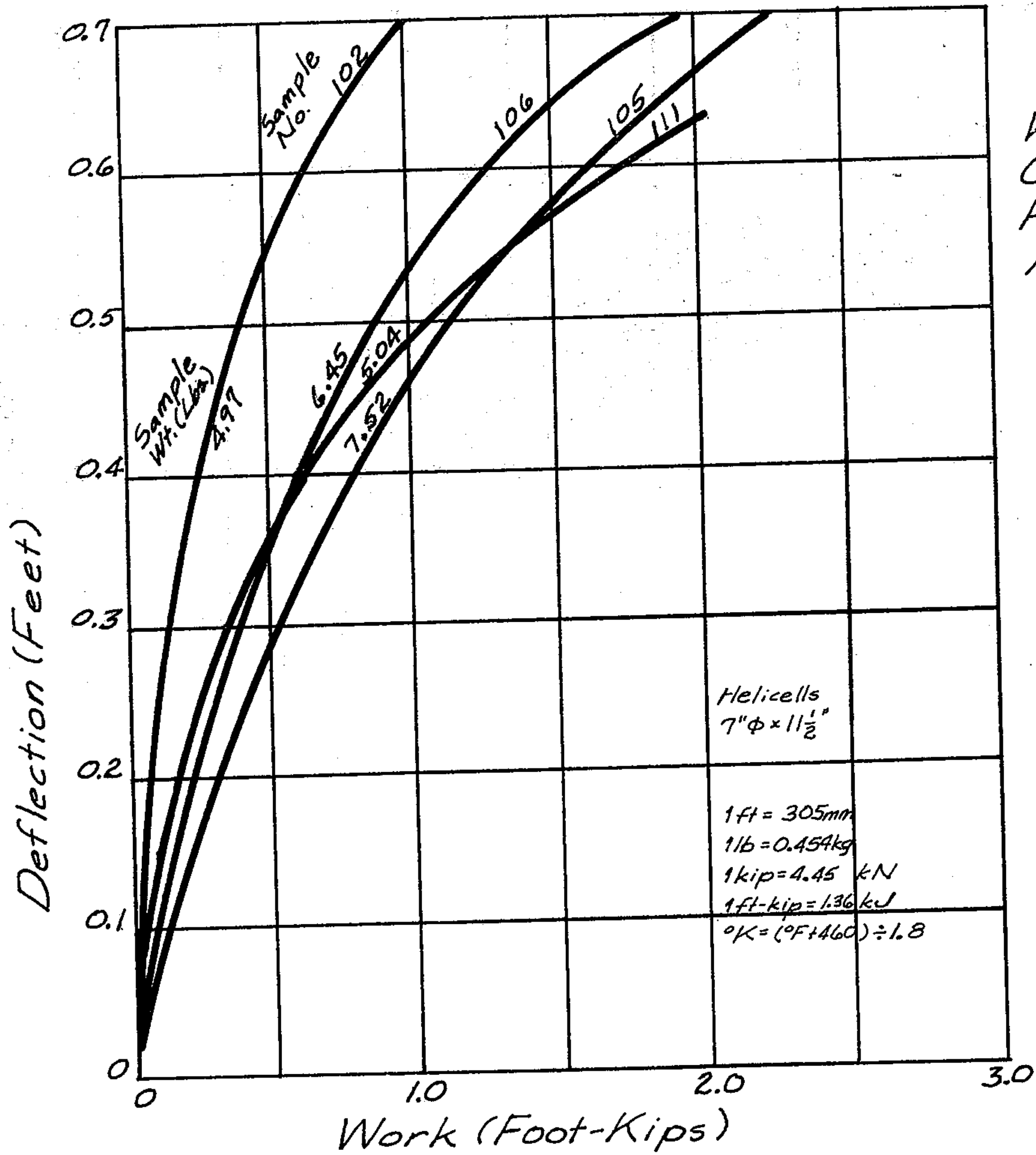

Hi-Dri Helicells
1975 Samples
Sample Nos.
111
112
105
108
106
104
110
107
109
103
102
101
Sample Wt. (Lbs)
5.04
4.97
6.82
5.52
4.82
(106) 6.45
8.85
6.84
4.91
(109) 6.83
(107) 6.6
(110) 4.88
Helicells
7"φ × 11½"
1 ft = 305 mm
1 lb = 0.454 kg
1 kip = 4.45 kN
Load (Kips)
Deflection (0.1 Foot)
0
1
2
3
4
5
6
7
8
9

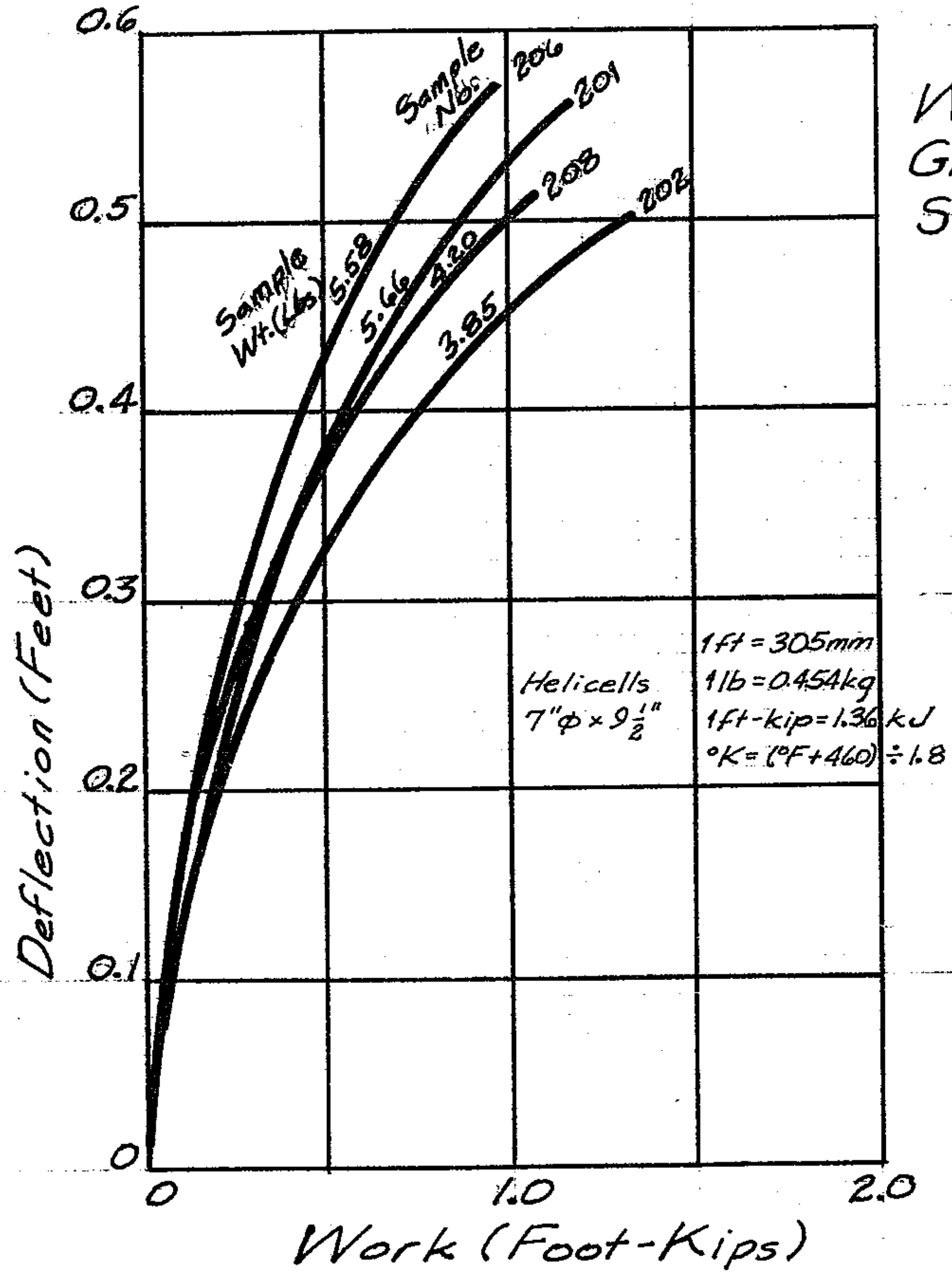
Figure 18


GREAT Helicells
1975 Samples
Sample No. (Wt-Lbs)
202 (3.85)
201 (5.66)
210 (4.10)
209 (4.20)
212 (4.05)
208 (4.20)
203 (5.59)
211 (5.62)
206 (5.58)
204 (5.70)
205 (5.69)
Helicells
7"φ x 9½"
1 ft = 305mm
1 lb = 0.454 kg
1 kip = 4.45 kN
Load (Kips)
Deflection (0.1 Foot)



Work Done to Compress Hi-Dri Helicells Statically At 75°F

Figure 19



Work Done to Compress GREAT Helicells Statically

Figure 20

E. Discussion of Test Results

1. General

A rigorous analysis of the test results is beyond the scope of this work; however, general observations will be made on the more obvious findings.

2. Static Load Compression Tests

The load-deflection curves in Figure 5 fall within a reasonably limited band of values. Comparing these curves with those in Figures 8, 11, and 14, the band of values is about the same for most tests despite specialized moisture and temperature conditions. Lighter weight samples seemed to deflect more for a given load than denser samples in Figure 5. Sample No. 1 has an erratic curve due in part to its being the first sample tested before the test procedure was well established. Figures 8, 11, and 14 provide stronger evidence of the density vs. deflection relationship. However, in Figure 17 the later Hi-Dri helicells appear to have no density/deflection relationship whatsoever, and in Figure 18 the GREAT helicells have a reversed density/deflection ratio.

This rather puzzling collection of data leads to the conclusion that one or more other factors besides density have an influence on the load vs. deflection curves. The manufacturing process is largely done by hand, and small batches of vermiculite concrete are made up at one time. A number of factors in this process could affect the helicell strength such as the grading of the vermiculite aggregate which sometimes is segregated in the bag or variations in bag weights. Some of the variations may also be a result of the compression test procedures. All other factors being equal, an increase in density probably does decrease the deflection of a helicell at any given load.

3. Fog Room Tests

Table 2 illustrates the significant fact that the aluminum foil coverings on the test samples prevented moisture absorption. Note that samples 17 and 18, with the aluminum foil coverings removed, absorbed 9.59 lb. (4.35 kg) and 7.73 lb. (3.50 kg) of water respectively. All other samples, with one exception, regardless of the duration of conditioning, did not absorb any significant amount of moisture. The average 0.03 lb. (0.01 kg) increase in weight is surface moisture as the samples were weighed in a saturated-surface-dry condition. The single exception was sample No. 15 which absorbed 0.8 lb. (0.36 kg) of moisture. This sample did not sustain any apparent rupture of the foil covering or appreciable change in either sample height or diameter.

Figure 8 shows that sample 17, the helicell with the jacket removed, had a lower strength. This illustrates the importance of the water tight seal on the helicells.

4. Temperature Sensitivity

For the number of samples tested, there does not appear to be any relationship between helicell temperature and the load vs. deflection curve.

5. Temperature Cycle Tests

After the helicells were cycled through temperature extremes, they did not have any noticeable changes in their load vs. deflection curve.

6. Dynamic Load Compression Tests

In Figure 16 the initial deflection of the helicells is plotted vs. the kinetic energy available to crush the helicell. The static test envelope from Figure 6 is also plotted for comparison. It is interesting to note that the dynamic test data generally fall within the static test envelope bounded by sample 2 and sample 22. The static test data envelope from Figure 19 for the later tests on Hi-Dri helicells is also included. This is a wider envelope; however, if sample 102 had been excluded and replaced with sample 106, this envelope would have been quite similar to the original static test envelope.

Although not plotted on Figure 16, the static load test envelope for the later tests on GREAT helicells shown in Figure 20 would also coincide with the original static test envelope in Figure 6. The ends of the GREAT curves are flattened out more because these helicells were shorter than the Hi-Dri helicells and were closer to reaching their maximum possible deflection.

The data in Figure 16 indicate that static load tests are good indicators of dynamic load behavior of the helicells for the range of test conditions used in this study.

For comparison, the average deflection of each helicell and the average kinetic energy dissipated per helicell from four vehicular impact tests were plotted on Figure 16. Test data are shown in Table 8. These values do not take into account energy expended in vehicle crushing, friction, differences in deflection of individual helicells, etc. Assuming these factors are of secondary importance, the vehicle test points plotted on Figure 16 fall within the envelopes of data points from this study. Data point D from the GREAT attenuator test lies off

Table 8

Average Kinetic Energy and Stroke Per Helicell in Vehicle Impact Tests on Crash Cushions

Test Symbol (Ref.No.)	Type of Crash Cushion	Veh. Wt. (Lbs.)	Impact Speed (mph)	Veh. Kinetic Energy (Ft-k)	No. of Helicells in Crash Cushion	Average Kinetic Energy Per Helicell (Ft-k)	Crash Cushion Stroke (Ft.)	No. of Helicells in Line	Average Stroke Per Helicell (Ft.)
A (3)	Hi Dri	3700	56	388	82	4.73	13.67	16	0.85
B (4)	Hi Dri	1800	58	203	82	2.48	12.25	16	0.76
C (4)	Hi Dri	3700	28.5	101	82	1.23	10.5	16	0.66
D (-)	GREAT	2300	60	277	126	2.20	12.5	21	0.60

* 1 lb. = 0.454 kg

1 ft. = 0.305 m

1 mph = 0.447 m/s

1 ft-k = 1.36 KJ

the curve of the Hi-Dri tests, perhaps because the helicells were 9 1/2(±) inches (241 mm) long rather than 11 1/2(±) inches (292 mm) as required in the Hi-Dri attenuators. Hence the curve must flatten out sooner as the deflections asymptotically approach the total helicell height.

7. Quality Control Procedures

The manufacturer was requested to provide evidence of a satisfactory quality control program for the various components of the crash cushions they produce. This request was made of both manufacturers of crash cushions as part of the ongoing overall program of quality assurance for highway materials provided to the California Department of Transportation.

The manufacturer subsequently provided a set of quality control procedures. The manufacturing process was described, and material specifications were provided. A random sampling of helicells is made during the manufacturing process to check hardness of the vermiculite concrete in the cell after it has cured using a simple penetrometer device.

IV. REFERENCES

1. Warner, Charles Y. and Walker, Grant W., "Crash Test Performance of a Prototype Lightweight Concrete Energy-Absorbing Guardrail System," Highway Research Record No. 343, 1971.

2. Walker, Grant W. and Warner, Charles Y., "Crash Test Evaluation of Strong-Post, Energy-Absorbing Guardrail Using a Lapped W-Beam for Transitions and Median Barriers," Highway Research Record No. 386, 1972.

3. Walker, Grant W., Young, Bruce O. and Warner, Charles Y., "Crash Tests of an Articulated Energy-Absorbing Gore Barrier Employing Lightweight Concrete Cartridges," Highway Research Record 386, 1972.

4. Walker, Grant W., Warner, Charles Y. and Young, Bruce O., "Angle and Small-Car Impact Tests of an Articulated Gore Barrier Employing Lightweight Concrete Energy-Absorbing Cartridges," Transportation Research Record 488, 1974.

V. APPENDIX

MEMO TO FILE

Date: July 19, 1972

File: Energy Absorbing Devices
Lightweight Concrete

Preliminary environmental and structural tests have been performed on lightweight concrete helicells, also known as crunchies. Mr. Grant Walker of Dynamics Research and Mfg., Inc., developed these helicells for energy absorbing barriers and block-outs for metal beam guardrail. The Energy Absorption Systems, Inc., which is marketing the helicells, submitted for testing twelve of them covered with aluminum foil and sealed with asphalt (Figure 0). The tests are considered preliminary because the results indicate certain trends in material properties which cannot be verified without more tests.

A summary of all tests performed is presented in Figure 1. Four of the helicells have been placed at sign rack locations representing various climates. These will be inspected periodically for deterioration, water absorption, etc.

Environmental Tests

Two helicells were submerged to test the effectiveness of the asphalt seal of the aluminum cover. One proved to be water resistant while the other leaked rapidly (Figure 2). Heating the water resistant helicell for two days at 140° F had no apparent effect on its sealing properties. The nearly saturated helicell was subjected to freeze-thaw tests.

Freeze-thaw tests were performed on two helicells, one as manufactured and one at various moisture contents. The nominal 24 hour cycle included 16 hours at 10° F and 8 hours thaw in air at room temperature. After 20 cycles, neither of the helicells showed any signs of deterioration except for spiral pullout. During the fourteenth thaw cycle, the spiral end embedded in the wet asphalt-vermiculite concrete pulled free. This situation may be avoided by hooking the embedded end of the spiral if possible.

Two helicells were subjected to a simulated salt spray environment, one for 14 days and one for 60 days. The helicells were placed upright in the salt spray containing 5% salt at 95° F (ASTM B117-61T). After 14 days, there were no signs of deterioration, but after 60 days, a 2" x 10" strip along one side of the aluminum cover had completely disintegrated and rust appeared on the spiral wire.

Handling loads were simulated by dropping one helicell three times from a height of three feet onto a concrete slab. Although the helicell suffered local dents, there was no apparent damage to the cover and no apparent change in its structural properties.

Structural Tests

Seven helicells were subjected to static compression tests. Attempts to maintain either a constant load rate or strain rate proved futile because of the variable slope of the load-deflection curve and the need to record deflections manually. However, the variable load rate (Figure 3) was the same for each test. Load-deflection curves for all tests are presented in Figure 3.

To demonstrate the dependence of energy absorption upon temperature, spiral spacing, and weight, Figures 4, 5, and 6 show the amount of energy required to obtain a given deformation. These curves are based upon the area under the load-deflection curve.

Conclusions

1. The cement-asphalt-vermiculite material has good resistance to freeze-thaw environments, regardless of moisture content.

2. The aluminum cover with asphalt seal is water resistant but not water proof.

3. The asphalt seal is not affected by high or low temperatures.

4. The aluminum cover is susceptible to salt spray environments.

5. Normal handling loads have no detrimental effect on the helicells.

6. The end of the spiral embedded in the helicell should be hooked, if possible, to minimize the chance of pullout.

7. The general shape of the load-deflection curve is desirable. The initial softness of the helicells tends to minimize the rate of onset of deceleration and maximize the sensitivity of a batrier to small cars.

*8. The energy absorbing characteristics of helicells are highly dependent upon ambient temperature and density of the cement-asphalt-vermiculite material.

*9. The energy absorbing characteristics are less dependent upon spiral spacing than upon temperature and density.

Those conclusions marked by an asterisk must be considered tentative until more tests are run to establish statistical significance.

Recommendations for Further Tests

To verify or deny the tentative conclusions, *8 and *9, we recommend that a minimum number of structural tests be run as follows:

1. 6 helicells at 70° F, 1" spiral spacing.
2. 6 helicells at 70° F, 5/8" spiral spacing.
3. 6 helicells at 10° F, 5/8" spiral spacing.
4. 6 helicells at 140° F, 5/8" spiral spacing.

These helicells should be randomly selected from a production run without regard to weight.

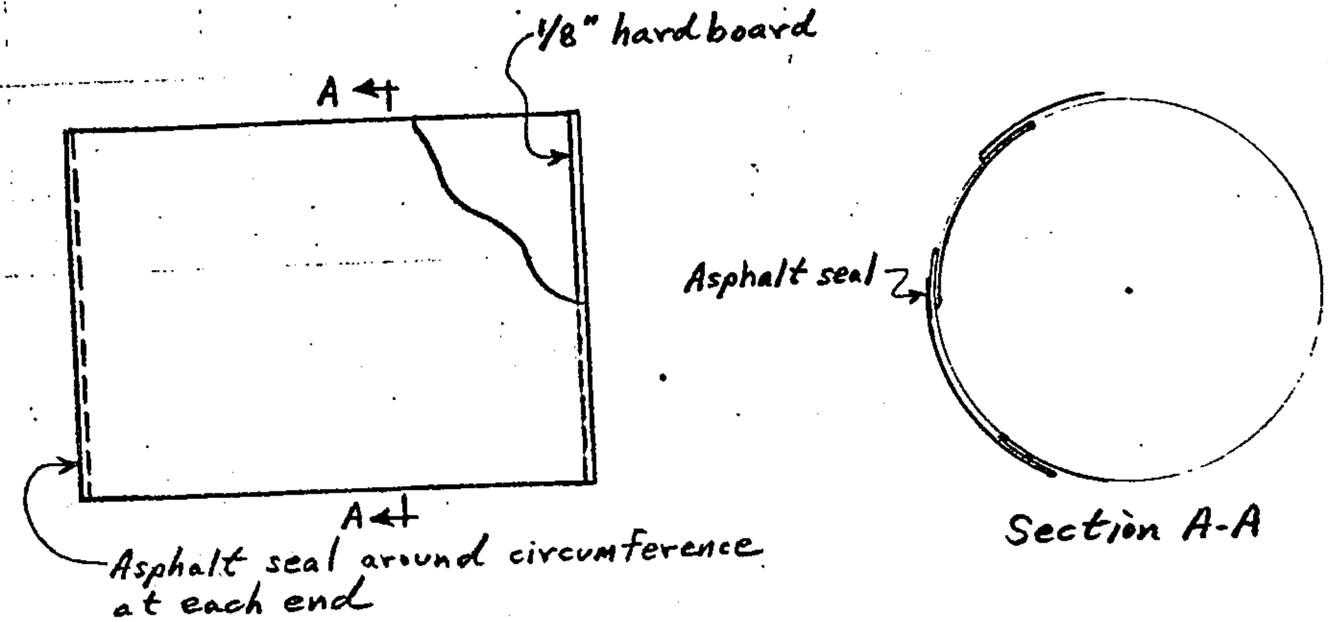
Fogroom tests should be considered to simulate a humid environment. Many helicells, say 10, would be required because of the varying degree of leakage. After an extended period of absorption, the wet helicells would be subjected to structural tests.

Drop weight tests should also be considered to simulate the dynamic environment. Such tests would be performed with a "Rube Goldberg" test set-up. The Foundation Section's driving rig may be suitable for such tests. Since the weight would be dropped from several heights, a large number of helicells would be required to develop energy-deflection curves.

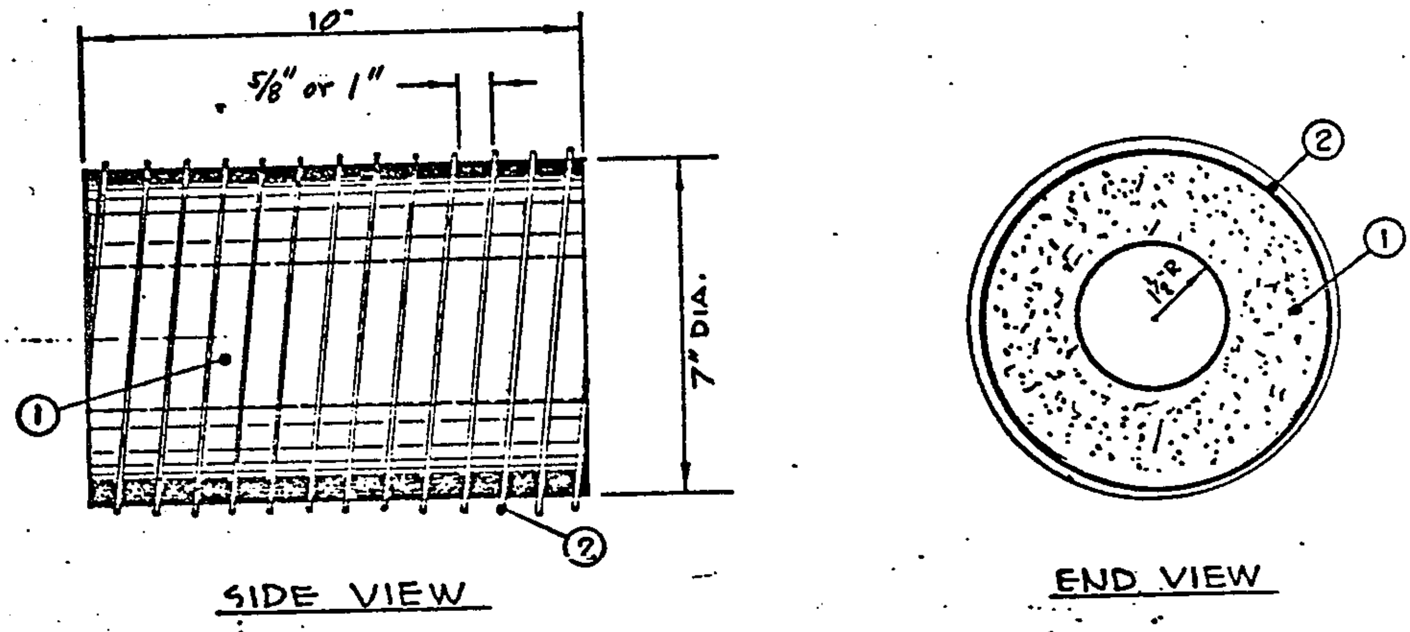
William F. Crozier
Assistant Bridge Engineer

WFC:mw

Attachments



ALUMINUM COVER



LEGEND

1. HELICELL - VERMICULITE, CEMENT & ASPHALT
2. WIRE WRAP - 12 GA. - GALVANIZED

HELICELL

Figure O

Figure 1

SUMMARY OF TESTS PERFORMED

Helicell Number	Weight Grams	Spiral Spacing Inches	Environmental Tests	Structural Test Temperature
CR-1	2053	5/8		10°F
CR-2	1897		Truckee sign rack	
CR-3	2081		Sacramento sign rack	
CR-4	2144		Fortuna sign rack	
CR-5	2171		Cambria sign rack	
CR-6	2007	1	(1) Water absorption (leaks) (2) Freeze-Thaw (3) Various moisture contents	70°F
CR-7	1987	5/8	(1) Water aborption (no leaks) (2) 140°F for 2 days (3) Water absorption (no leaks)	140°F
CR-8	1938	1	Salt spray - 14 days	70°F
CR-9	2050	5/8	Salt spray - 60 days	
CR-10	1992	1	Freeze-Thaw in dry condition	70°F
CR-11	1962	5/8		70°F
CR-12	2076	5/8	Simulated handling	70°F

Mean = 2030 grams

$\sigma = \pm 78$ grams or $\pm 3.8\%$

Figure 2. MOISTURE CONTENT FOR IMMERSION AND FREEZE-THAW TESTS

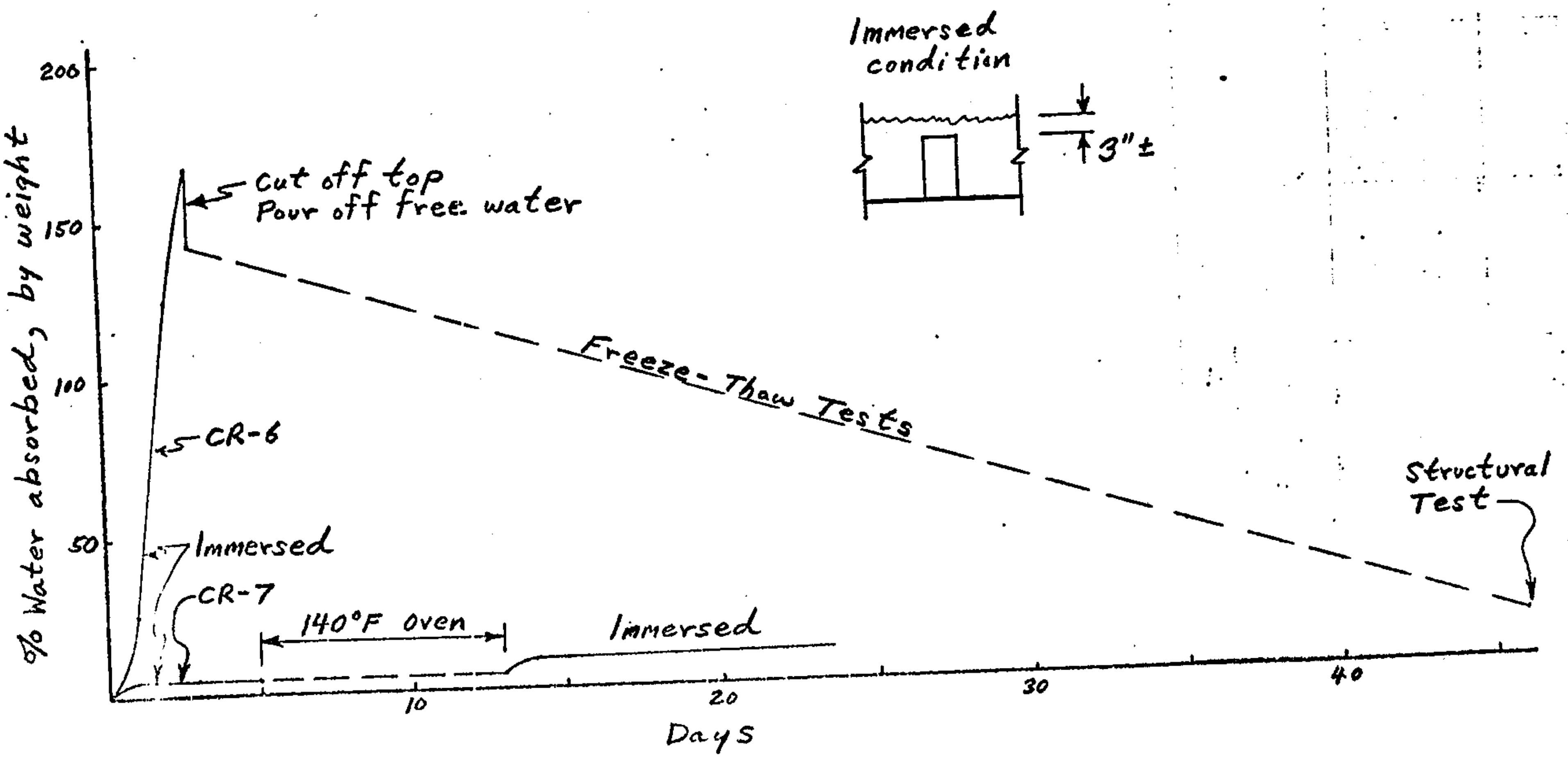


Figure 3. LOAD-DEFLECTION CURVES

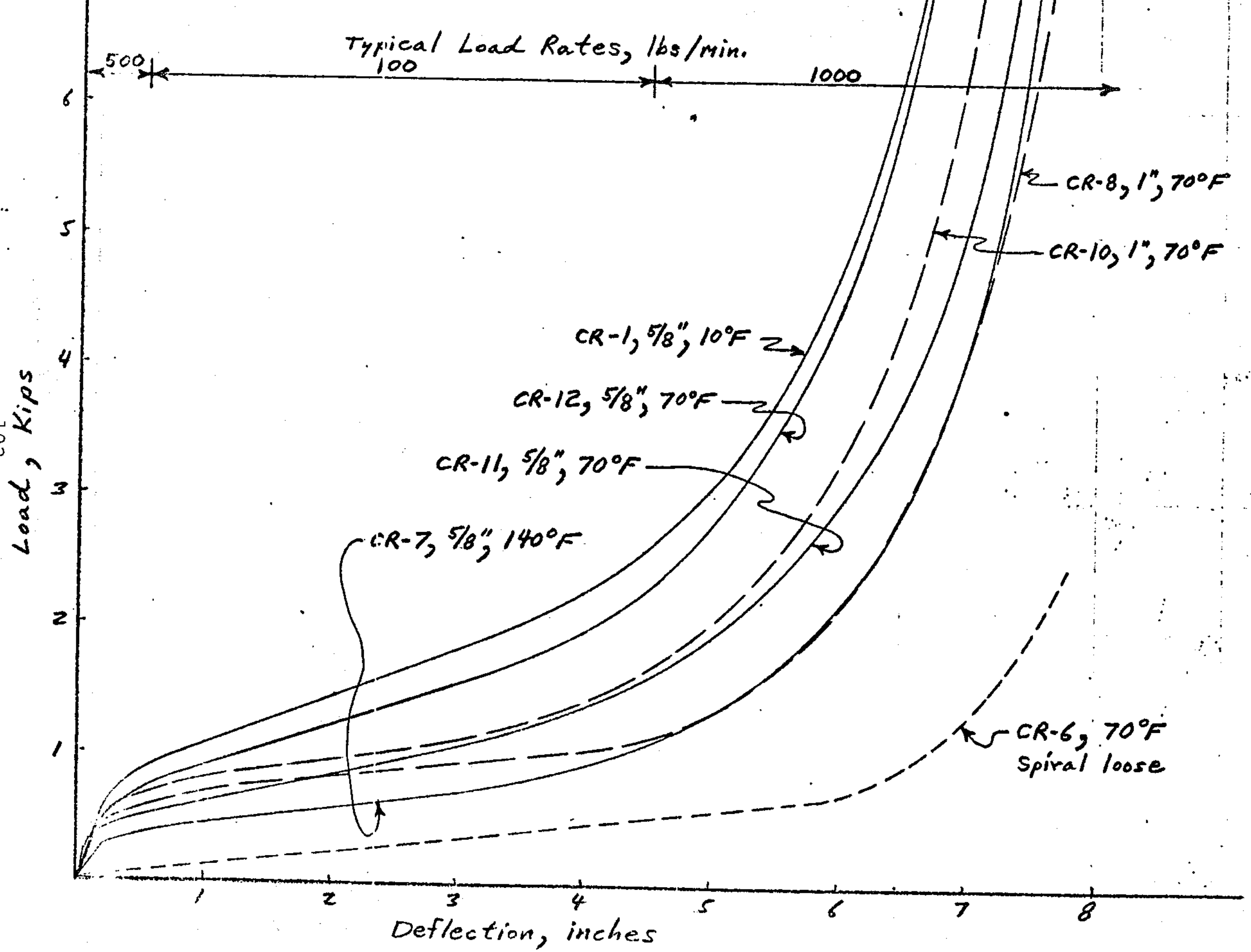
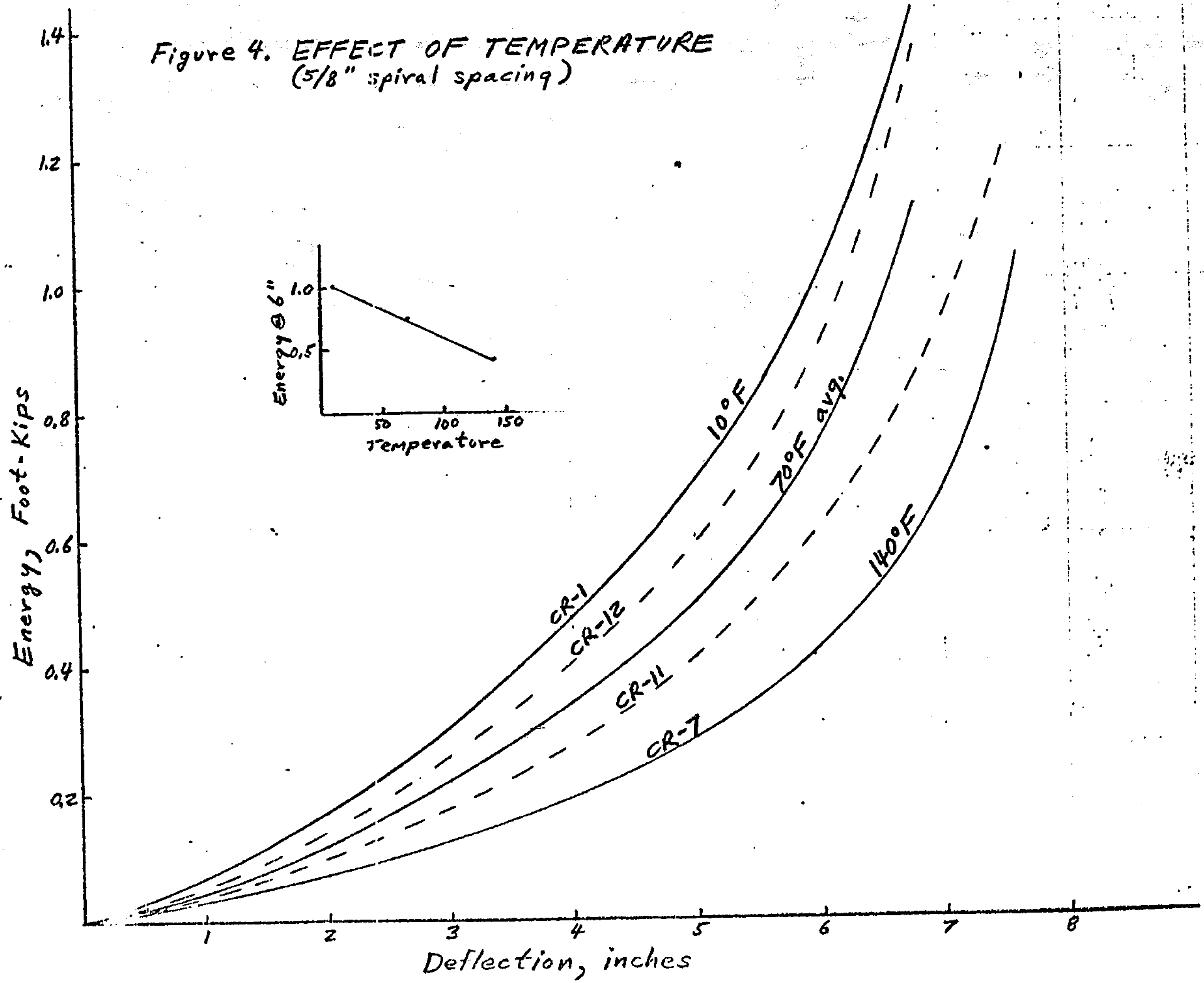


Figure 4. EFFECT OF TEMPERATURE
(5/8" spiral spacing)



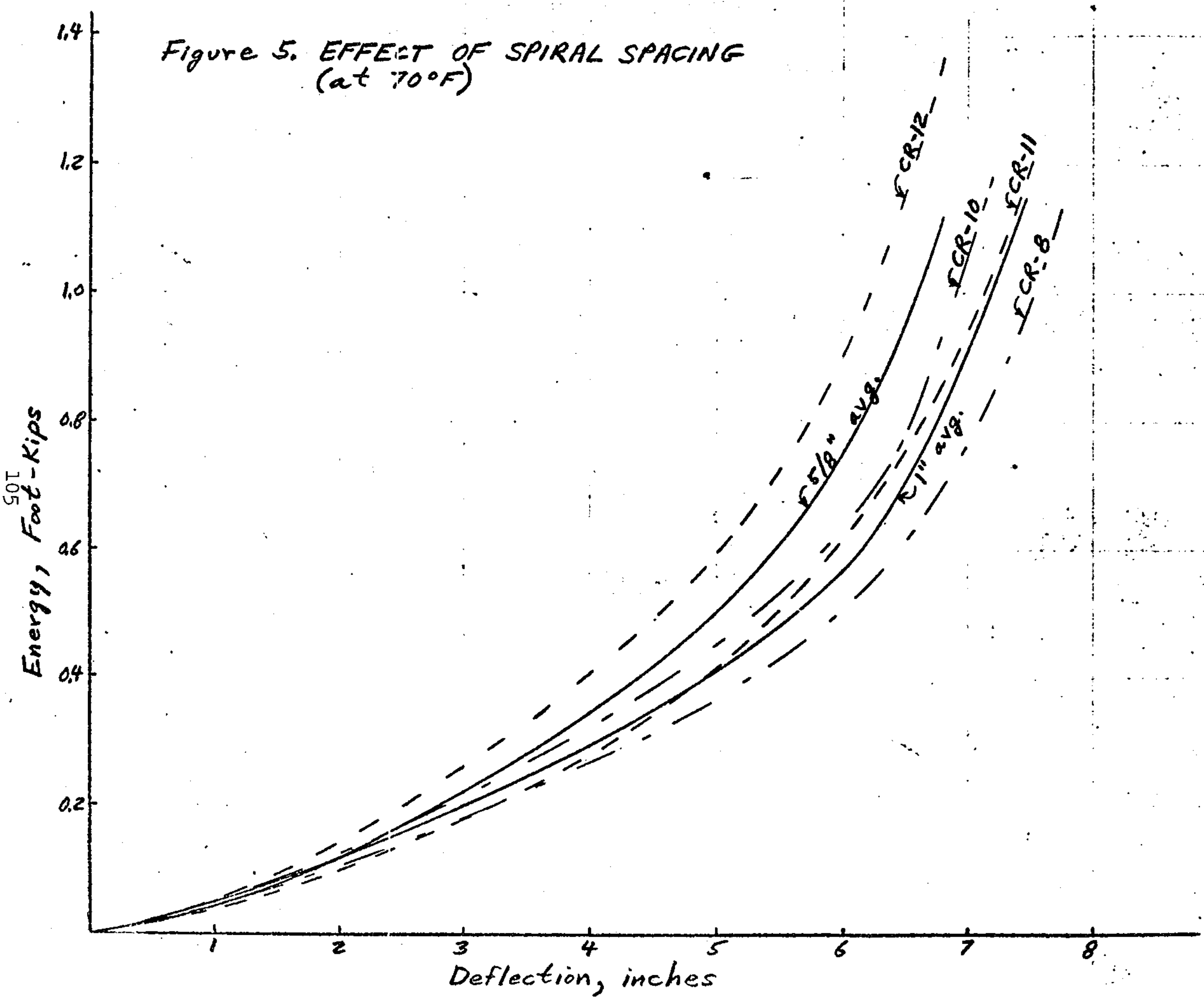
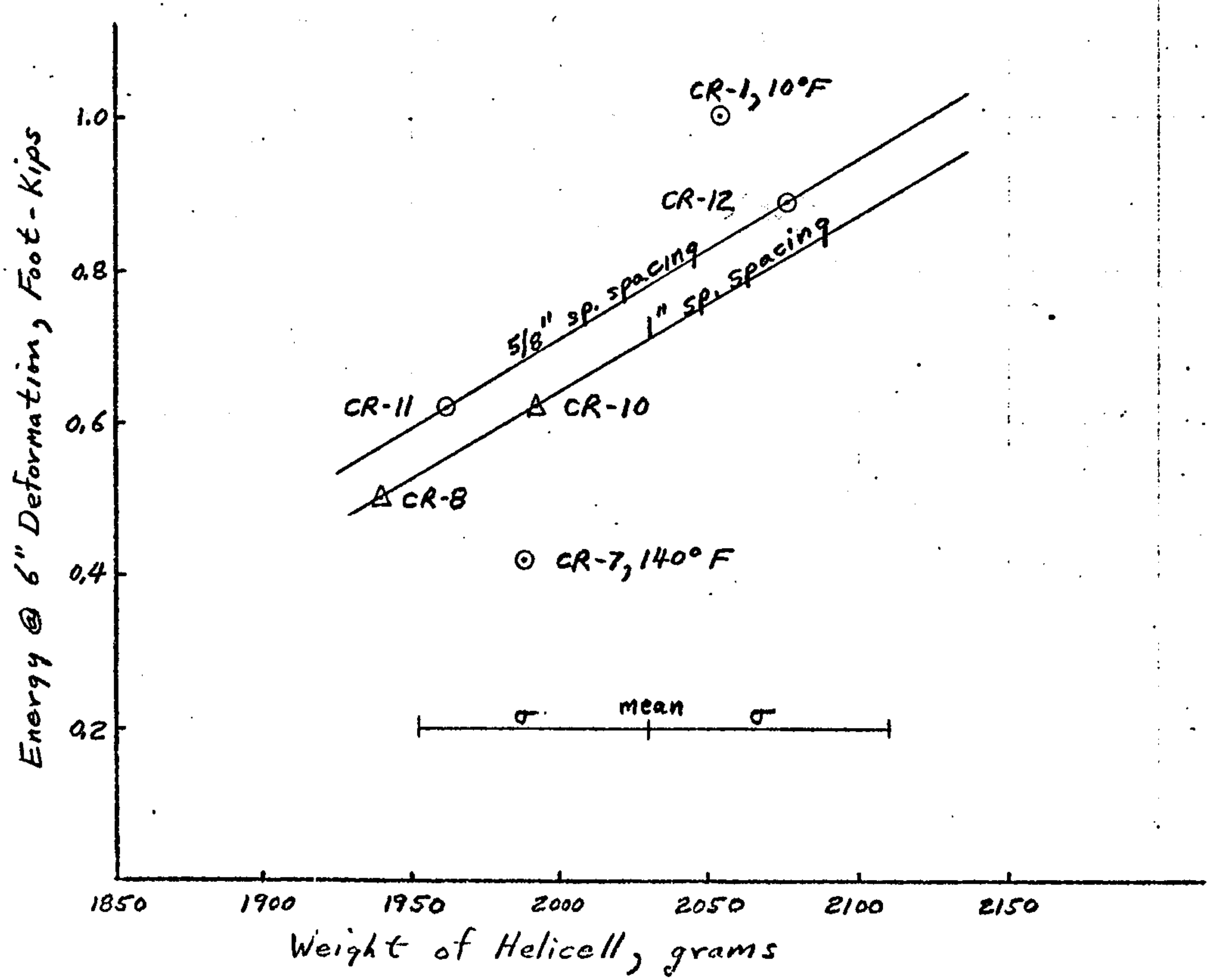


Figure 5. EFFECT OF SPIRAL SPACING
(at 70°F)
℄CR-12
℄CR-10
℄CR-11
℄CR-8
℄5/8" avg.
℄1" avg.
Energy, Foot-Kips
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1
2
3
4
5
6
7
8
Deflection, inches

Figure 6. EFFECT OF WEIGHT



MEMO TO FILE

Date: July 25, 1972

File: Energy Absorbing Devices
Lightweight Concrete

This memo is an addendum to my Memo to File dated July 19, 1972, regarding testing of helicells.

<u>Corrosion</u>

I spoke with Dick Stratfull of the Corrosion Testing Unit regarding the deterioration of the helicell in the salt spray chamber. He feels that the primary reaction is between the wet cement and the aluminum foil. The cement, when wetted via leakage, is very basic (pH = 12.5) and, therefore, readily oxidizes the aluminum. He guessed that the deterioration achieved by the salt chamber in two months could occur in an actual environment in six months.

He cited several secondary factors which enhance the rate of deterioration. In their order of importance, they are:

1. High temperature - the corrosion rate approximately doubles for every increase of 10° F.

2. Dissimilar metals - aluminum and steel.

3. Salt.

He feels that the presence of salt is of minor importance and that fogroom tests would produce corrosion similar to that achieved in the salt chamber.

<u>Freeze-Thaw</u>

I spoke with Don Smith of the Concrete Section regarding interpretation of the results of freeze-thaw tests. Based on his experience with similar materials, he feels that if the helicell material were susceptible to a freeze-thaw environment, it would exhibit deterioration after a few cycles. He, therefore, believes that the material has good freeze-thaw resistance.

Wm F. Crozier

William F. Crozier
Assistant Bridge Engineer

WFC:mw

Rec'd 7/25/72
EM 7/25/72

PART THREE: STRENGTH INVESTIGATIONS OF SAND-FILLED PLASTIC CRASH CUSHION BARRELS

I. INTRODUCTION

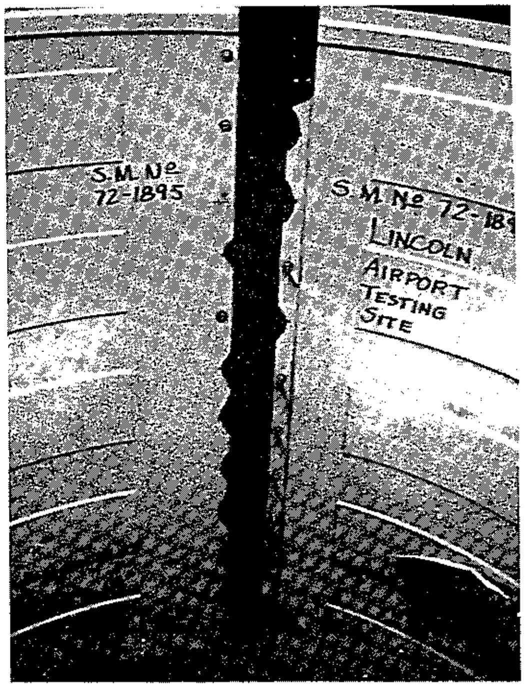
A. Background

The Fitch Inertial Barrier System uses three foot diameter sand-filled barrels made of frangible high density polyethylene. In early March 1972, seam separation occurred at the bottom of one of three barrels installed at the Lincoln Airport, former highway barrier crash test site of the Transportation Laboratory. The barrel had been in place since July, 1971. In the following weeks this barrel and one other of the three barrels completely separated at the riveted seam and the third barrel developed a seam separation at its center (Figure 1).

In September of 1972 a barrel of the same type installed at a Los Angeles in-service site completely separated at the seam after having been observed earlier the same day in apparently satisfactory condition. In all cases the failures occurred at the rivet holes of the seam connections (Figure 1).

The barrel walls of the Fibco Inertial Barrier System are three tenths of an inch thick with solid surfaces and a porous center. This sandwich design is accomplished with a Union Carbide injection molding process.

The plastic barrels are cast as two half-cylinders with a one inch overlap at the vertical seams. The overlapping seams are fastened by 3/16 inch (5 mm) diameter pop rivets on three inch (76 mm) centers.



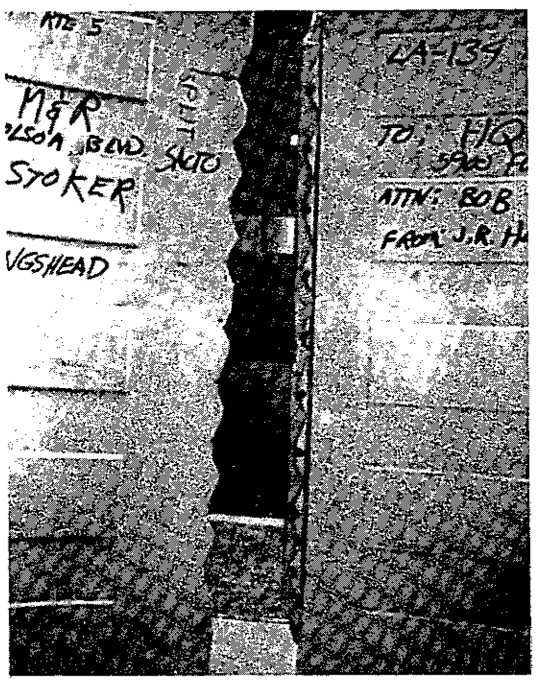


Figure 1 - Riveted Seam Failures

The following three failure hypotheses were developed:

1. That the barrel strength is reduced by exposure to the natural elements.

2. That the hoop stress developed in the barrel by the internal sand load exceeds the capacity of the riveted connection at the seam.

3. That the hoop stress described above is increased by expansion and contraction caused by daily thermal cycles.

B. Objectives

This project was initiated to determine the cause of the vertical rivet seam failures. Objectives included investigating the seam connection failure mode, the strength of the seam connection and the barrel material at different temperatures, the effect weathering may have on the barrel material and the effect of daily thermal cycles on the seam connection. At a later date tests were conducted on the barrel material specifically to determine the effects of ultra-violet radiation.

It was also hoped that the above investigations would be useful in evaluating the specifications and quality control procedures that were being prepared by the manufacturer at our request.

II. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

Conclusions

A. A few failures have occurred in the field with polyethylene sand filled barrels used in crash cushions. The manufacturers of these barrels have made a number of design modifications to minimize the number of these failures. However, a small number of failures are still occurring. The reasons for these last failures are unclear; a number of environmental factors combined with the material properties may be the cause.

B. The strength of the polyethylene used in the barrels was lowered significantly when the test temperature was raised from 70°F to 120°F (294 to 322 K); the strength increased when the temperature was lowered from 70°F to 30°F (294 to 272 K).

C. The original rivet strip design in the Fitch barrels had a strength much less than that of the polyethylene material. That design has since been modified.

D. Exposure of the polyethylene material to ultraviolet light in a weatherometer for 2000 hours led to a noncritical decrease in strength. Exposure of this material to a high temperature desert environment near Palm Springs, California for about three years led to a larger decrease in strength that was still considered noncritical.

Recommendations and Implementation

A survey by the Office of Traffic or Maintenance should be made of the Transportation Districts at six month or one year intervals to estimate the number of barrel failures that are occurring. It should be determined whether all barrels were on structures, all were 1400 or 2100 lb. (636 or 953 kg) modules, etc., in an effort to locate critical failure conditions. If the problem seems significant, then steps can be taken to eliminate the failure conditions or strengthen the barrels. Particular attention should be paid to barrels located in areas which have high temperatures for long periods of time and areas which have high temperature differentials.

Although the cause of occasional failures of polyethylene sand filled barrels in operation has not been isolated to date, the maintenance of a rigorous quality assurance program in the manufacture and acceptance of this product should minimize the occurrence of these failures.

III. TEST EQUIPMENT AND PROCEDURE

A. Description of Test Specimens

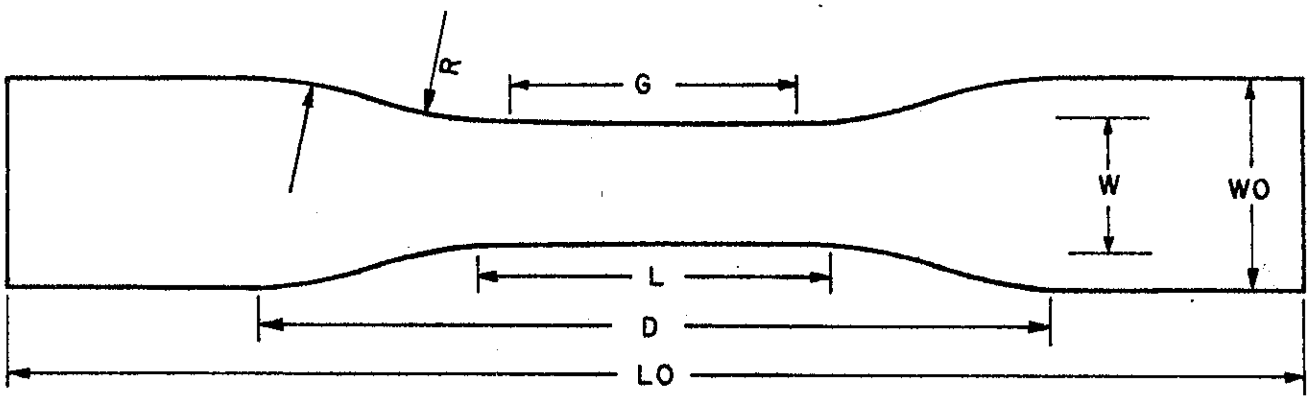
1. For the determination of ultimate tensile strength of the barrel material a one inch reduced section specimen configuration was used. Figure 2 shows the typical test specimen configuration and dimensions. A one half inch (13 mm) reduced section sample configuration was considered but rejected because of excessive variations in test results between like samples. ASTM D638 which standardizes tests for the tensile properties of plastics was used as a guide.

2. Seam strength test specimens were cut at intervals from the full length of the riveted seam of an unexposed control sample barrel. Each test specimen contained one rivet. Figure 2 shows the dimensions and configuration of the typical test specimen. The two 1/2 inch diameter holes were used to attach the specimen to the test machine.

B. Description of Test Equipment

1. A 5000 lb. (22.2 kN) universal testing machine was used for the tensile strength tests. For high and low temperature tests an environmental chamber was used in conjunction with the universal testing machine. This chamber holds the test specimen at the desired temperature while the tensile strength

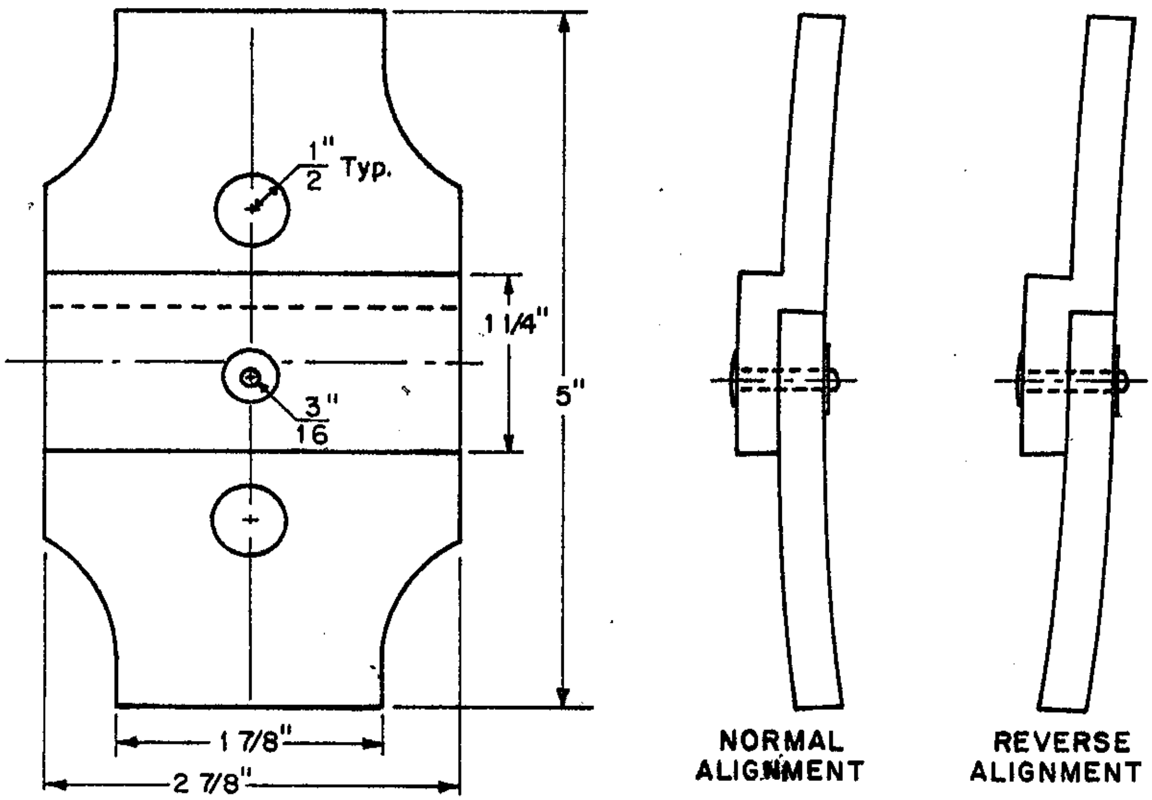
REFERENCE: ASTM D638



W (Width)	=	1"
L (Length)	=	2.4"
WO (Width Overall)	=	1.5"
LO (Length Overall)	=	9"
G (Gage)	=	2"
D (Shoulder Distance)	=	5.5"
R (Shoulder Radius)	=	3"

Scale: 3/4" = 1"

BARREL MATERIAL TENSILE SPECIMEN



SEAM CONNECTION TENSILE SPECIMEN

Figure 2

test is being performed. The jaws selected for tensile testing were a locking cam type. For all ultimate strength tensile tests a loading rate of 2 in. (51 mm)/min. was used.

2. An Atlas weatherometer conforming to ASTM designation G 23-69 was used to expose new control sample barrel material to ultra-violet radiation. The exposure cycle used consisted of an alternation of 102 minutes of light and 18 minutes of light and water spray.

C. Test Procedure

1. Sampling procedure for barrel material.

Three barrel assemblies were used for most of this testing. A new barrel labeled 72-1894 was the control sample. Two barrels that had failed in service, 72-1895 taken from the Lincoln Airport test site and 72-2010 taken from a Los Angeles freeway site, were also used to obtain samples.

Test specimens were cut from various locations on the barrel halves. Figure 3 contains a specimen source location diagram and an explanation of specimen identification.

2. Tests to determine the effect of in-service weathering on barrel material.

Tensile strength tests were performed on the in-service barrel samples (72-1895 and 72-2010) to determine the tensile strength of this weathered material and to compare it with the unweathered control sample material. Test specimens were cut from various locations on the sample barrel to assure a representative average of the tensile strength of the weathered material.

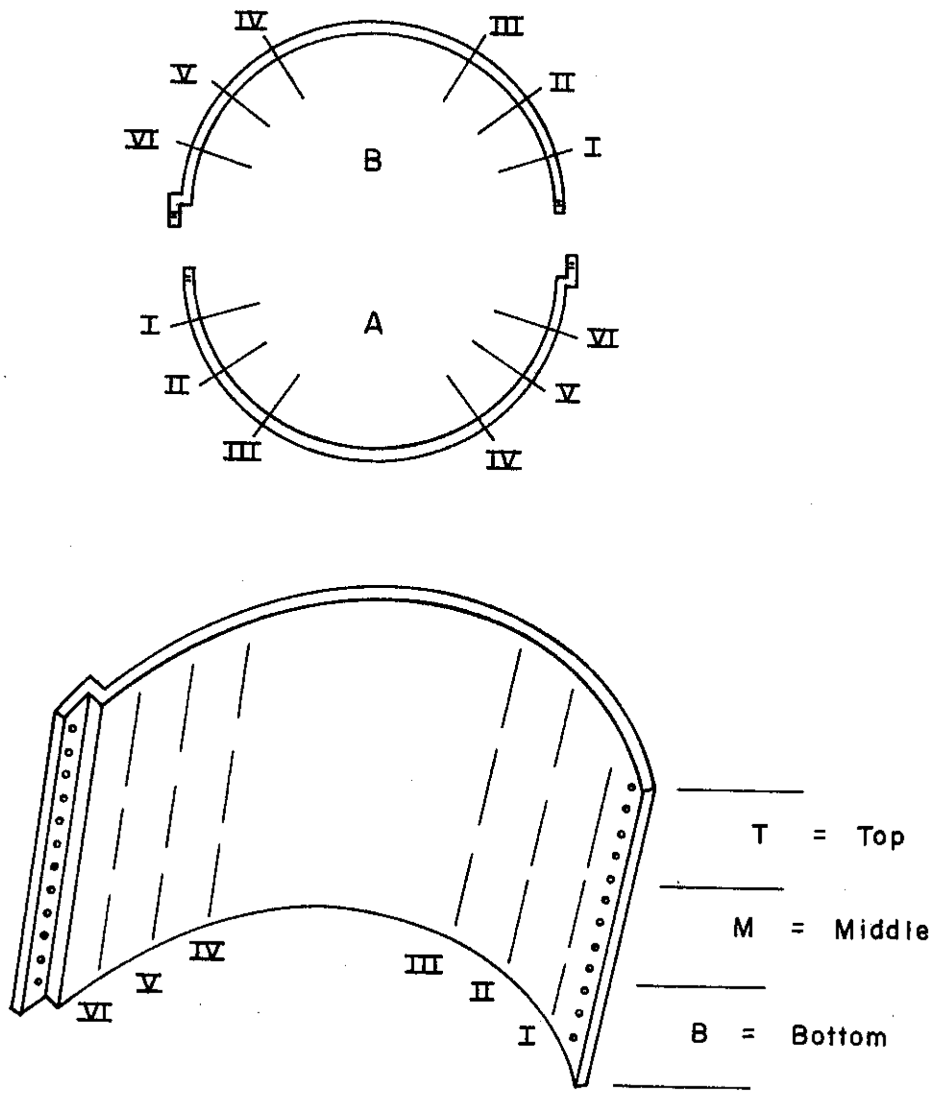
SAMPLE DESIGNATIONS

1894 - Control Sample (Unexposed)
1895 - Lincoln Site
2010 - L. A. Site

ILLUSTRATION:

1894 - A - III - T

- 1894 — Sample Barrel Designation
- A — Barrel Half
- III — Vertical Section
- T — Horiz. Section



SPECIMEN SOURCE LOCATION DIAGRAMS

Figure 3

3. Tests to determine the effect of temperature extremes on tensile strength of material specimens and seam connection specimens.

An environmental chamber was used to perform tensile tests at temperature extremes. The test procedure used was as follows:

a. Test specimens were seasoned for one hour in the environmental chamber at the selected temperature before testing.

b. After mounting in the testing machine jaws within the chamber, five minutes more were allowed for the sample to return to temperature after handling; then the tensile test was performed.

4. Recovery strength of the seam connection when subjected to temperature cycles.

For this test the specimen was a sample of the riveted connection containing one rivet. The specimen, supporting a 50 lb. (223 N) load, was cycled between 120°F (322 K) and 30°F (272 K) and the resulting variations in length of the connection noted.

5. Test procedures for weatherometer specimens.

Following is the test procedure used:

a. Ten 3 in. x 9 in. (76 x 229 mm) samples were cut from the undamaged nose barrel used in a metal beam guardrail bullnose test conducted on November 1, 1973. This barrel material had a slightly higher density than the material in barrels 72-1894, 72-1895, and 72-2010.

b. Five of these samples were placed in the weatherometer and the other five were stored in darkness as a control sample.

c. After 1000 hours exposure five 1 in. (25.4 mm) reduced section tensile specimens were cut from the exposed material, and the remaining material was returned to the weatherometer for additional exposure. Five tensile specimens were also cut from the control sample material and tensile strength tests were performed on these ten specimens.

d. After 2000 hours of exposure five tensile specimens were cut from the remaining exposed material and an additional five specimens from the remaining control sample and these ten specimens were subjected to tensile tests.

IV. TEST RESULTS

Tables 1 through 5 which follow summarize all testing.

Table 1

Tensile Strength of Polyethylene Fitch Barrel Material
Comparison of Sample Locations on Barrels
& Comparison of Weathered vs. Non-Weathered Barrels

Test Specimen Temperature: 70°F (294 K)

Sample Identification	Tensile Strength (lbs/lin.in.)	Sample Identification	Tensile Strength (lbs/lin.in.)	Sample Identification	Tensile Strength (lbs/lin.in.)	Average Tensile Strength (lbs/lin.in.)
1894-A-III-T	625	1895-A-III-T	621	2010-A-III-T	553	
1894-A-IV-T	560	1895-B-III-T	586	2010-B-III-T	624	
		1895-B-III-T	578	2010-B-III-T	618	
		1895-B-III-T	571	2010-B-III-T	617	
		1895-B-III-T	561	2010-B-III-T	529	
		1895-B-III-T	548	2010-B-III-T	494	
T-Avg.	592.5	T-Avg.	577.5	T-Avg.	572.5	581
1894-A-III-M	650	1895-A-III-M	634	2010-A-III-M	471	
1894-A-IV-M	490	1895-A-III-M	490	2010-A-III-M	431	
1894-A-IV-M	478					
1894-A-IV-M	458					
M-Avg.	519	M-Avg.	562	M-Avg.	451	511
1894-A-III-B	560	1895-A-III-B	607	2010-A-III-B	598	
1894-A-III-B	550	1895-A-III-B	529	2010-A-III-B	467	
1894-A-IV-B	525					
B-Avg.	545	B-Avg.	568	B-Avg.	532.5	548.5
All 1894 Avg.	552	All 1895 Avg.	569	All 2010 Avg.	519	
				All Samples Avg.		547

Note: 1894 - unweathered control barrel; 1895 - weathered barrel with seam failure, Lincoln Airport; 2010 - Weathered barrel with seam failure, Los Angeles freeway site.

*1 lb/in. = 175 N/m

Table 2

Tensile Strength of Polyethylene Fitch Barrel Material

Effect of Temperature on Weathered & Non-Weathered Samples

Test Specimen Temperature: 30°F (272 K)

Sample Ident.	Tensile Strength (lbs/lin.in.)	Sample Ident.	Tensile Strength (lbs/lin.in.)	Sample Ident.	Tensile Strength (lbs/lin.in.)
1894-A-III-T	852	1895-A-III-T	860	2010-A-III-T	845
1894-A-III-M	890	1895-A-III-M	901	2010-A-III-M	789
1894-A-III-M	710	1895-A-III-M	817	2010-A-III-M	551
1894-A-III-B	545	1895-A-III-B	595	2010-A-III-B	787
1894-A-III-B	743	1895-A-III-B	644	2010-A-III-B	624
1894 Avg.	748	1895 Avg.	763	2010 Avg.	719
				All Samples Avg.	743

Test Specimen Temperature: 120°F (322 K)

Sample Ident.	Tensile Strength (lbs/lin.in.)	Sample Ident.	Tensile Strength (lbs/lin.in.)	Sample Ident.	Tensile Strength (lbs/lin.in.)
1894-A-III-T	471	1895-A-III-T	432	2010-A-III-T	398
1894-A-III-T	459	1895-A-III-M	482	2010-A-III-M	385
1894-A-III-M	393	1895-A-III-M	392	2010-A-III-M	355
1894-A-III-B	300	1895-A-III-B	343	2010-A-III-B	379
1894-A-III-B	414	1895-A-III-B	385	2010-A-III-B	369
1894 Avg.	407	1895 Avg.	407	2010 Avg.	377
				All Samples Avg.	397

Note: 1894 - unweathered control barrel; 1895 - weathered barrel with seam failure, Lincoln Airport; 2010 - weathered barrel with seam failure, Los Angeles freeway site.

1 lb/ft = 175 N/m

Table 3

Tensile Strength of Polyethylene Fitch Barrel Seam Connections & Effect of Temperature on Connection Strength

Sample Temperature (°F)	Sample Alignment	Tensile Strength (lbs.)	Tensile* Strength (lbs/in.of barrel)
30	Normal	283 272 263 203	94 91 88 68
	30° Avg.	255	85
70	Normal	252 257 208	84 86 69
	70° Avg.(Norm)	239	80
70	Reverse	254 235 256	85 78 85
	70° Avg.(Rev)	248	83
	All 70° Avg.	244	81
110	Normal	163	54.3

*Rivet Spacing is 3 inches (76 mm) O.C.; this colum represents the connection strength divided by 3 for comparison with the other tables.

Sample Source 1894-B

Degrees K = (°F + 460)/1.8
1 lb = 4.45 N
1 lb/in. = 175 N/m

Table 4

Recovery Strength of a Polyethylene Fitch Barrel Seam Connection Specimen When Subjected to Temperature Cycles

Temperature (°F)	Elongation (inches)
120	0.084
31	0.048
119	0.088
30	0.051
122	0.093
30	0.054

If the initial cycles are regarded as conditioning cycles, it can be observed that in the last complete cycle from 30° to 120° to 30° F the specimen showed a relaxation of 0.003 inch.

*Degrees K = (°F + 460)/1.8

1 in. = 25.4 mm

Table 5

Tensile Strength of Polyethylene Fitch Barrel Material
Comparison of Control Samples & Weatherometer Samples

Test Specimen Temperature: 70°F (294 K)

Control		Weathered (1000 hrs.)	
Sample No.	Tensile Strength (lbs/lin.in.)	Sample No.	Tensile Strength (lbs/lin.in.)
C1	878	X1	785
2	834	2	712
3	837	3	750
4	761	4	642
5	880	5	686
Avg.	838	Avg.	715

Control		Weathered (2000 hrs.)	
Samples No.	Tensile Strength (lbs/lin.in.)	Sample No.	Tensile Strength (lbs/lin.in.)
C6	752	X6	722
7	812	7	224
8	752	8	726
9	820	9	734
10	850	10	648
Avg.	797	Avg.	610
		Avg. (highest four)	707

Note: Samples cut from Fibco Barrel used in Modified Bullnose test November 1, 1973.

*1 lb/in. = 175 N/m

V. DISCUSSION

The tensile test results indicate that when the specimens were at temperatures of 120°F (322 K), there was a 27% decrease in strength as compared to specimens at 70°F (294 K). Specimens at 30°F (272 K) had a 36% increase in strength over specimens at 70°F (294 K). The tests also indicate that the strength which could be developed at the rivet connection was much lower than the strength which could be developed in the barrel material. The effects of location of samples on the barrel and normal weathering were not significant.

It was observed that in tests conducted in 70° and 120°F (294 and 322 K) the riveted connection specimen failed by the rivet head rotating into the material and pulling through. In the tests at 30°F (272 K), the barrel material failed in a manner similar to that observed on the barrels that failed in the field, where small triangular pieces sheared out at the edge of the longitudinal seam at rivet locations (Figure 1).

Specimens that were in the weatherometer for 1000 and 2000 hours faded slightly and had stress crazing on one side. The specimens exposed for 2000 hours looked similar to those exposed for 1000 hours. Crazing indicates a brittle condition developing. Tensile test results reported in Table 5 indicate a decline in strength for the exposed specimens, but the strengths were still well above those reported in Table 1. Possibly this is because the samples were taken from the denser barrel material used by the manufacturer after mid-1973.

Other samples from the denser barrel material used in the weatherometer tests were placed on an exposure rack near Palm Springs, California in April of 1974. They were removed in February of 1977. Six specimens were submitted to a tensile test and had an average strength of 512 lbs. per lineal inch. This shows a considerable loss of stength from the control specimens which averaged 838 and 797 lbs. per lineal inch for two sets of five specimens each as shown on Table 5.

In January 1973, we received a letter from the manufacturer which indicated they had done some work concurrent with ours after the barrel failures in the field were reported. Their main theory on barrel failure was that "the modules expand during periods of high temperature, the sand settles and when the temperature drops, the module is unable to contract against the sand with resultant stress cracking at the rivet strip." The letter describes changes they made to strengthen the material and eliminate possible weak points. They modified the mold to provide two 1/16 inch (2 mm) deep locating strips longitudinally along the seam edges of each half so that they would lock together. These strips were added to reduce the stresses in the rivet hole areas. The manufacturer also changed to polyethylene with a lower melt index and a higher density that increased the weight of each barrel half by two pounds. This denser material reduced the extent of the voids in the inner layer of the barrel walls. A third change was the use of molded rivet holes, rather than hand drilled holes, and the use of rivets with larger heads and washers.

VI. LATER DEVELOPMENTS

The work described briefly in this section was not part of this research study, but it is included to update previous work on the barrel wall material.

A. Research Studies by Manufacturer

1. Report No. 75-01 "Results of Full-Scale Crash Test Program", by Robert A. Mileti, Fibco, Inc. Polypropylene (PP) was used in place of high-density polyethylene (HDPE) as the structural foam material of barrel walls. The barrels with PP were used in a vehicular impact test and proved equal to the HDPE barrels. The PP has a higher hoop stress capability and flexural modulus than HDPE. The main drawback of PP that was cited is its brittleness at sub-zero temperatures which would require special handling during assembly of a crash cushion in extremely cold areas. Thus PP provides a viable alternative to HDPE, but the manufacturer has not elected to change materials as of this time.

2. Report No. 75-03 "Results of Module Splitting Investigation", by Robert A. Mileti, Fibco, Inc. It was noted that earlier changes in barrel design had eliminated failures at the edge of the rivet strips, but that subsequently a few failures had occurred "at the center of the rivet strip, either through or around the molded rivet holes." Tests were conducted to determine the ultimate hoop strength of PP and HDPE barrels and to learn the effects of vibration and thermal cycling on increasing hoop stress. No reasons for barrel failure were observed in those tests. However, in the final test series, calcium chloride ($CaCl_2$) was added to the sand, high humidity was maintained and the temperature was cycled from -40°F to 120°F (233 to 322 K). Under these conditions failures occurred through the center of the rivet strips similar to those in the field.

It had been noted that many of the failures in the field were at locations where there were large temperature fluctuations, there were large bodies of water nearby to raise the humidity, and $CaCl_2$ had been added to prevent the sand from freezing. It was concluded that the $CaCl_2$, which is a deliquescent material, takes on moisture and increases the shear strength of the sand so that when the sand settles in the barrel as it expands during high temperatures, the sand later resists displacement as the barrel contracts during cold temperatures. Progressive bulging of the barrel walls ultimately results in failure at the weakest point, the rivet strip.

The elastic limit hoop strength reported for "5 melt PP" was 207 lbs./in. (36.2 kN/m) or 691.2 psi (4.77 MPa) and for "8 melt HDPE" was 138 lbs./in. (24.2 N/m) or 460.8 psi (3.18 MPa), assuming barrel wall thickness = 0.3 inch (8 mm).

The lateral pressure of 2100 lbs. (953 kg) of sand in a barrel was calculated to be 100 lbs./ft.^{2} (4.79 kPa) at the bottom of a 3 ft. (915 mm) high barrel (using the Rankine theories). The hoop stress due to this pressure would be 12.5 lbs./in. (2.19 kN/m); hence, hoop stress due to the lateral pressure of sand in the barrel does not, by itself, appear to be a critical factor.

B. Quality Control Procedures

The manufacturer was requested to provide evidence of a satisfactory quality control program for the various barrel components in 1974. This request had been made of both manufacturers of crash cushions as part of the ongoing overall program of quality assurance for highway materials provided to the California Department of Transportation.

The manufacturer subsequently provided a set of quality control procedures. Barrel halves were to be subjected to a number of tests at varying frequencies to check the weight, maximum void size, ultimate hoop strength, rivet strip alignment, and the impact strength within upper and lower limits.

C. Recent Barrel Failures

In the year and a half following June 1975, five barrel failures have been observed in Sacramento. At one site a 2100 lb. (953 kg) module had a split from ground to mid-height that passed near or through mold filler hole locations. The rivet strips were 90° (1.6 rad) around the barrel from the vertical split. There was no clear reason for this failure. The crash cushion was located on a structure, it had been in service for several months, and it had been subjected to temperatures ranging from about 30°F (272 k) in winter to 105°F (339 k) in summer. An inverted lid had been placed on the pavement and forced inside the barrel walls. Since the lip of the lid normally goes outside the barrel, the tight fit may have helped initiate or propagate the split.

The other four barrels had all split through or near the rivet holes. In two 2100 lb. (953 kg) modules the split extended from ground level to about six inches from the top of the barrel. In two 1400 lb. (636 kg) modules the split was about 18-20 inches (0.46 to 0.51 m) long, at mid-height on the barrel, but did not reach to the top or bottom of the barrels. All four barrels were located on structures which vibrated noticeably when traffic passed over them. These barrels were all dark green and had the interlocking rivet strip design. A cone of leaking sand was growing outside the splits at the time they were observed. No $CaCl_2$ had been added to the sand.

At one structure a seismometer was used to measure vibrations. Frequency of the vibrations varied from 2.0-3.5 Hz, but, in general, the frequency was about 2.5 Hz. Peak to peak displacements varied from 0.008 to 0.107 inches (0.203 to 2.72 mm) but may have been greater with truck loads because the upper limit of the seismometer was reached several times.

A nuclear gage was used to measure moisture content and density of the sand in three barrels at several depths. There was an increase in density near the bottom of the barrels.

Samples from the split barrels were given to the manufacturer at his request. Results of his tensile tests showed the material was not substandard.

There have been a limited number of other failures in California. A few barrels on structures in Oceanside have developed splits similar to those in Sacramento.

In summary it should be noted that the number of reported failures have been quite small. The manufacturer has been aggressive about investigating problems and improving the barrel design. At this time there is no single identifiable cause of the barrel failures. They may be the result of a number of factors in combination such as vibration, temperature cycles, creep, stress flow at the rivet holes, etc.

D. Energite Barrels

In November 1974, Energite modules manufactured by Energy Absorption System, Inc., were approved for use in crash cushions installed on California Highways. The Energite system is similar in design and function to the Fitch Inertial Barrier system. The inner and outer Energite module sand containers are a polyethylene material similar to that used in the Fitch barrels, but are each molded in one piece so there is no rivet strip. There have been a few problems with buckling and tearing in the Energite outer modules in field installations. The manufacturer has modified the molds which apparently has taken care of the problems. This manufacturer also has been aggressive about solving problems as they develop.

E. Other Studies

A report titled "Effects of Temperature Change on Plastic Crash Cushions" by Victor N. Toth and Clyde E. Lee of the University of Texas, Research Report 514-1F was published in January 1976. The authors performed accelerated tests on two plastic barrels each of the Fitch and Energite designs. The barrels were subjected to temperature changes of 130°F (328 K) over a two week period. Cracking or distortion was observed in three of the four specimens. The authors concluded that the "temperature changes induced volume changes in the plastic and in the sand which resulted in high tensile stresses in the sand-filled containers." They observed that problems might develop with field installations of the barrels over extended periods of time.