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16. Abstract

This study was conducted to determine the ability of two types of commercially available plastic crash cushion units to maintain their shape and integrity when filled with sand to normal service load and exposed to large temperature variations. The test program consisted of alternately subjecting four crash cushions to temperature changes of 130° F. The results indicated potential problems with material failure in both types of crash cushions. Temperature changes induced volume changes in the plastic and in the sand which resulted in high tensile stresses in the sand-filled containers. The ability of the plastic to withstand these stresses over extended periods of time must be considered in field applications. Cracking or distortion was observed in three of the four specimens.

17. Key Words

crash cushions, plastic, temperature effects, sand-filled energy attenuators

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EFFECTS OF TEMPERATURE CHANGE ON PLASTIC CRASH CUSHIONS

by

Victor N. Toth
Clyde E. Lee

Research Report Number 514-1F

Effects of Temperature on Plastic Crash Cushions

Research Project 3-10-76-514

conducted for

Texas
State Department of Highways and Public Transportation

by the

CENTER FOR HIGHWAY RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

January 1976

EFFECTS OF TEMPERATURE CHANGE ON PLASTIC CRASH CUSHIONS

I. INTRODUCTION

This study was conducted to determine the ability of two types of commercially available plastic crash cushion units to maintain their original shape and integrity when filled to normal service load and exposed to large temperature variations. In the interest of conserving time, an accelerated testing program was instituted wherein two samples of each type unit were subjected to wide-ranging controlled temperature conditions. The plastic crash cushions utilized in the study were standard production units, and in preparing the units for testing, the published assembly and sand-loading instructions were observed in detail.

A secondary effort in the study dealt with the effects of low temperature on the behavior of the sand that was used to fill the test specimens.

II. PRIMARY TEST PROGRAM AND EQUIPMENT

Initially, one each of two commercially available plastic crash cushions was scheduled for testing, but just prior to the start of testing it was learned that each manufacturer had introduced modifications to its product. The test was therefore delayed briefly so that the new models might be included, and actual testing was conducted using four units, one old and one new model from each supplier. Each unit was identified by using the first letter of the manufacturer's name and a number as follows:

Energite	E-1	(old model)
	E-2	(new model)
Fitch	F-1	(old model)
	F-2	(new model)

The difference between the old and the new Fitch models appeared slight and seemed to consist mainly of a minor change in the material density and in the configuration of the internal sand support platform. The Energite manufacturer had, however, redesigned the inner sand container to provide a five-point support base rather than the previous single-point center support.

Both Energite units were received fully assembled (Figs 1a and 1b). One Fitch unit (F-1) was received partly assembled; the other was completely disassembled (Fig 2). While assembly of the new Fitch model was simple (Fig 3), some difficulty was experienced with the "pop rivets" that were supplied. The rivet kit did not contain enough washers for the entire assembly, but had an excessive number of rivets. Additionally, some of the rivets failed to "pop," which resulted in the rivet head being pulled completely through the expandable sleeve and washer. In at least four instances, a second rivet application was required. This minor difficulty might have been due to faulty operator technique, however.

The crash cushions, after assembly, were placed, two per vehicle, on four-wheeled carts and filled with sand (Fig 4). Cushions E-1 and F-1, which were paired on the same cart, contained sand with an average moisture content of 2 percent while E-2 and F-2 were filled with sand having a moisture content of 5 percent. The two Energite models each accepted the full 1,400 pounds of sand, as specified. The Fitch models, even with light tamping and screeding, would hold only 1,350 pounds of sand. The washed sand which was used in this study was obtained locally and is the type that is normally used for making concrete in the Austin area.

During the sand-filling operation, one Energite and one Fitch unit were each instrumented with thermocouples. Two of these temperature probes were utilized per crash cushion; both were located at mid-depth, with one positioned approximately an inch from the outer wall and the other near the sand mass center. Additionally, each temperature chamber in which the tests were performed contained a similar centrally-located thermocouple for recording representative test-chamber air temperatures.

Upon completion of the sand-filling and instrumentation operation, the four crash cushions were prepared with reference markings to facilitate initial and subsequent dimensional measurements. Physical measurements of the cushions were dictated in part by their actual shape. The Fitch units, being right circular cylinders in form, were each marked for circumference measurements at five elevations: six, twelve, eighteen, and twenty-four inches from the top, and at the bottom edge (Fig 3). The Energite units, having slightly

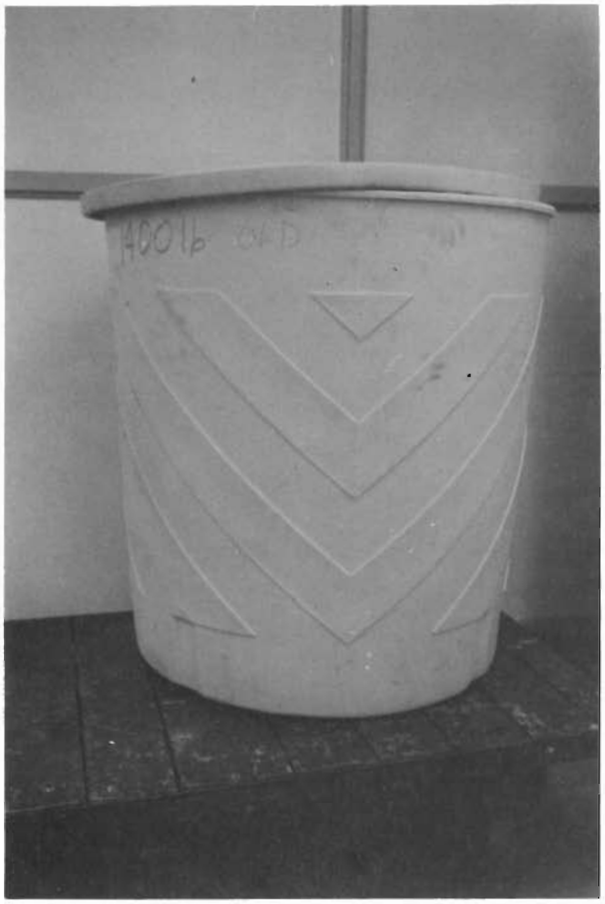


Fig 1a.

Fig 1b.

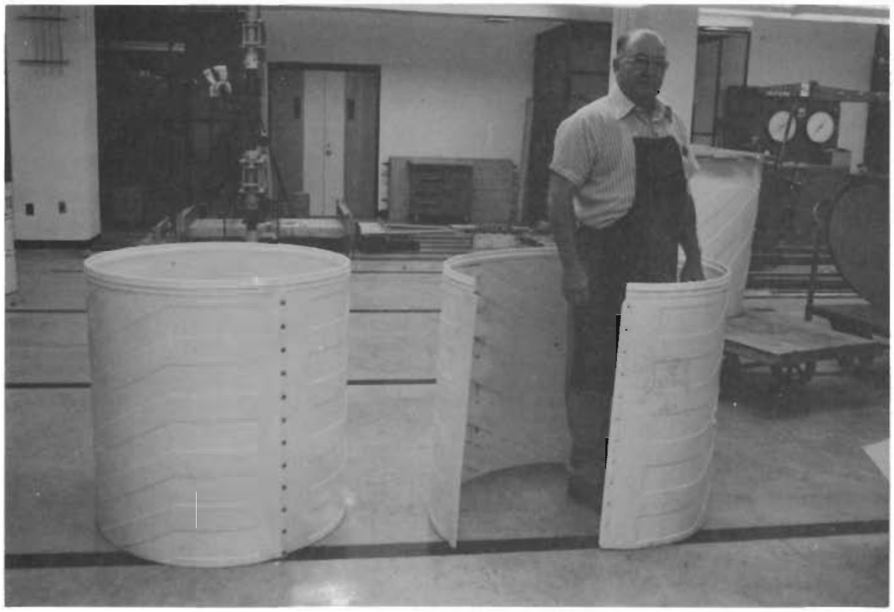


Fig 2.

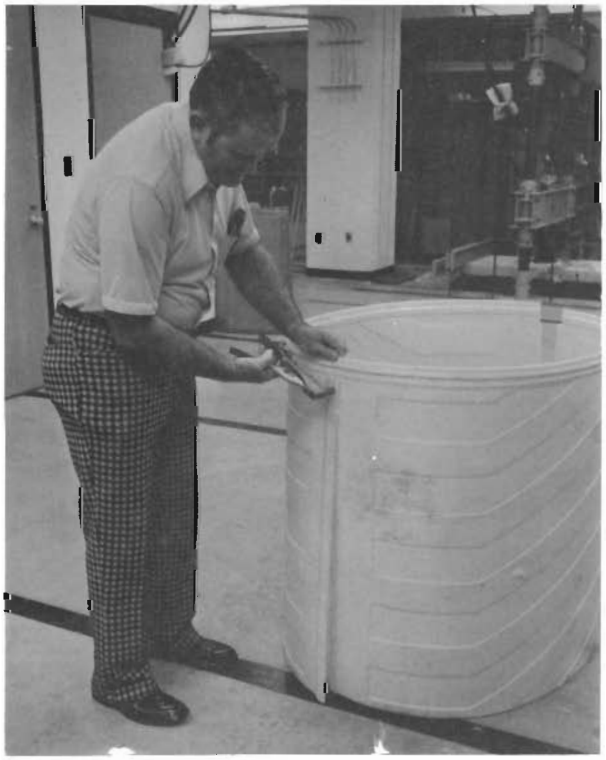


Fig 3.

Fig 4.

tapered sides, were each referenced for two circumference measurements and for six height measurements at 120-degree locations around the outside of each unit (Fig 5).

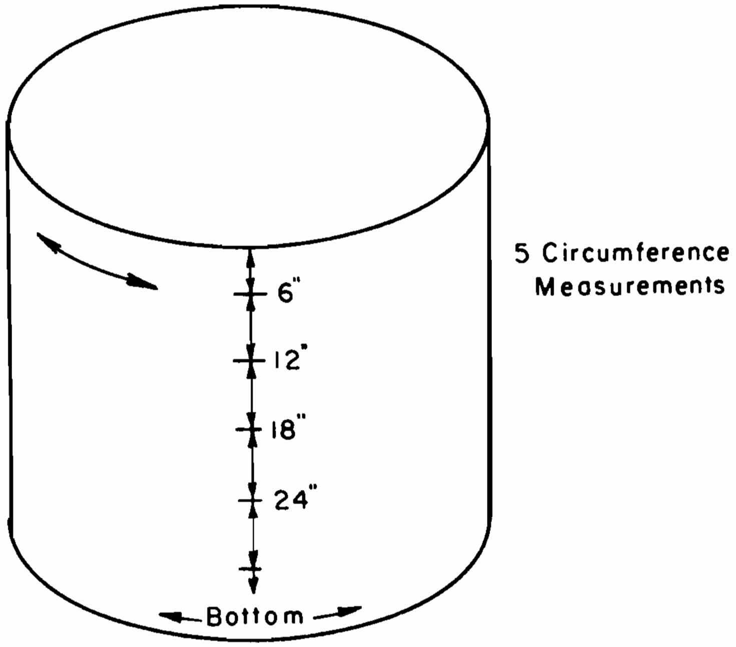
The actual test program consisted of alternately subjecting the four crash cushions to temperature changes of 130° F. This was achieved by utilizing two large adjacent temperature chambers (one maintained at 0° F ± 5° and the other at 130° F ± 5°) and by manually moving the carts carrying the cushions from one chamber to the other through a connecting doorway (Fig 6). Initially it was planned to cycle the test units on a 24-hour basis, but, after monitoring the temperature of the sand near the container wall and at the center of the sand mass during the first cooling period, it was determined that at least 48 hours were required to bring the center temperature to within 10 or 15 degrees of the chamber air temperature. The test was thereafter conducted on a 48-hour cycle basis except for weekends, which were 72-hour periods.

Routinely all dimensional measurements were made immediately after the test units were moved from the 0° F chamber into the 130° F chamber (Fig 7). Sand and chamber air temperature readings (Fig 8) were made on an 18 to 24-hour basis. At the end of each temperature cycle all test units received a close physical inspection for evidence of cracking or distortion.

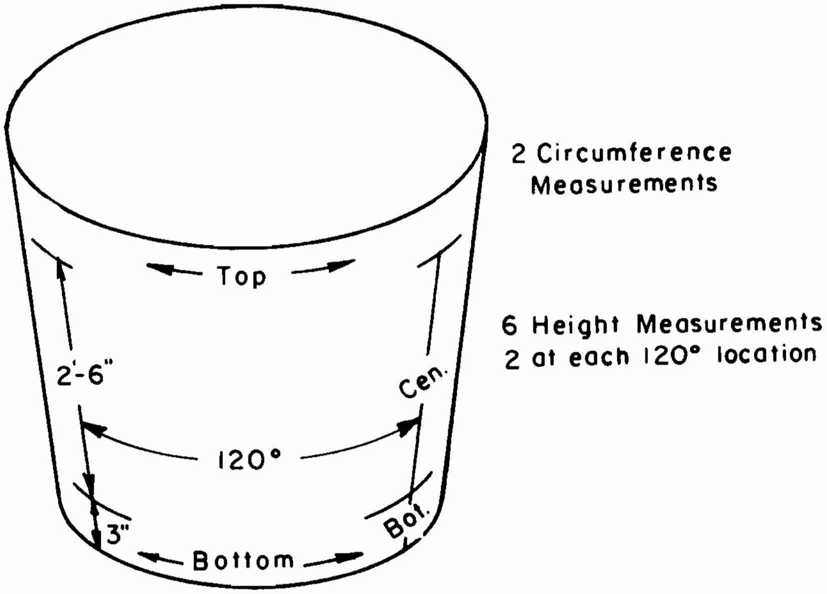
III. RELATED EXPERIMENTS AND RESULTS

Since the primary test program involved the behavior of sand at various moisture contents and at below freezing temperatures, several small-scale, simple experiments were conducted to investigate this behavior.

An area of particular interest was the effect of freezing temperatures on the strength of sand with varying moisture contents. Four sand specimens were prepared in 2-inch diameter by 4-inch high split molds, at moisture contents of 2-1/2, 5, 10, and 20 percent by weight of sand. All specimens were subjected to 0° F temperature for 30 hours, released from the molds, and immediately tested at room temperature (approximately 74° F). Despite the slight "melting" which occurred at the top and bottom loading surfaces during the unconfined compression test, which was conducted at about 0.05 inch per minute loading rate, each specimen exhibited significant ultimate compressive strengths as follows:



FITCH



ENERGITE

Fig 5. Dimensional measurement references.

Fig 6.

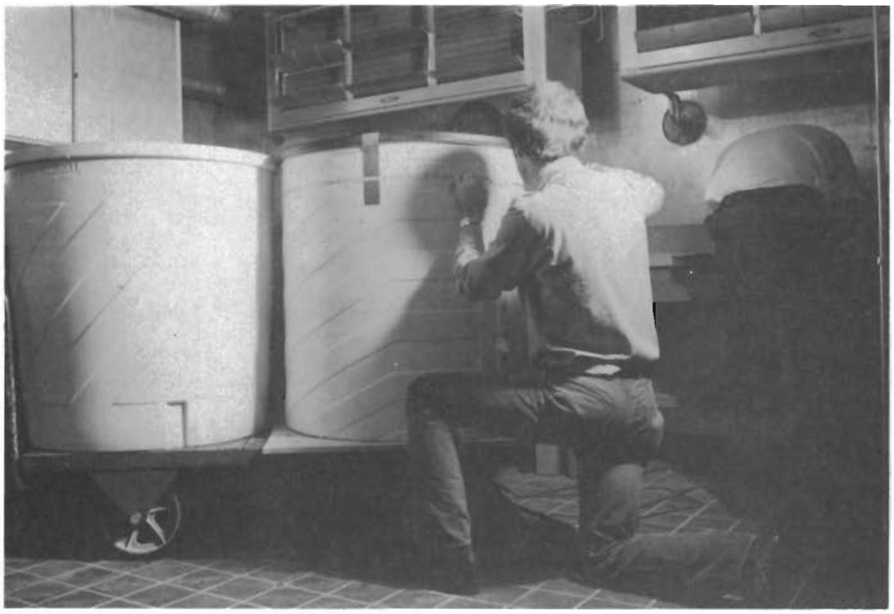


Fig 7.

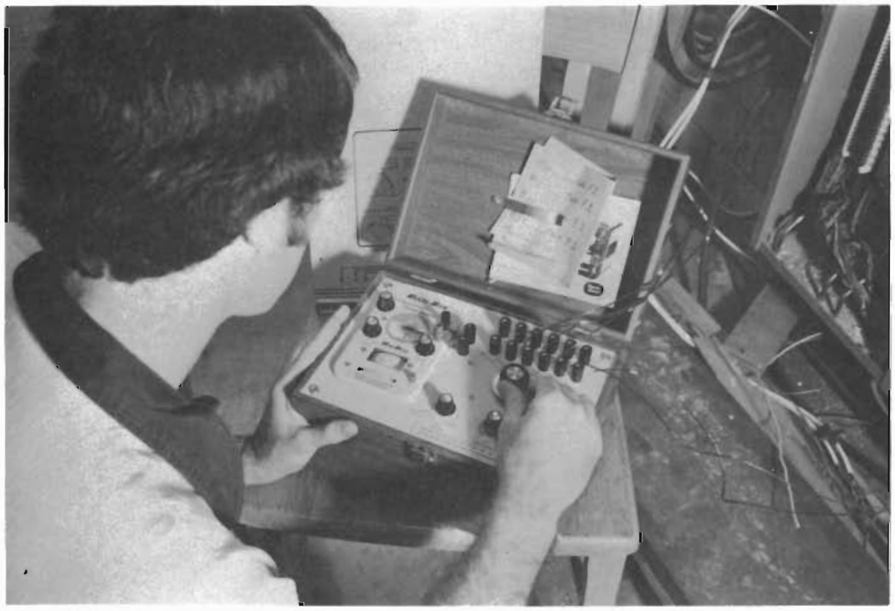


Fig 8.

Specimen/Moisture Content, %	Ultimate Compressive Strength, psi
20	1,060
10	640
5	250
2.5	160

Additionally, and for comparison, two freshwater specimens were prepared in plastic molds and subjected to 0° F temperature for 72 hours. After release from the molds these ice specimens were compression tested in a 0° F chamber and yielded an ultimate compressive strength of approximately 600 psi (Fig 9). Three more sand specimens were prepared with a 2 percent moisture content for indirect tensile (splitting cylinder) testing. These specimens had a 2-inch diameter and a height of 1.2 inches, and yielded tensile strengths ranging from 25 to 29 psi based on elastic theory.

Another experiment dealt with the drainage of free water from a saturated sand specimen. Two half-pint wax-paper cups with numerous small perforations in the bottom were filled with 400 grams of oven-dried sand. The sand was slowly covered with water, which permitted drainage through the bottom holes. After the top of each container was covered with aluminum foil, they were stored in a nominal environment of 75° F and 50 percent relative humidity. During the first 72 hours of drainage, the specimens lost more than 80 percent of the added moisture. Thereafter, the moisture loss slowed radically, and at the end of 18 days of drainage the specimens contained about 8 percent moisture (Fig 10).

Published reports dealing with sand-filled highway barrier systems make reference to the use of an antifreeze agent in conjunction with sand to prevent freezing. One frequently used agent is calcium chloride, in concentrations as high as 25 percent or more by weight. A cursory experiment conducted using fresh water and calcium chloride indicates that even a 25 percent solution tends to become a rather firm ice slush at 0° F. Any solution containing less than 20 percent calcium chloride froze into solid ice at 0° F temperature.

The crash cushions utilized in the primary portion of this study were filled with sand that was from the same supplier but was delivered at two different times. Units E-1 and F-1 received sand containing 2 percent moisture. Sand loaded into units E-2 and F-2 had a moisture content

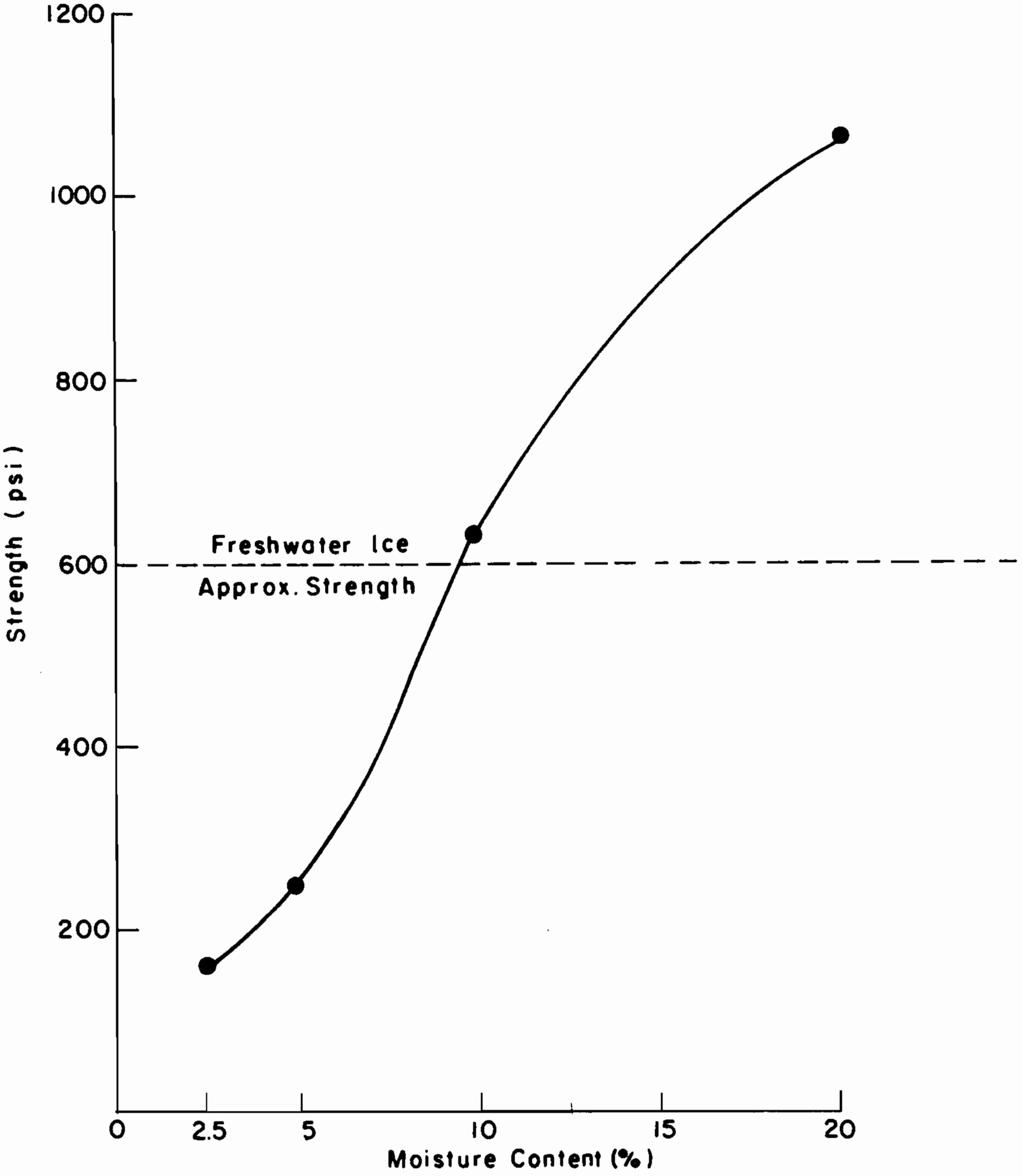


Fig 9. Effect of moisture content on ultimate compressive strength of frozen sand.

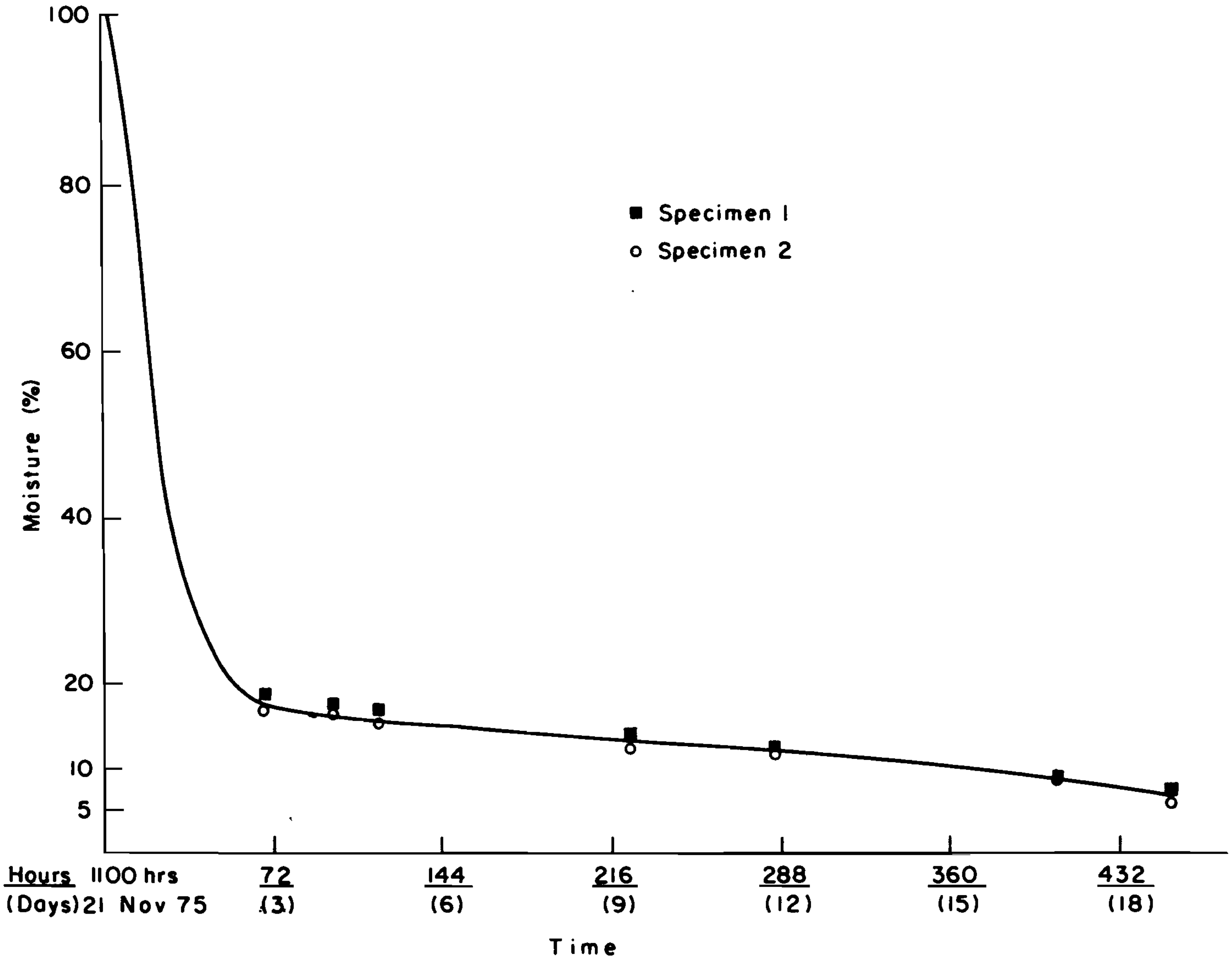


Fig 10. Water saturated sand drainage experiment (percent moisture content with time).

of 5 percent. At the conclusion of three complete hot-cold cycles, the top cover of unit F-1 was replaced with a new cover furnished by the manufacturer. When the original cover was removed, an ice crystal formation was noted on the inside cover surface (Fig 11). It is estimated that one to two ounces of water were contained in this formation. Additionally it was noted that some thawing had occurred before the cover was removed, as evidenced by wet spots on the sand surface (Fig 12). These conditions appeared to indicate considerable moisture movement within the sand mass and suggested that evaporation probably took place. Also visible (Fig 12) were cracks in the sand up to 5/16 inch wide and more than 1/2 inch deep. The exact cause of these cracks is unknown since the covers remained in place throughout the test except as noted above.

Based on these observations, two sets of moisture samples were taken from the two Fitch units at various depths with a special sampling tube; the results are shown in Table 1. It would appear from these samples that the sand moisture content varies with depth and that, overall, a moisture loss was occurring. At the time the second set of samples was obtained, the test units had been continuously exposed to dehydrating conditions in the controlled temperature chambers for more than 40 days.

IV. TEST RESULTS

Actual testing of the plastic crash cushions started on October 27, 1975, when the four sand-filled units were moved from a stable temperature of 80° F into a 0° F temperature chamber. The preliminary plan called for cycling the test units between 0° F and 130° F every 24 hours. At the end of the first 24-hour period, the temperature in the sand mass center had fallen to only 38° F in both the Fitch and the Energite units, as indicated in Fig 13. Obviously more time was required; therefore, it was decided to extend the temperature cycle time to a minimum of 48 hours. This scheme was followed throughout the remainder of the test except for weekend periods, which were 72 hours long. As indicated in Fig 13, center sand temperatures seldom exactly equalled chamber temperatures. All observed sand temperatures were, however, within about 10° F of the 130° F air temperature in the hot chamber, and the sand temperatures were below 32° F before the specimens were moved from the cold chamber in every case. Figure 13 also shows that, for the most part, the

Fig 11.

Fig 12.

TABLE 1. FITCH CRASH CUSHION MOISTURE CONTENTS

Unit/Location	Time	Percent Moisture
F-1 / Top	5th cycle	1.5
F-1 / Center	5th cycle	1.6
F-2 / Top	5th cycle	1.3
*F-2 / Center	6th cycle	3.2
F-1 / Top	8th cycle	0.1
F-1 / Center	8th cycle	1.0
F-1 / Bottom	8th cycle	1.5
F-2 / Top	8th cycle	0.4
F-2 / Center	8th cycle	1.4
F-2 / Bottom	8th cycle	2.6

*Initial attempt to obtain sample failed because the center was frozen solid.

Notes:

1. A second set of samples was taken during the hot cycle to avoid frozen sand conditions.
2. Initial sand moisture contents:

F-1	2%
F-2	5%

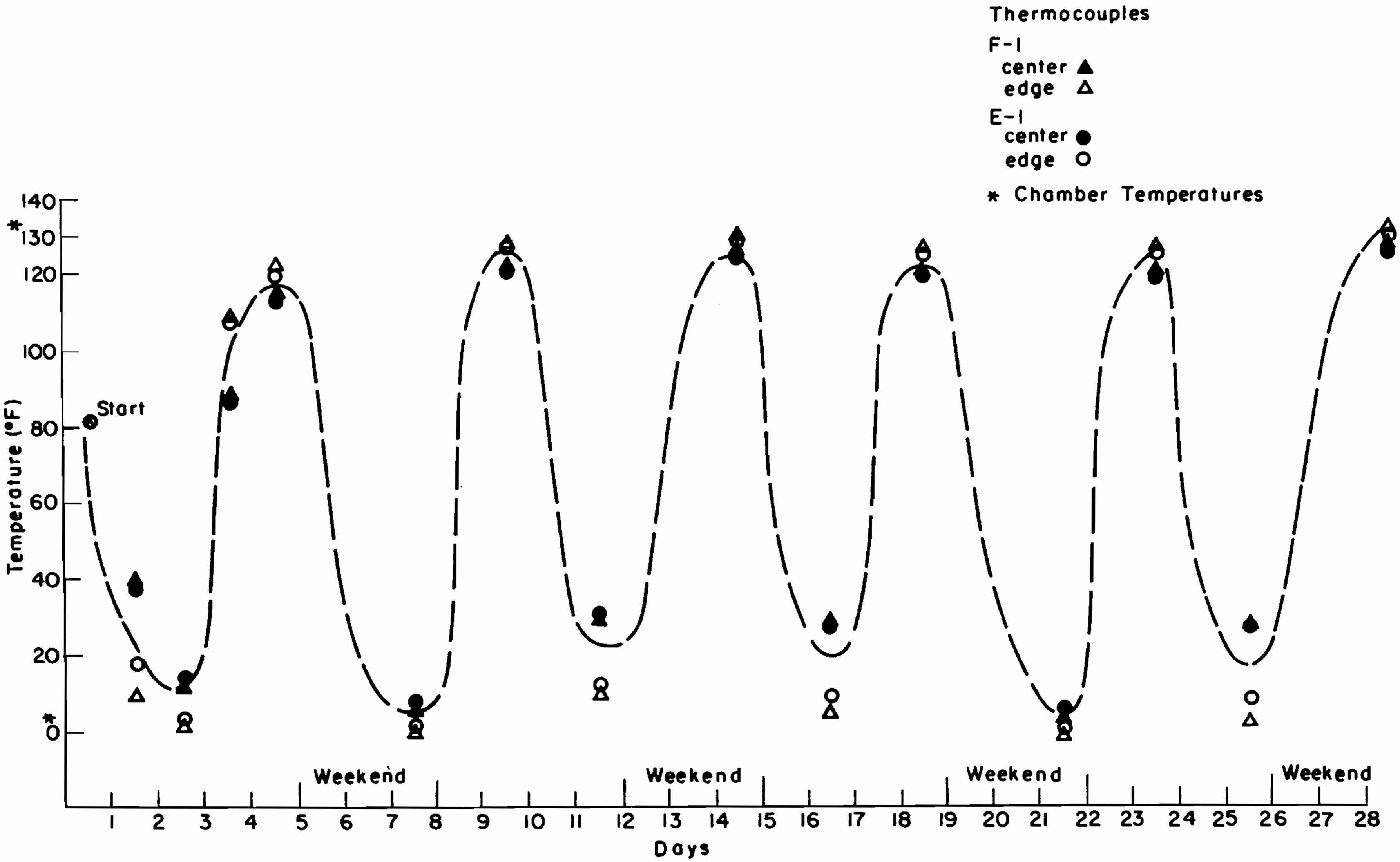


Fig 13. Temperature data.

Energite unit did not quite match the temperatures reached by the Fitch. It may be assumed that the air space inside the Energite functioned as an insulator and accounted for this characteristic.

As shown in Fig 5, a variety of dimensional measurements were made on all test units. These measurements were taken at the end of every cold and every hot cycle. Conditions under which the measurements were made were kept reasonably consistent and generally the measurements were concluded within a 15-minute period when the units were located in the 130° F chamber. Based on the consistency of data obtained, the measurement techniques appeared to be relatively free of significant errors.

Figures 14 and 15 show the dimensional changes which occurred with time and temperature changes in the two Fitch units. As reflected in Fig 14, the total circumferential expansion-contraction movement of F-1 increased with time from an initial 1/2 inch to about 3/4 inch for each cycle and then stabilized. The F-2 unit, as shown in Fig 15, experienced a relatively uniform and consistent expansion-contraction movement throughout the test period. Neither unit exhibited any significant permanent deformation.

Circumference changes with time and temperature changes for the Energite units are depicted in Figs 16 and 17. The E-2 measurements shown in Fig 17, except for an unexplained lack of cyclic initial movement at the bottom, experienced no unusual circumference changes. The E-1 unit, Fig 16, however, began reacting quite early in the test. As the plot indicates, a very definite circumference increase occurred at the top both initially and throughout the test period. By the end of the test, the top circumference had enlarged more than an inch. At the conclusion of the second cold cycle a visible deformation had occurred at the unit's bottom, as shown in Fig 18. Also noted at this time was the unit's partially sagging lid, Fig 19.

Figure 20 is a plot of the changes in height of the two Energite units with time and temperature changes. Except for the obviously greater actual expansion-contraction movements which occurred over the 2-ft 6-in. gage length at the center height of the units, there is no evidence of unusual height change.

After eight complete hot-cold cycles the cyclic temperature tests were terminated. All units were, however, maintained at 130° F for an additional seven days, at which time a physical inspection revealed that the E-1 unit had developed cracks throughout the outer shell, as shown in Fig 21. These cracks

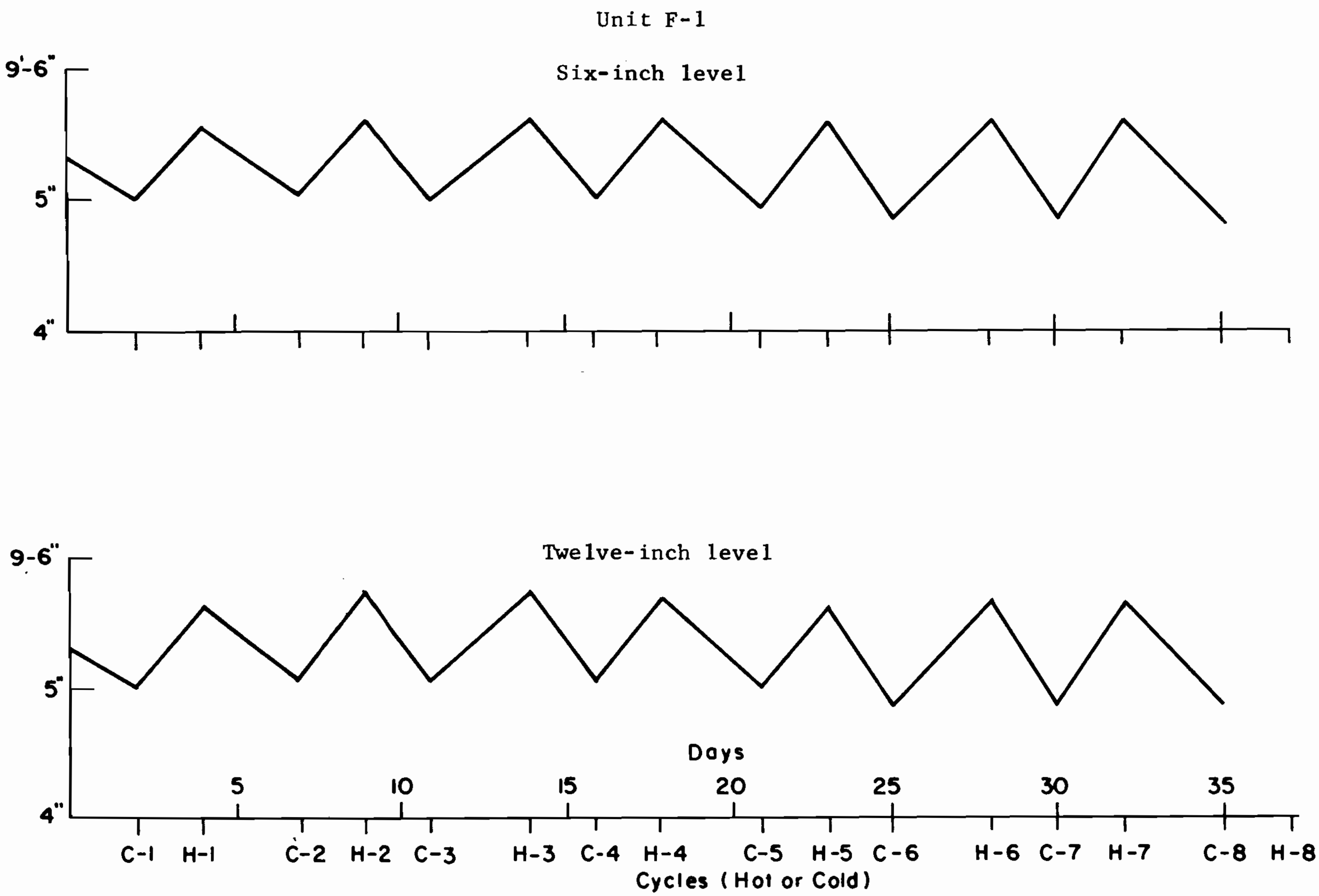


Fig 14. Circumference measurements with time and temperature.

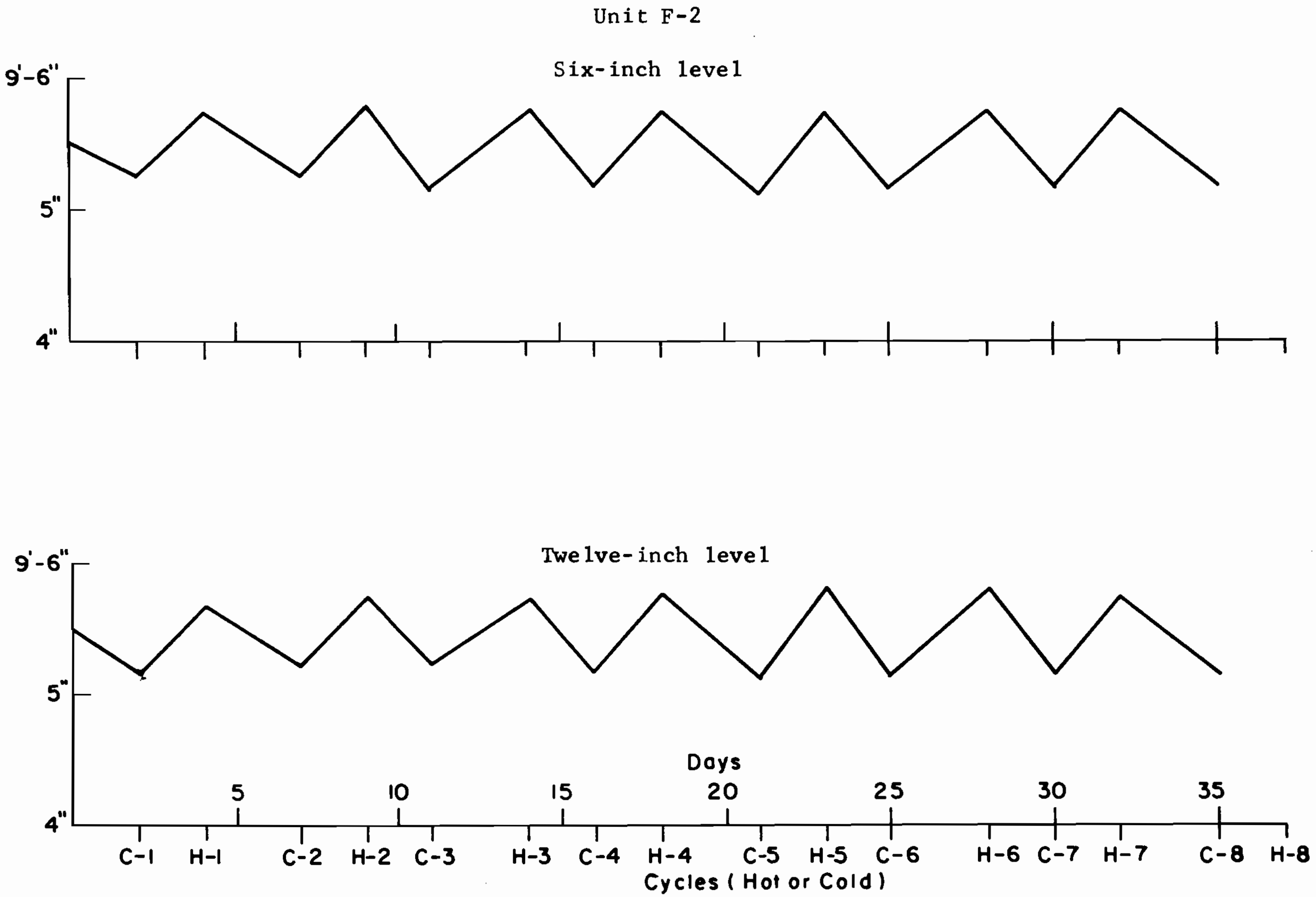


Fig 15. Circumference measurements with time and temperature.

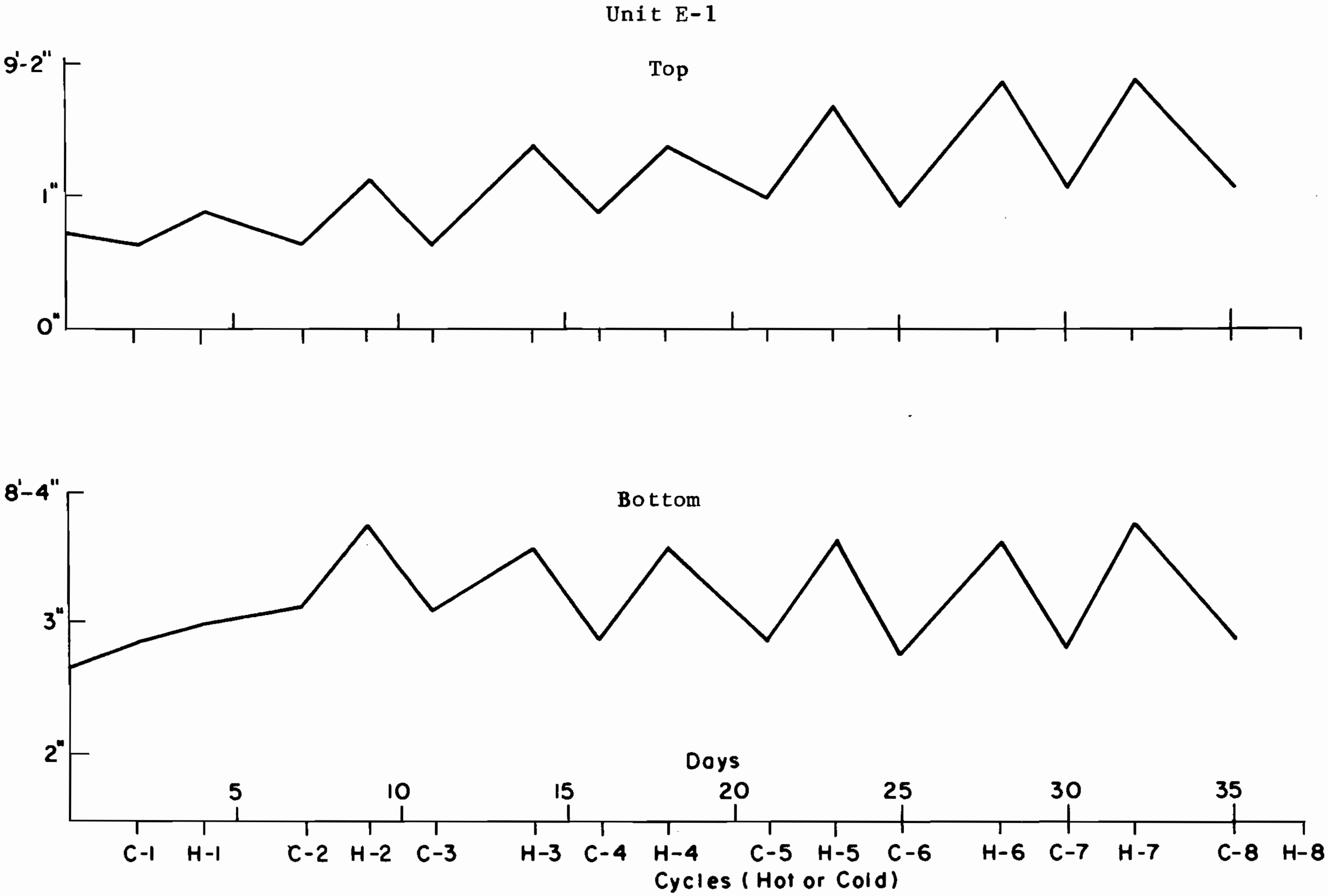


Fig 16. Circumference measurements with time and temperature.

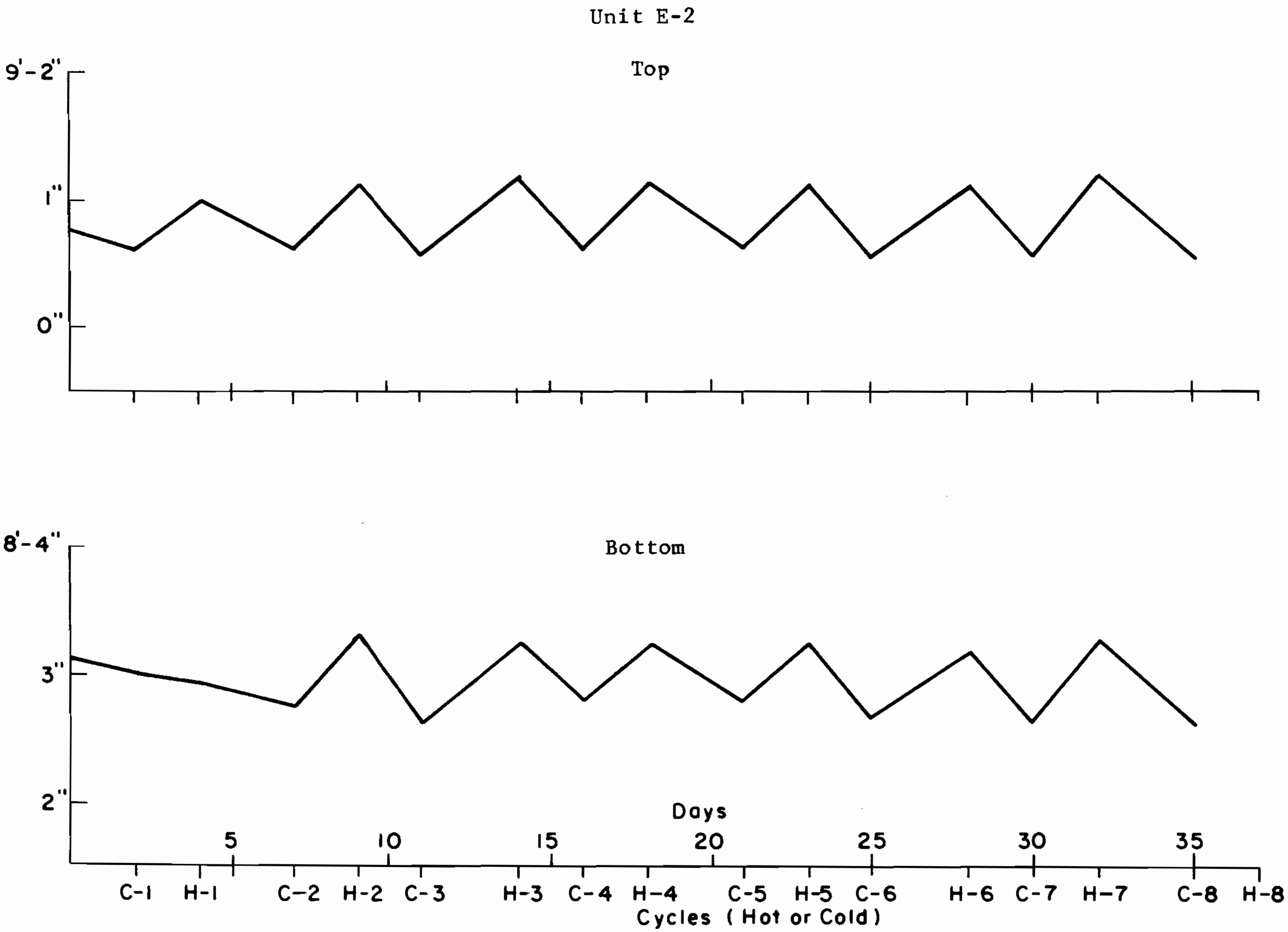


Fig 17. Circumference measurements with time and temperature.

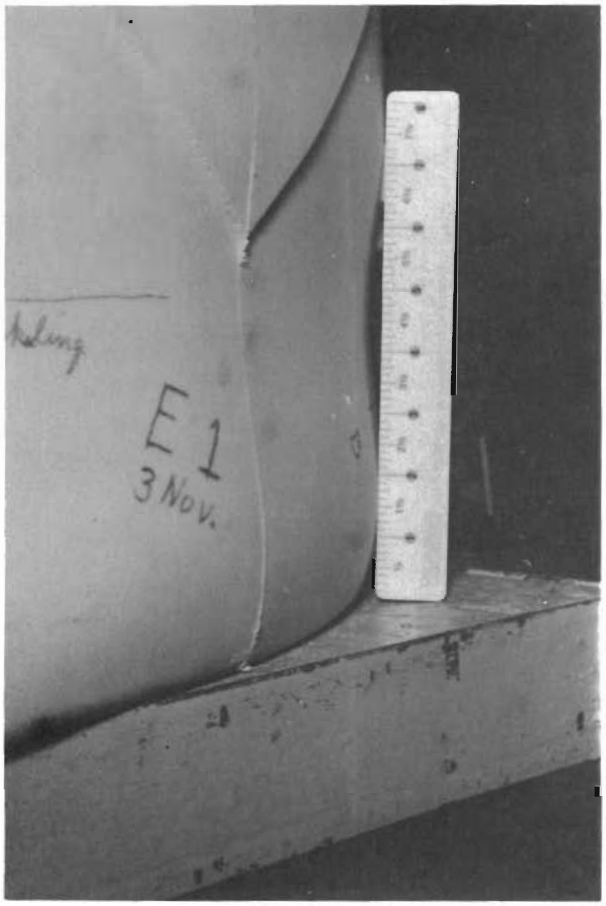


Fig 18.

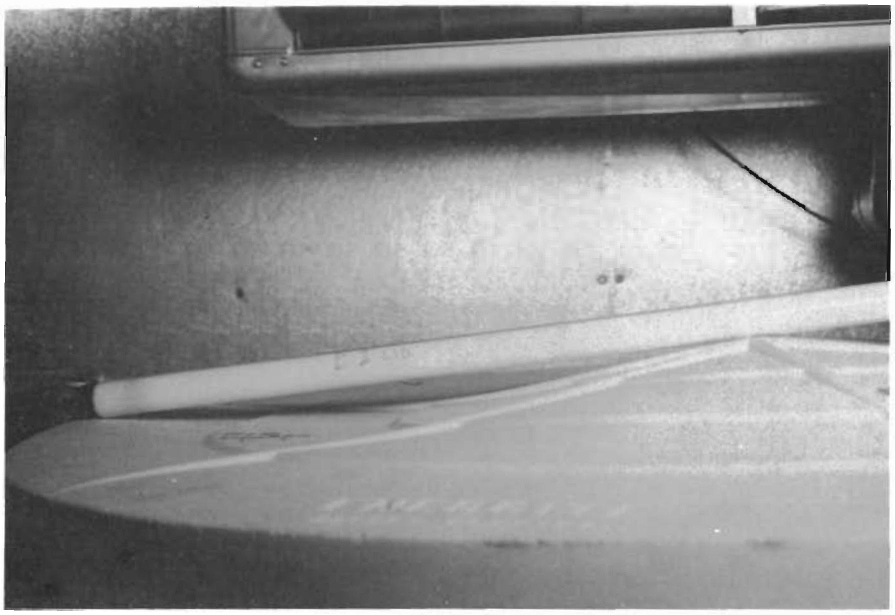


Fig 19.

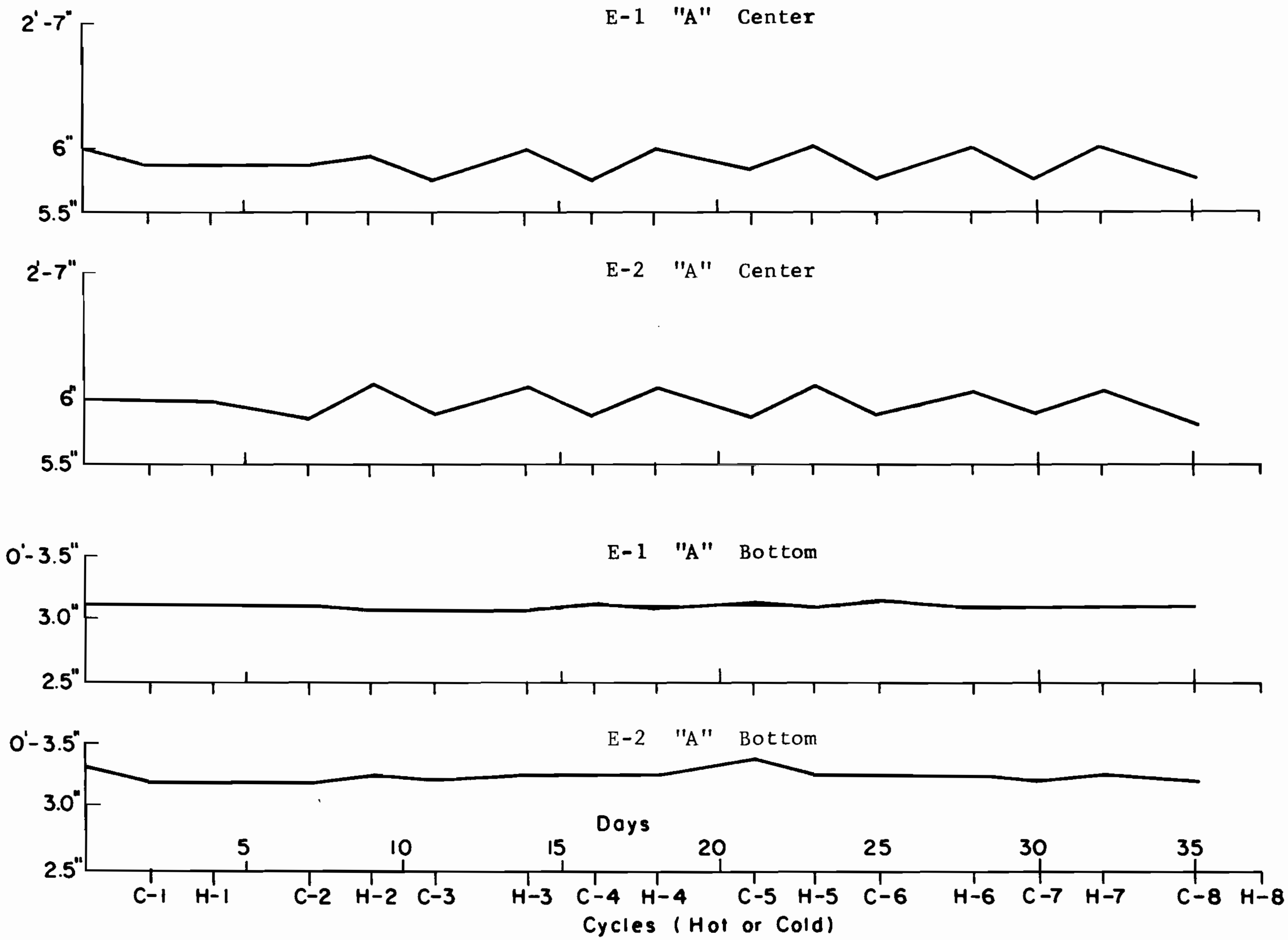


Fig 20. Average height measurements with time and temperature.

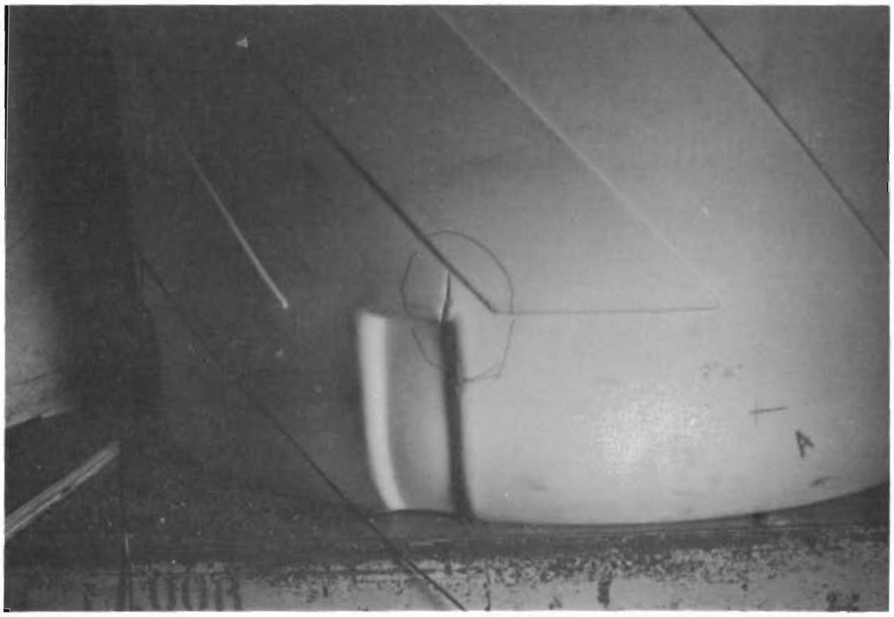


Fig 21.

were in evidence at each notch around the unit's bottom and coincided with the original bulge shown in Fig 18. Further inspection of this unit showed (Fig 22) that the sand had settled at least two inches in the inner container and that this container had slipped off the upper supporting edge of the outer shell and moved about one inch downward. These movements probably caused both the dimensional changes and the subsequent cracks in the outer shell of this unit. A detailed physical inspection of E-2, the newer Energite model, showed no indication of a similar phenomenon, as is evident in Fig 23. There was, however, some settlement of the sand in this unit during the testing period.

After the sand had been unloaded from the Energite specimens (December 29, 1975), three radial cracks were found in the bottom ribs of the white plastic liner of E-1. Several easily visible cracks were also discovered in the E-2 black plastic inner liner unit after the sand had been removed at this time. These cracks opened widest toward the inside of the liner and generally radiated into the horizontal bottom surface from the support pedestals (see Fig 25). Cracks were found in the bottom of several of the radial ribs between the pedestals. Two of these cracks extended through the full thickness of the liner, and light could be seen through the hairline openings on the outer surface. While no direct observation was made of the crack development, the fact that all the crack openings were wider on the inside surface than on the outside indicates that higher tensile stress concentrations were present on the inner surface. Stressing of the plastic liner by the sand load and the temperature cycling obviously caused permanent deformation in the material that resulted in tensile failure. There is no way of knowing the exact mechanism of crack formation, but these cracks evidence several points of serious stress concentration in the new model Energite unit.

The final inspection of all test units that was conducted immediately after the sand had been removed revealed that the F-1 unit had developed three fine vertical cracks at and adjacent to the sixth rivet hole on one side (Fig 24). These cracks were not evident during the test period and no significant dimensional changes occurred in this area of the F-1 unit during the cyclic temperature test.

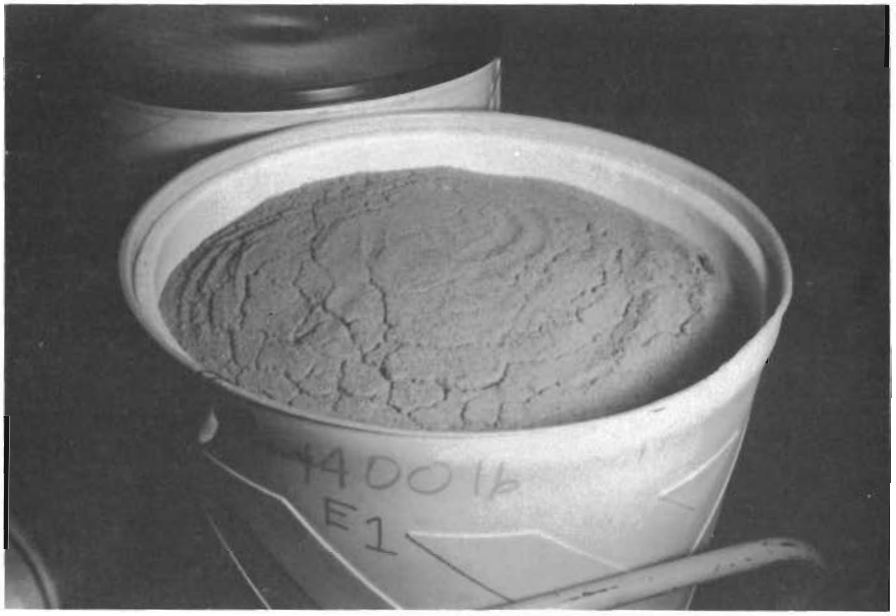


Fig 22.

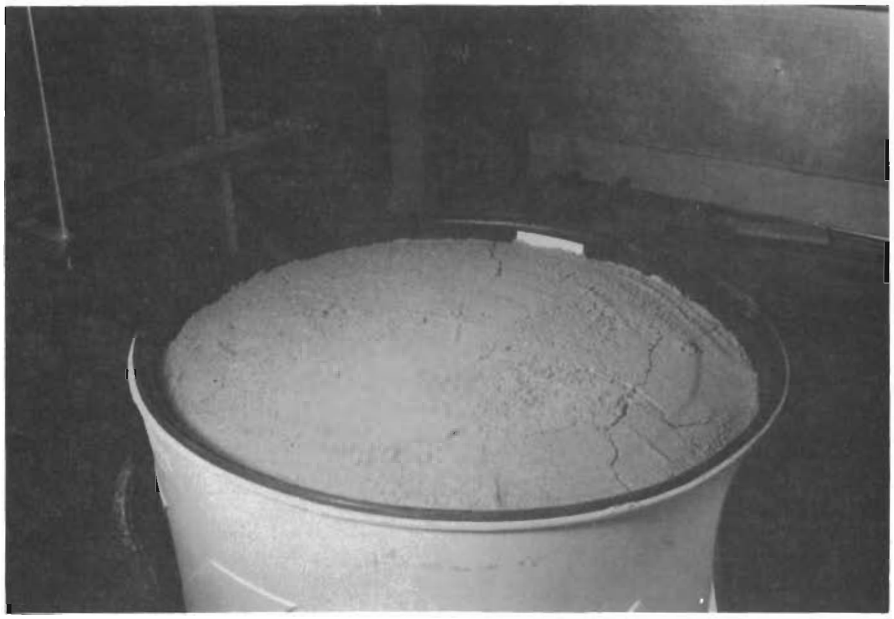


Fig 23.

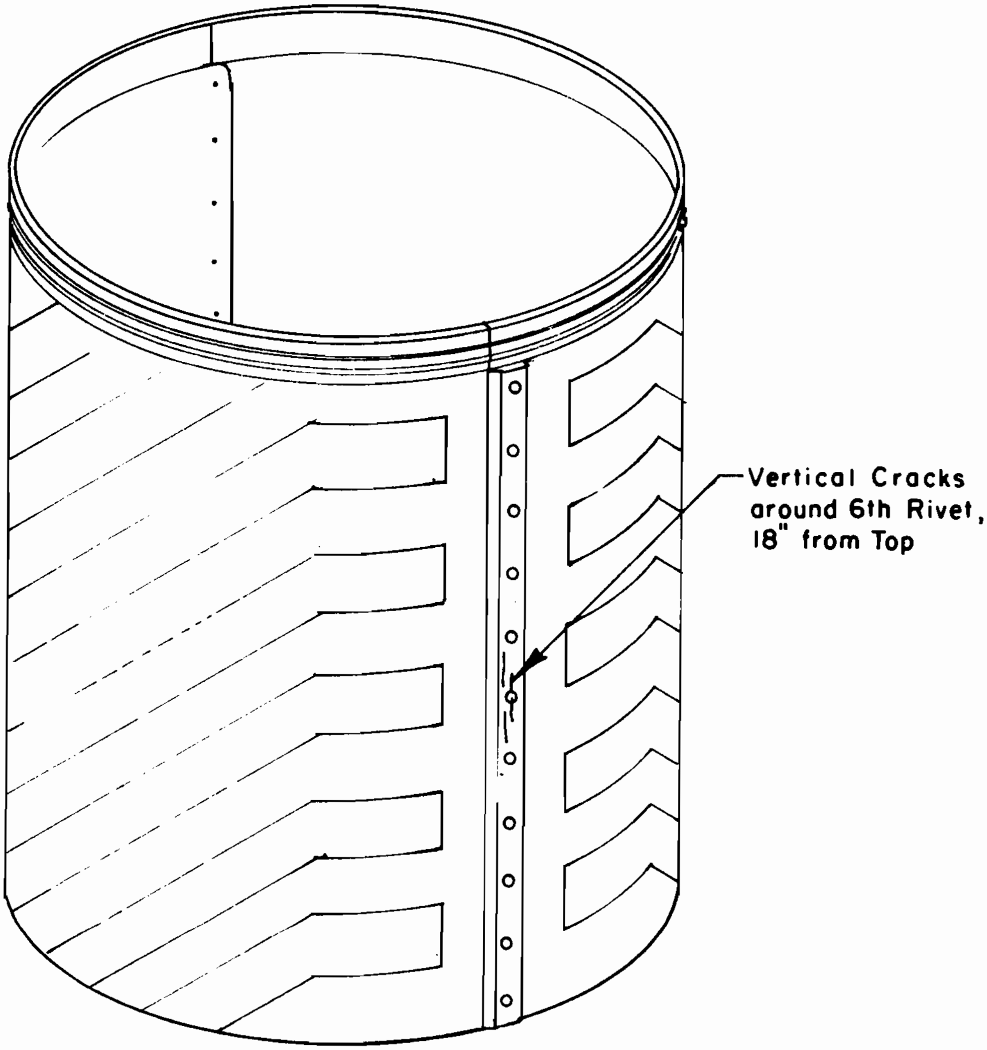


Fig 24. Location of vertical cracks in Fitch unit after cyclic temperature tests.

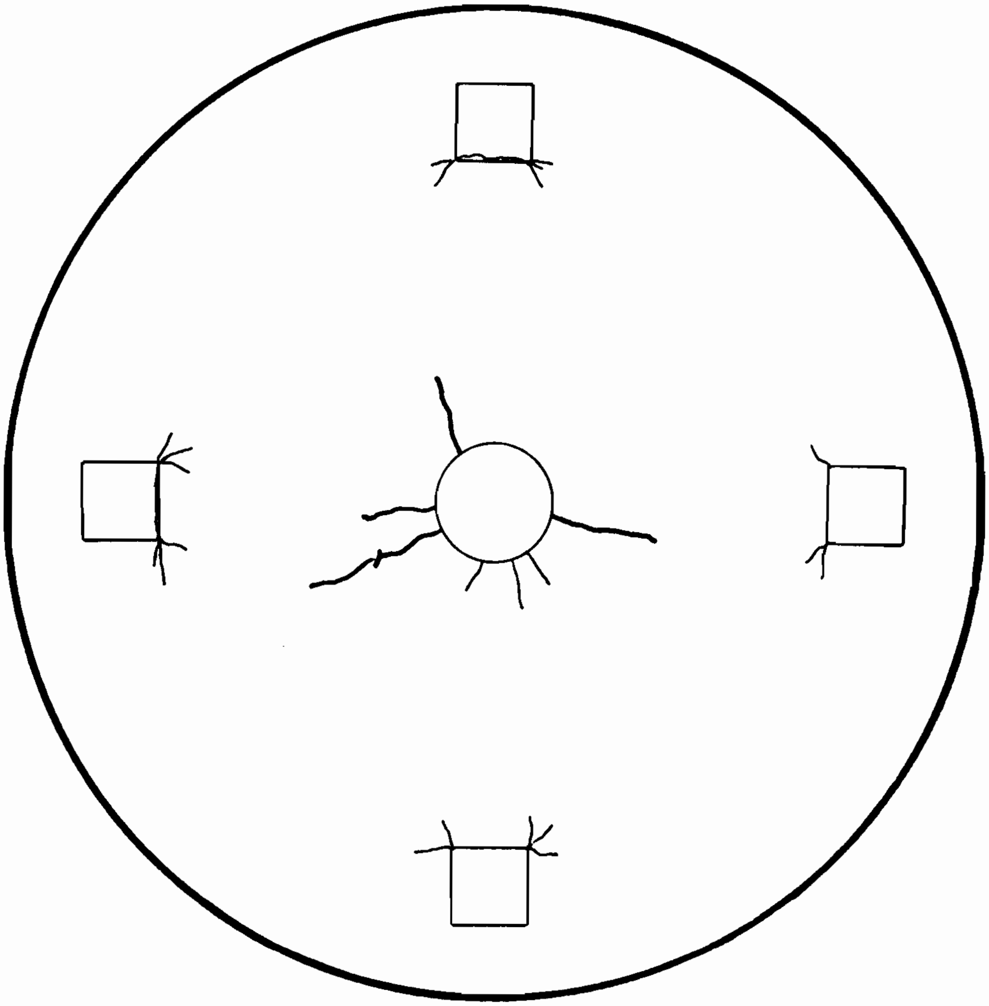


Fig 25. Inside view of the bottom of new model Energite liner showing crack locations after unloading.

V. CONCLUSIONS AND RECOMMENDATIONS

The specific test condition which dominated this study was a pattern of relatively sudden and extreme temperature variations. Four test specimens were subjected to eight 2-day cycles of 0^{o} F and 130^{o} F temperatures plus seven additional days at a sustained temperature of 130^{o} F. These temperature changes contributed to the stress conditions which resulted in distortion or cracking in both Energite specimens and in one Fitch crash cushion specimen by inducing volume changes in the container material as well as in the sand that was used to fill the units and by modifying the mechanical properties of the plastic of which the units were made.

Distortion and subsequent cracking in the outer shell of the old model Energite specimen occurred after the sand had settled in the white plastic inner liner and the liner had slipped downward off the upper supporting edge of the outer unit. Stresses in the plastic containers resulted from the weight of the sand plus the temperature-induced volume changes in the container and in the sand. Sequential expansion, contraction, and settlement of the sand along with creep distortion and softening of the plastic containers apparently caused the destructive downward movement of the inner shell that produced the damage to this unit. The new model Energite specimen, which incorporated five support pedestals in the black plastic inner liner, exhibited no external evidence of distress during the cyclical temperature tests, but several significant cracks were found in the liner after the sand had been removed.

Vertical hairline cracks around a rivet hole in one of the Fitch specimens (F-1) were detected at the end of the tests. Deformation measurements that were made throughout the program did not indicate significant circumferential changes in the vicinity of the cracks. There is no obvious explanation for these cracks appearing around the sixth rivet hole from the top of the specimen on one side only. There was no apparent damage to the F-2 unit.

The cyclical temperature tests were conducted in enclosed chambers with circulating low-humidity air over a relatively short period of time. Effects of long-term loading, varying humidity, and exposure to sunlight were not investigated. It was recommended that the test specimens be unloaded and moved to an outdoor site where they could again be loaded and observed over an extended period of time. This was accomplished on December 30, 1975, when the units were reloaded in an exposed ground area under the water tank on SDHPT property at Camp Hubbard in Austin. Weekly inspections will be conducted by SDHPT personnel in the future.

The accelerated testing program indicated potential problems with material failure in both types of plastic crash cushions. Temperature changes induced volume changes in the plastic and in the sand which resulted in high tensile stresses in the sand-filled containers. The ability of the plastic to withstand these stresses over extended periods of time must be considered in field applications. Cracking or distortion was observed in three of the four plastic crash cushion specimens which were included in the cyclical temperature tests.