NATIONAL BUREAU OF STANDARDS REPORT

5814

A STUDY OF Z-CRETE AS UNDERGROUND
PIPE INSULATION

by

Selden D. Cole
Paul R. Achenbach
Frank J. Powell

Report to
Office of the Chief of Engineers
Bureau of Yards and Docks
Headquarters, U. S. Air Force

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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A Study of Z-Crete as Underground Pipe Insulation

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Abstract

At the request of the Office of the Chief of Engineers, laboratory and simulated field tests were made of a Z-Crete system as a means for insulating underground steam and hot water lines. A typical Z-Crete system consists of an envelope of insulating concrete six inches thick around the pipe with the insulating concrete enclosed in a waterproof membrane, all supported on a dense concrete base pad. Z-Crete is the trade name for a lightweight concrete made of Portland cement, expanded vermiculite, an admix, and water. It is poured in the field and allowed to cure for a limited time before sealing up the waterproof covering on the outside. Simulated field tests in an earth-filled box showed that the Z-Crete did not crack under heat, that it did not adhere to the pipe because of the corrugated paper wrapping on the pipe, and that there was no measurable leakage of water through the waterproofing. The heat loss of the four-inch pipe ranged from 212 Btu/hr per linear foot when the system was surrounded with air-dried earth to 239 Btu/hr per linear foot with water standing over the earth cover. The waterproof covering prevented the complete drying out of the Z-Crete. The moisture in the one inch of Z-Crete nearest the pipe was transferred to the material farther from the pipe and remained there as long as the pipe was heated. The average moisture content in this inner one inch was about 7 percent whereas that in the remainder ranged from 50 to 100 percent of the dry weight of the material. Only the air space and about one inch of Z-Crete nearest the pipe were very effective as insulating material. The thermal conductivity of the oven-dry Z-Crete was 0.84 Btu/hr(ft^2)(°F/in.) at a mean temperature of 128°F. The average thermal conductivity of the Z-Crete envelope as tested underground was

more than 2 1/2 times this value. About three weeks were required to completely dry out a Z-Crete annulus 5 3/8 in. thick without exterior waterproofing when heated at the center.

1. Introduction

In response to the request of the Office of the Chief of Engineers, Department of the Army, an investigation was made of Z-Crete as an insulating material for underground heat distribution pipes operating at a steam pressure of about 120 psig corresponding to a saturation steam temperature of 350F.

Z-Crete is the trade name of a lightweight concrete made of Portland cement, expanded mica, an admixture, and water. The expanded mica used in Z-Crete is known commercially as Zonolite. Z-Crete is made with different admixes and with different sizes of Zonolite particles. The admix used for the Z-Crete specimen tested in the earth-filled box was identified as Zonolite Liquid Admix and the aggregate was Zonolite No. 3.

More recently, the Zonolite Company submitted two cylindrical specimens of a new Z-Crete mix for water absorption tests. The admix used in these specimens is B-Crete admix and the aggregate is "Zonolite No. 4 aggregate waterproofed," as identified by the manufacturer.

The sieve analysis for the standard Zonolite grades is as follows:

Sieve Size	Cumulative Percent Retained	
	Maximum	Minimum
Grade No. 3 (Density 7 to 10 lb/ft^3)		
8	10	0
16	60	20
30	95	65
50	98	75
100	100	90
Grade No. 4 (Density 8 to 12 lb/ft^3)		
16	5	0
30	65	15
50	98	60
100	100	90

A typical Z-Crete installation consists of a pipe or pipes surrounded by an envelope of insulating concrete six inches thick and enclosed in a waterproofing membrane, all supported on a concrete base pad. The proportions of the ingredients of such lightweight heat insulating concrete are varied as circumstances indicate. The mixture used for this investigation was that recommended for most ordinary conditions; namely, one bag of Portland cement (about 94 lbs. or 1 cu.ft), eight cubic feet of expanded mica (Zonolite), seven quarts of admix and twenty-six gallons of water.

To determine the characteristics of Z-Crete, thermal conductivity measurements, moisture absorption tests, and full scale trench tests under simulated use conditions were made.

The laboratory phase consisted of (1) determining the thermal conductivity by the standard hot plate method, and (2) determining the thermal conductivity of several concentric annuli of Z-Crete cast around a cylindrical ceramic heating tube as the material gradually dried from an initial condition after setting to a dry condition.

The full scale simulated use tests consisted of measuring the heat transfer of a Z-Crete envelope cast around a standard four-inch pipe under steady state conditions with the pipe temperature at 350F when (1) the envelope had not yet been covered with earth; (2) the envelope was covered with nominally dry earth; (3) the envelope was covered with earth and submerged under water; (4) the envelope was cooled to ambient temperature while under the high water table, followed by lowering the water table and reheating the pipe to 350F.

Moisture determinations were made of the earth surrounding the Z-Crete and also of the Z-Crete at selected distances from the heated pipe. Moisture absorption of the Z-Crete used in the trench tests and of a newer mix made with finer particles of Zonolite and a different admix was studied.

2. Description of Equipment

The thermal conductivity of Z-Crete was measured in an eight-inch guarded hot plate apparatus conforming with the requirements of Federal Specification LLL-F-321b and ASTM C177-45. The specification requires two specimens 8 x 8 x 1 inch in size, oven-dried to constant weight at 215F.

The Robinson ceramic core apparatus was used for determining the thermal conductivity of Z-Crete at various stages of drying. For this test a three foot long cylinder of Z-Crete, 12 inches in diameter, was cast on the 1.29-inch ceramic core which was centered lengthwise in the specimen. The ceramic core has numerous coaxial openings running lengthwise through it which contain electric resistance wires for heating the core. Thermocouples were placed at selected stations within the ceramic core to determine core surface temperature and at each third of the radial distance from the core to the surface of the specimen. The thermocouples used for determining thermal conductivity were centered lengthwise of the cylinder.

After casting, the cylinder was allowed to cure in the metal casing for six days, and in air for an additional seven days after removing the casing. The test was made without the metal casing. The specimen was supported on a platform scale so the loss of moisture could be observed as the test progressed.

The test of the Z-Crete system under conditions simulating an underground installation was conducted in a watertight box 4 x 4 x 12 ft in size. A piece of four-inch black iron pipe 14 feet long was suspended along the longitudinal center line of the box and pitched at a slope of 1/4 inch per foot toward the outlet end. The 14-foot length was divided into a four-foot measuring section at the center and a five-foot guard section on either end. The condensate formed in the measuring section was isolated from the guard sections by two half-moon baffles in the bottom and two half-moon baffles in the top of the pipe, each located slightly upstream of the lower baffles. Separate internal condensate drain lines were brought out from each of the three sections and connected to high pressure steam traps. The condensate from the measuring section could alternately be directed through a sight glass instead of the steam trap. In each case, the condensate from the traps, or the sight glass, was passed through a water-cooled heat exchanger to reduce its temperature to near room temperature so it could be collected and weighed in open vessels without loss by evaporation.

An electrically-heated steam boiler whose input could be varied in the range from 1.5 to 12 KW (5000 to 47,500 Btu/hr) produced steam at the desired pressure. The water level of the boiler was maintained by a float which opened and closed contacts in a solenoid valve circuit. The solenoid valve was in a line from a supply tank held at a higher pressure than that of the boiler. A check valve in the supply line before the tank and one in the line before the solenoid valve prevented loss of pressure in the system from back feed.

Steam was delivered from the boiler through a 3/4-in. pipe extending about one foot into the inlet end of the four-inch pipe. The one-foot extension was capped off at the end and was drilled with a series of 1/4-in. holes in its side walls. The aggregate area of the holes equalled 1.5 times the area of the open end of the 3/4-in. pipe. This produced a spray of steam on the side walls at the inlet end instead of a jet down the longitudinal center of the pipe.

The box was filled with dirt, a typical Chester loam, to something less than mid-height. A wooden form was then placed on the dirt below the pipe to make a sand and gravel concrete pad 22 inches wide and 4 inches thick, the upper surface to be six inches below the under side of the pipe and one edge to extend six inches from the side of the four-inch pipe. After the concrete was placed and set the first form was removed and a second wooden form constructed about the pipe and resting on the concrete pad. This form was 16 1/2 x 22 1/2 inches in size and was lined with a water resistant membrane as follows: six-foot lengths of 15-pound roofing felt were placed lengthwise on the sides of the wooden forms such that there was approximately an eight-inch gap between the two strips on the concrete pad and about six inches projected over the upper edge of the form. The gap on the concrete pad was covered with a strip of felt to give an overlap of about six inches. Hot pitch was mopped on the concrete pad and resoftened before the side felts were placed. The bottom was again hot mopped before the filler piece was laid inside. A second layer of felt pieces was placed over hot pitch in the same manner as the first layer but with the end joints being broken with respect to those beneath by about eight inches. Wooden bulkheads comprised the ends of the wooden form and these were not felted.

An eight-inch wide strip of fabric was set in hot pitch in the lower inside corners for reinforcement.

The four-inch pipe was now wrapped with a covering of corrugated paper secured with cotton string. The paper was used to prevent the bonding of the Z-Crete to the pipe and to allow space for linear movement of the pipe in the Z-Crete due to thermal expansion and contraction of the pipe. A two-inch pipe representing a return condensate line was suspended in the form such that its bottom edge was in a plane with the bottom edge of the four-inch pipe and its closest distance was four inches from the side of the four-inch pipe and six inches from the side of the form. The two-inch pipe was covered with corrugated paper in the same manner as the four-inch pipe. See Fig. 1.

The form was then filled with Z-Crete. The Z-Crete was mixed in a paddle type mixer and consisted of one bag or one cubic foot of cement, eight cubic feet of Zonolite, seven quarts of admix and 22 gallons of water per batch, designated as a one to eight mix.

After allowing the Z-Crete to set for about one week, the forms were removed, the top was covered with felt performing the operations in reverse order to that used for the bottom and the exposed portions of the envelope were mopped with hot pitch. The envelope was flashed to the walls of the box where it passed through the ends.

Before pouring the Z-Crete, five thermocouples were peened into the top of the four-inch pipe at positions 23 inches apart starting at midlength and extending in both directions. Five thermocouples were fastened to the surface of the concrete pad at positions two feet apart starting at the middle and extending in both directions. Thermocouples were placed for encasement in the Z-Crete envelope at mid-length in four strings in a plane perpendicular to the four-inch pipe. These four strings extended downward, laterally in both directions and in an upward direction from the four-inch pipe. The thermocouples were spaced on each string as follows: (1) on the pipe, (2) 1/2 inch from the pipe, (3) two

Fig. 1

at one-inch intervals from the preceding ones, (4) two at 1 1/2-inch intervals, (5) three at two-inch intervals on the long side only, (6) one on the inside surface of the waterproof membrane. The two-inch pipe had four thermocouples on it: one on the pipe and one on the surface of the paper two feet from the middle in each direction. Temperature stations were located on the steam traps and on the boiler. All thermocouples were of 26-gage copper-constantan wire and were used with a Rubicon portable precision potentiometer to indicate temperature.

In order that the water table in the box might be adjusted six 1/2-inch diameter pipes were spaced equally along each side of the box and extending vertically from the top to bottom. A 12-inch length of two -inch pipe was fitted to the top of each 1/2-inch pipe for ease in introducing water. There were 100 feet of cotton rope on the bottom of the box placed to provide distributing channels for the water introduced through these vertical pipes. Two 1-inch diameter vertical pipes placed diagonally from each other one foot from either end of the box and equally spaced between conduit and box side served as stand pipes for measuring the actual water level.

The 4 x 4 x 12 ft box and its necessary auxiliary parts were set up in a specially erected building, 12 feet wide, 24 feet long and about 10 feet high, constructed of insulated prefabricated panels. An air chiller with capacity to freeze the contents of the box if desired was placed at one end in the building. The air chiller was used to maintain a steady ambient temperature about the box when a test was in progress. The building was supplied with a 100-ampere, 3-phase, 208-volt electric service and a 1/2-in. water line with a line pressure of about 70 pounds.

3. Test Procedure and Results

3.1 Thermal Conductivity

The thermal conductivity of the Z-Crete was measured by casting two specimens 8 x 8 x 1 in. in size for placement in the hot plate apparatus after oven drying at 215F. The results of the thermal conductivity test are as follows:

Density, as tested, lb/ft^3	27.9
Thickness, as tested, inch	1.00
Mean temperature of specimens, °F	128.0
Temperature gradient in specimens, °F/in.	41.1
Thermal conductivity, Btu/hr ft^2(deg F/inch)	0.842
Loss of weight on drying, percent	3.7
Gain in weight during test, percent	0.8

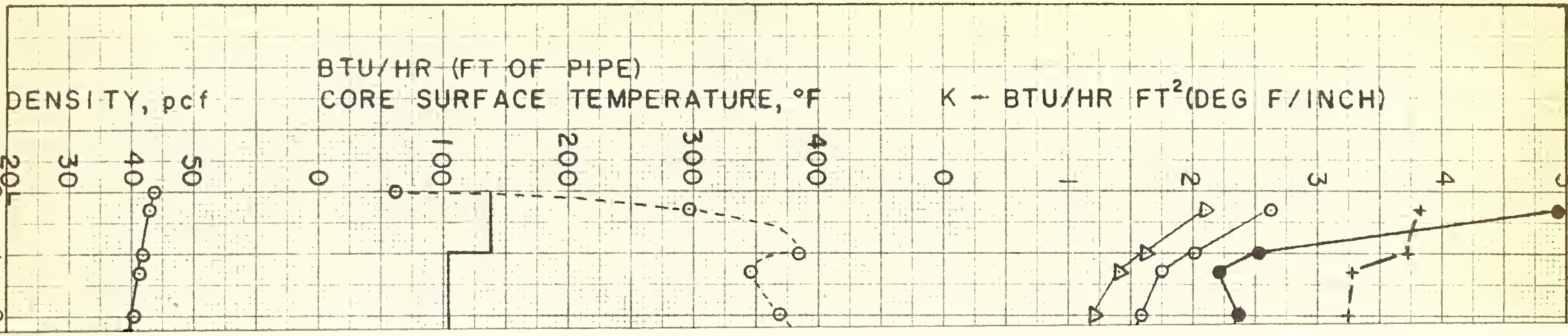
3.2 Tests with Ceramic Core Apparatus

The results obtained on the cylindrical Z-Crete specimen with the Robinson ceramic core apparatus are shown graphically in Fig. 2. The thermal conductivity and density of the material are shown together with the rate of heat transmission and core surface temperature for a 31-day test period while the specimen was losing moisture. The electric energy supplied to the ceramic core was reduced in a stepwise manner to maintain a core surface temperature between 350F and 400F until a steady state was reached with a final core temperature of 350F.

Fig. 2 shows that a steady state condition was attained after about 21 days of operation at which time the thermal conductivity of all three concentric annuli was essentially equal at about 0.87 Btu/hr(sq ft)(°F/in.), the density was about 26 lb/cu ft, the heat loss rate was 55 Btu/hr per foot of length, and the core surface temperature was 350F. The upper group of curves in Fig. 2 shows the progressive reduction in thermal conductivity of the several annuli of Z-Crete as drying progressed. About six or seven days wererequired to dry the inner third of the cylinder, about 15 days were needed to dry the middle third, and about three weeks were required to attain steady state thermal conductivity in the entire specimen. About 18 pounds of water were evaporated per cubic foot of Z-Crete during the tests.

3.3 Controlled Underground Tests

For underground studies of the heat loss of the Z-Crete system with controlled conditions, the manufacturer's recommended directions were followed in preparing the specimen, and simulated field conditions were used in carrying out the investigation.


DENSITY, pcf
20
30
40
50
BTU/HR (FT OF PIPE)
CORE SURFACE TEMPERATURE, °F
0
100
200
300
400
K - BTU/HR FT²(DEG F/INCH)
0
1
2
3
4
5
0
1
2

HEAT LOSS, THERMALCONDUCTIVITY AND DENSITY OF Z-CRETE BY CERAMIC-CORE APPARATUS

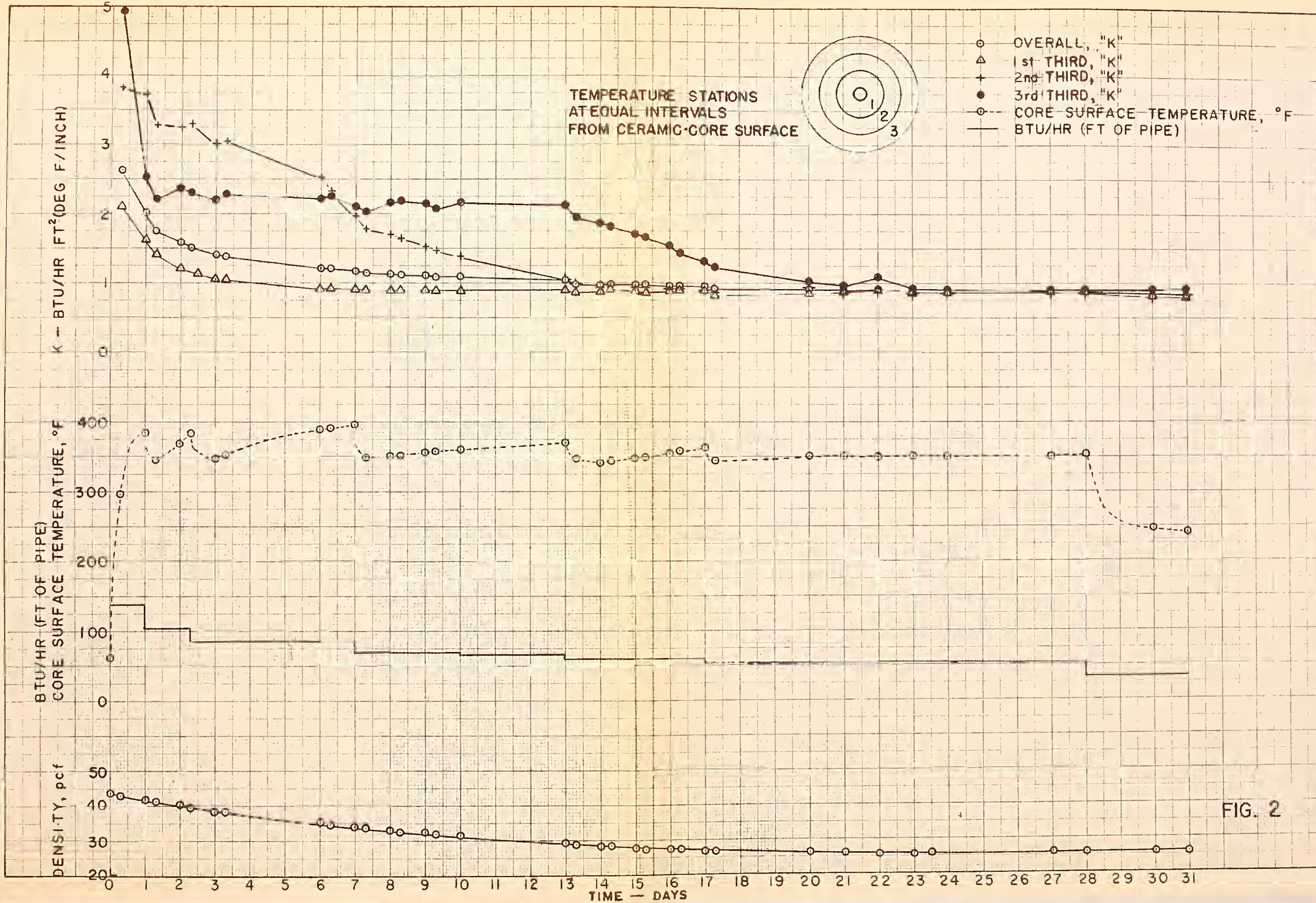


FIG. 2

With air surrounding the Z-Crete envelope, steam at a temperature of 350F was supplied to the four-inch pipe for a total of 44 days at which time the temperature observations in the system and the condensate measurements indicated that near steady state conditions of heat flow prevailed.

Dirt was then added to the box to cover the system while the heat remained in it. This test condition was maintained for 12 days. Four days after introducing the dirt a core sample was taken for moisture measurement. A vertical core was taken from top to bottom, midlength of the box, and half way between the Z-Crete envelope and the box on the narrow side. The sample was placed in a closed container for weighing before heating at a temperature of 215F until constant weight was observed. The moisture content of the dirt at the time of sampling was found to be 14.5 percent of the dry weight.

At the end of this 12-day heating period and with the heat on, water was added to the box until the surface of the dirt was under two inches of water. This water height was maintained for 14 days at which time observed temperatures and condensate rates indicated steady conditions prevailed.

At the end of the 14 days the heat was turned off and the water height maintained for ten days after which the 350F steam was again turned into the four-inch pipe. In a period of 48 hours the temperatures and condensate rate were at nearly the same values they were before the heat was turned off. After heating a few more days, with the water table below the Z-Crete envelope, the envelope was uncovered and opened up while keeping the heat on.

A section was sawed completely out of the top half of the conduit, crosswise of the length and at the middle of the measuring section. An additional slice about 1 1/2 inches thick was then sawed off the exposed end of the envelope and one-inch cubes were removed from the slice to permit measurement of the moisture gradient in the envelope in three directions from the heated pipe, as indicated by the cross section diagram in Fig. 3. The blocks were placed in weighed containers as soon as possible and sealed airtight immediately. After

MOISTURE CONTENT OF Z-CRETE VS DISTANCE FROM PIPE

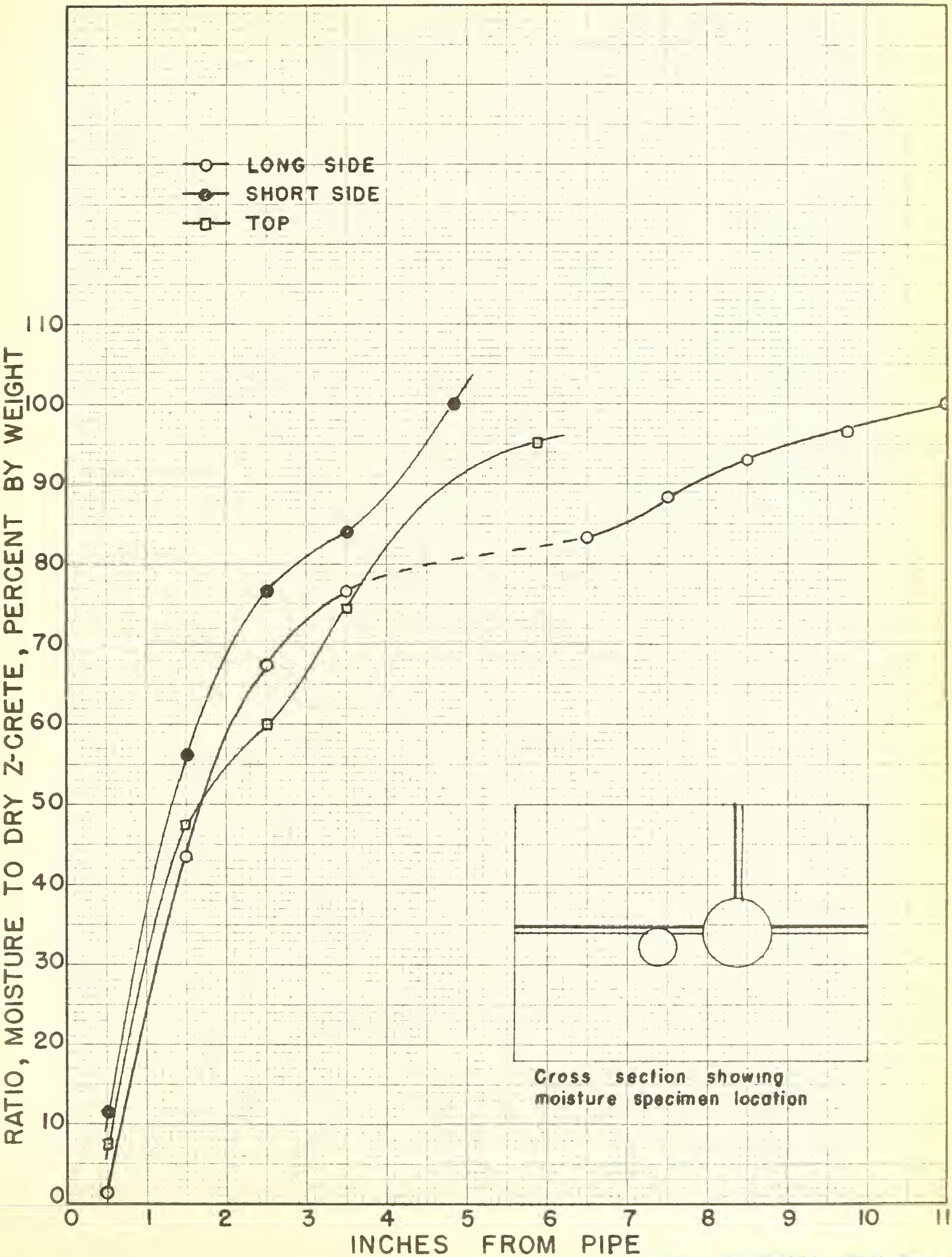


FIG. 3

oven drying at 215F the percent moisture to oven dry weight was computed. Although these ratios are portrayed graphically in Fig. 3 as a smooth curve, each plotted point represents an average moisture for a radial increment of one inch in most cases.

Fig. 3 shows that the average moisture content of the inner annulus one-inch thick was about 6.8 percent whereas that for the second annulus of the same thickness was about 49.5 percent. The moisture gradient was reasonably consistent in all three directions from the heated pipe to a distance of four inches from the pipe, but in the longer horizontal direction was slightly lower in the range from four to six inches from the pipe. It reached 95 to 100 percent in all directions just inside the waterproof covering. It should be noted that the Z-Crete specimen had been under heat a total of 84 days at the time of these measurements with one period of ten days intervening when the pipe was not heated.

The heat loss from the measuring section of the Z-Crete system in the earth-filled box is summarized in Table 1 for the three test conditions tried. There was only about ten percent greater heat loss with the system submerged than when surrounded with air-dried earth, and the heat loss with air surrounding the system was about half way between these two values. These data indicate that a 13 to 15 inch layer of air-dried earth surrounding the Z-Crete provided a little more insulating value than the air film that existed when there was no dirt in the box, and the water-soaked earth provided a little less insulating value than the air film.

The temperatures observed in the Z-Crete envelope during the tests with air-dried and water-soaked earth around it are shown in Fig. 4 and 5, respectively. The graphs show the temperatures observed in four directions from the heated pipe after substantially steady state conditions were established. The temperature gradient observed when the specimen was surrounded by air was not plotted because this is not a typical operating condition.

Table 1

Heat Loss of Z-Crete System in Earth-Filled Box, Ambient Air Temp, about 80F, Pipe Temp 350F

Surrounding Media	Earth Cover above C. L., ft	Water Table above C. L., ft	Duration of Test, days	Heat Loss, Btu/hr Linear ft	Heat Loss, Btu/hr Sq Ft Pipe Surf
Air	None	None	44	224	190
Air-Dried Earth*	+2	None	12	212	180
Earth & Water	+2	+2	14	239	203

*Moisture content, 14.5 percent, based on sampling during the test.

TEMPERATURE OF Z-CRETE VS DISTANCE FROM PIPE

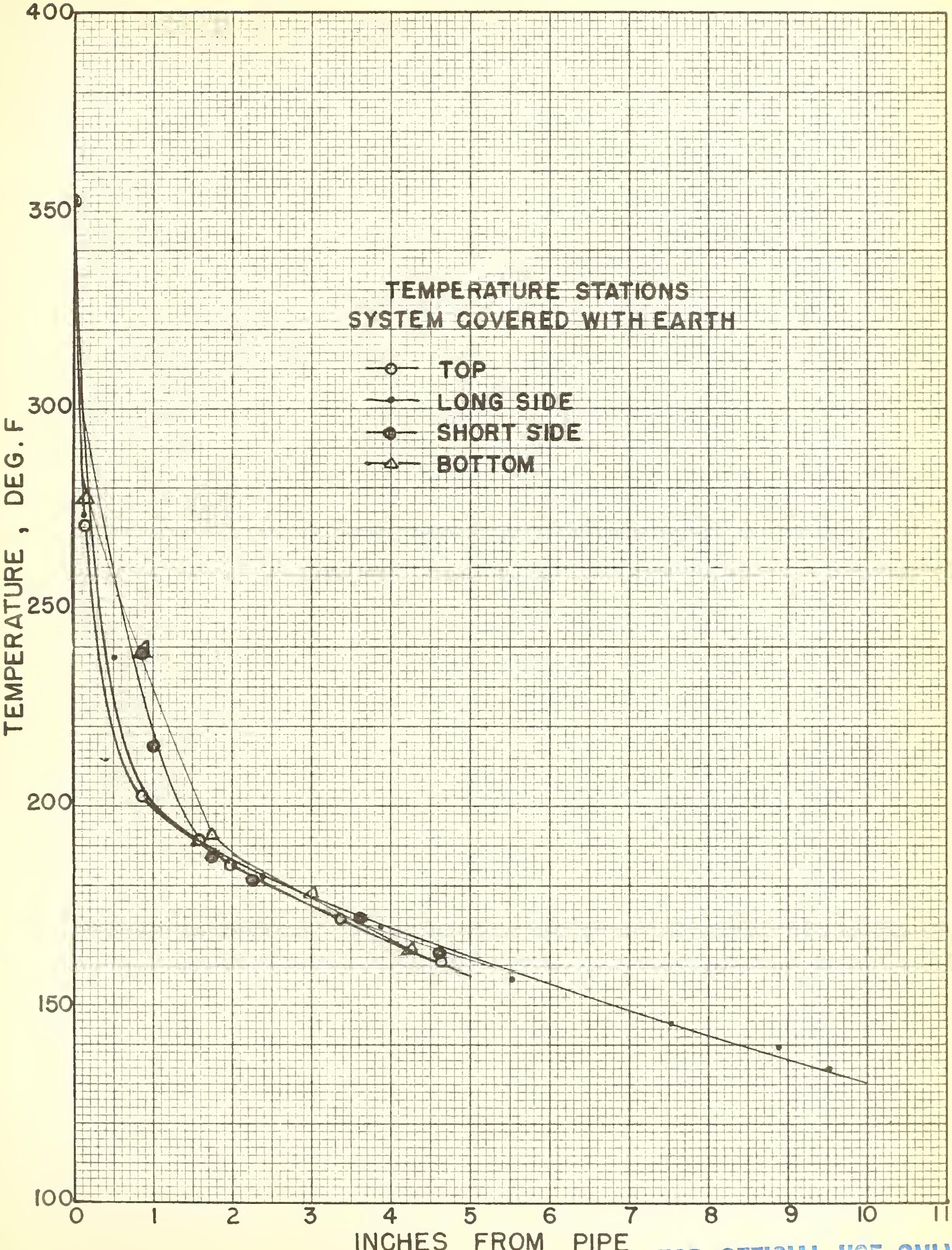


FIG. 4

TEMPERATURE OF Z-CRETE
VS DISTANCE FROM PIPE

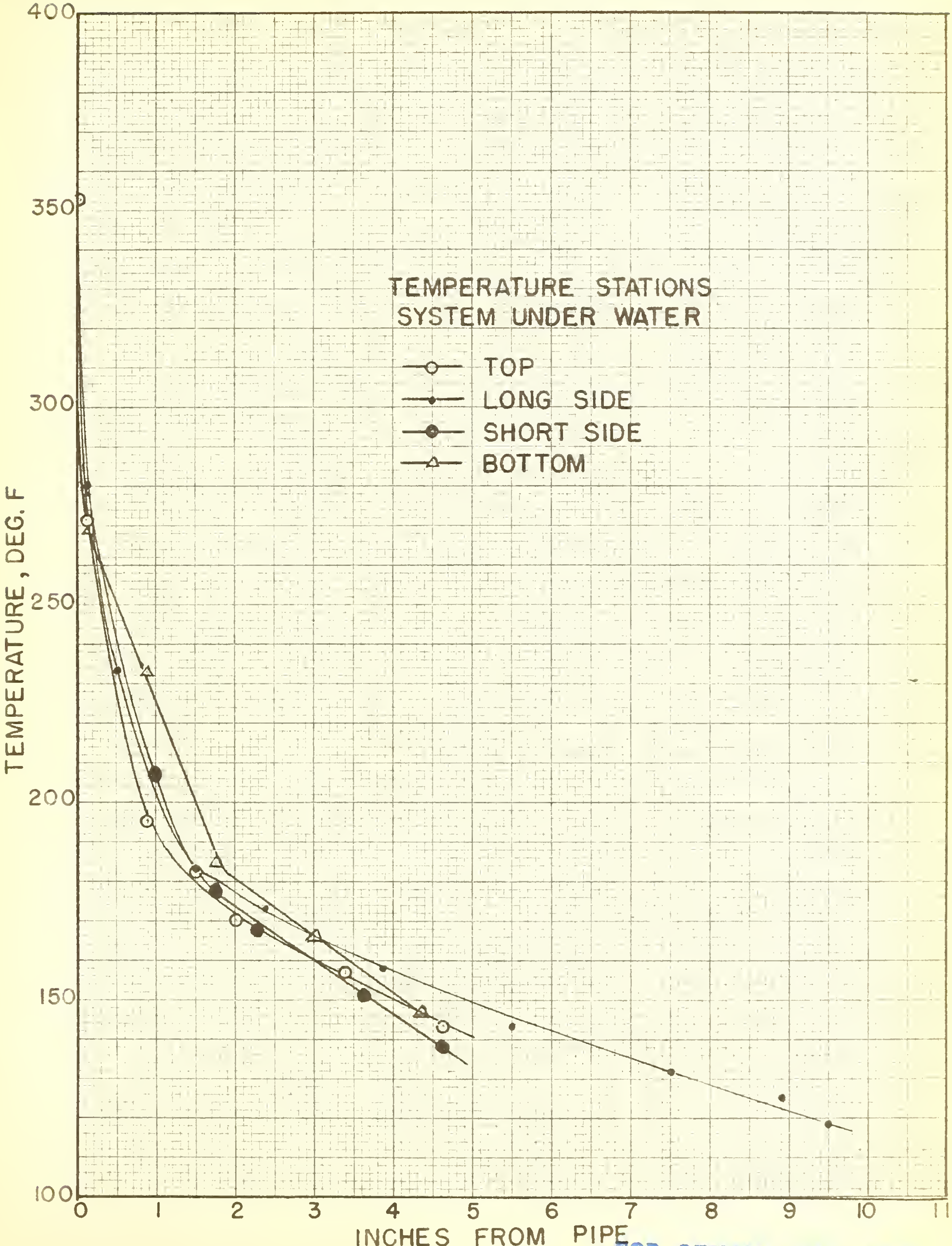


FIG. 5

Figs. 4 and 5 show a rather consistent temperature pattern in all directions from the pipe at distances from 1 1/2 to 4 1/2 inches from the pipe with some variation at distances less than 1 1/2 inches from the pipe. Since the Z-Crete envelope was not symmetrical with respect to the heated pipe the temperature pattern was observed at distances up to 9 1/2 inches from the pipe on the longer side. Figs. 4 and 5 show that the temperature on the outer surface of the Z-Crete envelope under the waterproofing (about 5 1/2 inches from the pipe) would be between 150F and 160F when surrounded by air-dried earth and between 130F and 140F when surrounded by earth flooded with water.

The average temperatures in the Z-Crete around the pipe were also plotted on semi-log graph paper in Fig. 6 for the two test conditions. The temperature gradient in a cylindrical envelope of uniform thermal conductivity would normally be a straight line when plotted on semi-log paper. The temperature gradient observed in the test specimen can be approximated by three straight lines of different slopes. The section of the curve on the right with the flattest slope corresponds to the air space formed adjacent to the pipe by the corrugated paper. This space was only about 1/8-inch thick. The center section of the curve in Fig. 6 corresponds approximately to the annulus of Z-Crete one inch thick which was essentially dry by virtue of its temperature being 212F or higher, whereas the left section of the curve with the steepest slope corresponds to the portion of the Z-Crete envelope which contained 50 to 100 percent of moisture and, therefore, had higher thermal conductivity.

In Fig. 6 the slope of the curve for the air space corresponds to a thermal conductivity of 0.25, the slope for the first inch of Z-Crete nearest the pipe corresponds to a thermal conductivity of 2.3, and the steepest part of the curve for the wetter portion of the envelope corresponds to a thermal conductivity of 7.6, all expressed in Btu/hr(ft^2) (°F/in.). These results indicate that the 1/8-inch air space adjacent to the pipe added appreciably to the insulating effect of the envelope, and that the insulating characteristics of the wet portion of the Z-Crete were comparable to that expected for a clay loam containing 10 to 20 percent moisture.

AVERAGE TEMPERATURE AROUND PIPE VS RATIO OF RADII

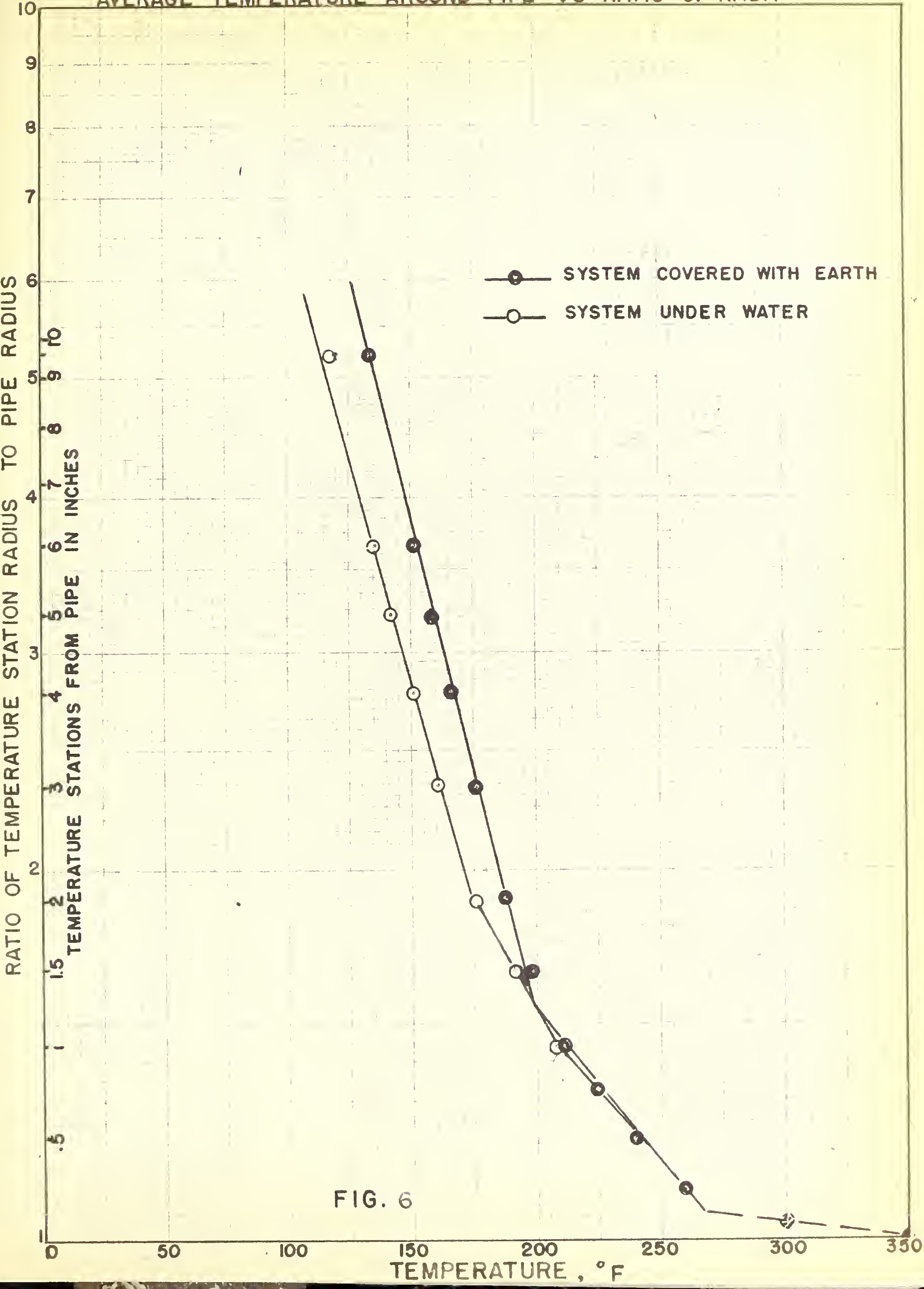


FIG. 6

These values for thermal conductivity were computed from the following formula for a cylindrical insulating envelope using the observed heat loss and temperature data.

$$k = \frac{6\,Q \ln \frac{r_o}{r_i}}{\pi\, L\, \Delta T} \quad \text{where}$$

Q = latent heat of saturated steam at the pipe temperature times the weight of condensate collected per hour in pounds

L = length of test section, ft

r_o, r_i = radius of the outside and inside of insulating envelope, inches

ΔT = temperature difference between positions r_o and r_i in the insulation as measured from the center of the pipe, °F

A small error in the values of the thermal conductivity is probably involved in this computation because the envelope of Z-Crete was rectangular and asymmetrical in cross section. However, the error is small because the thermal conductivity of the outer part of the Z-Crete was of the same order of magnitude as the surrounding earth.

Fig. 7 shows the average temperatures observed in the Z-Crete envelope for the two tests with air-dried and water-soaked earth around it, and the corresponding average thermal conductivity of several thicknesses of Z-Crete as measured from the pipe surface. That is, the average thermal conductivity from the pipe to a distance one inch from the pipe was 1.07 and 1.17 Btu/hr(ft^2)(°F/in.) for the two test conditions whereas that from the pipe to a distance four inches from the pipe was 2.23 and 2.30 Btu/hr(ft^2)(°F/in.) for the corresponding conditions. These average thermal conductivities include the effect of the 1/8-inch air space formed adjacent to the pipe by the corrugated paper wrapping. Fig. 7 shows that the average thermal conductivity of the entire Z-Crete envelope was more than 2 1/2 times as great as the hot plate value for the dry material.

TEMPERATURE AND THERMALCONDUCTIVITY OF Z-CRETE VS DISTANCE FROM PIPE

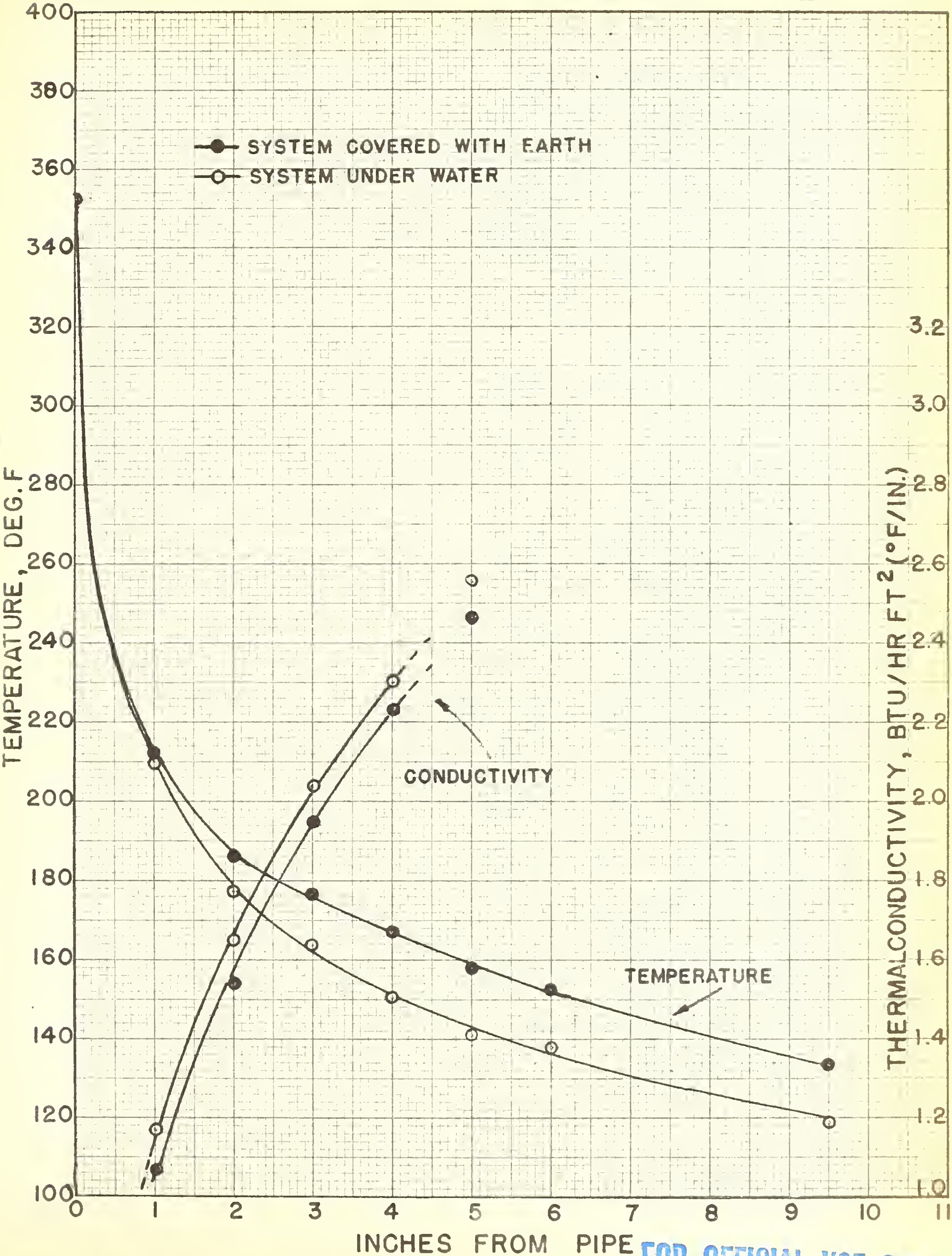


FIG. 7

There were no visible breaks in the waterproof covering and no cracks in the Z-Crete envelope at the end of the tests. The coal tar pitch revealed some plastic flow when the pipe was heated before covering the specimen with earth. There was no evidence of significant change in the moisture content of the Z-Crete during the course of the tests. Free water was visible on the inside of the waterproof covering when the Z-Crete was unwrapped. The appearance of the Z-Crete specimen tested in the earth-filled box is shown in Fig. 8 at the time it was uncovered after the tests.

3.4 Water Penetration Tests

Several blocks of Z-Crete were cut from the underground specimen after completion of the tests in the earth-filled box. Fig. 9 shows the rate of water absorption of three blocks of Z-Crete when immersed in cold water. Two of the three specimens absorbed 100 percent of their dry weight of water in 24 hours and the third specimen required about four days to absorb the same amount. All three specimens had absorbed about 130 percent of their dry weight of water after 30 days soaking.

The two cylindrical specimens of Z-Crete containing B-Crete admix and No. 4 aggregate were received wrapped in a plastic film to retain the initial water used when mixing. They were subsequently oven-dried at 215F and then immersed in water and periodically weighed to determine their absorption rate. The results observed on these two specimens and a similar one taken from the original Z-Crete used for the other tests are shown in Fig. 10.

Fig. 10 shows that the two new specimens, as received, had a water content of 86 percent and 69 percent of their dry weight, respectively. After oven-drying they absorbed 35 percent and 31 percent of water relative to their dry weight during the first day of immersion whereas the Z-Crete specimen cast here absorbed 132 percent of its dry weight during the same period. After 18 days immersion the water absorption was 64 percent and 58 percent for the two new specimens and 156 percent for the specimen cast here, related to the dry weight in each case. These results show a considerably lower water absorption for the newer Z-Crete mix than for that used for the simulated underground tests.

Fig. 8

MOISTURE ABSORPTION OF 3 Z-CRETE BLOCKS SUBMERGED IN WATER

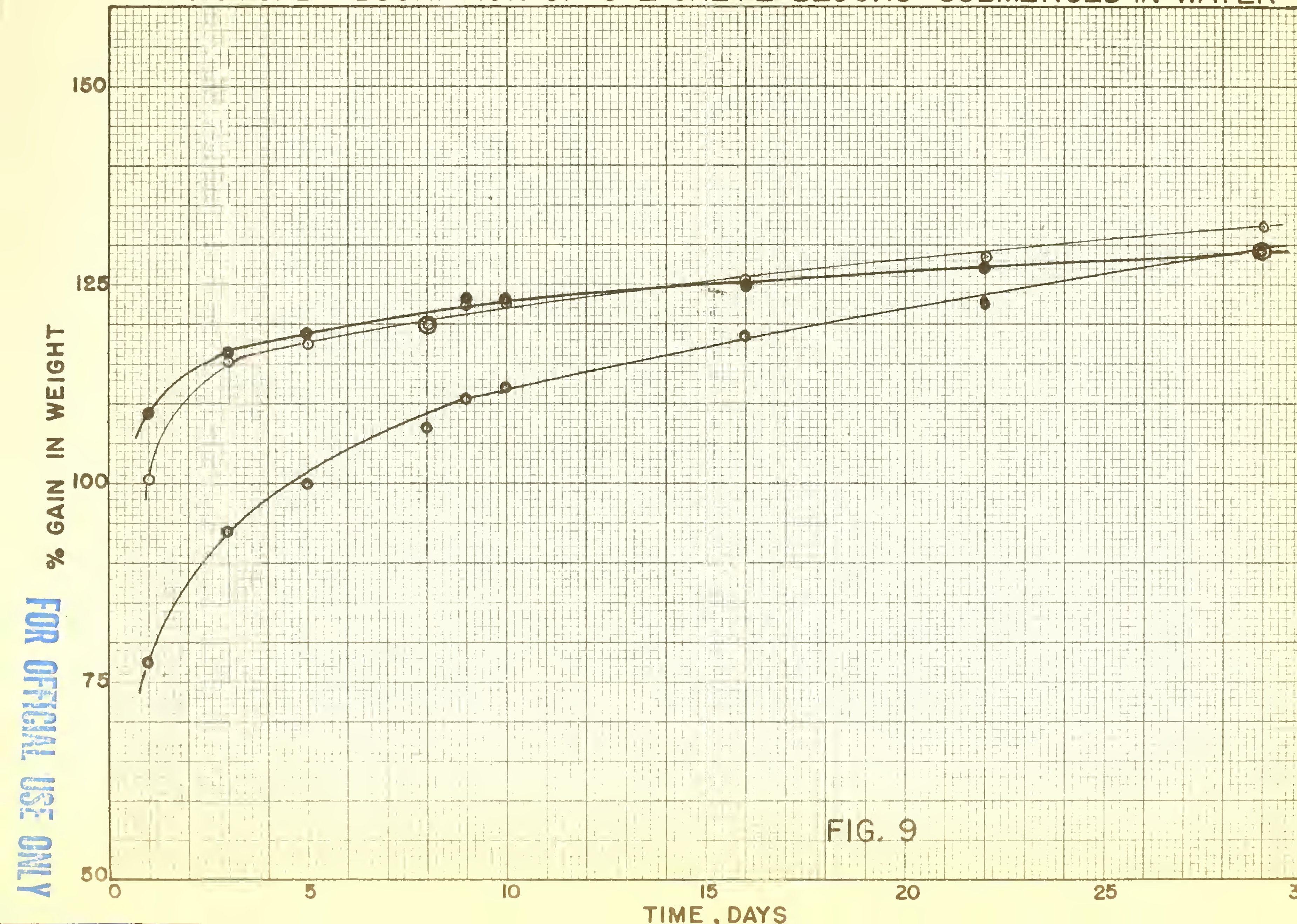


FIG. 9

MOISTURE ABSORPTION OF 3 Z-CRETE CYLINDERS SUBMERGED IN WATER

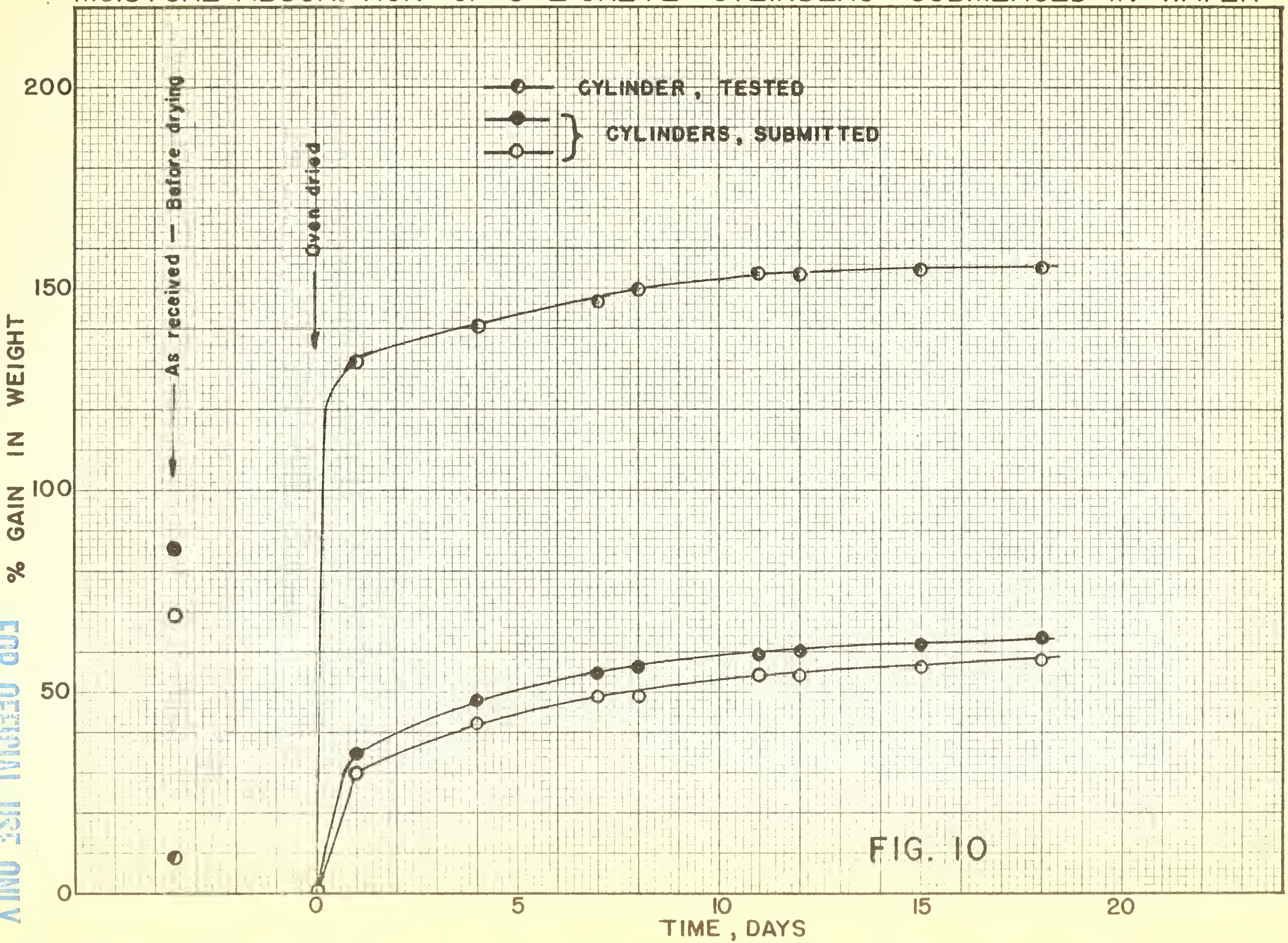


FIG. 10

4. Discussion and Conclusions

The laboratory and simulated field tests of Z-Crete indicated the following conclusions about the installation tested:

1. The Z-Crete did not crack during the course of the tests.

2. There was no evidence of leakage in the waterproofing surrounding the Z-Crete.

3. The Z-Crete did not adhere to the pipe because of the corrugated paper wrapping on the pipe;

4. The waterproofing prevented the complete drying out of the Z-Crete and resisted the entry of water from the surrounding earth;

5. The simulated field installation of Z-Crete had a higher thermal conductivity than oven-dried specimens from the same pour because the envelope was not dried out in the field.

6. The insulating concrete used for the simulated field test was hygroscopic and could absorb in excess of 100 percent of its dry weight in water. A newer Z-Crete mix was more resistant to water absorption than that used for the underground tests;

7. In the underground installation the moisture in the one-inch of Z-Crete nearest the pipe was transferred to the material farther from the pipe and remained there as long as the pipe was heated.

Only the air space and about one inch of Z-Crete nearest to the pipe was very effective as an insulating material. In this zone the Z-Crete had an average moisture content of about seven percent. Beyond the one-inch annulus the moisture content ranged from 50 to 100 percent of the weight of the dry Z-Crete. In this zone the thermal conductivity was comparable to that expected for a dry loam with 10 to 20 percent moisture.

8. The thermal conductivity of the oven dry Z-Crete used for the underground tests was 0.84 Btu/hr(ft^2)(°F/in.) at a mean temperature of 128F. The average thermal conductivity of the Z-Crete envelope as tested underground was more than 2 1/2 times this value. Consequently, the dry thermal conductivity of the material cannot be used to determine the heat loss from a pipe insulated in the manner of the test specimen.

9. About three weeks were required to completely dry out a Z-Crete annulus 5 3/8-inches thick cast on a ceramic core when the core was maintained at a temperature between 350F and 400F and there was no waterproof covering on the exterior. These results indicate that it would be impractical in most cases to attain complete drying in the field before application of the waterproofing.

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