NATIONAL BUREAU OF STANDARDS REPORT

7436

QUARTERLY REPORT

ON

EVALUATION OF REFRACTORY QUALITIES OF
CONCRETES FOR JET AIRCRAFT WARM-UP, POWER CHECK,
MAINTENANCE APRONS, AND RUNWAYS

by

W. L. Pendergast, E. C. Tuma, D. K. Ward

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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Building Research Division

Sponsored by:

Department of the Navy
Bureau of Yards and Docks

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Bruce E. Foster, Assistant Chief
Inorganic Building Materials Section

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1. INTRODUCTION

The purpose of this project is the development of criteria for the fabrication of jet exhaust resistant concretes. Concretes under development are evaluated by exposure to hot gases from a combustion chamber. The combustion chamber delivers these gases at velocities and temperatures approaching field conditions.

2. ACTIVITIES

Concretes Submitted from Naval Facilities

Four sets of concrete panels 18 x 18 x 6 inches, three in each set, were received during the period covered by this report.

One set of specimens was fabricated from the mix used in placing power check facilities at Cecil Field, Florida, a second set from Whidbey Island, Oak Harbor, Washington, a third from Oceana, Virginia Beach, Virginia, and a fourth from the Southwest Division, N. A. S. at Los Alamitos, Long Beach, California.

To date a total of 17 Naval Power Check Facilities have submitted 19 sets of test specimens, two sets each being received from the Naval Air Stations at Whidbey Island, Oak Harbor, Washington and Jacksonville, Florida. The first set, from Whidbey Island, was fabricated from a concrete mix that failed to meet the 28-day flexural strength requirement of 650 psi. A second set was fabricated from a mix composed of the same materials, but with an increase in the ratio of coarse to fine aggregate, increase in cement content and decrease in water-cement ratio was reported as developing 820 psi flexural strength. The first set of panels from Jacksonville, at the request of the Bureau of Yards and Docks, were sawed into beams 18 x 6 x 6 inches. The flexural strength, after 28-day moist curing, was determined. The second set from this installation, was subjected to the planned tests included in this phase of the project. The design and properties of the fresh concretes, together with the 28-day flexural strengths, when furnished, appear in Table I.

Ten jet impingement tests were completed during the quarter on panels submitted from the following power check facilities.

Two of the three panels from the Naval Air Station at Meridian, Mississippi were tested after 28 and 56 days drying at 73°F and 50% relative humidity. The panel tested after the 28-day drying period showed a spalling loss as did the panel previously reported as tested after 14 days drying. The panel tested after 56 days drying showed no failure.

Table I. Properties of Fresh Concrete [1/]

Identification	Type of Aggregate	Type of[2/] Cement	Admixture	Ratio by Wt. of Coarse to Fine Aggregate	Cement Content	Ratio w/c	Slump	Air Content	Flexural Strength 28 days
			oz/sack of ct.		sack/yd^3		inches	%	psi
5th Naval Dist. N.A.S. Norfolk, Va.	Trap Rock	I	Darex 1.0	66:34	7	.435	1 to 2	6.2	750
8th Naval Dist. N.A.A.S. Kingsville Texas	Basalt Variety	I	Darex 1.0	63:37	5.5	.58	2	5.0	650
8th Naval Dist. N.A.A.S. Chasefield Beeville, Texas	Basalt Variety	I	None	63:37	5.5	.61	1.5	2.0	655
11th Naval Dist. M.C.A.S. El Toro California	Expanded Shale	High[3/] Alumina Hydraulic	None	67:33	6.5	.75	3.25	4/	600
13th Naval Dist. N.A.S. Whidbey Is. Oak Harbor, Wash.	Quarry or Trap Rock	II	Darex[5/] 0.75	63:37	6.5	.42	2.0	5.2	450
6th Naval Dist. N.A.S. Sanford Florida	Blast-Furnace Slag	I	Darex 1.0	58:42	7.5	.39	2.0	4/	755
11th Naval Dist. U.S.M.C.A.A.S. Yuma, Arizona	Blast-Furnace Slag	II	Pozzolith 8AA 4.0	62:38	8.0	.43	3.0	7.7	704
6th Naval Dist. U.S.M.C.A.A.S. Beaufort, S. C.	Trap Rock	I	Aermix 1.75	57:43	7.0	.43	3.25	5.5	720
6th Naval Dist. N.A.S. Glynco, Georgia	Trap Rock	I	Darex 1.3	66:34	7.5	.40	4/	4/	4/
5th Naval Dist. M.C.A.S. Cherry Point, N. C.	Trap Rock	I	Darex 1.53	68:32	6.5	.46	2.5	6.4	650
6th Naval Dist. N.A.S Jacksonville, Florida	Basalt Variety	I	Darex 1.4	53:47	7.0	.43	1.25	5.8	610[6/]
11th Naval Dist. N.A.S. Miramar, California	Expanded Shale	High[7/] Alumina Hydraulic	Air-in 0.5	56:44	6.75	.60	2.0	5.0-8.0	660
12th Naval Dist. N.A.S. Lemoore, California	Expanded Shale	II	Liquid Plastair 2.75 Fl.oz.	47:53	7.5	.33	[8/] 1--1.25 2--1.25 3--1.75 4--1.00 5--1.25	4.1 3.2 3.2 4.1 3.2	685 4/ 695 625 635
Southeast Division N.A.S. Meridian, Miss.	Blast-Furnace Slag	I	Air-in 1.50	59:41	7.0	.53	2.0-3.0	5.0-8.0	765
Southwest Division N.O. Test Station China Lake, California	Expanded Shale	High[3/] Alumina Hydraulic	Durair 1.25	66:34	6.75	.475	3.0	6.3	9/
Cecil Field Florida	Blast-Furnace Slag	I	Darex 1.20	55:45	7.5	.39	1.0	6.5	810
13th Naval Dist.[10/] N. A. S. Whidbey Is. Oak Harbor, Wash.	Trap Rock	II	Darex 2.0-2.6 Pozzolith 1.0	68:32	7.0	.38	1.0-4.5	1.8-3.5	820
U.S.N.A. Oceana Virginia Beach Virginia	Diabase	I	Darex 1.33	65:35	6.75	.49	1.75	6.4	635
Southwest Division N.A.S. Los Alamitos Long Beach, California	Expanded Shale	High[3/] Alumina Hydraulic	Darex 0.75	37:63	6.75	.473	3.5	5.2	550

1/. Data furnished by testing laboratories.
2/ Portland unless otherwise specified.
3/ Imported; Fondu
4/ Data not received even after repeated inquiries.
5/ 0.25 oz. of Pozzolith per sack, also.
6/ Average of nine beams sawed from the panels submitted; as requested by Mr. P. P. Brown, Bureau of Yards and Docks, Washington 25, D. C.
7/ Domestic; Lumnite.
8/ Power Check Station number.
9/ Data not received.
10/ Second shipment from this facility; the concrete placed under the first contract was rejected for failure to meet the strength requirements.

Three panels, from the Southwest Division, Naval Ordnance, Test Station, Area E, China Lake, California were tested during this quarter after 21, 35, and 50 days drying respectively and showed no spalling failure. However, due to an oversight, these panels did not arrive at the N. B. S. until 92 days of moist curing had elapsed.

Three panels, from Cecil Field, Florida were tested after 15*, 29, and 43 days drying respectively. The extent of failure was severe*, moderate, and slight, respectively.

Two of the panels from Whidbey Island, Oak Harbor, Washington were tested after 40 and 54 days drying respectively. Neither panel evidenced any spalling loss. The history of these panels from the date cast until their receipt at the N. B. S. has not as yet been furnished. More complete data for the jet impingement tests are given in Table II.

The comparison of the flexural strengths determined on 18 x 6 x 6 inch beams, cut from panels either within or outside the test area, after the panel had been subjected to the jet impingement test, has been continued. The results continue to indicate that the loss in flexural strength between that reported as the 28 day moist curing strength and that after jet-blast exposure is due to water loss resulting during the drying period rather than due to the heat treatment during the jet-blast test.

Steam Pressure Developed Within Concrete During Rapid Heating

Six concrete cylinders, 6 x 6 inches, were exposed to steam pressure using the apparatus described in N. B. S. Report 7351. Three of these cylinders were fabricated using a concrete mix with diabase aggregate, three with a mix using blast-furnace slag aggregate. Portland cement was used in both mixes. In each instance leakage occurred between the concrete cylinder and the containing steel mold. Water also followed the thermocouple wires to the surface of the cylinder exposed to the atmosphere. Although steam pressure at the center of cylinders reached a maximum of 225 psi in tests mentioned in N. B. S. Report 7351 no such pressures were detected in these six tests.

Four additional cylinders were fabricated, two using a mix containing blast-furnace aggregate and two using diabase aggregate. These cylinders were equipped with closed-end tubes to contain the thermocouples. A ring of brass shim stock was soldered inside each mold in an attempt to prevent leakage between the specimen and the container. When these cylinders were subjected to steam pressure the modifications did eliminate the leakage along the thermocouple wires and slightly reduced the leakage between the test cylinder and the mold. However, during these tests no significant pressures were detected. To avoid such leakage that still exists, it is planned to change the shape of the test specimens from cylindrical to a truncated cone. This cone will be positioned in the pressure apparatus with the base exposed to the steam pressure. It will be jacketed with a room curing natural rubber compound. Pressure applied at the base of the specimen should then cause it to seal itself against the mold.

* This test was conducted during the conference referred to in the latter part of this report.

Table II. Data on Panels During Moist Curing, Drying, and Results of Jet Impingement Tests

Identification	Panel Number	Days in Sawdust	Water[1/] Content of Sawdust	Weight Change[2/] of Panel During Sawdust Storage	Storage in Fog-room	Weight Change[2/] of Panel During Fog-room Curing	Drying Period	Loss in Drying	Spalling Loss by Wt.	Spalling Loss by Sand Volume	Flexural[3/] Strength
			%	%	days	%	days	%	c.c.	c.c.	psi
5th Naval Dist.	1	15	38	-0.13	13	0.00	36	0.40	43.6	15.4	480
N.A.S. Norfolk,	2	15	do	-0.26	13	0.00	50	0.67	45.3	None	465
Virginia	3	14	do	-0.13	13	+0.14	68	0.82	90.6	1.20	455
	4	14	do	-0.13	13	+0.14	84	0.89	225.3	119.3[4/]	395
8th Naval Dist.	A	15	60.5	-0.14	13	+0.06	42	0.63	149.5	70.2[4/]	370
N.A.A.S. Kingsville,	B	15	60.5	-0.58	13	+0.16	58	0.87	43.9	24.6	430
Texas	C	15	60.5	-0.58	13	+0.16	Note[5/]	----	-----	-----	---
	D	17	52.0	-0.43	10	0.00	87	0.86	87.2	22.6	415
8th Naval Dist.	A	17	52.0	+0.57	10	0.00	42	0.57	303.0	226.0[4/]	370
N.A.A.S. Beeville,	B	17	do	+0.14	10	+0.14	59	0.83	43.6	26.2	495
Texas	C	17	do	+0.69	10	0.00	70	0.79	34.5	None	460
11th Naval Dist.	1	28	54.0	+2.26	6/	6/	42	8.20	68.0	None	135
U.S.M.C.A.S.	2	28	39.0	+3.02	"	"	56	8.22	206.5	"	130
El Toro, California	3	28	38.0	+1.86	"	"	71	5.49	96.3	Slight	205
13th Naval Dist. 7/	1	32	61.0	+0.23	6/	6/	43	1.70	49.9	None	485
N.A.S. Whidbey Is.	2	32	62.0	+0.34	"	"	56	2.00	50.7	"	400
Oak Harbor, Washington	3	32	57.0	+0.21	"	"	71	2.45	None	"	415
6th Naval Dist.	1	28	53.0	+0.76	6/	6/	42	0.79	50.7	9.0	385
N.A.S. Sanford,	2	28	53.0	+0.57	"	"	56	1.11	51.5	Slight	275
Florida	3	28	53.0	+0.57	"	"	71	0.94	514.6	331.0[4/]	390
11th Naval Dist.	1	37	60.0	-0.32	6/	6/	42	0.96	51.8	None	325
U.S.M.C.A.A.S.	2	37	60.0	-0.48	"	"	56	1.43	31.1	do	300
Yuma, Arizona	3	37	60.0	-0.16	"	"	70	1.13	93.0	do	300
6th Naval Dist.	2	120	47.5	+0.77	6/	6/	56	0.46	10.5	None	475
U.S.M.C.A.A.S.	4	"	"	+1.15	"	"	42	0.23	55.0	16.9	505
Beaufort, S.C.	5	"	9/	None	"	"	70	0.44	45.0	16.0	415
6th Naval Dist.	1	50	49.0	+2.31	6/	6/	42	0.45	38.0	None	365
N.A.S. Glynco	2	43	49.0	+0.71	"	"	56	0.31	68.0	Slight	465
Georgia	3	42	49.0	+2.62	"	"	70	0.71	237.0	181.0[4/]	490
5th Naval Dist.	1	20	43	+0.29	8	+0.06	42	0.40	98.0	59.0	445
M.C.A.S.	2	20	50	+0.29	8	None	56	0.43	48.0	38.0	570
Cherry Point, N.C.	3	20	52	+0.16	8	+0.06	70	0.47	93.0	76.0	490
6th Naval Dist.	1	47	18	-0.42	6/	6/	42	0.54	54.0	29.0	390
N.A.S.	2	"	27	None			56	0.42	82.0	None	515
Jacksonville, Fla.	3	"	65	None			70	0.72	28.0	None	565
11th Naval District	1	38	40	+0.77	6/	6/	6	0.68	161	None	170
N.A.S.	2	38	40	0.00			13	0.21	116	None	280
Miramar, California	3	38	40	-0.85			20	0.17	116.5	None	245

Table II - Continued.

Identification	Panel Number	Days in Sawdust	Water Content of Sawdust [1/]	Weight Change of Panel During Sawdust Storage [2/]	Storage in Fog-room	Weight Change of Panel During Fog-room Curing [2/]	Drying Period	Loss in Drying	Spalling Loss by Wt.	Spalling Loss by Sand Volume	Flexural Strength [3/]
			%	%	days	%	days	%	c.c.	c.c.	psi
12th Naval District [10/]											
N. A. S.	1 1	28	37	+0.97	6/	6/	17	0.48	170.0	None	365
Lemoore, California	2	do	do	+0.54			8	None	60.0	do	370
	3	do	do	+0.41			22	0.81	57.0	do	375
	2 1	28	38	+0.42	6/	6/	29	0.83	68.0	None	315
	2	do	do	+0.37			36	1.00	125.0	34	335
	3	do	do	+0.42			42	1.04	68.0	Slight	335
	3 1	28	53	+0.79	6/	6/	9	0.59	651.0	500.0 [4/]	395
	2	do	do	+0.79			20	None	65.0	None	380
	3	do	do	+1.09			23	0.86	26.0	None	405
	4 1	28	37	None	6/	6/	30	1.00	79.0	None	300
	2	do	do	+0.05			37	0.85	65.0	None	370
	3	do	do	+1.00			43	0.98	Not Tested	Not Tested	Not Tested
	5 1	28	69	+0.32	6/	6/	29	0.92	65.0	None	320
	2	do	do	+1.03			35	1.00	57.0	None	290
	3	do	do	+0.48			Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Southeast Division	1	21	41	-0.32	7	+0.16	14	0.19	105.0	26.0	310
N. A. S.	2	do	41	-0.10	7	+0.03	28	0.64	105.0	44.0	210
Meridian, Mississippi	3	do	41	-0.13	7	+0.03	56	0.84	54.0	None	325
Southwest Division	1	92	36	+1.90	6/	6/	21	3.97	82.0	None	240
N. O. Test Station	2	do	do	+1.47			35	6.21	334.0	None	120
China Lake, California	3	do	do	+2.97			50	5.84	108.0	None	8/
Cecil Field	1	14	36	+0.06	14	+0.25	15	0.44	270.0	227.0 [4/]	350
Florida	2	do	34	+1.45	do	+0.32	29	0.89	164.0	164.0 [4/]	320
	3	do	41	+0.48	do	+0.32	43	0.96	6.2	Slight	290
13th Naval Dist.	1	9/			6/		40	0.34	37.0	None	495
N.A.S.Whidbey Island	2						54	0.29	45.0	None	455
Oak Harbor, Wash.	3						8/	8/	8/		
U.S.N.A. Oceana	1	9/			6/		8/	8/	8/	8/	8/
Virginia Beach	2										
Virginia	3										
Southwest Division	1	29	65	+0.08	6/		8/	8/	8/	8/	8/
N.A.S. Los Alamitos	2	do	55	-0.17							
Long Beach, California	3	do	53	-0.25							

1/ $\frac{\text{wet weight-dry weight}}{\text{wet weight}} \times 100$

2/ Based on one day weight.

3/ Determined on beams cut from panels after jet impingement tests.

4/ Results of this magnitude indicate complete destruction of test surface.

5/ Flexural strength determined on 3 beams cut from panel at request of Budocks.

6/ Considered as moist cured during transit, 28 or more days

7/ The water in the sawdust was frozen through to the panels on receipt.
Since the concrete from which these panels were fabricated was rejected, as failing to meet flexural strength requirements; additional panels will be shipped fabricated from concrete used in new installation.

8/ Data not complete.

9/ Not packed in sawdust.

10/ Power Check Station number.

Effect of High-Pressure Air on the Permeability of Concrete

Using the appartus designed to determine the effect of high pressure air on the permeability of concrete several determinations have been made. This apparatus is of the same design as the one used in permeability determinations at low-head pressures except that copper tubing replaced the rubber hoses and the thickness of the seal box was increased to accomodate higher air pressures.

To determine the effect of high air pressure on the permeability of concrete to pressure at low-heads, the permeability is first determined on the specimen at low head pressure and then the specimen is subjected to high pressures (100, 200, or 300 psi, the capacity of our apparatus at the present time) for varying periods of time. The permeability at low head pressure is then redetermined. Although the work completed thus far has been exploratory, the results indicate an increase in permeability.

The Effect of the Water Present in Concrete on Temperature Gradient

The method used in measuring temperatures at different locations and at different depths was described in N. B. S. Report 7351. The temperature gradients occurring in six panels have been computed. Three of the panels were fabricated using a mix containing blast-furnace slag and three using a mix containing crushed diabase rock as the aggregate. These two aggregates were chosen to ensure a wide range of drying time required to resist spalling in the concretes made with them. Portland cement was used in both mixes. The panels made with the portland-blast-furnace slag mix were moist cured for 21 days and dried at 73°F and 50% relative humidity for 7, 21, and 35 days respectively. The panels made using the portland-diabase mix were moist cured for 28 days and dried for 42, 57, and 70 days respectively. These periods of drying were chosen by taking into consideration past jet-blast tests that indicated no spalling would occur after some minimum period of drying for each concrete.

After drying, each of the six panels was subjected to a jet impingement test. The testing of the blast-furnace slag concrete panels yielded workable data. Two of the diabase aggregate concrete specimens spalled slightly during the test rendering some of the data of little value for comparative purposes. Temperature gradients were calculated from the temperature-depth curves obtained during each test.

Figures 1 to 7 show graphically some of the temperature conditions existing within concrete during jet-blast exposure.

Figures 1 and 2 indicate that the length of the drying period has a significant effect on the temperature gradients during a jet-impingement test.

One panel fabricated from each of the two concrete mixes was subjected to further testing after oven drying and again after water soaking. This procedure was followed to accentuate the effect of moisture content on the temperature gradients during jet-blast. Figures 3 and 4.

Figures 5 and 6 were included to show the extreme effect of high moisture content. The leveling off of the time temperature curves at some depths is attributable to the high absorption of heat energy by the water present at temper-

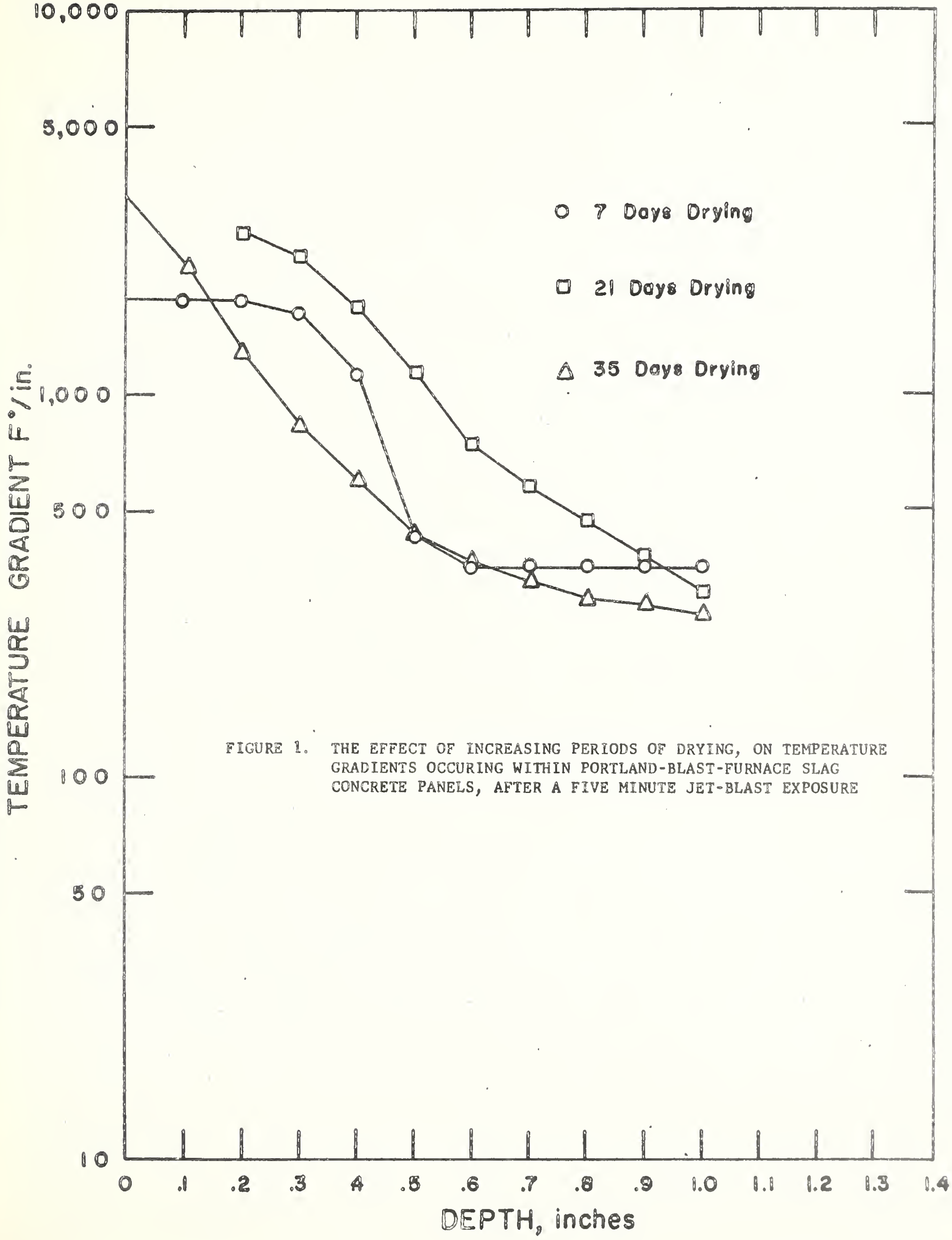


FIGURE 1. THE EFFECT OF INCREASING PERIODS OF DRYING, ON TEMPERATURE GRADIENTS OCCURING WITHIN PORTLAND-BLAST-FURNACE SLAG CONCRETE PANELS, AFTER A FIVE MINUTE JET-BLAST EXPOSURE

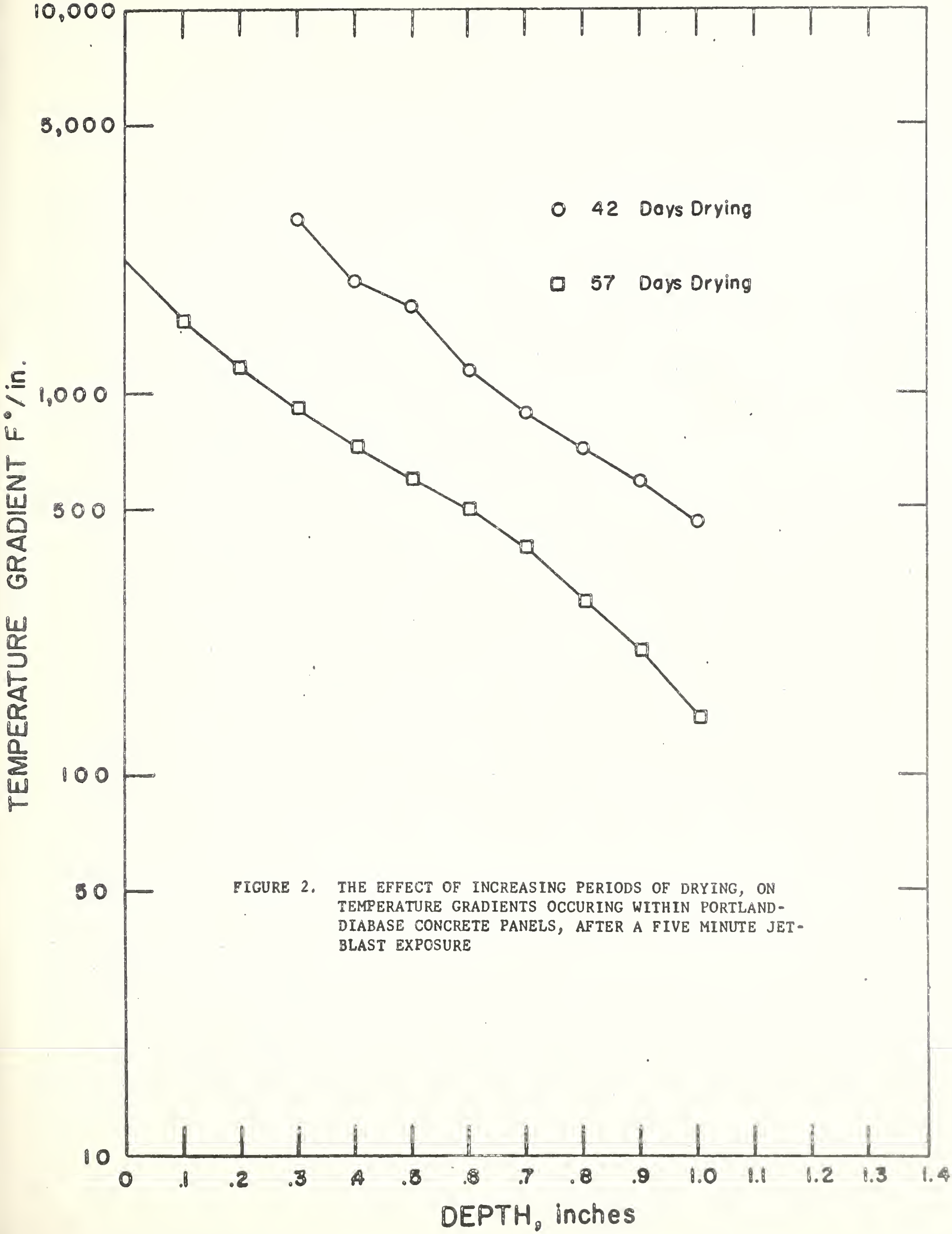


FIGURE 2. THE EFFECT OF INCREASING PERIODS OF DRYING, ON TEMPERATURE GRADIENTS OCCURING WITHIN PORTLAND-DIABASE CONCRETE PANELS, AFTER A FIVE MINUTE JET-BLAST EXPOSURE

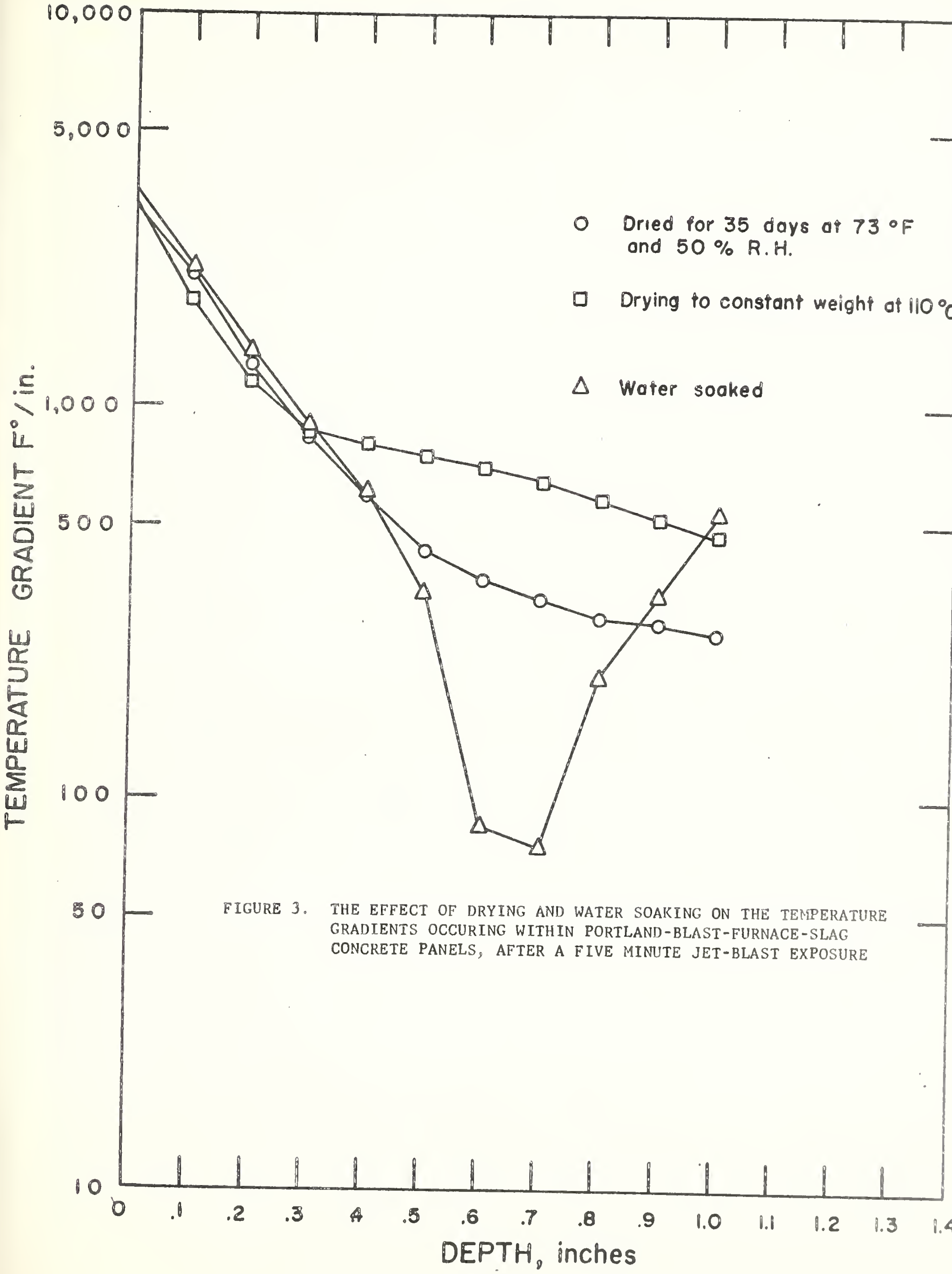


FIGURE 3. THE EFFECT OF DRYING AND WATER SOAKING ON THE TEMPERATURE GRADIENTS OCCURING WITHIN PORTLAND-BLAST-FURNACE-SLAG CONCRETE PANELS, AFTER A FIVE MINUTE JET-BLAST EXPOSURE

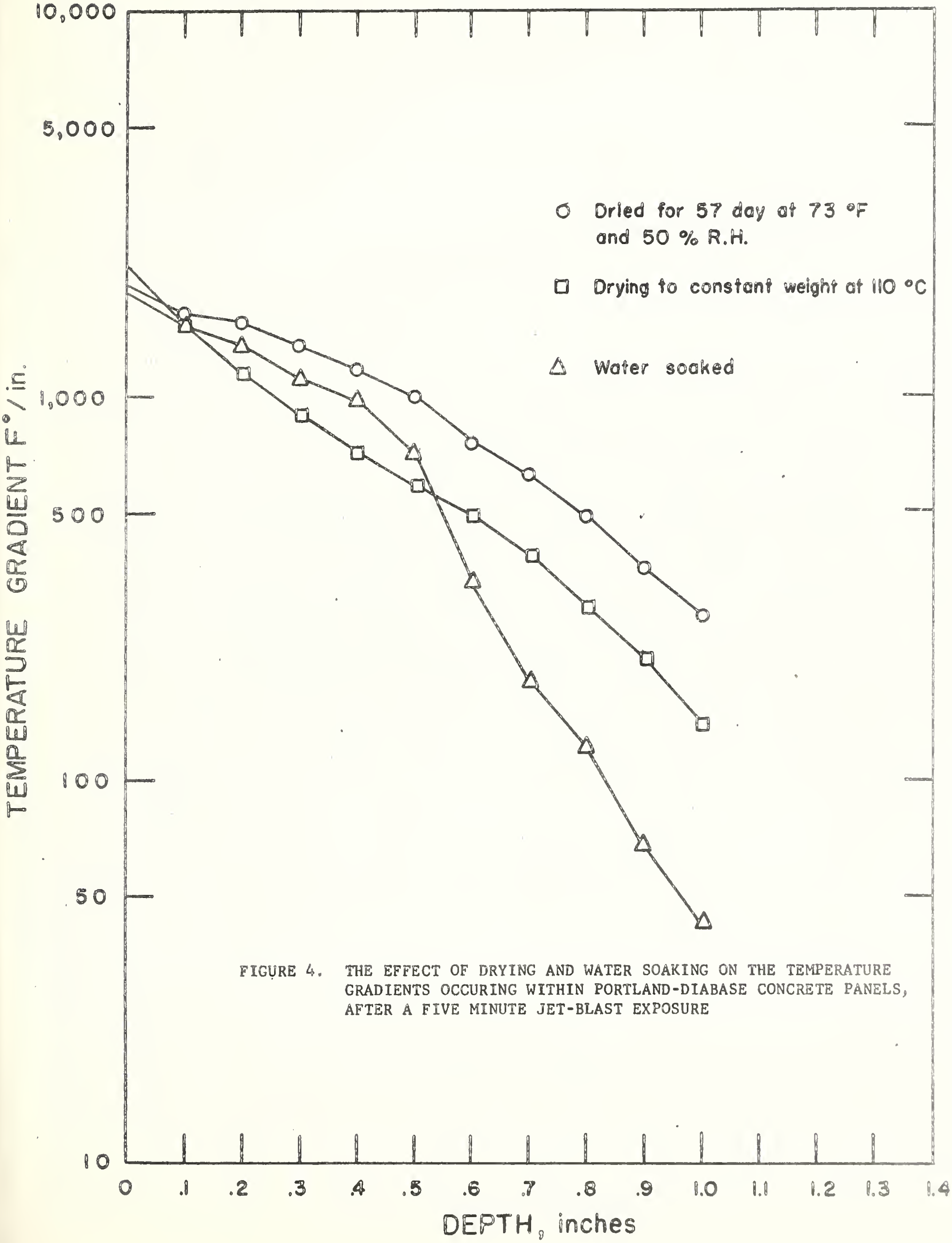


FIGURE 4. THE EFFECT OF DRYING AND WATER SOAKING ON THE TEMPERATURE GRADIENTS OCCURING WITHIN PORTLAND-DIABASE CONCRETE PANELS, AFTER A FIVE MINUTE JET-BLAST EXPOSURE

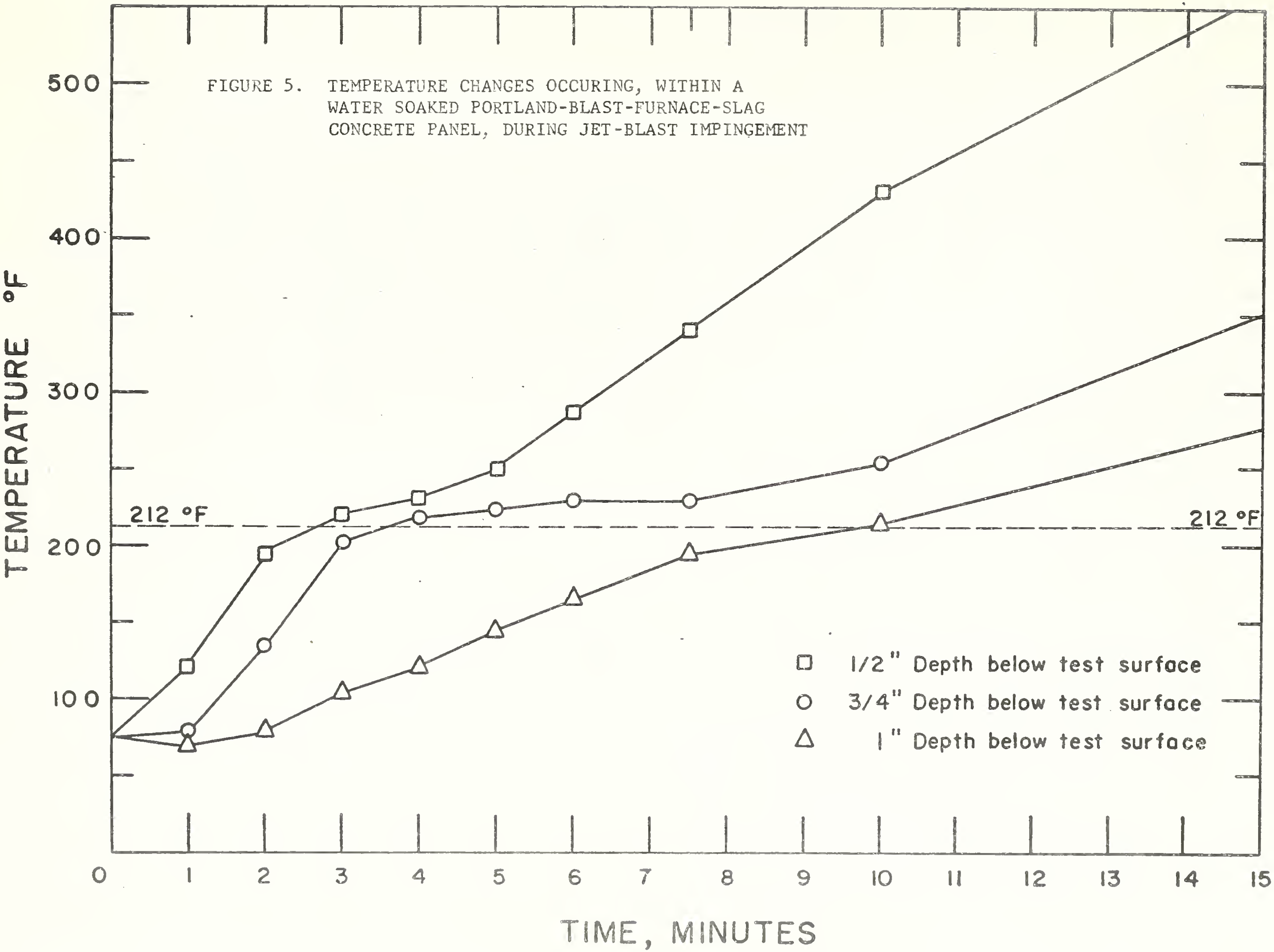
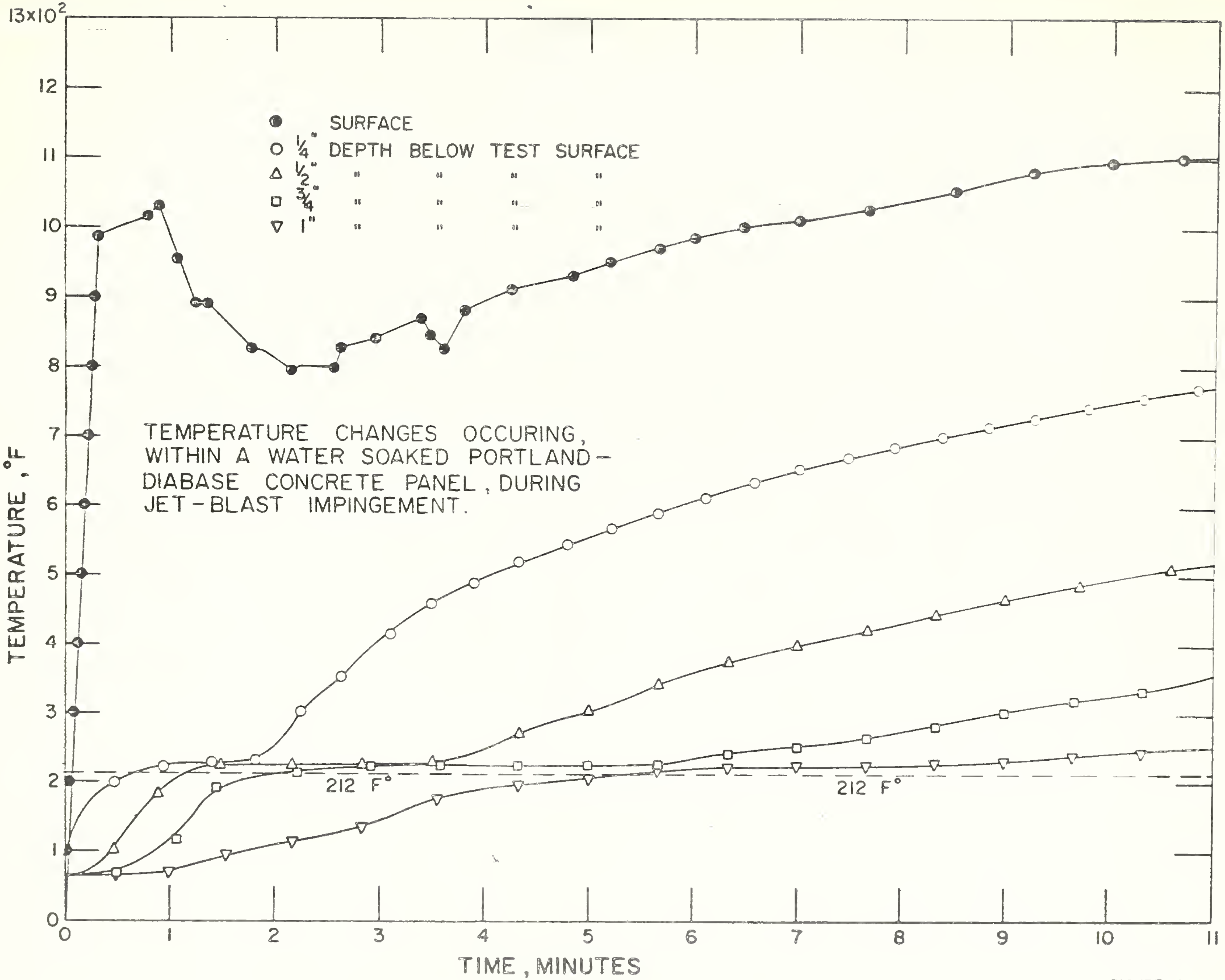


FIGURE 5. TEMPERATURE CHANGES OCCURING, WITHIN A WATER SOAKED PORTLAND-BLAST-FURNACE-SLAG CONCRETE PANEL, DURING JET-BLAST IMPINGEMENT


13x10²
12
11
10
9
8
7
6
5
4
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2
1
0
TEMPERATURE, °F
SURFACE
1/4" DEPTH BELOW TEST SURFACE
1/2" " " " "
3/4" " " " "
1" " " " "
TEMPERATURE CHANGES OCCURING, WITHIN A WATER SOAKED PORTLAND-DIABASE CONCRETE PANEL, DURING JET-BLAST IMPINGEMENT.
212 F°
212 F°
0
1
2
3
4
5
6
7
8
9
10
11
TIME, MINUTES

FIGURE 6

atures slightly above 212°F. Philleo and Verbeck, in their past unpublished work, noted this phenomona.

Figure 7 shows in greater detail the effect of the water soaking of diabase concrete at intermediate time intervals during a jet-blast test.

The changes in moisture content that occur in concretes during moist curing, drying at 73°F and 50% relative humidity, drying to constant weight at 110°C, water soaking, and subsequent jet-blast tests are shown in Figures 8 and 9. The relatively small changes in moisture content shown during the drying period at 73°F and 50% R.H. are due to the specimen being sealed on five surfaces and represent only the water loss near the test surface. (Figure 1 N. B. S. Report 5961.)

The data on temperature gradients have furnished a better understanding of the temperature conditions as they occur during jet-blast impingement. However, they do not give sufficient detail on the behavior of the top quarter inch of concrete in which spalling actually occurs. Attempts will be made to position more thermocouples in this critical area.

A conference was held at the National Bureau of Standards, November 21, 1961. The names of those in attendance follow:

Bureau of Yards and Docks -- P. P. Brown, and F. Knoop
Technical Director of NAVCECELAB -- Edward MacCutcheon
National Bureau of Standards -- Bruce E. Foster and W. L. Pendergast

Mr. MacCutcheon was briefed on the work thus far completed. The current work was discussed. A plan for inspecting power check facilities at Naval Air Stations was suggested. The installations referred to were those from which specimens fabricated from the same mix were submitted to the National Bureau of Standards for test.

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RAPID CHANGE IN TEMPERATURE GRADIENTS OCCURING IN WATER SOAKED DIABASE - CONCRETE DURING JET IMPINGEMENT

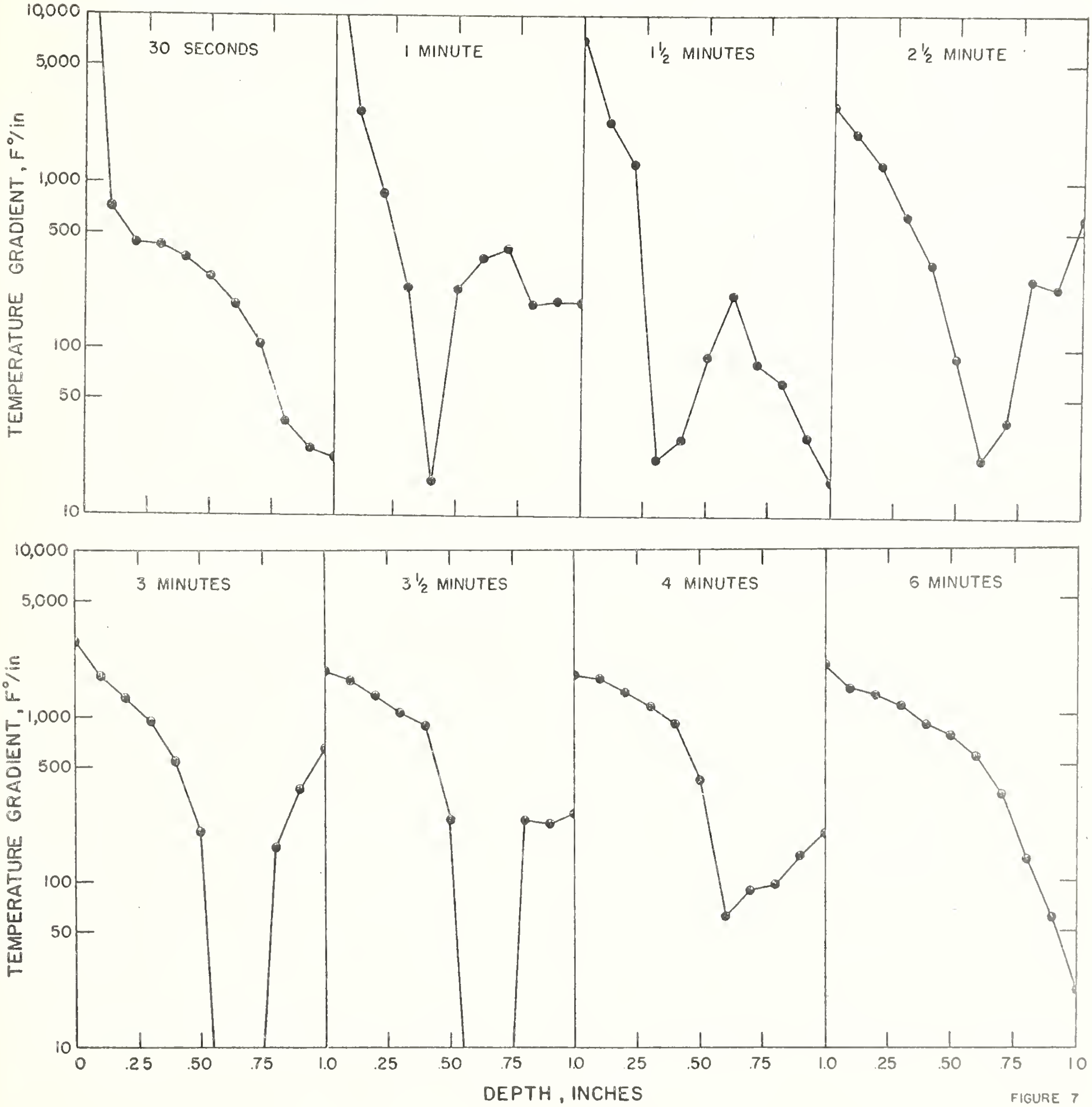

FIGURE 7

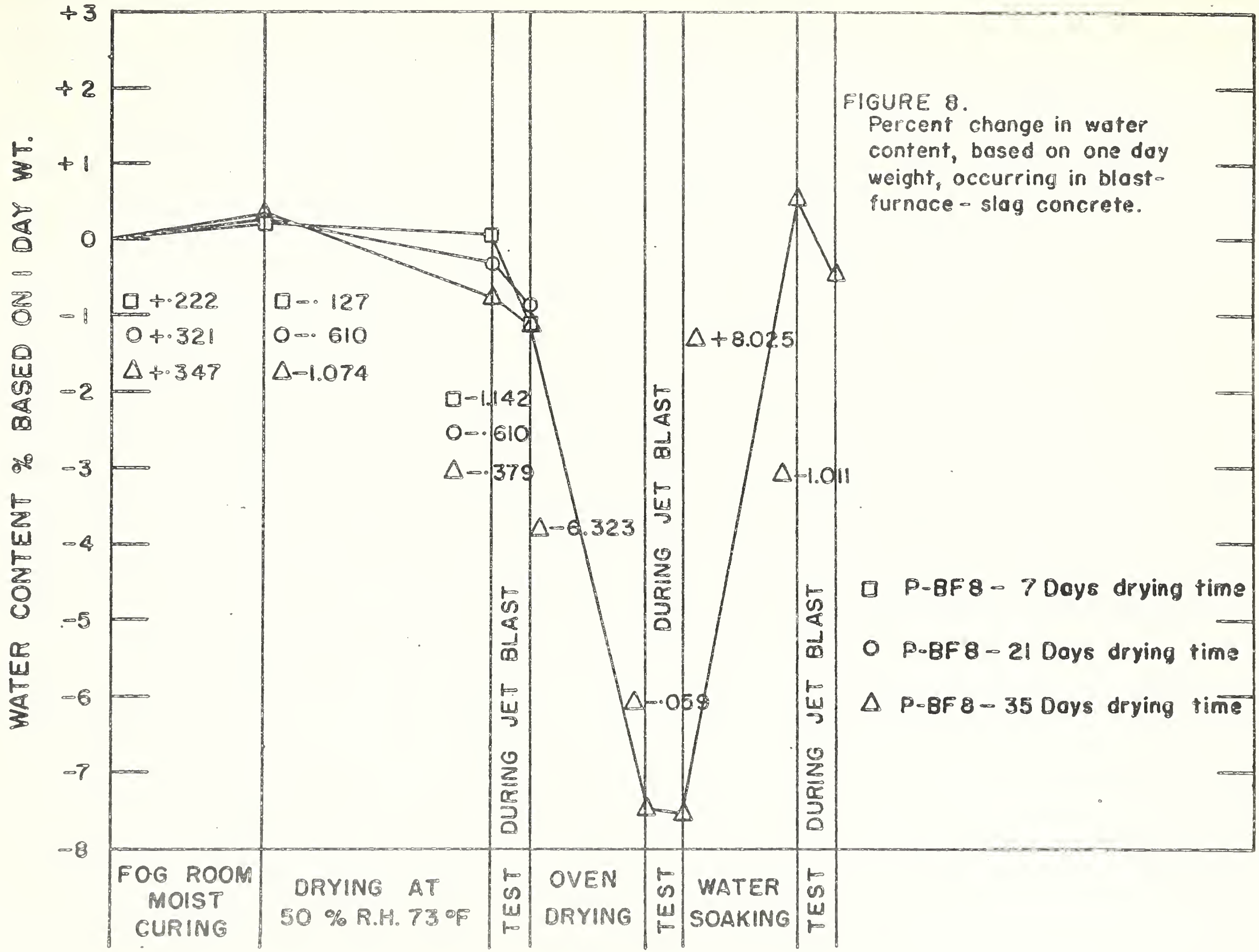

FIGURE 8.
Percent change in water content, based on one day weight, occurring in blast-furnace - slag concrete.

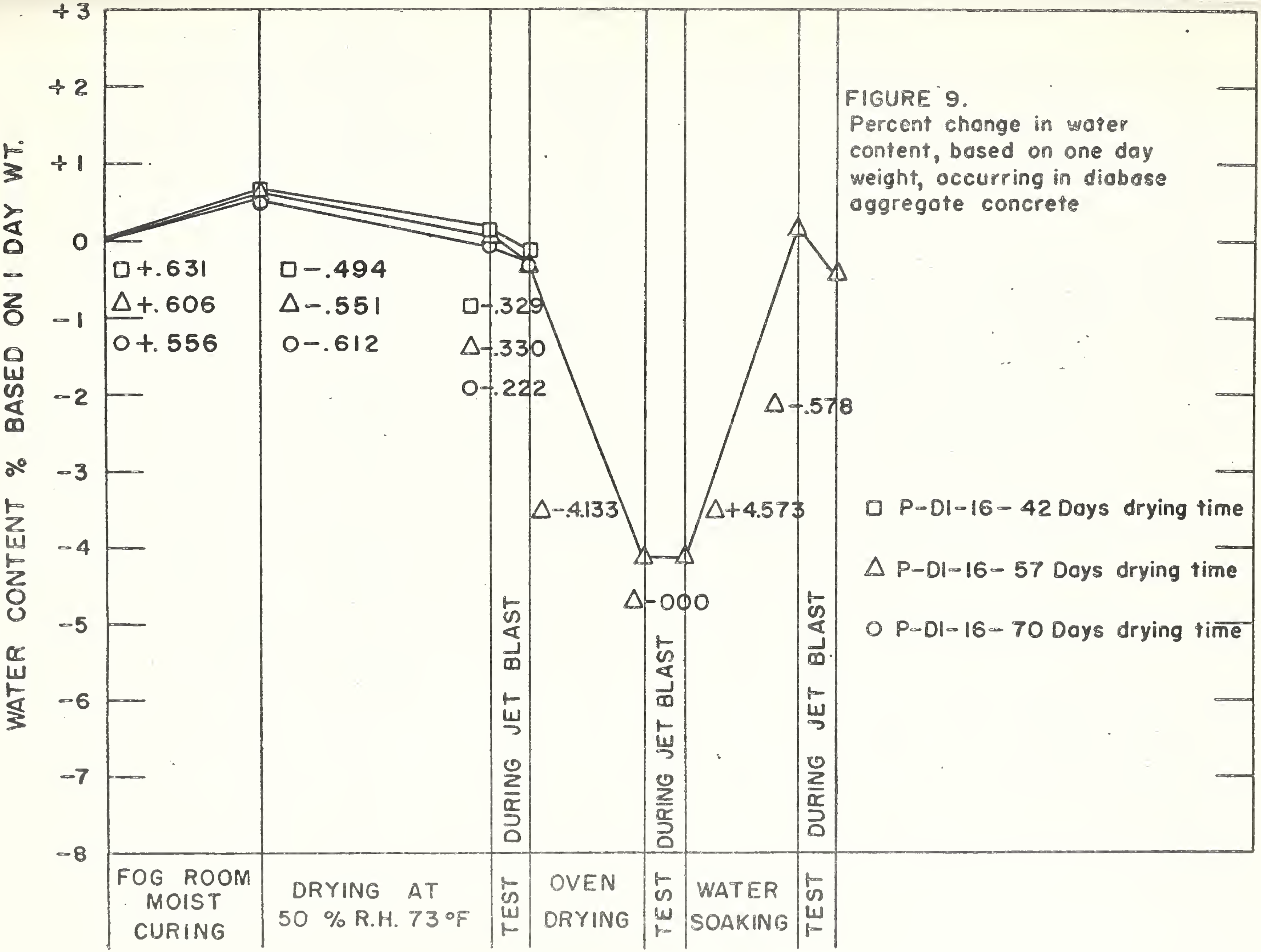

FIGURE 9.
Percent change in water content, based on one day weight, occurring in diabase aggregate concrete

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

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