10.00

NATIONAL BUREAU OF STANDARDS REPORT

7486

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

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (Includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | | **NBS REPORT**

1007-20-10472 April 18, 1962 7486

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
Inorganic Building Materials Section
Building Research Division

Sponsored by:

Department of the Navy
Bureau of Yards and Docks

Reference: Task Y-F015-15-102
NBS File No. 10.07/10472

Approved:
Bruce E. Foster, Chief
Inorganic Building Materials Section

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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

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

A. Concretes Submitted from Naval Facilities

Seven jet impingement tests were conducted during this quarter on panels submitted from the following power check facilities.

The third panel of a set of three from the Naval Air Station, Whidbey Island, Oak Harbor, Washington, was tested after a 68 day drying period at 73°F and 50 percent relative humidity. This panel, as did the two other panels in the set previously reported, evidenced no failure.

One set of three panels from the Naval Air Station, Los Alamitos, Long Beach, California, was subjected to jet blast impingement after 28, 42, and 72 days drying. None of the panels evidenced any failure.

The remaining set of three panels from the Naval Air Station, Oceana, Virginia Beach, Virginia was tested after 28, 62, and 76 days drying. The first and third panels tested showed significant failure, the second evidenced no failure. Since the information on the curing history of these panels was not furnished and they were not properly packed during shipment this might account for the magnitude and order of failure.

Detailed data on panels during moist curing, drying, and jet impingement appears in Table I.

The flexural strengths of beams, cut from these panels and from other panels previously subjected to the jet impingement tests, were determined during this quarter. The results of these determinations appear in Table II.

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 during the drying period rather than due to the heat treatment during the jet-blast test.

These tests complete the series that were planned for concrete specimens submitted by U. S. Navy power check facilities.

Table I. Data on Panels During Moist Curing, Drying, and Jet Impingement

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	460
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 I - Continued

Identification		Panel Number	Days in Sawdust	Water[1/] Content of Sawdust %	Weight Change[2/] of Panel During Sawdust Storage %	Storage in Fog-room days	Weight Change[2/] of Panel During Fog-room Curing %	Drying Period days	Loss in Drying %	Spalling Loss by Wt. c.c.	Spalling Loss by Sand Volume c.c.	Flexural[3/] Strength 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	55.0	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	115
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/	9/	9/	6/	6/	40	0.34	37.0	None	495
N.A.S. Whidbey Island		2	do	do	do	do		54	0.29	45.0	None	455
Oak Harbor, Wash.		3	do	do	do	do		68	0.15	47.0	None	415
U.S.N.A. Oceana		1	9/	9/	9/	6/	6/	28	1.13	180.0	107.0	572
Virginia Beach		2						62	0.34	2.7	None	587
Virginia		3						76	0.96	10.0	72.0	760
Southwest Division		1	29	65	+0.08	6/	6/	28	2.00	374.0	None	220
N.A.S. Los Alamitos		2	do	55	-0.17			42	2.18	80.0	None	250
Long Beach, California		3	do	53	-0.25			70	3.42	85.0	None	220

1/ $\frac{\text{wet weight - dry weight}}{\text{wet weight}}$ X 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.

TABLE II EFFECT OF JET IMPINGEMENT ON THE FLEXURAL STRENGTH OF CONCRETE BEAMS

Power Check Facility	Aggregate	Cement	Specimens Cut From Outside Test Area		Specimens Cut From Within Test Area
Beeville	Diabase	Portland I	459		494
Oak Harbor	"	Portland II	400		336
"	"	"	414		400
Sanford	Blast-furnace slag	Portland I	384		394
Cherry Point	Diabase	Portland I	490	460[1/]	460
Miramar	Expanded shale	High Alumina Hydraulic	170	190[1/]	150
"	"	"	245	275[1/]	245
Meridian	Blast-furnace slag	Portland I	310	295[1/]	280
"	"	"	210	305[1/]	280
"	"	"	325	305[1/]	195
China Lake	Expanded shale coated	High Alumina Hydraulic	240		
"	"	"	120		
"	"	"	115		125
Oak Harbor	Diabase	Portland Type II	495		552
"	"	"	524		510

[1/] Beams cut from outside test area and water soaked for 48 hour before testing.

B. Steam Pressure Developed Within Concrete During Rapid Heating

Four concrete specimens have been cast in molds instrumented as shown in Fig. 1. Two of the specimens contain blast-furnace slag as the aggregate, while the remaining two contain diabase aggregate. Portland cement was used in all specimens. The base of these specimens will be subjected to steam pressures up to 300 psi.

In past tests, leakage occuring between the concrete specimen and the mold, and around the thermocouple leads and probe tubes, made it impossible to record pressures and temperatures of any significant value.

The improvements in the design of the mold and measuring probes should correct this difficulty. The conical shape of the specimen has proven to be an effective way of reducing or even preventing leakage between the mold and the specimen.

C. The Effect of High Pressure Air on the Permeability of Concrete

Permeability determinations were made during this period on brick-shape specimens cut from samples of concrete submitted by various Naval Air Station power-check facilities. Each of the concretes selected contained one of the following aggregates: crushed diabase, blast-furnace slag, expanded shale, or expanded shale coated. Portland cement was used with the diabase and blast-furnace slag. High alumina hydraulic cement, Fondu, was used with the expanded shales.

The permability values were determined, at low head pressure, (less than 0.5 psi) on each of the concretes before and after exposure to high pressure air. The pressures to which the specimen were exposed were 100, 200, and 300 psi. The pressure to which a specimen could be exposed was limited by its strength. For this reason the lightweight aggregate concrete specimens were not exposed to 300 psi.

The specimen, while exposed to high pressure, absorbed air in amounts proportional to the pore and capillary volume. This was indicated by observation of the rate and duration of de-gassing. When the pressure on the specimen is reduced, the air within the specimen is slowly released as de-gassing occurs. The rate at which de-gassing occurs in a particular concrete is proportional to the pressure to which the specimen was subjected. The permeability, after high pressure exposure, was not determined until the pressure within the specimen has returned to atmospheric.

In general the permeability of concrete is increased by exposure to high pressure air. The magnitude of this increase seems to depend on the permeability of the concrete before exposure.

Some modifications are being made on the permeability apparatus to permit measurements of permeability at high pressure differentials (100, 200, or 300 psi). Until now, permeability determinations could only be made at pressure differentials of several inches water pressure.

When water, inherently present in concrete, is confined within a specimen during jet-blast impingement, high steam pressure will develop. This is one of the factors that causes explosive spalling. The pore space determined for the concretes made using four different aggregates, Table III, is a measure of their ability to permit the escape of water or steam.

Table III shows that concretes having low bulk density and high pore space lose more water during drying and jet-blast impingement. These concretes also gain in weight more rapidly during moist curing than the dense concretes, such as those made with diabase and blast furnace slag aggregate.

Since a study of temperatures during jet impingement gives an indication of the steam pressures involved, further data is required.

D. The Effect of Water Present in Concrete on Temperature Gradients

The data thus far obtained on temperature gradients, as they occur in concrete during jet-blast impingement, is of value, but does not give sufficient detail on the behavior of the top quarter inch of concrete where spalling actually occurs. To determine temperature and the rapid rate of change of temperature near the start of the jet-blast test, at depths of less than 1/8 inch, molds have been constructed and instrumented with thermocouples positioned in this critical area. Specimens to be used in this work have been prepared. We plan to improve our temperature recording facilities by using a continuous, high-speed, multi-channel recorder to obtain a time/temperature record of sufficient accuracy to calculate gradients near the surface of concrete specimens during jet-blast exposure.

Table III Properties and Performance of Concretes Submitted for Tests from Four Naval Air Stations

Type of Concrete		Bulk Specific Gravity	Absolute Specific Gravity	Total[1/] Pore Space	Open[2/] Pore Space	Closed Pore Space	Permeability[3/]	Average Loss in Wt.[4/] of Test Panels During Drying	During Jet-Blast	W/C Ratio	Cement Content
aggregate	cement	g/cm^3		%	%	%		%	%		$sacks/yd^3$
Diabase	Portland Type II	2.35	2.60	11.1	6.8	4.3	67×10^{-6}	0.25	0.13	0.49	6.75
Blast-Furnace Slag	Portland Type I	2.09	2.66	21.3	15.8	5.5	287×10^{-6}	1.17	0.18	0.39	7.50
Expanded Shale	Calcium Aluminate	1.58	2.52	37.3	15.3	22.0	190×10^{-6}	2.50	0.32	0.47	6.75
Expanded Shale Coated	do	1.49	2.60	42.6	31.7	10.9	1370×10^{-6}	5.34	0.58	0.47	6.75

1/ $1 - \frac{\text{Bulk Specific Gravity}}{\text{Absolute Specific Gravity}} \times 100.$

2/ $\frac{\text{Wet Weight - Dry Weight}}{\text{Wet Weight - Suspended Weight}} \times 100.$

3/ $\frac{cm^4}{(g)\ sec.}$ of dry air at room temperature.

4/ Assumed to be water.

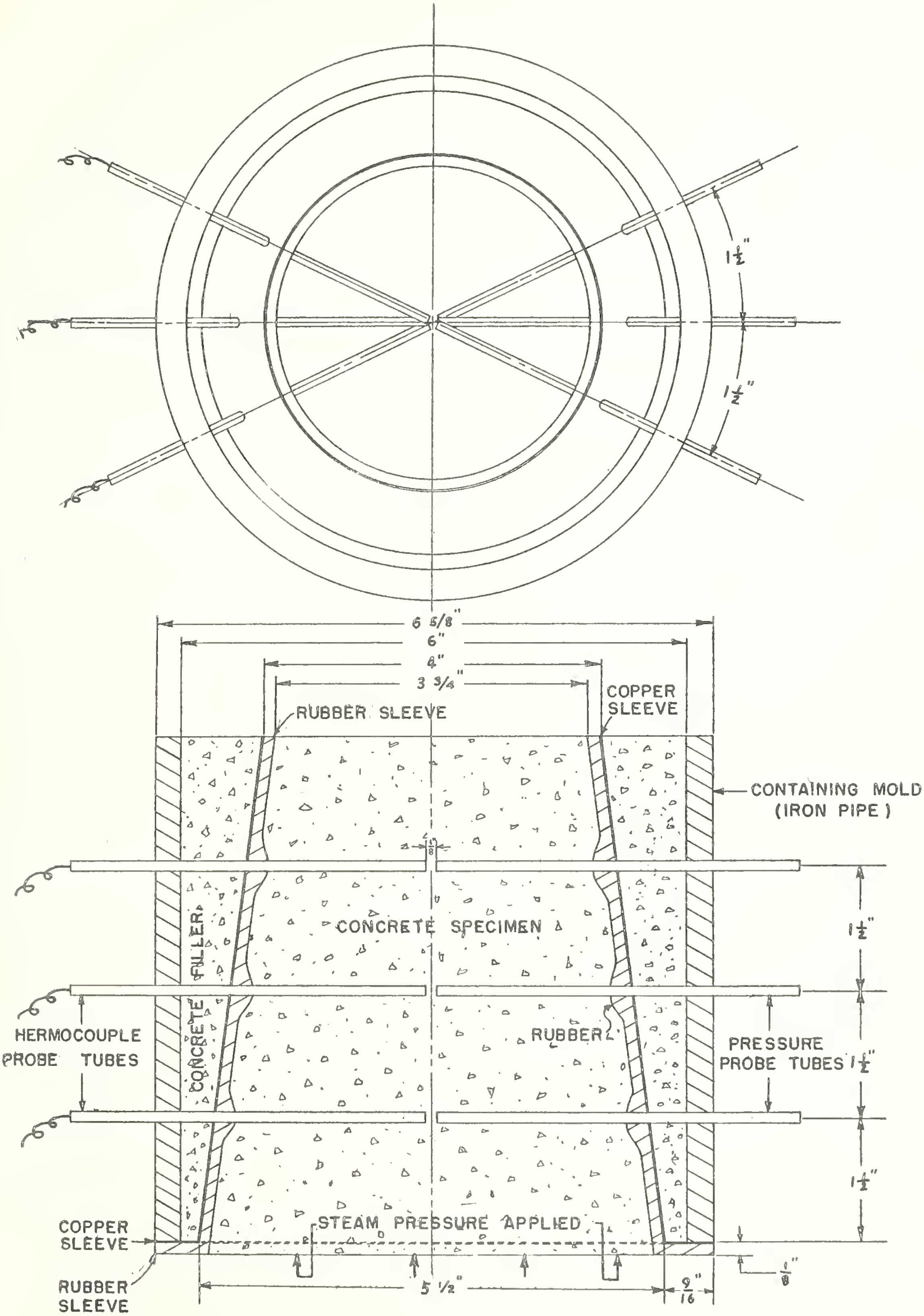

FIGURE 1. APPARATUS USED IN DETERMING THE EFFECT OF STEAM PRESSURE APPLIED TO CONCRETE

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

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

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

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

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS