4141

NATIONAL BUREAU OF STANDARDS REPORT

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CONTROL OF LEAKAGE THROUGH JOINTS
IN CAST-STONE MASONRY AT
THE NATIONAL NAVAL MEDICAL CENTER

Progress Report No. 1
by

A. Hockman, E. J. McCamley and
E. W. Krussell

To

District Public Works Office
Potomac River Naval Command
Bureau of Yards & Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

This is the first progress report of an investigation to determine causes and possible means of controlling leakage through the walls of some of the buildings at the National Naval Medical Center. An experimental waterproofing treatment applied to the masonry of Building No. 1, 19th floor and above is described, and results of treatment given. Laboratory studies of thermal and moisture properties were made on samples of the original cast-stone used at the center. Thermal coefficient computed for temperatures between -4 and +140° F was 6.2×10^{-6} per deg F and moisture expansion for 19 day immersion was 0.0385 percent.

Laboratory studies are in progress on 50 samples of calking materials. Tests including shrinkage, bond plasticity, rate of hardening, etc., are described.

Measurements of joint movements made on four elevations, Building No. 1, 19th floor, over a 7 1/2 month period, revealed movements averaging 0.0066 inches. A complete graphical record is given of all joint movements on four elevations. In general, joint movements corresponded to changes in temperature.

Inspection of the masonry made 7 1/2 months after the waterproofing treatment was applied, revealed the existence of cracks in 80 percent of the vertical joints examined. Cracks ranged from hairline (less than 0.001 in.) to 1/16 in. (corner joint, southwest). The average of the openings in the joints was estimated to be 0.006 in. No leakage has been reported since the application of the waterproofing treatment.

Plans for future study in the project include: (1) A continuation of joint movement measurements with a Brinell microscope and new type of gage station, (2) Completion of the study of calking materials, (3) Determination of the effects of various relative humidities on expansion properties of cast-stone, and (4) Study of effectiveness and durability of several types of silicone water-repellents.

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1. INTRODUCTION

At the request of the District Public Works Office of the Potomac River Naval Command and under the sponsorship of the Bureau of Medicine and Surgery, Department of the Navy, the National Bureau of Standards has started a study of the causes and possible control of leakage by wind-driven rain through the walls of some of the buildings at the National Naval Medical Center, Bethesda, Maryland. In planning the first part of this study, the Bureau proceeded with the assumption that some and possibly most of the leakage occurs through the open mortar joints; such faulty joints being prevalent throughout many of the buildings that are faced with the cast-stone panels. This decision was reached after several inspections were made of the Medical Center buildings by members of the Bureau staff. In order to facilitate the proposed investigation, all field observations, measurements, and experimental treatments were confined to Building No. 1, specifically to the cast-stone panels and joints located along the 19th floor level and above.

The report describes in some detail the progress of the study and includes a statement of plans for future study.

2. WATERPROOFING TREATMENT OF THE CAST-STONE AND JOINTS

In the early part of May 1954, a decision was made by representatives of the District Public Works Office of the Potomac River Naval Command, the Bureau of Medicine and Surgery, and the National Bureau of Standards to have Building No. 1 at the Medical Center waterproofed from the 19th floor level to the top of the building. The treatment was to include cleaning, grouting and re-pointing of the joints between the cast-stone panels (joints containing sound mortar were not to be re-pointed). In addition, all exposed exterior surfaces were to be treated with one coat of silicone water repellent. A specification was proposed by this Bureau and finally written by the District Public Works Officer of the Potomac River Naval Command, as Navdocks Specification No. 43445(SF). The contract (NOy 83739) was awarded to the U. S. Building, Cleaning, Renovating and Maintenance Company of Washington, D. C. The work was started on August 18 and completed on September 30, 1954.

2.1 Condition of joints and panels before treatment

Examination of the masonry at the 19th floor level before the treatment was applied revealed that practically every vertical joint contained cracks. These cracks occurring primarily at the sides of the joints varied in width from hairline to as much as one tenth of an inch; the latter occurring in some corners. Some of the cracks extended upwards continuously to the top of the building, while others only intermittently. There were a few instances of loose mortar in the vertical joints, the worst cases occurring in the corners. Many of the horizontal joints appeared in good condition up to the 10 ft. level. It was difficult to estimate the condition of the joints above this height. The cast-stone panels appeared to be in excellent condition with the exception of a few hairline cracks barely visible to the naked eye.

2.2 Field tests of silicone waterproofing

Three inconspicuous panels on the power plant building were selected for the testing of three samples of silicone waterproofing. The samples were: (1) Dow-Corning 129G resin, 5 percent in xylene; (2) General Electric, SR53 resin, 5 percent in xylene; (3) Linde Air Products C25 resin, 4 percent in mineral spirits. The three solutions were applied with a brush to the three panels, respectively, and were observed for water repellency and possible staining effect. All three types of treatments caused no discoloration and produced water repellent surfaces.

2.3 Preparation of the joints for treatment by contractor

The contractor started the job by brushing the joints clean of dirt and dust which was followed by the application of 1 1/2 in. of masking tape to both sides of all joints. The joints were then sandblasted to remove old calking compound and dirt from the surface and sides of the joints, and at the same time exposing the faces of cracks between the panels and the mortar (see figure 1-A).

2.4 Re-pointing and grouting of joints

All loose mortar joints were raked out and filled with a mortar containing one part of white portland cement to 3 parts of silica sand, by volume, followed by tooling to a smooth concave surface. All other joints were grouted with a mixture containing equal parts of white portland cement and silica sand, by volume. The grout was applied in the form of a heavy cream using a special grouting brush (see figure 1-B). The fine cracks in some of the cast-stone panels were also grouted.

2.5 Application of silicone solution

The silicone water repellent used by the contractor was "Sta-Dri" (5 percent Dow-Corning resin 129G in Xylene), manufactured by the Sta-Dri Corporation, Brentwood, Maryland. Ten days after the grouting and pointing job was finished, the silicone solution was applied with a power spraying machine. The masonry retained a slightly yellowish appearance for several days after treatment, but it subsequently faded to the natural appearance of the stone.

2.6 Effects of the waterproofing treatment

Figures 2-A,B illustrates a typical vertical joint before and after treatment. The photograph 2B was taken four days after the contractor completed the job. Also at this time a few panels were tested for water repellency by spraying with a stream of water. The cast-stone appeared to be highly water repellent.

No further inspections were made until November 5 when fine cracks were noticed in many of the vertical joints on all four sides of the building at the 19th floor level. (For results of a later inspection, see chapter 7).

3. LABORATORY STUDIES OF CAST-STONE

In view of the fact that no test data on the physical properties of the cast-stone used at the Medical Center have ever been made available, it seemed advisable to include such tests in this investigation. For this purpose, a small sample of cast-stone, originally used in a panel in one of the buildings at the Center (apparently the only sample available), was acquired from Mr. R. Corbin of the Maintenance Office. This sample was used for the study of thermal and moisture expansion and water absorption properties.

3.1 Thermal expansion test

3.1.1 Test procedure

Measurements of linear thermal expansion were made by means of the bonded wire resistance strain gage. Information on the development and description of the wire strain gage are given by Ramberg [1] 1/ and NBS Circular 528 [2].

A specimen of cast-stone and one of fused quartz were cut to the shape of a rectangular prism, 1 1/2 by 1/2 by 1/8 in. and both dried in an oven at 160°F ± 2° for four days. (Material of known thermal expansion, such as fused quartz is used as a reference sample along with the sample under test). Two SR4 (type A-11) strain gages connected in series, were attached with epoxy resin cement to opposite sides of each specimen, and the entire assembly placed in an oven at 160°F ± 2° for three hours, for curing of the cementing material (see figure 3). After waterproofing and binding with black cellulose tape, the specimens were placed in a thermal chamber in which the temperature could be varied from -4° to +140°F. (For detailed description of thermal chamber see Hockman and Kessler [3]. During the test, temperatures were measured

1/ Figures in brackets indicate the literature references at the end of the report.

by a three junction thermocouple located close to the test specimen. A Baldwin strain indicator (figure 4-B) recorded the linear changes directly in microinches per inch.

3.1.2 Test results

Figure 5 shows the thermal expansion curve obtained on the specimen of cast-stone when heated from -4 to +140°F (-20 to +60 deg C). The coefficient of linear thermal expansion was calculated to be 6.2×10^{-6} per deg F, or 11.1×10^{-6} per deg C, for this temperature range. Both the amount of the expansion and the regularity and shape of the curve appear to be within the normal range for cast-stone of this particular composition. On cooling, the specimen returned to its original length showing no tendency for residual or "permanent" expansion.

3.1.3 Comparative expansion data for stone used as facing material

For comparison purposes, linear thermal expansion coefficients for a few common building stones generally used as facing material in structures are given in Table 1.

Table 1. Thermal expansion values for common building stones

Material	Source	Mean coefficient of linear thermal expansion F X 10^{-6} -4 to +140°F
Limestone	Alabama	0.67
Limestone	Indiana	1.9
Marble	Tennessee	1.7
Marble	Georgia	2.2
Marble	Vermont	4.4
Granite	Various) sources)	3.4 average
Sandstone	Ohio	5.2

3.2 Moisture expansion test

3.2.1 Test procedure, non-waterproofed sample

Measurements of moisture expansion were made with a modified bonded wire resistance strain gage developed by Valore [2] at the National Bureau of Standards for measurements of internal strain in concrete.

A rectangular specimen, 2 1/2 by 1 1/4 by 1 1/4 in. was cut from the original piece of cast-stone received from the maintenance office of the Center and was dried at 220°F ± 2°F for 24 hours and cooled in a desiccator.

The gage (modified SR-4, type A-11) was then cemented with epoxy resin cement to one long face of the specimen, and the assembly heated for 4 hours at 160°F ± 2°. The specimen and gage, after cooling to room temperature in a desiccator, was placed in a small tank and water was poured into the tank until the level reached the top of the specimen. Movement of the cast-stone resulting from absorption of water was measured by a Baldwin strain indicator similar to the one used for the thermal expansion test. (See figure 4).

Expansion and contraction readings were taken over a period of 38 days in a room maintained at constant temperature ± 2°F. At the end of the 19th day the water was removed and the specimen allowed to dry while readings were continued. On the 36th day, the specimen was placed in an oven at 160°F ± 2° for 48 hours and a final reading taken on the 38th day.

3.2.2 Test procedure, waterproofed sample

The specimen used for moisture expansion study was dried for four days at 160°F ± 2° and after cooling, given a liberal brush coating of 5 percent Dow Corning silicone resin in xylene. After the coating had dried for two days the specimen was tested for moisture expansion.

3.2.3 Test results

Figure 6 gives the moisture expansion and contraction curves for a sample of cast-stone originally used at the Naval Medical Center. After 19 days immersion in distilled water at constant temperature (75°F ± 2°) the specimen expanded 385 microinches per in. or 0.0385 percent. The expansion curve rises sharply at the start of the test, attaining 15 percent of the total expansion after one hour and 66 percent after 24 hr. immersion. When the water was removed and the specimen allowed to dry, contraction proceeded at a comparatively slow rate. After 17 days of drying at room temperature, the specimen contracted to 50 percent of the amount it expanded when immersed. A heating of the specimen at 160°F for two days brought it back abruptly to its original length.

Figure 6, lower portion, shows the moisture expansion curve (dashed lines) of the waterproofed specimen of cast-stone. After 19 days of immersion, the sample expanded 115 microinches per in. or 0.0115 percent. Unlike that of the non-waterproofed specimen, the curve rises slowly and the expansion proceeds at a fairly uniform rate. Waterproofing of the cast-stone reduced the moisture expansion obtained on the non-waterproofed specimen by 92 percent for 24 hr. immersion and 70 percent for 19 days immersion.

3.3 Absorption test

3.3.1 Test procedure

Two specimens, weighing approximately 94 and 162 grams, respectively, were cut from the original piece of cast-stone obtained from the Medical Center. The specimens were dried for 24 hours at 220°F ± 2° and cooled in a desiccator until ready for test. After obtaining the dry weights to the nearest hundredth of a gram, the specimens were immersed in a pan of distilled water for 48 hours at room temperature. During immersion weighings were made at hourly intervals up to 6 hours followed by weighings at one and two days.

3.3.2 Test results

Figure 7 gives the absorption curve for total immersion of cast-stone in a 48 hr. period. The absorption value for 48 hours was 5.8 percent by weight. The curve rises sharply at the start of the test, attaining 75 percent of the total absorption after 1 hour and 98 percent after 6 hours. This behavior is characteristic of the natural building stones such as granite, limestone, marble and sandstone.

3.3.3 Comparative moisture expansion and absorption data for stone used as facing material

For comparison purposes, moisture expansion and absorption values for some building stones used as facing material in structures are given in table 2.

Table 2

Table 2. Moisture expansion and absorption values for common building stones

Material	Source	Moisture expansion 24-hr. immersion (average values) %	Absorption 48-hr. immersion (average values) % by weight
Limestone	Alabama	0.0032	5.6
Limestone	Indiana	.0028	5.3
Limestone	Texas	.0015	6.3
Marble	Alabama	.0010	0.1
Marble	Georgia	.0025	0.1
Marble	Vermont	.0010	0.1
Granite	Various sources	.0039	0.2
Sandstone	Amherst, Ohio	.013	6.0
Sandstone	Glenmont, Ohio	.010	7.3
Sandstone	McDermott, Ohio	.044	6.2

4. LABORATORY STUDIES OF PLASTIC CALKING MATERIALS

The use of plastic calking compounds as a joint sealer in masonry structures has been widely recognized by architects and engineers. The compounds serve as fillers for expansion joints, as waterproof sealers in the spaces between window and door frames, as pointing material in the joints of copings, sills, cornices, etc., and in most any joint where some movement is expected and water-tightness is required.

The compositions of the compounds are variable, the most typical consisting of treated drying and/or semi-drying oils, reduced to a plastic condition with inert fillers, plus some asbestos fiber and coloring matter. In addition many compounds contain some volatile solvent and chemical drier to aid in the formation of a protective "skin" after installation. Some manufacturers use synthetic resins with or without the oils. A few formulas include synthetic rubber bases.

The outstanding requirements for a good calking material are adhesiveness, plasticity and durability. Requirements of somewhat lesser importance are color permanence, possession of a non-staining vehicle, and ease of application.

In view of the fact that the installation of some type of plastic calking material might be necessary to prevent the leakage through the joints of the cast-stone at the Medical Center, it seemed advisable to include in this investigation a laboratory study of such materials that are presently available. For this purpose 50 samples have been acquired by purchase from retail stores and by donations from manufacturers. The samples cover practically all types of compounds that are being manufactured at the present time.

The following sections describe some of the laboratory tests which are now in progress. The data accumulated from the results of these tests will aid in the selection of the most promising material to be used as the joint filler. Many of these tests are described in detail in Federal Specification TT-C-598, while others are being designed for the particular requirements of this investigation.

4.1 Description of tests

4.1.1 Fabrication of the cast-stone blocks

Since an accessory porous material is necessary with which to test the calking compounds, six hundred blocks of suitable sizes were fabricated (to date) using the same type of materials and mix design (cement, sand and gravel) as that used for the fabrication of the cast-stone panels at the Medical Center.

4.1.2 Rate of Hardening

This is determined with a Penetrometer on a joint between cast-stone slabs spaced 3/8 in., filled with the plastic to a depth of 1 1/4 in. and length of 3 1/2 in. The depth to which a standard needle penetrates the material in 5 sec is recorded before and after curing for 15 days at room temperature. The rate of hardening is computed from the formula:

$$h = \frac{(P_1 - P_2)\,100}{P_1}$$

in which h is the rate of hardening, and P_1 and P_2 are the averages of the original and final penetrations, respectively. (See figure 9).

4.1.3 Shrinkage

This property is determined by means of a brass ring 2 5/8 in. in diameter and 1/2 in. high (volume, V, known to .01 ml), a ground glass cover plate and a slab of cast-stone, 3 1/2 by 3 1/2 by 1 in. (see figure 8-C,D). After the combined weight of the ring, slab and cover plate is determined, the ring is centered on the slab, 1/8 in. layer of compound is spread inside the ring, in firm contact with the stone and a weight determined (W_2). The ring is then filled over the calking with distilled water and a third weight determined (W_3). Since the volume of 1 gram of water is approximately 1 ml, the volume of the layer of calking, $V_c = V-(W_3 - W_2)$. The water is then poured off and the sample exposed at room temperature for 15 days, after which W_2' and W_3' corresponding to W_2 and W_3 are determined. The final shrinkage is calculated as follows:

$$Sh = \frac{(W_3' - W_2') - (W_3 - W_2)}{V_c} \times 100$$

4.1.4 Tenacity

After the brass ring is removed from the shrinkage test specimen, half of the calking layer is loosened from the stone and is folded over the remaining part and creased six times along the same line (see figure 8-E). Embrittlement or lack of tenacity can be observed. This test is also being made at below freezing temperatures.

4.1.5 Consistency

A metal trough 4 in. long, 1 in. deep and 3/8 in. wide is filled with the compound and suspended for 24 hours at room temperature, followed by a similar test at 122°F (figure 8-B). The material is observed for flow tendencies. Slump tests are also being made in cast-stone grooves.

4.1.6 Bond and plasticity at room temperature

The joint tested is made between two slabs of cast-stone, 6 by 7 by 1 in., one of which has a 2 1/2 in. round hole. Calking is placed between slabs which are held apart by a 1/4 in. brass spacer, making a joint 1/4 in. thick and 3/4 in. deep on all four sides of the stone. (Figure 10). After 30 days of curing at room temperature, the slabs are drawn apart by a special apparatus (figure 10), the amount of separation being measured by a 0.001 in. micrometer dial gage. At the start of the test, water is poured into the hole of the top block and the joint is watched for leakage as the blocks are drawn apart. Figure 10, right, shows a compound after test in which premature failure was caused by lack of bond.

4.1.7 Test at low temperature

The apparatus used to make this test is described in Federal Specification SS-R-406c, No. 223.11, for testing asphalt joint sealers. Two cast-stone blocks, forming a joint 2 x 2 x 3/8 in. is filled with calking and allowed to cure for 30 days at room temperature. After the test specimen is placed in a cold box for at least 4 hours, it is clamped into place in the stretching machine, and the blocks drawn apart at the rate of 1/8 in. per hour until the joint is extended 1/10 in. (figure 11). During the test the temperature is maintained at 0°F. Observations are made of the bond and plasticity properties.

4.1.8 Exposure studies

All samples of the calking materials are being exposed in cast-stone joints on the roof of the Industrial Building at the National Bureau of Standards. Periodic examinations are being made for changes in plasticity, adhesion, etc. Many of the tests described will be duplicated on test specimens that have been exposed to natural weather conditions.

5. MEASUREMENT OF JOINT MOVEMENTS

The 19th floor level of Building No. 1 of the Medical Center was selected for measuring joint movements resulting from the expansion and contraction of the cast-stone panels. This location seemed to be ideal for making measurements and observations because of its accessibility and the fact that leakage had occurred many times at this floor level. It was decided to use the Whittemore 5 in. strain gage to measure the movements of 16 vertical joints located on the northeast, northwest, southeast and southwest elevations.

5.1 Description of the strain gage

The Whittemore Strain Gage [4] is a precision mechanical gage which measures changes in length over a specified gage length (5 in. in this case) with a 0.0001 in. micrometer dial gage. The frame of the improved gage consists of two coaxial tubes (the innertube made of invar), connected near the ends by fulcrum plates of thin spring steel which constrain the tubes to move axially. A point is rigidly attached to one end of each tube. When the points are seated in small holes in the material to be measured the position of one tube with respect to the other is indicated on the micrometer dial clamped in the inner tube. Figure 12 shows the gage, standard bar and double pointed punch for spotting holes.

5.2 Installation of gage stations

Figures 13 and 14 give the exact locations of the gage stations installed in the cast-stone panels on the northeast, northwest, se and sw elevations. At the start of the investigation, six stations were installed at each elevation in such manner that each station straddled a vertical joint at the 4 1/2 ft. level. Stations Nos. 1 and 6 were installed for measurement of panel movements in corners. After many unsuccessful attempts were made to obtain dependable and accurate measurements of the corner joint movements, it was decided to abandon the corner stations and restrict the measurements to stations 2, 3, 4, and 5, on all four sides of the building.

Figures 15-A to F show the operations that were required to install a gage station. The finished station consisted of two cylindrical stainless steel plugs, 1/4 in. in diameter and 1/2 in. long, set into the cast-stone panels with high-early-strength cement, approximately 2 1/2 in. on each side of the vertical joint at about the 4 1/2 ft. level. Holes, 1.2 mm in diameter, were drilled into the plugs to accommodate the points of the gage. Figure 15-G shows a finished gage station and figure 15-H illustrates an operator making a measurement.

5.3 Frequency of measurements

Measurements of joint movements at the 16 gage stations were started on September 9, 1954, and continued until April 27, 1955.[2] During this period of 7 1/2 months, gage readings were taken on fifteen separate occasions. Attempts were made to include measurements on very hot and cold days. Such readings were taken on September 29 and January 31, respectively.

The first set of measurements, made on September 9 were recorded as "zero" readings. All subsequent readings that were numerically higher than the "zero" readings were called "plus", and indicated that the mortar joint expanded relative to its position at the "zero" reading. Readings that were numerically less than the "zero" reading were "minus" and indicated that the mortar joint contracted, relative to its position at the zero reading.

2/ All measurements except the first two were made after the joints were waterproofed.

5.4 Results of measurements of joint movements

Figure 16 and table 3 give the complete record of joint movements as measured at all 16 gage stations on 15 separate occasions from September 9 to April 27, 1955. In general, the joint movements were directly related to the changes in temperature. A rise in temperature caused the cast-stone panels to expand which resulted in a closing or contraction of the joints. This is illustrated by the September 29 readings, when the temperature rose to 90°F and the joints contracted in most instances (cast-stone panels expanded). Similarly, a drop in temperature to 39°F on December 4, 1954, caused most of the joints to open or expand (cast-stone panels contracted). Figure 17 shows the correlation between the joint movements and the air temperature recorded at the time of gage readings.

It is probable that joint movements resulting from wetting and drying of the cast-stone, caused by rains, were reduced to a minimum on account of the water-repellent surfaces of the cast-stone. However, it is also probable that movements of the cast-stone panels may have been affected by changing relative humidities - a problem which will be investigated at a later date.

Table 3 gives the maximum expansions and contractions of joints 2, 3, 4, and 5, on all four sides of the building, recorded from September 9, 1954, to April 27, 1955. During this period, the greatest change in temperature observed when measurements were made, was 64 F deg. (Weather Bureau records show a maximum change of 89 F deg.) The total movement in anyone joint ranged from a minimum of 0.0024 in. (1.0 percent of its initial width) as in joint No. 4, southwest, to a maximum of 0.0115 in. (4.6 percent) in joint No. 2, southeast. The average movement for all 16 joints was 0.0066 in. or 2.6 percent. The joints on the southwest side averaged the smallest movement, 0.0043 in., and the southeast side averaged the largest, 0.0083 inches.

6. RELATION OF LABORATORY TESTS TO FIELD STUDIES OF JOINT MOVEMENTS

The results obtained from the field measurements of the joint movements indicate that the average movement over the 7 1/2 month period, September 9, 1954 to April 27, 1955, was considerably less than what might have been expected if judged by laboratory tests alone. Laboratory studies (Chapter 3) indicate that the cast-stone expands 6.2×10^{-6} in. per deg F due to heating, and 0.0385 percent due to wetting. For a 64 degree change in temperature (the maximum observed) a 5 foot cast-stone panel is capable of expanding as follows:

$$6.2 \times 10^{-6} \times 64° \times 60 \text{ in.} = 0.0238 \text{ inches}$$

Assuming that a 5 ft panel is saturated with water the expansion would be:

$$0.000385 \times 60 \text{ in. or } 0.0231 \text{ inches}$$

Therefore, the total linear expansion of a 5 ft cast-stone panel due to heating and wetting is:

$$0.0238 + 0.0231 = 0.0469 \text{ inches}$$

Actual measurements on the building have shown that the maximum movement observed for all joints (or panels) averaged 0.0066 inches, or 14.1 percent of the maximum theoretical expansion indicated by laboratory studies.

Three factors might have contributed to the apparent discrepancy in the values of joint movements:

(1) It is very unlikely that the cast-stone panels heated or cooled throughout their entire volume, to the air temperature recorded at the time of measurement.

(2) Expansion due to absorption of water after heavy rains was probably reduced considerably because of the silicone waterproofing treatment.

(3) It is extremely unlikely that both moisture and temperature conditions coincide in such a manner as to produce maximum and minimum joint widths.

7. PRESENT CONDITION OF MORTAR JOINTS

On April 22, 1955, a visual examination was made of the vertical joints on the four sides of Building No. 1 at the 19th floor level. Wherever cracks were found, measurements of their width were made with a set of feeler gages. Table 4 gives the results of these measurements.

Although the authors have been informed by a representative of the maintenance department of the Medical Center that there has been no leakage of any consequence subsequent to the application of the waterproofing treatment, measurements made with the Whittemore gage indicated joint movements, which averaged 0.0066 in. for all four sides of the building, excluding the corner joints (chapter 5). Figure 18-A illustrates a corner joint (southeast) as it appeared the day before the waterproofing treatment was applied and figure 18-B shows the same corner as it appeared on April 22 approximately 7 months after the treatment.

The results of the examination of the joints made on April 22 corroborated to some extent the results obtained with the Whittemore strain gage. As shown in Table 4 joint cracks ranged in width from hairline (less than 0.001 in.) to a maximum of 1/16 in. - the latter in corner joint No. 6 on the southwest side. Except for the hairline cracks and the one large crack (1/16 in.), the average of the openings in the rest of the joints was 0.006 in. This latter figure is practically the same as the average movement of 0.0066 in. obtained with the Whittemore strain gage. However, this similarity appears to be only a coincidence since measurement of cracks on the northeast side made on April 22 revealed no opening greater than hairline (Table 4), whereas, previous strain gage measurements of these same joints showed an average movement of 0.0071 inches. Similarly, joints No. 2 to 5 on the northwest side had average cracks of less than 0.001 in. on April 22, whereas strain gage measurements revealed movements averaging 0.0065 in. for the same joimts.

Although cracks of various sizes are prevalent on all four sides of Building No. 1, 19th floor level, as indicated by inspection on April 22, they seem to be of insufficient size and number to allow leakage through the walls. It appears that the waterproofing treatment was instrumental in stopping the leakage that had occurred before the treatment was applied.

It might be noted here, that during the inspection of the joints on April 22, the senior author could, in many instances and with little effort, flake off, by means of a small knife blade, the thin coating of mortar from the side of a joint, and by so doing, reveal a crack that most likely existed before the grouting was applied. This indicates that, in many instances the cement grout did not penetrate into the opening of the joint, and was merely functioning as a thin shell-like coating over the existing crack.

The question still remains whether the walls of the Building No. 1 at the 19th floor level will be free from leakage for any reasonable length of time. If the cracks continue to increase in size and number due to continued movements of the panels or to the flaking off of thin layers of the cement coating, it is doubtful whether the mortar grout applied in the waterproofing treatment will continue to stop the leakage through the joints.

8. PLANS FOR FUTURE STUDY

1. The method of measuring the joint movements will be changed with the hope of obtaining more accurate data. The Brinell microscope, reading directly in hundredths of millimeters will replace the Whittemore strain gage. Figure 19 illustrates the microscope and the type of gage station that will be installed for its use. Joint movements will be measured at more frequent intervals and especially after long periods of extreme hot and cold weather.

2. The study of the properties of the various types of calking compounds and joint fillers will be continued until completion. Exposure tests under natural weather conditions will be made for all samples. If possible accelerated weathering tests will be made.

3. A study will be made of the effects of various relative humidities on the expansion properties of cast-stone.

4. Several types of silicone waterproofing formulas will be studied for effectiveness and durability.

9. SUMMARY

1. The NBS has started an investigation to determine the causes and possible control of leakage of rain through the walls of some of the buildings at the National Naval Medical Center, Bethesda, Maryland. All field studies were confined to the 19th floor level of Building No. 1.

2. An experimental waterproofing treatment as applied to 19th floor level and above is described. The treatment consisted of sandblasting of the joints followed by repointing of joints containing unsound mortar, and a grouting of all joints with cement, sand, water mixture of a cream consistency. The cast-stone panels and joints were finally given a spray coating of water-repellent solution (5% solution of silicone resin in xylene).

3. Laboratory studies were made on samples of the original cast-stone used at the medical center, and included tests for thermal and moisture expansion and absorption. The linear thermal expansion coefficient was 6.2×10^{-6} per deg F. for the range -4 to +140°F (11.1×10^{-6} per deg C, -20 to +60°C). The moisture expansion value for a 19 day immersion period at constant temperature was 0.0385%. This value was reduced by 70% for the same immersion period by waterproofing with silicone water-repellent. The absorption value was 5.78% by weight, for a 48 hour immersion period. Curves illustrating the expansion properties are given. For comparison, thermal and moisture expansion and absorption values are given for typical natural building stones.

4. Tests for evaluating the properties of plastic calking compounds are described in some detail. Fifty samples of almost every type of calking available are being tested for shrinkage, plasticity, bond, tenacity, rate of hardening, etc. The materials are being tested at various temperatures and compounds showing promise will be exposed to natural weather conditions for durability studies.

5. A series of measurements of joint movements resulting from the expansion and contraction of the cast-stone panels was completed. Joint

movements were measured with a 5 inch Whittemore strain gage, on 4 sides of the Building No. 1, 19th floor level, from September 9, 1954 to April 27, 1955. During this period readings were taken on a total of 16 vertical joints on 15 separate occasions. The maximum change in temperature observed for this period was 64 fahrenheit degrees. The average movement for all 16 joints was 0.0066 inches or 2.6% of the original 1/4 in. joint. The total movement in any one joint ranged from a minimum of 0.0024 inches to a maximum of 0.0115 inches, the latter occurring on the southeast elevation. In general, the joint movements were directly related to the changes in temperature, ie: a rise in temperature caused the cast-stone panels to expand resulting in a closing or contraction of the joints. Similarly, a fall in temperature caused a reverse movement.

6. Results obtained from the field measurements of joint movements were considerably less than what might have been expected if judged by laboratory tests of the cast-stone. Three factors might contribute to this apparent discrepancy: (1) It is improbable that the cast-stone panels heated or cooled throughout their entire volume, to the air temperatures recorded at time of measurement; (2) Expansion due to absorption of water after heavy rains was probably reduced considerably by the silicone treatment; (3) It is improbable that both moisture and temperature conditions were simultaneously such as to produce maximum joint movements.

7. An inspection of the joints at the 19th floor level made 7 1/2 months after the waterproofing treatment was applied, revealed the existence of cracks in 80% of the joints examined. The cracks ranged in width from hairline (less than 0.001 inches) to a 1/16 inch, the latter in a corner joint on the southwest side. The average of the openings in the joints was estimated to be 0.006 inches, excluding the hairline and the 1/16 inch cracks.

No leakage has been reported on the 19th floor level of Building No.1 since the waterproofing treatment has been applied. If the cracks continue to increase in size and number, due to the continued movements of the panels or to the flaking off of thin layers of the mortar grout, it is doubtful whether the grout applied in the waterproofing treatment will continue to be effective in controlling leakage through the joints.

Table 3. Maximum movements of joints, 19th floor level, Building No. 1, as recorded from September 9, 1954 to April 27, 1955.

Joint No.	Maximum Contraction 10^{-4} in.	Maximum Expansion 10^{-4} in.		Total Movement 10^{-4} in.	Total Movement %**
Northeast					
2	-14	+91		105	4.2
3	- 2	+55		57	2.3
4	-22	+58		80	3.2
5	- 4	+38		42	1.7
			Avg.	71	2.8
Northwest					
2	-36	+46		82	3.3
3	-30	+13		43	1.7
4	-30	+25		25	1.0
5	0	+109		109	4.4
			Avg.	65	2.6
Southeast					
2	-55	+60		115	4.6
3	-32	+60		92	3.7
4	-13	+35		48	1.9
5	-31	+45		76	3.0
			Avg.	83	3.3
Southwest					
2	-44	+29		73	2.9
3	-22	+13		35	1.4
4	-23	+ 1		24	0.96
5	-35	+ 6		41	1.6
			Avg.	43	1.7
			Grand Avg.	66	2.6

Joint Movements*

*Minus quantities indicate closing of joints as compared with "zero" readings on Sept. 9, 1954. Plus quantities indicate opening of joints relative to "zero" readings.

**Percentages based on one quarter inch joints.

Table 4. Condition of vertical joints, on four elevations, 19th floor level, Building No. 1, April 22, 1955.

Northeast	Condition of Joints *
Joint No. 1	Very few hairline cracks, 1st course and extending intermittently to top of building
2	" " " " in 1st course only
3	No crack visible
4	"
5	"
6	Very few hairline cracks extending intermittently to top
Northwest	
1	Cracks, .01 in. 1st course extending intermittently to top
2	Few hairline cracks, 1st course only
3	No cracks
4	"
5	Cracks, .002 in. 1st course extending intermittently to top
6	Wide cracks, .015 in." " " " "
Southeast	
1	Cracks, .004 in. 1st course extending intermittently to top
2	" .006 " " " " " "
3	" .003 " " " " " "
4	" hairline " " " " "
5	" .01 " " " " " "
6	" .01 " " " " " "
Southwest	
1	Cracks, .002 in. 1st course extending intermittently to top
2	" .002 " " " " " "
3	" .001 " " " " " "
4	Wide cracks, .015" " " " " "
5	Cracks, .005" " " " " "
6	Wide cracks,1/16" " " , extends, but narrows towards top

*Estimates of width of cracks apply to only the first course (10 feet). The condition of the joints above this level were judged with the aid of a pair of 3 power binoculars.

10. REFERENCES

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2. Characteristics and Applications of Resistance Strain Gages, National Bureau of Standards Circular 528 (1951).

3. A. Hockman and D. W. Kessler, Thermal and Moisture Expansion Studies of Some Domestic Granites, J. Research, NBS, Vol. 44, 395, R.P. 2087 (1950).

4. H. L. Whittemore, The Whittemore Strain Gage, Instruments, Vol. 1, No. 6, p. 299, (1928).

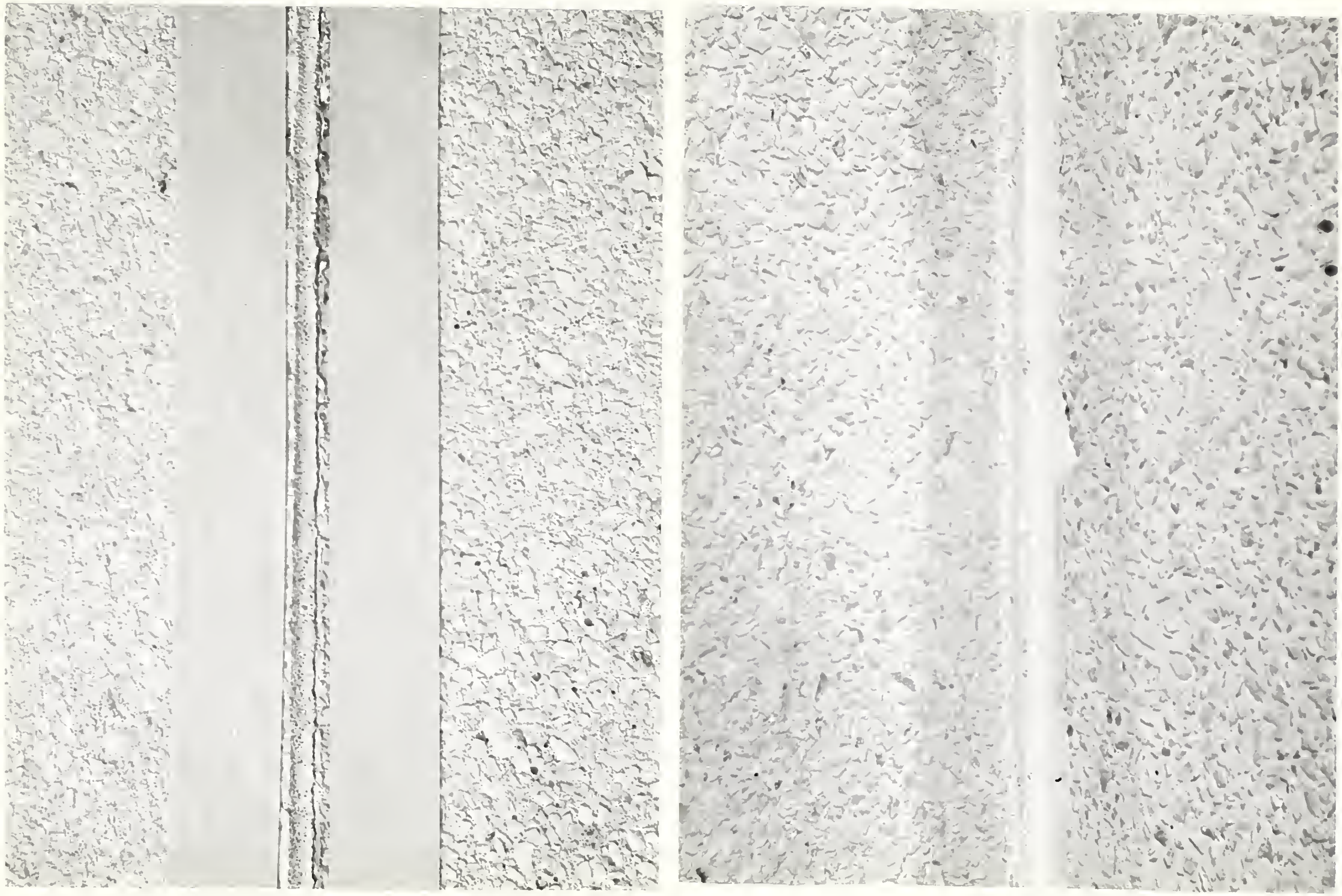
A.

B.

Fig. 1. Application of waterproofing to the mortar joints by contractor. (19th floor level, Building No. 1, Naval Medical Center).

(A) Sandblasting to remove old calking from surface of cast stone, and to expose cracks in joints.

(B) Applying the cement-sand grout to the joints.



A. B.

Fig. 2. Typical vertical joint as it appeared, (A) before the waterproofing treatment, (B) four days after the treatment.

Fig. 3. Resistance strain gage used to measure thermal expansion of cast-stone. Left, gage with felt covering and exposed wires. Right, specimens with gages attached and waterproofed, ready for insertion into thermal chamber.

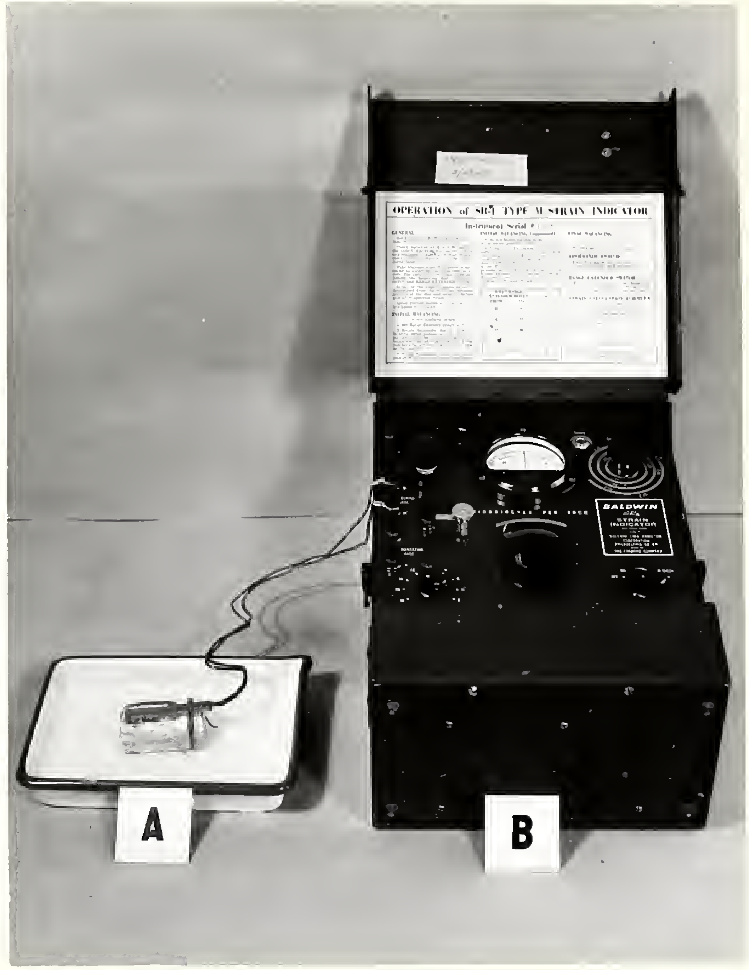


Fig. 4. Moisture expansion test
(A) Modified resistance strain gage cemented to cast-stone.
(B) Strain indicator

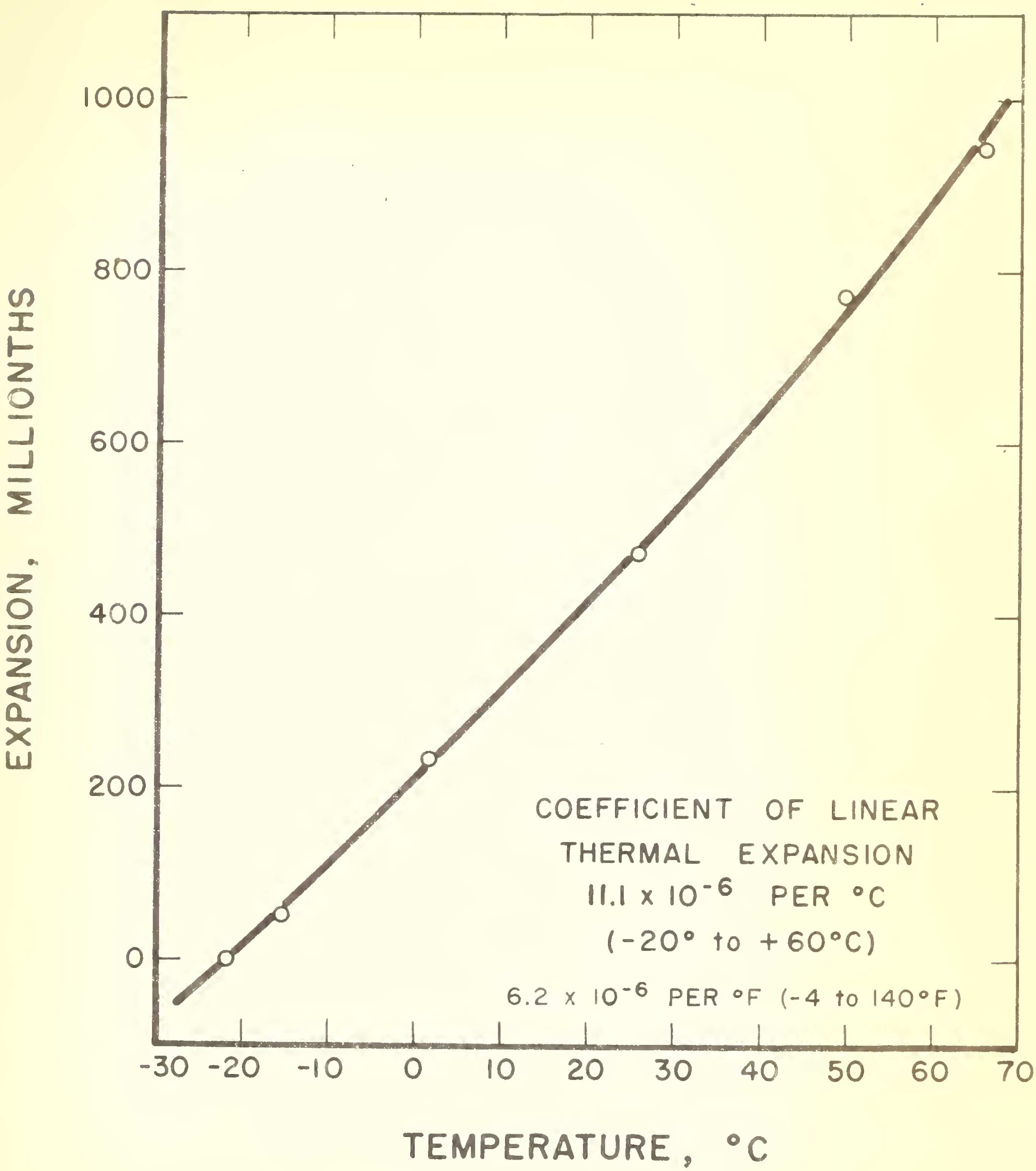


FIGURE NO. 5 THERMAL EXPANSION CURVE OF SAMPLE OF CAST STONE USED AT THE NAVAL MEDICAL CENTER.

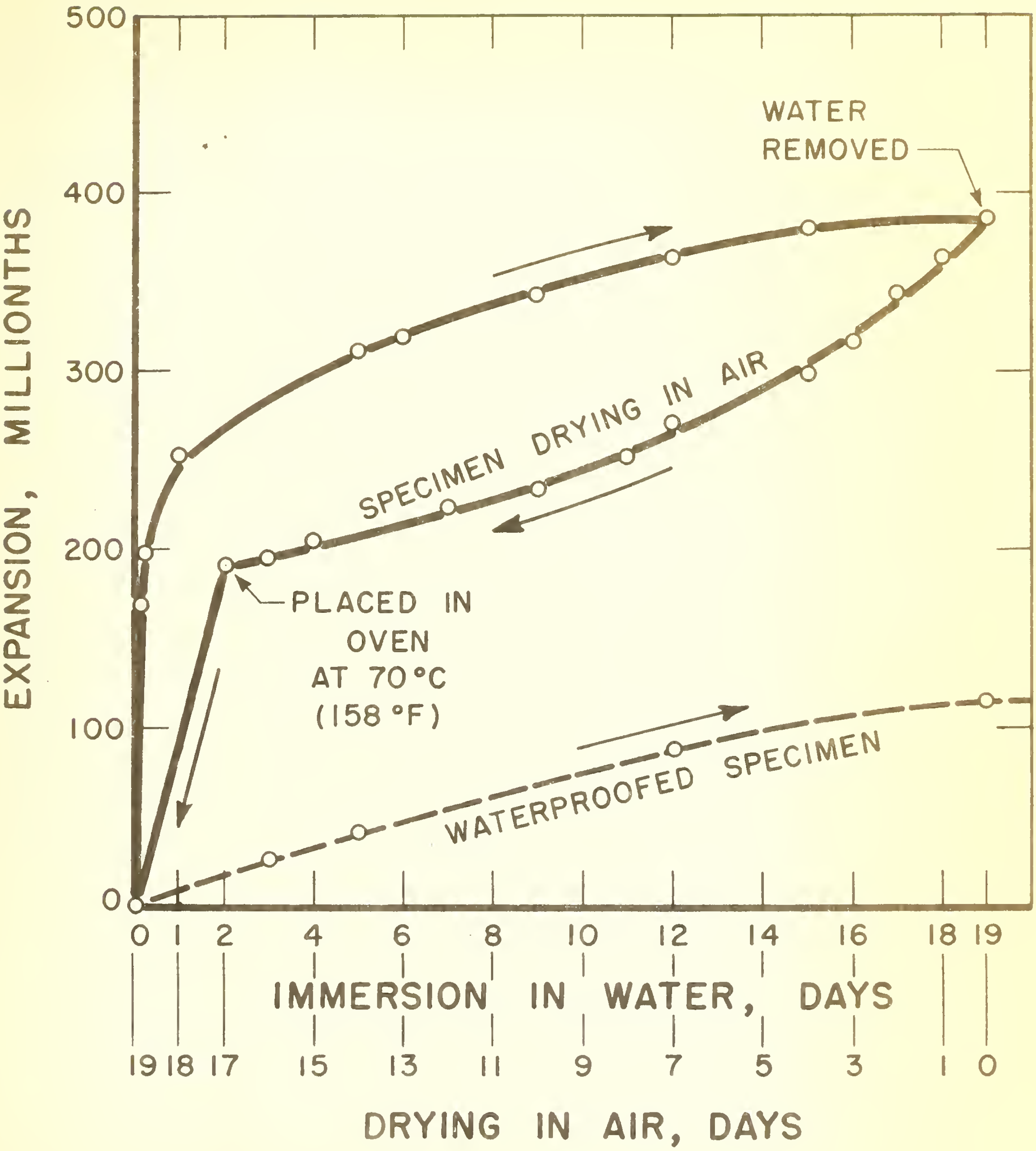


FIGURE NO. 6 MOISTURE EXPANSION AND CONTRACTION CURVES (75°F) OF CAST STONE USED AT THE NAVAL MEDICAL CENTER.

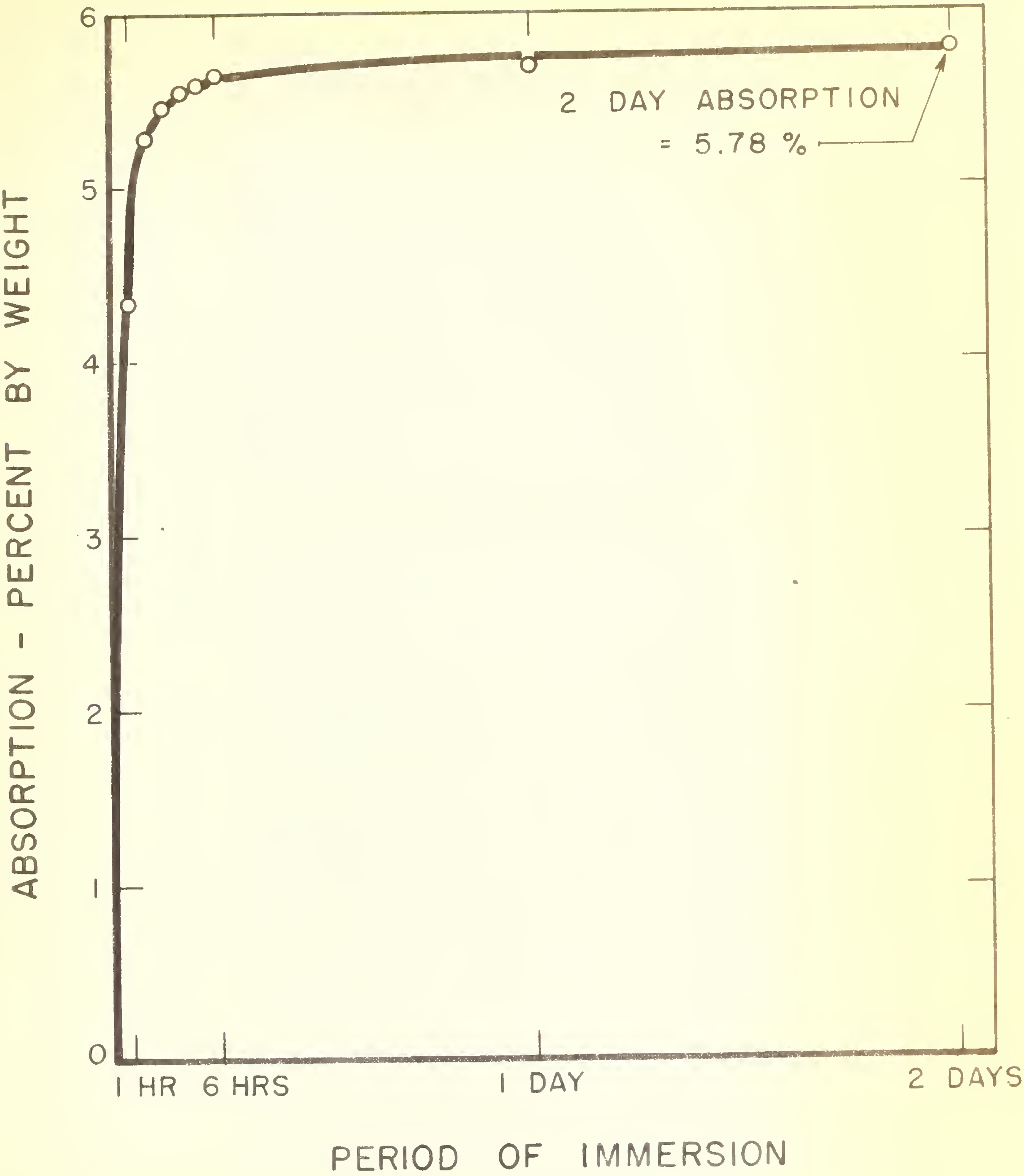


FIGURE NO. 7 WATER ABSORPTION CURVE OF SAMPLE OF CAST STONE USED AT THE NAVAL MEDICAL CENTER.

8.

9.

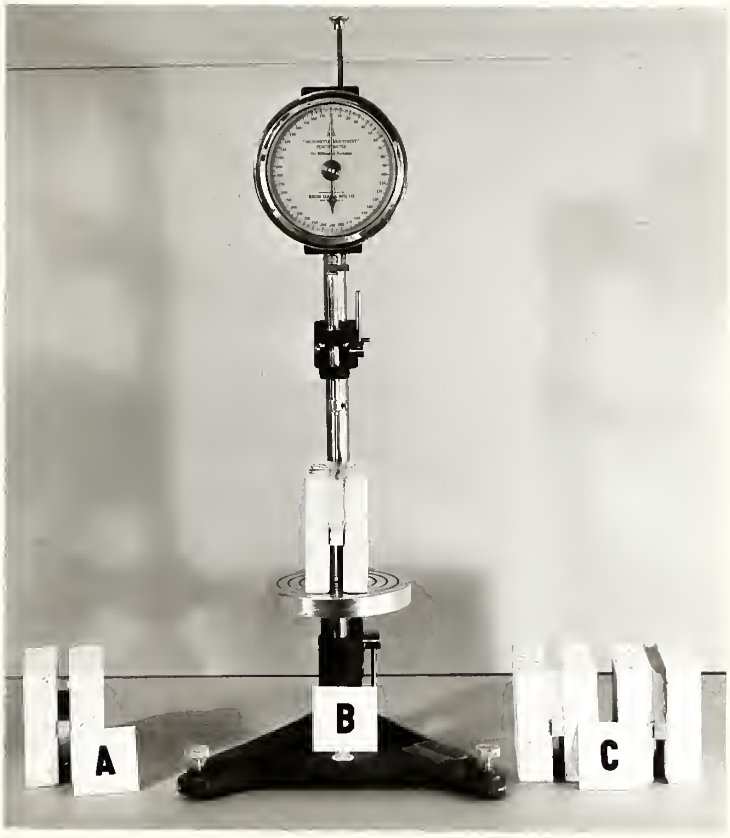


Fig. 8. Calking test specimens
(A) Test specimens used for plasticity and bond studies at cold temperatures, (B) consistency test specimens, (C,D) shrinkage test specimens, (E) tenacity test specimen.

Fig. 9. Rate of hardening test of calking materials
(A) Cast-stone specimen before filling joint, (B) calking ready for test with penetrometer, (C) calking in cast-stone joints ready for exposure test.

Fig. 11. Bond and plasticity test at 0° F. Calking test specimen is shown in place between two clamps ready for test.

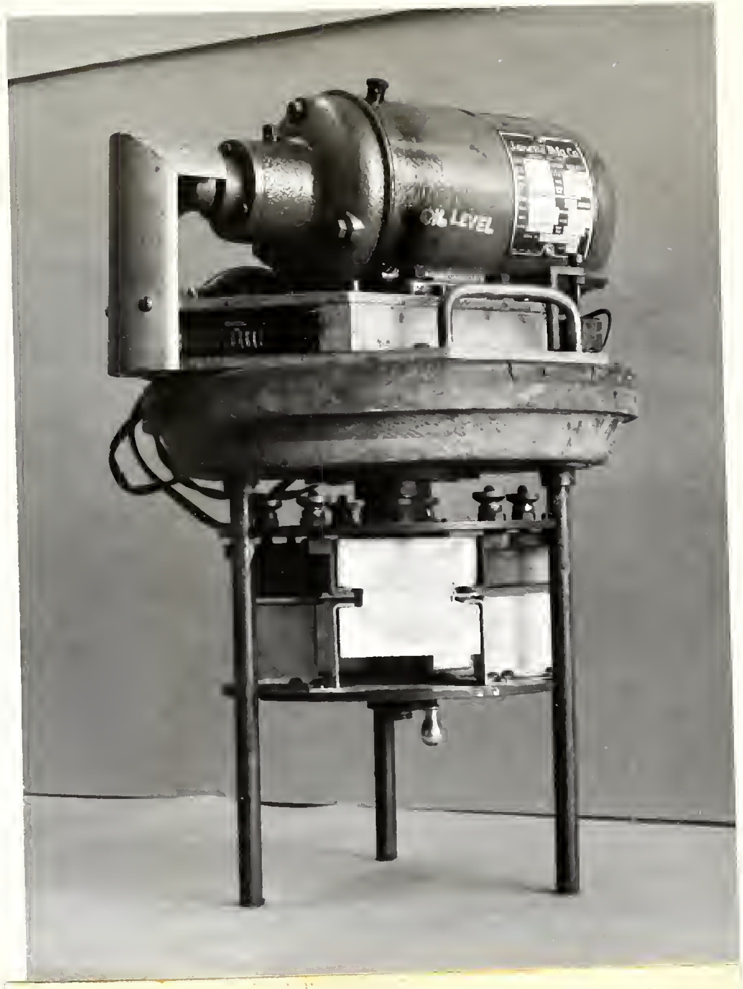


Fig. 10. Bond and plasticity test at room temperature. Left, cast-stone blocks before calking is applied. Center, calking under test. Right, example of failure of calking due to lack of bond.

Fig. 12. Whittemore strain gage and accessories
Top, double pointed punch to spot holes on 5-in. span.
Center, measuring instrument with dial.
Bottom, standard bar for correction of reading.

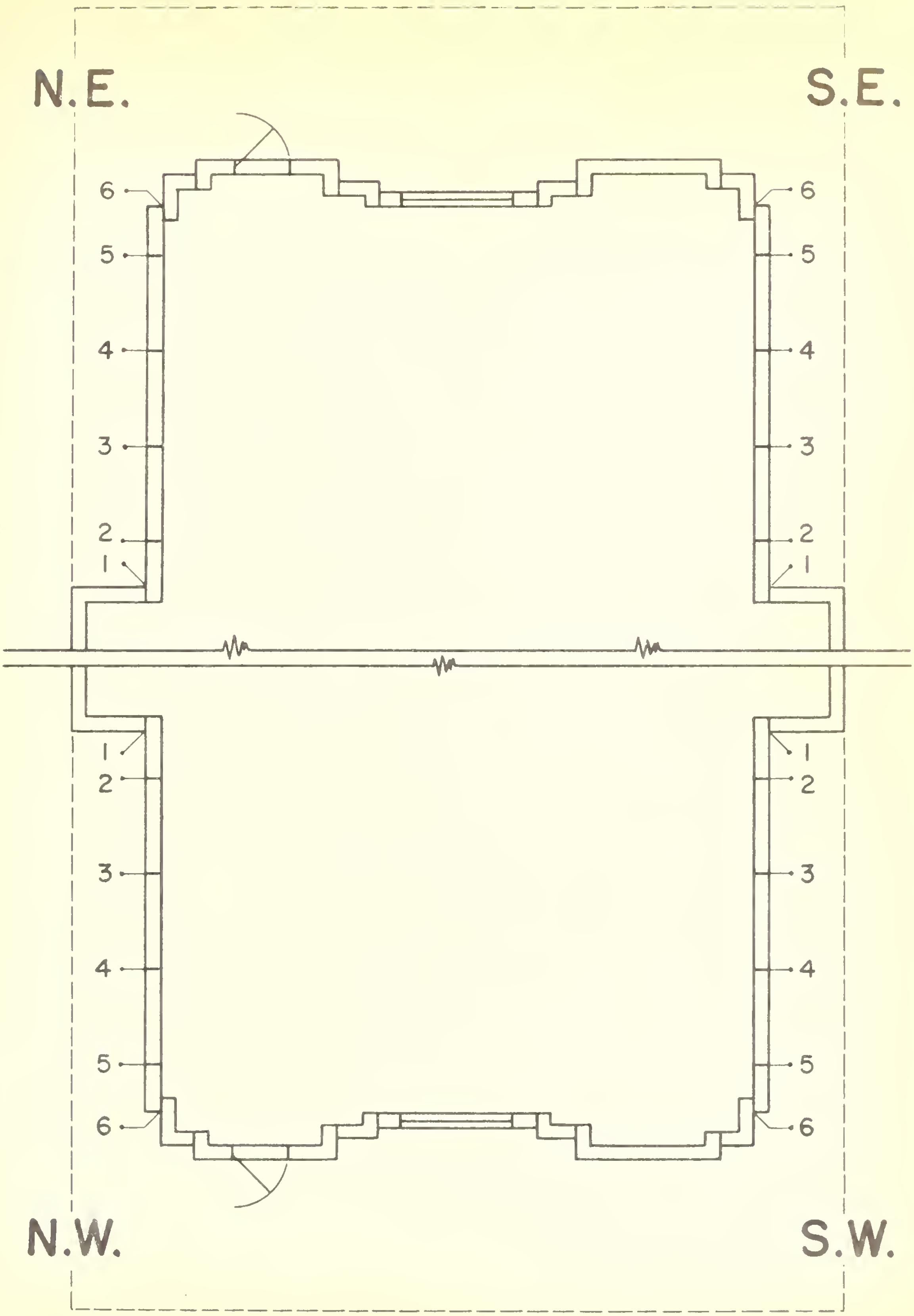


FIGURE NO. 13 PLAN VIEW SHOWING LOCATION OF ALL GAGE STATIONS USED IN MEASUREMENT OF JOINT MOVEMENTS. (19TH FLOOR LEVEL, BUILDING NO. 1, NAVAL MEDICAL CENTER.)

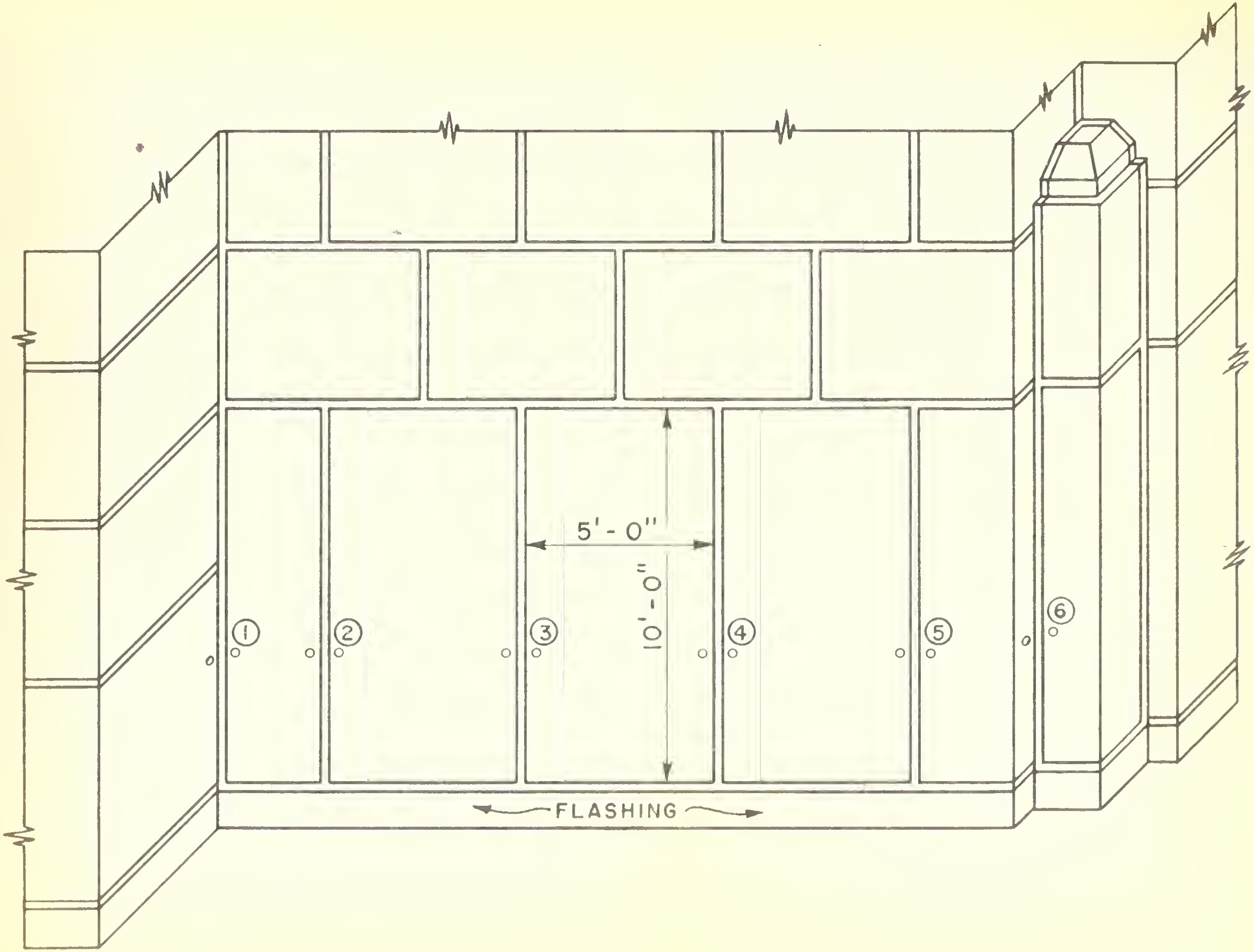


FIGURE NO. 14 TYPICAL WALL ELEVATION SHOWING LOCATION OF ONE SET OF GAGE STATIONS USED IN MEASUREMENT OF JOINT MOVEMENTS. (19TH FLOOR LEVEL, BUILDING NO. 1, NAVAL MEDICAL CENTER.)

A.

B.

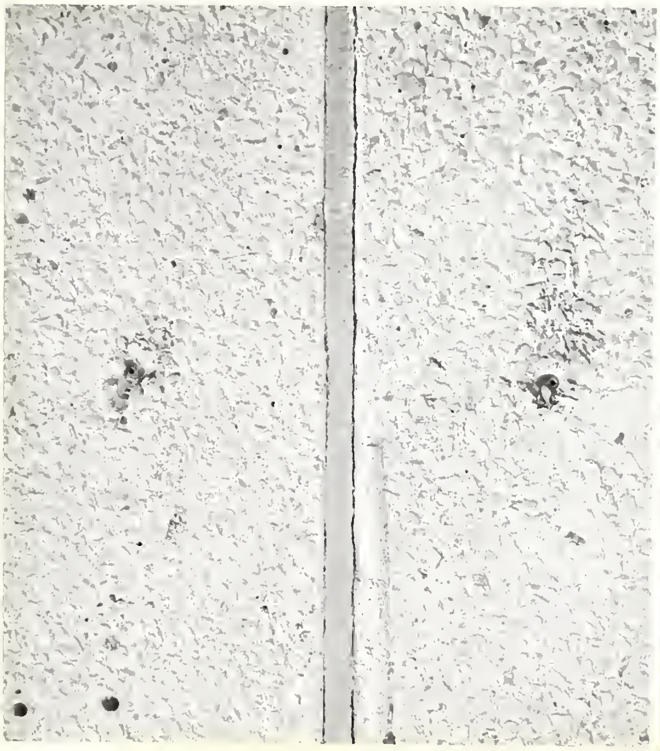
C.

D.

Fig. 15. Series of photographs showing operations necessary for installation of gage stations.
(A) Drilling holes in cast-stone.
(B) Wetting the holes for placing of mortar.
(C) Placing of the mortar.
(D) Insertion of the 1/4 in. dia steel plugs.

E.

F.



G.

H.

Fig. 15. (continued)
(E) Spotting holes with double pointed punch.
(F) Drilling 1.2 mm holes in steel gage plugs.
(G) Completed gage station.
(H) Operator taking readings with strain gage.

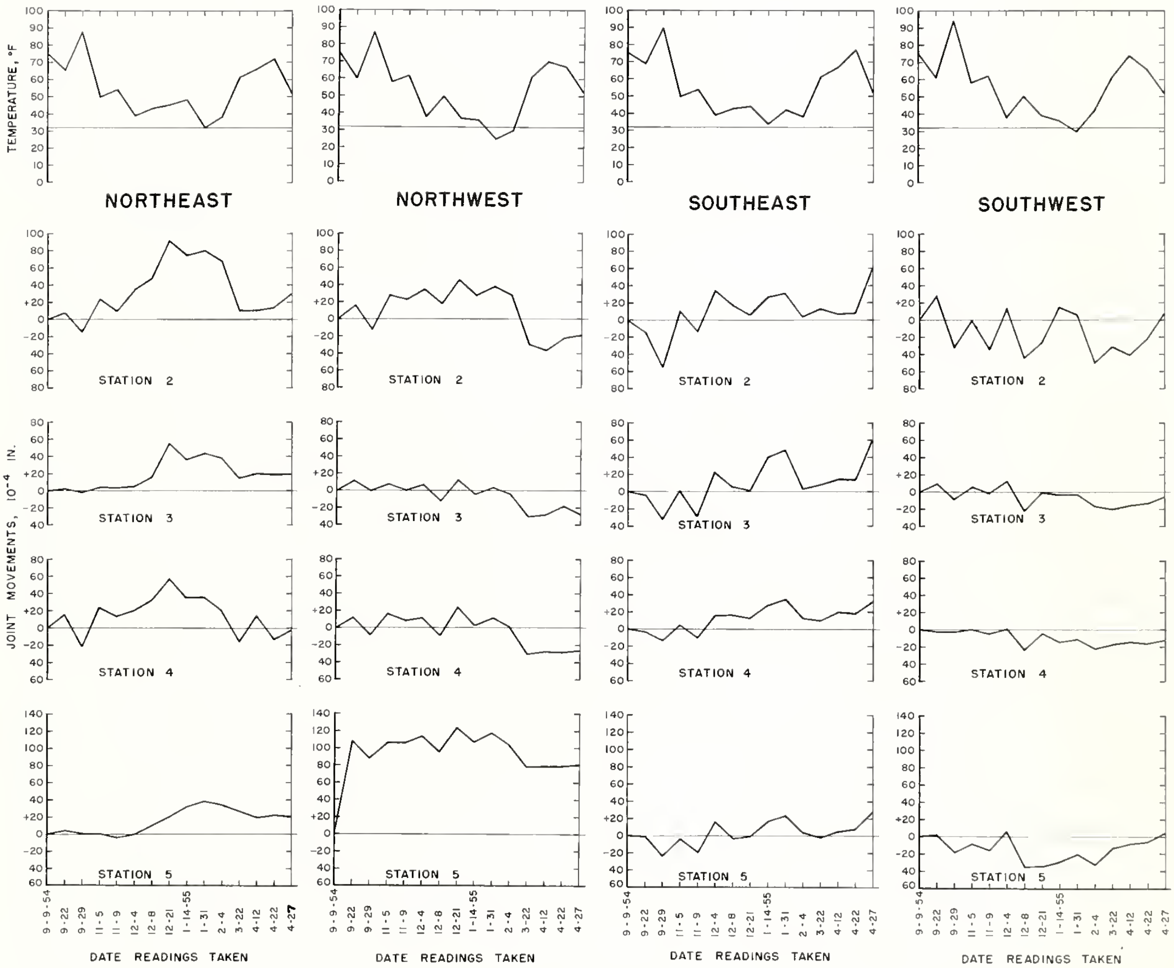


Fig. 16. Complete record of joint movements measured at 16 gage stations on 4 elevations. (19th floor level, Building No. 1, Naval Medical Center). Corresponding air temperatures for each date that readings were taken are plotted along the top of the graph.

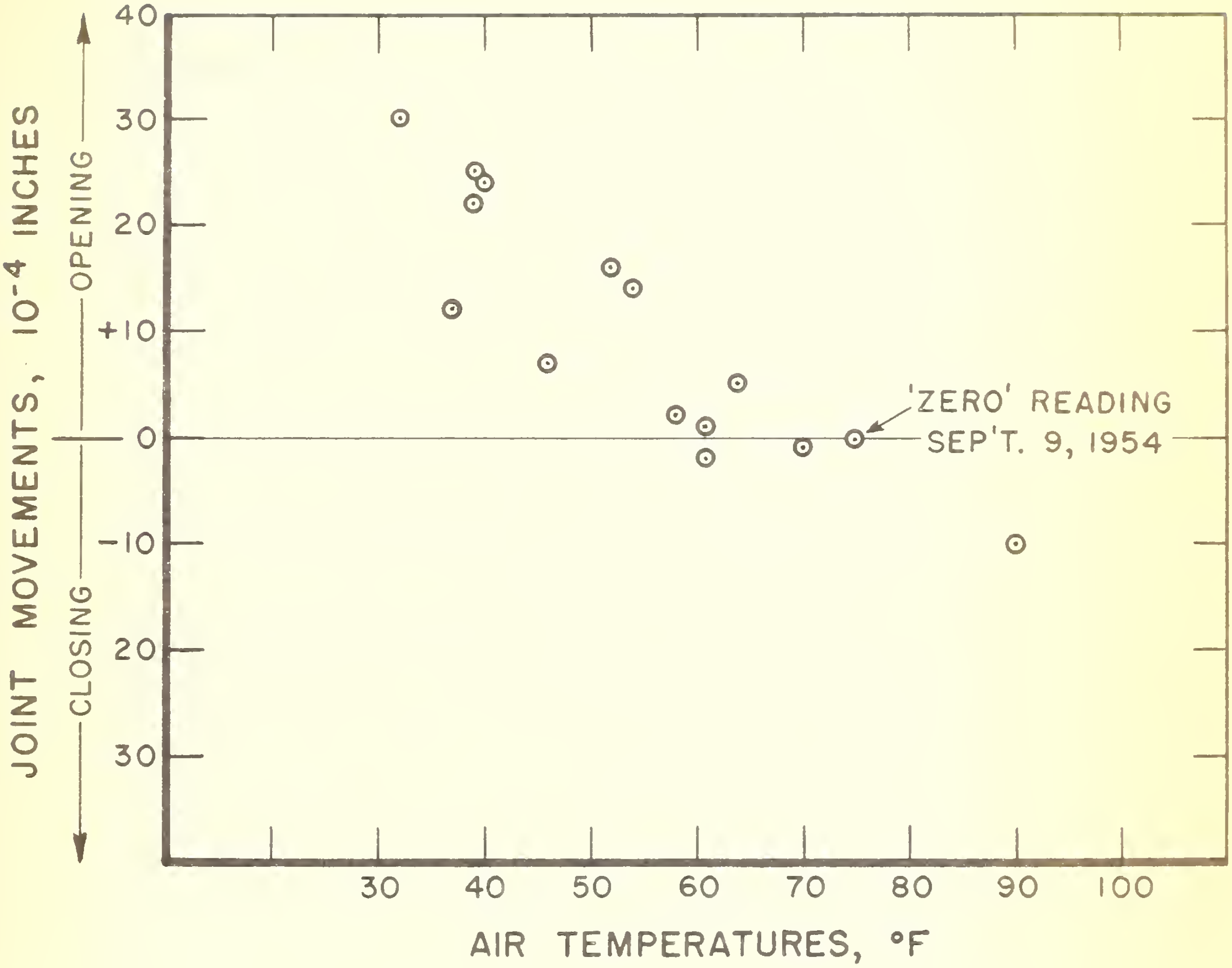


FIGURE NO. 17 RELATIONSHIP BETWEEN JOINT MOVEMENTS AND AIR TEMPERATURES RECORDED AT THE TIME GAGE READINGS WERE TAKEN. EACH POINT REPRESENTS THE AVERAGE DATA OBTAINED ON EACH OF THE 15 DAYS THAT MEASUREMENTS WERE MADE FROM SEP'T. '54 THROUGH APRIL '55. (19TH FLOOR LEVEL, BUILDING NO. 1, NAVAL MEDICAL CENTER.)

A.　　B.

Fig. 18. Illustration of a corner vertical joint on the southeast side, (19th floor, Building No. 1).
(A) Just before waterproofing treatment.
(B) As it appeared 7 months after treatment.

A. B.

Fig. 19. (A) Type of gage station, (rectangular stainless steel strips), being used at the present time for measurement of joint movements.
(B) Operator measuring the distance between steel strips with a Brinell microscope.

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