MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

#47

DETERMINATION OF YOUNG'S MODULUS OF FROZEN AND THAWED CONCRETE SPECIMENS BY SONIC METHOD

RESEARCH LABORATORY
TESTING AND RESEARCH DIVISION
AUGUST 3, 1943

APPLICATION OF SONIC METHOD TO FREEZING AND THAWING STUDIES OF CONCRETE

The measurement of natural frequencies of vibration of specimens of building materials has been used as a means of estimating changes in the material caused by aging, by cycles of freezing and thawing, or by similar treatments. The natural frequency can be determined at frequent intervals during a given treatment without harming the specimen, and the percentage change in square of the natural frequency may be used as an approximate measure of the breaking down of the structure of the material.

By substituting values of natural frequency into an equation relating that particular frequency to the dimensions of the specimen and the density and elastic constants of the material, a value is obtained for Young's modulus of that specimen. This has been commonly referred to as the sonic method of determining Young's modulus.

The sonic method is employed by the Research Laboratory of the Michigan State Highway Department as a research tool to assist in the evaluation of certain factors related to the durability of concrete pavement slabs. The use of this tool has attained such significance and general application that the report which follows has been prepared with the idea of establishing a complete record of the sonic method as used by the Research Laboratory. The report includes such subjects as the theory of the sonic method, a description of the sonic apparatus and its operation, the determination of Young's modulus, and a few comparative results pertaining to the sonic method versus the static method of determining Young's modulus. The record will also serve as a handbook for those workers who are, or who will become, intimately associated with the test.

Theory of the Sonic Method:

The flexural frequencies of a slender bar of uniform sections as outlined by Hornibrook (1), are given by the fundamental equation.

$$N = \frac{m^2 k}{\pi \times 2 \times L^2} \sqrt{\frac{Eg}{d}} \text{ - - - - - - - - - - (1)} \qquad \frac{m^2 k}{2\pi L^2}\sqrt{\frac{Eg}{d}}$$

from which

$$E = \frac{4\pi^2 L^4 d N^2}{m^4 k^2 g} \text{ - - - - - - - - - - (2)} \qquad \frac{4\pi^2 L^4 d N^2}{m^4 k^2 g}$$

where

E = Young's modulus of elasticity in pounds per square inch,

L = length of the specimen in inches,

d = unit weight of the specimen in pounds per cubic inch,

N = natural frequency in cycles per second,

k = radius of gyration of the section about an axis perpendicular to the plane of bending,

g = acceleration due to gravity, and

m = dimensional factor depending on mode of vibration and conditions of restraint.

The values L, d, and k can be measured directly, and g is known. For bars in which the thickness is appreciable compared to the length, a correction is required to account for the effects of rotary inertia and of lateral expansion and contraction of the bar.

Mason (2) has shown that these corrections can be made by using the proper value of m. Relationship between m and various ratios of thickness to length for rectangular bars vibrating in the fundamental flexural mode are presented graphically in Figure 1. The derivation of these relationships is based upon a value of .18 for Poisson's ratio, which represents an average figure for concrete.

For a cylindrical bar of concrete 4 inches in diameter and 16 inches in length, the modulus of elasticity E is determined as follows:

$k = \frac{d}{4} = 1"$,

$L = 16"$,

$R = \frac{\text{diameter}}{\text{length}} = 0.25$, and

$m = 4.50$ (found directly from the graph, Figure 1).

Substituting these values in equation (2) we have

$$E = 18.349 \ d \ N^2$$

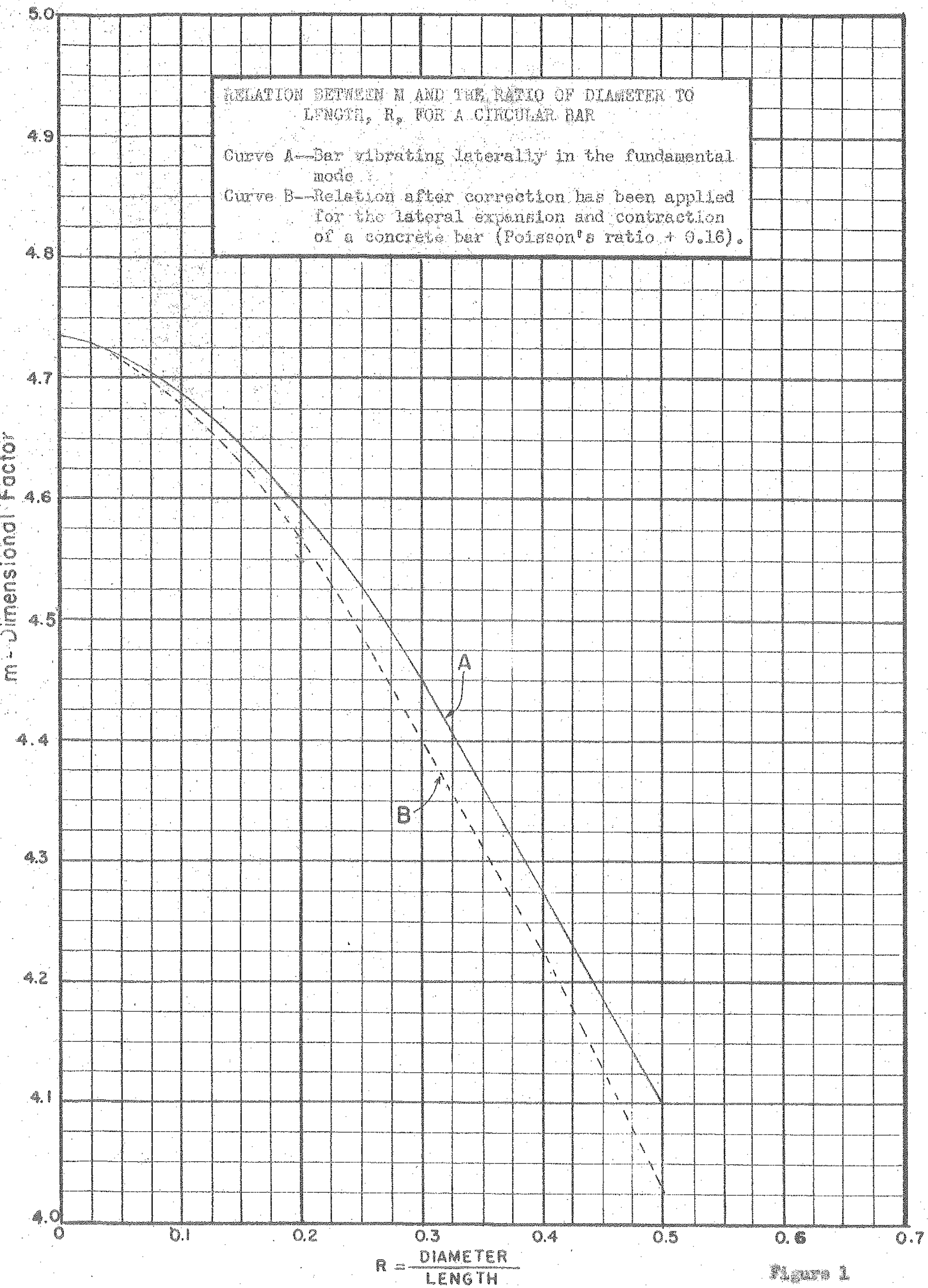
Letting p denote the specific gravity of the specimen and simplifying further we obtain finally

$$E = .5898 \ p \ N^2 \text{ - - - - - - - - - - } (4)$$

For a prismatic bar 3" x 6" x 15" the modulus of elasticity E is determined similarly by proper substitution in equation (2). For this type of specimen $k = \frac{3}{12}$, $L = 15$ inches, $R = \frac{3}{15} = 0.20$, $m = 4.52$ and we have

$$E = .5968 \ p \ N^2 \text{ - - - - - - - - - - } (5)$$

Values for Young's modulus may be determined rapidly and conveniently either by the use of nomographs constructed from equations (4) and (5), or by graphs of these functions on a logarithmic scale. See Figure 1A. As we have seen in the preceding analysis, the mathematical relationships in equation (1) have been reduced to an expression involving three variables E, N, and p. By varying p arbitrarily between the ordinary limits for concrete, we obtain a family of curves of the general form $E = CN^2$.



RELATION BETWEEN M AND THE RATIO OF DIAMETER TO LENGTH, R, FOR A CIRCULAR BAR
Curve A--Bar vibrating laterally in the fundamental mode
Curve B--Relation after correction has been applied for the lateral expansion and contraction of a concrete bar (Poisson's ratio + 0.16).
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
m - Dimensional Factor
A
B
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
R = DIAMETER / LENGTH

Figure 1

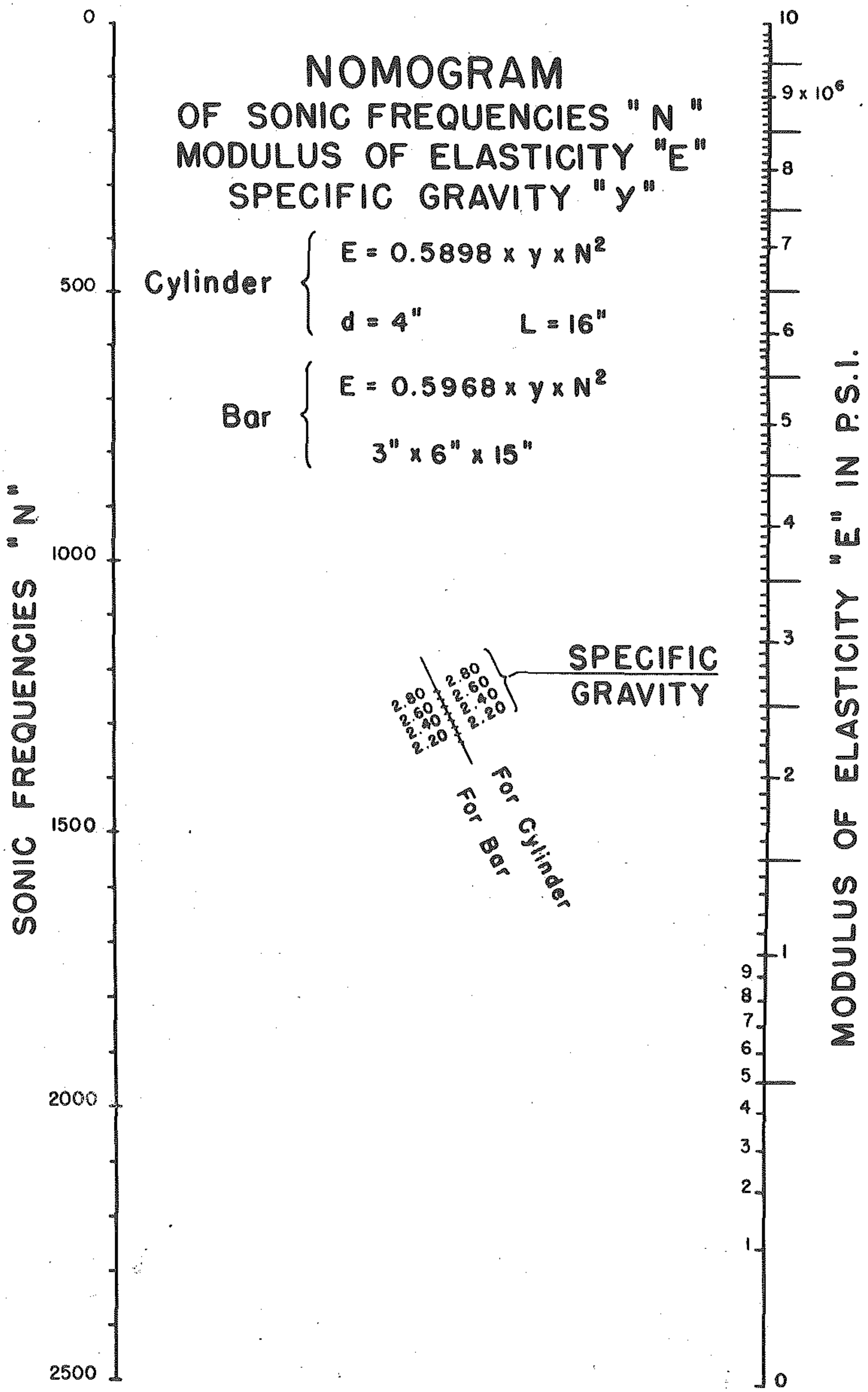

NOMOGRAM
OF SONIC FREQUENCIES "N"
MODULUS OF ELASTICITY "E"
SPECIFIC GRAVITY "y"
Cylinder
E = 0.5898 x y x N²
d = 4"   L = 16"
Bar
E = 0.5968 x y x N²
3" x 6" x 15"
SONIC FREQUENCIES "N"
0
500
1000
1500
2000
2500
MODULUS OF ELASTICITY "E" IN P.S.I.
10
9 x 10⁶
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
0
SPECIFIC GRAVITY
2.80
2.60
2.40
2.20
For Cylinder
For Bar

Figure 1A

The Sonic Apparatus:

An apparatus for determining the fundamental flexural frequency of a concrete specimen vibrating as a free-free bar has been developed by the Research Laboratory of the Michigan State Highway Department and constructed by the Davenport Laboratory, Detroit, Michigan. The design of the sonic apparatus is based on that of a similar instrument employed by the National Bureau of Standards and described by Hornibrook (1).

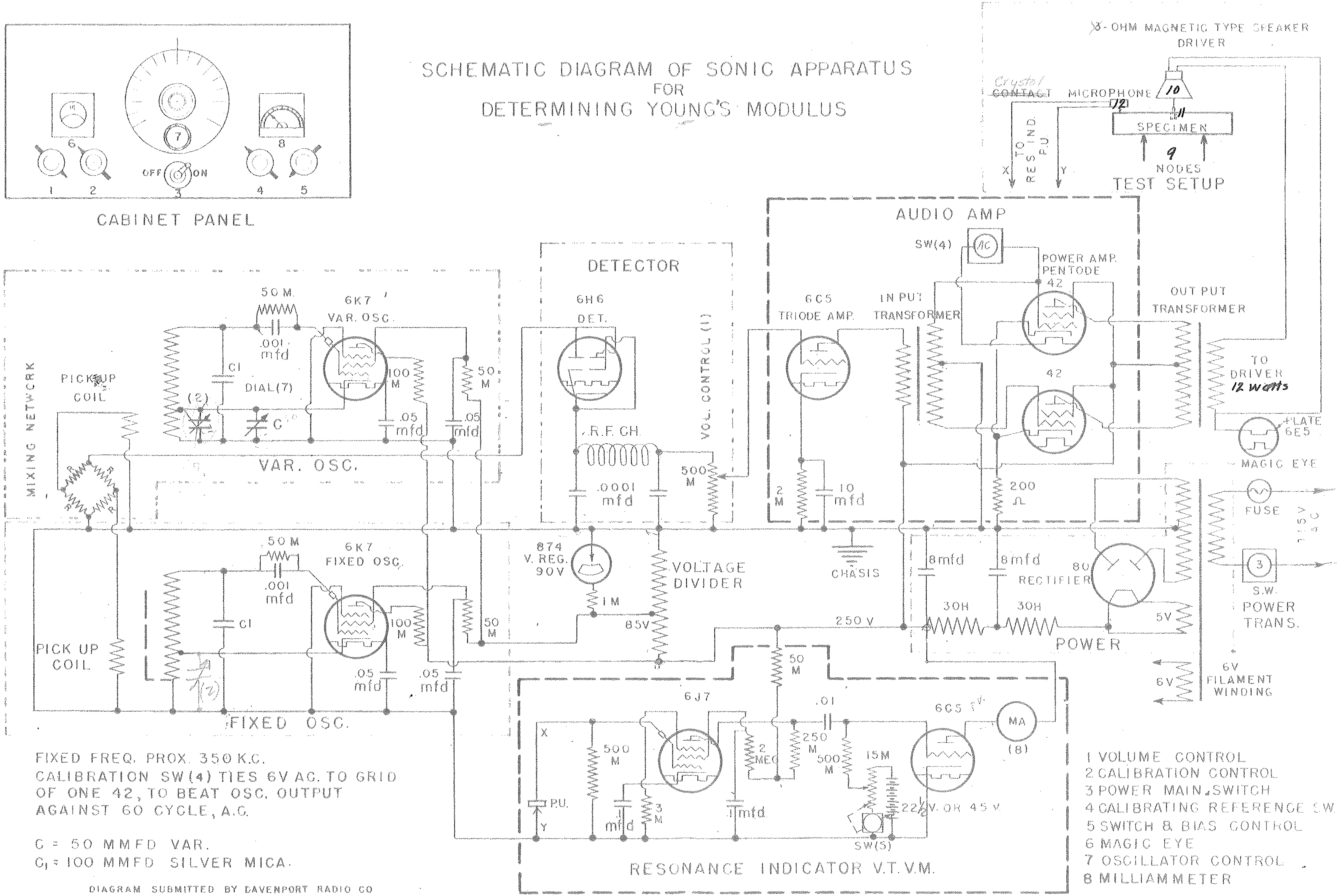
The sonic apparatus, as illustrated schematically in Figure 2 and pictorially in Figure 3, consists of several common electrical devices specially assembled into one compact housing to perform with greater facility its intended function. The several units are essentially a power unit, an audio amplifier, a detector, fixed and variable frequency oscillators, a magnetic type radio speaker and a resonance indicator. The various units are described briefly in the following text.

Power Unit: The sonic apparatus operates on 115 volt alternating current which upon passing through the power unit is rectified to direct current and the voltage increased to 250 volts. Also a 6 volt supply of current is made available for operating the tube filaments.

Frequency Oscillators: From experience it was learned that the maximum frequency range for concrete test specimens was approximately 2500 cycles per second. To obtain this range one fixed frequency oscillator and one variable frequency oscillator are used. The fixed oscillator operates at 350 kc and the variable oscillator operates between 350 to 353 kc. The two oscillators are properly connected so that beat frequencies up to 3 kc per second may be obtained for testing purposes.

Detector: A detector or rectifier consisting of a 6 H 6 tube is inserted between the oscillators and the audio-amplifier.

SCHEMATIC DIAGRAM OF SONIC APPARATUS FOR DETERMINING YOUNG'S MODULUS

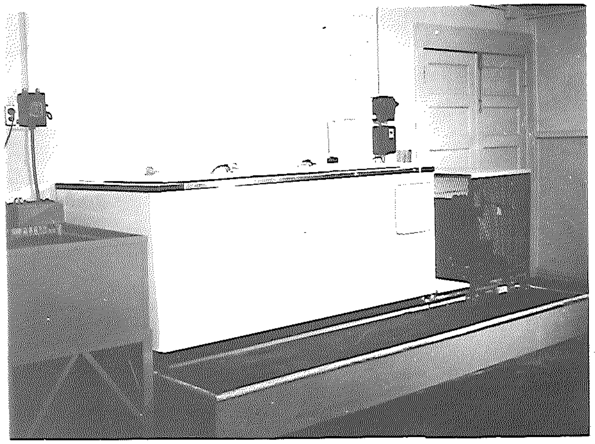


FIXED FREQ. PROX. 350 K.C.
CALIBRATION SW(4) TIES 6V AC. TO GRID OF ONE 42, TO BEAT OSC. OUTPUT AGAINST 60 CYCLE, A.C.

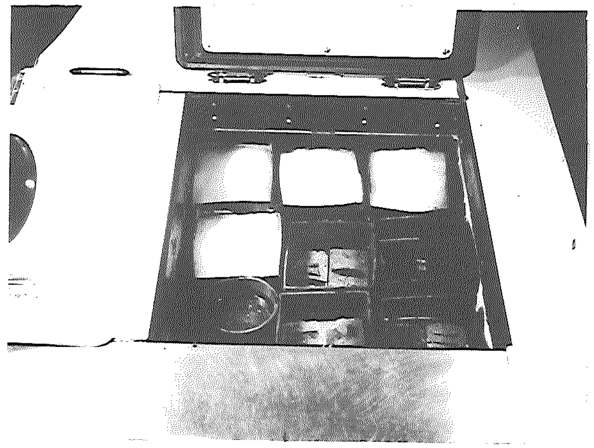
C = 50 MMFD VAR.
C_1 = 100 MMFD SILVER MICA.

DIAGRAM SUBMITTED BY DAVENPORT RADIO CO
DETROIT, MICH.

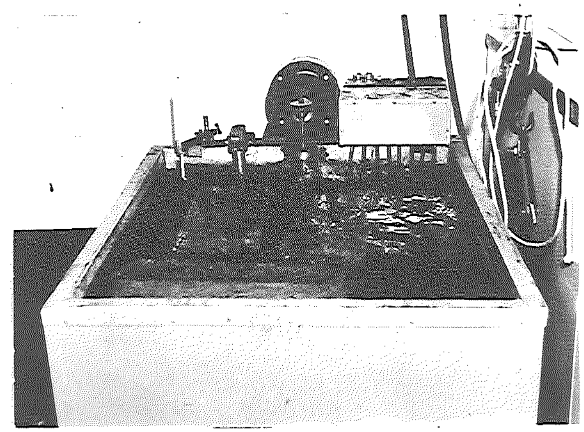
1 VOLUME CONTROL
2 CALIBRATION CONTROL
3 POWER MAIN SWITCH
4 CALIBRATING REFERENCE SW.
5 SWITCH & BIAS CONTROL
6 MAGIC EYE
7 OSCILLATOR CONTROL
8 MILLIAMMETER



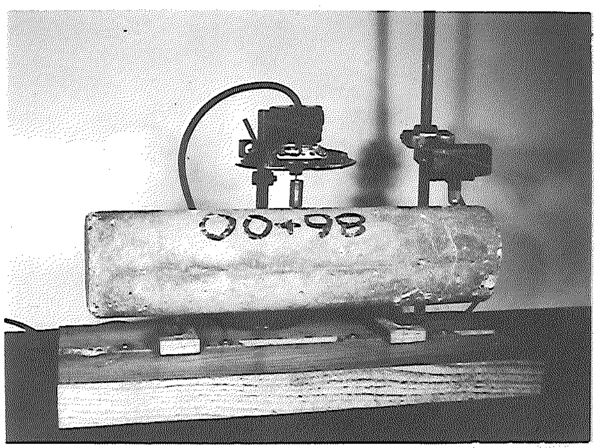
FREEZING UNIT



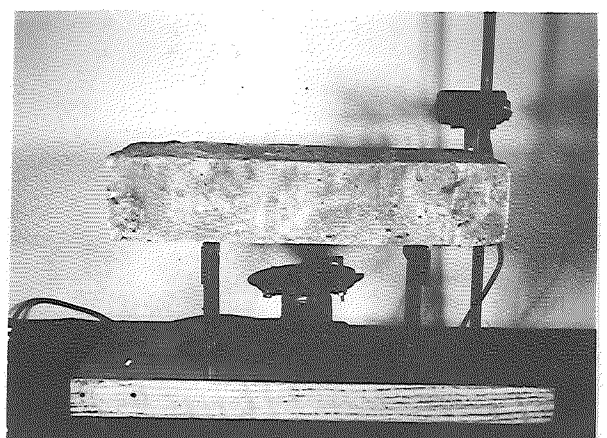
SPECIMENS IN FREEZING UNIT



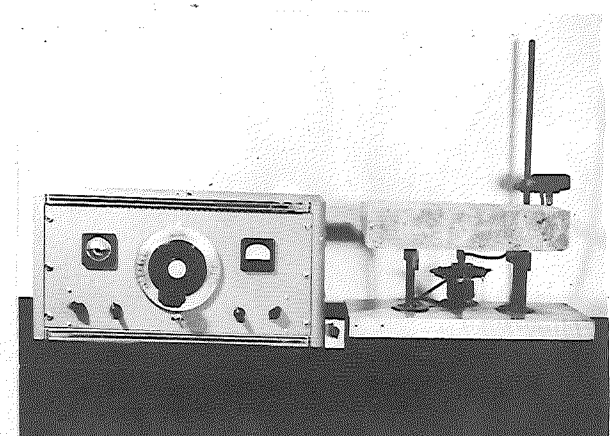
THAWING TANK



CIRCULAR BAR SPECIMEN



PRISMATIC BAR SPECIMEN



SONIC APPARATUS

Figure 3

Magnetic Speaker Driver: It was found that a 3 ohm magnetic type radio speaker was sufficient to oscillate the particular test specimens associated with the freezing and thawing tests as conducted by the Research Laboratory. A suitable metal rod, 1/16" in. diameter, is cemented to the core of the speaker cone. This metal rod is placed in contact with the surface of the test specimen midway between the specimen supports. The supports are located at the node points of the specimen at a distance of .244 L from each end of the specimen.

Resonance Indicator: The unit for detecting the resonance of the test specimen consists of a contact microphone, an audio-amplifier and a vacuum tube milliammeter for measuring maximum current flow. The vibrations are picked up by the contact microphone which is placed near the end of the specimen. Current set up by the vibrations in the microphone is amplified and indicated on the milliammeter. When the specimen is vibrating at natural frequency, the dial of the milliammeter indicates a maximum.

The various electrical devices described above have been assembled and mounted in a compact, modernized radio cabinet in order to facilitate operation of the apparatus. It is necessary that a definite test routine be followed in the performance of a sonic determination.

Operation of Sonic Apparatus:

The sequence of steps relevant to the operation of the sonic apparatus may now be described in detail. Before conducting tests, the main OFF-ON switch (No. 3) is turned to ON position and the apparatus allowed to warm up for approximately 1/2 hour. After the warming period, the next step is to check the calibration of the instrument. This is accomplished by setting frequency control dial (No. 7) at 60 and turning calibration switch (No. 4) to the ON position. Volume control (No. 1) is turned to full volume, then calibration control condenser (No. 2) is adjusted until the magic eye (No. 6) just closes. At the termination of these adjustments the apparatus will be calibrated for 60 cycles against the 60 cycles of the power input. Calibration switch (No. 4) and volume control (No. 1) are now turned to OFF position.

Turn bias control switch (No. 5) to ON position and adjust current volume so that the meter (No. 8) indicates a current between 5-6 milliamperes. The amount of current indicated by ammeter (No. 8) does not affect the frequency. The bias-control regulates the amount of current flowing through the ammeter only. The sonic apparatus is now ready for use.

The concrete specimen selected for modulus of elasticity determination is now placed on a special holder which supports the specimen at the nodes (No. 9).

(See test set-up, Figures 2 and 3). The magnetic driver (No. 10) is adjusted in position so that the driving rod (No. 11) is in positive contact with the specimen midway between the nodes.

The pickup (No. 12) is placed on the end of the specimen as illustrated in schematic diagram Figure 2 and in Figure 3. The resonant frequency of the specimen is determined in the following manner. Turn the frequency control switch (No. 1) on to full volume, adjust the frequency control dial (No. 7) until the ammeter reading (No. 8) indicates a maximum. This is the resonant frequency of the specimen and is designated by letter "N" in the equations given previously.

<u>Precautions</u>: Certain precautions must be observed in running the test.

1. It is important to check the calibration of the instrument after each test in order to check and correct for any drift of the apparatus during the test.

2. Many specimens vibrate at their natural frequency when excited at one-half, one-third, or even one-fourth their natural frequency. Therefore care must be taken to be certain that the oscillator and specimen are vibrating at the same frequency. This can be checked by placing the pickup, first on the speaker and then on the specimen. An identical frequency is shown if the maximum number of milliamperes appear on the dial of the ammeter for each case.

3. Be sure that the calibration switch (No. 4) is off when making measurements.

4. If ammeter does not register when bias-control switch (No. 5) is on, this may indicate that battery has been discharged.

5. Upon completion of tests turn all switches to OFF position.

The apparatus and its operation procedure are applicable to cement, mortar, or concrete specimens of a certain dimensional size. The specimens are subjected to some accelerated weathering tests such as freezing and thawing and the frequency of specimen determined at predetermined intervals. The accelerated weathering cycle and test procedure are discussed in the following text.

METHOD OF TEST FOR DURABILITY OF CONCRETE BY FREEZING AND THAWING

This method describes the procedure followed by the Research Laboratory of the Michigan State Highway Department in testing concrete specimens to determine their resistance to disintegration by freezing and thawing. Progressive deterioration is indicated by change in the value of Young's modulus for the specimen as measured by the dynamic, or sonic, method.

Apparatus:

The essential apparatus included in the freezing and thawing tests is described in detail in the following paragraphs.

Compressor: The compressor is a Frick type F-100FL conforming to the following specifications:

1. No. of cylinders; action, 2 cyl. single
2. Bore and stroke, 2 1/4" x 3"
3. R.P.M. (Comp.) 355
4. Motor H.P. 1 1/2
5. Normal suction pressure, 4 - 5 lb.
6. Normal discharge pressure, 110-130 lb.
7. Refrigerant - Freon 12 - dichlorodifloromethane CCl_2F_2
8. Cooling coils, 3/4", direct expansion.

This compressor is capable of maintaining the cabinet and its contents at a temperature of -20° ± 2°F.

Cabinet: The freezing unit consists of one model 105-LO Schaefer all-steel heavy duty storage cabinet having three compartments, each 23 inches in height, 52 inches in length, and 23 inches in width. Overall dimensions are 81 in. long x 42 1/2 in. wide x 34 1/2 in. high, and the total net inside volume is 29.4 cubic feet. The two end compartments contain a water-glycerin solution in the proportion of one part water to two parts glycerin by volume. The center compartment is used for freezing in air. The cabinet is insulated on all outside surfaces with six inches of corkboard, and has an access door in the top of each compartment. See Figure 3.

__Thawing Tank:__ The thawing tank is 52 in. long x 22 in. wide x 22 1/2 in. deep, which is of sufficient size to accommodate twelve containers, or the full load of one compartment of the refrigerator. It is equipped with heating elements, cooling coils, stirrer, and thermoregulator to control the water temperature, in the range of 70° to 100° F, within the limits of ± 1° F. See Figure 3.

__Container:__ The containers for the specimens are constructed of heavy rubber 3/16 inches in thickness, sealed at the edges and open at the top. They are of two types, one for beams, the other for cylinders. Inside dimensions of the first type are 6 1/4 in x 6 1/4 in. x 17 7/8 in. in height, and provide space for two beams of approximately 3 in. x 6 in. x 15 in. The second type is cylindrical in shape, 4 7/8 in. in diameter and 17 7/8 in. in height to accommodate one 4 in. x 16 in. cylinder. See Figure 4.

__Specimens:__

Concrete for the test is molded into rectangular beams, using a steel gang mold of four units, side by side, each 3" deep x 6" wide x 15" long. Each specimen of fresh concrete is rodded in two layers of approximately 1 1/2" thickness, struck off and finished with a minimum of troweling. The beams are then cured initially with wetted burlap followed by storage in the moist room at 70° F until time of test.

Concrete for the test is molded into cylinders, using 4" x 16" steel molds. Each specimen is rodded 25 times in three approximately equal layers

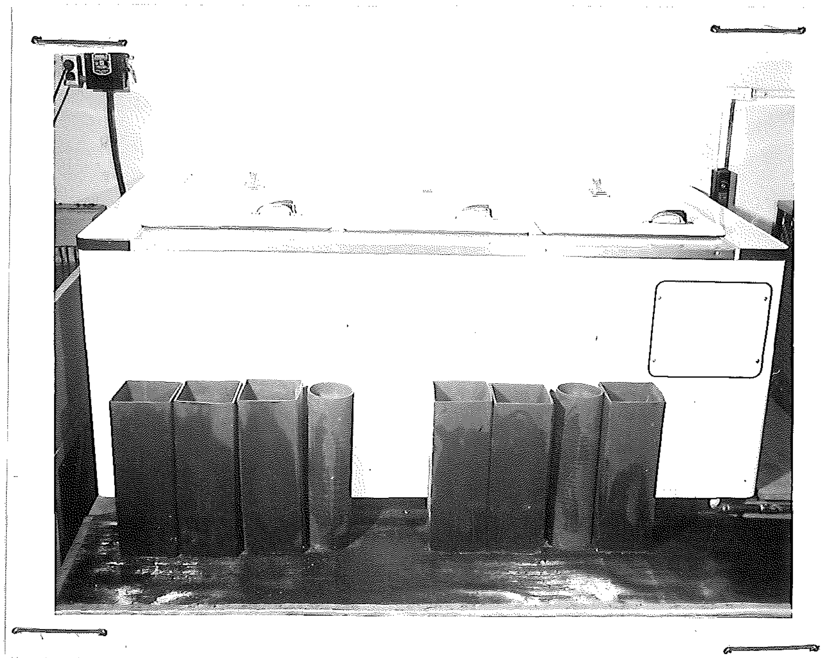


Figure 4. Freezing Cabinet and Rubber
Specimen Containers

struck off level with the top of the mold and finished with a minimum of troweling. The cylinders are then cured initially with wetted burlap followed by storage in the moist room at 70° F until time of test.

Preparation of Test Specimens:

The specimens are brought to a saturated, surface dry condition by immersion in water for a period of at least 24 hours, after which they are weighed, measured, and the specific gravity determined. The initial fundamental frequency is then determined by the sonic method, and the specimens are now ready to begin the test.

Method of Exposure:

After the initial data have been recorded, the specimens are placed in the rubber containers, and sufficient water or calcium chloride solution added to cover the specimens to a depth of about 1/4 in. The ratio of water to concrete by weight is approximately 0.11. The containers are then placed in the freezing bath of the refrigerator with the level of the liquids on the outside and inside of the container approximately equal. The temperature of the freezing bath is -20° ± 2° F at the time of immersion; but may rise to a maximum of + 26° F under full load. The capacity of the refrigerator is such that cooling takes place at approximately the following rate when loaded to 75 percent of capacity:

70° F to 52° F	2 hours
52° F to 30° F	4 1/4 hours
30° F to 15° F	1 1/2 hours
15° F to 0° F	3 1/2 hours
0° F to -10° F	4 1/2 hours
Initial to Final	16 hours

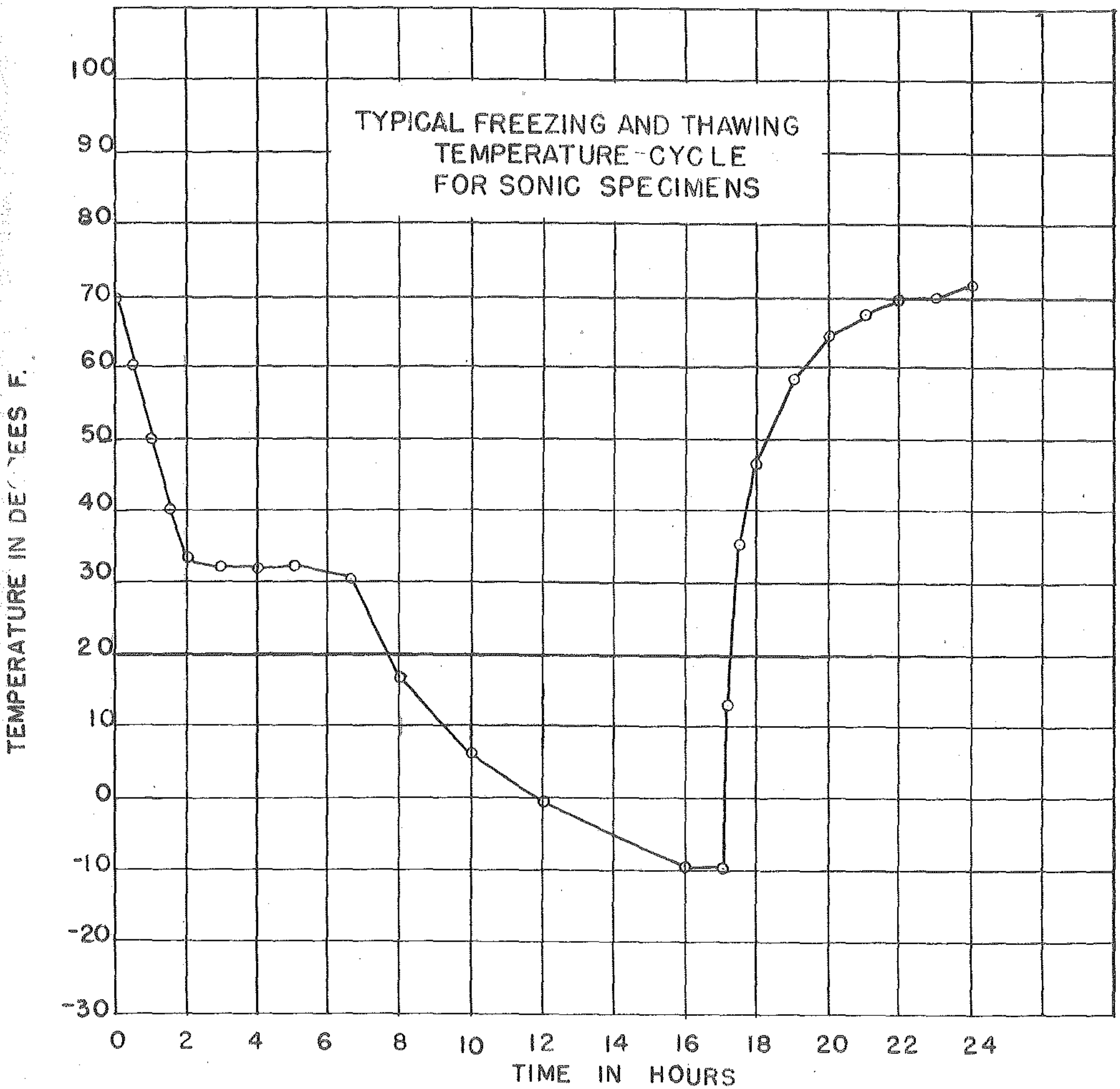

TYPICAL FREEZING AND THAWING
TEMPERATURE CYCLE
FOR SONIC SPECIMENS
TEMPERATURE IN DEGREES F.
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME IN HOURS

FIGURE 4A

At the end of the freezing period, the containers are removed from the refrigerator, wiped, and rinsed off on the outside with tap water and placed in the thawing tank which is maintained at a temperature of 90° to 100° F until the ice around the specimens is completely melted. The water is then drained from the containers, the specimens are turned end for end in the containers, and tap water at a temperature of 72° to 90° F again added to the proper level, after which the specimens are allowed to reach equilibrium in air at the room temperature. Total time required for complete thawing is 5 to 7 hours. This completes one cycle of freezing and thawing.

Measurement of Disintegration:

At the completion of the fifth cycle of freezing and thawing and at intervals of five cycles thereafter the specimens are removed from the containers, surface dried, weighed, and tested for fundamental frequency by the sonic method. The process of alternate freezing and thawing is continued until deterioration has progressed to a predetermined value of the fundamental frequency.

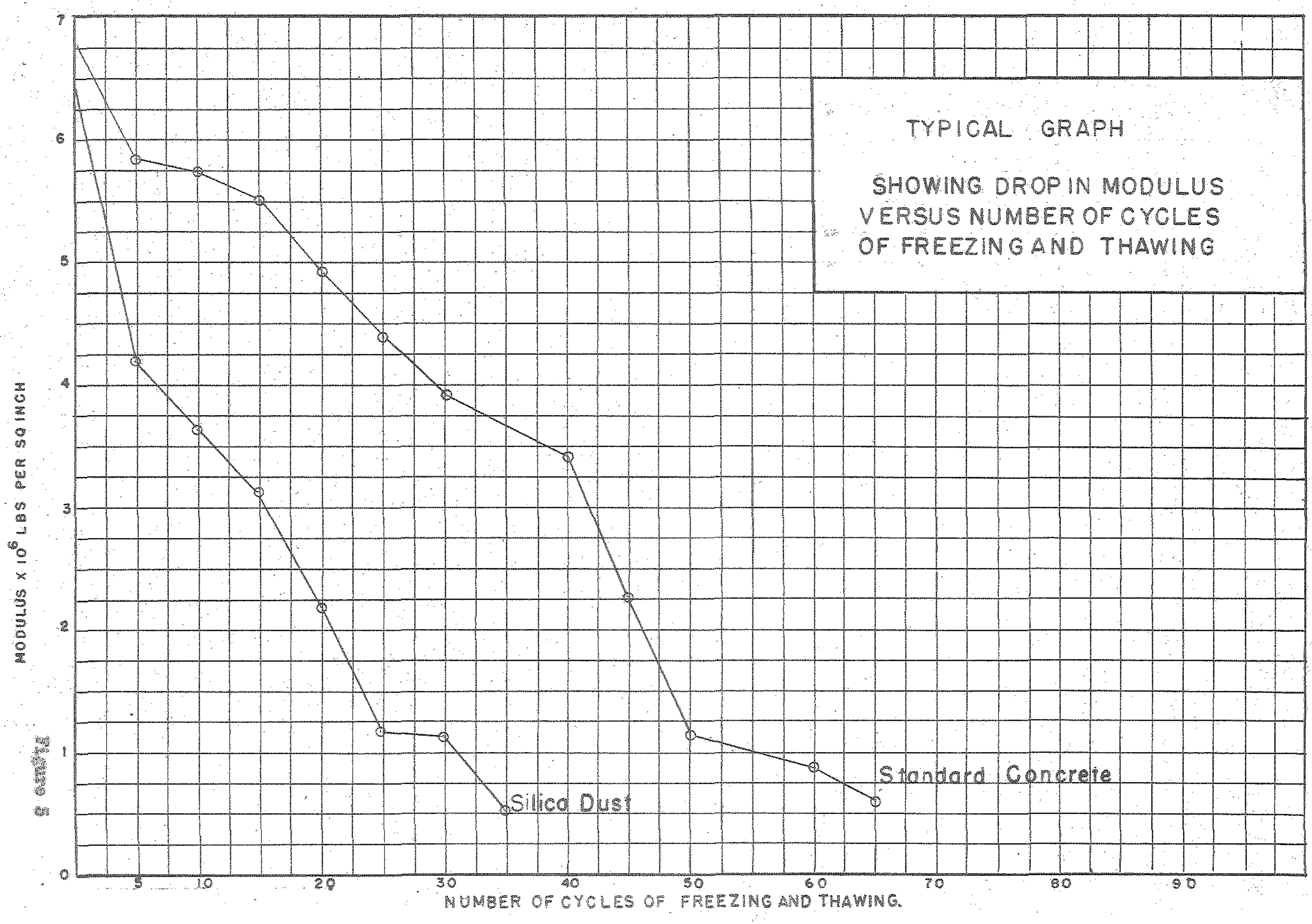
Determination of Young's Modulus:

Young's modulus of elasticity for a concrete specimen in the case of either a circular or prismatic bar, is determined in the following manner. The concrete specimen after being subjected to a definite number of freezing and thawing cycles is removed from the rubber container and its specific gravity determined. After completion of the specific gravity determination the specimen, in a saturated condition, is inserted in the sonic apparatus and the fundamental flexural frequency "N" determined by the sonic method as described previously. Investigation by Hornibrook (1) indicates that the saturated condition is well adapted for obtaining reproducible measurements on companion specimens.

Young's modulus can now be determined from either equation (4) or (5), depending on the type of specimen employed in the test, by solving for E after substituting the correct values for "N" and specific gravity. Approximate values may be determined more rapidly by reference to the nomographs given previously.

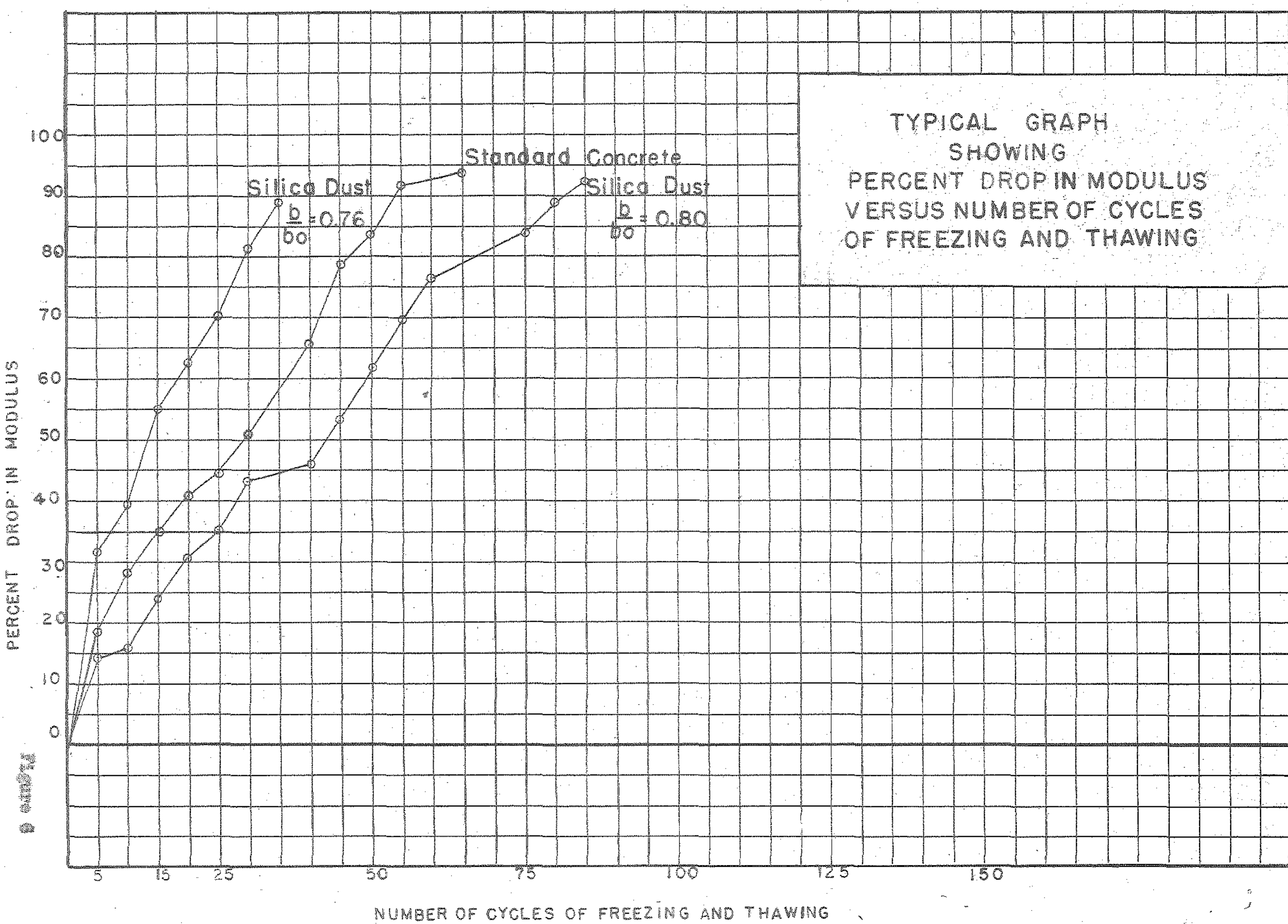
Equations (4) and (5) hold only for bars of the specific dimensions used in the Research Laboratory durability studies, namely a 4" by 16" cylindrical bar and a 3" x 6" x 15" prismatic bar. For sonic specimens of any other dimensions the appropriate values for L, k, and m must be inserted in equation (2).

Upon completion of the sonic determinations for the life span of the specimen, the sonic data may be presented in several ways to represent the rate of disintegration of the specimen. Two methods are illustrated in Figures 5 and 6. Figure 5 is typical of the relationship between modulus of elasticity and freezing and thawing, while Figure 6 is an example of the relationship between percent drop in modulus versus number of cycles of freezing and thawing as obtained from actual test data.



TYPICAL GRAPH
SHOWING DROP IN MODULUS VERSUS NUMBER OF CYCLES OF FREEZING AND THAWING
MODULUS X 10^6 LBS PER SQ INCH
NUMBER OF CYCLES OF FREEZING AND THAWING.
Silica Dust
Standard Concrete
0
1
2
3
4
5
6
7
5
10
20
30
40
50
60
70
80
90

Figure 5



TYPICAL GRAPH
SHOWING
PERCENT DROP IN MODULUS
VERSUS NUMBER OF CYCLES
OF FREEZING AND THAWING
Standard Concrete
Silica Dust
b/bo = 0.76
Silica Dust
b/bo = 0.80
PERCENT DROP IN MODULUS
0
10
20
30
40
50
60
70
80
90
100
5
15
25
50
75
100
125
150
NUMBER OF CYCLES OF FREEZING AND THAWING

THE SONIC METHOD AS A RESEARCH TOOL FOR STUDYING CHANGES IN CHARACTERISTICS OF CONCRETE SUBJECTED TO FREEZING AND THAWING

It has been clearly demonstrated by Powers (3), Hornibrook (1), and Reagel (4) that the sonic method of determining the change in modulus of elasticity appears well adapted for estimating the loss of flexural strength produced in concrete by freezing and thawing treatment.

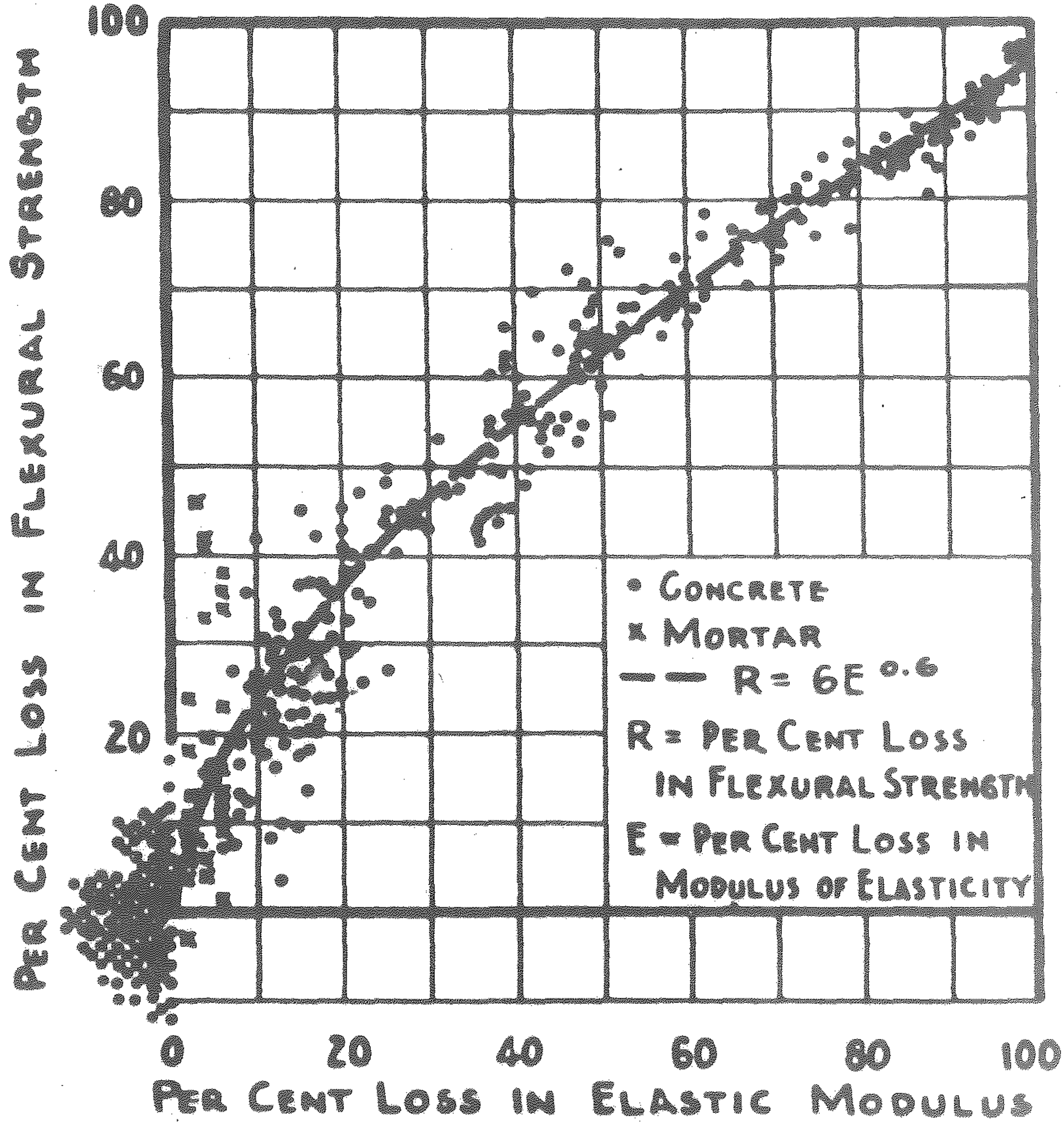
The work of Hornibrook definitely proves that the fundamental flexural frequency of a specimen can be determined rapidly and at frequent intervals with the sonic apparatus. Converting the frequencies into values for Young's modulus gives a continuous history of the change in modulus of elasticity of a single specimen during a given type of treatment or test. This fact is clearly illustrated in Figures 5 and 6.

Reagel in his studies relative to the freezing and thawing tests for concrete in which he uses the sonic method, shows in Figure 7 how closely the flexural strength is related to the elastic modulus of the specimen.

Powers points out that the value of the sonic method lies chiefly in its ability to indicate rapidly, without destroying the specimen, changes in the modulus of elasticity due to various conditions to which the concrete may be subjected, and may not be used per se to determine deflection or distortion in structural members under loads, except as a reference point.

Sonic tests were made by Powers on 5" x 5" x 18" bars and the stress-strain measurements taken on companion 6" x 12" cylinders tested in compression. Four mixes were used consisting of Elgin sand, gravel, and laboratory cement, ranging from very lean to rich. Specimens were tested at 7 and 28 days, using rotating mirror extensometers on two opposite sides of the specimen to measure strain.

RELATION OF LOSS IN FLEXURAL STRENGTH TO LOSS IN MODULUS OF ELASTICITY



Points plotted on and to left of zero abscissa represent control beams for flexural strength. Each point represents one specimen.

Figure 7

Results were plotted as stress-strain diagrams showing the deformation of each side of the cylinder separately, the average of the two, and a straight line representing the sonic value of the modulus. See Figure 8.

The diagram thus obtained showed that the sonic line either coincided with the compression line at low stress or appeared to be tangent to it at the origin, which indicates that the sonic method gives the modulus of the unloaded concrete, and its use thereby restricted to cases not requiring a consideration of deflection or distortion under load.

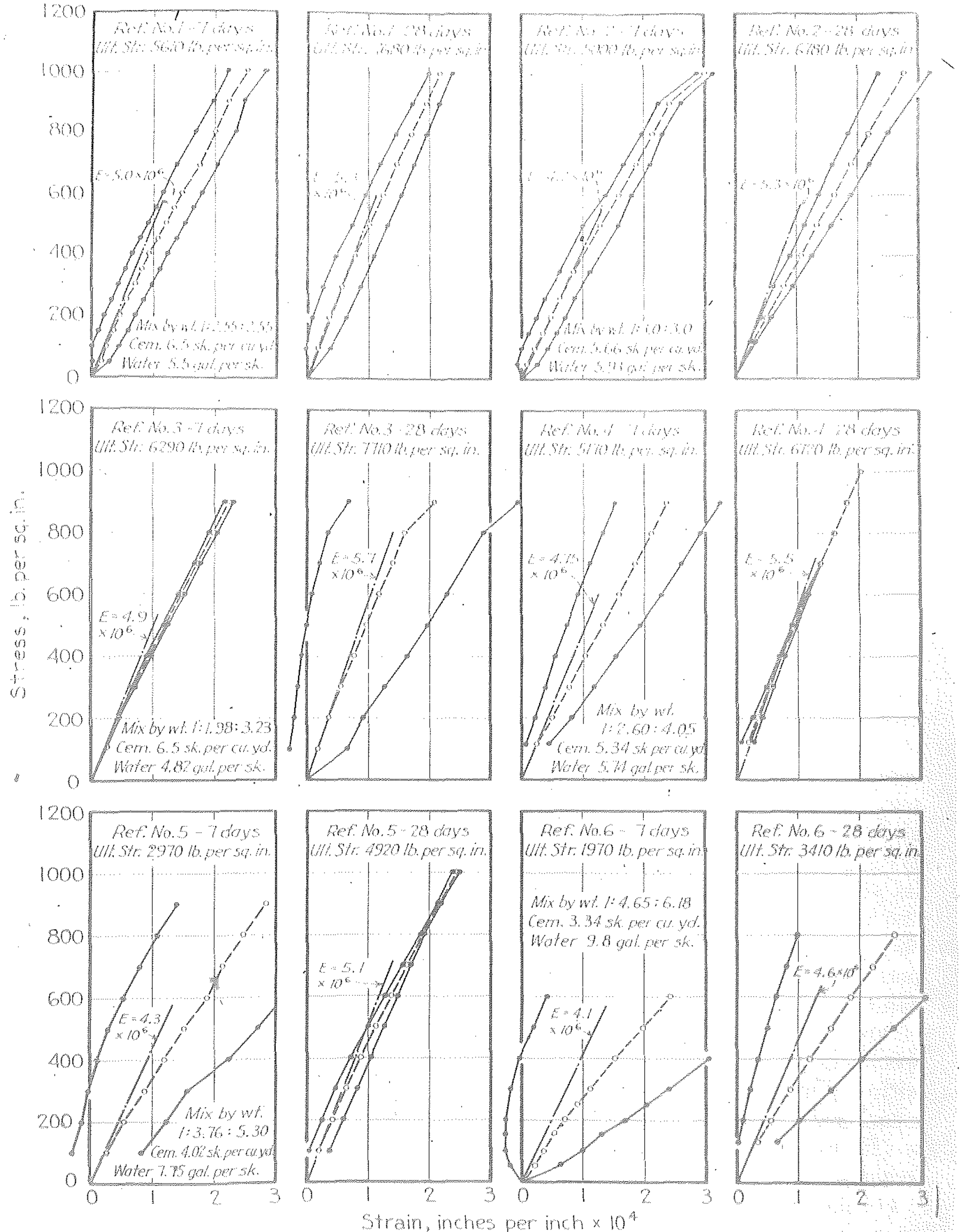
Further stress-strain tests were made on 2" x 2" x 9 1/2" bars by placing a load of 102 and 152 pounds at the center of a span of 8" between supports and measuring the deflection by means of a Federal dial reading to .0001 inch. The modulus of elasticity was computed from the equation $E = \frac{PL}{48yI}$ where P = applied load in pounds, L = distance between supports, I = moment of inertia, and y = deflection.

Close agreement was obtained between these values and those given by the sonic method.

Comparative Studies by Research Laboratory

To check the accuracy of the Sonic apparatus developed by the Research Laboratory for determining Young's modulus as compared with the standard static method several 4" x 16" concrete cylinders were subjected to sonic and compression tests.

Two of the concrete specimens were tested up to a total load of 25,000 lbs. at successive increments of 5,000 lbs. The remaining three specimens were loaded up to 35,000 lbs., in the same manner. The maximum loads corresponded to a unit stress of 1990 and 2786 lbs. per sq. in. respectively. Strain measurements at four equidistant points around the circumference of the test cylinders indicated a fairly uniform distribution of the load over the cross section.



—Comparison of E as Determined by the Sonic Method on 5 by 5 by 18-in. Bars with Stress-Strain Measurements Made on Companion 6 by 12-in. Cylinders Tested in Compression.

The slopes of the straight dash-dot lines are as indicated by the sonic test; the two series of solid points indicate the deflections as measured simultaneously on opposite sides of the specimen; the circles represent the average deflection. Stress-strain values represent the first loading of the specimen.

Figure 8

Stress-strain diagrams were plotted, (See Figures 9 to 13) using the average of the four dial readings as the indicated strain for each load in a gage length of 8 inches. An analysis of the curves obtained shows:

1. First application of the loads up to the maximum produces a permanent set and materially alters subsequent stress-strain relationships obtained by repetitions of the loading.

2. The modulus of elasticity varies with the intensity of the applied load, but is not proportional to it.

3. Young's modulus for concrete obtained by the sonic method corresponds very closely to the tangent modulus of the compression method, i.e. the modulus of elasticity of the concrete in the initial unloaded, or infinitesimally loaded condition.

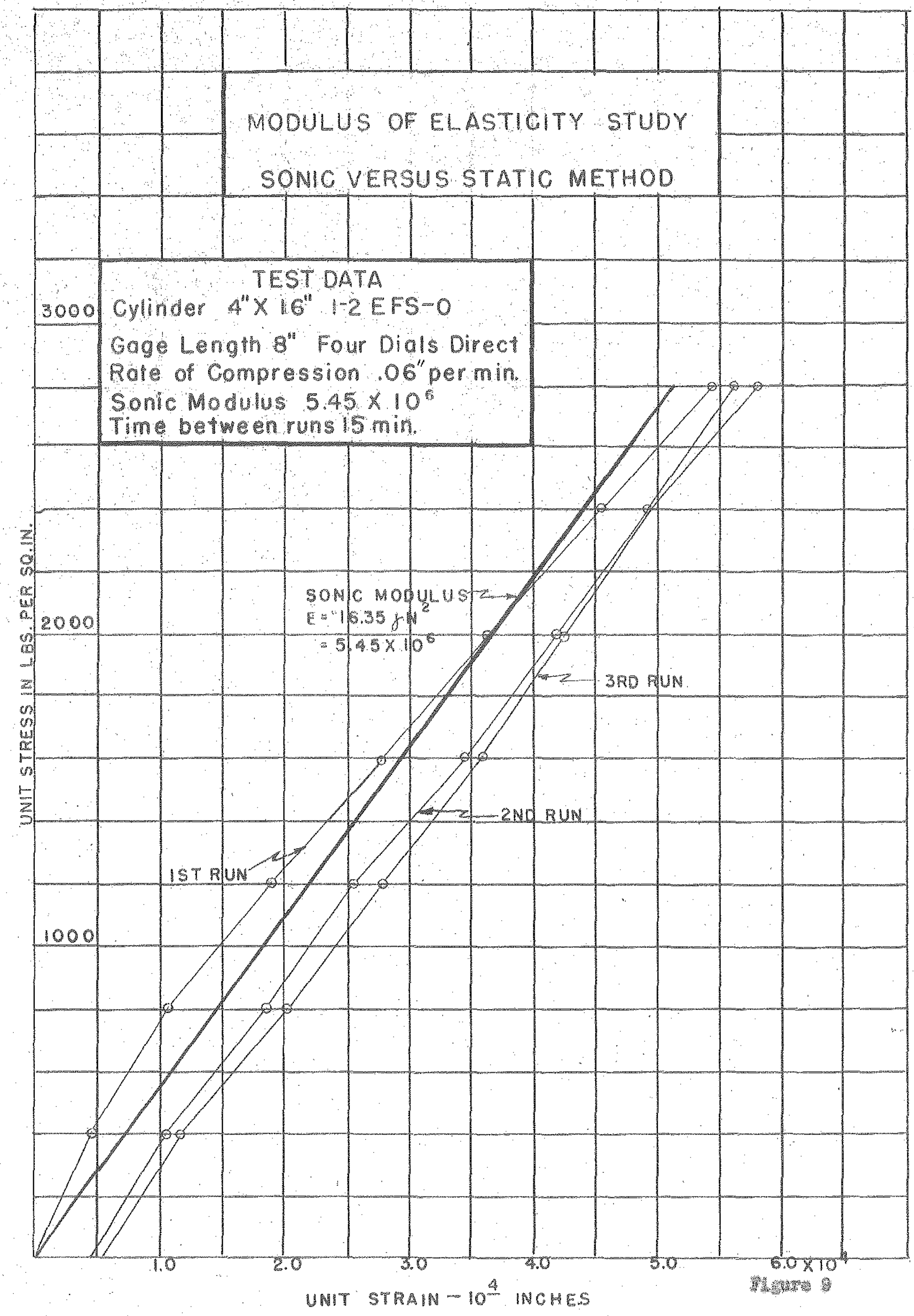
4. Increasing loads produce progressively greater deviations of the compression modulus from the sonic.

In the diagram obtained by Powers, using 6" x 12" cylinders, the sonic modulus corresponds very closely to the tangent modulus of the compression method, and in some cases coincides with the stress-strain curve at the lower loading. The curves obtained in our tests using 4" x 18" cylinders show a lower value for the slope of the sonic line in relation to the stress-strain curve, causing the line to cut the curve instead of being tangent to it at the origin.

This variation may possibly be due to the differences in the dimensions of the test cylinders.

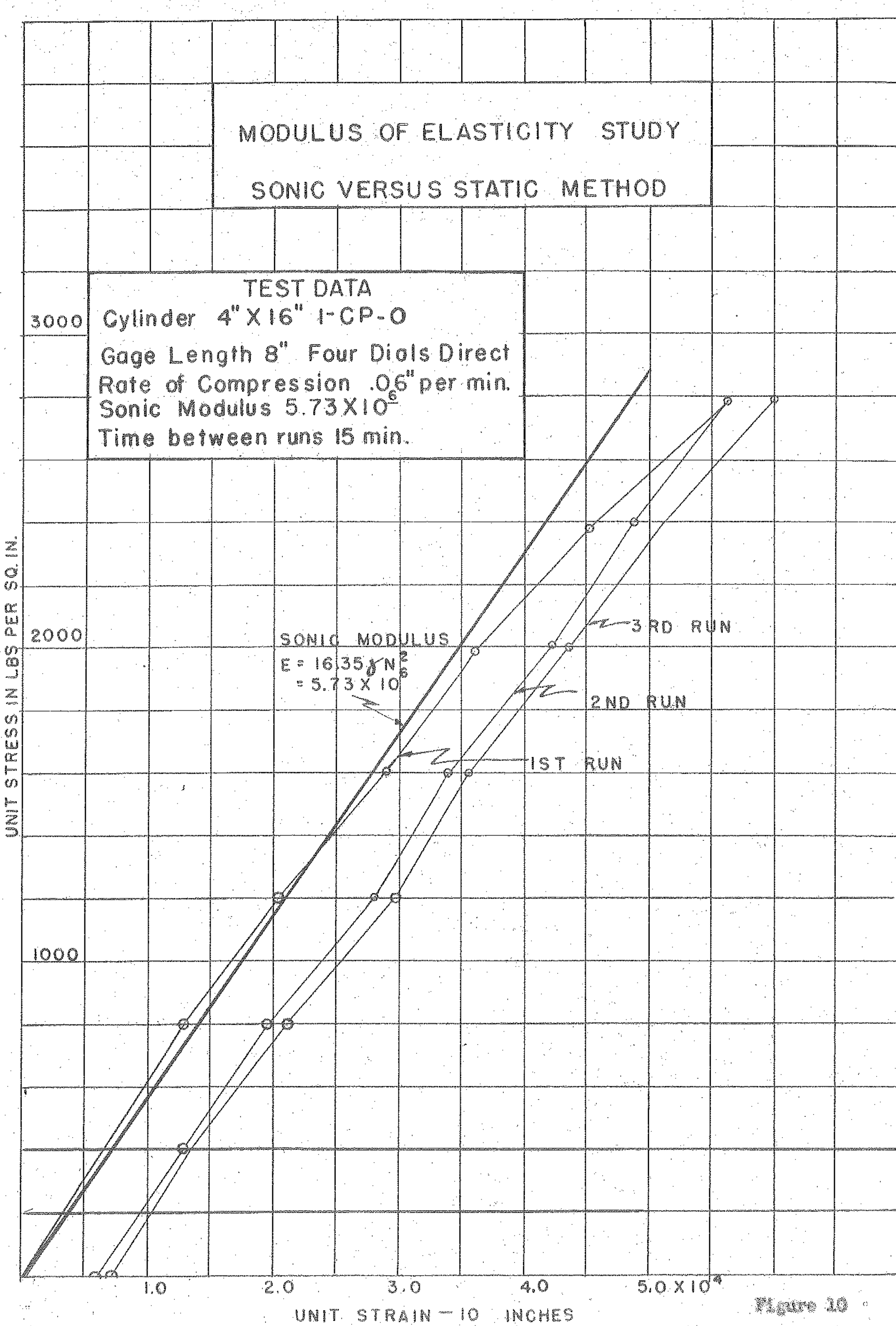
SUMMARY

On the basis of studies of the literature and results of laboratory tests on the subject of Young's modulus by the sonic method, the following general statements may be made:



MODULUS OF ELASTICITY STUDY
SONIC VERSUS STATIC METHOD
TEST DATA
Cylinder 4"X 16" 1-2 EFS-0
Gage Length 8" Four Dials Direct
Rate of Compression .06" per min.
Sonic Modulus 5.45 X 10^6
Time between runs 15 min.
SONIC MODULUS
E = 16.35 ƒ N^2
= 5.45 X 10^6
3RD RUN
2ND RUN
1ST RUN
3000
2000
1000
UNIT STRESS IN LBS. PER SQ. IN.
1.0
2.0
3.0
4.0
5.0
6.0 X 10^4
UNIT STRAIN — 10^4 INCHES

Figure 9


MODULUS OF ELASTICITY STUDY
SONIC VERSUS STATIC METHOD
TEST DATA
Cylinder 4" X 16" 1-CP-O
Gage Length 8" Four Dials Direct
Rate of Compression .06" per min.
Sonic Modulus 5.73 X 10^6
Time between runs 15 min.
3000
2000
1000
SONIC MODULUS
E = 16.35 γN²
= 5.73 X 10^6
3RD RUN
2ND RUN
1ST RUN
UNIT STRESS IN LBS PER SQ. IN.
1.0
2.0
3.0
4.0
5.0 X 10^-4
UNIT STRAIN — 10 INCHES
Figure 10

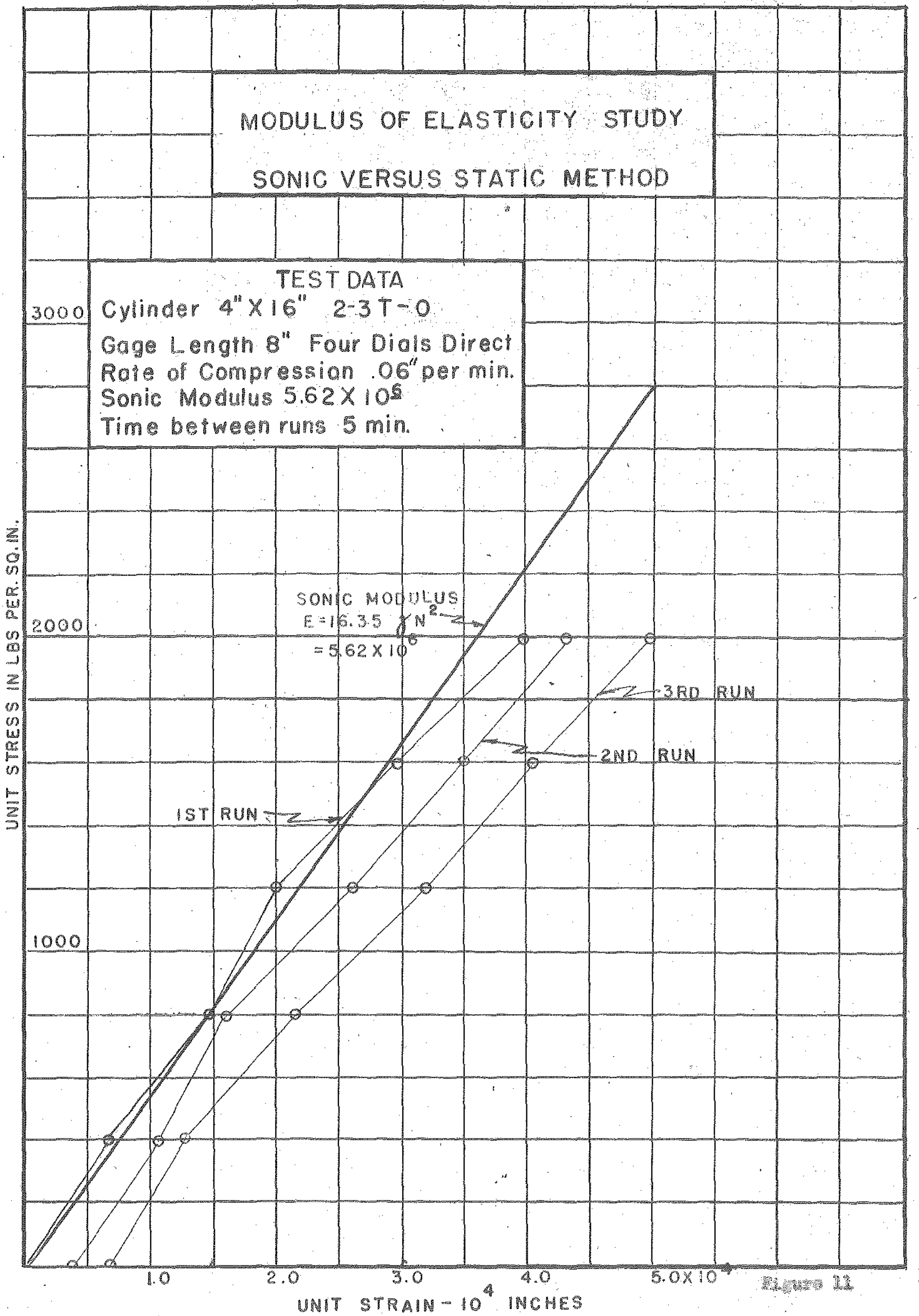
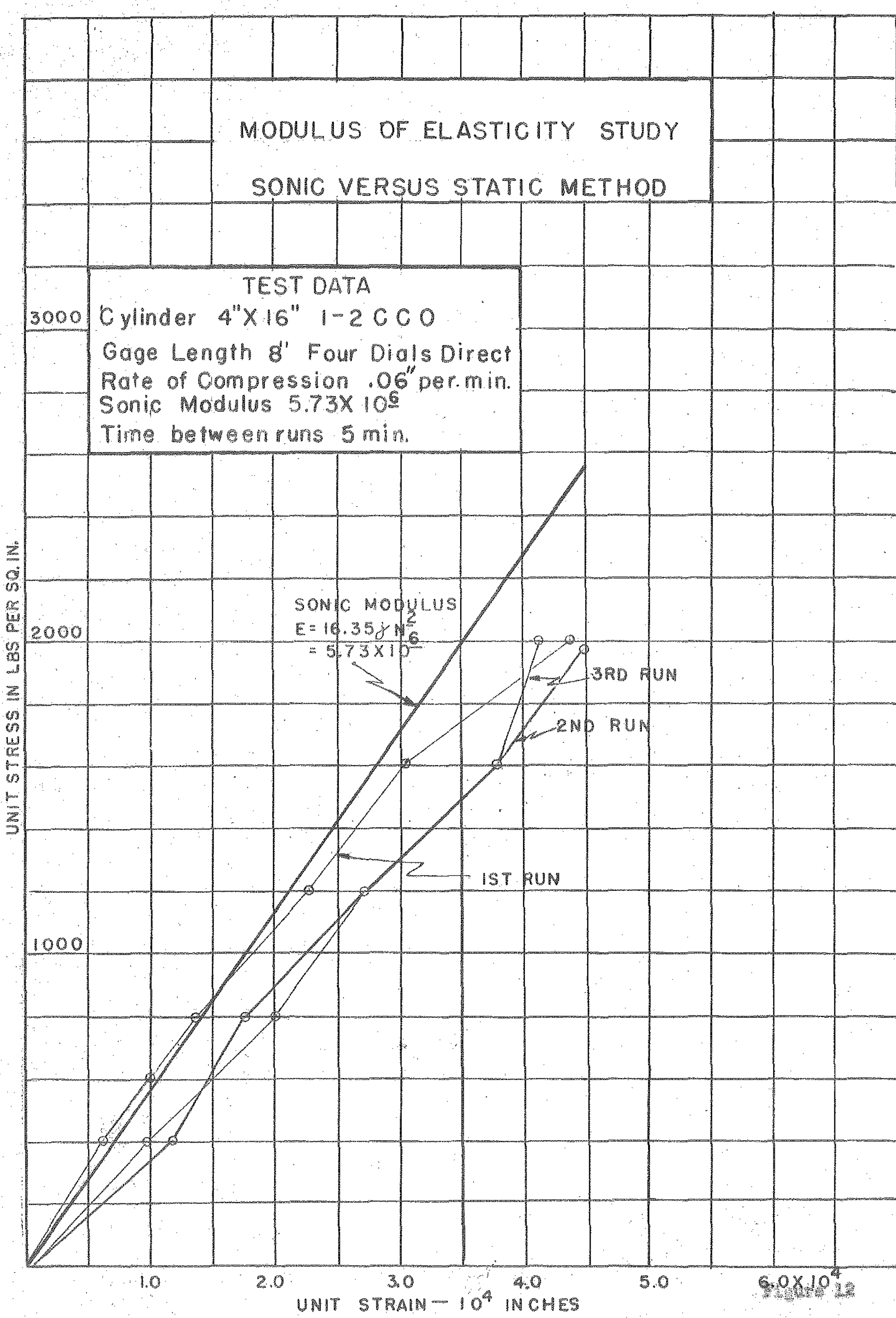
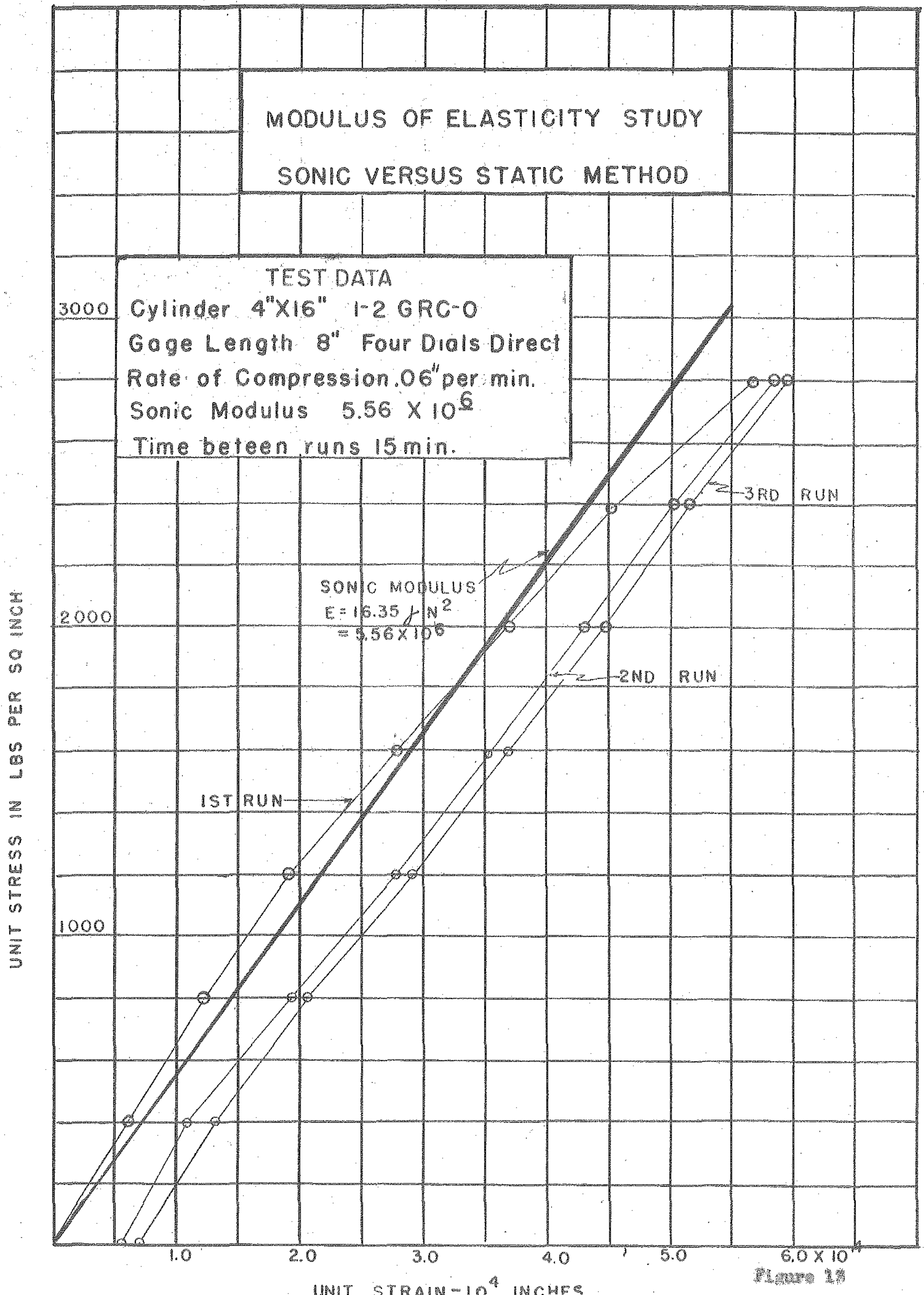

MODULUS OF ELASTICITY STUDY
SONIC VERSUS STATIC METHOD
TEST DATA
Cylinder 4" X 16" 2-3T-0
Gage Length 8" Four Dials Direct
Rate of Compression .06" per min.
Sonic Modulus 5.62 X 10^6
Time between runs 5 min.
SONIC MODULUS
E = 16.35 γN²
= 5.62 X 10^6
3RD RUN
2ND RUN
1ST RUN
3000
2000
1000
1.0
2.0
3.0
4.0
5.0 X 10
UNIT STRESS IN LBS PER. SQ. IN.
UNIT STRAIN - 10^4 INCHES

Figure 11



MODULUS OF ELASTICITY STUDY
SONIC VERSUS STATIC METHOD
TEST DATA
Cylinder 4"X 16" 1-2 C C O
Gage Length 8' Four Dials Direct
Rate of Compression .06" per. min.
Sonic Modulus 5.73X 10^6
Time between runs 5 min.
SONIC MODULUS
E = 16.35 γ N^2
= 5.73 X 10^6
3RD RUN
2ND RUN
1ST RUN
3000
2000
1000
UNIT STRESS IN LBS PER SQ. IN.
1.0
2.0
3.0
4.0
5.0
6.0 X 10^4
UNIT STRAIN — 10^4 INCHES

Figure 12



MODULUS OF ELASTICITY STUDY
SONIC VERSUS STATIC METHOD
TEST DATA
Cylinder 4"X16" 1-2 GRC-O
Gage Length 8" Four Dials Direct
Rate of Compression .06" per min.
Sonic Modulus 5.56 X 10^6
Time beteen runs 15 min.
3000
2000
1000
SONIC MODULUS
E = 16.35 / IN^2
= 5.56 X 10^6
3RD RUN
2ND RUN
1ST RUN
1.0
2.0
3.0
4.0
5.0
6.0 X 10^4
UNIT STRESS IN LBS PER SQ INCH
UNIT STRAIN-10^4 INCHES

Figure 15

1. Fundamental flexural frequencies of a specimen can be determined simply, rapidly, and accurately by means of the sonic method without harm to the specimen.

2. By determining the frequencies at given intervals, and converting these frequencies to values of Young's modulus, a continuous history of the specimen through accelerated freezing and thawing tests is readily obtained.

3. The natural frequency of a specimen of concrete is affected only to a negligible degree by temperature and moisture variations which could occur under the conditions of the test.

4. Flexural strength is closely related to the elastic modulus of the specimen as measured by the sonic method.

5. The dynamic method is the only kind of measurement that can give the true elastic modulus of those materials which exhibit permanent set or plastic flow. Since concrete falls within this category, the use of sonic values of Young's modulus is necessarily restricted to a study of relative change in the elastic properties of the material, and may not be applied as such to the computation of deflections of a concrete member, except where instantaneous values are required.

6. The sonic method makes it possible to determine evidence of failure, and to rate the relative behavior of test specimens considerably earlier than when judging the results according to appearance or loss in weight. Poor specimens can generally be detected within 20 cycles of freezing and thawing, and the changes in E for such specimens are large as compared with good concrete. The largest change in the modulus of elasticity takes place during the first few cycles of freezing and thawing, and even good concrete shows some decrease in the modulus of elasticity during this period.

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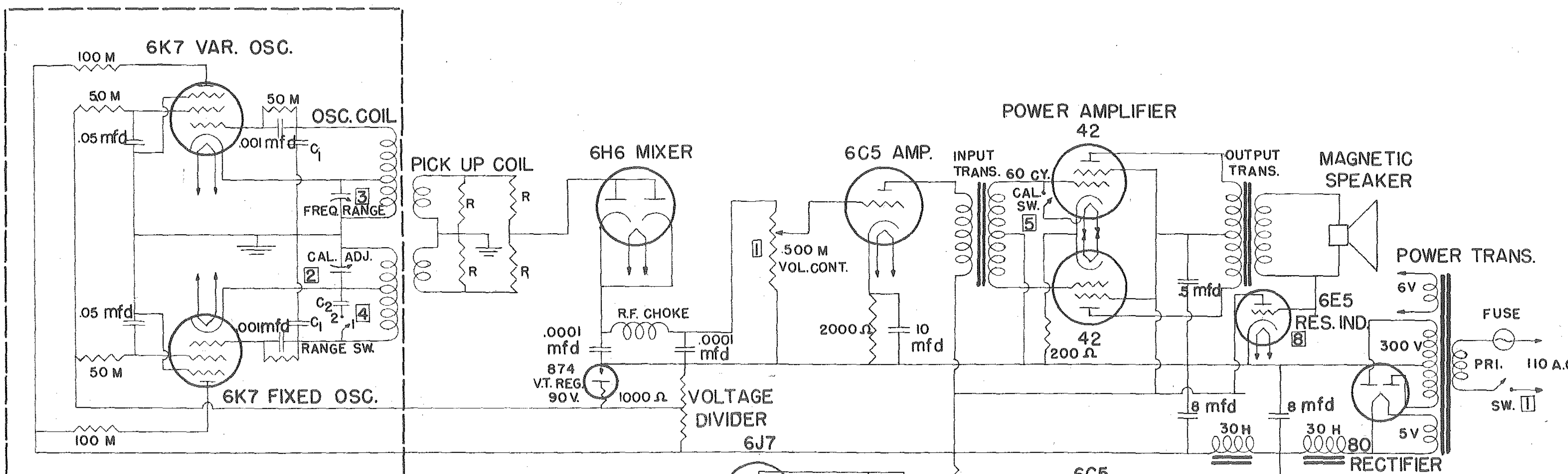
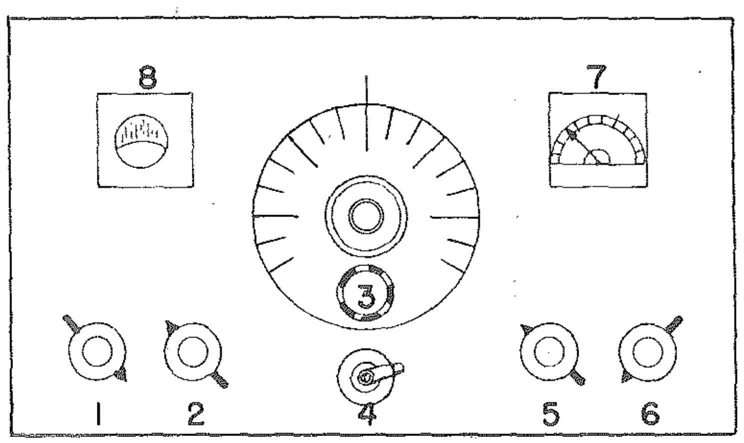
SCHEMATIC DIAGRAM OF SONIC APPARATUS FOR DETERMINING YOUNG'S MODULUS

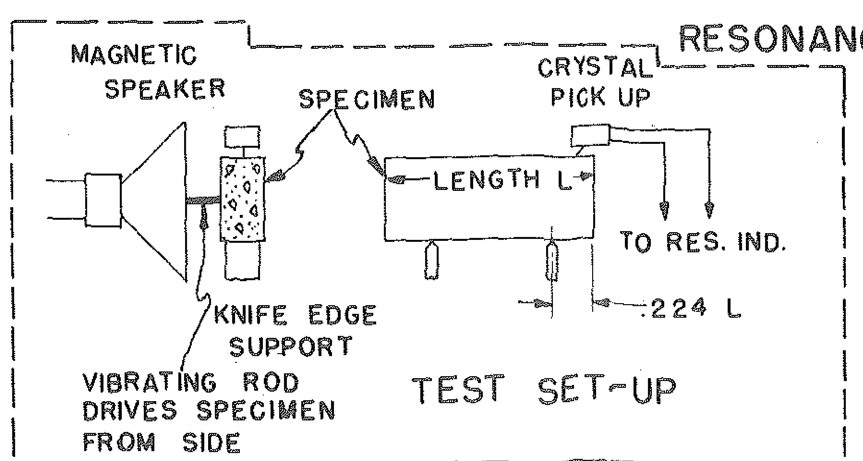


C_1 = OSC. COIL PADDING CONDENSERS - 50 mmfd VAR.
C_2 = 100 mmfd SILVERED MICA
FIXED OSC. FREQ. APPROX. 350 K.C.



CABINET PANEL

RESONANCE INDICATOR



TEST SET-UP

1 VOLUME CONTROL & POWER SWITCH
2 CALIBRATION ADJUSTMENT
3 FREQUENCY RANGE DIAL
4 RANGE SWITCH
5 60 CYCLE CALIBRATION SWITCH
6 ZERO ADJUSTMENT
7 MILLIAMETER RESONANCE INDICATOR
8 MAGIC EYE FOR CALIBRATION RESONANCE

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