A New Soniscope—"The Elastiscope"

DONALD R. LAMB, *Assistant Professor of Civil Engineering, University of Wyoming*

● A GREAT need has been felt for methods by which the quality of concrete could be determined without damage to the structure. It is necessary frequently to drill cores from field structures and to break the cores in the laboratory for strength determinations. In addition to the damage caused to the structure by the removal of the core, there is some evidence that the strength of the concrete may be reduced on the order of 10 percent by the operation of core drilling. Recent developments in the so-called sonic methods of testing allow the approximate estimation of strength and the determination of crack depths without cutting into or damaging the concrete in any way. The determination of strength is affected by many variables which are not now evaluated; as a result, this can be accomplished at present only in severely restricted cases. It is the purpose of this article to describe a new type of "Elastiscope" developed at the University of Wyoming.

Striking the concrete with a hammer and observing the "ring" has been a common practice for many years and is fundamentally related to the modern sonic procedures. It utilizes the basic principle that the tone or frequency of vibration is related, among other things, to the quality, or more precisely, to the modulus of elasticity of the concrete. The limitations of this method without modification lie in the circumstance that the dimensions, fixity, and support of the concrete also affect the tone. These difficulties can be overcome if regularly shaped concrete specimens of the same size are to be compared, and in 1938, T. C. Powers (*1*) described such a procedure in which he further obtained a numerical value for the tone by comparing it with a set of tuned metal bars of known frequency.

Further development of more convenient methods for evaluating laboratory specimens was rapid and today many testing laboratories use these methods. The fundamental natural frequency of the specimen is determined by causing it to vibrate at different frequencies by means of a driver actuated by a variable frequency oscillator. The relative magnitude of vibration is determined by a pickup, usually similar to a phonograph pickup, which has its output shown on a meter. The frequency which causes the greatest meter indication is recorded as the natural frequency of the specimen. The sonic modulus of elasticity is calculated by multiplying the square of this frequency by the weight of the specimen and by a constant depending on the dimensions: $E = CWn^2$. The procedure and equipment, as well as means for calculating the constant, are described in the American Society for Testing Materials Tentative Standard Method of Test C-215 52T (1952 Book of ASTM Standards, pp. 1072–1075). By a similar method, the fundamental torsional frequency can be determined and the modulus of rigidity calculated. Knowing both the modulus of elasticity and the modulus of rigidity, Poisson's ratio can be calculated.

These procedures are applied primarily at present in laboratory freezing and thawing tests to indicate the rate at which the concrete is deteriorating. The change in sonic modulus of elasticity gives a reliable indication of the change in the flexural strength of the laboratory specimens and this effect may be observed at different periods using just one specimen. An illustration of the type of data obtained is given in Figure 1, which shows the change in sonic modulus during freezing and thawing of concretes with different properties.

In certain other accelerated weathering tests, a considerable amount of cracking and reduction in strength may occur without a corresponding drop in sonic modulus. Among the cases in which this may occur are the alternate wetting and drying test and the alternate heating and cooling test. When cracking of the concrete occurs from these exposure conditions, it is probable that the material deposited in the cracks is an effective binder at the extremely low stresses induced by the sonic test, even though the concrete is greatly weakened. It is pertinent to note that the sonic modulus is higher, numerically, than the modulus of elasticity determined by static methods, and represents the tangent modulus of elasticity at approximately zero stress; hence it is free from the effects of plastic flow which act to give a reduced modulus in the static tests.

As mentioned above, the strength of the concrete is related in a general way to these elastic properties. However, different types of aggregates give different relationships, one aggregate showing higher strength than another for concretes with the same sonic modulus. The moisture content of the concrete also affects the relationship, drier concrete having a lower sonic modulus for a given strength. These and other variables require extensive study as their evaluation is particularly important to the extension of the application of direct measurements on structures in the field. The indications are that this evaluation will be successful and it will be possible to utilize dynamic methods in a wider and wider variety of field problems.

The determination of the sonic modulus of structures of irregular shape requires the measurement of the velocity of a sound wave in the concrete, an estimate of the concrete density and of its Poisson's ratio. Since the velocity in good concrete is on the order of 15,000 feet per second, extremely small time intervals must be measured. Several instruments have been constructed for this purpose; one outstanding device is the "Soniscope" developed by Leslie and Cheesman (*2*). With this instrument, measurements over distances as great as 40 feet have been made and it has been most useful in detecting cracks in the interior of mass concrete.

A simplified type of apparatus, tentatively termed an "Elastiscope," has been developed at the University of Wyoming. This instrument can be used to measure the velocity of a supersonic wave through 1 to 5 feet of concrete, a range which appears to be suitable for many structures.

OPERATION

Referring to Figure 2, a 115-volt, 60-cycle, alternating current is fed to a high gain twin triode. This is used as an overdriven amplifier to provide square waves. These are differentiated to sharp pulses in the differentiating circuit. The sharp pulse is fed to a 2050 thyratron which serves as the pulse and sweep generator. The firing of the thyratron provides pulses to the magnetostriction driver which causes it to vibrate at its resonate frequency.

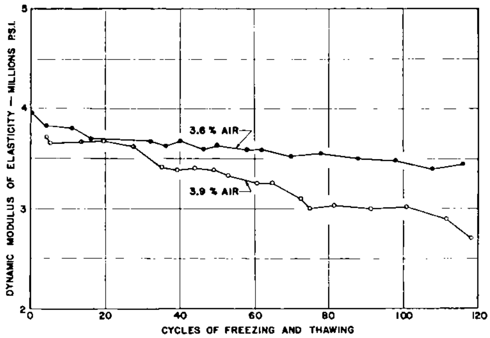

Figure 1. Effect of freezing and thawing on dynamic "E" of concrete.

These vibrations are transmitted to the concrete. The sound pulse is picked up through the back of a crystal microphone. The pickup is designed to resonate at 24 kc. with good response from 20 to 30 kc. The signal is amplified through a high gain three-stage pentode amplifier and fed to the vertical plates of the cathode ray tube.

The same thyratron that provides the pulses to the magnetostriction driver is used to provide the sweep voltage. This sweep voltage is fed through a sweep amplifier to the horizontal plates of the cathode ray tube.

This same sweep voltage is fed to another thyratron which provides the step voltage. This step voltage is applied to the upper vertical deflection plate.

Referring to Figure 3, the magnetostriction driver consists of a nickel tube of quarter wave length in which a permanent magnet has been placed for polarization. On one end a brass tip has been placed for two purposes: one to support the magnet and the other for the purpose of transmitting the pulse from the nickel tube to the concrete. By utilizing a point, the high unit pressure can be applied by hand. The other end is welded to a plate that is secured to a heavy lead weight. The weight also serves a twofold purpose: one is to give the operator a convenient object to grasp and the other is to help produce maximum vibration, due to inertia of the weight, to transfer the energy to the concrete sample.

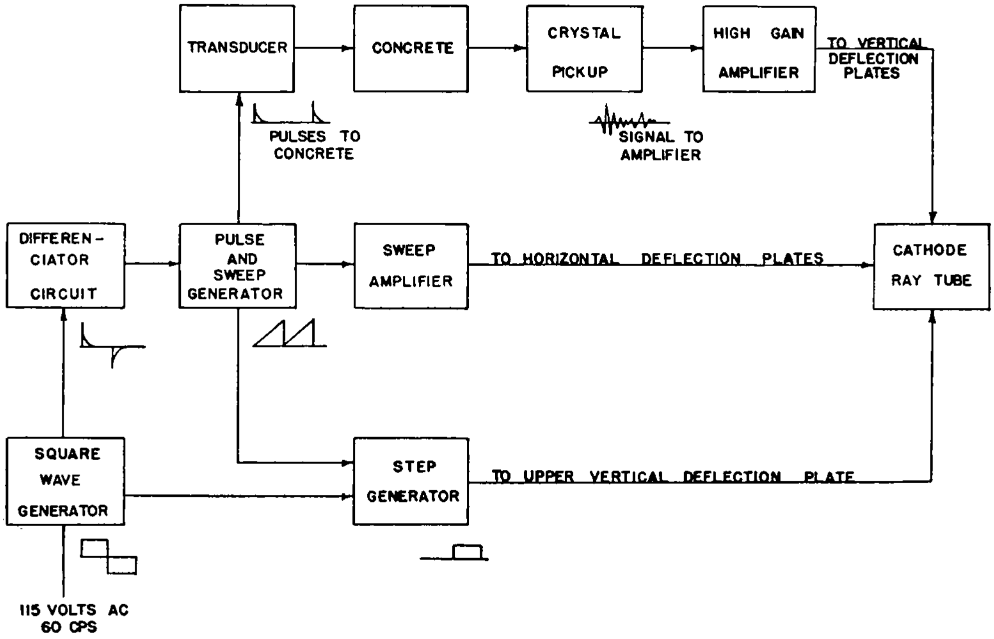

Figure 2. Schematic diagram of Elastiscope.

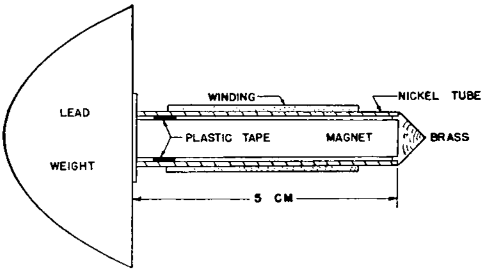

Figure 3. Magnetostriction driver.

The driving pulse is provided by the discharge of a condenser through the 2050 thyratron tube. Immediately following the discharge of the condenser through the tube, the tube de-ionizes and the condenser begins to recharge. The exponential rise of voltage is applied to the horizontal plates of the cathode ray tube as the sweep voltage. This makes it possible to use the 2050 thryatron tube both as pulse generator and sweep generator. The transmitted pulses are synchronized by peaks of voltage occurring at a repetition rate of 60 cycles per second. A high gain twin triode 6SN7 tube is used as an overdriven amplifier to provide square waves and the square waves are differentiated to sharp pulses in a condenser and resister circuit. The negative pulses are amplified during a period of non-conduction and have no effect. The rise of voltage at the plate of the pulse generator is from zero to about 130 volts. This voltage is applied through a voltage divider to the grid of the other 2050 thyratron which is used as the step generator. A positive voltage, selected by a precision potentiometer, is applied to the cathode and determines the point at which the thyratron, which produces the step, begins to conduct. When it conducts, the voltage at the cathode rises to a steady state value during the remainder of the cycle.

This rise in voltage is fed to the lower vertical deflection plate, producing the step. A part of the output of the square wave generator is coupled to the cathode of the 2050 thyratron step generator which serves to de-ionize it at the end of the sweep.

The presentation of the "Elastiscope" on the scope appears as a straight line with a step. The signal from the crystal pickup after being amplified is then superimposed as shown in Figure 4.

MODIFICATIONS

The following defects were noted throughout the work with the original equipment:

1. The crystal pickup originally used was not efficient for frequency used.
2. The signal strength of the transducer was very weak.
3. The amplifier did not give enough amplification.
4. More amplification of sweep was needed to increase the accuracy.

The crystal that was available at that time was one from a regular hearing aid unit that had a resonate peak at 3.5 kc. Another unit, with a resonate peak at 24 kc. and with a usable frequency range of from 20 to 30 kc. was obtained. This unit gives much better response.

The half wave length magnetostriction driver gave very weak signals. It was decided that by using a magnetostriction driver of quarter wave length and a heavy weight on one end, a node would be produced at that end instead of the middle of the magnetostriction driver; hence, maximum vibration would be produced at the other end of the tube. When this was tried, it proved very satisfactory with a much stronger signal and less distortion, but the frequency was lowered to 20.5 kc. The lowering of the frequency will not cause trouble because the amplifier was tuned to this frequency and is still within the range of the crystal pickup.

The amplifier proved to be the most critical component. Because of the very small signal picked up from the concrete, it was necessary to have a very high gain amplifier. With such an amplifier the stray pickup of the 60-cycle frequency was very troublesome. Also, the direct current surge voltages from the first and second stages broke down the coupling capacitor between the second and third stages. This was efficiently remedied by the use of a coupling transformer with its secondary side tuned to the signal frequency of 20.5 kc.

When measuring small lengths of concrete, the signal appears very close to the beginning of the sweep. Because of this, the accuracy of the "Elastiscope" was greatly reduced. Another amplifier was added to the sweep circuit to give a larger horizontal spread, so that the leading edge of the incoming signal could be more easily distinguished.

Figure 4 shows the trace on the scope of the "Elastiscope" and Figure 5 shows the position of the step in the cathode ray track when a signal is received. The final wiring diagram of the "Elastiscope" is shown in Figure 6.

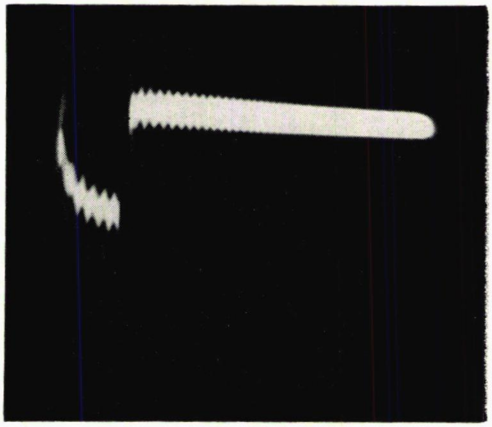

Figure 4. Step and signal as seen on the "Elastiscope."

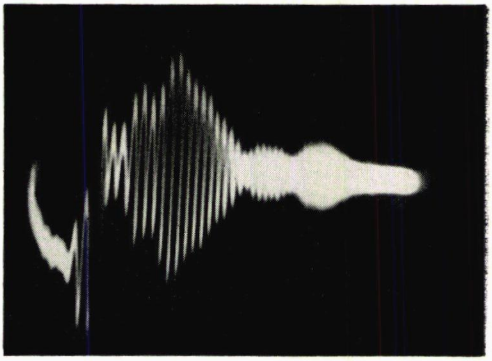

Figure 5. Signal on cathode ray tube trace.

The "Elastiscope" has been used along with the laboratory resonant frequency in checking controlled specimens as they change in properties during curing and later air drying.

ACKNOWLEDGMENTS

The author wishes to thank the many laboratory assistants who helped in the work, especially Robert Mears and Roy Henderson; also the members of the Electrical Engineering staff, Professor V. O. Long, Head of the Department, and R. Kenneth Beach who gave their time and knowledge; and to Professor A. J. McGaw, Head of the Civil Engineering Department, who both encouraged and gave his time and energy to the author.

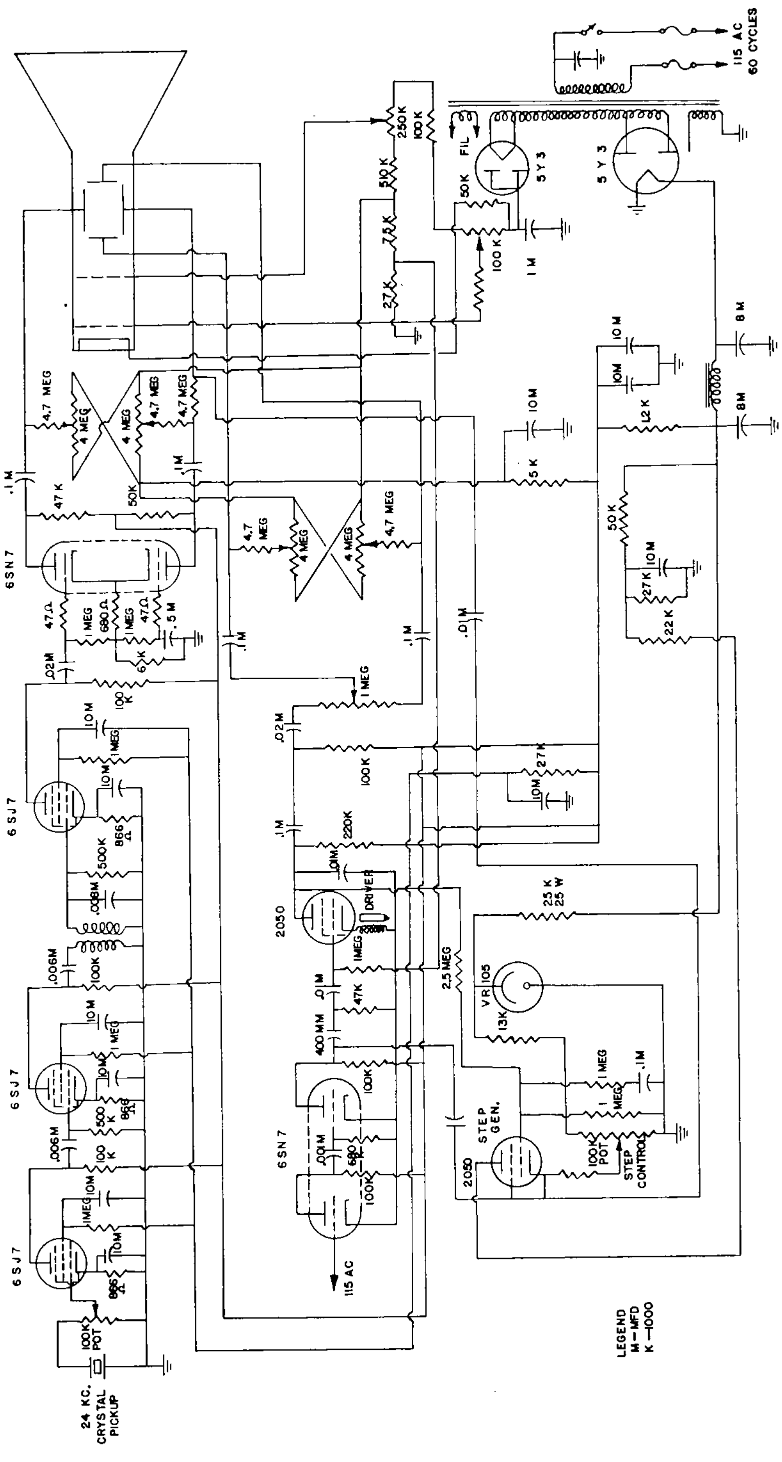

Figure 6. Circuit diagram for Elastiscope.

REFERENCES

1. Powers, T. C., "Measuring Young's Modulus of Elasticity by Means of Sonic Vibrations," Proceedings, ASTM, Vol. 38 Part II, 1938.

2. Leslie, J. R., and Cheesman, W. J., "An Ultrasonic Method of Studying Deterioration and Cracking in Concrete Structures," Proceedings, ACI, Vol. 46, 1949.

APPENDIX

TABLE 1
DYNAMIC MODULUS OF ELASTICITY AND ITS ASSOCIATED PULSE VELOCITY FROM THE ELASTISCOPE

Dynamic Modulus of Elasticity	Pulse Velocity
psi	*ft./sec.*
3,780,000	11,100
3,900,000	11,010
4,370,000	12,800
4,560,000	12,600
4,625,000	12,700
4,760,000	12,800
5,060,000	13,063
5,310,000	13,700