DYNAMIC TESTING OF CONCRETE WITH THE SONISCOPE APPARATUS

W J. CHEESMAN, *Assistant Research Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Canada*

SYNOPSIS

The Soniscope is an instrument which has been developed to measure the velocity of transmission of ultrasonic pulses through concrete The dynamic modulus of elasticity of the concrete can be calculated from this pulse velocity, and the values so obtained have been found to agree closely with tests by the flexural resonance method. The Soniscope test method has the advantage that it can be applied equally well to field structures, pavements, and laboratory specimens, regardless of their size or shape

Soniscopes have been used extensively during the past two years by the Hydro-Electric Power Commission in Ontario, and the Portland Cement Association in the United States, to examine dams, bridges, pavements and long-time study field specimens The pulse velocity has been found to be a reliable measure of the quality or condition of the concrete While many areas of advanced deterioration can be found by older test methods, such as hammer tapping, the Soniscope detects incipient trouble and has the great advantage of providing a quantitative rather than a qualitative assessment of the concrete The pulse velocity in good concrete is from 13,000 to 16,000 ft per sec , while velocities under 5,000 ft. per sec. have been found in badly deteriorated portions of field structures

The dynamic modulus of elasticity has been found to be a very useful quantity in studies of the quality and the performance of concrete, and the flexural resonance method of determining it has become widely used and accepted The advantages of a non-destructive method such as this are obvious The resonance method has the limitation, however, that the calculations involve the size and shape of the specimen, which limits its use in practice to laboratory specimens of simple geometry

The techniques, such as those developed by Long, Kurtz and Sandenaw, for measuring velocity of longitudinal waves in concrete provided a method of determining its dynamic modulus of elasticity in the field Low frequency waves, generated by a hammer blow, are used in this method, resulting in some limitation of its scope During the past three years devices for measuring the time of transmission of high frequency or ultrasonic pulses through concrete have been developed independently by the Roads Research Laboratory in England, and the Research Division of the Hydro-Electric Power Commission in Ontario The British apparatus was designed for the study of laboratory samples and at present has a maximum range of about four feet, so that its field application is limited. At the Ontario Hydro-Electric Power Commission the original purpose of the project was to devise a means of discovering the existence of and measuring the extent of cracks in mass concrete.

The Soniscope, which was developed for this purpose, is suitable for the accurate measurement of the time of transmission of ultrasonic pulses through concrete bodies from 1 to 50 ft. thick Therefore it can be used to determine the dynamic modulus of elasticity of the concrete of pavements, mass concrete structures and laboratory specimens.

APPARATUS

The Soniscope consists of three main components (Fig 1) An electronic control chassis, weighing about 60 lb , houses a pulse generator which drives the ultrasonic transmitter and amplifiers for the received signal, and a cathode ray tube and its associated circuits. The ultrasonic transmitter (Fig 2) is a block of piezoelectric crystals housed in oil and covered with a rubber diaphragm. The receiver (Fig 3) also consists of a block of crystals, coupled to a battery-operated preamplifier so that long cables can be used between the control unit and the transducers

METHOD

Three groups of waves are generated by any disturbance in a solid medium. These are the longitudinal or compressional waves, the shear or transverse waves, and the Rayleigh or surface waves. The compressional waves have the greatest velocity, travelling at about 15,000 ft. per sec. in good concrete, and it is the group velocity of these waves which is read by the Soniscope. The shear and Rayleigh waves have velocities in concrete which are about half as great as that of the compressional wave. In some cases their group velocities can be measured with the Soniscope, but this is generally difficult because of interference from later waves in the compressional group.

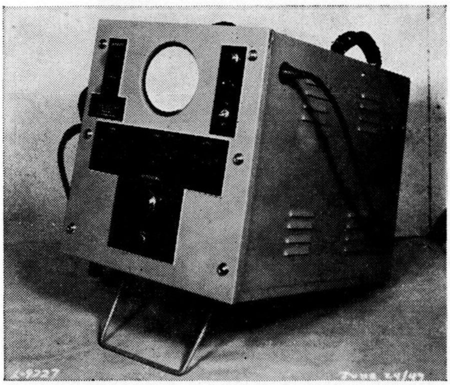

Figure 1. Soniscope Control Unit

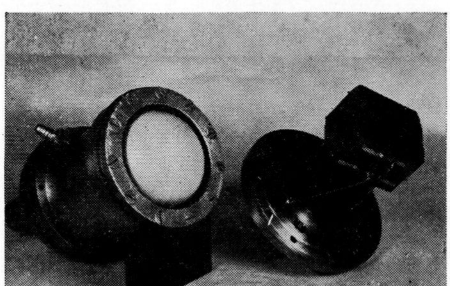

Figure 2. Soniscope Transmitter

Figure 4 shows the three types of waves. This transmission was through a monolith about 30 ft. thick, with the transducers each about 10 ft. from one side. Thus the path of the compressional and transverse waves was 30 ft., but that of the Rayleigh wave was 50 ft. So far, it has been only in such situations as this that we have been able to distinguish the three groups. Measurement of their velocities would be of value because, while only the compressional velocity is involved in the formula for the modulus of elasticity, knowledge of Poisson's Ratio for the material is also required, and it is proportional to the ratio of any two of these velocities.

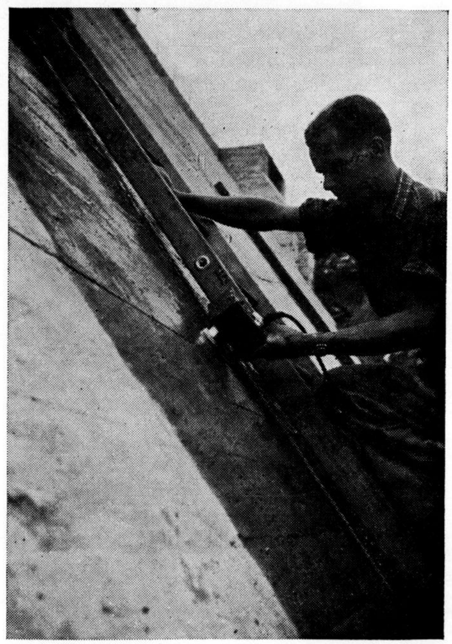

Figure 3. Soniscope Receiver—Held Against Downstream Face of Dam

In using the Soniscope the rubber window of the transmitter is pressed firmly against the concrete surface, which is wetted with either oil or water to give good transmission of the ultrasonic pulse, and the receiver is similarly placed at the other end of the piece of concrete under test. As seen in Figure 4, the transmitted and received pulses are displayed in Radar fashion and the elapsed time between them can be measured to an accuracy of better than one per cent. The effective beam width of both the transmitting and receiving units is quite wide so that they need not be pointing towards each other for adequate signals. Thus transmission times can be measured across corners with the faces of the transducers at right angles to each other. This fact is particularly useful in testing pavement slabs, since it allows the transmitter to be placed on the edge of the slab at the shoulder and the receiver held at various points on the upper surface.

The concrete tested in this way will be that lying in the diagonal path from the transmitter to the surface at the receiver. By measurements over several such paths the average modulus of the concrete in any portion of a slab can be found. Pulse velocities can also be measured between two points on the surface of a slab, but this method may only test the surface layer of concrete. It must be appreciated, however, that it is inherent in the Soniscope method that the transmission time measured is that of minimum elapsed time, and since the presently used transducers are not directional, it is not necessarily the time for a pulse to travel the shortest distance between the transducers. While this fact may appear to be a weak point in the method, since the straight line distance is used in calculating the velocity, it has the advantage that it tends to make the velocity readings something of a "weighted average" for the concrete lying between the transducers.

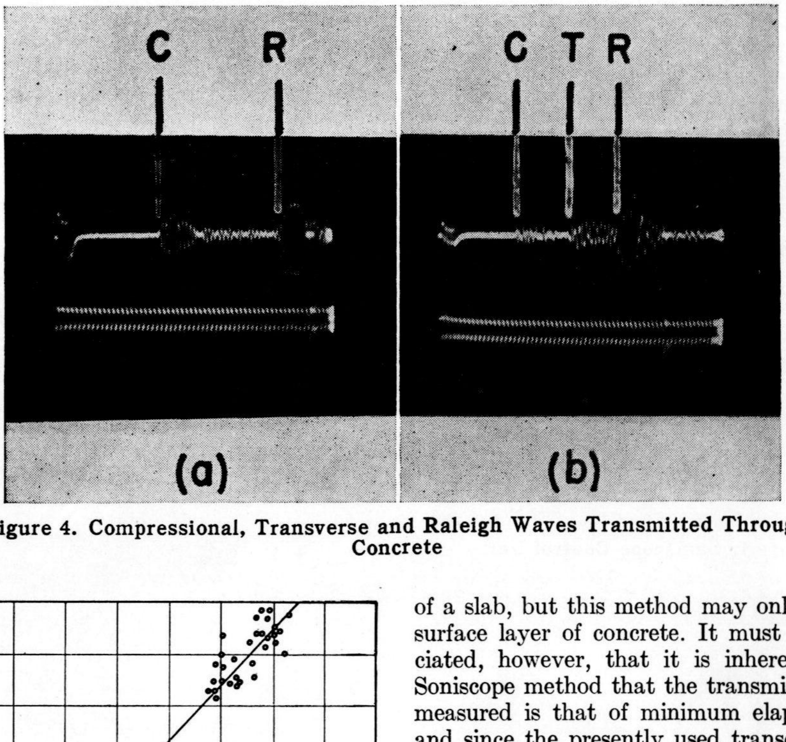

Figure 4. Compressional, Transverse and Raleigh Waves Transmitted Through Concrete

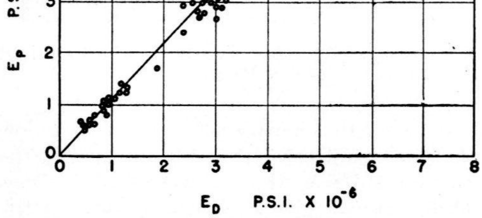

Figure 5. Correlation Between Dynamic and Pulse Modulus for 300 Laboratory Beams 16 by $3\frac{1}{2}$ by 4 in.

LABORATORY MEASUREMENTS

In order to correlate the Soniscope tests with the modulus value obtained from the resonance or sonic method, tests were made on beam specimens of normal concrete and three lightweight mixes, all of which were subjected to freezing and thawing cycles. Values of Poisson's Ratio, which are required for calculation of the modulus from the pulse velocity, were found by measuring the torsional as well as the flexural resonance of the beams (Fig. 5).

Using these values good correlation was found between E_D, which is the modulus from the flexural method, and E_p which is that calculated from the pulse velocity. Only a representative selection of points are plotted on this graph.

That it is just as satisfactory to use the pulse velocity itself as a measure of the quality of the specimens, without the necessity of calculating the modulus from it, is illustrated by comparing the deterioration curves of one specimen (Figs. 6 and 7).

designed for tests on large structures, the accuracy is very low on specimens under one foot long. Modifications are being planned to increase this accuracy. They consist chiefly of using transducers of higher frequency to give a sharper leading edge to the pulse, and reduction of the length of the oil path between the crystals and the rubber diaphragm, since this introduces a correction which varies with the pressure applied. The time required to make a test depends only on difficulties involved in placing the transducers. Once these are correctly placed the transmission time can be read in a second.

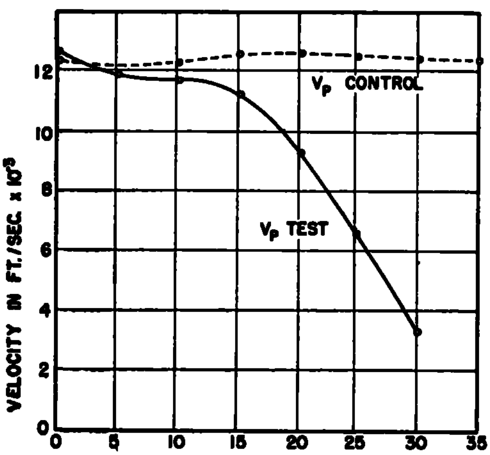

Figure 6. Decrease in Pulse Velocity in a Specimen Undergoing Freezing and Thawing

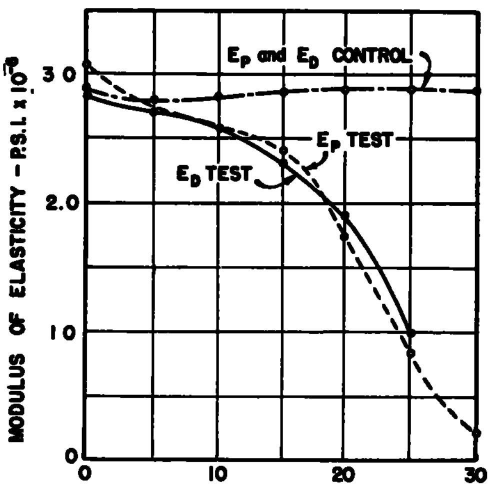

Figure 7. Comparison of Pulse and Sonic Modulus in a Specimen Undergoing Freezing and Thawing

Soniscope apparatus is now in regular use in the Concrete Laboratory of the Ontario Hydro-Electric Power Commission for determination and comparison of the modulus of concrete mixes, and to follow changes in them as they undergo various treatments. Data are also being gathered on the relation between the pulse velocity and compressional strength, by making a Soniscope measurement on cylinders just before they are compression tested.

It has also been found possible to follow the build up in strength of concrete during the setting and curing periods by casting it in forms fitted with rubber windows for the transducers and measuring the increase in velocity during the first hours after casting. Since the present apparatus was primarily

FIELD MEASUREMENTS

In the three years that we have had this apparatus, it has been used very extensively in the field, chiefly on our new water-power developments, of which two have been completed recently and five others are still under construction. Within the limitation of the present transmission range of 50 ft., the structures are examined for internal cracks and the depths of visible surface cracks are measured. No serious internal cracks have been found. Periodic readings are taken on the surface cracks. Most of them decrease in depth as the structure cools.

On all our new projects we are taking datum values of Soniscope pulse velocity in the concrete at several representative points, and can follow any changes that occur in the future In the unusual cases, where damage to the concrete has possibly been caused by such accidents as a fire in the formwork or rupture of the forms before the concrete is set, the Soniscope can and has been used to ascertain that no deep-seated damage has resulted. Should the test cylinders made during the pour and tested 7 and 28 days later, show that some batches of the concrete may not have been quite up to standard, the Soniscope provides a quick non-destructive way of testing these areas periodically. Thus it can be determined whether this concrete does attain a final strength acceptable for the structure.

By the middle of 1950 we will have taken about 30,000 Soniscope readings on one of our older dams. This is a slab and buttress type of structure erected in 1914, which has already required three repairs and is still deteriorating

Prior to the development of the Soniscope it was our practice to inspect this dam by tapping it with a hammer and thus mapping out the areas in which the concrete sounded dead or bad. The new apparatus, which is fundamentally a quantitative measurement using the same underlying principle as the hammer tapping, is now being used to study this structure foot by foot While much is already known about the causes and nature of its deterioration, further knowledge will be gained now by these quantitative tests, which knowledge should be of great general use, in addition to providing guidance for any future repairs of this dam Some idea of the wide range of quality of the concrete at present in this structure is given by the fact that the Soniscope velocities measured in it vary from 16,000 ft. per sec to as low as 1,000 ft. per sec We are planning to remove cores from some of these low velocity areas for close examination of the material.

TABLE 1
PULSE VELOCITY TESTS ON CONCRETE PAVEMENTS

Test No	Compressional Pulse Velocity, fps	Age, years	General Condition	
			Rating	Details
1	15,800 to 16,000	2	Excellent	Air-entraining concrete, 6 bags cement per cu yd of concrete, compressive strength of standard test cylinders 7-day—2100 psi 14-day—3000 psi 28-day—3600 psi
2	16,000	18	Good	Some transverse cracking, very little scaling
3	16,200	23	Good	Some transverse cracking, very few popouts, sound aggregate
4	15,900	21	Good	Some transverse cracking, non-progressive scaling
5	16,000	20	Fair	Slight map cracking, some disintegration and scaling at joints
6	16,200	18	Fair	Some transverse cracking
7	15,400	24	Fair to good	Some disintegration at transverse cracks, a few popouts
8	13,300 to 14,100	16	Poor to fair	Bad popouts, considerable chert in aggregate
9	8500 to 15,300	20	Poor to fair	Breaks due to chert aggregate and subgrade failure, no popouts
10	8000 to 14,000	19	Poor to fair	Disintegrating, aggregate high in chert, rotten gneiss, argillaceous limestone
11	9000 to 12,000	18	Poor	Disintegrating, aggregate high in chert and soft stone
12	7000 to 13,000	18	Bad	Many popouts, aggregate very high in chert content
13	6300 to 15,100	19	Very bad	Almost complete disintegration in places, cracking in all directions and progressive scaling, aggregate very high in chert

Another hydraulic structure which we tested recently was 45 years old, but only a surface layer of concrete on its south and west sides was found to be of low velocity In the remainder of it, velocities varied from 13,000 to 16,000 ft per sec

A few Soniscope tests of pavements were made by us in cooperation with the Ontario Department of Highways (Table 1)

In all but the first case only visual rating was available for comparison, but on this basis the velocity seemed to be a good indication of the condition of the concrete. The Portland Cement Association began this year to use their Soniscope in the long-time study test roads and in some work at Kansas State College and it will be interesting to hear their findings.

CONCLUSION

Based on the experience to date it appears that for standard concretes velocities of 12,000 to 16,000 ft per sec. indicate that its condition is good to excellent. Even with high water cement ratios at the extreme end of a series of proportioning tests, velocities under 12,000 ft. per sec. in cured specimens have rarely been found Therefore, we believe that velocities from 12,000 down to 10,000 ft. per sec. indicate what might be called "border line" concrete or "incipient deterioration" in older structures. In all cases where velocities under 10,000 ft. per sec. have been found some other evidences of trouble have usually been present and therefore any velocity under this value has come to mean bad concrete to us.

The Soniscope appears to be a reliable measure of the condition of concrete, and the fact that it is an impersonal quantitative test which can be used in the field, should make it very valuable for studies of durability in actual pavements and structures, as well as laboratory specimens.

REFERENCES

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2. Jones, R , "The Non-destructive Testing of Concrete," Mag. of Concrete Research (London, England) June 1949, No 2, p 67
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DISCUSSION

W. J. Arndt, State Highway Commission of Kansas—In Kansas, we were fortunate to become experienced in the use of the Soniscope for concrete pavement examination through the past summer and fall Through Professor Scholer of Kansas State College, we obtained a loan of the Soniscope which had originally been the property of the Portland Cement Association. We obtained the services of an electronics engineer from the staff at Kansas State College, to conduct the tests.

He was permitted to spend some time in the laboratory of the Portland Cement Association in Chicago, familiarizing himself with the mechanics and the working of this piece of apparatus. This training period enabled him to have a fundamental understanding of the Soniscope, but, having had no actual experience, much more was learned during the following weeks. He found, after working with the Soniscope for a month or so, that much of his technique had to be revised from time to time to enable him to obtain accuracy and to properly interpret the wave which appears on the scope. This electronics engineer, Mr. J. G. Chubbuck, knew nothing about concrete. This fact was quite advantageous since the operator must interpret the sound wave which appears and is apt to be influenced by the type of concrete which he is measuring if he is conscious of the fact that that particular piece of concrete is in a particularly obvious condition.

The same idea applies to the operator, who must be a specialist in electronics. The Soniscope has such a complicated series of hook-ups and parts that it is absolutely necessary for the operator to have complete knowledge in this field.

We believe the Soniscope has great possibilities for examining the condition of concrete pavements and structures, simply and without destruction. At the present time, Mr. Chubbuck is assembling the parts for the construction of a new and more compact Soniscope from blueprints sent to us recently by Mr. Cheesman and Mr Leslie

The State of Kansas constructed two concrete pavement test roads during the past summer (1949). One, 5 miles long near McPherson, consisted of 60 sections using various pozzuolanic additions to five different cements. The purpose of this test was to attempt to reduce concrete expansion. The cements used ranged in reactivity from high to low. As is commonly known, this reactive expansion manifests itself by serious map cracking and decreased densities.

We have taken a series of initial ultrasonic readings on each of these sections at an age of 28 days. We intend to repeat these readings every 6 months and anticipate that we will eventually be able to detect the expansion by is being presently produced by most manufacturers This cement was called "modern cement." The third cement was that which is chemically similar to modern cement but was ground to a fineness the same as the "old fashioned" cement. This third type was called "modern-coarse ground" cement.

The Soniscope readings on each section have been recorded at the age of 28 days. Further readings will be taken each 6 months hereafter as on the McPherson project. The purpose of the Topeka readings is to measure a different character of change than on the McPherson project On this project, we are attempting to achieve a concrete that has a continuous

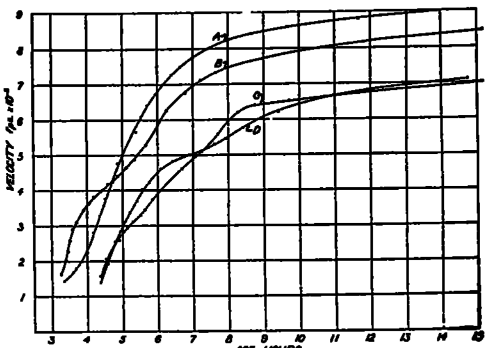

Figure A. Velocity Vs. Early Age—Topeka Project — Three Types of Cement — Pouring Temperature 75 to 85 F.
Curve A—1.43 Cement Factor, Modern Cement
Curve B—1.72 Cement Factor, Modern Cement, Coarse Ground
Curve C—1.72 Cement Factor, Old Fashioned Cement
Curve D—1.62 Cement Factor, Old Fashioned Cement

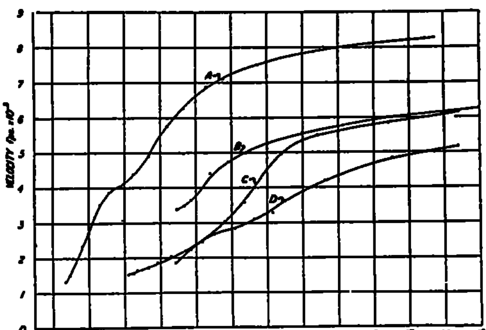

Figure B. Velocity Vs. Early Age—Topeka Project — Three Types of Cement — Pouring Temperature 65 to 75 F.
Curve A—1.62 Cement Factor, Modern Cement
Curve B—1.62 Cement Factor, Modern Cement, Coarse Ground
Curve C—1.62 Cement Factor, Old Fashioned Cement
Curve D—1.43 Cement Factor, Old Fashioned Cement

sonic measurements. The original readings on each of these types of concrete has resulted in detection of different sonic moduli. We have not yet had time to correlate these readings with the strength of the concrete since the project was finished only within the past month or two.

The second of the concrete pavement test projects consisted of 8 miles of 22-ft. pavement south of Topeka on U. S. 75. This project consisted of 36 sections composed of concrete made of cement meeting the analysis of "old fashioned" cements as made about 1925, that is lower C_3S and a coarser grind than is common today. The second cement was that which

strength gaining ability. This we hope to obtain in the sections which contain the old fashioned cements and perhaps the modern-coarse ground cements.

Both test projects have test slabs adjacent to each of the experimental sections. Each slab will produce 20 6-in. by 9-in. by 6-ft. beams. One beam from each slab will be tested for modulus rupture each 6 months at the same time that the ultrasonic measurements are made. With these data, we should be able to build up a correlation between the ultrasonic readings and the modulus of rupture.

The construction of the Topeka project produced a series of extremely interesting

Soniscope readings involving the three cements, "old fashioned," "modern" and "modern-coarse ground." There was a distinctly noticeable difference in the setting times and the setting phenomena for each of these three different types of cements. The old fashioned cement was slow to set and would bleed at the surface for as long as 3 hr. after placement even though the weather was hot, dry and windy. The modern cement, on the other hand, was quick to set and at times the finishers would have great difficulty in creating the joints before the concrete was too hard. The modern-coarse ground cement was observed to be slower in this respect than the modern but faster than the old fashioned.

As a matter of interest, we tried using the Soniscope to obtain this picture of the setting process for each cement. The Soniscope readings were begun just as soon as the concrete was firm enough to obtain an initial reading. Subsequent readings were taken each 15 min. throughout the first 12 to 15 hours. The results of these several readings proved to be very interesting and revealing. It is unfortunate that we were unable to obtain more such curves but the idea did not occur soon enough to do so.

The setting processes of these various cements are described in Figures A and B. They show the comparative picture of the setting and strength achieving process for each cement under two different temperature ranges. It has been commonly realized that the temperature of the concrete during placement and during the setting process affected the rate of setting. These two figures revealed this fact as well as the difference in the rate of setting of the coarser ground and the old fashioned cement. At the present time, no effort will be made to evaluate these curves as they pertain to the purpose of the project. They are shown here solely to demonstrate the value of the Soniscope for describing these processes.

Our time has been so filled with taking the readings on these test roads that very little opportunity has been available to obtain values from existing concrete pavements. We fully intend to use the Soniscope to evaluate these older pavements as soon as the new apparatus is completed.

TABLE A
A FEW TYPICAL SONISCOPE READINGS OF OLDER PAVEMENTS
(All regular Portland Cement)

Description	Velocity (ft per sec.)	E (psi × 10^{-6})
1 New Pavement—Age 28 days—Condition O K	14,500	5 5
2 Pavement—Age 1 year—Condition O K	14,230	5 5
3 Pavement—Age 5 years—Condition Poor	9,000	2 2
4 Pavement—Age 9 months—Condition Scaling	13,500	4.5

Table A is typical of the few readings which we have obtained on other pavements at this time. We think that Mr. Cheesman and Mr. Leslie are to be highly congratulated in achieving this development. Visiting engineers have shown a great interest in the Soniscope and undoubtedly it will find a permanent place in the engineering world.