Fundamentals of Field Soniscope Testing

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The soniscope as a laboratory instrument for non-destructive testing of concrete has been the subject of numerous papers. Its uses and limitations for the field testing of concrete, for which it was intended, are not as well known. This paper describes some aspects of such use, being based on a series of tests on piers, abutments, slabs, and other concrete members.

The significance of sound velocities in various materials are discussed, along with the added information that can be secured from measurement of signal amplitude. Special test patterns and layouts for applying the transducers to the surfaces being tested will often facilitate data interpretation. These vary with the design and type of structure under test.

Practical problems of soniscope field testing are described, including procedures used and difficulties encountered. Inaccuracies introduced by components of this complex electronic instrument are also discussed.

● IN recent years the nondestructive testing of materials has gained widespread interest. Several such methods for testing concrete have been advanced and some of them have found considerable use. Of these the hammer rebound method has the insurmountable disadvantage that it will test only a limited depth below the surface of the material. The resonant frequency method, which is probably the most widely used today, cannot be used on concrete in place because it is limited to specimens of simple geometric dimensions. The soniscope, which the authors believe to be the most promising device developed so far, has neither of these limitations. It suffers, however, from a considerable complexity in the collection and interpretation of data.

The soniscope measures the group velocity of a sound wave passing through concrete. This has been found to have a close correlation with condition. Quality, amount of deterioration, extent of cracking, and other characteristics can all be determined with it for structures varying from a few inches to more than fifty feet in thickness.

As to operation, a series of high frequency (20,000 cycles per second) sound waves are generated in a sending transducer, passed through the material, and picked up on a receiving transducer. By means of electronic circuits the received signal in the form of a standing wave is made to appear on a cathode ray tube. A means is provided whereby the position of this wave can be measured to get the time of travel through the concrete in micro-seconds.

The construction of the soniscope and its operation have been described extensively elsewhere (*1–6*); it will be assumed that the reader is familiar with it.

PURPOSE OF PAPER

It is the purpose of this paper to discuss in some detail the significance and dependability of each of the main factors which affect soniscope testing. Their interrelationship might be outlined briefly as follows:

The instrument measures the elapsed time of the transmitted sound waves. This is combined with a measured path length to yield velocity which is the basic information desired from testing. Additional information can be gained from the amplitude of the received signal. An important source of information is the "test strategy" which governs the collection of data.

SIGNIFICANCE OF SONISCOPE DATA

Velocity

It is well known that the velocity of the transmitted wave is directly related to the modulus of elasticity of the concrete under test. Formulas have been advanced for this relationship (*2*). It is usually more convenient, however, to relate velocity directly to concrete quality. The following tentative classification has been suggested (*5*) for normal concrete having a unit weight of approximately 150 lbs. per cu. ft., in which continuity is not affected by cracks or joints.

Group Velocity, feet per second	Concrete Condition
Above 15,000	Excellent
12,000–15,000	Generally good
10,000–12,000	Questionable
7,000–10,000	Generally poor
Below 7,000	Very poor

In a concrete structure of uniform quality, with no reinforcing, cracking, etc., present, a calculated velocity can be compared to these ranges to determine its approximate quality.*

There is, unfortunately, no means available to measure velocity directly. Rather, it must be calculated by dividing the path length of travel by the elapsed time which it takes the sound wave to pass through the material. Obviously, the resulting velocity will be in error if either of these quantities is not correct. A consideration of each of them follows.

Elapsed Time. The only value measured directly by the instrument is the elapsed time between signal initiation and reception. It is a total time equal to the summation of all the time intervals that it takes the sound wave to travel through the various masses of different quality (sound paste, sound aggregate, deteriorated paste, deteriorated aggregate, etc.) in the concrete. It would be highly desirable to know each of these intervals, as they are directly related to the problems that are under investigation, but, unfortunately, there is no way of measuring each one separately in place in the concrete.

Path Length. Direct Path: The minimum distance between the two transducer faces. The calculation of the velocity of sound is generally based on this minimum distance between the two transducer faces. This is determined from field measurements or from construction drawings. In material of uniform quality without major defects this direct path should be the same as the actual path.

Actual Path: The path actually traveled by the fastest sound wave. It would be particularly useful to know the path actually traveled by the sound that first reaches the receiving transducer, for this is the wave that is actually measured to determine elapsed time. Unfortunately, there is no way of positively determining it.

Assumed Path: The best possible attempt at assuming the actual path. When it is desired to know the distance that the fastest wave actually traveled, an assumption must be made as to what the path was. It is hoped that this assumed path will be as close as possible to the actual one. For transverse readings through uniform concrete it will be identical to the direct path. In the cases of a crack extending into the structure beyond the direct path, in the presence of reinforcing steel, some zones of deterioration, or diagonal direct paths, there may be a considerable difference between the direct and assumed paths.

The assumed path length can be calculated if the proper test strategy has been used in taking readings, and may then yield the desired information about structural defects (*2, 7*).

Illustrative Examples. Five simplified sketches of sound waves traveling through concrete under varying conditions show the influence of path length and elapsed time on calculated velocities (Figure 1). Other similar situations could be drawn. The circles radiating from the sending transducer represent the progression of sound wave fronts. The distances between them represent a unit of time, say 100 microseconds.

If a structure is of uniform quality with no reinforcing, cracking, etc., present, the sound would travel along a direct path. Uniformly deteriorated concrete is distinguished by a uniform drop in velocity, resulting from an increase in elapsed time of travel of the sound wave through the concrete (Sketch a and b). Values should compare with the accepted ranges indicated earlier.

A mass of good concrete enclosing a badly deteriorated zone of limited width is shown in Sketch c. This zone would cause a local reduc-

* Velocity through reinforcing steel is approximately 17,000 ft./sec.

tion of velocity as shown by very short distances (t) between successive wave fronts. Outside this zone the velocity would be that of good concrete. The resulting calculated value could be very similar to that for uniformly deteriorated concrete (Sketch b).

An equal resulting velocity might be obtained if an internal crack extends across the direct path (Sketch d). The received sound would not have traveled along the direct path as an air gap of as little as 0.001 inches will not transmit it (*2*). Rather, the waves would be diverted around the end of the crack along a considerably longer actual path. A velocity computed from the direct path might be identical to that for uniformly deteriorated concrete, and would obviously give an incorrect impression of internal conditions.

A high velocity can result from the presence of reinforcing steel (*7*). Sketch e shows a situation with a reinforcing rod parallel to the direct path. Although only a small percentage of the sound would travel through the rod, it would arrive at the receiving transducer ahead of the rest of the sound that would have traveled through concrete. The resulting calculated velocity would not be at all representative of true conditions. Fortunately, the presence of reinforcing rods can usually be determined from construction drawings.

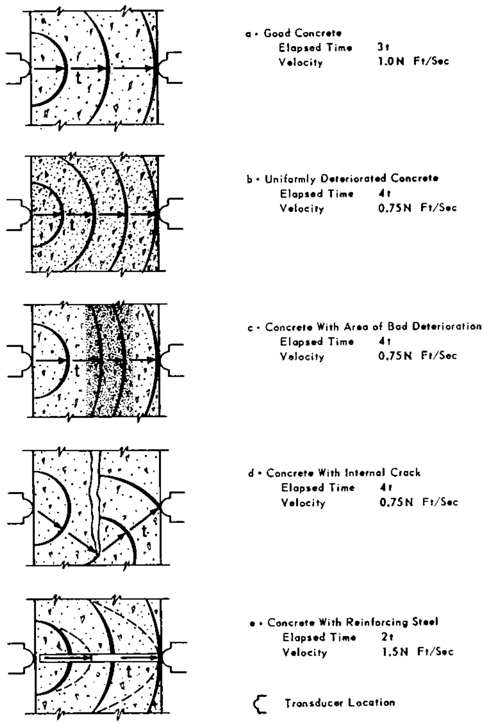

Figure 1. Diagrams Showing Progression of Sound Through Concrete.

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Amplitude

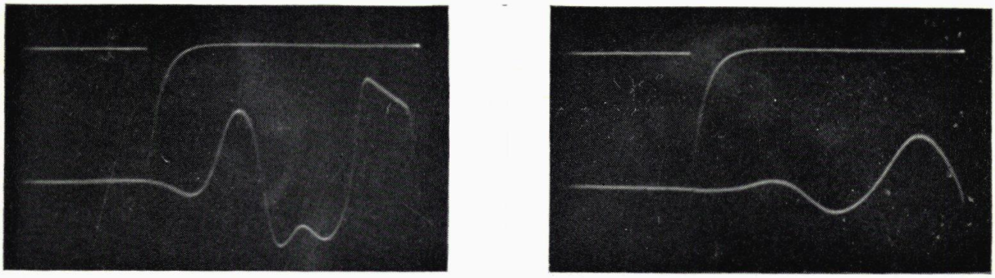
The received wave on the cathode ray tube is used primarily for the measurement of elapsed time. The amplitude can be roughly measured, although the instrument does not provide any means of doing so directly. Data on it have been found by the authors to have considerable usefulness.

Amplitude is practically independent of velocity, for as the sound wave travels through the concrete it is attenuated, though velocity may not change. The extent of this is influenced by the quality of or defects in the material. Data on it are therefore helpful as supplementary information.

The usefulness of amplitudes in interpreting velocities is shown by the permanent installation of the transducers on specimens being subjected to structural tests (Figure 2). The transducers were placed on a prestressed beam being tested in flexure (*7*). The test path was about two feet long, diagonally through the bottom flange of the beam. The wave before load application is shown in (a), while (b) shows it after several cracks had appeared in the bottom flange and the beam had undergone considerable deflection. The difference in amplitudes is obvious, while the difference in velocities is fairly small.

This might be explained as follows: As the cracks develop they cut off the direct path and force the fastest sound wave to travel farther up into the uncracked zone, causing an increasingly long actual path and increasing deviation in direction (Figure 1d). The longer actual path results in a slight decrease in the velocity calculated from the direct path (*6*). The changes of direction and attenuation occurring in the weakened material just beyond the end of the crack cause a marked drop in amplitude. Thus, in this case, the amplitude change has indicated the presence of cracking far more than velocity readings would alone.

Amplitude readings have been found to be a valuable general check on velocity data. Mistakes in reading or recording data on the



a Before Cracking
V = 13,900 Ft/Sec
A = 0.4 inches

b After Cracking
V = 10,050 Ft/Sec
A = 0.1 inches

Reduction
V = 28%
A = 75%

Figure 2. Amplitude and velocity changes due to cracking in prestressed concrete beam.

latter may occur in the field and can cause confusion later during interpretation. In several cases amplitude data have clarified the problem of whether an unusual calculated velocity was an error or was in fact a correct value.

Finally, amplitudes are an indication of the accuracy of a given set of data. As discussed later under dependability of data, readings taken with waves of high amplitude can be relied upon to be free of error far more than with those of low amplitude.

Test Strategy

One of the most important of all considerations in collecting and analyzing soniscope data is the test strategy or plan of attack by which the structure is tested. It has been found that if the test program is not properly, adequately, and systematically planned in advance the resulting data are of only limited usefulness.

Obviously, as in any test program, enough test readings must be taken to yield a statistically valid sample. It would be easy to apply the transducers to only a few locations on a structure, and then draw conclusions from the data obtained, but these would be of little value. At the other extreme, the entire structure could be covered with readings, resulting in a program of interminable magnitude. A compromise between these extremes must be found. Advance surveying and preparation, and the setting up of the instrument and auxiliary equipment take so much time that collection of a reasonable amount of additional information represents only a small amount of extra effort.

A decision usually cannot be made in the field as to whether or not enough readings have been taken, because the data must be computed and plotted before their significance or trend becomes obvious. By that time a return to the structure may be impossible.

The need, then, is to combine all the factors that will contribute information to a soniscope test program into a pattern of testing that will give the maximum amount of information in return for the minimum of effort.

The test strategy varies for each structure and can be best determined after preliminary field inspection and previous experience with similar jobs.

A shrewd layout of the test paths is probably the most important way to increase the value of data. Testing a structure by passing waves through it in one direction only might yield results of limited usefulness, as many of the internal defects might not show up at all in this manner. On the other hand, a proper selection of diagonal paths superimposed on transverse ones may create various patterns of direct and assumed paths that will yield valuable information. The value of such patterns has been shown previously (*6*). In tests on a bridge pier at Amesbury, Mass. (*7*), the only significant findings about cracks at right angles to the surfaces resulted from the use of diagonal paths.

The depth of a crack may be found by a comparison of velocities computed along direct and assumed paths, when the average velocity of the structure is known (*1*). The presence of reinforcing steel is a major consideration in planning the test strategy.

DEPENDABILITY OF MEASUREMENTS

So far this paper has discussed the various kinds of data that must be gathered and synthesized when determining concrete quality with the soniscope. Each type of data is subject to certain limitations in collecting it, which if not treated properly can cause errors in the test results.

Elapsed Time

Inaccuracies in elapsed time may be due to one or more of several factors:

Leading Edge. Determining the beginning of the received signal and measuring the leading edge of it in microseconds can be one of the most vexing problems when operating the soniscope. With high amplitudes the wave is steep, making determination of the leading edge relatively easy. Different operators will have little trouble getting identical readings. On waves of low amplitude, however, (Figure 3), this determination is more difficult. In that case a much greater spread in readings must be expected from the different operators.

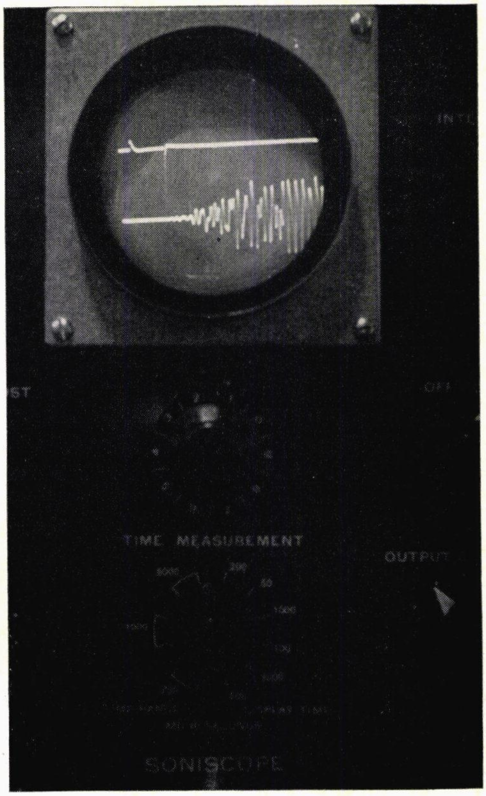


Figure 3. Leading edge of very low amplitude.

The authors have observed that leading edges of low amplitude result in elapsed time readings which are as much as four microseconds higher than readings on the same path with steep leading edges. Others have observed that the wave front can be determined to an accuracy of about two percent in a 20-inch specimen of concrete (*4*).

Another problem of even greater importance occurs when the first wave or waves are obscured by small ambient noise or "grass". One of the later waves may then be mistaken for the first one, resulting in a calculated velocity which is too low.

Zero Correction. The zero correction is mainly the time taken by the signal to travel through the oil within the transducers. It is measured by placing them together, face to face, and reading the elapsed time. Since the path length in this case is zero, with reference to the material being tested, the value obtained must be subtracted from elapsed time values for all readings taken through the structure.

Care must be taken that the pressure on the transducers used in determining the zero correction* is the same as that with which all readings on the structure are taken, so that the path length of the signal through the oil will not vary. This can be assured by placing a cork spacer ring on both transducer heads and pressing until this ring is in contact with the concrete surface. On very rough or uneven surfaces, however, the spacer ring may be more of a hindrance than a help.

The zero correction on the equipment used by the authors varies considerably, from over a usual range of about three microseconds to as high as 12. This former value would cor-

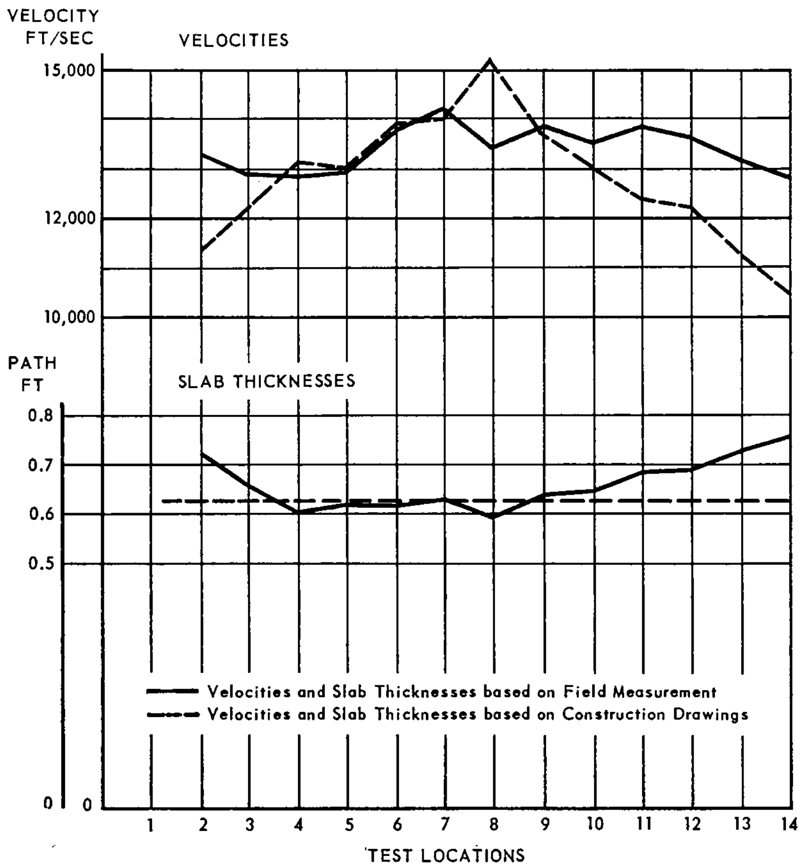
* Zero correction is called "initial delay" in our organization in order to avoid confusion with the zero adjustment (1) which has to be made at the same time.

respond to an inaccuracy of four percent on a path length of one foot in good concrete.

Electrical Drift. Warm-up: Many electronic devices change their characteristics slightly as they warm up, and the soniscope is no exception in this regard. A variation in readings of four microseconds can occur as the instrument operates. This will occur gradually along a curve similar to that in Figure 5. The rate and extent will depend on numerous factors, such as outside temperature, supply voltage, etc. It is recommended that the instrument be turned on at least ten minutes before use, and that frequent zero adjustments be made during the first hour of operation.

Voltage Change: Power for the soniscope is usually supplied by a portable generator, the output voltage of which may vary considerably. On the instrument used by the authors, signal output fails at about 100 volts (Figure 5) and the screen blacks out in the expanded ranges at about 110 volts. An error of from two to ten microseconds can be introduced into data by a variation of five volts in input current. This particular instrument works best at 105 volts, necessitating a voltage regulator even when normal line current is used.

Path Length. The direct path length is usually either taken from the construction drawings or measured in the field. In both cases the probable error in measuring it is practically independent of the overall length of path. However, the relative effect on velocity of such an error is closely related to the path length. If the thickness of a bridge slab is seven inches, an error in measurement of



East Boston Expressway - Test Row "G"

Figure 4. Effect of path length variation on curve of computed velocities.

only one inch introduces an inaccuracy of 14 percent. On the other hand a one inch error in measuring a 35-foot abutment results in an inaccuracy of only 0.24 percent.

A frequent source of error occurs when it is assumed that the structure was built in accordance with the construction drawings. An illustration of this is given in Figure 4, showing test results on a deck slab of the East Boston Expressway. It should be noted that the measurements of slab thickness at all test points were made by a survey party and that this required roughly as much time as the actual soniscope testing. The figure shows how camber in the structural steel caused slabs which were supposed to be of uniform thickness to vary by as much as several inches. The use of design dimensions in calculating velocity would have resulted in a false impression of the structure.

In some cases the absolute value of the velocities is not needed; then the accurate determination of the direct path length may be an unnecessary expense. This can occur if observations of identical paths over a period of time are being made for comparative purposes, or if neighboring test readings on the same structural member are to be compared for continuity of data. It must always be kept in mind, though, that velocities obtained without accurate field measurements may be of no significance.

Path lengths can also affect computed velocities when there is improper positioning of one or the other transducer. This occurs when the surveyed test pattern on one side of a structure is not located exactly opposite its mate on the other side, or when the transducer is not positioned over a test spot. The former condition will cause a constant error, the latter a random one. The error will be small if the direct path length is not changed much by this displacement but could in some cases become serious enough to cause significantly faulty velocity results.

Amplitude

Variations in amplitude are of interest only if caused by the material being tested. It is important, therefore, to keep the other conditions that might affect it constant. These occur at the interface between transducers and concrete surfaces and within the instrument itself. The former conditions include the

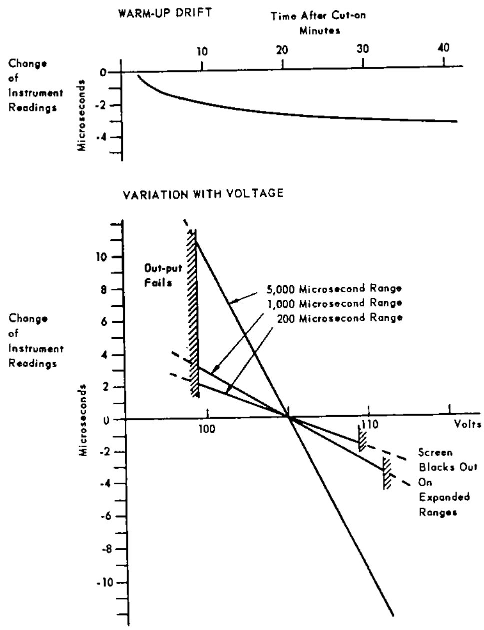


Figure 5. Variation of instrument readings caused by warm-up and voltage fluctuation.

loss of signal strength due to poor contact of the transducers with the surface, as a result of its texture and condition, as well as insufficient contact pressure or presence of air voids.* The latter are affected by the settings of the output and gain control switches on the instrument.

On tests of any given structure the authors have found that texture and surface condition of the structure are usually similar over the entire test area, and that they can hold the four variables that are due to the instrument essentially constant. By doing this they gain the amplitude as an additional item of collected data (*2*).

CONCLUSIONS

The authors feel that a soniscope offers definite possibilities as a useful tool for field testing of concrete structures, especially in connection with periodic maintenance work. However, they have attempted to point out some of the factors which can affect the results obtained. It has been shown that velocity

* Lubrication with water, castor oil, etc., serves to assure good contact.

computed from elapsed time and direct path is often not a conclusive indication of the quality of a concrete structure. Other factors contribute important additional information, and should be considered in planning a test, gathering the data, and analyzing the results. The accuracy of the final results depends heavily on the accuracy of each factor contributing to it.

ACKNOWLEDGMENTS

The experimental work with the soniscope is being conducted by the Joint Highway Research Project, established at the Massachusetts Institute of Technology by a grant from the Massachusetts Department of Public Works for research in the field of highway engineering.

The authors wish to express their sincere appreciation to J. F. McGovern and G. J. Wayne of the Bridge Maintenance Division of the Department of Public Works, for their advice, suggestions, and active participation in the field tests. J. T. Murphy, Research Assistant of the Joint Highway Research Project staff, has also contributed much valuable advice and assistance.

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