# Evaluation of Pulse Velocity Tests Made by Ontario Hydro

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The soniscope was developed primarily as a non-destructive method for following the cracking behaviour in concrete gravity dams by pulse velocity techniques. Internal cracks are detected by an abnormal increase in transmission time and/or reduction in pulse amplitude. The depths of surface cracks are determined by measuring the time required for a pulse of sound to travel around these cracks. Subsequently, a relationship was established between pulse velocity and the quality of concrete which has made it possible to assess the relative condition of structures. Consequently, having established datum pulse velocity measurements, the progress of deterioration in both field structures and laboratory specimens is followed by repetitive tests. While no well-defined correlation between pulse velocity and 28-day strength has been established as yet by this laboratory, the soniscope has been used to some extent to follow strength development of concrete at early ages. Limited success was also achieved in using pulse velocity techniques to study the setting behaviour of concrete.

Like most test equipment, the soniscope is subject to certain limitations and possible errors. Knowledge of these should not discourage its use but provide a better understanding of the apparatus and thereby permit a more intelligent interpretation of results. Pulse velocity is found to increase when specimens are saturated and a further significant increase in velocity is observed when these specimens are frozen. Large quantities of reinforcing steel near and parallel to the transmission path, also influence the results of pulse velocity measurements. The best assurance for reducing the possible errors to a minimum and obtaining the most from the equipment, is a competent operator capable of using sound judgement in the interpretation of the results.

● THE SONISCOPE has been used by the Ontario Hydro for the evaluation of the condition of concrete structures for the past several years. This instrument was developed primarily as a rapid, non-destructive method for detecting the presence of internal cracks and to measure the depth and follow the behaviour of surface cracks in mass concrete structures. Subsequently, it was discovered that pulse velocity varied in different locations of a structure and from specimen to specimen in laboratory concrete. From this was established a general relationship between pulse velocity and quality which has been used extensively in the evaluation of concrete structures, for outlining areas of probable deterioration as well as to follow the advance of such deterioration by repetitive measurements.

The soniscope has been adequately described in earlier papers (1, 2) and the purpose of this paper is to present a general review of the application and interpretation of pulse velocity measurements as conducted by Ontario Hydro. In addition to crack investigations and the assessment of quality and deterioration, attempts have been made to correlate pulse velocity with compressive strength and to follow the setting behaviour and strength development of fresh concrete. In addition, limited data are presented concerning the effect of certain variables and possible errors on pulse velocity measurements. It is hoped that the data presented will contribute in some small way to the general fund of knowledge and assist in a better understanding of the apparatus and interpretation of results.

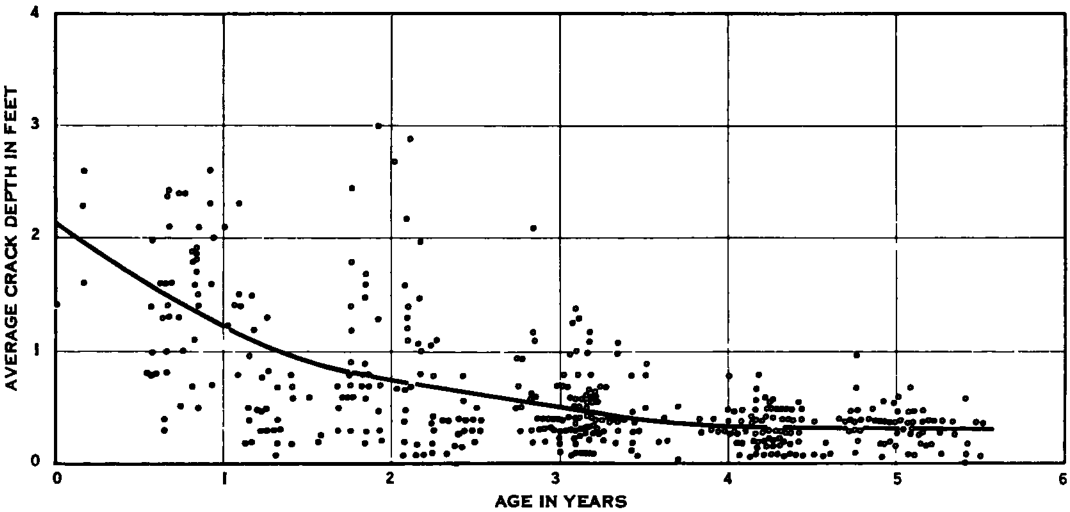


Figure 1. Crack depth vs age.

## Measurement and Detection of Cracks

In view of the Ontario Hydro's technique of placing concrete in lifts up to 50 ft, a practice viewed with mixed feelings by other organizations, an extensive investigation was undertaken to study the cracking behaviour of their mass concrete structures. Leslie and Cheesman (1) found that high frequency sound would not cross an air-filled crack and thereby established the basic principle of crack detection by ultrasonics. Accordingly, large internal cracks could be detected by an abnormally long transmission time and/or a large decrease in the amplitude of the sound pulses. Likewise, by measuring the time required for sound to travel around a surface crack and the pulse velocity in adjacent, sound concrete, the depth of a surface crack could be determined.

Before adopting the pulse velocity method for crack depth determinations, the results were compared with measurements on the same cracks by the dye-injection method. Good correlation was obtained between the two methods and because of speed and convenience, crack depth measurements have since been made exclusively with the soniscope.

Since early 1949, periodic surface crack surveys have been conducted on all of the Commission's new gravity structures. The main cracks studied were those appearing on the downstream face of the dams and these measurements were taken by a man lowered down the face of the dam in a bosun's chair. Attempts were also made to measure cracks appearing in the inspection tunnels but due to the concentration of steel in these regions, the measurements were of doubtful validity.

In general, cracks examined shortly after form removal were found to have an average depth of 2 ft. However, repetitive measurements disclosed that these became gradually shallower with time until after a period of 5 years, when they averaged only 4 in. in depth (Fig. 1).

Concurrent with the surface crack surveys, pulse velocity measurements were made through the interiors of the dams to establish whether or not they were free of internal cracks. Due to the limiting range of the soniscope (50 ft), however, these measurements were restricted to about the upper third of most structures. Although the inspection tunnels provided limited access to the lower and more critical portions near the foundation, these regions could not be completely studied. This restriction was overcome at one location by drilling two vertical 6-in. holes 40 and 80 ft from the upstream face of the dam. Two special transducers that would operate in these holes were constructed thereby permitting pulse velocity measurements to be made the total depth of the dam. These measurements disclosed only a relatively small zone immediately below one construction joint suggestive of thermal cracking but not considered as a threat to the stability of the structure.

No claims are made for high precision, particularly with the measurement of crack depths, since it must be assumed that (a) the path of the crack is normal to the surface of the concrete and (b) no foreign substance is bridging the gap between the walls of the crack. It is felt, however, that the apparatus will differentiate between deep and shallow cracks as well as detect internal cracks large enough to cause significant increases in the transmission time or abnormal reduction in pulse amplitude. On the basis of the soniscope investigations on these structures, therefore, it was concluded that there were no cracks that posed a threat to the stability of the structures and that surface cracks tend to become shallower with time and after a period of three to four years they average less than half a foot in depth.

## Condition Surveys of Structures

The soniscope has been used in assessing the condition of many of the Commission's structures as well as some owned by other organizations. Situations that required investigation have included frost damage at early ages, exposure to fire and natural deterioration resulting over a period of years. The most extensive survey undertaken was on a slab and buttress dam built in 1914. Pulse velocity measurements were made on every foot of all slabs and buttresses resulting in over 48,000 test points. With this close spacing of readings, it was possible to plot velocity "contours" and thereby outline and classify the zones of deterioration.

The pulse velocity readings were grouped into four ranges: under 5,000, 5,000 - 10,000, 10,000 - 12,000, and over 12,000 fps. Low velocity areas, those in which the values fell below 10,000 fps are shown in Figure 2. Since low velocity measurements do not reveal the exact nature of the trouble but may reflect either a low modulus in the material or a long transmission path introduced by internal cracking, 2-in. diameter cores were removed from the structure for additional study. The locations selected for sampling were chosen to permit comparisons of zones representing the full range of pulse velocity values. Compressive strength values were made on all

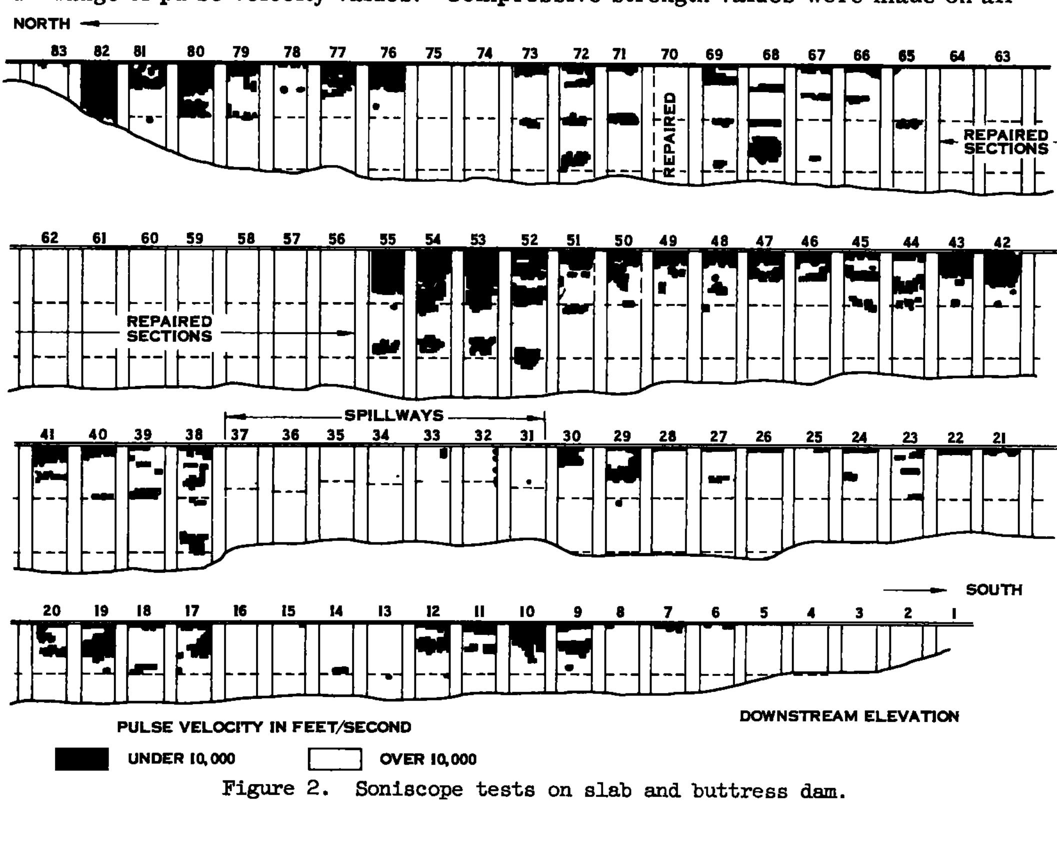


Figure 2. Soniscope tests on slab and buttress dam.

specimens of suitable length; however, due to the poor condition of the concrete in the low velocity regions, it was not possible to obtain suitable test specimens in such zones. Thus, while a pulse velocity-strength relationship was obtained (Fig. 3) this was confined to concrete above 2,000 psi and 10,000 fps, the range of relatively good concrete and where strength discrimination is difficult. On the other hand, drilling observations and core recovery correlated very well with pulse velocities. In areas where the velocity was below 5,000 fps, concrete was weak and could not be cored and no samples were obtained. Between 5,000 and 10,000 fps, only three cores suitable for testing were recovered. The core recovery corresponding to velocities above 12,000 fps was extremely good.

As a further evaluation of the soniscope, pulse velocity measurements were compared with an index of drilling resistance. During the coring operation, drilling resistance was arbitrarily assessed and divided into three categories, high, medium and low. Each hole was rated in accordance with the number of inches of the three types of resistance encountered in twelve inches of drilling. Data for holes not drilled the full 12 in. were suitably adjusted. High resistance was arbitrarily established as three units of resistance per inch and medium and low resistance two and one units, respectively. Ratings therefore, ranged from a low of 12 for 12 in. of low resistance to 36 for 12 in. of high resistance. The ratings were plotted against the corresponding pulse velocity readings for the concrete in-situ (Fig. 4). It was noted that a reasonable correlation was obtained.

Subsequent to the initial survey, 6 slabs were selected for repetitive measurement to provide a general picture of the progress of deterioration. In the over-all analysis of the results, over a period of 5 years, limited extensions of the low velocity zones were observed (Fig. 5) as well as a progressive reduction in pulse velocity. Apart from this general trend, a point-by-point study of the measurements revealed a number of discrepancies due in part to possible misalignment of the transducers, incorrect calculation of path length and normally poor reproducibility in deteriorated concrete. These sources of possible error are covered more completely in a later section.

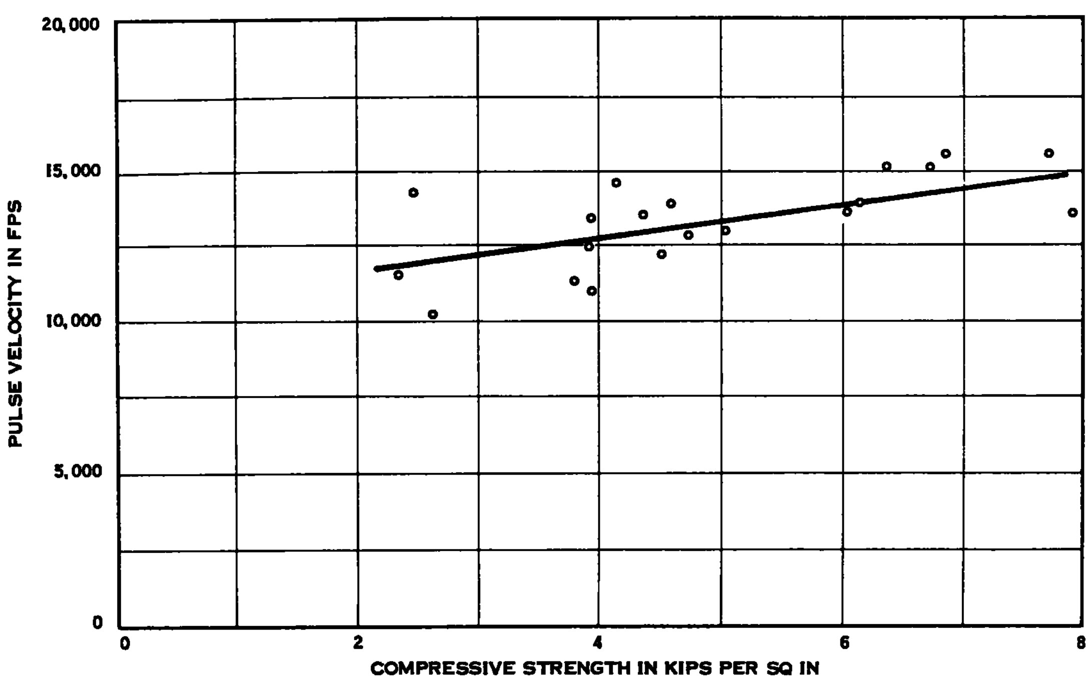


Figure 3. Pulse velocity vs compressive strength for 2-in. diameter cores from 40 year old dam.

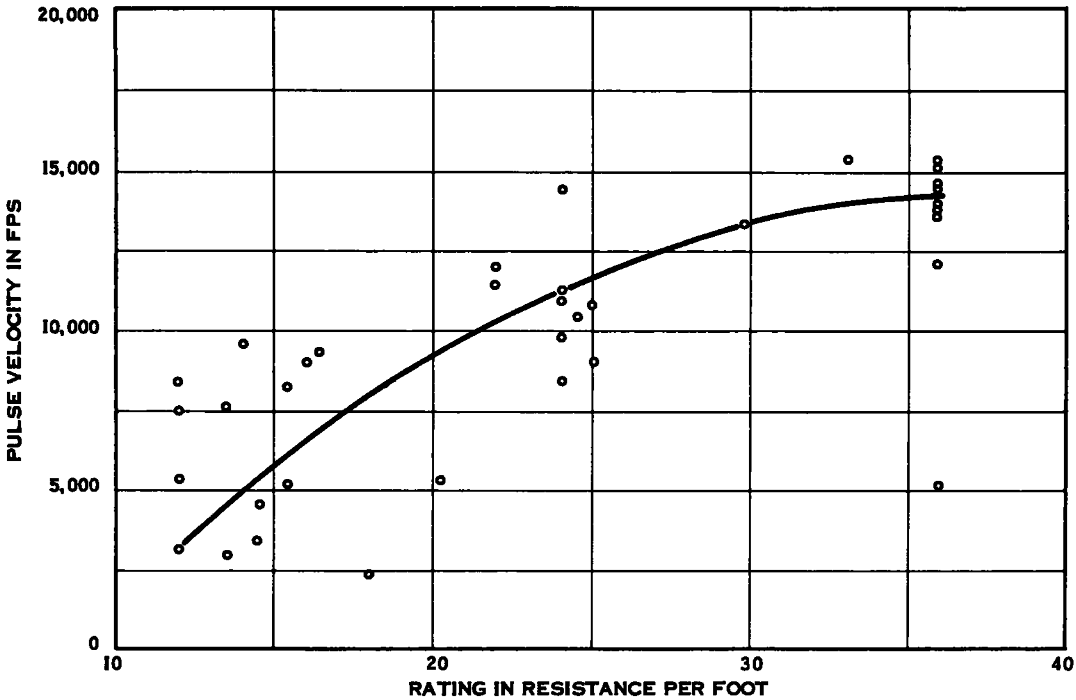


Figure 4. Pulse velocity vs drilling resistance in 40 year old dam.

## Strength Development

Early re-use of formwork or discontinuance of curing and protective measures are often necessary from an economic point of view. The rate at which concrete develops strength is generally the limitng factor in such operations. Accordingly, the ability to follow non-destructively the strength development in a structure is often desirable.

Such a problem arose recently in connection with the tunnel concreting at the Commission's new Sir Adam Beck Generating Station at Niagara Falls, Ontario. There it

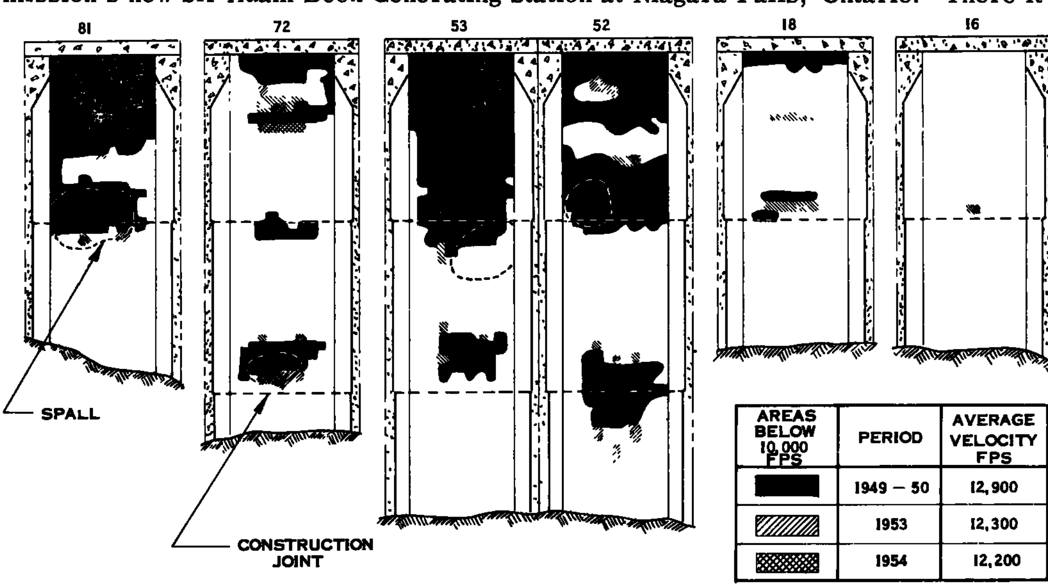


Figure 5. Soniscope tests on slab and buttress dam.

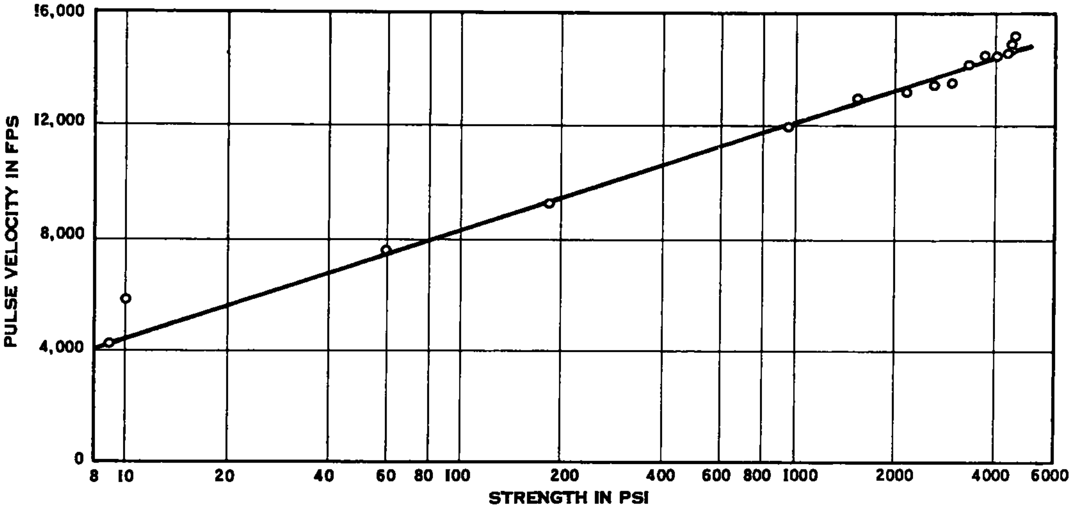


Figure 6. Pulse velocity vs strength, aluminous cement concrete.

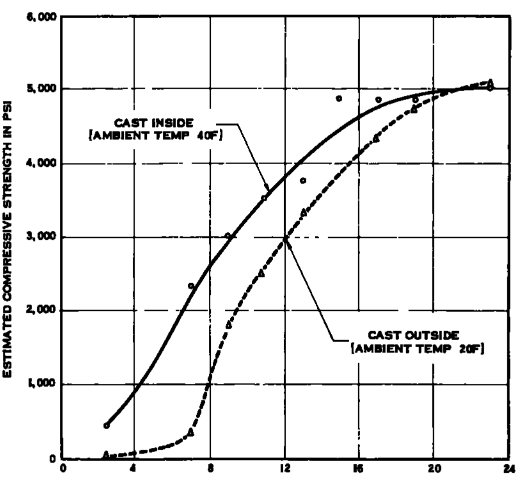


Figure 7. Estimated strength vs age, aluminous cement concrete (mixed and placed at 50 F).

was required that the concrete attain adequate strength to permit stripping of the steel forms at the age of twelve hours. During the test program, considerable data were obtained relating pulse velocity and strength. These data were previously reported by Parker (4) who demonstrated that this relationship between pulse velocity and strength would be practical at levels below 1,000 or 1,500 psi where variations would not be likely to exceed a few hundred pounds per square inch. At the higher strengths, however, the possible errors could exceed 1,000 psi and such variation would be too large to predict strength with sufficient accuracy.

In a later investigation (5), the soniscope was used to study means of facilitating winter construction of tower footings in remote northerly locations. Preliminary tests in the laboratory established the pulse velocity-strength relationship shown in Figure 6 for an aluminous cement concrete using job materials. Two test slabs, using these materials, were cast and cured under field conditions. Both slabs were protected by insulation but one was cast inside a tent where the average foundation temperature was 40 F while the other was cast outside where the foundation temperature averaged 20 F. For comparison, companion slabs, using a high-early-strength cement and 2 percent calcium chloride, were similarly prepared and cured. From the pulse velocity measurements on the aluminous cement specimens, which were started as early as 3½ hours after casting, the age-strength relationship shown in Figure 7 was established. However, it was not possible to transmit through the HES specimens under these conditions, until they had reached an age of 18 hr. Further indication of the superiority of the aluminous cement in this application was provided by an examination of specimens removed from the slabs 4 days after casting. This revealed that fractures, which occurred in the specimens during removal, were confined to the mortar in the HES concrete but in the aluminous cement concrete were also through the aggregate. Portions of rock adhering to the bottom of the latter specimens also illustrated the excellent bond that existed between the concrete and the foundation.

This last example has demonstrated a practical application of the soniscope in providing quantitative data on the behaviour of these materials under actual field conditions where other testing methods would have been impossible and only limited qualitative information could have been obtained.

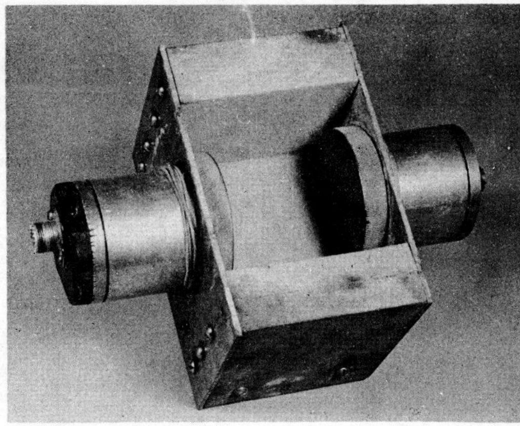

Figure 8. Specimen mould for studying setting behaviour of concrete.

Pulse Velocity vs Strength

The previous investigations, while demonstrating reasonably good correlation between pulse velocity and strength at early ages, have also shown that pulse velocity is an insensitive index of strength at higher levels. Further confirmation of this was provided by soniscope measurements on more than 200 standard test specimens immediately before they were tested in compression. Although a relationship did exist, it was not sufficiently precise to allow the accurate prediction of compressive strength.

In condition surveys of structures in service, most soniscope operators have been requested, at one time or another, to predict the compressive strength of the concrete on the basis of pulse velocity measurements. This, of course, is generally impossible, not only because of the relatively poor relationship between pulse velocity and strength in in mature concrete but also the effect of the various ingredients of the concrete on these properties. Similarly, it has been shown that pulse velocity measurements are greatly influenced by either a cracking condition in the structure or a low modulus concrete, whereas compressive strength is a poor indication of these conditions.

Setting Behaviour of Concrete

In view of the relationship established between pulse velocity and age of concrete by these previous tests, as well as work done by Whitehurst (6), Jones (7) and others, it seemed only natural that pulse velocity techniques should be used to study the setting behaviour of concrete. Although the accuracy of soniscope measurements decreases as the path length is shortened, early tests showed that a short path length is necessary in plastic concrete due to the high attenuation of the signal strength. Hence, a special mold (Fig. 8) was made for such studies. This consisted of rubberized cork sides and steel end plates in which the transducers were set. It was therefore possible to make pulse velocity measurements immediately after the concrete was placed. This procedure did, however, limit the number of specimens that could be tested at any one time. Figure 9 shows the velocity vs age relationship for several batches of a high early strength concrete mix. It was observed that the pulse velocity remained steady at values between 1, 000 and 2, 000 fps for approximately 1½ hr and then, at a time closely coinciding with the time of set (Vicat) of the cement, abruptly began to increase at a constant rate. Eventually another change in slope of the curve was observed, but this was gradual, often poorly defined and varied from specimen to specimen. While these tests seem to give a good picture of the actual hardening process in the concrete they do dispel any idea that "final set" is a well-defined condition.

Effect of Reinforcing Steel

Since the velocity of sound in steel is somewhat higher than in concrete there is naturally speculation as to the effect of steel in the proximity of the transmission path on the apparent pulse velocity. Limited studies were made on a 6-, 12-, 20-in. block of concrete with a 1-in. diameter steel bar parallel to and 3 in. from the 6-, 12-in. face. The velocities of sound in the steel and concrete were measured and the shortest periods

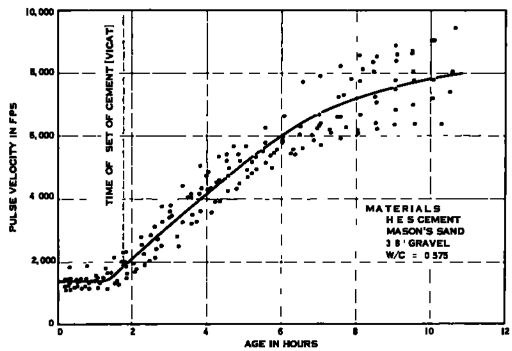


Figure 9. Study of setting behaviour of HES concrete by pulse velocity technique.

for traversing the block were calculated for various positions of the transducers. Measurements were then made and the results compared with the theoretical curves (Fig. 10). Although these tests showed such excellent correlation between the actual and theoretical behaviour, similar tests on a precast concrete slab with ½-in. diameter bars showed negligible effect when transmissions were parallel to and within an inch of the steel. When one transducer was located directly on the steel, or when transmissions were diagonally across its path only slight effects were observed. Similarly, in tests on concrete piers in the field, it was not possible to detect the presence of ¼-in. diameter stirrups by an increase in pulse velocity. On the other hand, attempts to ascertain the depth of cracks in inspection tunnels were nullified by the concentration of reinforcement in these regions.

Although the determining factor is the bond between the concrete and the steel, certain obvious conclusions were drawn from these experiences. These are, that the effect of steel on pulse velocity measurements depends upon the proximity of the steel to the transmission path, the size and concentration of the reinforcing, the distance between transducers and, of course, the relative velocities in concrete and steel. Although light reinforcement seems to have negligible effect upon pulse velocity measurements, in view of the many uncertainties, it is advisable to avoid where possible transmissions close and parallel to the direction of steel particularly in heavily reinforced structures.

## Effect of Moisture Content on Pulse Velocity

In order to evaluate the quality of the concrete in one of the Commission's gravity structures, 6-in. cores were removed for study. Laboratory tests included soniscope measurements on 6-, 12-in. specimens in both the dry and saturated conditions. With a few exceptions, the results showed increases in pulse velocity, when the specimens were saturated, by amounts varying from 6 to 22 percent. The average increase was

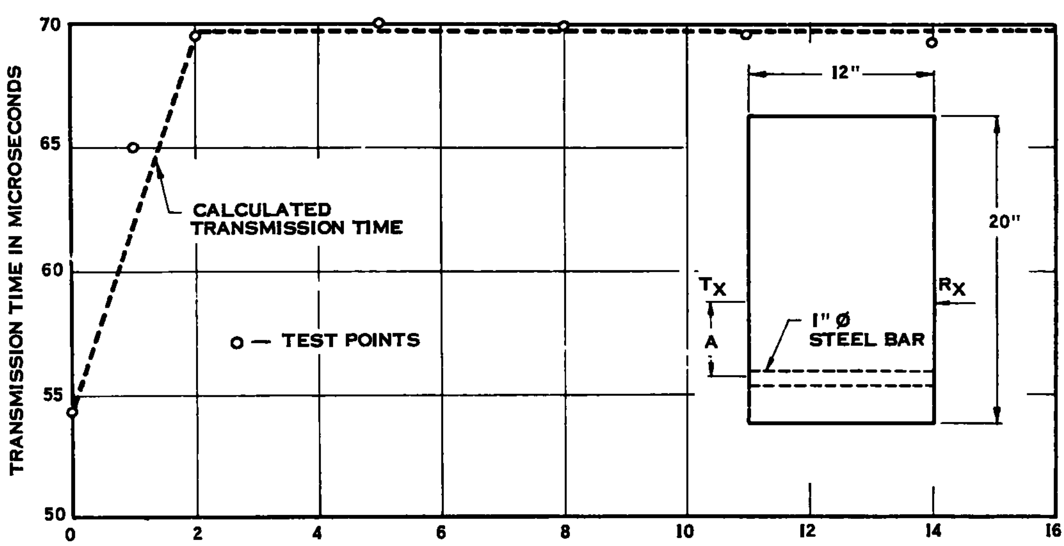


Figure 10. Effect of reinforcing steel on pulse velocity measurements.

TABLE I

EFFECT OF FREEZING
ON
PULSE VELOCITY AND RESONANT FREQUENCY
OF GREEN CONCRETE

| CONDITION | AGE AT INITIAL FREEZING IN HOURS | | | | | |
|---|---|---|---|---|---|---|
| | NON-AIR-ENTRAINED | | | AIR-ENTRAINED | | |
| | 24 | 48 | 72 | 24 | 48 | 72 |
| A ... PULSE VELOCITY IN FPS | | | | | | |
| BEFORE FREEZING | 12,700 | 14,200 | 14,700 | 11,000 | 13,100 | 13,500 |
| 6 HRS. IN FREEZER | 17,000 | 17,500 | 17,100 | 16,000 | 15,900 | 15,700 |
| 23 HRS. IN FREEZER | 17,500 | 17,300 | 17,600 | 16,200 | 16,000 | 16,100 |
| AFTER THAWING – 7 HRS. AT 73F | 12,600 | 14,100 | 14,700 | 11,700 | 13,000 | 13,400 |
| B ... RESONANT FREQUENCY IN CPS | | | | | | |
| BEFORE FREEZING | 1510 | 1760 | 1850 | 1380 | 1600 | 1720 |
| 6 HRS. IN FREEZER | 2190 | 2240 | 2220 | 2060 | 2070 | 2060 |
| 23 HRS. IN FREEZER | 2260 | 2290 | 2260 | 2100 | 2070 | 2090 |
| AFTER THAWING – 7 HRS. AT 73F | 1600 | 1750 | 1810 | 1480 | 1600 | 1700 |

approximately 12 percent. It was first suspected that perhaps the larger increases were associated with higher absorption and/or voids content of the specimens. However, a comparison of these properties with the increase in pulse velocity showed no coherent relationship. Although, the effect of moisture content of concrete must obviously be taken into account in analysing pulse velocity data, its magnitude cannot be predicted with certainty. However, in order to reduce the variability in laboratory specimens, it is customary to carry out comparative measurements in the saturated condition, a practice followed by most organizations for resonance testing, which is similarly affected by the moisture content of the specimen. In surveys of small structures such as tower footings, the attempt to repeat measurements is made at the same time of year. In large masses of concrete, it is felt that moisture content will change very slightly and the variation would therefore be less important.

Recently, soniscope measurements were made on a 4-, 6-ft slab, 6 in. deep that had been allowed to dry. Due to an abnormal amount of interference on the screen, it was not possible to define the first received pulse properly. However, when the slab was again saturated, the interference was eliminated and velocity measurements were readily obtained. Similar interference has been encountered in relatively dry cores and discarded durability specimens. The problem was diagnosed as a case where reverberations were set up in the dry concrete due to the relatively high pulse repetition rate (100 per second). This problem was subsequently overcome by reducing the pulse repetition rate in the instrument to 50 per second. While this information may be of little technical importance, it has been included for the benefit of those who may have experienced similar difficulties.

## Effect of Freezing Concrete on Pulse Velocity

Several specimens of both air- and non-air-entrained concretes were made and frozen at different ages, viz, 24, 48 and 72 hours. Both pulse velocity and resonant frequency measurements were made, immediately before freezing, 6 and 23 hours after freezing and 7 hours after thawing (Table 1). Pulse velocity and resonant frequency values increased appreciably with 6 hr freezing, and a further slight increase was

TABLE II

EFFECT OF FREEZING
ON
PULSE VELOCITY AND RESONANT FREQUENCY
OF DETERIORATED CONCRETE

| CONDITION | SPEC. NO. 1 | SPEC. NO. 2 | SPEC. NO. 3 | SPEC. NO. 4 |
|---|---|---|---|---|
| A ... PULSE VELOCITY | | | | |
| DRY [167 DAYS IN LAB. AIR] | 4700 | 7300 | 8500 | 9400 |
| SATURATED [48 HRS. IN WATER AT 73F] | 9400 | 10,200 | 11,900 | 12,200 |
| FROZEN [21 HRS. AT 0F | 15,800 | 16,200 | 16,200 | 16,200 |
| THAWED [23 HRS. IN WATER AT 73F] | 9000 | 10,400 | 11,400 | 12,000 |
| B ... RESONANT FREQUENCY | | | | |
| DRY [167 DAYS IN LAB. AIR] | 1480 | 1190 | 1090 | 940 |
| SATURATED [48 HRS. IN WATER AT 73F] | 1360 | 1240 | 1040 | 1100 |
| FROZEN [21 HRS. AT 0F] | 2070 | 2060 | 2070 | 2000 |
| THAWED [23 HRS. IN WATER AT 73F] | 1520 | 1220 | 980 | 1060 |

observed after the additional 17 hr at below freezing emperatures. Of particular interest was the fact that although the younger specimens had lower intitial velocity and frequency values than the older specimens, after 23 hr in the frozen condition the values were approximately the same in all specimens, regardless of age. Also, when the specimens were thawed, the pulse velocity and resonant frequency returned to the values observed immediately before freezing.

Similar tests were made on specimens of hardened concrete that had failed in the freezing and thawing tests and were considered to represent various degrees of deterioration. After a period of several months in laboratory air, these specimens were saturated, frozen and subsequently thawed. Pulse velocity and resonant frequency measurements were made on each specimen in the dry, saturated, frozen and thawed conditions (Table 2). As expected, the velocity increased after the concrete was saturated but the resonant frequency increased in two specimens and decreased in the others. When frozen, however, both the pulse velocity and resonant frequency values increased appreciably and were again approximately equal for all specimens regardless of the level of these values before freezing. Upon subsequent thawing, the values dropped to a level varying only slightly from those observed in the earlier saturated, unfrozen condition. Apparently, the cracks and discontinuities of the deteriorated concrete, which normally act as sound barriers, when filled with ice, increase the rigidity of the specimen and the concrete behaves like a homogeneous material. Consequently, there is a danger of erroneous conclusions when pulse velocity measurements are made on a deteriorated structure in which the concrete is in a saturated and frozen state.

## Detection of Small Voids in Concrete

In order to assess the ability of the soniscope to detect small voids or other inclusions, several blocks of concrete were cast in which miscellaneous objects were buried. Without previous knowledge by the operator of either the nature or the location of these objects, soniscope measurements were made on each block and zones having doubtful properties were outlined. Abnormal responses were observed in regions which were later revealed to contain pockets of aggregate and pieces of insulating board; it was not possible, however, to locate several lengths of ½-in. diameter steel conduit (Fig. 11). This is probably due to a combination of the normal variability of pulse velocity in concrete and the fact that the sound pulses are not sufficiently directional and could therefore travel around the smaller voids without a detectable increase in the transmission time. However, it must be realized that the soniscope was developed primarily as a field tool for assessing massive concrete structures and the frequency, transducer size and range were designed accordingly. Although it has on occasion been suitably adapted for testing small specimens it does suffer certain limitations in the shorter path length. However, with certain modifications some of the shortcomings may be overcome.

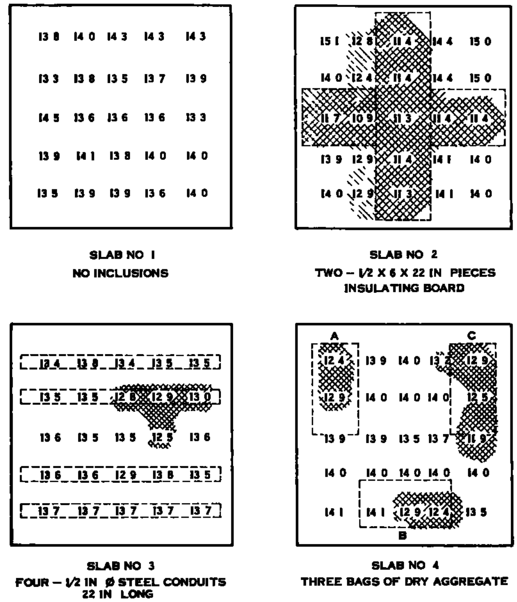


Figure 11. Detection of voids in concrete blocks. Figures shown are pulse velocity x $10^3$ through 8 in. of concrete showing normal variation in uniform concrete (slab No. 1) and the effects of various discontinuities (slabs No. 2, 3 and 4).

## Possible Errors in Soniscope Testing

Like most test equipment, the soniscope is not without limitations and is subject to certain testing errors. In general, the magnitude of the error or errors is dependent upon the transmission path, and may be negligible in the long path lengths but could be appreciable in the shorter distances. However, even in the latter case, the possible errors can be limited by thoughtful planning and exercising certain precautions in testing.

In the survey on the slab and buttress dam, described earlier, some difficulty was encountered in maintaining alignment of the transducer since the transmitter had to be lowered into the headpond by ropes. Since the slab varied in thickness from 11 to 27 in., if the transmitter were off by as little as six inches, errors up to 14 percent could be introduced. It was found, however, that misalignment of the transducers could often be detected when an appreciable and unexpected increase in transmission time was observed and particularly if there was no corresponding effect upon the pulse amplitude. To reduce the possibilities of errors caused by the transmitter drifting from its test point, periodic checks were made by moving the receiver until the position of minimum transmission time was obtained. By these precautions, it was estimated that errors due to misalignment alone were kept below 7 percent.

Changes in the pulse velocity of the concrete in the dam, after an interval of four years, are illustrated in Figure 12. Apart from deterioration that had taken place during this period, misalignment of the transducers along with operator and random errors undoubtedly account for part of the variations. The large discrepancies in the zones of originally low velocity, however, are mainly due to pulses in cracked or deteriorated concrete being ill-defined in any case. Mather (8) also observed that reproducibility is poor in concrete of this quality. Low amplitude and/or poorly defined pulses are often in themselves an indication of low quality concrete although they do complicate attempts to establish trends in deterioration. In this concrete, however, it was estimated that over the 4-yr interval, the average pulse velocity decreased by 480 fps and 750 fps, respectively, in the low and high velocity regions.

Incorrect measurement of the transmission path is a further source of error that is difficult to assess. Such errors may be introduced where the path length must be calculated or scaled from construction drawings or merely by inaccurate measurements. If the error is large, it may be detected by the experienced operator by readings that

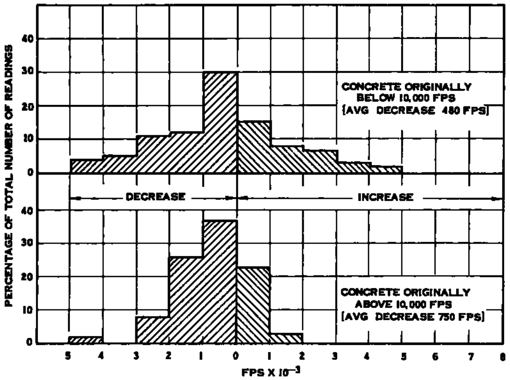


Figure 12. Changes in pulse velocity in a 40 year old dam from 1949 to 1953.

are obviously inconsistent with amplitude of the pulses and the apparent quality of the concrete.

Many errors could be introduced into pulse velocity measurements by inexperienced or disinterested personnel handling the equipment. Obviously, the only way to overcome this problem, is to use conscientious operators who are fully aware of the implications and are willing to put forth a little extra effort to produce consistent results. In order to reduce errors resulting through the incorrect reduction of results, special data sheets, in which the calculations follow a systematic order, have been found particularly helpful.

From past experience the following sequence has been established and proven to be of considerable assistance in preparing for a series of soniscope measurements. The set is permitted to warm up for a period of 10 to 20 minutes before tests are commenced, after which it is calibrated on all ranges to be used and suitably adjusted if required. With the time dial set to zero, the strobe and the transmitted pulse are aligned. Since it has been found that the polarity of the first received pulse may be either positive or negative, depending upon the transducer combination, it is advisable to establish this polarity by transmitting through a few feet of air prior to beginning the tests. Zero error, or the transducer delay time, is determined by holding the transmitter and receiver in contact and measuring the delay time. In this operation it may be necessary to reduce the output of the transmitter to its minimum to prevent overloading the circuit and hence avoid erroneous results. The transducer delay should be recorded and must be subtracted from all subsequent measurements. If tests with the soniscope continue for an extended time, periodic checks of the calibration and the transducer delay time are recommended to determine any shift in the relative position of the traces.

## Concluding Comments

The Ontario Hydro has found pulse velocity testing with the soniscope the best method to date for assessing the quality of concrete in place. The depth of surface cracks has been measured with what is considered to be a reasonable degree of accuracy. Successful transmissions through mass concrete blocks are considered indicative of freedom from internal cracks. Although the soniscope has been used to follow the strength development of concrete, the accuracy with which strength can be estimated from pulse velocity values is limited; however, under certain conditions, this may be adequate. In condition surveys there is no attempt, at the present, to reduce pulse velocity to other properties (e.g. compressive strength or modulus of elasticity) but base assessment on the measurements themselves particularly when datum readings are available. Undoubtedly, if a relationship could be established between strength and velocity, the value of the soniscope would be increased appreciably.

Like most other test equipment, the soniscope is not without limitations, and perhaps these may have been over-emphasized. However, this is not intended to induce a lack of confidence in the apparatus but to provide a better understanding and perhaps a more intelligent interpretation of the results. Undoubtedly, the best assurance for reducing the possible errors to a minimum and obtaining the most from the equipment is a competent operator capable of using sound judgement in his interpretation of the results.

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