Use of the Soniscope by Concrete Division, U. S. Army Engineer Waterways Experiment Station

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●THE CONCRETE Division, U. S. Army Engineer Waterways Experiment Station, was first introduced to soniscope measurements of velocity in concrete in June 1948, when it observed tests conducted at the Tuscaloosa Lock and Dam by representatives of the Portland Cement Association. The first soniscope was obtained in December 1951, another in December 1954.

Since 1951 soniscopes have been employed on a variety of field and laboratory projects, some of which are selected for comment here because of the bearing that they have on this subject. In 1957 the method was standardized for use in the Corps of Engineers by the publication of "Method of Test for Pulse Velocity of Propagation of Elastic Waves in Concrete" (CRD-C 51-57) (1).

REPRODUCIBILITY

One question that has interested many users of soniscopes is whether different soniscopes and different operators will give similar results on the same concrete. A series of comparative tests were arranged in 1952 between representatives of the Hydro Electric Power Commission of Ontario, the Portland Cement Association and the Corp of Engineers, the results of which have been previously published (2). It was indicated that checks within 2 percent could be obtained from readings through uncracked concrete of moderate path length but that when the path length was 1 ft or less or the concrete was cracked, differences between operators and instruments were greater. Since 1955 the obtaining of comparisons between the two soniscopes has been considered. The relatively frequent absence of one or the other, either on field jobs or for repair, has prevented doing so to date. It is believed, however, that they can be adjusted to check within ±1 percent. Better requirements on tolerances in electrical and electronic components and adherence thereto would probably improve the situation generally.

RELATION OF VELOCITY TO OTHER PARAMETERS

Another question that has interested many users has been that of relating velocity determinations to other parameters of the concrete. The application of velocity data has been generally limited to comparison of velocities rather than conversion of velocities to other parameters for comparison. In connection with reporting changes in specimens at field exposure stations where changes have been customarily reported in terms of relative dynamic Young's modulus of elasticity (E)—that is, change in the square of the resonant frequency; changes based on soniscope measurements have been expressed as change in the square of the velocity since E varies as the square of the velocity. Batchelder and Lewis (3) also used variation in velocity squared when relating changes indicated by soniscope tests to changes indicated by resonant frequency tests of specimens subjected to freezing and thawing, as pointed out by Woods and McLaughlin in their paper in this symposium. In a few cases it has been asked that dynamic Young's modulus be calculated from velocity data. In one set of 42 test specimens velocities from 12,000 to 21,000 fps were found, giving calculated values for E from 4 to 14 x 10^6 psi, while corresponding values of E from flexural frequency ranged from 2.3 to 6.1 x 10^6 psi. The six specimens having values of E calculated from velocity over 9 million all had E values of 6. 0 to 6. 1 calculated from flexural frequency. The accuracy of the velocity values greater than about 15,000 fps is doubtful.

The relation of velocity to strength of concrete has been much discussed—perhaps best by Whitehurst (4). One lot of 6 x 12 concrete test cylinders consisting of six sets of three each that gave average velocities between 14,000 and 16,000 fps has been tested. The cylinders were then broken in compression giving average compressive strengths from 2,700 to 4,900 psi. The average strengths and average velocities fall very close to the correlation line for these seven sets of data. This is probably an exception to the general rule.

In the course of tests involving the Schmidt rebound hammer, soniscope tests were made on four concrete panels that were fabricated for rebound hammer tests. No relation was found between rebound number and velocity. However, it was noted that a consistent difference was found between velocities through the same specimen over different path length—the velocity decreasing with increase in path length.

EFFECT OF SPECIMEN SIZE AND PATH LENGTH ON VELOCITY

The question of actual differences in velocity with size of specimen has been long considered. Long et al. in January 1945 (5), stated the assumption that, in small specimens, longitudinal strain is accompanied by lateral expansion or contraction that retards the wave, while in large masses, lateral displacements are suppressed and the wave travels at greater velocity. Leslie and Cheesman in 1950 (6), and later Whitehurst (7), in 1954, imply that this difference was not significant, since they indicated that if E were to be computed from velocity, the equation recommended by Long et al. for mass concrete should be used for all concrete regardless of size of the member.

Data have been obtained both from tests of relatively small prisms, 6 by 12 by 12 in., and relatively large blocks, 5 by 10 by 15 ft and 5 by 10 by 20 ft, in which velocity was found to decrease with path length—or perhaps, as Long suggested, velocity increases with increase in volume of concrete normal to the path. In the case of the small specimens (6 by 12 by 12 in.) velocities were measured over a 6-in. path ending in the centers of 12- by 12-in. faces; over a 12-in. path ending in the centers of a 6- by 12-in. face, and diagonally over a 10-in. path between points on the opposite 12 by 12 faces. On the average, velocities were found to decrease with increasing path length from 17. 3 thousand fps over 6-in. length to 16. 7 over the 10-in. length to 16. 2 over the 12-in. path. In the larger blocks that had velocities of 14. 8 to 16. 0 over a 10-ft path, the velocities over a 15-ft path were 14. 0 to 15. 3, or 95 to 97 percent of those over the 10-ft path. These are averages of two paths in each direction in each of seven blocks with tests at four ages. Twenty-five 5- by 10- by 20-ft blocks were tested along four 20-ft paths, and six 10-ft paths at each of four ages. Again the longer path gave lower velocities. At two days age the average velocity at 10 ft was 13. 7 as compared with 13. 0 at 20 ft and at 365 days age the 10-ft average was 15. 9 as compared with 15. 0 for 20 ft.

Data comparing velocity along different path lengths through the same specimen do not permit a decision regarding the question as to whether the consistently lower velocities over the longer path are due directly to greater path length or due to lower concrete mass per unit length of path. Further tests are planned to see if this question can be answered.

EFFECT OF MOISTURE CONTENT ON VELOCITY

Data on the effect of moisture content on velocity would be desirable. Others, e. g., Sturrup, have reported that the velocity is found to increase when specimens are saturated. As an exploratory step in this direction a molded prism, 6 by 6 by 45 in., about 90 days old, that had been stored in the laboratory was obtained. It had a velocity in this condition of 15,000 fps. After soaking in water for two weeks, the velocity increased to 15,800. After drying for a week, it had dropped to 15. 5 and at a month to 15. 4. Then readings ceased. This experience may be similar to that reported by Sturrup on the dried slab tested in his laboratory. Then the specimen was soaked for

72 hr and the velocity was 15.4 again. It was then decided to cut the specimen into two 22-in. lengths and store one immersed, the other at 50 percent RH. The results of tests on these have shown a disappointing scatter. The two halves showed a difference in velocity initially—15.6 and 16.0; they both appeared to increase in velocity for the first few months, to about 15.9 and 16.3, respectively; then both showed an apparent tendency to decline. The one stored at 50 percent RH dropped after two years to about 14.5 and the one that is stored immersed to about 15.6. Insofar as these data may be regarded as demonstrating anything, they seem to tend to confirm the argument that velocity should be greater through a soaked (wet) concrete than through dry concrete merely because velocity through water is some four times greater than velocity through air. Data on the rate and smoothness of the increase of velocity with increasing moisture content and decrease of velocity with decrease in moisture content is still desired.

EFFECT OF AGGREGATE PARTICLE SIZE ON VELOCITY

Jones (8) and others have discussed the effects of differences in velocity of the aggregate used in the concrete on the velocity measured through the concrete. The work of Whitehurst and Bullock (included in this symposium) is a most valuable contribution to this question. The authors of this paper, being concerned rather more than many soniscope users with concrete made with large aggregate, have wondered whether the grading of the aggregate had an effect. For one study limestone coarse and fine aggregate having a velocity of about 19,000 fps was used. From mixture proportions the percentage of paste and aggregate that should have been intersected by a random straight line through the concrete was calculated. A typical example was 17 percent paste, 83 percent aggregate. Since velocity in the concrete was 15,400 fps, it would follow that the velocity in the paste would theoretically be 8,000 fps. In further studies of this relation, a 6- by 6- by 30-in. paste specimen at an 0.4 w/c was made. It had velocities of 9.9, 11.7, 12.3, and 12.1 thousand fps at 2, 14, 182, and 400 days age. A similar prism of 0.4 w/c paste and limestone sand so proportioned as to have 45 percent by volume sand had velocities of 12.3, 14.3, 15.0 and 13.8 thousand fps at comparable ages. From these data, calculating the difference in observed and theoretical velocities, it is found that on the average an excess of 11.5 microseconds or 6.3 percent of the travel time, is actually required over what the theoretical calculations indicate. It is suggested that this is due to the need for the wave to pass through paste-aggregate interfaces, to go a longer distance to go around low velocity spots (air?), or be retarded by lateral movement. Similar calculations on a concrete specimen, indicate an increase in actual over theoretical travel time of only about one percent—this tends to confirm the assumption that the actual time is greater than the theoretical due to interface effects, since the effect is due less to coarse than to fine aggregate, coarse aggregate particles contribute fewer interfaces per unit path length.

EFFECT OF CONDITION OF CONCRETE

Now the factor--or rather collection of factors—that was of most concern in the use of the soniscope will be discussed. The first field job, in January 1952, was to attempt to outline the distribution of longitudinal vertical cracking in a floodwall that had been cracked by reverse loading as flood waters that had gotten behind it loaded it after the flood stages in the river fell. The detection of the extent of severe cracking was successful. It was indicated by later removal of concrete during repair work, that hairline cracking extended somewhat beyond the areas outlined by velocity measurements.

In another field project an outline of the position of inferior concrete placed in a bridge pier was required. The bad concrete was later shown (9, Fig. 1) to have been due to an overdose of air-entraining admixture sufficient to bring the air content up to about 25 percent and the 28-day compressive strengths down to about 900 psi. The soniscope clearly outlined the position in the structure in which this inferior concrete was located.

A somewhat similar project involved the concrete represented by the cylinders referred to previously.

The use of the soniscope has been fairly satisfactory for detecting major differences.

in condition of concrete in a given structure at a given time when, in the absence of abnormal factors, the condition would have been expected to be similar.

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