Effect of Certain Variables on Pulse Velocities Through Concrete

R. E. BULLOCK, Assistant Professor of Civil Engineering; and
E. A. WHITEHURST, Associate Director, Engineering Experiment Station,
The University of Tennessee

● IT HAS been recognized, almost since pulse velocity testing of concrete was first successfully accomplished, that there are many variables involved which will influence the velocity. Few reports, however, have been published of work undertaken to clearly establish the effect of even the more common variables. One notable exception exists in the work of Jones,[1] who reported as a result of his studies, that pulse velocities might be adequately employed as a measure of variation in concrete quality if the aggregate-cement ratio of the concretes did not vary.

With the continually increasing use of pulse velocity techniques for examining concrete in place, it has become clear that an investigator must have some knowledge of the effect of variables upon pulse velocity if he is to intelligently evaluate the pulse velocity differences which may be found within a structure. This study was undertaken to determine the effect of variations in type of aggregate, maximum size of aggregate, percentage of paste, water-cement ratio, age, and curing conditions upon pulse velocities. The work was accomplished in the laboratories of the Department of Civil Engineering at the University of Tennessee under the supervision of the Engineering Experiment Station.

MATERIALS

Two types of coarse and fine aggregate were employed throughout the study. One was manufactured from a dolomitic limestone obtained from the Mascot Quarries of the American Zinc Company. This aggregate has a saturated surface dry specific gravity of 2.81. The other was a Tennessee River sand and gravel supplied by the Knoxville SanGravl Materials Company and has a saturated surface dry specified gravity of 2.64.

All cement used in the study was a Type I portland cement supplied in a single order by the Volunteer Portland Cement Company.

PROCEDURES

Three specimens were made from each mix. They were cast into steel molds nominally 3 by 4 by 16 in. with the 3-in. dimension vertical. After one day in the molds the specimens were removed and stored in a moist room. They were periodically removed from the moist room for only a sufficient time to permit pulse velocity measurement by the use of a soniscope, and then immediately returned.

After 28 days of moist curing, one specimen from each mix was removed and stored in air in the laboratory for an additional 28 days. The others remained in the moist room. At an age of 56 days, all specimens were tested with the soniscope and then broken in flexure by third-point loading on a 12-in. span with the 4-in. dimension vertical. One end of each broken beam

TABLE 1

AGGREGATE DESIGNATIONS OF SPECIMENS

Central No.	Max. Size	Type
6	No. 4	Limestone
7	3/8 in	Limestone
8	1/2 in.	Limestone
9	3/4 in.	Limestone
10	1 in.	Limestone
11	No. 4	River Aggregate
12	3/8 in.	River Aggregate
13	1/2 in.	River Aggregate
14	3/4 in	River Aggregate

[1] Jones, R., "Testing of Concrete by Ultrasonic-Pulse Technique." HRB Proceedings, Vol. 32, p. 258 (1958).

was then tested in compression using 3- by 3-in. steel plates to apply the load at the end of the specimen, along the 4-in. axis. Care was takenthroughout the experiment to insure that moist specimens remained moist until tested.

The type and maximum size of aggregate and the water-cement ratio for each specimen is indicated by a specimen designation. A prefix letter, A, B, or C, was used to indicate a water-cement ratio of 5, 6, or 7 gallons per sack, respectively. The central number indicates the type of aggregate and maximum size thereof as shown in Table 1. All aggregates were well graded below the indicated maximum size. A final number identifies the individual specimen within a group. Thus, Specimen B-8-2 was the second specimen in a group having a water-cement ratio of 6 gallons per sack and limestone aggregate having a maximum size of ½ in.

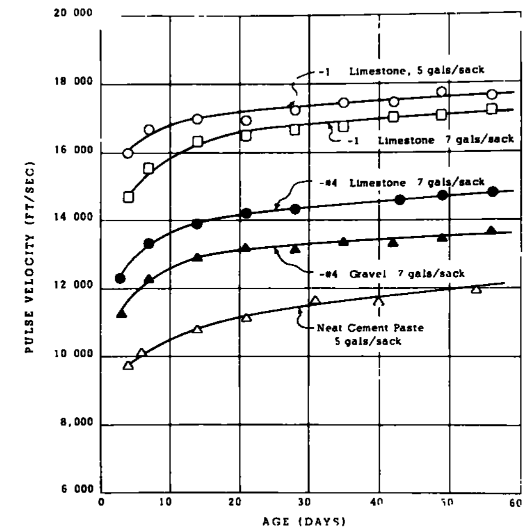

Figure 1. Variations in pulse velocity with age during continuous moist curing.

RESULTS

Figure 1 indicates the variation of pulse velocity with age for a number of specimens selected from those stored continuously in the moist room. In all cases the pulse velocity increases at a decreasing rate similar to a strength versus age curve.

Figure 1 also indicates variations between mixes. The lowest curve on the figure is for a neat cement paste having a water-cement ratio of 5 gallons per sack. Moving up the graph the next two curves represent concretes containing river and limestone aggregates, respectively, in which the maximum size aggregate passed the No. 4 sieve and the water-cement ratio was 7 gallons per sack. The top two curves represent concretes containing limestone aggregate all of which passes a 1-in. sieve, with the lower of the two curves having a water-cement ratio of 7 gallons per sack and the higher a water-cement ratio of 5 gallons per sack.

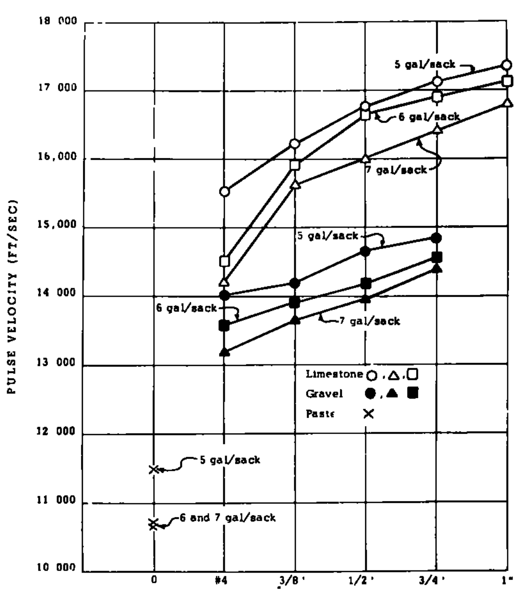

Figure 2. Variations in pulse velocity with maximum size of aggregate after 28 days curing.

Figure 2 shows the effect of aggregate, both type and maximum size, upon pulse velocities through concrete at an age of 28 days. Points at the lower left of the figure represent tests through specimens of neat cement paste. It should be observed that the specimens made from pastes having water-cement ratios of 6 and 7 gallons per sack had identical velocities. There was considerable cement particle settlement before initial set in the specimen having the highest water-cement ratio, the resulting upper surface was quite concave, and the specific gravities of the two specimens were determined to be equal to 1.89. It is believed that sufficient settlement occured in the specimen made with a 7 gallon per sack water-cement ratio to reduce its actual ratio to a value quite near to 6 gallons per sack.

When aggregate was added to the paste the velocity increased considerably, regardless of the type or size of the aggregate. In every case the velocity continued to rise as the maximum size of aggregate was increased, from the No. 4 size to ¾ in. in the case of the river aggregate or to 1 in. in the case of the limestone aggregate. It should also be observed that all mixes containing limestone aggregates had considerably higher velocities than did similar mixes containing river aggregate.

Since it is clearly evident that the addition of aggregate to cement paste increases the pulse velocity materially, it might be presumed that the pulse velocity is a function of the percentage of paste. Figure 3 shows a relationship between the percentage of paste and pulse velocity for mixes of each of the three water-cement ratios with the limestone aggregate concrete. In a general sense the velocity decreases as the percentage of paste increases. At the left edge of the three curves, however, are three points representing tests on specimens having essentially the same paste content but differing in maximum size of aggregate. In each case, velocity increased as the size of the aggregate increased although the percentage of paste remained practically constant. It is thus indicated that the velocity is a function of both the percentage of paste and the maximum size of aggregate.

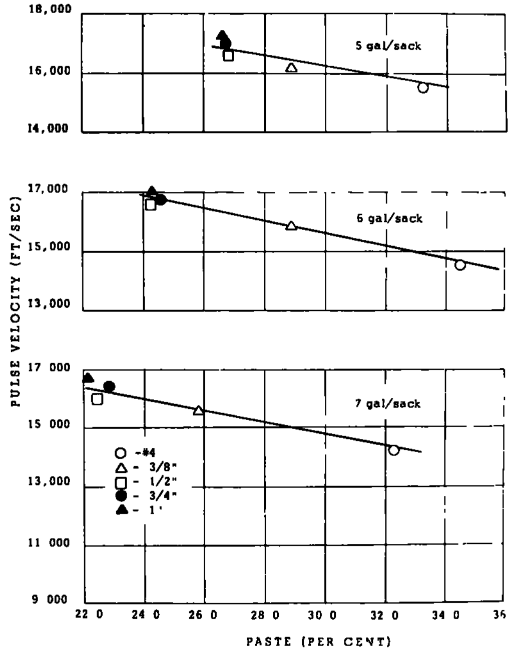

Figure 3. Variations in pulse velocity with paste content for limestone aggregate concrete.

TABLE 2

EFFECT OF DRYING UPON PULSE VELOCITY

Mix No	Type Curing[1]	Velocity at Indicated Age (days) 28	35	42	56
A-7	1	16,100	16,300	16,400	16,700
A-7	2	16,200	16,100	16,300	16,300
A-8	1	16,700	17,000	17,100	17,300
A-8	2	16,700	16,700	16,800	16,900
A-10	1	17,300	17,500	17,500	17,700
A-10	2	17,500	17,500	17,500	17,500
A-13	1	14,600	14,800	14,800	14,900
A-13	2	14,700	14,300	14,400	14,400
B-7	1	15,900	16,000	16,200	16,300
B-7	2	15,900	15,900	16,000	16,100
B-8	1	16,700	16,600	16,800	16,900
B-8	2	16,700	16,500	16,500	16,600
B-10	1	17,100	17,300	17,400	17,600
B-10	2	17,100	16,900	16,900	17,200
B-13	1	14,100	14,400	14,400	14,500
B-13	2	14,100	14,000	14,000	14,000
C-7	1	15,600	15,800	15,900	16,000
C-7	2	15,600	15,400	15,500	15,600
C-8	1	16,000	16,000	16,300	16,500
C-8	2	16,000	15,900	16,000	16,100
C-10	1	16,700	16,800	17,100	17,200
C-10	2	16,700	16,500	16,600	16,600
C-13	1	14,000	14,100	14,300	14,300
C-13	2	14,000	13,600	13,700	13,700

[1] Types of curing: 1. Continuously moist for 56 days.
2 Moist for 28 days, followed by exposure to laboratory air for 28 days

The specimens which were removed from the moist room at the end of 28 days and stored in air in the laboratory for the succeeding 28 days were studied carefully in an effort to determine the effect of drying, or the dicontinuance of moist curing, upon pulse velocities. The noted effect was small. Typical results are shown in Table 2 which shows velocities through companion specimens at the end of 28 days of moist curing and at the end of 7, 14, and 28 additional days of either moist curing or drying in the laboratory.

All but one specimen exhibited a slight decrease in velocity or no change during the first week of drying. All of the limestone specimens then exhibited an increase in velocity or no change during additional air storage. At the end of 28 days air storage, the limestone specimens made from 5 gallons per sack mixes had an average increase over the pulse velocity at the end of moist curing of 140 ft per sec, those from 6 gallon per sack mixes had an increase of 40 ft per sec, and those from 7 gallons per sack mixes averaged no change. Companion limestone specimens continuously moist cured showed an average increase of very nearly 500 ft per sec over the same period regardless of their water-cement ratio. On the other hand, the specimens made from river aggregate averaged a decrease in velocity at the end of 28 days air storage. The average decrease from the pulse velocity at the end of moist curing was 150 ft per sec for specimens made from both 5 and 6 gallons per sack mixes, and the average decrease was 250 ft per sec for those specimens made from 7 gallons per sack mixes. Companion river aggregate specimens which were continuously moist cured, showed an average increase of 330 ft per sec over the same period. The river aggregate specimens also lost a slightly greater percentage of weight in drying than did the limestone aggregate specimens.

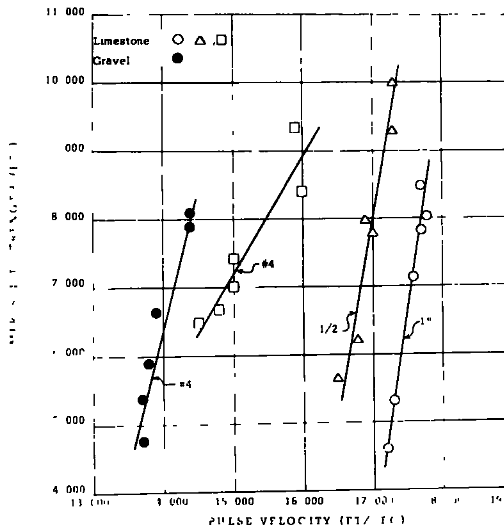

Figure 4. Relationship of compressive strength to pulse velocity after 56 days moist curing.

A comparison of the compressive strengths of the ends of the continuously moist cured specimens tested as modified 3-, by 3-, by 4-in. prisms with pulse velocities measured through the specimens immediately prior to test is shown in Figure 4. There appears to be a reasonably good straight line relationship between compressive strength and pulse velocity for any particular aggregate type and gradation. In general, however, the slopes of the lines are very steep, indicating a large change in strength for a comparably small change in velocity. Since the inherent accuracy of the soniscope is such that the measurements of velocity on small specimens may not be expected to be more accurate than 100 ft per sec, it is suggested that considerable errors in strength prediction might occur. No apparent relationship was found between pulse velocities and flexural strengths of the specimens tested.

SUMMARY

The results of the tests described above indicate the following:

1. Pulse velocities through concrete continue to increase during moist curing of the concrete to ages of 56 days. This increase is essentially terminated when moist curing is terminated and in the case of some specimens a small decrease in velocity is noted when the specimens are removed from the moist room and stored in air in the laboratory.
2. Pulse velocities through neat cement paste are appreciably lower than those through concrete containing the paste.

3. For the same water-cement ratio and maximum size of aggregate, the pulse velocity will vary markedly with aggregate type.
4. For the same water-cement ratio and type of aggregate, the pulse velocity increases as the maximum size of aggregate increases and as the percentage of paste decreases.
5. For the same maximum size and type of aggregate, the pulse velocity decreases as the water-cement ratio increases.
6. A relationship between compressive strength and pulse velocity can be determined but it is different for each aggregate and aggregate gradation.

These results indicate that strength and pulse velocity are not affected in the same way by mix variables and suggest that the investigator of concrete quality in field structures must have rather accurate knowledge of any variations in age, materials, or mix proportions if he is to adequately interpret velocity variations.