Designation: C 597 – 97

Standard Test Method for Pulse Velocity Through Concrete[1]

This standard is issued under the fixed designation C 597; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the velocity of propagation of compressional waves in concrete. This test method does not apply to the propagation of other types of waves within the concrete.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 215 Test Method for Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens[2]

C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions[2]

3. Summary of Test Method

3.1 Pulses of compressional waves are generated by an electro-acoustical transducer that is held in contact with one surface of the concrete under test. After traversing through the concrete, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer. The transit time T is measured electronically. The pulse velocity V is calculated by dividing L by T.

4. Significance and Use

4.1 The pulse velocity, V, of compressional waves in a concrete mass is related to its elastic properties and density according to the following relationship:

$$V = \sqrt{\frac{E\,(1-\mu)}{\rho\,(1+\mu)\,(1-2\,\mu)}} \tag{1}$$

where:

E = dynamic modulus of elasticity,
μ = dynamic Poisson's ratio, and
ρ = density.

4.2 This test method may be used to assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, to estimate the depth of cracks, and to evaluate the effectiveness of crack repairs. It may also be used to indicate changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking. When used to monitor changes in condition over time, test locations are to be marked on the structure to ensure that tests are repeated at the same positions.

4.3 The degree of saturation of the concrete affects the pulse velocity, and this factor must be taken into consideration when evaluating test results. The pulse velocity of saturated concrete may be up to 5 % higher than in dry concrete.[3] In addition, the pulse velocity in saturated concrete is less sensitive to changes in its relative quality.

4.4 The pulse velocity is independent of the dimensions of the test object provided reflected waves from boundaries do not complicate the determination of the arrival time of the directly transmitted pulse. The least dimension of the test object must exceed the wavelength of the ultrasonic vibrations (Note 1).

NOTE 1—The wavelength of the vibrations equals the pulse velocity divided by the frequency of vibrations. For example, for a frequency of 54 kHz and a pulse velocity of 3500 m/s, the wavelength is 3500/54000 = 0.065 m.

4.5 The accuracy of the measurement depends upon the ability of the operator to determine precisely the distance between the transducers and of the equipment to measure precisely the pulse transit time. The received signal strength and measured transit time are affected by the coupling of the transducers to the concrete surfaces. Sufficient coupling agent and pressure must be applied to the transducers to ensure stable transit times. The strength of the received signal is also affected by the travel path length and by the presence and degree of cracking or deterioration in the concrete tested.

4.6 The results obtained by the use of this test method should not be considered as a means of measuring strength nor

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregatesand is the direct responsibility of Subcommittee C09.64on Nondestructive and In-Place Testing.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] Bungey, J. H., *Testing of Concrete in Structures*, 2nd ed., Chapman and Hall, 1989, p. 52.

as an adequate test for establishing compliance of the modulus of elasticity of field concrete with that assumed in the design. The longitudinal resonance method in Test Method C 215 is recommended for determining the dynamic modulus of elasticity of test specimens obtained from field concrete because Poisson's ratio does not have to be known.

NOTE 2—When circumstances permit, a velocity-strength (or velocity-modulus) relationship may be established by the determination of pulse velocity and compressive strength (or modulus of elasticity) on a number of samples of a concrete. This relationship may serve as a basis for the estimation of strength (or modulus of elasticity) by further pulse-velocity tests on that concrete. Refer to ACI 228.1R[4] for guidance on the procedures for developing and using such a relationship.

4.7 The procedure is applicable in both field and laboratory testing regardless of size or shape of the specimen within the limitations of available pulse-generating sources.

NOTE 3—Presently available test equipment limits path lengths to approximately 50 mm minimum and 15 m maximum, depending, in part, upon the frequency and intensity of the generated signal. The upper limit of the path length depends partly on surface conditions and partly on the characteristics of the interior concrete under investigation. The maximum path length is obtained by using transducers of relatively low vibrational frequencies (20 to 30 kHz) to minimize the attenuation of the signal in the concrete. (The resonant frequency of the transducer assembly, that is, crystals plus backing plate, determines the frequency of vibration in the concrete.) For the shorter path lengths where loss of signal is not the governing factor, it is preferable to use vibrational frequencies of 50 kHz or higher to achieve more accurate transit-time measurements and hence greater sensitivity.

4.8 Since the pulse velocity in steel could be up to double that in concrete, pulse-velocity measurements in the vicinity of the reinforcing steel may be higher than in plain concrete of the same composition. Where possible, avoid measurements in close proximity to steel parallel to the direction of pulse propagation.

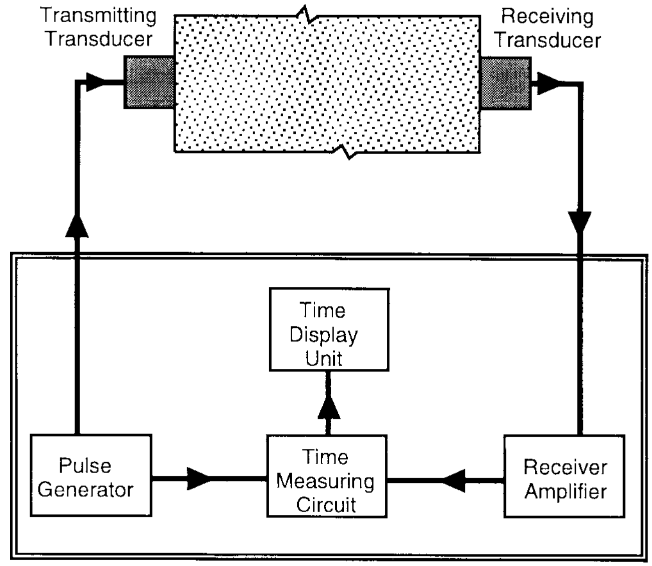
5. Apparatus

5.1 The testing apparatus, shown schematically in Fig. 1, consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, a time display unit, and connecting cables.

5.1.1 *Pulse Generator and Transmitting Transducer*—The pulse generator shall consist of circuitry for generating pulses of voltage (Note 4). The transducer for transforming these electronic pulses into wave bursts of mechanical energy shall have a resonant frequency in the range from 30 to 100 kHz (Note 5). The pulse generator shall produce repetitive pulses at a rate of not less than 3 pulses per second. The transducer shall be constructed of piezoelectric, magnetostrictive, or other voltage-sensitive material (Rochelle salt, quartz, barium titanate, lead zirconate-titante (PZT), and so forth), housed for protection. A triggering pulse shall be produced to start the time measuring circuit.

NOTE 4—The pulse voltage affects the transducer power output and the maximum penetration of the compressional waves. Voltage pulses of 500 to 1000 V have been used successfully.

[4] "In-Place Methods to Estimate Concrete Strength," ACI 228.1R, American Concrete Institute, PO Box 9094, Farmington Hills, MI.



NOTE 1—It is advantageous to incorporate the pulse generator, time measuring circuit, receiver amplifier, and time display into one unit.

FIG. 1 Schematic of Pulse Velocity Apparatus

NOTE 5—Transducers with higher resonant frequencies have been used successfully in relatively small laboratory specimens.

5.1.2 *Receiving Transducer and Amplifier*—The receiving transducer shall be similar to the transmitting transducer. The voltage generated by the receiver shall be amplified as necessary to produce triggering pulses to the time-measuring circuit. The amplifier shall have a flat response between one-half and three times the resonant frequency of the receiving transducer.

5.1.3 *Time-Measuring Circuit*—The time-measuring circuit and the associated triggering pulses shall be capable of providing an overall time-measurement resolution of at least 1 µs. It should be initiated by a triggering voltage from the pulse generator and should operate at the repetition frequency of the latter. The time-measuring circuit shall provide an output when the received pulse is detected, and this output shall be used to determine the transit time displayed on the time-display unit. The time-measuring circuit shall be insensitive to operating temperature in the range from 0 to 40°C and voltage changes in the power source of ± 15 %.

5.1.4 *Display Unit*—Two types of display units are available. Modern units use an interval timer and a direct-reading digital display of the transit time. Older units use a cathode ray tube (CRT) on which the pulses transmitted and received are displayed as deflections of the traces in relation to an established time scale.

5.1.5 *Reference Bar*—A bar of metal or other durable material for which the transit time of compressional waves is known. The transit time shall be marked permanently on the reference bar.

5.1.6 *Connecting Cables*—Where pulse-velocity measurements on large structures require the use of long interconnecting cable, the low-capacitance, shielded, coaxial type shall be used.

5.1.7 *Coupling Agent*—A viscous material (such as oil, petroleum jelly, water soluble jelly, or grease) to ensure efficient transfer of energy between the concrete and the transducers. The function of the coupling agent is to eliminate air between the contact surfaces of the transducers and the concrete. Water is an acceptable coupling agent when ponded on the surface, or for underwater testing.

6. Procedure

6.1 *Functional Check of Equipment and Zero-time Adjustment*—Verify that the equipment is operating properly and perform a zero-time adjustment. Apply coupling agent to the ends of the reference bar, and press the transducers firmly against the ends of the bar until a stable transit time is displayed. Adjust the zero reference until the displayed transit time agrees with the value marked on the bar. For some instruments, the zero adjustment may be made by applying coupling agent and pressing the faces of the transducers together. These instruments use a microprocessor to record this delay time which is automatically subtracted from subsequent transit time measurements. For such instruments, measure the transit time through the reference to verify that the proper zero-time correction has been made. Check the zero adjustment on an hourly basis during continuous operation of the instrument. If the displayed time cannot be adjusted to agree with transit time of the reference bar, do not use the instrument.

6.2 *Determination of Transit Time*:

6.2.1 For testing existing construction, select test locations in accordance with Practice C 823, or follow the requirements of the party requesting the testing, whichever is applicable.

6.2.2 For best results, locate the transducers directly opposite each other. However, because the beam width of the vibrational pulses emitted by the transducers is large, it is permissible to measure transit times across corners of a structure but with some loss of sensitivity and accuracy. Measurements along the same surface shall not be used unless only one face of the structure is accessible since such measurements may be indicative only of surface layers, and calculated pulse velocities will not agree with those obtained by through transmission (Note 6).

NOTE 6—One of the sources of uncertainty in surface tests is the lengths of the actual travel paths of the pulses. Hence, individual readings are of little value. However, surface tests have been used to estimate the depth of a lower quality surface layer by making multiple measurements of transit time with varying distances between the transducers. From the plot of travel time versus spacing, it may be possible to estimate the depth of the lower quality concrete.[5]

6.2.3 Apply an appropriate coupling agent (such as water, oil, petroleum jelly, grease, or other viscous materials) to the transducer faces or the test surface, or both, to avoid entrapped air between the contact surface of the faces of transducers and the surface of the concrete. Press the faces of the transducers firmly against the surfaces of the concrete until a stable transit time is displayed, and measure the transit time (Note 7). Measure the length of the shortest direct path from the centers of the faces.

NOTE 7—Repeat measurements should be made at the same location to minimize erroneous readings due to poor contact.

7. Calculation

7.1 Calculate the pulse velocity as follows:

$$V = L/T \quad (2)$$

where:
V = pulse velocity, m/s,
L = distance between transducers, m, and
T = transit time, s.

8. Report

8.1 Report at least the following information:

8.1.1 Location of test or identification of specimen.

8.1.2 Location of transducers.

8.1.3 Distance between transducers, stated to greater precision than 0.5 % of distance.

8.1.4 Transit time, stated to greater precision than 0.5 % of transit time.

8.1.5 Pulse velocity reported to the nearest 10 m/s.

9. Precision and Bias

9.1 *Precision*:

9.1.1 Repeatability of results have been investigated using devices with CRT displays. It is expected that the repeatability with digital display devices will be better than stated below.

9.1.2 Tests involving three test instruments and five operators have indicated that for path lengths from 0.3 to 6 m through sound concrete, different operators using the same instrument or one operator using different instruments will achieve repeatability of test results within 2 %. For longer path lengths through sound concrete, attenuation of the signal will decrease the absolute repeatability of the transit-time measurement, but the longer transit time involved will result in a calculation of velocity having the same order of accuracy.

9.1.3 In the case of tests through badly cracked or deteriorated concrete, the variation of the results are substantially increased. Attenuation is affected by the nature of the deterioration and the resonant frequency of the transducers. Differences between operators or instruments may result in differences in test results as large as 20 %. In such cases, however, calculated velocities will be sufficiently low as to indicate clearly the presence of distress in the concrete tested.

9.2 *Bias*—Nothing is being said concerning the bias of this test method.

10. Keywords

10.1 concrete; nondestructive testing; pulse velocity

[5] Chung, H. W., and Law, K. S., "Assessing Fire Damage of Concrete by the Ultrasonic Pulse Technique," *Cement, Concrete, and Aggregates*, CCAGDP, Vol 7, No. 2, Winter, 1985, pp. 84–88.