A COMPREHENSIVE REVIEW OF ULTRASONIC PULSE VELOCITY TESTING.

Introduction: The Ultrasonic Pulse Velocity method is truly a non-destructive method resulting in no damage to the Concrete element being tested. This method makes use of Mechanical Waves. A test specimen in a particular location can be tested multiple times using this method, which helps in monitoring concrete undergoing internal structural changes over a long period of time. This method can be used for detecting internal cracking and other defects as well as changes in Concrete such as deterioration due to aggressive chemical environment, freezing and thawing. This method can also be used to estimate strength of concrete test specimens and in-place concrete.

Principle: Three types of propagating mechanical waves, also called Stress Waves, are created when surface of an elastic medium is disturbed by a dynamic or vibratory load. There are three types of propagating mechanical waves:

1) Compressional Waves also known as Longitudinal or P-waves.
2) Shear Waves also called Transverse or S-Waves.
3) Surface Waves also called Rayleigh Waves.

The compressional waves propagate through the solid medium in a fashion analogous to sound waves propagating through air. Each wave type propagates with its characteristic velocity. For a given solid, compressional waves have highest velocity and surface waves the lowest and therefore, compressional wave is received fast by the transducer. The velocity of pulses is almost independent of the geometry of the material through which they pass but it depends on only elastic properties of the material through which they pass. Therefore, the pulse velocity method is an useful technique for investigating in-situ concrete because comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. The crack, void or flaws in the concrete come in the way of transmission of pulses, and then the pulses pass around the discontinuity resulting in the longer transmission path, consequently lower velocity. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete and density. The modulus of elasticity of aggregate also significantly affects the pulse velocity. For the Concrete, the value of pulse velocity typically ranges from 3000 to 5000 m/s.

Apparatus: As per IS: 516(Part-5/Sec: 1):2018, Ultrasonic Pulse Velocity Testing, the apparatus for Ultrasonic Pulse Velocity measurement shall consist of the following:

1) Electrical Pulse generator.
2) Transducers- One pair.
3) Standard Calibration Bar.

4) Amplifier.
5) Electronic Timing Device.

Piezoelectric and magneto-strictive type of transducers may be used, but magneto-strictive type is more suitable for the lower part of the frequency range. High frequency pulses have a well-defined onset but as they pass through the concrete, they become attenuated more rapidly than pulses of lower frequency. It is preferable to use high frequency transducers (60 KHZ to 200 KHZ) for short path length of around 50mm. The low frequency transducers (10 KHZ to 40 KHZ) are for long path length up to 15m (Maximum). Transducers with a frequency of 25KHZ to 100KHZ are found to be useful for most applications. The apparatus shall be capable of measuring transit times to an accuracy of ±1 percent over a range of 20 microseconds to 10 milliseconds.

Determination of Pulse Velocity: The basic idea on which the pulse velocity method is established is that the velocity of a pulse of compressional waves through a medium depends on the elastic properties and density of the medium.

Fig-1: Pulse Velocity Instrument (Ref: 3)

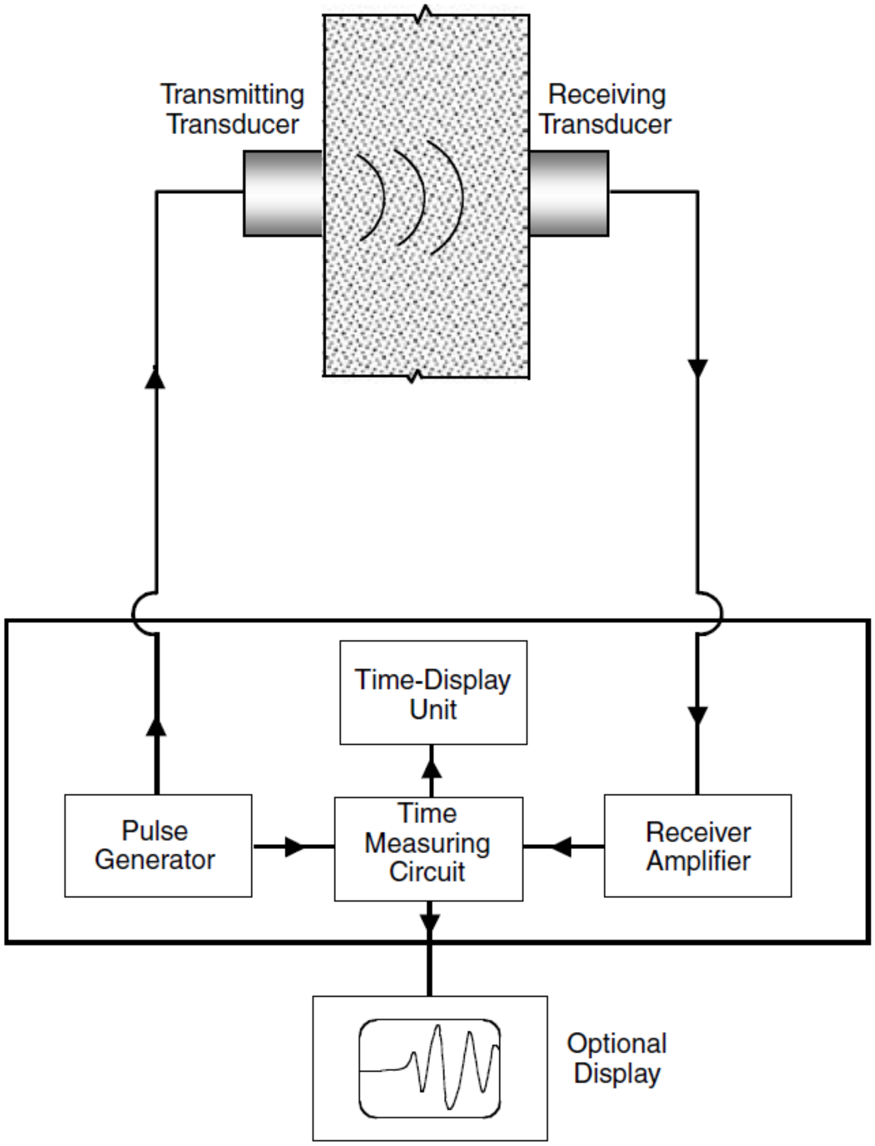

Fig: 2: Schematic Diagram of Pulse Velocity Test Circuit (Ref: 3)

The transmitting transducer of the pulse velocity instrument transmits a wave into the concrete and the receiving transducer, at a distance L, receives the pulse through the concrete at another point. The pulse velocity instrument "DISPLAY" indicates the transit time "T", it takes for the compressional wave pulse to travel through the concrete. The compressional wave pulse velocity "V", therefore is V=L/T. The compressional pulse transmitted through the concrete undergoes scattering at various aggregate mortar boundaries. By the time the pulse reaches the receiving transducer, it becomes transformed into a complex wave form, which contains multiply reflected compressional waves and shear waves. Of course, compression waves travelling the fastest arrive first at the receiver.

Precautions to be taken during Test: To transmit or to receive the pulse, the transducer must be in full contact with test object. Otherwise an air pocket between the test object and transducer may introduce an error in the indicated transit time. This error is introduced because only a negligible amount of wave energy can be transmitted through air. There are many couplants available in the market, the use of which eliminates air pockets. Those couplants are Petroleum jelly, Grease, Liquid Soap and Kaolin-glycerol paste. The couplant layer should be as thin as possible. While applying constant pressure on the transducers, repeated reading at a particular location should be taken until a minimum value of transit time is obtained. If the concrete surface is very rough, thick grease should be used as couplant. In some cases, the rough surface may have to be grounded smooth or a smooth surface may have to be established with the use of plaster of paris or suitable quick-setting cement paste or quick setting epoxy mortar.

Transducers arrangement: When two transducers are placed on opposite faces of the specimen, the maximum energy is propagated and it is called "DIRECT TRANSMISSION". When two transducers are placed on adjacent faces, it is called "SEMI-DIRECT TRANSMISSION". When two transducers are placed on the same face, it is called "INDIRECT OR SURFACE TRANSMISSION".

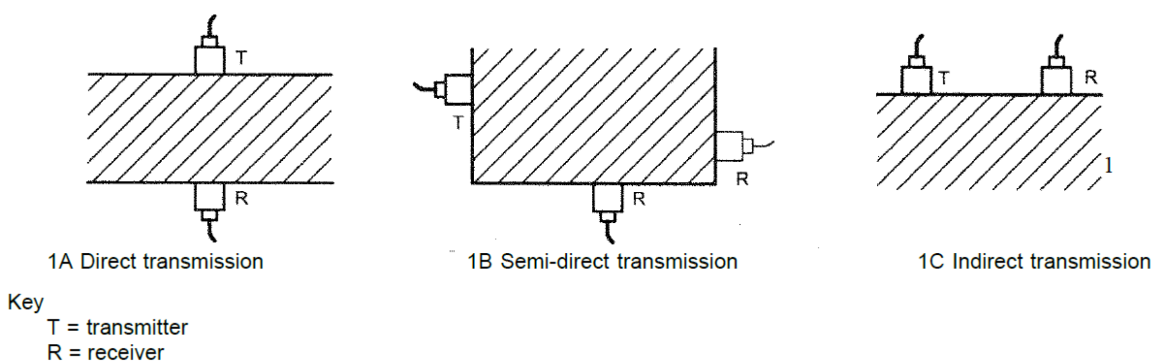

Fig: 3: Positioning of Transducers {Ref: 1)

The indirect transmission arrangement is the least sensitive and is used when only one face of the concrete is accessible or when the quality of the surface concrete relative to the overall quality is of interest. The semi-direct transmission arrangement is used when the direct arrangement cannot be used, for example at the corners of structures.

The above three methods have been defined in IS: 516 (Part 5/ Sec 1} 2018, Ultrasonic Pulse Velocity Testing. But in addition to above, BS EN 12504-4, 2021, Determination of Ultrasonic Pulse Velocity Test (British Standard) describes another method which is called "PULSE-ECHO

TRANSMISSION”. This method like indirect transmission is used only when single face of the specimen is available. But this method uses only one transducer both for transmitting and receiving. In this case of Pulse-Echo transmission, the receiver detects pulses which have travelled through the concrete to the opposite surface and have been reflected back to the first surface. The sensitivity of this test is comparable with “Direct Transmission”.

Path Length Measurements: For direct transmission, the path length is the shortest distance between the transducers. The measurement of the path length shall be recorded to the nearest 1 percent of the measured distance. For semi-direct transmission, it is generally found to be sufficiently accurate to take the path length as the distance measured from center to center of the transducer faces. The accuracy of path length is dependent upon the size of the transducer compared with the center to center distance. With indirect transmission, the path length is not measured but a series of measurements is made with the transducers at different distance apart. For Pulse-Echo transmission the path length is two times the distance from the surface where the transducer is placed and the opposite surface. The path length shall be recorded as per the direct transmission. Since size of aggregates influences the pulse velocity measurement, it is recommended that for direct transmission method, the minimum path length shall be 100mm for concrete in which the nominal maximum size of aggregate is 20mm or less and 150mm for concrete in which the nominal maximum size of aggregate is between 20mm and 40 mm.

Interpretation of Results: The Ultrasonic Pulse Velocity of concrete depends on the materials and mix proportions used in the making concrete as well as method of placing, compaction and curing of concrete. If the concrete is not compacted as thoroughly as possible, or if there is segregation of concrete during the placing or there are internal cracks or flaws, the pulse velocity will be lower, although the same materials and mix proportions are used. The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc. (indicative of the level of workmanship employed) can be assessed using the guidelines given in Table-1, taken from first amendment of IS: 516 (Part 5/ Sec 1} 2018, Ultrasonic Pulse Velocity Testing. This table is only for concrete quality grading and shall not be used for estimating concrete grades from Ultrasonic Pulse Velocity values. When comparison is made based on Table-1 amongst different parts of a structure, which have been built at the same time with supposedly similar materials, construction practice and supervision, the assessment of quality becomes more meaningful and reliable. When the UPV values are lesser by more than 10 percent of average value of the member/part of structure, the location shall be considered as having internal flaws or segregation caused by poor workmanship or there could be micro cracks.

Table 1 Velocity Criteria for Concrete Quality Grading

(*Clause* 2.5.2)

Sl No.	Average Value of Pulse Velocity by Cross Probing km/s	Concrete Quality Grading
(1)	(2)	(3)
i) For concrete (≤ M 25):		
a)	Below 3.5	Doubtful[1)]
b)	3.5 – 4.5	Good
c)	Above 4.5	Excellent
ii) For concrete (> M 25):		
a)	Below 3.75	Doubtful[1)]
b)	3.75 – 4.50	Good
c)	Above 4.50	Excellent

[1)] In case of 'Doubtful quality', it shall be necessary to carry out additional tests.

Determination of pulse velocity-Indirect Transmission: With indirect transmission, there is some uncertainty regarding the exact length of the transmission path because of the significant size of the areas of contact between the transducers and the concrete. It is preferable to make a series of measurements with transducers at different distances apart to eliminate this uncertainty. To do this, the transmitting transducer shall be placed in contract with concrete surface at a fixed point and the receiving transducers shall be placed at fixed increments X_n along a chosen line on the surface. The transmission times recorded shall be plotted as points on a graph showing their relation to the distance separating the transducers. The slope of the best straight line drawn through the point (1/tanØ) shall be measured and recorded as the mean pulse velocity along the selected line on the concrete surface where the points measured and recorded in this way indicate a discontinuity, it is likely that a surface crack or surface layer of inferior quality is present and a velocity measured in such an instance is unreliable.

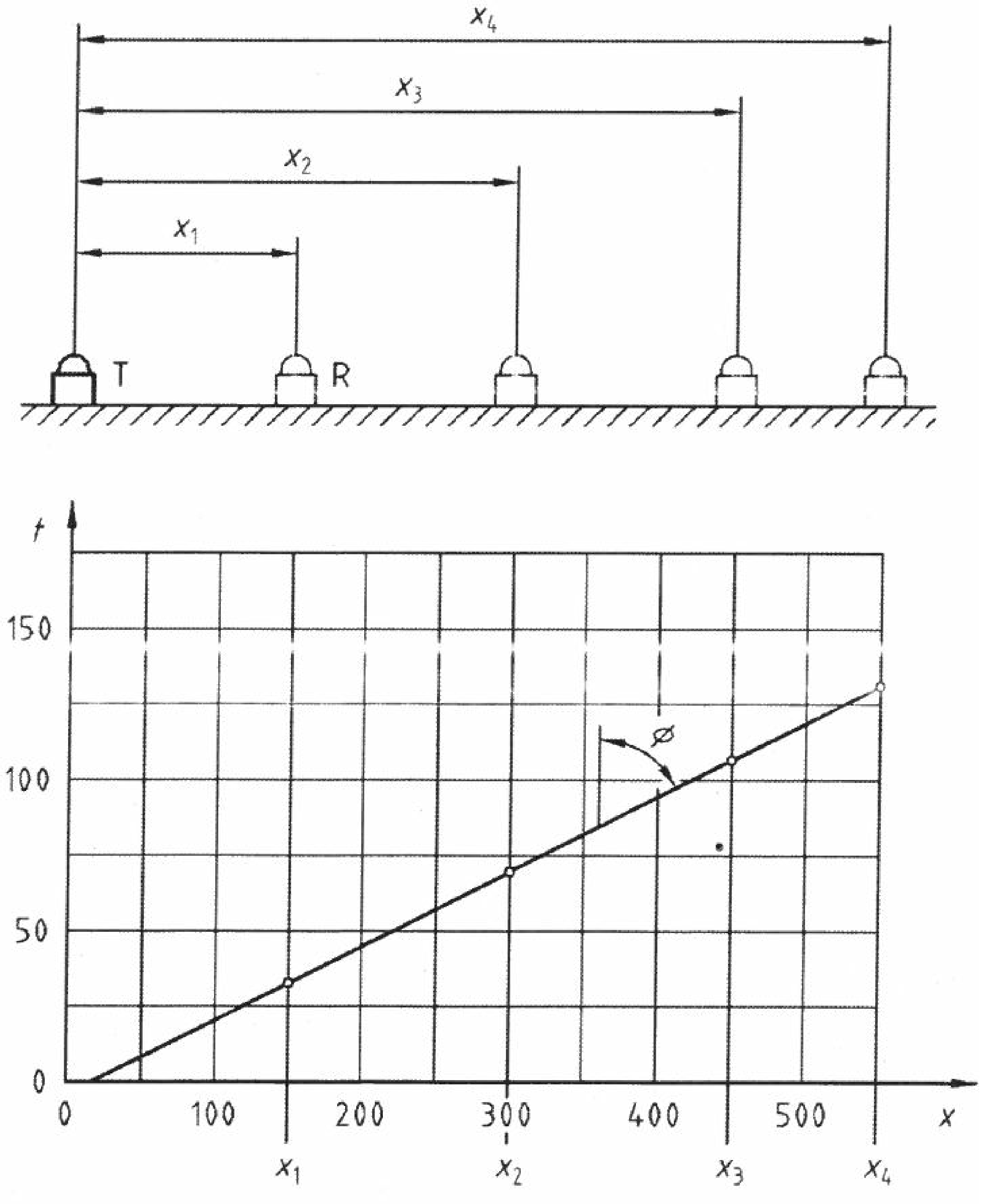

Figure-4: Example of determination of Pulse Velocity by Indirect (Surface) transmission (Ref-2)

R= Receiver Transducer.

T= Transmitter Transducer.

t = Transit Time.

X_1= Distance between transmitter and receiver transducer.

As per IS: 516 (Part 5/Sec-1): 2018, Ultrasonic Pulse Velocity Testing, surface probing in general gives lower pulse velocity than in case of cross probing and depending on number of parameters, the difference could be of the order of about 0.5 Km/s. In view of this, it is recommended that in surface probing method the pulse velocity may be increased by 0.5 Km/s, for values ≥ 3.0 Km/s.

Correlation of Pulse Velocity and Compressive Strength: The assessment of compressive strength of concrete from Ultrasonic Pulse Velocity values is not adequate because the statistical confidence of the correlation between Ultrasonic Pulse Velocity and Compressive Strength of Concrete is not high. This is because large numbers of parameters are involved which influence the pulse velocity and compressive strength of concrete to different extent. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of Concrete Strength can be made by establishing suitable correlation between the Pulse Velocity and the Compressive Strength of concrete specimens made with such materials and mix proportions, under the environmental conditions similar to the structure. The estimated strength may vary from the actual strength by ±20 percent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials. If correlation graph is not available, but the velocities on concrete cubes are available, the average pulse velocity in members of structures are not expected to deviate more than 10 to 15 percent of Pulse velocity values obtained on concrete cubes(Dry Surface).

Other uses of Ultrasonic Pulse Velocity Testing: As per IS: 516 (Part 5/Sec-1): 2018, Ultrasonic Pulse Velocity Testing, this testing can be used:

1) For estimating the depth of a surface crack.
2) For determining the dynamic young's Modulus of Elasticity(E) of the concrete.

Factors influencing Pulse Velocity Measurements:

1) Surface Condition and moisture content of concrete.
2) Path length, Shape and Size of Concrete member.
3) Temperature of Concrete.
4) Influence of Stress.
5) Effect of Reinforcement.
6) Contract between Transducer and Concrete.
7) Cracks and voids.

Point of Discussion: As per IS: 516 (Part 5/Sec-1): 2018, Ultrasonic Pulse Velocity Testing, concrete quality grading has been divided into three categories:

1) Excellent
2) Good
3) Doubtful.

The code says that in case of "Doubtful Quality", it shall be necessary to carry out additional tests.

From the above, can it be inferred that the concrete quality grading of "Excellent" and "Good" may not require any structural intervention and attention shall be paid only to Concrete Quality Grading of "Doubtful Category"?

References:

1) IS: 516 (Part 5/Sec1):2018, Hardened Concrete-Method of Test, Part (5) Nondestructive Testing of Concrete, Section-1, Ultrasonic Pulse Velocity Testing with Amendment-1.
2) BS EN 12504-4:2021 Testing Concrete in Structures, Part 4: Determination of Ultrasonic Pulse Velocity.
3) Handbook of Nondestructive Testing of Concrete edited by V.M.Malhotra and N.J.Carino.