By: Dr. Shamshad Ahmad

LECTURE NO. 4-5

ULTRASONIC* PULSE VELOCITY METHODS

Objectives:

- To introduce the UPV methods
- To briefly explain the theory of pulse propagation through concrete
- To explain equipments, procedures, calibrations, interpretations, applications and limitations of UPV methods

*Ultrasound refers to sound waves with frequencies above the audible range, which is generally taken to be about 20 kHz.

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INTRODUCTION

- UPV measurement through concrete was initiated in the USA in the mid 1940s and later adopted everywhere as NDT on concrete
- UPV methods basically consists of transmitting the mechanically generated pulses (in the frequency ranges of 20-150/s) through concrete with the help of electro-acoustic transducers and measuring the velocity of the longitudinal waves generated by the applied pulses
- UPV is correlated to many desirable information pertaining to concrete, such as:
  - Elastic modulus, strength, and uniformity of concrete
  - Layer thickness, cracking, honeycombing, and deterioration of concrete
- The UPV measurements on concrete may reveal the above information if appropriate calibration charts are available

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THEORY OF PULSE PROPAGATION THROUGH CONCRETE

- Following three types of waves are generated by an impulse applied to a mass:
  - Surface waves having an elliptical particle displacement and slowest
  - Shear or transverse waves with particle displacement at right angles to the direction of travel and faster than the surface waves
  - Longitudinal or compressive waves with particle displacement in the direction of travel and fastest providing more useful information
- Electro-acoustical transducers used for UPV measurements on concrete produce longitudinal waves which, as mentioned above, are fastest and provide more useful information
- UPV depends primarily upon the elastic properties of the material and found to be almost independent of geometry

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THEORY OF PULSE PROPAGATION THROUGH CONCRETE

- For an infinite, homogenous, isotropic elastic medium, the compression wave velocity is given as:

$$V = \sqrt{\frac{K.E_d}{\rho}}$$

Where:

V = compression wave velocity (km/s)

$K = \dfrac{(1-\nu)}{(1+\nu)(1-2\nu)}$

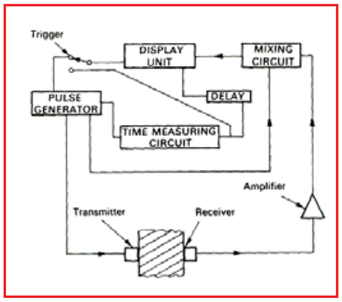
E_d = dynamic modulus of elasticity (kN/mm^2)

ρ = density (kg/m^3)

ν = dynamic Poisson's ratio

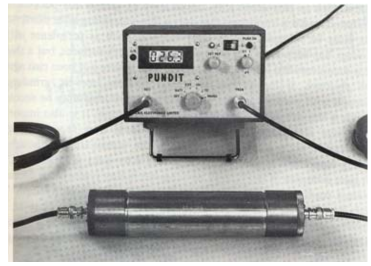
UPV TEST EQUIPMENT

- The UPV equipment is used for the following purposes:
  - Generating a pulse mechanically
  - Transmitting the generated pulse through concrete
  - Receiving and amplifying the pulse
  - Measuring and displaying the transit time
- The circuitry of a typical UPV testing equipment is shown below:



UPV TEST EQUIPMENT

Commercially available UPV equipments are shown below:



PUNDIT Equipment with flat transducers popularly used for UPV test

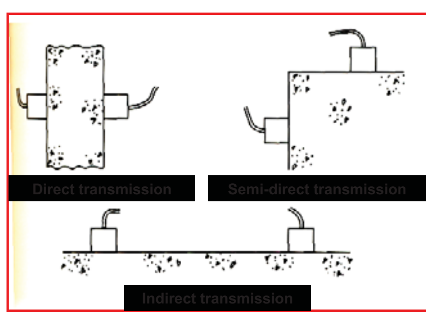
Exponential probe transducers used for UPV test on rough or curved surfaces

UPV TEST PROCEDURE: Coupling of transducers

- A good acoustic coupling between the concrete surface and the face of the transducers is essential for reliable results
- Coupling is provided by a medium such as petroleum jelly, liquid soap or grease
- Air pockets must be eliminated, and it is important that only a thin separating layer exists-any surplus must be squeezed out
- A light medium such as petroleum jelly or liquid soap is found to be the best for smooth surfaces
- A thicker medium such as grease is recommended for rough surfaces which have not been cast using smooth shutters
- In case of very rough or uneven surfaces, grinding or preparation with plaster of Paris or quick-setting mortar may be necessary before coupling

UPV TEST PROCEDURE: Arrangement of transducers

- Following are three basic ways in which the transducers my be arranged:
  - Transducers coupled on opposite faces (direct transmission)
  - Transducers coupled on adjacent faces (semi-direct transmission)
  - Transducers coupled on same faces (indirect transmission)
- The above mentioned arrangements of transducers are shown below:



- The direct method is the most reliable from the point of view of transit time measurement as well as path length measurement
- The semi-direct method is less reliable than the direct method and should only be used if the angle between the transducers is not too great, and if the path length is not too large
- The indirect method is the least accurate because received signal is subject to errors due to scattering of pulse by discontinuities

UPV TEST PROCEDURE: Selection of transducers

- Selection of the transducers for UPV test mainly depend on the following:
  - Whether point contact is needed or not, as in case of rough or curved surface, the exponential probe transducer is suitable
  - The required transducer frequency, which is related to the dimensions of the member under test, for example, for 10 m path length a transducer should have a frequency of 54 kHz and the transducer should have a frequency of 82 kHz for a path length of 3 m (higher frequency required for lower energy output)

UPV TEST PROCEDURE: Equipment calibration

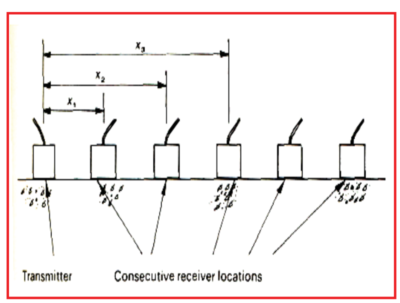
- Before use, the time delay adjustment must be made by setting the zero reading for the equipment. For this, the equipment should regularly be checked during and at the end of each period of use.
- The time delay adjustment is carried out with the help of a calibrated steel reference bar which has a transit time of around 25 *μs*.
- It is recommended that the accuracy of transit time measurement of the equipment should also be checked by measurement of a second reference specimen , preferably with a transit time of around 100 *μs*.

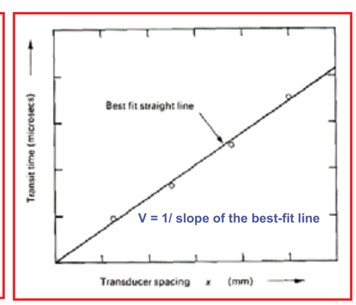
UPV TEST PROCEDURE: Velocity determination

- Determination of pulse velocity requires measurement of the transit time using the UPV equipment with an accuracy of ± 0.1 μs and measurement of path length with an accuracy of ± 1%
- The transit time readings are repeated by complete removal and reapplication of transducers to obtain a minimum value for the transit time, which is taken as final reading
- Once the transit time and the path length are measured, the pulse velocity is determined by dividing the path length by the transit time, as follows:
  V = path length/transit time
- In case of direct transmission, the path length is just the thickness of the member under test.
- In case of semi-direct transmission, the path length is taken as distance between center to center of transducer faces

UPV TEST PROCEDURE: Velocity determination

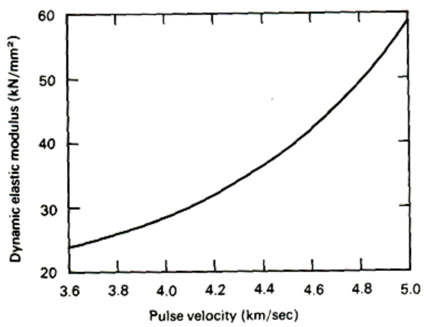
- In case of indirect transmission, the pulse velocity is determined by recording the transit times by placing the receiver at different distances from the fixed position of the transmitter and then obtaining the mean pulse velocity as inverse of slope of a best fit line plotted using spacing versus transit time data, as follows:





CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Dynamic elastic modulus

- The calibration chart between pulse velocity and dynamic elastic modulus shown below (developed by conducting resonance and UPV tests on prisms) may be used to determine the dynamic elastic modulus of concrete:



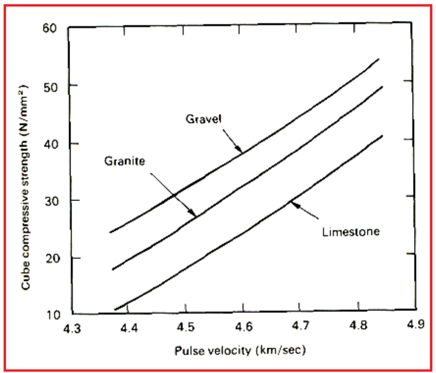
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Compressive strength

- Coarse aggregate type, shape, size, quantity; sand type; cement type; w/c ratio; and maturity of concrete are the important factors which affects the correlation between pulse velocity and strength

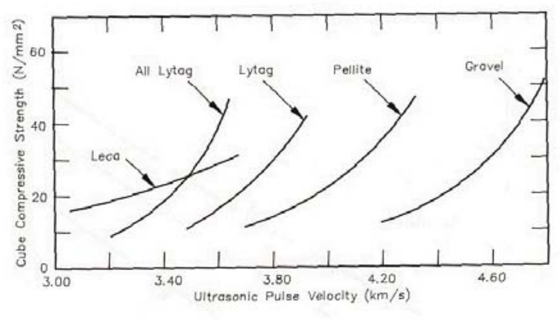
- Therefore separate strength calibration charts are needed for accurate interpretation of the test results for strength, considering the effect of each of the above factors

- Following are few typical strength calibration charts taking the effect of aggregate types and proportions:

CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Compressive strength



CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Compressive strength



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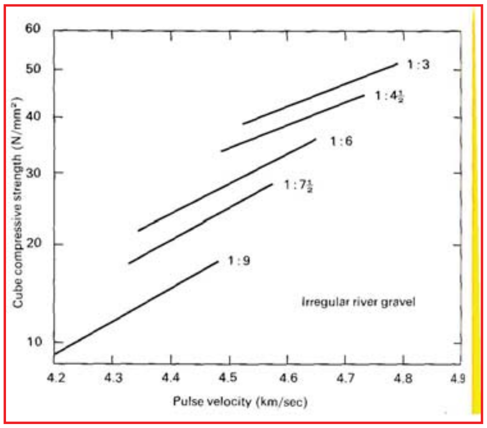
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS:
Compressive strength



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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS:
Compressive strength

- Due to the fact that the precise relationship between pulse velocity and strength is affected by many variables, a calibration model in the following form should be fitted by least squares techniques using the experimental data:

$$f_c = Ae^{BV}$$

Where:

f_c = equivalent cube strength
e = base of natural logarthims
V = pulse velocity
A and B= constants

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS:
Practical Factors Influencing Measured Results

Following are the practical factors which affect the measured results:

- **Temperature**
- **Stress history**
- **Path length**
- **Moisture conditions**
- **Reinforcement**

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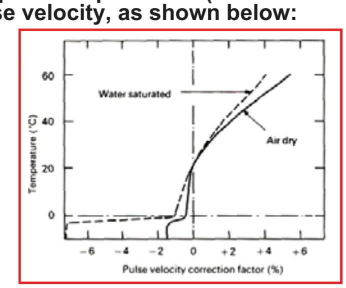
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS:
Practical Factors Influencing Measured Results: Temperature

- **Normal operating temperature (i.e., around 20 °C) <u>does not</u> significantly influence the pulse velocities**
- **However, the peak temperatures (above 20 °C and below 0 °C) affect the pulse velocity, as shown below:**



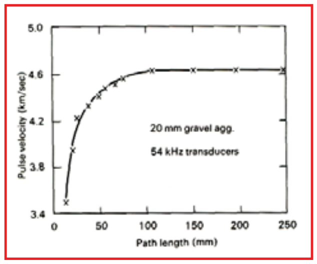
- **The measured velocity should be corrected by multiplying with the factor obtained corresponding to the operating temperature**

CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Stress history

- Any type of stress (compressive or tensile or flexural or prestress in prestressed concrete members) with a low magnitude does not affects the pulse velocity
- It is reported that the pulse velocity in laboratory cubes stressed up to 50% of its crushing strength remains unaffected
- No correction is required for measured velocity through concrete members stressed less than or up to one-third of cube strength
- Care should be taken for overstressed members and in case if tensile stresses have caused cracking
- The internal microcracks affect both path length and width resulting into reduction in the measured pulse velocity

CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Path length

- Unless the path length is excessively small, pulse velocity is not affected by it
- The effect of path length on pulse velocity for a concrete with a maximum aggregate size of 20 mm is typically shown below:

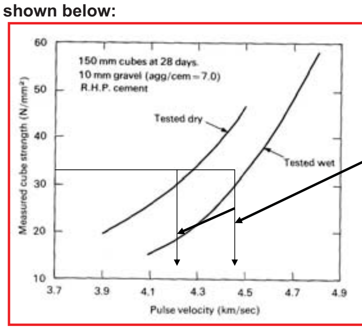


For no effect of path length, it is recommended to select a minimum path length of 100 mm in case of concrete with aggregate having max. size of 20 mm and a minimum path length of 150 mm for concrete with aggregate having max. size of 40 mm.

- A reduction of 5% in the measured velocity is typically observed for a path length increase from approximately 3 m to 6 m.
- The pulse velocity is also affected if the path length is too long because of attenuation of the higher frequency pulse components

CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Moisture conditions

- Pulse velocity through a wet concrete is found to be up to 5% higher than that through the same concrete in dry condition (effect of moisture is less for high-strength concrete than the low-strength concrete)
- However, the strength of a dry concrete is found to be more than that of the same concrete in wet condition
- The effect of moisture condition on both pulse velocity and concrete strength is typically shown below:



As shown, for same strength of a concrete the pulse velocity is less when tested in dry condition than that when tested in wet condition

CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Moisture conditions

- Tomsett (1980) has proposed following calibration model for determining actual strength of in-situ concrete tested in any moisture condition:

$$\log_e \frac{f_1}{f_2} = k f_1 (V_1 - V_2)$$

where f_1 is the strength of a 'standard' saturated specimen
f_2 is the 'actual' strength of the in-situ concrete
V_1 is the pulse velocity of the 'standard' saturated specimen
V_2 is the pulse velocity of the in-situ concrete

k is a constant reflecting compaction control
= 0.015 for normal concrete
= 0.025 for poorly compacted concrete

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

- The effect of reinforcement, if present under the domain of pulses, is to increase the pulse velocity because of the fact that steel has more elasticity than concrete
- Since the velocity along a bar is more than the surrounding concrete, in presence of reinforcement the measured velocity is more than the actual because measured velocity is steel not the concrete
- The pulse velocity along a rebar (V_s) depends on its diameter, velocity of pulses in concrete (V_c) and the condition of bond between rebar and concrete
- The increase in the pulse velocity through a concrete member, measured in vicinity of reinforcement depends on:
  - Proximity of the test points to rebars
  - Diameter and number of rebars
  - Orientation of rebars with respect to the path of pulse propagation

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

- The measured pulse velocity in presence of reinforcement may be corrected as follows:

$$V_c = k\, V_m$$

Where:

V_c = actual pulse velocity through concrete without the effect of reinforcement

V_m = measured pulse velocity in presence of reinforcement

k = correction factor

- The correction factor, *k*, depends on the following:
  - The ratio of pulse velocity through concrete to the pulse velocity along rebar (γ)
  - Rebar diameter and location with respect to measurement points

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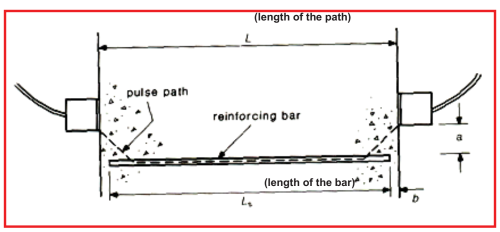
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

(A) Correction factor (*k*) in case of <u>reinforcement parallel to pulse path</u>:



(i) Equation for *k* when a > 2b

$$k = \gamma + 2\left(\frac{a}{L}\right)\sqrt{1-\gamma^2}$$

(ii) Equation for *k* otherwise

$$k = \gamma + 2\left(\frac{\sqrt{a^2+b^2}-\gamma b}{L}\right)$$

(iii) If the bar is directly in line with the transducers (i.e., a = 0), the correction factor is given by:

$$k = 1 - \frac{L_s}{L}(1-\gamma)$$

In all the above equation, the velocity ratio $\gamma = V_c/V_s$

The value of the velocity ratio γ for a given bar diameter and pulse velocity through concrete (V_c) may be determined using the following chart recommended in BS 1881: Part 203

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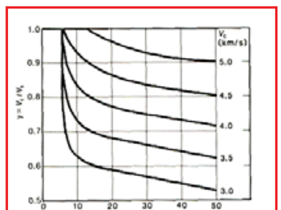
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

Case of <u>reinforcement parallel to pulse path</u>:



Relationship between the bar diameter and velocity ratio for the bars parallel to pulse path

The value of correction factor *k* is determined using the following iterative steps:

1. Assume some reasonable value of V_c and determine γ using the chart for given bar diameter
2. Using determined value of γ and geometry of bar and testing points, determine the value of *k* by substituting γ etc. in the appropriate equation
3. Calculate kV_m and compare it with V_c
4. Repeat the iterative procedure till kV_m is found to be equal to the V_c

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

Example for the case of reinforcement parallel to pulse path:

Example B1

The beam contains 16 mm diameter main bars with 10 mm links as shown in Figure B1. The measured pulse velocity across the top of the beam away from links is 4.2 km/s. Determine the anticipated measured apparent velocity when readings are made directly in line with a link.

As main bar will have no practical influence on measured values, $V_c = 4.2$ km/s. Hence from Figure 3.15 for $V_c = 4.2$ km/s and 10 mm bar,

$$\gamma = 0.88$$

thus allowing for 25 mm cover at each end of link

$$\frac{L_s}{L} = \frac{150}{200} = 0.75$$

thus

$$k = 1 - 0.75(1 - 0.88) = 0.91$$

$$\therefore \text{ anticipated } V_m = \frac{4.2}{0.91} = 4.62 \text{ km/s.}$$

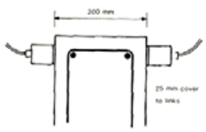

Figure B1

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

Example for the case of reinforcement parallel to pulse path:

Example B2

An uncracked beam shown in Figure B2 has well bonded 20 mm bars with 50 mm end cover. Measurements at 150 mm offset yield $V_m = 4.65$ km/s. Estimate the true pulse velocity in the concrete (V_c).

$$a > 2b \quad \text{and} \quad a/L = 0.075.$$

For trial values of V_c evaluate kV_m as in Table B1, and plot as shown in Figure B3.

On the basis of these values, try $V_c = 4.10$ then $\gamma = 0.79$, $k = 0.88$ hence

$$V_m = \frac{4.10}{0.88} = 4.66 \text{ km/s (OK)}$$

thus

$$\text{estimated } V_c = 4.10 \text{ km/s}$$

(note: RILEM 'maximum effect' factors suggest $V_c = 3.75$ km/s).

Figure B2

Table B1

Trial V_c	γ (Fig. 3.15)	k (Fig. 3.16)	kV_m	$(V_c - kV_m)$
4.5 km/s	0.87	0.94	4.37 km/s	+0.13
3.5 km/s	0.68	0.79	3.67 km/s	−0.17

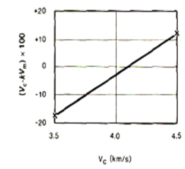

Figure B3

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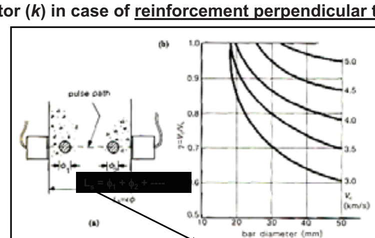
CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

(B) Correction factor (*k*) in case of reinforcement perpendicular to pulse path:



$$k = 1 - \frac{L_s}{L}(1 - \gamma)$$

The value of correction factor *k* is determined using the following iterative steps:

1. Assume some reasonable value of V_c and determine γ using the chart for given bar diameter
2. Using determined value of γ and geometry of bar and testing points, determine the value of *k* by substituting γ etc. in the above equation
3. Calculate kV_m and compare it with V_c
4. Repeat the iterative procedure till kV_m is found to be equal to the V_c

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CALIBRATION AND INTERPRETATION OF UPV TEST RESULTS: Practical Factors Influencing Measured Results: Reinforcement

Example for the case of reinforcement perpendicular to pulse path:

Example B3

Measurements across a 300 mm wide beam containing three No. 32 mm bars give a value of $V_m = 4.4$ km/s. Estimate V_c.

Then $$\frac{L_s}{L} = \frac{3 \times 32}{300} = 0.32.$$

For trial values of V_c, evaluate kV_m as in Table B2 and plot Figure B4.

Thus try $V_c = 4.25$ km/s, then $\gamma = 0.89$ and $k = 0.965$ hence

$$V_m = \frac{4.25}{0.965} = 4.40 \text{ km/s (OK)}$$

thus estimated $V_c = 4.25$ km/s (note RILEM 'maximum effect' factors suggest $V_c \simeq 3.9$ km/s).

Table B2

Trial V_c	γ (Fig. 3.18)	$k\left(= 1 - \frac{L_s}{L}(1-\gamma)\right)$	kV_m	$(V_c - kV_m)$
4.5 km/s	0.92	0.974	4.28 km/s	+0.22
4.0 km/s	0.85	0.952	4.19 km/s	−0.19

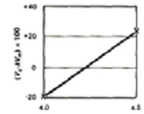

Figure B4

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APPLICATIONS OF UPV TEST RESULTS

- Monitoring strength development or deterioration in laboratory specimens subjected to varying curing conditions or to aggressive environment
- Measurement of in-situ concrete uniformity
- Detection of cracking and honeycombing in in-situ concrete
- Measurement of crack depth
- Strength estimation of in-situ concrete
- Assessment of in-situ concrete deterioration
- Measurement of layer thickness in in-situ concrete
- Measurement of elastic modulus of in-situ concrete

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APPLICATIONS OF UPV TEST RESULTS: Laboratory applications

- UPV test may be used for monitoring strength development or deterioration in laboratory specimens subjected to varying curing conditions or to aggressive environment
- The detection of the onset of micro-cracking may also be carried out during loading tests on structural members

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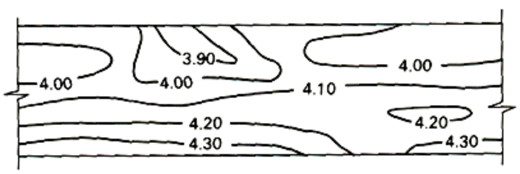
APPLICATIONS OF UPV TEST RESULTS: Measurement of in-situ concrete uniformity

- Measurement of in-situ concrete uniformity is probably the most valuable and reliable application of UPV test in the field
- The uniformity of concrete may be obtained by conducting the UPV test on a regular grid over the member (with a spacing of 1 m or less)
- Typical pulse velocity contours plotted for a beam constructed from a number of concrete batches are shown below:



Typical pulse velocity beam contours (km/s)

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APPLICATIONS OF UPV TEST RESULTS: Detection of cracking and honeycombing

- UPV test may directly detect cracking and honeycombing in concrete, without need for detailed correlation of V with any other property of concrete
- Since presence of cracking or honeycombing (i.e., void) along the pulse path decreases the velocity due to increase in attenuation, the cracking and honeycombing may be detected by observing at a location where measured value of V is found to be less than that found at a sound location
- Water-filled cracks can not be detected using UPV test
- A given void is more difficult to detect as the path length increases

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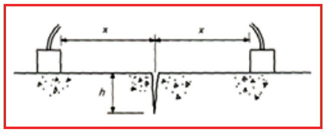
APPLICATIONS OF UPV TEST RESULTS: Measurement of crack depth

An estimate of crack depths may be obtained by the use of indirect surface readings, as shown below:



Path length without crack $= 2x$

Path length around crack $= 2\sqrt{x^2 + h^2}$

Surface travel time without crack $= \frac{2x}{V} = T_s$

Travel time around crack $= \frac{2\sqrt{x^2 + h^2}}{V} = T_c$

and it can be shown that

crack depth, $h = x\sqrt{\left(\frac{T_c^2}{T_s^2} - 1\right)}$.

For calculation of *h* using the derived equation:

- T_s will be taken as transit time observed when the transducers are placed at sound concrete
- T_c will be taken as transit time observed when the transducers are placed each side of the cracked concrete

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APPLICATIONS OF UPV TEST RESULTS: Strength estimation

- With the help of suitable calibration chart or model, UPV test may be used to estimate the strength of concrete.
- However, the strength estimate by UPV method is not found to be accurate. The error ranges from ±10 to ±20%.
- Error in the strength estimation increases at higher strength levels, and estimates above 40 MPa should be treated with great caution

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APPLICATIONS OF UPV TEST RESULTS: Assessment of concrete deterioration

- UPV test may be used to assess the deterioration of concrete by following:
  - Fire
  - Mechanical effects
  - Frost attack
  - Chemical attack
- The depth of fire or surface chemical attack may be determined using the following:

  $t = TV_c – L$

  Where:

  t = depth of deterioration

  T = transit time for a path length L including one damaged surface zone

  V_c= pulse velocity measured at a sound location

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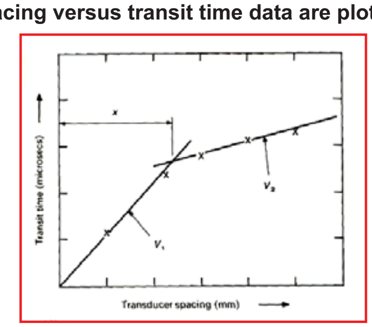
APPLICATIONS OF UPV TEST RESULTS: Measurement of layer thickness

- UPV test may be used to measure the thickness of top layer of concrete below which the concrete is found to have different quality
- For determination of the layer thickness (t), the UPV tests are conducted by varying the transducer spacing
- The spacing versus transit time data are plotted as shown below:

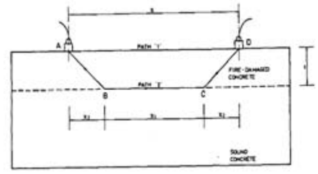


$$t = \frac{x}{2}\sqrt{\frac{(V_2 - V_1)}{(V_2 + V_1)}}$$

APPLICATIONS OF UPV TEST RESULTS:
Assessment of fire damage

- When a concrete member is subjected to fire, the exterior of the member is heated up drastically, while the interior remains at a relatively low temperature
- Therefore, only a thin surface layer of the concrete is subjected to severe damage
- Knowledge of the thickness of damaged layer is very useful to the engineer in estimating the repair work
- Thickness of the fire damaged layer can be assessed by measuring UPV along the surface, in the same way as described earlier

APPLICATIONS OF UPV TEST RESULTS:
Assessment of fire damage



Length of Path 1 = A D

Length of Path 2 = (A B + C D) + B C
(in damaged concrete) (in sound concrete)

The transit time along Path 1 is given by

$$T_1 = AD/V_d = X/V_d$$

The transit time along Path 2 is given by

$$T_2 = \frac{AB + CD}{V_d} + \frac{BC}{V_s} = \frac{2\sqrt{(X_2^2 + t^2)}}{V_d} + \frac{X - 2X_2}{V_s}$$

where

V_d = pulse velocity in damaged concrete,
V_s = pulse velocity in sound concrete, and
t = thickness of damaged concrete.

For the minimum value of T_2, $dT_2/dX_2 = 0$, that is

$$(2/V_d)(1/2)(X_2^2 + t^2)^{-1/2}(2X_2) - (2/V_s) = 0$$

or

$$\frac{X_2^2}{V_d^2(X_2^2 + t^2)} = 1/V_s^2$$

Therefore

$$X_2 = \frac{V_d t}{\sqrt{(V_s^2 - V_d^2)}}$$

Substitute X_2 into Eq 2

$$T_2 = \frac{2t\sqrt{(V_s^2 - V_d^2)}}{V_s V_d} + \frac{X}{V_s}$$

At a certain value of $X = X_0$, the transit times along both paths are equal, that is

$$T_1 = T_2$$

Then

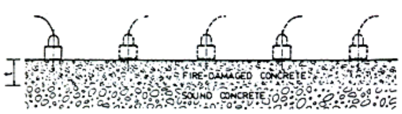
$$\frac{X_0}{V_d} = \frac{2t\sqrt{(V_s^2 - V_d^2)}}{V_s V_d} + \frac{X_0}{V_s}$$

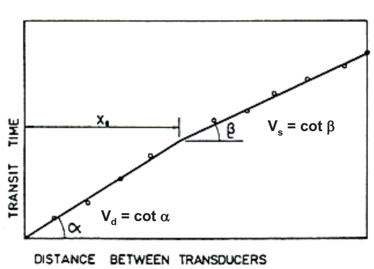
Therefore

$$t = \frac{X_0}{2}\sqrt{\left[\frac{V_s - V_d}{V_s + V_d}\right]}$$

APPLICATIONS OF UPV TEST RESULTS:
Assessment of fire damage

Determination of V_d and V_s





APPLICATIONS OF UPV TEST RESULTS:
Measurement of elastic modulus

- Elastic modulus is the property of concrete which can be determined with the greatest accuracy using UPV test
- Elastic modulus may be calculated by substituting the measured value of pulse velocity and suitably assumed values of Poisson's ratio and density in the equation relating pulse velocity with the elastic modulus

APPLICATIONS OF UPV TEST RESULTS:
Advantages and limitations

Advantages

- UPV test is truly non-destructive and can be performed both in lab as well as in-situ
- UPV measurement has been found to be a valuable and reliable method of examining interior of a body of concrete
- Modern UPV test equipment is robust, reasonably cheap and easy to operate, and reliable even under site conditions

Limitations

- Operators must be well trained and aware of the factors affecting the readings
- It is essential that the test results are properly evaluated and interpreted by experienced engineers who are familiar with the technique

APPLICATIONS OF UPV TEST RESULTS:
Advantages and limitations

Limitations -----continued

- The UPV method only gives an estimate of the extent of cracking within concrete, however, the use for detection of flaws within the concrete is not reliable when the concrete is wet
- The UPV test is least reliable for estimation of strength of concrete because of the many factors affecting calibrations
- Application of the UPV test for determining depth of fire damage is limited to only the portions which are free from cracking due to very high temperature