

THE ASSESSMENT OF CONCRETE QUALITY BY ULTRASONIC PULSE VELOCITY

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Abstract

In the present study, the uniformity and potential internal defects of concrete elements in situ were assessed by using Ultrasonic Pulse Velocity (UPV) testing method according to TCVN 9357:2012. Thirteen cross beams with dimension of $4.8 \times 1.5 \times 1.5 \text{ m}^3$ were selected to measure the pulse velocity. Three cross beams were used to check potential internal defects in concrete and 10 cross beams were used to assess the uniformity of concrete in the elements. The results showed that there is no potential internal defect with size over 100 mm in three tested beams and concrete quality of all tested beams is good with the coefficient of variation (CV) of ultrasonic pulse velocity results of all tested points is lower than 2%.

Keywords: concrete; homogeneity; internal defects; ultrasonic pulse velocity.

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1. Introduction

Ultrasonic Pulse Velocity (UPV) test is one of non-destructive testing methods frequently used to assess the quality of concrete structures. A pulse of longitudinal vibrations is generated by an electro-acoustical transducer, which is held in contact with one surface of the concrete. When the pulse is transmitted into the concrete from the transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. The first waves to reach the receiving transducer are the longitudinal waves. These waves are converted into an electrical signal by a second transducer. Longitudinal pulse velocity is given by:

$$v = \frac{L}{T} \quad (1)$$

where v is the longitudinal pulse velocity, (m/s); L is the path length, (m); T is the time taken by the pulse to through that length, (s).

The equipment consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device to measure the time interval between the initiation of a pulse produced at the transmitting transducer and its arrival at the receiving transducer (Fig. 1). The equipment should be capable of measuring transit time over path lengths ranging from about 100 mm to the maximum thickness to be inspected to an accuracy of $\pm 1\%$. Generally the transducers should be in the range of 20 to 150 kHz although frequencies as low as 10 kHz may be used for very long concrete path lengths and as high as 1 MHz for mortars and grouts or for short path lengths. High frequency pulses have a well-defined onset but, as they pass through the concrete, become attenuated more rapidly than

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pulses of lower frequency. It is therefore preferable to use high frequency transducers for short path lengths and low frequency transducers for long path lengths. Transducers with a frequency of 50 kHz to 60 kHz are suitable for most common applications [1].

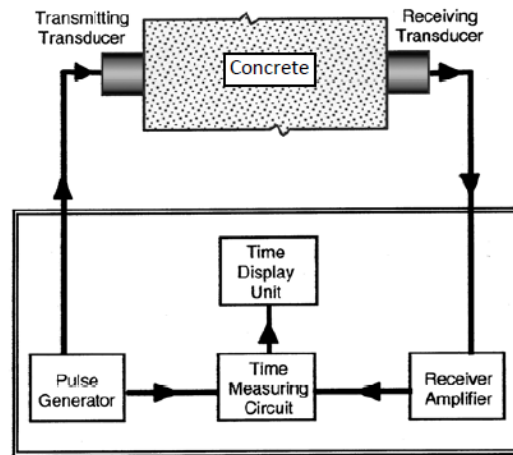


Figure 1. Schematic of Pulse Velocity Apparatus [2]

UPV is a function of the bulk modulus, shear modulus and density of the material [1]. Thus, UPV is affected by concrete porosity and cracking because they directly influence the aforementioned properties, and high crack density and high porosity yield lower UPV values. Moreover, different concrete mixtures can have different densities (e.g. variation in the content of air entrained or the aggregate density), resulting in differences in UPV that are associated with the level of damage. This explains why the UPV can vary from one structure to another, even if the concrete exhibits no signs of damage [3]. Measurement of the velocity of ultrasonic pulses of longitudinal vibrations passing through concrete may be used for the following applications [4–8]:

- Determination of the homogeneity of concrete in and between members.
- Measurement of changes occurring with time in the properties of concrete.
- Correlation of pulse velocity and strength as a measure of concrete quality.
- Determination of the modulus of elasticity and dynamic Poisson's ratio of the concrete.

The present study assesses the uniformity and potential internal defects of concrete beam elements in situ. These concrete structures have appeared some defects on surface of the elements such as honeycombs, surface cracks and cold joints. Therefore, the quality of hardened concrete in the structures should be checked by non-destructive testing (NDT) methods as the request of the employer, client and consultant. Thirteen cross beams with dimension of $4.8 \times 1.5 \times 1.5 \text{ m}^3$ were selected to measure the pulse velocity. Three cross beams were used to check potential internal defects in concrete and ten cross beams were used to assess the uniformity of concrete in the elements.

2. Experimental design and methods

2.1. Experimental design

The homogeneity of concrete is evaluated by comparing the pulse velocity of the ultrasonic signal through concrete according to TCVN 9357:2012 - Normal concrete - Nondestructive methods - Assessment of concrete quality using ultrasonic pulse velocity [4]. The equipment is PUNDIT LAB

- Proceq ultrasonic tester. To reduce the effect of steel reinforcements on the pulse velocity value, the steel bar detector is also used. The arrangement of the transducers is opposite faces (direct transmission). The distance between tested areas or tested points on the surface of the element should be less than or equal to 1000 mm. According to Appendix C of TCVN 9357-2012 [4], the concrete in tested elements is considered as homogeneous when the variation coefficient of ultrasonic pulse velocity results is less than 2–3%.

In order to assess the homogeneity of concrete in cross beam, array of the tested areas were determined on the whole surface of the structures with the distance between the tested areas does not exceed 1000 mm. In each tested area, 03 tested points are measured the ultrasonic pulse velocity to get the average values of the tested area (Figs. 2 and 3).

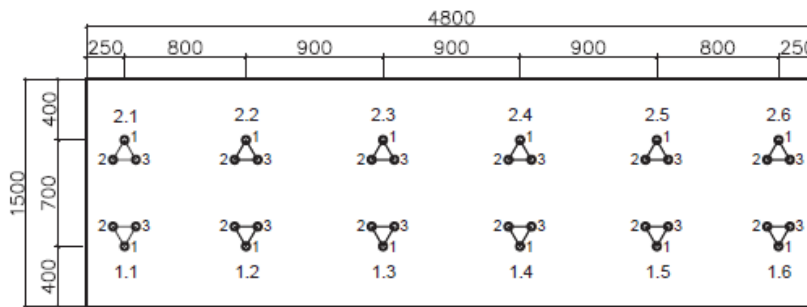


Figure 2. Array of tested areas and tested points on the cross beams



(a) Homogeneity testing



(b) Potential internal defect testing



(c) Ultrasonic tester

Figure 3. Measurement of ultrasonic pulse velocity on concrete beams

The internal defects in concrete located between two sensors of ultrasonic testing which have their size bigger than diameter of the sensor will decrease the pulse velocity of ultrasonic through concrete. The accuracy of the experiment and the detectable size of defects depend on the distance between tested points arranged on the structures.

To assess the potential internal defects in concrete of cross beams, an area of $1000 \times 3000 \text{ mm}^2$ on the selected cross beam will be selected and examined. Array of tested points with the grid of 100 mm will be arranged on this tested area (Figs. 3 and 4). Ultrasonic pulse velocity through concrete will be examined at all the tested points. If the variation coefficient of all the results is less than 2 to 3%, concrete in the tested areas is homogeneity and it can be concluded that there are no defects

with the size over 100 mm in this tested area. If there is any result having a too low velocity value (lower than 20% compared to the average value), the ultrasonic pulse velocity at this tested point is rechecked carefully. If the low result is correct, there is potential internal defect at this point. The size of this defect will be estimated by adding a new array of tested points with a denser grid in this area.

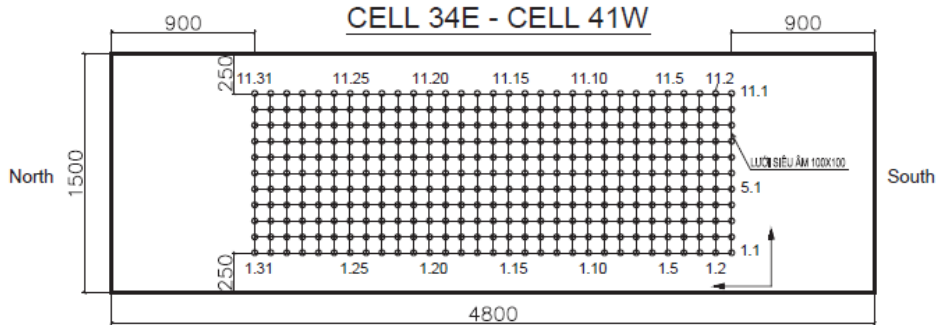


Figure 4. Array of tested points with the grid of 100 mm in $1000 \times 3000 \text{ mm}^2$ on the cross beams

2.2. Calculation of the coefficient of variation (CV) of pulse velocity results

The homogeneity of concrete beams is evaluated through the coefficient of variation of pulse velocity results. The coefficient of variation (CV) of ultrasonic pulse velocity results is defined as the ratio of the standard deviation (S) to the mean of pulse velocity results as followed:

$$CV = \frac{S_K^H}{V_{th}} \times 100 \quad (2)$$

with

$$\left(S_K^H\right)^2 = \frac{\sum_{i=1}^n (V_i - V_{tb})^2}{(n-1)} \quad (3)$$

and

$$V_{tb} = \frac{\sum_{i=1}^n V_i}{n} \quad (4)$$

where S_K^H is standard deviation of the measurement, $(S_K^H)^2$ is variance; V_{tb} is mean of ultrasonic pulse velocity results, (m/s); V_i is ultrasonic pulse velocity result at tested point (area) number i , (m/s); n is the total number of tested points (areas).

3. Results and discussion

3.1. Potential internal defects in concrete beams

The ultrasonic pulse velocity values at the tested points on the elements is measured and recorded. At first, the homogeneity of concrete at the tested areas (1000×3000 mm²) with 341 tested points/beam (Fig. 4) was assessed by the coefficient of variation (CV) of ultrasonic pulse velocity results (Table 1). The results showed that the coefficient of variation (CV) of ultrasonic pulse velocity results of all tested points at all the 03 tested areas is lower than 2%. The distribution of ultrasonic pulse

velocity values at tested points on the elements (Figs. 5, 6 and 7) also showed how concentrated the values of tested points are. According to TCVN 9357:2012, concrete in the tested areas is considered homogeneous.

Because the grid of the tested points array is 100 mm, the difference between the ultrasonic pulse velocity result of all the tested points and the average value is not exceeded 20% (Table 1), there is no potential internal defect with defect's size over 100 mm in the tested concrete areas.

Table 1. Results of investigation of homogeneity and potential internal defects in concrete beams

No	Name of element	Ultrasonic pulse velocity, m/s			Variance, $(S_K^H)^2$	Coefficient of Variation, (CV)
		Max	Min	Mean		
1	Beam 1A	4590	3980	4259.4	5692.41	1.77
2	Beam 2A	4559	4063	4364.7	5583.70	1.71
3	Beam 3A	4414	4104	4268.6	3653.40	1.42

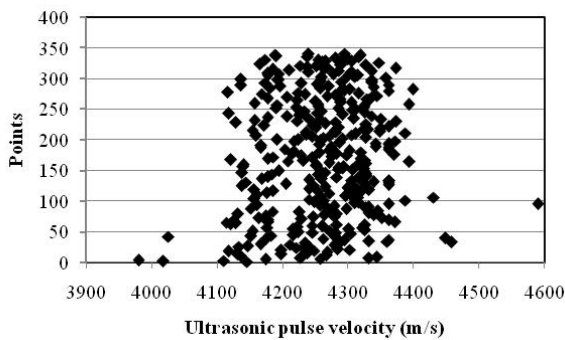


Figure 5. Distribution of ultrasonic pulse velocity values at tested points on Beam 1A

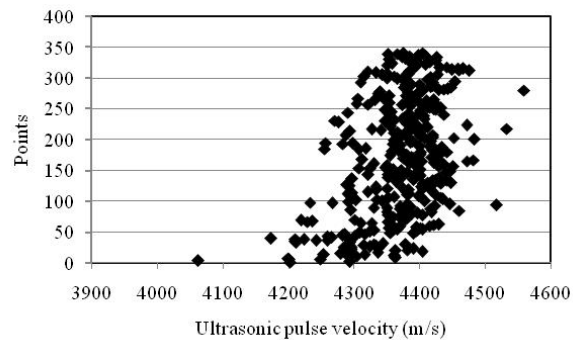


Figure 6. Distribution of ultrasonic pulse velocity values at tested points on Beam 2A

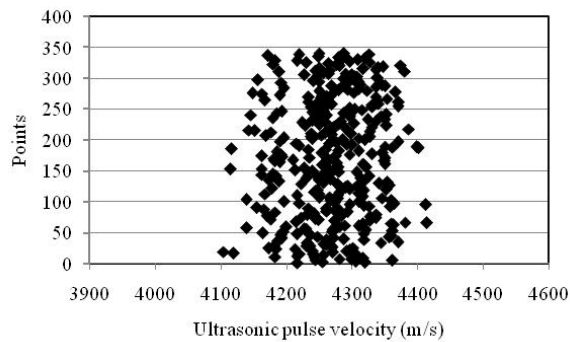


Figure 7. Distribution of ultrasonic pulse velocity values at tested points on Beam 3A

3.2. Homogeneity of concrete in beams

All 10 cross beams in the construction were assessed the homogeneity of concrete by measuring 12 tested area/beam. Each tested area has 03 tested points to measure the average ultrasonic pulse velocity of the area. According to TCVN 9357:2012, the grid of array of the tested areas on the cross beams is not over 1000 mm and given in Fig. 2. Thirty-six tested points/beam are measured and the ultrasonic pulse velocity values are recorded. The homogeneity of concrete in the cross beams were

assessed by the coefficient of variation (CV) of the average ultrasonic pulse velocity results of tested areas (Table 2). The results showed that the coefficient of variation (CV) of ultrasonic pulse velocity results of all tested areas on all the elements is lower than 2%. The distribution of ultrasonic pulse velocity values at tested points on the elements (Figs. 8 to 17) also showed how concentrated the values of tested points are. According to TCVN 9357:2012, concrete in the cross beams is considered homogeneous.

Table 2. Results of investigation of homogeneity and potential internal defects in concrete beams

No	Name of element	Ultrasonic pulse velocity, m/s			Variance, $(S_K^H)^2$	Coefficient of Variation, (CV)
		Max	Min	Mean		
1	Beam 1B	4471	4181	4325.1	3237.3	1.32
2	Beam 2B	4391	4196	4305.1	1011.2	0.74
3	Beam 3B	4422	4189	4308.2	1950.9	1.03
4	Beam 4B	4498	4267	4382.2	1293.6	0.82
5	Beam 5B	4426	4136	4300.6	2790.3	1.23
6	Beam 6B	4385	4139	4264.5	1644.6	0.95
7	Beam 7B	4406	4147	4269.4	1590.6	0.93
8	Beam 8B	4452	4116	4334.9	2660.8	1.19
9	Beam 9B	4450	4237	4348.2	1155.1	0.78
10	Beam 10B	4440	4127	4336.9	2709.6	1.20

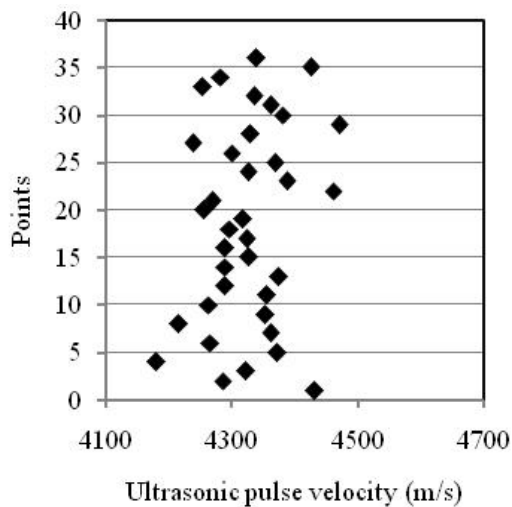


Figure 8. Distribution of ultrasonic pulse velocity values at tested points on Beam 1B

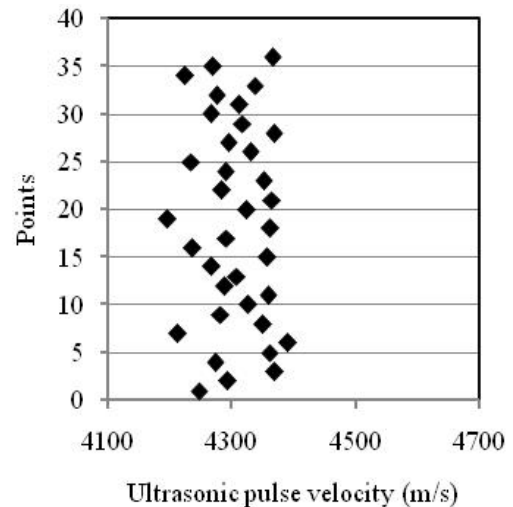


Figure 9. Distribution of ultrasonic pulse velocity values at tested points on Beam 2B

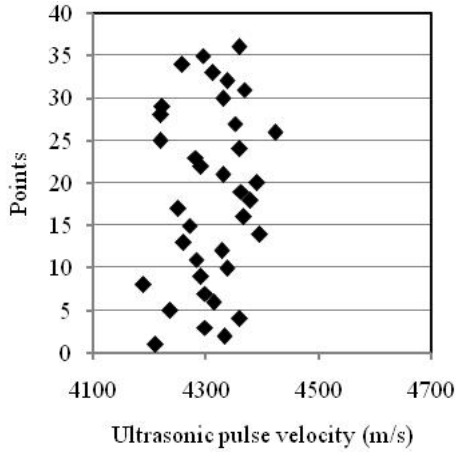


Figure 10. Distribution of ultrasonic pulse velocity values at tested points on Beam 3B

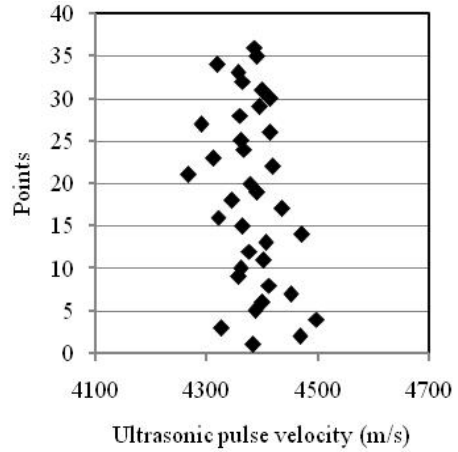


Figure 11. Distribution of ultrasonic pulse velocity values at tested points on Beam 4B

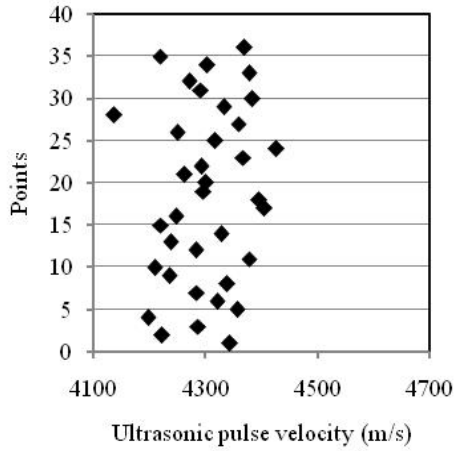


Figure 12. Distribution of ultrasonic pulse velocity values at tested points on Beam 5B

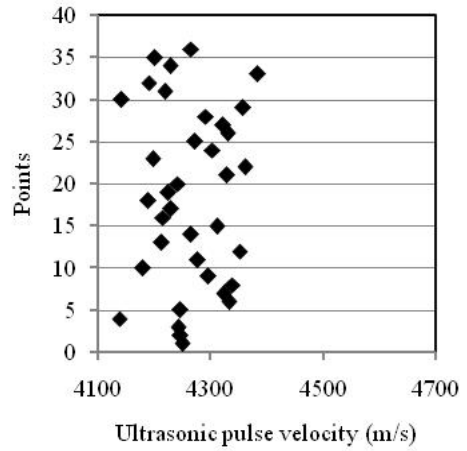


Figure 13. Distribution of ultrasonic pulse velocity values at tested points on Beam 6B

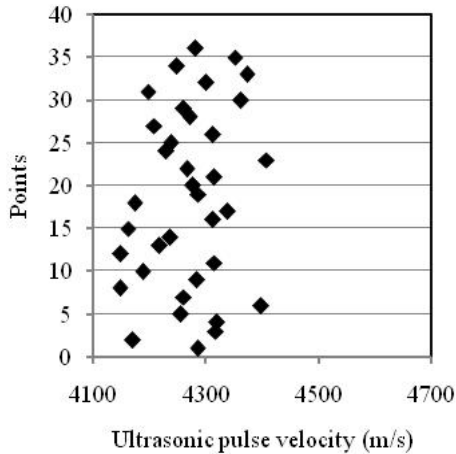


Figure 14. Distribution of ultrasonic pulse velocity values at tested points on Beam 7B

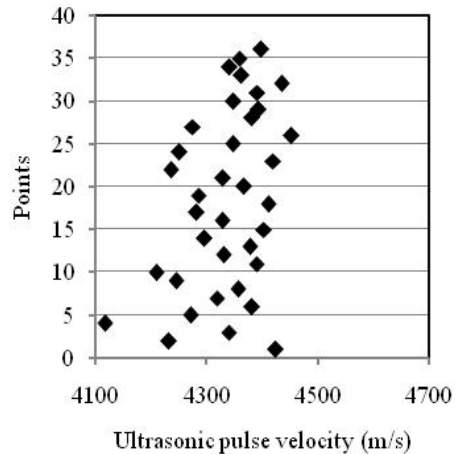


Figure 15. Distribution of ultrasonic pulse velocity values at tested points on Beam 8B

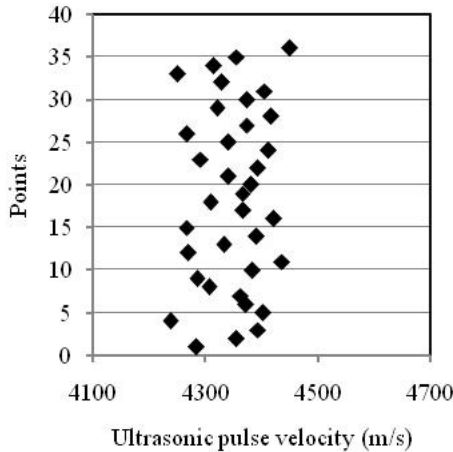


Figure 16. Distribution of ultrasonic pulse velocity values at tested points on Beam 9B

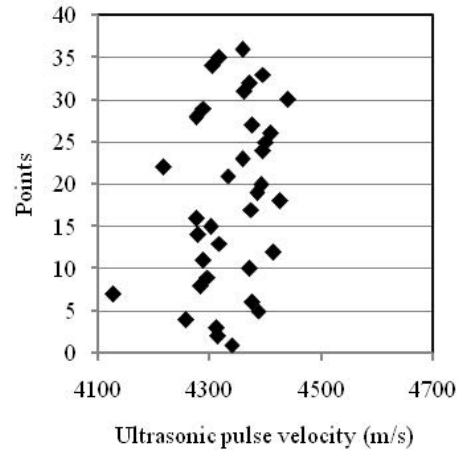


Figure 17. Distribution of ultrasonic pulse velocity values at tested points on Beam 10B

4. Conclusions

From the results of this study, it can be concluded that the homogeneity and potential internal defects in concrete elements can be assessed by Ultrasonic Pulse Velocity (UPV) testing method according to TCVN 9357:2012. The coefficient of variation (CV) of ultrasonic pulse velocity results of all tested points at all the tested concrete beams is lower than 2%. It means that concrete in all the elements is uniform and there is no potential internal defect with size over 100 mm in three tested beams although there are some honeycombs, surface cracks and cold joints appearing on the surface.

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