Structural Durability & Health Monitoring
DOI:10.32604/sdhm.2020.06403
Article

Comparison of Fuzzy Synthetic Evaluation and Field Measurement of Internal Defects in Assembled Concrete Detected by Ultrasonic Waves

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Received: 19 February 2019; Accepted: 31 December 2019

Abstract: Analyze and compare the basic principles of ultrasonic detection of voids in concrete, choose ZBL-U520/510 non-metallic ultrasonic detector, and use the opposite detection method to test the void size in the joints of prefabricated concrete structures. The results show that: ultrasonic method by testing the waveform, sound, and speed of sound analysis can effectively determine the position of the defect, and through the conversion formula can estimate the void size. Ultrasonic parameters are used to distinguish the internal defects of Assembly concrete. Sometimes there are different results with different parameters. It is difficult for engineers to directly determine the internal defects. Fuzzy comprehensive evaluation can establish an overall evaluation of things or objects controlled by multiple factors by establishing membership functions. Through the inspection of engineering examples: the fuzzy comprehensive judgment method has no difference between the judgment of some good quality points and the judgment results of the original criteria, but for some abnormal points or points near the critical value, the advantages of fuzzy criteria can be achieved. The judgment process will be more scientific by considering several parameters in a comprehensive manner and digitizing the original subjective judgments.

Keywords: Ultrasonic wave; assembly type; internal defects; fuzzy comprehensive evaluation

1 Introduction

In recent years, with the vigorous promotion of national policies, the prefabricated buildings have developed rapidly, but the connection quality of the fabricated nodes is a major constraint factor for the development of assembly. Since the connection of nodes is a concealed project, quality inspection is difficult. Testing after the completion of concrete structure construction is an important means to ensure the safety and durability of buildings [1]. The extraction method and the core drilling method are traditional concrete testing methods used in engineering. The pulling method is to pull out the anchors in the concrete structure and determine the strength of the concrete according to the ultimate pullout force of the concrete; The core method is to drill a core sample on a concrete structure, which is commonly used for the detection of concrete structural strength and internal defects. However, these two methods are destructive tests for small-scale local sampling of concrete [2,3], which will cause a certain degree of damage to the concrete structure and the lack of randomness of the test results, which cannot fully and objectively reflect the overall quality of the concrete [4]. Therefore, it is necessary to adopt a non-destructive testing method to obtain the internal structure of the concrete without damaging the concrete structure, and then to evaluate the quality of the concrete structure.

As a non-destructive testing method, ultrasonic testing technology has been widely used in the field of civil engineering [5]. Li et al. [6] used ultrasonic single-sided flat test to detect the depth of concrete structure cracks, and evaluated the influence range of concrete cracks by crack depth test results. An et al. [7] studied the correlation between the corrosion degree of steel bars and the ultrasonic wave velocity, and used the ultrasonic wave velocity detected at a certain moment to estimate the corrosion damage degree of reinforced concrete. Zhang [8] used the spectrum analysis method to obtain the spectral characteristics of the ultrasonic wave. By comparing the spectral difference between the intact concrete and the defective concrete acoustic wave test, the internal defects of the concrete were comprehensively judged. John et al. [9] used the ultrasonic pulse velocity (UPV) method to conduct experimental research on the stratification of concrete, and evaluated the location and size of the layer on the plate. Parisa et al. [10] applied dynamic acoustic elasticity testing (DAET) techniques to monitor damage inside materials. Farid et al. [11] explored the feasibility and sensitivity of ultrasonic testing for mechanical damage of reinforced concrete slabs in reinforced concrete slab bending tests, and analyzed the effects of alkali-silicon reactions in concrete or concrete. Pahlavan et al. [12] studied the interaction of ultrasonic waves with locally closed surface cracks in concrete structures. Nevbahar et al. [13] revealed the strength of reinforced concrete by ultrasonic P and S wave velocities. Benaicha et al. [14] used the ultrasonic velocity method to evaluate the non-segregation filling ability of self-compacting concrete, and compared the uniformity and quality of concrete. Xu et al. [15] discussed the correctness and feasibility of ultrasonic testing technology for testing small diameter concrete filled steel tubular specimens. Huang et al. [16] have shown that ultrasonic pulse waves have strong penetrating ability and are suitable for detecting concrete. Ultrasonic testing equipment is simple and easy to operate, and is widely used in concrete structure defect detection.

The biggest characteristic of ultrasonic data is its ambiguity. When detecting ultrasonic internal defects, ultrasonic waves generally consider a series of influencing factors such as wave velocity, amplitude and waveform [17], which makes it difficult to accurately determine the size of concrete internal defects. Fuzzy comprehensive evaluation is an evaluation method based on the ambiguity of evaluation factors when considering the influence of multiple factors [18–22]. As an important method of risk assessment, fuzzy comprehensive evaluation is widely used in engineering field. Starting from the influencing factors of comprehensive evaluation of building engineering quality grade, the fuzzy comprehensive evaluation of building engineering quality [23]. The fuzzy comprehensive evaluation method is used to quantitatively calculate the risk level of the foundation pit, and the fuzzy comprehensive evaluation method is used to analyze the example. The obtained result is in line with the actual situation of the project [24]. The fuzzy comprehensive evaluation method is used to evaluate the reliability of the service structure. The engineering example shows that it is scientific, reasonable and practical to use this quantitative method to deal with a large amount of uncertain information in structural reliability evaluation [25]. Therefore, the fuzzy comprehensive evaluation method in fuzzy mathematics is used to fuzzify the defects inside the concrete detected by ultrasonic.

Because the result of ultrasonic testing is affected by many factors, the criterion is still not uniform. In order to better apply the fuzzy comprehensive assessment method, the actual field statistical data is used as the value standard in the fuzzy comprehensive assessment method to fully verify the reliability of the assessment results.

2 Ultrasonic Method to Estimate the Internal Void Method

2.1 Basic Principles of Ultrasonic Detection of Internal Voids

The speed of ultrasonic propagation in a uniform grouting material medium and steel material is basically constant, which is a constant. When there is no void in the prefabricated coagulation structure, the overlapping steel bars need to be positioned accurately, and the propagation sound should be fixed or change within a certain range. When the sound wave is transmitted between two points, the principle of the least time-consuming path propagation is automatically selected. When the sound wave passes through a certain section of concrete containing void defects, the pulse can only propagate along the boundary of the defect (the principle of low-frequency diffusion). In this way, because the diffraction path is longer than the straight path, the acoustic time is longer than normal. However, the speed of sound is calculated by taking the distance L between the holes on both sides as the propagation distance, and the sound speed thus obtained is smaller than normal.

2.2 Concrete Defect Estimation

When the internal defects of concrete are composed of loose materials or low density areas, there are two possible propagation paths for sound waves. As shown in Fig. 1: one is to propagate along the boundary of the defect as the void defect, and the other is to propagate through this low-density material. In short, the measured sound at the defect site is longer and the speed of sound is smaller. In both cases of seamless gaps and gaps, the ultrasonic wave can infer the presence, absence, position, and state of the gap through the time difference, phase change, and amplitude attenuation of a given distance. Finally, the compactness of the concrete can be determined.

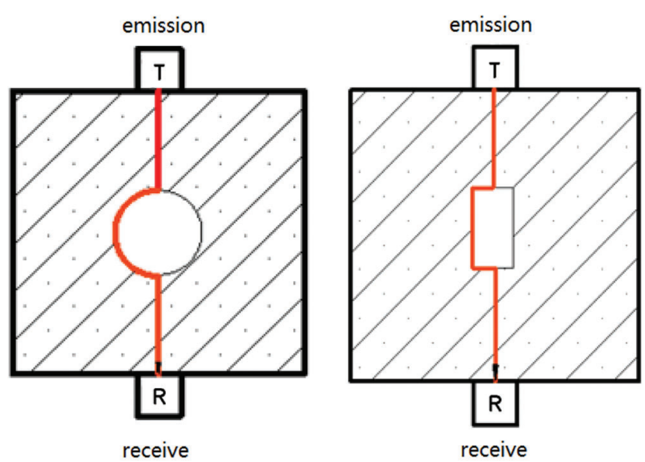


Figure 1: The propagation path of ultrasonic waves in defective concrete. (a) Round defect, (b) Rectangular defect

When ultrasonic waves propagate in dense concrete:

$$t_1 = \frac{a}{v_1} \tag{1}$$

When ultrasonic waves propagate in circular defect concrete:

$$t_2 = \frac{(a - D) + \pi D/2}{v_1} \tag{2}$$

When ultrasonic waves propagate in rectangle-defect concrete:

$$t_3 = \frac{(a - a_1) + a_1 + b_1}{v_1} \tag{3}$$

t_1 is the sound propagation of ultrasonic waves in compacted concrete, t_2, t_3 is Ultrasonic sound propagation in defective concrete, a is the distance measurement, v_1 is the propagation speed of ultrasonic waves in concrete, D is the diameter of circular defects, a_1, b_1 is the length of the rectangular defect.

Available from Eqs. (1) and (2):

$$\frac{a}{t_1} = \frac{(a - D) + \pi D/2}{t_2} \tag{4}$$

Available from Eqs. (1) and (3):

$$\frac{a}{t_1} = \frac{(a - a_1) + a_1 + b_1}{t_3} \tag{5}$$

3 Experimental Design and Analysis

3.1 Experimental Design

3.1.1 Mixing Ratio

The specifications of the concrete specimens used for the test were 100 mm × 100 mm × 100 mm cube test pieces; the details of their mixing ratios are listed in Tab. 1.

Table 1: Mix ratio

Concrete strength grade		Cement marking	Stone particle size (mm)	Temperature (°C)	Slump (mm)
C30		Po42.5	10–20	20–30	50–70
Material usage (kg/m^3)				Mix ratio	
Water	Cement	Sand	Stone	C:S:G:W	
175	295	700	1117	1:2.37:3.79:0.59	

3.1.2 Raw Materials

Cement: Grade 32.5 Portland cement. Gansu Qilianshan Cement Group Co., Ltd.; Sand: Medium sand; Stone: Pebble (pore size 5–25 mm); Specimen production: Mechanical mixing, mechanical vibrating; Specimen size: 150 mm × 150 mm × 150 mm; curing conditions: indoor natural conservation; age: 7 days.

A total of 4 specimens were produced. Among them, hollow specimens are shown in Fig. 2. There are different sizes and types of defects in the core concrete.

Specimen 1, compact concrete test block, size 100 mm × 100 mm × 100 mm;

Specimen 2, a circular cavity defect with a cross-section was set at the center. The cross-sectional diameter of the defect was 30 mm round, the defect height was 100 mm, and the emptying rate was 7% (the rate of emptying was the ratio of void volume to the total volume);

Specimen 3 is provided with a circular cavity defect in its center. The defect has a cross-sectional diameter of 50 mm in diameter, a defect height of 100 mm, and a voidage of 20%.

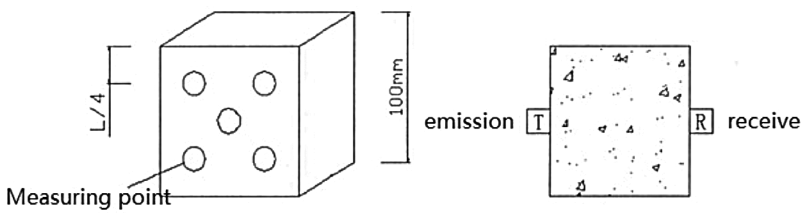
Figure 2: Specimen

Specimen 4, a rectangular cavity defect was set in the center, the defect section size was 50 mm × 30 mm, the defect height was 100 mm, the emptying rate was 15%, and the test was performed along the long side.

3.2 Ultrasonic Testing Test of Different Void Rate Test Pieces

3.2.1 Detection Process

Ultrasonic wave was used to measure the sound during the measurement. Five measuring points were arranged on each of the two measuring surfaces, as shown in Fig. 3a. During the test, it is necessary to apply evenly to the probe, and then the center of the probe is centered. The axes of the transmitting and receiving transducers need to be kept on the same straight line. As shown in Fig. 3b, the sound velocity of the test block is the average of five sound speeds. The thickness of the test piece was measured twice, and the average value of the two measurement results was taken as the ultrasonic distance L of the sample of the grouting material. The test specimen is shown in Fig. 4.



(a) (b)

Figure 3: Measuring point layout

Figure 4: Field test chart

3.2.2 Test Results

1 Sound Speed Analysis

From the test results of the test specimens with different void ratios in Fig. 5, the following conclusions can be drawn: When there are voids in concrete, the sound velocity values of the voids using ultrasonic testing are obviously smaller than those of similar solid concrete test data. The reason is that In the defective specimens, acoustic waves propagate along the edges of the defects. Since all the waves are of the same kind, the wave velocity does not change very much, but the calculated acoustic velocity is a fixed distance L. The acoustic wave propagates long in the defective specimen and the calculated acoustic velocity value is small.

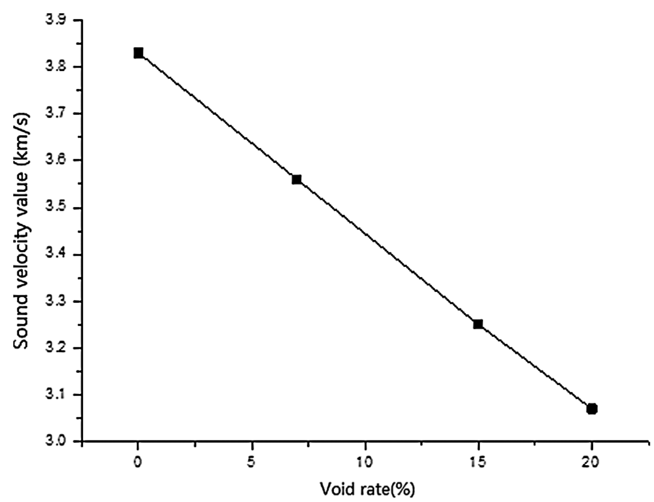


Figure 5: Curves of sound speed values for specimens with different voidage rates

2 Waveform Analysis

It can be seen from the waveform in Fig. 6 that when the sound wave passes through the non-defective concrete, the waveform of the received wave is steep and the amplitude is large. In the second half of the first cycle, the wave amplitude reaches a higher amplitude, and there is no abnormality in the waveform of the first cycle. It can be seen from the waveform in Fig. 7 that when the sound wave passes through the defective concrete, the first wave of the receiving wave is gentler and the amplitude is smaller. In the second half of the first cycle, the increase in amplitude is still not enough. Second, the second The three-period waveform is distorted, and when the defect is severe and the range is large, acoustic waves cannot be received.

3 Wave amplitude analysis

It can be seen from Fig. 8 that when the acoustic wave passes through the defective concrete area, the amplitude of the wave decreases significantly, and the larger the cavity rate, the greater the attenuation of the amplitude, but the difference is not significant.

3.2.3 Analysis of Test Data

1 Waveform Analysis

The test waveform of solid concrete specimens is shown in Fig. 5. The first wave is smooth, the waveform is stable, and the pattern continuity is good. The waveforms of hollows with hollow specimens are shown in Figs. 6–8. The first wave is deviated, the waveform is unstable, and the pattern continuity is poor.

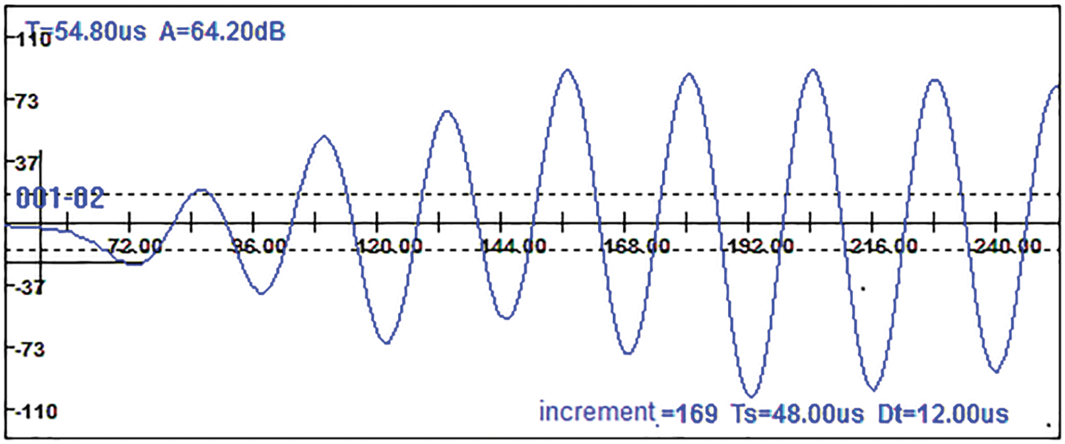


Figure 6: Received waveforms of defect-free concrete

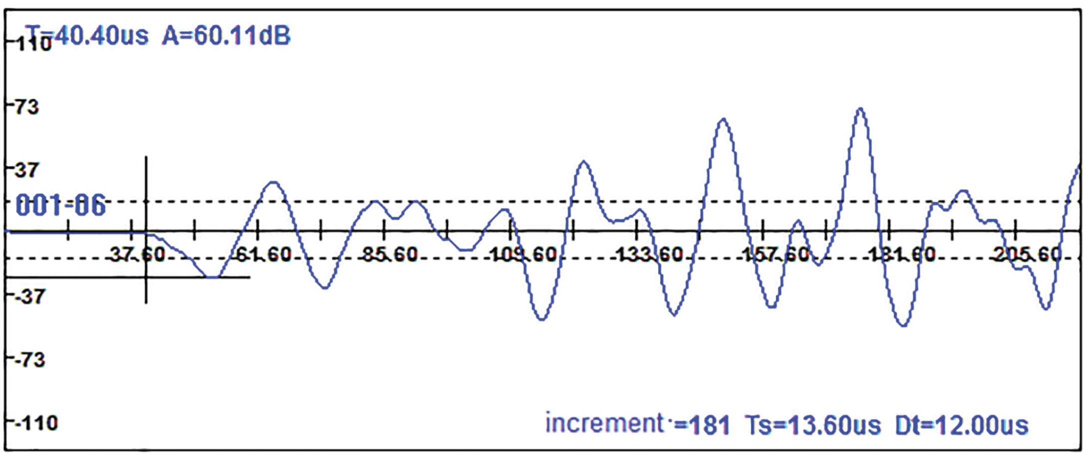


Figure 7: Received waveforms of defective concrete

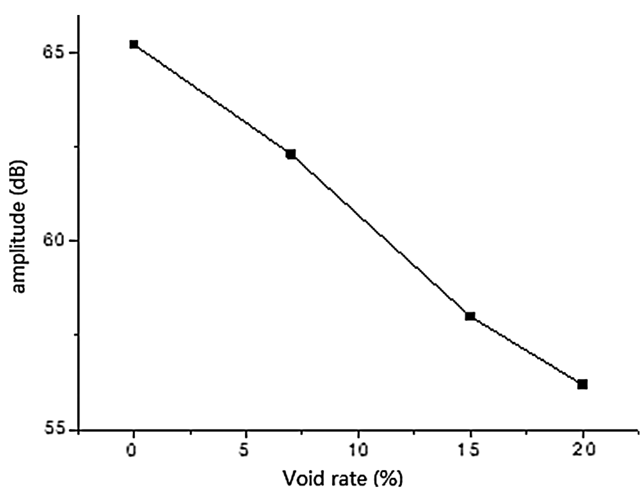


Figure 8: Curves of the variation of the amplitude of the specimens with different emptying rates

2 Analysis of Sound Velocity

Compared with similar solid concrete test data, the presence of voids in concrete shows that the acoustic velocity value of ultrasonic testing using voids becomes significantly smaller. The reason is that sound waves propagate along the edges of flaws in the presence of flawed specimens because they are all of the same species. Medium, the wave speed changes little, but the calculation of sound speed is to use a fixed distance L, the sound wave propagation time in the defective specimen, the calculated sound speed value is small.

3 Acoustic Time Analysis

Acoustic waves travel longer than solid specimens in hollow specimens. The reason is that sound waves propagate from rectilinear to polyline in defective specimens. The propagation path lengthens at the same propagation speed, and the sound is naturally extended.

4 Analysis of Amplitude

It can be seen from Fig. 8 that when the acoustic wave passes through the defective concrete area, the amplitude of the wave is significantly reduced, and the larger the cavity rate, the greater the attenuation of the amplitude.

3.2.4 Void Size Estimation

The test sound average data is brought into Eqs. (4) and (5), respectively, to obtain the data shown in Tab. 2.

Table 2: Void size estimation

Test block name	Hole size/cm	Sound time/μs	Detect hole size/cm	Test error
Specimen 1	—	42	—	—
Specimen 2	3	51	3.36	10.7%
Specimen 3	5	63	5.87	14.8%
Specimen 4	5 × 3	56	9.03	11.4%

4 Ultrasonic Field Test

Ultrasonic testing was performed on a column of an underground parking lot, and 15 columns (1,145 measuring points) were selected by artificial percussion. The overall acoustic velocity measurement of the column is accomplished by scribing the grid at intervals of 200 mm on both sides of the column and measuring the transmission speed of the sound velocity at the intersection. The entire column is visually inspected and consulted by measuring the speed of sound. To estimate the defective part inside the concrete.

The test results are shown in Tab. 3. The sound speed distribution is shown in Figs. 9–11. An average value of 3895 m/s and a standard deviation of 170 m/s were calculated from the sound speeds of all pillars/pillars studied, and a lower limit (average value-standard deviation) of 3725 m/s was used as a criterion for determining defects.

Pillar A looks relatively good in appearance and finds that Pillar B is defective. The average speed of sound for pillar A is 3977 m/s, the standard deviation is 117 m/s, the average speed of sound for pillar B is 3820 m/s, and the standard deviation is 103 m/s. According to the standard deviation of less than 170 m/s and the speed of sound less than 3725 m/s, pillars A and B illustrate their internal defects (marked as ○) in Fig. 12. In the pillar A, although a crack on the surface was visually observed, no problem due to the speed of sound was detected.

Table 3: Column sound speed test results

Member	Test results			Failed	Major defects	Reference
	Average value (m/s)	Standard deviation (m/s)	Measurement points	Average value—standard deviation (m/s)	Average value –500 (m/s)	
All columns	3995	170	1340	3825	3495	Need further determination
Column post A	4072	112	48	3860	3577	Qualified
Column post B	3922	105	48	3817	3420	Defective

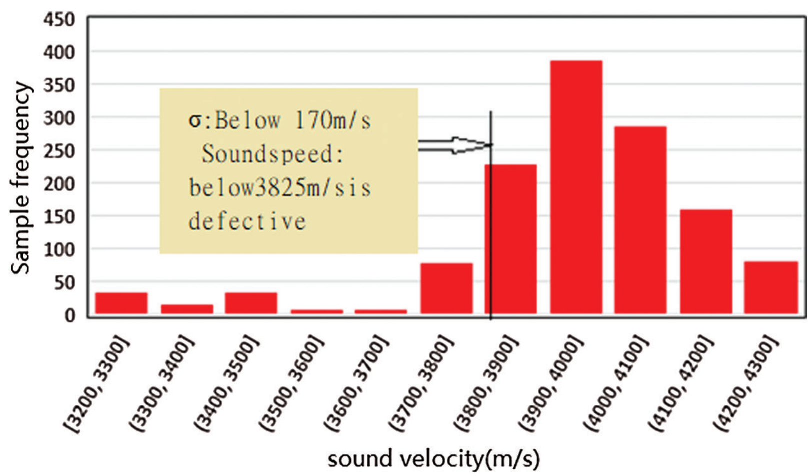


Figure 9: Distribution of sound speed in all columns

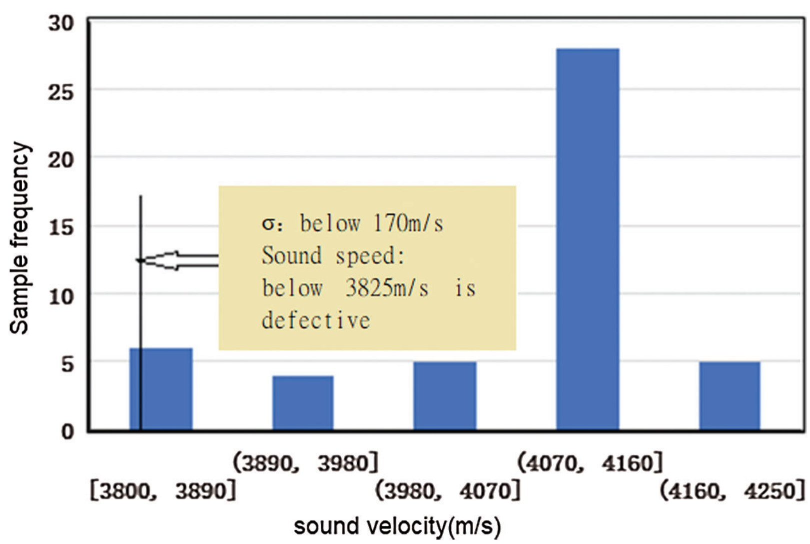


Figure 10: Sound velocity distribution of column part A

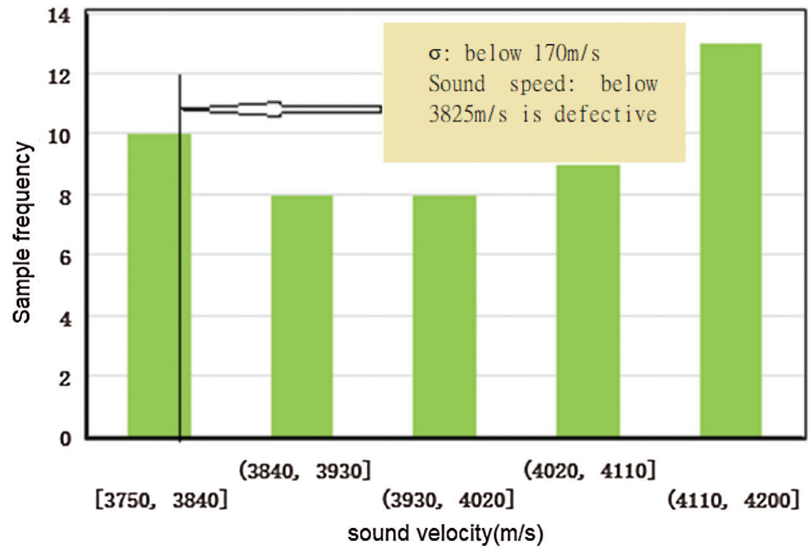


Figure 11: Sound velocity distribution of column part B

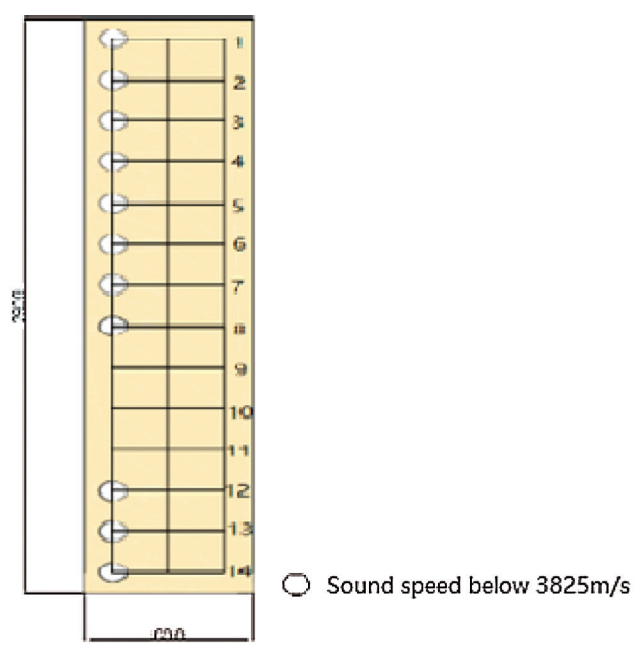


Figure 12: Pillar B test result diagram

5 Comprehensive Evaluation Method of Fuzzy Mathematics

There is ambiguity in the detection of ultrasonic data. Because of the complexity of the scene environment and the diversity of the detected objects, the processing methods of ultrasonic data are ambiguous, which causes a series of problems, making it difficult for people to evaluate them with absolute objective reality. Therefore, through the establishment of membership function and the use of fuzzy comprehensive evaluation method, we can comprehensively evaluate the status of the subordinate grade of the evaluated things from multiple evaluation factors. On the one hand, we can take into account the diversity of the tested objects, so that the evaluation criteria and influencing factors can be concretized; on the other hand, we can make full use of them in the evaluation. Give full play to people's experience to make the evaluation results more objective and in line with the actual situation. Fuzzy comprehensive evaluation can combine qualitative and quantitative factors, expand the amount of information, improve the credibility of evaluation and make the evaluation conclusion credible.

5.1 Creating a Fuzzy Set

1 Establish a Set of Factors

When using the fuzzy comprehensive assessment method to evaluate, consider the speed of the wave speed is the most intuitive and stable, amplitude and waveform sensitivity to the defect is relatively high and can reflect the wave energy decline situation, but the change is greater. Not very stable. Considering the influence of wave speed, amplitude, and waveform, establish a set of ultrasonic evaluation factors: U = {wave velocity, amplitude, waveform}.

2 Create an Evaluation Set

Then establish an evaluation set composed of m evaluation results: $V = \{V_1, V_2, V_3, \ldots, V_m\}$, where V_i is the evaluation of the judging factor. The criteria established in this paper are Class *A* Excellence, Class *B* Qualification, and *C*. If the class is not qualified, the evaluation language set will be established: V = {excellent, qualified, unqualified}.

3 Establishing a Weight Set

For the weight assigned to each factor, a weight set is established as the weight vector: $A = (a_1, a_2, a_3, \ldots, a_n)$, where a_i is the weighted value of the ith factor, i.e., the judging factor sets the importance of the single factor u_i. The coefficient is generally defined as $\sum_{i=1}^{n} a_i = 1$.

In this paper, the subjective assignment method is used to determine the weight set on the weight set, and the weight set is normalized and can be obtained: $A = (0.6, 0.3, 0.1)$.

4 Establish a Judgment Matrix

The univariate fuzzy evaluation of the ith factor is the fuzzy subset on V: $R_i = (r_{i1}, r_{i2}, r_{i3}, \ldots, r_{im})$, where r_{im} is the index membership degree of the m-th assessment of the i-th element, thus determining the evaluation. The matrix R is: $R = \left\{ \begin{matrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{21} \\ r_{31} & r_{32} & r_{33} \end{matrix} \right\} = \begin{pmatrix} A_1(x) & A_2(x) & A_2(x) \end{pmatrix}'$, where $A_{\mathrm{i}}(x)$ is the evaluation index for the ith element Membership degree subsets.

According to the combination of the weight set *A* and the fuzzy evaluation matrix *R*, the comprehensive evaluation matrix $B = A \cdot R$ is obtained through fuzzy comprehensive evaluation. By establishing the evaluation model $M = (\wedge, \vee)$ on the comprehensive evaluation matrix *B*, the test data can be judged.

5 Establishment of Membership Function

Three commonly used membership functions are selected: large (excellent), intermediate (qualified), and small (unqualified). In the ultrasonic detection of internal defects in concrete, the degree of membership of the wave velocity and amplitude is calculated and established using a formula. The degree of membership of the waveform is determined by the method of comprehensive assessment.

Larger (excellent):

$$A(x) = \begin{cases} 0 & x < b \\ \dfrac{x-b}{c-b} & b \le x < c \\ 1 & x \ge c \end{cases} \tag{6}$$

Intermediate type (qualified):

$$A(x) = \begin{cases} 0 & x < a \\ \dfrac{x-a}{b-a} & a \le x < b \\ \dfrac{c-x}{c-b} & b \le x < c \\ 0 & x < c \end{cases} \tag{7}$$

Smaller (unqualified):

$$A(x) = \begin{cases} 1 & x < a \\ \dfrac{b-x}{b-a} & a \le x < b \\ 0 & x \ge b \end{cases} \tag{8}$$

Since the flaws in concrete are detected by ultrasonic waves, several reference points are selected before each measurement to determine the reference value. Therefore, the division of the wave speed membership range is determined by using the reference value, that is, the reference value is used as the critical value. Other data were compared and analyzed. First determine the critical value of the wave speed: $V_c = V_m - 1.6\sigma$, and then determine the wave speed membership range: $a = V_m - 1.6\sigma$, $b = V_m$, $c = V_m + 1.6\sigma$. Since the division of the wave speed membership degree has a certain degree of subjectivity, It can be appropriately relaxed in the implementation.

Excellent V_1:

$$A(x) = \begin{cases} 0 & x < V_m \\ \dfrac{x-V_m}{1.6\sigma} & V_m \le x < V_m + 1.6\sigma \\ 1 & x \ge V_m + 1.6\sigma \end{cases} \tag{9}$$

Qualified V_2:

$$A(x) = \begin{cases} 0 & x < V_m - 1.6\sigma \\ \dfrac{x-V_m+1.6\sigma}{1.6\sigma} & V_m - 1.6\sigma \le x < V_m \\ \dfrac{V_m+1.6\sigma-x}{1.6\sigma} & V_m \le x < V_m + 1.6\sigma \\ 0 & x \ge V_m + 1.6\sigma \end{cases} \tag{10}$$

Failed V_3:

$$A(x) = \begin{cases} 1 & x < V_m - 1.6\sigma \\ \dfrac{V_m-x}{1.6\sigma} & V_m - 1.6\sigma \le x < V_m \\ 0 & x \ge V_m \end{cases} \tag{11}$$

Similarly, the division of the amplitude membership area is also determined using a reference value, that is, the comparison of the reference value as a critical value with other data. First determine the amplitude critical value: $A_c = A_m - 1.3S$, and then determine the amplitude of the degree of membership: $a = A_m - 1.3S$, $b = A_m$, $c = A_m + 1.3S$. It can also be appropriately relaxed.

Excellent A_1:

$$A(x) = \begin{cases} 0 & x < A_m \\ \dfrac{x - A_m}{1.3S} & A_m \le x < A_m + 1.3S \\ 1 & x \ge A_m + 1.3S \end{cases} \tag{12}$$

Qualified A_2:

$$A(x) = \begin{cases} 0 & x < A_m - 1.3S \\ \dfrac{x - A_m + 1.3S}{1.6\sigma} & A_m - 1.3S \le x < A_m \\ \dfrac{A_m + 1.3S - x}{1.3S} & A_m \le x < A_m + 1.3S \\ 0 & x \ge A_m + 1.3S \end{cases} \tag{13}$$

Failed A_3:

$$A(x) = \begin{cases} 1 & x < A_m - 1.3S \\ \dfrac{A_m - x}{1.3S} & A_m - 1.3S \le x < A_m \\ 0 & x \ge A_m \end{cases} \tag{14}$$

5.2 Application of Fuzzy Comprehensive Evaluation System

Before analyzing and processing the test data, first determine the abnormal points according to the criteria for the sound speed of the defect point obtained from the previous on-site inspection, and then judge each defect point by the fuzzy comprehensive evaluation method.

1 Pillar A Evaluation

According to the "Ultrasonic Method for Detecting Concrete Defects Technical Specifications", the defect data of pillar A inspection data is shown in Tab. 4.

Table 4: Pillar a defects judgment

Component number	Test items	Detection points	Maximum	Min	average value	Critical value	Standard deviation	Type of judgment
A	Wave speed	42	4065	3874	3977	3770	117	Qualified
	Amplitude	42	76.24	57.04	68.36	58.23	9.77	Failed

Critical value $X_0 = m_x - \lambda_1 \cdot s_x$

Among them m_x: average value, λ_1: test point number parameter (standard check table is obtained), s_x: standard deviation.

The second detection point of Pillar A has a wave velocity value of 3915 m/s, an amplitude of 57.04 db, a standard deviation of wave velocity of 117 m/s, and a standard amplitude of 9.77 db. The waveforms are shown in the Fig. 13.

The first wave of the waveform is slightly deviated, and the waveform is relatively stable. The engineering personnel evaluate it as $u_3 = (0.8, 0.2, 0)$; through the fuzzy comprehensive evaluation parameter amplitude $A = 54.04$ db $< A_m - 1.3S$ according to the amplitude membership function: $u_2 = (0, 0, 1)$; The wave velocity value is $V_m - 1.6\sigma \leq x = 3950$ m/s $< V_m$, which is obtained according to the wave speed membership function: $u_1 = (0, 0.86, 0.14)$. The evaluation matrix is:

$$R = U \times V = \begin{bmatrix} 0 & 0.86 & 0.14 \\ 0 & 0 & 1 \\ 0.8 & 0.2 & 0 \end{bmatrix}.$$

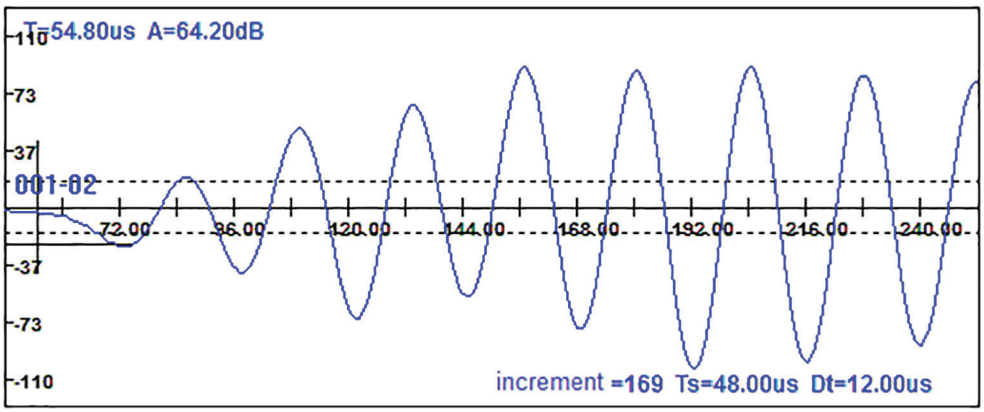


Figure 13: Waveform of the second detection point

The evaluation fuzzy subset $B = A \times R = (0.08, 0.536, 0.384)$ can be obtained from the weight coefficient $A = (0.6, 0.3, 0.1)$. This conclusion is passed by the evaluation model $M(\wedge, \vee)$, and the results are in line with the measured results.

(2) Pillar B Evaluation

According to the "Ultrasonic Method for Detecting Concrete Defects Technical Regulations", the defect data of pillar B inspection data is shown in Tab. 5.

Table 5: Pillar B defects judgment

Component number	Test items	Detection points	Maximum	Min	average value	Critical value	Standard deviation	Type of judgment
B	Wave speed	42	4010	3512	3820	3650	103	Failed
	Amplitude	42	79.21	72.15	76.35	74.63	1.32	Failed

The 6th detection point of pillar B has a wave velocity value of 3512 m/s, amplitude of 72.15 db, standard deviation of wave velocity of 103 m/s, and amplitude standard value of 1.32 db. The waveforms are as shown in Fig. 14.

The first wave of the waveform is slightly deviated, the waveform is unstable, and the figure is poor. The engineering personnel evaluate it as $u_3 = (0.2, 0.1, 0.7)$; through the fuzzy comprehensive evaluation parameter wave amplitude $A = 72.15$ db $< A_m - 1.3S$, according to the amplitude. The membership function is given by: $u_2 = (0, 0, 1)$; the wave speed value is $x = 3512$ m/s $< V_m - 1.6\sigma$. According to the wave speed membership function, $u_1 = (0, 0, 1)$. The evaluation matrix is:

$$R = U \times V = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0.2 & 0.1 & 0.7 \end{bmatrix}.$$

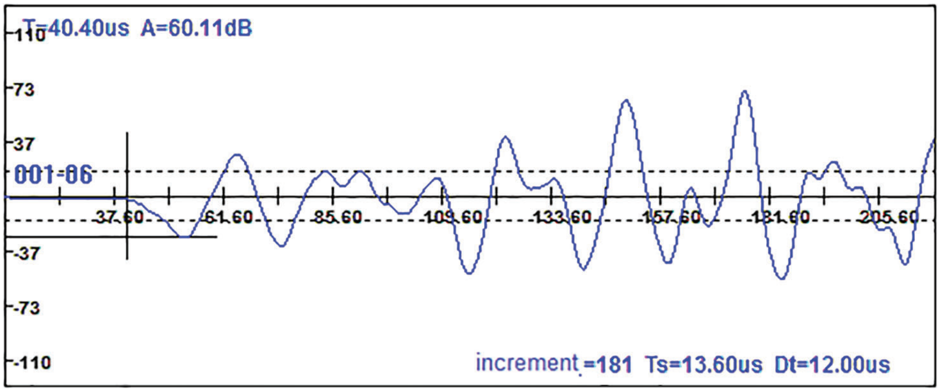


Figure 14: Waveform of the sixth detection point

The evaluation fuzzy subset $B = A \times R = (0.02, 0.01, 0.97)$ can be obtained from the weight coefficient $A = (0.6, 0.3, 0.1)$. This conclusion was found to be unsatisfactory by the evaluation model $M(\wedge, \vee)$, which is consistent with the measured results.

5.3 Comparison between On-Site Measurement and Fuzzy Comprehensive Evaluation

The field measured data of all columns were compared using the criterion judgment and fuzzy comprehensive evaluation as shown in Tab. 6.

Table 6: Comparison of all column specification judgment and fuzzy comprehensive evaluation

Column	Detection points	Wave speed comprehensive judgment	Amplitude comprehensive judgment	Fuzzy comprehensive judgment
1	42	Qualified	Failed	Qualified
2	42	Failed	Failed	Failed
3	42	Qualified	Failed	Qualified
4	42	Failed	Qualified	Failed
5	42	Qualified	Failed	Qualified
6	42	Failed	Qualified	Failed
7	42	Qualified	Failed	Qualified
8	42	Qualified	Failed	Failed
9	42	qualified	Failed	Qualified
10	42	Failed	Failed	Failed
11	42	Qualified	Failed	Failed
12	42	Qualified	Failed	Qualified
13	42	Failed	Qualified	Qualified
14	42	Failed	Failed	Failed
15	42	Qualified	Failed	Qualified

The detection of ultrasonic data is fuzzy. Due to the complexity of the field environment and the diversity of the detected objects, sometimes there is a spear to distinguish the defects from the ultrasonic data parameters, such as velocity, amplitude and waveform, which makes it difficult for people to evaluate them with absolute objective reality. Therefore, by establishing the membership function and adopting the method of fuzzy comprehensive evaluation, we can make a comprehensive evaluation of the membership level of the evaluated things from multiple evaluation factors. On the one hand, we can take into account the diversity of the tested objects, so that the evaluation criteria and influencing factors can be specified; on the other hand, we can give full play to human experience in the evaluation, so that the evaluation results are more objective and consistent According to the actual situation. Fuzzy comprehensive evaluation can combine qualitative and quantitative factors, expand the amount of information, improve the reliability of evaluation, and make the evaluation conclusion credible.

It can be seen from Tab. 6 that when the judgment result of the tested component is inconsistent with the judgment of sound wave and amplitude, it can be judged by the method of comprehensive judgment of fuzzy mathematics.

The tested components selected in this experiment are some abnormal points that can be found by the original criteria, or points where the amplitude, velocity, and frequency are all near the critical value of the original criteria. The judgment result will be inconsistent with several single factor judgments. It is difficult to conclusively determine the results of engineering and technical personnel on the test results. However, the method of comprehensive judgment using fuzzy mathematics can effectively combine the detection results of wave speed, amplitude, and waveform to make the determination more reasonable and scientific.

6 Conclusion

The fuzzy comprehensive judgment method can effectively solve the inconsistency of several single factor judgment results when the ultrasonic method is used to detect the internal defects of prefabricated concrete. By considering the weights of the influencing factors, the comprehensive judgement of the defects makes the judgments reasonable and effective.

1. Ultrasonic method can effectively detect the position of internal defects of concrete structures by ultrasonic wave detection and amplitude analysis of different blanking test pieces. For holes with a hole size of 3–5 cm, the cavity is estimated by the equivalent formula derived from the change of propagation path and parameters. Dimensions, the estimated results are basically the same as the actual.
2. When the ultrasonic method judges the internal defects of concrete through the specification, the results of wave amplitude, wave velocity, and frequency will be inconsistent, and it is difficult for engineering inspectors to make a conclusion on the detection. Through the inspection of engineering examples, fuzzy comprehensive judgment method has no difference between the judgment of some good quality points and the judgment results of the original criteria, but for some abnormal points or points near the critical value, the advantages of fuzzy criteria are reflected in its comprehensive consideration of several parameters, and the quantification of the original subjective judgments makes the judgment process more scientific.
3. The calculation method of fuzzy mathematics is very important for the distribution of weights. For different projects, the weights appropriate to their engineering characteristics should be selected according to the analysis of their engineering technicians or experts.

Funding Statement: The authors are grateful for the financial support received from the National Key R&D Program (2017YFF0205003); Hebei Province Higher Education Science and Technology Research Project (ZD2018249); Special funded by the Beijing Institute of Housing and Urban-Rural Science and Technology.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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