Study on the Methods of Ultrasonic Testing for the Cracks in Concrete

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Abstract. The cracks existing in the concrete components have a strong impact on the safety of their structures. Ultrasonic testing is an effective non-destructive testing method for fast excluding surface and internal defects of concrete in construction engineering. The concrete specimens were tested by the calculation methods of ultrasonic single plane testing (CMSPT) and first wave reversed phase testing (FWRPT), and the test data were processed and analyzed. The results show that the depth of the tested cracks is close to that of the set defects. The average detection error of CMSPT is 4.35%, while the average detection error of FWRPT is 1.94%. Therefore, FWRPT has a better stability, higher testing accuracy and easier actual operation, but the lower roughness of the concrete surface is needed in the testing process.

Introduction

As being one of the major building materials, the concrete has characteristics of extensive material source, low cost, easy to construction and better acclimatization ability, which is widely used in construction, road and even the project of marine pipeline. However, due to unfavorable construction environment, poor management, worse tensile and shear strength, concrete applied in engineering could be more prone to construction surface and internal defects like cracks.[1,2] The presence of cracks will cause the bearing capacity of structure descend and permeability enhancement, which will reduce their durability because of the carbonation of concrete. It can be seen that even if the strength of the concrete structure has been researched the standard, the existence of the internal defects are still crisis of the security of the whole structure.[3,4] Therefore, it is an important measure to exclude engineering risks that the location, size and nature of crack defects are accurate and reliable tested, and work out a practical, reliable remedial measures.

In recent years, the emergencies of concrete structure occur frequently, people pays more and more attention on the detection, analysis and processing for internal defects of concrete, especially the crack.[5] At present, the method of non destructive testing (NDT) is one of the effective way to detect the defect of concrete. The commonly used methods include radar, the shock echo, laser infrared imaging and ultrasonic. [6,7] Ultrasonic testing can not only test the cracks in concrete, but detect the crack depth, and the influence of component is smaller. At the same time, this type testing has good repeatability, and the trend of the development of cracks can be judged.[8] Hence, it is a vital significance for ensuring and improving the quality of the concrete by ultrasonic wave testing. By using ultrasonic testing technology for crack defects in concrete, we analyze and compare the advantages and disadvantages of the testing methods, and find out the efficient ways of detecting cracks in concrete. The quantitative analysis was carried out.

The fundamental method of ultrasonic testing concrete

The principle of ultrasonic testing concrete. Using the relative change of transmitted times (or velocity), received wave amplitude and frequency of pulse wave in the same technology condition of the concrete (refer to the age of raw mix ratio of concrete), a lot of defects are detected. [9] Ultrasonic propagation velocity in concrete is connected with its quality (especially the density), the higher speed of sound indicates the better dense of concrete. Because concrete is composed of anisotropic materials, such as gravel, sand and cement, the difference of acoustic impedance values between concrete and air is very large. The internal defect can greatly undermine its density, and cause the multiple diffraction, refraction, and reflection in ultrasonic transmission process, and thus increase its propagation path and the sound value, and reduce the speed of sound. [10] By integrated analyzing the relative change values of acoustic parameters, we can discriminate the location and extent of its defects, or estimate the size of the defect.

Calculation and processing of acoustic parameters. According to CECS 21:2000 [11], When CMSPT (ultrasonic single plane testing) is used, the depth of shallow cracks (crack depth ≤500 mm) on the concrete surface is calculated. At the same time, the mean value and standard deviation of the sound value (or sound velocity), amplitude and frequency of concrete in a component or a testing area are also calculated, and the judgment value X_0 of abnormal situation can be discussed according to the distribution of abnormal points.

The main instruments and the parameters of concrete specimen. The non-metal ultrasonic detector ZBL-U520 manufactured by Beijing ZBL (Zhi Bo Lian) Science & Technology Co., Ltd. and the C30 strength grade of concrete specimens was used. The size of concrete specimen is 250 cm× 230 cm× 200 cm. The wedge organic glasses were prepared in each concrete specimen as the artificial crack, and could be pulled out after casting, and the crack depth was 80, 90, 100 and 135 mm, respectively.

Result and analysis

The calculation method of single plane testing (CMSPT). When first wave did not appeared in the method of ultrasonic single plane testing, the detection step of concrete crack can be divided into non cross-stitch measuring point testing and cross-stitch measuring point testing, shown in Fig. 1.

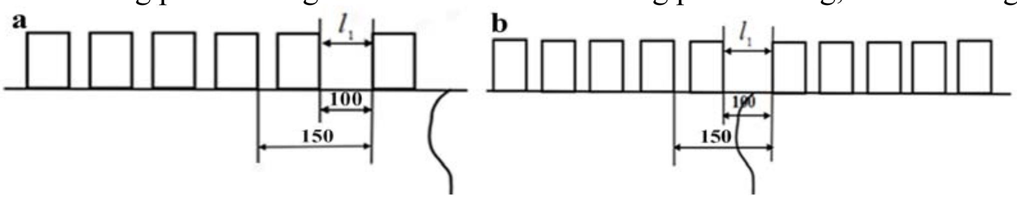

Fig. 1 The testing points arrange plan of non cross-stitch and cross-stitch
a non cross-stitch, b cross-stitch.

Non cross-stitch testing. The measuring distances were set as 100, 150, 200, 250 and 300 mm, respectively. The receive transducer would be moved to different position of measuring point in turn, and the sound value t_i of each measuring point could be automatically read and storaged by ultrasonic detector, as shown in Table 1.

Table 1 The sound value of non cross-stitch testing /μs and the measured values of the straight line regression equation parameters.

Samples	Measuring distance [mm]					a [mm]	b [km/s]
	100	150	200	250	300		
1#	16.40	29.60	39.20	50.80	62.20	22.4	4.53
2#	18.90	32.10	39.70	53.20	67.90	20.4	4.21
3#	17.80	25.40	37.40	49.90	63.50	20.6	4.40
4#	20.20	34.90	41.70	56.60	67.10	21.3	4.32

Cross-stitch testing. In the detection of cross-stitch measuring point, the transmitting transducer and receiving transducer were put on both sides of the crack, respectively, and the measuring points were set bilateral symmetry of crack, as shown in Fig. 1b. The measuring distances were 100, 150, 200, 150 and 300 mm, respectively, and read the sound value t_{ci} under different measuring points. This is the ultrasonic transmission time around the end of the crack, the results show in Table 2.

Table 2 The testing data of cracks detected by CMSPT and FWRPT.

Crack number	CMSPT				FWRPT		
	Testing distance [μs]	The sound value [μs]	Crack depth [mm]	Mark	First wave	The sound value [μs]	Crack depth [mm]
LF 1	100	32.80	90.1	Retaining	BRP	35.70	
	150	56.80	88.0	Retaining			
	200	70.80	73.6	Retaining	BRP	51.00	
	250	64.00	67.6	Removing			
	300	86.80	88.9	Retaining	RP	130.80	81
LF 2	100	33.20	103.0	Retaining	BRP	38.70	
	150	56.40	98.1	Retaining			
	200	80.40	87.6	Retaining	BRP	59.00	
	250	88.80	92.5	Retaining			
	300	96.40	94.9	Retaining	RP	98.80	92.5
LF 3	100	31.60	98.8	Retaining	BRP	48.70	
	150	56.80	88.0	Retaining			
	200	79.60	110.6	Retaining	BRP	71.60	
	250	78.00	120.9	Removing			
	300	86.00	107.3	Retaining	RP	130.80	103
LF 4	100	72.00	143.1	Retaining	BRP	53.70	
	150	101.20	210.0	Removing	BRP		
	200	77.20	133.6	Retaining	BRP	83.70	
	250	86.00	137.6	Retaining	BRP		
	300	92.80	138.9	Retaining	RP	130.80	134

Note: BRP- before reversed phase; RP- reversed phase

Statistic and analysis of testing data. In CMSPT process, with the increasing of the measuring distance, the sound values also increases. But when the sound values appear mutations of measuring point, the measured accuracy of the crack depth will be greatly reduced. In the LF1, when the measuring distance is 200 mm, the sound value is 70.8 μs, and the measured crack depth is 73.6 mm. And similarly, the other values are 300 mm, 86.80 μs, and 88.9 mm, respectively. However, when the measuring distance is 250 mm, the sound value is 64.0 μs and occurs mutations. The detected crack depth at this measuring point is 67.6 mm. Therefore, the larger deflection of abnormal will be removed. The average value of the crack depth can be used as the final detected one.

The method of first wave reversed phase testing (FWRPT). FWRPT is a kind of new method for detection of concrete cracks. As shown in Fig. 2a, when the measuring distance of half *a* is greater than or equal to the crack depth, the waveform of the first wave can occur a reversal phenomenon. We can utilize the outstanding changes to obtain the crack depth.

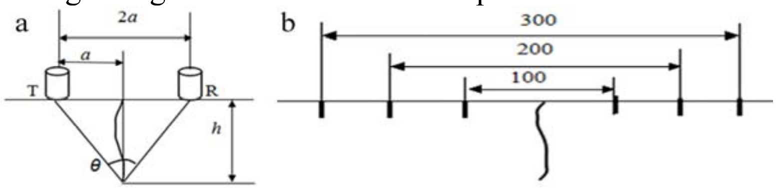

Fig. 2 The method of first wave reversed phase
a fundamental picture, b the arrangement measuring area

When FWRPT detects the cracks in concrete, we choose appropriate areas near the crack as a measuring area, (shown in Fig. 2b). Three measuring areas are selected to set in bilateral symmetry of cracks, the length of measuring area is 100, 200 and 300 mm, respectively. The transmitting and receiving transducer are uniformity moved according to the measuring area in turn. The first wave reversed point values are read, and the measuring distances are tested.

Table 2 is the statistical results of the sound values of first wave reversion points. As can be seen from Table 2, with the uniform increase of the measuring distance, the sound value of ultrasonic wave has enlarged. As shown in testing data of the LF 5, the sound value before the first wave reversed phase is 53.70, 83.70 and130.80 μs, and the difference is 20 and 47.1 μs, respectively. However, when the first wave occurs reversal, the mutation of the sound value is 130.80 μs, the difference of the sound value between adjacent points is 47.1 μs. This is far more than that before the first wave reversed phase. Thus, it can be seen that the sound value can also occur obvious mutation when the first wave occurs reversal (shown as Table 3).

Table 3 The statistical testing results of the specimens detected by CMSPT and FWRPT.

Crack number	CMSPT				FWRPT			
	Testing depth [mm]	Real depth [mm]	Error [%]	Average error [%]	Testing depth [mm]	Real depth [mm]	Error [%]	Average error [%]
LF 1	84.9	80	6.10	4.35	81.0	80	1.25	1.94
LF 2	95.1	90	5.67		92.5	90	2.78	
LF 3	103.2	100	3.20		103.0	100	3.00	
LF 4	138.3	135	2.44		134.0	135	0.74	

Comparative analysis. It is shown in Table 2, 3 that CMSPT and FWRPT can be used to detect the crack depth in concrete. But the fluctuation of testing error of crack depth using CMSPT is larger, its minimum testing error is 2.44%, and the maximum testing error is 6.10%. By using FWRPT, the minimum testing error is 0.74%, the maximum testing error is 3.00%. In contrast, the maximum and minimum testing error detected by FWRPT is smaller than the former. It is stated that as the same crack in concrete specimens under the same testing conditions, FWRPT is more testing stability than that of CMSPT. Moreover, the average error of CMSPT is 4.35%, and that of FWRPT is only 1.94%. The average error rate is about 45%. Therefore, in the same testing conditions, the accuracy of FWRPT is higher than that of CMSPT, but the requirements of the surface roughness is higher.

Conclusions

The crack depth in concrete is detected by ultrasonic testing using CMSPT and FWRPT. By means of treatment, judgment and analysis of the testing data (amplitude, frequency and the sound value, etc.), the results can be seen that when CMSPT is adopted, the average error is 4.35%. And when FWRPT is used, the average error is 1.94%. The average testing error of FWRPT is about 48% of the former, and the testing error values have less fluctuate. As a result, when the crack depth in concrete is detected by ultrasonic testing, FWRPT has a higher accuracy, better stability and simple operation, but there are the higher requirements on concrete surface roughness.

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