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Comparison Study of Ultrasonic and Surface Wave Methods for Crack Depth Detection in Concrete Panels

A.P. Ir.Mohd Nasir Bin Hussin, Yudi Wang

Infrastructure University Kuala Lumpur, Malaysia

Abstract: This paper studies the accuracy comparison between ultrasonic and surface wave methods for crack depth detection. A concrete panel with a thickness of 10 cm, located in a 112 km long water conveyance channel, was used as the object for crack depth detection. A total of 114 cracks were detected using both ultrasonic and surface wave methods, and the results show that the detection values of ultrasonic method are smaller than those of surface wave method. In addition, the data of 9 cracks that penetrated the concrete panel were compared and analyzed, and the results show that the detection error of ultrasonic method is between -22% and 41%, while that of surface wave method is between -7% and 27%. Based on the comprehensive analysis of experimental results, the following conclusions are drawn: (1) Both ultrasonic and surface wave methods can effectively detect crack depth; (2) The detection values of both methods are smaller than the actual crack depth; (3) Compared with ultrasonic method, surface wave method has higher detection accuracy and its detection results are closer to the actual crack depth.

Keywords: Concrete Structure, Non-destructive Testing, Crack Depth Detection.

1. Introduction

As buildings age and are used, the safety and stability of their structures have become a highly concerning focus for people. The occurrence and development of cracks have become a common problem, posing a serious threat to the structural safety and service life of buildings. Therefore, crack depth detection has become increasingly important(Pu & Sun, 2006). In the process of detecting crack depth, ultrasonic and surface wave methods are the two most widely used non-destructive testing methods, which have been widely applied in buildings, bridges, tunnels, water conservancy projects and other fields. However, due to the differences in measurement principles and instrument equipment, the accuracy comparison between these two methods in practical applications has always been a highly concerned issue. To address this problem, we selected the concrete panel crack defects of the water conveyance channel as the research object, and detected 114 cracks on the panel using both ultrasonic and surface wave methods, and compared and analyzed cracks with known depth that penetrated the cracks. The aim of this study is to compare and analyze the accuracy of ultrasonic and surface wave methods in crack depth detection in practical applications, in order to provide valuable reference information for related fields(Zhang et al.2015).

2. Experiment and Methods

2.1. 2.1 Experimental Section

The experiment selected for this study is the water conveyance channel of a hydroelectric power station. The total length of the channel is 112 kilometers, with concrete panels laid on both sides of the channel, each panel having a thickness of 10 cm. After a comprehensive inspection, 114 cracks were found in the channel, posing significant safety hazards. In order to detect the depths of these cracks, we used both ultrasonic and surface wave methods for testing. For cracks that were partially through, we were able to confirm a depth of 10 cm, and thus compared the detection accuracy of the ultrasonic and surface wave methods. The following is a live picture of the panel crack defects.

Figure 1. Partial cracks of channel panel

2.2. Ultrasonic Method

The ultrasonic method is a non-destructive testing method that utilizes the propagation characteristics of ultrasonic waves in materials. By measuring parameters such as the time, intensity, and reflection of ultrasonic waves propagating in materials, the existence of internal defects in the material can be determined. In crack detection, ultrasonic waves are typically used in two types: longitudinal waves and transverse waves. Longitudinal waves propagate faster in materials and

are suitable for detecting deep defects, while transverse waves propagate slower and are suitable for detecting surface defects(Bin Wang et al.2017).

The principle of using ultrasonic waves to measure the depth of cracks is to calculate the depth of the crack by measuring the propagation time of the ultrasonic wave in the material. When the ultrasonic wave propagates to the defect in the material, reflection and refraction occur, forming an echo signal. By measuring the propagation time and velocity of the echo signal, the depth of the crack can be calculated. The specific calculation Equation is:

$$h = \frac{d}{2}\sqrt{(t_1/t_0)^2 - 1} \quad (1)$$

Equation:

h -- Crack depth, cm;

t_1 -- Ultrasonic propagation time around seam, US;

t_0 -- Ultrasonic seamless propagation time, US;

d-- ultrasonic propagation distance between transducer probes, cm.

The advantage of the ultrasonic method is that it can detect crack depth quickly and accurately without damaging the material. In this experiment, the ultrasonic method was used for crack depth detection. When performing cross-crack detection, the sensors on both sides were placed 100mm away from the crack, and one measurement point was added every 50mm. Three measurement points were placed on each side, as shown in Figure 2.

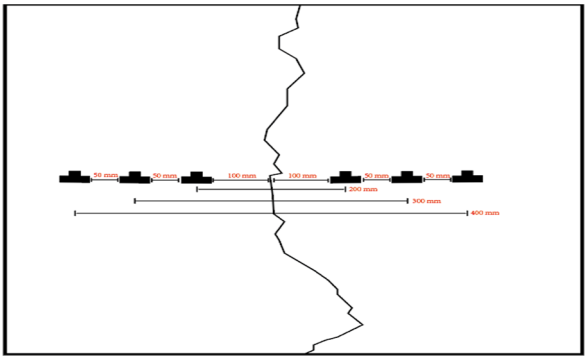

Figure 2. Ultrasonic method line layout

2.3. Surface Wave Method

Surface wave method is a non-destructive testing method based on the principle of sound wave propagation on the surface of materials to detect crack depth. When the sound wave propagates on the surface of the material, it will excite a special surface wave, also known as the Rayleigh wave (R wave), which forms a wavefront along the propagation direction on the material surface and decays along the direction perpendicular to the surface. When there is a crack or defect on the surface, the propagation path and velocity of the surface wave will be affected. According to the acoustic principle, wave velocity is related to material density and elastic modulus(Liu et al. 2018). Therefore, when there is a crack or defect on the surface, the wave velocity will change, and the magnitude of the change is related to the depth of the crack. The wave velocity of surface wave is lower than that of longitudinal and transverse waves, and its velocity can be expressed by Equation (2):

$$V_R = \frac{0.87 + 1.12\mu}{1+\mu}\sqrt{\frac{E}{2\rho(1+\mu)}} \quad (2)$$

Equation:

E --elastic modulus of the material;

μ --Poisson's ratio;

ρ --density.

The Rayleigh wave is mainly concentrated on the surface and shallow part of elastic media, and its characteristics are very suitable for detecting the depth of cracks. In this experiment, the surface wave method was used to detect the depth of cracks. The distance between the sensor and the crack should be set to 40 cm, and the distance between the excitation point and the sensor should be set to 50 cm. The arrangement of measurement points is shown in Figure 3.

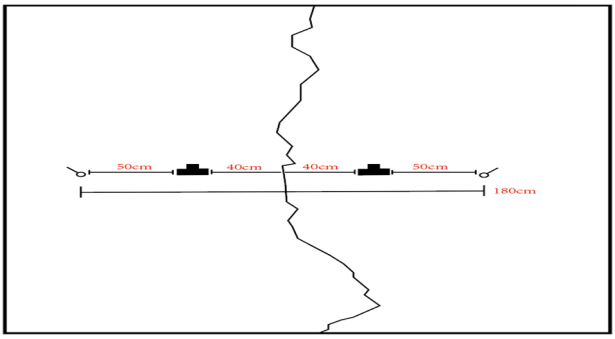

Figure 3. Surface wave method line layout

3. Data Comparison and Analysis

First, we used ultrasonic testing and surface wave testing methods to conduct overall detection and analysis of the depths of 114 cracks on the channel panel, in order to determine the detection capabilities and patterns of the two

methods. The detection results are shown in Table 1.

Table 1. Panel crack depth detection results

Crack number (panel)	Ultrasonic method crack depth (mm)	Surface wave method crack depth (mm)	Crack number (panel)	Ultrasonic method crack depth (mm)	Surface wave method crack depth (mm)
crack-1	46	52	crack-58	23	42
crack-2	52	65	crack-59	56	64
crack-3	60	67	crack-60	47	56
crack-4	40	52	crack-61	44	55
crack-5	29	38	crack-62	77	91
crack-6	28	33	crack-63	50	61
crack-7	34	47	crack-64	51	65
crack-8	54	62	crack-65	45	56
crack-9	23	40	crack-66	47	55
crack-10	45	57	crack-67	69	81
crack-11	35	48	crack-68	50	59
crack-12	39	46	crack-69	43	49
crack-13	56	68	crack-70	38	50
crack-14	28	37	crack-71	45	63
crack-15	54	65	crack-72	54	61
crack-16	60	69	crack-73	72	89
crack-17	50	61	crack-74	36	43
crack-18	43	53	crack-75	41	57
crack-19	40	54	crack-76	41	52
crack-20	42	56	crack-77	38	50
crack-21	32	49	crack-78	52	63
crack-22	64	82	crack-79	61	74
crack-23	55	62	crack-80	78	93
crack-24	29	40	crack-81	25	36
crack-25	56	61	crack-82	35	44
crack-26	24	39	crack-83	37	44
crack-27	46	58	crack-84	29	35
crack-28	25	36	crack-85	55	64
crack-29	41	65	crack-86	61	73
crack-30	56	64	crack-87	39	52
crack-31	27	37	crack-88	50	60
crack-32	58	68	crack-89	46	60
crack-33	40	49	crack-90	61	69
crack-34	29	41	crack-91	44	59
crack-35	50	62	crack-92	51	62
crack-36	48	59	crack-93	59	65
crack-37	58	69	crack-94	23	32
crack-38	60	77	crack-95	43	56
crack-39	70	88	crack-96	57	66
crack-40	29	40	crack-97	40	57
crack-41	59	73	crack-98	29	37
crack-42	33	43	crack-99	61	77
crack-43	61	72	crack-100	43	55
crack-44	26	38	crack-101	30	44
crack-45	33	45	crack-102	51	67
crack-46	70	84	crack-103	51	59
crack-47	57	65	crack-104	52	65
crack-48	62	53	crack-105	49	56
crack-49	55	63	crack-106	30	46
crack-50	40	56	crack-107	55	70
crack-51	26	36	crack-108	36	49
crack-52	55	65	crack-109	46	58
crack-53	66	85	crack-110	51	65
crack-54	56	70	crack-111	34	41
crack-55	41	53	crack-112	40	53
crack-56	48	58	crack-113	42	50
crack-57	39	48	crack-114	33	42

According to the crack depth detection results in Table 1, both ultrasonic testing and surface wave testing can

effectively detect the crack depth of the panel, with a detection rate of 100% for valid data. After analyzing the data, we compared and analyzed the data results, as shown in Figure 3.

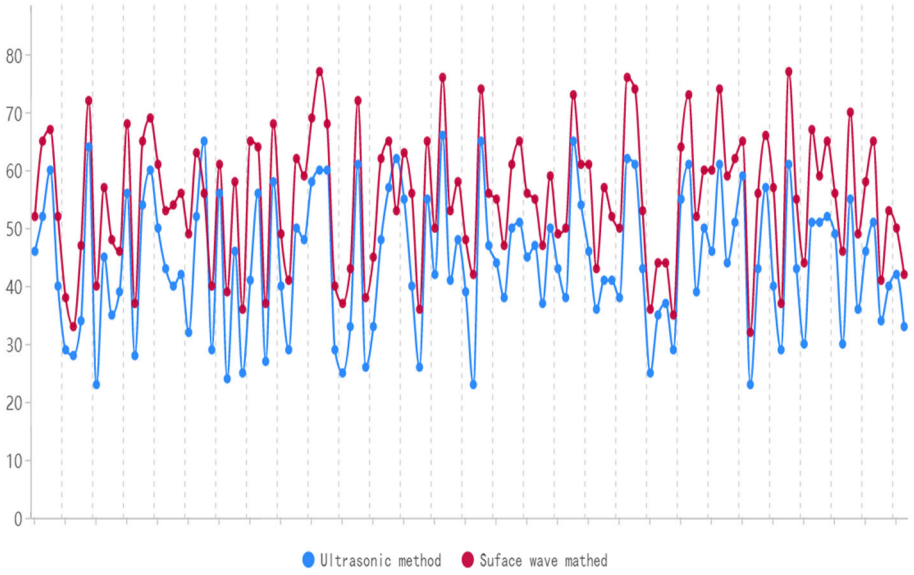

Figure 3. Comparison of detection results of panel crack depth

According to the crack depth detection results in Table 1, it can be seen that both ultrasonic testing and surface wave testing can effectively detect the crack depth of the panel with a 100% success rate. After analyzing the data, we compared and analyzed the results as shown in Figure 3.

From Figure 3, we can see that for crack depth detection, the values detected by ultrasonic testing are smaller than those detected by surface wave testing. Therefore, in order to investigate which method is closer to the actual crack depth value, we selected 9 data points with cracks running through them as the experimental basis for crack depth accuracy testing, and conducted a separate comparative analysis. The detection error results are shown in Table 2.

Table 2. Comparison results of cracks depth detection errors

Crack number	Detection method	Actual Crack depth /mm	Detect crack depth /mm	Error/ %
crack-22	Ultrasonic method	100	64	-36.0
	Surface wave method	100	82	-18.0
crack-39	Ultrasonic method	100	70	-30.0
	Surface wave method	100	88	-12.0
crack-41	Ultrasonic method	100	59	-41.0
	Surface wave method	100	73	-27.0
crack-46	Ultrasonic method	100	70	-30.0
	Surface wave method	100	84	-16.0
crack-53	Ultrasonic method	100	66	-34.0
	Surface wave method	100	85	-15.0
crack-62	Ultrasonic method	100	77	-23.0
	Surface wave method	100	91	-9.0
crack-67	Ultrasonic method	100	69	-31.0
	Surface wave method	100	81	-19.0
crack-73	Ultrasonic method	100	72	-28.0
	Surface wave method	100	89	-11.0
crack-80	Ultrasonic method	100	78	-22.0
	Surface wave method	100	93	-7.0

The comparison results show that the detection error of the ultrasonic method is within -22% to -41%, while the detection error of the surface wave method is within -7% to -27%. The surface wave method is closer to the actual crack depth, and its detection accuracy is more accurate compared to the ultrasonic method.

4. Conclusion

Through comparison and analysis, we draw the following conclusions:

(1) Both ultrasonic method and surface wave method can effectively detect the depth of cracks in practical engineering applications.

(2) The detection values of both ultrasonic method and

surface wave method are smaller than the actual depth of the cracks.

(3) Compared with ultrasonic method, the surface wave method has higher detection accuracy and the results are closer to the actual depth of the cracks.

Crack detection accuracy is not only related to the detection method, but also affected by various factors, such as the shape, depth, width of cracks, as well as the performance and use conditions of the detection equipment, etc. Therefore, in the crack depth detection work, in addition to selecting the appropriate detection method, it is also necessary to comprehensively consider various factors in order to obtain more accurate and reliable detection results. This study compared and analyzed the accuracy of ultrasonic method and surface wave method in detecting crack depth in practical applications, in order to provide valuable reference information for related fields.

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