

Analysis of Experimental Data for Fracture Depth Measurement by Horizontal Measurement Based on Data Analysis Software

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Abstract: The experiment of measuring the depth of concrete cracks by single-side plane measurement is the most simple and easy-to-understand depth measurement experiment. In this paper, the experimental data of this single-side horizontal measurement method for measuring the depth of concrete cracks will be analyzed in depth, and its validity will be tested based on data analysis software. According to a certain sound speed principle, the error and its causes are analyzed.

Keywords: experimental data; data analysis software; depth of cracks; effectiveness; error

1. Introduction

In the ultrasonic measurement of crack depth, single plane method is more common. Secondly, the methods of double-sided in clinometry and borehole to borehole measurement are widely used in engineering. In this experiment, the concrete cracks on the floor of the factory building are measured by the method of one-sided leveling [1-3]. Some experimental data have been obtained and a relatively complete experimental report has been formed. In data processing, there are a series of regression methods and error analysis methods. In this paper, we will use data analysis software to test its

effectiveness, and analyze the errors and the causes of errors [4].

2. Experimental Data

The specific principle of single plane method is to measure the sound wave propagation time of concrete without cracks at a certain distance by using the ultrasonic testing method. Measure the sound wave propagation time of concrete with cracks at the same distance correspondingly. Calculate the relation formula of crack depth by using a certain geometric relation, and calculate the crack depth by the data measured by the experiment. According to the calculation, the relation formula of fracture depth is

$$h_i = \frac{l_i}{2} \sqrt{\left(\frac{t_i}{t_0}\right)^2 - 1} \tag{1}$$

Where, l_i is the modified data of the measured distance, t_i , t_0 are the acoustic time of the distance l_i across the seam and no across the seam respectively, so the experimental data are the original distance measurement value l_0 , and the corresponding acoustic time of the across seam and no across the seam.

The data of this experiment is shown in Table 1.

Table 1. Experimental data

l_0/mm	80	90	100	110	120	130	140	150	160	180	190	200
$t_i/\mu\text{s}$	26.8	33.6	39.6	41.6	41.8	42	42.4	48	48.4	50.8	52.2	55.2
$t_0/\mu\text{s}$	8	14.4	22.8	27.2	27.6	31.2	34.8	38.5	38.8	44	47.2	48

3. Test Data Correction and Test Results

3.1 Principle of Distance Correction

Since the data measured is the distance from the inner edge side to the inner edge side at both ends of the instrument, and the distance measured by the instrument is the distance from the center point to the center point, it is necessary to correct the distance l . At this time, the intercept should be obtained according to the linear

regression method, corrected, and the linear regression formula should be used [5-7].

$$\begin{cases} b = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \\ a = \bar{y} - b\bar{x} \end{cases} \tag{2}$$

After obtaining a and b , the linear regression equation can be established according to the following formula

$$\hat{y} = \hat{b}x + \hat{a} \tag{3}$$

The linear regression equation is $l = 39.9625 + 3.06t$ (4)

Since the intercept is 39.9625, the correction number a is about + 40mm.

3.2 Distance Correction Table

The data after distance correction is shown in Table 2.

Table 2. Revised data sheet

l_{a0}/mm	80	90	100	110	120	130	140	150	160	180	190	200
a/mm	40	40	40	40	40	40	40	40	40	40	40	40
l_i/mm	120	130	140	150	160	170	180	190	200	220	230	240

3.3 Fracture Depth Table and Final Fracture Depth of Experiment

According to formula (1), the fracture depth h_i corresponding to each measurement and the average fracture depth h_{a0} can be calculated. After removing the

test data of $l_i < h_{a0}$ and $l_i > 3 h_{a0}$, the average fracture depth h_a can be calculated again. At this time, h_a is the final calculation result. The above calculation process is shown in Table 3.

Table 3. Fracture depth

l_i/mm	120	130	140	150	160	180	190	200	220	230	240	
h_i/mm	191.8	137.0	99.4	86.7	90.9	76.	62.6	70.7	74.6	63.5	54.3	68.2
h_{a0}/mm	89.7											
Choose	Yes	Yes	Yes	No	Yes	No	No	No	No	No	No	No
h_a/mm	103.9											

4. Error Analysis

4.1 Analysis of the Validity of Linear Regression Equation

According to the relevant theoretical knowledge, there is a functional relationship between distance l and acoustic time t . However, the linear regression method and linear regression equation are used in the experiment, which shows that there is a correlation between them to some extent, rather than a functional relationship. As we all know, in the experiment, there are inevitably various errors, which will make the resulting function become a nonlinear function, contrary to the theory. So here we use correlation instead of function relation, and use regression line to fit the corresponding function curve [8, 9]. Whether the regression equation can fit the function curve well is very important in the experiment. Only when the function curve can be fitted can the next operation be carried out, so this needs to be tested. At this time, data analysis software, Excel or SPSS software will be used.

The significance test of linear regression equation can be divided into two types: t test and F test. The principle of t test and F test is basically the same. Both of them use the fitting formula of t distribution function and F distribution function to find out the corresponding t value and F value. Compared with the critical t value and F value, determine their significance or find their corresponding p value to find their significance. The calculation process and principle are relatively complex, which will not be explained here. If Excel software is used, the conclusion can be drawn, as shown in Table 4.

Table 4. Data analysis software

	T	F	$p(T)$	$p(F)$
t	15.0126	225.3783	1.12E-07	1.12E-07
l	3.2439		0.010095	

4.1.1 T value and F value test

When the confidence reaches 99%, the significance of regression equation is very high, so we use 99% confidence as the test method.

From table 4, t value is 15.0126 and 3.2439, the total data is $n = 24$, then $t_{0.01}(n-2) = 2.5083$, because 15.0126 and 3.2439 are both greater than 2.5083, then the confidence is 99%, that is to say, the regression model and regression equation reasonably reflect the correlation between distance and sound time.

From table 4, if f value is 225.3783, then $f_{0.01}(1, n-2) = 7.95$. Since 225.3783 is far greater than 7.95, it is considered that its significance is extremely high significant, and there is a strong correlation between them.

4.1.2 P value test

P value refers to the probability that the original assumption is not tenable, that is, the probability that the linear regression equation is not enough to fit the correlation relationship. When p value is large, it is considered that the error probability is high, and the correlation between them is small. When p is small, it is considered that the error probability is small, and the correlation between them is large. It can be seen from the above table that both $p(T)$ and $p(F)$ are very small. For example, the value of $1 - p$ is very close to 1, so the error

probability is very small, and the correlation between the two is very significant.

Whether it is the result of *t*-value test, *f*-value test or *p*-value test. All of them come to a conclusion that there is a strong correlation between distance *L* and acoustic time *t*, that is to say, the linear regression equation well fits the functional relationship between acoustic time and distance, that is to say, the simulation of linear regression equation is effective.

The linear regression equation well simulates the first-order equation function relationship between acoustic time and distance, so the fitting error here is very small, which can be regarded as complete fitting.

4.2 Sound Speed and Distance Error

4.2.1 Sound velocity error

The propagation speed of sound in the air is 340 m/s, while the propagation speed of sound in concrete is about ten times of that in the air that is 3400 m/s. And different concrete strength grade also affects the speed of sound propagation in it. A large number of experiments show that when concrete is used as floor material, the wave velocity of C15 concrete is about 2900 m/s, that of C20 concrete is 3200 m/s, that of C25 is 3500 m/s, that of C30 is 3800 m/s, and that of C35 is 4000 m/s [10, 11].

Assuming that the plant floor is the floor, and the design strength of the general floor concrete is 20 MPa, that is to say, the strength grade is C20. From the above, the sound velocity is $v = 3200$ m/s.

In the regression line, we can get the fitted sound velocity through the slope

$$V_1=3060 \text{ m/s}$$

If the fitting V_1 is used, the concrete is between the strength ranges and close to C20.

The error is

$$V_1-V=140\text{m/s}$$

Assuming that the sound velocity between 15 MPa and 20 MPa is linear, the fitting concrete strength is about 17.67 MPa. Therefore, the error between the concrete strength experiment and the theory is 2.33mpa, which is within the acceptable range.

4.2.2 Spacing error

According to the measurement results, the diameter *D* of the measuring head is about 33mm. When both ends are placed on the inner edge side at the same time, the distance from the center point to the center point will be more than two radius correction numbers, that is, more than one diameter correction number, so the correction number should be about $v = + 33\text{mm}$ in theory and $v_1 = + 40\text{mm}$ in experiment. Its spacing error is

$$v_1-v=7\text{mm}$$

The distance error is large, which cannot be ignored.

4.3 Error in Experimental Data

From the above experimental data, it is easy to see that the residual error is large, and the data cannot be eliminated, which indicates that the dispersion degree is

large, then the mean square error is introduced to calculate the dispersion degree error [12, 13].

Due to the limited number of crack depth measurements and the change of fracture depth with time, there is not a more accurate true value as the relative calculation in the calculation, so it is not possible to use the conventional calculation method of using true error to calculate the mean square error, that is, to use the similar true error to calculate the mean square error. In applied statistics, the two sides are the differences between the overall standard deviation and the sample standard deviation. Then use the following formula to calculate.

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \quad (5)$$

According to the calculation, then

$$S=38.933$$

It can be seen that the mean square error is large. From this phenomenon, it can be seen that the data is very discrete, that is to say, most of the data are very different from the average value. There are many human error factors, so the average value cannot represent the fracture depth value, so it needs to be measured again.

5. Errors and Causes

Errors are mainly caused by the following four factors: human factors, environmental factors, instrument error, theoretical error. 1) In this experiment, whether the mean square error is large or the intercept error is large, most of the reasons are from the human error. The inaccurate experimental data is caused by unstable sound wave, inaccurate positioning of measuring head, and disoperation of instrument. 2) Environmental factors are inevitable. It is possible that temperature, air pressure and other factors affect the experimental results, but the influence degree is very small. 3) The instrument is not adjusted well, and the error caused by the high sensitivity of the instrument itself. This experimental instrument is ultrasonic instrument, which is greatly affected by external factors. 4) There is a function relationship between sound time and distance. No matter how linear regression fitting is, it is impossible to perfectly fit a very accurate function curve and produce a certain theoretical error.

6. Conclusion

Concrete structures often produce cracks, which affect the safety and durability of the structure. The method of non-destructive testing crack depth is particularly important here. The single plane method is the most commonly used and simplest method of non-destructive testing crack. Although it is simple, there are many shortcomings, such as the need for a higher level of operation and more attention to many things, in order to make the error not exist. However, there are still many unavoidable errors, which make the experimental data not very accurate. We need to further study and experiment to find a more simple and less error non-destructive detection method of crack depth.

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