Method of Measuring Crack Depth of Concrete uses Ultrasonic

1. Ultrasonic

The ultrasonic is a sound wave of the frequency of 20kHz or more. Here, the following relation exists between the wave length, sound speed, and the frequency.

wave length＝sound speed／frequency

The sound wave has the following feature.

(1) The sound wave is transmitted in the air. However, the one with high frequency (about 10kHz or more) of ultrasonic is not transmitted in the air.
(2) The sound wave is transmitted in water.
(3) The ultrasonic reflects on the boundary side.
(4) The radiation trouble like X rays and the γ line, etc. is not caused in the ultrasonic.

Sound speed on a concrete inside is about 4000m/s. By the way, sound speed about 340 m/s in air and about 1500 m/s in water. (air < water < concrete)

2. Method of measuring crack depth

The method of measuring the crack depth which uses the ultrasonic includes ① Tc-To method (L-L method), ② T method, ③ Delta method, ④ Short distance detour wave method (SDDW method), ⑤ British standards method (BS method), ⑥ Diffraction wave method (Lamp method), ⑦ S-S method, ⑧ R-S method, ⑨ Leslie method and ⑩ Low frequency transverse wave ultrasonic method. Moreover, there are a lot of kinds of measurement equipments of the ultrasonic. Here, the outline of the Tc-To method (L-L method), T method, the delta method, short distance detour wave method (SDDW method), and British standards method (BS method) is explained based on using UST made by Marui Ltd. in Japan (Ultra Sonic Tester (UST) : oscillator for P wave of the frequency 50kHz and two terminal method) which can be applied to measure the crack depth.

(1) Tc-To method (L-L method)

In the Tc-To method, the transmission time which becomes a standard is requested by arranging longitudinal wave oscillator and receiver at intervals 2a on the surface of the health part of the examination body. Next, the transmission time is requested by arranging oscillator and receiver at intervals 2a so that the crack may become a center. The crack depth is obtained from the next equation.

$$d = a\sqrt{(t_c / t_o)^2 - 1} \tag{1}$$

d：depth of crack (mm), 2a：distance between oscillator and receiver (mm), tc：transmission time of crack position (μs), to：transmission time on surface of health part (μs)

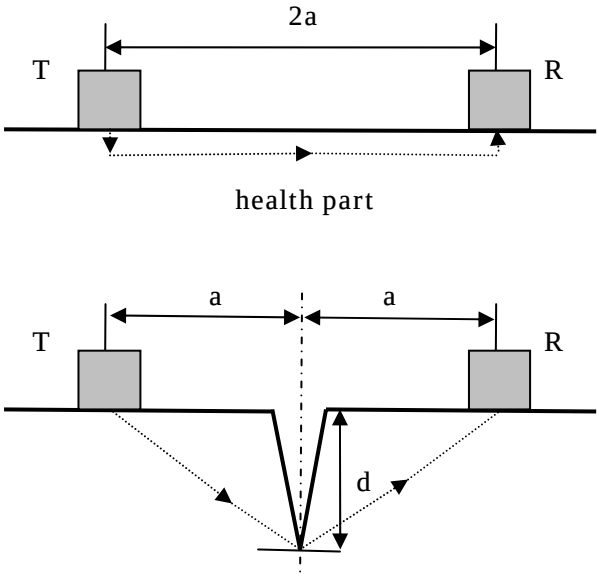


Fig. 1 Tc-To method (L-L method)

(2) T method

T method is a method of requesting discontinuous time T at the crack position from the curve (relation between the transmission distance and the transmission time) at the run of the fixation of oscillator and the movement of receiver at constant intervals, and calculating the crack depth from the next equation.

$$d = T \cdot \cot\alpha \cdot \frac{T \cdot \cot\alpha + 2L_1}{2(T \cdot \cot\alpha + L_1)} \tag{2}$$

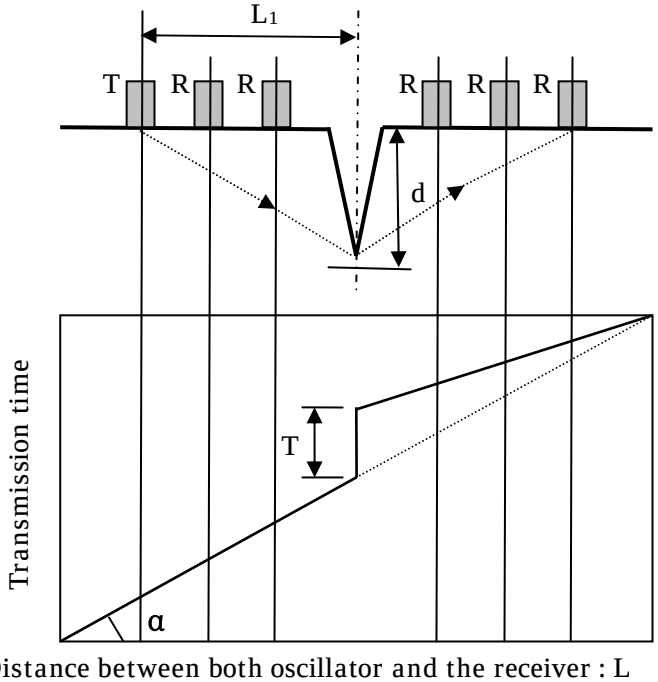


Fig. 2 T method

(3) Delta method

The delta method is fundamentally the same as the L-L method, and method of measuring the transmission time by placing the crack and arranging oscillator and receiver, and obtaining the crack depth from the next equation.

$$d = \sqrt{\left\{\frac{T^2 - R^2 + (V \cdot t)^2}{2V \cdot t}\right\}^2 - T^2} \tag{3}$$

T：distance from crack to surface of oscillator (mm), R：distance from crack to surface of receiver (mm), V：Sound speed in health part by surface scanning method at each intervals of between oscillator and receiver (km/s), t：transmission time of crack position (μs)

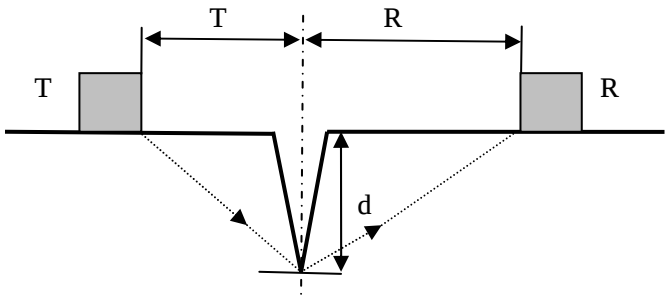


Fig. 3 Delta method

(4) Short distance detour wave method (SDDW method)

Short distance detour wave method is fundamentally the same as the L-L method, and method of measuring the transmission time by arranging oscillator and receiver at placing near side of crack, and obtaining the crack depth from the next equation. The difference with the L-L method is to arrange the terminal to be near of crack.

$$d = Vo \cdot \frac{t}{2} \tag{4}$$

d：depth of crack (mm), Vo：sound speed of examination body (km/s), t：shuttling transmission time (μs)

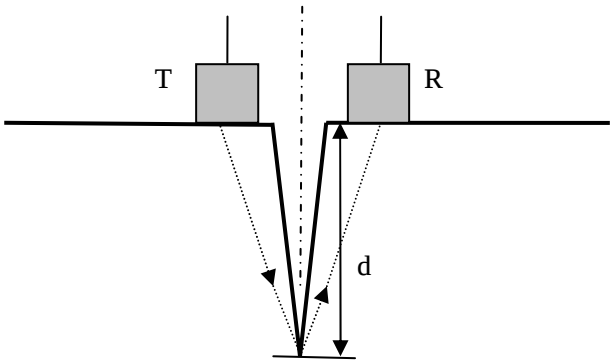


Fig. 4 Short distance detour wave method

(5) British standards method (BS method)

The British standards method is a method recommended by BS4408, and the method of calculating the crack depth by arranging oscillator and receiver from the crack at equal intervals at transmission time t2 of X2=300mm and transmission time t1 of X1=150mm.

$$d = 150\sqrt{\frac{4t_1^{\,2} - t_2^{\,2}}{t_2^{\,2} - t_1^{\,2}}} \tag{5}$$

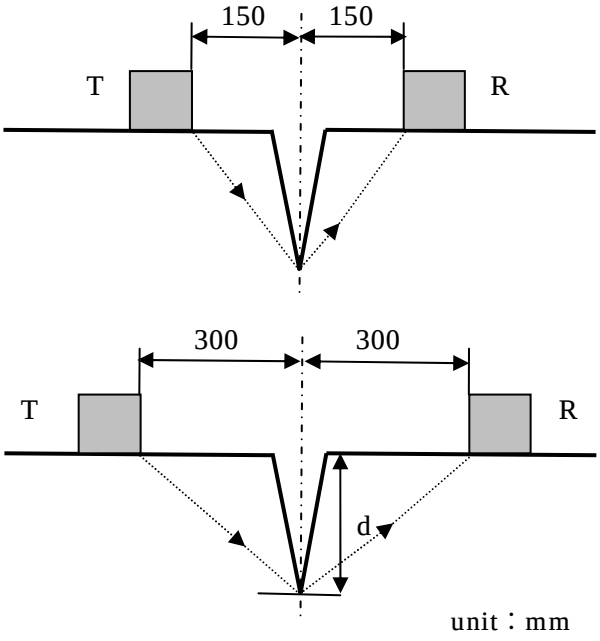
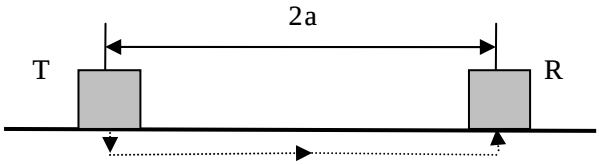


Fig. 5 British standards method

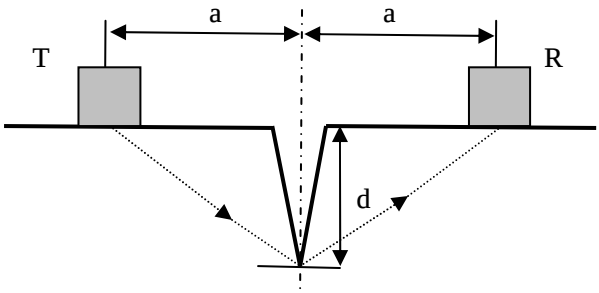
[Appendix]

How to lead and the condition of the equation in Tc-To method (L-L method), Delta method and short distance detour wave method (SDDW method) are shown.

(1) Tc-To method (L-L method)



health part



Tc-To method (L-L method)

Sound speed in the health part is assumed to be Vo and in the crack position is assumed to be Vc. Vo and Vc can be obtained as follows by measured use of the transmission time and the transmission distance.

$$V_o = \frac{2a}{t_o}, \qquad V_c = \frac{2\sqrt{a^2 + d^2}}{t_c}$$

Here, the transmission distance of Vo is assumed to be distance 2a between oscillator and receiver. The transmission distance of Vc is assumed to be isosceles triangle of distance a from the crack to the oscillator and receiver, and d in the crack depth. To is transmission time on the surface of the health part, and Tc is transmission time of crack position.

Because the ultrasonic same in concrete, sound speed is the same.

$$V_o = V_c$$

Therefore, the equation of the L-L method can be obtained as follows.

$$\frac{2a}{t_o} = \frac{2\sqrt{a^2 + d^2}}{t_c}$$

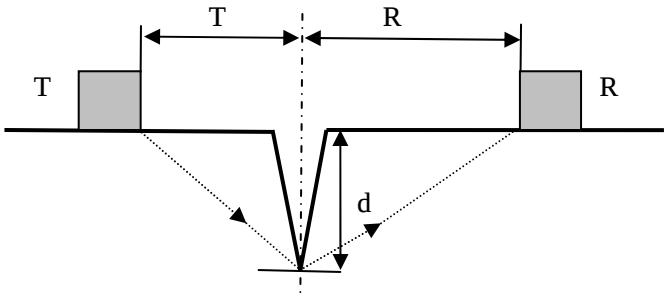
$$a\frac{t_c}{t_o} = \sqrt{a^2 + d^2}$$

$$a^2\left(\frac{t_c}{t_o}\right)^2 = a^2 + d^2$$

$$d^2 = a^2\left(\frac{t_c}{t_o}\right)^2 - a^2$$

$$d = a\sqrt{\left(\frac{t_c}{t_o}\right)^2 - 1}$$

(2) Delta method



Delta method

The equation of Delta method is as follows.

$$d = \sqrt{\left\{\frac{T^2 - R^2 + (V \cdot t)^2}{2V \cdot t}\right\}^2 - T^2}$$

Here, distance T from crack to oscillator and distance R from crack to receiver is assumed to be the same. The equation can be transformed as follows.

$$d = \sqrt{\left\{\frac{T^2 - T^2 + (V \cdot t)^2}{2V \cdot t}\right\}^2 - T^2}$$

$$d = \sqrt{\left(\frac{1}{2}V \cdot t\right)^2 - T^2}$$

V is sound speed in the health part.

$$V = \frac{2T}{t_o}$$

When this condition is applied to the above equation, the equation is as follows.

$$d = \sqrt{\left(\frac{1}{2} \cdot \frac{2T}{t_o} \cdot t\right)^2 - T^2}$$

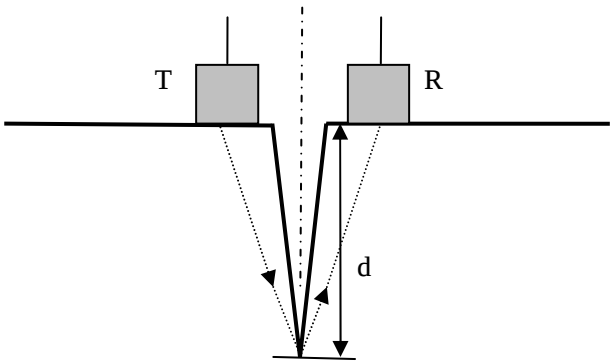
$$d = \sqrt{\left(\frac{T}{t_o} \cdot t\right)^2 - T^2}$$

$$d = \sqrt{T^2 \cdot \left(\frac{t}{t_o}\right)^2 - T^2}$$

$$d = T\sqrt{\left(\frac{t}{t_o}\right)^2 - 1}$$

Thus, if the distance from the crack to oscillator and receiver is the same, the equation of Delta method and L-L method become the same.

(3) Short distance detour wave method (SDDW method)



Short distance detour wave method

Short distance detour wave method is fundamentally the same as the L-L method. Sound speed in the health part is assumed to be Vo and in the crack position is assumed to be Vc. Vo and Vc can be obtained as follows by measured use of the transmission time and the transmission distance.

$$V_o = \frac{2a}{t_o}, \qquad V_c = \frac{2\sqrt{a^2 + d^2}}{t_c}$$

Moreover, because oscillator and receiver are set up the short distance of the crack, a=0 is added to the expression of Vc.

$$V_c = \frac{2\sqrt{d^2}}{t_c}$$

$$V_c = \frac{2d}{t_c}$$

$$d = V_c \cdot \frac{t_c}{2}$$

Because the ultrasonic same in concrete, sound speed is the same.

$$V_o = V_c$$

Therefore, the equation of short distance detour wave method can be obtained as follows.

$$d = V_o \cdot \frac{t_c}{2}$$

(4) Condition

To lead the expression of Tc-To method (L-L method), Delta method and short distance detour wave method (SDDW method), the following three conditions are needed.

1) Transmission distance of sound speed in the health part is distance between oscillator and receiver.
2) Transmission distance of sound speed in crack position is isosceles triangle of distance a from the crack to the oscillator and receiver, and d in the crack depth.
3) Because the ultrasonic same in concrete, sound speed is the same. Vo=Vc

In condition 1, it is understood that the transmission distance in the surface scanning method (surface method) becomes the distance between terminals. The ultrasonic pulse will transmit in concrete not internal but the surface neighborhood.