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# The Canny Edge Detection Method vs. the Radius of Curvature Method for Determining the Time of Flight on Ultrasound

Hicham Banouni, Bouazza Faiz, Driss Izbaim El Houssaine Ouacha,
Mostapha Boutaib and Mourad Derra
Laboratoire De Metrologie et De Traitement De L' Informationfaculte
Des Sciences Universite Ibn Zohr, Agadir, Morocco

**Abstract:** In this study, two methods are proposed to calculate a signal time flight time. The acquired ultrasonic signals during the transmission through the cement past in solidification under different temperatures are subject to the radius of curvature method and the Canny edge detector method to extract the flight time and then to compute the velocity of compression waves. Although, these two methods are based on the same principle which is the maximum variation of the signal, the Canny edge detection method is privileged to calculate the flight time. The comparison between the velocities calculated by these methods and the ones computed using the phase velocity equation shows a great similarity.

**Key words:** Flight time, longitudinal wave velocity, Canny edge detection, radius of curvature, calculated

## INTRODUCTION

Ultrasonic nondestructive waves control is our method to characterize materials and to have information about several physicochemical parameters of the material. The study of one or more of those parameters requires various mathematical tools. When a wave passes through a material medium, it undergoes many changes depending on its characteristics. Then, we can notice that a signal changes when it is transmitted through a changing environment such as the cement paste during solidification.

Multiple works have been proposed in the field of material characterization by ultrasound. In dairy products, specifically UHT milk, we demonstrated the reliability of the ultrasonic transmission technique to characterize the contamination induced by the presence of an air trace inside the UHT milk package (Ouacha *et al*., 2015). Other studies have exploited the measurements of attenuation and velocity changes to determine if the frozen fish had suffered from many freezing and defrosting (Malainine *et al*., 2011; Kadi *et al*., 2011). The use of ultrasound techniques to control the quality of pasting has provided new tools to determine the status of sticking plates (Faiz, 1995). These techniques have been used to understand the phenomena of cement materials structuration (mortars, concrete and reinforced concrete). To do this an ultrasonic reflection technique has been developed to control the cement materials by evaluating the viscoelastic parameters of the signals that are back scattered by these materials (Lotfi *et al*., 2013).

Edge detection on image processing continues to progress. Wrinkles detection on images to estimate the age is one of the latest finding in the field (Ouloul *et al*., 2015). Now a day, there is even a talk about active edges which is a method used such as secure area where an image is compared with a reference. Many methods exist for edge detection but the method of Canny is the most suitable one to determine the flight time for noisy signals (Banouni *et al*., 2015).

The fight time is an essential parameter to determine the longitudinal wave velocity in materials. It depends on the longitudinal wave velocity and varies significantly at the beginning of the cement solidification and then it stabilizes at the end. The use of the cross-correlation is a method to determine the flight time however, in the case where the medium changes with time is terms of properties as the cement paste becomes more and more diffusive, some remains little.

## MATERIALS AND METHODS

**Theory:** We proposed two methods two methods to determine the time of flight. The first method used the curvature radius of the signal Hilbert envelope. The second method used the Canny edge detector to find the contour of a cement signal characteristic image. Then, we compare these methods to an other that calculate the phase velocity using the following equation:

**Corresponding Author:** Hicham Banouni, Laboratoire De Metrologie et De Traitement De L' Informationfaculte Des Sciences Universite Ibn Zohr, Agadir, Morocco

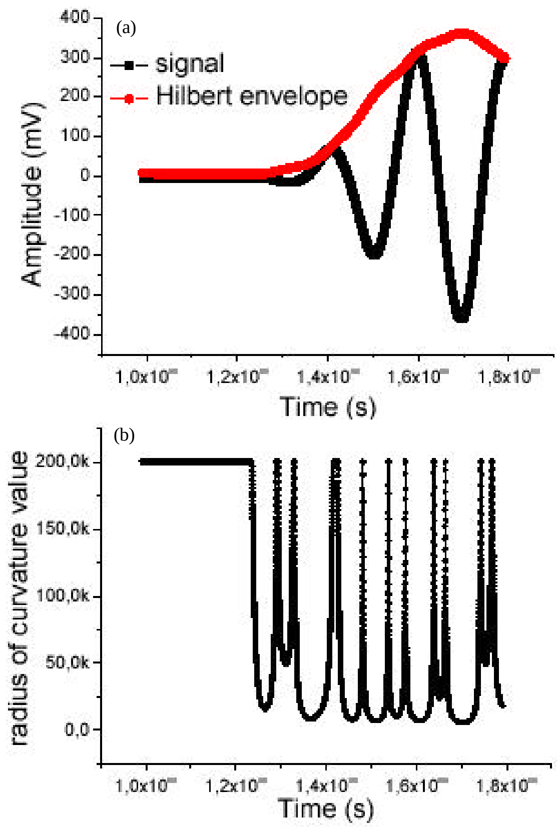


Fig. 1: a, b) Example of the echo transmitted after 14 h of the mixture of the cement and its Hilbert envelope at the temperature 35°C. Graphical representation of the absolute value of Hilbert envelope radius of curvature associated with figure with a threshold 200000 determine the time of flight, we extract the first

$$\text{Vciment}(\vartheta) = \frac{\omega d V_{ref}}{\omega d + V_{ref}(\varphi_{ciment} - \varphi_{ref})} \quad (1)$$

**Radius of curvature:** Figure 1 shows the device of measurement used. The real signal presents fluctuations due to noise accompanying the signal that's why it is difficult to detect the longitudinal wave front time which is the time of flight from the real signal. The Hilbert envelope of the signal has less fluctuations then the signal itself for this reason we propose to use the radius of curvature of Hilbert envelope. This later is given by the equation:

$$\|y(t)\| = \|x(t) + iH[x](t)\| \quad (2)$$

The radius of curvature of a function y = f(x) is given by Eq. 3:

$$R(x) = \frac{\sqrt{(y^2+1)^3}}{y} \quad (3)$$

We look for the first minimum of Hilbert envelope radius of curvature, this point presents the first curvature of the function after being constant and null. Since, the radius of curvature of constant function or a point of infection is infinite (very big), we choose a threshold above which we will not consider the value calculated and we will take the chosen threshold as a value of the radius of curvature. Furthermore, the radius of curvature can take positive or negative values by abuse of calculation we take the absolute value as shown in Fig. 1a, b, this method gives approximately the real value of time of flight of the transmitted signal. This method can be used in real time during the temporal signals acquisition, hence the calculation of the time and the velocity of the transmitted wave.

**Edge detection:** The edge detection method is based itself on the signal derivative it can be used in 2D, this is why we juxtapose all the transmitted signals through the solidification in cement to construct an image on which we apply an edge treatment. In order to determine the time of flight, we extract the first contour. We take into account the Signal Noise Ratio (SNR) to detect the appearance of the first echo. Since the first echoes are immersed in noise, their amplitudes are comparable to those of noise (Fig. 2a, b).

Since, our goal is to find the flight time and the image x-axis is the time of the signal, then by finding the coordinates of each signal, by determining the coordinates of each first contour point, we determine the evolution of the flight time during the solidification of the cement. All this is deduced for each given temperature.

## Experimental part

**Experimental descriptive:** Our experience is composed of following equipment:

- A signal generator/SOFRANEL Model 5052PR
- A PicoScope
- Two transducers of frequency 0.5MHz
- A computer HP with Windows7 as an operating system
- Data acquisition is done under LabView2011
- Thermo-adjustable basin

**Cement paste preparation:** We choose CPJ 35 cement in our experience and the 0,4 value for the mass ratio water/cement to prepare the cement paste the vessel containing the cement is of 3 mm thick walled

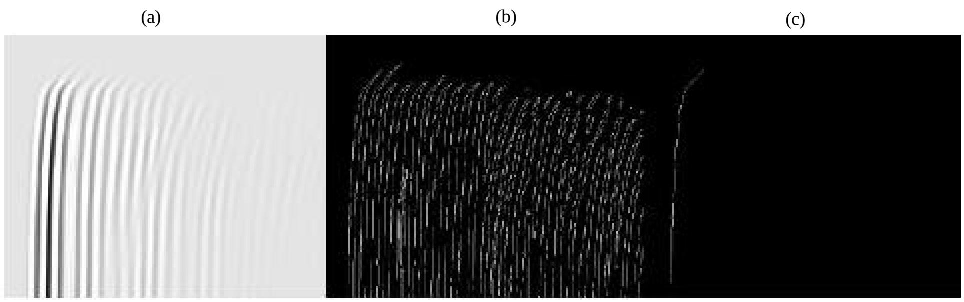


Fig. 2: a) juxtaposition of signals: the axis of abscissas represents the time signal from the index 14000 (8 ns sampling (sampling is reduced to decrease the size of the image)) the y-axis represents time gain. Figure 2b shows the application of the contours in Fig. 2a. Figure 2c collection of the first contour of Fig. 2b

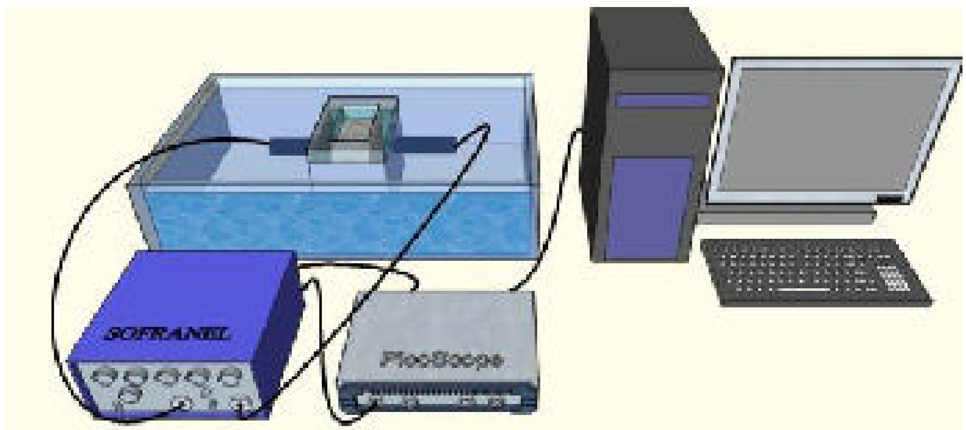


Fig. 3: Representing the equipment of the experience and its electrical installation

plexiglas. The transmitter/receiver transducers are attached to a support so that they are facing and in contact with the tank walls. The center frequency of the two transducers is 500 kHz. After the mixture of the prepared paste and when putting it in the tank we flow it gradually on one of the walls to avoid the formation of bubbles. At the end, we give shot vibrations in the tank to facilitate the escape of the bubbles probably formed during the cement pouring. The basin where the tank is placed has an adjustable temperature (Fig. 3).

**Recuperation of signals:** The cement paste is very absorbent, even at a low thickness,the acoustic signals can't get through it. At the beginning of the experience, the signal is almost null. The time of the first crossing of the echo depends on the temperature. Nevertheless, we collect from the start all the signals by a woven program in the laboratory. These signals are sampled at 800 ps and recorded from each five minutes under the form of text files, then juxtaposed one over the other to construct a matrix assembling all signals obtained during the cement solidification. The results obtained subsequently are taken under different temperatures (Fig. 4).

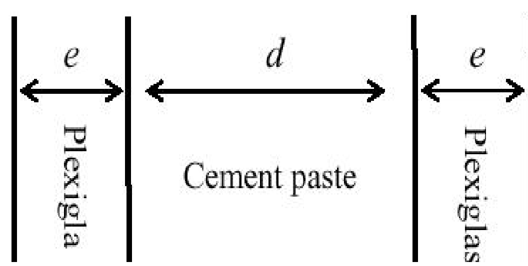


Fig. 4: Simplified schema of ultrasonic wave trajectory trough the vessel

## RESULTS AND DISCUSSION

**Application of the curvature radius method:** This method is applicable at the time of signals acquisition, the chosen

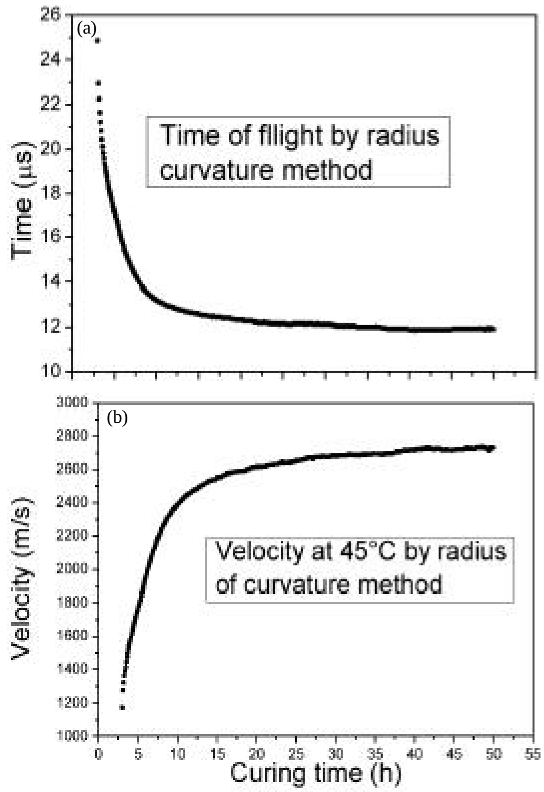


Fig. 5: a) represents the variation of flight time to short the solidification of the cement at the temperature 45°C by the radius of curvature method. Figure 5b calculated in Fig. 5a expressing the variation of the speed of the longitudinal wave in the solidification of cement paste at the temperature 45°C

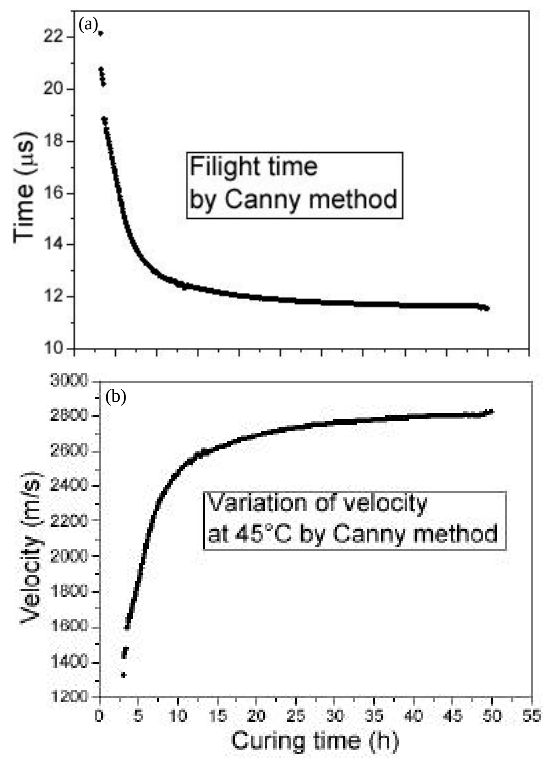


Fig. 6: a) represents the variation of flight time during the solidification of the cement at the temperature 45°C by the Canny edge detection method. Figure 6b calculated from Fig. 6a expressing the variation of the speed of the longitudinal wave in the solidification of cement paste at the temperature 45°C

threshold for the curvature radius of Hilbert envelope of these signals is 250000. The obtained curve during the experience Fig. 5a is taken under the temperature 45°C and presents the flight time variation at the time cement paste solidification. The speed variation curve of the primary ultrasonic waves derived from the previous curve is shown in Fig. 5b to calculate the velocity of the transmitted wave in the cement sample, we programmed the relationship in Eq. 3 drawn from the simplified diagram of the wave run from one transducer to another as the following:

$$V_C = \frac{d}{t - \frac{2e}{Vp}} \tag{4}$$

Where:

$V_C$ = Velocity of longitudinal wave on cement
t = Flight time
Vp = Velocity in plexiglas

**Application of the Canny edge detection method:** Since, the transmitted signal is almost null in the beginning, the time of its appearance depends on the temperature in addition, the noise effect is also very significant at this time that is when the first flight time depends on the SNR. Furthermore, the Canny edge detection method is only effective if the SNR exceeds 11 dB (Banouni *et al*., 2015). The time of the first echo detection is relative because previous echoes are drowned in the noise or absolutely null. The coordinates of each point of the first contour have the time of flight of each signal and constitute the curve of the flight time variation based on the cement setting time (Fig. 6).

**Comparison between the methods of longitudinal wave velocity calculating:** The two methods are comparable and show similar results: Fig. 7 shows the variation of flight time calculated by the Canny edge detection method and by the radius of curvature method. The graph shows the same variation aspect. The variation of the time of flight calculated by the two methods presents the same appearance, one can see that the two methods have the same evolution.

**Calculating the standard deviation:** During the experiment, we extracted six signals spaced with intervals of one second, each signal is the average of fifty signals

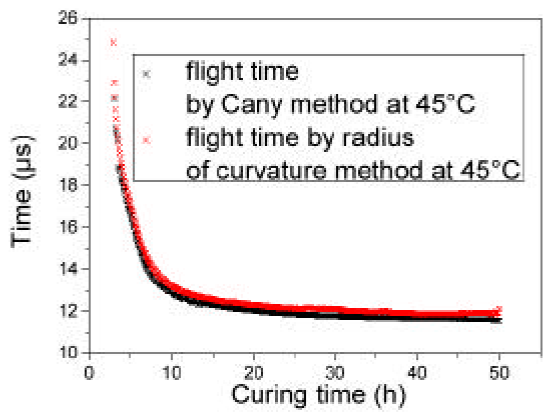


Fig. 7: The variation of flight time

simultaneously, this is repeated every five minutes. From these acquisitions we calculate the flight time and the longitudinal wave velocity using the both methods, then we extracted the standard deviation for each value of the velocity during the solidification time (Fig. 8).

Based on the standard deviation value, we notice that the method of calculating the longitudinal velocity by Canny edge detector is more accurate and has more stability than the method using the calculation of the radius of curvature.

**Calculation of the longitudinal velocity:** To determine the wave velocity, we use the Eq. 4. The following graphs gave the final results of the longitudinal velocity change during the cement solidification at different temperatures using the two methods described previously (Fig. 9).

The two methods are similar in the determination of the flight time and the deduction of the longitudinal velocity variation of ultrasonic waves through the cement solidification.

**The results predicted by calculating the phase velocity:** Since, the water was used to acquire the signal passing through the cement paste before putting it in the tank, we choose as a reference the water in the relation. This later

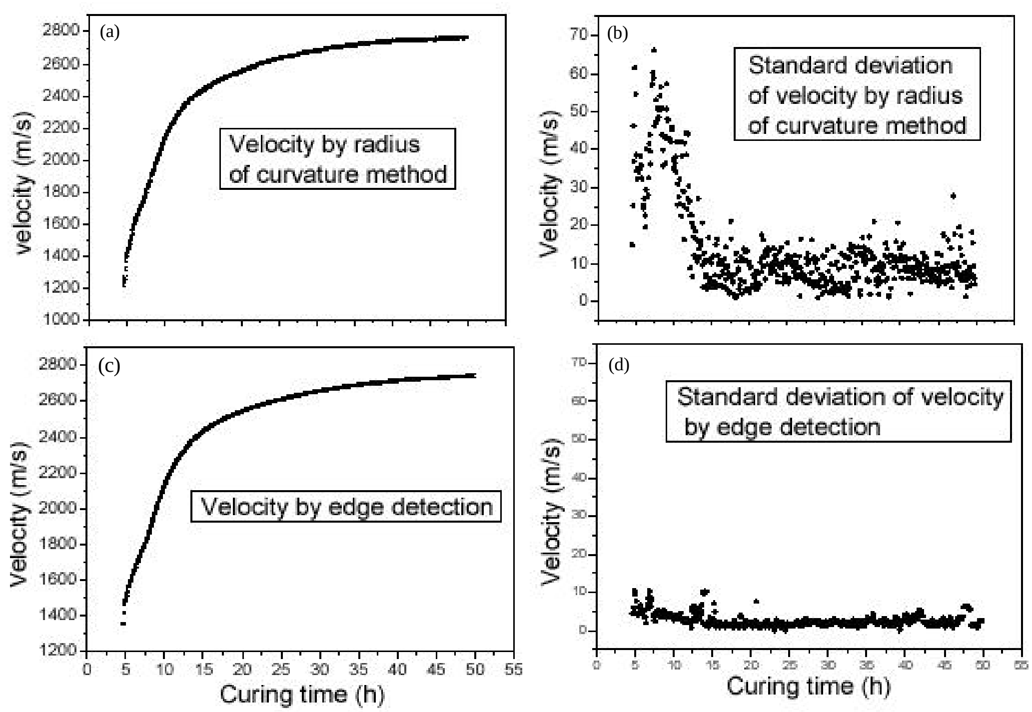


Fig. 8: a, c) show the change in the longitudinal velocity calculated by the two methods and the Fig. 8b, d have the variance value of each of the two methods

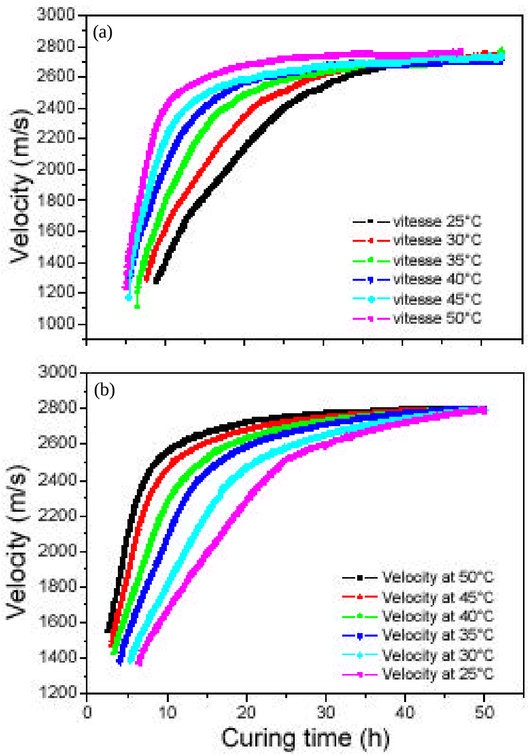


Fig. 9: a, b) Present the variation of the speed of the longitudinal wave through the solidification cement paste under different temperatures by two different methods Fig. 9a by the method of the radius of curvature and Fig. 9b by the edge detection method Canny

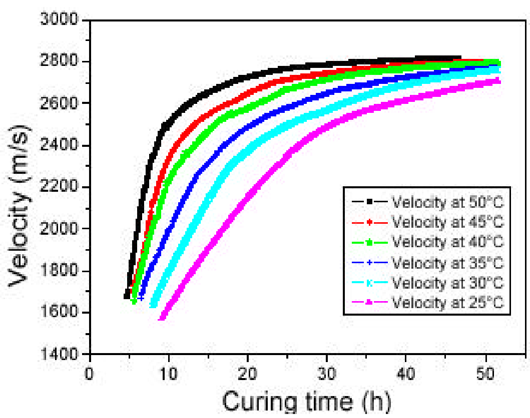


Fig. 10: Variation through the cement past solidification

allows us to follow the velocity change in the sample. We use then, the relation to determine the longitudinal wave variation through the cement past solidification what is shown on the graph Fig. 10. In equation, we have taken as the frequency that corresponds to the maximum of the signal frequency spectrum and not as the transducer center frequency which is 500 kHz.

**Notes and discussion:** The velocity evolution in the cement past is very important. The absence of signal transmitted through the cement past at the beginning shows that the cement past is very absorbent vis-α-vis the acoustic signals. The time of the first crossing depends on the temperature.

The method using the phase velocity extract the signal speed through the cement past during solidification earlier than the other methods. However, this method has the inconvenient that the signal depends strongly on the nature of the residual past. Hence, when the mixture of cement and water is not done in the same way, we will obtain different products with different transmitted signals which leads to many phases little different. Contrariwise, the two methods proposed in this study are based on the exact value of the time flight and has also a near value to the speed of the longitudinal wave.

The radius of curvature method is slightly shifted from the Canny edge detection. Indeed, the curvature radius method is based on the detection of the first minimum of the curve radius Hilbert envelope and not on the first non-zero value of the signal which is the wavefront real value and can not be detected because of the noise accompanying the signal. The first minimum of the curvature radius sufficiently close to the time of flight remains the right approach to calculate the time of flight especially when crossing the first waves. These first waves have very low magnitudes due to the phase change of the cement paste. The radius of curvature method is very effective to compute the flight time when the signal is highly attenuated at the beginning of the paste solidification by choosing a threshold of curvature radius which is very high. Therefore, we can use this method to determine the time of the first crossing of the waves to cement paste.

The edge detection method has the advantage of being the most appropriate for calculation of flight time, it holds its values directly from the signals and gives the closer values to the wavefront time, hence its more stable and the error committed on the values of speed is minimal during the taking of signals.

## CONCLUSION

The methods of calculating the flight time presented in this study prove their validity in determining the ultrasonic compression wave velocity in the cement paste. Although, there's privilege for the Canny edge detection method on that of the method of the radius of curvature seen comparing the errors made by the two methods, the second method can be used for the detection of early echoes through cement paste. Against by the edge detection method has high stability and accuracy especially during the solidification of the cement.

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