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Experimental study on ultrasonic propagation in water-based bentonite slurry

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Abstract: Drilling fluid is a common flushing medium used in pile foundation, geological drilling and petroleum drilling. Study on ultrasonic propagation properties in drilling fluid is of vital importance, not only for developing equipments to non-contact measuring concrete casting level for bored pile, but also for developing equipments considering drilling fluid as signal channel. The existence of clay particles makes the ultrasonic propagation and attenuation in drilling fluid much different from pure water. In order to know the relation among ultrasound frequency, slurry density and depth, a series of laboratory experiments about ultrasound propagation in water-based bentonite slurry were finished. Wavelet method was adopted to process the gained original waves of ultrasonic propagation in slurry, so we knew the velocity and attenuation coefficient of ultrasound propagated in different drilling fluids with different density. The first group experiments shows that with density of drilling fluid increase, ultrasonic velocity will decrease but attenuation coefficient will increase if ultrasonic frequency keep constant. The second group experiments shows that the power of ultrasound will intensify in small bore hole, the attenuation coefficient is much smaller than theoretical value.

Key words: ultrasound; drilling fluid; propagation properties; ultrasound velocity; ultrasonic attenuation

Introduction

Drilling fluid is a common flushing medium used in pile foundation, geological drilling and petroleum drilling. Study on ultrasonic propagation properties in drilling fluid is of vital importance, not only for developing equipments to non-contact measuring concrete casting level for bored pile, but also for developing equipments considering drilling fluid as signal channel.

As a convenient non-contact method, ultrasonic measurement is widely used in distance measurement in air media, and in liquid density or concentration measurement (Lan, 2008). Although some literature reports the ultrasonic propagating results in liquid media (Zhao *et al*., 1999; Su *et al*., 2002; Zhang *et al*., 2005; Wang *et al*., 2006; Sakurai *et al*., 2006), there are fewer papers referring ultrasonic propagation in water-based bentonite slurry (Podio *et al*., 1990; Orban *et al*., 1991).

Based on echo method, laboratory experiments were designed to study the relationship between ultrasonic velocity, attenuation coefficient and properties of drilling fluid. This makes a theoretical preparation for the relative study referring ultrasound propagation in drilling fluid.

1 Laboratory experiments

Laboratory experiments were finished in Drilling Laboratory Hall of China University of Geosciences. The aim of the experiments is to clarify the relation-

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ship between ultrasonic propagating characters and properties of drilling fluid. For this reason, two kinds of experiments were done:

Group 1: Ultrasound with different frequencies propagates in different drilling fluids;

Group 2: Ultrasound with constant frequency propagates in drilling fluids with constant density and different depth.

1.1 Frequency of ultrasound

Choosing the optimal frequency of ultrasound is of vital importance to the success of laboratory experiments. The results from Professor Podio (1990) showed that the practical frequency for drilling fluid ranges from 200 kHz to 600 kHz. In the experiments finished by Baker Hughes (Orban *et al.*, 1991), 280 kHz was adopted. Shao Chun (2006) thinks that low frequency ultrasound should be used for long distance propagation in drilling fluid. Based on these literatures, two frequencies (50 kHz and 200 kHz) were used in our experiments. The power of the ultrasound is 300 W.

1.2 Materials

Two kinds of experiments were finished in two different pipes, the sizes of the pipes list in Table 1.

Table 1 Sizes of experimental pipes

Characters	Pipe 1	Pipe 2
Properties	steel	UPVC
Thickness (m)	4×10^{-3}	6.5×10^{-3}
Inner diameter (m)	0.60	0.237
Length (m)	0.95	3.87

Calcium bentonite used in the experiments was coming from Bureau of Geological Exploration & Development of Hubei Province; tap water was used to mix with bentonite; and electric blender was chosen to mix drilling fluid.

1.3 Experiments design

Group 1 was aimed to clarify ultrasound propagation and attenuation characters in drilling fluids with different densities. Experimental apparatus and methods were illustrated in Fig. 1. Properties of the water-based bentonite slurry prepared for these experiments listed in Table 2, which were tested in Drilling fluid laboratory of China University of Geosciences.

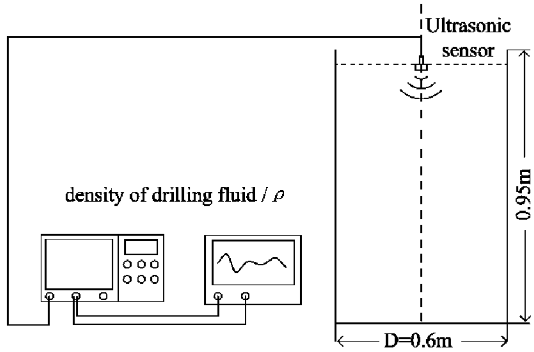

Fig. 1 Apparatus and experimental methods for experiment Group 1

Group 2 was aimed to clarify ultrasound propagation and attenuation characters in drilling fluids with constant density but different depths. Experimental apparatus and methods were illustrated in Fig. 2. The density of drilling fluid in these experiments was 1.14 g/cm^3, and the depth of the drilling fluid in Pipe 2 was 3.715 m.

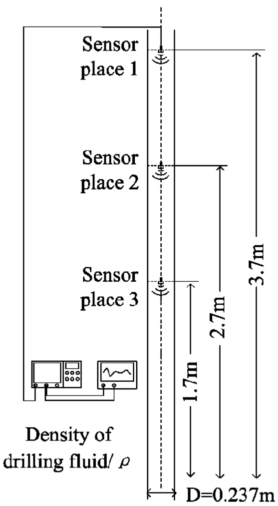

Fig. 2 Apparatus and experimental methods for experiment Group 2

2 Experiments results and signal process

In our experiments, ultrasound with 50 kHz frequency cannot gain clear echo signals after propagating in drilling fluids compared with 200 kHz ultrasound. So the results listed in this paper are gained from echo signals generated by 200 kHz ultrasound. On the other hand, this situation corroborates that 200 kHz ultrasound is valid for propagating in water-based bentonite slurry.

2.1 Results from experiments Group 1

Fig 3 shows the received signal wave for 1# slurry listed in Table 2. We should locate the exact echo signal from the received signal wave, for this reason, noises in original signals should be eliminated. In our research, wavelet method was used and Fig 4 shows the details and approximations of the received signals. In the same way, signal waves for 2# and 3# slurry can be processed to locate the echo pitch.

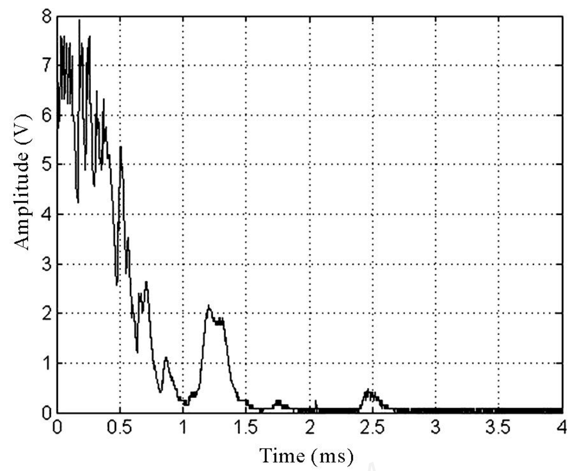

Fig 3 Signals for 200 kHz ultrasound propagating in 1.03 g/cm³ drilling fluid

Table 2 Test results for drilling fluids in experiment Group 1

Slurry number	Density (g/cm³)	Echo distance (m)	Viscosity (mPa · s)	Water temperature (℃)
1#	1.03	0.88	21.6s (Funnel viscosity)	2.7
2#	1.16	0.87	8 (Absolute); 7.5 (Apparent); 7 (Plastic)	2.7
3#	1.20	0.85	11 (Absolute); 9.5 (Apparent); 8 (Plastic)	2.7

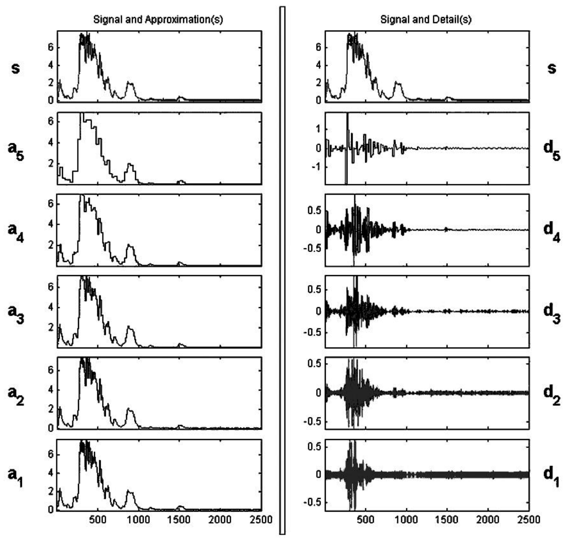

Fig 4 Details and approximations of signals from 1# slurry

2.2 Results from experiments Group 2

Fig 5 shows the received signal wave when 200 kHz ultrasound propagating in drilling fluid whose density is 1.14 g/cm³ and depth is 3.7 m. Wavelet method was used to eliminate noises. And Fig 6 shows the details and approximations of received signals. In the same way, signal waves when depth is 2.7 m and 1.7 m can be processed to locate the echo pitch.

3 Result analysis

3.1 Data post-process for experiment Group 1

The depth of slurry in pipe 1 is 0.88 m when 1# slurry was used. Because the face of the sensor is 5.3 cm below the slurry surface, the distance from sensor face to the bottom of the pipe is 0.827 m. Using wavelet method, we can gain the singular signal points, point 316 and point 895. For sample time interval is 2 μs, we can gain the velocity of 200 kHz ultrasound propagating in water-based bentonite slurry whose density is 1.03 g/cm³. It is 1 428.3 m/s when temperature is 2.7 ℃. Using the received amplitudes for point 316 and 895, we also gain the attenuation

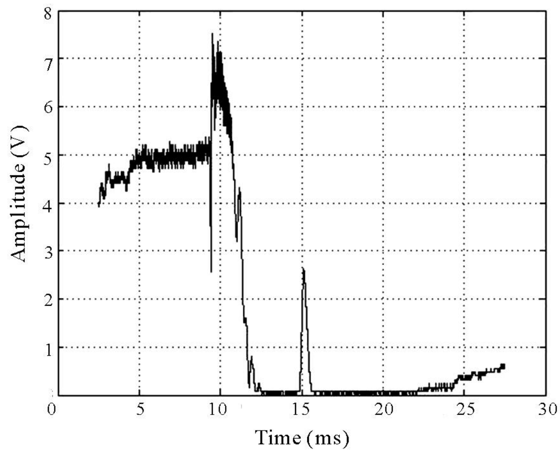

Fig. 5 Signals for 200 kHz ultrasound propagating in 1.14 g/cm^3 and 3.7 m slurry

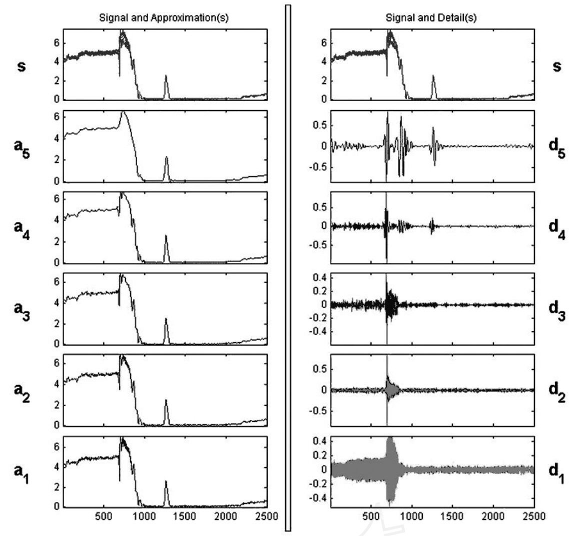

Fig. 6 Details and approximations of received signals from 1.14 g/cm^3 and 3.7 m slurry

coefficient of 200 kHz ultrasound propagating in water-based slurry whose density is 1.03 g/cm^3. It is 6.646 3 dB/m when temperature is 2.7 ℃.

In the same way, velocity and attenuation coefficient for 200 kHz ultrasound propagating in 2# and 3# slurry are listed in Table 3.

The depth of slurry in pipe 2 is 3.715 m when slurry density is 1.14 g/cm^3. The distance from sensor face to the bottom of the pipe is 3.635 m under the first condition. Using wavelet method, we can gain

Table 3 Ultrasonic velocity and attenuation coefficient propagating in slurry calculated from exprimental results

Experiment Group 1				Experiment Group 2			
Density (g/cm^3)	Echo distance (m)	Velocity (m/s)	Attenuation (dB/m)	Density (g/cm^3)	Echo distance (m)	Velocity (m/s)	Attenuation (dB/m)
1.03	0.827	1428.3	6.6463		3.635	1356.3	1.2597
1.16	0.812	1425.1	13.1209	1.14	2.715	1289.2	0.3632
1.20	0.800	1248.0	26.1107		1.715	1218.0	0.5151

the singular signal points, point 735 and 1271. For sampling time interval is 10μs, we gain the ultrasonic velocity and attenuation coefficient under this test condition. They are 1 356.3 m/s and 1.259 7 dB/m.

In the same way, velocity and attenuation coefficient for 200 kHz ultrasound propagating in the other two different depths are listed in Table 3.

3.3 Data analysis

Experiments Group 1 discover that ① with the increase of fluid density, ultrasonic velocity would decrease non-uniformly; ② with the increase of fluid density, solid volume increase and energy dissipation become obvious, so the ultrasonic attenuation increases. Because the diameter of pipe is ten times than that of ultrasonic sensor, so we can ignore the size effects and the results can reflect ultrasonic attenuation in drilling fluid.

Experiments Group 2 discovers that with the increase of distance velocity and attenuation coefficient would increase if fluid density keeps constant. But Table 3 shows 2 abnormal phenomena. ①Experiment Group 2 exits size effect and the results show that if sensor's diameter is comparable to pipe diameter, ultrasonic attenuation would decrease, which is helpful to long distance propagation. ②When fluid density keeps constant, measured velocities are diverse; we think that is from the error of equipment. In other words, because the PVC pipe is very long, the density of the lower fluid was great than the upper section for settlement and flocculation effects. That causes the fluctuation of measured velocity and attenuation.

4 Conclusions

200 kHz ultrasound is more competent to propagating in water-based bentonite slurry than 50 kHz.

Wavelet method can be used to process echo signals and obtain ultrasonic velocity and attenuation.

Size effect exits in experiments and it shows that ultrasonic can propagate much farther in small pipe.

With the increase of fluid density, ultrasonic velocity would decrease gradually and attenuation would increase sharply.

Laboratory equipments should be reformed to eliminate fluid settlement and flocculation effects to results.

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