EXPERIMENTAL STUDY ON THE CHARACTERISTICS OF RIVERBED MATERIALS USING AN ULTRASONIC SENSOR

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Abstract: The scouring process is complex and subject to many factors. Recently, experiments for real-time bridge scour monitoring have been active as means for a more reliable scour prediction. Riverbed materials are an important factor in bridge scouring; therefore, an accurate estimation of riverbed material is critical in predicting a scour. As a part of this approach, an ultrasonic sensor, which can not only detect river bottom during floods but can also be installed close to the underwater structures, was developed. This sensor is able to map the river bottom using an ultrasonic waves with the characteristics of the returning wave, reflected from an object or bottom ground. The reflected wave is unique according to the situations, or materials below. Therefore, it would be possible to identify the consisting materials of a riverbed if we could reveal each characteristic in the received signals. In this study, a preliminary experiment was performed in the laboratory to identify and classify received signals, which is unique to each material. The analysis of this experiment gives the graph, which makes it possible to identify materials of the river bottom through the ultrasonic signals. The proposed graph was verified through a comparison with the actual field data measured in river.

Keywords: realtime bridge scour monitoring, ultrasonic sensor, reflective characteristic, riverbed material.

1. INTRODUCTION

Major damage to bridges at river crossing occurs during floods. Damage is caused for various reasons, the main reason being riverbed scour at bridge foundations, namely piers and abutments. The scour processes are complex and subject to many factors (Bruce et al., 2000). Riverbed material is one of the most important bridge scour factors. Therefore, an accurate estimation of riverbed materials is very crucial in predicting a scour. Bridge-scour research, such as erode, vortex, scour, channel beds, and so on, has been studied for many years. However, an experimental study using ultrasonic scour sensor to each riverbed materials have not been completed.

The purpose of this study is to propose a method that can classify riverbed materials using the ultrasonic scour sensor, UDM200. UDM200 sensors are already in use for real-time monitoring in various locations in Korea.

Returning ultrasonic wave contains unique characteristics of a detected target object. Therefore, with the collected wave signals, it is possible to identify the riverbed materials. Moreover, physical difficulties on site are no longer a concern, since the data from the sensor is transmitted through wireless connection.

2. INTRODUCTION TO THE LABORATORY EXPERIMENTS

2.1 Ultrasonic scour sensor: UDM200

Ultrasonic scour sensor, UDM200 was developed for real-time bridge scour monitoring (see figure 1). The sensor sends out signals, or waves, to the bottom of the river and calculates its distance to the bottom using the returning time of the signals. The UDM200 signals are continuous so that the changes on the riverbed and scour depths are updated simultaneously.

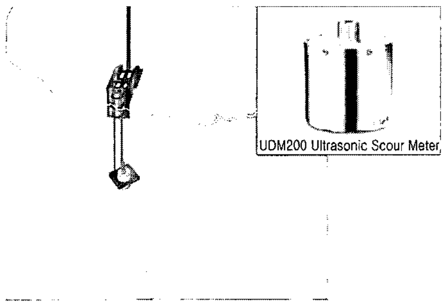


Figure 1. The view of the ultrasonic bridge scour sensor UDM200.

The velocity of the ultrasonic waves underwater is greatly influenced by temperature. The formula to calculate the velocity and the distance is:

$$c=1449+4.59T-0.053T2+0.0163D \qquad (1)$$

$$L=c\times\Delta t/2 \qquad (2)$$

Where,

c= underwater velocity of ultrasonic wave (m/s)

T= temperature (°C)

D= depth (m)

L= distance (m)

The UDM 200 can be used close to the bridge pier because the spreading angle of the beam is small enough to minimize the pier effect and to detect the signal at the point of river bottom. The sensor can measure the distance from 0.6m to 60m with the accuracy of less than 2mm and the resolution of 1mm. This sensor also uses a frequency of 170 kHz, which makes it possible to obtain a detailed data. Table 1 shows a detailed specification of the UDM200.

Table. 1 The specification of UDM200

Operation Range	0.6 ~ 60 m
Accuracy	0.3%(@ FS Range 25℃) or 2mm
Sensor Output	RS485
Resolution	1 mm
Cable Length	Maximum 200 m
Frequency	170 kHz
Beam Angle	7.5°
Power Supply	DC 12 V
Operation Temperature	-30 ℃ ~ 60 ℃

2.2 Materials used in experiments

Laboratory experiments of this study were conducted on materials that can normally be found in the river, such as, sand, gravel, and boulder. Each material was categorized by its size. The diatomite was prepared to imitate the viscous bottom. The sizes of the each material used were:

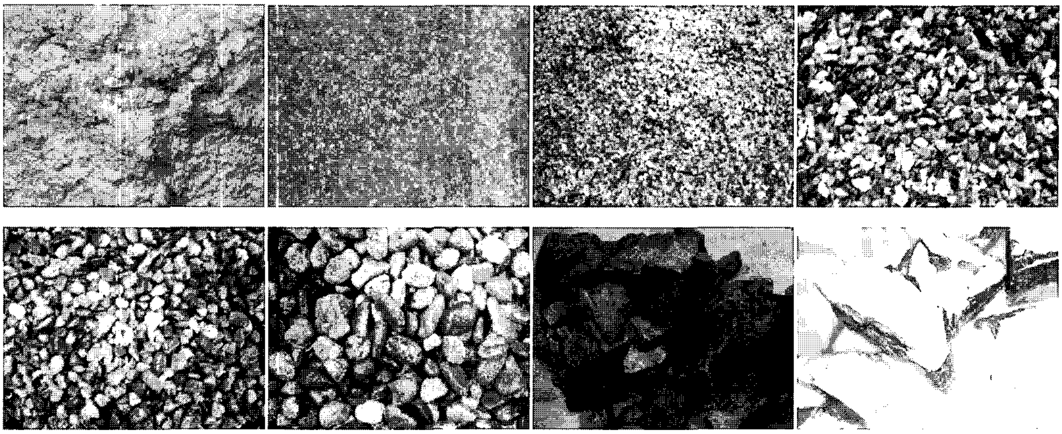


Figure 2. The materials used laboratory experiments.

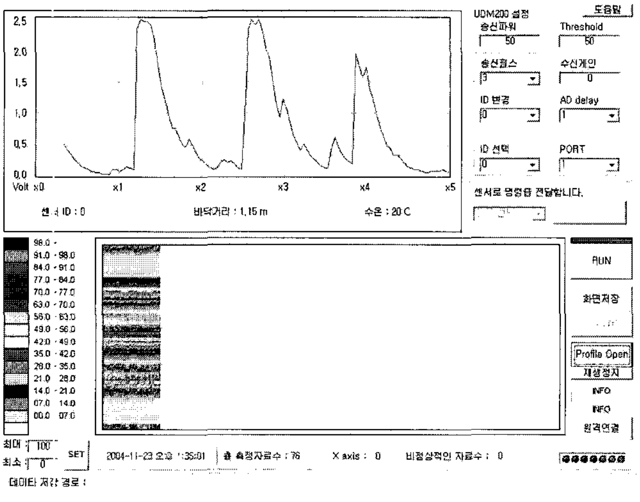
Diatomite: 0.14mm and 0.074mm.
Sand: 0.25mm and 2.5mm
Gravels: 10.0mm and 13.0mm
Boulder: non-specific

Mixed materials of boulder-diatomite and boulder-sand were also used. Figure 2 shows the pictures of the exact materials used in the experiments.

2.3 Sensor (UDM200) control software

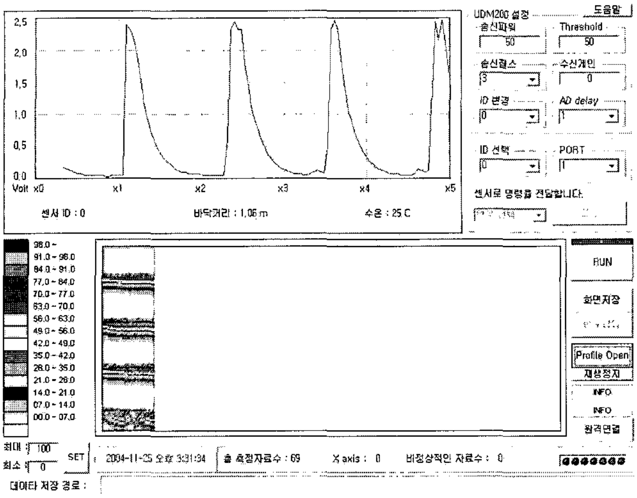
Figure 3 shows acquired data from the reflected ultrasonic waves through the control software. The software is able to analyze the distance to the river bottom and also it can control the UDM200. The distance to the bottom can be found from the first echo on the graph. The graph of figure 3 shows the echo variation in time scale. The vertical axis is the intensity of reflectance and the horizontal axis is the distance to the bottom.

The role of this program is to collect data, calculate distance, and to change the settings of the UDM200 through the wireless control.



송신파워 50
Threshold 50
송신펄스 3
수신게인 0
ID 변경 0
AD delay 1
ID 선택 0
PORT 1
센서로 명령을 전달합니다.
센서 ID : 0
바닥거리 : 1.15 m
수온 : 20C
최대 100
최소 0
2004-11-23 오후 1:35:01
총 측정자료수 : 76
X axis : 0
비정상적인 자료수 : 0
데이타 저장 경로 :

Figure 3(a). The control program of UDM200



UDM200 설정
송신파워 50
Threshold 50
송신펄스 3
수신게인 0
ID 변경 0
AD delay 1
ID 선택 0
PORT 1
센서로 명령을 전달합니다.
센서 ID : 0
바닥거리 : 1.06 m
수온 : 25 C
최대 100
최소 0
2004-11-25 오후 3:31:34
총 측정자료수 : 69
X axis : 0
비정상적인 자료수 : 0
데이타 저장 경로 :

Figure 3(b). The control program of UDM200

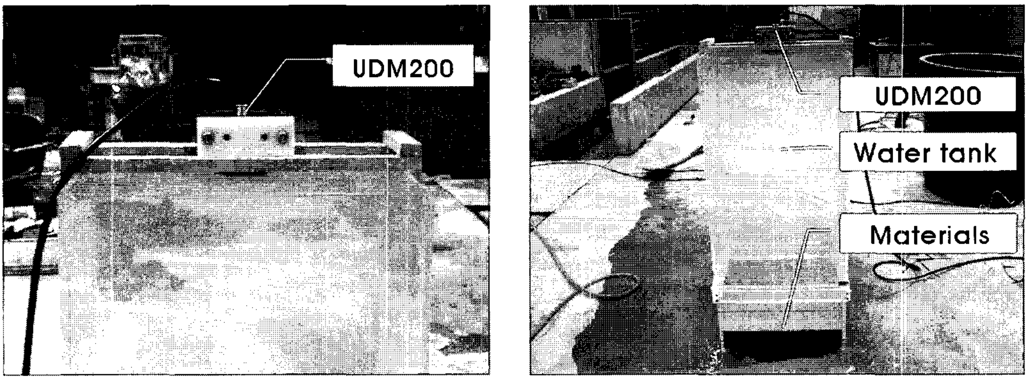


Figure 4. The view of laboratory experiments (Sensor, water tank and materials)

2.4 Water tank used for the experiment

The water tank used for the experiment was made of colorless acrylic. For efficiency purposes, the tank was made 120cm high and 50cm wide because the angle of spread beams of UDM200 is 7.5° while the minimum measurable distance is 60cm. Figure 4 is a view of the laboratory experiment using the water tank.

3. THE LABORATORY EXPERIMENTS

3.1 Preliminary experiments

A preliminary experiment was conducted before the major experiment. If the height of the materials in the water tank is too low, the bottom of the tank may affect the ultrasonic wave due to the wave's properties. Results of the preparatory experiment were used to decide the elevation of the materials for the major experiment.

Figure 3 shows the results of the experiment using 0.25mm sand at the height of 5cm and 15cm. The preliminary experiments were conducted at the height of 1cm, 2cm, 5cm, 10cm, and 15cm. As the graph shows, the ultrasonic wave was not affected at the height of 15cm (figure3 (b)). In figure 3(a), the ultrasonic waves were represented in irregular forms due to the harder bottom than the experiment materials

3.2 Major experiments

Reflective signal echoes slightly vary even if the target materials are the same, and the slight differences also vary from one material to another. Reflective intensities were also varying depend on the material. Laboratory experiments were conducted to reveal this information for each material.

The experiments were conducted through the following methods: first, major experiments were conducted at the material elevation of 15cm, a result from the preparatory experiment. Then, the data was sent from the UDM200 to the control software on the computer with serial port.

Figure 5 graphs the 200 data, collected from the major experiment. The black line shows the average value. The data from the starting point of the first echo to the starting point of the second echo was analyzed. The reflective intensity is the inner area of the black line and the variance is sum of the area, which is equal to the difference between black graph and other graphs. Table 2 lists the values of the reflective intensity and the variance of each material in the major experiment.

Figure 6 shows that the wave's reflective intensity is stronger and its variance is smaller on the flat bottom, which consists of small particles. On the contrary, reflective intensity is weaker and the variance is bigger in irregular bottom, which consists of large particles. The unique location of each material on the graph verifies the possibility of identifying the materials on the riverbed using the UDM200.

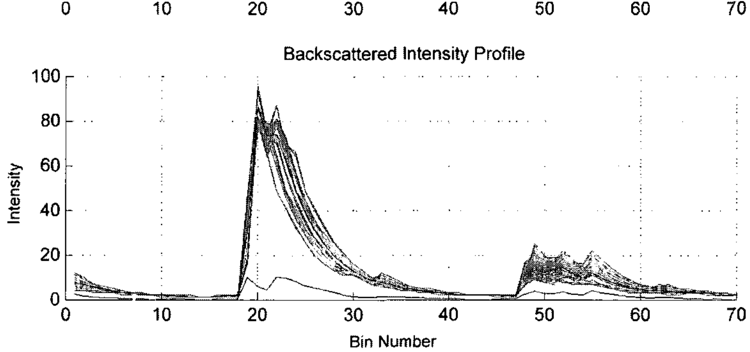


Figure 5 The sum of reflectance and variance versus distance from bed (upper graph) and the intensity of reflected ultrasonic wave versus distance from bed (lower graph)

Table. 2 The values of reflective intensity and variance about each material

	Reflectance	Variance		Reflectance	Variance
bare acryl	1120.5	779.0	gravel 13 (13mm)	337.2	873.5
layer silt (0.14μm)	939.7	348.9	rock	323.7	1078.9
fine sand (0.25mm)	715.2	238.9	gravel 40 (40mm)	215.2	555.2
coarse sand (2.5mm)	578.0	532.3	silty-rock	109.8	81.8
gravel 10 (10mm)	509.2	229.2	sandy-rock	107.7	41.2
silt(0.074mm)	452.1	237.1			

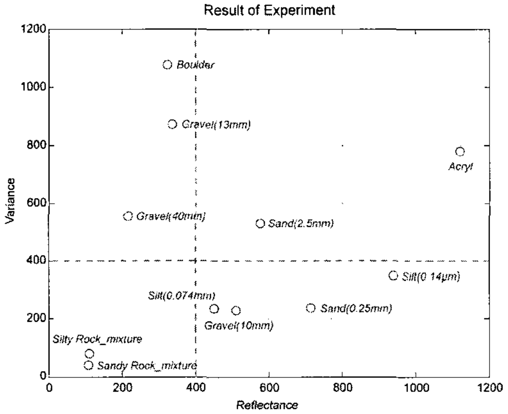


Figure 6. The results of reflective intensity and variance about each material

4. EXPERIMENT RESULTS AND FIELD DATA COMPARISON

The results of the experiments being used in the field were compared with the results from the real field data of the Han river.

The UDM200 has been working at the pier 19 of Mapo Grand Bridge on the Han-river. Fig.8 is the data of Mapo grand bridge during the 2004 flood. Figure 8(a), 8(b), and 8(c) represent the existing field data for before, during and after the flood of 2004. The riverbed materials of Mapo Grand Bridge were consisted of silt and sand and the flow velocity was 0.95m/s during the flood of 2004. This flow velocity is obtained through the flow sensor which is mounted with UDM200 at the pier 19 of the bridge. No significant scour has occurred.

Figure 7 compares the field data and the data from the experiment. Before, during, and after the flood periods are situated in the area of diatomite and sand in the experiment. As shown on the graph, the reflective intensity is lower and its variance is larger before than after the flood. This is possible to analogize some gravel, which is a little bigger than were flowed in by the flood.

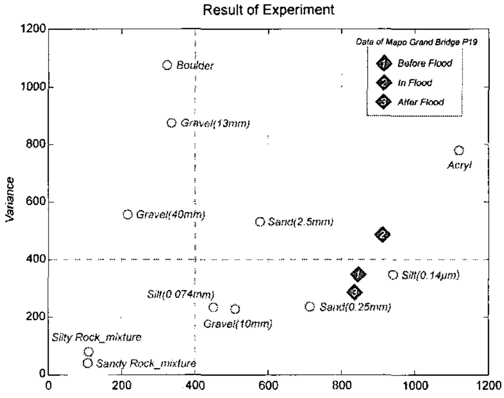
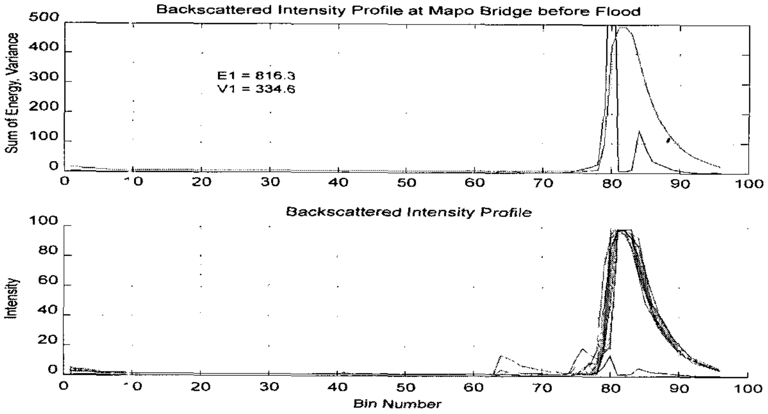
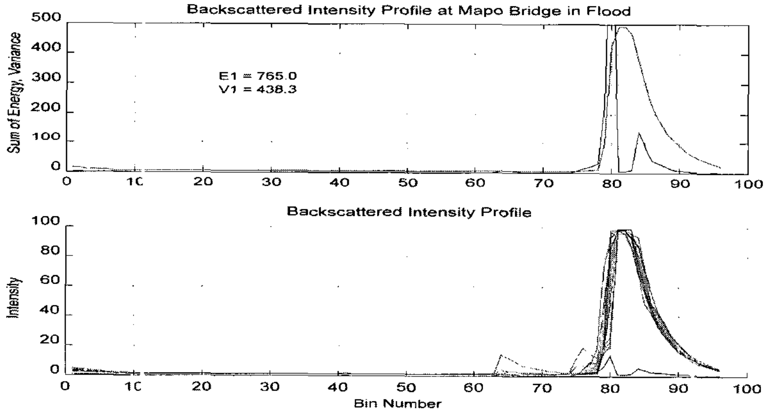


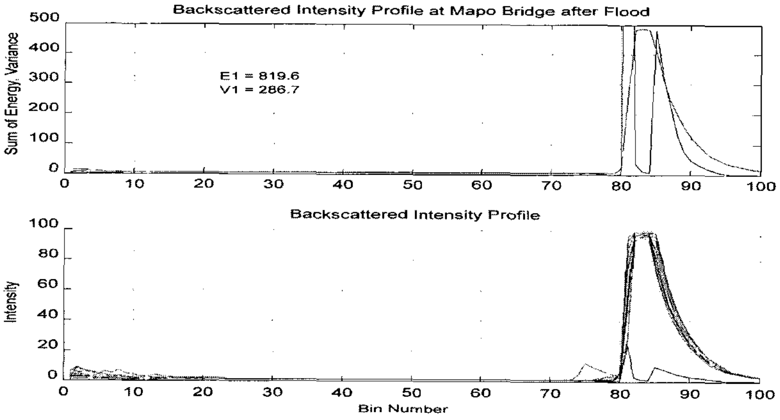
Figure 7. The comparison of the result graph of experiments with the field data



(a) Before



(b) Ongoing



(c) After

Figure 8. The field data of Mapo Grand Bridge on floods in 2004

5. CONCLUSIONS

The laboratory experiments using the UDM200 sensor, which can directly measure the change in the riverbed, was used to identify the type of riverbed materials.

In this study, a laboratory experiment was conducted to identify the received signal characteristics, which were unique depending on the riverbed materials. As a product of this experiment, we proposed a graph (Fig 6 and 7) that is possible to identify the materials of river bottoms through the received ultrasonic signal.

However, additional experiments were necessary under live conditions such as the mixed riverbed materials and the variety flow condition, as the experiments in this study were conducted under clean and rather simplified conditions.

ACKNOWLEDGEMENTS

This research was supported by a grant (Project 1-1-2) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program, and is very much appreciated.

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