Development of an In-Situ Acoustic Scourometer - The SM263

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I. Introduction

During the last decade there has been growing interest in the effects of scour on the safety of bridges in Korea. Expansion of bridge piers and the lack of upstream sediment input as a result of erecting large dams has accelerated the bridge scour process, especially in upstream areas where the failures of several small and medium size bridges are believed to be bridge scour related (Yeo and Kang, 1997). Recently, active development of the coastal areas has brought increased pressure to build coastal bridges such as the SeoHae, YoungJong and KwangAn Grand Bridges. Interestingly, the site of the SeoHae Grand Bridge was not a favorable site on which to build a bridge due to the relatively large tidal motion. Additionally, the tidal flow at the SeoHae Bridge construction site was substantially increased by several coastal construction projects in the area.

Due to strong semi-diurnal tidal activity near the SeoHae Grand Bridge site, scour process were shown to be accelerated. Further, the pile group foundation method made conventional types of bridge scour research approaches inefficient. As a result, the SeoHae Grand Bridge construction agency invited proposals for practical and new technologies to better understand scour at the site. The first thing recommended at advisory board meetings was for 24-hour monitoring of bridge scour processes every day to show whether a clear trend in bridge scouring would be revealed. Thus a device to measure bridge scour processes in turbid and salty water would be needed. Under the circumstances, an acoustic distance meter (depth sounder) was chosen as best suited the purpose of monitoring the bridge scour near the SeoHae Grand Bridge.

One drawback with using an acoustic depth meter for monitoring bridge scour processes for this project is the relatively expensive price and long delivery time since the device had to be purchased from a foreign manufacturer, as such a device was not available domestically. The

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cost of installing foreign products at the 10 bridge piers was estimated to surpass 10,000,000 WON and the grace period to manufacture and deliever the products was estimated to be greater than 3 months. In addition, the technology to use the device and integration of the device into a bridge scour measuring system had not been attempted before. Finally, the authors (Myong-Ji University) decided to develop such a device as part of an integrated system. As a partner in the development of the device, the third author (Shin Chang Co., Ltd) joined the team. Following several re-designs and numerious tests within the two month design cycle, the Scourometer (SM263) was ready. Installation costs of the new device have now been re-estimated to be only 40% of the cost of a foreign bought device.

In the following sections, details of the SM263 will be presented in the least technical terms for easier understanding for non experts. The idea of measuring distances accurately and rapidly in turbid and salty water is discussed in greater detail. Then some discussion of the calibration tests in the laboratory and field are given to assure the reader of the excellent performance and potential of the SM263.

II. Underwater acoustic wave propagation theory

After the second world war, the use of acoustic pulses in underwater conditions were tremendously increased due to both scientific and military interests. The most famous acoustic device is the well known acoustic sonar, employed on every submarine, which is used to detect objects in water. To detect submarines hiding in deep water, a destroyer pings acoustic pulses and listens to abnormal backscattering pulses indicating a hiding submarine. Even though underwater acoustic devices have been widely accepted and deployed for military purposes, there exists many civilian applications of acoustic devices. For a good example, the recent famous movie "Titanic" might not be possible if no acoustic side-scan sonar was available to find the buried sunken ship in the deep ocean and create an interest in people worldwide.

All of the above acoustic devices are based on a simple but important idea. Acoustic waves propogates long distances without much loss of the signal strength and coherence in both fresh and salty water. No other waves have same characteristics, for example Ground Penerating Radar (GPR) uses microwaves but can only penerate fresh and clear water not salty and turbid water. That is the reason that an acoustic distance meter (fathometer, echo sounding devices) are recommended for bridge scour research (Richardson and Price, 1993). Even a GPR device can be used to survery bridge scour depth but its application is limited to only fresh and clear waters which are actually not the most common or interesting periods when scour will occur. The characteristics of acoustic waves come from the fact that the acoustic wave frequency is low compared to other waves. Normally, underwater acoustic devices use frequency bands from a few kHz to a few MHz. But if we compare these to microwaves, the frequency bands are much lower and the acoustic waves propagates well without much loss. Consequently, the frequency determines how far an acoustic wave propagates as well as the resolution of the backscatterred wave information (Kinsler and Frey, 1962)

For bridge scour research the acoustic frequency bands of 200 kHz are used based on the optimization between the propagation distance and the resolution of the backscatterred wave information (Landers et al., 1993). This frequency band gives an accuracy of a centimeter in natural bottom condition but can propagate more than a hundred meters (Lee and Yeo, 1998). The basic mechanism of an underwater distance meter, fathometer or altimeter are similar. An acoustic source is generated by electric excitation of a piezo-electric material. This physical vibration of the material radiates an acoustic pulse into the water and also receives the backscatterred acoustic signal as it returns from the bottom. The signal which arrive are converted into electric pulses by the same transducer. If we measure the time of the outgoing and the incoming pulses accurately enough, we can calculate the total time of travel from the transducer's lens-face to the bottom because it is the half of total time of travel. Mathematically it is written as

$$L = c \times \Delta t / 2$$

where L is the distance to the bottom, c is the acoustic wave speed in water, Δt is the total time of travel. The acoustic wave speed, c, is fairly close to the contant value of 1500 m/s in natural water but varies a little depending on a few parameters, especially the temperature of water (T) as follows

$$c = 1449 + 4.59\,T - 0.053\,T^2 + 0.0163\,D$$

where D is the depth in meters (Loeser, 1992).

III. Hardware design of the 263 kHz acoustic scourometer (SM263)

The background theory of an acoustic distance meter is very simple as explained above but the manufacturing of such a product is not an easy task. The first thing is to design a nice piezo-electric acoustic transducer. This requires very skillful manufacturing techniques and long test hours to obtain the best performance in the given material and shape. The SM263 uses a polyurethane material and round shape transducer which has a diameter of 59 mm. The transducer impedance was checked carefully to get the best response and then a 263 kHz driving frequency was chosen from the test results.

The second step is to design a circuit to drive the transducer. The on-board micro-processor generates 263 kHz standard TTL signals, the drive circuit generates high-voltage pulses to excite the transducer. Because returning signals from the bottom are very weak, an amplification circuit is needed to boost the return signal up to a normal TTL signal. Normally the amplification factor is 800 times for the SM263 transducer. The third step is a filtering procedure to clean up the return signal mixed with other noise. A 263 kHz center-frequncy, band-pass filter was designed and implemented.

Through whole procedure signals showing the propagation history of the acoustic pulses are prepared. The next step is to detect the moment of reflection from the bottom in the signal by comparing the return signal to a given threshold condition. If the return signal is stronger than the threshold condition, the moment is believed to be a bottom hitting moment signal and then the total time of travel can be estimated by substracting the time at which the outgoing pulse occurs.

Usually the threshold condition requires an empirical tunning procedure in real field situations and the SM263 was tuned many times to find the best threshold condition. Finally, the estimated time to bottom is relayed to the RS-485 port for communication to a host computer. Figure 3.1 shows a block diagram of hardware functions of SM263.

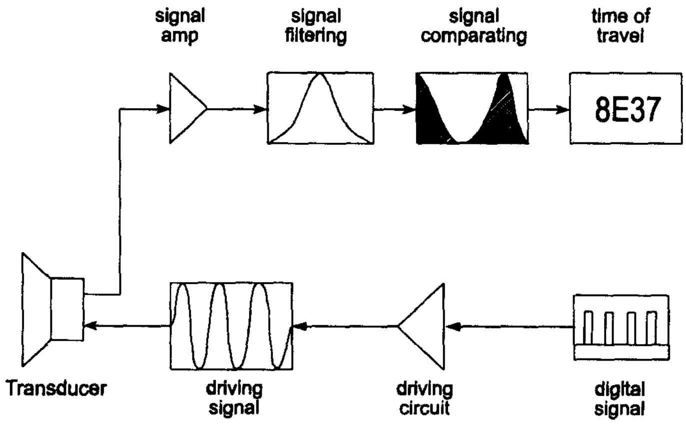

Figure 3.1 Block diagrams of hardware functions of SM263.

IV. Software design of SM263

The SM263 is not designed solely for bridge scour research. It is a very versatile and useful underwater distance meter which can be used in any marine operation. The on-board PIC micro-processor controls whole sensing operation under the commands given by a external host computer. Through a simple RS485-RS232 converter, up to 16 SM263's can be connected to an external computer. Therefore, a single external host can log all the results from 16 SM263 scourometers on a series of different bridge piers. The complete system of several SM263's with a single hosts can be individually configured for any bridge design, since each device has its own unique ID numbers and communicates with the host computer with this ID.

The on-board software program in the SM263 also has a lot of convenient functions for versatile control of the SM263. Status byte checks facilitate the routine check of current status and the quarter-second continuous sampling mode makes it possible to use the SM263 for navigation, sampling and surverying uses. A sleep-mode implementation saves battery power for long term deployments and a bulk dumping of output mode gives an idea about the real strength of the returned signals which may be interpreted as a bottom material classification. Also, the 9600 baud high speed serial communication provides muti-channel sampling at sub-second intervals. This high sampling speed is very beneficial for studying bridge scour processes due to turbulence which is a high frequency natural process and is very hard to measure using conventional devices. In addition, the control program of the PIC micro-processor was all written using assembly language which results in a high timing accuracy of within the SM263. Thus the accuracy of distance measurements is as high as 1.5 mm in laboratory tests.

V. Calibration and test runs of the SM263

Calibration runs of the SM263 were held frequently in the Myong-Ji University Hydraulic Laboratory's water tank. The tank dimensions are 3 m × 1 m × 1 m. The SM263 was placed at the 2.78 m position from the side of the tank and operated continuously. The water temperature was 13℃, and therefore the acoustic wave speed was set to 1500 m/s. The measured result was determined to be exactly 2.78 m and it stayed same value until the power was terminated. Figure 5.1 shows a sequence of 100 distance measurements during a calibration run.

Test runs of the SM263 were also held at the SeoHae Grand Bridge construction site. At Pier 58, 4 SM263's were installed and operated for three days continuously. The distance from the lens-face to the bottom was estimated to be 9.95 m and it matched a staff gage measurement exactly.

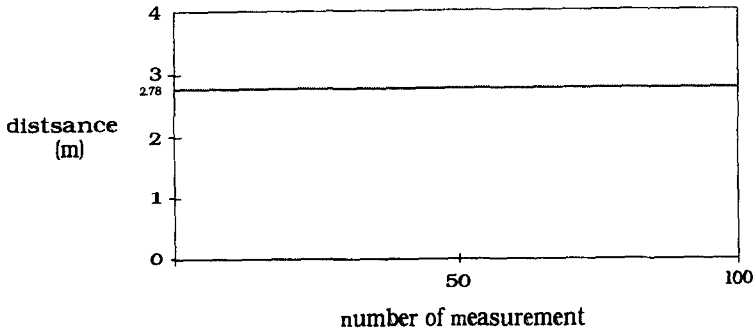

Figure 5.1 Distance estimation of a calibration run

VI. Conclusions

A newly developed scourometer (SM263) has been shown to be an excellent tool for measuring bridge scour depth in real field conditions and the accuracy is more than sufficient for studying bridge scour processes. All techniques to manufacture the SM263 were developed by the Myong-Ji University and Shin Chang Co., Ltd team. Thus it was possible to reduce the cost of a scourometer to less than 40% of comparable systems from foreign manufacturers. Because an acoustic device is best suited for bridge scour research, the SM263 is expected to be used in many field bridge scour research experiments which have very different flow conditions compared with scaled laboratory model tests. Considering the present domestic economic situation, the SM263 will hopefully provide a boost to the domestic bridge scour research community which has difficulty with the high cost of buying foreign products and obtaining technical support from foreign manufacturers.

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