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A new type of temperature-based sensor for monitoring of bridge scour

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ABSTRACT

This paper introduces a sensor measuring the scour depth around the bridge based on the theory of heat conduction. The heat dissipation rate is different in different, heat losses faster in water environment than that in soil environment. Therefore, the position of mud surface can be judged by measuring the temperature change of the sensor in underwater environment. The sensor consists of a stainless steel cuboid shell, a heating piece and two probes of temperature sensor. The continuous power supply to the heating piece can make it heated, and the temperature statistics of two probes of temperature sensor is continuously measured during this process. Meanwhile, the temperature time-history curve in different environment can be drawn. The quantitative indicators K_e and R^2 using for judging environment can be obtained by fitting the curve. The environment can be judged according to the environment coefficient K_e and the coefficient of determination R^2. Also, the scour depth can be obtained. The laboratory experiment has proved that this sensor can distinguish environments such as air, flowing air, soil, sand, mud, water and flowing water.

1. Introduction

Scour is one of the important reasons causing the bridge failures. The scour by flowing water to the bridge pile foundation makes the foundation around the pier gradually eroded. The pier usually obstructs the water, causing the water flowing too fast and the whirlpool emerging. The foundation of the bridge pier is eroded, leaving the bridge unsafe [1–4]. Statistics show that 60% of the collapse accidents of bridge in U.S. in recent 30 years are caused by the damage of bridge scour. The safety issue caused by water scour gradually arises people's attention [5–9]. The monitoring of structure scour has become an important task of bridge health monitoring.

Up to now, many techniques and methodologies have been proposed to monitor bridge scour and measure the scour depth at bridge piers, such as sonar, radar, time-domain reflectometry (TDR), sliding collar and FBG [10–15]. However, most of these available techniques have limited applications. For example, the results of sonar and radar techniques often contain much noise and are difficult to interpret. The sonar signal suffers from attenuation and noise and signal patterns are often complex. In addition, they are not reliable for real-time monitoring of bridge scour. The TDR technique achieves scour monitoring by generating an electromagnetic pulse and coupling it to a transmission line. It suffers problems such as loss of TDR signal and noise of the electromagnetic environment and it's not applicable when water contains salt. The sliding collar method can effectively measure the scour depth but requires reinstallation after each measurement. The FBG method is still limited by the FBG sensors and the spatial resolution is dependent on the number of FBG sensor,

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this may limit its application, and the sensor's readings are significantly influenced by static water and soil pressures, both of which increase with foundation depth [16,17]. What's more, The optical Fiber Bragg Grating meets the needs quite well. Francesco Ballio and others used optical fiber sensing technology to determine the depth of river bed: The equipment emits infrared through fiber probe and the light travels to the river bed then reflects back to the fiber. Finally the equipment receives the light and analyses it so that the depth can be determined. This technology only does the indoor stimulating experiment. It is hard to adjust to the intricate underwater environment due to the outside disturbance and limitation of riverbed terrain [18]. In 2004, Y. B. Lin devised a kind of local scour monitoring sensor based on optical FBG, which employs a cantilevered plate to measure the variation of scour depth. However, the sensor could not exclude the influences of soil pressure and static water pressure varying with the depth [19,20]. An 80 mm resolution is also coarse Relative to gravel particle sizes. Of the non-time-recording devises available, plastic practice golf ball scour monitors have proven to be practical and to measure scour depth reliably to a resolution of approximately 40 mm. These devises can also be applied in large numbers to provide meaningful information on spatial distributions of scour. It is impossible, however, to identify visually the time that an indicator ball is mobilized during a flood because the water is too turbid for remote observation from the bank and too dangerous for the observer to enter [21]. In addition, Chung-Yue Wang et al., devised an upgraded piezoelectric film type scour sensor and a real-time monitoring system for bridge piers [22]. The core idea of developing this scouring sensing system is based on the physical characteristic that output voltage can be generated as the piezoelectric film is deformed by the flowing media. A laboratory experiment had been conducted to evaluate the sensing ability of piezoelectric film under water flow in a flume. The laboratory data shows that the piezoelectric film type sensor is an effective way to identify the interface change between water and sediment. When there is no wind, however, is difficult to distinguish between air and soil.

This paper designs a sensor used for measuring the scour depth around the bridge. The working principle is to use the difference of speed of heat dissipation rate in water and soil. The speed of the heat dissipation rate of the environment which sensor is in can distinguish water from soil. The existing fiber grating sensor takes the grating wavelength as the media, and senses the external physical changes through the wavelength variations. It is vulnerable to the underwater environment and the soil transportation which results in inaccurate monitoring and high cost. In contrast, the sensor mentioned in this article is researched and developed based on the principle of heat conduction, The measurement results is only related with the external environment media, and its accuracy can be adjusted according to the specific requirements with low cost. Therefore, The sensor is of high accuracy and good durability. It will not be disturbed by the underwater turbulence and soil transportation. The sensor also has the function of remote automatic real-time monitoring of underwater scour.

2. Working principle of the sensor

Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams and from around the piers and abutments of bridges [23]. The water flowing to the bridge when obstructed by the pier, will change its structure rapidly. The flow around of flowing water makes the flow line rapidly bend, and the whirlpool nearby the surface of river bed incaves the waterward end of the pier and sediment around the pier. This leaves the bridge in an unsafe state (Shown in Fig. 1(a)).

As shown in Fig. 1(b), the sensors are placed on the bridge foundation in equidistance, ensuring that one part is beneath the mud surface and another part above. By measuring the sensor and judging the environment media, the depth and position of water-soil interface can be obtained.

The sensor is designed based on the theory of heat conduction: The heat conduction is a process which massive molecules of matter impact during the thermal motion, so that the energy can be passed from the high-temperature part of the matter to the low-temperature

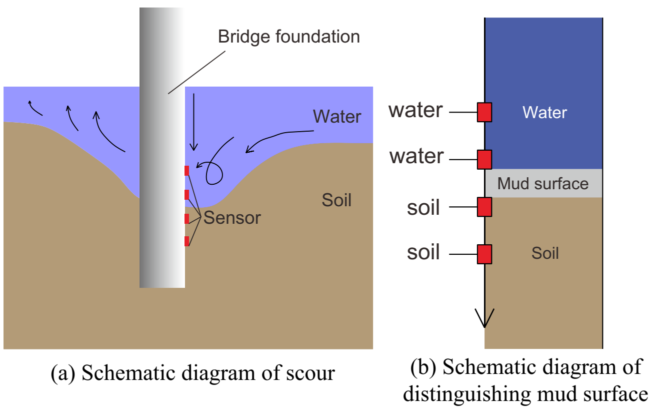

Fig. 1. Working principle of sensor.