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REAL-TIME BRIDGE SCOUR MONITORING SYSTEM BY USING CAPACITOR SENSOR

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ABSTRACT

Scour is the erosion of stream bed or bank material from bridge foundations due to flowing of water. Data logging from sensor and electronic communication systems can monitor scour in real-time to ensure the integrity of bridge structure. A number of parameters are associated with scour, thus different types of sensor are required to measure the individual affecting factor. A simple capacitive type direct scour sensor system is proposed and validated by simulation. The result shows that any change of the river bed dielectric property is a direct indication of scour. Due to simple capacitive structure of the sensor system, it is highly robust and easy to implement. The system can easily be implemented with an existing bridge structure. A wireless telemetry system can be used to send the real-time data from the proposed sensor to a desktop computer at the monitoring lab.

Keywords: Scour, Bridge Monitoring, River Bed Erosion, Capacitor Sensor

INTRODUCTION

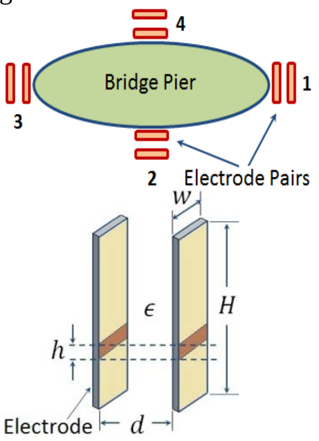
Bridge scour is the meaning of removal of soil, sand and rocks from around a bridge supports or piers as shown in Fig. 1. Rapidly moving water can wash out the river bed materials and make scour holes, compromise the existence of a bridge structure [1]. Scour happens under the water and it is hard to see by naked eye. As a result, every year a number of bridges are collapsed all over the world which causes a lot of financial and life loses. The three main reasons of bridge failure are collision, overloading and scour. It has been estimated that 60% of all bridge failures is happened due to scour and other hydraulic-related causes [2]. Score is a complex natural occurrence and a number of parameters are associated with it. Hence to predict the bridge failures and real time scour monitoring, different types of sensor are required to measure the individual affecting factor [3], [4]. Among them sonar altimeter can be used to measure the distance between sensor and river bottom [5]. A change in distance-to-bottom is an indication of scour. Non-contract radar water level sensor can be used to measure the water level across a wide temperature range and varying water surface conditions [6]. Ultrasonic water velocity sensor and side-looking acoustic Doppler current meter can be used to measure bidirectional velocity of the water. The sensors read all the parameters including scouring, water levels and water flow velocity. These sensors reading is transferred to a computer through wire or wireless communication systems. The reading is programmed to give an early warning to the monitor. These sensors are generally selected and arranged based on local weather conditions, climate change effect, natural hazards and environmental conditions. Most of these type sensors are complex and very expensive. The dielectric property of different materials such as pure water is 80, dry soil is 5-8 and mud is 30-65. This dielectric property can be used to measure the scour.

A bridge scouring real-time monitoring system [7] can provide a comprehensive, instant and functional monitoring platform to monitor the safety of the bridge. It will reduce the costs of physical monitoring and bridge maintenance. Mobile communications can be used to transmit relevant information to bridge maintenance and management units and users when a bridge would be potentially damaged by manmade or natural disasters. The instant conveying of information will allow the bridge management unit to implement instant disaster rescue measures and to notify users to avoid dangerous situation that can protect people's lives and properties.

Fig.1 Bridge scour [1]

DEVELOPMENT OF CAPACITOR SENSORS

Design and development of capacitor sensors for measuring the parameters, which are related with the bridge scouring, is a challenging issue. 4 to 6 pairs of separate water-resist metal flat bar electrodes surroundings each of the bridge piers can be used to measure the scour. The electrodes are piled vertically under the river bed and each pair of electrode act as a parallel plate capacitor as shown in Fig. 2. Since the dielectric constant of the water is higher than the dielectric constant of the soil and mud, any amount of soil when washout between the electrodes, increases the capacitance. By measuring the capacitance of individual pair of electrode can give a direct measurement of scouring.



(a) (b)

Fig.2 (a) Cross sectional top view of bridge pier and electrodes arrangement, (b) Enlarge view of a single electrode pair

If the dielectric constant ϵ between each electrode pair is considered as constant then the total capacitance of electrode pair can be represented as:

$$C_T = \frac{\epsilon w H}{d} \tag{1}$$

When any scour hole is occurred surrounding the bridge pier, the dielectric constant all over the space between the electrode pair is no longer remained constant. If the electrode pair is divided into n numbers of vertical strips and the dielectric constant between each of the small h strip is considered as a constant then the total capacitance of each electrode pair can be calculated as follows:

$$C_T = \frac{\epsilon_1 w h_1}{d} + \frac{\epsilon_2 w h_2}{d} + \dots \dots \dots + \frac{\epsilon_n w h_n}{d} \tag{2}$$

or, $$C_T = \frac{w}{d}\sum_{i=1}^{n} \epsilon_i h_i \tag{3}$$

Here, $H = h_1 + h_2 + \dots \dots \dots + h_n$ and $\epsilon_1, \epsilon_2, \dots \dots \dots \epsilon_n$ are the dielectric constant of each segments respectively.

The change of dielectric constant at any segment is the result of change of total capacitance of the electrodes. In normal situation the electrode capacitance will be remained constant over a long period of time. An AC Wien bridge oscillator circuit (Fig. 3) can be used to measure the electrodes capacitance change. The frequency of oscillation of the Wien bridge oscillator is determined by Eq. (4).

$$f = \frac{1}{2\pi\sqrt{R_3 R_4 C_{Ref} C_{ELECT}}} \tag{4}$$

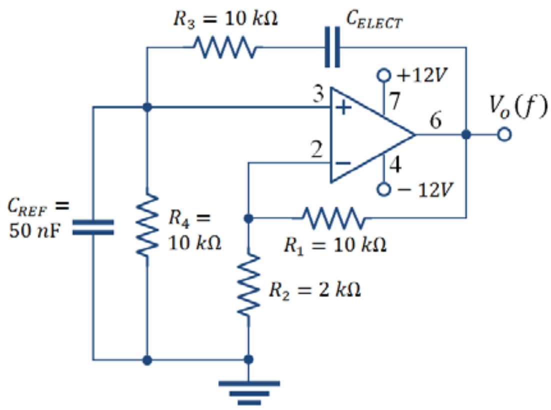


Fig. 3 A basic Wien bridge oscillator circuit

For a particular circuit, the values of resistors R_3, R_4 and the reference capacitor C_{REF} are generally kept constant. Therefore, the Wien bridge oscillator circuit's frequency is inversely proportional to the squire root of the electrode capacitance and the relation can be represented by Eq. (5)

$$f \propto \frac{1}{\sqrt{C_{ELECT}}} \tag{5}$$

Eq. (5) indicates the frequency becomes low when the electrode's capacitance C_{ELECT} increases and it can be happened if there is a scouring. The important thing is that in this case, no need to measure the absolute value of the electrode's capacitance; it can directly show that the change of frequency means there is a scouring.

RESULT AND DISCUSSION

A PSPICE simulation is studied for the proposed bridge scour monitoring system and the result is shown in Fig. 4.

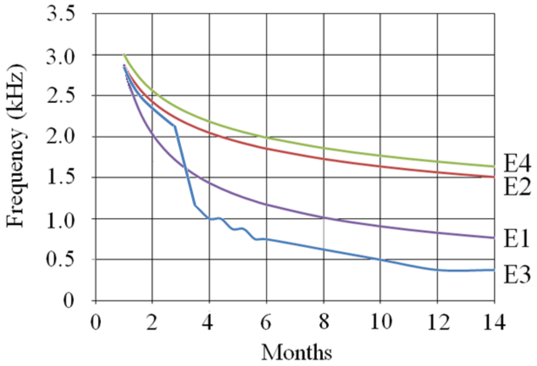


Fig. 4 Variation of frequency with change of electrode capacitance

In this simulation, it is considered that the river water stream direction is from electrode 1 to electrode 3 (Fig. 1). From Fig. 4, it is found that there is a slow scouring effect at the beginning, but near about third month, there is an abrupt change of frequency (low frequency) observed related with the electrode number 3. It means a huge scour is suddenly occurred at this bridge pier.

CONCLUSION

A capacitor type sensor with an oscillator can be used for bridge scour monitoring system. The change of frequency of the oscillator is a direct indication of the scour and it does no need to measure the exact value of sensor capacitor. This principle may help to develop a simple and low cost real-time bridge scour monitoring system.

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