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Dissolved Oxygen Sensors for Scour Monitoring

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***Abstract*—Scour, or the removal of supporting bed material by currents and waves, can jeopardize the stability of river and marine structures. A novel scour sensing scheme is proposed whereby an array of miniature dissolved oxygen (DO) probes detects scour depths. While buried, the probes detect minimal DO levels. Scour exposes the sensors to flowing water, causing a significant rise in the detected DO. The proposed sensing scheme was validated through small-scale experiments in a flume.**

***Index Terms*—Dissolved Oxygen, Scour, Structural Health Monitoring, Substructure**

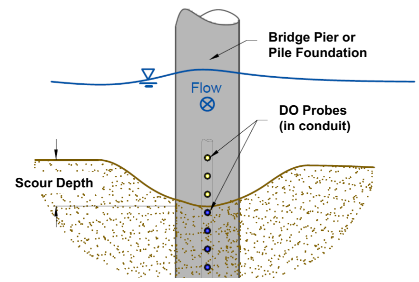

Fig. 1. A schematic of the scour sensing scheme using DO probes is shown.

I. Introduction

SCOUR is the erosion of bed material from around the supports of a structure by flowing water. Structures such as bridges, pipelines, and offshore wind turbines are prone to scour-induced damage and failure. Bridge scour, specifically, has received much attention due to the prevalence of scour-induced of overwater bridges failures [1]-[3]. Several scour sensors have been developed over the years, such as sonar, float-out devices, tilt meters, and piezoelectric sensors [3]-[5]. Ongoing research aims to develop sensors that may resolve current shortcomings, such as high costs, vulnerability to debris, installation difficulties, and signal interpretation complexities [4], [5].

The scour sensing system introduced in this paper uses miniature dissolved oxygen (DO) probes. DO levels acquired from probes installed at multiple depths along the buried length of the structure are used to obtain discrete measurements of the maximum scour depth (Fig. 1). Buried probes detect minimal DO levels. The measured DO increases significantly once scour exposes the sensing tip of the probes to flowing water. Therefore, scour depths can be deduced from the elevations and responses of the DO probes. In the field, the probes will be secured inside a vertical pipe support which can be installed in the streambed by driving, jetting, or other techniques used for installing similar scour sensing devices involving driven/buried rods [3]. In this study, the sensing concept behind this scour monitoring scheme was examined and confirmed through small-scale laboratory experiments.

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II. Experimental Details

Scour experiments were performed in a flume, where a vertical array of four probes was installed along the length of a cylinder acting as a pier or pile. The DO sensors used in these experiments were fiber optic oxygen dipping probes (from PreSens Precision Sensing GmbH) and were only 4 mm in diameter. For a detailed description of the probes and the experimental setup, refer to [6]. Three rounds of scour tests were conducted with different bed materials and probe elevations. DO was recorded at a rate of 0.2 Hz using a four-channel fiber optic oxygen transmitter data acquisition system (OXY-4 mini from PreSens).

III. Results and Discussion

In the first round of experiments, clean sand was used as the bed material, and the DO sensors, namely S1, S2, S3, and S4, were installed at 2, 4, 6, and 8 cm below the initial bed level, respectively. Before covering the probes with sand, they all exhibited DO levels of ~8.36 mg/L, which corresponded to the water DO level at the time of testing. The sensors were then covered, and flow was initiated at a very low velocity (<0.1 m/s). The DO levels dropped to 8.2, 8.18, 8.13, and 8.05 mg/L at S1, S2, S3, and S4, respectively. After 10 min, flow velocity was increased to induce scour. The jump in DO levels and the emergence of each sensing tip from below the sediments were almost simultaneous (Fig. 2). The sensing tip of S4 was not exposed, but by the time scour was stopped at ~5 min, S4 was less than 1 cm below the soil level, which was why the DO levels at S4 increased slightly but did not reach the water DO

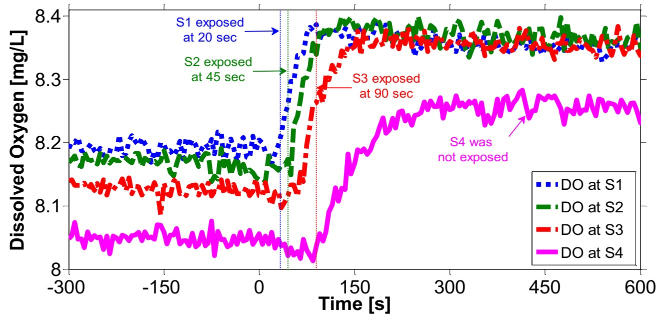

Fig. 2. Results from test conducted using clean sand are shown. The DO probes were located at 2, 4, 6, and 8 cm below the bed surface.

level. Thus, the sensing concept was confirmed.

However, the fact that embedded DO values were still fairly close to the water DO did not represent anticipated conditions in the field, where the probes would be installed at deeper elevations (*e.g.*, ~50 cm apart) with negligible DO levels. To account for this scaling effect, two subsequent tests were conducted where the highly permeable clean sand was mixed with 35% or 50% ground silica. The resulting bed material had lower permeability and shallower oxygen penetration depths. In addition, DO probes were mounted deeper, namely, at 5, 9, 11, and 20 cm below the initial bed level.

The results from the experiment with 35% silica are shown in Fig. 3. In preparation for this test, the setup remained latent overnight with water flowing at a very low velocity so as to prevent scour. DO levels at all sensors had dropped to below 0.05 mg/L before starting the scour experiments. DO signals were unaffected while the probes were buried, but they increased to water DO levels once scour removed the sediments and exposed the sensor tips to flowing water. The jump in DO at S3 was slightly more gradual than that of S1 (at 4 min) and S2 (at 25 min), because the rate of scour decreased with time, and therefore, S3 went through a series of partial soil removal and refill until it was finally exposed at 53 min.

Fig. 4 presents the results from the test with 50% silica. In this experiment, scour conditions were initiated 3 h after setup; therefore, the DO levels did not have enough time to drop to their minimum prior to scour. The DO scour sensing concept was once again confirmed; DO levels at S1, S2, and S3 soared as soon as the probe tips were exposed at 4.5, 24, and 71 min, respectively, while DO at S4 remained unaffected

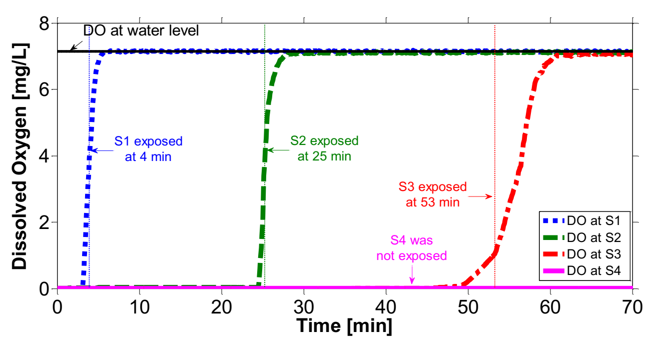

Fig. 3. Results from test conducted using "65% clean sand + 35% silica". The DO probes were located at 5, 9, 11, and 20 cm below the bed surface.

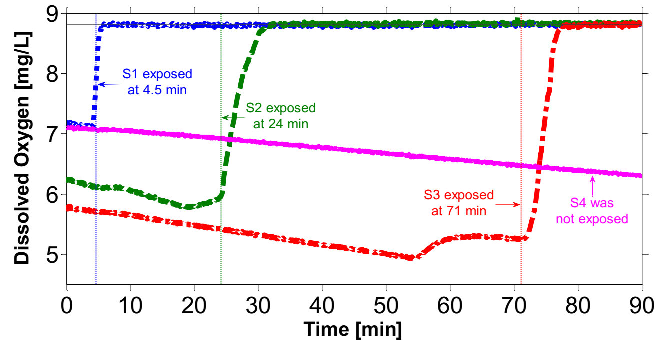

Fig. 4. Results from test conducted using "50% clean sand + 50% silica" are shown. The DO probes were at 5, 9, 11, and 20 cm below the bed surface.

as the probe remained buried throughout the test. This experiment also revealed a few other noteworthy points. First, DO levels kept decreasing during the test while the sensors were buried, even though the water flow velocity was increased to 0.35 m/s. Second, while S1, S2, and S3 had initial DO levels corresponding to their depth (*i.e.*, lower DO at lower elevations), DO values at S4 were initially close to that of S1. This may be due to inadequate soil compaction and the existence of a cavity close to the sensor tip. Nevertheless, these issues did not affect the scour sensing concept.

IV. Conclusions

DO measurements can provide a direct binary indication of scour depth. Unlike float-out devices, which become inoperable after a single scour event, DO probes can detect subsequent backfill and scour episodes. DO probes are mechanically robust, and, because of their small size, they are less susceptible to debris and do not interfere with the performance of the host structure. However, since DO is temperature dependent, field applications may require an additional reference DO probe above the soil level or auxiliary temperature measurements. The effects of biofouling, water turbidity, turbulence, and biological activity on the DO scour-sensing concept should also be examined in future research and field investigations.

References

[1] J. Hong, Y. Chiew, J. Lu, J. Lai, and Y. Lin, "Houfeng bridge failure in Taiwan," *Journal of Hydraulic Engineering*, vol. 138, pp. 186-198, 2012.

[2] B. W. Melville and S. E. Coleman, *Bridge scour*, Water Resources Publication, 2000.

[3] P. F. Lagasse, *Instrumentation for measuring scour at bridge piers and abutments*, No. 396, Transportation Research Board, 1997.

[4] L. J. Prendergast and K. Gavin, "A review of bridge scour monitoring techniques," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 6, pp. 138-149, 2014.

[5] L. Deng and C. Cai, "Bridge scour: prediction, modeling, monitoring, and countermeasures—review," *Practice Periodical on Structural Design and Construction*, vol. 15, pp. 125-134, 2010.

[6] F. Azhari, P. Scheel, and K. J. Loh, "Monitoring Bridge Scour using Dissolved Oxygen Probes," *Structural Monitoring and Maintenance*, vol. 2, pp. 145-164, 2015.