DEMONSTRATION OF ELECTRICAL CONDUCTANCE DEPTH PROBES FOR WAVE HEIGHT MONITORING

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ABSTRACT

The School of Civil and Environmental Engineering at the University of Adelaide has conducted many coastal and beach erosion studies over the years. This continues at the present time with a post graduate study of beach sand patterns produced by wave action. In most of these studies, scale models of each site were constructed, and the wave action monitored by an array of depth probes connected to a data logging computer. The depth probes were designed and built inhouse and consisted essentially of two parallel stainless steel wires held in place by plastic spacers. They work on the principle that water will conduct an electrical current according to the concentration of the dissolved solids in the water, the temperature of the water, the spacing between the wires and the diameter of the wires. Most of these are fixed by the probe construction. Therefore, the conductance of the probes is a function of the depth that the probe wires are immersed in the water, enabling the wave height to be measured. An array of only 4 probes will be used in this demonstration where a personal computer equipped with a commercial data acquisition package will be used to display the wave data.

1. INTRODUCTION

In recent times, computer based mathematical models have been developed to assist engineers with the design of coastal construction projects such as marinas. However in some cases, scaled model studies are also required to verify the results because of uncertainties with some of the assumptions used within the mathematical models. An array of wave height sensors can be used with the scaled models to obtain the necessary data for the verification. However, since a large number of these height sensors are usually required, their unit cost must be kept low in order to keep the project costs under control. Electrical conductance probes are simply and cheap to construct, but have some inherent problems. However, when used under controlled laboratory conditions, together with a personal computer equipped with a modern data acquisition package, they have proved to be a very cost effective measuring instrument for wave heights.

2. WATER CONDUCTANCE PROBES

Water conductance probes are simple to construct and consist of two parallel stainless steel wires held in place at the bottom and top by plastic spaces. These are variations of probes previously constructed in the School for use in projects by final year engineering students, who carried out many different tests to evaluate their accuracy and to prove their worth.

2.1 Principle of Operation

The probes work because water containing dissolved solids (such as salt) will conduct an electric current according to the concentration of dissolved solids in the water, the diameter of the wires, the spacing between the wires, and the distance that the wires are emersed into the water. Given that the diameter of the wires and the spacing is fixed by the construction of the probes, the electric current through the probe wires will be proportional to the length that the wires are covered with water and the electrical conductance of the water.

2.2 Problems and Sources of Error

The transfer function of the probe will change in proportion to the electrical conductance of the water. Water temperature will also influence the electrical conductance because a change in temperature of about 5 degrees Celsius will change the electrical conductance of the water and the transfer function of the probe by about 10%.

Further errors may result from the dynamic action of the wave as it passes across the probe. Insufficient wetting of the wires at the wave crest, and water hang on at the wave trough will result in a lower output signal than should be expected. Since the probes are essentially two parallel wires spaced a short distance apart, the wave action could potentially alter the spacing between these wires, and change the transfer function. Another source of error could be caused by the fouling of the wires with grease or dirt. When two or more probes are positioned on the grid in close proximity to each other, there is the potential for interference errors to occur. In other words, the output signal from one probe could be changed by the wave action on an adjacent probe.

All the above are potential sources of error and must be addressed if accuracy is to be kept at an acceptable level.

2.3 Student Project Error Management

Previous student tests proved that the dissolved solids concentration in the water varied a negligible amount during the duration of the scaled model tests. Some leaching of salts out of the mortar used to built the model could have occurred but was not detected. The reason for this was probably due to the relatively large body of water in relation to the small model size.

Daily ambient air temperature variations rarely changed the water temperature in the model by more than two degrees, and in turn the electrical conductivity by more then five percent. For most of the student projects, this amount of error was acceptable, and in some cases, probe calibration was only carried out at the beginning of a series of tests, and not every day.

Probe fouling was not a problem during any of the student projects because the water was always relatively clean. However, scale did form on some of the probe wires during storage, requiring them to be washed with detergent before they were used again. Some corrosion on the fittings was also detected, but this would not effect probe accuracy.

Questions were asked early in the development of these probes about their ability to accurately follow the crests and troughs of the water wave. This resulted in one student group designing and running an experiment to assess the probe's ability to accurately follow the wave shape. Figure 1 is a simplified diagram of the set up that the students used. The hydraulic ram drove the rod, pivoted at one end by a hinge, while the probe under test was attached to the other end of the rod and allowed to move up and down in the water container. This arrangement was necessary in order to extend the measuring range of the probe, because the ram displacement was limited. The output from the displacement sensor, which was incorporated into the ram, was compared with the output of the wave probe over a range of frequencies from 0.7 Hz to 1.4 Hz. At these frequencies, the agreement between the probe and the ram was within 1.5%.

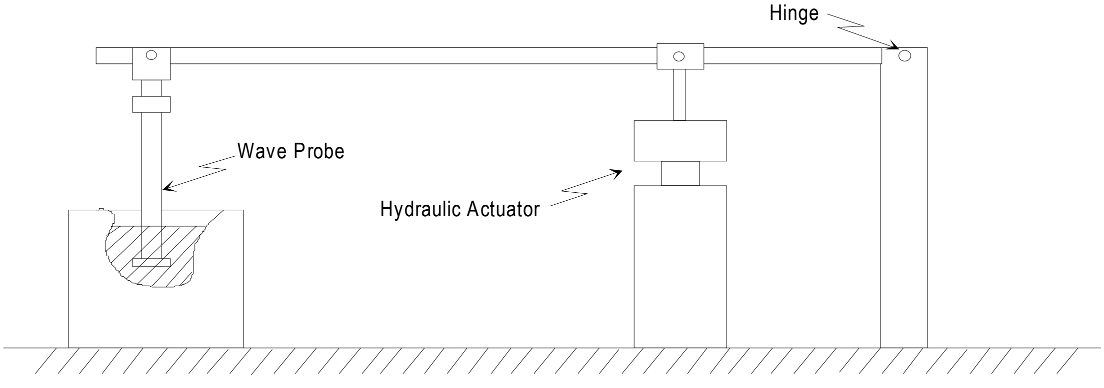

Figure 1
Dynamic Accuracy Test Set Up

While the probe wires must remain parallel to achieve a linear transfer function, the calibrated procedure (described later) was able to compensate for the small irregularities that are unavoidable in practice. Minimising adjacent probe interference was one of the reasons why the probes were made with two parallel wires as the active elements. In operation, one of the wires is electrically common with all other probes, and since this is the closest element to it's parallel 'active' wire, very little conduction will occur across the much longer path to the next probe. In practice, noticeable interference can be detected when the probes are place closer than 100 millimetres from each other. However, rarely are the probes required to be placed closer than 500 millimetres apart. Consequently, adjacent probe interference has not been a problem.

2.4 Probe Construction

Figure 2 illustrates the construction of the probes used for this demonstration. The tops of the two probe wires pass through slots cut into the small plastic box, where they are soldered directly to the signal conditioning printed board which is mounted inside. The probes are made from 0.8 mm diameter stainless steel wire. A bracket is fixed to the plastic case to enable the probe to be mounted into position on the sensor grid, while a 9 pin connector provides power to the circuit board and transfers the output signal to the computer.

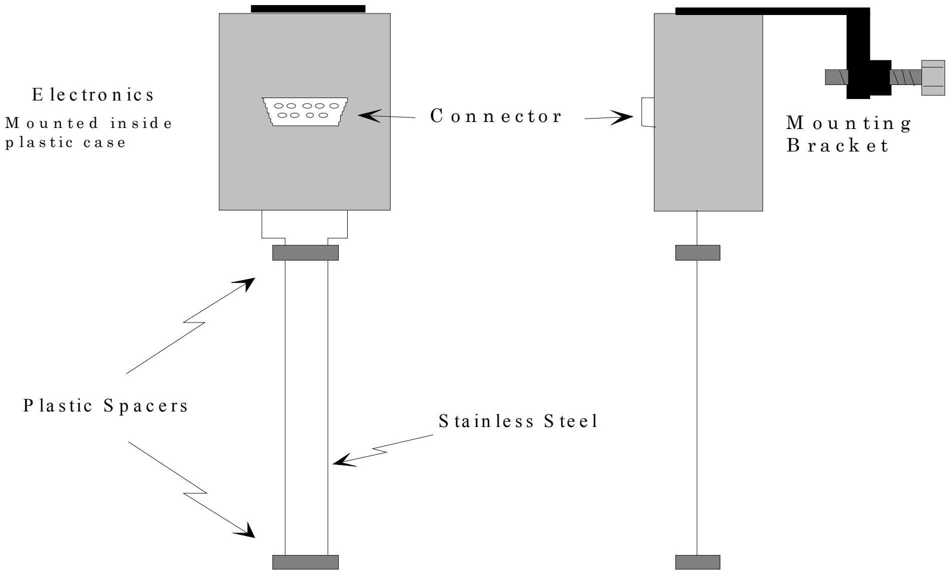

Figure 2
Electrical Conductance Probe Construction

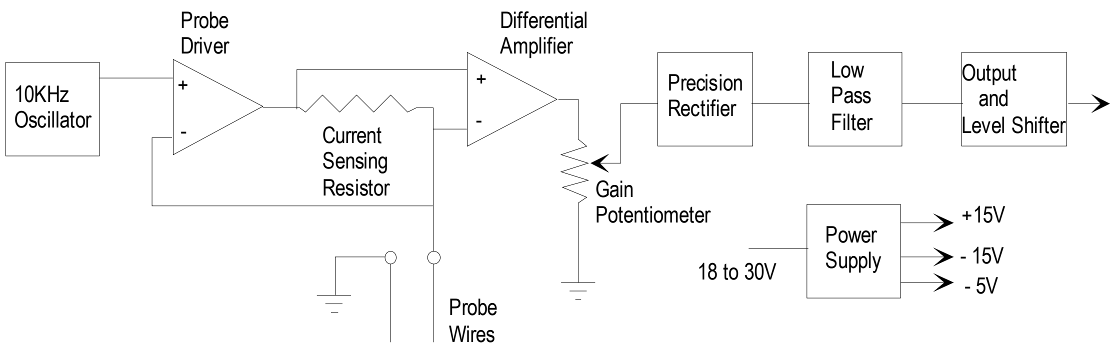

Figure 3
Signal Conditioning Circuit Block Diagram

3. SIGNAL CONDITIONING CIRCUIT

Figure 3 is the block diagram of the signal conditioning circuitry contained within the plastic case. A 10 KHz sine wave oscillator is used to generate the AC drive signal across the probe wires.

Note that a DC voltage cannot be used here because polarisation of the probe wires due to electrolysis would occur. The voltage across the probe wires is maintained at the same level as the oscillator by the action of the probe driver. This is done by passing current through the resistor positioned between the amplifier output and the active probe wire. The amount of this current is directly proportional to the depth of water covering the probe wires. This resistor transforms the conduction current into a voltage that is amplified by the following differential amplifier. The gain of this differential amplifier, together with the value of the resistor, and the potentiometer setting, controls the overall slope or transfer function of the circuit. The potentiometer may be adjusted, and/or the resistor changed, to suit the dissolved solids concentration of the local water.

Following the differential amplifier is a precision rectifier, where the AC voltage signal is converted to a DC voltage. This is passed through a single pole low pass filter, before going to the output stage. The cutoff frequency of the low pass filter must be high enough to pass the required high frequency components of wave signal, and low enough to sufficiently attenuate the rectified 10 Khz probe drive signal. For most tests a cut off frequency of about 35 Hz was used.

The output stage isolates the low pass filter from the external monitor (usually the A/D converter input) and it also functions as a voltage level shifter where the 0 to 5 volt signal from the filter is converted to an output signal of -5 to +5 volts (10 volts total).

4. CALIBRATION

4.1 Initial Calibration

Prior to the initial calibration of the probes a visual inspection is required to check that the probe wires are clean and reasonably parallel. As mentioned earlier, the gain of the probes can be set by the potentiometer or by changing the probe drive resistor.

4.2 Test Calibration

The probes are usually calibrated at the beginning of each test in the model basin, using the same water that would be used for the test. This method removes the effects of salinity and water temperature from the probes transfer function. The output voltage at four points, typically the bottom, the top (maximum wave height) and two intermediate points, are entered into an Excel spread sheet and a linear regression done to get the line of best fit. This value was then used as the calibration constant for the data acquisition program.

5. DATA ACQUISITION

The data acquisition machine used for this demonstration is capable of measuring 40 channels with 12 bit resolution at up to 25K samples per second . However only 4 channels are used in this demonstration. All the electrical conductance probes are scaled such that 10 volts represents a wave height of 150 mm. This means that the resolution of the system is 0.037 mm which is far better then the accuracy of the probes.

6. CONCLUSION

Electrical conductance probes can be used successfully for the measurement of water wave heights under controlled laboratory conditions. This is despite the inherent problems associated with changes in water conductivity and temperature. They are simple to construct and low in cost, which makes them an attractive proposition for use in coastal model studies where large numbers are required. When used in conjunction with a modern data acquisition computer, overall accuracies of ± 5% or better can readily be achieved.