Performance of a New Submersible Tide-Wave Recorder

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Abstract - **This paper considers the comparative performance of a new pressure sensor wave recorder with that of two acoustic wave recorders. This new recorder is small (265mm x 38mm OD), and can be mounted on the sea or harbour floor, fastened to an existing structure, or attached to a mooring line. Recorders of this new type have been deployed in an open bay alongside both Nortek AWAC and RD Instruments ADCP acoustic instruments. The output of interest of any wave recorder is the significant wave height. It was demonstrated that as the sea-state became rougher, the new recorder correlated well with both acoustic systems. For calmer seas, the new recorder showed some discrepancies with the AWAC system, however, the AWAC was able to detect much higher wave frequencies during these episodes. This is a consequence of the deployment depth and the different measuring techniques of the AWAC system and the pressure-based recorder which is disadvantaged because the pressure signal of higher frequency waves experiences rapid attenuation with depth. These deployments demonstrated that the new recorder is a viable low cost method of measuring tide and sea-state in moored applications provided care is taken with the mooring details. To optimize the deployment, a new method for computing attenuation and other parameters is presented.**

I. INTRODUCTION

A new pressure sensor based tide-wave recorder has been developed – the TWR-2050. This recorder is self-contained and small (265mm x 38mmOD). The recorder operates on two type 123 lithium camera batteries and is equipped with an 8 Mbyte flash memory for data storage. This configuration provides sufficient power and storage for a two month deployment in which the recorder can capture tide data at a 10 minute sampling period with 1024 wave readings every 30 minutes. The recorder uses an absolute pressure sensor with an accuracy of 0.05% equivalent to 5mm in the most sensitive configuration. The pressure sensor is combined with a temperture sensor offering an accuracy of 0.002°C. The tide-wave recorder is designed for moored applications in shallow conditions, the maximum recommended depth of operation is 40m.

II. THEORY OF OPERATION

The tide-wave recorder measures the pressure of the water above it. By transforming the pressure to depth (water height above the logger), tides can be seen as the slow changes of depth and waves can be seen as higher frequency changes.

A. Pressure to depth

There are two possible methods for calculating depth. Both methods require that the pressure reading (*p*), which is taken with an absolute pressure transducer, be adjusted using the atmospheric pressure:

$$pressure = p - Atmospheric \quad \text{(dBar)} \qquad (1.1)$$

Then, the depth (meters) can be calculated using either:

a. The "Simplified" method:

$$depth = \frac{pressure}{0.980665\rho} \quad \text{(m)} \qquad (1.2)$$

where ρ is the density of the water.

or:

b. The "Seawater" method taken from UNESCO [1]:

$$x = \sin(latitude)$$

$$g = 9.780318\left(1.0 + 5.2788e-3 \cdot x^2 + 2.36e-5 \cdot x^4\right) + 1.092e-6 \cdot pressure$$

$$depth = \frac{1}{g}\sum_{i=1}^{4} c_i \cdot pressure^i \qquad (1.3)$$

$$where: \; c_1 = 9.72659, c_2 = -2.2512e-5, \quad c_3 = 2.279e-10, c_4 = -1.82e-15$$

[1] UNESCO Technical Paper in Marine Science No. 44. UNESCO 1983.

B. Tides

Tides are represented in the long term changes in the depth of the logger. Fig. 1 shows seven days worth of depth data representing the tide. A maximum high tide was approximately 12.6m above the logger, with a minimum low tide of approximately 11m.

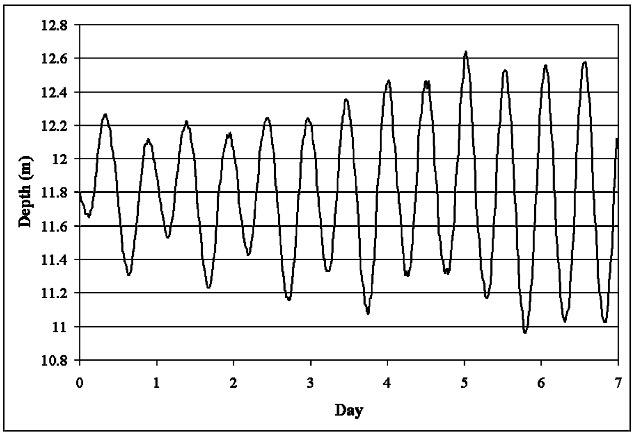

Fig. 1. Typical tide data: 7 day tide plot of depth versus time

Tide measurement requires the recorder to detect low frequency variations of the depth, ignoring any waves. Averaging can be applied to the tide measurements in the tide-wave recorder to remove wave noise.

C. Waves

Waves are high frequency changes in the depth measurements. The tide-wave recorder can be deployed to take samples of the waves at regular intervals. The logger collects a burst of data of 512, 1024 or 2048 samples at rates of 1Hz, 2Hz or 4Hz. Both the number of samples and the sampling rate can be programmed independently.

The rate defines the highest possible frequency that the logger can detect and is set by the Nyquist criterion Eqn 1.4. So at 4Hz, the highest possible frequency to be detected by the logger is 2Hz. However, as will be discussed later, the depth of water will influence the absolute maximum frequency detectable in any given deployment.

$$f_{\max} = \frac{rate}{2} \qquad \text{(Hz)} \qquad (1.4)$$

The number of samples determines the lowest frequency to be detected. The lowest frequency is given by:

$$f_{\min} = \frac{rate}{number\ of\ samples} \qquad \text{(Hz)} \qquad (1.5)$$

The wave periods are the reciprocal of the rate and the minimum frequency heresents the maximum period; hence at 4Hz and 2048 samples, f_{min}=0.00195Hz, equivalent to T_{max}=512secs.

The method of operation during wave sampling is to collect a burst of pressure data and hence depth data and to relate this to the sea surface to obtain a view of the waves. The physics of the deployment dictates that the individual frequency components of the pressure signal are attenuated with depth and the higher frequencies are attenuated more than the lower frequencies. The attenuation is a complex function being affected by both the depth of the logger and the overall depth of the water at the deployment location:

$$A(f,z) = \cosh(k\{h-z\}) / \cosh(kh) \quad \text{(dimensionless gain)} \qquad (1.6)$$

where: f is the frequency of interest (Hz)
z is the logger depth (m)
h is the total water depth (m)
k is the wave number (radian/m) obtained from:

$$\omega^2 = gk\tanh(kh) \quad ([\text{radian/sec}]^2) \qquad (1.7)$$

where: ω is the radian frequency = $2\pi f$ (radian/sec)

Fig. 2 shows the effect of depth on the maximum frequency to be seen at the logger.

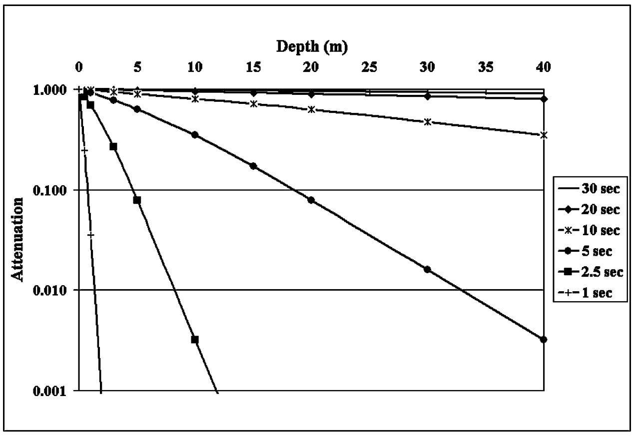

Fig. 2. Plot of the wave attenuation with depth for different wave periods

From the recorded time sequence of wave data, the RBR Windows Software generates a time sequence of the surface of the sea. This is done in three major steps:

a. The time sequence is transformed to its frequency components using Fourier analysis.
b. Each frequency component is multiplied by the inverse of the attenuation suffered by that particular frequency due to the depth of the logger. This action is limited to attenuations <1/20 to avoid injecting noise into the reconstruction.
c. The augmented frequency information is transformed back to a time sequence using the inverse Fourier transform.

The RBR Windows Software now has a view of the surface waves during each wave burst. It must be noted that these views will be deficient in high frequency information because the depth will attenuate such frequencies. However, for careful deployment, the reconstruction will give useful information. To assist the user, the deployment screen of the RBR Windows Software defines the range of useable frequencies. A reconstructed surface wave is shown in Fig. 3. This wave data contains 1024 samples collected at a rate of 4Hz.

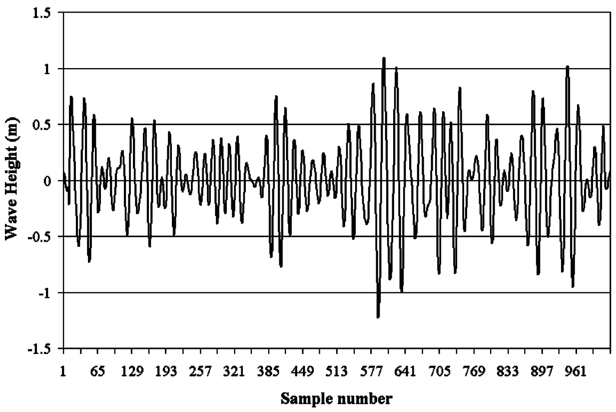

Fig. 3. Surface wave time series reconstructed from a TWR-2050 logger (1024 samples @ 4Hz)

The RBR Windows Software calculates several parameters from the reconstructed surface wave, these are:

- the significant wave height ($H_{1/3}$);
- the significant wave period ($T_{1/3}$);
- the maximum height; and
- an estimate of the energy in the wave sample.

The significant wave height ($H_{1/3}$) is a standard indicator of sea state as it coincides with the observations made by a skilled human observer.

III. COMPARISON

Two of the TWR-2050 tide-wave recorders under discussion were deployed off the Nova Scotia, Canada coast in September 2004. They were deployed on the platforms of bottom dwelling acoustic wave monitoring devices made by Nortek (AWAC) and RD Instruments (ADCP Waves Array). The data associated with the AWAC were collected at 20m and those associated with the RDI at 10m.

When reviewing the tide data returned from all instruments, the TWR-2050 performed at a level equal to or better than the acoustic systems and within the expected accuracy and resolution of the pressure transducers. The performance of the TWR-2050 with regard to wave data did vary from the acoustic systems and this variation will be discussed. Note that, unlike the acoustic systems, the TWR-2050 does not record wave direction and this aspect will not be discussed further.

During quiet periods (significant wave heights of less than 0.2m), the TWR-2050 reported the significant wave height consistently lower than both acoustic systems by typically 15%. Reviewing the raw data from both systems, it is clear that the AWAC and RDI systems are able to “see” high frequency wave activity on the surface of the sea during this period that is invisible to the pressure recorder at depth simply because of the physics described by Eqn. 1.6 and illustrated in Fig. 2. A more important area for review is the performance during wind-driven wave events.

Fig. 4 shows the response of the Nortek AWAC system and the TWR-2050 to the same wind-driven wave event. The event produced significant wave heights in the region of 1.5 meters. Note that both methods of determining the significant wave height were comparable in the intervals 0-0.5 days and from the peak at 1.5 days to 3 days. The difference between the two systems is shown in the interval 0.5 to 1.5 days. Again a review of the raw data shows that the discrepancy is due to the pressure signal attenuation with depth.

Fig. 5 shows the response of the RDI system and the TWR-2050 to the same wind driven event depicted in Fig. 4. The second deployment was approximately 1km from the first, closer in-shore and at a depth of 10m. We can make similar comments for this deployment as for the one associated with the AWAC. The TWR-2050 follows the RDI over a larger interval, showing a discrepancy only over the interval 1 to 1.5 days. Again a careful examination of the data shows that the RDI system can detect surface activity unseen by the TWR-2050. However, because this deployment was at a shallower depth of 10m, the pressure-based TWR-2050 was able to “see” higher frequencies on the surface which meant a smaller interval of discrepancy.

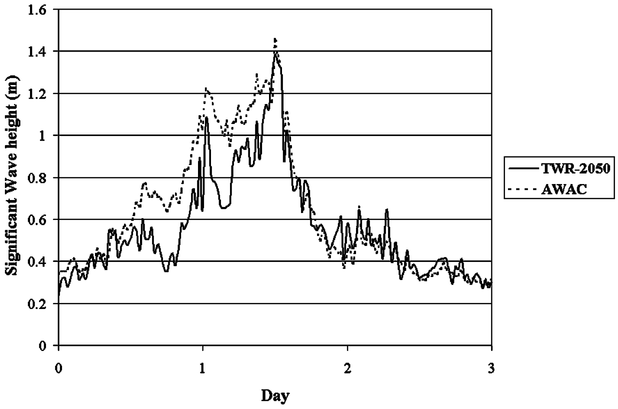

Fig. 4. Significant wave height assessed over the same 3 day period by the AWAC and TWR-2050 systems.

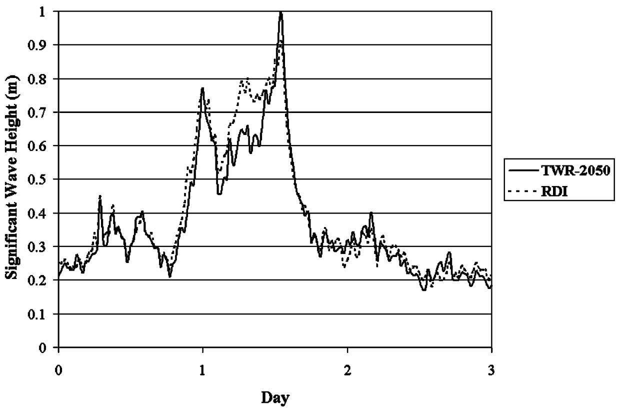

Fig. 5. Significant wave height assessed over the same 3 day period by the RDI and TWR-2050 systems.

IV. DEPLOYMENT OPTIMIZATION

It is clear from the observations made in the Comparison section that the deployed depth of the pressure-based logger makes a significant impact on the ability to discriminate high frequency components in the surface wave. Secondly, the two deployment parameters of length of wave burst and burst sampling rate determine the manner in which the surface wave is observed. Therefore, it is imperative that the user, in preparing to deploy such an instrument, be given an opportunity to experiment with the interplay of these parameters to obtain an optimal deployment. In recognizing these facts, the RBR Windows Software provides the user with a deployment setup screen that offers feedback on the ability of the TWR-2050 logger to perform as the parameters are changed.

The first considerations to be addressed are the parameters h and z to be found in Eqn. 6. The operator must have an idea about a value for the total height of water at the deployment site, h. A value is required to be entered into the deployment setup window to enable the estimates to be made, however, after a deployment, the actual value will be calculable from the pressure data recorded in the logger as outlined below.

z is the height of water above the logger. The setup window, in fact, asks for input on the expected height of deployment above the seabed. This must be established with some accuracy and is a deployment requirement. This height is usually the distance up a mooring line that the logger will be anchored or the height above the seabed for the anchoring to a quay or dock. This parameter is actually the quantity $(h\text{-}z)$, note that z is measured by the logger during its deployment and h can be calculated after deployment from the known deployment height and the measured depth z.

The next two parameters to be considered are the number of samples in a wave burst and the burst sampling rate. As these are changed, they will influence the reported values of maximum and minimum wave frequencies (also given in terms of wave periods) that can be measured. The maximum frequency is the minimum of the Nyquist value (Eqn. 1.4) and that determined by the attenuation (Eqn. 1.6). The practical cut-off that is used when converting the attenuation to a maximum usable frequency is the lowest frequency whose attenuation falls below 1/20. The deployment setup window shown in Fig. 6 illustrates the use of the parameters just described. At the top right are boxes to input the "Expected mean depth of water" or h, "Expected height of logger above seabed" or $(h\text{-}z)$. These two parameters immediately define the maximum frequency limit as a function of attenuation which appears on the left of the window as the maximum frequency 0.3077Hz (minimum wave period of 3.25 secs). Although the sampling rate is set at 4Hz, the Nyquist frequency of 2Hz has been superseded by the value set by attenuation. The other end of the frequency range is determined by the 4Hz and 1024 samples from Eqn. 1.5. i.e 0.0039Hz (256 secs of wave period).

The calendars show a one month deployment and with the additional parameter settings for tide and wave sampling periods as well as the averaging applied to the tide data, the deployment will fill about 55% of the 8 Mbyte memory while taking about 25% of the rated capacity of the batteries.

Changing the deployment to an expected height of the logger above the seabed of 1m, as in the RDI deployment, reduces the highest frequency to 0.2252 (4.44 sec period).

V. CONCLUSIONS

The pressure sensor based tide-wave recorder (TWR-2050) as presented here is a small low-cost self-contained instrument suitable for logging tide and wave data. If supplied with an underwater connector, it can offer real-time observation for tides and sea state. In this configuration the logger is ideally suited to harbour applications.

When compared to acoustic instruments, the logger has proved capable of performing in an identical manner when tides are considered and with a few discrepancies when waves are considered. The discrepancies have arisen because of the pressure-based measurement technique of the TWR-2050 which inherently limits the high frequency end of the wave spectrum that can be measured. However, for careful shallow deployments, the logger does offer high quality information of the waves and sea state. Finally, the software for deployment provides the operator with an excellent understanding of the quality of data to be recorded.

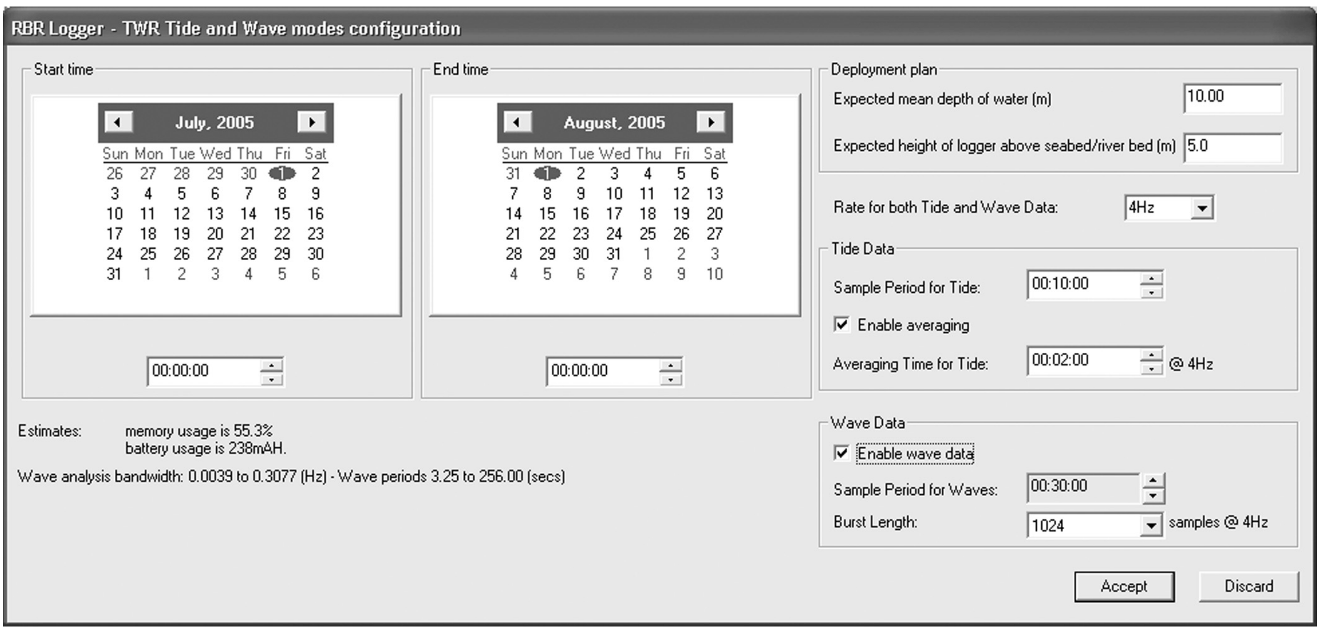

Fig. 6. Deployment setup window used to prepare a TWR-2050 tide-wave logger for data collection.