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Dredging Research Technical Notes

A Comparison of Zero-Moment Wave Height to the Standard Deviation of a Vitel Tide Gage

Purpose

This technical note describes a comparison between the zero-moment wave height measured by a Baylor wave gage and the standard deviation of measurements from a Vitel tide gage.

Background

During the period July-October 1992, the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) collected data simultaneously from a Vitel tide gage and a Baylor wave gage at the Field Research Facility (FRF) in Duck, NC. The Vitel gage sampled the water height at 4 Hz and calculated an average water level and standard deviation every 6 min. A zero-moment wave height (H_{m0}) was calculated using 34 min of data obtained from the Baylor wave staff. A comparison was made between the standard deviation of the Vitel gage and the zero-moment wave height as measured by the Baylor wave gage. It was found that the relationship between the standard deviation and the zero-moment height was nearly linear.

Additional Information

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Introduction

Site-specific wave data are sometimes desirable for planning, design, or contract administrative purposes of a dredging project. While conventional wave gages usually can satisfy the data acquisition requirements, the operation and maintenance cost of a long-term, sole-purpose gage

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often cannot be supported or justified. Moreover, the degree of data detail provided by conventional gages may be greater than necessary to satisfy project requirements. An alternative is proposed herein whereby conventional tide gages, which often are used to support dredging projects, can be used to provide a quantitative estimate of the local sea state.

The term "sea state" is preferred herein because no estimates of wave period are derived from the tide gage data. The wave climate estimates are, however, expressed in terms of zero-moment wave height. The tide gage used for this study was a Vitel model WLS-1. The gage uses a down-looking acoustic transceiver that determines the water level by measuring the time of flight of an acoustic pulse confined to a small tube as it travels vertically to the water surface and returns. The gage samples the water surface elevation at approximately 4 Hz, fast enough to avoid aliasing of all but the very highest frequency gravity waves. The Vitel gage normally computes a mean water level averaged over 3 min; for the specific instrument involved in this study, a 6-min average was used. In addition to the mean water level, the gage also computes the standard deviation (Gaussian distribution assumed) and number of outliers (those water level elevations exceeding three standard deviations from the mean).

The rationale involved in using the standard deviation as an indication of sea state stems from the definition of the zero-moment wave height, defined as 4 times the square root of the variance of the wave record. Since the standard deviation is the square root of the variance, the zero-moment wave height should, in principle, equal 4 times the standard deviation. The field study described herein compares the wave heights determined using a surface-piercing wave staff and standard spectral analysis techniques with the values of standard deviation computed by the Vitel gage.

Equipment

The Vitel gage is typically used for tidal measurements along coastal regions. The gage consists of a hollow tube (0.5 in. (1.3 cm) in diameter) with an acoustic transceiver at one end. The tube is mounted vertically with the transceiver elevated above the water and the open end submerged to a depth below the lowest expected water level. The transceiver emits a sonic pulse and monitors the return echo from the surface of the water. Based on the length of time from the emission of the pulse to the return echo, the instrument calculates the distance of the water surface from the transceiver and, hence, the water level.

A standard Vitel gage samples the water height in the tube at 4 Hz for 3 min and then calculates an average water height and standard deviation of the water height over that 3-min time period. The Vitel gage used to collect this data set was modified to a sampling interval of 6 min with the same sampling frequency.

The Baylor wave gage is an impedance-type wave staff that samples the water height at 2 Hz. The gage samples over a 34-min period and calculates a zero-moment wave height for that 34-min period. The energy density spectrum for the sampling interval is calculated; then the spectrum is integrated over all frequencies from 0.04 to 0.50 Hz. This gives the total variance (which could also be calculated from the average of the square of the individual wave heights) (Earle and Bishop 1984). The estimate of the zero-moment wave height is obtained by taking the square root of the total variance and multiplying by 4.0.

The Vitel and Baylor gages were mounted on the pier where the water depth was approximately 25 ft (7.6 m) at mean low water. The Vitel gage was mounted in a stilling well that was attached to the landward side of one of the pilings of the FRF pier. A stilling well was used in this application, to provide structural support for the relatively fragile sounding tube (0.5 in. (1.3 cm) in diameter) rather than to damp the wave field. In fact, the well was completely open at the bottom end, and no special hydraulic damping was used. Users desiring to use the Vitel gage in an application as described herein should ensure that the gage observes an undamped

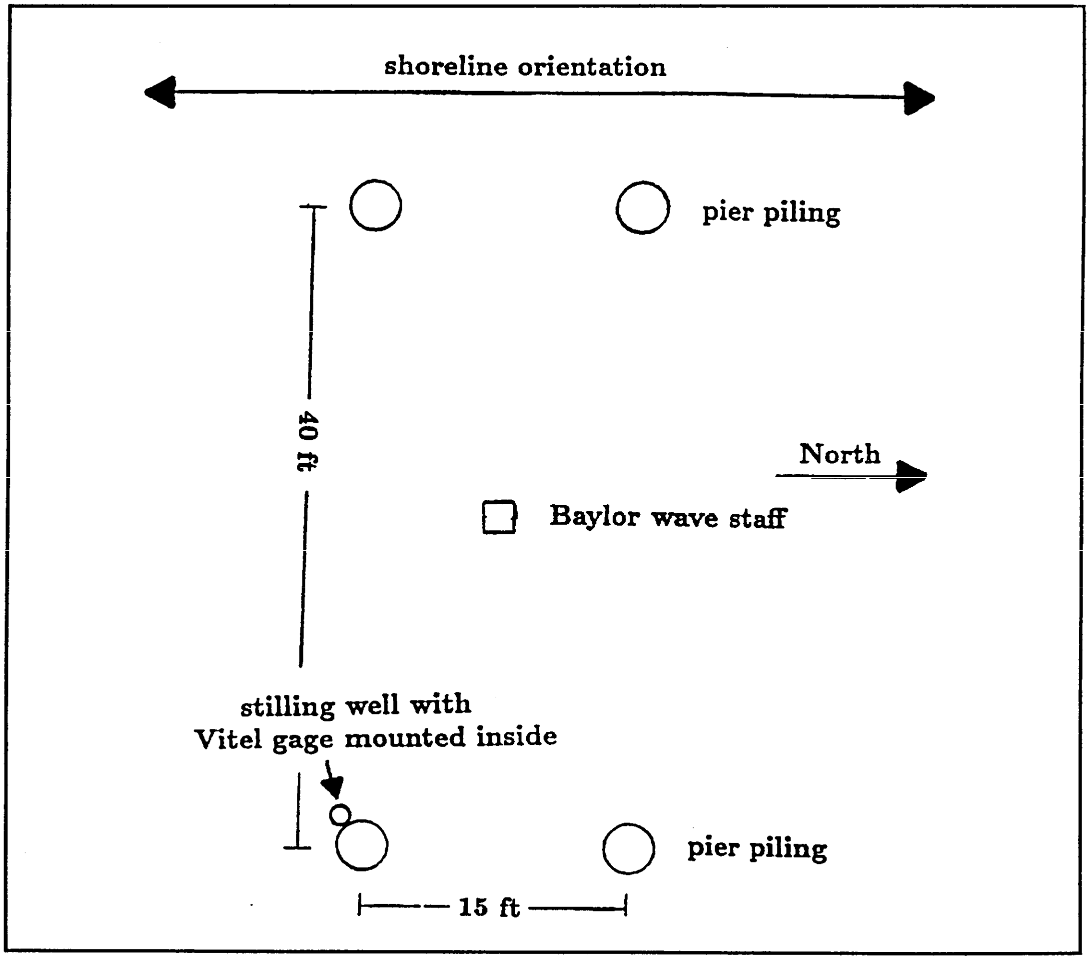

Figure 1. Orientation of the Vitel gage and the Baylor wave gage on the pier

wave field. The Baylor wave gage was mounted along the center line of the pier halfway between the pile with the Vitel gage on it and the next landward pile (Figure 1).

Data Collected

From the beginning of July 1992 until mid-October 1992, there were approximately 73 days during which data were collected simultaneously with the Vitel gage and the Baylor wave gage. These data included a variety of wave conditions, ranging from calm to periods with a zero-moment wave height of approximately 3.25 m. There were a few periods during this time when the Vitel gage was not operational, and one short period when the gage was operational but did not appear to be functioning properly. The data from this latter period were edited out.

The wave gage data are continuous, with the exception of a few gaps of no more than 4 hr. The data for each of the months from both the Vitel gage and the wave gage are presented in Figure 2.

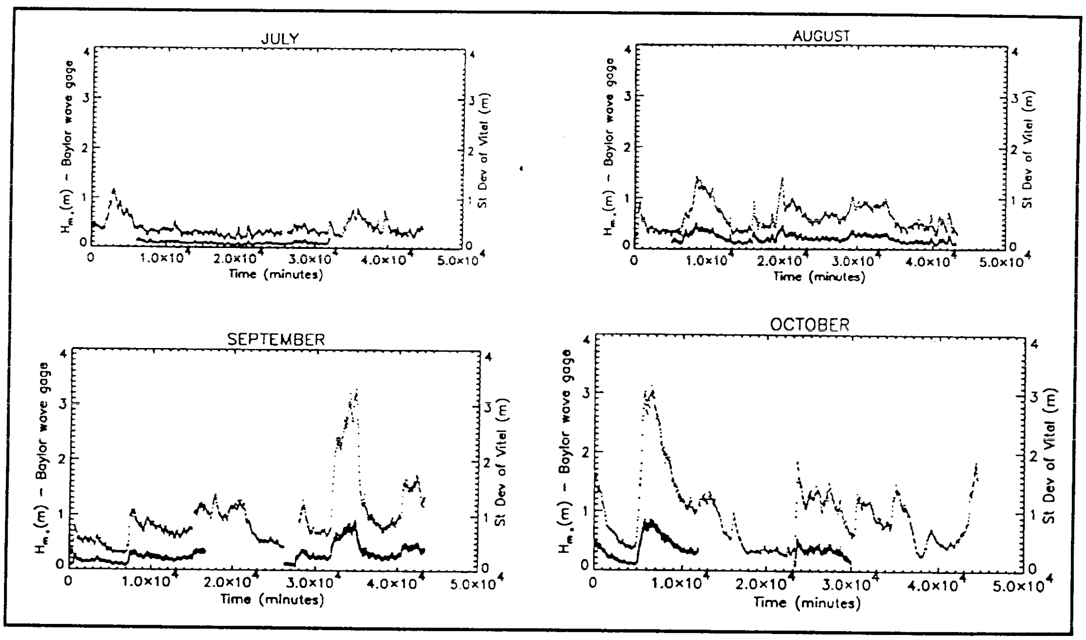

Figure 2. Time series of standard deviation of the Vitel gage and zero-moment height from the Baylor wave gage, July-October 1992. (Note: Upper line is Baylor wave gage; lower line is Vitel gage)

Comparison of Gage Measurements

The zero-moment wave height is estimated from the Baylor wave gage data by multiplying what is in essence the standard deviation of the wave record (as calculated from the energy density spectrum) by 4.0. Therefore, there should be a linear relationship of a factor of 4 between the standard deviation measured by the Vitel gage and the zero-moment wave height measured by the Baylor gage. A comparison was made between the standard deviation of the Vitel gage and the zero-moment wave height measured by the wave gage to determine if there was such a relationship.

Since the sampling interval of the instruments was different, it was necessary to average several records of the standard deviation from the Vitel gage to compare to the zero-moment wave height calculated by the wave gage. To obtain a proper estimate of the average standard deviation, it was necessary to square the individual standard deviations from the Vitel gage, average the squares, and then take the square root of that average. The sampling interval of the wave gage was not an even multiple of the sampling interval of the Vitel gage; therefore, it was sometimes necessary to average six readings from the Vitel gage and other times, five readings.

Figure 3 is a plot of the zero-moment wave height versus averaged standard deviation for all available data. From Figure 3 there appears to be a nearly linear relationship between the zero-moment wave height and the standard deviation (std dev) of the Vitel gage. Using the method of least squares, a first-, second-, and third-order polynomial were fitted to the data. The first-order polynomial is shown as a solid line and has the form

$$H_{m_0} = -0.10 + 3.71 * \text{std dev}$$

The second-order is shown as a short-dash line and has the form

$$H_{m_0} = 0.06 + 2.40 * \text{std dev} + 1.87 * \text{std dev}^2$$

The third-order is shown as the long-dash line and has the form

$$H_{m_0} = 0.14 + 1.41 * \text{std dev} + 5.08 * \text{std dev}^2 - 2.77 * \text{std dev}^3$$

The standard deviation of the fit (in meters) is 0.09 for the first-order polynomial, 0.07 for the second-order polynomial, and 0.07 for the third-order polynomial.

Another comparison was made between the zero-moment wave height from the Baylor gage and the individual, unaveraged standard deviations from the Vitel gage (Figure 4). A linear relationship was observed, similar to that for the averaged Vitel data. A least squares fit of a first-, second-, and third-order polynomial was performed. The first-order polynomial, represented in Figure 4 by a solid line, has the form

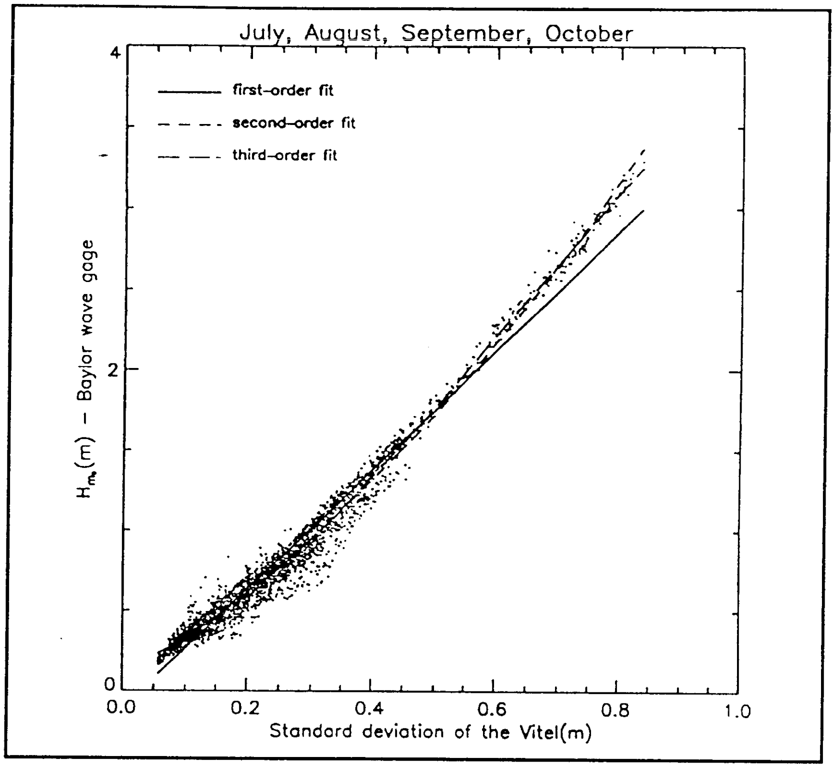

Figure 3. Plot of zero-moment wave height from the Baylor wave gage versus averaged standard deviation from the Vitel gage

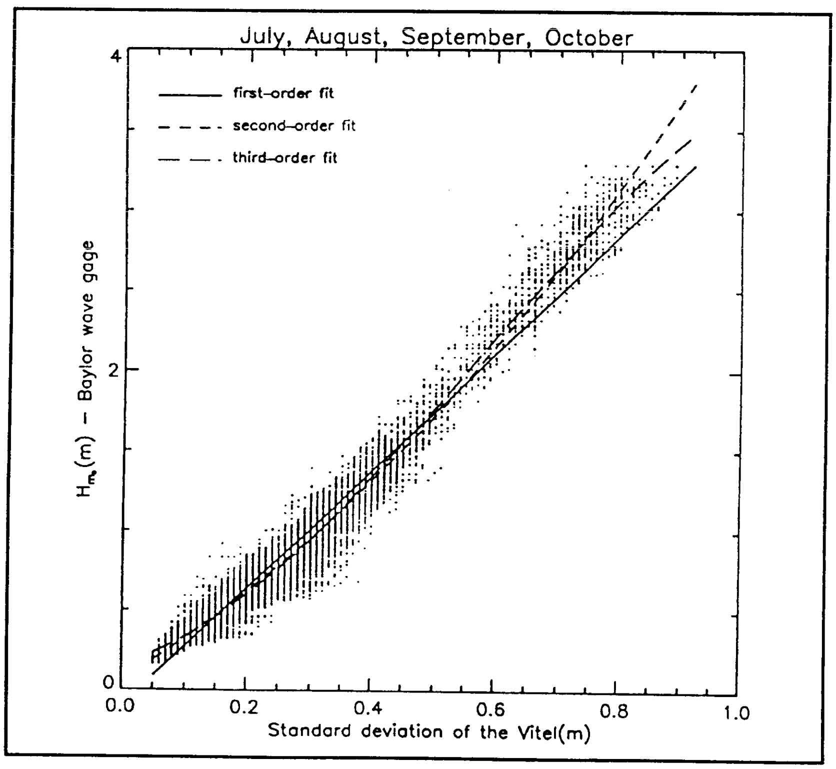

Figure 4. Plot of zero-moment wave height from the Baylor wave gage versus individual standard deviations from the Vitel gage

$$H_{m_o} = -0.09 + 3.68 * \text{std dev}$$

The second-order polynomial, shown as a short-dash line, has the form

$$H_{m_o} = 0.06 + 2.43 * \text{std dev} + 1.77 * \text{std dev}^2$$

The third-order polynomial, shown as the long-dash line, has the form

$$eH_{m_o} = 0.16 + 1.21 * \text{std dev} + 5.69 * \text{std dev}^2 - 3.35 * \text{std dev}^3$$

The standard deviation of the fit is 0.11 m for the first-order polynomial, 0.09 m for the second-order polynomial, and 0.09 m for the third-order polynomial.

Discussion

For the best linear fit to this data set, the zero-moment wave height was related to the standard deviation of the Vitel gage by a factor of 3.71. As discussed, the theoretical value for this factor should be 4.0. Several factors may explain this discrepancy:

- The Baylor gage integrated only over the frequency range from 0.04 to 0.50 Hz instead of the full frequency range.
- The Vitel gage was located along a piling (3 ft (0.9 m) in diameter), as shown in Figure 1. The piling may have affected the wave pattern at this location, especially for low-amplitude, high-frequency waves and waves from certain directions. The Vitel gage was mounted inside a stilling well, which also served to filter out the low-amplitude, high-frequency surface waves.
- For the Vitel gage, water has to flow up and down inside a small tube. The friction between the sides of the tube and the water may have altered the height of the water in the tube relative to the true water level by retarding the flow of the water.
- A slight difference in the sampling intervals of the instruments occurred.

Conclusions

Conclusions based on this comparison study are summarized below.

- The use of a Vitel gage to measure the wave climate at a location has promise.

- Correlation between the standard deviation of the water level measured by the Vitel gage and the H_{mo} may be site specific. Therefore, the correlation between the standard deviation and the H_{m_0} must be determined/verified at each new site.
- Because of mounting constraints, nearby structures, and prevailing wave climate, the Vitel gage may not give acceptable estimates of the H_{mo} in some applications.
- Six-min averages from the Vitel gage produced estimates of H_{mo} nearly as good as 30- or 36-min averages. Depending on requirements, averaging of the gage output may not be needed.
- Statistical analysis of the data is needed to establish confidence intervals on the correlation of the Vitel gage measurements to the H_{mo}.

Reference

Earle, Marshal D., and Bishop, Joseph M. 1984. *"A Practical Guide to Ocean Wave Measurement and Analysis,"* Endeco, Inc., Marion, MA, pp 38-40.