Geo-Mar Lett
DOI 10.1007/s00367-010-0206-y

ORIGINAL

Acoustic density measurements of consolidating cohesive sediment beds by means of a non-intrusive "Micro-Chirp" acoustic system

Ho Kyung Ha · Jerome P.-Y. Maa · Charles W. Holland

Received: 9 September 2009 / Accepted: 9 March 2010

Abstract A non-intrusive "Micro-Chirp" acoustic system and a signal-processing protocol have been developed to estimate the bulk density of consolidating cohesive sediment beds. Using high-frequency (300–700 kHz) Chirp acoustic waves, laboratory measurements were conducted with clay–water mixtures. Because acoustic echo strength is proportional to variations in acoustic impedance, and the speed of sound in the clay bed hardly changed during consolidation, the bulk density could be successfully estimated without disturbing the sediment bed. Based on acoustic signal analysis, this study demonstrates that the reflection coefficient and bulk density at the water–sediment interface increase with consolidation time, and that a single speed of sound value can be used for practical bulk density estimation in muddy environments.

Introduction

Cohesive sediment deposits are ubiquitously found along many coasts and estuaries (Flemming 2002; Partheniades 2006). Such sediments generally exhibit the strongest gradients in physical properties near the water–sediment interface (Mehta and Dyer 1990; Winterwerp and van Kesteren 2004; Holland et al. 2005). These gradients result from repeated bed formation and destruction caused by complex near-bed processes (e.g., erosion, deposition, consolidation, and bioturbation). Understanding the properties (e.g., bulk density and erosion threshold) of the uppermost layer (≈0.1 m) therefore can provide important information on sedimentary history and mechanical sediment behavior.

A number of studies have addressed the characteristics of the top layer of consolidating and/or consolidated beds (e.g., Hawley 1981; Torfs et al. 1996; Sills 1998; Lintern et al. 2002; Winterwerp and van Kesteren 2004). Nonetheless, there are few reliable methods to adequately measure the bulk density of this layer, because most current approaches are of the intrusive type, and commonly severely disturb the target layer (e.g., Hamilton 1971; Briggs and Richardson 1996; Maa et al. 1997; Seifert et al. 2008; Stark and Wever 2009). Direct coring is therefore still considered as the standard against which to compare other methods requiring elaborate calibrations for estimations of bulk density. Coring, however, is a time- and labor-intensive procedure, and cannot provide the high spatial and temporal resolutions required for most purposes.

Alternative techniques include (1) nuclear-ray (e.g., γ- and X-ray) attenuation, (2) attenuation of natural radioactivity, (3) electrical impedance change, (4) tuning fork, and (5) acoustic wave attenuation. The principle of a nuclear device is based on the fact that sediments absorb more nuclear radiation as the bulk density increases (Hirst et al. 1975; Been and Sills 1981; Sills 1997, 1998; de Groot et al. 2009). Thus, the attenuation of nuclear radiation passing through a sediment layer can be used as a proxy for estimating the bulk density. In addition, the relationship between the concentration of natural radioactive isotope and sediment properties can be used to determine the sediment composition and bulk density (Jacob

H. K. Ha (✉)
Korea Polar Research Institute, KORDI,
Incheon 406-840, South Korea
e-mail: hokyung.ha@gmail.com

J. P.-Y. Maa
Department of Physical Sciences,
Virginia Institute of Marine Science, School of Marine Science,
College of William and Mary,
Gloucester Point, VA 23062, USA

C. W. Holland
Applied Research Laboratory, Pennsylvania State University,
State College, PA 16804, USA

Published online: 24 March 2010