The Bremen Lance Insertion Retardation Meter for Assessing Seafloor Stability

A New Tool to Check the Ocean Bottom's Properties by Logging and Integrating the Motion of a Penetrating Lance

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Seafloor stability is extremely critical for cable trays, offshore structures and instrument-to-ground coupling during deployment of deep-sea observatories like ocean bottom seismometers. Penetrometers are very well-known geotechnical devices to quantitatively determine seafloor stability from soil parameters such as shear strength or the layering in the upper few meters.

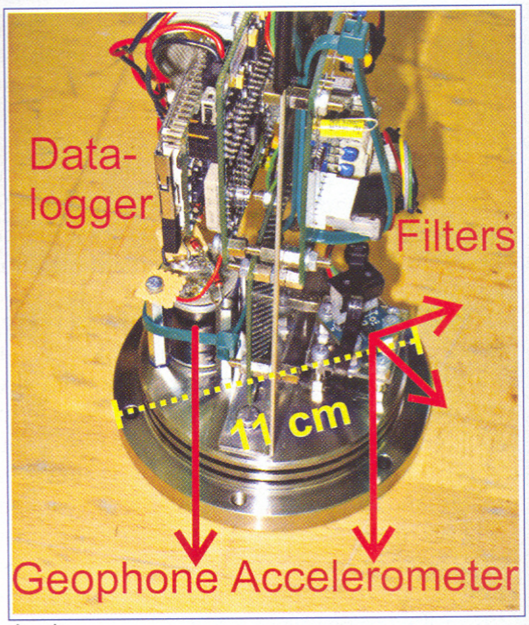
However, modern penetrometers are stand-alone and often large devices. For a straightforward pre-site survey to qualitatively check the upper soil—possibly by means of a ship of opportunity—those instruments are costly. Moreover, they mostly have a limited operational depth of less than 1,000 meters, so deep-sea areas are hardly accessible. Consequently, there is a demand for a compact and easy-to-use tool to check ground stability.

The lance insertion retardation (LIR) meter, developed by Universität Bremen, is an inexpensive, small and autonomously operating device that can be lashed to any type of lance like a gravity corer, a heat probe or a bare rod. It is able to qualitatively determine ground stability in a simple way.

The LIR meter can operate in any depth and records data of the retarded motion of a lance while a soil sampling and/or a heat flow measurement is performed. It provides maximum flexibility, increases the efficiency of data collection and reduces the cost.

Numerical random integration determines the penetration depth from the acceleration data of the LIR meter, whereas a built-in geophone acts as impact detector and is used to examine the penetration depth. Thereafter, acceleration and velocity of a penetrating lance can be analyzed independent of the penetration depth and compared with the layering obtained by gravity coring or thermal conductivity measurements.

This article presents the LIR meter design, the principle of the random integration, the impact detection and first data collected parallel to heat flow measurements in the deep-sea Tonga Trench.



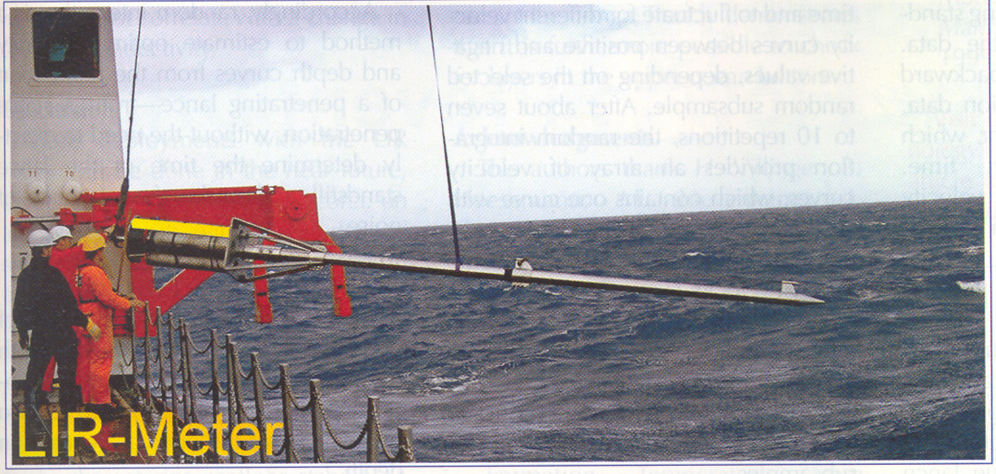
Unbolted LIR meter prototype with an 11-centimeter outer diameter with triaxial accelerometer, uniaxial geophone, data logger and filter electronics.

LIR Meter Design

The LIR meter fits in a small titanium pressure housing of 0.11 meters outer diameter and 0.8 meters outer length. It has no outside connectors and is very robust, able to withstand peak accelerations of up to 20,000 units of gravity during rough offshore operation.

A low-cost triaxial microelectromechanical systems accelerometer and a one-axis geophone independently measure the LIR meter's motion. Both sensors are firmly screwed to the lower endcap of the pressure housing. One axis of the accelerometer and the axis of the geophone are aligned with the long axis of the pressure housing so that the pressure housing itself aligns with the long axis of the lance and with the lance's direction of motion.

The remaining two axes of the accelerometer provide the inclination



(Above) Deployment of the LIR meter on top of the six-meter Bremen heat probe on board RV Sonne.

(Below) (a) Acceleration record, estimation of optimal velocity by random integration and determination of penetration depth. (b) Comparison between acceleration, optimal velocity and geophone data with the layering derived from heat flow measurements.

of the LIR meter in order to determine and correct tilted penetrations.

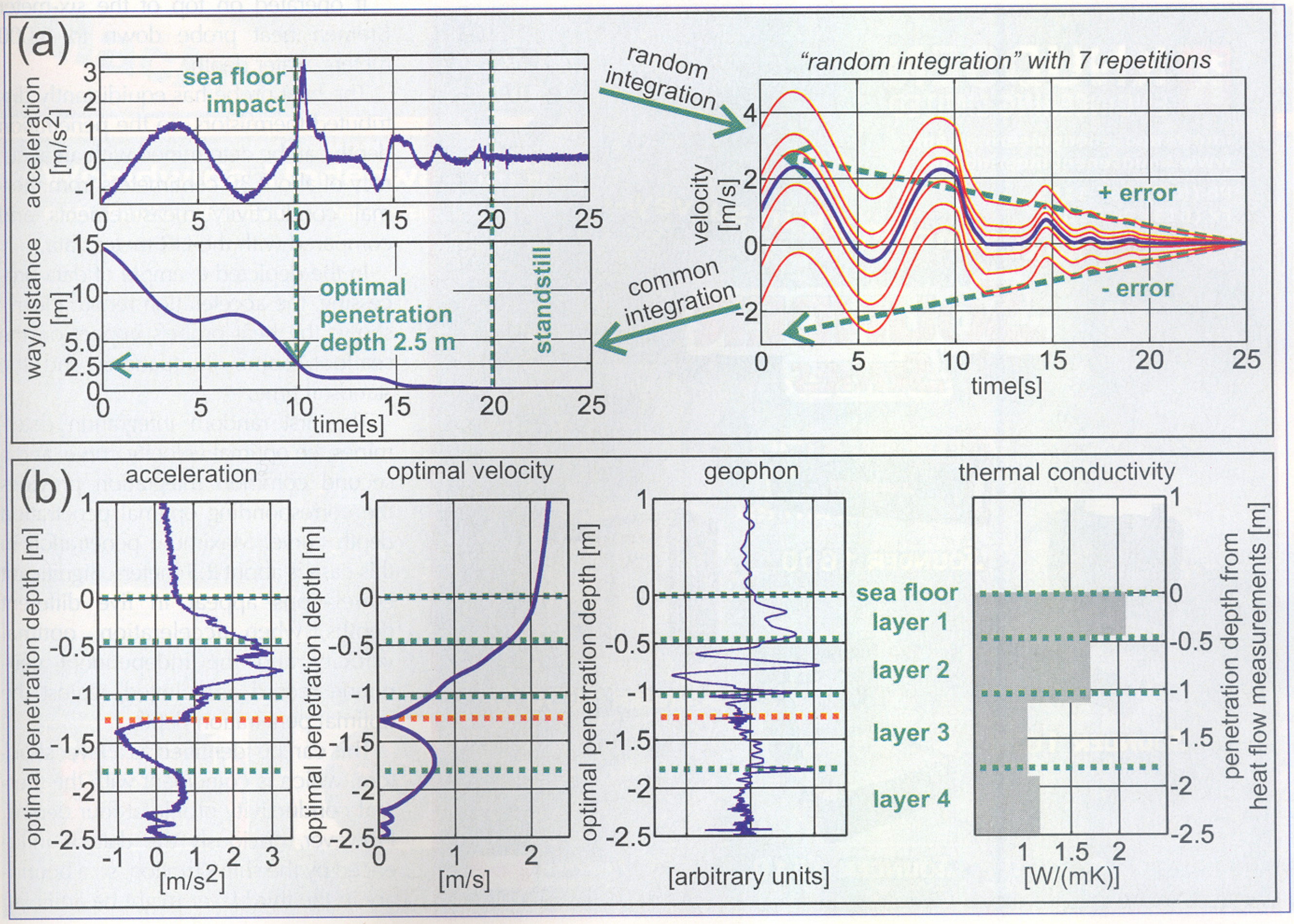
Signals pass through analog anti-alias filters to a 16-bit data logger with a non-volatile SanDisk (Milpitas, California) CompactFlash card for data recording. Resolution of acceleration in the direction of the lance penetration is 0.5 milliunits of gravity in a measuring range of plus or minus 3.5 units of gravity at a sampling rate of 500 hertz. Resolution of the lance displacement for a typical speed between one meter per second and up to 10 meters per second ranges between five millimeters and five centimeters, respectively. Geophone data are sampled at the same rate.

A rechargeable battery pack provides power for more than 48 hours of continuous operation, and a built-in thermistor controls the operating conditions.

Random Integration

The numerical method of random integration estimates optimal velocity and depth curves from the acceleration data of a single lance penetration in the seafloor. It is assumed that at the end of a penetration, the lance stands still. The lance acceleration, which has been recorded during penetration, can now be integrated backwards in time, starting at the end of a measurement, to obtain the corresponding velocity. A second integration provides the way of the lance. Acceleration as well as velocity can be plotted against the traveled distance to get acceleration and velocity profiles for a penetration.

However, such an integration of acceleration data is often not easily possible. The acceleration data is contaminated by random broadband noise from electronics and seafloor motions as well as by a constant offset from gravity. The offset can be removed by subtract-



ing the mean acceleration during standstill, but noise remains in the data. Velocity data, calculated by a backward integration of noisy acceleration data, would normally show an error, which increases with integration time. Therefore, it is assumed that velocity data, which do not show such an integration time-dependent error, provide the true lance velocity during penetration.

The random integration thus determines the optimal velocity data, which shows a minimum integration time-dependent error and is therefore the best approximation of the true lance velocity. A subsample of about five to 10 percent of the acceleration data during standstill of the lance is randomly selected. All acceleration data are normalized to the average of this subsample. Then velocity data are calculated by a backward integration over time, and the obtained velocity curve is plotted over time. This procedure is repeated several times with randomly selected subsamples from the same data set of the standstill. The integration time-dependent error of the different velocity curves turns out to vary linearly in time and to fluctuate for different velocity curves between positive and negative values, depending on the selected random subsample. After about seven to 10 repetitions, the random integration provides an array of velocity curves, which contains one curve with a very small error.

This curve is assumed to show the optimal velocity curve (i.e., a good estimation for the true lance velocity during penetration). A standstill time of about five to 10 seconds appeared to be a good choice to record enough data for such a type of random selection of subsamples.

A second common backward integration over time of the optimal velocity curve provides the way of the lance. As the impact of the lance on the seafloor is mostly visible as a significant signal anomaly in acceleration data, the penetration depth of the lance can be derived when acceleration is plotted together with the traveled distance. A laboratory test of the random integration for a vertical displacement of the LIR meter of 21 meters with an elevator provided a positioning error of less than five percent.

Accordingly, random integration is a method to estimate optimal velocity and depth curves from the retardation of a penetrating lance—from a single penetration, without the need to exactly determine the time of the lance standstill and under the presence of noise.

Geophone as Impact Detector

To examine whether determination of optimal velocity and penetration depth curves by random integration is convincing, the geophone record is also plotted against the optimal penetration depth.

The geophone is a sensitive electrodynamic velocity sensor and acts as an impact detector. It shows signal anomalies when the lance hits the seafloor or a layer boundary. Hence, those signal anomalies of acceleration, which were previously used to derive the penetration depth, correlate with these signal anomalies in the geophone record.

Test Data From Tonga Trench

During cruise SO 195 of the German RV *Sonne* in January and February, the LIR meter had its first deployment and provided surprisingly good data.

It operated on top of the six-meter Bremen heat probe down to 6,000 meters' water depth.

The heat probe has equidistantly distributed thermistors, so the penetration depth can be determined with an accuracy of about 30 centimeters from thermal conductivity measurements and compared with the LIR meter data.

In the depicted example of data processing, the acceleration record clearly shows the heat probe's impact on the seafloor, some fluctuations and the standstill time.

The first random integration determines the optimal velocity curve, and a second common integration provides the corresponding optimal penetration depth curve. Maximum penetration in this case is about 2.5 meters. Significant correlations appear in five different depths, when acceleration, optimal velocity and the independent geophone record are plotted against the optimal penetration depth.

This can be identified as a layer structure, which is coincident with the thermal conductivity profile at four depths. However, obviously the data is influenced by the ship's motion, so a boundary in the third layer might be artificial, as it does not correlate with a change in thermal conductivity.

Discussion

More deployments with the LIR meter will be done in the near future, especially on top of a gravity corer, on top of bare rods with a well-defined shape like penetration cones and in areas with known subsoil. This will allow comparison of the LIR meter data with special soil characteristics and provide the chance to describe seafloor properties with higher accuracy. The LIR meter is undoubtedly useful to qualitatively characterize seafloor stability. A soft and unstable ground can be recognized by a smooth retardation of the lance and a slow decrease in velocity with penetration depth, whereas stable ground would cause strong retardations and a rapid loss in velocity.

Conclusions

The LIR meter is a very compact, rather inexpensive and easy-to-use tool to monitor the penetration of a lance into the seafloor and to qualitatively check for seafloor stability in a simple way at any water depth. The deep-sea test in the Tonga Trench demonstrates that it is furthermore possible to check for layers in the upper-ocean bottom.

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