THE SPEED OF SOUND IN WATER

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The introduction of the echo sounder into routine hydrographic surveying, replacing dependence on use of the lead line, produced a major change. It must be remembered that a sounder actually registers a time interval and that the speed of sound must be known to convert the time to depth. The International Hydrographic Bureau resolved that 1500 metres per second should be adopted as a standard velocity. Most Canadian waters are cold enough that this causes an overestimate and for calibration the value of 1463 metres per second (800 fathoms per second) is frequently used. Since fresh water has to have a temperature of 14.2°C before this speed is attained most soundings in deep lakes will be overestimated with this calibration.

The velocity of sound in water depends upon temperature, concentration of dissolved constituents (for which salinity is the conventional quantity in oceanography) and pressure. The actual value at a given location and time may be evaluated by use of one of the following procedures:

(1) A "bar check" by which the echo from a reflector lowered to a known depth is observed. This is conveniently carried out in shallow water with low currents, gives a mean velocity to the observed depth and simultaneously checks the calibration of the sounder. It is not too useful if the bottom soundings become very different from the check value because the average velocity is likely to change with depth.

(2) Direct measurement of the sound velocity as a function of depth. The appropriate mean velocity must then be calculated. This procedure can be time consuming in deep water and one must be satisfied that the velocimeter has been accurately calibrated.

(3) Reference to files of oceanographic or limnological station data observed in the same area at a similar time of year. The sound velocity is then found by reference to tables or use of an appropriate formula.

Early tables (up to 1939) were based on calculation from laboratory measurements of compressibility and additional thermodynamic data. Matthews' tables proved especially convenient since in addition to tables enabling calculation of in situ velocities he divided the oceans into oceanographically similar areas and published tables listing sounder corrections.

Following the introduction of digital computers formulas were fitted to the tabular data to permit large numbers of sound velocities to be routinely calculated.

By 1952 it had been shown that the near surface velocities given by Matthews and similar tables were about 3 m/s too low. In 1960 Wilson published the first measurements which included the variation with pressure to the values reached in the ocean depths. His formulas were widely adopted by oceanographers, replacing the earlier computation schemes. It is worth noting that in spite of the 3 m/s increase in near-surface velocity from earlier values the Wilson results agree with the tables for pressures corresponding to depths of 2000 metres.

Over the next decade there arose some questions about values from the Wilson equation. Part of this arose from the fact that the observations used by Wilson in developing his equation included combinations of temperature, salinity and pressure not found in nature. In addition it appeared that his atmospheric pressure values were high, perhaps as a result of inadequate abolition or correction of systematic errors. There was of course no guarantee that additional systematic errors were not introduced at high pressures.

A new program of determining sound velocities over range of temperature, salinity and pressure matching conditions throughout the oceans was engaged in by Del Grosso and Mader of the Naval Research Laboratory, Washington. Their results have been fitted to a new equation by Del Grosso which is also valid for fresh water. Recalculation of velocities for a meridional section of oceanographic stations in deep water gives velocities near the surface 0.2 m/s less than Wilson with the discrepancy at greater depths increasing, until the Del Grosso formula gives velocities 0.5 to 0.6 m/s less than the Wilson Formula. Recently Medwin has published a much simpler formula than Del Grosso's which for depths less than 1000 metres gives values in good agreement with those from the more complete formula.

An independent study of the dependence of sound velocity on temperature, salinity and pressure is being carried out by Kroebel and Mahrt of the University of Kiel. Their preliminary work, at atmospheric pressure, in both fresh and sea water agrees with that of Del Grosso within a few centimetres per second. They have not yet reported results on pressure dependence.

The effect of the changes in sound velocity formulas on echo sounding can be summarized as follows. In marine waters of Canadian interest Matthews gives corrections to raw depths read from a sounder calibrated for 1463 m/s. As percentages of the raw depth these are:

	approximate depth		
	200 m	3000 m	4800 m
Off Nova Scotia	1.5%	1.7%	--
Off Labrador	0.5%	1.6%	--
SE of Grand Banks	--	2.3%	3.2%
Arctic	-1.5%	0.5%	--
Near B.C. Coast	0.5%	1.5%	--
Pacific Offshore	--	1.7%	--

These are of sufficient magnitude to deserve consideration.

Going from Matthews' velocities to those of Wilson involves a further correction increasing depths by up to 0.2% of their value. It is probably not worth applying such a modification to values from the tables because the zone boundaries as published do not exactly describe the oceanographic conditions. The formula of Del Grosso predicts depths about 0.04% less than those given by use of Wilson's formula.

Use of the modern sound velocity formulas for correcting soundings in areas with adequate oceanographic coverage will give better estimates of true depth. Great care must be taken in combining old and new soundings to avoid contouring in imaginary features arising solely from the use of different depth corrections.

Because oblique propagation as is involved in side scan sonar is affected in a complicated manner by ray bending depending on the gradient of velocity with depth the effects of the different formulas cannot be easily summarized.

References

There is considerable literature on sound velocity in water. I have referred to work reported in a small number of papers. Examination of the recent papers will provide a comprehensive list.

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NOTE: Purists may cavil at the use of the word "velocity" to describe a scalar magnitude. However it is the conventional use in underwater acoustics.

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