THE VELOCITY OF SOUND IN SEA-WATER (*)

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SUMMARY. The velocity of sound in sea-water varies with the temperature, the pressure and the salinity. For scientific measurements it is obligatory to introduce the true mean values in the calculations, but for practical purposes a uniform value of 1500 m/sec. is proposed.

In the present day practical application of hydrophony, acoustic soundings play an important rôle. In taking such acoustic soundings the sound is produced near the surface of the water and is propagated to the bottom where it is reflected. The echo is caught, generally on a chronometric device, which is released the instant the sound is given out. The measurement of the depth is established as a time measurement on the basis of the product of half the time interval of the sounding by the velocity of sound. To measure a distance, simultaneous radio-electric and hydrophonic signals are emitted, the distance between the places of emission and reception being determined by the chronographic difference in their reception, by multiplying the time elapsed by the velocity of propagation of sound in water.

To obtain sufficient accuracy with the two methods, it is necessary to know the exact velocity of sound in sea-water.

F. AIGNER (1), in 1920, gives for the sole value measured in open water, that determined by COLLADON and STURM in Lake Geneva, over 100 years ago (1826), which at a water temperature of 8° was $a = 1435$ m./se.

In the last few years a series of measurements have been taken and worked out not only in Germany (2) but in England (3), America (4) and France (5) in very different seas. These measurements serve as check on the calculated velocity of sound. The oscillatory process takes place adiabatically and for that reason we may take the adiabatic compressibility K_a as the basis instead of the isotherm K_i, which is more frequently measured in these experiments. The necessary correction due to this factor is obtained by dividing K_i by the ratio of the specific heats $\varkappa$. We then have $a = \sqrt{\frac{\varkappa}{\rho\, K_i}}$ where the density ρ, K_i and $\varkappa$ are dependent of the temperature T, the salinity σ and the pressure P. The pressure is dependent first on the depth, *i.e.* the stationary pressure of the water over the observation spot and secondly on the acceleration of gravity, and hence on the geographical latitude.

The compressibility of water decreases with increasing temperature, increasing pressure and increasing salinity. This results in an increase in the velocity of sound.

(*) *The attention of the I.H.B. was directed to this article by the Verein Deutscher Ingenieure of Berlin.*

(1) F. AIGNER: *Unterwasserschalltechnik, Berlin, Krayn* 1922, p. 44.

(2) H. MAURER, *Ann. d. Hydro. etc.*, 52 (1924), pp. 75 and 221.

(3) A. B. WOOD, *Proc. Roy. Soc. London (A)* 103 (1923), 284.

(4) E. B. STEPHANSON, *Phys. Rev.* 21 (1923), 181; E. A. ECKHARDT, *Phys. Rev.* 24 (1923, 452; N. H. HECK and J. E. SERVICE, *Special Publication N° 108, U. S. Coast & Geodetic Survey, Washington,* 1924; N. H. HECK and J. H. SERVICE, *Science* 64 (1926), 627; J. H. SERVICE, *John Franklin Institute,* 206 (1928), 779.

(5) H. BRILLIÉ, *Génie Civil* 75 (1919), 171, 191 and 218; M. MARTI, *Comptes Rendus,* 169 (1919), 281; M. MARTI, *Annales Hydrographiques,* 705 (1920), 165.

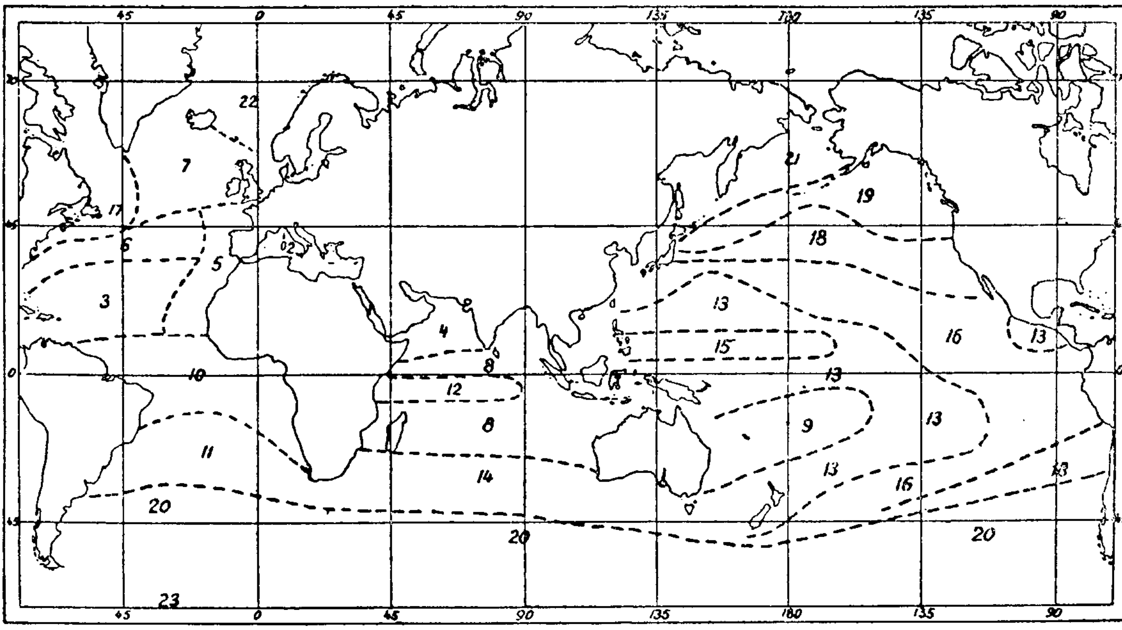

FIGURE 1.

Division of the seas into 23 zones of equal velocity of sound propagation according to the proposal of the British Admiralty.

The density increases with increasing temperature from 0° to 4° C. and increases with increasing salinity and pressure. It does not influence the velocity of propagation as greatly as the compressibility.

As an approximation we may state that the velocity of sound *a*

1. increases for each increase of 1°C by 0,2 %,
2. is augmented for each 100 m. depth by 0,11 %
3. increases about 0,1 % for about 1 % increase in salinity.

The British Admiralty (6) has divided the seas of the world into 23 different areas, for which they assume approximately equal velocities of sound propagation in echo-sounding (Fig. 1). The German exploring vessel *Meteor* measured the temperature and salinity at all levels at 310 stations in 6 of these 23 areas.

According to Professor MAURER (7), the velocities of sound determined from these observations agree very closely with those of the British Admiralty however, the boundary of zone 10 should be moved somewhat to the northward. In the eastern, colder part the velocities are somewhat lower than those given by the British Admiralty.

But taking all the 310 stations at which accurate measures were taken, only eight echo-distances were found which differed more than 20 metres from the value calculated from the tables, consequently if these English values are confirmed in other sea areas, they may be used to convert the apparent echo-distances, obtained on the assumption of a constant velocity, to true echo-distances.

The variation in mean velocity in terms of the depth is evident from Figure 2. There is, first, a decrease in the mean velocity with a drop in temperature, then an increase as a result

(6) *Tables of the velocity of sound in pure water and sea-water for use in echo-soundings and sound-ranging. Hydrographic Department, Admiralty, London,* 1927.

(7) *I am indebted to* Prof. H. MAURER *for kindly placing at my disposal a copy of his report drawn up at the end of April* 1924 *for the International Hydrographic Bureau.*

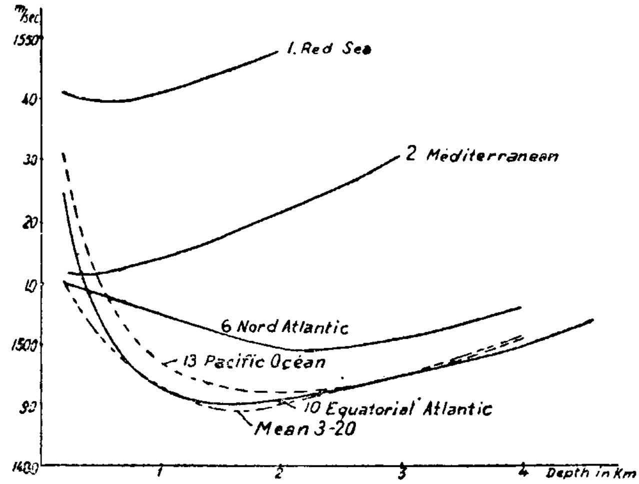

FIGURE 2.
Average velocity of sound in the different areas of the oceans, relative to the total depth.

of the influence of pressure. Average values are deduced for the areas 3 to 20, *i.e.* excluding the very warm seas (Red Sea and Mediterranean) and the very cold polar seas.

The mean value therein for all depths is 1496 m./sec.

While the values thus observed by the *Meteor* are in close agreement with those calculated by the British Admiralty, differences arise in the determination of sound velocities in relatively shoal water, *i.e.* generally less than 50 metres over considerable distances. Table I gives the most recent observations (8).

TABLE I.

Observer	*Temperature* °C	*Salinity* %	*Depth* m	*Velocity in m/sec.* Observed	H. & S.	Brit. Ad.
STEPHENSON........ 1923	− 0,3	33,5	18 − 50	1453,0	1449	1442,2
MARTI................ 1919	15	32,5	13	1504,15	1503	1500,9
WOOD, BROWNE... 1923	6	35	30	1474,15	1474	1472,0
WOOD, BROWNE... 1923	7	35	30	1477,3	1478	1476,1
WOOD, BROWNE... 1923	16,95	35	30	1510,4	1514	1510,4
ECKHARDT 1924	13	33,5	30	1492,3	1498	1495,5

The value observed by WOOD in summer is presumably the most accurate and should not differ more than 0,5 m/sec. from the true value. As the observations were all made near the coast it must not be forgotten that foreign matter and gases in solution have an effect over great distances in the water which up to the present it has not been possible to determine. Further an explosion was used as a signal to bridge these long distances of 50 km. and more. But depth measurements have shown that when several echoes occur with the use of an explosion as a source of sound-waves, the first echo-interval is shorter than the following ones, which latter show close agreement amongst themselves, *i.e.* the sound waves are propagated at first with increased velocities.

The exact values of sound velocities are of very great importance for surveying and for oceanographic research. For purposes of practical navigation a mean value suffices, since it is materially impossible for a merchant vessel to observe the distribution of temperature and salinity.

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(8) *For purposes of comparison with observed values, the last column gives those deduced by calculation according to the* HECK & SERVICE *(H. & S.) and the British Admiralty (Brit. Ad.) tables.*

For navigational purposes, such important features as submerged islands, shelves of the continents, etc. may be marked on charts as echo intervals multiplied by a definite uniform velocity of sound. When acoustic sounding has come into general practical use, a wealth of soundings will be available shortly afterwards in all the seas. These values could not be used by other sea-farers unless it is known on what velocity of sound the soundings are based.

An international agreement on this question is advisable. *For this reason a request was made of the Committee on Oscillations of the Verein Deutscher Ingenieure, with the view to obtaining uniformity in sonic sounding appliances and to facilitate the general use of published soundings, to support the proposal made by the German Navy Department to the International Hydrographic Bureau at Monaco,* i.e., *the adoption of a standard velocity of sound in sea-water for depths greater than* 200 *metres* (*). *As a uniform sound velocity, the value* a = 1500 m/sec. *is proposed.* Up to now the German Navy has used $a = 1490$ m/sec.; but the mean value of the British Admiralty Tables lies closer to $a = 1500$ m/sec.

SUMMARY.

For purposes of surveying and oceanographic research, the value of the mean velocity of sound in sea water to be employed in the determination of the depth must be exactly known. The Tables prepared by the British Admiralty for the computation of the mean sound velocity at definite depths and in definite areas of the sea show close agreement with the measurements which have actually been carried out.

For the purposes of practical navigation, it will suffice to adopt one single velocity of sound for calculation of depths, consequently it is proposed that the value $a = 1500$ m/sec. be adopted internationally as uniform value of sound velocity.

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(*) *The Directing Committee of the International Hydrographic Bureau invites attention to Resolution N*° 22, *adopted in April* 1929 *by the First Supplementary International Hydrographic Conference :—*

1. (a) "*that the soundings obtained by echo be plotted on charts after having been corrected as much as possible.*

(b) "*that they should not be distinguished from other soundings marked on the chart.*"

2. *The Conference did not adopt a standard velocity for propagation of sound through sea-water.*