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THE LITTORAL SEMI-DIURNAL TIDAL WAVE IN THE GULF OF BISCAY (**)

– At the same time as the technological developement of a new deep-sea tide gauge, taking advantage from the work of Eyries [1], scientific studies on the off-shore tides are carried at the Oceanographic Center of Brest. First of all, we made a rapid survey on tide at the limit of the littoral part of the Gulf of Biscay.

The positions of the six stations on the bathymetric line of 200 meters are given by the fig. 1. The current measurements were made by Aanderaa currentmeters and those regarding the variation of the sea level by a prototype of the french tide gauge using a differential manometer with vibrating strings. The measurements lasted for about two days. During this period, the semi-diurnal tide is represented by the M2 component of a period $T_0 = 12.42$ hours $= 2\pi/\omega_0$. –

At the six stations current was measured at depths of 50, 100, 150 m. Simultaneous measurements of the varation of the sea level were made at the three southern stations; in the northern part we were not able to make further measurements because we lost the tide gauge, but we had the data of Eyries [1] at our disposition.

The elaboration of the current and height data consisted in an extraction, by means of harmonic analysis, of the M2 components. The Table I presents the characteristics of these components in form of amplitude and phase difference of ζ, variation of the sea level, and of u and v, east and north components of the current. Times are expressed in mean lunar time, with an origin chosen to be the instant of the M2 high water in Brest. A special column gives for each record the value of the tide " coefficient " which is used in France to keep into account the tide variations: it is stated as the amplitude ratio of the semi-diurnal tide in Brest to a characteristic height which has a value of $3 \cdot 21$ m. In the last column, the r coefficient gives the amplitude ratio of the local M2 component to the simultaneous Brest one.

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We notice that there is a question mark on two current measurements near the surface, because of the effect of swell and transient phenomena.

Before giving an interpretation of the measurements it is good to place in its general context the problem of the M2 tide in the Gulf of Biscay. The fig. 2 shows the chart of cotidal lines of the M2 oceanic tidal wave in the Northern

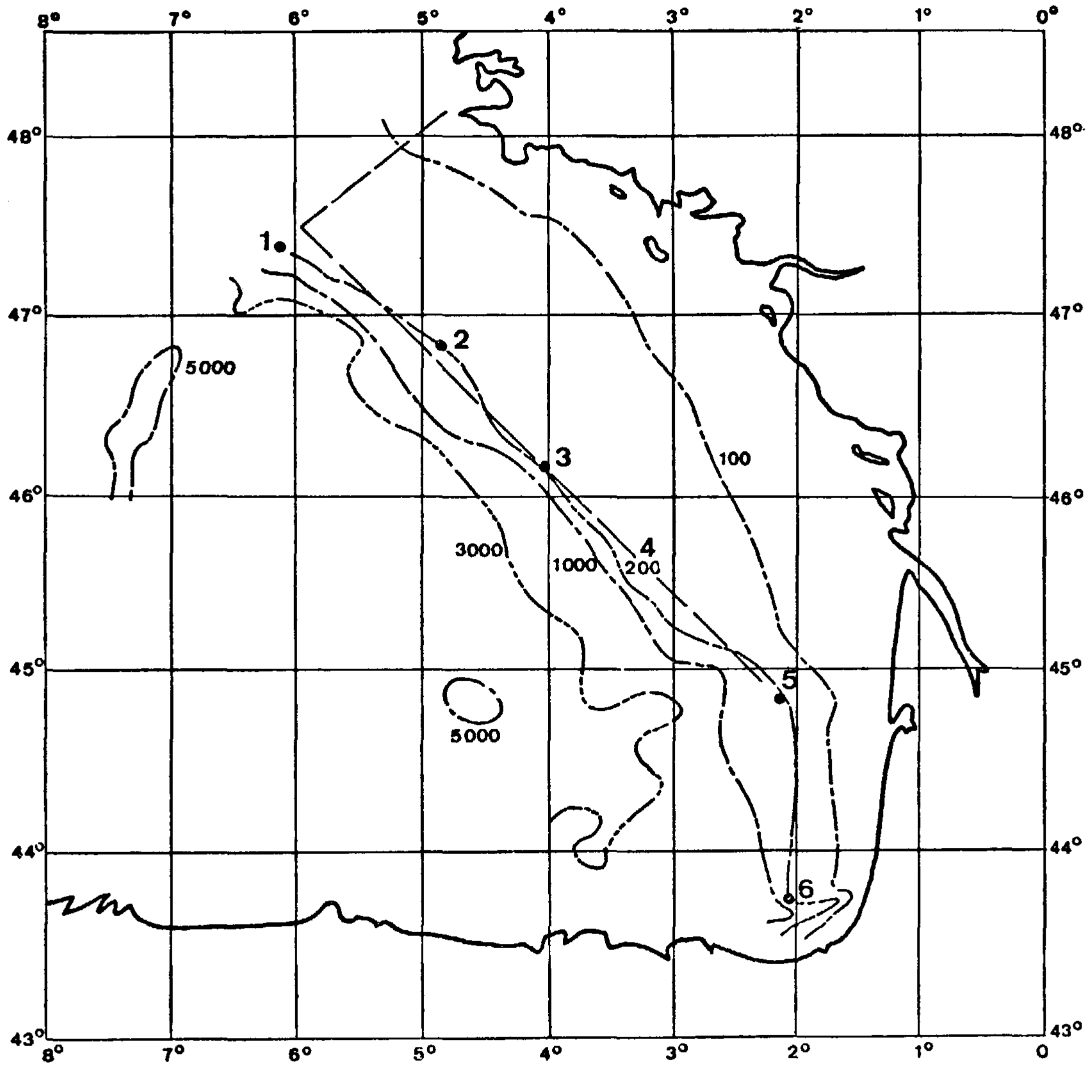

Fig. 1. – Positions of the stations.

Atlantic, following Dietrich [2]. We can see it is characterised by an amphidromy and that the oceanic wave reaches the littoral part at about 3 h of cotidal time. Dietrich gives to this cotidal line a special drawing making it to penetrate in the Gulf of Biscay before coming back to the Finisterre Cap.

The problems we dealt with are the connexion between the oceanic wave and the littoral wave, and the effect of the shore and of the bottom friction on the littoral tidal wave. Is there any creation of a progressive wave with energy transmission, at the limit between ocean and the littoral part?

TABLE I.

Characteristics of the M 2 *components.*

			u		*v*			ζ		
Station	Prof.	Coef.	Amplitude	Retard	Amplitude	Retard	Coef.	Amplitude	Retard	*r*
1	35 m	85	45 cm/s	—1h39 mn	—54 cm/s	+1h29 mn				
	85 m	85	44 cm/s	—1 20	—53 cm/s	+1 35				
	135 m	85	34 cm/s	—1 14	—52 cm/s	+1 37				
2	45 m	80	25 cm/s	—2h16 mn	—23 cm/s	+1h58 mn	70	140 cm	—21 mn	0,70
	95 m	80	33 cm/s	—2 25	—18 cm/s	+1 46				
	145 m	80	33 cm/s	—2 30	—27 cm/s	+1 31				
3	50 m	85	23 cm/s	—2h23 mn	—21 cm/s	+0h35 mn				
	100 m	85	26 cm/s	—2 12	—28 cm/s	+1 28				
	150 m	85	27 cm/s	—2 27	—25 cm/s	+1 10				
4	? 50 m	50	17 cm/s	—2h39 mn	—16 cm/s	+0h13 mn	50	82 cm	—18,5 mn	0,59
	100 m	50	17 cm/s	—2 58	—21 cm/s	+0 37				
	150 m	50	24 cm/s	—3 27	—26 cm/s	+0 42				
5	50 m	68	—19 cm/s	+1h56 mn	—13 cm/s	+0h07 mn	68	116 cm	—25 mn	0,59
	100 m	68	—12 cm/s	+1 34	—15 cm/s	+0 05				
	150 m	68	—24 cm/s	+1 33	—16 cm/s	+0 32				
6	? 44 m	84	4 cm/s	+3h43 mn	6 cm/s	+0h24 mn	84	167 cm	—44,5mn	0,65
	94 m	84	—11 cm/s	+2 05	— 6 cm/s	—0 59				
	144 m	84	—23 cm/s	+2 23	—15 cm/s	—1 18				

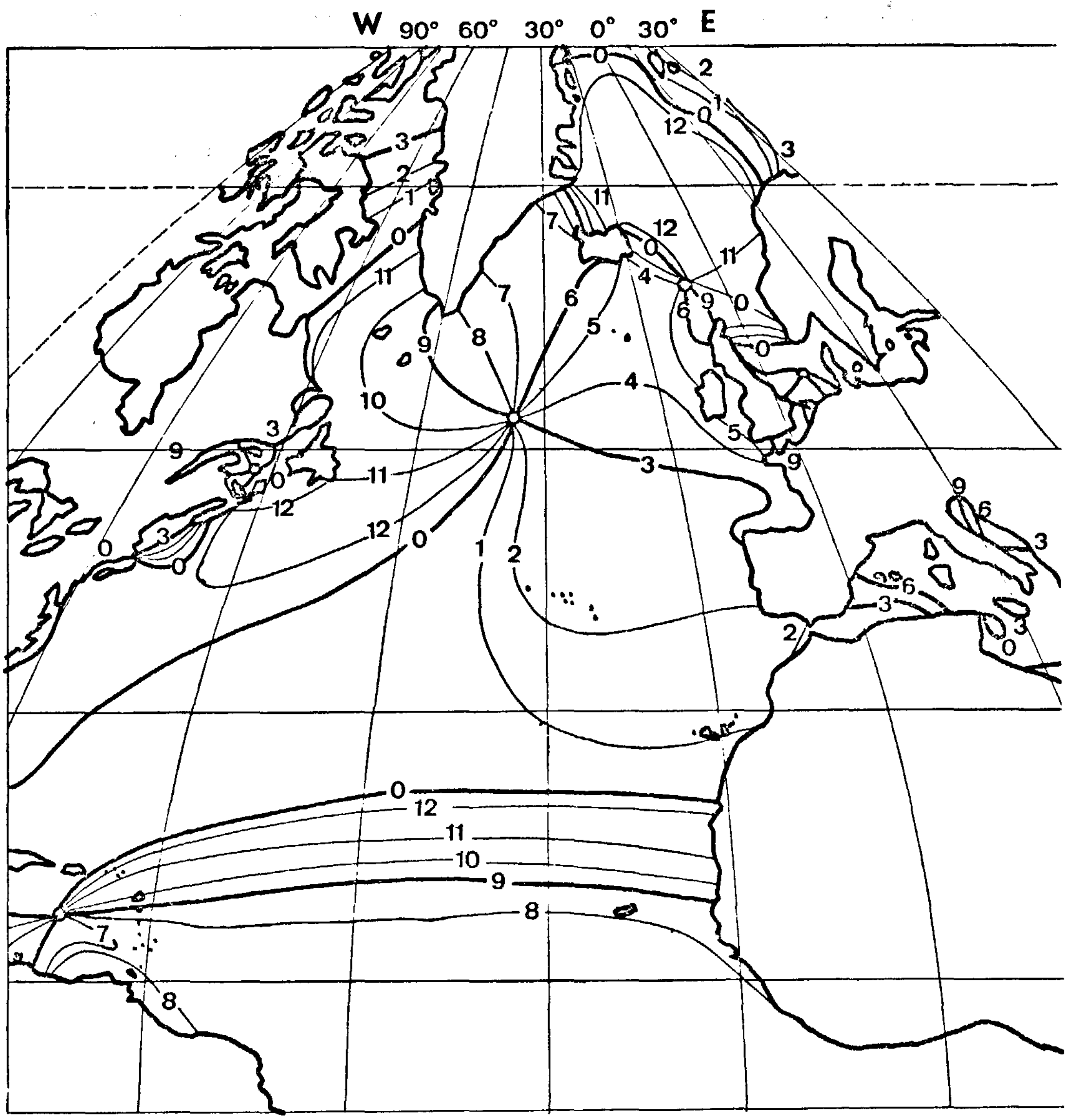

Fig. 2. - M2 tide in the northen Atlantic.

On this limit the depth law has a discontinued derivative and the classical assumptions of the general tidal equations:

$$\left\{ \begin{aligned} &\frac{\partial \vec{V}}{\partial t} + \vec{V}\nabla\cdot\vec{V} + 2\,\vec{\Omega}_n \wedge \vec{V} + g \operatorname{grad}(\zeta - \overline{\zeta}) + f\frac{|\vec{V}|}{h+\zeta}\,\vec{V} - \nu\Delta\vec{V} = 0 \\ &\frac{\partial \zeta}{\partial t} + \nabla(h+\zeta)\,\vec{V} = 0 \end{aligned} \right.$$

are not verified any more. On the littoral part the depth h is small and the action of the generating potential may be neglected: the littoral wave is governed by the oceanic wave. The friction becomes important and the effect of the non linear terms is to modify the mean level and to give superior harmonics in the currents and in the variation of sea level.

The fig. 3 gives the chart of the M2 wave in the Gulf of Biscay deduced from our measurements. The cotidal lines were drawn starting from a value of 3 h 36 mn for the cotidal hour for Brest, so that the figures are compatible with those of Dietrich. The equal amplitude lines are written down in ratio with the M2 wave at Brest. It will be noticed that the 3 h 15 m cotidal line and the shore line hawe almost the same curvature. The slight variation

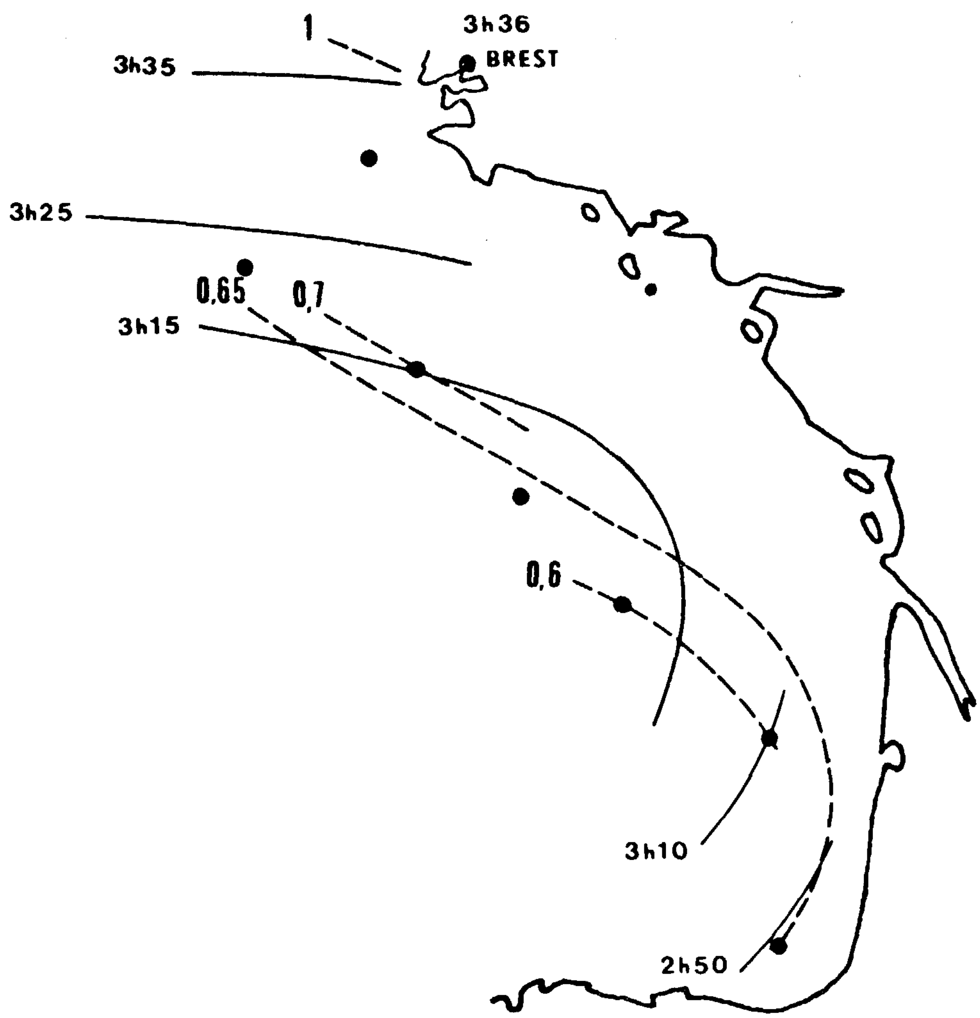

Fig. 3. – M2 tide in the gulf of Biscay.

of the high water time on the whole shelf show that we have a quasi-stationary wave. At the latitude of Brest the apparent celerity is of about 150 m/s while the Laplace formula gives only 40 m/s. The M2 chart so outlined allows a correction of those proposed by Dietrich and Fichot.

Special curves of the M2 tidal current were not shown. It is therefore interesting to notice that we obtained currents ranging from 50 to 20 cm/s from North to South and regulary turning on their right. The maxima values of current and amplitude are coherent with the ratio $\sqrt{h/g}$ theoretically obtained for a unidimensional stationary wave without geostrophic effect. Also characteristic are the differences of phase between current and sea level variation, of about 3 lunar hours. At the time of local M2 high water, the current direction progressively turns from S E (for the northern station) to S (for the central stations), to S SW and SW W for the two last stations. We see in these results the geostrophic effect increased by the deflection effect of the shore. The water mass transport so created may explain the curvature of the equal amplitude lines tending towards those of the shore.

The stationary character of the M2 wave makes the use of an energetic budget method delicate because of the difference of phase between the current and the change of the sea level. In a general way, if Σ is a finite area of the geoid, whose boundary $S = S_1 + S_2$ (S_1: shore, S_2: open boundary) has $\vec{n}$ as unit normal.

$$\int_{S_2} \{\rho g \vec{V} \cdot \vec{n} (\zeta - \overline{\zeta})\} (h + \zeta) \, dS_2 =$$

$$= \int_{\Sigma} \left\{ \frac{d}{dt} \frac{1}{2} \left(\vec{V}^2 + \frac{g}{h+\zeta} \zeta^2 \right) + f \frac{|\vec{V}|}{h+\zeta} \vec{V}^2 + g \frac{d\overline{\zeta}}{dt} \right\} \rho (h + \zeta) \, d\Sigma$$

expresses the budget of time-rate of doing work across S_2 and of energy inside Σ. For a littoral sea, astronomical terms with $\overline{\zeta}$ may be neglected, and if we only consider the M2 tide with mean values upon the period T_0, we have:

$$\int_{S_2} \frac{1}{2} \rho g h \, \zeta_{max} \, (\alpha u_{max} \cos \omega_0 \vartheta_0 + \beta v_{max} \cos \omega_0 \vartheta_0') \, dS_2 = \int_{\Sigma} \frac{4 \rho f}{3\pi} (u_{max}^2 + v_{max}^2)^{3/2} \, d\Sigma$$

formula in which:

a) α and β are the east and north components of $\vec{n}$;

b) ϑ_0 and ϑ_0' are the phase differences between u and v with ζ.

Our measurements on the six current stations give us the value of $4 \cdot 10^{10}$ W as mean value of the time rate of doing work going open across the boundary of the stations line. The experimental value of $2 \cdot 10^{-3}$ for the adimensional coefficient f of the quadratic frictions law, corresponds to this loss of energy due to friction on the whole shelf.

It is also interesting to note that the slope of $3 \cdot 10^{-7}$ of the sea water surface at the high current time and in the direction of the general flow, correspond to a value of f of about $2 \cdot 10^{-3}$ if we make the assumption of an equilibrium between friction and surface gradient. This value is coherent with those found in other littoral seas.

By the harmonic analysis, the estimation of the amplitude of superior harmonics of ζ was 0.10 m for a M2 amplitude of about 1.4 m.

REFERENCES

[1] EYRIES M., *Marégraphie par grand fond.* Cahiers Océanographiques, XVI^ème^ année, n. 9, novembre 1964.

[2] DIFTRICH and KALLE, *Allegemeine Meereskunde.*