CHAPTER 165

QUANTIFICATION OF LONGSHORE TRANSPORT IN THE SURF ZONE ON MACROTIDAL BEACHES

Field experiments along the western coast of Cotentin (Normandy, France)

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ABSTRACT : Many *in situ* measurements of hydrodynamic parameters and sediment transport in the surf zone have been carried out on the beaches of the western coast of Normandy. The vertical and cross-shore distributions of the sediment transport induced by breaking waves have been identified in a set of various hydrodynamic conditions. Several longshore sediment transport formulas have been devised. The comparison between measured and computed transport rates enables choice of the best formulation according to the hydrodynamic context. This formulation emphasizes the indirect effect of tidal fluctuations on the wave characteristics and the sediment transport processes.

INTRODUCTION

For engineering purposes, the prediction of long term evolution of a sandy coastline requires insight into sediment circulation on beaches, specially sand movement along coasts where oblique waves induce longshore currents.

Many formulas exist to calculate the longshore sediment transport in the surf zone, but they have been defined for microtidal environments from experimental research. The goal of this paper is to present field results in a very specific tide dominated environment and to evaluate the performance of some empirical formulas in these hydrodynamic conditions.

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PROJECT SITE

In order to prevent erosion that was affecting thc west coast of Cotentin Peninsula, the local government authorities decided to implement in 1989 a research programme aimed at elaborating a global coastal defence policy (Levoy F., Avoine J., 1991).

Field studies, carried out in the framework of this project constitute the R.O.M.I.S. program, a French acronym for Réseau d'Observations et de Mesures In Situ (field observations and measurements system). The main goals of this program were to understand how sediments respondes to various hydrodynamic conditions. It was applied from the Cape Carteret to Mont-Saint-Michel Bay, in a macrotidal area, where the tidal range decreases from 15 m in the South to 12 m in the North during high spring tides (Fig. 1).

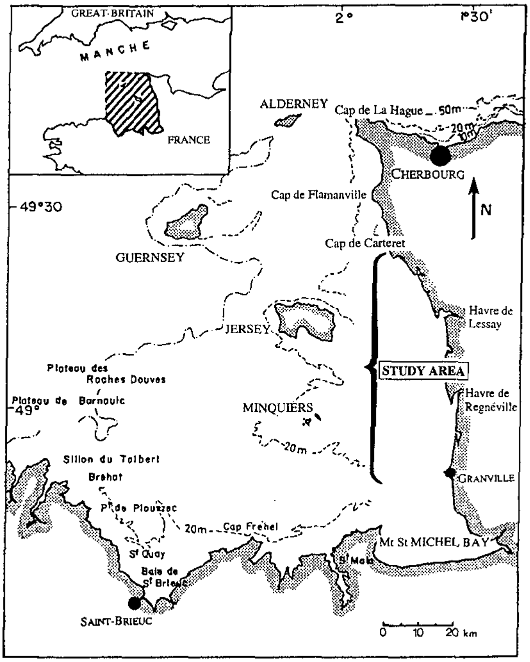

Figure 1. Location map of the study site

Open to the west offshore area, the western coast of Cotentin is exposed to long waves coming from North Atlantic Ocean. The propagation of these waves is affected by a complex bathymetry with numerous shoals and islands. The annual significant wave height in the north of the study area is about 4.2 metres. The attenuation coefficient of waves crossing the Channel island barrier reaches 0.7. The modal breaker height varies from 0.7 to 0.9 m and Dean's parameter, Ω (Hb/Ws.T) from 4 to 1.5.

This coast is characterized by a wide tidal flat with a steeper high tidal zone. At high tide, the upper foreshore behaves like a microtidal beach and long waves or, frequently, wind-waves induce opposite residual longshore movements, materialized by opposite spits near small inlets. In the surf zone, plunging breakers are often observed on a steeper beach slope. At mid-tide, spilling breakers take place on a smooth slope.

MEASUREMENT TECHNICS

To quantify the longshore sediment transports, 19 field experiments were carried out under the R.O.M.I.S program. Several parameters were recorded at different locations (table 1):

(1) dynamic parameters:

- tidal variations,
- tidal and wave induced currents with EMC and dye injections,
- on the lower part of the beach, wave characteristics (Hs, Tp, Ts, direction of propagation...) with S4DW from Interocean Corporation,
- breaker height with a graduated rod,
- wind conditions.

(2) morphological parameters and sediment characteristics:

-beach slopes with surveys at low tide using an electronic theodolite and infrared-ray distance meter,
- grain-size.

CAMPAIGN	date	time	Hb	Tp	Lp	Gamma	beach slope	grain size	grain size	Alpha	Q measured
			(m)	(s)	(m)	parameter	tan beta	of the beach	in the trap	degree	kg/m/mn
								Md (m)	Md (m)		
PORSLD1D	26.2.91	17:45	1.25	9.9	75.37	0.95	0.04	0.0002555	0.000166	14	3.20
PORSLD1E	27.2.91	17:12	1.35	13.7	95.85	0.99	0.026	0.0002555	0.000175	24	16.00
GOUCOU1B	17.4.91	11:00	0.5	4.6	29.82	0.96	0.0618	0.00051	0.0002	67	0.13
GOUCOU1C	18.4.91	8:40	0.75	3.4	17.93	0.78	0.1016	0.000652	0.00035	22	3.35
COUHAU1	15.5.91	19:40	0.65	3.4	17.77	0.78	0.0636	0.000243	0.000175	22	0.13
GERCRE1A	10.6.91	19:45	1.2	4.5	25.35	0.68	0.0185	0.000243	0.000163	19	0.32
GERCRE1B	11.6.91	17:00	0.6	9.6	42.81	0.56	0.0164	0.000243	0.000175	1	0.05
GERCRE1C	11.6.91	18:25	0.7	10.4	71.88	0.67	0.0195	0.000243	0.000181	3	0.06
GERCRE	13.6.91	20:00	1.1	10.8	76.88	0.78	0.0195	0.000243	0.000187	6	0.14
GERCRE1F	13.6.91	21:00	1.25	13	101.35	0.57	0.0613	0.000243	0.000187	12	1.30
GERCRE2	5.11.91	17:30	0.7	10	63.35	0.5	0.0175	0.000213	0.000181	9	0.40
GOUCOU2A	11.3.92	13:00	1.02	14.5	89.23	0.77	0.055	0.00035	0.000186	6	2.30
BARCAR2A	1.4.92	18:35	0.94	9.6	58.45	0.65	0.021	0.00038	0.000164	27	2.10
COUHAU2	29.4.92	20:30	0.87	4.1	20.9	0.78	0.0737	0.00038	0.000194	21	2.10
PORSLD2	23.9.92	17:15	0.79	3.8	20.38	0.64	0.0373	0.000316	0.000223	12	0.27
SPMJUL2	22.10.92	18:05	0.86	4	22.11	0.62	0.0262	0.000465	0.000268	7	1.70
UNSMB2	18.11.92	17:15	0.91	6	29.08	0.81	0.0524	0.00037	0.000296	42	37.60
SJTDRA2A	12.1.93	11:14	0.79	16.4	118.92	0.99	0.0539	0.00035	0.000535	40	35.80
SJTDRA2B	14.1.93	12:08	1.07	9.6	65.73	1.08	0.0539	0.00035	0.000235	25	10.60

Table 1. Characteristics of the field experimentation conditions

Sediment transport was measured in the breaker zone with streamer traps (Rosati J.D & al., 1990). Cross-shore distribution, with 3 or 4 traps perpendicular to the shoreline, and vertical distribution of sand fluxes, with 4 streamers on a single trap permit to calculate an integrated rate across the breaker zone. The duration of the runs varies from about 5 to 15 minutes on the mid tidal or high tidal zone, with typically one person carrying one trap. The sediment transport rates (Fig. 2) were calculated using the numerical method defined by Kraus and al (1989).

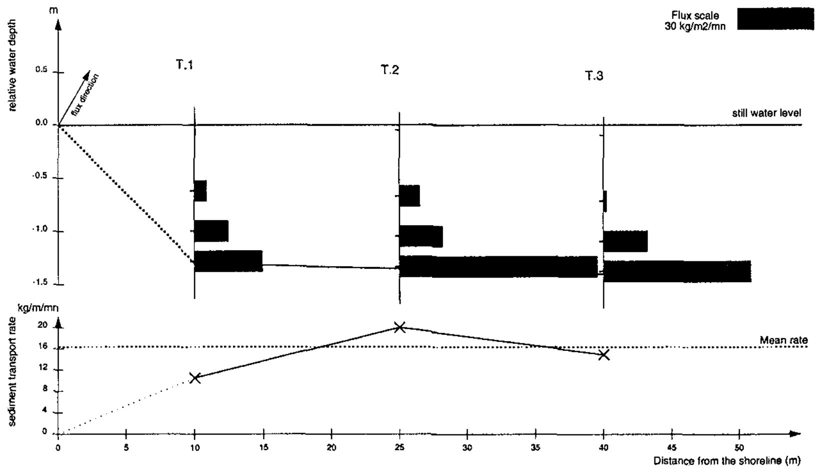

Figure 2. Example of results obtained from runs using sand traps in the surf zone

Various hydrodynamic and morphosedimentary conditions were observed during the experiments. The breaker height varied from 0.5 m to 1.35 m, the peak period, from 3.4 to 16.4 seconds, the γ parameter, from 0.5 to 1.08 and the beach slope from 0.016 to 0.1. The grain size on the beaches increased from the mid-tide beach to the upper foreshore, between 0.210 to 0.510 mm.

RESULTS

The first part of the field experiments consisted in measuring the hydrodynamics conditions.

Breaker and longshore current characteristics:

The breaker height, measured about 4 metres above the mean sea water level was always greater that the significant wave height on the lower foreshore, about 2 metres under the MSWL. The factor between these parameters varied from 2 to 1.15 when offshore wave conditions increased. During a typical semi-diurnal tidal cycle, the large variability of wave height induced a large variability of breaker wave characteristics (Fig. 3).

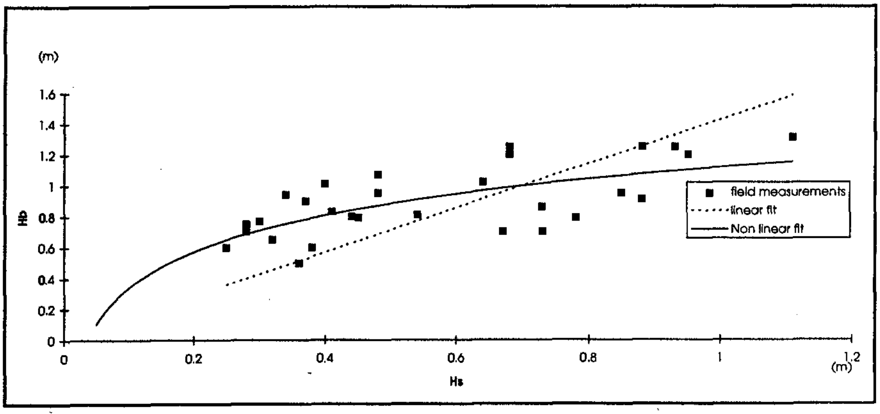

Figure 3. Significant wave height versus breaker height

The measurements confirmed the relationship between the γ parameter (breaker height to water depth ratio) and the beach slope (tan β). The modification of the slope along the beach profiles induced a temporal evolution of the γ parameter during a tidal cycle with a constant modification of the breakers characteristics (Fig.4).

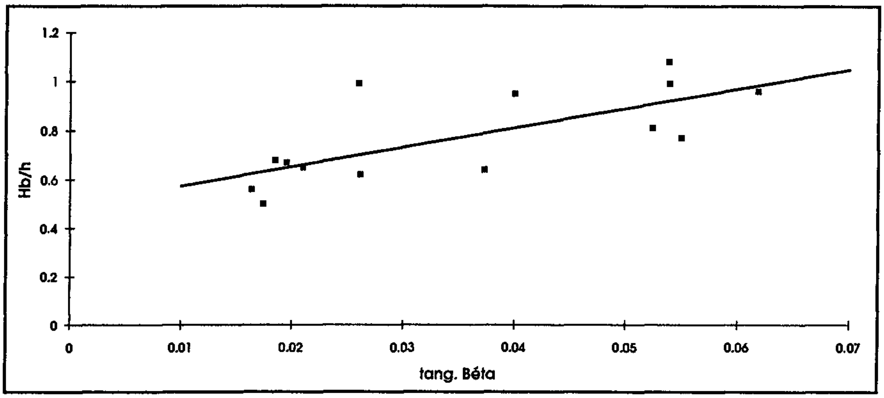

Figure 4. γ parameter versus beach slope

Some LST formulas use the longshore current velocity. The comparison between the calculated and the measured longshore velocities with some classical formulations did not give satisfactory results (Fig. 5). Most of the results were overpredicted. The best agreement between measured and calculed longshore currents was obtained with the Van Rijn formula (1990), derived from the Longuet-Higgins formula (1970). The empirical coefficient of this formulation was found to be equal to 5 in the field experiments (Fig. 6).

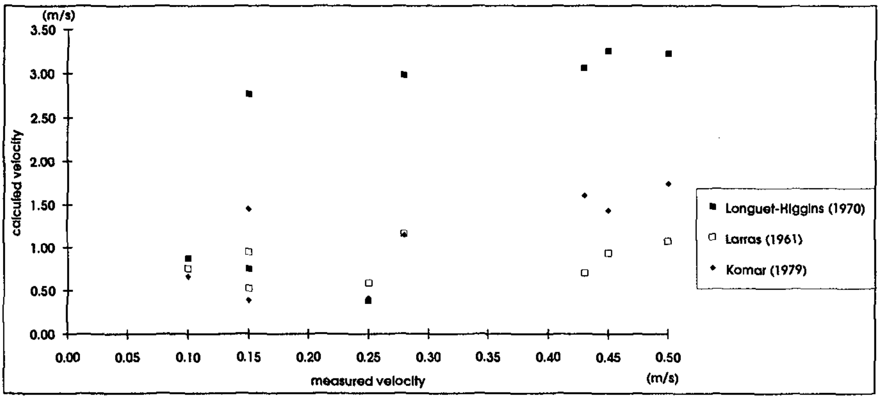

Figure 5. Comparison between measured and calculated longshore velocities with various formulations

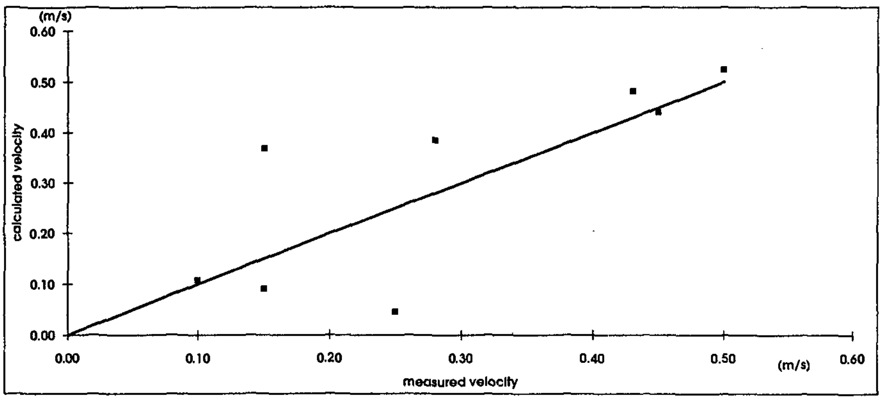

Figure 6. Measured and calculated velocities of longshore currents with modified Van Rijn formula (empirical coefficient=5)

Vertical and cross-shore distributions:

The vertical distributions of sand fluxes were best fitted with an exponential relationship, like the one described by Rosati and al (1991). The correlation coefficient, 0.67, was smaller than those obtained in American programs (0.9 during SUPERDUCK, 0.79 at Ludington), but the hydrodynamics and beach conditions observed along the western coast of the Normandy vary a lot, with specially long and wind-wave conditions (Fig. 7).

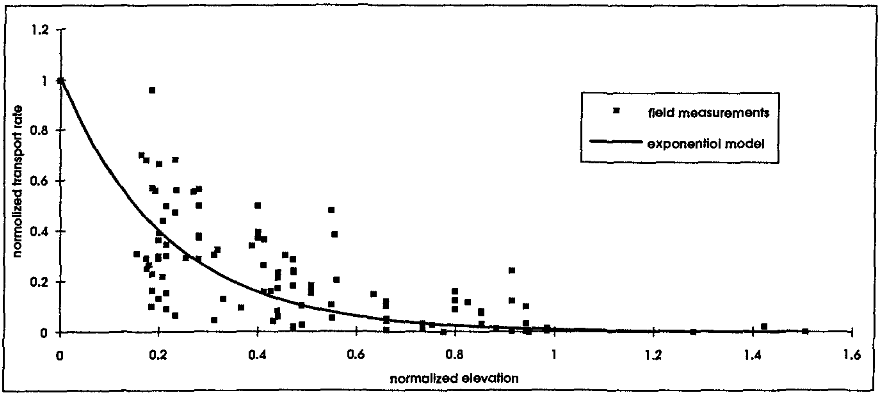

Figure 7. Vertical distribution of longshore sediment transport in the surf zone

In fact, there were two types of vertical sediment distributions in the surf zone:

- with long wave periods, suspended sediment transport dominated (Fig.8a),

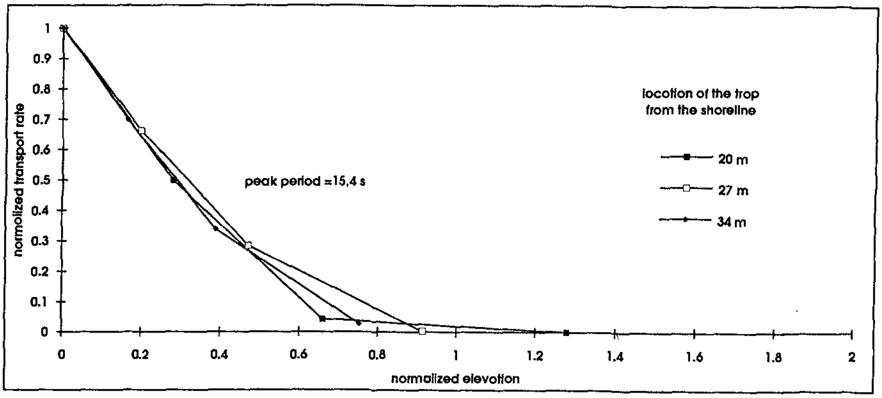

Figure 8a. Vertical distribution of longshore sediment transport during long wave conditions

- with short wave conditions, the bed-load transport became higher (Fig. 8b).

The bi-modal wave climate in the English Channel explains the dispersion of vertical distribution of sediment transport rates in the surf zone.

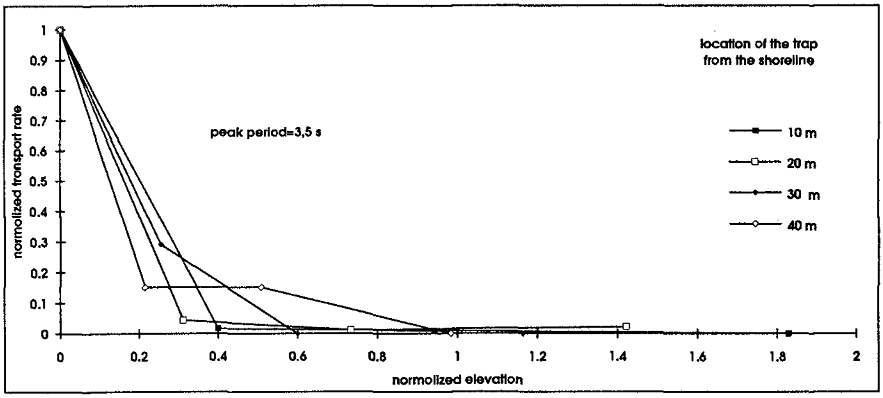

Figure 8b.Vertical distribution of longshore sediment transport during wind-wave conditions

For the cross-shore sediment transport distribution in the surf zone, two kinds of peak locations were observed (Fig. 9):

- first, in the swash zone (0.15<X/Xb<0.35), the normalized sediment transport rate sometimes attained 3 or 4 times the mean longshore sediment transport rate integrated over the width of the breaker zone. These movements were measured during wind-wave conditions, acting on steep beaches with small or medium breaker height.

-the second peak, more classical, was observed near the breakerline (0.6<X/Xb<0.7). The sediment transport rate was lower than in the swash zone and more homogeneous over the entire surf zone. These circulations were observed during long wave conditions at mid-beach level.

However, as opposed to Kamphuis' experimental investigations (1991), these two kinds of distributions were recorded independently, showing the narrow relationship between the hydrodynamic conditions and the transport processes.

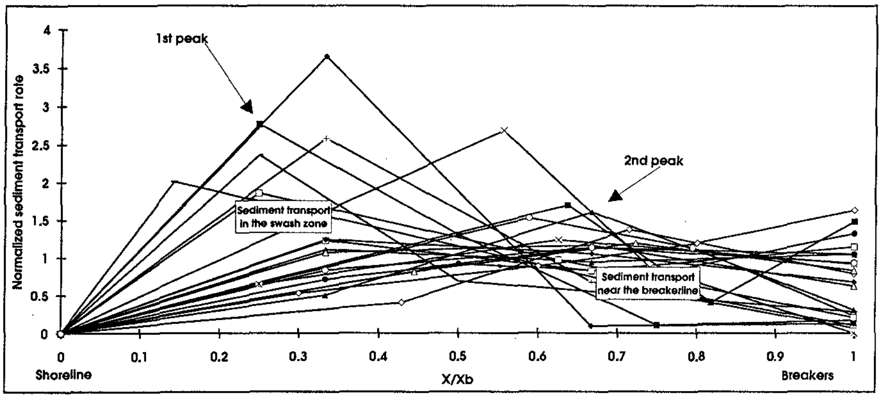

Figure 9. Cross-shore distribution of the longshore sediment transport in the surf zone

Grain size gradients in the surf zone

The traps used to calculate the sediment transport rate allowed collection of sand grains at several locations in the surf zone. Grain sizes of the bed were used to compare the ground sedimentary stock and the moving materials (Fig. 10).

During long wave conditions and large breaker height, with a well-sorted sediment on the beach, the moving sand grain size was lower than the beach grain size. The vertical and transversal distributions of the grain size were very close. Good mixing of the sediment was observed.

With wind-wave conditions, vertical and transversal grain size gradients appeared. The gradients were more important with a badly sorted sediment on the beach than with a well-sorted material. With bed-load processes prevailing during short wave conditions, only fine sediments were trapped in the upper layer of water. Between the bed and the water surface, the grain size was noted to vary from 1 to 2.

Even with a well-sorted sediment on the beach floor, a transversal gradient was identified. The coarser sediments were located in the swash zone, according to the cross-shore distribution of the sediment transport rate. The finer grain sizes, with a median diameter lower than that of the beach sand, were observed in suspension near the breakerline.

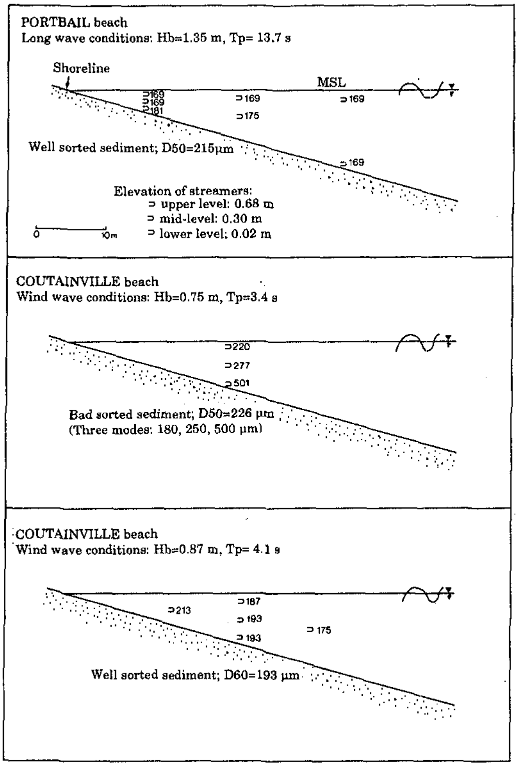

Figure 10. Grain sizes in the surf zone in various hydrosedimentary conditions

Comparison between measured and calculated rates

Several L.S.T. formulas were compared with results coming from in situ measurements. Two methods of calculation were used:

- Integral method:

(1) 1986' Kamphuis formula:

$$Q = 1{,}28.\frac{Hb^{3,5}}{D50}.\tan\beta.\sin 2\alpha b$$

with: Q= sediment transport rate (kg/s),
Hb= breaker height (m)
D50= median grain size (m),
tanβ= beach slope
αb = incident wave angle.

(2) 1990' Kamphuis formula:

$$Q = 0{,}0013.\left(\frac{Hb}{Lp}\right)^{-1{,}25}.\tan\beta^{0{,}75}.\left(\frac{Hb}{D50}\right)^{0{,}25}.\sin^{0{,}6}2\alpha b.\frac{\rho.Hb^3}{Tp}$$

with:
Q= sediment transport rate (kg/s),
Lp= peak wave lengh according to the peak period Tp (m),

(3) 1982' Kraus formula

$$Q = \frac{A}{\gamma b.\tan\beta}.Hb^2.Vl$$

with:
Q= sediment transport rate (m^3/s),
γb= Hb/Ht, Ht is the mean water depth,
Vl= longshore current velocity (m/s),
A= empirical coefficient equal to 0.00038

- Local method:

(4) 1989' Van Rijn Formula

In most cases, all these formulas overpredicted the sediment transport rates, especially when the transport was weak. The ratios between computed and measured rates were very high with the Kamphuis formulas, even though the second formulation improved the result (Fig. 11).

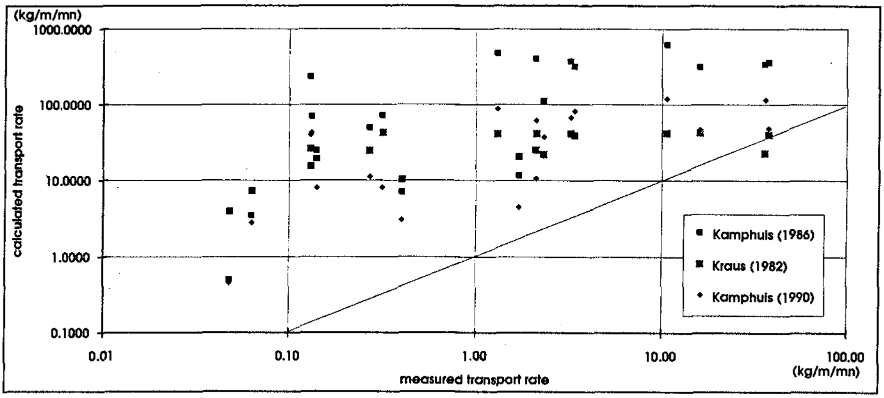

Figure 11. Comparison between measured longshore sediment transport rate and calculated rate with the Kamphuis and Kraus formulas.

Best agreement (factor of 1 to 3) was obtained in high energy condition, when the measured rate was greater than about 35 kg/m/mn. But under 5 kg/m/mn, the 1990' Kamphuis formula overpredicted with a factor of 10 and sometimes more for small sediment movements.

Kraus and Van Rijn formulas gave the best prediction of L.S.T. (Fig.12). But it was necessary to adapt the formulation to the hydrodynamical context (Fig. 13):

- on the upper part of beaches, when γ parameter was higher than 0.78 and incidence angle between the wave crests and the shoreline direction was greater than 25 degrees, a factor of about 2 was found between calculated and measured rates. In these cases, LST rates were greater than 10 kg/m/mn.

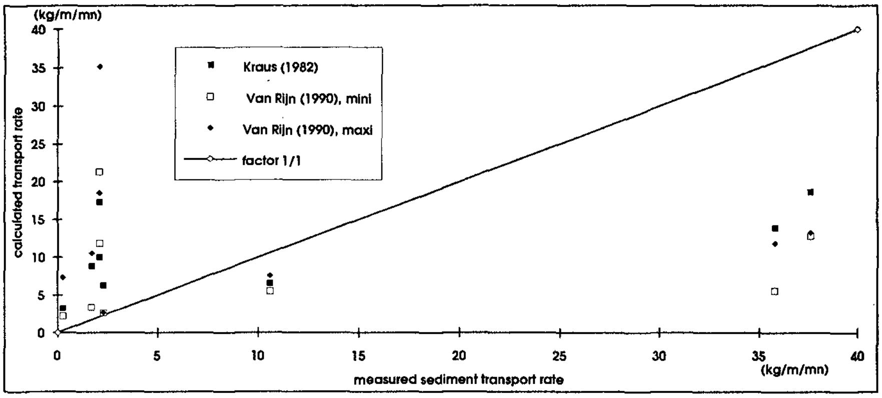

Figure 12. Comparison between longshore sediment transport rate and calculated rate with Van Rijn and Kraus formulas.

- when wave crest incidence angle was lower than 25 degrees and γ parameter lower than 0.78, the LST rate, in our experiments, was smaller than 5 kg/m/mn. In these cases, formulas overpredicted sediment movements (factor of 5).

A new formulation is proposed to calculate LST rates, taking into account the important variability of the wave approach incidence to the coast and the modification of γ parameter during the tidal cycle.

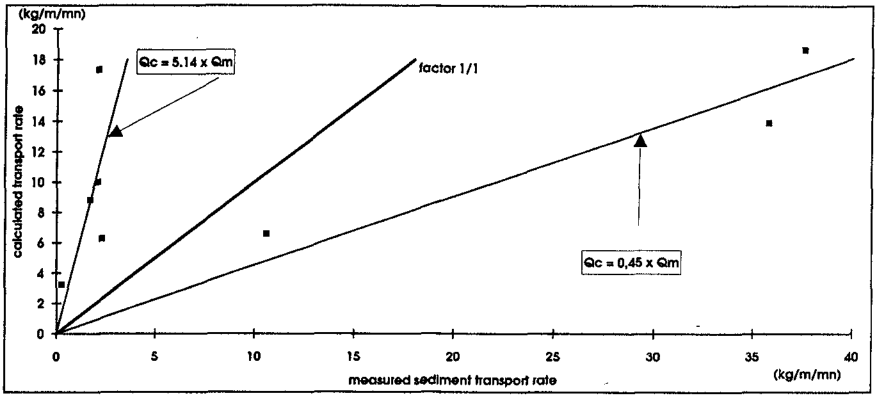

Figure 13. Comparison between measured longshore sediment transport rate and calculated rate with Kraus formula (the longshore velocities were deduced from field measurements)

Table 2 sumarizes the results obtained along the western coast of Normandy. It is necessary to underline the relationship between the tidal level, the beach slope and the breaker type. For each beach state, a new empirical coefficient derived from the Kraus formula can be calculated. But the factor between these two coefficients is about 10. ·As a result of this, in calculating a global longshore sediment transport, there is an important discripancy between the upper and the midforeshore rate. This dicripancy is not realistic.

Tidal level	Beach state	Breaker type	Empirical coefficient
high tide	reflective	plunging	$8.36 . 10^{-4}$
mid-tide	dissipative	spilling	$0.73 . 10^{-4}$

Table 2

CONCLUSIONS

(1) Several longshore sediment transport formulas have been tested and compared to our field experiment results. The Kraus formula gives the best agreement between the rates computed and the calculated values, during a large set of hydrodynamic conditions. But, it will be necessary to test other formulations in this kind of environment (S.P.M...).

(2) A local adaptation of the empirical coefficient is necessary to adapt the Kraus formulation to the regional hydrodynamic conditions. On macrotidal beaches, the tidal fluctuations, firstly, and the wave climate, secondly, induce a great temporal variability of several parameters in the surf zone. The breaker type, at different levels of the tidal cycle, connected to the beach slope and the water depth, is a parameter

which controls the sediment transport rate. The bi-modality of the wave frequency also induces two kinds of vertical and cross-shore sediment transport distributions, modifying the global sediment movement.

(3) Lots of field data will be necessary to reduce the factor between the new empirical coefficients. Their values should be defined taking into account, quantitatively, parameters that include the breaker type and the tidal fluctuation. The use of a combination between the RTR parameter defined by Masselink and Short (1994) and the Ω parameter should be a new way improving modelling of LST on a concave and wide beach profile such as that of macrotidal beaches.

ACKNOWLEGEMENTS

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