Wave-induced cross-shore sediment transport in the Ebro delta inner shelf

Transporte de sedimento transversal inducido por olas en la plataforma interna del Delta del Ebro

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ABSTRACT

The near-bottom wave-induced cross-shelf sediment transport is one of the main mechanisms to maintain morphologically inner shelves. In opposition to suspended sediment transport by currents that controls fine sediment dispersal (and in consequence sediment deposits) in the shelf according to the ambient current direction, when waves actively resuspend and transport sediment in the inner shelf, their contribution is generally shoreward. In this paper, the wave-induced cross-shore sediment transport in the Ebro delta inner shelf is analysed and a method to predict their importance is presented. The obtained results show that the efficiency of the waves can be predicted in terms of the Ursell number that indicates how non-linear the waves are. Thus, it was estimated that the annual frequency of occurrence of efficient waves to promote cross-shelf sediment transport in the Ebro delta is about 4.8% and that the integrated cross-shelf sediment transport is about 4.7 m³/m/yr.

Key-words: *inner shelf, Ebro delta, sediment transport, wave asymmetry.*

RESUMEN

El transporte transversal de sedimento inducido por olas es uno de los principales mecanismos actuantes en el balance de sedimentos de la plataforma interna. En el caso del transporte en suspensión por corrientes, la dirección de éstas determinará la dispersión del sedimento fino en la plataforma (y, en consecuencia, de los depósitos existentes). Sin embargo, cuando las olas resuspenden y transportan el sedimento ya existente en la plataforma interna, su contribución neta es generalmente hacia tierra. En este artículo, se analiza el transporte de sedimento a través de la plataforma interna del Delta del Ebro y se propone un método para predecir su importancia. Los resultados obtenidos muestran que la eficiencia de las olas en cuanto al transporte se puede predecir utilizando el número de Ursell que indica el grado de no-linealidad de las olas. Así, se ha estimado que la frecuencia de presentación anual de las olas que contribuyen a dicho transporte es de sólo un 4.8%, y que dicho transporte integrado en una año climático medio es del orden de 4.7 m³/m/a.

Geogaceta, 27 (1999), 223-226
ISSN: 0213683X

Introduction

Cross-shelf sediment transport is one of the key processes to be considered when long-term / large-scale coastal evolution is analysed, being the main responsible for sediment deposits in continental shelves. When this transport is associated to the role of ambient currents (of any origin), the resulting effect is the dispersal of fine sediments in the shelf according to the direction of the currents. On the other hand, when the coarser material (sand) already deposited in the self is considered, one of the main interests is the role of the waves to resuspend and to transport such sediment. This wave-induced cross-shelf sediment transport is generally very weak (1-10 m³/m/yr) but as the period of integration increases (decades to centuries), it becomes of larger importance due to their cumulative effects. This can be reflected in their role to feed some coastal zones (specially when rivers are absent or do not supply sediment). In fact, long-term shoreface evolution models include this wave-induced transport as the only agent (with exception of rivers) to supply sediment to the upper inner shelf and, in consequence, to "maintain" the shoreface (e.g. Niedoroda *et al.* 1995; Stive and de Vriend, 1995).

Although the role of such transport in oceanic inner shelves has been extensively analysed (e.g. Wright, 1995) this is not the case for enclosed basins such as the Mediterranean Sea. Within this framework, the main aim of this paper is to analyse the relative importance of the wave-induced cross-sediment transport at the Ebro delta inner shelf and to characterise the wave conditions able to promote such transport.

Wave-induced sediment transport at the Ebro delta inner shelf

To analyse the potential contribution of the wave-induced cross-shelf sediment transport in the Ebro delta inner shelf an "event" approach was followed. This was done by schematising the meteo-oceanographic climate in "events", each one defined by

specific dynamic characteristics. If the inner shelf behaviour for each condition is known, adding the contributions of the different events can assess the integrated response of the inner shelf during a certain period. This implies to "know" the sediment transport under the different events during a year to be afterwards integrated.

To start with, sediment transport at the inner shelf was studied at a small scale by means of some field campaigns where near-bottom velocity, pressure and suspended sediment concentration were measured under different meteo-oceanographic conditions (Jiménez *et al.*, 1999). Once the measurements were acquired, the contribution of waves to sediment transport at the inner shelf was estimated and those situations under which transport rates were significantly different from zero were identified.

According to Jiménez *et al.* (1998), Simón (1999) and Gracia *et al.* (1999), the wave induced sediment transport at the Ebro delta inner shelf presents a pulsating behaviour. Under fairweather conditions, with small wave heights and short wave periods, currents govern most of the sediment transport in the shelf. However, under wave storms –high waves and with relatively long periods- the near-bottom sediment transport is mainly governed by wave action and it is directed shoreward (net contribution to the upper inner shelf). Jiménez *et al.* (1998) related this to the fact that only under such storm conditions the wave-induced velocity field is effectively modified (from symmetric to asymmetric velocities) in the Ebro delta inner shelf.

However, the Ebro delta, as most of the Mediterranean coasts, is a fetch-restricted area where long period waves (swell) are hardly found (e.g. Jiménez *et al.* 1997). Due to this, the main question is which are the waves able to produce such transport at the inner shelf and how frequent they are.

Transport-efficient wave conditions in the Ebro delta shelf

In general, the wave-induced sediment transport under non-breaking waves (typical conditions of the inner shelf except under very large storms), S_t, is assumed to be proportional to some power of the near-bottom wave-induced velocity field, u, as

$$S_t = K \langle |u^{n-1}| u \rangle$$

where < > means - time averaging, K is a proportionality constant and the most common value of n is 3 (e.g. Ribberink and Al-Salem, 1994). Cross-shore sediment transport time series close to the bottom were analysed to test the validity of this expression and, to find the "proper" value of n. Results showed that the standard third-order velocity ($n=3$, which represents the wave velocity asymmetry) is a good predictor for sediment transport, i.e. the higher the u^3 is, the larger the transport will be (Simon, 1999; Gracia et al., 1999). However, to forecast the wave-induced sediment transport using such expression, detailed hydrodynamics calculations for all the wave conditions have to be done (e.g. Jiménez, 1996).

To avoid this cumbersome procedure, a simple parametric predictor of the potential transport capacity due to wave action based on u^3 was investigated. As this velocity moment is indicative of the degree of non-linearity of the waves, a parameter characterising such non-linearity should potentially predict its magnitude and, in consequence, the induced transport. Two non-linearity parameters, the Ursell number, Ur (e.g. Doering and Bowen, 1995) and the Π number (Goda, 1983), were investigated. The analysis of recorded time series of near-bottom velocity under different energetic wave conditions gave as main result that significantly different from zero asymmetry only occurred for wave states with relatively high values of Ur and Π numbers (Fig. 1). Under "linear" wave states (with low values of Ur and Π), u^3 is very low and, in con-sequence, the transport capacity of such waves will be insignificant (zero). On the other hand, the larger the parameter is (Ur or Π), the higher the moment will be (Fig. 1), and as a result, the transport capacity will increase.

Considering the so found relationship between Ur-Π and the third-order velocity moment, these parameters could be used to "predict" the sediment transport capacity for wave states. Simon (1999) and Gracia *et al.* (1999) found a linear relationship between near-bottom wave-induced sediment transport and the Ursell number when Ur exceeds a certain threshold. This relationship was used to analyse the potential transport capacity of the wave climate off the Ebro delta and to build a probability distribution of the cross-shelf sediment transport in the area. By analysing six years of wave data recorded in the Ebro shelf, it is concluded that the frequency of occurrence of efficient wave conditions off the Ebro would be only about the 4.8% (Fig. 2). Thus, in average, the yearly-integrated wave induced near-bottom sediment transport at the inner shelf of the Ebro delta verifies in only 2.5 weeks and it amounts about 4.7 m³/m/yr. This transport rate is of the same order of magnitude of existing computations based on detailed hydro-

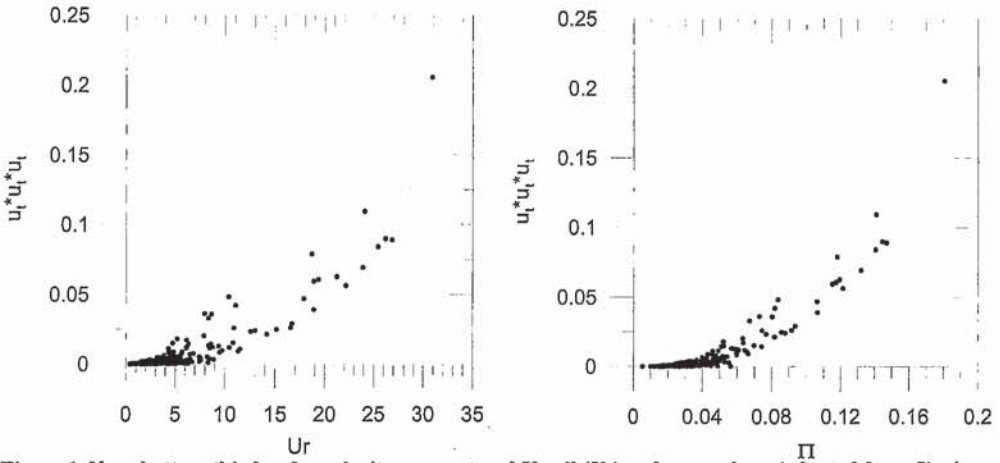

Figure 1. Near-bottom third order velocity moment and Ursell (Ur) and π numbers (adapted from Jiménez et al. 1998).

Figura 1.- Momento de tercer orden de la velocidad cerca del fondo y números de Ursell (Ur) y (adaptado de Jiménez et al. 1998)

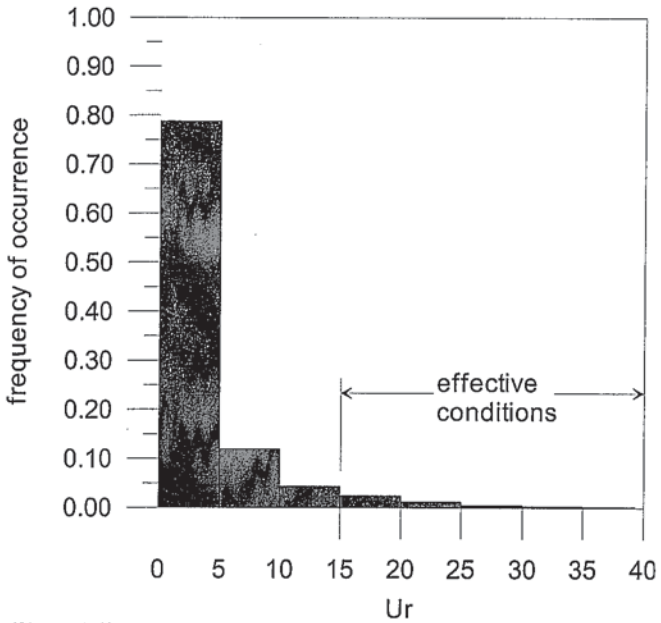

Figure 2. Frequency of occurrence of transport-efficient wave conditions based on the use of the Ursell number (statistics based on six years of wave data).

Figura 2. Frecuencia de aparición de condiciones de ola de transporte eficiente, basadas en el empleo del Ursell (estadística basada en seis años de datos de olas)

dynamics (3-5 $m^3/m/yr$, see Jiménez, 1996; Jiménez *et al.*, 1997; Stive *et al.*, 1999).

Conclusions

Detailed measurements of water and sediment fluxes in the inner shelf of the Ebro delta have permitted to detect the existence of near-bottom cross-shelf sediment trans-port induced by wave action. This transport is only significant under wave storms and under such conditions the near-bottom sediment transport is directed shoreward. It was found that this transport is due to the existence of a near-bottom asymmetric velocity field that can be parameterised by using the third-order wave-induced velocity moment (u^3). Since this asymmetry is significant under non-linear waves, a simple non-linearity predictor was investigated to predict the cross-shelf sediment transport induced by waves. Results showed that the Ursell number, *Ur*, can be used to predict u^3 and, in consequence, the induced transport. From this, it was estimated that the frequency of occurrence of efficient wave conditions to promote near-bottom sediment transport in the Ebro delta inner shelf is about 4.8% (17 days) and that the yearly-integrated transport amounts to 4.7 $m^3/m/yr$. This transport rate is of the same order of magnitude of existing predictions done by using detailed hydro-dynamic commutations.

Acknowledgements

This work was mode in the framework of the TRASEDVE and FANS projects funded by the CICYT (MAR98-0619-C02-01) and EU (MAS3-CT95-0037) respectively. This is a contribution to the IGCP Project 396 "Continental shelves in the Quaternary".

References

Doering, J.C. and Bowen, A.J. (1995): *Coastal Eng.*, 26: 15-33.

Goda, Y (1983): *Rep. Port Harbours Res. Inst.*, 22, 3: 3-30.

Gracia, V., Jiménez, J.A., Sánchez-Arcilla, A., Guillén, J. and Palanques, A. (1999): Coastal Sediments'99, ASCE, 341-353.

Jiménez, J.A. (1996): *Tesis Doctoral*, Universitat Politécnica de Catalunya, Barcelona.

Jiménez, J.A., Sánchez-Arcilla, A., Valdemoro, H.I., Gracia, V. and Nieto, F. (1997): *Mar. Geol.*, 144, 59-79.

Jiménez, J.A., Rodríguez, G., Clariana, I. and Sánchez-Arcilla, A. (1998): *FANS 2nd Plenary Workshop*, paper 4.3, Bangor.

Jiménez, J.A., Guillén, J., Gracia, V., Palanques, A., García, M., Sánchez-Arcilla, A., Puig, P., Puigdefábregas, J. and Rodríguez, G. (1999): *Mar. Geol.*, 157, 219-239.

Niedoroda, A. W., Reed, C. W., Swift, D. J. P., Arato, H. and Hoyanagi, K. (1995): *Mar. Geol.*, 126, 181-200.

Nittrouer, C.A., and Wright, L.D. (1994): *Rev. Geophys.*, 32(1): 85-113.

Ribberink, J.S., and A.A. Al-Salem. (1994): *J. Geophys. Res.*, 99(C6), 12707-12727.

Simón, L. (1999): *Tesina especialidad,* Universitat Politécnica de Catalunya, Barcelona.

Stive, M.J.F. and De Vriend, H.J. (1995): *Mar. Geol.*, 126:235-248

Stive, M.J.F., Cloin, B., Jiménez, J.A. and Bosboom, J. (1999): *Coastal Sediments'99, ASCE*: 505-518.

Wright, L.D. (1995): *Morphodynamics of inner continental shelves*, CRC Press.