CHAPTER 69

Influence Of Breaker Type On Surf Zone Dynamics

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1. Introduction

Two of the most significant variables for surf zone hydrodynamic analyses are the mean rate of wave energy dissipation, D, and the longshore current velocity, Vl . A detailed theoretical model is extremely difficult to establish (definition of bottom and free surface boundaries, stochastic forcing terms, intense turbulent mixing, etc). The type and amount of existing measured values (laboratory and field) also preclude any accurate calibration, particularly for the more complex formulations.

The paper, therefore, presents an average (cross-shore) comparison among state-of-the-art models for D and Vl. This illustrates the dependence of these variables on the surf zone dynamic state (closely related to the beach stage, (Short, 1978)), characterized by Iribarren's parameter, Ir. Well defined relationships with Ir are obtained for these variables. An expansion of the range of validity of certain models is also attained by calibration of their characteristic free parameters as functions of Ir using a large set of field and laboratory data, and by comparing their general expresion with that of (Losada and S.Arcilla, 1985), which does not include any free parameter.

Therefore, theoretical laws for D and Vl as simple functions of beach, wave and dynamic state parameters are presented, together with an improved estimation of the empirical coefficients appearing in the various models, suitable for prediction in all ranges of Ir, even though data on the collapsing-surging range are scarce and should require further calibration.

2. Rate Of Wave Energy Dissipation (D)

No complete theoretical models for the rate of wave energy dissipation (i.e. including bottom friction and percolation, turbulent mixing, front roller, etc.) are nowadays available. Most of them just consider turbulent (mixing) dissipation and have been indirectly calibrated, via the computed longshore current velocity or transport, the corresponding wave attenuation and set-up, etc., as local values of D require accurate local measurements (difficult to encounter).

To get a better insight of the relationship between D and the dynamic state, a cross-shore average value, $\bar{D}$,has been derived from the selected models. It has been obtained assuming stationary and longshore

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uniform conditions together with a constant bottom slope, m :

$$\bar{D} = \frac{1}{xb} \int_0^{xb} D(x)dx \qquad (1)$$

$\bar{D}$ being the average (cross-shore) value for D , and xb the width of the surf-zone. It is shown that this value is easily related to the dynamic state via the Iribarren's parameter Ir (or Irb when referring to breaking conditions), defined as:

$$Ir = m / (H/Lo)^{1/2} \qquad (2)$$

where m is the bottom slope (assumed to be constant through surf-zone), H wave height and Lo the deepwater wave length.

To get a better insight of the relationship between D and the dynamic state, a non-dimensional value, $\hat{D}$, is defined, refering $\bar{D}$ to an order of magnitude rate of wave energy dissipation Do:

$$Do = \rho g \frac{Hb^2}{T} \qquad (3)$$

where T is the wave period, g is the gravity acceleration and ρ is the water density.

Do may be obtained from dimensional analysis or bore (hydraulic jump) dissipation theory. This reference value can be also obtained via an energetic balance in the surf zone, relating eddy viscosity coefficients to wave energy dissipation:

$$D <> \text{Stress x velocity} \qquad (4)$$

Characteristic stresses for this problem are, typically, the Reynolds stresses (related to eddy viscosity coefficients):

$$\tau_r = - \rho \overline{u' v'} = - \rho A \frac{dV}{dx} \qquad (5)$$

where A is the eddy viscosity coefficient, and u', v' are the (x,y) components of the turbulent velocity. The eddy viscosity coefficient has the dimension of a typical length times a typical velocity:

$$A \sim l . V' \qquad (6)$$

Following (Harris et al, 1962) typical scales for length and velocity can be respectively H and H/T . The eddy viscosity coefficient must therefore be of order H^2/T .

The characteristic velocity, V', is assumed to be a typical scale of the turbulent velocity, that can be related, in the surf zone, to the shallow water wave celerity:

$$V' \simeq \hat{B} \, (g \, hm)^{1/2} \qquad (7)$$

where $\hat{B}$ is a dimensionless constant accounting for breaker type (therefore related to Ir) and hm is an average or characteristic depth through the surfzone.

The energetic balance can be set as in (Battjes, 1975):

$$\frac{\text{Rate of wave energy dissipation}}{\text{Area}} = \frac{\text{Rate of turbulent energy produced}}{\text{Area}} =$$

$$= \frac{\text{Rate of turbulent energy dissipated}}{\text{Area}}$$

(neglecting bottom friction, percolation or any other dissipation phenomena than turbulence).

From this and (5):

$$D < > \text{Stress} \, . \, \text{velocity} = \rho A \frac{dV}{dx} \, . \, V' \qquad (8)$$

Following the control volume approach presented in (Losada, S.Arcilla and Vidal, 1986) to estimate the partial derivative in (8), the rate of wave energy dissipation can be written as follows:

$$D = \rho A \frac{Vlb}{xb} \, . \, \hat{B} \, (g \, hm)^{1/2} \qquad (9)$$

Vlb being the longshore current velocity at the breaker line, depending on wave, beach and dynamic state parameters.

Assuming (Losada, S.Arcilla and Vidal, 1986) that A , $\hat{B}$, and other parameters involved in the Vlb formulation (γ,Kr,etc.) are Ir functions, it is easy to show that:

$$\frac{D}{\rho g A} = F \, (\, Ir) \, . \, \cos \Theta b \qquad (10)$$

where Θ is the angle of wave incidence.

In this dimensionless equation F(Ir) is a known function that comes from the formulation used to evaluate Vlb. If we choose (Losada, S.Arcilla and Vidal, 1986), F(Ir) can be written as follows:

Author	$\hat{D}$	Free parameters and order of magnitude or suggested values
Longuet-Higgins, 1970	$\frac{(2\pi)^{1/2}}{8}\gamma^{1/2} Irb$	---
Losada, S.Arcilla and Vidal, 1986	$\frac{(2\pi)^{1/2}}{8}\gamma^{1/2}(1-Krb^2)\cos\theta b\ Irb$	---
Dally, Dean and Dalrymple, 1984	$\frac{(2\pi)^{1/2}}{8}\gamma^{1/2}\ Irb$	---
Battjes, 1978	$\beta \cdot \frac{B\gamma_B^4}{4\ (0{,}7 + 5m)}$, $\beta = 0{,}1134$	$B \sim O(1)$ or $B\gamma_B^4 \sim O(1)$
Battjes and Janssen, 1978	$\frac{1}{xb}\int_0^{xb}[\frac{\alpha}{4}\ Qb \cdot (\frac{Hm}{Hrms})^2]\ dx$	$\alpha \sim O(1)$
Stive, 1982	$\beta \cdot \frac{\gamma}{4} \cdot A_\varepsilon\ Ad$	$A_\varepsilon \sim$ 2tanh (5 Iro) or 2tanh (5 Irb) if Irb < 0,4
Svendsen, 1984	$\beta \cdot \frac{\gamma}{4} \cdot As\ [(1+\gamma\frac{\eta c}{H})(1+\gamma(\frac{\eta c}{H} - 1))]^{-1}$	$As \sim O(1)$
Guza and Thornton, 1985	$\frac{1}{xb}\int_0^{xb}[\frac{3(\pi)^{1/2}}{16} \cdot B^3\ \gamma\ (\frac{Hrms}{Hb})^2]\ dx$	$B \sim O(1)$ or $B^3 \sim O(1)$

Table 1. Expressions of non-dimensional average rate of wave energy dissipation, D, as functions of Irb dependant variables, for various analytical models.

$$F\,(Ir) = \frac{\hat{B}\,.\,\tilde{A}}{4\,(2)^{1/2}}\,.\,\gamma^{1/2}\,.\,(1-Kr^2)\,m^2 \qquad (11)$$

where Kr is the reflection coefficient and γ is the breaker index.
Then, assuming that $A \simeq H^2/T$, it follows that:

$$\frac{D}{\rho g\,H^2/T} = F\,(Ir)\,.\,\cos\theta b \qquad (12)$$

and the reference rate of wave energy dissipation, Do, can be correctly expresed by $\rho g\,H^2/T$.

Using this reference value, average non-dimensional expressions for the rate of wave energy dissipation can be obtained for all formulations considered, even though some of them require numerical evaluation. These expressions are shown in table 1, together with their free parameters, suggested values for them, and range validity. The dimensionless $\hat{D}$ values are known functions of parameters that depend on Ir. It follows that $\hat{D}$ itself is a function of Ir for all models.

The only formulation including reflection and large angles of wave incidence, without any free parameters, and being valid for the whole range of Ir values, is that of (Losada, S.Arcilla and Vidal, 1986). It will be, therefore, compared to other models to enlarge their range of validity via an estimation of their free parameters as functions of Ir. Values of Kr are taken from (Battjes, 1974). The comparison is made numerically in all cases using laboratory and field data taken from:

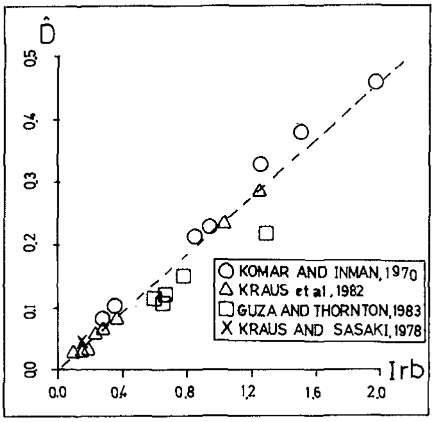
Laboratory (Putnam, Munk and Traylor, 1949) (Galvin and Eagleson, 1965) (Mizuguchi et al., 1978) (Kamphuis and Readshaw, 1978) (Vitale, 1981) (Kamphuis and Sayao, 1982)

Field (Komar and Inman, 1970) (Kraus and Sasaki, 1978) (Kraus, Isobe et al, 1982) (Guza and Thornton, 1983)

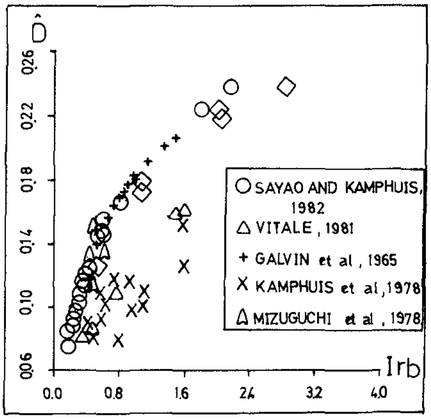
Results from (Losada, S.Arcilla and Vidal, 1986), (Battjes and Janssen, 1978) and (Guza and Thornton, 1985) are shown in figures 1a to 1c, as an example of the results of some of the models analysed.

To test the models, wave, beach and dynamic state measured parameters are used to estimate the average non-dimensional rate of wave energy dissipation. It is shown that $\hat{D}$ is greater for laboratory than for field data, because viscosity and bottom efects are overestimated in laboratory tests.

The adjustment of free parameters as Ir functions is shown in Table 2. Figures 2a to 2c illustrate the results for (Battjes and Janssen, 1978), (Stive,1982) and (Guza and Thornton, 1985) models, being an example of the fit made for all models.



a)



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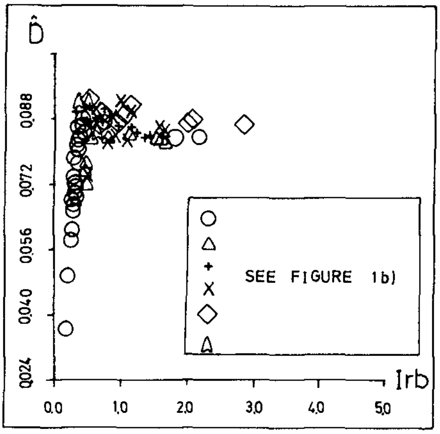


c)

Figure 1. Results of non-dimensional average rate of wave energy dissipation, $\hat{D}$, for:

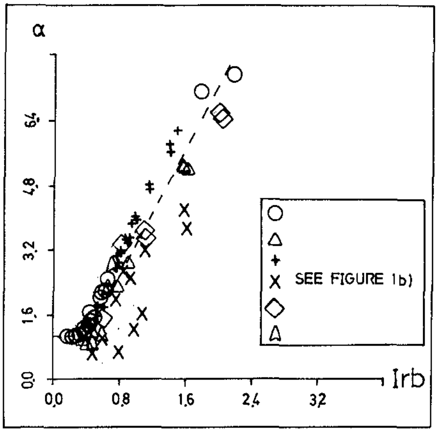
a)(Losada, S.Arcilla and Vidal, 1986) model. Field data.

b)(Guza and Thornton, 1985) model. Laboratory data.

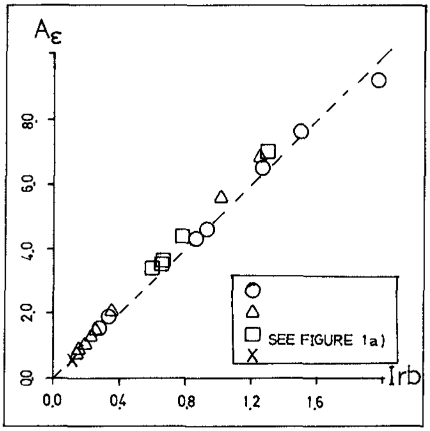
c)(Battjes and Janssen, 1978) model. Laboratory data

Author	Free parameter	Initial value of original range of validity	Proposed adjusted value Laboratory		Proposed adjusted value Field	
Battjes, 1978	8	1.... 2	5.875 Irb		4.800 Irb	
(regular waves)	$8\ \gamma_B^4$	1.... 2	$12.862\ Irb^2$		$7.706\ Irb^2$	
Battjes. Janssen, 1978	α	0(1)	1.000	$Irb \leqslant 0.4$	1.100	$Irb \leqslant 0.4$
(irregular waves)			3.680.Irb	$Irb > 0.4$	2.583.Irb	$Irb > 0.1$
Stive. 1982	A_ε	A_ε = 2 tanh (5Iro)	4.24 Irb		5.000 Irb	
Svendsen, 1984	As	1	5.100 Irb		8.000 Irb	
Guza , Thornton, 1985	8^3	0(1)	1.875 Irb		2.474 Irb	

Table 2. Expressions of free parameter adjustements for all analytical models. obtained by comparison to (Losada and Sanchez-Arcilla and Vidal, 1986) formulation.



a)



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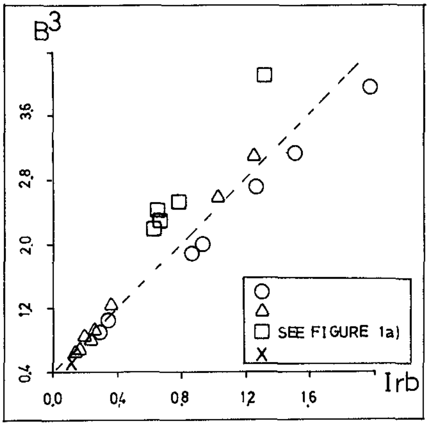


c)

Figure 2. Results of the adjustment of the free parameters:

a) α (Battjes and Janssen,1978),laboratory data

b) A_{ε} (Stive,1982),field data

c) B (Guza and Thornton,1985),field data

as functions of the Iribarren's parameter Irb

As final remark, a bell-shaped behavior is expected for $\hat{D}$ vs Ir due to:

- incipient spilling breakers, corresponding to low Ir values, produce small dissipation per unit horizontal area (wide surfzone together with a small depth affected by turbulence)

- collapsing-surging breakers, in the higher Ir range, produce small dissipation per unit horizontal area (highly reflecting beach conditions).

- maximum dissipation corresponds to late spilling and plunging breakers, generating maximum turbulence

3. Longshore Current Velocity

Analytical (state-of-the-art) models for the longshore current velocity are based on time and vertically-integrated conservation equations for stationary and longshore uniform conditions with constant beach slope. Most of them also use shallow water linear wave theory.

All formulations depend on two poorly known coefficients, each representing one of the two main retarding terms considered in the momentum balance equation:

- cf, bottom friction coefficient

- M, lateral mixing coefficient, related to eddy viscosity

From the given definition for Iribarren's parameter Ir, (2), an Ir-dependent expression for Vlb may be obtained for each of the selected longshore current velocity models (Table 3). These equations depend on Ir directly or via other parameters related to it (γ, Kr, etc).

From these expressions and order of magnitude considerations, a reference velocity Vo can be defined to obtain a non-dimensional value for Vl:

$$Vo = \frac{Hb}{T} \sin \Theta b \qquad (13)$$

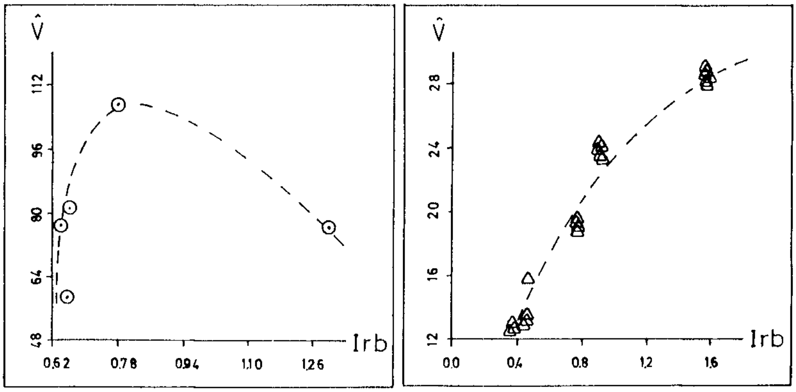
$$\hat{V} = Vl / Vo = \frac{Vl}{(Hb/T \, . \, \sin \Theta b)} \qquad (14)$$

Testing these formulae with the set of data mentioned in section 2, general trends for a relationship between Vlb and Irb may be obtained (an example of them being figure 3):

- lower values of Vlb appear associated to incipient spilling breakers (low range of Irb values)
- stabilized or decreasing values for collapsing-surging breakers (high values of Irb)
- maximum values for Vlb are attained for late spilling and plunging

Author	$\dot{V} = Vlb / Vo = Vlb / (Hb/T \cdot \sin\theta b)$	parameters
Longuet-Higgins, 1970	$\frac{(50\pi^3)^{1/2}}{16} \cdot \frac{\gamma^{1/2}}{cf} \cdot [P(1-P1)(P1-P2)]^{-1} \cdot Irb$	$P = \frac{\pi N m}{\gamma cf}$, $P1 = -3/4 + (9/16+1/P)^{1/2}$ $P2 = -3/4 - (9/16+1/P)^{1/2}$
Losada, S.Arcilla and Vidal, 1985	a) linear bottom friction law : $\frac{3\,(2\pi)^{1/2}}{18} \cdot \gamma^{1/2}(1 + 3/5 \sin^2\theta b)^{-1} \cos\theta b\,(1-Krb^2)\, Irb$ b) cuadratic bottom friction law: $\frac{(\pi)^{1/2}}{2} \cdot K \cdot \left(\frac{(1-Krb^2)\,\gamma}{m\,cf\,\sin\theta b\,\cos\theta b}\right)^{1/2}$	$K = Vlb/Vm \simeq O(1)$ $Vm = Vmean$
Liu and Dalrymple, 1978	$\pi \cdot \frac{(\pi)^{1/2}}{2} \cdot \gamma^{1/2} \cdot \frac{1}{m \sin\theta b} \cdot Irb \cdot f11\left(\frac{\sin\theta b}{cb}, ghb, \gamma\right)$ $\left(\frac{\pi}{2}\right)^{1/2} \cdot \gamma^{1/2} \cdot \frac{1}{m \sin\theta b}\, Irb \cdot f12\left(\frac{\sin\theta b}{cb}, ghb, m, f\right)$	$Vl \ll Um$ $Vl \gg Um$
Kraus and Sasaki, 1979	$\frac{(50\pi^3)^{1/2}}{16} \cdot \frac{\gamma^{1/2}}{cf} \cdot fks(\sin\theta b, P, Q)\, Irb$	$P = \frac{\pi}{2}\Gamma\frac{m^*}{cf}$; $Q = \frac{\pi}{2}\Gamma\frac{m}{cf}$ m^* : modified bottom slope (accounting for set-up)
Madsen, 1978	$\lambda \cdot \frac{(50\pi)^{1/2}}{8} \cdot \frac{\gamma^{1/2}}{f} \cdot fm(P)\, Irb$	$P = \frac{\pi \gamma m^*}{f}$
Komar, 1970	$1.35\,(\pi)^{1/2} \frac{\gamma^{1/2}}{m} \cdot Irb$	
Bijker, 1976	$\frac{(25\pi^3)^{1/2}}{8} \cdot \frac{C}{(g \gamma fw)^{1/2}}\, Irb$	C : Chezy coefficient
Guza and Thornton, 1985	$\frac{23(2)^{1/2}}{20}\,\frac{\gamma^{1/2}}{cf} \cdot \frac{a^{1/5}\,hb^{9/10}}{Hb}\left[1 - hb^{23/4}\left(\frac{1}{ho^{23/4}} - \frac{a}{yo^{5/2}}\right)\right]^{-6/5} Irb$	$a = (\frac{23}{15}\, (\frac{g}{\pi})^{1/2} \frac{\gamma^4 m}{B^3}\, T$

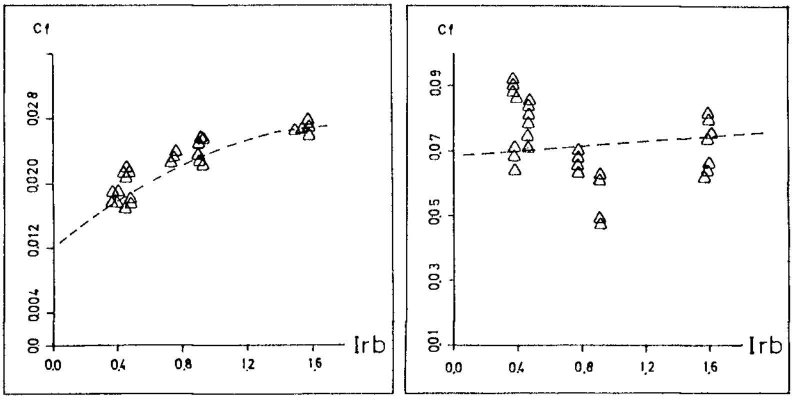
Table 3. Non-dimensional longshore current velocity at the breaker line for all models considered.



a) b)

Figure 3.

Non dimensional longshore current velocity at the breaker line vs Irb
a) field data taken from (Guza and Thornton,1985)
b) laboratory data taken from (Vitale,1981)



a) b)

Figure 4.

Calibration of bottom friction coefficient , Cf, as a function of Irb
for:
a) (Losada,S.Arcilla and Vidal,1986) model
b) (Guza and Thornton,1985) model
using (Vitale,1981) laboratory data.

breakers ($Irb \sim 1$)

In the formulations presented, the friction coefficient is shown to be the numerically most significant parameter, defining the order of magnitude for Vl, while lateral mixing, through its caracteristic coefficient, governs the profile shape. Thus, to study the variation of the friction coefficient with the dynamic state, an order of magnitude estimate for the characteristic lateral mixing coefficient is used. With this, the friction coefficient is adjusted by comparing estimated and measured values, taken from the mentioned data set (being figure 4 an example of a good and a bad parameter fit).

In these conditions a general formulation for Vlb can be written as:

$$Vlb = Vo \cdot G(Ir) = \frac{Hb}{T} \sin \Theta b \cdot G(Ir) \qquad (15)$$

where G(Ir) is a function of the Iribarren's parameter, to be obtained by calibration with measured data.

4. Conclusions

4.1. Rate of wave energy dissipation, D

A general formulation for $\bar{D}$ can be written as:

$$\bar{D} = Do \cdot Fl(Irb) = \rho g \frac{Hb^2}{T} \cdot Fl(Irb) \qquad (16)$$

where Fl(Irb) is a function of the dynamic state that must be calibrated from laboratory and field data.

The relationship between $\hat{D}$ and Irb appears to be bell-shaped from physical considerations and using the (Losada, S.Arcilla and Vidal, 1986) model, that considers reflection (Kr estimation is critical for the formulation results). Comparing this model to other formulations expands their original range of validity, by obtaining Ir dependent expressions for their free parameters.

The values of $\hat{D}$ estimated for the set of field data are always lower than those obtained from laboratory data, because viscosity and bottom friction effects are overestimated in model tests.

4.2. Longshore Current Velocity, Vl

The driving term in the time-and vertically-integrated momentum conservation equation is well defined using the radiation stress concept. The dependance of this term on Ir is shown through the relationship between D and Ir:

$$\frac{\partial Sxy}{\partial x} = D.\left(\frac{\sin\theta}{C}\right) = D(Ir).\left(\frac{\sin\theta}{C}\right) \qquad (17)$$

where Sxy is the (x,y) component of the radiation stress tensor.

Bottom friction is the (numerically) most significant retarding term in longshore current velocity estimation. Therefore a good estimate of Cf is critical for all model results. No theoretical model is available to obtain this coefficient as a function of Ir, which hinders prediction (only qualitatively through flow conditions which determine bed forms).

Lateral mixing, through not very significant numerically, cannot be neglected. The use of an order of magnitude value appears to provide more accurate results than neglecting lateral mixing.

The bottom friction coefficient determines the order of magnitude of Vl while the lateral mixing coefficient defines the shape of cross-shore profiles. A measured Vl profile can therefore be used for a joint bottom friction and lateral mixing coefficients evaluation, while if there are only two measured values of Vl through the profile, such a joint fitting may have a non-unique solution.

The relationship between $\hat{V}lb$ and Ir appears to be bell-shaped from: i) physical considerations , ii) obtained formulae and iii) field and laboratory data (figures 3a and 3b). Further measurements are required, particularly for large Ir values (collapsing-surging) to confirm and calibrate the behaviour of $\hat{D}$ and $\hat{V}l$ vs Ir, as well as to determine a predictive relationship between the bottom friction coefficient, Cf, and Ir (figure 4). Finally a general formulation for Vl is presented:

$$Vlb = \frac{Hb}{T} \sin\theta b.\ G(Irb) \qquad (18)$$

where G(Irb) is a function of the dynamic state to be calibrated from laboratory and field data.

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