Verification of the Sleath criterion for sand ripples in pulsed flow

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ABSTRACT: In 1984, Sleath proposed an empirical criterion to distinguish rolling-grain ripples from vortex ripples. Very precise experiments have been conducted in the laboratory to study the transition between rolling grain and vortex. In these experiments, we confirm the validity of the criterion and we propose an explanation for the maximum value of the apparent slope.

1. INTRODUCTION

Sand ripples produced by fluid oscillations are of two types. The first type are very small ones, incipient, called rolling-grain ripples, occurring in the very initial stages of interface deformation. After a transient regime, the second type of ripples, the so-called vortex ripples, which are ripples of large amplitude and large height producing a detached inertial vortex at each side of the ripple at each half oscillation, appear. Modern experiments (Stegner et al. 1999) confirm that the initial incipient rolling grain ripples are a transitory regime evolving with time toward the vortex ripples regime after a brutal change in height and wavelength of the ripples.

In 1984, Sleath proposed the following criterion to distinguish rolling grain ripples from vortex ripples (Fig. 1): when *h*, the height of the ripples over λ, the wavelength of the ripple, is $h/\lambda < 0.1$ then the ripple is a rolling-grain ripple, else if $h/\lambda > 0.1$ the ripple is a vortex ripple. This criterion, for the apparent slope, must not be mistaken with the maximum slope of the ripples (Fig. 1).

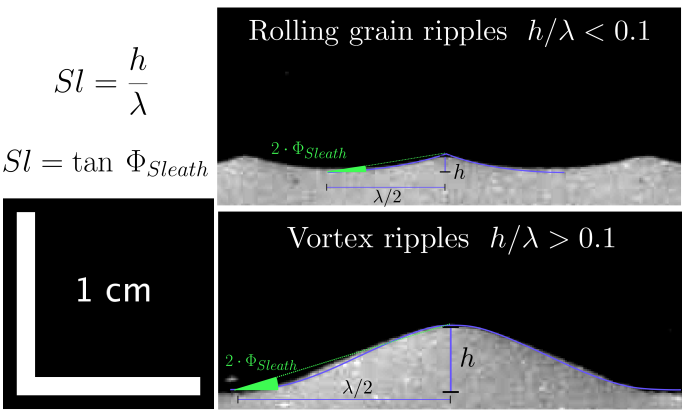

Figure 1. Definition of Sleath criterion for rolling grain and vortex ripples.

On Figure 1, we can also observe that the rolling grain ripples are peaked structure (maximum slope near the summit of the ripples), as the vortex ripples are smoother, as the maximum slope is far from ripple’s crest.

1.1 *Experimental setup and data treatment*

We use the setup that has been described in Rousseaux et al. (1999) to produce underwater sand ripples by flow oscillations in the laboratory. Moreover, we have made modifications to ensure a higher spatial and temporal resolution of the experiments. We use an annular cell of diameter 13 cm and gap 2 cm and height 9 cm over a rotating axis. The plate oscillate with amplitude *A* and frequency *f*. As a granular material, we use glass beads of diameter between 224-250 μm. To get a statistical collection of measurements about ripples, we need a high spatial and temporal resolution. To achieve this, we use a camera in front of the experimental cell in macro mode and we stop the oscillations periodically. Then, we rotate the apparatus at slow speed and record a movie. The vertical resolution is fixed by the camera and the horizontal resolution is controlled with the speed of the tank while recording. We reach a spatial resolution of 160 μm/pixel for the vertical and the horizontal scale. Ripples with a different shape can grow if the apparatus is violently stopped or restarted (Caps et al. 2004). To avoid this we use a linear varying envelope for amplitude of oscillations over 10 oscillations when we start or stop the apparatus at equal time intervals *dt*. We have verified that this does not impact the dynamics of the ripples by following some representative variables of the evolution of the ripples like λ and Φ_{max} the mean local maximum slope of the ripples. We gather local information about ripple height of each half-ripple h_i measured by the difference of y-position between a maximum and a consecutive minimum, and local wavelength λ_i measured by 2*(difference of x-position between a maximum and a consecutive minimum). We gather information about the left and right side of the ripple and we extract statistical information about each ripple. This criterion must not be mistaken with local maximum slope of the ripples.

1.2 *Results*

We can mesure the value of the local slope and the local Sleath apparent slope for each ripple. We make 10 experiments with fixed parameters (A = 2 cm, f = 1 Hz, dt = 50 s, t_{final} = 7200 s) to gather a meaning statistical collection of measurements. In Figure 2, we show a spatio-temporal diagram of the value of these slopes for each ripple in the experiment.

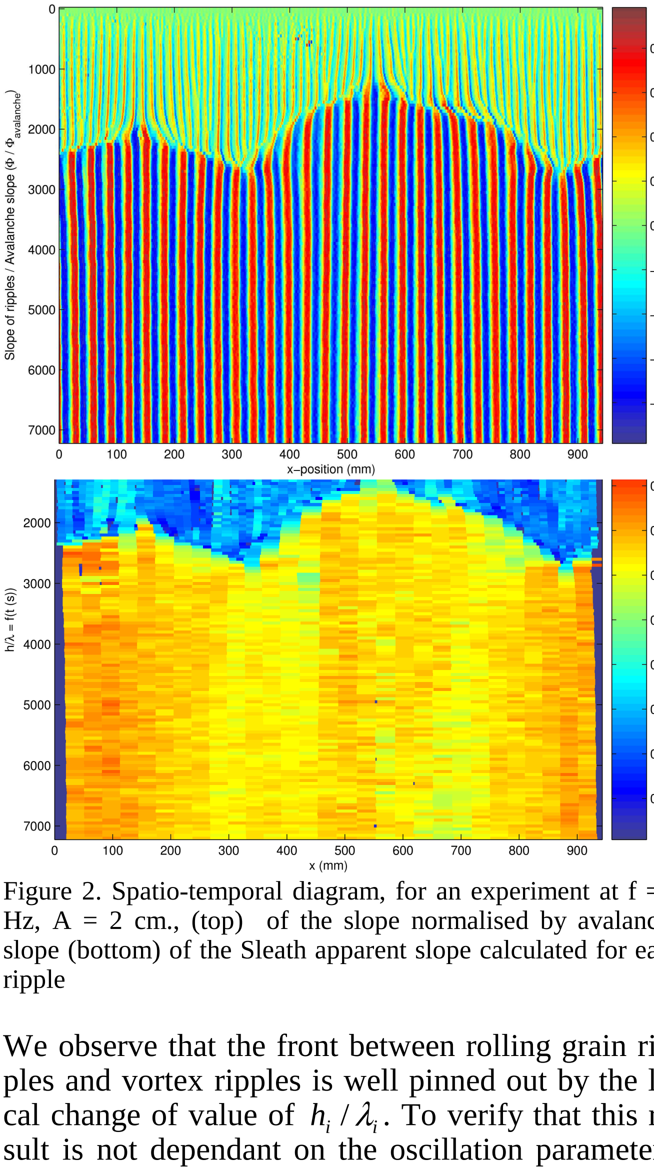

Figure 2. Spatio-temporal diagram, for an experiment at f = 1 Hz, A = 2 cm., (top) of the slope normalised by avalanche slope (bottom) of the Sleath apparent slope calculated for each ripple

We observe that the front between rolling grain ripples and vortex ripples is well pinned out by the local change of value of h_i / λ_i. To verify that this result is not dependant on the oscillation parameters, we have performed experiments at different amplitudes and frequencies

In Figure 3, we show the accumulation over time and over all experiments of (λ, h) points corresponding to all the ripples. We observe that the line h = 0.1 λ (± 5%) line corresponding to the Sleath criterion distinguishes correctly rolling grain ripples from vortex ripples. The Sleath criterion is therefore confirmed by these experiments.

In Figure 4, we plot the Sleath parameter measured over all experiments. We observed that its maximum value never exceeds h/λ_{max} = 0.14. We observe that the criterion is not relevant globally for the rolling-grain ripples, but is valuable locally.

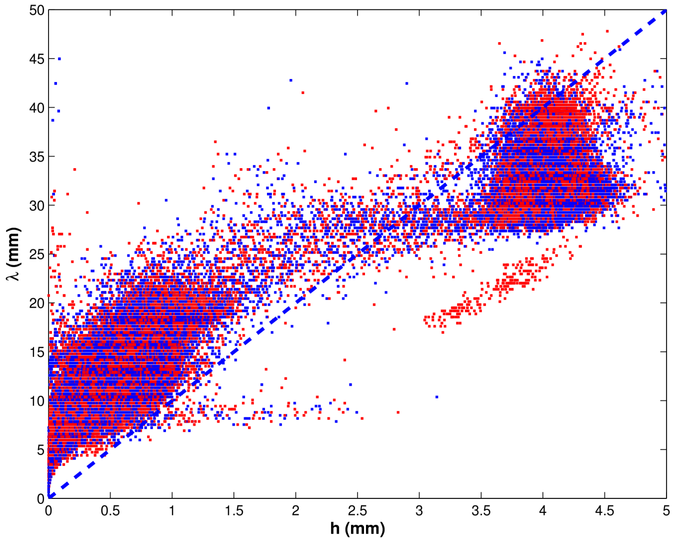

Figure 3. Cumulative h-λ diagram integrated over time and over all experiments at (f = 1 Hz, A = 2 cm). The dashed line represents h/λ=0.1. The red points are calculated on the left side of the ripple, respectively blue on the right side.

The mean apparent angle defined by this criterion in the final stage of the ripple growth (Fig. 2) $\Phi_{final}^{Sleath} = \text{Arctan}(2h/\lambda) \approx 15\,\text{deg}$ is inferior to the measured static avalanche slope angle of our granular material : $\Phi_{avalanche} = 30\,\text{deg}$.

In Figure 4, we show the mean value of Sleath criterion versus time for repeated experiment with constant parameters.

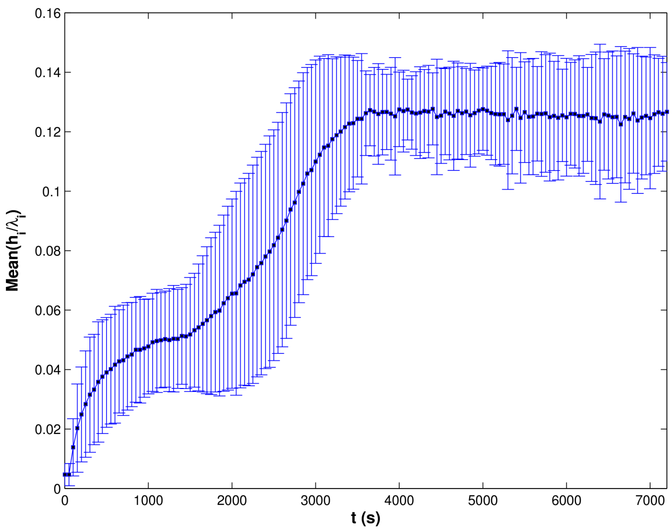

Figure 4. Sleath apparent slope versus time for a repeated experiment at A=2 cm, f = 1 Hz.

1.3 *Discussion of the results*

The Sleath criterion is related to the form factor of the ripples. The coefficient is not derived from physical considerations. This coefficient seems to be linked to the length of the recirculation zone (L_R) of the flow past the ripple at each half-oscillation. Normally, in laminar regime, the length of the recirculation zone grows with the hydrodynamical Reynolds number *Re*. In turbulent regime, this length is constant versus Re : in the case of a backward-facing step the asymptotic value is $L_R = 7h$ (Armaly et al. 1983). It is clear that L_R cannot exceed the distance between two ripples (λ) : $L_R < \lambda$. This condition gives a maximum Sleath apparent slope *Sl* < 0.14, (with the value of Armaly et al.) which is compatible with our results (Fig. 4).

2 CONCLUSION

In this paper, we have verified the validity of the Sleath criterion to discriminate rolling grain from vortex ripples. This distinction is very precise. Furthermore, we found that the Sleath apparent slope = 0.14 for vortex ripples and is a very stable value. This differs from previous investigations where Sleath = 0.2 for vortex ripples. This is due to the resolution of measurements and consequence of automation which enable gathering of meaningful statistical data.

3 REFERENCES

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