Compaction process in underwater sand ripples in pulsed flow

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ABSTRACT: Vortex ripples are generated under pulsed flows. We observe vortex ripples on a very long time scale when the flow is stopped after an initial period of time used to generate the pattern. We observe during the oscillations decompactation of the granular substrate. This sub-compaction is relaxed on two time scales. We compare this behaviour to a model used with dry granular material and give some insights into the potential implications of this behaviour over geological scenarios.

1. INTRODUCTION

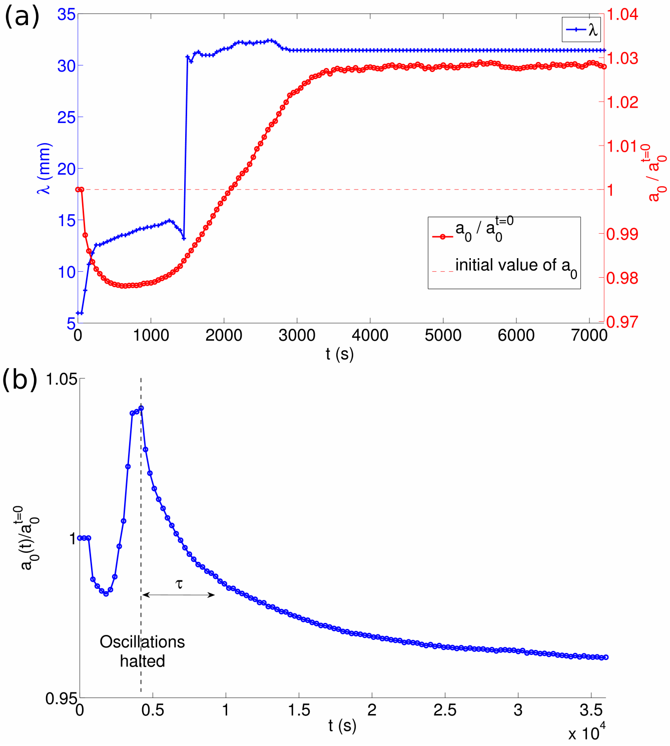
In general, the experiments and models about ripples focus on the interface description and not with the the granular media itself. We present here a first study on the evolution of compaction dynamics during the pattern formation. In most experimental systems, this hypothesis of a granular material exchanging grains with the flow cannot be trialed, because of the spatial configurations (for example, linear apparatus with boundary conditions making impossible to use mass conservation as an hypothesis) or insufficient resolution of data acquisition regarding the evolution of the quantities involved. To study the compaction phenomenon, we use the apparatus described in *Kruithof&Wesfreid* in same conference.

1.1 *The zero-mode*

In order to study the compaction process, we use the zero-mode in Fourier decomposition of the signal, representing the mean height of the interface. For a typical experiment, we observe (Figure 1a) that during the formation and coarsening of rolling-grain ripples, during which the wavelength λ of the ripples increases from its initial value λ_0 due to the coarsening process and the compaction of the granular material increases versus its initial value. We verified that this effect is not linked to the rolling-grain ripple formation and is a remnant of our initialization protocol for the interface which leaves a sub-compacted interface. When the vortex ripples appear with a higher λ, by a nucleation and front propagation process which gives a jump of this parameter, the compaction decreases and reaches a stable value inferior to the initial value. So the vortex ripples are in a decompacted state, and it is this sub-compaction which is relaxed when the oscillations are stopped (Figure 1b).

1.2 *Observation*

We produce a vortex ripples pattern with an oscillating flow over a granular planar surface. To observe the compaction phenomenon we use a binary spatio-temporal diagram of the instability (Figure 2). We observe that after the forcing is halted, the crest of the vortex ripples rounds and the space between ripples is filled with sand, decreasing the height of the ripples.



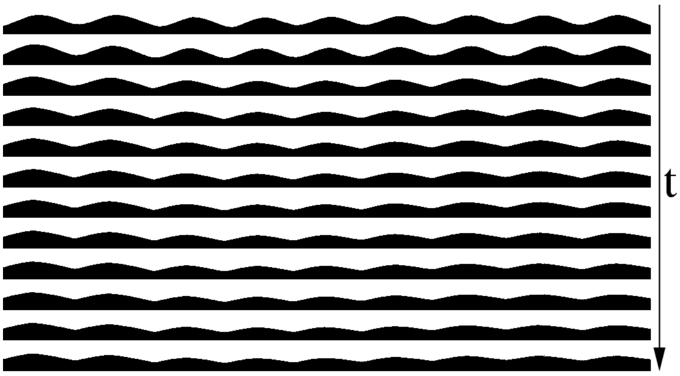


Figure 1. 1a) Topical Evolution of a_0, the amplitude of the zero-mode, representing the mean height of the interface, during an experiment at A = 2 cm, f = 1 Hz 1b) Evolution of a_0 before and after the oscillations are stopped in an experiment at A=2 cm, f=1 Hz with a preparation time of t=3600s

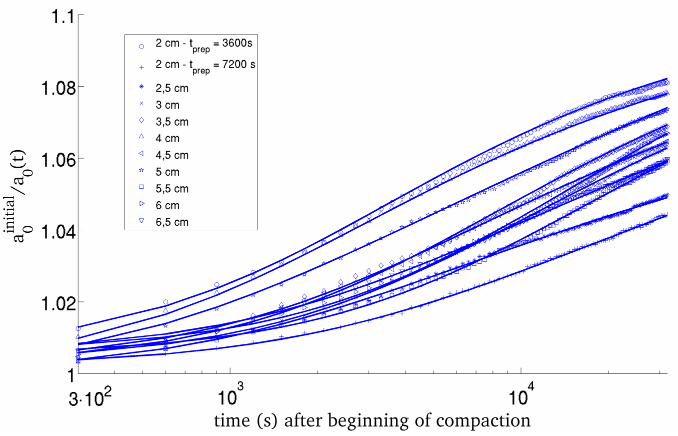


Figure 2. Binarized spatio-temporal diagram after stopping the oscillations for an experiment at high shear, f = 1 Hz, A = 5 cm, dt = 3000 s.

1.3 *Observation*

We produce a vortex ripples pattern with an oscillating flow over a granular planar surface. To observe the compaction phenomenon we use a binary spatio-temporal diagram of the instability (Figure 2). We observe that after the forcing is halted, the crest of the vortex ripples rounds and the space between ripples is filled with sand, decreasing the height of the ripples.

2 EXPERIMENTAL DATA

We make experiments at constant frequency and different amplitudes to study compaction for different heap size, as $\lambda \propto A$ and h/λ=constant=0.14 for vortex ripples (see *Kruithof&Wesfreid*, same conference). We also study the influence of the preparation time for an experiment close to the threshold of formation of the ripples. We observe that after the oscillations are stopped, the sub-compaction of vortex ripples is relaxed. We observe that there is a short time scale for the compaction process at its beginning, where most of the compaction happens, and a slow relaxation process where the remaining part of compaction takes place (Fig. 1b).

2.1 *Results*

2.1.1 *Interpretation*

To analyze the results, we use a model that has been derived for the compaction of a dry granular column submitted to jamming by a hammer (*Nagel et al).* This model can be interpretated by a reorganization process of the granular material (*Ben Naïm et al).* The model in our adimensionalized form has three parameters : $1/a_0^f$ the asymptotical value reached by compaction, τ the characteristic time for the short scale, and B, a coefficient. In our setup, we can use an equivalent formulation for compaction (ρ) because of grain conservation: $\rho \propto 1/a_0$ and $\rho_1/\rho_2 = a_0^2/a_0^1$. The adimensionalized model takes the following form:

$$\frac{a_0^i}{a_0(t)} = \frac{a_0^i}{a_0^f} + \frac{\Delta a_0^\infty}{a_0^f}\left(1 + B\log(1 + t/\tau)\right)^{-1}$$

Fitting the model to the experimental data gives good agreement (Figure 4).

Figure 4. Evolution of mass fraction after the compaction process begins, fitted with the model. Experiments done at constant f = 1 Hz and varying amplitude.

2.1.2 *Coefficients of the model*

We observe that the characteristic time for the short time scale is $\tau \propto 10^4 s$. The value of the other coefficients is also stable for our amplitude range. We observe that the asymptotical value of the compaction is about stable and higher than the initial compaction (ρ_0) of the grain heap
($a_0^i/a_0^f = \rho_f/\rho_0 \approx 1.2$).

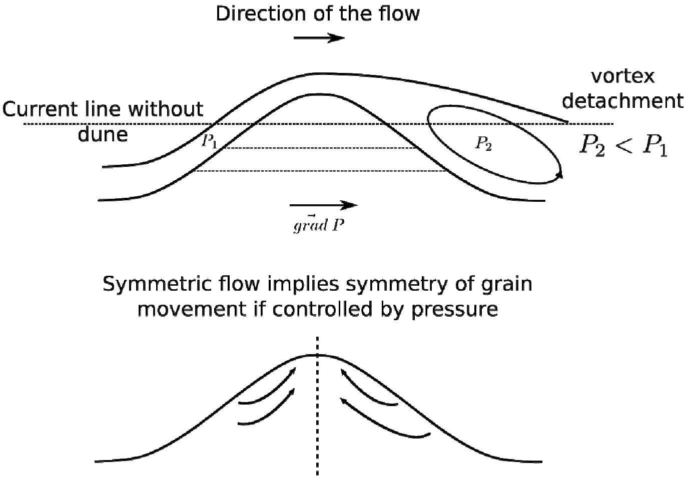


Figure 5. Interpretation of the sub-compaction of the vortex ripples. A pressure gradient is generated inside the ripple at each half-oscillation

2.2 *Granular interpretation*

The short time scale of granular compaction is a reorganization of the grain made possible by the low compacity of the substrate. The long time scale reflects the slower reorganization when the compactness raises.

2.3 *Ripple decompaction process interpretation*

The decompaction of the ripples is due to the oscillating pressure difference of the flow around the ripple produced by the recirculation (Figure 5)

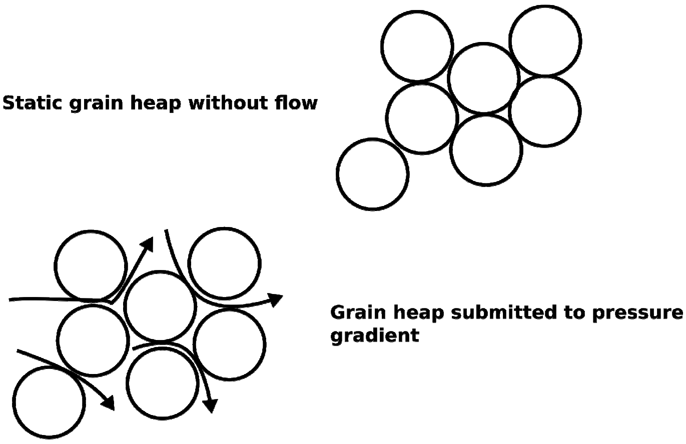


Figure 6. Difference between a static heap and a grain heap submitted to pressure gradient.

The pressure gradient forces a flow of water between the grains. This water is kept inside the heap because of the alternative pressure gradient generated by the flow at each half-oscillation. The compaction of the heap diminishes (Figure 6).

To assess this, visualizations on a long time scale of a ripple heap has been done, which confirms the existence of flowing cells of grains inside the ripple.

3 CONSEQUENCES ON SEDIMENTATION PROCESSES

We made precise experiments at a long time scale to study the process of ripple decompaction and the relaxation of this sub-compaction. We propose an interpretation for the compaction process, in terms of pressure gradient in underwater vortex ripples in oscillating flow.

Furthermore, experiments of the resilience of this compaction were done at the laboratory and will be presented in a forthcoming paper with extended study of the compaction process.

REFERENCES

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