EROSION OF THE GRANULAR LAYER DUE TO THE COLLISION OF THE VORTEX RING

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Summary The erosion of a granular layer due to the normal impact of a vortex ring was investigated in detail. We observed two characteristic surface patterns, *grooves* and *dimples*, depending on the magnitude of the vortex ring and the properties of the granular material. In order to clarify these pattern formation mechanisms, we measured the temporal variation of the layer thickness using the transmitted light intensity, as well as the velocity field using particle image velocimetry (PIV). These patterns are found to be generated by successive collisions of the primary vortex ring and the secondly vortex ring which develops on the granular layer.

INTRODUCTION

A vortex ring has a well-defined localized structure and translates as if it were an isolated particle with mass, momentum and energy, and quite a number of theoretical, experimental and numerical investigations have so far been performed on its behavior and stability.[1] In particular, interactions of the vortex ring with a solid wall or a fluid plane, and the collision of two vortex rings have been studied in detail for understanding fundamental aspects of the vortex dynamics and their breakdown process into turbulence, the control of fluid dynamical forces and the fluid momentum transport associated with the vortex rings, and so on. In recent years, the impact of a vortex ring on the *granular layer* has attracted much attention, and the characteristic erosion pattern called "spoke-like scars"[2], or "grooves"[3, 4], which has radial striations from the central depressed region to the outer edge of the rim, were elucidated. In the latter papers, different type of pattern, named "dimples" which is characterized by isolated small depressions around the outer edge of the main crater, was also studied. In the present investigation, we shall present a quantitative measurement of the thickness of the granular layer by the impact of the vortex ring, and elucidate these pattern formation mechanisms.

EXPERIMENTAL APPARATUS

We show our experimental setup in Fig.1(a). A vortex ring was generated in water by impulsively ejecting the same fluid vertically downward through a circular pipe, whose outlet was submerged below the free surface of water. The acceleration and duration of water ejection, and hence the magnitude of the vortex ring, were controlled by computer which drove the piston-motor system. The vortex ring proceeded downward and collided with the initially flat granular layer of sufficient thickness, which was placed at a prescribed distance Z_0 from the nozzle. The motion of the vortex ring and the process of the formation of the collision pattern were recorded by a high-speed digital video camera. The velocity field was measured by particle image velocimetry(PIV) and the circulation Γ of the vortex ring was calculated. We also measured the layer thickness by means of the intensity of transmitted light through the layer. The dependences of the pattern on Γ, Z_0 and d (the grain diameter) were examined. The typical Reynolds number $Re \equiv 2UR/\nu$ or Γ/ν (U is the translational velocity of the vortex ring, R is the radius of the vortex ring, and ν is the kinematic viscosity) ranged from 1800 to 5200. The Shields parameter $\theta \equiv U^2/(\gamma - 1)gd$ (γ is the ratio of the particle density to that of the fluid and g is the acceleration of gravity) ranged from 1 to 800.

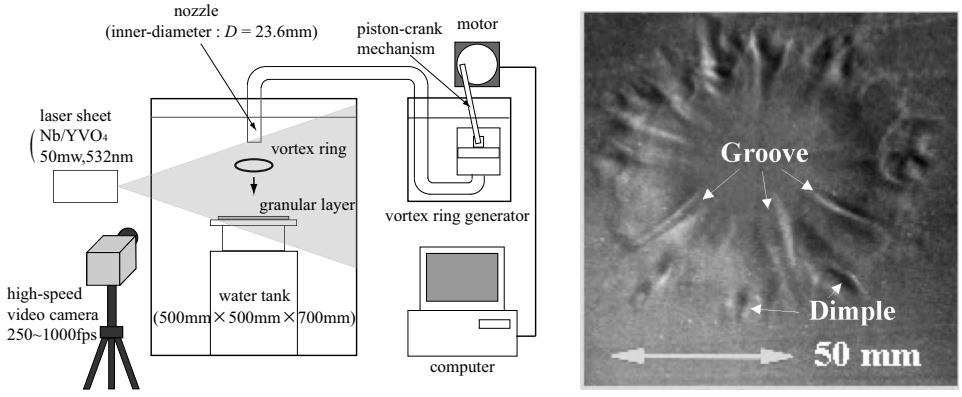

Figure 1. (a) Schematic diagram of the experimental apparatus. (b) Typical patterns due to the collision of the vortex ring with the granular layer: *grooves* and *dimples* (Re=5000).

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RESULTS

Fig.2(a) is an example of the contour lines of the layer thickness due to the collision of the vortex ring. The central circular mound was created by the primary vortex ring, whereas the smaller depressions around the outer periphery (dimples) were created by the secondly vortex ring. The latter was generated by the primary vortex ring near the boundary, which developed into hairpin vortices (see also the side-view of this process in Fig.2(b)). The dependence of the pattern formation on the Reynolds number and the Shields parameter is shown in Fig.2(c).

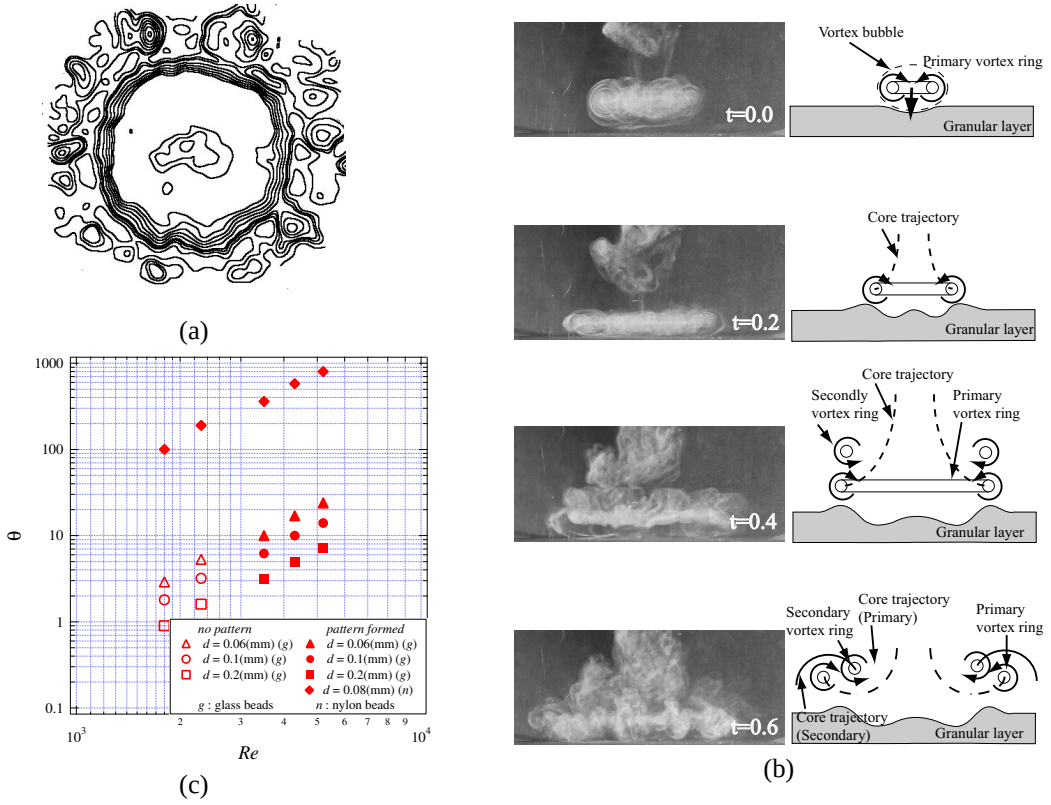

Figure 2. (a) Contour lines of the central mound and dimples outside of the circular ridge (Re=5200). (b) Side-view of the pattern formation process (left column: flow visualization by sodium fluorescein; right column: illustration based on observation). (c) Dependence on the Reynolds number and Shields parameter.

CONCLUSIONS

An experimental study was carried out on the normal impact of the vortex ring on the granular layer. The typical surface pattern "dimple" is found to be generated by the successive collisions of the primary and secondly vortex ring which was induced by the former. The secondary vortex ring is deformed into hair-pin vortices and woven in around the former, and engraves the granular layer at discrete positions outside of the main circular crater. The pattern forming region was examined, which reveals the emergence of a surface pattern above a certain Re and θ.

References

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