Quicksand During Earthquakes- the Effect of Horizontal Vibration on the Hopper

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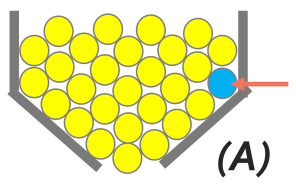
Whether the hourglass is vibrating, possibly causing different flow conditions. This study gives a horizontal sine wave to the hourglass. The experiment is conducted with different variables, such as frequencies and amplitudes generated by two motors. To compare the differences between the different variables, we look at the surface layer, the whole flow field, and a specific particle inside the hourglass.

Introduction

We change different frequencies and amplitudes to generate different sine waves to make the hourglass vibrate.



The definition of the acceleration amplitude is $\Gamma = \frac{a\omega^2}{g}$ and the velocity amplitude is $\Omega = \frac{a\omega}{\sqrt{g(D_h - kd_p)}}$. θ is defined as the angle between the surface layer of airsoft pellets and the vertical line. To study the discharge rate, we count the area of stacked particles at $t = 0(s)$ and $t = 3(s)$ to obtain the lost area. We track the trajectory of the airsoft pellet at corner ***(A)***.

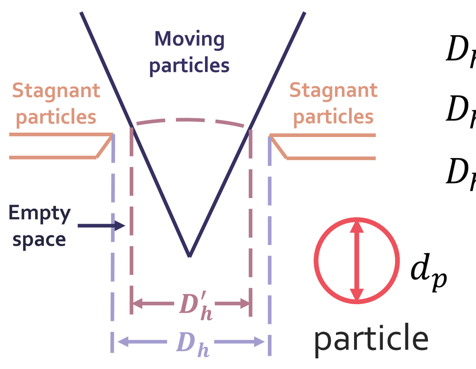
Theory

The type of flow varies with vibration and hopper opening angle. There are three types of the hopper of flow: [1]

- Mass flow: the whole particles drop averagely.
- Funnel flow: the particles in the center discharge first.
- Inverted-funnel flow: the particles at the periphery discharge first.

The discharge rate can be written as [2]

$$W = C\rho_b A'_h \sqrt{g(D_h - kd_p)}$$



$D_h > 6d_p$, the particles uninterrupted flow.
$D_h = 6d_p$, the particles discharge irregularly.
$D_h < 4d_p$, the flow could stop completely.

(C : a constant, depends on the type of material, k : particle shape constant, A'_h : opening area, ρ_b: the bulk density)

Simulation

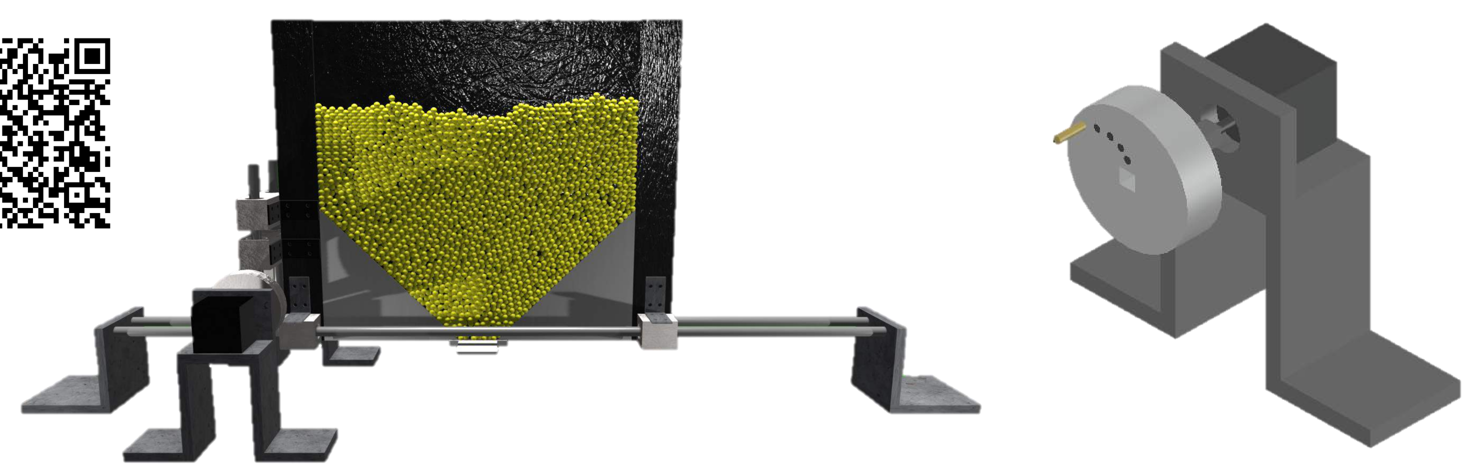
To make the simulation close to reality, the variables we set are as follows.

- Friction :
  How much velocity is lost in tangent direction.
- Bounciness :
  How much velocity is remained in normal direction.

- Airsoft pellets:
  - Friction: 0.2
  - Bounciness: 0.5

- Walls:
  - Friction: 1
  - Bounciness: 0

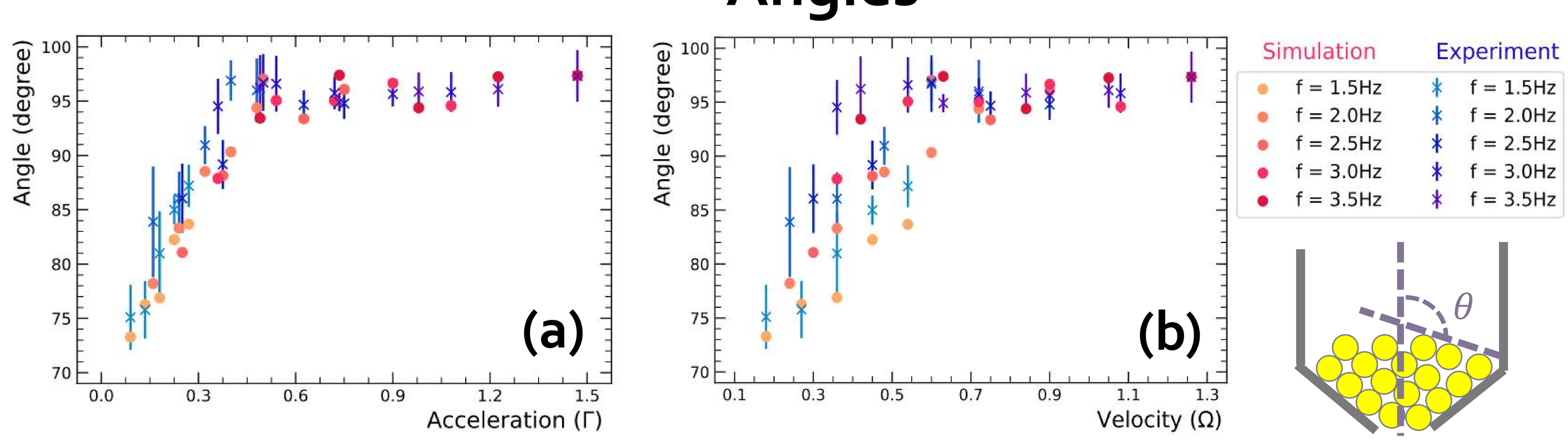
Experimental Setup



Using two stepper motors to push the hopper and changing the amplitudes by the holes in different locations. The details can be viewed by scanning the QR code.

Results

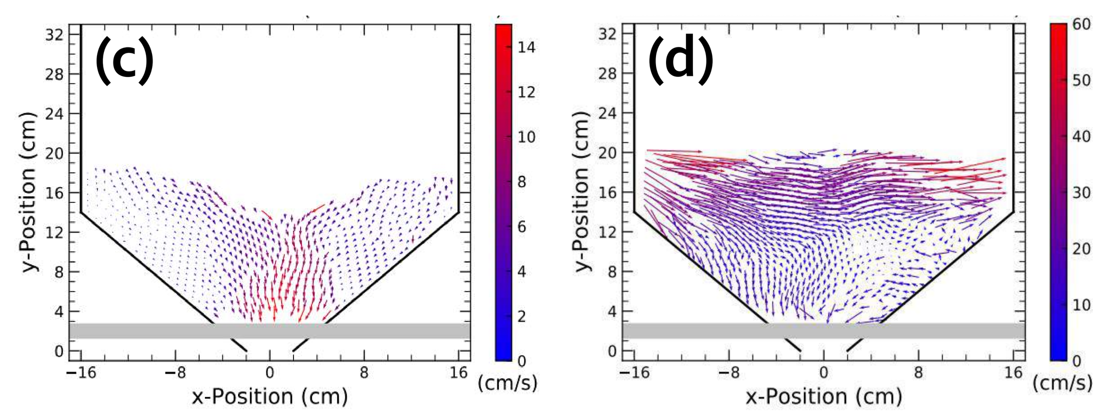
Angles



Change the different frequencies (1.5Hz, 2Hz, 2.5Hz, 3Hz, 3.5Hz) and different amplitudes (1cm, 1.5cm, 2cm, 2.5cm, 3cm), (a) Γ-θ, (b) Ω-θ

From **(a)**, with a larger Γ, the inclined angle of the surface layer is increasing. Above $\Gamma \approx 0.5$, the inclined angles are approaching saturation. From **(b)**, the inclined angle increases to saturation faster in higher frequency than in lower frequency when Ω is getting larger.

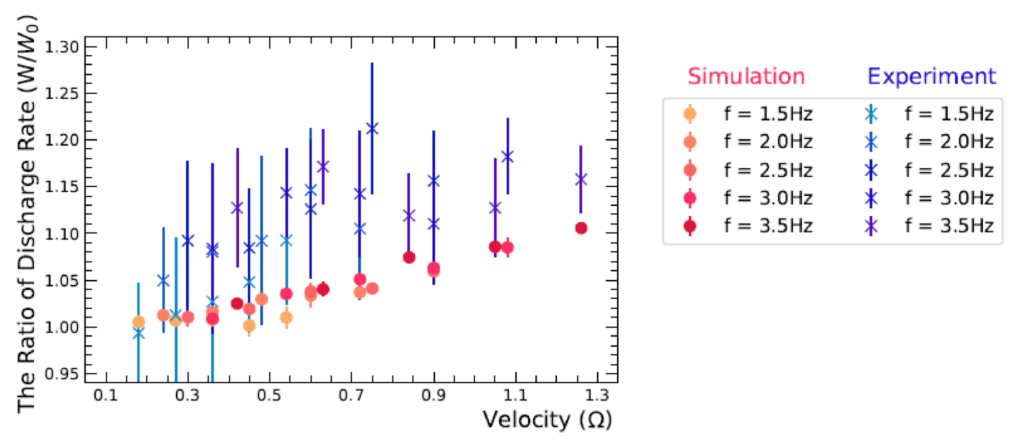
Flow Field



The arrows show the airsoft pellets' velocities.
(c) The flow field without vibration. (609 airsoft pellets)
(d) the flow field with 3.5Hz and 3cm vibration. (729 airsoft pellets)

In **(c)**, it shows the funnel flow. The airsoft pellets in the middle discharge first. In **(d)**, it shows the inverted-funnel flow.

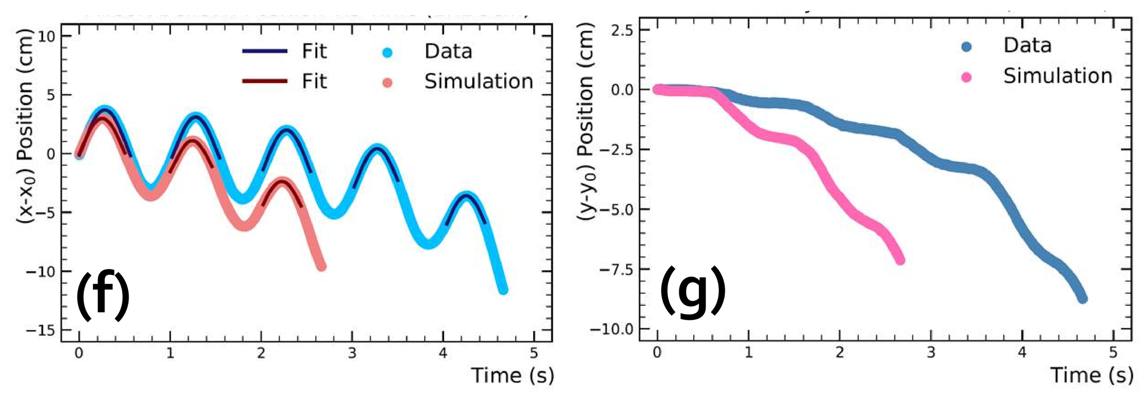
The Ratio of Discharge Rate



(e) The ratio of discharge rate is defined as W/W_0. W_0 is the discharge rate without vibration. Each point was averaged with 10 measurements in the experiment and was averaged with 3 measurements in simulation.

From **(e)**, the ratio of discharge rate will increase with Ω, and the ratio of the experiment is larger than that of the simulation.

Trajectory of Particle



The trajectory of an airsoft pellet next to the wall with 1Hz and 3cm vibration.
(f) The trajectory of the pellet in the x-direction.
(g) the trajectory of the pellet in the y-direction.

Simulation	Frequency(Hz)	1.020	1.002	0.962		
	Amplitude(cm)	2.874	2.982	2.913		
Experiment	Frequency(Hz)	1.026	1.070	1.006	1.071	1.050
	Amplitude(cm)	3.130	2.912	3.191	2.855	2.891

(h) Fitting result for simulation and experiment.

Surrounding airsoft pellets and setup impact the movement of the tracking pellet, so the frequency and the amplitude will be slightly different. Due to the difference in bulk density, simulation is faster than experiment with the same falling distance.

Conclusions

1. The higher the frequency is, the bigger the angle is. However, the tendency of different frequencies seems to be consistent.
2. Funnel flow occurs when there is no vibration.
3. Inverted-Funnel flow occurs when there is vibration (3.5Hz,3cm).
4. The tendency of the ratio of discharge rate is getting larger with increasing Ω.
5. The trajectory and the discharge rate of the airsoft pellet is affected by the surrounding particles and setup.

References

[1] M. L. Hunt, R. C. Weathers, A. T. Lee, and C. E. BrennenC. R. Wassgren, Effects of horizontal vibration on hopper flows of granular material (1999) Doi: 10.1063/1.869903
[2] P. A. Shamlou, Handling of Bulk Solids, Theory and Practice, 1st ed. (Butterworths, London, 1988)