The Growth of Root in the Pebbles

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The behavior of root growth in the pebbles is what we are interested in. Therefore, the experiments are used to simulate the situations that the trails of roots with several lengths in the different-sized pebbles. The fiber is used to be our root and it moves forward in the brass cylinders used to mimic the pebbles. Three things are observed in our experiments. First, The longer fiber, the easier to bend. Second, the more dense brass cylinders are packed, the easier the fiber bends. Last, the composition of the brass cylinders does affect the motion of the fiber.

Introduction

When the typhoon visits Taiwan, the mudslide often happens and usually causes lots of damage. The trees take an important role to prevent the mudslide especially the deep-rooted trees. The deep-rooted plant often grows to be the taproot system. In contrast, the shallow-rooted plant often grows to be fibrous root. By changing the length of the fiber, we can imitate the comparisons between the deep-rooted and shallow-rooted tree. For example, the betel nut in the mountain of Taiwan is the shallow-rooted plant and is no help to prevent mudslide. We design the experiment after learning the granular medium experiment[1], and show why fibrous root plant almost to be shallow-rooted, and varieties of the ground cause a different degree of mountain collapse.

Experimental Setup

The grains are fixed in a cuboid space(Fig.1), whose bottom is the glass and the walls are made of brass. The shape of grains is hollow brass pipe(outer diameter $R = 6{,}7{,}8mm$). Three types grains(3-type) are used to make the different compositions of the experiments(Fig.2). The static friction coefficient of glass-brass and brass-brass are $\mu_{bg} = 0.737 \pm 0.062$ The step motors provide power to drive the fiber(Fig.3), and the camera is used to record the experimental data. The material of the fiber is plastic pad slice. The video is analyzed by the ImageJ to obtain the results.

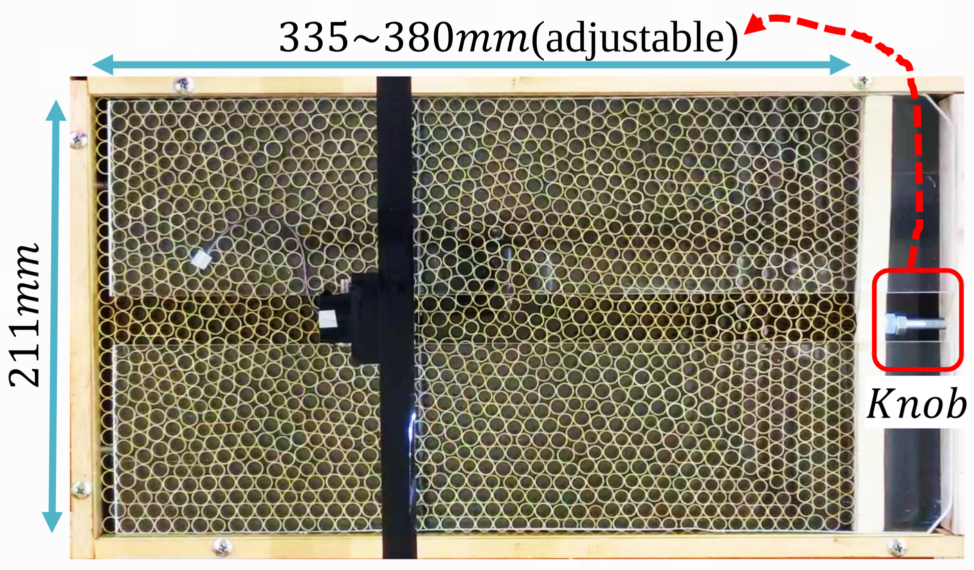


Fig. 1 The cuboid space with grains(single size) and fiber.

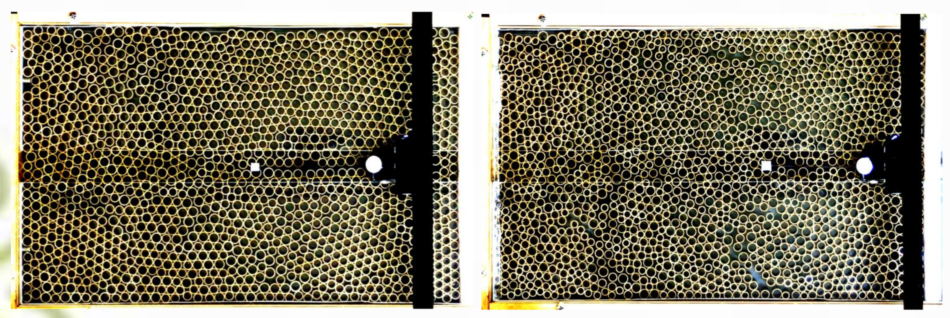


Fig. 2 2-type(left) & 3-type(right) experiment.

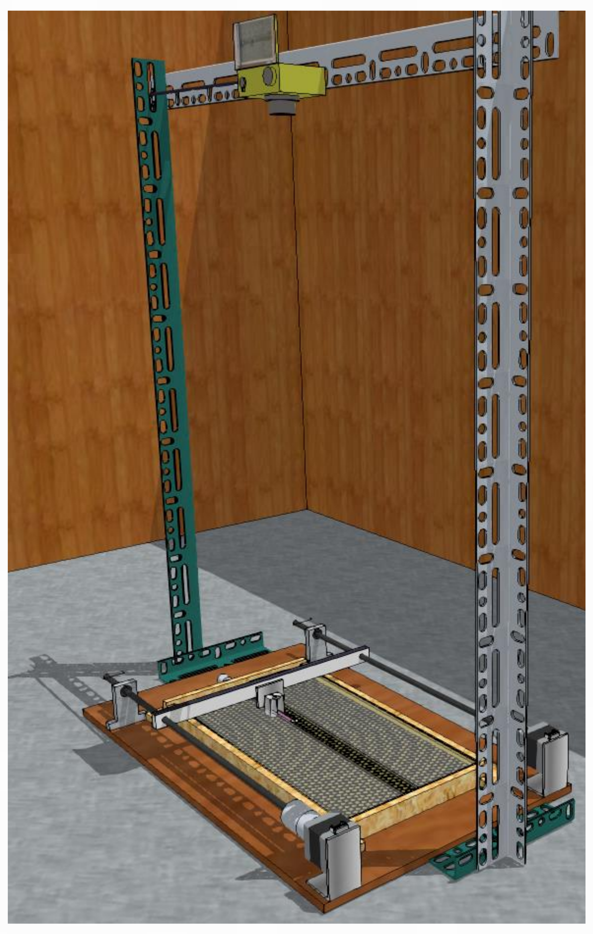


Fig. 3 Experimental setup. Two pairs of step motors drive the fiber. The high speed camera records the terminals of fiber.

Theory

As shown in Fig. 4, the force acting on the fiber is F_n and F_b, the Euler force from the motion of the fiber and recovery force from the bending of the fiber.

$$F_n = F \times \mu_{bg} = \frac{L\delta}{2}\phi h \rho g \mu_{bg}, \quad F_b = \frac{8EI}{L^3}$$

$L\delta/2$ is the occupation of the base area grains. h is the grain height. L is the length of the fiber. δ is the small lateral movement of fiber. ρ is the average density of the particle space. g is the gravitation constant. ϕ is the packing fraction. E is the Young's modulus of the fiber. I is the moment of the inertia. t is the thickness of the fiber. When the property of the fiber makes the Cauchy number $C = F_n / F_b = 1$, it is the critical point. In the range of $C < 1$ ($C > 1$), the fiber will be almost jiggling Fig. 5(a) (bending Fig. 5(b)). The critical point is the boundary of bending and jiggling. The critical curve of the theory is Eq. (1).

$$L_c^L \approx t\left(\frac{4E}{3\mu_{bg}\phi\rho g t}\right)^{\frac{1}{4}} \qquad (1)$$

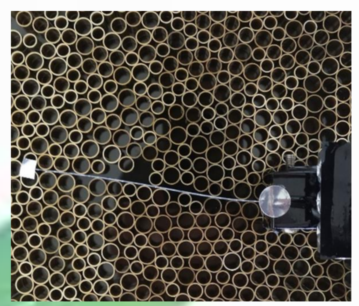


Fig. 5(a) jiggling(C<1)

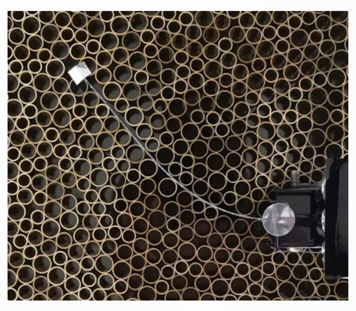


Fig. 5(b) bending(C>1)

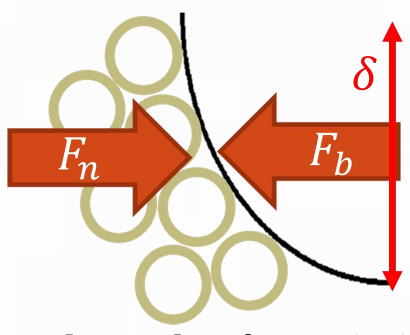
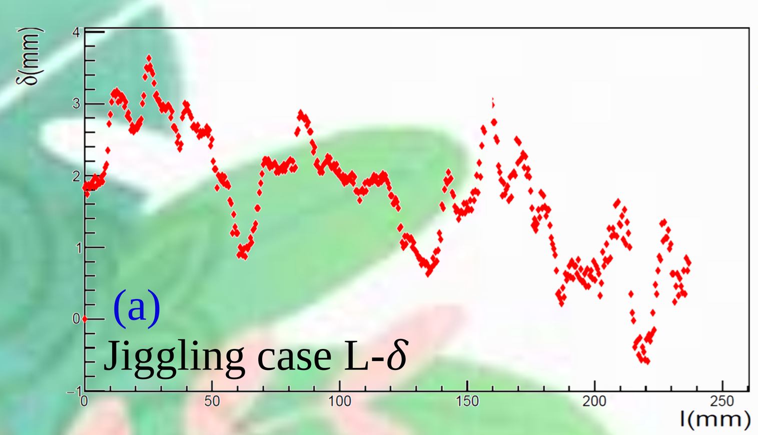


Fig. 4 The Euler force (F_n) and the recovery force (F_b) act on fiber.

Fig.6 Base on the reference [1], it said that the progress during bending can be described by the exponential function. We use Eq. (2) to fit it. The coefficient p means the degree of F_n/F_b. As for the second half of Fig. 6(b), it is called the unloading area. Unloading area happens when the F_b of the bending fiber is larger than F_n. F_n and F_b increase gradually during progress, called loading.

$$\delta = \delta_0 e^{p(x-l_0)} \qquad (2)$$



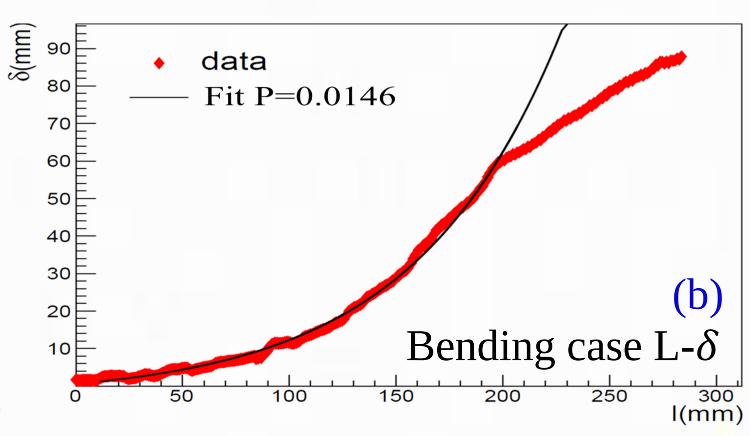


Fig. 6 δ-l graph of fiber in experiment. (a) jiggling case. (b) bending case.

Experimental Results

The results(Fig.7) show that the coefficient p during the loading part in different measurements are the same. This is called the similarity of the bending case. It also shows that it is reasonable to determine the behavior of the fiber in only 3 or 4 measurements.

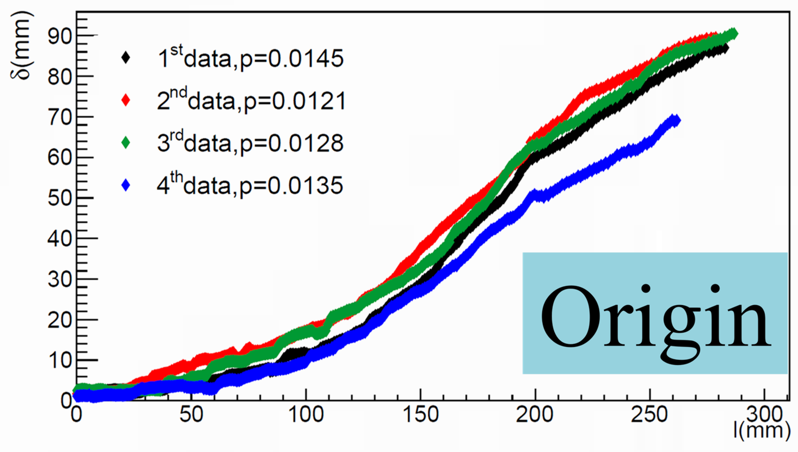


Fig.7(a) shows the result in the case of bending from 4 different measurement.

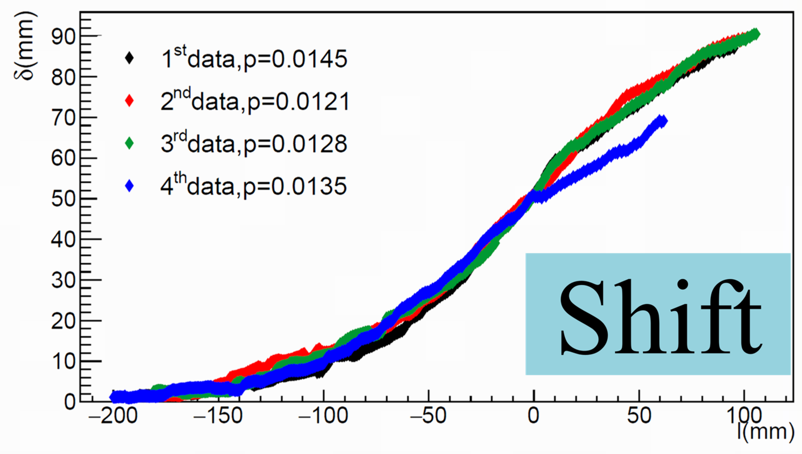
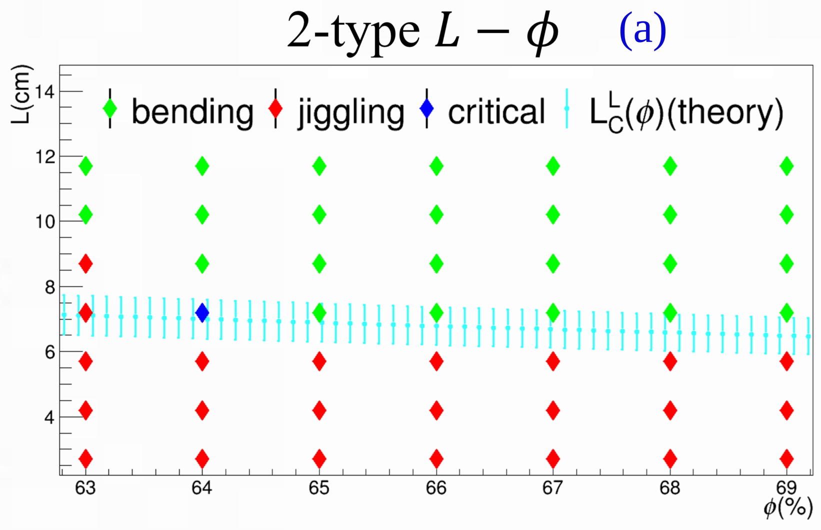


Fig.7(b) shows the result in Fig. 7(a) shifted by $\delta_{max}/2$.

Second, changing the fiber length and the packing fraction(ϕ) of grains, whether the fiber is bending or jiggling can be determined. Fig.8 shows the phase diagram for various cases in the 2-type case. The theoretical prediction is also given(L_C^L). The uncertainty on prediction is given by the uncertainty of μ_{bg}.

Experiments show that in the case of 2-type, we can find the critical point at $\phi = 64\%$, L =7.2cm. In the 3-type experiments, the condition of the critical point is the same. However, when L=5.7cm, $\phi \geq 65\%$, the phenomenon of bending is seen. In general, the fiber in 3-type case is easier to bend than the 2-type case. It shows that the trend shifts to the lower right corner, and this is not mentioned in the theory.

2-type $L - \phi$ (a)



3-type $L - \phi$ (b)

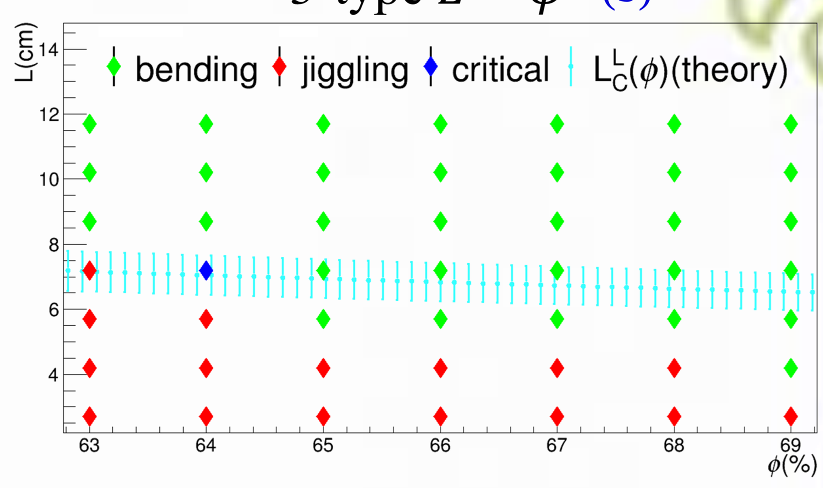


Fig. 8(a) is the complete data for 2-type grains experiment with the theory line L_C^L. Green point is bending case, red is jiggling case, and navy blue is the critical point. Light blue line is theory line with error of parameter μ and E. Fig. 8(b) is the complete data for 3-type grains experiment.

In the case of the 1-type grain(Fig 9). It is filled with R=7mm grains. The ϕ ranges from 80% to 86%. However, the permutation of the grains is so regular that the fiber passes through the slit of grains, which means that only jiggling can be observed. Therefore, we stop performing more experiments in the 1-type case. We think the permutation of grains is not considered in the theory.

1-type $L - \phi$

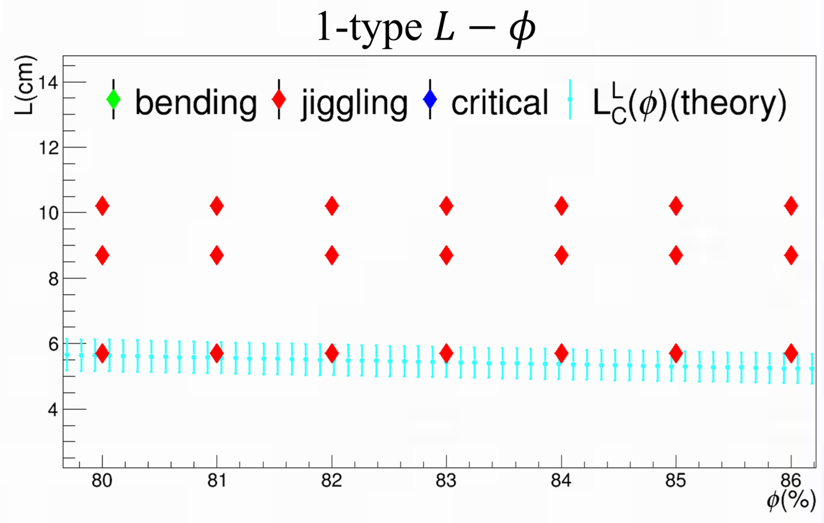


Fig. 9 The result of the 1-type case. It shows that the fiber jiggle where it should be bending from the prediction of the theory.

Conclusion

- The longer fiber, the easier to bend.
  - The longer root grows not straightly under the ground.
- The denser medium, the easier to bend.
  - In the softer ground, the root reaches the deeper ground.
- The more variety of the medium particles, the easier to bend.
  - Single size of the medium may make the root deeply.

References

[1] Bending transition in the penetration of a flexible intruder in a two-dimensional dense granular medium' PHYSICAL REVIEW E 97, 022901 (2018)

Fig REF betel-nut: https://www.newsmarket.com.tw/areca-betel-nut/part1-08/