IOP Conf. Series: Earth and Environmental Science **31** (2016) 012001 doi:10.1088/1755-1315/31/1/012001

Influence of Contactopy on Two-Dimensional Brazil-Nut Effect

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Abstract. Using hard sphere collision scheme and molecular dynamics method simulation, two-dimension Brazil-Nut Effect (BNE) is conducted. BNE inital configurations are artificially created to obtain number of contacts between the grains, called as contactopy. It is observed that from initial condition until the end of BNE observation, center-of-mass in vertical direction tends to decrease, while contactopy tends to increase, which are similar to the reported results in a *Gedankenexperiment* (Viridi et al., 2014). Initial configurations which are also dependent on contactopy influence the rise time since it can override influence of density ratio that should affect rise time (Möbius et al., 2001). We investigate on how the intruder rise time influenced by contactopy, as well as density.

1. Introduction

Brazil-Nut Effect (BNE) is a granular material phenomena, where larger grains (usually known as intruder) could rise, reaching the surface of the granular system when vibrated. Some results of experiments have shown the that intruder is able to rise due to the system normalized acceleration factor, Γ, which is a function of the vibrational frequency and amplitude [1]. It is possible to design BNE observation environment under two- [2,7] or three-dimensional system [3]. When BNE phenomenon occured, it has been investigated that the intruder rise time, t_{rise}, is influenced by the density ratio between the intruder and the granular bed [5].

Computer simulation via molecular dynamics (MD) has been applied to predict a variety of BNE behaviour types [4]. Influence of BNE properties, such as grain and vibrational parameters, can be measured comprehensively [6]. Furthermore, initial configurations which are dependent on position of the grains can be artificially designed to observe the trajectory as well as its rise time. This approach implies a wide opportunity to explore related mechanism, describing the effect of system parameters of the phenomena.

In this paper, we report the results of our simulation investigating the intruder rise time influenced by initial number of contacts between the grains (called as contactopy), for certain ratio density on two-dimensional granular bed. The simulation method and the initial configuration setup is presented in §2. We show the evolution of intruder position, contactopy, and average rise time in §3. Based on our trend analysis on the results, we describe future works and conclusions in §4.

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2. Simulation Method

A single intruder two-dimensional BNE system is modeled using MD simulation of hard spheres collision scheme. The total number of grains (intruder and granular bed) is 157. The grains are placed inside a two-dimensional rectangle container. The width of the container is fixed, while the container base fluctuates following the sinusoidal motion when vibrated. Diameter ratio between the intruder and the granular bed is $d / d_m = 7.5$ and the density ratio ρ / ρ_m is varied from 0.1 to 1.8. The restitution coefficient is 0.99 for the grains and 0.26 for the container. There is no friction force acting between the grains. The coefficient of friction for the container is 0.98.

The simulation is initialized by arranging in order the granular bed above the intruder. The container is not vibrated at this stage as the granular bed move downwards and condensed under gravity. Snapshots of the situation for this initial configuration is shown in figure 1.

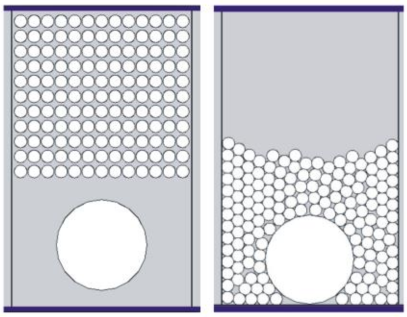


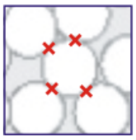
Figure 1. Configuration of BNE system. (left) granular bed initially in order on top. (right) Condensation state.

The contactopy, C, can be determined from its geometry as

$$C = \sum_{i=0}^{N}\sum_{j>i}^{N}\left[\frac{\max(0, R_i + R_j - |r_i - r_j|)}{R_i + R_j}\right] \tag{1}$$

which describe the number of contacts between the grains, where R is the grain radius and r is the distance from a reference point to its center of mass [8]. We could generate different contactopy from the initial configuration by setting up certain arrangement of the granular bed (table 1).

Table 1. Grains configuration and its relationship with C.

Configuration	Contactopy
	4
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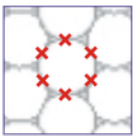	6

From this condensation state, the initial configuration is recorded. As the container vibrated, the intruder rise time counter is started. The system normalized acceleration is specified by using constant vibrational frequency $f = 13$ Hz and the amplitude A as

$$\Gamma = \frac{A(2\pi f)^2}{g} \tag{2}$$

where g is gravitational acceleration. We consider the normalized acceleration to be relatively high, $\Gamma = 5$, to ensure that BNE has a high probability to occur. Thus, the intruder rise time can be determined by the time it reaches the surface of the granular bed.

3. Results and Discussion

We generated 82 random initial configuration for 20 different values of ratio density and obtained possible numbers of contactopy between 328 and 355. Some of the contactopy snapshots are shown in figure 2. When the vibration applied, we examined the system in correspondence with some published experiments of similar normalized acceleration, regardless the distinction of contactopy [4,5]. It has been confirmed that all 1640 initial configurations used in our simulation model exhibit BNE phenomenon.

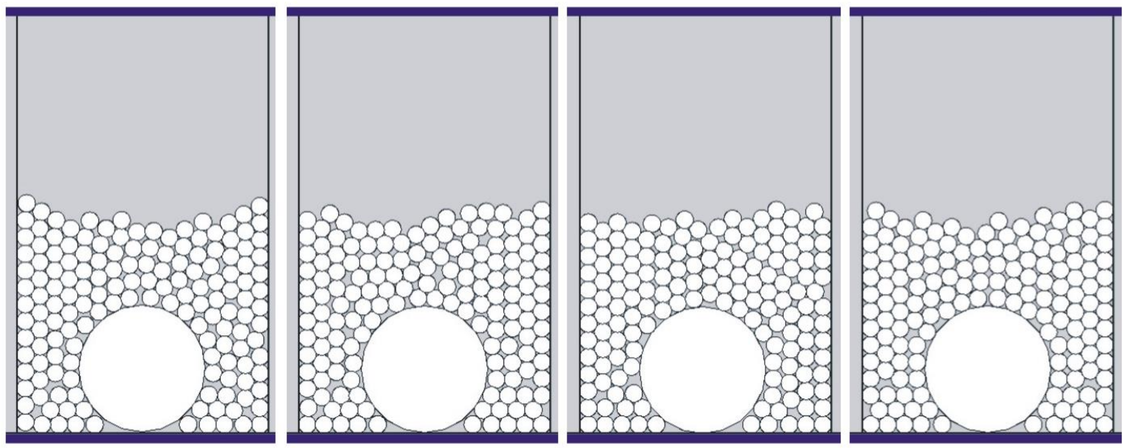

Figure 2. Samples of contactopy from 157 grains of BNE system.

It has been observed that from the initial condition until the end of BNE observation, the center-of-mass in vertical direction y_{CM} tends to decrease, while contactopy tends to increase as shown in figure 3 (left panel), which are similar to the reported results in a *Gedankenexperiment* (Viridi et al., 2014) [8]. Let C' denote the number of contactopy at $t = t_{rise}$ representing the highest number of contactopy from the system obtained in our simulation. As the system vibrates, grains configuration tends to be more compact toward C' and grains average speed in the vertical direction v_y^2 decreases as the vertical center-of-mass y_{CM} decreases. This relation is given in figure 3 (right panel). Since all grains in average do not moves in horizontal direction, value of v_x^2 is nearly zero.

To determine the intruder rise time in average as a function of density ratio, we classified the initial configurations into 0.1-1.8 range of density ratio. We did not, however, obtain the similar pattern as reported by Möbius et al. [5], that the density ratio should affect the rise time. One possible reason is that the simulation used two-dimensional system, which contains fewer degrees of freedom than the three-dimensional setup used by Möbius.

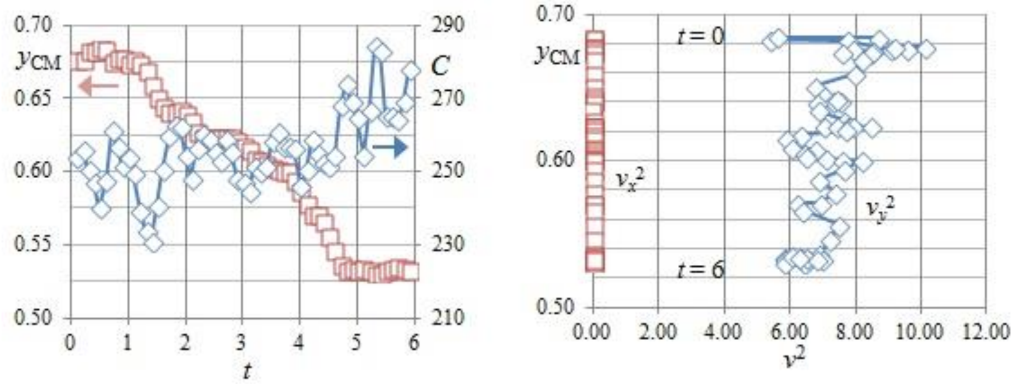

Figure 3. (left) Evolution of y_{CM} and initial configuration at $C = 328$, as a function of time. (right) Evolution of average speed in *x* and *y* direction at certain vertical direction.

In the next step, we plotted the intruder rise time as a function of contactopy. We found that the rise time minimum values vary in the range from 0.3 to 1.5 seconds as shown in figure 5 (left panel), while the maximum values have a wider range from 8.6 to 50.4 seconds. The associated density ratios for these values does not seem to have a unique relationship. This means that from all initial configurations, the minimum and maximum rise time cannot be distinguished from its contactopy, as well as density.

Interestingly, we found that the rise time in average tends to decrease as the number of contactopy increases as shown in figure 4. We suggest that this is due to the tendency of the vibrated system to become more compact before rising intruder out of the surface. Our simulation also indicates that there is a related pattern of compaction at the time it raises the intruder. Figure 3 presents that contactopy tends to increase toward C'. This may explain that the higher contactopy from the initial configurations used in the simulation, the nearer its distance from C' and result in the decrement of the rise time.

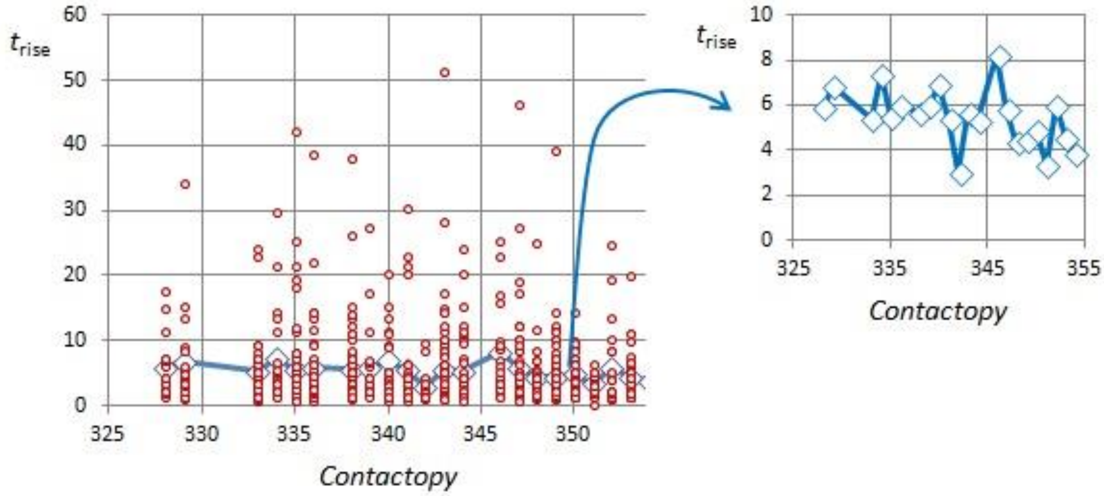

Figure 4. Contactopy does influence the average of rise time, $<t_{rise}>$.

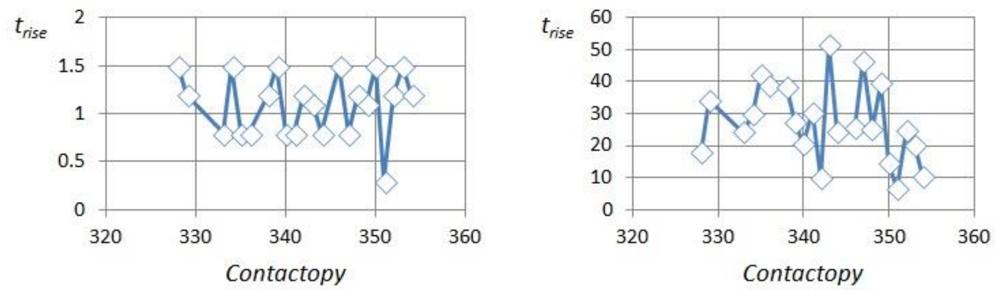

Figure 5. (left) Minimum and (right) maximum intruder rise time, t_{rise}, obseved as a function of contactopy from the initial configuration.

4. Conclusions

Contactopy can be generated into a certain range of number from the initial BNE system configurations of two-dimensional MD simulation. 157 grains in our simulation generates numbers of contactopy between 328 and 355. As the system vibrated at $\Gamma = 5$, the intruder rise time observed as a function of contactopy from the initial configurations. It shows that the rise time in average tends to decrease as the number of contactopy increases.

The future work should be focused on compaction detail during the intruder rising process. We hope to examine our assumption that the dynamic contactopy tends to a certain compaction in order to raise the intruder.

5. Acknowledgement

This work is funded by a Penelitian Unggulan Perguruan Tinggi - Desentralisasi DIKTI Tahun 2015 with project number 310i/I1.C01/PL/2015.

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