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# Predicting the Motion of an Intruder in a Vertically Vibrated 2D-Granular-Bed using Contact Points Approximation

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## Abstract

In this study, 2-dimensional Brazil nut effect experiments were setup. An intruder moves from its initial position at the middle-bottom of a container to its final position at the top of the granular bed. To predict the motion of the intruder, the number of contact points for each grain around the intruder was counted manually for grains in the first layer until the third layer. The average numbers of contact points from grains in each of 8 directions respected to the center of the intruder were calculated to determine the direction of total force acting on the intruder by grains in the first layer, in the first two-layers, and in the first three-layers. The result will be more acceptable using the data of two or three layers of grains in predicting intruder movement.

**Keywords:** granular materials, vibration, Brazil-nut effect, contact points

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## 1. Introduction

Brazil-nut effect (BNE) is a phenomenon when larger grains rise to the top of smaller grains subjected to vibration [1]. The opposite phenomenon when an intruder (larger grain) sinks in a vibrated granular bed (smaller grains) is called reverse Brazil-nut effect [2]. However, it also was found that the position of an intruder in a vibrated granular bed remains unchanged when compaction occurred [3]. There are many points of view to explain this BNE, such as through its phenomenon of void filling [4] and a condensation mechanism [2,5], through its intrinsic properties of grains such as the comparison of mass ratio and diameter ratio of the two grain types [5], the surface roughness of intruder [6], the base roughness of the container [6] and also through the reduction in potential energy of the system [7,8].

BNE occurred in 2-D and pseudo 2-D granular system [9,10,11] where grain configurations can be recorded and the intruder can also be traced automatically, e.g., using OpenCV application [10]. The positions of all grains were determined using a screen snapshot or an image of the system to be digitized using web browser running an HTML equipped with a JavaScript code and represented in pixels [12] and in SI-units [13]. The zigzag trajectory of an intruder in pseudo 2-D granular bed had been observed

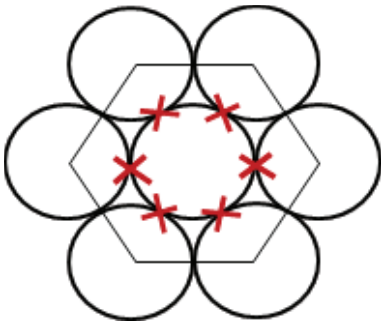

**Figure** 1: A grain has maximum 6 contact points in hexagonal closed packed arrangement.

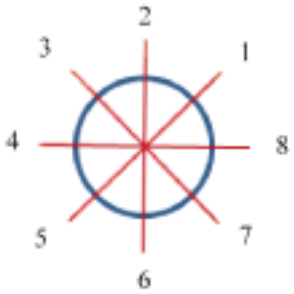


**Figure** 2: Eight directions with its origin at the center of intruder.

in the previous work [10]. However, when hexagonal closed packed configuration in the granular bed has been attained then the intruder is difficult to move [8,14,15].

This paper discusses about motion of an intruder in a vertically vibrated 2D-granular-bed in which BNE phenomenon occurred. The intruder motion is influenced by the arrangement of grains around the intruder resulted from the vibration. The number of contact points among grains around the intruder is counted to determine the total force acting on the intruder in order to predict the direction of the intruder motion.

## 2. Theory

In this study, all possible states of a 2-D granular material are visualized by the configurations of the grains and are expressed by the number of contact points among grains. Indeed, contact point is actually a projection of contact line between two grains on a plane which is perpendicular to the line; the plane is the front surface of the 2-D container. The number of contact points on a grain with all its nearest neighbors is counted. Hence, number of contact points is greater for denser grain arrangement. Using thin cylindrical grains, the maximum number of contact points on a grain is 6 that occurred when hexagonal closed packed arrangement established.

It is proposed for simplicity that there are 8 directions which may sufficient to encounter the influences from the nearest grains to predict the direction of the intruder movement as illustrated in Fig 2. Grains nearby an intruder are grouped to be the first layer, second layer, and third layer as shown in Fig 3.

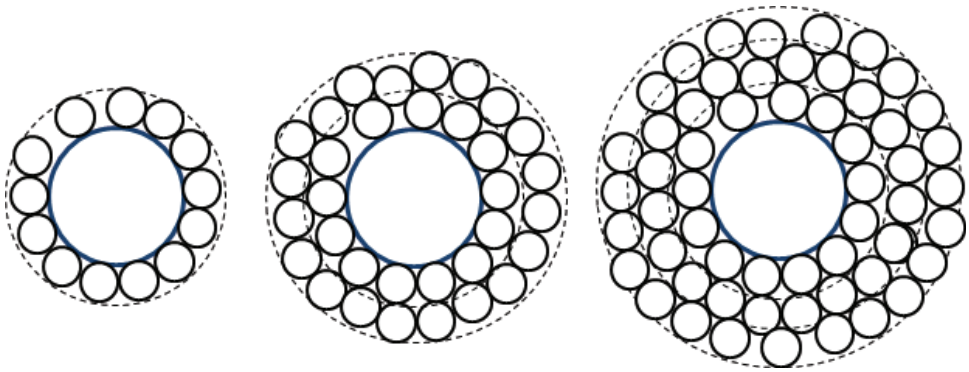

**Figure** 3: Grains around an intruder: (a) one layer, (b) two layers, and (c) three layers.

The number of contact point for each grain in the first layer, second layer, and third layer around an intruder is counted manually. Pressure is proportional to the number of contact points. It can be seen from Fig. 3 that intruder is subjected to pressure by grains from all direction. If the pressure to the intruder is not the same in all directions then intruder moves toward the region of lower pressure. The total force $\vec{F}_k$ acting on the intruder by $N_k$ grains in $k$ layers ($k$ = 1, 2 or 3) is proportional with the number of contact points as follows:

$$\vec{F}_k \approx -\frac{1}{8}\sum_{i=1}^{8} \bar{c}_{ik}\,\vec{r}_i \tag{1}$$

$$\bar{c}_{ik} = \frac{\sum_{j=1}^{N_{ik}} c_{ijk}}{N_{ik}}. \tag{2}$$

$\bar{c}_{ik}$ is the average number of contact points of $N_{ik}$ grains inside $k$ layers in direction $i$ with respect to intruder and $\vec{r}_i$ is the position of grains in direction $i$ with respect to intruder

$$\vec{r}_i = \left[\cos\left(\frac{2\pi\, i}{8}\right), \sin\left(\frac{2\pi\, i}{8}\right)\right]; \quad i = 1,\ 2,\ 3,\ ...,\ 8. \tag{3}$$

Since the grain arrangement changes from time to time due to vertical vibrations to the granular bed thus the number of contact points of each grain is a function of time. Therefore, the total force $\vec{F}_k$ acting on the intruder is also a function of time. This total force is used to predict the direction of intruder movement and this prediction is compared to the experimental results of intruder position in the next time step.

## 3. Experimental Setup

A 2-dimensional Brazil-nut effect experiment was setup with the diameter of intruder and bed granular are 2.4 cm and 0.68 cm respectively in a slab container with sizes 20 cm ×10 cm × 0.2 cm for internal heigh, width, and thickness respectively. The

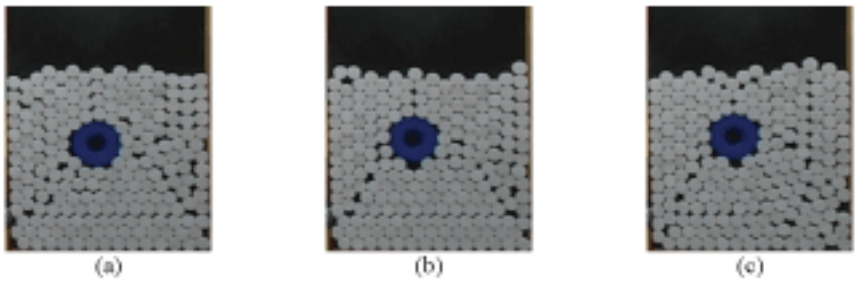


**Figure** 4: Pictures are taken at different time: (a) *t* = 84, (b) *t* = 85 and (c) *t* = 86.

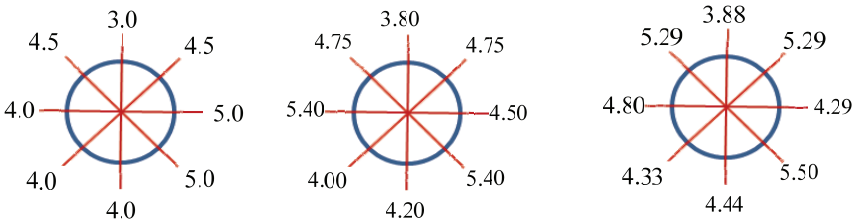


**Figure** 5: Average numbers of contact points around an intruder for grains at *t* =84 within: (a) the first layer, (b) the first two- layers, and (c) the first three-layers.

density (g/cm$^3$) is 0.4375 for intruder and 0.118 for bed granular. The granular system was vertically vibrated with frequency of 14 Hz and constant dimensionless vibration acceleration $\Gamma$ of 3. In order to give time in taking picture of the granular system, the system was discontinued each time after one-second vibration. Pictures were taken each second from initial observation (*t* = 1) when intruder at the bottom until at the top of the granular bed (*t* = 100) [3]. Position of intruder was determined [13] and the number of contact points of each grain around intruder were then obtained manually from the pictures.

## 4. Results and Discussion

Figure 4 shows three pictures taken sequential at time *t* = 84, 85 and 86. Position $\vec{R}_t(x, y)$ of intruder at time *t* = 84, 85 and 86 are $\vec{R}_{84}(4.45, 5.26)$, $\vec{R}_{85}(4.26, 5.49)$, and $\vec{R}_{86}(4.24, 5.62)$ in centimeters with origin of the coordinate is at the bottom of the slab container in the left. Intruder moved to about direction 3 or upper-left from *t* = 84 to *t* = 85 and a little bit upward from *t* = 85 to *t* = 86.

The average numbers of contact points of grains around the intruder using only the first layer, the first two- layers, and the first three-layers for picture at *t* =84 are shown in Fig. 5.

In this paper, it is only the direction of total force acting on the intruder was obtained. The direction of the total force $\vec{F}_k\left(F_{kx}, F_{ky}\right)$ at time *t* = 84 using grains the first layer, the first two-layers, and the first three-layers are $\vec{F}_1(-0.21, 0.13)$, $\vec{F}_2(-0.01, 0.04)$, and $\vec{F}_3(-0.04, 0.01)$. Using the same method for *t* = 85, it is obtained $\vec{F}_1(-0.02, -0.52)$, $\vec{F}_2(0.14, 0.24)$, and $\vec{F}_3(0.11, 0.02)$. These results show that using grains more than one layer give similar tendency for the total force, i.e. $\vec{F}_2$ and $\vec{F}_3$ have similar directions. The

use of number of contact points of grains in the first layer could give correct direction of total force if there is no empty space (vacancy) in the layer in size of about one grain. Figure 4b shows that there is free space below intruder in size almost one bed particle so that the prediction using one layer is not sufficient. The direction of total force at $t$ = 84 predicted that intruder would move to the upper-left and this is accepted for the intruder movement from $t$ = 84 to $t$ = 85. However, for $t$ = 85, the result predicted that intruder would move upper-right but the experiment showed intruder move upward.

## 5. Conclusions

Intruder movement in a 2-D vibrated granular bed has been predicted using contact points approximation. The direction of total force acting on intruder can be obtained from the number of contact point of grains around the intruder. The result will be more acceptable using the data of two or three layers of grains since the use of only one layer could not overcome vacancy of a grain.

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