Effect of horizontal vibration on pile of cylinder avalanches as a pseudo-two dimensional granular system

Y Mardiansyah¹, Yulia¹, S N Khotimah¹, Suprijadi²,³, S Viridi¹

¹Nuclear Physics and Biophysics Research Division, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
²Theoretical High Energy Physics and Instrumentation Research Division, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
³Research Center for Nanosciences and Nanotechnology, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia

E-mail: yopymardiansyah2@gmail.com

Abstract. Dynamics of pseudo-two dimensional granular material consisted of two layers cylinder piles positioned on top of a horizontally vibrated plate is reported in this work. It is aimed to observe structural change of the cylinder pile vibrated in certain frequency and amplitude. Dimensionless acceleration $\Gamma = \frac{4\pi^2 f^2 A}{g}$ (with $g$ is gravitational acceleration), which is generally used in granular materials to observe transition between states, e.g. stable, rotating without slipping, rolling and slipping in $\Gamma$–$f$ plane, does not work well for this system. For this system additional states for the piles can also be observed, e.g. stable and flowing states. Observations parameters are frequency $f$ (measured in Hz) and amplitude $A$ (measured in cm). These parameters are used to construct the $A$–$f$ plane instead of $\Gamma$–$f$ one.

1. Introduction

Granular material is unique type of material compared to other material since it can have various "states" similar to the states of matter of other substances, while those substances can only have one state at certain body temperature. The uniqueness of the material can give rise to unique phenomena that can be utilized in industry, e.g. for mixing [1] and segregation processes [2], and also be used to modelled natural disasters, e.g. landslides [3, 4] and avalanches [5, 6]. Experiments using a hexagonal shaped cylinder piles give results that the distribution of pressure at the bottom is identical to any grain particles in the base layer and does not rely on heavy load on it [7]. This is what makes the hourglass accurate use even though with different number of sand and independent on particle sharpness [8].

Experiment to see the phenomenon of avalanches in two-dimensions is discussed in this work. Cylinder pile is used as granular material which is vibrated in horizontal direction with variations of vibration frequency $f$ and amplitude $A$. Details of the instrumentation part have been explained in previous work [9]. Only two layers of cylinder are used in the experiment since the size of the system is already similar to the simulation of three grains stability [10]. Phenomenon in two-dimensions related to natural disasters (avalanches) can be observed by using the cylinder pile as the granular material and then it is subjected to vibration in horizontal direction (perpendicular to the direction of gravitational acceleration).
2. Experiment

Two-dimensional granular particles are in the form of cylinder with 25 mm diameter and 75 mm length made of PVC pipe. These particles are placed in a horizontal rectangular plate made of acrylic, which is attached to a horizontal vibration system. The plate has frames in two sides to force the particles only moving in one-dimension as the avalanche of particles pile occurring. The pile must be stable before vibration introduced to the system. Due to the small friction between particles and also between particles and the base plate only two layers can be used as initial configuration. Some pile configurations are used as given in figure 1, which are labelled as (2,1), (2,3), and (3,4) configurations.

Figure 1. Three configurations two layers cylinder pile: (a) (2,1) configuration, (b) (3,2) configuration, and (c) (4,3) configuration.

The horizontal vibration system (see figure 2) consists of electric motor rotating a circular plate (CP), piston-like part (PP) that translate the rotation motion to translation motion, rail (RL) for directing the base plate, base plate (BP) where to put the granular particles, and reader (AR) for displaying acceleration of the base plate motion.

Figure 2. Horizontal vibration system and its parts CP, PP, RL, BP, and AR (see text for explanation).

Avalanche phenomenon is characterized by varying vibration amplitude $A$ and frequency $f$. Minimum values of $A$ and $f$, which can perform an avalanche, are observed. Technically, input signal is only voltage which controls angular velocity of the electric motor $\omega$. Position of piston-like part will couple the rotation motion into translation motion and determine $A$. A plane of $f$-$A$ will be constructed to analyze the phenomenon.
3. Results and discussion
It is very interesting to observe that structural change of every initial configuration is not always the same, especially the (4,3) configuration. Illustration how the avalanches destroy the pile initial configuration is given in figure 3.

![Figure 3](image)

**Figure 3.** Steps of structural changes for the three configurations: (a) one step in (2,1) configuration, (b) one step in (3,2) configuration, and (c) two steps in (4,3) configuration.

After set the amplitude $A$ to a certain value, frequency $f$ is varied by varying the voltage $V_e$ given to the electric motor. If the pile is not stable at some value of $(A, f)$ the time requires for the pile to collapse is also recorded as shown in figure 4.

![Figure 4](image)

**Figure 4.** Avalanche duration of three cylinder pile configurations with numbers shown in each point represent the mean value of avalanche duration for certain amplitude $A$ and frequency $f$.

Frequency values $f$ represent the minimum frequency to avalanche the cylinder pile. The highest the frequency required to avalanche the pile configuration, the most stable the configuration is. Based on figure 4, the most stable configuration is (3,2) for lower amplitude value. It means that this
configuration is more difficult to have structural changing than the other two. Minimum frequency is not proportional to the avalanche duration.

Interesting thing from structural change of each cylinder pile is in configuration (4,3). It is prone to be similar to configuration (3,2) before it is perfectly destroyed as illustrated in figure 3.(c). Minimum frequency required for configuration (3,2) to collapse entirely compare to transition from (4,3) to (3,2) is shown in figure 5.

![Figure 5](image.png)

**Figure 5.** Comparison of mean avalanche duration of configuration (3,2) that initially from (4,3) (blue colour) and the real configuration (3,2) (red colour).

Figure 5 shown the comparison of avalanche duration of (4,3) and (3,2) cylinder pile configuration. The avalanche duration of configuration (4,3) was taken based on condition in figure 3.(c) from (3,2) configuration until perfectly destroy. Based on the graph, the configuration (3,2) that come from configuration (4,3) is more stable than directly initial configuration (3,2), which is indicated by the time required by the configuration to be destroyed. The avalanche duration of configuration (4,3) becomes configuration (3,2) is noted on table 1 as \( t_1 \) and the time required for configuration (4,3) to perfectly collapse is \( t_2 \). Then the duration of configuration (3,2) to be perfectly destroyed is simply \( \Delta t_{21} \)

\[
\Delta t_{21} = t_2 - t_1.
\]

**Table 1.** Avalanche duration of configuration (4,3).

| No | \( A \) (cm) | \( f \) (Hz) | \( t_1 \) (s) | \( t_2 \) (s) | \( \Delta t_{21} \) (s) |
|----|-------------|-------------|-------------|-------------|---------------------|
| 1  | 15          | 6.97        | 3.398       | 18.102      | 14.704              |
| 2  | 13          | 7.98        | 8.762       | 34.598      | 25.836              |
| 3  | 12          | 7.04        | 11.686      | 20.566      | 8.88                |
| 4  | 11          | 7.15        | 20.074      | 33.752      | 13.678              |
| 5  | 9           | 7.19        | 21.436      | 23.188      | 1.752               |
| 6  | 7           | 9.68        | 21.816      | 39.684      | 17.868              |
| 7  | 6           | 11.15       | 36.414      | 46.094      | 9.68                |
| 8  | 5           | 11.37       | 35.352      | 64.376      | 29.024              |
Figure 6. Illustration of $t_1$ and $t_2$ in transition from (4,3) to (3,2) and to perfectly collapse.

Illustration of (1) is given in figure 6. A relation for minimum $f$ and $A$ can be defined as

$$\Gamma = A^{c_A} f^{c_f}$$  \hspace{1cm} (2)

where $c_A$ and $c_f$ are varied and the relation between $\Gamma$ and $f$ is fitted with linear function. Values of coefficient of determination $R^2$ are plotted as contour given in figure 7. Values near lower right corner cannot be considered since it will give $f$ against $f$ curve, which $R^2$ will approach 1. According to the figure 7 there is no simple relation between $\Gamma$ and $f$ which can explain the minimum $A$ and $f$ for destroying the pile.

Figure 7. Contour of $R^2$ of (2) in $c_A$-$c_f$ plane of (4,3) configuration.
The well known values $c_A = 1$ and $c_f = 2$ giving form of

$$\Gamma = \frac{4\pi f^2 A}{g}$$

(3)

can not also be used as transition condition between stable and unstable configuration, which is usually already common in other granular systems. Another transition condition must be defined.

Back to the implementation of this system to natural disaster, if larger system could be designed and the time $t_1, t_2, t_3, \ldots, t_N$ can also be observed, then this will give us a very important information how a granular pile evolves, releases its energy, and how long the duration between its stable states are. Normally, the $t_i$ is unknown and we are interested only in $\Delta t_{21}$ for two states landslides or avalanches. But it could be that $t_{N,N-1}$ which we are interested in, since we do not know the history of the pile. While the granular materials can do have a memory due to aging process [11], this will make it more unpredictable and also the behaviour of $t_{N,N-1}$.

4. Conclusion

Duration of avalanche seems independent to the vibration amplitude and frequency. Stability of the two layers cylinder pile is not dependent on the amount of particles in the upper layer. Usual transition condition $\Gamma = 4\pi f^2 A/g$ does not work for this system.

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