The Strengthening of a Pile of Ball Bearings

Qudsia Wahab

Dr. Rena Zieve

University of California Davis

REU Program 2012

August 23, 2012

Abstract:

The goal of our study was to make a granular pile stronger and prevent avalanches in granular piles. In our experiment about 3500 single ball bearings were rotated in a two dimensional drum that made one full rotation in an hour, and the maximum angles of stability were obtained. A single chain of 40 balls long was added to the drum and maximum angles of stability were obtained. Finally, eight chains that were 40 balls long were added to the drum and once again the angles were obtained. The same procedure was repeated with doubles. The results of this experiment show that a single chain is able to make a pile of single ball bearings stronger. With the further accumulation of the chains, the maximum angles of stability increase resulting in an even stronger pile. However, the average maximum angle of stability does not increase when a chain or a number of chains are added to a pile of doubles.

A granular material is a collection of macroscopic particles. Some examples of granular materials are sand, soil, corn flakes, rice, coffee, pills and ball bearings. Granular materials play an important role in many of our industries, such as mining, agriculture, civil engineering and pharmaceutical manufacturing. In our everyday world, matter is usually classified into solids, liquids, and gases. However, granular materials do not belong to a single phase of matter. They have characteristics of solids, liquids, and gases. A good example to look at is sand. It takes the shape of a container or flows in an hourglass like a liquid, but one grain of sand or a pile of sand is obviously a solid. Granular materials are very important to study because of their unusual properties. The behavior of a single grain is very simple. However, when there is a collection of grains, the behavior gets very complex and hard to understand. A better understanding of the behavior of granular materials may allows us to select better building sites for structures, dig more stable mines, and create better pharmaceuticals.

When there is a pile of granular materials on an inclined surface, avalanches take place. Specifically, a lot of attention has been given to avalanches in fields such as geology and soil mechanics where granular matter flows along an inclined surface. Studying avalanches is important in understanding what causes instabilities within the pile in order to prevent failure of granular piles. A granular pile is stable below the repose angle. However, when the pile gets steeper it exceeds the repose angle and reaches maximum angle of stability. When maximum angle of stability is exceeded, an avalanche occurs. The grains along the slope move resulting in a lower angle. Our goal is to predict avalanches and find patterns. We also want to find ways to make our granular pile stronger and more stable. In our lab, grains of different size and shape are rotated in a two dimensional drum. As the drum rotates, the pile of grains gets steeper until eventually an avalanche occurs.

Our grains are composed of 1/8“diameter steel ball bearings. The grains used are shown in Figure 1. In this experiment we worked with single ball bearings and doubles which are created by welding two single ball bearings together, shown at the bottom left. Our chain was twice as long as the one in the figure. Spheres are used because they minimize friction and blocking while moving past each other. It is also easy to work with spheres when computer simulations are used. Our drum is composed of a 1/8“ thick aluminum sheet with a 14“diameter circle cut out of it. The aluminum sheet is sandwiched between two sheets of Plexiglas. A strip of rubber is glued to the inner edge of the aluminum in order to prevent balls from sliding along the walls of the container. The drum rotates about its center on an axle that is connected to a motor. The motor controls the speed of the rotation. The setup can be seen in Figure 2. In this experiment the drum makes one full rotation in about an hour. Working with such a slow speed has various advantages. At this speed the rotation of the drum itself can be neglected during an avalanche. Also the slow speed allows the computer to process each avalanche and not fall behind.

Figure 1: Grains and chains used in this experiment

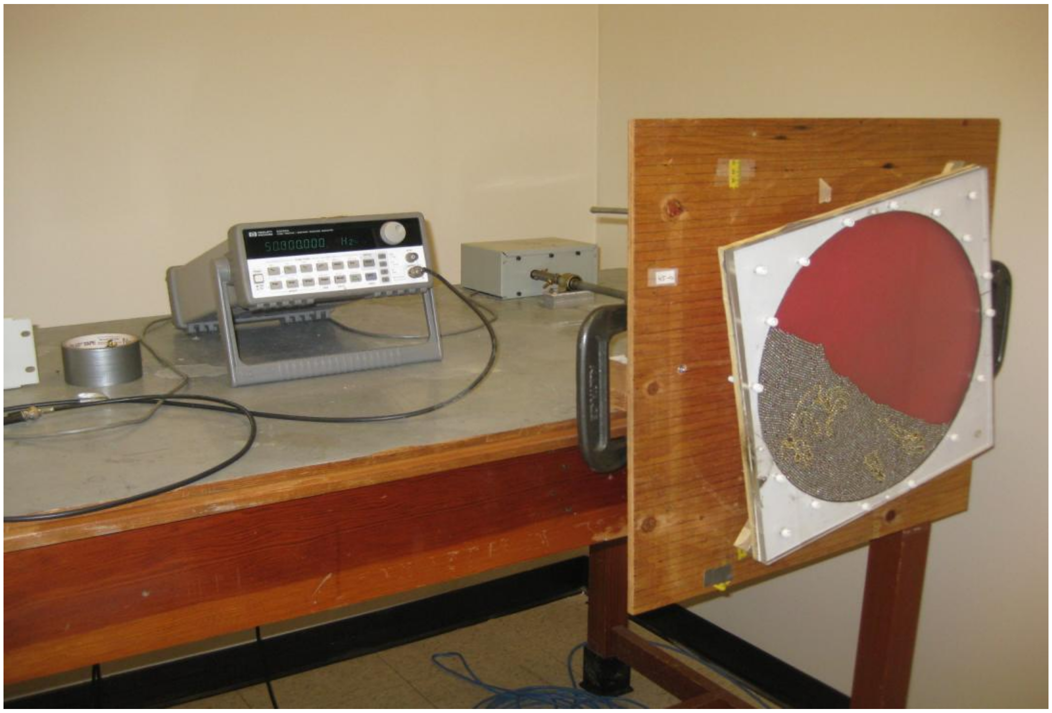

Figure 2: Experimental setup with rotating drum on the right and the motor on the left

The entire rotation of the drum is recorded with a camera. Results show that avalanches take place every 2 - 4 minutes where the angle decreases after each avalanche.

The data are then inputted directly from the camera to the computer. Software is written using the Python programming language to pick the frames before and after each avalanche. There are over 2500 frames for each avalanche, so saving all the frames fills out the memory of the computer very fast. That is why only two frames for each avalanche are saved which makes the process very efficient. In addition to the frames a report for each avalanche is also saved to the computer. The report includes avalanche number, angles for before and after each avalanche, and the time and date each avalanche occurred.

In order to find the edge of the circle, the program initially roughly guesses the center. It then scans to find the edges in four different directions. (The X's at the the lines in Figure 3 are the spots the computer identified as the edges of the drum). Then it averages chord intercepts to get a better guess of the center. In order to get even a better idea of the center, it draws in 20 radii in different directions and once again averages their chord intercepts. This gives a better value for the center and radius of the circle. We know the true radius of the circle in inches, but this software gives the radius in pixels. We can use this information to find how many pixels are in one inch or how many pixels make up a ball bearing.

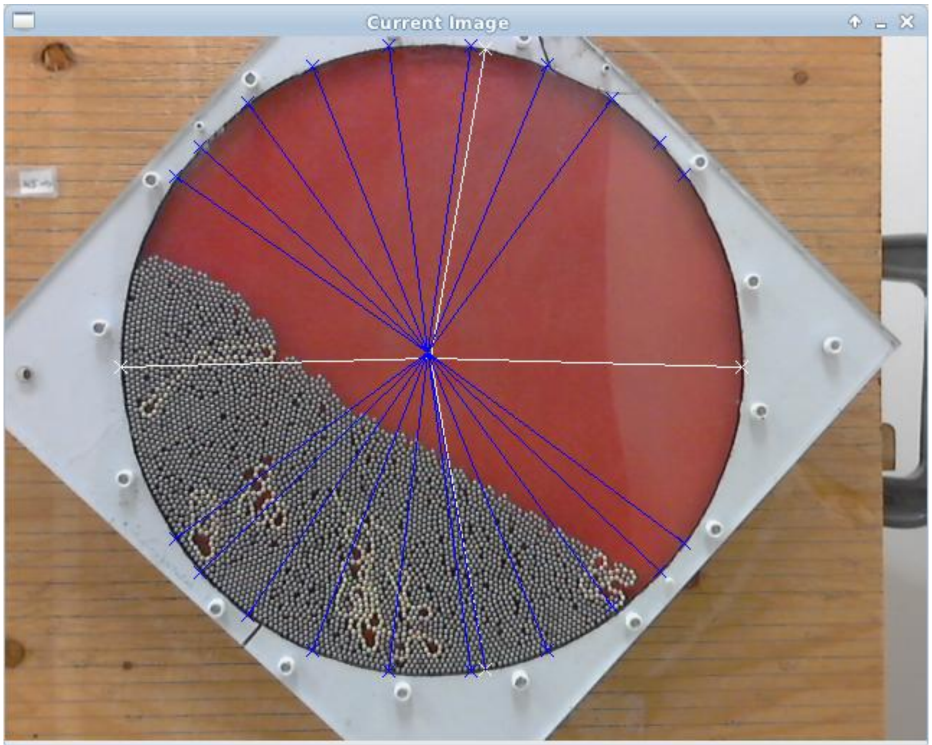

Figure 3: Python based program that finds the edge of the drum
The original four directions are shown with white lines,
the next 20 are shown with blue lines

In order to find the angle of the pile, the software starts at the top of the pile, and then scans clockwise as shown in Figure 4 until it encounters any color other than red. This means that it is in the region of the balls and therefore has reached the bottom of the pile. It then roughly fits a line along the slope. Finally, this line is used to get the angle of the pile.

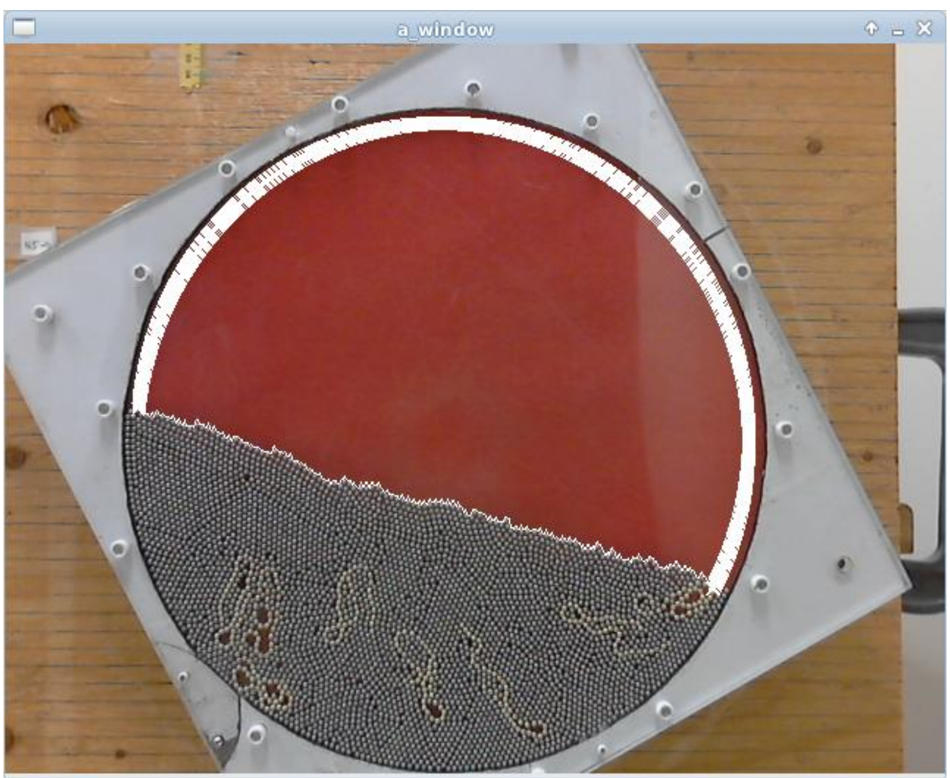

Figure 4: Python based program that finds the angle of the pile

In the experiment we wanted to increase the strength of a granular pile by adding chains to it. In order to compare the difference in the avalanche angle for ball bearings with and without a chain, the experiment was done a few times. The first time, the drum was filled with single ball bearings with a mass of 458.1grams (about 3500 balls) and rotated for 17 hours. Later a single chain of 40 balls was added to the granular pile and data were collected for another 17 hours. In order to observe further effects that the chains produce on the granular pile, eight chains were added to single ball bearings with a mass of 458.1 grams, and data were collected for 66 hours. The same procedure was repeated with doubles with a mass of 410.1 grams.

The results of this experiment suggested that the addition of even a single chain can make the pile of single ball bearings stronger. The addition of more chains to the pile makes the maximum angle of stability increase even more.

Single ball bearings produce a very low avalanche angle. Ball bearings are very smooth, so when the container rotates, they move past each other very easily causing the angle to decrease. The average angle for a pile of single ball bearings in a rotating drum is 32.66 degrees. When a single chain is added to the pile of ball bearings, the average angle increases to 33.17 degrees. A graph of avalanche number versus maximum angle of stability is generated. In Figure 5, it is noted that most avalanches for single ball bearings take place between 30 - 34 degrees.

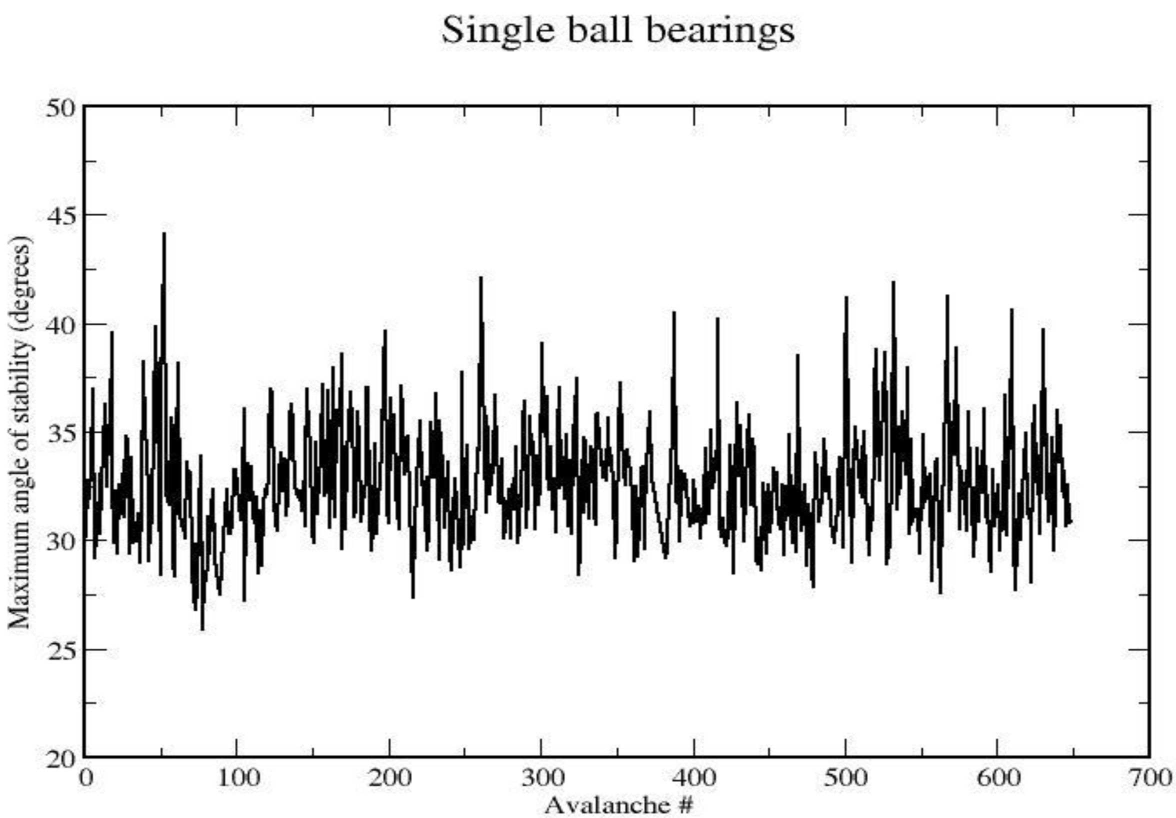

Figure 5: A graph of avalanche number (x-axis) vs. maximum angle of stability (y-axis) is generated for single ball bearings.

Since a single chain increases the maximum angle of stability, we added more chains to the pile to observe the effects on the angle. The results suggest that the average angle increases to 35.63 degrees. In Figure 6, the blue bars correspond to the single ball bearings and red bars are for single ball bearings with eight chains. It can be observed that for single ball bearings most avalanches occur between 30 - 34 degrees. However, when chains are added to the pile, most avalanches occur on slopes between 30 to 40 degrees. The range of angles increases as well. When the chains are added, some really high angles are noticeable with the highest angle being 51.85 degrees.

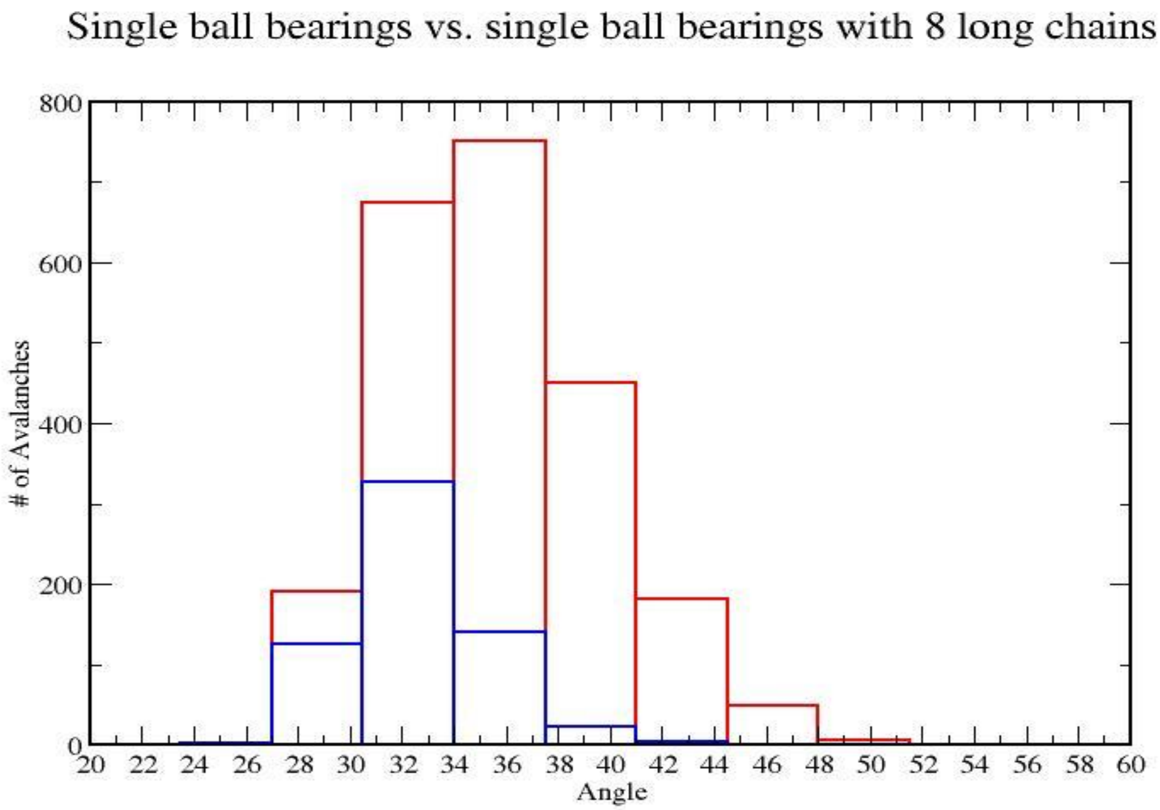

Figure 6: Histogram compares the range of angles for single ball bearings and single ball bearings with eight chains. Blue bars represent single ball bearings without chains and red bars represent single ball bearings with chains

Compared to single ball bearings, doubles are more stable. They have a rough surface and produce a higher maximum angle of stability. The average angle for doubles is 42.84 degrees. With the addition of a single chain, the maximum angle of stability only increases to 42.89 degrees. Similarly, when eight chains are added, the angle only increases to 42.85 degrees. There is no noticeable change in angle when chains are added to doubles. In Figure 7, it can be observed that the average angle for both doubles and doubles with chains is in the range of 41 to 44 degrees. However, the addition of chains does increase the range of the angles. Higher angles are noticeable when chains are added.

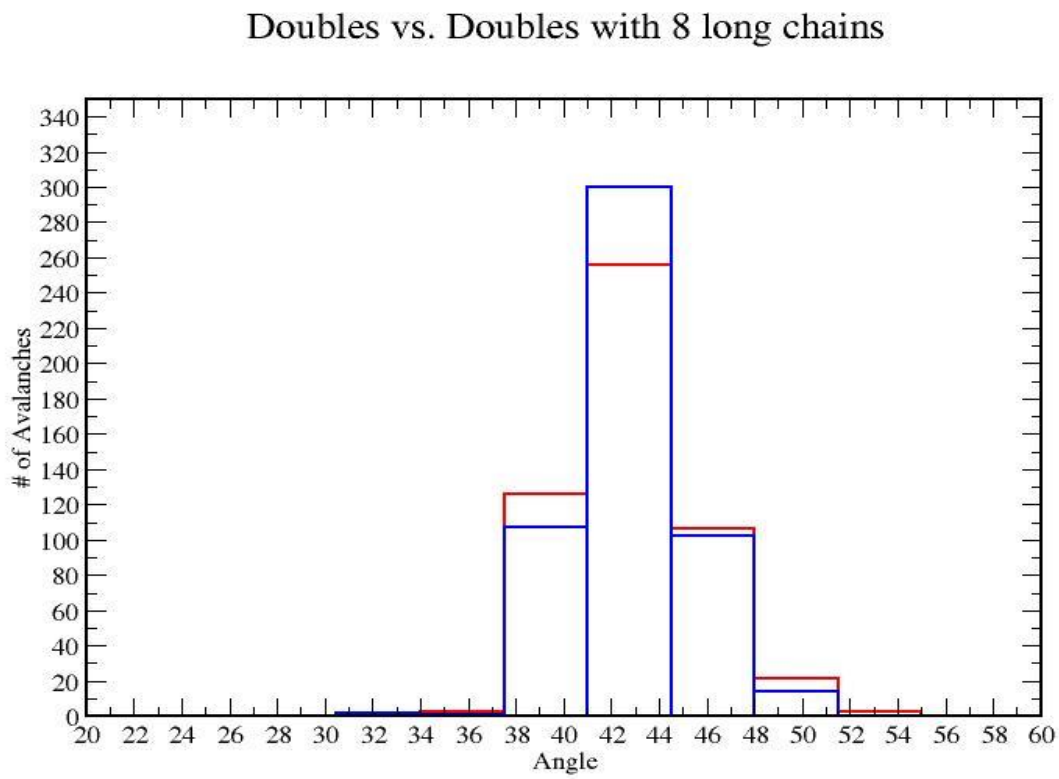

Figure 7: Histogram compares the range of angles for doubles and doubles with eight chains. Blue bars represent doubles without chains and red bars represent doubles with chains.

From the images, a pattern is observed. It can be seen that most high angles occur when the chain is at the top of the pile and most low angles occur when the chain is at the bottom of the pile. This pattern does not repeat 100% of the time. Sometimes, a high angle occurs when the chain is at the bottom of the pile and vice versa.

Maximum angle of stability was measured for single ball bearings, doubles, single ball bearings with chains and doubles with chains. We find that the addition of chains that are 40 balls long to a pile of about 3500 single ball bearings can make the pile stronger. This could help prevent failures of granular piles, avalanches, and erosion. It can be seen that chains that are at the top of the pile produce higher maximum angles of stability. Similarly, chains that are at the bottom of the pile produce lower angles. Further research will focus on adding chains to a pile of hexagons. It is important to examine the shape of the chain as the container rotates and find a pattern between the shape of the chain and maximum angle of stability.

Acknowledgements:
I want to give special thanks to my mentor Dr. Rena Zieve for her intellectual support, guidance, and an opportunity to work in her lab. This study was conducted through the REU program, supported by the National Science Foundation.

Bibliography:

Olson, M. Priester, J. Luo, S. Chopra and R.J. Zieve, "Packing Fractions and Maximum Angles of Stability of Granular Materials" (2004:2), Physics Department, University of California at Davis, 2012 Aug 07
http://arxiv.org/abs/cond-mat/0412666v1

Macari, E.J., "Dr. Emir Jose Macari – Civil Engineer" (2002: 1), SACNAS, 2012 Aug 07
http://bio.sacnas.org/beta/pdf/macari_emir_M.pdf