UNDERSTANDING LANDSLIDES THROUGH GRANULAR FLOW SIMULATIONS

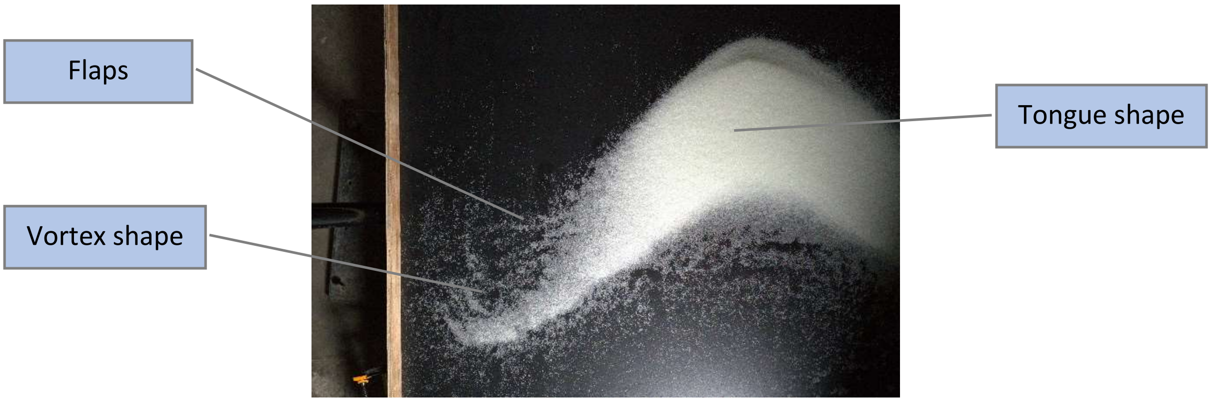
SURGE 2023 END-TERM REPORT

Mentor: Dr. Sanjay Kumar | Dept. of Aerospace Engineering
Stuti Gupta | 2330308

Abstract:

Landslides are a significant threat to infrastructure, humans, and the environment, and the behavior of granular flow during a landslide is crucial in determining its impact. Very little information is available about how grains behave once they reach the flat ground after rolling down the inclined surface of a hill/mountain. Hence, this research project aims to simulate landslides in the lab and study how grain size variations, and surface inclination affect different parameters of granular flow and structures formed by granular particles on a flat terrain after rolling down an inclined surface. Spherical glass grains of a fixed size (diameter = 0.88mm) were dropped from the top of a glass inclined surface (of variable inclination) onto a large plywood table with a Sunmica finish.

The flow of these grains was recorded using DSLR and high-speed cameras. The experimental results show that the grains formed a static-recurve shape (refer to the image below): a vortex-like structure on each side of the main central tongue-like profile. Flap-like designs could also be seen on the tongue shape's outer surface. This kind of structure is formed (a) as particles collide with each other and cause loss of energy and (b) due to some properties of the interaction between the glass grains and Sunmica surface. Engineers, decision-makers, and academics striving to lessen the effects of landslides on the environment can benefit from the findings, as they can help shape the development of prevention strategies and disaster management regulations.



Left section of top view (45° angle of inclination)

Introduction:

Landslides are a major natural hazard that can cause widespread damage and loss of life. They are often triggered by rainfall, earthquakes, or other events that cause the ground to become unstable. Granular flow simulations and models are a powerful tool for understanding the dynamics of landslides. This allows researchers to study the factors that influence landslide initiation, movement, and runout.

Granular flow simulations have been used to study a wide range of landslides, including debris flows, rockfalls, and mudflows. These simulations have helped researchers to better understand the mechanisms that drive landslides, and to develop more accurate models for predicting landslide risk.

This internship was done as a part of the SURGE 2023 Program conducted by IIT Kanpur. This work comes under the broad heading of Granular Flows, in the Department of Aerospace Engineering, under the guidance of Dr. Sanjay Kumar. My role was to design the experimental setup, conduct the experiments and obtain all the possible data from the readings.

The objective is to study how different properties of the resultant shape of the particles vary as a function of the angle of inclination of the inclined plane on which the grains are released. Various elements were used to model the different elements of landslides- glass beads for the debris and mud in landslides, a glass inclined plane for the slanted surface of the mountain and a plywood table for the flat ground at the foot of the mountain.

Literature Review:

Extensive research has already been conducted in the field of granular flow, but not much information is available on the work we have done in this project. Our aim is to bridge this gap in knowledge and better equip engineers and scientists working on studying landslides and landslide damage control.

However, there are a few research papers published on the topic of granular flows pertaining to landslides in the Journal of Fluid Mechanics by the authors A.N. Edwards, F.M. Rocha, B.P. Kokelaar, C.G. Johnson, J.M.N.T. Gray. The paper investigates the segregation of particles of different sizes in a granular flow that forms a self-organized channel. The authors use a 2D discrete element method to simulate the flow, and they vary the size ratio of the particles. They find that the smaller particles tend to accumulate in the centre of the channel, while the larger particles tend to accumulate near the walls. This segregation is caused by the difference in the kinetic energy of the particles. The smaller particles have a higher kinetic energy than the larger particles, so they are more likely to be transported to the centre of the channel is caused by the difference in the kinetic energy of the particles. The smaller particles have a higher kinetic energy than the larger particles, so they are more likely to be transported to the centre of the channel.

Another research paper was published in the Journal of Fluid Mechanics by Akhil K. Mathews, Aqib Khan, Bhanuday Sharma, Sanjay Kumar and Rakesh Kumar. The paper presents a numerical study of granular shock waves over a circular cylinder using the discrete element method (DEM). The DEM is a computational method that simulates the motion of individual particles as they interact with each other and with a surrounding fluid.

The paper first describes the DEM model and the experimental setup used to validate the model. The model is then used to simulate the flow of granular particles over a cylinder at different speeds. The results of the simulations show that a shock wave is formed when the particles collide with the cylinder. The shock wave propagates downstream, and the particles behind the shock wave are decelerated.

The paper then analyzes the flow field in the shock wave region. The results show that the volume fraction of particles suddenly increases across the shock wave, and the pressure also increases. The pressure is due to both collisional and streaming effects. The streaming pressure is generated by velocity fluctuations in the granular flow.

The paper concludes by discussing the implications of the results for understanding granular shock waves. The results show that the rheological complexity of granular shock waves is a direct manifestation of the dissipative and frictional nature of granular collisions. The new insight into granular shock waves could be relevant to a variety of applications involving granular-fluid–solid interactions.

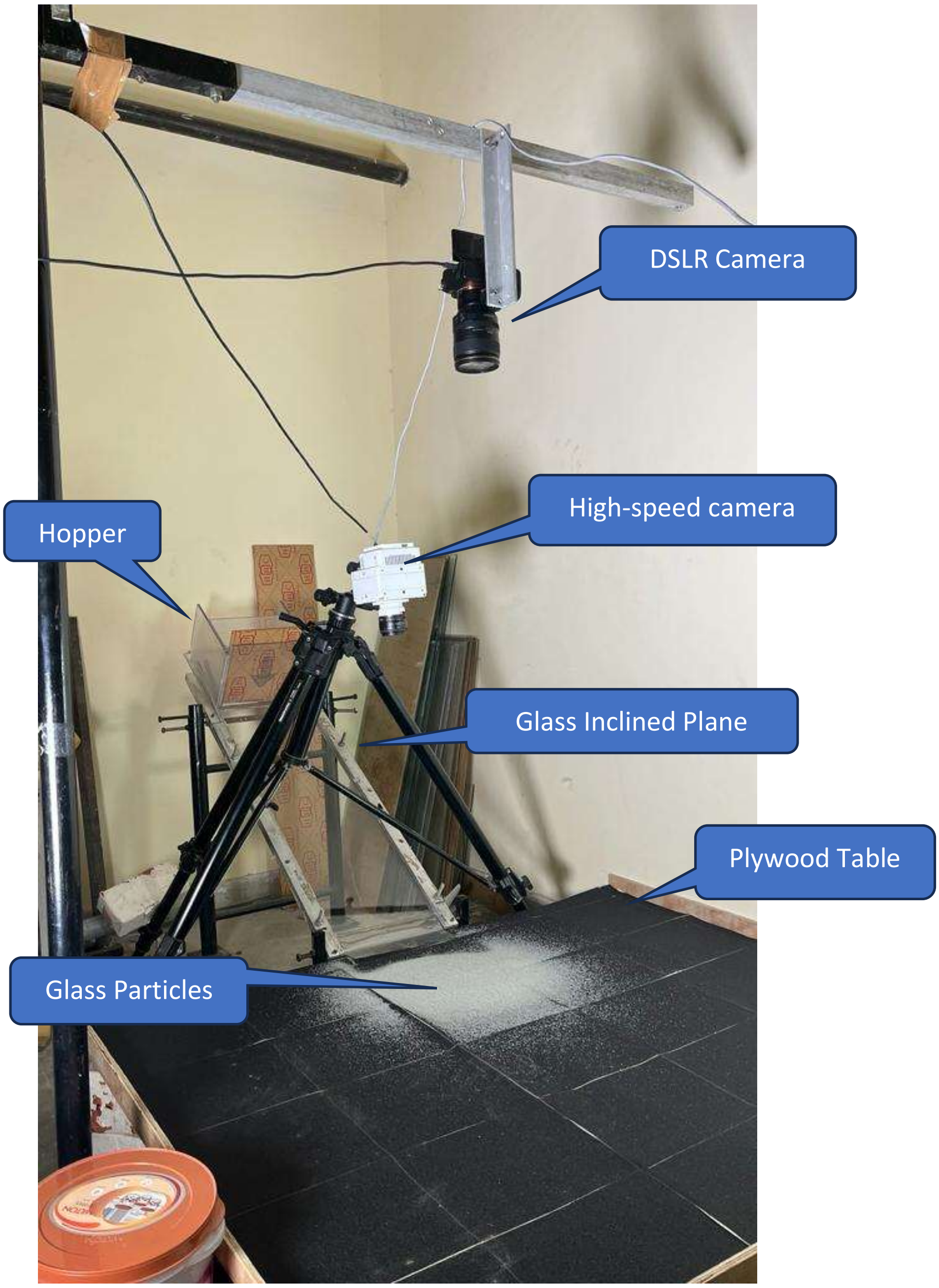
Methodology:

Firstly, a setup was designed for the experimentation. An inclined plane of variable angle of inclination was finalized. Glass beads of diameter 0.88 mm were used and a large table of plywood with a Sunmica surface finish was constructed. The table had dimensions 146 cm x 122 cm.

1.5 kg of the glass particles were measured and filled into the plexiglass hopper. The angle of inclination of the inclined plane was set and the particles were allowed to fall on the inclined plane onto the table. A high-speed Phantom VEO camera was placed at the inlet of the board and a Sony ILCE-7M3 DSLR camera was positioned at a height to capture the flow of the particles. Once the particles started falling onto the table, the high-speed camera was started and a video was captured of the same.

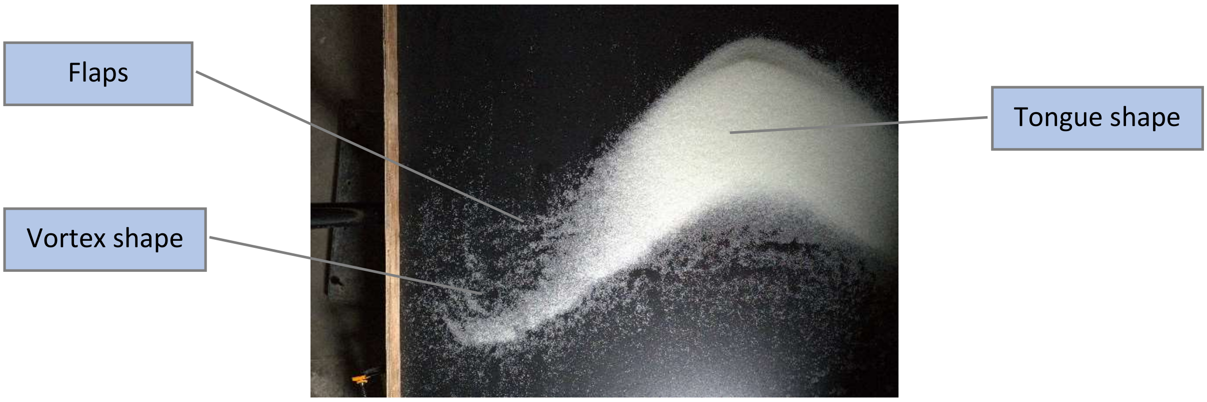
When the final stationary structure was formed, an image was taken of the entire board.

The final image was analyzed on a software called ImageJ, where the structure was curve-fit to find the radius of the best fitting circle on the top and bottom surfaces and position of the structure on the board.



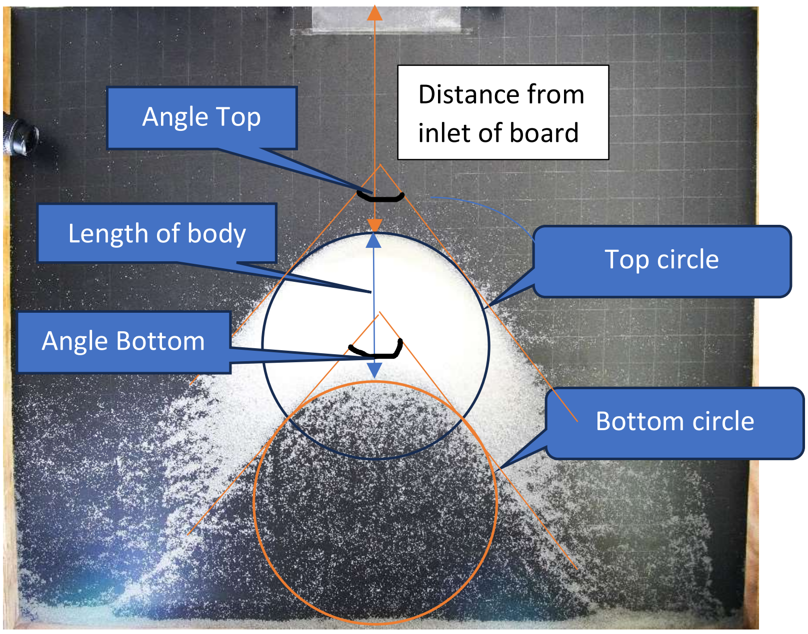
Results:

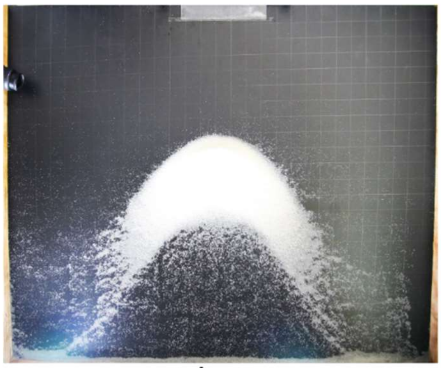
The experimental results show that the grains formed a static-recurve shape (refer to the image below): a vortex-like structure on each side of the main central tongue-like profile. Flap-like designs could also be seen on the tongue shape's outer surface. This kind of structure is formed (a) as particles collide with each other and cause loss of energy and (b) due to some properties of the interaction between the glass grains and Sunmica surface.



Left section of top view (45° angle of inclination)

As the angle of inclination of the glass inclined plane is increased, we can see that the width of the structure increased and its length decreases. When curve-fitting was done, we can see that the radius of the top circle remains almost constant, however, the radius of the bottom circle increases and the bottom surface approaches a straight line. The structures on an average move towards the inlet of the board as we increase the angle of inclination.

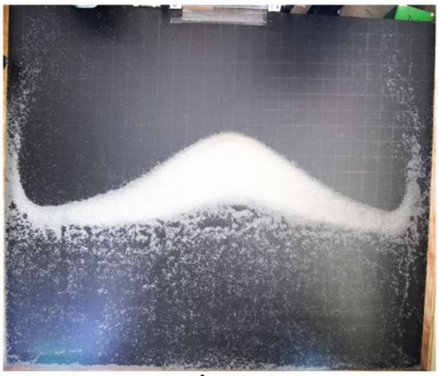




35 degrees

40 degrees

45 degrees

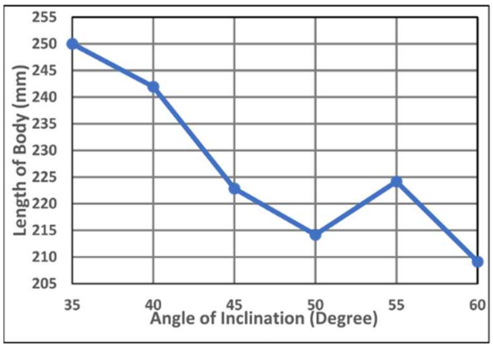


50 degrees

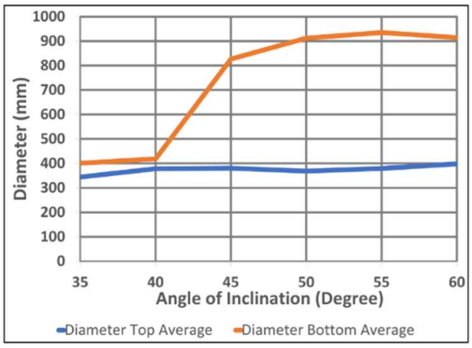
55 degrees

60 degrees

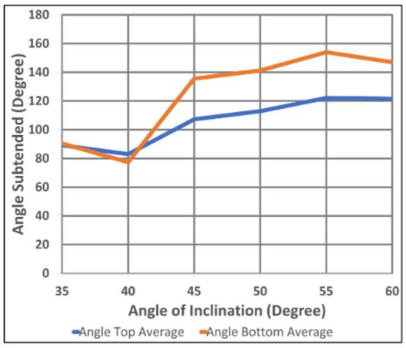
Resultant Structures Formed



Graph 1



Graph 2



Graph 3

Graph 1- Length of the body vs Angle of Inclination of glass panel

Graph 2- Diameter of the top and bottom circles vs Angle of Inclination of glass panel

Graph 3- Angle subtended by tangents to top and bottom circles vs Angle of Inclination of glass panel.

Stages of vortex structure formation captured by high-speed camera (10,800 fps)

Discussion:

These results will help scientists and engineers working in this field to develop landslide damage control strategies. Our results can be extrapolated to real life situations and an estimation can be made as to how far and wide landslide debris will spread. We can get an estimate as to upto how far residents living in the area need to be evacuated. We can also see that in the middle area a void is formed and so residents living in that area need not be evacuated. If a sharp object is kept in the top itself, the particles will deviate in the start, so that most of the area will remain unaffected.

Conclusion:

Engineers, decision-makers, and academics striving to lessen the effects of landslides on the environment can profit from the findings as they can help shape the development of prevention strategies and disaster management regulations.

References:

1) https://www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/shockshock-interactions-in-granular-flows/0930AF5A1EEEE19BEBFC9D79FB4C3199
2) https://www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/detachment-of-strong-shocks-in-confined-granular-flows/71C8E3B78AB664CE56BE37D6CCCCAB14

3) https://www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/numerical-investigation-of-granular-shock-waves-over-a-circular-cylinder-using-the-discrete-element-method/295D2038D6E66A64BB55926B97B7D22D
4) https://www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/particlesize-segregation-in-selfchannelized-granular-flows/F5C9D8ECA80687A78F4A09C794C8B74D