Particle entrainment due to a turbulent jet impinging a loose soil bed

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Purpose

The purpose of this experiment is to understand crater formation resulting from of a jet of air striking a bed of particles. The geometry of the crater (width, volume, and depth) was determined. The goal is to gain a better understanding of the behavior of different types of soils to address the problem of brownouts and whiteouts during helicopter landings and cratering due to rocket blast.

Materials

- Sand
- Glass beads
- Polypropylene
- Wooden box approx. 5’ x 5’ x 1’
- Plexiglas 62 cm x 28 cm x ¼”
- Screws
- Lights
- Nozzle -- ½ inch diameter
- Air supply
- Registration marks
- Pitot tube
- Video camera
- Computer
- MatLab
- Timer

Methods

Preparation

One part of the preparation for this experiment was the physical setup. An air nozzle was hooked up to an air supply. The air nozzle was secured at the top of the wind tunnel and pointed down. We constructed a wooden box with dimensions 5’ x 5’ x 1’. A 54 cm x 23.5 cm opening was left in the center of the front of the box and covered with the Plexiglas sheet ¼ inch thick. One side of the top edge of the Plexiglas was milled at an angle to make a sharp edge in order to interrupt the air flow less. Around the four corners of the window, we placed the registration marks at measured points. We centered the window under the air nozzle, leveled it, and screwed it to the bottom of the wind tunnel. In front of the wind tunnel, we set up a video camera on a tripod centered on the window of the wooden box to record the evolving crater geometry. We put up a timer in the back of the wind tunnel that was withing the field of view of the camera to track time. We put a fluorescent light with the beam angled downwards on a tripod on each side of the box towards the front to control the lighting for the pictures.

Another part of the preparation included writing a MatLab program to analyze the data. The program takes a picture from the experiment and prompts the user to input the points from which we determine the scale of the photo. The user clicks on the registration points placed around the window in the box for which we know the measurements. Then the program prompts for the offset points so that we can center the crater around the point (0, 0). The user clicks on each endpoint of the crater at the height of the top of the box. Then the program shows the user each of the 3 color layers of the photo, and the user chooses which layer provides the best contrast to use for the edge detection. The program then shows the edge detection results. The user enters a new value for the threshold until the edge of the crater has been clearly shown without background edges interfering. After the threshold is chosen, the points extracted from the edge detection process are plotted in a line graph. The user clicks on two points to choose the range of the data wanted. Then a list of the file name, the data points, and other relevant values are written into a data file. We are currently working on adding a calculation of the crater volume to the program. This is made more complicated by the various shapes of craters that can be formed, as shown in Figures 1, 2, 3, and 4.

Running the Experiment

First, we set the timer to zero. Then we set the camera in the proper position, on the tripod with the aim centered at the center of the window of the box. We make sure the air nozzle is at the proper height, which is 60, 40, 30, 20, 10, 5, 3, or 1.5 cm. Next, we align the Pitot tube under the center of the nozzle and record initial velocity measurements. Then we smooth out the sand in the box, making sure the sand is leveled evenly. We make sure the lights are on and in the proper position. Next, we press record on the video camera, turn on the clock, and then turn on the air supply.

Due to the constraints of our video camera and our clock, we have to change tapes and reset the clock after 1 hour. Some of the experiments needed to be run for up to 5 hours, others only 1.5 hours. The only definitive way to determine if the experiment was finished is to analyze the data to see if the depth is still increasing.

Figure 1: Crater after 3.5 seconds with the nozzle at height 20 cm.

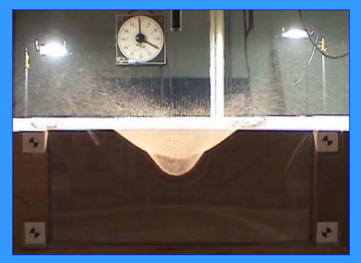


Figure 2: Crater after 30 seconds with the nozzle at height 20 cm. Notice the 2 slopes of the sides of the crater.

Figure 3: Crater after 2 hours 32 minutes with the nozzle at height 20 cm.

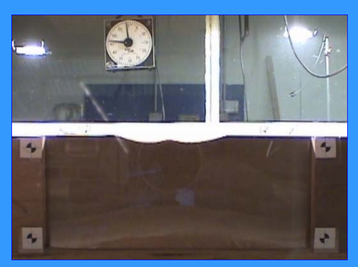


Figure 4: Crater after 1 minute 6 seconds with nozzle at height 60 cm. Notice the mound in the middle of the crater.

Analyzing the Results

To analyze the results, pictures must be pulled from the video of the experiment. Pictures are taken starting at .5 seconds doubling the increment each time until the increment reaches 30 minutes, at which increment we continue taking pictures until the end of the experiment. Each picture must be rotated so that the top of the box is leveled horizontally and any tilt from the camera is removed. Then we crop each picture to remove unnecessary background, which helps the edge detection run faster. Next, we run our MatLab program on each picture. We then import the file of data points created from the program into Microsoft Excel in order to create graphs. For the data points from each picture, we take the minimum of the y-value, which is the deepest point of the crater. We then put all those values into a graph.

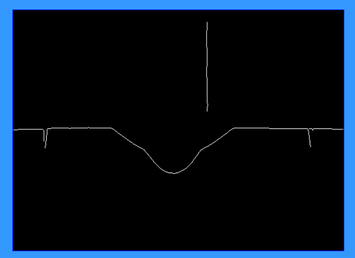


Figure 5: Edge detection of Figure 2.

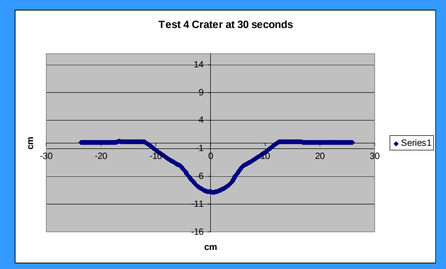
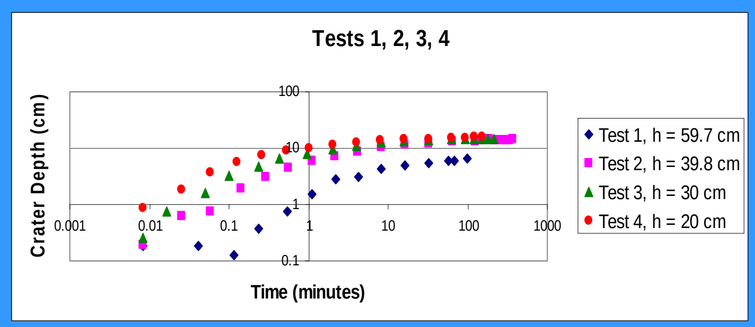


Chart 1: Graph of Figure 5.

Results

These are the results from our first four tests with sand at an approximate air velocity of 60 meters per second. For tests 1, 2, 3, and 4, the air nozzle was 59.7 cm, 39.8 cm, 30 cm, and 20 cm away from the sand respectively. The graph takes the depth in relation to the time for each test. There is a noticeably faster rate of increase in depth at the beginning of the test as compared to the end of the test.



Summary

The purpose of this experiment is to analyze the effects of a jet of air at various speeds on different types of materials. Currently, we have only started experimenting with sand and a jet of air at approximately 60 m/s velocity at heights 59.7 cm, 39.8 cm, 30 cm, and 20 cm. We are continuing these experiments at heights 10 cm, 5 cm, 3 cm, and 1.5 cm. Then we will move on to different material types including glass beads and polypropylene. After we have finished those experiments, we may move on to try different air velocities.