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Flow Visualization
Team Report # 2
4/1/12

The purpose of this image, seen in Figure 4, was to capture the flow of sand on top of a vibrating surface. This essentially is to demonstrate what happens during tectonic plate movement that causes the earth's surface to vibrate. To be able to properly capture this effect was to use a small layer of sand on top of the vibrating surface. A thicker layer of sand made it difficult to capture the movement of the sand particles and would cause the image to appear still. The smaller layer of sand allowed the sand particles to bunch together and cause more interesting patterns. The last difficulty in capturing this phenomenon was to use a vibration frequency that allowed the sand to bunch together, but prevent the flow from moving too rapidly making it difficult to capture the image. Using a low vibration frequency would not allow enough time for sand particles to bunch together into dunes and using a high vibration frequency caused sand particles to move to rapidly making it difficult to capture a clear image. The end result was to turn the tectonic basin device, described later on, to a vibration frequency to about 80% of the maximum vibration frequency. It would be nice to know the exact frequency of plate vibration, but unfortunately that information is not readily available.

The flow apparatus or tectonic basin device that was utilized to capture this flow is from renowned artist Ned Kahn and built in 1996 and is on display in the third floor of the Integrated Teaching & Learning Program and Laboratory, ITLL. An image of the device can be seen in Figure 1, and the purpose of the project was to create a device that can simulate the effects of tectonic plate movement on the surface of the earth. The apparatus itself stands at about 20 inches in height and has an overall diameter of 4 feet and an interior diameter of 3.5 feet. The depth into this apparatus is 7 inches and contains a fine grade of tan sand, along with various other things that have been accidentally placed into the sand area. The apparatus has a single self-contained light source that is a light with a diameter of 3 inches placed halfway up the depth of the portion containing the sand. The sand sits on top of a rubber like material with a vibration sources underneath causing the rubber like material to vibrate.

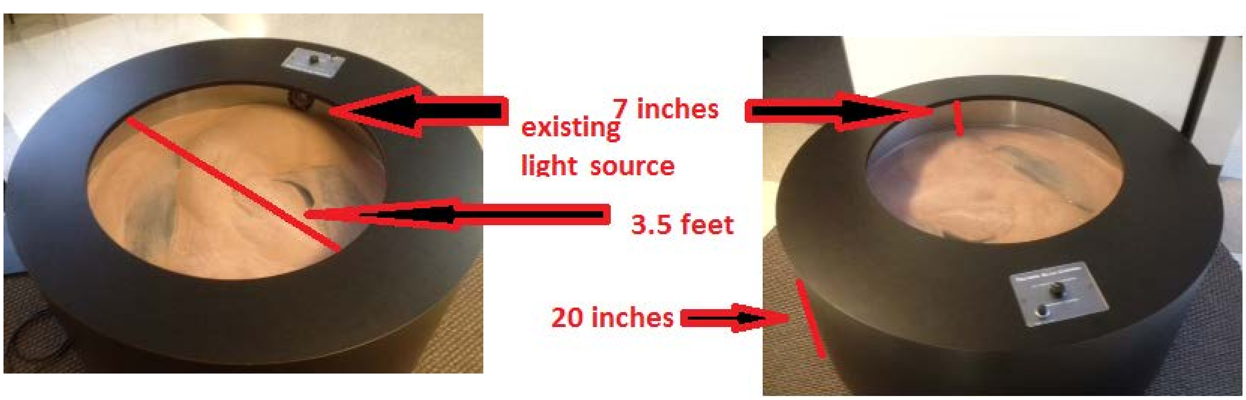

Figure 1

The purpose of this apparatus is to demonstrate the effects of tectonic plate's movement have on the objects placed on top of the vibrating surface and in this case is a rubber like material. The vibrations allow sand particles to easily slide past one another to move to an area of the plate where the vibrations of less violent nature and form dunes of sand. This is formally known as soil liquefaction where sand particles under shear stress begin to take on property movements like a liquid. Shear stress is experienced by sand particles due to shear waves created by tectonic plate movement. These shear waves are also known as S-waves or secondary waves because of how they arrive well after compressional primary waves during an earthquake. The shear waves are created in this particular instance where two tectonic plates are moving away from each other creating perpendicular, relative to the rubber surface, forces that only have the ability to move through solid surfaces, rock formations. When traveling through the solid rock the shear forces cause the tectonic plates to move in opposite directions causing a vibration effect and transferring shear stresses to the objects or in this case sand particles on top of the surface. However, as previously mentioned the sand particles do not have the ability to support the shear stress and begin to act like a liquid. Since the shear stresses are vertical forces this creates areas where the vibrations are going to be more violent along fault lines or the boundary between to plates. This causes the sand which is now acting more like a liquid than a solid to diverge away from high vibration areas and form sand dunes along less violent vibration areas.[1,2,3,4,5]

To be able to get data that will be great representations of this phenomenon it will be to calculate first the drag force of the sand particles. To be able to do this the Stokes formula will be used and can be seen below.

$$F = 6\pi\mu\frac{D}{2}V$$

(F) is the drag force, (μ) is the dynamic viscosity, (D) is the diameter of the sand particles, and (V) is the velocity of the sand particles. μ is the most difficult number to find since viscosity is the representation of a fluid or gases resistance to shear and tensile forces. Dynamic viscosity more specifically is the amount of tangential force per unit area required to move an object with respect to

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[1] Corapcioglu, M. Yavuz. *Advances in Porous Media*. Amsterdam: Elsevier Science, 1994. Print.

[2] Knappman, Krista. "Granular Material: Liquid-like Properties of Sand." *The Ohio State University* 1999. Print.

[3] Molnar, Peter H. "Tectonic Basins and Rift Valleys (landform)." *Encyclopedia Britannica Online*. Encyclopedia Britannica. Web. 12 Apr. 2012. <http://www.britannica.com/EBchecked/topic/585476/tectonic-basins-and-rift-valleys>.

[4] "Structural Geology and Tectonics." *Stanford School of Earth Sciences*. Web. 12 Apr. 2012. <http://pangea.stanford.edu/research/groups/structure/research.php?rg_id=33>.

[5] "Earthquake." *National Disaster Management Office*. Web. 12 Apr. 2012. <http://www.fdoe.gov.fj/newndmo/index.php/earthquake>.

velocity. Referencing the Geotechnical Earthquake Engineering[6] book a dynamic viscosity of sand under an acceleration of 10 G's it can be seen in the range of 3.1-4.41 kPa ·s. For my purposes I will be assuming normal conditions of 1 G and interpolating to find a dynamic viscosity of μ=0.31 kPa·s or 31.611 kg s/m^2. The diameter of fine sand particle was then needed for this equation and referencing the Earth ScienceL A study of a Changing Planet[7] book, sand particles range in the size of 0.05-2mm. For my purposes and the observation that the sand seemed to be a fine grade, the diameter of the sand will be 0.05mm or $5x10^{-5}$ m. Now the more difficult part was to calculate the velocity of the sand particles. Using video footage of the sand particles movement at the same frequency the picture was taken, I calculated the distance a single sand dune traveled and was found to travel 6 inches or 0.1524 m. It took the sand dune to move this distance 13 seconds and therefore the velocity is 0.0117 m/s. Using these values the drag force is found to be 1.7×10^{-4} kg/s^2.

Now it becomes useful to calculate the drag coefficient and then find the Reynolds number for this fluid flow. Drag coefficient is calculated using the equation below.

$$Cd = \frac{2F}{\rho V^2 A}$$

The density (ρ) of a sand particle depends greatly on the type of sand it is and how much moisture is contained with the sand. For my purposes I am going to assume the sand was completely dry and the sand was loose making the density to be 1602 kg/m^2. (A) is the reference area which will be a single grain of sand and assuming it is perfectly spherical the sand area will be $\pi(D/2)^2$= $1.96x10^{-9}$ m^2. Making the drag coefficient(Cd) to be 810,970, which is a dimensionless number.

Now, I am going to calculate the Reynolds number for this experiment using the equation below:

$$Re = \frac{V^2 * \rho}{\frac{\mu * V}{D}}$$

With this equation the Reynolds number is found to be 2.96×10^{-5}. This is a very small number and seems impossible to have a flow with that low of a Reynolds number, but in this case this is the Reynolds number. Since this is such a low Reynolds number the flow is laminar and when observing this flow it was obviously laminar flow because of how sand particles seemed to move.

This image, seen in Figure 4, was done using the apparatus described above and using the light source of the apparatus along with another light source. This light source was placed above the existing light source and angled at a 45 degree angle downward onto the surface of the sand. Again the frequency knob was turned to 80% maximum frequency and the image was taken directly across from

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[6] Towhata, Ikuo. *Geotechnical Earthquake Engineering*. Berlin: Springer-Verlag, 2008. Print.

[7] Berey, David, and Robert B. Daley. *Earth Science: A Study of a Changing Planet.* Newton, MA: CEBCO, 1987. Print.

both light sources. The camera was placed inside of the apparatus approximately 3 inches from the surface of the sand at a downward angle of -30°. For a clearer representation of the angles and exact locations of the light sources please refer to Figure 2.

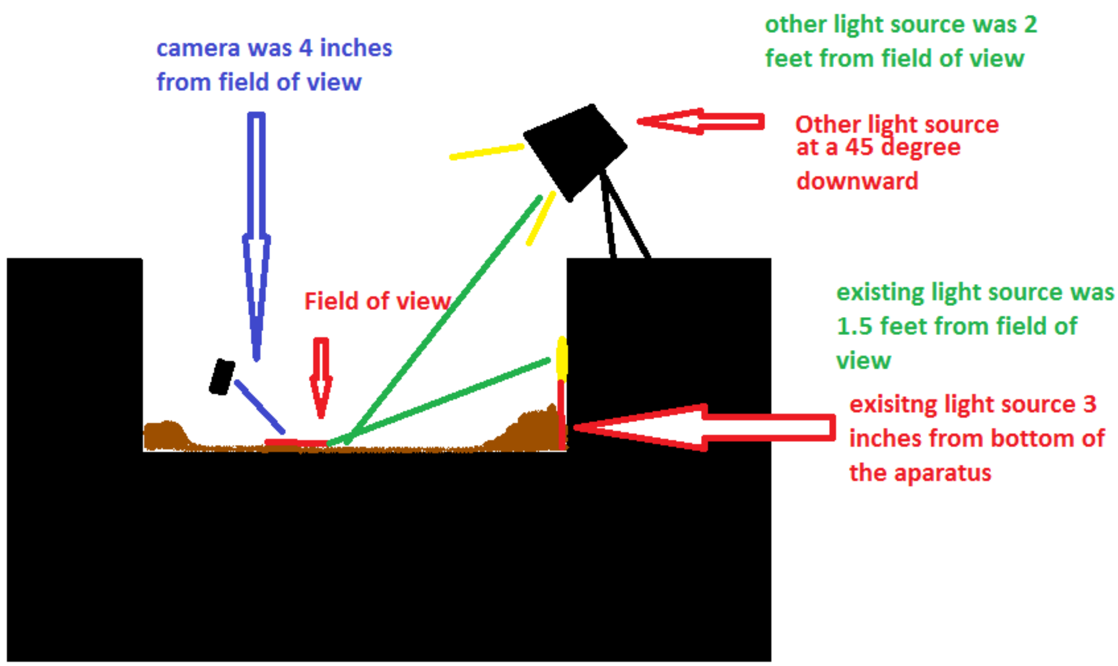

Figure 2

The size of view the photo was taken in was 5 inches by 5 inches or an area of 25 in^2. The cameras lens was 4 inches from the center of this photo. The camera I used is a Pentax Optio WS80 digital camera with a focal length of 6.2 mm. This picture had a shutter speed value of 1/160 of a second and an Aperture Value of 3.852. The ISO setting used was 64. The final image, Figure 6 was also minimally Photoshoped because too much manipulation distorted the image too much. The manipulations that did occur were a basic cropping of some of the sand that was not as interesting in the image. The contrast of the image was than increased to make the sand grains to have more of an outline. Curves function was also utilized to make the grain outlines and dunes to have stronger outlines. While using this function an accident occurred where the blue curves was set really high and made the image to gain the red filter effect. This accident made the image to seen extraterrestrial and was left to make the image become more unique. The original and final images can be seen below:

Original Image:

Figure 3

Width: 3648 pixels
Height: 2736 Pixels

Final Image:

Figure 4

Width: 3648 pixels
Height: 1974 pixels

The image reveals the effects of vibrations or shear stress has on sand particles. It makes sand to behave more like a liquid than a solid. It makes the sand particles to leave areas of high vibration or shear stress to areas of less vibration or less shear stress and form sand dunes. This image clearly shows the sand forming into several dunes. The few questions I do have is why is there less research done on dry sand rather than wet sand? I understand most soil liquefaction studies is done by civil engineers to understand the effect earthquakes have on sand to prevent sink holes in roads and buildings from losing good foundation. Those studies though mostly dealt with sand with large moisture content. Also it would have been nice of Ned Kahn to provide more of the physics behind his artwork as it would have become very handy in writing this report. If I had to do this experiment again I would have removed the external lighting source because without it the sand dunes displayed some cool shadow effects by only utilizing the existing light source. To further develop this idea I would have created my own apparatus so that I would know the exact frequency of the vibrations and be able to calculate the exact shear stress the sand particles exhibit to be able to create this image.