Rising in the bulk

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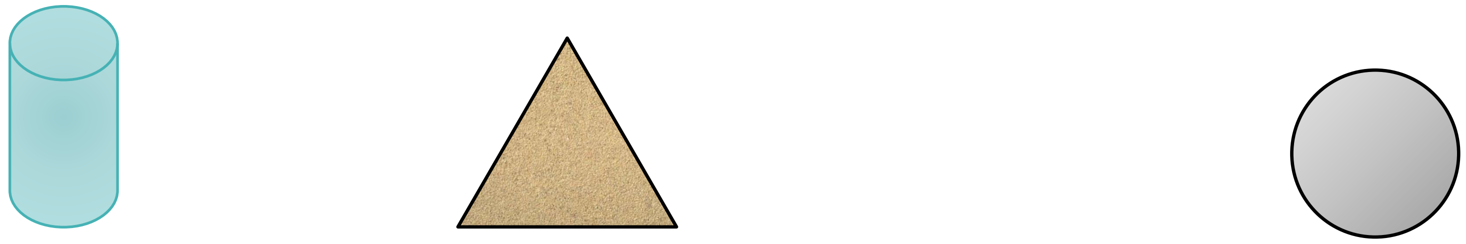
TEAM POLAND

The problem

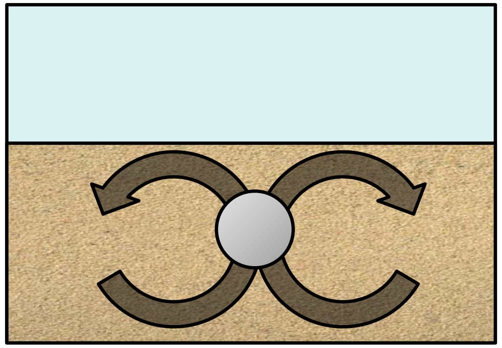


- *If a vessel containing granular material is shaken appropriately, an item placed at the bottom will ascend upward through the material and emerge at the top.*
- The task was to: *explain the phenomenon and devise the most energy efficient shaking technique to raise the item up.*

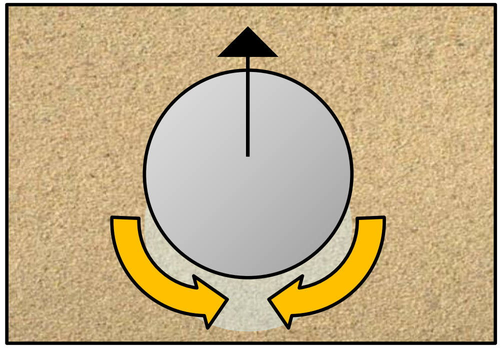
Brazil nut effect

Most known explanations:

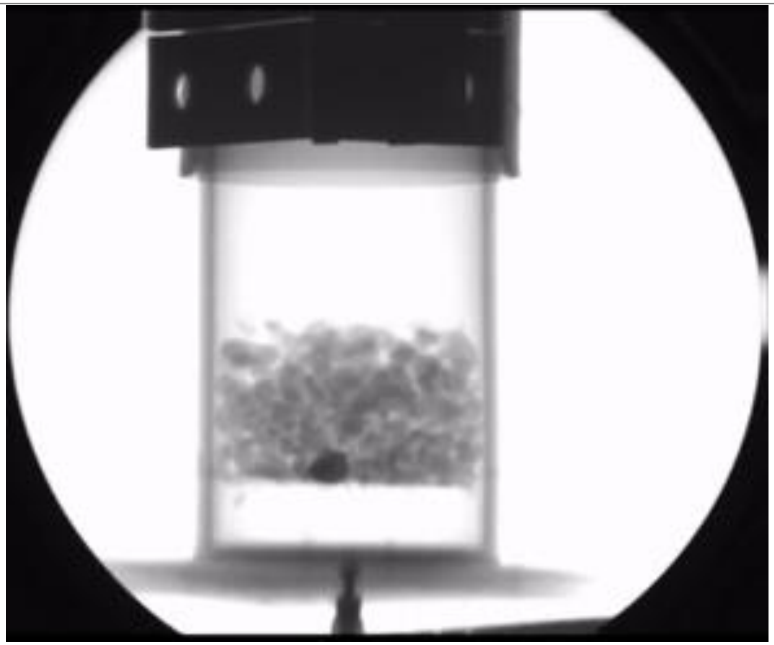
- Granular convection
  - [1]Vibration-induced size separation in granular media: The convection connection James B. Knight, H. M. Jaeger, and Sidney R. Nagel 1993
  - [2]Why the Brazil nuts are on top: Size segregation of particulate matter by shaking Anthony Rosato, Katherine J. Strandburg, Friedrich Prinz, and Robert H. Swendsen 1987



- Grains filling empty space below object
  - [3] The segregation of particulate materials. A review J.C.Williams 1976



Achieving The Effect



Vibrations

- Granular material behaves like a fluid
- Constant supply of energy

https://youtu.be/eQiJwG93YsU

Taps

- The material comes to a stop, making subsequent taps independent
- The energy is lost after each tap

https://youtu.be/XTM-okBCX8U

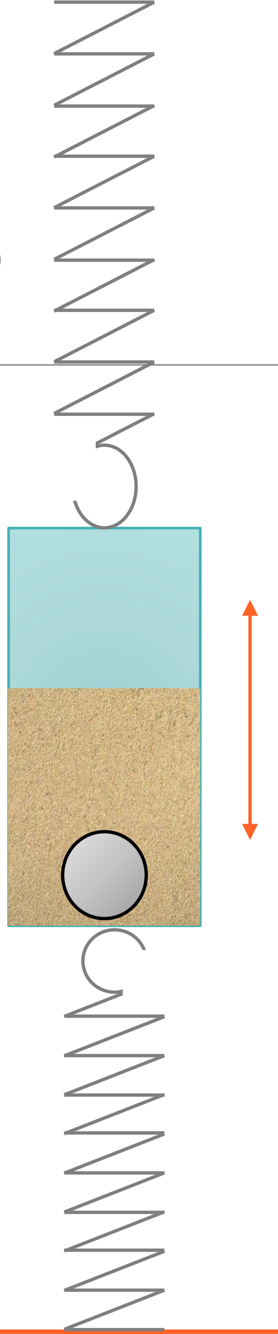
How much energy is required?

Harmonic oscilator:

$$m\ddot{x} + (k_1 + k_2)x \ = mg?$$

$$a_{min} = -A\frac{k}{m}$$

$$E = \frac{kA^2}{2} = \frac{a_{\min}^2 m^2}{2k}$$



a_{min} – minimum (negative) acceleration, A – initial amplitude, $k = k_1 + k_2$, E – energy supplied

- Total mass around 72 g
- Springs with k around 20 N/m
- 2 cm by 7 cm cylinder
- 4 gram steel ball
- Energy used: **<u>0.07 J</u>**
- Minimum energy 0.006J

- Total mass around 0.9 kg
- Springs with k around 100 N/m
- 4 cm by 20 cm cylinder
- 100 gram steel ball
- Energy used: **<u>4 J</u>**
- Minimum energy 0.2J

Effectiveness

Energy gain:

5 cm * 3 g * 9.81 N/kg = 0.0015 J (0.07 used)

Effectiveness around 1/47 (or better)

Energy gain:

13 cm * 75 g * 9.81 N/kg = 0.1 J (4 J used)

Effectiveness around 1/40 (or better)

There is also some energy left in the oscilations (0,002 J and 0,03)

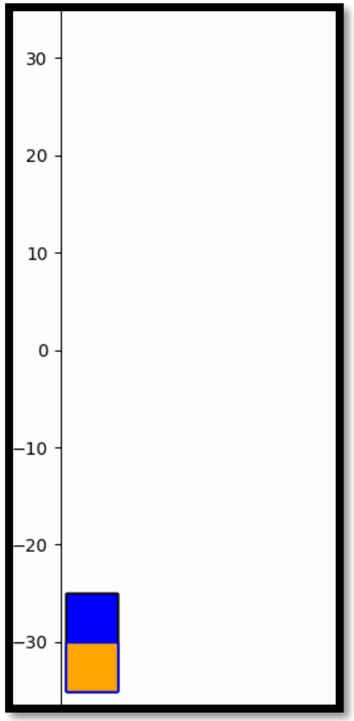
Other methods

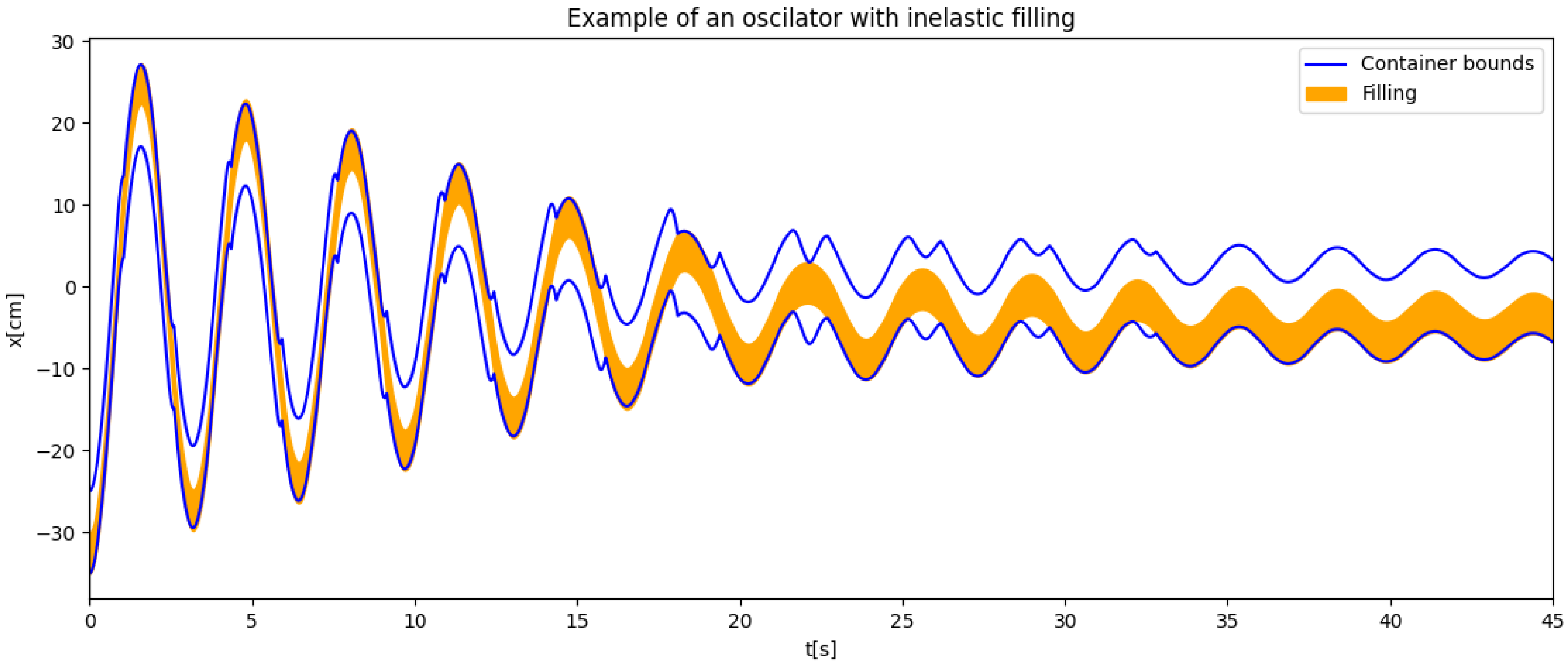
Using independent taps would require about the same amount of energy, but times the required number of taps

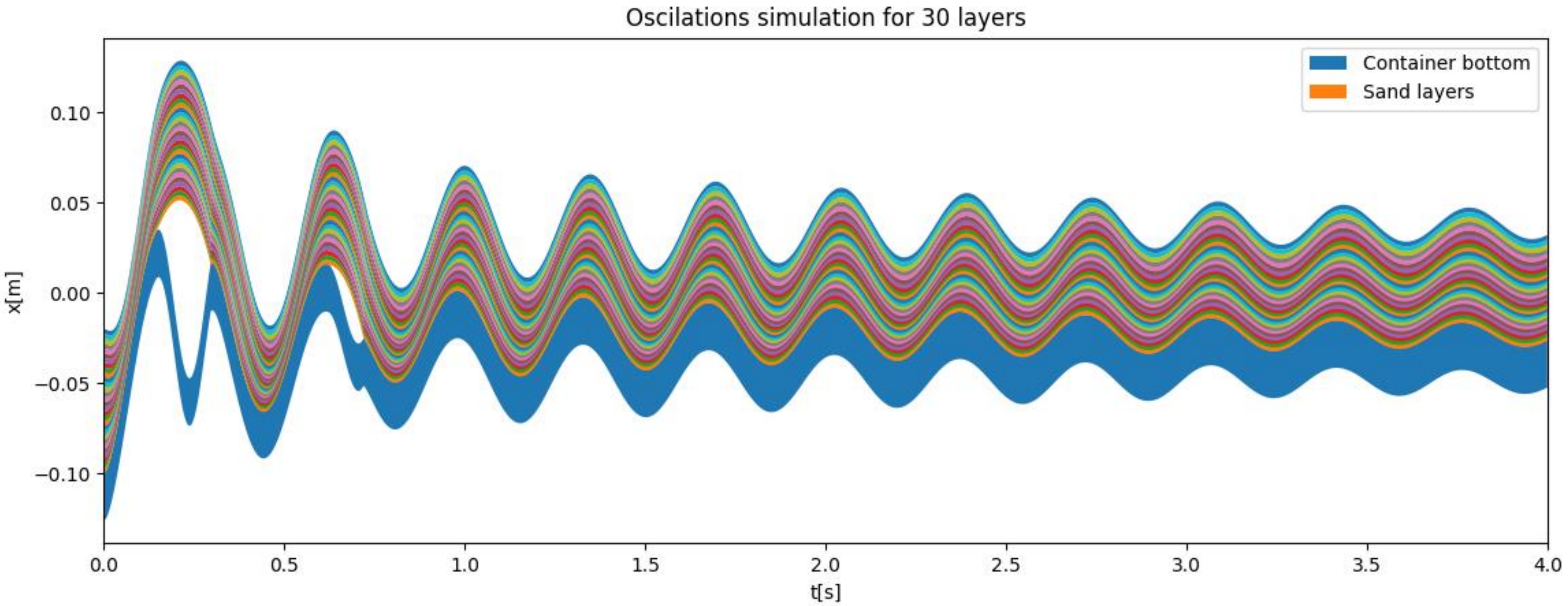
If one were to find an ever more efficient way, it would probably use ’taps’

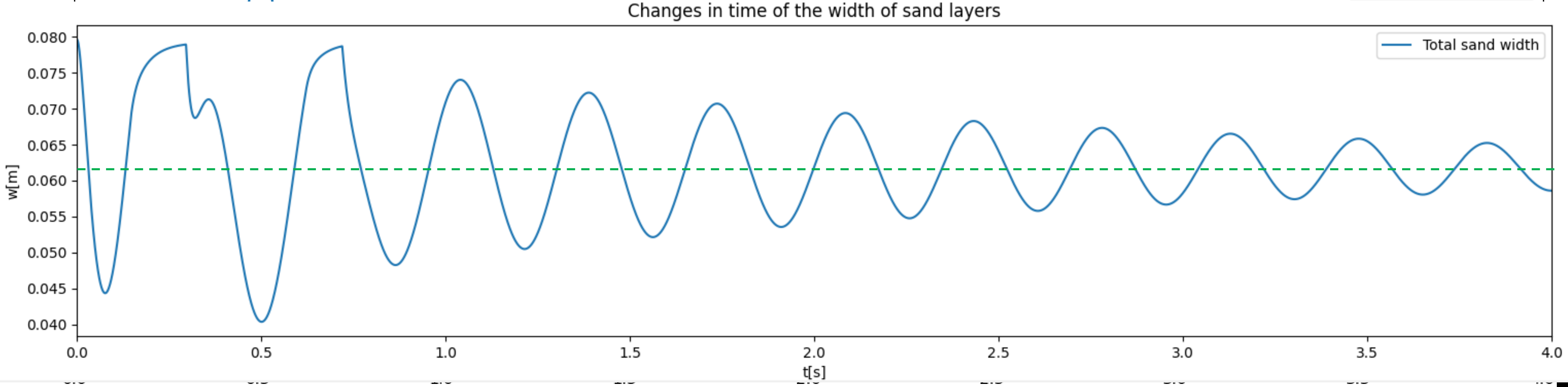
Using vibrations, if induced with an electric device, even if it only took one second for the object to rise, the maximum power available to match our method would be that of a small lightbulb

Inelastic harmonic oscilator



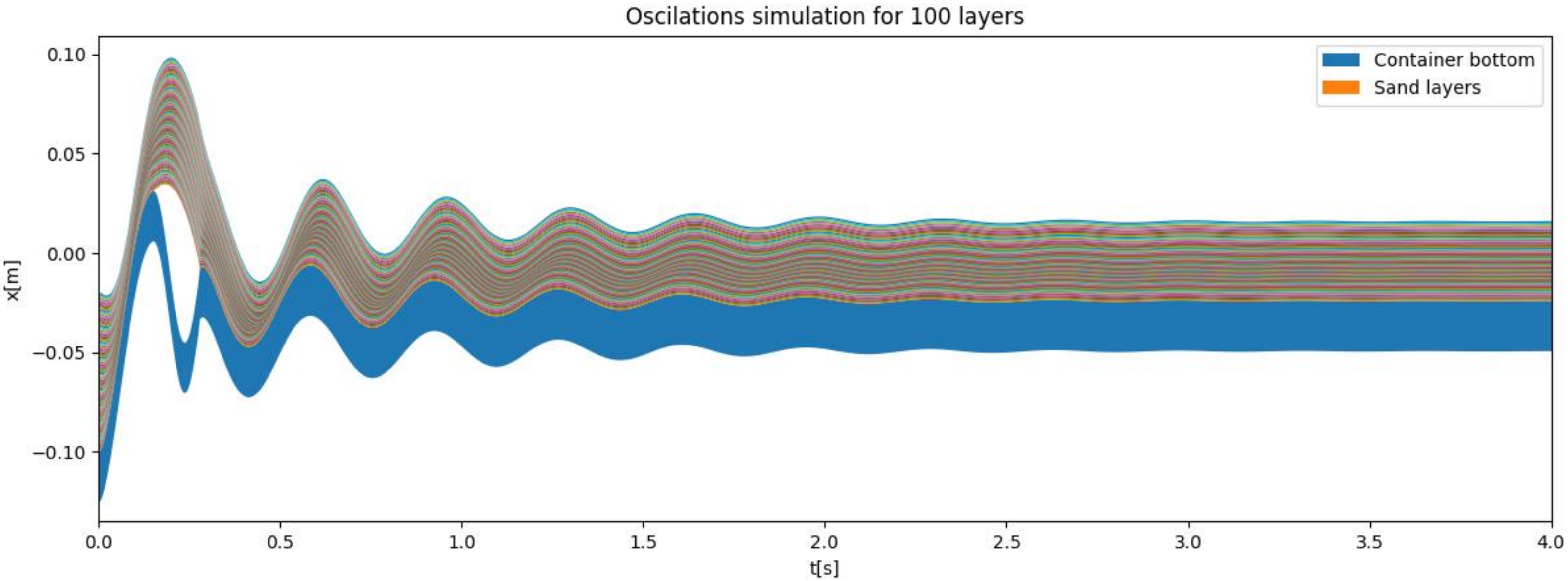






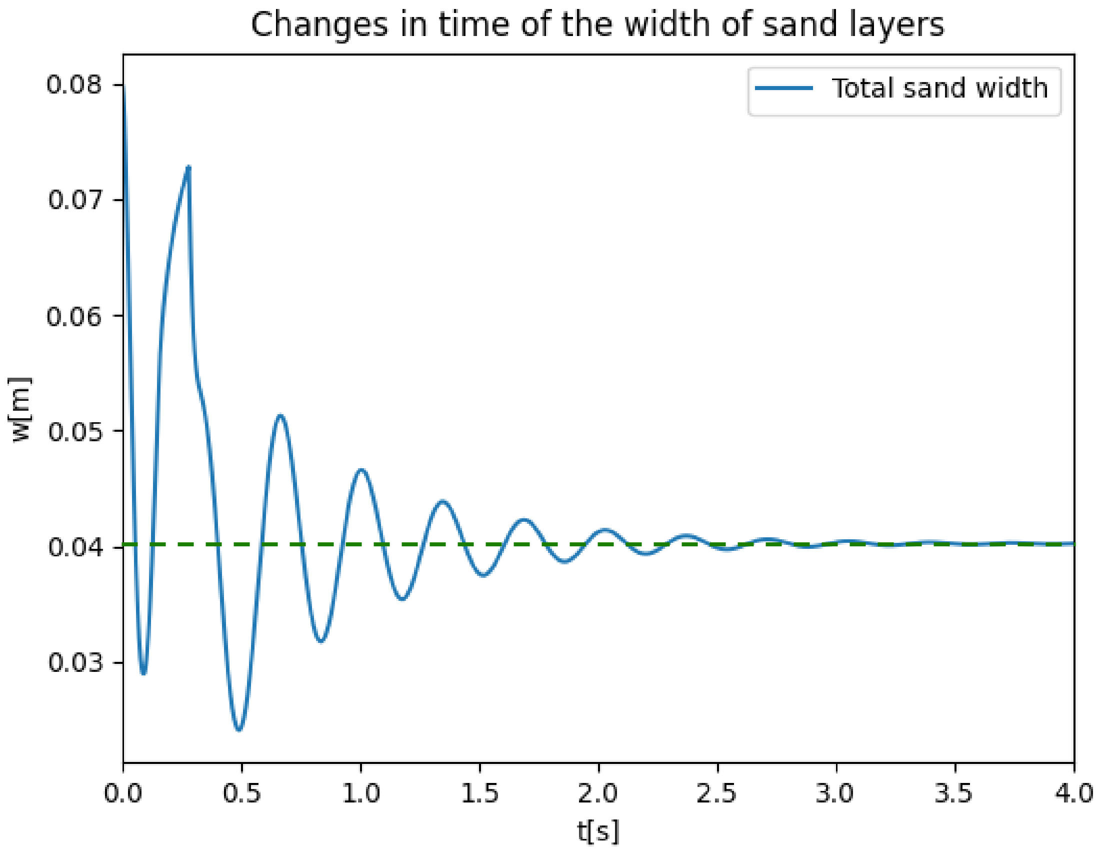
dt = 0.0005 s, CoR=0.6

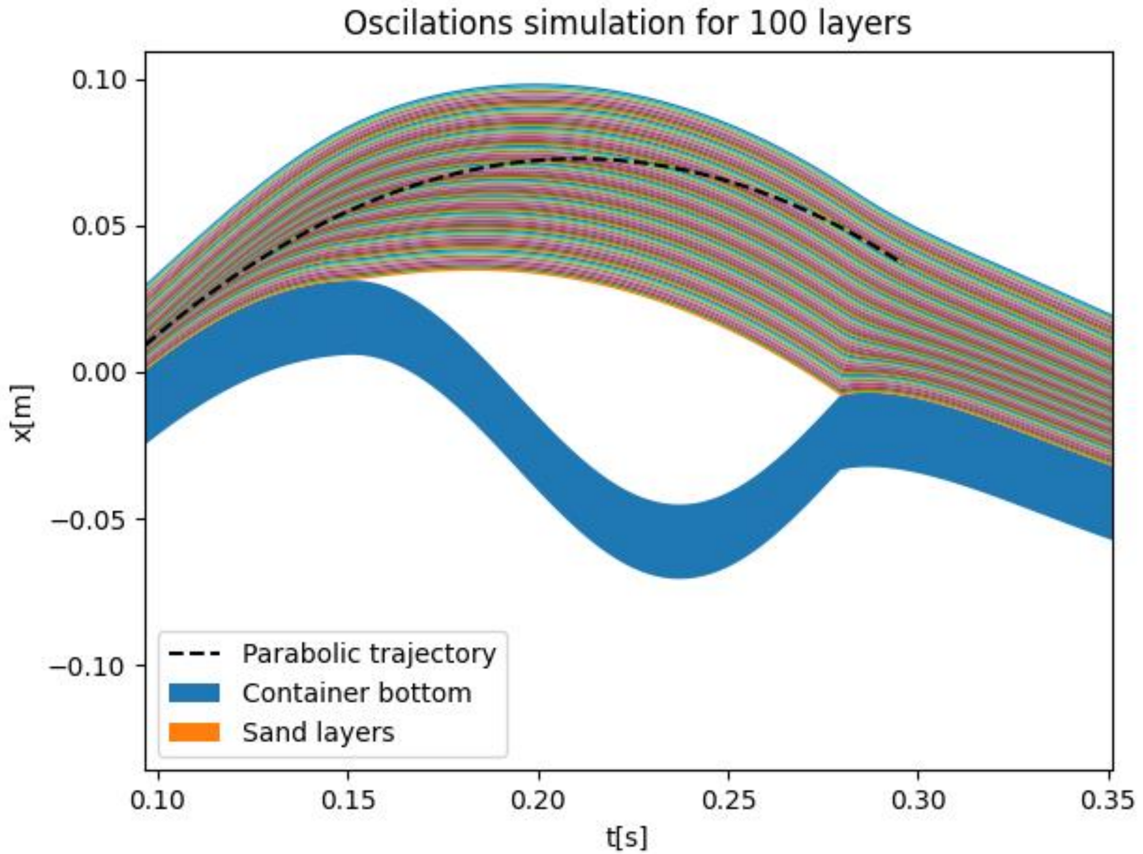
One dimentional layer simulation



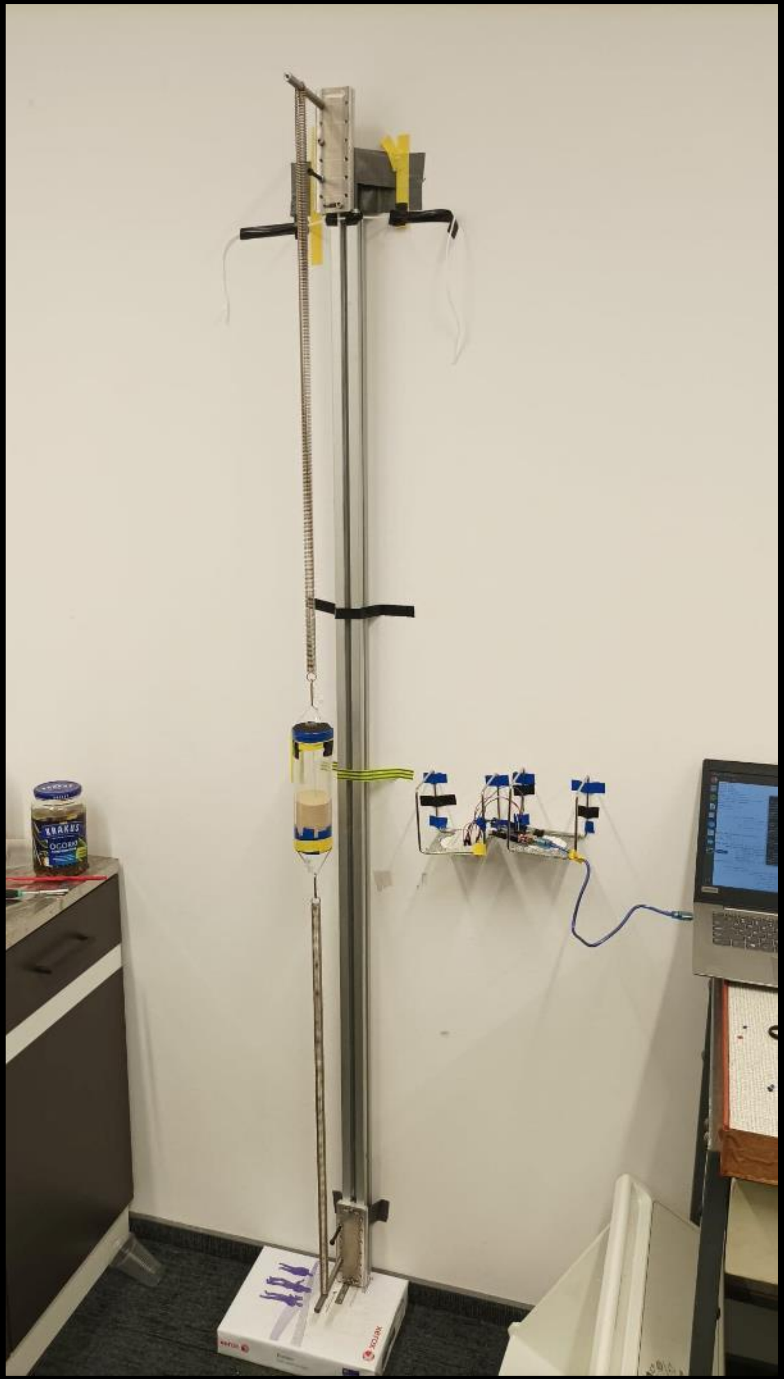
dt = 0.0001 s, CoR=0.8

Sand loosening





dt = 0.0001 s, CoR=0.8



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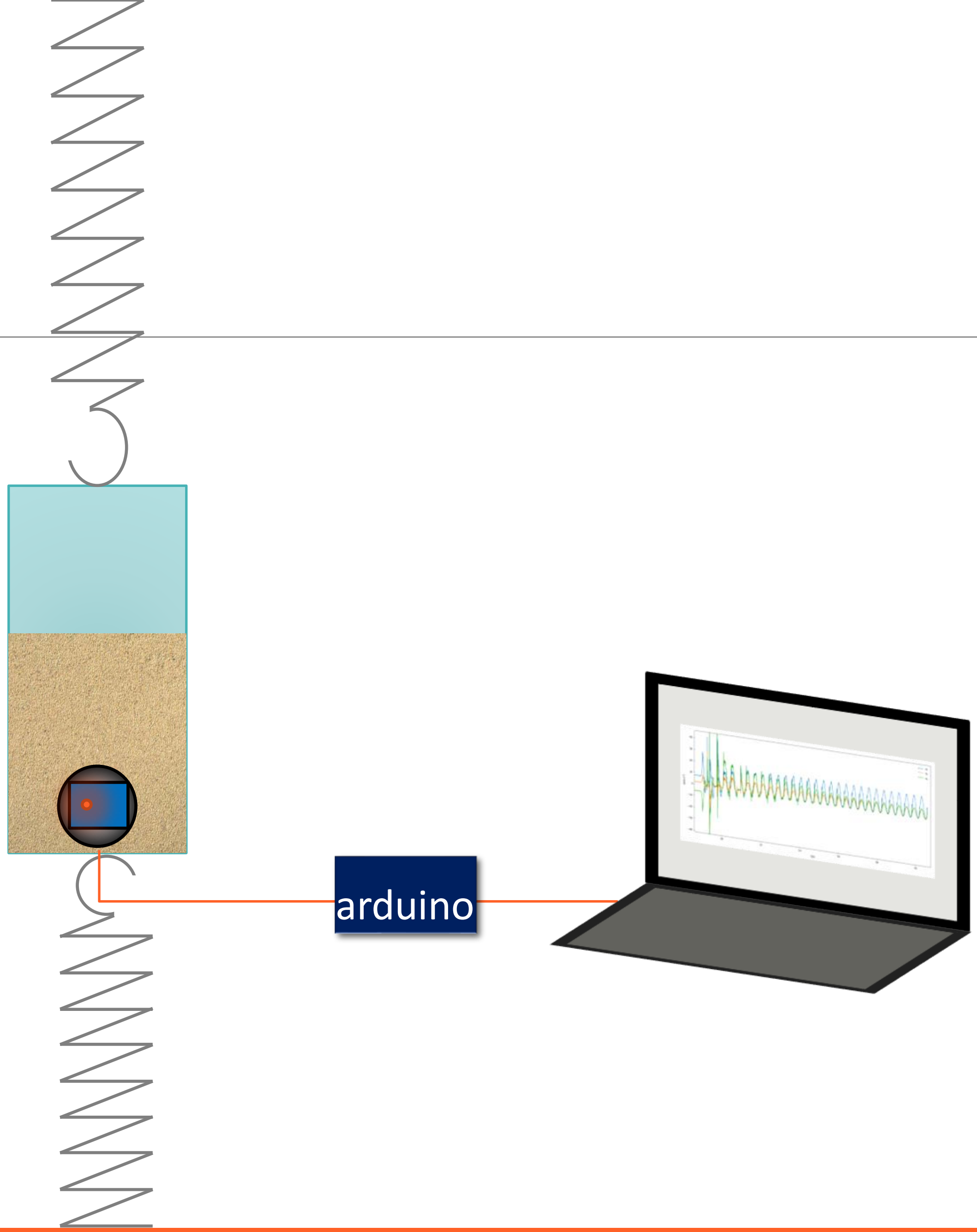
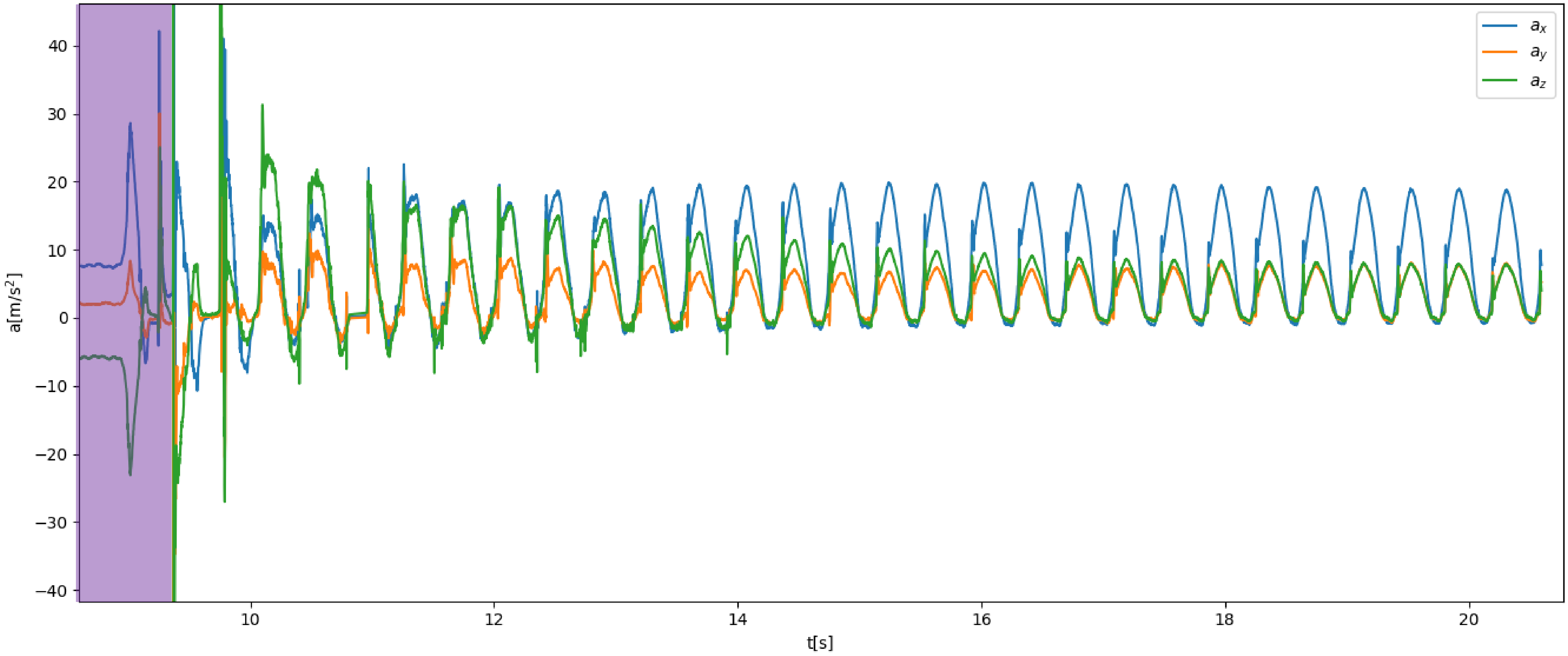
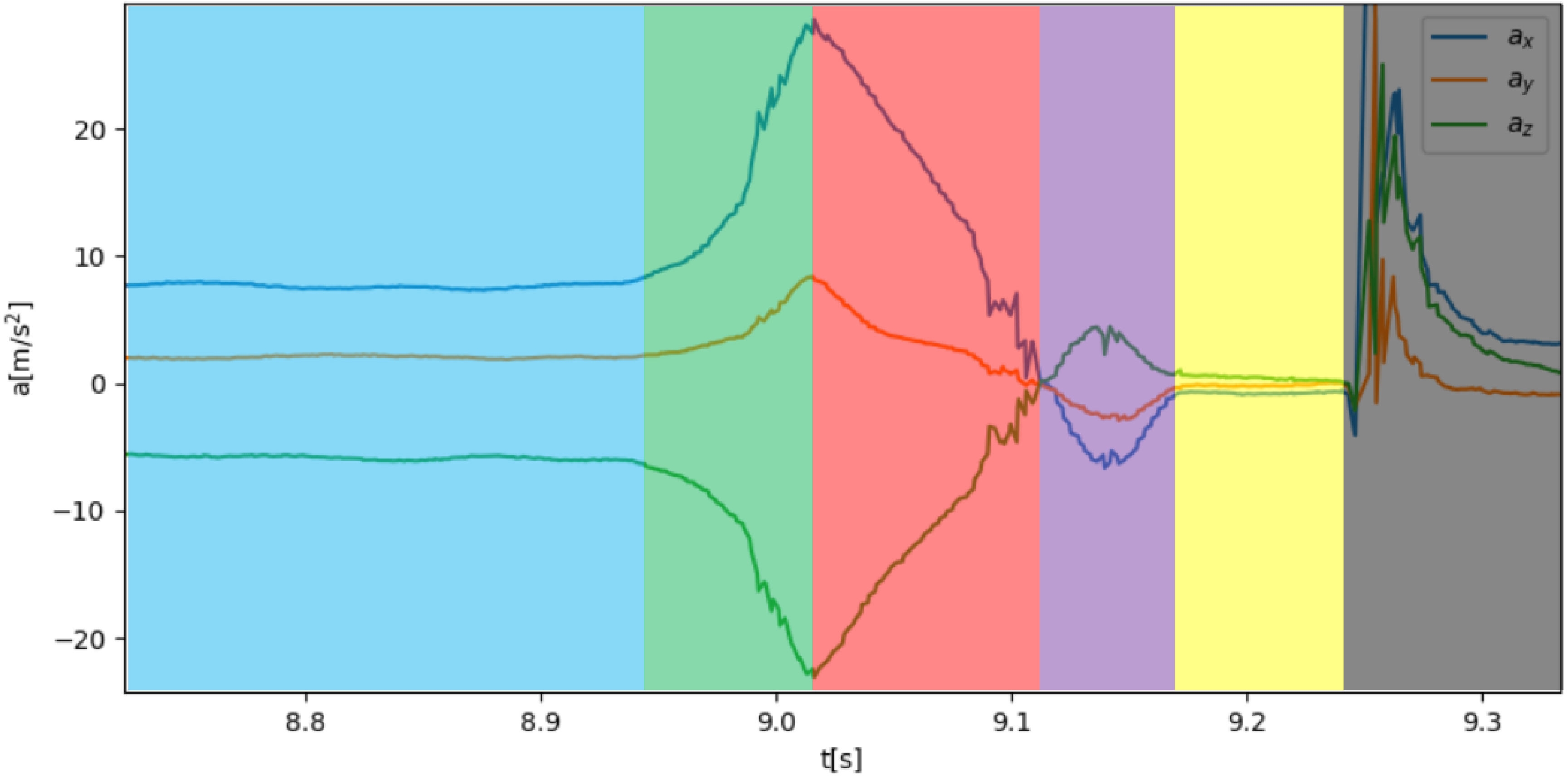


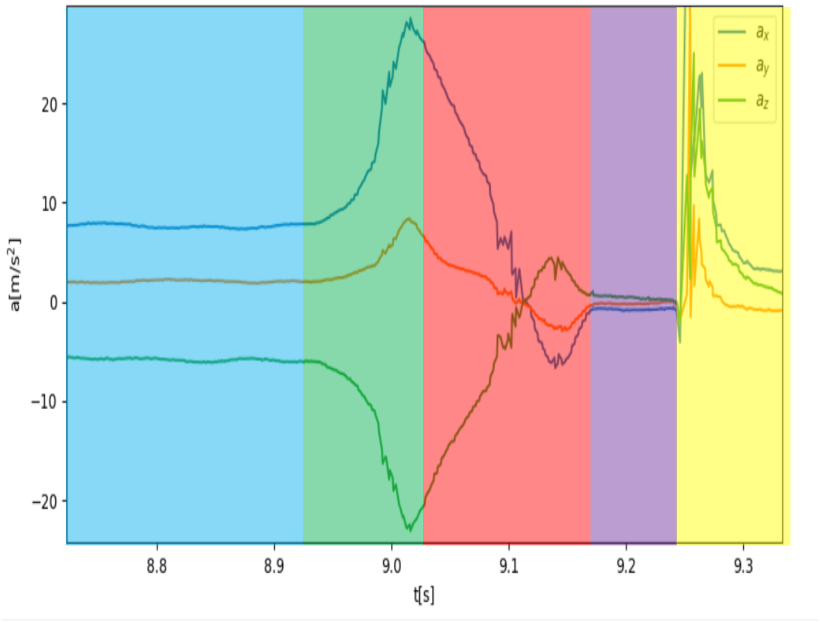
Results

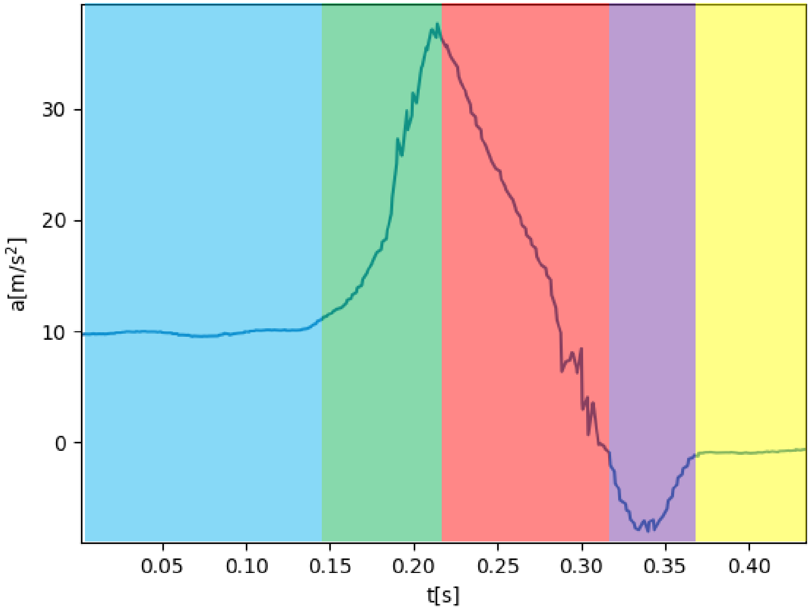


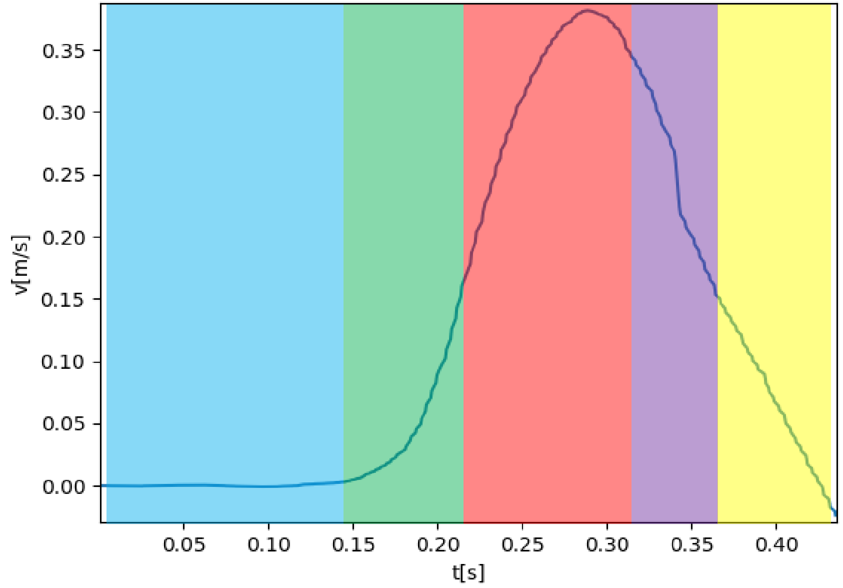
Resistance



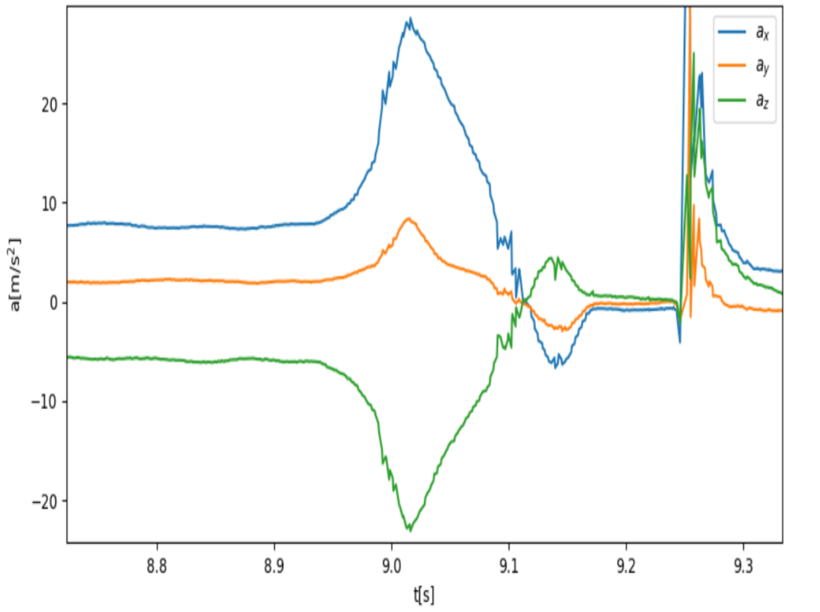
Acceleration before free fall

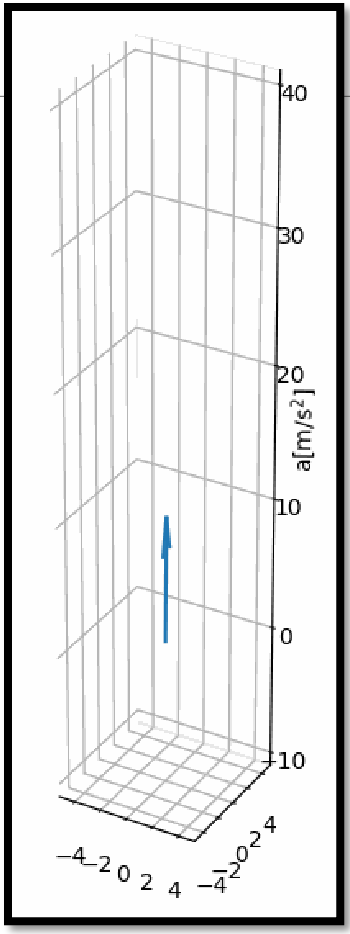


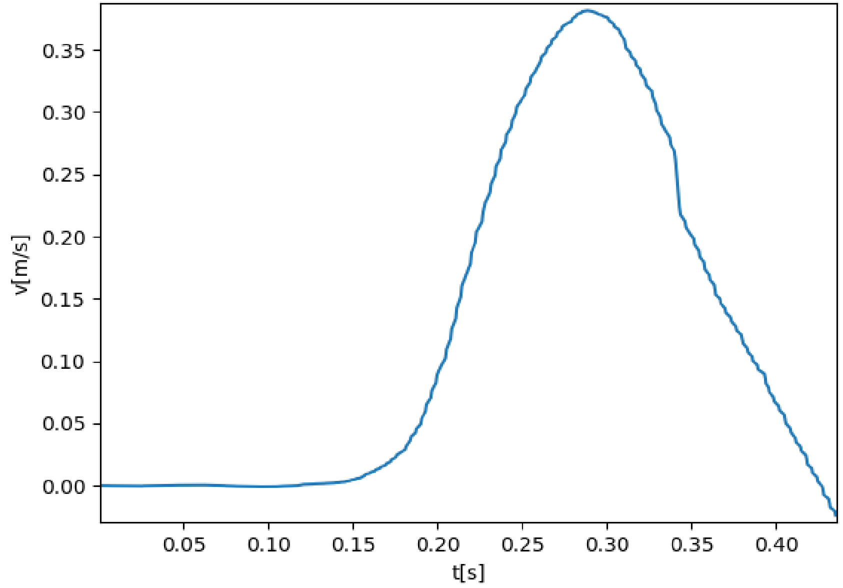




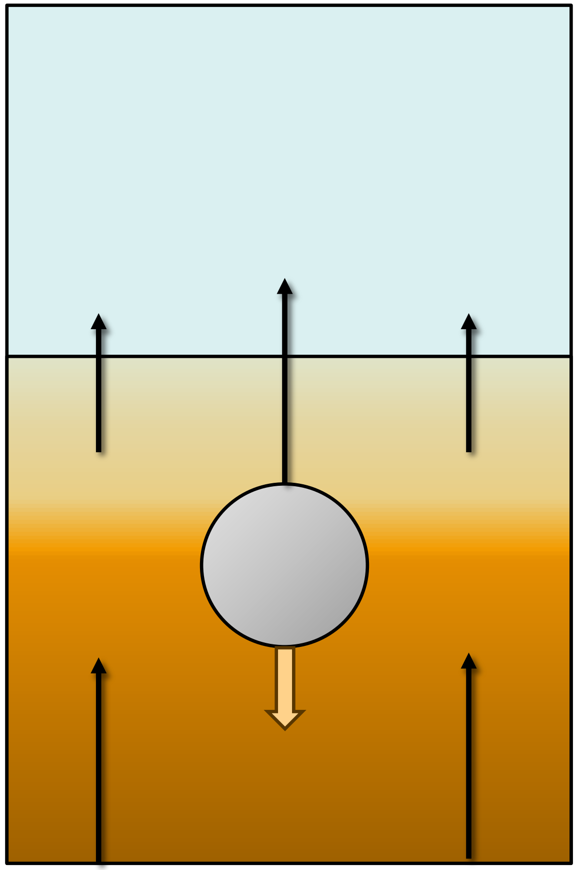
Visualisation

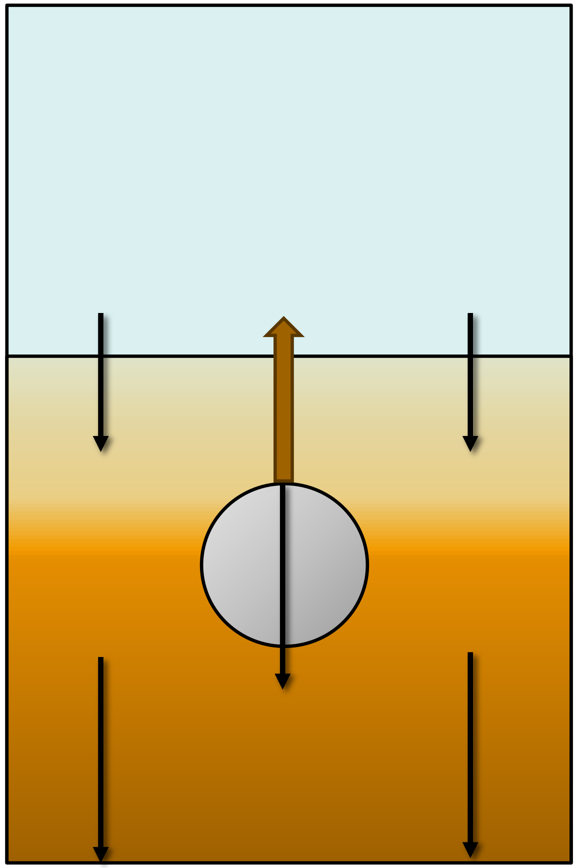






Explanation





Step-by-step

Parameters

Qualitative observations:

- Heavier objects rise more easily
- Objects rise easier in smaller grains
- There needs to be enough space for the object to rise
- Other shapes of the object and the vessel could improve effectiveness

Conclusion

- For the chosen variables we found a **very energy efficient** shaking technique
- There are many different effects that can cause an object to rise in granular material, but in our method, using a layer model **simulation**, we explained that the main cause of the effect is the dispertion of sand layers in air

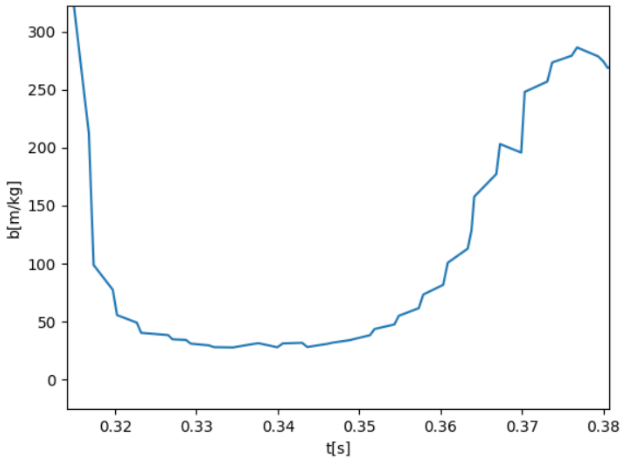
1. The sands rises into the air from the top first
2. The ball has a higher velocity than the sand already in air
3. Because of the ball’s size and mass, it goes through the sand, although feeling some resistance
4. There is no reverse effect because the sand becomes dense before the ball hits it

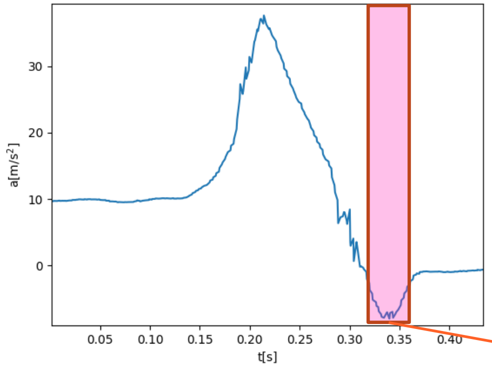
- We performed an experiment that proved **when** the passing through the layers occurs by looking at the **resistance** felt by the ball

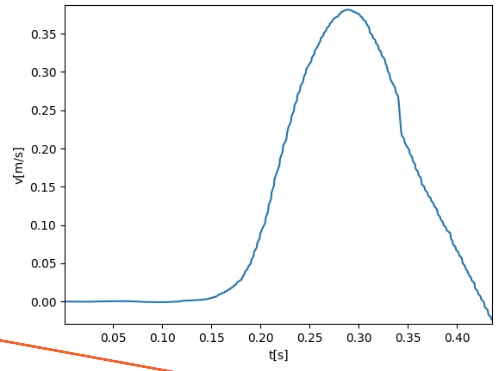
’*Ammodynamic* drag’

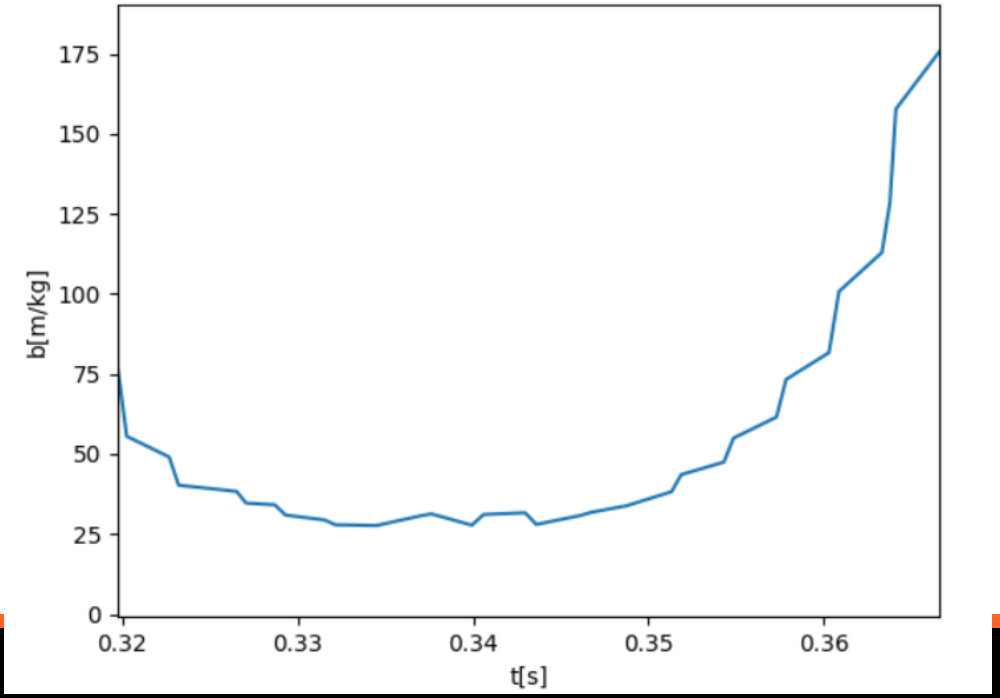
$$ma = mv' = -bv^2$$

$$b = -v^2/ma$$

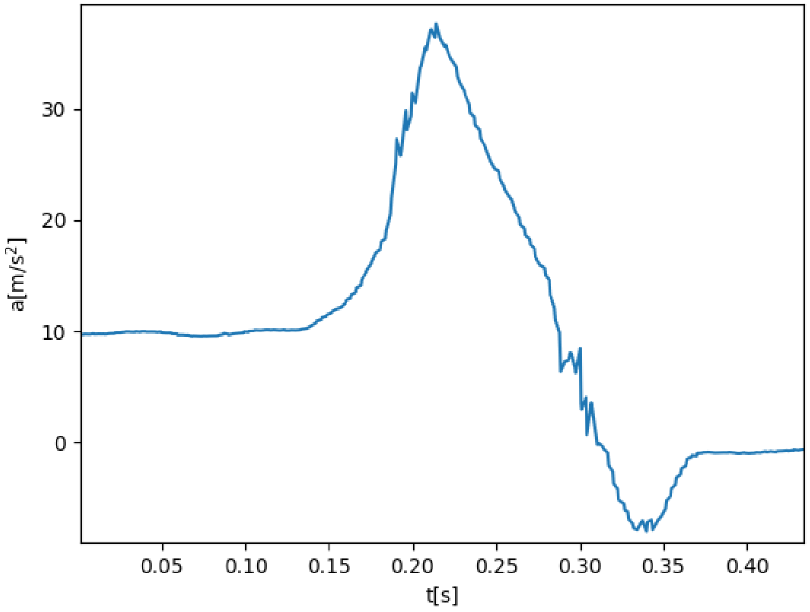


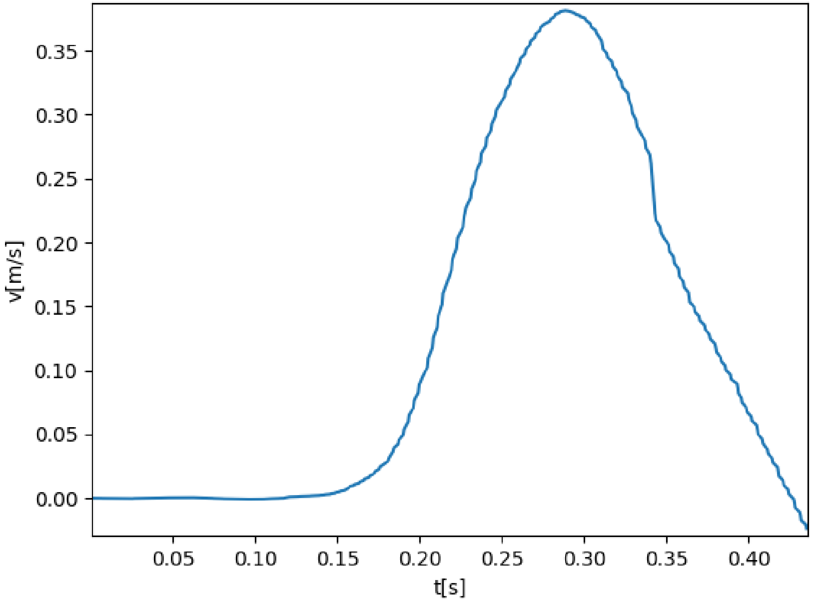


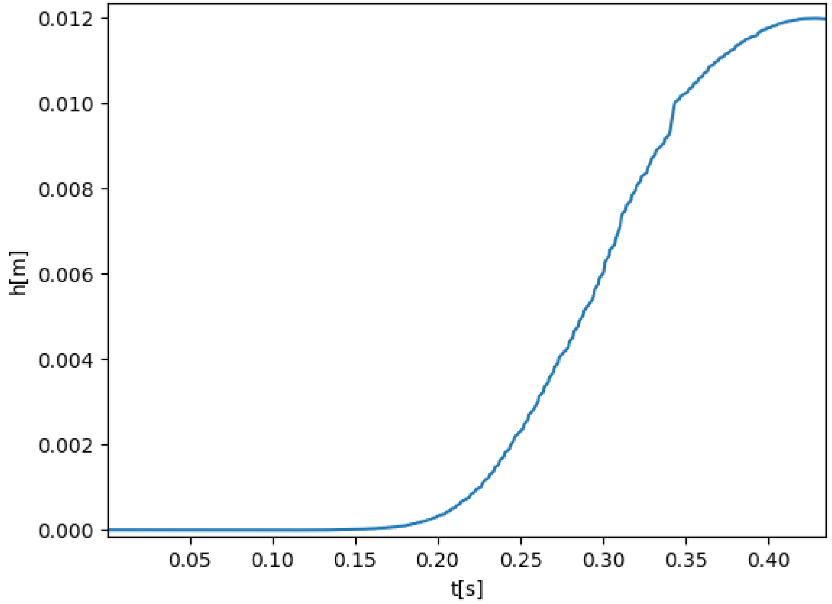




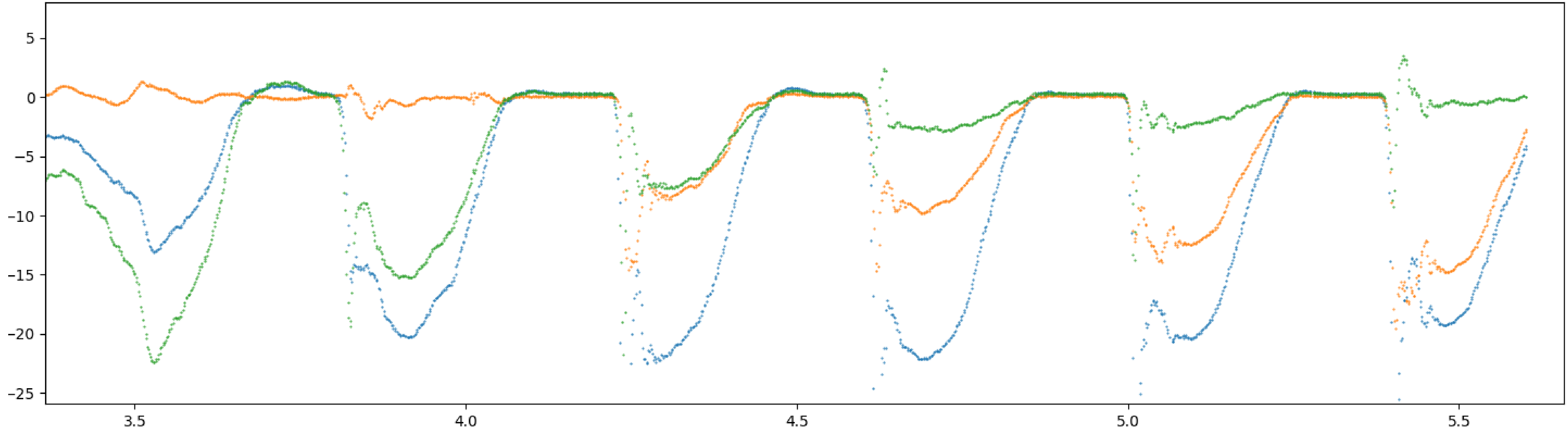
Integration



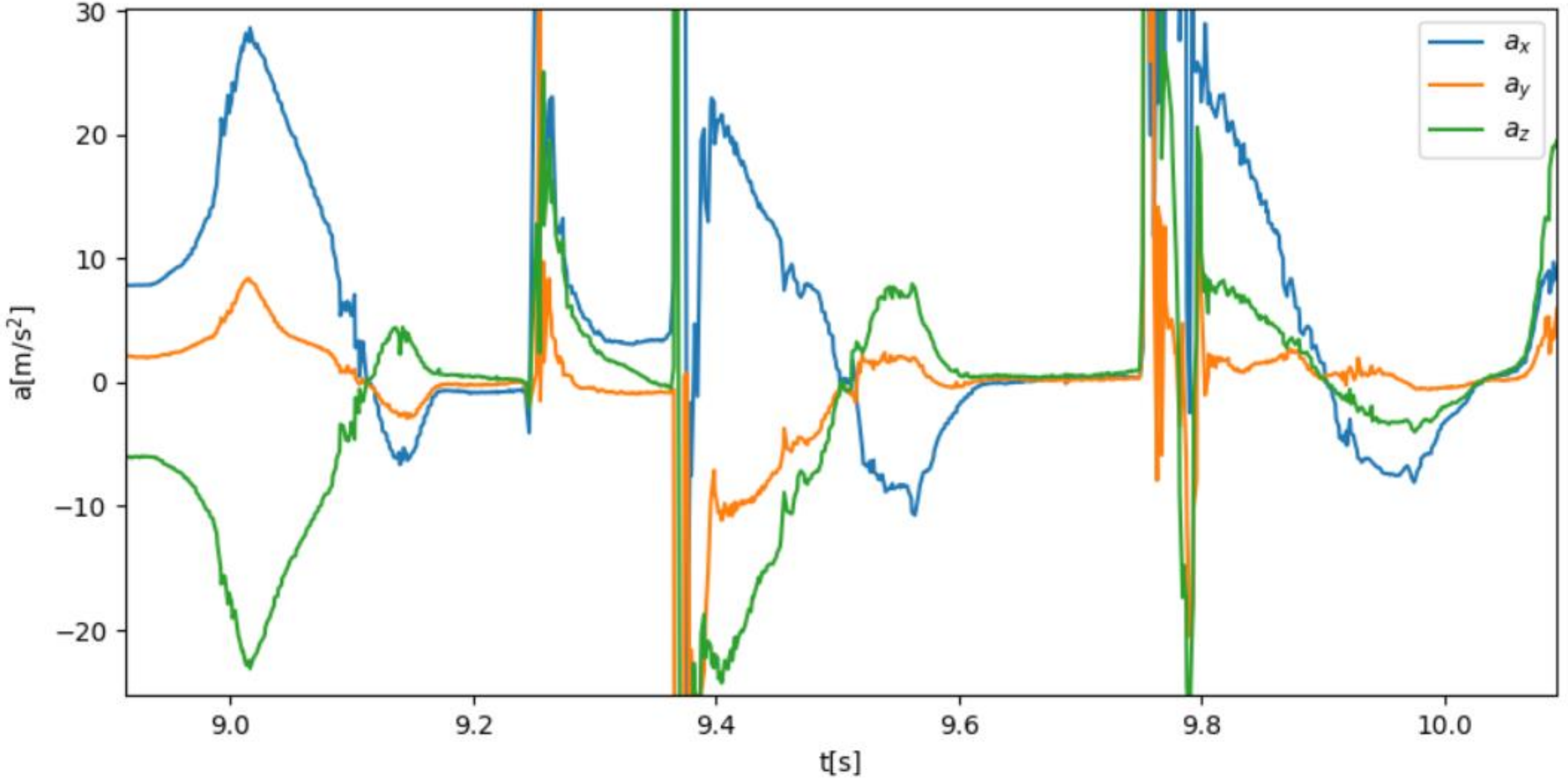




If the ball is on the top



Repetetiveness



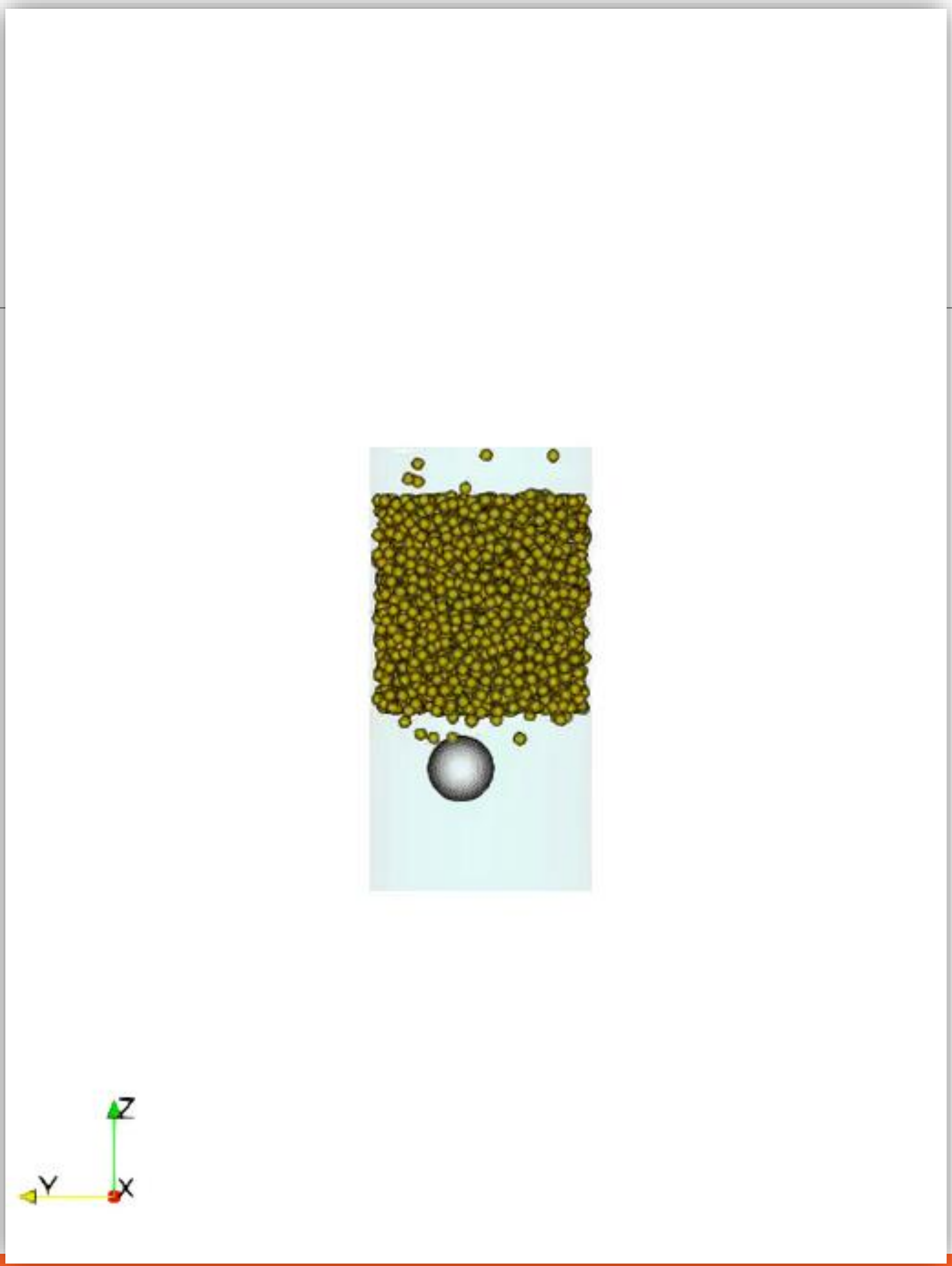
Free space

- More free space means bigger sand dispertion
- Maximum amount of time for the object to rise

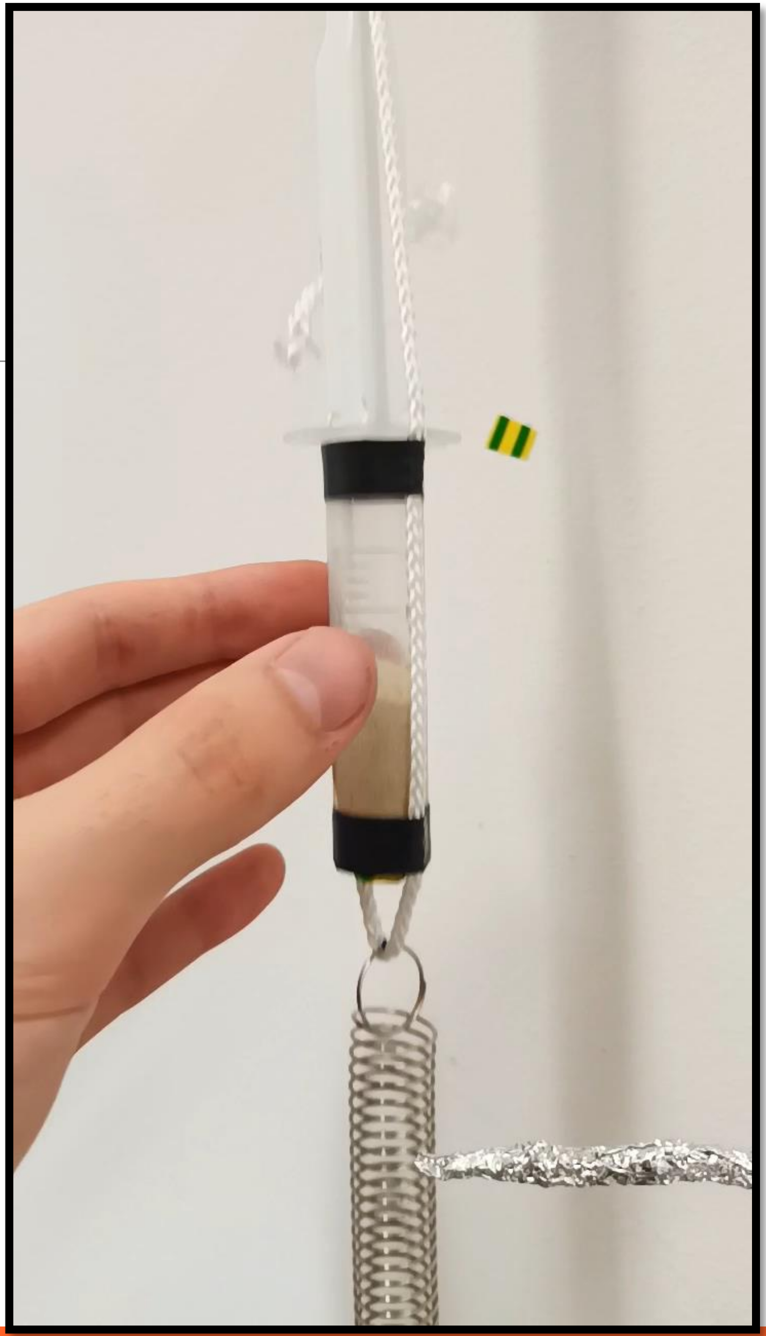
- Bigger energy losses
- Smaller number of ’taps’

Sand dispertion

Other ideas



Ammodynamics of a cone



Grain size