The egg survivor

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1. Abstract

In this experiment we have designed and constructed a tridimensional structure based on the principles of Hooke's law in order to avoid the breaking of an egg in a roller-coaster.

2. Objectives

The objective of this experiment is to verify Hooke's law and then, construct an structure applying it in order to make an egg survive on the roller-coaster.

Fig. 1. The egg survivor

3. Motivation

It is a great opportunity to apply a theory we had learned in physics class with a view to performing a challenge that might seem complicated: to avoid an egg breaking on the roller-coaster, motivated us to work in this project.

4. Theory

The basis of our experiment is the infrastucture that will avoid the breaking of the egg. The infraestructure consists of an empty poliedrical figure, in the centre of which the egg was placed, subjected by six springs, two for each dimensional axis x, y and z (see in Figure).The principal idea is based on Hooke's Law, which stablishes that the force (F) applicated on a string is equivalent to the deformation (Δx) of the string multiplied by the string constant (k):

$$F = k\,\Delta x$$

Appllying also Newton's Second Law, $F = ma$, we have that:

$$k\Delta x\; - k(-\Delta x) = ma_{max}$$
$$\Delta x = \frac{ma_{max}}{2k}$$

Where m is egg's average mass; a_{max} is the maximum acceleration in a determined axis; and k is string's elastic konstant. Both are known variables, as we calculated the maximum acceleration of each axis using an accelerometer.

This calculation is available only when the elastic force is the only extern force that influences the egg (in the case of x and z-axis). However, in the y-axis we also have to take in account the gravitational force, g. Also, the direction of this force changes depending on if at that moment the roller coaster is going uphill (against the movement) or downhill (in favor of the movement),

$$k\Delta x \pm mg \ - k(-\Delta x) = ma_{max\,y}$$
$$\Delta x = \frac{m(a_{max} \pm g)}{2k}$$

This way, we can calculate the string deformation and then, the structure dimensions.

5. Method and experimental procedure

Materials

- Eggs
- Digital accelerometer
- Digital scales
- Tape
- 6 compresion strings of 10 N/m, 20 N/m and 50 N/m.
- 6 meters of plastic rods with 5 mm of diametre
- Flanges
- Plastic pipes with 7 mm of diametre
- 2 cameras
- Tripod
- 6 screws
- Roller coaster of Tibidabo

Experimental descriprion

1. Measure the acceleration in the axes x, y, z of the roller coaster using digital accelerometer. Get the maximum accelerations of each axis.
2. Take five eggs, measure the mass of each one with the digital scale and their size with the tape. Calculate the average size and mass.
3. Calculate the deformation for springs of 10 N/m, 20 N/m and 50 N/m. Calculate the dimension needed for each case.
4. Design and build the three-dimensional structure.

5. Fix the dimensional structure in a wagon of the same rollercoaster using flanges. Start the movement of the roller coaster and record the movements of the egg using two cameras. Check if the egg breaks. Analyze the movements of the egg.

6. Results

6.1. Experimental data

Average mass of the egg

After measuring five eggs, we obtained the average mass of 0.1 kg.

Average dimension of the egg

After measuring five eggs, we obtained the average dimensions showed in *Fig 2*.

Axis	Average dimension
x (cm)	4.3
y (cm)	5.5
z (cm)	4.3

Fig. 2. Egg's average dimension

Accelerations

Afer a travel on the roller coaster, we obtained its maximum accelerations in each axis (see in *Fig.3*):

Axis	Maximum acceleration (m/s^2)
x	22.751
y	25.925
z	14.935

Fig. 3. Roller coaster's maximum accelerations (Tibidabo)

For the y-axis, the gravitational force accerelation is disccounted from the maximum acceleration..

6.2. Data processing

Using the experimental data, we calculated the theoretical prolongations of the strings of 10 N/m, for each dimension, as we can see in *Fig. 4*. The lower the elastic konstant, the larger will be the prolongations, so the structure designed based on the 10 N/m strings will be useful also of strings of a higher elastic konstant.

Axis	Prolongacions (cm)
x	11.4
y	17.9 (uphill) 8,06 (downhill)
z	7.5

Fig. 4. Estimated prolongations of the string of 10N/m

6.3. Design the tridimensional structure

We designed the structure so that we could see and record from outside the movement of the egg. We added the correct dimensions of the egg to the prolongations shown in Fig 3 with the formula:

$$Dimension = 2\,x\,prologation + egg's\,dimension$$

For the y-axis, in which there are two possible prolongations, we divided the structure into two parts: the upper part and the lower part. The dimension of each part is the sum between the prolongation and half of the egg's dimension (see in *Fig. 2*).

So the minimum dimension of the structure must be:

Axis	Dimensions (cm)
x	27,1
y	20,65 (uphill) 10,81 (downhill)
z	19,3

Fig. 5. Minimum dimensions requered of the structure

In order to design a more stable structure, we take the z-axis dimension the same as the x-axis', since the distance needed in z-axis is smaller than the x-axis', it doesn't matter. We also needed the bottom part being flat, in order to be able to fix it firmly in the roller coaster.

Taking all these conditions into account, we built the structure shown in *Fig. 6* and *7*.

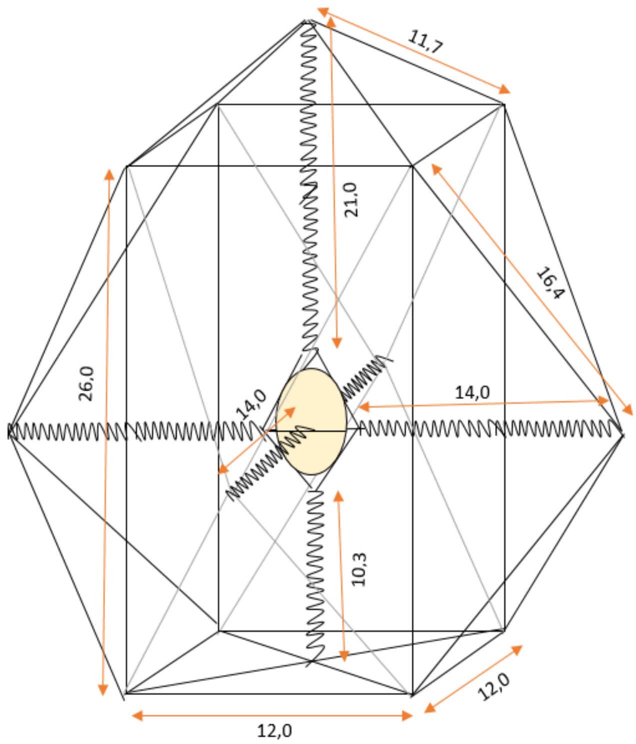

Fig. 6. Drawing of the structure
(It is not done at exact scale)

Fig. 7. The structure constructed

6.4. The egg survivor

The day of the experiment we prepared the three types of springs (10N/m, 20 N/m and 50 N/m) with the appropiate elastic constant for X, Y and Z axis. The experiment was successful, as the egg survived in all three trips. We were able to use the springs of less elastic constant without the egg breaking, which allowed the egg to move all the way around our structure. The details of egg's movement during the trip are shown on the video.

7. Conclusion and evaluation

This experiment proved in a different way the Hook's Law. Even though the egg didn't break, we approximated many results to make sure that the egg would survive. We could have found a way in order to be able to change some dimensions to find more adjusted results. Moreover, we didn't take into account the position of the egg in the moment it experienced the maximum acceleration, because if it wasn't in the centre of the infraestructure, the prolongation should have been calculated from that position. As a future work, we can analyze the movement of the egg from the recordings, and see the position of the egg in the moment it experiences its maximum acceleration in order to improve the experiment.