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P5_12 Killercoaster

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Abstract

In this paper we seek to find out whether the world-famous roller coaster, Saw The Ride, at Thorpe Park, could be adapted to kill a human being if the height of its biggest drop were increased. We find that the ride could indeed kill a person if it were high enough, with estimates of 65 m being enough to knock someone unconscious and 87 m potentially being enough to kill a person- just under 3 times higher than the current ride.

Introduction

Thorpe Park boasts to have one of the steepest free fall roller coasters in the world [1], Saw The Ride. We can take advantage of this to create a simplistic model to make estimates because we already know that for its biggest drop, the only component of force in the downwards direction is gravitational. G-force is the acceleration felt by an object as a multiple of g, the gravitational acceleration on the Earth, 9.81 $\mathrm{ms^{-2}}$. When an impact force is felt from a rapid acceleration or deceleration, it is lethal to a person to the point that the agreed average human limit when travelling horizontally where loss of consciousness occurs is thought to be ∼9G (88.3 $\mathrm{ms^{-2}}$) with possible death or serious harm at ∼12G (117.72 $\mathrm{ms^{-2}}$) [2]. To satisfy our innate morbid curiosity, we investigate how Saw could be adapted to kill a person using G force.

Analysis

Saw The Ride is 30 m high and slightly inverts before there is a vertical drop [1]. Using Google Images, we traced multiple photos of Saw which were taken perpendicular to the direction of the roller coaster car at the drop. Then using these images and the known 30 m height of the ride, we were able to deduce, by taking averages and scaling measurements up, the heights of critical points where the acceleration vector changes as shown by Figure 1. Using a compass and ruler on the images, we discovered the bottom part of the ride up to 14 m can be approximated to a section of a circle with a radius, r, also equal to 14 m. To create a deadly version of the ride, we have added height to the vertical drop section, Δh, and the rest of the ride keeps its original shape as seen in Figure 1. The moving car has a mass of 5000 kg and holds 8 people at one time [1]. The mass of an average person is 62 kg [3] so the total mass of the car at typical capacity, m, is about 5496 kg. The size of the car is unknown but from photos we can deduce that it has a length and height of about 2 m and 1.5 m respectively from the front and can be modelled as a cuboid, with a front facing cross-sectional area, A, of 3 $\mathrm{m^2}$. From Figure 1, we can see there is a rapid change in acceleration when the car goes from free falling to circular motion meaning the riders experience an impact G-force at this point.

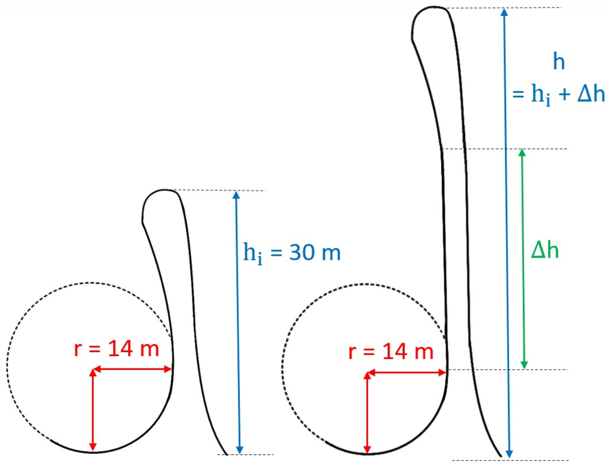

Figure 1: A diagram showing the initial height of the roller coaster (left) and its adjusted deadly height (right) where the radius of the circle, height and change in height are given by the red, blue and green arrows respectively

As the car is constrained to travel in this circle, we can assume that a significantly large part of its acceleration is towards the centre of the circle in the form of centripetal acceleration. Knowing this we can approximate that the centripetal acceleration is $a_c = v^2/r$ where v is the tangential velocity. Although it is an equation for uniform circular motion and does not account for the tangential acceleration of the car due to its weight, it can be used as a good approximation for the rapid acceleration in a completely different direction (towards the centre of the circle) so that a G-force experienced by the passengers can be calculated. Therefore from the deadly acceleration (12G) we can work out the deadly tangential velocity of the car travelling round the circle, 41 ms^{-1}. From this we can work out the deadly kinetic energy $E_k(= (1/2)mv^2)$ of the car at the bottom of the fall to be 4.5 MJ. This kinetic energy will be equal to the gravitational potential energy, $E_g(= mgh)$, at the top of the fall minus any energy dissipated on the way down due to frictional forces. For the purposes of this paper we will assume the frictional forces from the wheels on the track are negligible as there is limited information on the exact design mechanisms of the roller coaster in the literature but steel roller coasters are known for minimising friction. Therefore, the energy dissipated we will calculate comes from the drag force on the roller coaster as it travels through the air. The average drag force is given by

$$F_D = (1/2)\rho(v/2)^2 C_D A \tag{1}$$

where ρ is the density of air (1.23 kgm^{-3}), C_D is the drag coefficient of a cuboid (2.1), v is the killer velocity and $v/2$ is the average velocity. Thus the approximate energy dissipated is given by

$$W = F_D[(h - r) + r\theta] \tag{2}$$

where W is the work done by the drag force, $(h - r)$ is the distance travelled by the car until the circle and $r\theta$ is the distance travelled by the car along the bend where θ is 1.57 rad. Therefore if we equate E_g to the sum of E_k and W and then rearrange for the height of the drop we get

$$h = \frac{(1/2)mv^2 - (1/8)\rho v^2 C_D A r(1-\theta)}{mg - (1/8)\rho v^2 C_D A} \tag{3}$$

By substituting the previously mentioned values into Eq. (3) we get a killer height of 87 m- just under 3 times higher than the current ride. By substituting 9G in we get a height that could knock someone unconscious of 65 m, just over double the current height of the ride. To test if Eq. (3) gives an adequate value for the height, we can substitute in the known value of the maximum speed of the drop (25 ms^{-1}) [1] from the actual ride- this substitution gives a value of 31 m for the height of the ride, only a 1 m (3%) difference from the known height. This is a demonstration of how even crude approximations can give reasonable estimates hence we can conclude that the height of Saw The Ride that could kill a person is roughly 87 m.

References

[1] `https://www.thorpepark.com/` [Accessed 8 November 2020]

[2] H.Crawford, HSL 2003/09, 19

[3] `https://en.wikipedia.org/wiki/Human_body_weight` [Accessed 10 November 2020]