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P5_7 Examining the Material Properties of Slinky Dog

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Abstract

In this paper we aim to analyse the properties of the spring that comprises the character "Slinky Dog", from the Toy Story franchise. By using scenes from Toy Story 4, we determined that the spring constant of Slinky would be around 6 $\mathrm{Nm^{-1}}$ and the maximum force to reach the elastic limit would be around 30 N. Thus, making Slinky a very fragile toy to play with.

Introduction

Walt Disney Pictures and Pixar Animation Studios franchise, Toy Story, is the 20^{th} highest-grossing film franchise of all time. The franchise is constructed around the premise that children's toys are sentient and only appear still when observed. One of the toy characters in the film, Slinky Dog (A.K.A Slinky), is a dachshund whose front and rear ends are conjoined by a large spring, or "slinky".

In this paper we will examine the properties of the spring that holds Slinky together, to determine the spring constant and the max loading force at the elastic limit of the material. To do this we need to assume the weights and heights of the toys utilising various sources, and real life scale figures of the characters. We will also use specific scenes from various films within the franchise to determine the distances that Slinky is stretched under different forces and conditions.

Theory

All springs obey Hooke's Law within a specific limit as defined by the properties of the material. Hooke's Law states that the force required to extend (or compress) a spring by some displacement, x, is scaled with a linear proportionality to said displacement. This is described in Eq. (1) [1],

$$F_s = -kx \tag{1}$$

where F_s is the restoring force exerted by the spring that acts in the opposite direction to that of the displacement, i.e. the restoring force always seeks to restore the spring to its equilibrium state. $-x$ describes the displacement of the spring in reference to the restoring force, hence the negative value, and k is the spring constant which defines the linear relationship between the force and displacement.

Once a spring reaches its "elastic limit" it ceases to obey Hooke's Law and undergoes the process of plastic deformation. As the relationship between the load force and the displacement is no longer linear, when the load force is removed the restoring force will reduce the displacement back towards the equilibrium point. However, this restoration force follows the linear relationship and therefore, the displacement does not return to zero, as shown in Figure 1.

To determine the force required to reach the elastic limit of Slinky, we will use information

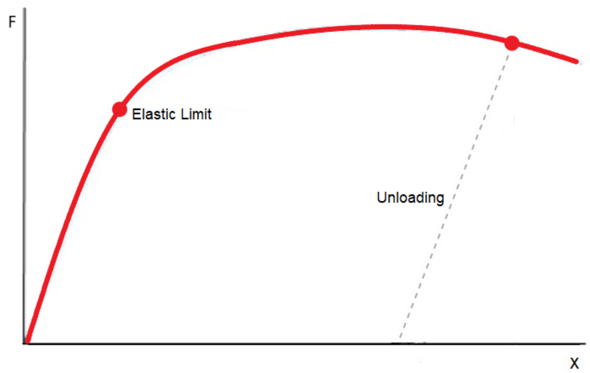

Figure 1: A diagram detailing the relationship between load force and displacement of a spring.

directly from Toy Story 4, where Slinky is stretched to his elastic limit under force from other characters.

Analysis and Results

To first calculate the spring constant of Slinky's spring we analysed a scene from the opening act of Toy Story 4, where Slinky is extended under the weight of two other characters, "Woody" and "RC". From information found on various websites detailing sizes and weights of these characters and their replica toys, determining that the total weight of the load would be approximately 1180 g [2] [3] [4]. By using the average height of two story residential homes and their windows [5], and applying this to the reference scene we concluded that the displacement Slinky experiences is around 175 cm. By applying these values for F_x and x to Eq.(1), we determined that the value of the spring constant was around 6 Nm^{-1}. When this value is compared to that of a thin stainless steel wire, almost identical in dimensions, we find that the spring constant for Slinky is around 1371 times smaller [6], this shows that Slinky does not posses a very stiff spring. Earlier in the same scene, Slinky is used as a safety line for the character Woody, as he tries to rescue RC. During this rescue mission Slinky is stretched until he has "no more slink", which we interpreted as he reached his elastic limit. By assuming distances in the scene we determined that the maximum displacement was roughly equal to 5 m. By inputting this value, along with the value for k, we found that the maximum loading force that Slinky can endure without plastic deformation is approximately 30 N.

Conclusion

The investigation into the properties of Slinky and the spring from which he is conjoined, has shown us that it is in fact a very loose, flexible spring. Slinky does not require very much force, less than 30 N to exhibit large displacements, whilst still retaining elastic deformation. The spring has a spring constant of around 6 Nm^{-1}, which is considerably lower than the spring coefficient of 8230 Nm^{-1} of a steel spring boasting similar dimensions.

References

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[6] `https://www.acxesspring.com/espanol/spring-constant-calculator.html` [Accessed 24th November 2020]