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A3_10 Stretched to the Limit

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Abstract

In this paper we investigate the superhero Elastigirl. We used a scenario in 'The Incredibles' in order to calculate her Young's modulus, which was found to be 7.6×10^7 Pa. By comparing this to other materials such as rubber this value seems plausible. The study was then taken further to determine the elastic potential energy stored by Elastigirl during this scene, which was found to be 1.3×10^7 J.

Introduction

In this paper we analyse the elasticity of Elastigirl based on a scene in 'The Incredibles'. This is done by estimating how far she stretches, and the force acting on her when holding an aircraft together [1]. Her Young's modulus can be obtained and by completing further calculations we estimated the elastic potential energy stored in this scenario.

Method

In order to begin this investigation estimations based off the scene had to be made. These estimations were required as they were needed to calculate the Young's modulus of Elastigirl. These values allowed the calculation of the stress and strain, which were then used in equation (1),

$$Y = \frac{\sigma}{\epsilon}, \tag{1}$$

in order to calculate the Young's modulus. In the above equation, Y is the Young's modulus, σ is the stress and ϵ is the strain.

The stress was found by calculating the force, F, over the area, A, it is acting on. This is seen in equation (2),

$$\sigma = \frac{F}{A}. \tag{2}$$

The strain was then found by computing the change in length over the original length of the material being stretched, in this case Elastigirl. This can be seen in equation (3),

$$\epsilon = \frac{\Delta L}{L}. \tag{3}$$

The stress and strain values can then be used in equation (1) in order to calculate the Young's modulus. The investigation was then extended by attempting to determine an estimation for the elastic potential energy stored in Elastigirl when stretching in this scene. To do this Hooke's law,

$$F = k\Delta L, \tag{4}$$

was rearranged in order to find her spring constant, k. Then using the estimated force, F, acting on her and the change in her length, ΔL, an estimated spring constant was calculated. This was then used in equation (5),

$$U = \frac{1}{2}k\Delta L^2, \tag{5}$$

to estimate the elastic potential energy, U.

Findings

To find the Young's modulus the stress and strain were initially calculated. To find the stress, calculated using equation (2), an estimate was made for the force acting on Elastigirl and the area the force affected. The force was estimated by evaluating the mass of the aircraft held in the scene [1]. We assumed that the aircraft held would have a similar mass to that of a wing of a Boeing 747 due to the sheer size seen in the movie [1]. Given this, the mass is approximately 43,000 kg on each side, resulting in a total mass of 86,000 kg [2]. After multiplying by gravity the force was found to be approximately 840,000 N. The area affected was assumed to be entirely on her wrist, which was approximated to be 6.3×10^{-4} m^2. This was estimated by assuming the semi-major axis, a, of the wrist was 0.02 m and semi-minor axis, b, was assumed to be 0.01 m. The area was calculated using the area of an ellipse equation, $A = \pi ab$. Given the force and area the stress was then calculated to be 1.3×10^9 Pa. Next, the length of Elastigirl's normal arm span was based off her height. We found her height to be approximately 1.7 m and therefore assumed her arm span, L, is approximately the same [3]. Then by considering the scene in the movie, we estimated her change in length, ΔL to be roughly 30 m [1]. This was estimated by comparing her extended length to her surroundings, in this case an RV van [1]. This allowed the strain to be calculated and it was found to be 18.

The values of stress and strain allowed the calculation of the Young's modulus, which was calculated to be approximately 7.6×10^7 Pa. As Young's modulus is a measure of resistance to it being stretched this should be much less than in other materials, which was found to be true as most materials have a value of 10^9 Pa [4].

Next, the elastic potential energy, U, was estimated using the method outlined previously. By dividing the force, 840,000 N, by the extension, 6.3×10^{-4} m^2, the spring constant of Elastigirl was found to be 28,000 Nm^{-1}. This was then used in equation (5) along with the change in length, ΔL, to calculate the elastic potential energy in this scene. This was found to be 1.3×10^7 J. This energy is extremely large, however, given that in the scene she is in visible pain and cannot seem to hold this force for much longer this could be at her limit, meaning this could be near the maximum energy possible [1].

Conclusion

To conclude, we calculated the stress and strain occurring on Elastigirl as she holds together an aircraft. This allowed us to calculate a Young's modulus value for her, which was found to be 7.6×10^7 Pa. This value seemed large at first but by comparing it to values for other materials, such as rubber, 10^8 Pa, it is clear that this value is viable as an initial approximation. The investigation was taken further by estimating the elastic potential energy stored during this scene, which was calculated to be 1.3×10^7 J. Again this seems large, however, this could be close to the maximum energy stored for Elastigirl as she was seen to be in pain during this scene. An extension to this could be done to try and determine the maximum possible length stretched by ignoring Elastigirl's pain threshold.

References

[1] *The Incredibles* (2004) Directed by Brad Bird, Produced by Disney [Accessed 30th Nov 2020]

[2] `https://tinyurl.com/Boeing747mass` [Accessed 30th Nov 2020]

[3] `https://tinyurl.com/elastigirlheight` [Accessed 30th Nov 2020]

[4] `http://www-materials.eng.cam.ac.uk/mpsite/properties/non-IE/stiffness.html` [Accessed 30th Nov 2020]