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A3 3 Standing Tall: Can the Colossal Titan Support Itself?

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Abstract

The Colossal Titan from the show and manga *Attack on Titan* is depicted as a 60 m tall humanoid. This report tests whether a real biological structure based on human proportions, could support itself if it was the size in the show. Using the square-cube law and scaling factor, the Titan has a mass of 3.08×10^6 kg. The compressive stress on the bones when distributed on two legs is 30.7 MPa, giving us a safety factor of 6.7. Allowing a theoretical height of 401 m.

Introduction

The Colossal Titan appears in the popular manga and anime series *Attack on Titan*. It is depicted as a 60 metre tall humanoid with exposed musculature and no skin, capable of kicking a breach in the protective Wall Maria [1]. Could a being of this size support its own weight and perform the actions shown in the series, or would it collapse under its own mass? This report will be looking at the whether the titan's skeletal strength could possibly hold up its weight and could an animal like this ever exist in real life. To achieve this result, we will use the cross-section the bone and muscle and relate them to the volume or weight of the titan using the square-cube law. Where, volume grows as the cube of the linear size L, While the cross-section of a bone or muscle expands only as L^2.

Method

As the titan shows the physiology of a human male, we will be using data base of human males [2]. Using an assumed average height of a human male, H_h [2] and mass, M_h. The Titan's linear scale factor L is determined to be:

$$L = H_T/H_h. \tag{1}$$

Where H_T is the height of the Titan.

We also assume the whole-body fat-free mass density of the Titan is the same as a human, $\rho = 110$ kg/m^3 [3]. Since the Titan's density is assumed to equal a human's, its mass scales in direct proportion to its volume. The density therefore cancels in the ratio above, and the mass of the Titan can be related to that of a human by:

$$M_T = M_h L^3. \tag{2}$$

To calculate the bone strength, we use the compression that the bone bears. Stress, $\sigma = W/A$ (3), where $W = M_T g$ (4) is the weight of the Titan, g is the acceleration due to gravity (assumed to be the same as real life), and A is the total cross-sectional area of load bearing bone. A scales with L^2 while W scales with L^3, relating the stress in the Titan and height:

$$\sigma_T = \sigma_h L. \tag{5}$$

Where σ_T is the compressive stress in the Titan's bones and σ_h is the compressive stress in human bones.

Results

We can calculate the Titan's linear scale factor using equation (1). Taking the average height of a human, $H_h = 1.7$m with a mass, $M_h = 70$kg, we get a value for $L = 35.3$.

Substituting L into equation (2) the mass of the Titan can be calculated to be, $M_T = 3.08 \times 10^6$ kg. And further giving us the Weight using equation(4), $W = 3.02 \times 10^7$ N.

Using Nieves et al [4] measured value for the mean cross-sectional area of the cortical bone in the femoral shaft, 394.3 mm^2, we can determine the stress on the bone for a human. The total cross-sectional area for 2 legs for human is given by, $A_h = 7.9 \times 10^{-4}$ m^2. So using the average weight of a human [2], the stress on cortical bone for a human can be calculated using equation (3). Which gives $\sigma_h = 0.87$ MPa. Equation (5) can be used to scale it up for the Titan. Where $\sigma_T = 30.7$ MPa.

The maximum compressive strength of a human femur along its length is measured to be $\sigma_M = 205$ MPa [5]. If we do σ_M/σ_T, it gives us a safety factor of around 6.7. Setting $\sigma_T = \sigma_M$ we can get the critical value of which the structure of the bone will fail, $L_M = \sigma_M/\sigma_h = 236$, or a Titan height of 401 m.

Discussion

The result signifies that the theoretical height the Titan could reach, 401 m, is well beyond what we see in the show, 60 m. This is backed with a safety factor of around 6.7, meaning that it could potentially hold 6.7 times the weight of the Titan before the bone failed. Thus adequate for the Titan to stand with 2 feet with its own weight.

However, the bone calculations only consider bone compression. In reality there are other forces that have been ignored, such as tension and torsion. But the biggest one would be bending. The load on the bone would not act perfectly straight down the bone's axis. Realistically, it would act at a certain angle to the femur, as the femur slightly bows. Not to mention that if the Titan would bend its legs or not just stand straight, the bending forces on the femurs would amplify. Taking all this into account, the safety factor would decrease, and in turn lower the potential height that the Titan could be. We have also used average human tissue properties and the Titan's "true" density is unknown. During the show we see the Titan depicted to release a lot of steam and heat and likely had no internal organs. This would change the average density drastically.

So why have we not seen an animal this size before? As it scales up, its weight grows faster than the strength of its bones and muscles, not allowing it to get too big. Comparing the Titan to the largest land animal that has ever been recorded, the "Patagotitan mayorum" [6], the mass has been estimated to be roughly 69 tonne with a height of around 37 m long. The Titan is almost twice the height and around 45 times heavier. So an animal like the Colossal Titan would still very much be within the realms of fiction.

Conclusion

It has been shown that the Colossal Titan's leg bones could support its 3.08×10^6 kg mass, with a compressive stress force of 30.7 MPa against the femur. The calculated safety factor demonstrates the Titan's femur could withstand 6.7 times its mass before breaking. However, the muscles would likely fail first and not allow much movement to occur.

An animal of this size is highly unlikely to exist in the real world due to many limitations, such as the square-cube problem, where the size scales with L^2 and weight with L^3.

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