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P1 4 Pyramid of Geezers 2: Electric Boogaloo

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Abstract

In this paper, we recalculate the theoretical maximum number of tiers in a human pyramid, originally calculated in a previous PST paper, using the ultimate compressive and yield strength of cortical bone. We found the maximum number of tiers to be between 8 and 10 before the ring metacarpal bone begins to yield and 14 to 17 before breakage.

Introduction

A PST paper in 2014 titled 'Pyramid of Geezers' [1] calculated the theoretical maximum number of tiers possible in a human pyramid under the assumptions, both implied and stated, that: arm strength was the limiting factor for tiers, the weight of a person above is evenly distributed across the people below and is evenly split across each limb [1]. We believe that weight is not evenly distributed across each tier, as gravity acts directly downwards, and explore the limiting factor being the compressive strength of their bones rather than the muscle, as we believe you can hold much more than you can lift. We ignore joints for simplicity's sake.

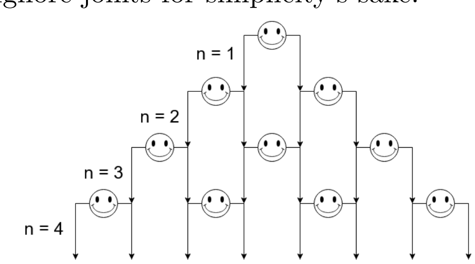

Figure 1: Diagram showing the forces acting directly downwards through limbs in a human pyramid.

Theory

In a human pyramid, hands and knees are placed on the shoulders and hips of the people below, This would create essentially a straight line of arms and legs down to the ground. We assume that all the weight acts down each 'column', as can be seen by the arrows in figure 1, of limbs and is split evenly over each limb. We derived the following equation:

$$F(n) = \begin{cases} (n-1/2)mg & n \in 2\mathbb{N} \\ nmg & otherwise \end{cases} \quad (1)$$

Where $F(n)$ is the maximum force experienced (felt by the bottom centre member(s)), n is the number of tiers in the human pyramid, m is the mass of each person and g is the force of gravity. We assume that each person's limbs are completely straight and the bones inside take the weight of the person above them. The arm bones will be the weakest link as the femur is well known to be the strongest bone in the body and it is assumed that the participants are on their knees and fists rather than open palms as this keeps the forces as straight as possible. The seven bones we need to consider are: the humerus, the Ulna, the Radius and the four metacarpal bones in the palm (the thumb is off to the side thus we assume that no weight is placed on it). All these bones are the same type, Cortical bone, with an ultimate compressive strength of 205 ± 17.3 MPa [2]. We have used femoral cortical bone strength in this case, as the strengths are assumed to be similar across each bone due to the low variation in porosity among cortical bone [2]. We know the breaking forces of the Ulna, Humerus and Radius to be 9.9 ± 2.28 kN, 19.75 ± 4.7 kN and 8.03 ± 2.86 kN respectively [3]. We take the strength (pressure) and the area to calculate the force at which the four metacarpal bones break using the definition of pressure.

Discussion

Bone	Diameter (mm)	Breaking Force (N)
Index Metacarpal	2.6	1090 ± 92.0
Middle Metacarpal	2.7	1170 ± 98.7
Ring Metacarpal	2.3	852 ± 71.9
Little Metacarpal	3.0	1450 ± 122

Table 1: The minimum diameter [4] of each metacarpal bone and its breaking force.

The Radius and the Ulna run parallel, thus we assume that the force would be equally split between them and the same for each metacarpal. The ring metacarpal is clearly the weakest and would break first. Because the metacarpal is holding 1/4 of the weight from the arm, which is holding 1/4 of the total weight, the total force is split 16 times, therefore the break would occur when the person undergoes a total force of 13.6 ± 1.15 kN.

While the bone would break at this force, it is likely the human pyramid would fail much earlier as the compressive yield strength of Cortical bone is 115.06 ± 16.36 MPa [2]. Therefore, the metacarpal ring would begin to yield at 7.65 ± 1.09 kN. Figure 2 shows the two values and uses a mass of 83.6 kg for the average man, as in the original paper [1] for direct comparison.

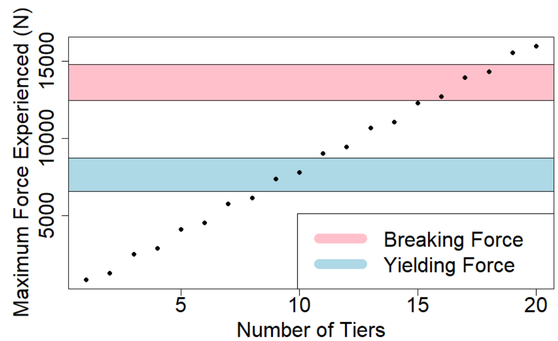

Figure 2: Maximum force felt by the centre member(s) at the bottom of an n-tiered human pyramid. Ranges of maximum force before breakage (pink) and yielding (blue) are shown.

Conclusion

In conclusion, we found that in a human pyramid the maximum number of tiers is 8 to 10 before yielding begins and 14 to 17 before breakage of the ring metacarpal bone. This is slightly higher than in the original paper [1].

References

[1] H. Allison, et al. "View of A5 6 Pyramid of Geezers," Journal of Physics Special Topics, Nov. 06, 2014. https://journals.le.ac.uk/index.php/pst/article/view/2220/2124 (accessed Nov. 27, 2024).

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