Godzilla vs Biewener

Size matters - but so do posture and movement

by

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In the good old days, the only way to make a big, apocalyptic monster was to have a guy in a suit stomp and shuffle through miniature sets. Granted, it was hokey, but that was ok; after the original Godzilla movie (Gojira, 1954), which was probably a sincere expression on the horrors of the atomic age, the primary purpose of the subsequent movies was to entertain. Entertaining they were; the guy in the suit destroying all those exquisitely crafted models, and the close-ups of somebody with a blow-torch melting the little tanks took us back (all the y chromosome carriers, anyway) to the time when we were monsters. The fun we might have had with atomic breath rather than M-80 firecrackers! And the budgets! The guy in the suit was destroying thousands of dollars worth of models with every step. I would agonize for days over the destruction of one fifty-cent model car.

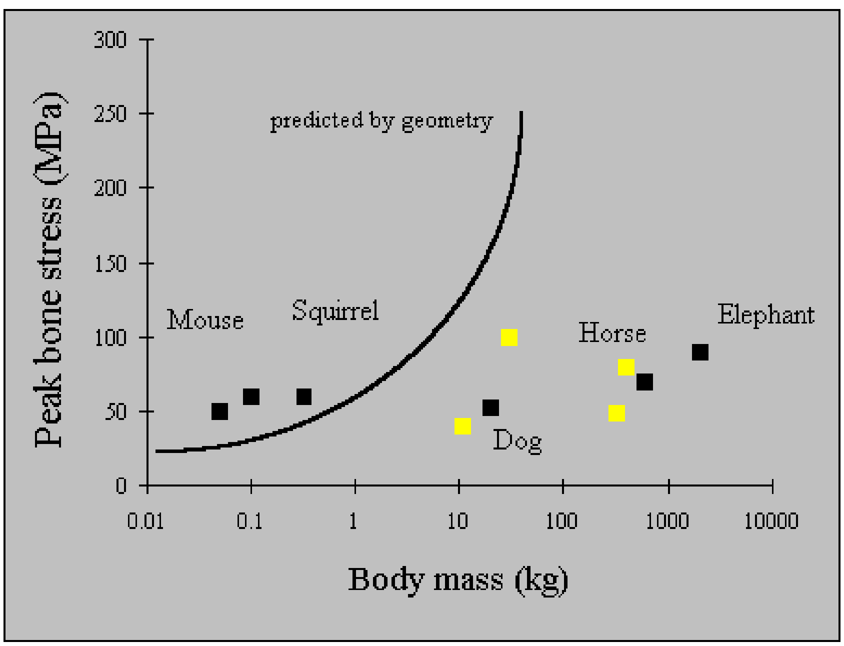
Mine was the last generation of actual monsters - our destructive impulses actually destroyed. Now, such tendencies manifest themselves mostly as joy-stick movements and firing buttons, with the payoff being an explosion or spurting blood on the computer monitor. Without debating the merits of each outlet (no doubt many psychology dissertations have done exactly that), I here simply state that the trend is toward a visually realistic virtual experience, and away from a misrepresentative actual experience. Yeah, I got to actually blow stuff up, but it was small potatoes, and there was no way to make it seem like anything other than small potatoes. On the contrary, current human monsters [children] don't actually destroy stuff, but their virtual destruction can appear - and pretty realistically - to be on a truly monstrous scale.

Godzilla (Centropolis Entertainment, and Fried Films and Independent Pictures Production, 1998) is the latest manifestation of this trend toward computer-generated realism. With the aid of computers, the film makers have abandon the guy-in-the-suit for a virtual monster, one that they concluded (after watching lots of film of smaller lizards) would look and move much more like the real thing. Ironically, the creators of the new virtual Godzilla created something less realistic than the guy-in-the-suit; their new computer beast is all wrong, and on a grand scale. Why?

They did get something right - *size does matter*. Animals are three-dimensional; they have height, width, and depth. This means that if one were to turn a 1 meter marine iguana into a 150 meter thing-that-ate-New York, while maintaining the proportions of the original animal (as virtual Godzilla did), the mass of this big critter would not be just 150 times the original iguana; mass is a function of volume, and volume is length • width • depth. Stated another way, the mass (m) of an animal increases as a function of the cube of a linear dimension (L), or m • L^3. Thus, virtual Godzilla would weigh 3,375,000 times as much as the original harmless iguana. Unfortunately for Godzilla (or any other animal), the strength of its bones and muscles are a function of their cross-sectional areas - which are two-dimensional (width • depth). So while the big lizard's mass has increased as a function of L^3, the strength of its bones and muscles has increased only as a function of L^2. As a result, the stress (force divided by x-sectional area; in this case mass • gravity • area^{-1}) on the bones will have increased in direct proportion to the increase in length; that is, the stress on Godzilla's bones and muscles will be 150 times that of the stress on the iguana's. Given that the bones can handle only about two to four times their normal peak locomotor forces, virtual Godzilla's legs would have broken as soon as he stood - to say nothing of running through downtown New York (a stress all its own). Of course, this assumes virtual Godzilla had bones and muscles of normal intrinsic strength; virtual Godzilla supporters will, no doubt, arm wave this away with a simple, "Hey, if radioactivity can make a marine iguana 150 meters long, it can make its bones and muscles stronger." Touche' .

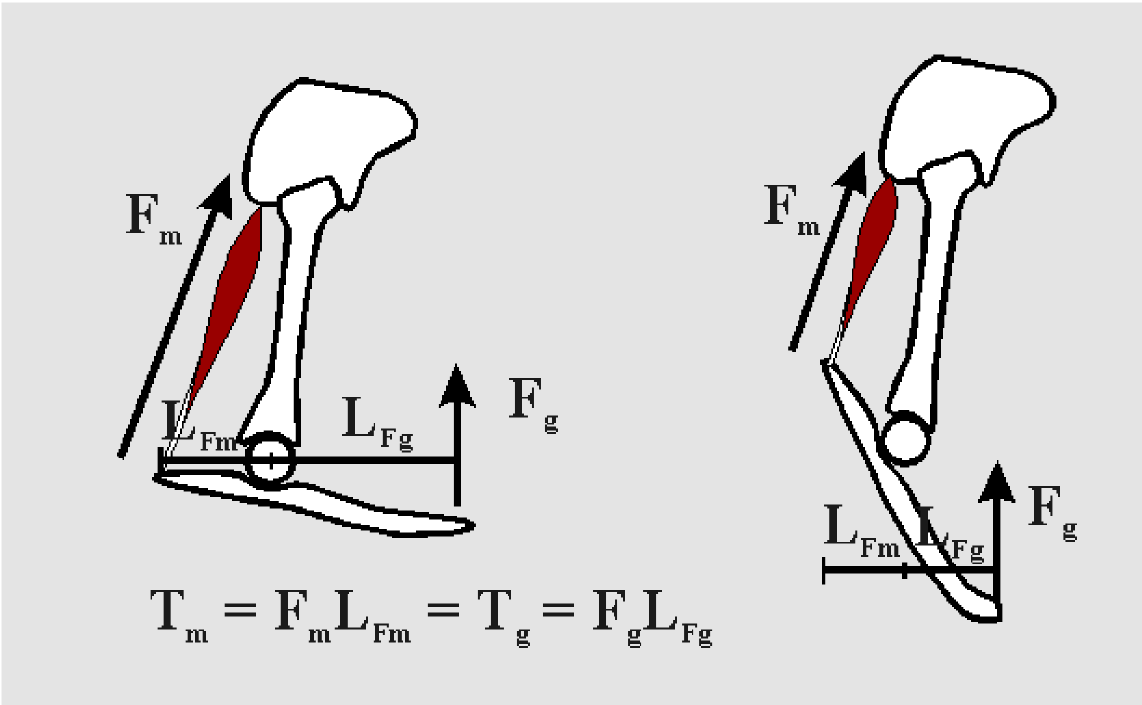
The original Godzilla is still more believable.

Terrestrial species of extreme size have evolved many times; have they all been on the verge of breaking? Dr. Andrew Biewener, Harvard University Professor and current director of the Concord Field Station, asked that very question in a series of studies[1] on bone stress. He hypothesized that selection would not favor a decrease in the safety factor in bones - that is, evolution would not create animals living on the very edge of their bones' limits. He thus predicted that the measured stress in the bones of terrestrial animals should be constant across animals of all body masses[2], despite the fact that stress should increase as a function of the increase in linear dimension, or $mass^{0.33}$. Using force plates to measure ground reaction forces and x-ray cine film to measure joint angles (black markers below), or strain gauges (red markers) to measure bending of bones during locomotion, Biewener and other researchers[3] found that the locomotor stresses on the bones of animals ranging from mice (<.1 g) to elephants (>1000 kg) were nearly uniform.



After Biewener, Bioscience 1989.

How do big animals avoid the increasing bone stress? By adopting a more upright posture, large animals reduce the amount of stress on muscles and bones, thereby offsetting the natural increase in stress resulting from geometric scaling. Below are illustrations of a simple leg (with one joint - an 'ankle'), with its simple joint in different postures. View the bottom bone as a foot, with the foot of the left landing flat, and the one on the right landing only on the tip of the foot. Assume that the muscle will need to exactly counter the ground reaction force (F_g), so that no net torque is produced around the joint (i.e $T_m = T_g$)

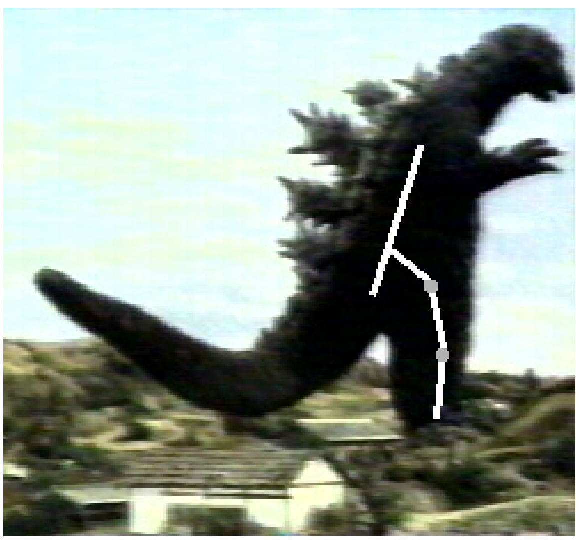


The muscle (in red) acting on the joint on the right enjoys a greater mechanical advantage in absorbing the ground reaction force (F_g) of the footfall over the one on the left. That is, with a more upright posture, the animal has reduced the lever arm of the ground reaction force (L_{Fg}) , and thus reduced the torque (T_g) that the ground reaction force produces around the joint. Hence, the force the muscle will need to produce (F_m) to equal this torque will be reduced, and, consequently, the stress on the bone will be reduced. (A simple illustration of the principle of effective mechanical advantage and posture can be provided by attempting to stand for a long period with knees slightly bent versus knees deeply bent). The evolution of terrestrial animals of extreme mass (e.g. Sauropods such as *Brachiosaurus* , mammoths and elephants) thus required the concomitant evolution of extremely upright postures........such as is seen in the original Godzilla.

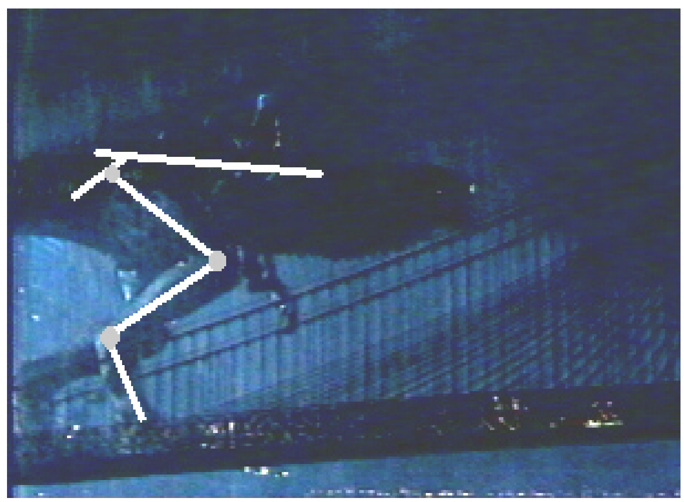
Note the stout (almost sumo-esque) legs and nice, upright posture of the original Godzilla.........

…………relative to the kangaroo rat posture of virtual Godzilla:

From a lateral view, the extremely obtuse (if not straight) joint angles on the original King of Monsters, and the "realistic," bone-breaking, computer-generated joint angles of virtual Godzilla become apparent.



From Godzilla vs Mothra (1964)



From Godzilla (Columbia/TriStar, 1998)

I admit that the energetic, limber computer generated Godzilla is more dramatically compelling, but, as an old school geek, the stiff, graviportal locomotion (that is, he moves like a bipedal elephant) is important; I can only suspend so much of my understanding of how the world works before I become disinterested. I think the makers of the original Godzilla knew this - it wouldn't surprise me if they had a couple of engineers working on the set, having the time of their lives - and they clearly abide by the fundamental laws of bioengineering. Indeed, I'll take the liberty of speaking for the actual monster generation and suggest a contest pitting our champion against that of the virtual monster generation. My money is on the guy in the suit.

Footnotes and citations:

[1]Biewener, A. A. 1982. Bone strength in small mammals and bipedal birds: do safety factors change with body size? *J. exp. Biol.* 98:289-301.

Biewener, A. A. 1989. Mammalian Terrestrial Locomotion and Size. *BioScience* 39(11):776-783.

Biewener, A. A. 1989. Scaling body support in mammals: limb posture and muscle mechanics. *Science* 245:45-48.

[2]Surveys of animals over a wide range of body mass indicate that the bones of large animals are proportionally a little larger than those of small animals, resulting in an expected scaling of stress of $m^{.28}$.

[3]Also see Rubin and Laynard (1982) and Alexander et al. (1979).