

Transient Dynamics Study of the Tibia during the Impact

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Abstract. The transient dynamic response exists between the lower limb and the ground at the moment of a quadruped's paw-strike movement. In order to analyze the property of the transient dynamics, which is a highly nonlinear problem, firstly, the tibia bone of the hind limb was selected as the study material in this paper, and the elastic modulus was precisely determined by the nano-indentation experiment; then the contact-impact process between the tibia and the ground was simplified for the numerically solution; finally, the velocity wave, acceleration wave, displacement wave propagating along the length of the simplified model was obtained.

1. Introduction

Quadrupeds such as the cheetah, the cat etc. usually have an excellent mobility during daily activities. However, the duration of the contact-impact between the lower limb and the ground is very short, especially during the high speed movement. Therefore, there exists the transient dynamic response during impact loading activities such as walking and galloping. While, the impact forces that imposed on the joints or other body structures due to the high speed movement are usually attenuated primarily in the lower limbs. Muscles and other soft tissues play an important role in the shock absorption ability [1, 2, 3]. As known that the fatigued musculoskeletal system could decrease the body's mobility. While, though the structure such as flexible back of the feline may assist in the absorption of the impact energy during landing [4], skeletons and soft tissues are essential to the shock absorbing and cushioning properties of the body, especially, when a subject is not fatigued from daily activities [5, 6].

As presented above, the body experiences a brief impact during the landing movement, however, the value of the impact forces are usually sizeable, i.e., during the paw-strike, the joint contact force is usually larger than body weight [7], which may cause dynamic response to bones. This transient impact is considered to the major reason of resulting in musculoskeletal injuries. So it is necessary to accurately present the contact-impact process to decrease the risk of injury. The goal of this study is to develop a mathematical model that can describe the shock wave initiated during the impact of the paw striking [8].

Because the forces causing stress fractures are generated primarily when the paw strikes the ground, the tibia of quadrupeds is a common site of bone stress injuries during high speed movement, however, the loading of the tibia during high speed movement is not well understood, there has been few work on numerical modeling the transient dynamic response of the tibia.

Therefore, the tibia of the hind limbs of a small feline was selected to investigate the transient dynamic response of bone material during the impact in this research. A nano-indentation technology was used to experimentally determine the elastic moduli of the tibia precisely. To solve the high nonlinear problem for the transient impact, the substructure technique was introduced in dynamics



equations to solve the transient dynamic response of the simplified contact-impact model and to obtain the transient dynamic response properties of the tibia.

2. Materials and methods

In order to obtain accurate biomechanical data in the process of the animal's movement, a small feline was dissected and the animal study was conducted in accordance with laboratory animal welfare laws and local ethics committee guidelines.

To study the transient response of the bone during the impact, the contact-impact between the tibia and tarsus of virtual joints structure of the feline had been simplified as shown in Fig.1. The tibia was simplified into a plane rod with a length of L , the tarsus was simplified into a rigid surface, which had a infinite modulus, and the tibia was falling down acted under the force of F as shown in Fig.1b. The cross-sectional area of the tibia was A , the elastic modulus was E , the contact clearance was H .

In this paper, the transient impact problem was solved by using the dynamic substructure method as shown in Fig. 1c, by using the dynamic substructure method, the modal order of the finite element could be reduced, while the results precision could also be guaranteed. In the dynamic substructure method, the contact rod was discretized into several substructures with a same length, every substructure was divided into four two- nodes rod element, u was the physical displacement of the nodes, point P was the contact point:

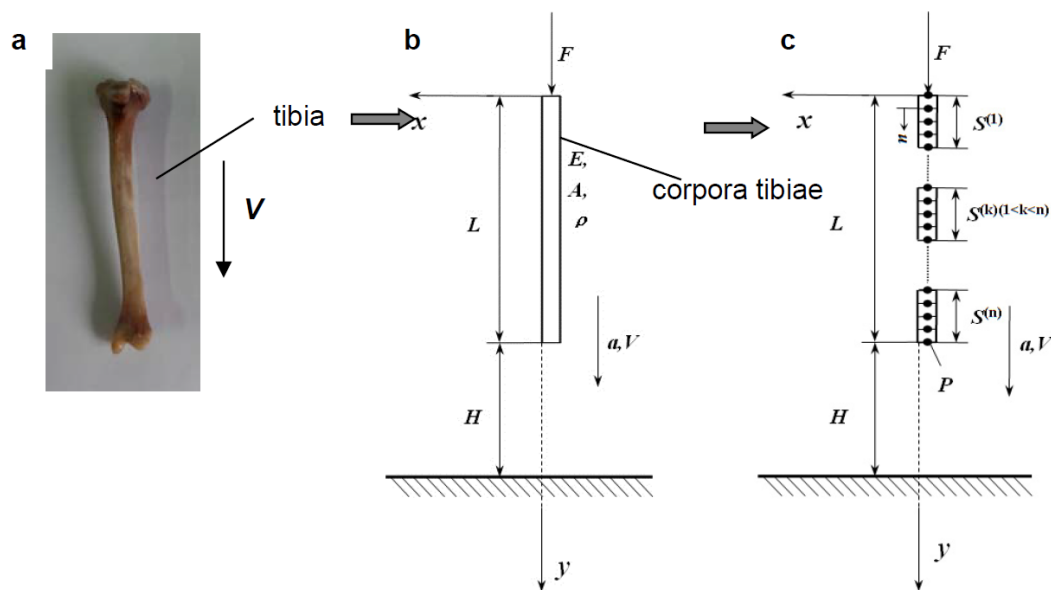


Fig 1. a. the tibia, b. the simplified mode of the transient dynamic response, c. the dynamic substructure method for the impact between the rod and the rigid surface

3. results

Under the action of a certain mass loading, the tibia fell freely and impacted the rigid surface. As shown in Fig. 2, the impact point was on the right side, the mass loading acted on the left side. Stress wave propagated from the right side to the left side in the form of a rectangular wave. Once the stress wave reached the left side, the back propagation of the reflected stress wave would start. During both forward and backward propagation period, the amplitude of the rectangular stress waves were always stable.

At the moment of the tibia impacted the ground, the stress wave generated by the mass loading gravity would also simultaneously move from left side to right side, and the stress wave propagated with a stable rectangular wave. Because of the smaller magnitude, the influences of the mass loading stress wave comparatively less.

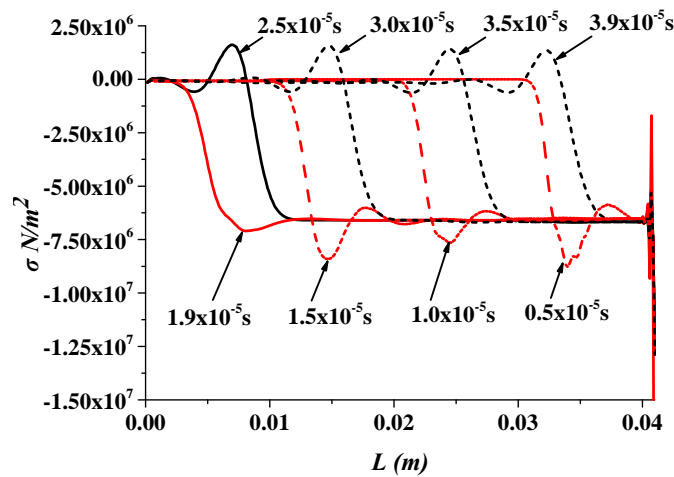


Fig 2. Stress wave propagating along the tibia, red lines were the forward waves, black lines were the backward waves

The velocity wave and the stress wave have a similar propagation pattern. As shown in Fig. 3, the impact stress wave reached the left end, the velocity wave also propagated to the left end of the simplified rod. The velocity of each point in the rod gradually decreased, and began to propagate from the left end to the right end with the same amplitude. As shown in Fig. 3, the velocity wave distributed along the rod was decreasing gradually during the velocity wave propagating, but the velocity wave surface changed more rapidly, which was directly related to the variation of the acceleration wave inner the rod in Fig. 4.

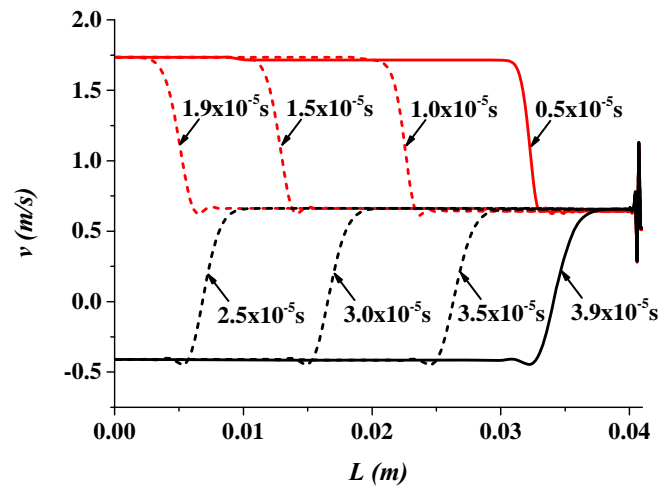


Fig 3. Velocity waves propagating along the tibia

There were always two peak waves during the propagation of acceleration waves. As time went by, the peak value of the acceleration wave gradually decreased and the wave width gradually increased. As shown in Fig. 17, at 0.5×10^{-5} s, two peak waves, one negative and one positive.

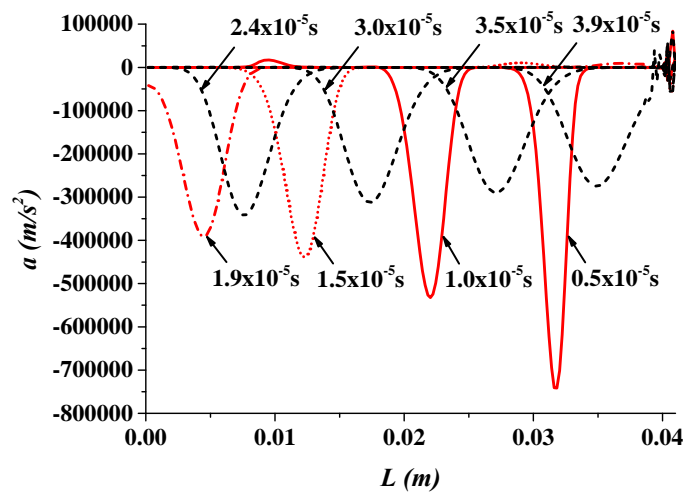


Fig 4. Acceleration waves propagating along the tibia

Different from velocity and acceleration waves, the variation of displacement waves changed linearly. As shown in Fig. 5, within the period of 5.8×10^{-5} s, a straight line with a certain slope appeared on the front of the displacement wave, which indicated that during the propagation of the displacement wave, the displacement of the part of the rod remained unchanged. Therefore, the tibial body showed more obvious elastic movement property during the impact. When the stress wave was reflected back to the contact end, the displacement wave started to change from positive to negative in the rod. At this moment, the mass points in the rod began to bounce away from the rigid surface.

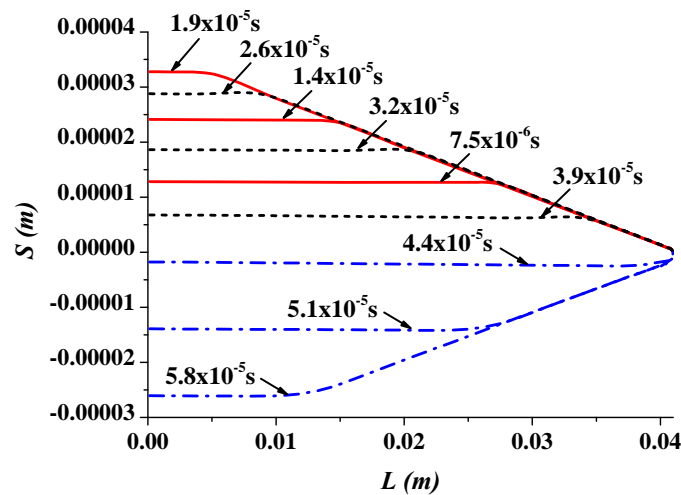


Fig 5. The variation of the displacement waves travelling through the tibia

While, there still have been a lot of characteristics of the transient response waves of the musculoskeletal system, we will improve the study in the future work.

4. Conclusion

In order to study the loading of the tibia during the high speed movement, the numerical solution i.e. the dynamic substructure method was used in this paper. The tibia of the hind limb was simplified to a plane rod to solve the characteristics of the transient dynamic response of the tibia during the impact.

The transient dynamic response waves were finally obtained in this paper. The methods and results presented in this paper, could provide a reasonable scheme for the bionic mechanism design and improvement.

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