CAEDS: AN APPLICATION TO SPORTS BIOMECHANICS

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Introduction

Computer assisted design (CAD) and finite element modeling and analysis have become increasingly popular over the last 14 years in the engineering world (Kensinger, 1986). In Biomechanics it has primarily been applied in the area of bone research. The purpose of this study was to apply CAEDS (computer assisted engineering design system) to the field of sports biomechanics and to experience its limitations and advantages. A stress analysis on a 2-dimensional foot model with maximum forces experienced at impact during a karate kick was performed.

For this study it was assumed that the foot was a solid block of cortical bone. Precise values were not considered crucial since it was of greatest interest to see trends predicted by the model and to experience advantages and limitations using CAEDS applied to sports biomechanics.

Review of Literature

Skeletal bone is composed of cortical and cancellous bone with the boundaries between bone types not clear cut (Franklin & Nordin, 1980). Young's modulus of elasticity for cortical bone was found to be between 11.7 GN/m^2 (Frasca, Jacayna, Harper, & Katz, 1981) and 25 GN/m^2 (Mattson, Black, Richardson & Pollack, 1980). Different values were due to different methods employed to obtain Young's modulus of elasticity, the bone used, dry or wet bone, young or old bone and the size of osteons. A common value of 14 GN/m^2 for Young's modulus and .3 for Poisson's ratio for cortical bone were used in previous studies (Beaupre & Hayes, 1984; Walker, Granholm, & Lowerey, 1982; Hayes, Swenson,

& Sherman, 1978).

The foot is an arrangement of bones, muscle, fatty tissue, tendons and skin which are movable against each other (McKinnon, 1986). Furthermore, liquids are present in the living structure. These components have different material properties. The connection of these components to each other are different and may display different behaviors when under stress.

Methods and Procedures

Measurement of Impact Forces

An AMTI model OR6-3 force platform with an AMTI SGA6-1 signal conditioner/amplifier was used to measure forces in the z-direction during a front-kick. The force platform was mounted vertically to the wall. Sampling time was set at .5 seconds with 100 sampling points and a sampling rate of .005 seconds. Trigger level was 10 N at impact with the z-channel being the trigger channel. Average peak force was 3360 N. The average contact area was 27 cm^2. The average force per cm^2 was therefore 125 N.

Modeling and Stress Analysis

A contourogram of the right foot was drawn. This contourogram was digitized. A 2-dimensional profile with a thickness of 1 cm was made. A mesh of 1 cm element length consisting of parbolic square elements was created. Material properties were set as follows: Young's modulus of elasticity E was 14 GN/m^2, and Poisson's ratio was set at .3 (Evans, 1973). Forces were applied along the edge of 4 elements (4 cm) at the ball of the foot which is the left side in Figure 1. The force applied was 125 N/cm. Restraints were set for the x- and 7-direction along the right side of the foot (Figure 1).

Figure 1. Modelled Foot with Generated Mesh, Force Vectors and Restraints.

Arrows to the left represent force vectors. Arrows to the right are restraints for the x- and y-directions.

Three assumptions were made for this model:

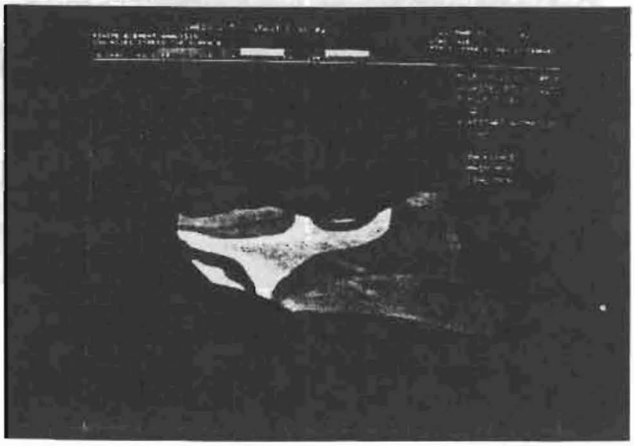
1. Forces applied were evenly distributed over the contact area.
2. The force used was 125 N/cm^2. 125 N/cm were applied along the edge, since the material had a thickness of 1 cm. Therefore, forces at top and bottom node were 20.83 N, mid-element node 83.3 N, and at nodes between elements 41.6 N.
3. The foot was assumed to be a solid block of cortical bone.

The stress analysis was performed with the program Superb.

Results

Figure 2 shows the Van Mises stress distribution across the foot. Stress values ranged from .16463 N to 359.383 N. Two areas of highest stress were observed; part of the area where contact was made with the force platform (ball of the foot) and the posterior part of the foot. The heel and the toes experienced the least stress.

Figure 2. Van Mises Stress distribution.



Discussion

In this two dimensional model it is very difficult to interpret which bone structure was actually exposed to the highest stress values. This researcher expected to see a high stress area at the place of impact, with the stresses dissipating over the rest of the foot and the stress being lowest at the farthest distance away from the impact area. The two high stress areas are on sites opposite from each other. The location and distribution of the stress may be due to the curvature of the foot. Factors influencing the results of this stress analysis were:

1. The simplistic two-dimensional model used.
2. The assumption that the foot is a rigid body with the same structure and modulus of elasticity throughout.
3. The shape and dimension of the mesh generated.
4. The assumption that forces were evenly distributed across the impact area, and the angle at which they were applied.

In vivo-stresses may have different values and distributions since some of the stress is distributed in the third dimension (z-direction). Bones can move to a certain degree, and skin, muscle, ligaments and tendons absorb some of the forces. One comment needs to be made with respect to this. The subject experienced some pain during impact at the contact area and at the lower third of the anterior and posterior part of the tibia but not at the posterior part of the foot. This indicates that high stress areas in vivo are different than the ones shown in this model.

At the same time this simplified model may predict a trend which is similar to in vivo conditions. As Beaupre and Hayes (1985) pointed out,"precise values were not considered crucial since it was of greatest interest to see trends predicted by the model." Interpretations have to be made with care since in many models structural elements (sheets, plates, etc.) have to be used which often predict artificially high stresses. Studies by Pugh, Rose, and Radin (1973) were quoted in which unusually high stresses on the subchondral plate were predicted. Their model foresaw immediate failure for many normal activities, e.g. stair climbing or running. No muscular forces or structural changes within the subchondral plate were taken into account (Beaupre, & Hayes 1985).

Alan D. Benz (1986), President of Kensinger Integrated Technologies Corporation complained that computer assisted design and analysis was and is still perceived by too many users as a solution to problems without realizing that it is no more than a powerful tool. He sums it up nicely when he writes, "...then along came computers with all sorts of neat graphics that always gave impressive pictures, and everyone forgot the problem started with assumptions. If a computer's answer was not accompanied by an error message, it had to be right....nothing could be farther from the truth. What computers do is allow you to make larger, more expensive mistakes, much sooner, and with a higher degree of confidence than ever before." And as it was

Conclusions

In this study CAEDS was applied to a problem in sports biomechanics. A more complex part of the body under stress, the foot, was investigated. The more complex and irregular shaped a body is, the more assumptions and simplifications have to be made in order to fit problems to rules. Even when working with single bone cells many assumptions have to be made to fit problems to rules (Beaupre & Hayes, 1985; Hayes et al., 1978). One has to realize these limitations and also the fact that computer assisted designs and analyses are powerful tools that may support other tools but are not solutions in themselves.

The researcher in sports biomechanics has to realize these limitations and has to decide if time and money is wisely spent in utilizing a system like CAEDS.

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