IMPACT SIMULATION OF KICKING USING FLUID AND STRUCTURE INTERACTION ANALYSIS

Takeshi Asai[1], Takao Akatsuka[2], and Yasuhisa Kamata[3]

1)Faculty of Ed., Yamagata University, Koshirakawa, Yamagata-city, Yamagata, 990, Japan.
2)Faculty of Engi., Yamagata University, Jyounan, Yonezawa-city, Yamagata, 990, Japan.
3)Faculty of Ed., Iwate University, Ueda, Morioka-city, Iwate, 020, Japan.

INTRODUCTION

The motion analysis of kicking have been studied by several investigators (Plagenhof, 1971; Roberts &Matcalfe, 1968). These studies have focused on the kinematic analysis. Also, the dynamic analysis about the joint force or torque have been studied by Roberts et al., (1974) and Zernicke & Roberts, (1978). Compute simulations about the joint torque and ball speed have been studied by a few investigators (Asai, et al.,1983). However, only a few studies of the impact process itself have been previously done before. The kinematic analysis at impact using a high speed camera (500fps) have been studied by Asami & Nolte (1983).
The purpose of this article is to clarify the ball-foot interaction at the instep-kick in football using a high speed video camera (4,500 fps) and fluid-structure interaction Finite Element Analysis.

METHODS

Six university football players were chosen as the subjects. The players kicked a ball with the instep toward a mini football goal 4m away. The high-speed camera was set up 1.5m away in the side direction. The ball used in this experiment was an official FIFA ball (434.6 g, 90,000 Pa.). This experiment was photographed using the high-speed camera (FASTCAM-ultima), which can take 4,500 frames per second with 256×256 pixels, which was recorded on a VTR.

Nine markers for digitizing were attached to the kicking leg of the subjects (tibia, lateral malleolus, calcaneus, tubersity of the base of fifth metatarsal, head of fifth metatarsal, toe, etc.). The coordinate values were input in the computer by a video-position-analyzer. In order to analyze the degree of plantar flexion of the foot joint in the impact process, three angles, A, B and C, were measured from the graphic data. Angle A is made up by markers No.2-3-6, angle B by the markers No.3-6-8, and the angle C by the markers No. 3-7-9. The foot velocity and ball velocity were calculated numerically from the value of digitized data. The contact time of the instep with the ball was obtained from the number of frames in which the contact between them was observed.

The computational analysis is important for the study of short term events such as ball kicking similar to experimental analysis and theoretical analysis. The ball-foot interaction model using this study is shown in Figure 1. The foot model and the surface of the ball is defined using Lagrangian frames of reference. The Lagrangian processor uses finite element formulation. The ball model is defined using Eulerian frames of reference. The Eulerian processor uses finite volume formulation. The air model inside ball is defined the gamma low equation of state.

$$p = (\gamma - 1)\ \rho E \qquad (1)$$

E= specific internal energy per unit mass

ρ = overall material density

γ = a constant

The coupling technique of this study is general coupling. The lagrange mesh acts as a boundary to the flow of materials in the Euler mesh.

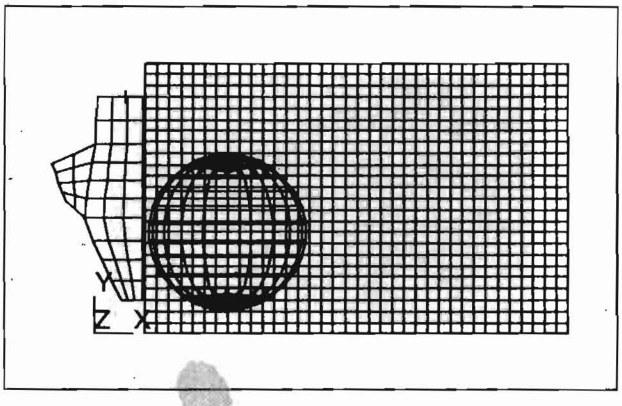

Fig. 1. The ball-foot interaction model using Eulerian and Lagrangian frames.

Usually, static problems can be analyzed quasi-statically, but the technique is only cost effective if the problem incorporates significant nonlinearities. Explicit codes are suitable for short term events such as high speed impact and large deformations. Then, this study used explicit time integration codes (MSC/DYTRAN) of Finite Element Analysis. The timestep of the implicit analysis must subdivide the shortest natural period of interest in the structure, but that of explicit analysis must subdivide the shortest natural period of the mesh. Thus, the timestep for an implicit analysis is normally 10 to 100 times greater than that for an explicit analysis. The finite element model of kicking foot and ball using this study has a very simple structure.

The first half of the horizontal velocity of the simulation data is similar to that of the experiment data, but the second half is not very similar to the experiment data. The compute simulations as a collision problem were executed for Case 1, Case 2, and Case 3. The hitting point of the foot and the ball in Case 2 was the middle of the instep, that in Case 1 was 0.03 m higher than Case 2, and that in Case 3 was 0.03 m lower than Case 2.

RESULTS AND DISCUSSION

The velocity of the tubersity of base of the fifth metatarsal (No. 8) is slightly greater than that of the lateral malleolus (No. 3) just before impact, and the velocity of the tubersity of the base of the fifth metatarsal (No. 8) is slightly smaller than that of the lateral malleolus (No.3) after impact. In the case of this trial, the contact time of the foot with the ball is 9.3 msec., the horizontal contact distance is 144 mm, and the horizontal velocity of the ball after the impact process is 25.2 m/sec.. The average value of the horizontal contact distance is 147 mm. It becomes clear that the contact of the foot with the ball ends before the instep of the foot moves by the diameter (223 mm) of the ball. There is a tendency that the angles A, B and C of the foot joints are increased during the impact process.

An example of a contour plot of pressure on the deformed shape of the ball is shown in Figure 2.

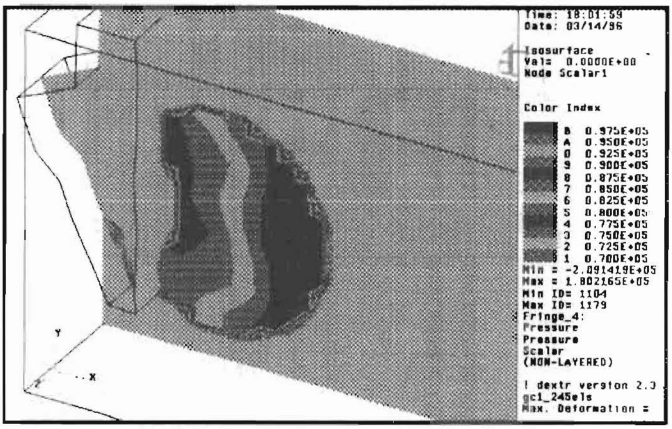

Fig. 2. An example of ball pressure on the deformed shape.

The material properties and boundary condition of this simulation are summarized as follows.

Young'modulus	30.0	(foot)	MPa.
Poisson's ratio	0.3	(foot)	MPa.
Initial condition (collision velocity)	25		m/sec.

This simulation used a the six-sided solid element with eight grid points (HEXA). The elements use one-point Gaussian quadrature to integrate the gradient/divergence operator. The Gauss point is located at the element centroid. The maximum ball pressure of the frame in this case is 0.095 MPa and the minimum pressure is 0.085 MPa. The maximum foot pressure of the frame in this case is 0.180 MPa and the minimum pressure is -0.209 MPa. The stress wave is propagated from the contact surface to the tibia, talus, and toe of the foot. At half impact, high intensity compressive stress is observed in the instep and a high intensity tensile stress is observed in the tibia. The horizontal ball velocity after impact in Case 1(upper hitting) was 37.31 m/sec., the horizontal ball velocity after impact in Case 2(middle hitting) was 29.89 m/sec., and the horizontal ball velocity after impact in Case 3(lower hitting) was 24.78 m/sec.. When comparing the ball velocity after impact in Case 1, Case 2, and Case 3 by compute simulation, Case 1(upper hitting) has the fastest velocity, the Case 2(middle hitting) has the second highest velocity, and the Case 3(lower hitting) has the lowest velocity.

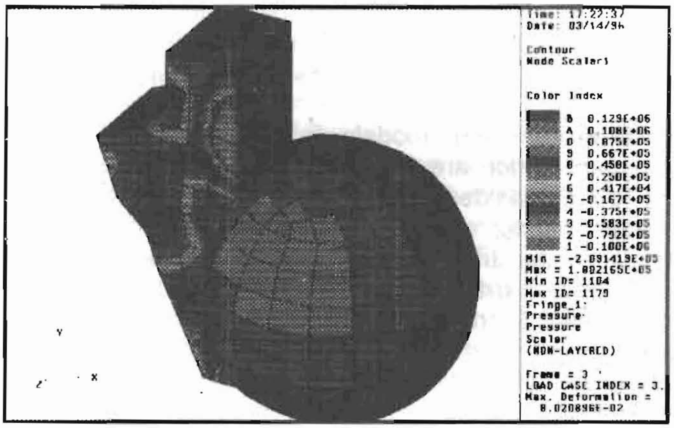

Fig. 3. Contour plot of pressure on the deformed shape in Case

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