Computer aided sand wedge shape assessment by using particle simulation

T. Koizumi, N. Tsujiuchi, H. Horii, M. Miki & J. Hidaka
Doshisha University, Japan

Abstract

In this research, a computational simulation model of a bunker shot for assessing sand wedge shapes is constructed using the particle element method, PEM. The PEM is one particle simulation method which simulates particle phenomenon by tracing the motion of all particles and calculating the interaction among them. The simulation model is composed of a club head, a golf ball and a large number of particles of sand. Firstly, the reproducibility of the simulation model was verified by comparison with actual bunker shots which were observed using a high speed video camera, then the simulation results gave good agreement with the observational results. Secondly, the simulation model was applied for assessing the property of a new special sand wedge which had a hollow processed on the sole, then the feature of the wedge and its cause were revealed. This simulation model provides numerical understanding of the property of sand wedges and reasons why the effective property occurs.

1 Introduction

As rapidly enlargement of the performance of computer and the computer aided engineering, CAE, computational simulation has been used for design and development of golf equipments, such as clubs and balls. Ordinary clubs, such as woods and irons, have been assessed by computational simulation models constructed by using the finite element method, FEM, handled as collision of a club head and a ball [1]. However, the sand wedges have been done by designers’ and players’ empirical intuition and trial-and-error, because of the difficulty of simulation modeling of the bunker shot.

The difficult point of the bunker shot modeling is that the model has to take account of the influence of the bunker sand, because a club head and a ball do not
collide directly but through the sand. In order to take account of the influence of the sand, we constructed the bunker shot simulation model by using the particle element method, PEM [2]. The PEM is one of the particle simulation methods which simulates particle phenomenon by tracing the motion of all particles and calculating the interaction among the particles [3]. The simulation model is composed of a club head, a golf ball and a large number of particles of sand.

In this paper, firstly, the reproducibility of the simulation model is verified by comparison with actual bunker shots which are observed by using a high speed video camera. Secondary, the simulation model is applied for assessing the property of a new special sand wedge which has a hollow processed on the sole, then the feature of the wedge and its cause are investigated. This simulation model provides numerical understanding of the property of the sand wedge and that of reasons why the effective property occurs.

2 Bunker shot simulation model

The bunker shot simulation model is constructed by using the PEM. In this section, firstly, the outline of the PEM is described, then the computational model is constructed.

2.1 Outline of particle element method

The PEM, also known as the discrete element method, DEM, is a discrete numerical model of simulating the behavior of powdered particles, such as understanding a flow of powdered material in a chemical plant[4, 5]. In order to understand a behavior of powdered particles by numerical analysis, the behavior is regarded as a swarm of the particles. The PEM simulates the behavior of particles by tracing the movements of all the particles and calculating the interaction force among the particles by Voigt model presented in Fig. 1.

![Figure 1: Explanation of interaction force between particles by Voigt model.](image-url)
Table 1: Properties of sand wedges.

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole shape</td>
<td>hollow</td>
<td>smooth</td>
<td>hollow</td>
</tr>
<tr>
<td>Loft angle [deg.]</td>
<td>58</td>
<td>58</td>
<td>52</td>
</tr>
<tr>
<td>Bounce angle [deg.]</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft length [mm]</td>
<td></td>
<td>700</td>
<td></td>
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</tbody>
</table>

2.2 Computational modeling of bunker shot

The bunker shot is an interactive phenomenon among three kinds of elements, a club head, a golf ball and a large number of particles of bunker sand. The computational model is composed of the elements in two-dimensional space of 320[mm] in width and 150[mm] in height.

2.2.1 Modeling of sand wedges

The feature of the shape of the sand wedges different from the other iron clubs is that the sole part of the sand wedge bulges out under the leading edge. The distinctive shape is called “bounce”. An included angle of a sole part and horizontal line is called “bounce angle” and an included angle of a face part and vertical line is called “loft angle”. We construct three types of sand wedges, Type A, B and C by using two-dimensional CAD data of actual products on the market presented in Fig. 2. The type A is a new special sand wedge which has a hollow processed on the sole. The type B is an ordinary sand wedge which has a smooth sole. The type C is another new special sand wedge which has a different loft angle from the type A. The properties of the three is presented in Table 1. The intention of the hollow processed on the sole is to make escaping from a bunker easy and the special shape satisfies the intention. We think that more efficient sand wedge is able to be designed by providing numerical understanding of the mechanism.

The motion of a club head is represented by a circular movement as a following equation. Here, \( M_o \) is a moment of the swing force, \( M_g \) is a moment of the gravity of the club head, \( M_p \) is a moment of the contact force among a club head and particles of sand, \( I_h \) is a inertia moment and \( \theta \) is an phase.

\[
\frac{d^2 \theta}{dt^2} = \frac{M_o + M_g + M_p}{I_h} \tag{1}
\]

2.2.2 Modeling of golf ball and bunker sand

The golf ball is represented as a disk with a diameter of 43[mm] and 0.6[mm] in thickness which is the same as the diameter of the bunker sand. The particle of the bunker sand is represent as a spherical particle with a diameter of 0.6[mm]. The bunker sand is filled up to about 100[mm] in height at the analytical region of
320[mm] in width and 150[mm] in height. The total number of particles of sand is about 100,000.

3 Experiments

In this section, the reproducibility of the computational simulation model is verified, then the model is applied for assessing the property of a new special sand wedge.

3.1 Verification of reproducibility

The reproducibility of the computational simulation model is verified by comparing with actual bunker shots which are observed by using a high speed video camera. The procedure of this experiment is as follows.

1. Recording actual bunker shots by using a high speed video camera.
2. Measuring the initial conditions of the swings and the flight movements of the balls from the observational movies, such as swing velocity, angles and positions of the wedges, and release velocity and angles of the ball.
3. Setting initial conditions of swings on the computational simulations same as the observational data.
4. Verifying of the reproducibility by comparing the flight movements of the balls of the computational simulations with those of the observational data.

The actual shots were held twice in two different depth, shallow and deep. The depth were 15[mm] and 27[mm] under the ball and it was set the same depth on the computational simulations. Examples of an actual shot and a computational simulation are presented in Fig. 3. Release velocity and release angle at actual shot and computational simulation are presented in Fig. 4.
Though the difference of the movements of the balls at the two different conditions on the computational simulations was less than that of the actual shots, the computational results showed the same tendency, such as the release velocity became fast and the angle became small at the shallow shot and the release velocity became slow and the angle became large at the deep shot. The primary reason of the error is that the actual shot was three-dimensional phenomenon, while the computational simulation was two-dimensional model. We assume that introducing some compensation parameters is necessary to improve the reproducibility.

Figure 3: Examples of actual shot and computational simulation.

3.2 Assessment of sand wedge shape

The computational simulation model is applied for assessing the property of a new special sand wedge which has a hollow processed on the sole, then the feature of the wedge and its cause are investigated. The sand wedge shapes are assessed by using the following values, the release velocity and angle of balls and the impulse of horizontal and vertical axis from bunker sand on the entire club head and the sole part presented in Fig. 5. The computational simulations of the three types of the sand wedges, type A, B and C were set the same conditions except the shapes. Fig. 6 presents the computational results.

Firstly, the release velocity and angle of the type A were slower and larger than those of the type C. It is generally said that a large loft angle makes a release
velocity slower and an release angle larger. So the result showed the behavior as same as the above commonly accepted view.

Secondly, the impulse of vertical axis and the release angle of the type A were bigger and larger than those of the type B. Those results were occured by the following reason. The force which pushed up the club head became large according to the against force which was occured by the hollow processed on the sole. We conclude that processing a hollow on a sole reduces the risk of digging a club head into a bunker. We think that assessing properties of various head shapes on
the computational simulation enables us to improve the performance of the sand wedge.

4 Conclusion

In this paper, a computational simulation model of a bunker shot for assessing sand wedge shape was constructed by using a particle simulation method, the PEM. The reproducibility and the effectiveness of the simulation model were verified by applying them to assess the properties of actual products on the market. We conclude that our simulation model provides numerical understanding of the properties of sand wedges and the causes of the effectiveness, and also that is helpful for preliminary consideration of various or special sand wedge designs.
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References