Experimental Study of the Mechanisms of Skiing Turns.
Effects of a Side-Cut on Ski Turns

スキーの回転機構の実験的研究
サイド・カットの効果

SAHASHI Toshio, ICHINO Shoji

佐橋　稔雄，市野　聖治

(Received October 21, 2000)

大同工業大学紀要　第36巻（2000年12月）抜刷

Experimental Study of the Mechanisms of Skiing Turns. Effects of a Side-Cut on Ski Turns

スキーの回転機構の実験的研究
サイド・カットの効果

SAHASHI Toshio*,　ICHINO Shoji**
佐橋　稔雄　市野　聖治

Summary
The effects of a side-cut of skis on ski turns were investigated in ski descent experiments using model skis on soft sand surfaces of various thicknesses. The side-cut shapes of the model skis are linear, reel, and barrel types. When the sand was thick and the tracks of the descending ski remained on the sand surface, the effect of the side-cut was very small. When the sand was extremely shallow and only faint tracks of the edge of the ski remained on the sand surface, the effect of the side-cut was large. The shallow sand surface is considered to be equivalent to a hard snow surface such as an icy slope. When the ski is edged on a sand surface, the surface is deformed according to the shape of the edged ski. The turning mechanism of linear-type skis is explained using the deformation of the sand surface.

Keywords: ski, side-cut, turning descent, ski edge, edging

1. Introduction

Snow plow, stem turn, parallel turn and wedeln styles of ski descent were performed on a snow plane, and the loci of the skis were investigated and drawn on a sheet.[1] These ski descents on a snow plane consist mainly of turns. To investigate the mechanisms and causes of turns, we have been performing experiments using model skis on a soft-sand surface. The results obtained revealed that flexion of the front part (forebody) of the skis and edging are the important factors in ski turns.[2] The edging angle was not the angle β formed between the ski surface and the sand plane, but the angle β_0 formed between the ski surface and the horizontal plane.[3] That is, $\beta_0=0^\circ$ is the condition for realizing a straight descent (straight down-hill run and traverse, as well as straight down-hill run and traverse with side-skidding), and $\beta_0\neq0^\circ$ is the condition for a turning descent. The ski turns in the direction of the edging angle β_0. This phenomenon is referred to as the β_0 rule.[4] This β_0 rule was verified in cases of a skier on snow.[4] Edging of a ski on a sand (snow) surface results in deformation of the sand (snow) surface in the shape of the edged ski. The β_0 rule also holds on the deformed surface.

Meanwhile, according to many skiing textbooks,[5-7] the turning mechanism of skis is explained using the effect of the side-cut. In our experiment,[2] the side-cut had almost no effect on ski turns. Therefore, we performed a detailed investigation on the effects of a side-cut on ski turns. The results indicated that the side-cut affected ski turns in some but not all cases.

In the discussion, the mechanism of uphill turns of linear-type skis without a side-cut is explained using flexion of the forebody of the skis and edging.

---

* Department of Electrical Engineering
**Department of Physical Education, Aichi University of Education

(Received October 21, 2000)

* Daido Institute of Technology,
Minami-ku,Nagoya,457-8530,Japan
**Kariya, Aichi 448-0001, Japan

2. Experimental method

2.1 Skis

Model skis were fabricated from vinyl chloride plates (19×2×0.08cm^3), as shown in Figs.1(a) and 1(b). The ski was a plate (without camber) when no load is applied, with the tip bent upward. Three types of skis were prepared by changing the shape of the side-cut: linear (radius of curvature r=infinite, Fig. 1(b)), reel (r=150cm, Fig.1(c)), and barrel (r=−150 cm, Fig.1(d)). The widths of the center part of the three types of skis were the same (w cm). An aluminum cylinder and an iron plate were mounted on the ski, and the center of gravity of the ski was varied by moving magnets placed on the iron plate. The total weight of the ski including the magnets was approximately 36g. Coordinates (x,y,z) were fixed on the ski, and the center of gravity was represented as (x_0,y_0,z_0). In the experiments, only the values of x_0 were varied while keeping y_0=0cm and z_0= approximately 1.2cm. Hereafter, the center of gravity is represented by x_0, and all units are in cm unless otherwise specified.

2.2 Gate-type ski

Figure 2 shows a gate-type ski which was used in several experiments to maintain a constant edging angle β during descent.[2)] The gate-type ski has two auxiliary skis (F and G) which are parallel to the sand surface. Aluminum piece B is fixed onto aluminum piece A, while piece B is supported by the gate-holder so that it is always vertical to the sand surface. Since piece B can move freely in the vertical direction, the edging angle β of the central main ski H (linear-, reel- or barrel-type) is always maintained at a constant value during descent. The weight of the gate-holder, excepting the main ski, is 30g.

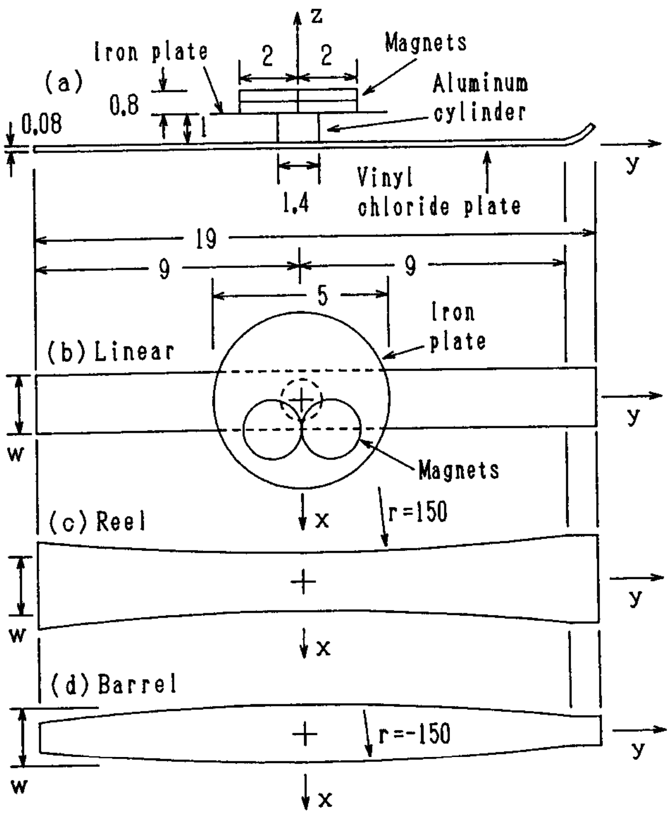

Fig.1. Model skis. (a) A side view of model skis. (b) Top view of the linear-type ski, (c) reel-type ski, and (d) barrel-type ski.

2.3 Ski slope

The skis descended on a soft sand surface (inclination angle α=26°, grain size 0.05 cm or less). The sand was put in a box (180×80×5cm^3) to a thickness of s cm. In order to prevent the sand from sliding on the bottom of the box when tilted, cotton cloth, onto which the sand was placed, was glued onto the bottom of the box. X and Y axes were set in the plane of the sand surface, with the Y axis in the direction of the fall line.

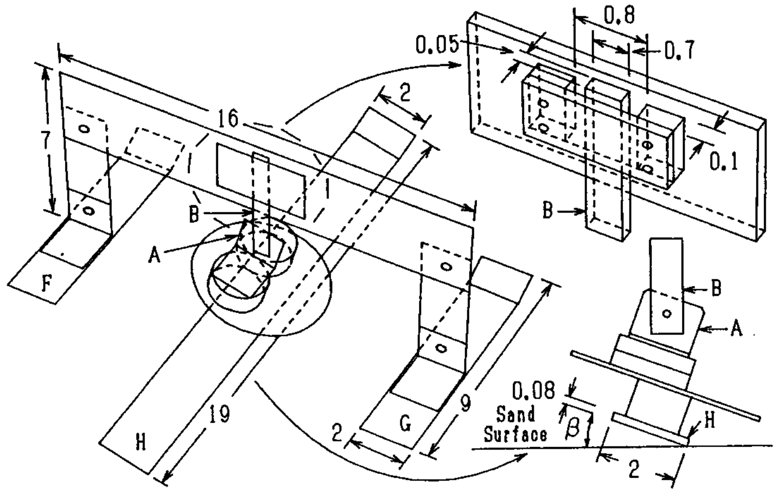

Fig.2. Gate-type ski. F and G are auxiliary skis both consisting of a flat plane. H is the main ski, whose edging angle β is fixed.

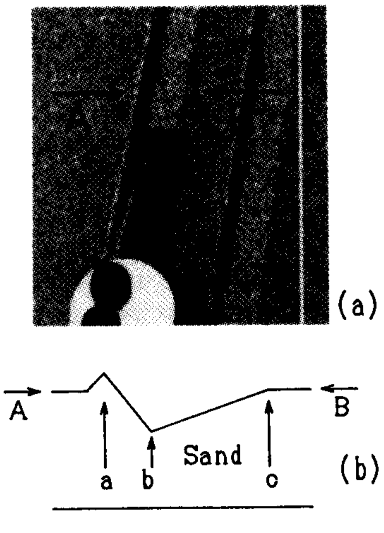

Fig.3. Photograph of the ski track. A-B in Fig.3(b) represents the sand surface, and corresponds to A-B in Fig. 3(a).

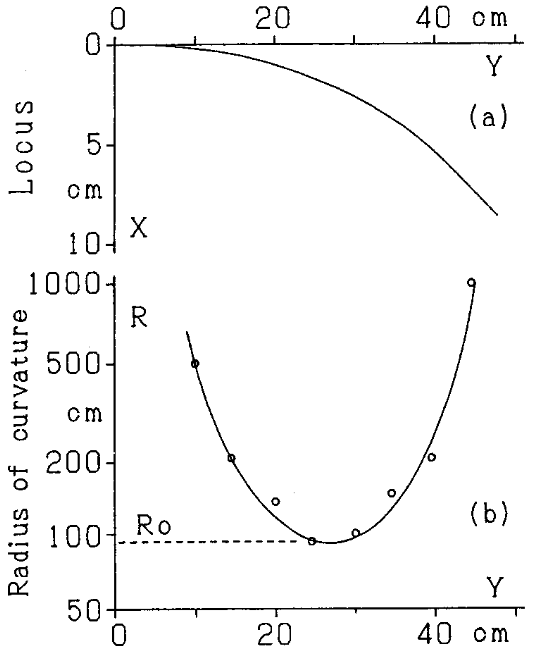

Fig.4. Example of the locus and the radius of curvature of a barrel-type ski. It is the main ski of the gate-type ski. s=0.5cm, *w*=2.25cm, β =15°.

2.4 Loci of the center of gravity of the ski

The ski descended on the sand surface, and the tracks of the ski were traced (Fig.3). This figure 3(a) corresponds to Fig.5(c). The tracks were drawn using three lines, namely, the track lines a, b and c. The track line b was used as the locus of the center of gravity of the ski. Figure 4(a) shows a locus of b. In our previous report,[3)] we obtained the loci of the center of gravity of skis from sequential photographs of the skis taken at intervals of 0.25s. The loci were obtained using two methods, and the relationship between the inflection point of the locus and the position where β_o=0° was investigated. The results showed that the inflection point of the locus was almost the same as the point where β_o=0° for both methods.

In this study, we obtained the radius of curvature *R* from the track line b; the minimum value of *R* was represented as *Ro* (Fig.4(b)). Hereafter, the track of the skis descending on a sand surface is called a track, and the track line b is called the locus of the center of gravity.

3. Results

3.1 Center of gravity, xo, and minimum radius of curvature, Ro

The width of the center of each of the three-types of skis was set as *w*=2.25cm. The depth of the sand was *s*=1.4cm. Descent experiments were performed by varying the center of gravity *xo* of the ski while the ski was set in the direction of the fall line FL. The results of the experiments revealed that all three types of skis made an uphill turn in the direction of the displacement of the center of gravity, although a slight difference was observed in the descent behavior of the three skis. Figure 5 shows an example of the experimental results for the barrel-type ski. Figure 6 is an example for the reel-type ski.

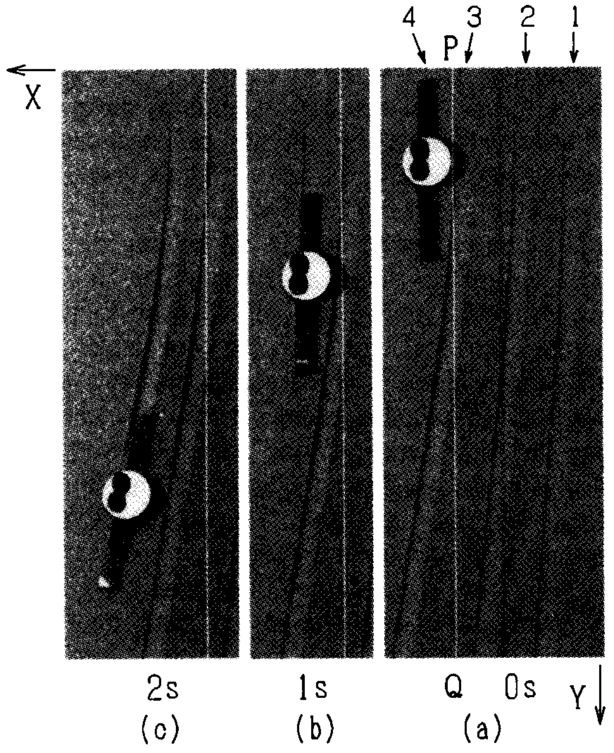

Fig.5. Uphill turn of a barrel-type ski. Tracks 1,2,3 and 4 represent the results for the cases *xo*=0.31cm, 0.37cm, 0.43cm and 0.46cm, respectively.

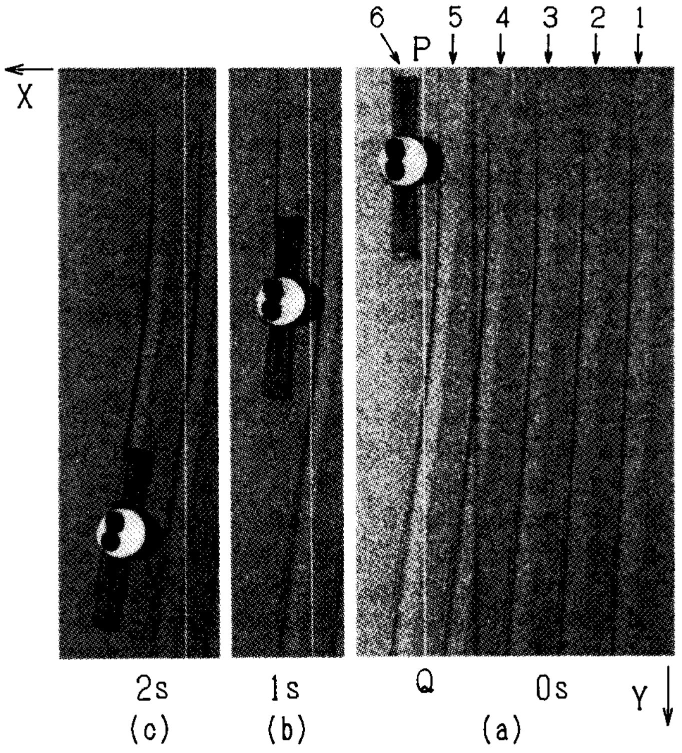

Fig.6. Uphill turn of a reel-type ski. Tracks 1,2,3,4,5 and 6 represent the results for the cases *xo*=0.19cm, 0.25cm, 0.31cm, 0.38cm,0.44cm and 0.50cm, respectively.

The *X*,*Y*-plane lies in the sand slope. The *Y*-axis is along the fall line. *w*=2cm.
The white line P-Q is a thread streched along the fall line 4cm above the slope.

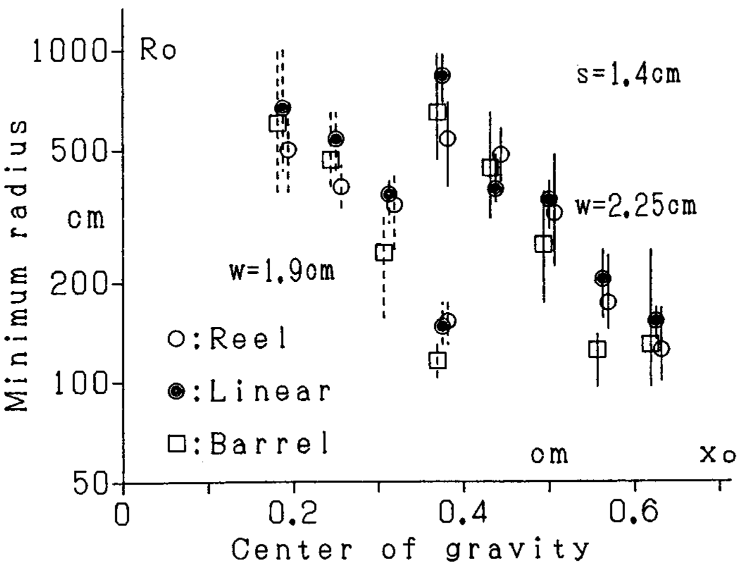

Fig.7. The center of gravity x_0 and the minimum radius of curvature R_0.

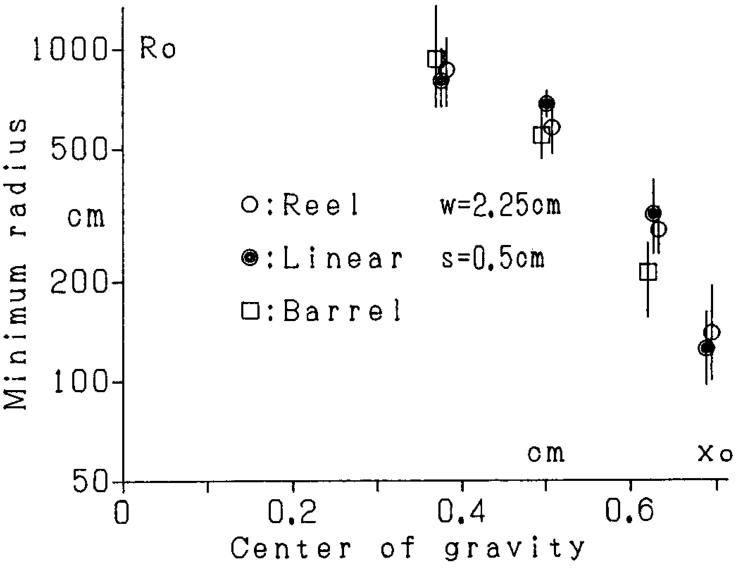

Fig.8. The center of gravity x_0 and R_0.

R_0 was obtained from the loci of these skis, which are shown in Fig.7. The vertical axis represents R_0, and the horizontal axis represents the center of gravity x_0. Measurements were carried out four times. Mean measured values for reel-type, linear-type and barrel-type skis are represented by ○, ● and □, respectively, and the lines superimposed on the measurement values represent their range of scatter. The values of x_0 for the three skis are the same, but they are shifted to $x_0+0.1$cm for the reel-type and to $x_0-0.1$cm for the barrel-type for clarity. In this figure, we can see that R_0 decreased as x_0 increased because, as x_0 increases, the ski inclines more easily, resulting in an increase in the edging angle, which decreases R_0. The values of R_0 for the three types of skis are similar.

Thereafter, the skis were set along the FL prior to descent in all experiments. The number of measurements and the method used to produce the graph were the same as those described in this section.

3.2 *Ski width w, xo and Ro*

The same ski descent experiments as those described above were performed by varying the ski width w as 1.5cm, 1.9cm and 2.5cm. In Fig.7, values of R_0 for w=1.9cm are represented by a dotted line. For all values of w, R_0 was similar for the three types of skis. In addition, when the value of x_0 was constant, R_0 decreased with decreasing w. These phenomena can be explained as follows. As w decreases, the ski inclines more easily, resulting in an increase in the edging angle, which leads to a decrease in R_0.

3.3 *Depth of sand s, xo and Ro*

The experiments described in section 3.1 were performed using skis with w=2.25cm, while s=0.5cm. Figure 8 shows the results obtained. For each of the three types of skis, R_0 decreased as x_0 increased. The values of R_0 for the three types of skis were similar. However, when x_0=0.5cm and w=2.25cm, R_0 shown in Fig.8 is larger than R_0 shown in Fig.7, because as the sand depth decreases, the ski inclines less easily, resulting in a decrease in the edging angle, which leads to an increase in R_0.

Let us assume that shallow sand corresponds to hard snow since it is not easily deformed, and deep sand to soft snow since it is easily deformed. Then, the experimental results obtained in section 3.3 agree with our experience that *skis turn easily on soft snow*.

3.4 *s and xo*

The same ski descent experiments as those shown in Fig.7 were performed by varying the sand depth within a range of $0.05\text{cm} \leqq s \leqq 1.4\text{cm}$. Figure 9 shows results for the three types of skis. For $0.2\text{cm} < s$, all three types of skis made an uphill turn in the edging direction and showed a similar value of R_0. When $s < 0.1$cm, the value of R_0 for each type of ski was different. In particular, the reel-type ski did not make a simple uphill turn; instead, it descended with a zig-zag movement. Thus, differences in the descent behavior among the three types of skis were observed when the sand depth was shallow. When $s < 0.2$cm, it was more difficult for the reel-type ski to descend straight compared with the other two types of skis. When $s < 0.1$cm, the skis were descending mostly on the cotton cloth since there was almost no sand on the cotton cloth.

3.5 *xo for the gate-type ski*

For the gate-type ski with the linear-ski as its main ski, as shown in Fig.2, β was set at 20°, w was 2.25cm and s was 0.5cm. The center of gravity of the ski was varied within a range of $-0.62\text{cm} \leqq x_0 \leqq +0.62\text{cm}$. In this experiment, the ski made an uphill turn in the edging direction. The value of R_0 did not change greatly with the change in the value of x_0

(Fig.10). Following this experiment, x_0=−0.31cm was used in experiments using the gate-type ski.

3.6 *β for the gate-type ski*

Each of the three types of skis was mounted on the gate-holder, and the descent experiments were performed with w=2.25cm and s=0.5cm. As shown in Fig.11, 5°≦ β ≦35°. In this range, all three types of gate-type skis made an uphill turn in the edging direction and showed a similar value of R_0. Within 5° ≦ β ≦20°, as β increased, the ski turned with greater ease and R_0 decreased. However, when 20°≦ β ≦35°, as β increased, the ski turned with grater difficulty and R_0 increased. Reasons for this phenomenon will be discussed later.

3.7 *s for the gate-type ski*

Changes in the value of R_0 for the three types of skis were investigated for 0.05cm≦s≦1.4cm (Fig.12), and w=2.25cm and β=20°, using the gate-type ski. As shown in Fig.12, all three types of skis made an uphill turn in the edging direction when 0.5cm≦s, and the values of R_0 were similar. However, when s≦0.2cm, the barrel-type ski made zig-zag turns. In addition, R_0 of the linear-type ski was significantly larger than that of the reel-type ski. Thus, differences in the descents of the three types of skis arose when s≦0.2cm. With this sand depth, the width of the track of the ski remaining on the sand surface was 1/10 or less than the actual ski width.

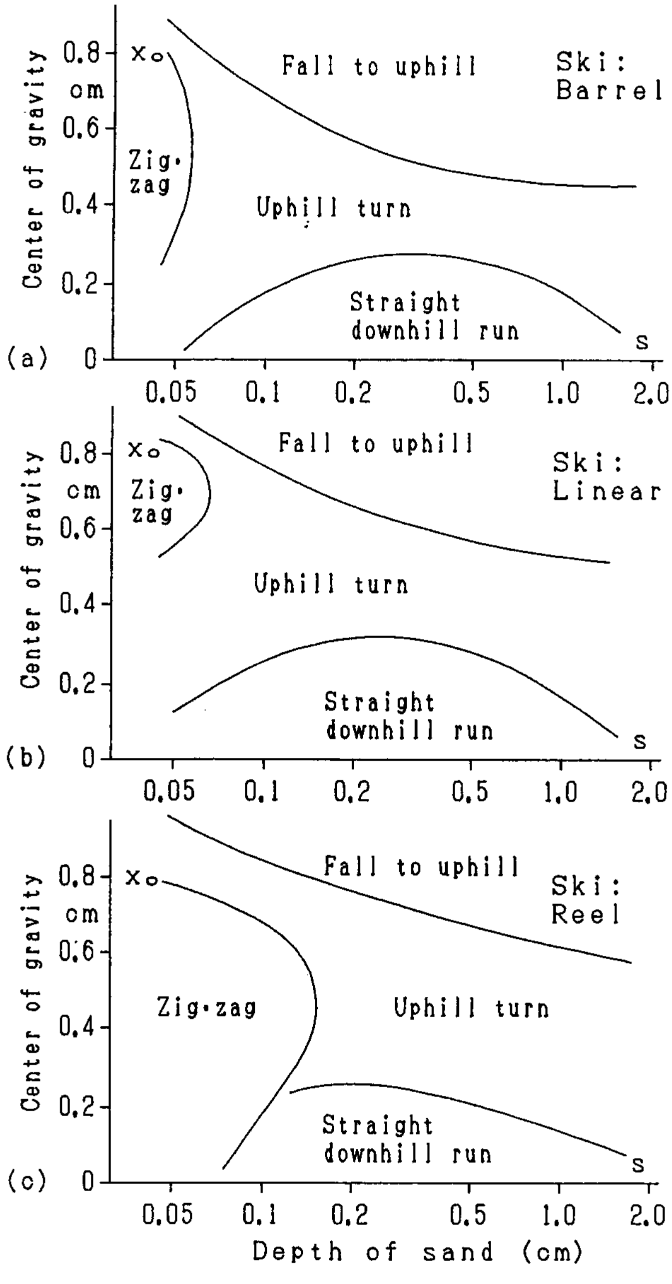

Fig.9. x_0 and s. (a) Barrel-type ski. (b) Linear-type ski. (c) Reel-type ski.

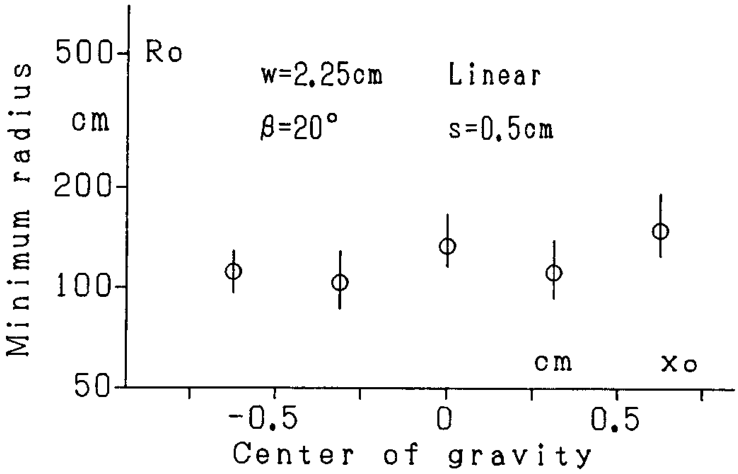

Fig.10. x_0 and R_0 for the gate-type ski.

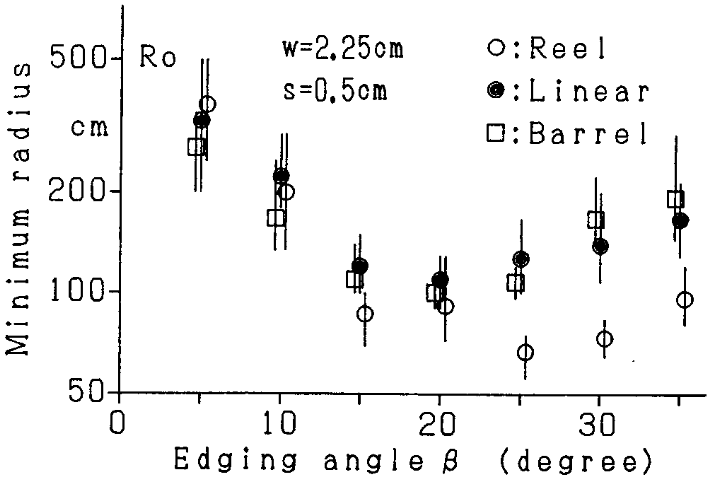

Fig.11. The edging angle β and R_0 for the gate-type ski.

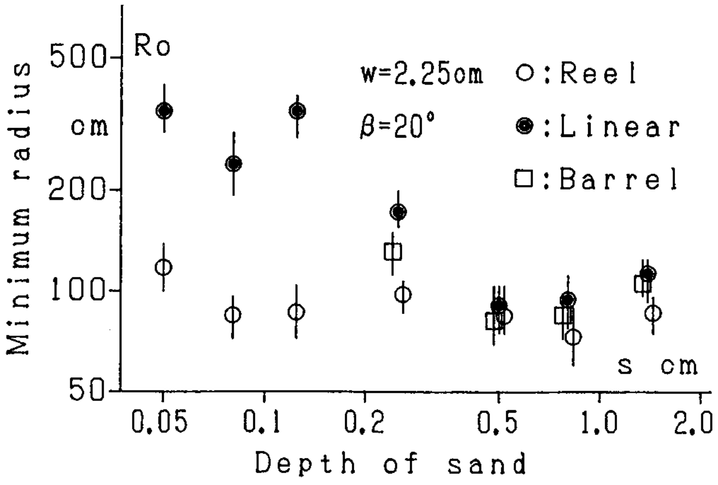

Fig.12. s and R_0 for the gate-type ski.