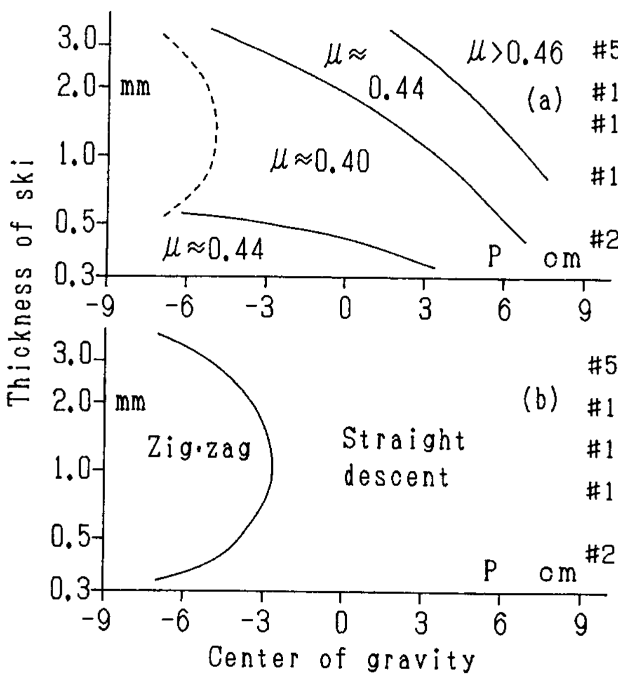

Fig.7. Loading point P, the thickness of the ski, and μ. (a) Coefficient of kinetic friction. (b) Descent conditions.

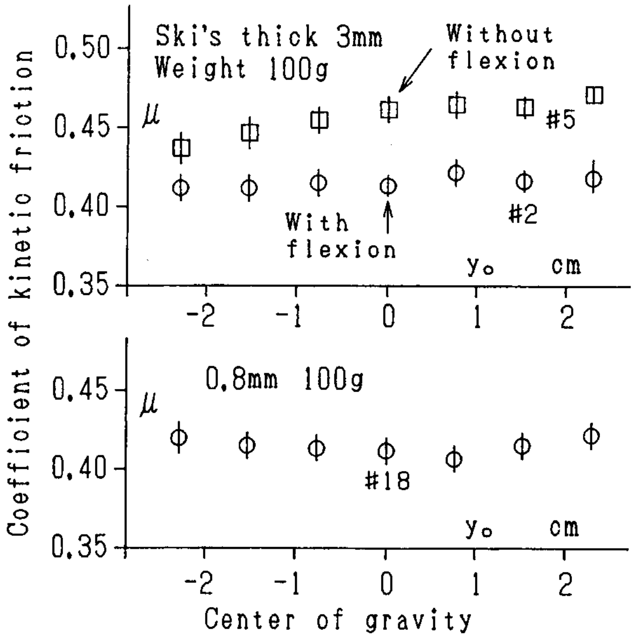

Fig.8. Center of gravity and μ.

Figure 7(a) shows the relationships between P and μ for skis without flexion for each thickness. When a ski has the appropriate thickness, the value of μ of the ski decreases as the ski becomes thinner (softer). In addition, μ decreases as the loading position is shifted to the afterbody of the ski. Figure 7(b) shows the status of descent. When $-3\text{cm}<P$, the ski performed a stable straight downhill run. When $P<-4\text{cm}$, the ski sometimes performed a zig-zag descent. The region where measurement of μ was impossible is represented by the dotted lines shown in Fig.7(a). This experiment reveals the following. *Flexion of the front part of the ski has the effect of decreasing μ. The rear part of the ski has the effect of the improvement of the straight-descent feature of the ski.*

When descending on a deep-snow plane, it is generally said that a skier travels with more speed if he leans backward. This can be explained by the following result shown in Fig.7: as the center of gravity is shifted backward, the effect of flexion increases and the ski descends more easily, resulting in a decrease in μ.

3.4 Relationship between the center of gravity on the ski and μ

Setting P=0cm in Fig.1, the center of gravity y_0 of the ski was varied by adjusting the position Q of the magnets. Skis with 5 different thicknesses were used in this experiment. The weight of each ski was 100g. The center of gravity was x_0=0cm, y_0=−2cm~2cm, z_0=1cm~1.5cm. Then the values of μ were obtained. Figure 8 shows the relationships between the center of gravity y_0 and μ, for cases of 3mm-thick and 0.8mm-thick skis. The change in μ values was similar to that obtained when the loading points were varied, as shown in Fig.6. In the case of a 3mm-thick ski without flexion, μ decreased as the center of gravity was shifted backward. When the center of gravity is positioned at the rear of the ski, the front part is raised and an effect similar to flexion can be obtained. In Fig.8, the range of variation of the center of gravity is narrow, and the change in μ is slight. In the case of 3mm-thick skis with flexion, μ was small and its dependence on the center of gravity was small, as observed in the case of 0.8mm-thick skis.

In cases of snow skis where the skier's foot position is fixed on the skis, the descent conditions are ~~experientially~~ thought to change when the center of gravity is varied toward the front or rear from the initial position. However in this experiment, regardless of the occurrence of flexion, the range of variation of the center of gravity was narrow and the change in μ was also small. The condition of ski descents was almost the same.

3.5 Turning descent of a gate-type ski

In this experiment, the gate-type ski shown in Fig.3 was used with a main ski selected from skis of 5 thicknesses; the edging angle of ski H was set at β=20° or 10° for P=Q=0cm, x_0=−0.3cm, y_0=0cm, and z_0=1cm~1.3cm. Descent experiments were performed by adjusting the magnets mounted on the iron plate so that the weight of ski H was 50g. The skis performed an uphill turn in the edging direction. Figure 9 shows 2 examples of the results obtained, showing the loci of the skis and their radius of curvature. The method of drawing the loci of the skis was described in a previous report.[5] Figure 9(a) shows the results of 3mm-thick skis with or without flexion, with β=20°, and (b) shows the results of 0.8mm-thick skis without flexion,

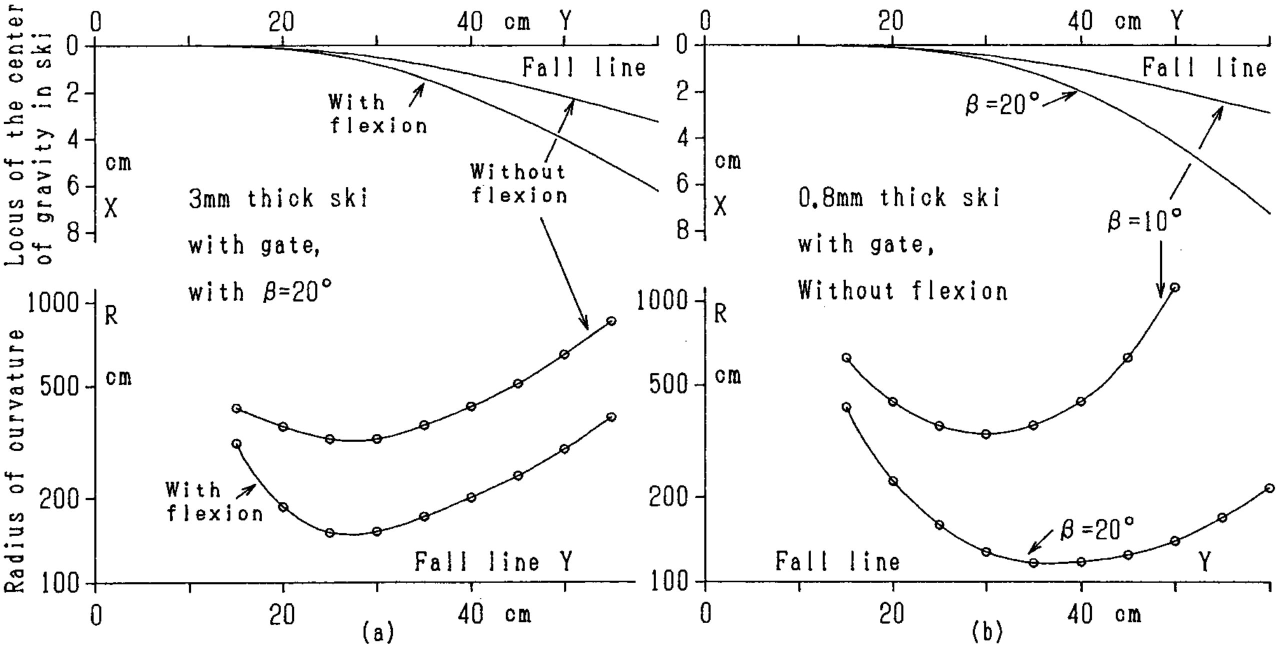

Fig.9. Locus of the descent and the radius of curvature in the case of a gate-type ski.

with $\beta=20^\circ$ or 10°. The loci of the skis and the radius of curvature for each pair of the following sets of conditions are similar.

"$\beta=20^o$, 3mm-thick ski with flexion," and "$\beta=20^o$, 0.8mm-thick ski without flexion."

"$\beta=20^o$, 3mm-thick ski without flexion," and "$\beta=10^o$, 0.8mm-thick ski without flexion."

Thus, we can see that if the ski has the appropriate flexion, the turn of skis does not depend on the thickness of the skis.

The same experiments as those shown in Fig.9 were performed for skis of 5 thicknesses by varying β in the range of $5^\circ \leqq \beta \leqq 35^\circ$. All skis performed an uphill turn in the edging direction. Figures 10(a) and 10(b) show examples of the relationship between the minimum radius of curvature *Ro* of a locus[5] and β. In these figures, the relationship between *Ro* and β for the 3mm-thick ski with flexion and the 0.8mm thick ski without flexion are similar. In addition, *Ro* for the 3mm-thick ski without flexion is larger than that of the 3mm-thick ski with flexion. That is, it is difficult for a ski to make a turn when it does not have flexion.

When $5^\circ \leqq \beta \leqq 20^\circ$, *Ro* decreased with increasing β. However, when $20^\circ \leqq \beta \leqq 30^\circ$, *Ro* increased with increasing β. When the value of β is too large, the flexion and turning of a ski are difficult. The reason for this is described in the previous report.[5]

We investigated the relationship between *Ro* and β, for skis of 5 thicknesses without flexion, in the range of $5^\circ \leqq \beta \leqq 35^\circ$. Figure 10(c) shows the results. In the case of skis without flexion, as the thickness decreases (the ski becomes thinner and softer), the ski turns becomes easy.

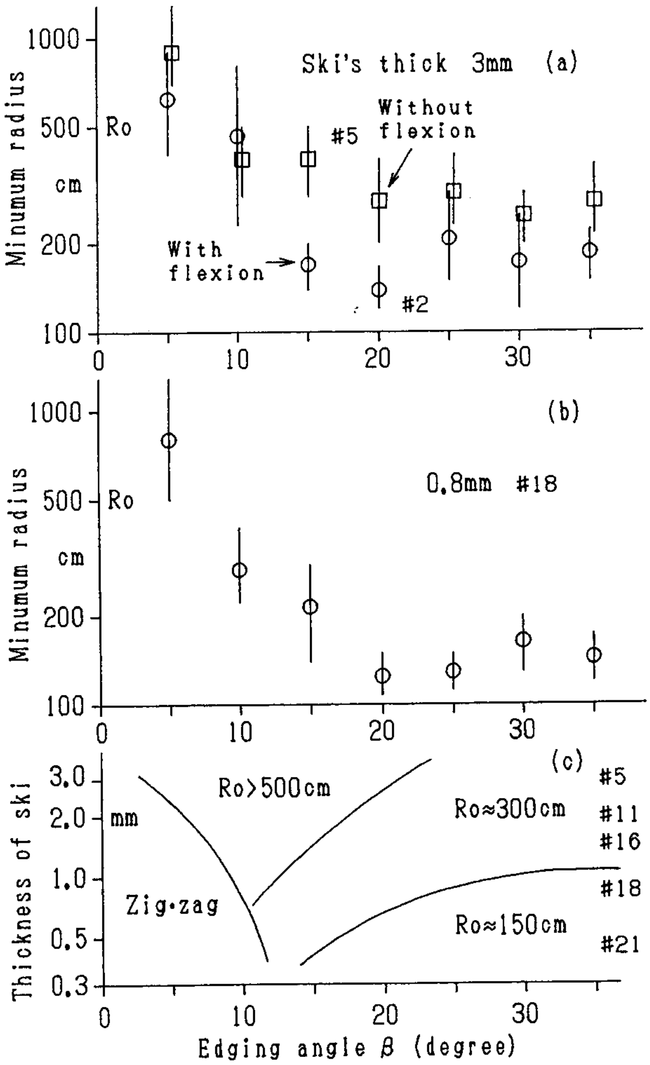

Fig.10. (a) and (b): Edging angle β and the radius of curvature of the locus *Ro* in the case of gate-type skis. (c) β, *s*, and *Ro*.

3.6 Contact area between ski and sand

Using a 0.8mm-thick transparent ski (the same shape and material as #18, shown in Fig.2), we investigated the contact area between the ski and the sand.[5,6] Figure 11(a) shows the results for $P=Q=0$cm, $x_0=0.56$cm, $y_0=0$cm, and $z_0=1.2$cm. The contact areas are represented by diagonal lines. The center of gravity of ski G is represented by a double circle.

The ski was positioned along a direction 35° from the fall line (Y axis). The ski skidded to A→B, with a parallel movement. Then, it made a slight downhill turn, B→C→D, and then a uphill turn, F→G→ ··· →J.

Figure 11(b) shows a front cross-sectional view of the inclination of the ski, the horizontal plane and the sand surface. (1) represents β, β_0 and β_1 for the center of the ski positioned at $Y=10$cm (arrow). The angles are the measured values. Lines d–j and e–f represent a horizontal plane, line d–k is an inclined (sand) surface, and line g–h is the surface of the ski. β is the edging angle of the ski against the sand surface, and β_0 is the edging angle of the ski against the horizontal plane.[3] Observed from the front, the center of gravity of the ski is on the left side, but the ski inclines to the right due to the light load. Since the ski descends easily in the direction of inclination (to the right), it is easy for the ski turn to become a downhill turn (B→D). However, during (F)→(J), the ski inclines to the left side, which leads to an uphill turn. In (2) of Fig.11(b), the edging angle of the ski whose center of gravity is positioned at $Y=15$cm is shown. Lines e–f and g–h expressed in (1) are omitted in (2) and they are also the same with (3), (4), ···.

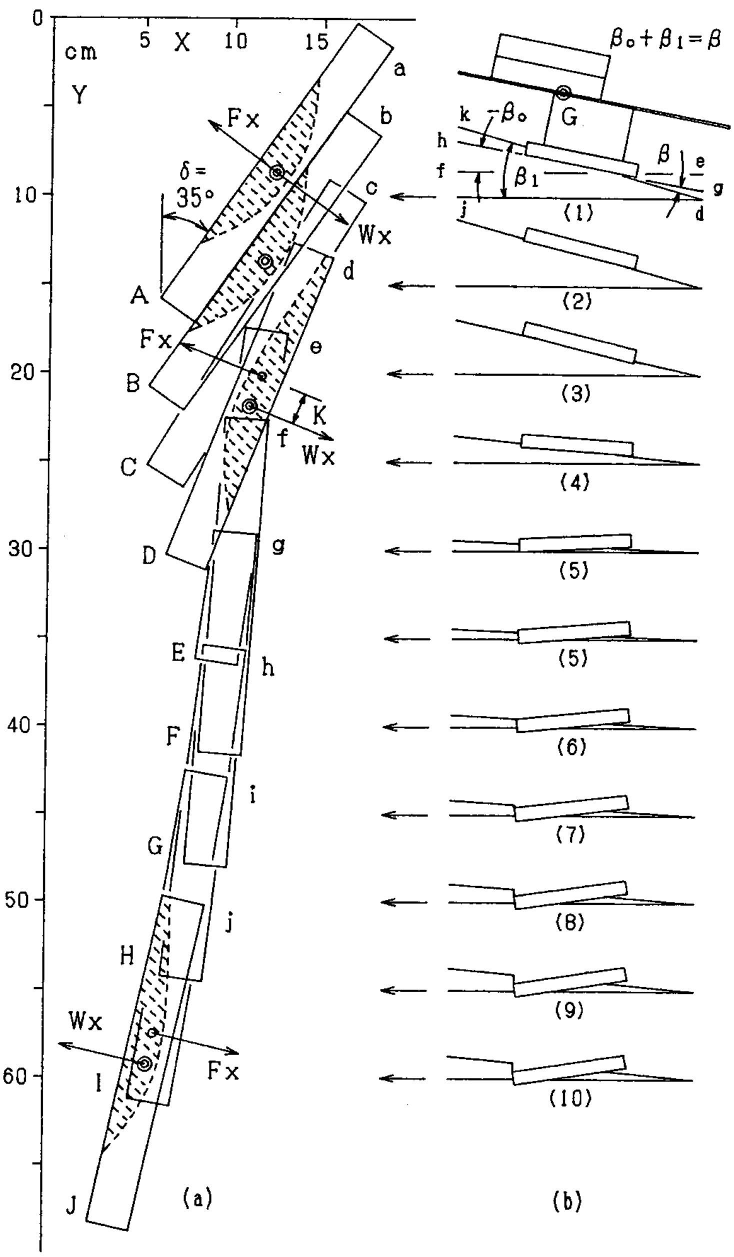

Fig.11. Change in the contact area between the ski and the sand surface.
(a) Contact area represented by diagonal lines.
(b) Cross-sectional view of the center of the ski observed from the front. G is the center of gravity.

Let us examine the mechanism of descent on the coordinates (x, y) fixed on the ski. In ski A, due to the edging of the ski, the gravitational component W_x of the entire ski is applied in the $-x$ direction which is perpendicular to the ski length, and the frictional resistance F_x of the ski is applied in the $+x$ direction. Since ski A represents a ski just after placement on the sand surface, the area of the contact surface at the front of the ski is almost the same as that at the rear of the ski, and the length K between W_x and F_x is zero; thus no couple of force is generated. Accordingly, the ski skids to A→B, undergoing a parallel movement.

During this parallel movement to A→B, a slight degree of flexion may be generated in the forebody of the ski. Therefore, the contact area at the front of ski D decreases and that at the rear increases. As a result, the point of action of F_x shifts from the center of gravity to the afterbody of the ski. Accordingly, $K\neq0$ holds and a couple of force is generated, and the ski performs a downhill turn (B→D) accompanied by a leftward rotational motion. Since the center of gravity is positioned in the $+x$ direction, as the ski turns toward the direction of the fall line, the ski edges toward the $+x$ direction. For ski J, the direction of W_x becomes opposite and that of F_x also becomes opposite, and $K\neq0$ holds. A rightward rotational motion is generated and the ski performs an uphill turn.

A rotational motion generated from a gravitational component in the $+y$ direction, W_y, and frictional resistance in the $-y$ direction, F_y, can also be considered; however, this rotational force is neglected here since the length between W_y and F_y is small.

4. Discussion

4.1 Flexion

When a ski has sufficient stiffness to maintain its shape, the thinner (softer) the ski, the easier it is for the ski to exhibit flexion, leading a smaller μ value, as shown in Fig.4. The stiffness of the ski depends on the weight loaded onto the ski (such as the skier) (Fig.5). It was shown that the effect of the flexion of skis on ski turns is similar in the following two cases.

(1) In the case of a ski having sufficient stiffness to maintain its shape, flexion is induced in the ski prior to descent.

(2) In the case of a soft ski which can be easily deformed, flexion is spontaneously formed in the ski during descent.

In either case, the front part of the ski rises due to the flexion, leading to a decrease in the μ value.

As shown in Fig.7, *the front part of the ski has the effect of decreasing the μ value due to flexion, and the rear part of the ski has the effect of facilitating straight descent of the ski.* Therefore, when the center of gravity is positioned at the rear of the ski, the degree of the effect of flexion increases and μ decreases; however, the straightness of descent of the ski deteriorates. When the center of gravity is positioned at the front of the ski, the μ value increases but the straightness of descent is improved.

4.2 Relationship among edging, flexion and ski turn

For the example of ski D in Fig.11(a), the contact area is shifted to the $-x$ direction. Due to the edging of the ski, a gravitational component W_x in the $-x$ direction [5] is generated and a frictional resistance F_x in the $+x$ direction is generated. Due to flexion of the ski, the contact area is shifted to the rear part ($-y$ direction), and the point of action of the frictional resistance shifts from the center of gravity to the rear part. Accordingly, a couple of force is generated and a leftward rotation occurs. In ski J, a rightward rotational motion occurs.

The leftward and rightward motion are determined by sigh of edging β_0. In the previous paper[5], it is reported that the rotational motion is made by the flexion and edging of the ski. A combination of the force in the X direction by the edging β_0 and flexion, and the force in the Y direction (fall line) produces a revolutional motion. The revolutional motion is also divided into an uphill turn and a downhill turn due to the sigh of edging β_0. A combination of rotational motion and revolutional motion produces a ski turn.

4.3 One-legged ski turn

In this study, we consider parallel turns in which skis do not leave the snow surface as the ski turns. In snow plows and stem turns, the two legs of the skier perform different motions with each other. Accordingly, the forces of the two skis acting on the snow surface differ, resulting in a left or right turn. If the two forces acting on the snow surface are the same, then the skis will perform the straight motion (descend).[4] In the case of one-legged ski descent, if the forces of the left and right sides of one ski acting on the snow surface are the same, then the ski will descend straight.

It is possible, for one-legged turns, to draw a ski track on the snow slope which is very similar to the ski track for parallel turns.[4] Therefore, in the case of one-legged turns, different forces from the snow surface must be applied to the left and right sides of the ski. The difference in the force is due to the shift of the contact area produced by edging and flexion of the ski. These findings were described in the previous paper [5] and this paper.

In two-legged parallel turns, more than 70% of the body weight is thought to be applied to the outer ski.[8] In fact, a skier performs ski turns using only his outer ski. For example, when a skier shifts from a right turn to a left turn, he shifts his weight from the left leg to the right leg at the points of inflection. Namely, the skier seems to perform parallel turns using both his legs, but essentially, he uses either his right or left leg, and performs the one-legged ski turns described above.

5. Conclusions

By providing flexion to a ski, the ski descends and turns easily. Due to flexion and edging of the ski, the contact area between the ski and the sand (snow) surface shifts to the after body of the ski, resulting in rotational motion of the ski. Due to flexion and edging, the force in the X direction is made. A combination of the forces in the X direction and in the FL (Y) direction induces revolutional motion of the ski. A combination of rotational motion and revolutional motion produces uphill and downhill turning descent of the ski.

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