ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 2 (2010) 2901–2906
Procedia Engineering
www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

Investigation on the ski-snow interaction in a carved turn based on the actual measurement

Takeshi Yoneyama[a,*], Motoki Kitade[a], Kazutaka Osada[b]

[a]*Kanazawa University, Kakuma-machi, Kanazawa 920-1192, Japan*
[b]*Ogasaka Ski Company, Nagano, Japan*

Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

Abstract

Based on the actual measurement on the ski deflection, ski-snow contacting pressure, boot-ski load, turn radius, snow groove geometry in a carved turn and the bending stiffness distribution of the ski, mutual relations have been investigated to elucidate the ski-snow interaction mechanism. Boot-ski load and the contacting pressure distribution on the running surface satisfy force equilibrium and moment equilibrium. The deflection of the ski is related with the moment distribution and bending stiffness distribution of the ski. The pattern of the pressure distribution changed with the bending stiffness distribution of the ski on the same hardness of the snow in the measurement.

Keywords: Ski; measurement; deflection; pressure;bending stiffness; ski-snow interaction;carving turn

1. Introduction

Although the ski-snow interaction mechanism is significant in the ski turn, and has been investigated by many researchers through analytical method or experimental method, the relation among ski deflection, ski-snow contact pressure, and forming of the snow groove and other factors are still not clear [1]- [7]. The authors have developed actual measuring system for the deflection and the contacting pressure during the turn [8] [9]. Next subject is to make clear about the relations among these factors.

In this study, ski deflection, contacting pressure and boot-ski force are measured in the long carving turn on the two skis of different bending stiffness. From the measured result, relations among these factors are investigated. The contacting status between the deflected ski and the forming snow groove is estimated using the result obtained from the measurement. Force and moment equilibrium is investigated and the influence of the bending stiffness of the ski on the contacting pressure is discussed.

---

* Takeshi Yoneyama. Tel.&fax: +81-76-234-4683.
E-mail address: yoneyama@t.kanazawa-u.ac.jp.

doi:10.1016/j.proeng.2010.04.085

2. Measurement

2.1 Measuring equipment

The measuring system is shown in Fig.1. Deflection sensor beam attached on the upper surface of the ski detects the ski deflection during the turn. It consists of 9 bending sensors connected with 6mm square bars. The middle of the sensor beam is fixed at the boot center. The front side and the rear side of the sensor beam can slide along the longitudinal direction of the ski. From the static bending test, the deflection profile obtained from the deflection sensor was confirmed to coincide with the profile measured by displacement meters. In the vibration test, the deflection detected by the sensor agrees well to the displacement by the laser displacement meter in the range of 10 Hz. Eight pressure sensor blocks, which contain commercial pressure sensors, are fixed 6 mm apart from the side edge along the longitudinal direction of the ski. The detection surface of the pressure sensor is adjusted in the running surface. The output of the pressure sensor was calibrated by air pressure applied on the sensor surface.

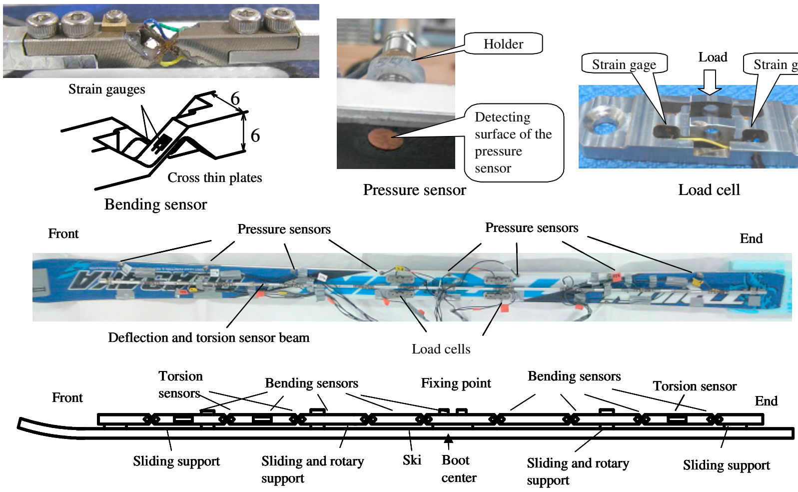


Fig.1 Measuring equipments for ski deflection, contacting pressure and boot-plate load

Four original load cells are inserted between the binding plate and the upper surface of the ski. Binding plate is made of aluminum alloy plate divided into right and left plates to make a space for inserting the deflection beam. Each plate is connected to the front and the rear load cells. The force from the boot is conducted through the pin joints, which are supported by lateral beams. Strain gages are fit on the surface of the lateral beams. Rear side of two pin joints can slide on the binding plate so as not to disturb the ski deflection.

Bending stiffness of the two skis with the binding plate is shown in Fig.2. Compared with ski A, the stiffness in the rear part of the boot center is higher in ski B. The radius of the side curve was both 23m. The length of the ski was both 175mm.

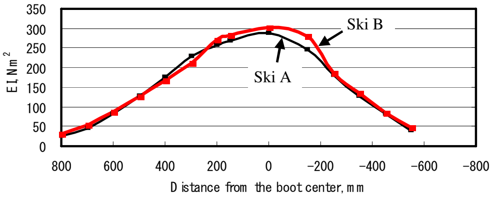


Fig.2 Bending stiffness distribution of the ski

2.2 Measurement during the long turn

The measurement was carried out at Shiga Kogen in Nagano, Japan. The subject was a test skier of Ogasaka Ski Company. The height and the weight of the skier were 1850mm and 90kg respectively. The skier took a ski with sensors on the left foot. Because the pressure sensors are installed along the right side edge of the ski, the pressure on the outside ski during the right turn is detected in this system.

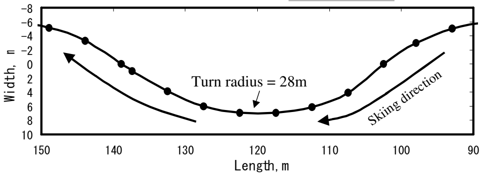
Inclination angle of the slope was 20 degrees. After the initial straight decent, the skier performed a series of long carving turn. Data sampling time was 2ms. After the twice of the measurement of the turn using one set of the ski, the skier performed the same long turn on the similar turn course twice using another ski of different bending stiffness. The time period between the two measurements was about one hour and the snow condition was similar in both turns.

3. Measuring result

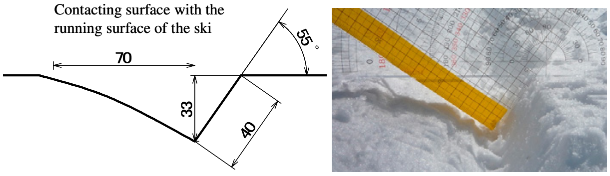
3.1 Turn trajectory and snow groove

Turn trajectory of the second right turn with ski A is shown in Fig.3(a). That with ski B was almost the same. The turning speed was about 70km/h. The turn radius around the maximum width was about 28m.

Cross section of the outside snow groove is shown in Fig.3(b). The width of the outside surface of the groove was about 40mm. This surface is made of hard snow by the contact with the running surface of the ski. The angle of the outside surface to the snow surface was about 55 degrees, which corresponds to the edging angle of the ski. Inside surface of the snow groove is a cut surface and slightly round from the top edge to the bottom. The angle between the outside and the inside surfaces is larger than 90 degrees.



(a) Turn trajectory



(b) Cross section of the snow groove of the outside ski

Fig.3 Turn trajectory and snow groove

3.2 Force from the boot to the ski

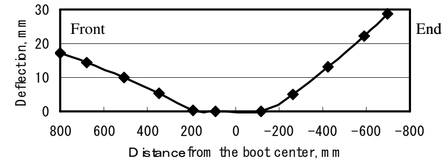
From the four points loads, the sum of the front two loads is expressed as front load and that of the rear two loads is expressed as rear load. In the turn with ski A, the value of the both load is similar in the initial period of the turn, but the rear load becomes larger than the front load in the later period of the turn. In case of ski B, front load is larger than rear load in the initial part of the turn. The rear load becomes larger than the front load as in the case of ski A, but the difference between the two loads is not so larger than that in ski A. The mean value of the load in the later period of the turn by ski A is 350kN in front and 800kN in rear. Those of the turn by ski B are 450kN in front and 700kN in rear. Sum of these forces corresponds to the combination of gravitational force and centrifugal force.

3.3 Ski deflection and the contacting pressure

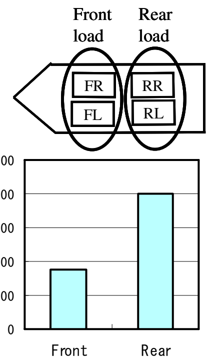
The deflection of ski A and the pressure distribution in the middle part of the right turn is shown in Fig. 4. Both data are average of 0.2s. Deflection is expressed as a displacement profile above the boot center in the running surface. Maximum front deflection is about 20mm and that in rear is about 30mm.

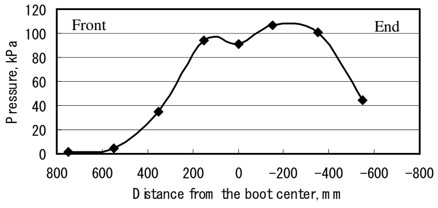
Pressure is high around the boot center and the value is nearly constant from 200mm front of the boot center to its 400mm behind. Applying load is also attached in the figure.

The deflection of ski B and the pressure distribution in the middle part of the right turn is shown in Fig.5. Front deflection of ski B is relatively larger than that in ski A. Pressure shows a triangle shape with a peak at the rear part. But it something decreases at the boot center. The value of the pressure at the front part is relatively larger than that in ski A, but that at the peak is lower. Applying load is also attached in the figure.



(a) Ski deflection

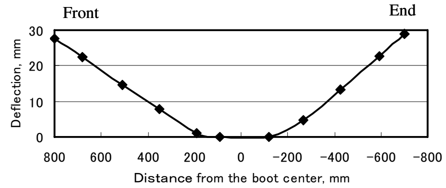




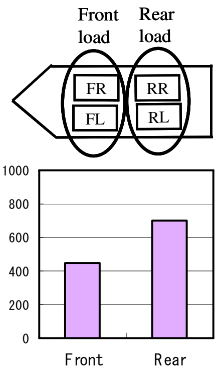
(b) Pressure distribution

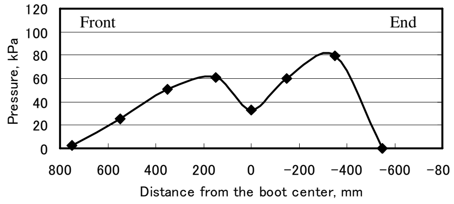
(c) Load from the plate

Fig.4 Deflection, contacting pressure and load in ski A



(a) Ski deflection





(c) Loads from the plate

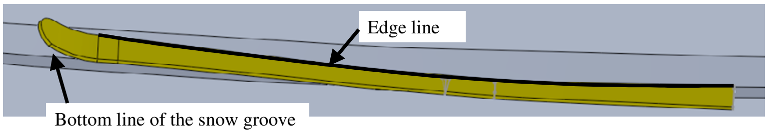
(b) Pressure distribution

Fig.5 Deflection, contacting pressure and load in ski B

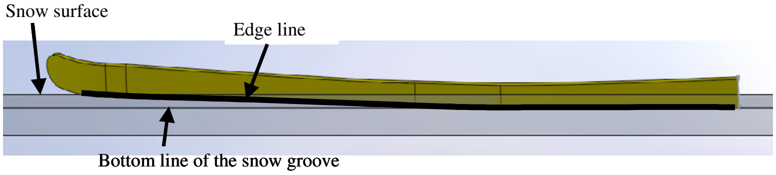
4. **Investigation on the interaction of ski and snow**

4.1 Investigation on the contact of ski and snow

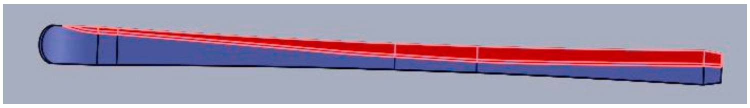
From the result that pressure applies over the rear part of the ski, the running surface of the rear part of the ski must contact with the snow groove surface. Snow deforms plastically by the applied pressure and the deformation will not return after the peak pressure. Therefore the compressive deformation of the snow finishes around the peak pressure and the formed groove remains after the pressure peak region to the tail of the ski. The rear part of the ski with low pressure must be contacted on the formed snow groove surface. On the other hand, the front top of the ski may be above the initial snow surface. The deflected ski was constructed as the 3D model and it was fit on the 3D model of snow groove. The result is shown in Fig.6. Contacting width increases from the top to the middle part of the ski and then almost keeps constant to the tail of the ski.



(a) Edge line from the view of vertical direction to the snow surface



(b) Edge line from the view of parallel direction to the snow surface



(c) Contacting area between ski and snow

Fig.6 Investigation on the contact between the deflected ski and the snow groove using the 3D model

4.2 Investigation on the force and moment equilibrium and the ski deflection

The sum of the force from the boot must coincide with the sum of the pressure applied from the snow surface. And also moment by the force from the boot must coincide with the moment caused by the pressure on the running surface. Load distribution per unit length on the running surface is estimated from measured pressure distribution and the contacting width distribution. Moment distribution is also obtained from the boot-ski load and the distribution of force per unit length. Ski deflection is calculated using the moment distribution and bending stiffness distribution. Examples of the results are shown in Fig.7. In both ski A and ski B, applied load from the boot, bending stiffness distribution of the ski, ski deflection and contacting pressure on the running surface are related with each other on the base of force equilibrium, moment equilibrium and bending theory of material strength.

4.3 Difference by the bending stiffness distribution of the ski

The patterns of the pressure distribution in ski A and ski B remain even if the balance of the front load and rear load changes during the turn in the measurement. On the other hand, if the bending stiffness distributions are exchanged between the combination of applying load and pressure distribution in the simulation, the change of the deflection is small. Further investigation must be necessary to elucidate the effect of the bending stiffness distribution on the pressure distribution through the detail examination on the ski deflection.

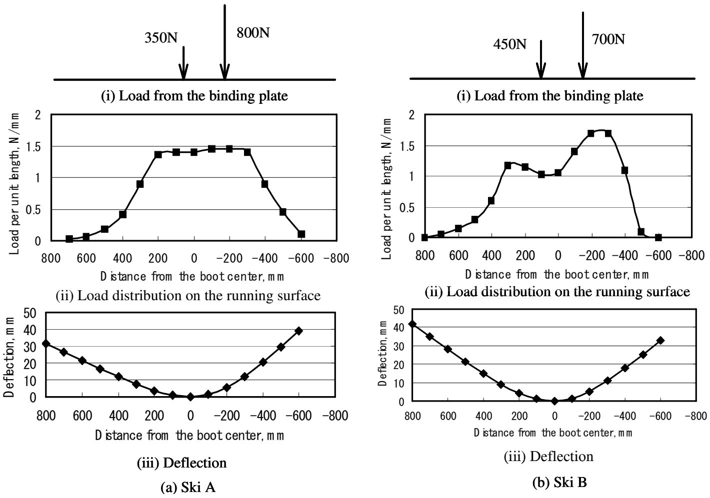


Fig.7 Load distribution that satisfies force and moment equilibrium and the obtained ski deflection

5. Conclusions

The relations among ski deflection, contacting pressure and boot-ski load have been investigated from the actually measured data. The applied force from the boot and the pressure distribution on the running surface satisfies force equilibrium and moment equilibrium. The deflection of the ski is obtained from the moment distribution and bending stiffness distribution of the ski. On the snow surface of the same hardness in this experiment, the pattern of the contacting pressure distribution changed with the bending stiffness distribution of the ski.

Acknowledgements

The authors wish to thank their colleagues Dr. Hiroyuki Kagawa, Takeharu Hashimoto, Daichi Tatsuno in Kanazawa University and Dr. Nathan Scott in Western University of Australia for the efforts to develop this research.

References

[1] Federolf, P.A. Finite element simulation of a carving snow ski, *Doctor of Technical Sciences dissertation ETH* No. 16065, Swiss Federal Institute of Technology, Zurich, 2005.

[2]Heinrich, D.,Kaps,P.,Moessner,M.,Schretter, H.and Nachbauer,W. Calculation of thepressure distribution between ski and snow, *The proceedings of the Fourth International Congress on Science and Skiing,* 2009, p.229-241.

[3] Piziali, R. L. & Mote C. D. Jr. Snow ski as a dynamic system, *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, 1972,**94** Ser G 2 p.133-138.

[4] Sakata T. & Tagawa T., Dynamic Bending Analysis of a Ski (Comparison between Numerical and Experimental Results) , Journal *of the Japanese Society of Mechanical Engineers(C)* (in Japanese), 1993,**59** 567, p.3357-3363.

[5] Kitazawa S., Kazama T., Shimada T., Omura T. & Kobayashi M. Experimental Method of Measuring Load Distribution under Edging Ski Plate, *Journal of Japan Society of Sports Industry*, 2001,**11**, No.1, p. 65-71.

[6] Hirano,Y., Tada,N., *Int.J.Mechanical Science,* Vol.36, No.5(1994), p.421-429.

[7] Tada N. & Hirano Y. Experimental determination of snow resistance forces acting on a turning snow ski, in Haake S., ed., *The Engineering of Sport*, 1998, Blackwell, p.423-430

[8] Yoneyama, T., Scott, N. Ski deflection measurement during skiing and estimation of ski direction and edge angle, *Sports Engineering*, Vol.11,No.1(2008), p.3-13.

[9] Scott, N., Yoneyama, T. Measurement of ski-snow pressure profile, *Sports Engineering*, Vol.10, No.3(2007), p.145-156.