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A New Generation Rammsonde Having Multiple Sensors

By

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Abstract

A new generation rammsonde (NGR) having multiple sensors was designed and tested in this paper. The NGR can detect snowpack properties in a second. The NGR measures snow depth from the surface according to the principle of the Wiedemann effect. At the same time the NGR can measure the reflectivity of the electromagnetic wave of 660 nm at the end of a cone, the resistivity of the cone to penetrate the snowpack, and the direct current electrical conductivity of snow around the cone. These four quantities are measured and recorded continuously and immediately. Subsequent analysis of these data produces three kinds of vertical snow profiles against the snow depth. By the combination of these optical, mechanical and electrical properties, the NGR can sensitively detect every layer of the snowpack whether the layer is thin or thick, strong or weak, dry or wet, and etc.

Key words: Rammsonde, Snowpack, Instrumentation

1. Introduction

The physical properties of a snowpack change in relation to time and position. The properties of the snow are usually obtained from snowpit observations. However, these observations take a great deal of time and effort. The ram penetrometer is still popular for measuring the strength profile of the snowpack. Haefeli (1954) reported that a ram profile can alleviate the following tasks ; (a) the general and comparative evaluation of the properties of snowcover, (b) the evaluation of avalanche danger, and (c) the identification of the layers. Thus a ram-type instrument whereby a snow profile can be obtained without making a snowpit is very convenient for field studies.

Recently, some new probes that penetrate the snowpack from the surface have been developed. Matsuoka (1968) tested the ability to measure the direct current electrical resistance of the snow. Dowd and Brown (1986) developed the digital thermo-resistograph which measures reactive forces on a cone. In addition, a fiber optic snow layer sonde was developed by Abe (1991), and Sensoy and Decker (1992) to measure optical reflectivity. However, the snowpack cannot be described by only one physical property. To measure the multiple snow properties simultaneously, a new generation rammsonde was developed.

2. Description of New Generation Rammsonde

A new generation rammsonde (NGR) consists of four parts as shown in Figure 1 ; a probe, a signal conditioner, a recorder and batteries. The probe includes a position sensor (Santest, Type GYTL) which utilizes the Wiedemann effect. The signal conditioner consists of a depth meter, a photometer, an amplifier and an electrical conductivity meter. The range of the depth meter is 1 m. For data storage, a four-channel analog magnetic tape recorder is supplied. In total four batteries are necessary : a 12 V battery for both the depth meter and the photometer, two 4.8 V batteries for the amplifier and a 3.2 V battery for the electrical conductivity meter. Figure 2 shows the operation of the NGR. The NGR can be carried on the back for snow surveys. The total weight of the NGR is 12.5 kg. As shown in

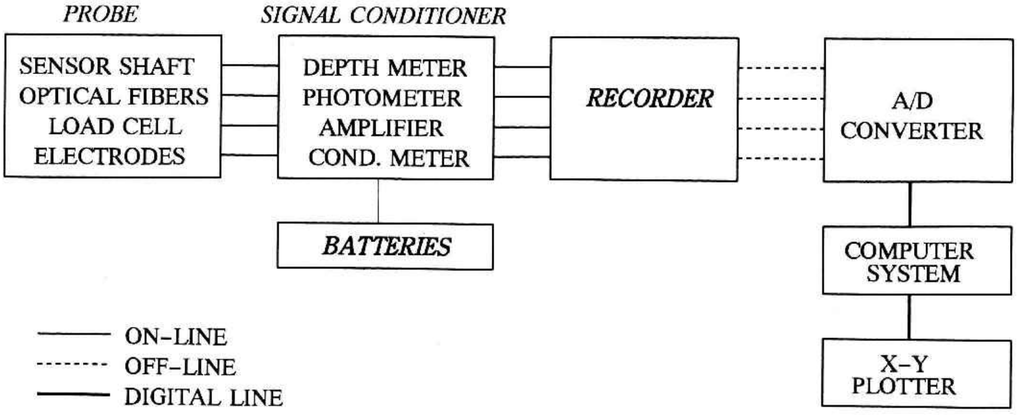

Fig. 1 Block diagram of the NGR consisting of four parts and its analyzing system.

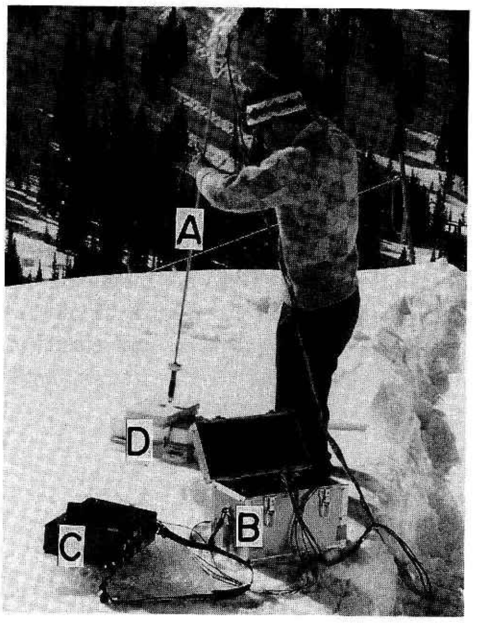

Fig. 2 Operation of the NGR in the field. A : probe, B : box for signal conditioner and batteries, C : data recorder and D : spacer for position sensor.

Figure 3, the main part of the cone is made of Teflon, and the three sensors are built up around this cone. Optical reflectivity, resistance of the cone to penetrate the snowpack and electrical conductivity are the essential properties in the detection of every layer of a snowpack. In designing the NGR these three parts were discussed as follows.

2.1 Reflectivity

Figure 4(a) shows light power versus output voltage of the photometer (OMRON, Type E3XA-CC4A) which is connected to the acrylic resin optical fibers. The total light power of the incident rays is 34.7 μW, and its wavelength is 660 nm. The reflectivity R, obtained by optical fibers is defined by :

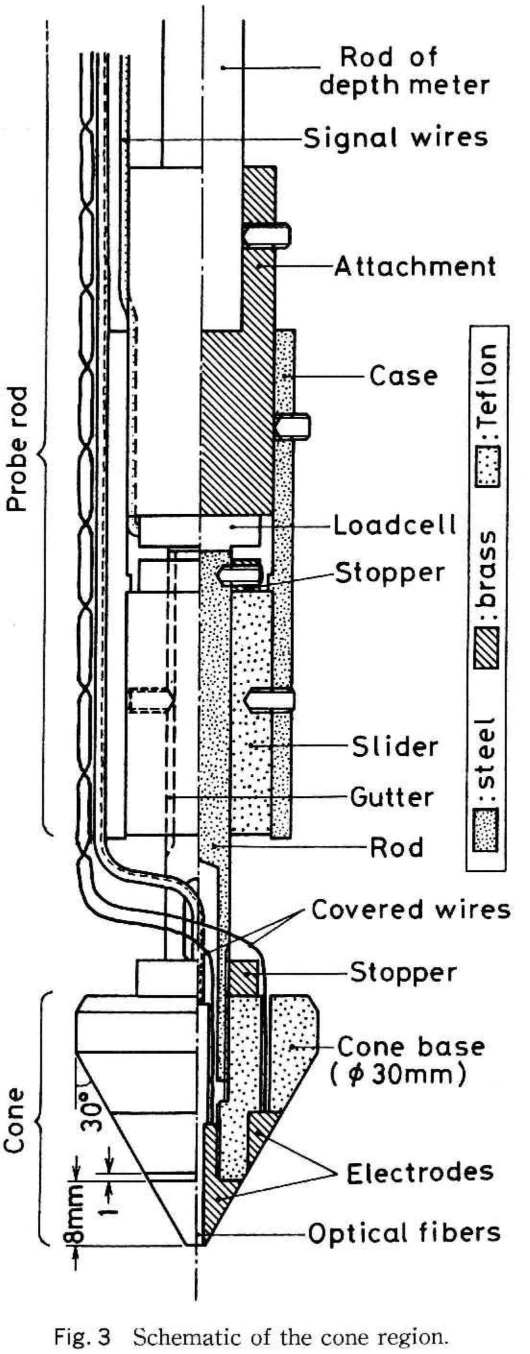

Fig. 3 Schematic of the cone region.

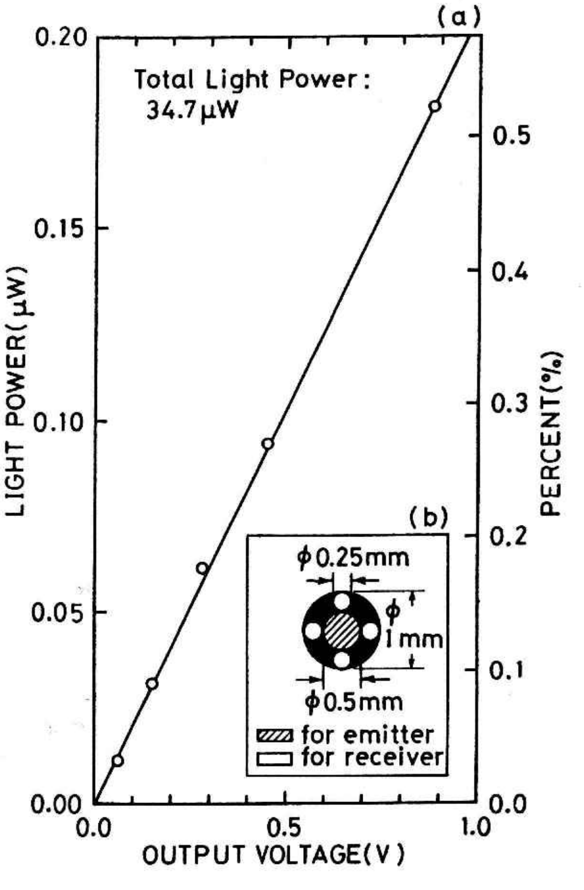

Fig. 4 Light power vs output voltage (a) and cross section of the fiber optics at the end of the probe (b).

$$R=(I_r/I_i)\times 100\ (\%) \tag{1}$$

where I_r and I_i are the total intensities of the reflected rays and incident rays, respectively. The intensity of light emitted from the LED of the NGR is considered to be constant during measuring. To illuminate the snow an optical fiber of 0.5 mm in diameter is used, and to measure the reflected rays from the snow particles four optical fibers each of 0.25 mm in diameter are used. As shown in Figure 4(b), one end of these optical fibers is opened at the end of the cone, the other is connected to the photometer.

2.2 Penetration force

Penetration force F (in Newtons) in this paper refers to the total resistance force of the penetrating cone within the snow. A rod connected to the cone is contacted with a small loadcell (see Figure 3). The cone angle is 60 degrees, the same as that of the traditional rammsonde and its maximum diameter is 30 mm. The capacity of the loadcell is 100 N. A very small amplifier (NEC San-ei, Type 4142) is connected to the loadcell.

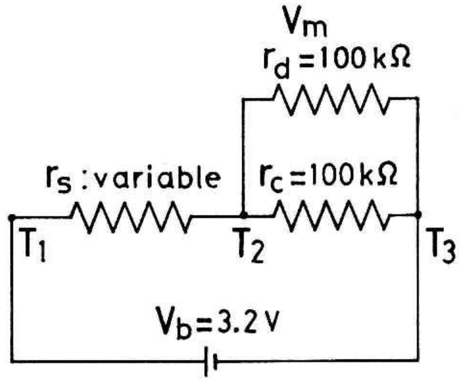

Fig. 5 A circuit to measure electrical conductivity. T_1, T_2 : electrodes, T_2, T_3 : measuring points for output voltage.

2.3 Electrical conductivity

The electrodes, made of brass, are two rings around the cone, which are separated by a distance of 1 mm along the depth (see Figure 3). To measure the electrical conductivity of the snow between the electrodes, a simple circuit was designed as shown in Figure 5. The electrical conductivity is defined as the inverse of the resistance, i.e.,

$$E=1/r_s \tag{2}$$

where, E is electrical conductivity (in mhos), and r_s is the electrical resistance of the snow calculated by Ohm's law. However the input impedance r_d of the data recorder is comparable with both r_s and the constant resistance r_c, so that r_d is added into the calculation,

$$r_s=(V_b/V_m)/(V_m/(1/r_c+1/r_d)) \tag{3}$$

Here, V_b, V_m are voltage of the battery and variable voltage measured between the electrodes within the snow, respectively.

2.4 Frequency responses of the sensors

All sensors constituting the NGR have high frequency responses as shown in Table 1. This is the most significant performance to detect the thin layers in the snowpack.

3. Interpretation of the NGR Data

Interpretation of data obtained by the NGR, namely, the reflectivity, the penetration force and the electrical conductivity are essential to understand the state of the snowpack.

3.1 Reflectivity

Reflectivity decreases with low density, high liquid water content and large grain size (Abe, 1991). Abe (1991) ascertained that for nearly the same grain size as compared with the diameters of the optical fibers,

Table 1 Specifications of the NGR.

ITEM	RANGE	RESOLUTION	FREQUENCY RESPONSE
DEPTH	0 - 1 m	0.0001 m	1 kHz
REFLECTIVITY	0 - 3 %	0.01 %	1 kHz
FORCE	0 - 100 N	0.01 N	5 kHz
CONDUCTIVITY	0 - ∞ Ω^{-1}	Variable	> 1 kHz

deflection from the average signal level of the reflectivity increased during the process of penetration. Certainly, the reflectivity is related to the other optical properties. The optical properties are attributed to changes of grain shape and the size of the snow particles, density, water content and impurities of the snow. It can be generally assumed that reflectivity increases with the albedo or diffusion coefficient of snow. Theoretical and observational studies suggest that the albedo and the diffusion coefficient decrease as the grain size of the snow particles increases (Grenfell and others, 1981 ; Choudhury, 1981), and as the water content of the snow increases (Hukami and Kojima, 1980).

When the cone is penetrating the snowpack, it is possible for a piece of pulverized snow to form on the penetrating end of the cone, because the end face is flat. However the diameter of the flat face is only 2.3 mm, so the pulverized zone must be small.

3.2 Penetration force

The penetration force depends on the strength of the snow layers. The resistance force against the penetrating cone is usually correlated with both the compressive and shear strengths of the snow (Kinoshita, 1964). Kinoshita (1958) also found that snow is deformed destructively above a certain critical speed of the compression. The certain critical speed of the destructive deformation for snow reported by Kinoshita (1958) is 1.7×10^{-4} m/s at 0°C. The penetration rate of the NGR obviously exceeds the critical speed, therefore, the speed is in the destructive deformation. In the field test of the digital resistograph Brown and Birkeland (1990) showed that there is no appreciable affect on performance for penetration rates between 0.1 m/s and 0.5 m/s, though above 0.7 m/s there appeared to be some shift in output.

3.3 Electrical conductivity

Electrical conductivity is measured in order to detect a wet snow layer. When the cone is penetrating the snowpack, a pulverized snow region is formed around the cone (Kinoshita, 1964). The NGR has two ring electrodes around the cone as shown in Figure 3, therefore, electrical conductivity is measured on the snow disturbed around the cone.

Electrical conductivity consists of both the surface and bulk conductivities of the snow, and can be primarily related to liquid water content, specific surface, density and impurities of snow. Matsuoka (1968) reported from a field test that the most sensitive parameter for the electrical resistance of the snow is the liquid water content. The direct current electrical conductivity of the snow increases suddenly at the melting point (0°C) compared to the freezing temperature (Langham, 1981). At temperatures above approximately -25°C, both the surface conductivity and bulk conductivity of ice are comparable with each other (Hobbs, 1974). Therefore in the case where the snow has a much greater specific surface than ice the surface conductivity of the snow dominates over its bulk conductivity. Concerning the impurities Hammer (1980) found that a direct electrical current between two electrodes with a high voltage field on the surface of the ice core at -14 °C, has a good relationship with the acidity included in the ice core.

4. Results of the Field Test

4.1 Preliminary procedure

The NGR was tested at the Alta ski area near Salt Lake City, Utah in the United States. All data was stored on the magnetic tapes of a four-channel analog recorder, and the data was converted to digital output by an A/D converter. The sampling frequency was set at 500 Hz. The periods spent on a single measurement were between 2 to 10 seconds. The total number of the digital data for a measurement is 20,000 (10 sec × 500 Hz × 4 ch) in maximum. Figure 6 shows an example of the time series of ; (a) the depth where the tip of the probe is located, (b) reflectivity R, (c) penetration force F and (d) direct current electrical conductivity E. Using the same data set as shown in Figure 6 through the computer system, snow profiles for three different kinds of physical parameters, i.e.,

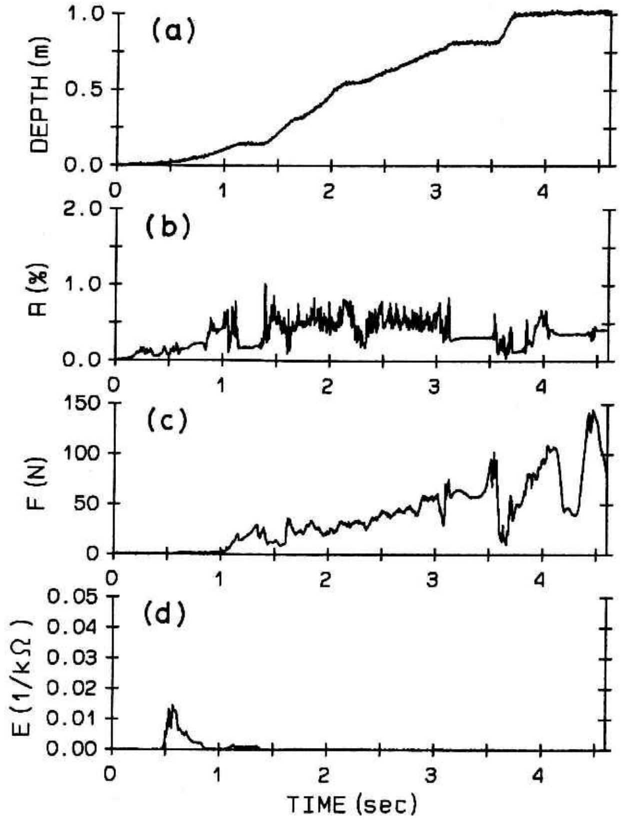

Fig. 6 An example of the time series data obtained by the NGR.

the reflectivity, the penetration force and the electrical conductivity along the depth are plotted as shown in Figure 7.

4.2 Case 1 (15 : 05, Feb. 26, 1992)

Figure 7 shows a comparison between the NGR data and snow pit data measured manually at the same point on a slope. The depth was measured along the normal axis to the slope. All parameters are shown in a linear scale, and the snow pit data are summarized under the International Classification (IASH, 1990) system. The mean penetration rate of the probe was 0.5 m/s ranging 0 - 0.75 m/s. In the afternoon the snow surface melted due to solar radiation under clear sky, consequently, a wet snow layer of high density was formed on the surface as shown in Figure 7. In the same figure low reflectivity, low penetration force and high electrical conductivity on the surface indicate the existence of a weak wet snow layer. The reflectivity changes very quickly with depth and decreases at both the depth hoar and the granular snow. Among the three parameters measured the reflectivity is the most sensitive parameter. The penetration force increases gradually with depth to 0.8 m, however, the penetration force decreases in the depth hoar layer between the depth of 0.87 m and 0.98 m. A small spike of the penetration force at the depth of 0.3 m corresponds to two ice plates as shown by the snow pit data and is marked as an arrow (A) in Figure 7. The penetration force also increases suddenly at 1.0 m depth because the cone penetrated a hard layer formed by ski tracks. The operator could not penetrate the hard layer with the probe and the force exceeded the loadcell's capacity.

4.3 Case 2 (21 : 40, Feb. 28, 1992)

The NGR can be used to obtain snow profile data even during the night. Figure 8 shows the NGR profile obtained under a clear sky at night after two days at

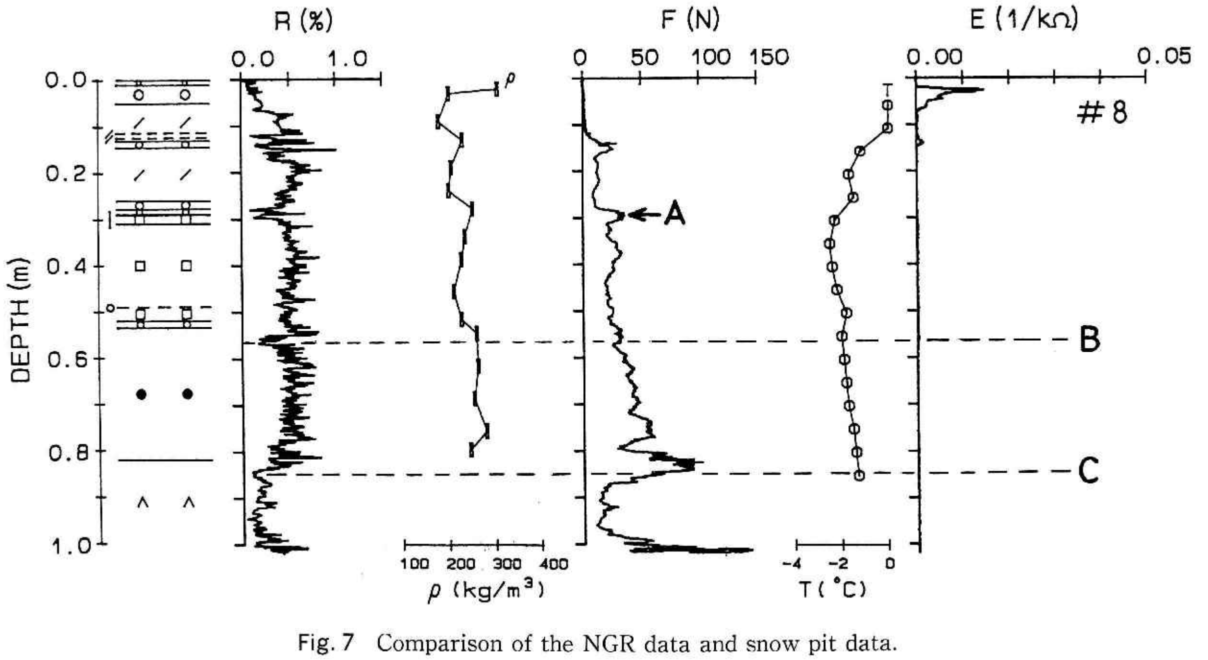

Fig. 7 Comparison of the NGR data and snow pit data.

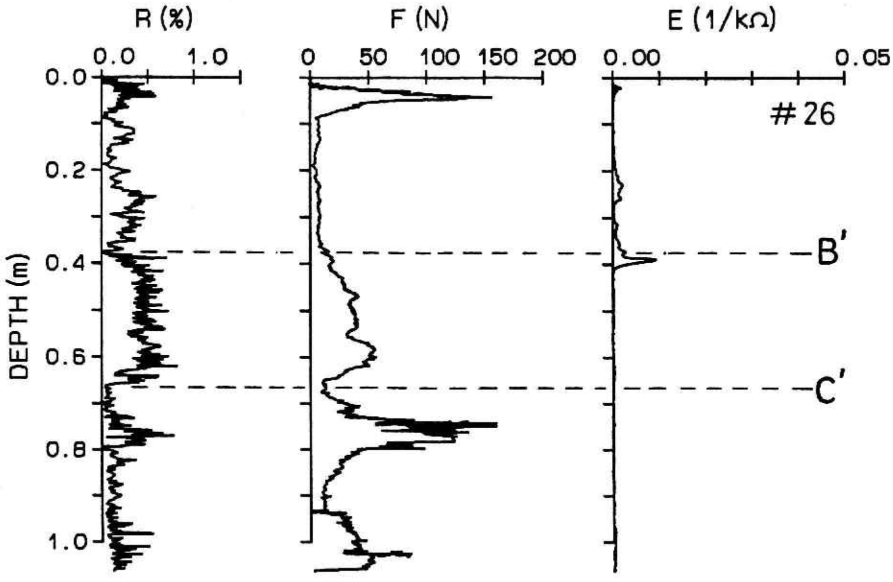

Fig. 8 An NGR profile at the same location as shown in Figure 7 two days later.

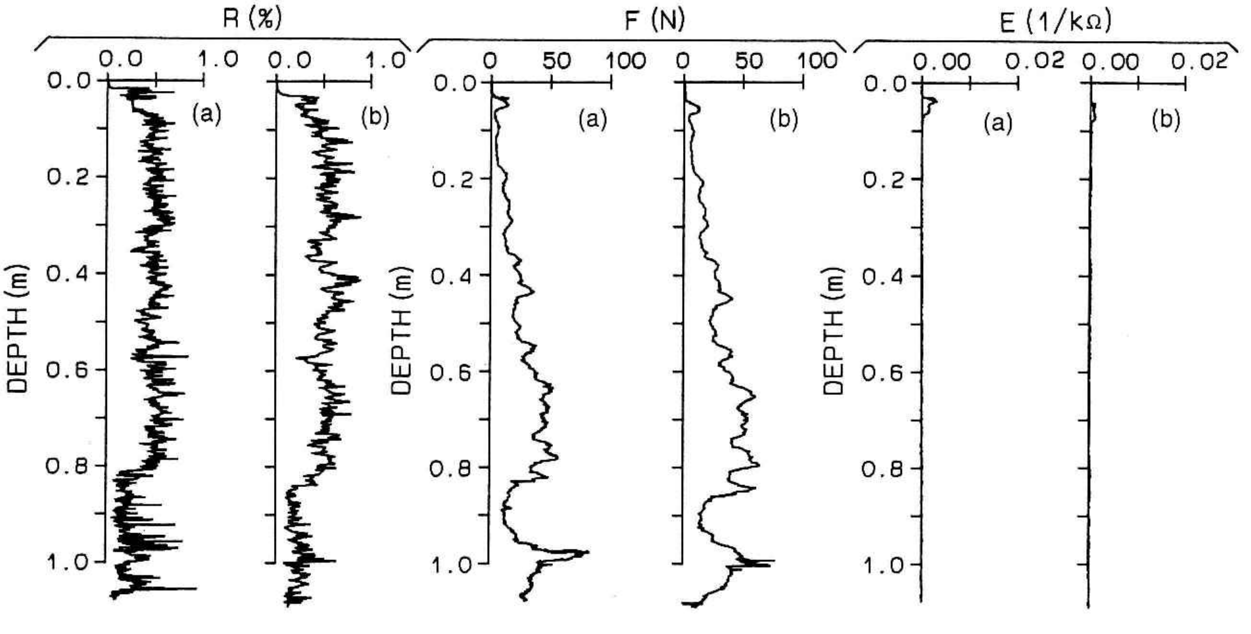

Fig. 9 Repeatabilities on the NGR data in two cases at the same location. Penetration rates were 0.38 m/s and 1.14 m/s for (a) and (b).

the same place used for case 1. The mean penetration rate was 0.42 m/s ranging 0 - 1.7 m/s. In this time a crust layer was formed on the snow surface, so that the penetration force on the surface increased greatly. Low reflectivity, a low penetration force and two peaks of electric conductivity at the depths of 0.23 m and 0.39 m indicate that weak wet snow layers remain with no change under the crust layer. It was considered that the snow layers of the surface to a depth of 0.56 m (B) in Figure 7 were depressed down to the layers between the surface and a depth of 0.38 m (B′) in Figure 8. The layers between the depths of 0.56 m (B) and 0.85 m (C) as shown in Figure 7 must be kept in the layers between the depths of 0.38 (B′) and 0.66 m (C′) in Figure 8.

4.4 Repeatabilities of the NGR

To ascertain the repeatabilities of the NGR data two to three shots of measurement from 0.2 m to 0.3 m apart from each other were conducted at one measurement location. The two results are compared in Figure 9. The penetration rates of these two cases were 0.38 m/s and 1.14 m/s for (a) and (b). Concerning repeatabilities on the reflectivity and penetration force, the NGR produced similar profiles. Brown and

Birkeland (1990) proved a good repeatability on the penetration force with their newly designed sonde. Abe (1991) also proved a good repeatability on the reflectivity with his new sonde. The electrical conductivity by this NGR showed a good correspondence in regard to depth but with a slight difference in magnitude.

4.5 Detection of thin layers

A performance on detection of thin layers is important for a ram-type instrument. As mentioned above, among these three parameters reflectivity is the most sensitive parameter. Since the intensity of reflective rays by snow particles decreases exponentially as the transmission distance increases, the reflectivity is significantly affected by the close region of the end of the cone. The penetration force of the cone itself is not able to detect a soft thin layer which is sandwiched by two hard layers and when the thickness is usually less than the height of the cone (Haefeli, 1954). To measure the electrical conductivity, two ring electrodes with a distance of 1 mm along the cone axis are used. As described above the snow region around the cone which the electrical conductivity is intended to measure is pulverized by the penetrating cone. However when the wet snow layer is thicker than the distance between the two electrodes, considerable electrical conductivity can be detected.

5. Conclusions and Discussion

A new generation rammsonde having multiple sensors with a high frequency response was designed and tested. The NGR can simultaneously measure three kinds of snow profiles, i.e., optical, mechanical and electrical properties of snow. The NGR is not able to obtain the absolute physical parameters such as the temperature and density of the snow, but reflectivity, the penetration force and electrical conductivity can be measured easily and quickly by an analytical method through a computer system. To obtain the absolute values of snow temperature and density, further investigations must be made. For example by fixing a thermometer with a high frequency response onto the NGR, snow temperatures can be measured (Dowd and Brown,1986). To specify the state of the snow, for example, metamorphism of snow, the parameters can be compared each other. These mutual comparisons of the NGR data will yield much useful information concerning the internal structure of the snowpack. For example, the NGR can detect thick and/or thin layers, strong and/or weak layers, dry and/or wet layers, ice plates, etc.

For thin layers the reflectivity is the most sensitive parameter of the three parameters. The NGR can also be used to obtain the profile data during the night. Instead of an analog data recorder for data storage, digital memories should be replaced for practical use in the field. The 100 N capacity of the loadcell prepared for measuring the penetration force was underestimated to penetrate hard layers. To measure deeper snow layers than 1 m of this NGR, a longer probe must be prepared.

A lot of the data obtained by the NGR can identify the state of the snow quantitatively. The NGR will improve the field studies of snowcover and avalanche forecasting in the future.

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複合センサー付き新世代ラムゾンデ

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要　旨

複数のセンサーを持つ新世代の積雪検層ゾンデ（NGR）を考案し，実試験を行った．NGR は，数秒間のうちに積雪の成層構造を調べることが可能である．NGR は，ヴィーデマン効果により積雪表面からの深さを測定し，同時にコーン先端における積雪層の 660 nm の電磁波の拡散反射率，コーンの貫入抵抗およびコーン周辺の積雪の直流電気伝導度を測定する．これらの 4 つの項目は，連続的にかつ一瞬のうちに測定・記録される．これらのデータから 3 種類の異なった垂直分布が得られる．NGR は，積雪の光学的，力学的および電気的性質の相互比較により，積雪層の層厚，強弱，乾湿などを判別することができる．

キーワード：ラムゾンデ，積雪，計測器