Snow Densities to Estimate Ground Snow Loads in Mountainous Areas of Japan

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Introduction

It has recently been reported that some buildings and bridges in mountainous areas have collapsed due to heavy snow loads. When constructing new facilities in snowy regions, it is necessary to define the ground snow load at the site in advance. In Japan the ground snow load is usually obtained from the maximum snow depth multiplied by mean snow density. The maximum snow depth at a site is usually defined by statistical analysis based on snow data around the site. To obtain the mean snow density some guidelines prepare quantitative definitions based on snow data observed in flat land areas (Mihashi *et al*., 2001; Sakurai and Joh, 2001, etc.). The mean snow densities described in these guidelines increase with snow depth. However no attempt has been made to apply the quantitative definitions in the guidelines to very deep snow in mountainous areas.

Snow Observation Network

A snow observation network comprising seven observation sites was established in mountainous areas in 1994 by the National Research Institute for Earth Science and Disaster Prevention (Nakamura *et a1.*, 1997). Five observation sites were simultaneously installed at the foot of various mountains throughout Japan. The observation sites

Figure 1: Data Collection Platform (DCP).

are distributed from Hokkaido to the San-in district (Table 1). Maximum snow depths exceeding 5 m have occasionally been recorded in Japan. A Data Collection Platform (DCP) was developed at each station by T. Kimura and others (Shimizu *et al.*, 1996). Figure 1 shows an example of the DCP installed in Iwakisan at 1,238 m above sea level. Data on the following items have been obtained from the DCPs installed at each site: snow depth, snow weight, air temperature and solar radiation. The infrared optical snow depth meter (Kimura *et al.*, 1975) and the pressure pillow type snow weight meter with a metal wafer (Kimura, 1977) were used in this study. Careful maintenance was conducted for both instruments prior to the winter for each year studied. Furthermore, snow depth and snow weight were observed manually in mid winter at some observation sites, and were compared with those measured by the DCP. It has been confirmed that both values corresponded with each other. All data from some sites were automatically transferred to the institutes at hourly intervals via dedicated phone lines. For the remaining stations, all data were stored into a data logger every hour and were downloaded to a computer at one time every spring.

Table 1: Snow observation sites. Upper: Mountain, Lower: Foot.

District	Site Name	Symbol	Latitude North	Longitude East	Distance (km)	Elevation (m)	Difference (m)
Hokkaido	Tokachidake	TK	43°29'	142°36'	15	520	270
	Biei	BE	43°36'	142°30'		250	
Tohoku-North	Iwakisan	IW	40°39'	140°18'	16	1238	1218
	Fujisaki	FJ	40°39'	140°29'		20	
Tohoku-South	Gassan	GS	38°29'	140°00'	43	710	538
	Shinjo	SN	38°47'	140°19'		127	
Hokuriku-East	Okutadami	OK	37°09'	139°14'	42	1205	1108
	Nagaoka	NG	37°25'	138°53'		97	
Hokuriku-Middle	Myoko	MK	36°52'	138°05'	31	1310	1297
	Takada*	TD	36°06'	138°15'		13	
Hokuriku-West	Hakusan	HS	36°11'	136°38'	45	835	829
	Kanazawa*	KN	36°35'	136°38'		6	
Sanin	Daisen	DK	35°20'	133°35'	17	875	720
	Hokimizokuchi	HM	35°18'	133°25'		155	

*: Established by the Japanese Meteorological Agency

Mean Snow Densities

Mean snow densities are obtained from the network by direct and continuous measurements of both snow depth and snow weight on the ground. Three types of mean snow densities, ρ_1, ρ_2, and ρ_3 are calculated at different times for each site every winter. ρ_1 and ρ_3 are densities for maximum snow depth, with the maximum snow weight appearing in the winter for both parameters. ρ_2 is a density that is logically determined to obtain the maximum snow weight from the maximum snow depth, which is calculated from the maximum snow load divided by the maximum snow depth in the winter. ρ_2 refers to the equivalent snow density. To estimate the snow load on the ground the equivalent snow density, ρ_2 is usually used. The relationship between the three densities can be defined as $\rho_1 < \rho_2 < \rho_3$.

Results

Data for both snow depth and snow weight were collected for a maximum period of 10 years using the snow observation network. Most maximum snow depths were recorded during the period from the middle of February to the middle of March. Conversely, the maximum snow densities were recorded during the period from the beginning of March to the end of April. The maximum snow depth and the maximum snow weight were respectively recorded during a period of between 2 - 56 days.

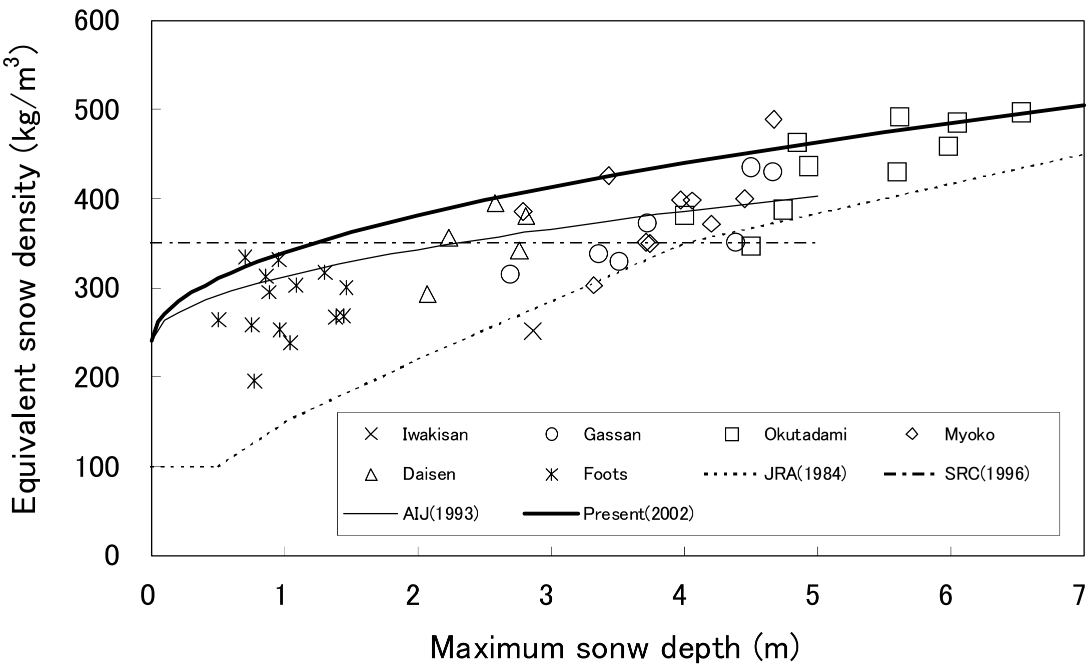

Figure 2: Equivalent snow density, ρ_2 vs maximum snow depth, H_{max}

Figure 2 shows the equivalent snow density, ρ_2 vs the maximum snow depth, H_{max}. Each plot was obtained at individual sites every winter using the snow observation network. At some plots less than 2 m of the maximum snow depth were obtained at the foot of the mountains. All data used in this study were observed daily at 9:00 hours. The three thin lines indicate guidelines prepared by the following three organizations, the Japan Road Association (1984), the Architectural Institute of Japan (1993) and the Snow Research Center (1996). The measured densities are greater than the estimated densities, exceeding 4 m with maximum snow depth in particular. It is considered that since the maximum snow weights are usually obtained by snow pit observation manually at 10-day intervals, the values are smaller than those observed on a daily basis. Consequently, the other three guidelines sometimes produce values that are underestimated. The new guideline, which includes extremely deep snow, is conducted using the following equation,

$$\rho_2 = 100 * SQRT(H_{max}) + 240. \qquad (1)$$

Here, the number of 240 is almost the same as that for normal snow depth reported by Sakurai and Joh (2001). Equation 1 shows the maximum equivalent snow density at each maximum snow depth, making this the guideline with the highest level of safety in application among all the guidelines currently available. Equation 1 should therefore be used in Honshu, since no data has been obtained in Hokkaido to date.

Concluding remarks

Maximum equivalent snow density was conducted using the maximum snow depth and the maximum snow weight obtained on a daily basis for each winter over a 10-year period. The present guideline is considered to have the highest degree of safety when used in mountainous areas in Honshu, Japan.

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