ABSTRACT: A vibration experiment was conducted to understand the seismic response of the snowpack on a slope. The following were found. 1) The dynamic magnification factor of a snowpack on a slope increases linearly with increase in the height of the snowpack when the input seismic motion has a short period. 2) Regardless of the snow grain shape, the natural mode of a snowpack on a slope is the primary mode. 3) The dynamic magnification factor is greater for melt forms than for rounded grains, and is greater for wet snow than for dry snow. Using the results of this experiment, we suggest that the method that estimates earthquake-induced avalanche occurrences that incorporate the stability of the snowpack on the slope by using the modified static lateral force method.

KEYWORDS: vibration experiment, snowpack on a slope, seismic response

1. INTRODUCTION

During the snowy season, avalanches caused by earthquakes have the potential to obstruct activities and rescue operations. It is important to consider for such situations under the assumption that earthquakes can cause avalanches. To enhance disaster prevention and damage mitigation with respect to earthquake-induced avalanches, clarification of the occurrence mechanism of earthquake-induced avalanches and proposals for a risk assessment method for such avalanches are thought to be useful.

There have been many reports of avalanche damage following earthquakes in the U.S.A., Russia, the western Himalaya Mountains, Switzerland, Japan and elsewhere (e.g., Podolskiy et al., 2010a; Pérez-Guillén et al., 2014). To clarify the conditions under which earthquake-induced avalanches occur, Podolskiy et al. (2010a) investigated the relationship between the location of earthquake-induced avalanches and the scale and distance from the epicenter of the earthquake by using the previous cases. As for the stability of the snowpack on a slope, Chernouss et al. (2002), Matsuzawa et al. (2007), Kamiishi et al. (2012a), Matsushita et al. (2013a) and Pérez-Guillén et al. (2014) conducted theoretical examinations in which seismic motions were considered. Chiba et al. (2015) conducted a seismic response analysis in which the snowpack on the slope was modeled by a particle system shear model.

There have been reports on analyses based on vibration experiments using snow blocks that reproduced the snowpack on a slope during an earthquake. Podolskiy et al. (2010b) demonstrated that snowpack failure resulting from seismic motion is initiated when tensile failure occurs in a weak layer. Kamiishi et al. (2012b) examined the failure of a snowpack that included a weak layer and showed that it is possible for the horizontal vibration to affect the snowpack more than the vertical vibration does. Matsushita et al. (2013b) demonstrated that the acceleration in the direction in which the snow layers are subjected to tensile force was greater than the acceleration in the direction in which the snow layers are subjected to compressive force.

The above-stated assessment methods for the stability of the snowpack on the slope, which consider the seismic motion, assume that an earthquake-induced avalanche occurs when the ground surface acceleration generated by the seismic motion is the same as the acceleration of the snowpack on the slope. However, depending on the magnitude and frequency of the seismic motion,
the snowpack may undergo greater acceleration than the ground surface does. In addition, the transfer of seismic acceleration in the snowpack may differ with differences in grain shape. It is thought to be necessary to clarify the basic relationship between the state of snowpack and the seismic motion. In this study, the authors conducted vibration experiments to investigate the characteristics of the seismic response of the snowpack on a slope. Based on the experimental findings, we proposed a method for estimating the risk of earthquake-induced avalanches in which snowpack stability is considered in static analysis. Our current study addresses only the lateral vibration, and the avalanches are assumed to start as a result of shear fracture.

2. EXPERIMENTAL METHODS

The experiment was conducted at the Ishikari Test Field, Japan (N43°12'55", E141°23'23") from January 2014 to March 2015. The measured items were the acceleration of the snowpack specimen (hereinafter: "the specimen"), the acceleration of the shaking table, and certain physical properties of the specimen (snowpack height, and snow layer structure, grain size, density, hardness and temperature).

First, snow blocks were cut from natural snowpack to make the specimens. Each snow block was re-shaped into a parallelogram specimen (angles: 60° and 120°) 40 cm wide by 55 cm long by 40 to 70 cm high. A slope model (50 cm wide by 55 cm long) with an angle of 30° was anchored to a shaking table (200 cm wide by 200 cm long: SPTDU-20K-85L-50T) installed inside a building. The specimen was placed on the slope such that the snow layer structure would parallel the slope (Fig. 1). To prevent the underside of the snowpack from sliding, 5-cm nails were installed on the slope at 6-cm intervals in the downslope and cross-slope directions. In addition, the L-steel member on the acceleration (positive) side was fixed with a clear acrylic board and vises.

Next, 3 to 6 accelerometers (18 × 18 × 24 mm, 40g: ASW-5A) were inserted into the snowpack with a vertical spacing of 10 to 20 cm. For some experiments, we used specimens weighted with a 15-kg lattice weight (30 cm wide by 45 cm long by 5.3 cm high) fixed to the snowpack with 32 U-shaped fixtures each weighing 0.075 kg (8 cm wide by 15 cm long).

After the accelerometers were installed, the specimen was accelerated in the horizontal direction for 3 min (Fig. 1). By means of sweep acceleration where the acceleration of the shaking table was fixed and the frequency was varied between 1 and 10Hz. The range of input acceleration to the shaking table was varied between 0.1G and 0.9G (1G = 9.81 m s⁻²). The accelerations of the specimen and the shaking table were measured every 0.04 sec.

3. EXPERIMENTAL RESULTS

3.1 Response characteristics of the specimens

The vibration experiment was conducted 194 times, with combinations of specimen conditions and accelerations varied. In this experiment, the maximum value of the rate of acceleration of the snowpack on the shaking table (hereinafter: “the dynamic magnification factor” (DMF)) of snowpack on the slope was found to be about 10Hz (period: 0.10s) for all specimens. The DMF was higher for greater input accelerations and greater weights, and for higher locations in the snowpack varied from 1 to 10Hz. Figure 2 shows the relationship between frequency and DMF.

3.2 The DMF by grain shape and height

Using the results of this experiment, we compiled the following data on each specimen: snow grain shape, mean snow density (kg m⁻³), mean snow hardness (kN m⁻²), specimen weight (kg), snowpack depth (m), “weight converted snowpack depth (m)” for the weighted specimen (the total of...
the specimen’s weight and the weight is converted to snow depth), input acceleration (G) and the max. value of DMF (hereinafter: "max. DMF") measured by the accelerometers. We measured the max. DMF at various input accelerations and created 800 data profiles. In this study, we classified the snow type as "dry rounded grains", "wet rounded grains", "dry melt forms" or "wet melt forms", based on the 50% higher grain shape and dry or wet of the specimen. The accelerometers were installed at four height ranges: 10 - 20 cm, 30 - 39 cm, 40 - 49 cm, and 50 - 60 cm.

We performed single regression analyses to obtain correlation coefficients. The objective variable was the max. DMF for each height range and snow types. The explanatory variable was one of the following: input acceleration, mean snow density, mean snowpack hardness, specimen weight, snowpack depth. The analyses found a positive correlation between the heights of the accelerometers and the input acceleration (G), weight (kg), and the weight converted snowpack depth (m) in all types of specimens and for all levels of accelerometer height. For the correlations between accelerometer heights and snow depth (m), mean density (kg m⁻³), and mean hardness (kN m⁻²), some of the data points plot with positive correlations, others with negative correlations, and yet others with near zero correlations. We made multiple regression equations for each group of accelerometers grouped in accordance with the range of installed elevation from the underside of the snowpack (i.e., 10 - 20 cm, 30 - 39 cm, 40 - 49 cm, and 50 - 60 cm) for each snow type (hereinafter: "accelerometer elevation") (Tbl. 1). Where, y is the max. DMF, x₁ is the input acceleration (G) and x₂ is the weight (kg). The weight converted snow depth was treated as being included in the weight, because the snow depth was determined based on the weight. Wet rounded grains was excluded from this analysis because too few cases with such snow quality were found.

When the DMF at the frequency of 10 Hz is 100%, the average value of the increase ratio in the DMF was calculated by using the data for each grain shape at the 30 - 39 cm accelerometer height and at 0.5 Hz intervals. For each snow type, the acceleration at 1 Hz (period: 1.0 S) was 0%; in other words, the acceleration was about the same as that of the shaking table. However, when the frequency increased gradually and approached 10 Hz (period: 0.10 S), the acceleration gradually increased. The DMFs increased about 80 percentage points from 5 Hz (period: 0.20 S) to 10 Hz (period: 0.10 S), and about 25 percentage points between 9 Hz (period: 0.11 S) and 10 Hz. No marked differences in the tendency of increase based on the grain shape were found. The relationship between snow type and increase in the DMF relative to the frequency increase was determined as shown in Table 2.

### 3.3 Trial calculation for DMF of snowpack on a slope

We calculated the max. DMF, y, by substituting an arbitrary input acceleration for x₁ and by substituting the mean snowpack weight for each snow type for x₂. The snowpack weight was calculated as the product of volume and density. The volume of snow for each snow type was obtained by multiplying the mean cross-sectional area of the specimen at the time of the experiment (0.176 m²) by the mean value of converted snowpack depth, which was 0.689 m for the dry rounded grains, 0.658 m for the dry melt forms and 0.624 m for the wet melt forms. Density was set in accordance with the Japanese Dictionary of Snow and Ice (2014) as follows: 325 kg m⁻³ for dry rounded grains, 400 kg m⁻³ for dry melt forms and 500 kg m⁻³ for wet melt forms. Consequently, the values calculated for normal snowpack weight were as follows: 39.4 kg for dry rounded grains, 46.3 kg for dry melt forms and 54.9 kg for wet melt forms.

### Tbl. 2: Relationship between the increase ratio of DMF (v (%)) and the frequency (ν), when the DMF at 10 Hz is 100 %

<table>
<thead>
<tr>
<th>Snow type</th>
<th>N</th>
<th>Relational equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rounded grains</td>
<td>97</td>
<td>y = 0.041x²</td>
<td>0.989</td>
</tr>
<tr>
<td>Dry melt forms</td>
<td>44</td>
<td>y = 0.045x²</td>
<td>0.992</td>
</tr>
<tr>
<td>Wet melt forms</td>
<td>48</td>
<td>y = 0.041x²</td>
<td>0.994</td>
</tr>
</tbody>
</table>

Note: Wet rounded grains was excluded from this analysis due to the small number of such samples.
From the normal snowpack weights and the multiple-regression equation for arbitrary acceleration (Tbl. 1), the DMFs were obtained. Figure 3 plots the DMF for each mean accelerometer elevation (Tbl. 1). A linear approximation was made for the DMF plotted for each input acceleration. The results show that the DMF increases proportionally to the accelerometer elevation. The acceleration is higher for the accelerometers at higher elevations. Consequently, regardless of the snow type, the natural mode of specimens that assumed snowpack on slope is the primary mode. At the acceleration of 0.2G, the distribution of DMFs for melt forms has roughly the same shape as that for rounded grains. At accelerations of 0.4G or greater, the DMF is greater for melt forms than for rounded grains, and the DMF is greater for wet snow than for dry snow.

4. ESTIMATION OF THE LIKELIHOOD OF EARTHQUAKE-INDUCED AVALANCHES

First, the snowpack stability on the slope (SI: stability index) was assessed. Then, the risk of avalanche occurrence was estimated by using the results of the vibration experiment in Chapter 3 and the snowpack data measured at the time of previous avalanches.

4.1 Stability of the snowpack on the slope

The SI value is used for assessing the stability of the snowpack on the slope and for indicating the occurrence of avalanches (Equation (1) and Fig. 4 (a), e.g., Japanese Society of Snow and Ice, 2010).

\[ SI = \frac{\Sigma_s}{\sigma_n \sin \psi} = \frac{C + \sigma_n \cos \phi}{\sigma_n \sin \psi} \tag{1} \]

Where, \( \Sigma_s \) is the shear strength (N m\(^{-2}\)) of the subject snow layer, such as a weak layer; and \( \sigma_n \) is the snowpack load (N m\(^{-2}\)) per unit volume above the weak layer as determined from the thickness \( D \) (m), density \( \rho \) (kg m\(^{-3}\)), and gravitational acceleration \( g \) (m s\(^{-2}\)) of the layers above the weak layer \( (\sigma_n = g \rho D) \). \( \psi \) is the slope gradient (°). The right-hand side of Equation (1) is the shear strength \( \Sigma_s \) expressed in terms of the Mohr-Coulomb yield criterion. Maeno and Kuroda (1986) maintained that when the density of snow is low or the vertical load \( \sigma_n \) is great, application of this criterion does not produce accurate results because of the compressibility of snow. However, Nakamura et al. (2010) demonstrated that the criterion held well even for low-density snow. Therefore, the authors of this study assume that the Mohr-Coulomb yield criterion holds for all types of snow.

\( C \) is the cohesive force (N m\(^{-2}\)) of snow particles. In this study, a measured value of shear frame index SFI is used. \( \tan \phi \) is the internal friction coefficient of the snow particles.

For actual snowpack on a slope, the critical value for avalanche occurrence is not necessarily 1 at the stability expressed in Equation (1) (Japanese Society of Snow and Ice, 2010), because other factors such as lateral connection between the sides of the snowpack and the sides of the surrounding snow cover influence the stability of the snowpack on the slope SI. To clarify the critical value for avalanche occurrence, examinations for critical stability index SI have been done using actual cases of avalanches. For example, in Canada, a value of about 1.5 was presented as the threshold value of stability indicator SI for avalanche occurrence (Jamieson, 1995). A study on avalanche occurrences at roadside slopes in Hokkaido, northern part of Japan, in which a snowpack model was used to investigate the snowpack stability index SI at the time of avalanche occurrence, found that avalanches tend to occur when the snowpack stability index SI is 2.5 or lower and that the number of avalanches markedly increases when SI falls to 2.0 or lower (Nishimura et al., 2005). Based on the above, a stability index of 2.0

Fig. 3: Relationship between accelerometer elevation and DMF based on experiment (10Hz).
or lower is considered to be the threshold for avalanche occurrence in this study, and an SI of 1.5 - 2.0 is classified as "small risk", 1.0 - 1.5 is classified as "middle risk", and 1.0 or lower is classified as "great risk".

4.2 Stability of the snowpack on the slope considering seismic motion

The stability of the snowpack on the slope at the time of an earthquake $S_{IE}$ is expressed by Equation (2), which is obtained by adding the horizontal seismic coefficient $a$ (Fig. 4 (b)), as an external force, to Equation (1) (e.g., Matsuzawa et al., 2007).

$$SI_E = \frac{C + \sigma_n (\cos \psi - a \sin \psi) \tan \varphi}{\sigma_n (\sin \psi + a \cos \psi)}$$

The horizontal seismic coefficient $a$ of Equation (2) is a ratio of the horizontal acceleration of seismic motion (gal) to the gravitational acceleration (gal), which is a horizontal acceleration (G). The horizontal seismic coefficient $a$ is used for assessing the stability of the embankment at the time of earthquake and for examining the aseismic performance of road facilities (Japan Road Association, 2010a; Japan Road Association, 2010b). Therefore, we used the horizontal seismic coefficient $a$ in examining the conditions for avalanche occurrence at the time of earthquake.

When we assume that the natural mode of snowpack on the slope, which was determined in Chapter 3, holds true even for snow depths greater than those in our vibration experiment, the horizontal seismic coefficient $a$ of an arbitrary snow depth $H'$ and frequency $f$ is expressed by Equation (3).

$$a' = a\left(\frac{SR_{10Hz}}{10Hz} - 1\right)IR + 1$$

Where, $SR_{10Hz}$ is the DMF (Tbl. 1, Fig. 3) at the height $H'$ of the snowpack on the slope at 10 Hz, and $IR$ is the rate of increase in DMF for a given frequency when the DMF for 10 Hz is regarded as 100 % (Tbl. 2). In addition to proposing Equation (2), Matsuzawa et al. (2007) proposed the stability index of the snowpack on the slope as $S_{IE}'$. In their proposal, the seismic motion and the tensile force (tensile fracture strength) that is generated by the bonding between snow particles and that acts in the slab on the slope were considered. The index was proposed based on the safety factor assessment of embankment slopes at the time of earthquake. In this study, we propose Equation (4), in which the above-mentioned horizontal seismic coefficient $a'$ is considered in the equation of Matsuzawa et al.

$$S_{IE}' = \frac{CL + \sigma_n L(\cos \psi - a' \sin \psi) \tan \varphi + \Sigma D}{\sigma_n L(\sin \psi + a' \cos \psi)}$$

Where, $L$ is the length of snowpack on the slope (m), $\Sigma$ is the tensile fracture strength of the snow (N m$^{-2}$), and $D$ is the thickness of the snow layer above the weak layer (m).

4.3 Stability of the snowpack on the slope at avalanche occurrence

To investigate the occurrence conditions of earthquake-induced avalanches, Matsushita et al. (2014) examined earthquake-induced avalanches for which snow cover observation data, including avalanche type and snowpack data were available. In the current study, we use four cases of slab avalanches from the report of Matsushita et al. whose peak ground acceleration (gal) and frequency (Hz) were measured by the Strong Motion Seismograph Networks (K-net, KiK-net) of Japan’s National Institute for Earth Science and Disaster Prevention, and we perform a trial calculation for the stability of snowpack on the slope. (Tbl. 3) The snowpacks above the bed surface in the earthquake-induced avalanche in northern Nagano Prefecture were melt forms (Kamiishi et al., 2012a), and those in northern Tochigi Prefecture were mainly rounded grains (Matsushita et al., 2013a). Therefore, we use a relational equation of tensile fracture strength (Eqs. (5a), (5b)) for each snow type developed by Watanabe (1977).

$$\Sigma_{i} = 7.78 \times 10^{-3} \rho_{i}^{2.60}$$

(Rounded Grains) (5b)

$$\Sigma_{j} = 3.40 \times 10^{-4} \rho_{j}^{3.24}$$

(Melt Forms) (5a)
The stability of snowpack on the slope for each of the earthquake-induced avalanches was calculated based on the above. The left graph in Fig. 5 compares the stability $S_{IE}'$ in which the horizontal seismic coefficient $a'\gamma$ is used to consider the DMF (Equation (4)) and the stability $S_I$ in which the $a'\gamma$ is not considered (Equation (1)). There were cases with $S_I$ (shown as the horizontal axis) of 1.5 or lower (i.e., the mid to high degree of avalanche occurrence risk). It was thought that, in these cases, the snowpack on the slope was in an unstable condition before the earthquake. For cases with $S_I$ of 1.5 or higher, the $S_{IE}'$ is 1.5 or lower. It is thought that, in these cases, the snowpack had been relatively stable before the earthquake, and when the external force of the earthquake motion was exerted on the snowpack, it became unstable and avalanches occurred. The right graph in Fig. 5 compares the $S_{IE}'$ determined by using Equation (4) and the $S_{IE}$ determined by substituting the horizontal seismic coefficient $a'$ of the seismic motion into Equation (4) (i.e., the equation of Matsuzawa et al.). The difference between the two is shown as the absolute difference between the calculated $S_{IE}'$ values. In the earthquake in northern Nagano Prefecture (frequency: 11.2 Hz), the decrease in #1 was 0.95 and the decrease in #2 was 0.99. In the earthquake in northern Tochigi Prefecture (frequency: 4.3 Hz), the decrease in #1 was 0.15 and the decrease in #2 was 0.11. The above demonstrates that, for seismic motion with short periods and for snowpack whose snow depth $H'$ below the weak layer is great (Tbl. 3), the decrease in stability is great.

### 4.4 Trial calculation of the risk of avalanche occurrence based on snow depth and horizontal seismic coefficient

When expressing avalanche occurrence likelihood, the use of the stability of snowpack on the slope as an index is not practical, because it is necessary to estimate the stability of snowpack on the slope based on the snowpack observation data each time. We had assumed that the risk of avalanche occurrence increases in stages when the snowpack stability of the slope $S_{IE}'$ is 2.0 or lower, and we conducted a case study to show the avalanche occurrence risk at the time of earthquake. In our study, which is based on Equation (4) and considers snow type, the depth of snowpack $H$ (Fig. 4 (a)) is used as an index. Here, we assume a dry slab avalanche. The model slope shown in Fig. 4 (a) is used, and the
In our current study, to assume faceted crystals that can become a weak layer exists in the rounded grains layer, and the rounded grains layer above the weak layer starts to flow when seismic motion (horizontal motion) with a frequency of 10 Hz causes a shear fracture in the weak layer. The density of 325 kg m\(^{-3}\) is set for rounded grains (Sec. 3.3), and the density of 200 kg m\(^{-3}\) is set for faceted crystals by selecting the smallest value for the density range of 200 - 400 kg m\(^{-3}\) (Japanese Society of Snow and Ice, 2014). For the slope gradient \(\psi\), 40° is selected, because many dry slab avalanches occur on slopes with gradients of 30° - 45°, and the frequency peak of the occurrence distribution is near 40° (McClung and Schaerer, 2006). In addition to the above settings, the variables for Equation (4) are set as follows.

The cohesive force of snow particles in the weak layer \(C\) (N m\(^{-3}\)) is determined by using the relation as shear strength \(\Sigma\), which was measured by Watanabe (1977) in the condition without snow load above the weak layer (Equation (6)). In this case, it is possible to regard \(\Sigma = C\), because Equation (1) gives \(n = 0\) for the snow load \(a_s\).

\[
C = 3.56 \times 10^{-5} \rho^{3.36} \quad \text{(Faceted Crystals)} \quad \text{(6)}
\]

\(C = 1918\) N m\(^{-2}\) is obtained by substituting a density of 200 kg m\(^{-3}\) for faceted crystals into Equation (6).

The internal friction coefficient \(\tan \phi\) is considered in the cases for precipitation particles, decomposing and fragmented precipitation particles, and faceted crystals, but is negligible for the other types of snow (Yamanoi and Endo, 2002; Jamieson and Johnston, 1998). In a previous study, the internal friction coefficient for precipitation particles \(\tan \phi = 0.46 \cdot 2.0\), that for decomposing and fragmented precipitation particles \(\tan \phi = 0.23\), and that for faceted crystals \(\tan \phi = 0.21\) (Seki et al., 1998; Zeidler and Jamieson, 2006; Matsuzawa et al., 2007). In our current study, to assume faceted crystals as the weak layer, 0.21 was set as the internal friction coefficient.

For the thickness of the snow layer above the weak layer \(D\) (m), we used 0.60 m, which was roughly the average value of the occurrence frequency distribution of slab thicknesses (i.e., the thickness above the weak layer) obtained from 200 dry snow slab avalanches examined by McClung and Schaerer (2006).

For the snow load above the weak layer per unit volume \(a_s\) (N m\(^{-3}\)), \(a_s = 1911\) N m\(^{-2}\) was obtained by multiplying 325 kg m\(^{-3}\), which is the density of the rounded grains layer, by the thickness of the snow layer above the weak layer \(D = 0.6\) m and the gravitational acceleration \(g\). The tensile fracture strength \(\Sigma\) (N m\(^{-2}\)) for the snow above the weak layer was obtained as \(\Sigma = 46771\) N m\(^{-2}\), based on Equation (5b), which is an equation for the tensile fracture strength of rounded grains.

For the length of the snowpack on the slope \(L\) (m), 10 m and 20 m were used. The arbitrary snow depth \(H'\) and the horizontal seismic coefficient \(a'\) at frequency \(f\) were obtained using Equation (3), Table 1 and Fig. 3. The arbitrary snow depth \(H'\) can also be determined by using Equation (7).

\[
H' = H_s - \frac{D}{\cos \psi}
\]

Fig. 6 shows the relationships between the snow depth \(H_s\) and the horizontal seismic coefficient of seismic motion \(a\) when the stability of snowpack on the slope \(SL_E'\) is 1.0, 1.5 and 2.0. The length of the snowpack on the slope in 10 m and 20 m. The regions above the blue curves in the figures indicate the regions where the stability of snowpack on the slope \(SL_E'\) is 2.0 or lower. The curves in the graphs show that the snow depth and the likelihood of avalanche occurrence are proportional, and that when \(SL_E'\) becomes 1.0 or lower (red curves and the regions above them), the avalanche occurrence likelihood becomes very high.

**Calculation conditions**
- Frequency: 10 Hz
- Slope gradient: 40°
- Snowpack: rounded grains
- Weak layer: faceted crystals
- Internal friction coefficient of the weak layer: \(\tan \phi = 0.21\)
- Length of the slope: 10 m (left), 20 m (light)

![Fig. 6: Relationship between snow depth \(H_s\) and horizontal seismic coefficient \(a\) of seismic motion.](image-url)
With increases in the horizontal seismic coefficient and the length of the snowpack on the slope, the snow depth that has to be considered in the risk assessment of avalanche occurrence became smaller.

From the above, it is thought that the risk of earthquake-induced avalanche occurrence can be indicated by using snow depth \( H_s \) and horizontal seismic coefficient \( a \) as indexes and by using Equation (4), for which variables are set based on the concept of stability of snowpack on the slope. When the weak layer is assumed to be near the bottom of the snowpack, it is also thought that risk assessment of the occurrence of full-depth avalanches is possible by giving an appropriate friction coefficient to the equation.

5. SUMMARY AND FUTURE ISSUES

In this study, a vibration experiment was conducted that focused on the seismic response of the snowpack on the slope. Using the results of this experiment, we propose a method for estimating the risk of avalanche occurrence in which the snow depth at the time of earthquake \( H_s \) and the horizontal seismic coefficient \( a \) are used as indexes. In the future, we will further investigate the risk of avalanche occurrences for various snow types and vibration frequencies in winter.

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