Conditions under which the downslope interval between avalanche prevention bridges can be increased and consideration of construction cost savings

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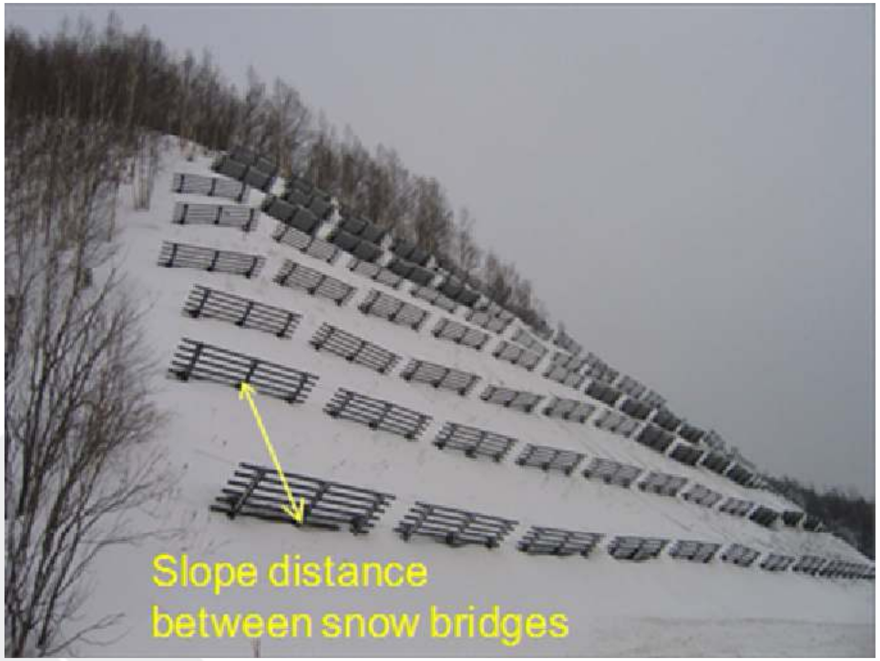
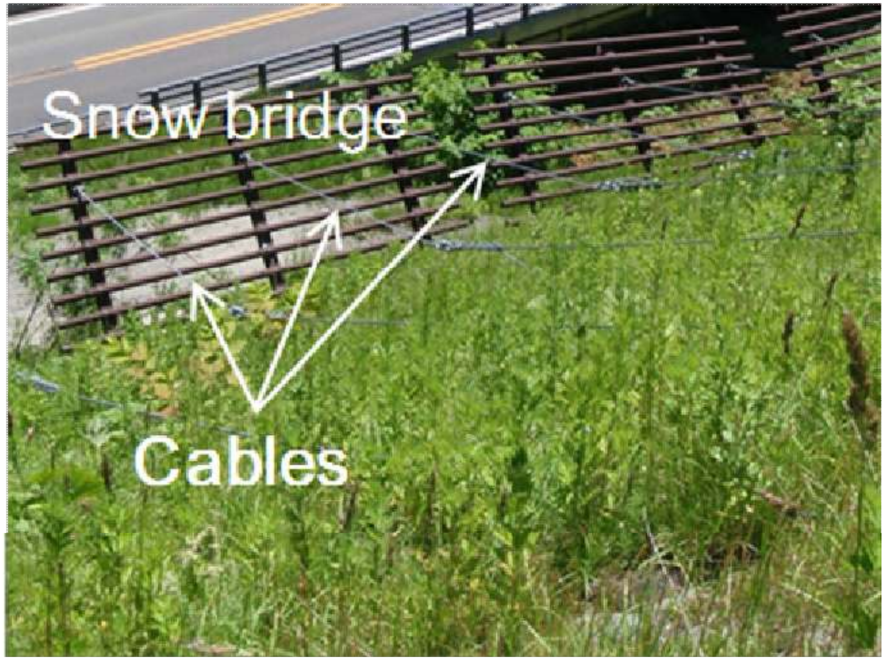
0. CONTENT

1. INTRODUCTION

Snow bridges are often installed on slopes as a measure to prevent avalanches onto roads in cold snowy regions.

The number of snow bridges needed for a slope (i.e., construction cost) depends on the downslope interval between the snow bridges.



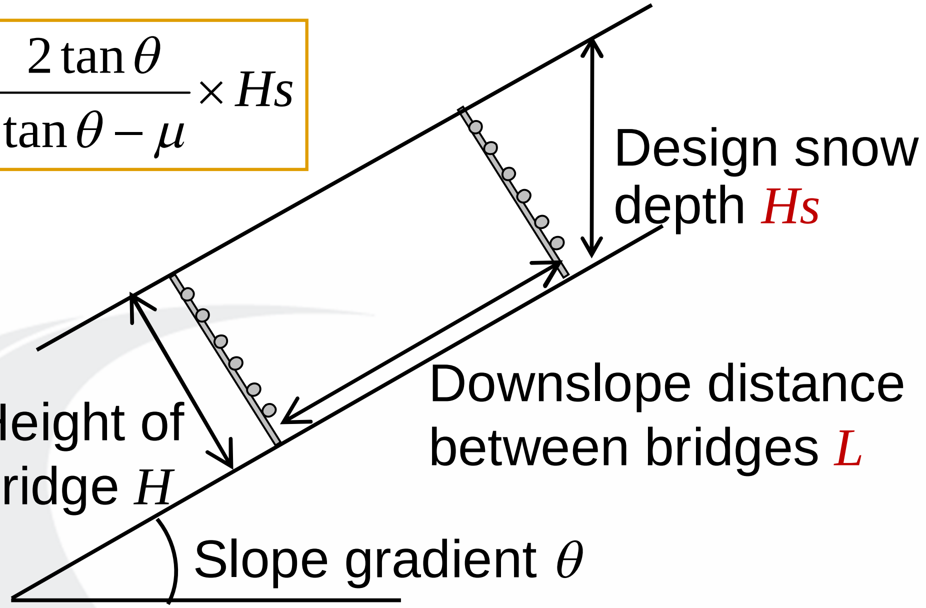


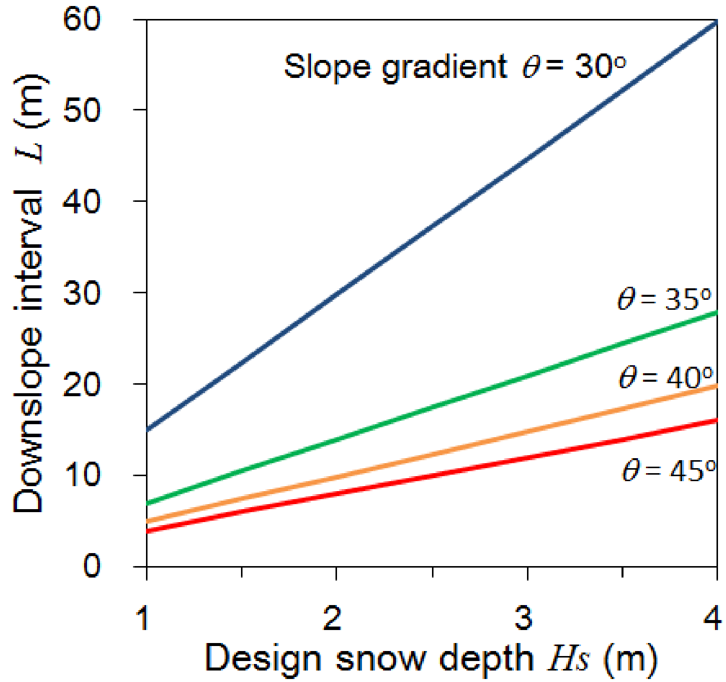
2. Problem in the current design method

Downslope interval between snow bridges L is proportional to the design snow depth H.

Because shallower snow depth requires shorter downslope interval between snow bridges, the number of bridges (i.e., construction cost) increases in region of shallower snow depth.

$$L = \frac{2\tan\theta}{\tan\theta - \mu} \times Hs$$





μ : coefficient of friction between snow and ground

3. OBJECTIVE

In the current design method, because shallower snow depth requires shorter downslope interval L between snow bridges, the *number of bridges (i.e., construction cost) increases in region of shallower snow depth*.

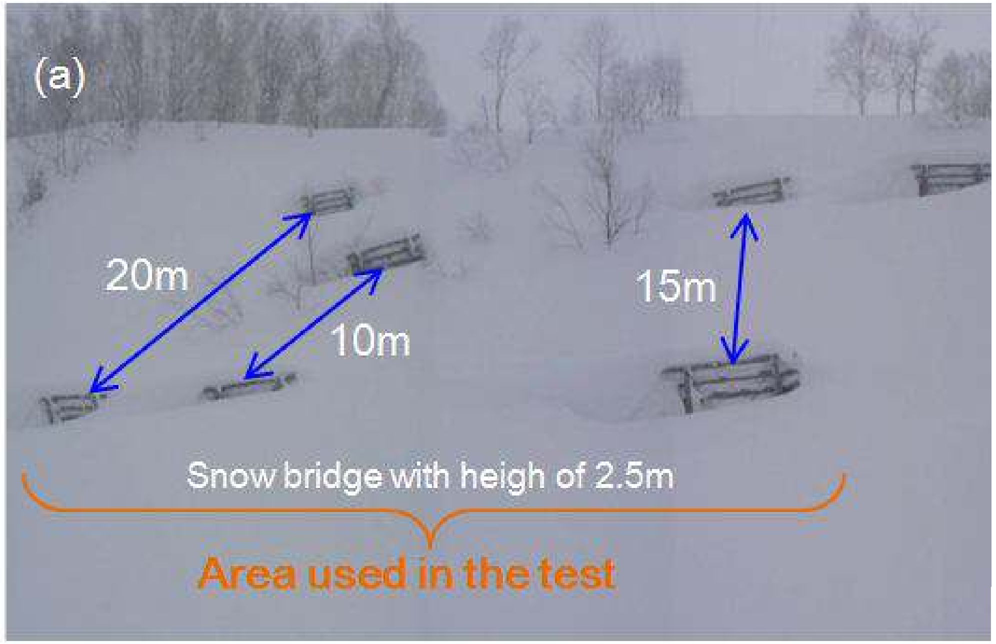
To address this problem, we have examined *feasibility of increasing the downslope interval L* between snow bridges from the current design value, based on the results of field experiments and theoretical examinations focusing on snow cover failure.

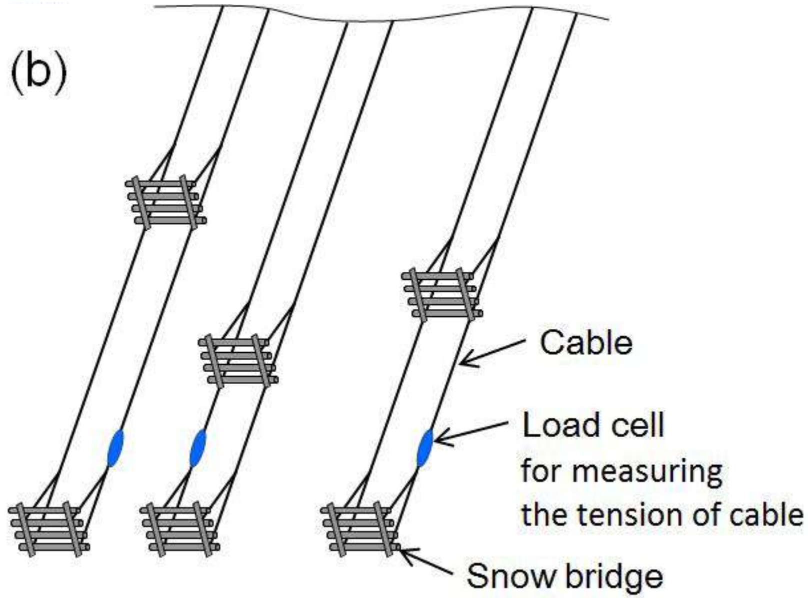
4. FIELD TEST - Outline -

Design snow depth Hs at this site is 2.6 m, height of snow bridge is 2.5 m.

Design downslope distance between snow bridges L is 15 m.

Snow pressure acting on the snow bridges S were measured by a load cell installed on one of two main cables.

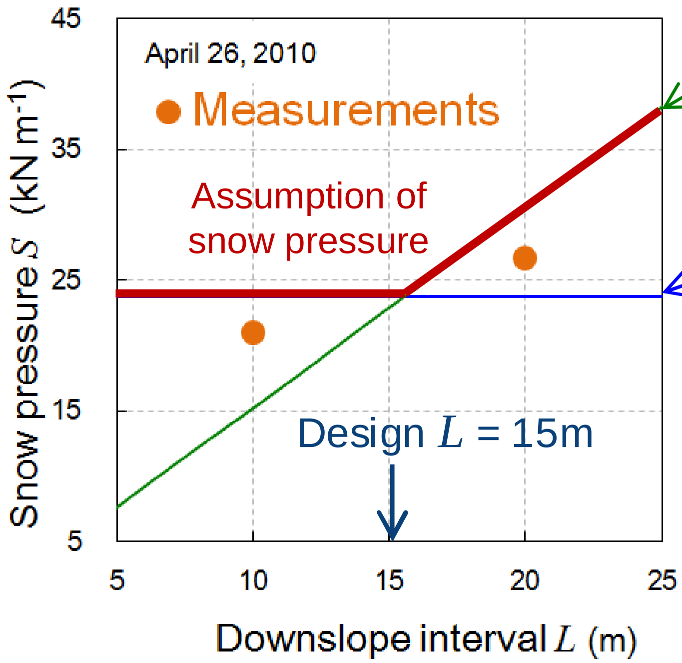




4. FIELD TEST - Result -

When L was 20 m (longer than the design value), the measured snow pressure S was greater than the design snow pressure S_1, but was smaller than the theoretical snow pressure S_2.

This suggests the feasibility of increasing the L from the current design value by taking into account the increase in snow pressure S_2.



S_2 in case of higher glide speed

$$S_2 = \rho g H_s \cos\theta(\sin\theta - \mu\cos\theta)L$$

S_1 in case of lower glide speed
(Current design of snow pressure)

$$S_1 = \rho g \frac{H_s^{\ 2}}{2} KN$$

Equation of L is obtained by combining two equations for snow pressure.

$$L = \frac{2\tan\theta}{\tan\theta - \mu} \times H_s$$

5. THEORETICAL EXAMINATION - Method -

When L is increased, there is a risk of avalanche due to failure of snow on the slope stemming from the increased snow pressure.

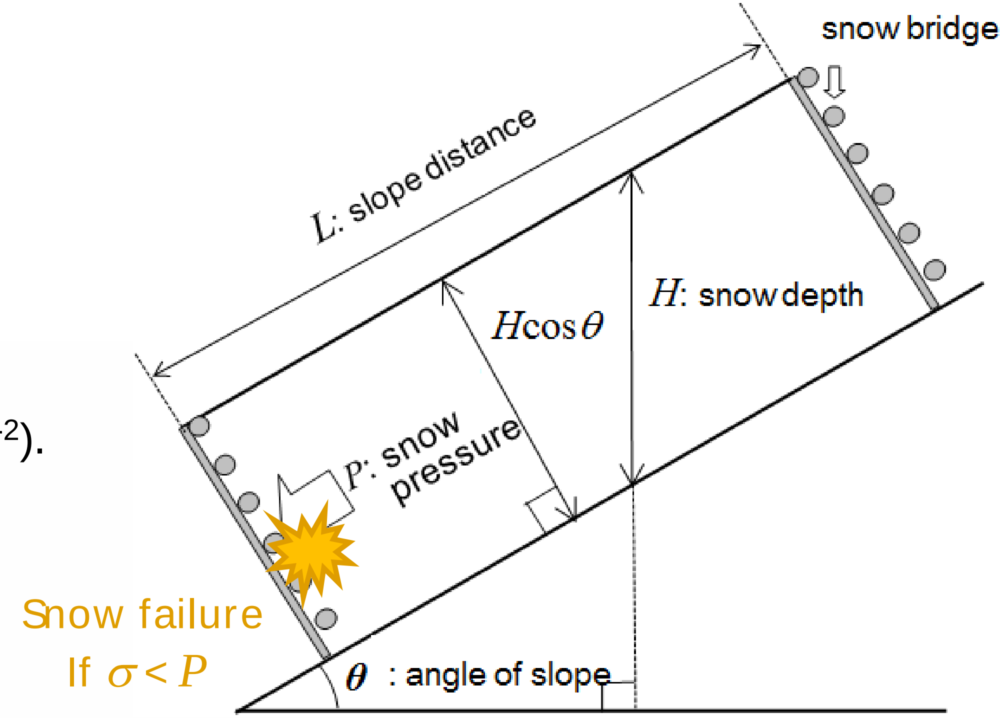
To avoid the failure of snow, the increased snow pressure P_2 should not exceed the strength of snow σ.

$$\sigma > P_2 = \rho g(\sin\theta - \mu\cos\theta)L$$

Where,
P_2 is snow pressure per unit area (N m^{-2}) converted from snow pressure S_2,
σ is compressive strength of snow (N m^{-2}).

$$P_2 = \frac{S}{H\cos\theta} = \rho g(\sin\theta - \mu\cos\theta)L$$

$$\sigma = 4.38\times10^{-4}\rho^{2.97}$$



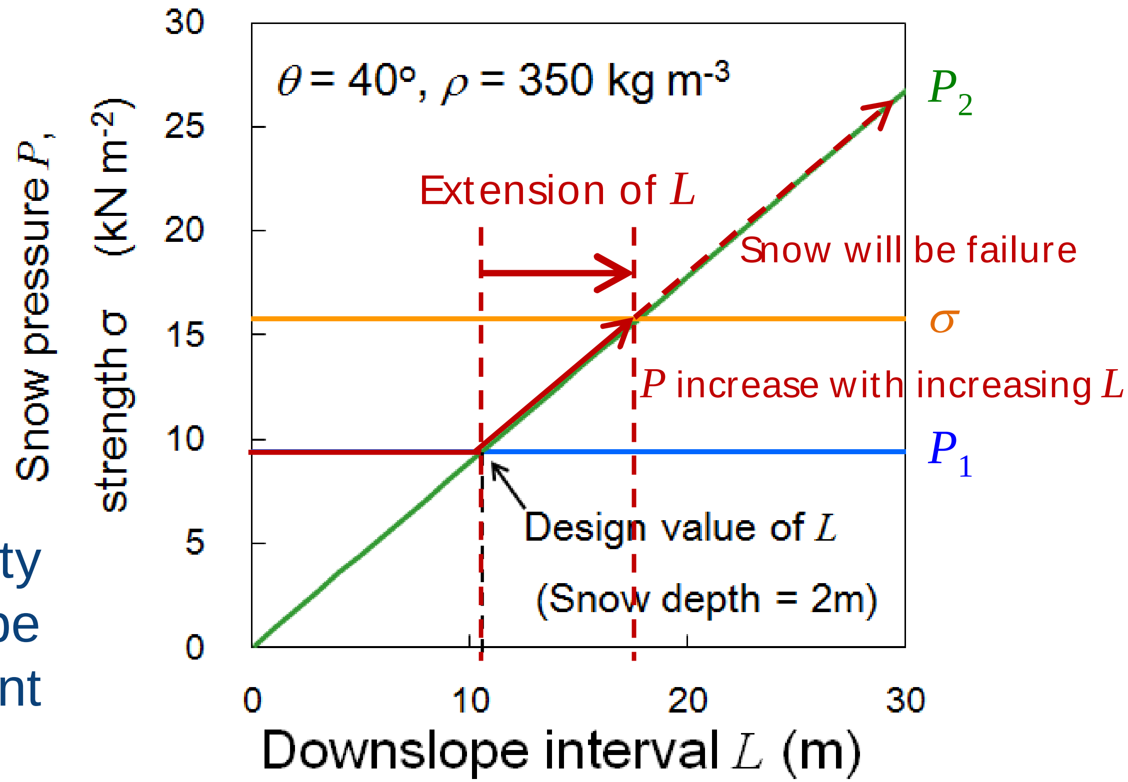
5. THEORETICAL EXAMINATION - Result -

If the L is greater than the intersection between snow pressure P_2 and strength σ, then snow compression failure on the slope will occur.

Therefore, the maximum permissible value of the L can be expressed in

$$\sigma > P_2 = \rho g(\sin\theta - \mu\cos\theta)L$$

$$L < \frac{\sigma}{\rho g(\sin\theta - \mu\cos\theta)}$$



It shows a range of feasibility of increasing the downslope interval L from the current design value.

6. Feasibility of increasing the L from the current design

According to the Swiss guideline, the maximum distance factor fL is determined as 13 for the maximum permissible value of L.

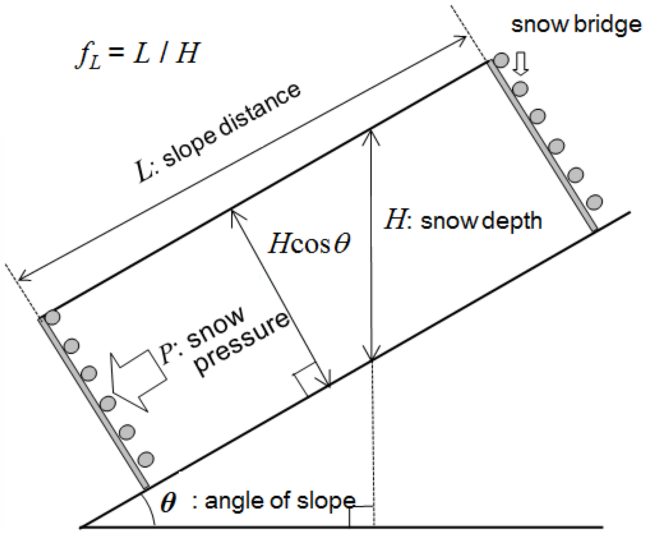
Therefore, it will be possible to increase the downslope interval L when two conditions are satisfied:

(I) the snow pressure P_2 does not exceed the compressive strength σ,

$$L < \frac{\sigma}{\rho g\left(\sin\theta - \mu\cos\theta\right)}$$

(II) the distance factor fL (L / H) is less than 13.

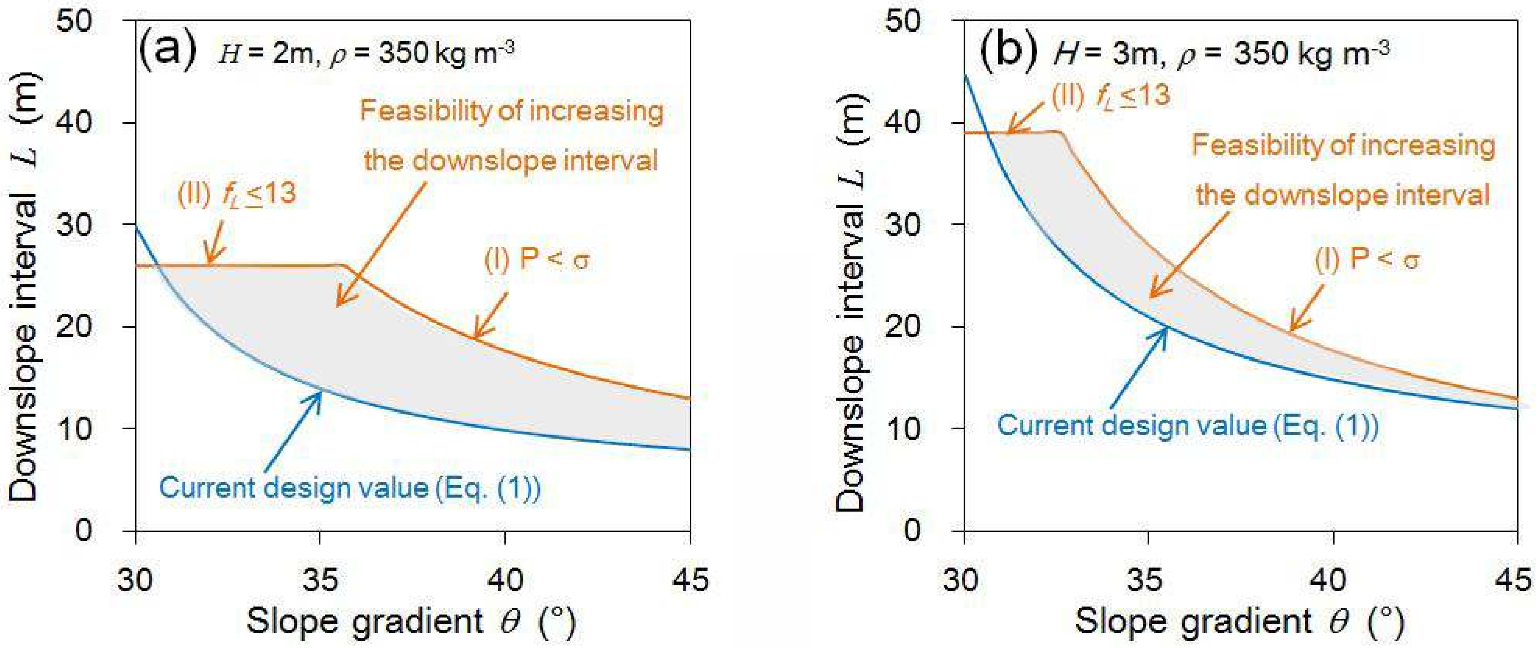
$$fL < 13$$



6. Feasibility of increasing the L from the current design

Figure summarizes the conditions under which the L can be increased from the current design, in case of snow density ρ is 350 kg m^{-3} (in accordance with the design guidelines of the Hokkaido Regional Development Bureau).

It is presumed that the L can be increased mainly in cases where snow depth and slope gradient values are small (i.e., left Figure(a)).

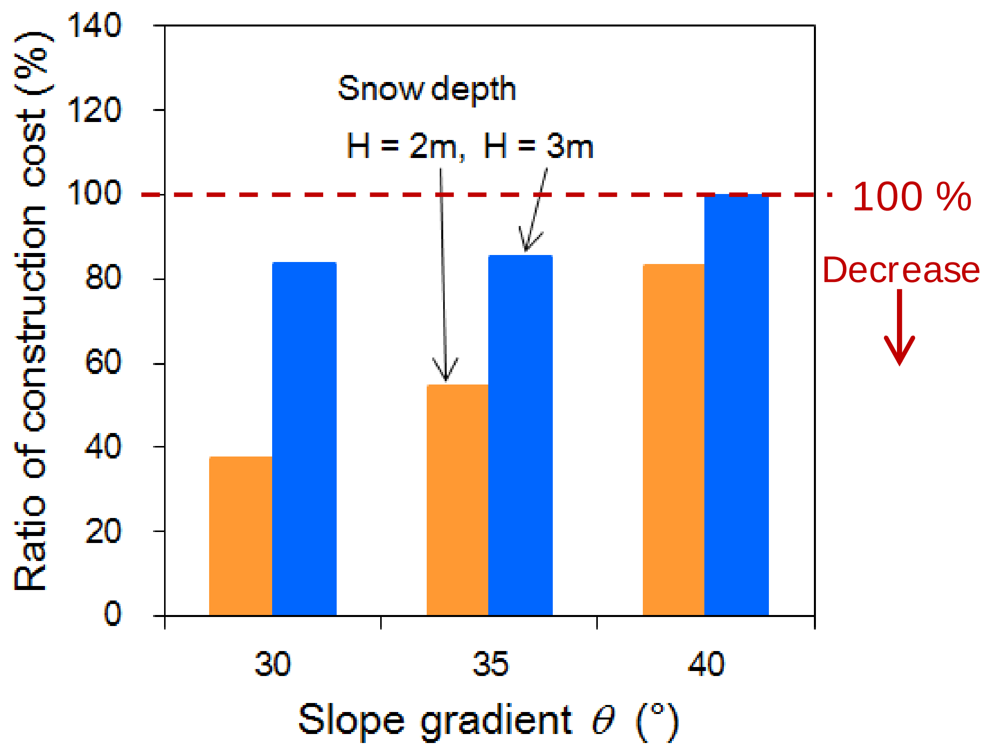


7. Construction cost of snow bridges

Cost for constructing snow bridges were calculated in which the L is increased under conditions (I) and (II) from the current design value.

The cost will decrease due to decreasing the number of snow bridges in case of increasing the L based on conditions (I) and (II).

In addition, the cost reduction in case of snow depth 2 m is much greater than that in case of snow depth 3 m.



Ratio of construction cost for snow bridges installed with increased downslope interval to the construction cost for snow bridges installed based on the current design. (Slope length = 100 m, ρ = 350 kg m^{-3})

8. CONCLUSION

In the current design method, because shallower snow depth requires shorter downslope interval L between snow bridges, the number of bridges (i.e., construction cost) increases in region of shallower snow depth.

Using two conditions proposed in this study,

(I) the snow pressure P_2 does not exceed the compressive strength σ,

$$L < \frac{\sigma}{\rho g(\sin\theta - \mu\cos\theta)}$$

(II) the distance factor fL (L / H) is less than 13,

$$fL < 13$$

will make it possible to increase the L and, thus, to reduce the cost for constructing snow bridges in regions where snow depth and slope gradient are small.

It should be noted that the study was conducted for snow with a density of 350 kg m^{-3}, and separate investigation should be performed for areas characterized by low-density snow (e.g., 270 kg m^{-3} in Switzerland).

Thank you for your kind attention

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