SETTLEMENT PRESSURES ON ROOF STRUCTURES

by

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INTRODUCTION

There are areas in the western ranges of North America where winter snowfall sometimes accumulates enough to bury structures. For example, buildings at Paradise and Sunrise on Mt. Rainier in Washington and at Timberline Lodge on Mt. Hood in Oregon have been completely or partially covered with snow. Damage noted on parts of these buildings suggests that they may have been subjected to loads greater than the projected weight of snow; when the surrounding snowpack settled, some of its weight may have been transferred to the buildings through bridging.

EXAMPLE OF DAMAGE DUE TO SETTLEMENT FORCES

A major structure, the original visitor center at Paradise on Mt. Rainier, Washington was so severely damaged by snow during the winter of 1949 that it had to be destroyed. This building, called the Community Building, was located at an elevation of 1646 m. It was a classic example of 1920's national park architecture and was built with a heavy timber frame structure. During the winters of 1948, 1949, and 1950 the snowpack was well above the average depth (7.5 to 8 meters on the ground) and extensive drifting was noted during the storms. The Community Building was completely covered with snow. The depth and density of the snowpack on the roof and in the area surrounding the building was increased by additional snow deposited by rotary snowplows. The combination of these factors caused tremendous damage to this building.

EXISTING LITERATURE

In a theoretical study on the subsidence force of snow Yosida (1954) proposed an expression for the settlement force acting on a unit length of horizontal bar supported within the snowpack. Oura (1956) predicted the settlement force of snow using photo-elastic models. Oura (1957) described the force with which a beam supports the ceiling of a snow cave and indicated that the beam load included forces due to the surrounding snow-pack. In a subsequent paper Oura (1957) stated that the fracture of (roof) eave beams was attributed to the settlement force of snow. T. E. Lang, H. Nakamura and O. Abe (1985) proposed a method of computer modeling to obtain the settlement force on a beam supported within the snowpack. In another study, Nakamura and Abe (1985) measured the settlement forces on a test beam which was completely buried with snow. They found the settlement forces of snow at times to be much higher than the projected weight of snow. The total loads on the beam evidently included considerable load in addition to the weight of snow directly over the beam. This additional load was transferred through shear from the adjacent snow pack.

ONE ENGINEER'S APPROACH

Presently there is no direct and simple approach to determining design roof loads for a building which could at some time be completely covered with snow. Where this condition could exist, as described in the existing literature on this subject, the load on a structure which is completely buried in the snow can be considerably greater than the weight of snow directly over the roof. The equation proposed in the next paragraph as

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applied to Figure 1 takes into account the weight of snow directly over the roof plus the settlement force from the surrounding snowpack which could be transferred to the roof through shear around the perimeter of the roof. For any given value of the snow shear strength, the settlement force portion of the roof load tends to be an upper bound value because the existing state of shear stress on the roof perimeter will ordinarily be less than the failure shear strength. One of the subjects left to be addressed by future study is how this settlement force is distributed over a two-dimensional roof structure.

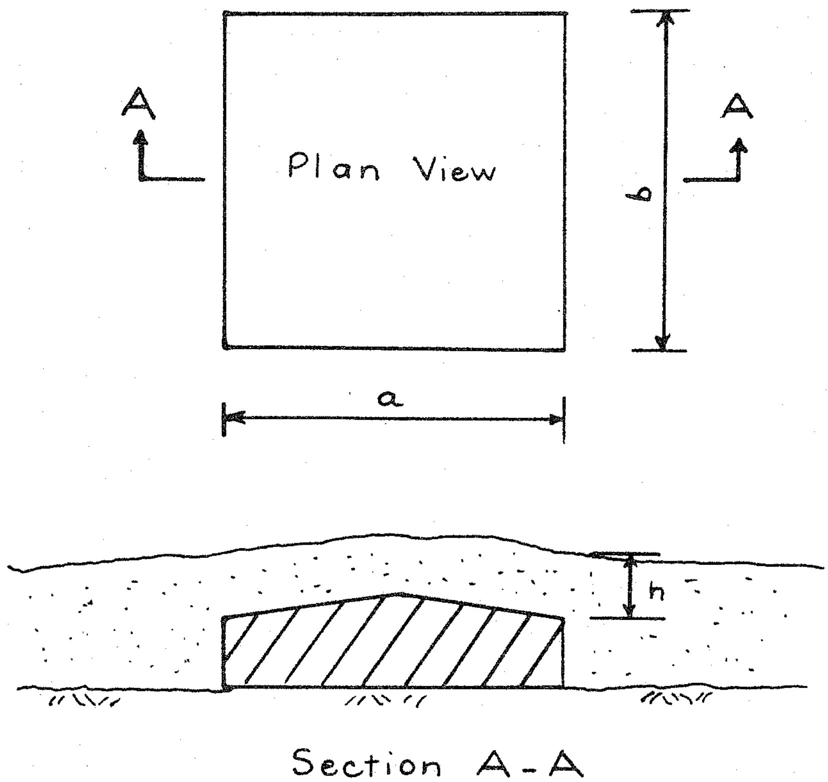

Figure 1. STRUCTURE COVERED WITH SNOW

Given the building shown in Figure 1 which is assumed to be completely covered with snow, it is proposed that the total roof load due to snow directly over the roof plus the additional forces due to the eventual settlement of the surrounding snowpack could be determined by the following expression:

$$\text{Total roof snow load} = \left[(a)(b)(\rho) + (f_v)(h)(2a + 2b)\right] g \quad \text{where:}$$

a = width of building

b = length of building

ρ = average mass density of snow above the eaves

f_v = the average shear strength of the snow from the eave line to the snow surfaces

h = depth of the snow above the roof (avg.)

g = gravitational constant

On page 25 of his thesis, McClung (1974) presents a plot of the tensile strength of snow against the corresponding density of snow. The data for this graph was obtained by experiment at his Mt. Baker test site. McClung states on page 27 that "the shear strength of the snow is at least one half the tensile strength." The graph shown in Figure 2 is adapted from this idea and from McClung's tensile strength vs. density data.

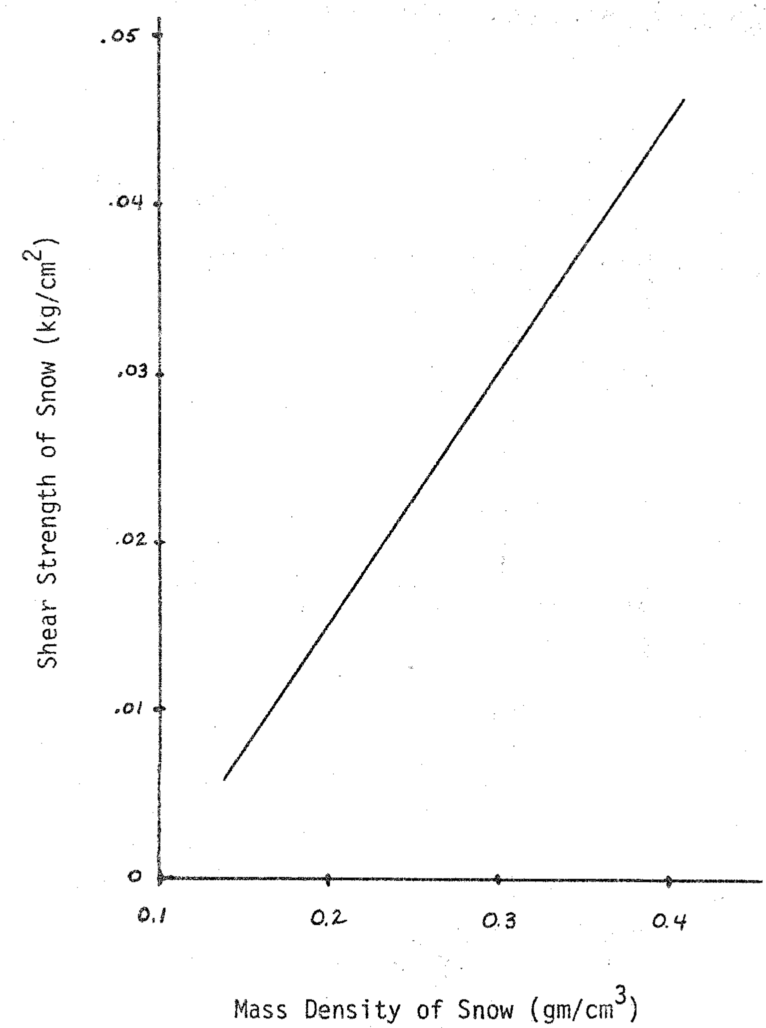

Figure 2. SHEAR STRENGTH OF SNOW BASED UPON McCLUNG (1974)

COMPARISON OF CALCULATED VALUES AND EXPERIMENTAL DATA

In order to check the validity of this proposal, calculations of the predicted settlement force on the test beam used by H. Nakamura (Lang, et al, 1985) were made. The test beam (Figure 3) used by Nakamura was supported about 60 cm. above the ground surface and was instrumented so as to measure the total load applied to the beam by the snow. Snow density measurements according to Nakamura (Lang, et al, 1985) were used to calculate the load directly over the beam. Shear values based upon this snow density and upon McClung's measurements (McClung, 1974) were calculated. The calculations and the test data were based upon a one meter long portion of a 10 cm. wide beam.

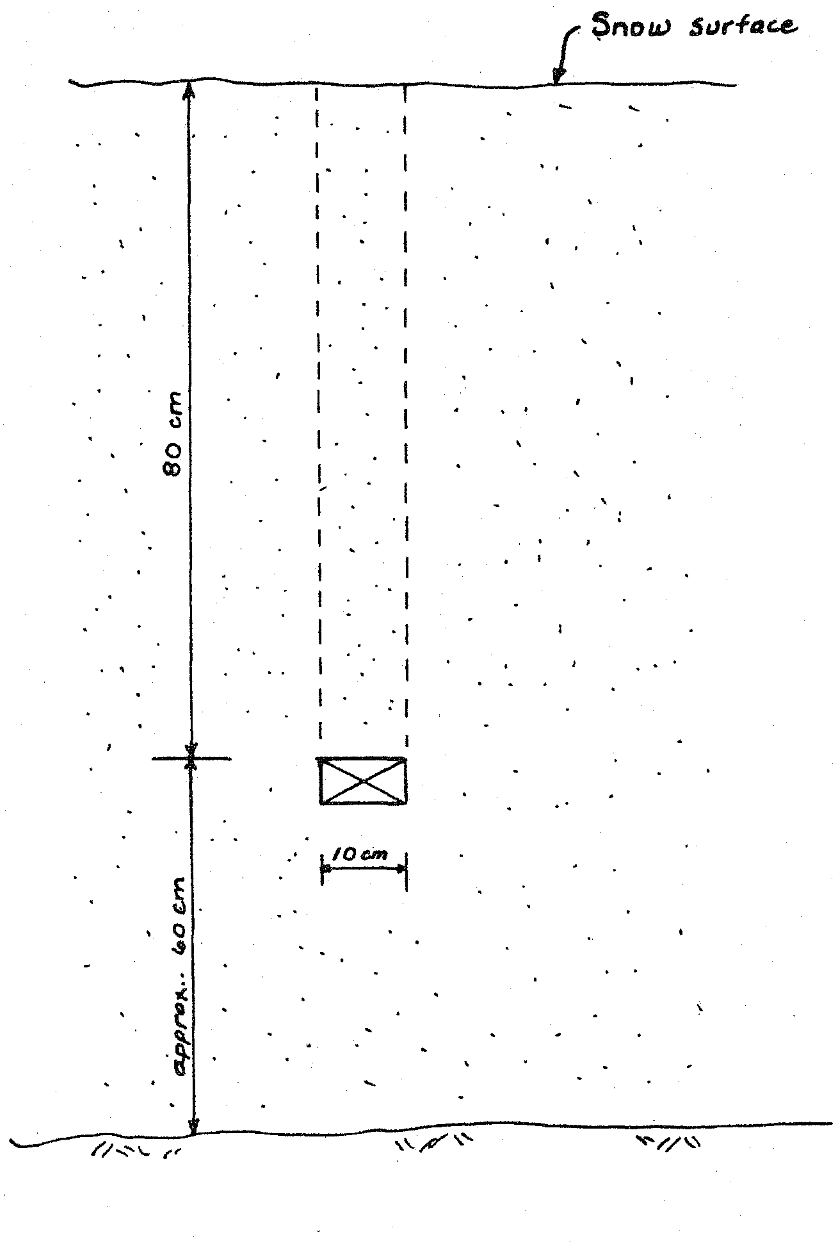

Figure 3. TEST BEAM (cross section)

The graph in Figure 4 is a plot of the load on Nakamura's test beam vs. time (listed as dates throughout the winter of 1981). The data points which are circled are taken from Nakamura's experimental data (1985). The points enclosed in squares represent calculated values predicted by the proposed procedure.

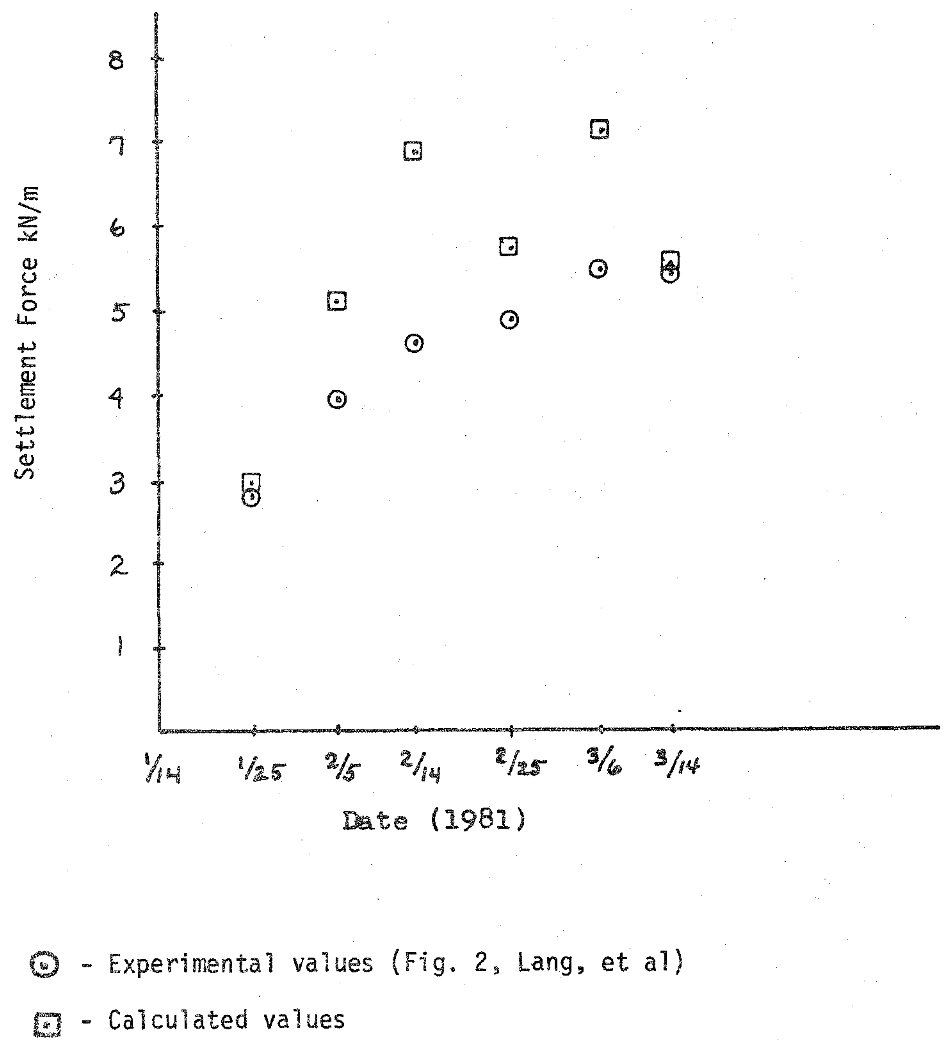

Figure 4. EXPERIMENTAL AND COMPUTED SETTLEMENT FORCE ON THE TEST BEAM

The following example is the calculation for one point on the graph (Figure 4). The data used was taken on January 25, 1981 at the test site at Shinjo, Japan. The depth of the snow above the top surface of the test beam is 80 cm. The average mass density of the snow directly over the beam as obtained from Figure 3 (Lang, 1985) is 0.22 gm/cm^3. The shear strength of the snow above the top surface of the beam as estimated from Figure 2 is 0.0175 kg/cm^2. A section through the test beam is shown in Figure 3.

Load directly over beam	= (100 cm)(10cm)(80 cm)(0.0022 kg)(9.8) =	196 N/m
Load which could be transferred by shear	= (100 cm)(80cm)(2)(0.0175 kg/cm^2)(9.8) =	2746 N/m
	Total load predicted =	2916 N/m

The total load predicted by this method of calculation is only slightly greater than the values measured experimentally on Nakamura's beam. According to Nakamura (Lang, et al, 1985) the measured settlement force at this data on the test beam was 2800 N/m. The predicted (calculated) and measured (experimental) values for the entire winter of 1981 are shown in Figure 4. From this graph it appears that the calculated values are consistently greater than the settlement forces on the test beam.

CONCLUSION

Further research is required in order to develop procedures and data for obtaining reliable settlement forces to be used in structural design. In the meantime, upperbound design values could be estimated using the expected snow density and unit shear values.

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