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Research Article

Multilayer Settlement Measurement Tower: An Instrument to Measure the Settlement of Layers in Snowpack

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Abstract

Snow is a visco-elastic material with its viscosity directly dependent on density of snow as well as temperature of snow. Viscosity of snow varies between 10^8 Pa-s to 10^{14} Pa-s (Martin Stoffel, 2006 et al,). An accurate model for snow densification and avalanche forecast must take temperature dependent viscosity into account. To measure the viscosity, there is a requirement to study the mechanical behaviour of the snow described in terms of stress in the snowpack. Stress can be calculated by measuring the settlement of the snowpack with respect to time. A new instrument, Multilayer Settlement Measurement Tower (MSMT) was designed and tested for measuring settlement of different layers separately using magnetic field sensor array, temperature profile using thermocouple array and the viscosity was calculated using empirical formula. Experiments were successfully carried out on the prototype of MSMT at the field research station to check the functionality of the instrument. The instrument is being fabricated and planned to install in field stations for snow layers settlement measurement.

Keywords: *Settlement, Viscosity, Magnetic field sensor, Snowpack*

1. Introduction

Snow is one of the most complex materials appearing in nature (DM Gray and DH Male, *et al*, 1981). The physical and mechanical properties of snow have been studied for many reasons. The primary reason to study the snow has been the threat posed by snow avalanches to mountain communities. The mechanical properties of snow have been the subject of research. Mechanical tests with snow show that snow strength is a function of the strain rate (Martin Stoffel, *et al*, 2006). Snow cover is subjected to gravitational forces which causes deformation. Compression of snow perpendicular to the slope under its own weight is settlement (Tony Dafferen, *et al*, 1999). Settlement is the progressive densification of a snow pack due to gravity, overburden pressure and metamorphism which is a very gradual process. Settlement depends on the temperature and initial density of the new snow as well as grain size and shape (David McClung & Peter Schaerer, *et al*, 1993). In general, substantial settlement of new snow layers is a stabilizing influence on a mountain snowpack. As metamorphism advances, the snow not only loses strength but viscosity also increases (Bruce Tremper, *et al* 2001, E R LaChapelle, *et al*, 1985). Viscosity and temperature profile of snow are important input parameters for snow pack model which gives the vertical densification of the snow pack which in turn is used to prepare avalanche forecast (Bruce Tremper, *et al*, 2001).

The aim of developing a multilayer settlement measurement tower is to mark the settlement of each layer of the snowpack separately as it gradually descends downwards and to measure the temperature at each layer of the snowpack to generate a temperature profile of the snowpack which is under study. The conventional technique to find out the settlement of the snowpack is to use a snow pole. Snow pole is a vertical pole on which measurement scale is graduated. This method is not automated and one has to read the scale on daily basis to find out the settlement of snowpack. This method gives settlement of snowpack as a whole without giving settlement of individual layers separately and is prone to error due to human involvement.

A settlement gauge, developed by E LaChapelle and M M Atwater in 1961 was based on Wheatstone bridge (E LaChapelle and MM Atwater, *et al*, 1961). A nichrome resistance wire was suspended vertically in the centre of a smooth level area in the study plot and was long enough to clear the maximum winter snow depth. This vertical resistance wire forming one side of the circuit. Following each snowfall, a wooden lattice supporting a crocodile clip connector was placed on the snow surface and the clip attached to the resistance wire. Its buried position at any time may be determined by connecting the test set and balancing the bridge, as indicated by zero reading on the galvanometer. Occasional erratic operation of the settlement gauge has been noted, appearing in the form of anomalies or "bumps" in the settlement curves of several centimetre magnitudes.

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In an alternate design of settlement gauge (Moiz Chasmai, Atul Tomar, *et al*, 2011) developed by SASE, the sliding contact between the wire and the plate was made with the help of a brass bead, so that the bead always remains in direct contact with the wire and hence ensuring correct reading. The settlement data was collected using a data acquisition system at regular intervals. It works on the principle that the change in distance between the two output terminals connected to a conducting wire significantly changes the output resistance that is measured in terms of output voltage.

Another design developed by SASE was based on inductive proximity sensor array in which the plate was not having any wired connection, but instead it had one metallic strip riveted along the hole in the plate (Mandeep Kaur, Moiz Chasmai, *et al*, 2012). The diameter of the sensor was $15x10^{-3}$m, which increased the complexity of sensor fitting in the tower to give 10^{-2}m accuracy. Also, the length of the sensor was $37x10^{-3}$m, which forced to use a tower with a diameter of 0.118m. With such a large diameter, easy movement of the plate along the tower became difficult.

Although the previous instruments were able to measure the settlement data but the plates had to be placed manually on layers of snowpack. Also, a separate instrument was required to be installed to measure the temperature profile of the snow pack. MSMT has been designed to automate the process of placing the plates on the snowpack and also generating the temperature profile of the snowpack.

2. Design of MSMT

An array of magnetic field sensors (figure 1) is used to locate the height of each layer in the snowpack. Whenever a magnet comes in the vicinity of the magnetic field sensor, the sensor detects the magnet and gives a high output. The sensor is normally open (NO) when there is no magnet. When the magnet is detected, the circuit is closed and the sensor activates, indicating the detection of the magnet.

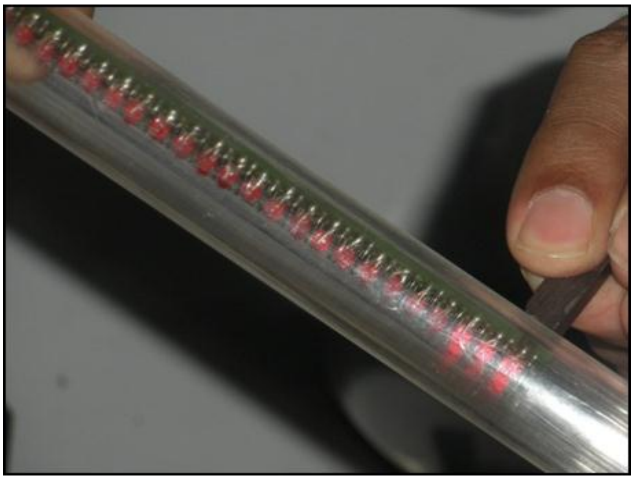

Fig.1 Magnetic Field Sensor Array

An array of sensors was formed by placing 25 magnetic field sensors at a distance of 0.01m from each other in a tube. A plate with a magnetic ring at its inner circumference was made using Perspex sheet. This plate was allowed to slide down the tube to validate the detection of the plate at any instance. This concept was used to measure the settlement of the layers of snowpack in MSMT.

Figure 2 shows the complete schematic diagram of MSMT. It comprises of a pole which is further divided into segments of 0.25m each. Cross section of one such segment is shown in figure 3. It consists of 25 magnetic field sensors fitted at a distance of 1cm from each other vertically. Also, there are 25 thermocouples arranged in similar way as shown in figure. The height of MSMT is customized based on the number of segments attached. The number of segments in a system are decided based on the seasonal snowfall at the location where it is to be installed. This arrangement makes MSMT portable, provides easy mobility of the equipment during installation and gives a customized height as per requirement. Mechanical arrangement is provided to couple the parts with each other.

The plates are made of perspex sheet and are circular in shape with a hole of 0.022m diameter at the center and pores across their area. For detection of the plate by the magnetic field sensors, a magnetic ring is fitted along the circumference of the hole as shown in figure 4. A precipitation indicator is mounted on the pole to detect the beginning and end of snow spells. A roof is provided over the plates to protect them from snow.

A plate release mechanism is made as shown in the figure 2 for releasing the plate onto the snow pack surface. This arrangement is designed in such a way that the plates are held vertically on the top segment of the pole with a clip that does not allow the plates to slip downwards. The inclined pole (1.8m) is made at an angle of 60^0 for free release of plate once the clip is removed. This mechanism is triggered by the Precipitation detector. The plate is released after 24 hours of snow spell by unplugging the clip and releasing the plate automatically. A roof is designed in such a way that it protects the plates in the rack from snowfall and at the same time does not interfere with the snowfall over the plates placed on the snowpack.

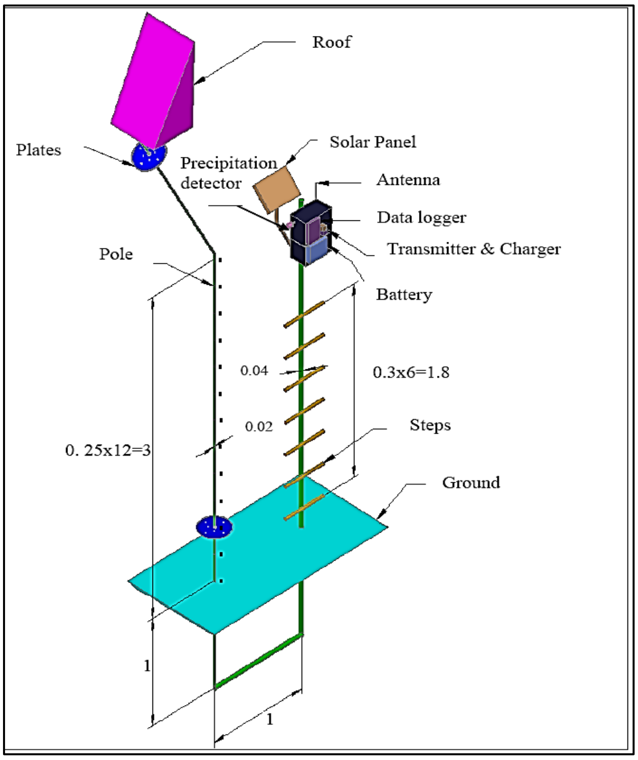

Fig. 2 Schematic diagram of MSMT (All dimensions are in m)

The data of magnetic field sensors pertaining to the height of plates, settlement and viscosity of individual layers is stored in a data logger once every hour. Initial density of the snow is required to be fed to the system to calculate the viscosity. This data can be fed using a PDA device that has a wireless connectivity with the equipment. The PDA device works at a frequency of 2.4 GHz upto the range of 150 m. The data logger has the capacity to store the data generated over a span of one year. A rechargeable Lead Acid battery of 12V/45AH powers the data logger, is charged using solar panel. The data collected by the data logger is transmitted to the PDA device wirelessly on hourly basis.

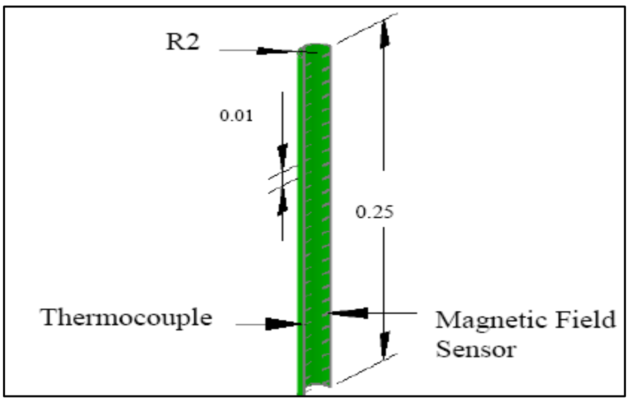

Fig.3 Perspex Sheet Plate

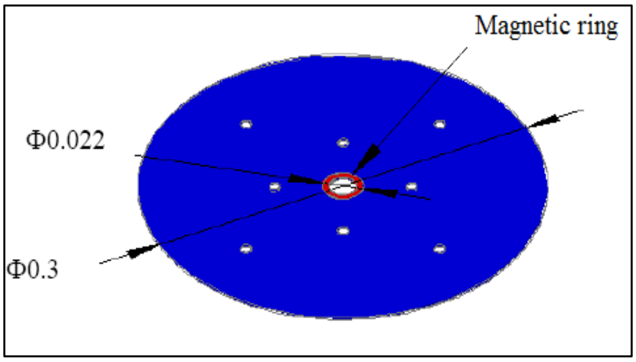

Fig. 4 Perspex sheet plate

3. Methodology

The plate has a magnetic ring riveted along the circumference of the hole. During the settlement of the snow, the plate gradually moves downwards along the pole which has magnetic field sensors incorporated inside it. At any instance, the plate comes in front of only one magnetic field sensor. The plate is detected by that sensor as the magnetic ring intercepts the magnet, thus activating the sensor. Each magnetic field sensor has a Unique Identification Number (UIN), based on which, corresponding UIN of the sensor is displayed in terms of its equivalent depth. This interception is recorded in the data logger providing the exact location of the plate inside the snowpack on an hourly basis. The settlement is measured by calculating the change in the height of the plate with respect to time. This technique does not require power for activating the sensors as the sensors are passive components.

The prototype of MSMT was developed at SASE and was installed in the field research station Dhundi, Manali for its functional testing during winter. The system was tested with four segments of 0.25m each and having sensors at a distance of 0.025m each. The position of plates was detected using 10 LEDs for each segment placed inside a hermetically sealed container. The experiments were conducted to test the working of the magnetic sensors and thermocouples.

During the experimentation, one plate (L1) was placed at Sensor No. 8 of segment No. 01 on day 1. After medium snowfall on day 3, another plate (L2) was placed at sensor No. 3 of sub pole No. 02. On day 8, after heavy snowfall, the third plate (L3) was placed over the surface of snowpack at sensor No. 7 of segment No. 04. On day 10, it was observed that the plate L1 settled down and moved to sensor No. 5 of segment No. 1, L2 moved to sensor No. 01 of segment 2 and L3 moved to sensor No. 4 of segment No. 4. These data were validated using manual observations on snow pole. Thermocouple readings were also recorded.

4. Results and discussions

Experiments were conducted at field research station to validate the functionality of the instrument. The graph of settlement of snow with time for 10 days is shown in figure 5. The data were collected for 3 layers for duration of 10 days at an interval of 6 hours. Plate L1 in the graph shows the gradual settlement of the bottom snow layer. Initially, the height of the bottom layer of snow was 0.175m from ground which gradually decreased as the settlement of the snow proceeded. After 10 days, the height of the bottom snow layer was recorded at 0.1m reflecting settlement of 0.075m. Plate L2 in the graph shows the gradual settlement of the middle snow layer. Initially, the height of the L2 was 0.3m from ground and was recorded to be 0.25m on 10^{th} day reflecting settlement of 0.05m. Plate L3 in the graph shows the gradual settlement of the complete pack that includes the bottom and the middle snow layer. Initially, the height of the pack was 0.9m which gradually decreased to 0.825m on 10^{th} day reflecting settlement of 0.075m for complete snowpack. The readings of the settlement were also taken manually with graduated scale which compares well with the settlement data of the MSMT.

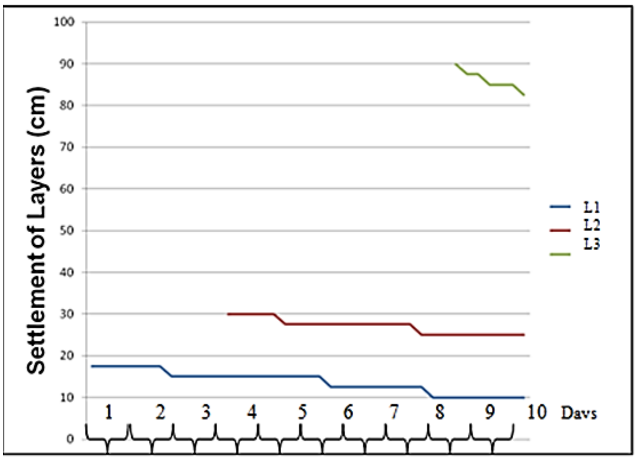

Fig. 5 Settlement v/s Time Plot

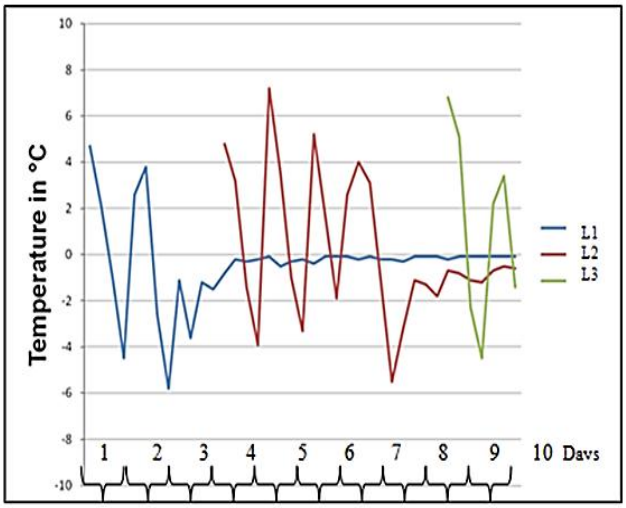

Fig. 6 Temperature v/s Time Plot

Figure 5 shows the graph of the settlement of all three layers with respect to time. Figure 6 shows the temperature profile of each layer with respect to time. The graph shows that when the plate is on the surface, the temperature of the surface varies with the ambient temperature as the top surface is exposed to the ambient temperature. Once the plate is buried in the snow, the temperature remains in subzero degrees.

The detailed calculations for viscosity and density are given below:

Viscosity (Malcolm Mellor, *et al*, 1975) is calculated using the empirical formula:

$$\eta = \sigma/\varepsilon^* \quad (1)$$

Where, η is the viscosity, σ is the stress and ε^* is the strain.

$$\text{Also, } \sigma = \rho L g \quad (2)$$

Where, ρ is the initial density of snow, L is the initial height of snowpack layer, and g is the acceleration due to gravity.

$$\text{And, } \varepsilon^* = (dl/dt)/L \quad (3)$$

Where, dl/dt is the change in height of the snowpack layer with unit time

Estimation of density change during settlement:
According to conservation of mass,

$$\rho 1 L1 = \rho 2 L2 \quad (4)$$

Where $\rho 1$ is the initial density of snow, L1 is the initial height of snowpack layer, $\rho 2$ is the final density of snow; L2 is the final height of snowpack layer.

Figure 7 shows the plot of viscosity v/s density for different layers. The viscosity calculated from the data of settlement gauge matches well with the viscosity reported (Agraj Upadhyay, DN Sethi, *et al*, 2008).

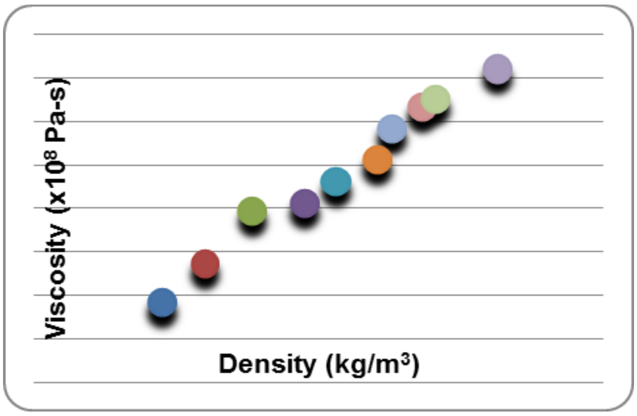

Fig. 6.Viscosity v/s Density graph

This data can be used in the snow cover simulation model as one of the input parameters while processing for the snowpack stability which in turn will help in avalanche forecast.

Conclusion

Viscosity and temperature profile of a snowpack are essential inputs for estimating snowpack stability and avalanche forecast. We have successfully designed Multilayer Settlement Measurement Tower for measuring settlement of all the layers in a snowpack, temperature profile and calculated viscosity of the snow. The system was successfully tested and validated using conventional methods. Results are presented from the tests carried out at the field research station of SASE.

Scope for future work

The instrument is under development and will be installed in various field stations once ready. Also, data of full season will be collected and analysed after installation. This data will be incorporated into the snow cover simulation model to access snowpack stability as viscosity and temperature profile are important input parameters in the model.

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