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# Snow loads on wire mesh and cable net rockfall slope protection systems

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**Abstract**

Snow load on mesh systems is complicated by many factors. This paper presents field instrumentation data on snow load variation with temperature, snowfall and snow depth on a mesh system. It was found that snow load pattern on mesh systems changed with temperature even without variation in snow depth. It reached its maximum value when the temperature rose just above freezing to melt the interface. The field data was used to formulate appropriate snow load models for the various conditions of temperature in the field. The snow load models were used to study the performance of a number of mesh systems in North America and estimate the interface friction that was prevalent for the different surface conditions.


*Keywords:* Snow load; Wire mesh; Cable net; Field instrumentation; Interface friction; Stability

## 1. Introduction

Wire mesh and cable net systems have been widely used to control rockfall on actively eroding slopes in North America since the 1950s. Generally, these systems consist of a steel fabric/mesh draped over a steep slope, which is suspended from upslope anchors. The system derives its support from both the anchors and available interface friction between the mesh and the ground. To date, these systems have been designed primarily by empirical methods, engineering judgment, and experience. While most installations have performed satisfactorily, within the last decade, a number of system failures have occurred due to snow loading. Somewhat confusing is the amount of snow load associated with failed versus functional systems. For example, systems that have been performing well otherwise have failed under moderate-depth snowpack, while other systems exposed to larger snowpack have continued to perform well (Muhunthan et al. 2005). Such variation of perfor-

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mance and the apparent increasing number of failures demonstrate the necessity for a detailed examination of the effects of snow load on system performance.

Snow is one of the weakest natural materials. It has distinct physical and mechanical properties such as a wide range of densities, stages of metamorphism, and free water content that distinguishes it from other common natural materials. Since snow load on structures is highly temporally and spatially variable, the research here focuses on the load transfer to the system. Most of the current knowledge about snow load on structures is restricted to roof structure design and snow avalanche defense. In the case of snow load on roofs, the main concern is on the vertical component that detrimentally contributes to wall moments. Comparatively, the load component parallel to the slope surface is the main concern for both avalanche defense structures and wire mesh and cable net slope protection systems. As a snowpack can persist and accumulate over weeks to months in duration, the load transfer characteristics of snowpack on the mesh are complicated by temperature variations and metamorphism.

In order to evaluate the mechanism(s) of snow load on mesh systems, it was decided first to instrument a cable net system in the State of Washington that annually develops snowpack. Field observations and instrumentation data are used to formulate appropriate snow load models for wire mesh and cable net systems.

The interface friction between the mesh and the slope surface is a major contributor towards the overall stability of wire mesh/cable net systems. The presence of snow has been found to reduce the interface friction. Field measurement of this parameter is difficult in practice. The proposed snow models are used here to study the performance of six mesh systems in snowy regions and evaluate the interface friction prevalent at these sites.

## 2. Field instrumentation

Strain gauges were installed by the Washington State Department of Transportation at a cable net installation located on the eastern slope of the Washington Cascades. The site is located in Tumwater Canyon along U.S. highway 2 at Milepost (MP) 97.0. The installation was instrumented in early November 2001, and was continuously monitored with an electronic data logger through April of 2002. The cable net system had been constructed several years prior to instrumentation. The details of the system and the location of strain gauges are as shown in Fig. 1. The specific objective of the instrumentation was to determine how snow load varied with snow depth, snowfall, and temperature and how it was accommodated within the support cables and anchors.

Twenty Phoenix Geometrix vibrating wire strain gauges were installed at locations 1 through 10 (Fig. 1). Strain gauges were installed in couple and welded onto cable clamps on the wire ropes with one gauge on the top of the cable and another on the bottom. The values from the two gauges were averaged to lessen error due to differential strain on the cable. The strain gauges were continuously monitored using a multiplexer and a Campbell Scientific CR10x data logger. The instrumentation was sampled twice daily at noon and midnight. The 19 mm cables have an elasticity modulus of $103.4 \times 10^9$ Pa with a metallic cross sectional area of 175.5 $mm^2$. The cables were not slacked to install the strain gauges, but they were installed on cables that were already sustaining the static load of the system. Consequently, the measured loads reflect a change in load relative to the initial readings.

Due to the variation of the topographic and ground conditions, the measured loads and their trends at each location were not consistent. Furthermore, the times at which the maximum loads recorded by the various strain gauges were also different. Therefore, appropriate averages of the readings were calculated in order to obtain an overall trend of the load variation with temperature, snowfall, and snow depth. Accordingly, the readings at locations 1, 3, 5, 6, and 8 were averaged to study the variation of loads on the vertical ropes (Fig. 1). Similarly, the readings at locations 2, 4, 7, and 9 were averaged to study the variation of loads on the top horizontal ropes (Fig. 1). The snowfall and snow depth data used for this research were collected at the Leavenworth 3S weather station (National Climatic Data Center #454572) located about 3.2 km east of the site and at a similar elevation.

In order to compare the data, the loads, temperature, and snowfall were normalized with respect to their individual maximum values. The variations of