

# PANDALP : A new penetrometer for snow investigation

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**ABSTRACT :** This paper presents a new tool for snow investigation, issued from a portable dynamic penetrometer Panda with variable energy for soil investigation. After a brief presentation of this apparatus, a comparable study between this tool and other tests is carried out. The application of this apparatus in different sights shows that in couple with other tests such us nivological test or temperature test, we could use this portable machine to make snow investigation.

## 1 INTRODUCTION

The Pandalp is a portable dynamic penetrometer with variable energy adapted to Haeffeli probe. It allows to measure very finely the snow resistance with a great easiness of implement. On the basis of the application with this apparatus, many treatments could be realized through geostatistical analysis, the couple with other tests such as temperature measurement is also interesting.

## 2 PANDALP

### 2.1 Introduction

The PANDA (Autonomous Dynamic Numerical Computer aided Penetrometer) has been developed from a project supported by the Research Ministry together with an university and a private limited company [1]. Initially it was designed to control the compaction of dikes or road embankments. It was later adapted for studying the stability of snow fields at the request of the CEN (Institute of Snow Study), essentially by using the same method (points and rods) as the Haeffeli tool but by manufacturing the parts from polyethylene in order to make the apparatus lighter. The apparatus has been used successfully for five seasons in the resorts of Avoriaz, La Plagne, l'Alpe d'Huez in France as well as in Switzerland and Italy.

The Pandalp allows the stratigraphic profiles of the snow cover to be determined using the same principle as the Haeffeli probe (or Rammsonde). These in-situ tests of penetration resistances are essential in order to gain an understanding of the snow cover and its evolution. They are widely used in avalanche warning as well as for research.

Also the Pandalp can be fitted with a temperature probe which allows the mechanical properties to be combined with temperature profiles.

### 2.2 Principle

The principle of the Pandalp is described in the following figure (Fig.1) [2] :

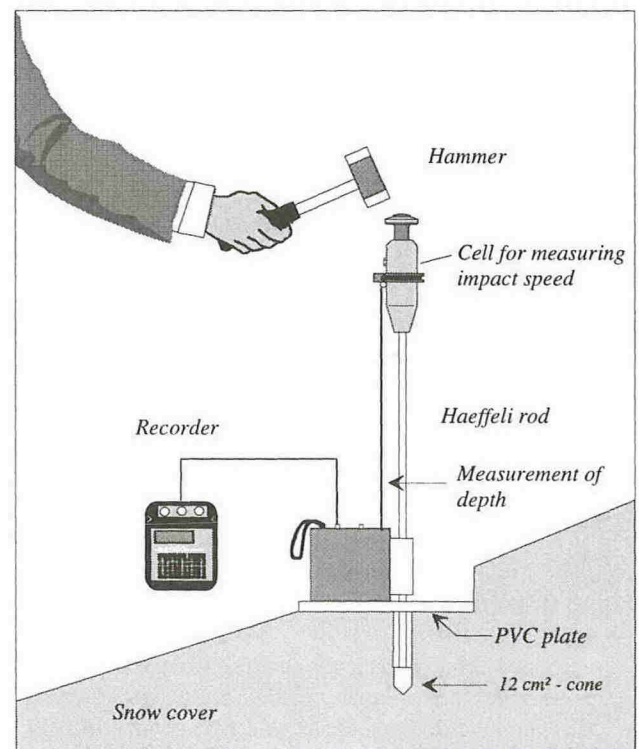


Figure 1 : Principle of the Pandalp

The box for measuring depth is linked to the head of the tool by a retracting notched belt, the shortening of this belt determines the depth driven by each blow of the hammer. The hammer, of a given mass ( $M$ ) strikes a piston, which has a magnet fitted inside. The piston slides into the head, which rests on top of the rods and cones, and the magnet passes two proximity switches located in the head. The time taken for the magnets to pass the two switches (a given distance  $l$  apart), gives the velocity of impact by the Hall effect. Hence with the velocity known it is easy to calculate the kinetic energy  $E_c$  given to the set of rods :

$$Ec = \frac{1}{2} Mv^2$$

We can now see how the energy function is used to calculate the cone resistance.

### 2.3 Adaptation of the Dutch formula

The Dutch formula is based on an assessment of energy and is most widely used formula for this type of application. The formula gives us the cone resistance and the expression is as follows :

$$q_d = \frac{mgh}{Ae} \times \frac{m}{m+m'}$$

$h$  is the height from which the hammer falls  
 $A$  is the area of the cone  
 $e$  is the depth due to one blow of the hammer  
 $m'$  is the mass of the struck objects  
 $m$  is the mass of the hammer  
 $g$  is acceleration due to gravity

The expression for potential energy,  $mgh$ , is replaced by the expression for kinetic energy  $\frac{1}{2}mv^2$  where  $v = l/t$  represents the speed of the piston.

$$q_d = \frac{\frac{1}{2}m \times l^2/t^2}{Ae} \times \frac{m}{m+m'}$$

### 3 COMPARISON WITH THE HAEFFELI SONDE

A lot of comparable tests has been carried out in different types of snow. The two tests showed (Fig. 2) permit us to point out that there is a good analogy between them.

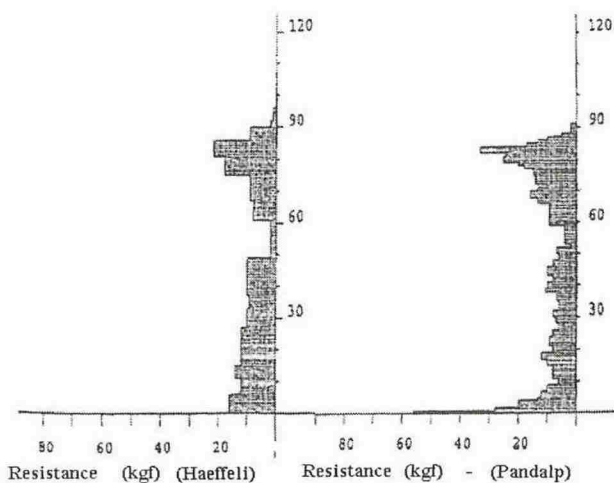


Figure 2. Comparison of two displays Haeffeli/Pandalp for a same test on GELINIV

## 4 COMPATIBILITY OF THE PROCESSING WITH GELINIV

### 4.1 Description of GELINIV

Since the winter season of 1985/1986 the mountain stations Meteo-France responsible for avalanche prediction have been equipped by the CEN (Institute of Snow Study) with computer application for processing all the data provided by the nivo-meteorological network.

This application was developed at a departmental scale is named ADIPRA. Within the framework of the protocol proposed by Meteo-France in autumn 1992, it was decided to provide the nivo-meteorological stations with derived software adapted to a local scale named GELINIV (Local Processing of the nivo-meteorological Information), if they wish to be provided.

Version 1 was distributed for the first time in January 1993. Since then the software has been constantly developed by integrating the new data gathered through international collaboration.

The current version is numbered 2.4 and GELINIV now runs on every computer and manages a skiable field, which can include up to 9 measurement sites carrying out observations and/or driving tests. The number of tests is limited to 4 per day DD/MM/YY and an hour. Entering the data into the computer from a classical nivological form of Meteo-France creates the test, furthermore the software integrates all the parameters of nivology. The printed sheet integrates the stratigraphy, the evolution of temperature and the mechanical resistances in kgf. Four tests can be displayed on one sheet, which allows an estimation of temporal evolution of the snow cover.

If the tests are well located and well spread, we are then able to estimate the features of the snow cover in other places.

### 4.2 Interface between the files Pandalp and the software GELINIV

Collaboration between the CEN and private companies led to a new Panda program called «PANDANEIGE». Through two phases this program allows data recorded in the Pandalp recorder to be integrated into the GELINIV software.

Two difficulties have arisen : firstly GELINIV can only receive 50 pairs of data made up of depth and resistance. The data given by the Pandalp had to be adapted. The work carried out by Franck Deplagne [5] on the processing of the files have allowed the two types of signal compatible (especially smoothed data). Secondly the values of the Panda for soil investigation, which includes resistance in MPa, had to be converted to a value in kgf on the CEN's request. This conversion to kgf of Pandalp files was made using a macro in Microsoft Excel. All these programs have been used to create a link with GELINIV. The new version of GELINIV has been provided by the CEN.

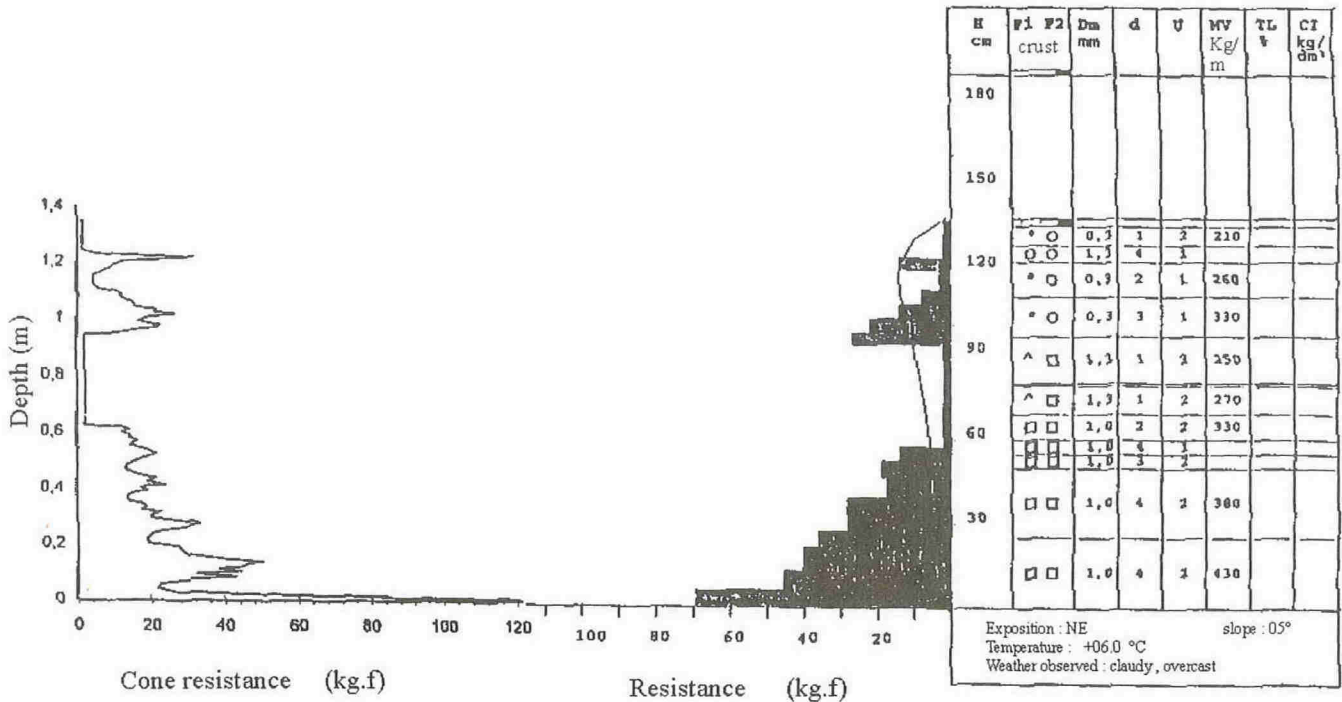


Figure 3. Conversion of the Pandalp signal into a GELINIV signal

The data is recorded as follows :

The test is recorded by the microcomputer on sight in a slightly different way to the old method as the new recorder allows different driving depths to be recorded found while testing in snow, as well as the classical information recorded about the site :

- sinking depth of PVC plate,
- driving depth of the rod,
- driving depth when the head is installed (Fig. 3).

Of course the principle of the test does not vary. During the transfer, the PANDANEIGE data are imported into GELINIV in order to obtain the resistance of the test.

## 5 INVESTIGATION OF LAYER : LA PLAGNE

### 5.1 The resorts

Located in Savoie at 25 km from Bourg Saint Maurice, France, the big Plagne consists of 10 resorts belonging to the same massif. The lower glacier limit is 1250 m while the upper limit is 3250 m and skiing is available all the year round. The high altitude guarantees sufficient snow for nivology and allows studies to be extended into the spring. The resorts are linked by a net work of more than 210 km.

From 1971 La Plagne became a member of the nivo-meteorological observation network created by Meteo-France with the installation of the post of Plagne Center. It was not until 1978 however that the resort began the local forecasting of avalanche risk with the opening of the Glacier massif of Bellecôte (3250m). The Plagne area needs this forecasting due to its surface and the diversity of its slopes. The quality of the forecast is linked to the observer as far as the in situ measurements are concerned.

However an attentive observation of the avalanche prone activity also helps accurate forecasting. La Plagne collects precise data on natural avalanches or avalanches triggered by explosive, which help to give a better understanding of snow cover.

As far as computer applications are concerned, the resort uses three different types of software, GELINIV, ASTRAL (statistic analogy for local avalanche risk). This allows a link to be established between the characteristics of the present day and the 10 most similar days recorded in the memory, and hence the avalanche activity of those 10 days can be observed. Finally OASIS (Observation of Avalanches of the Sight and Statistical Interrogations).

### 5.2 The sights

The daily nivological study carried out is based on four reference sights, with different altitudes and aspects. Tests are carried out every week, however in some situations tests can be carried out more often on high risk sights, where more information is required.

The measurement fields are protected from human interference by ranging poles and a rope. They are easily accessible from ski lifts.

#### 5.2.1 Site of La Plagne Center

Exposed to the North East at an Altitude of 2160 m with a 5degree slope. This is a very important sight for the state of the snow cover and is within 15 minutes of the Verdens chairlift.

#### 5.2.2 Site of Champagny

This sight is exposed to the south and formed from a protective shelf with no vegetation near by. The sight is

exposed to wind as well as intense solar radiation and hence shows great weekly variations. The slope angle is 3 degrees and is not influenced by drifting snow.

### 5.2.3 Montchavin

This site is a 10 degree north facing slope at an altitude of 2100 m. As it is quite small in size it only just allows a double measurement during three months (with both the Pandalp and the Haeffeli probe). It is however interesting as it gives a reference for north facing slopes with little sunshine.

### 5.2.4 Cemagref

This site goes by the name of the organization, which carried out the tests. It is located at a height of 2990 m, in a comb below the glacier of La Chiaupe. A 10-degree west-facing slope it is an interesting slope as it allows the study of nivology at high altitude.

During the winter of 1996-1997, 30 days were spent carrying out classical tests on reference sites (that is to say 120-140 tests) Two days were spent measuring space variability (65 tests).

## 5.3 Investigation of the layers

After the apparatus had been validated, the first concern was to determine if it was possible to detect the homogeneous layers making up the snow cover using cone resistance that means without opening the snow cover [3].

### ALGORITHM FOR THE CUTTING OUT OF THE SIGNALS

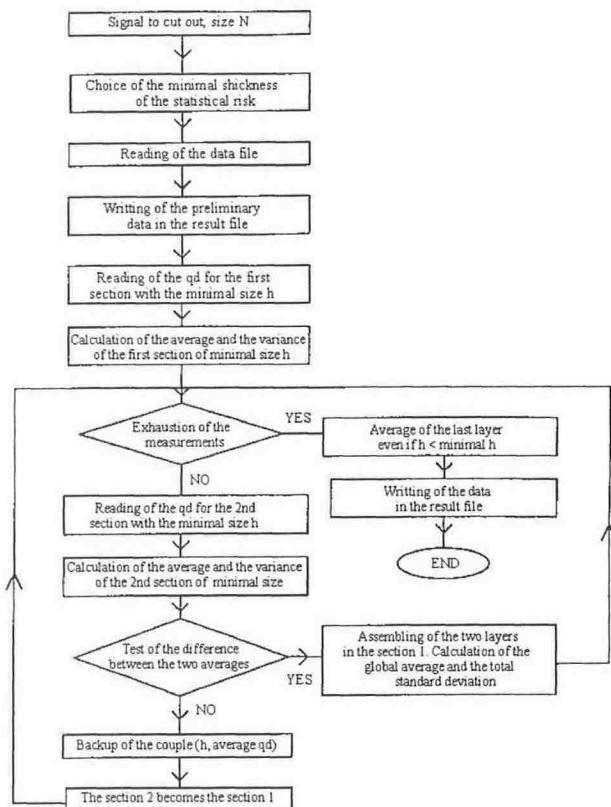


Figure 4. Algorithm for the cutting out of the signal

Firstly the homogeneity of a body must be considered, as well as scale phenomena. We can say that two samples are homogenous if they are statistically the same with in certain limits.

Firstly we can say that if two consecutive layers values of  $q_d$  are equal then the two measurement points must surely belong to the same layer. In order to divide the snow cover into different layers (each layer being almost homogenous, statistical testing must be carried out. This is based on the comparison between the average values calculated and two consecutive elementary strata. In fact the transition from one strata to another is based upon a significant change in cone resistance from one depth to another. The  $q_d$  pressure gradient defines the layer change (Fig. 4).

In order to investigate the different stratum by a statistical test we must do the following :

Firstly we must define a statistical risk of decision corresponding to the variation limit allowed over a homogenous layer.

Secondly we must determine the minimum thickness of a homogenous layer. In order to define a minimum thickness we have to answer the following questions :

What is the degree of accuracy of our apparatus? What is our aim?

As far as the accuracy goes it is about half a centimeter. In a problem of the stability of snow cover, a layer with weak mechanical features will be a danger source as they could combine to form a large failure surface which could trigger an avalanche.

The thin planes can hardly be sufficiently large in order to constitute preferential gliding planes.

We have tried to cut the snow cover at several minimal heights and with different statistical risks in order to observe the influence of these parameters on the investigation of homogeneous stratum (Fig. 5).

Then we can read the measured values of resistances for the first two elementary sections and we calculate the M1 and M2 arithmetic averages as well as the estimates of S1 and S2 standard deviations. Then we carried out the test called Student. We calculate the experimental value  $t$  and we compare it to the value found in the Student chart. From this result, either we gather together the two samples, or we distinguish the two stratum.

If the two samples are statistically homogeneous, we merge them. We cumulate the number of samples and then we calculate the global average and the new standard deviation. These two values will be allocated to the stratum when the test becomes negative.

If the two layers are statistically different, then it means that the stratum are not homogeneous as each one has its own average  $q_d$  and standard deviation. The procedure has to be continued by comparing the last sample of the two to a third one with always the initial size.

This method permits to obtain a statistical risk from 1% up to 90% [4] while the minimal thickness which is the most adapted is 2 cm either to our investigation tool or to our aims.

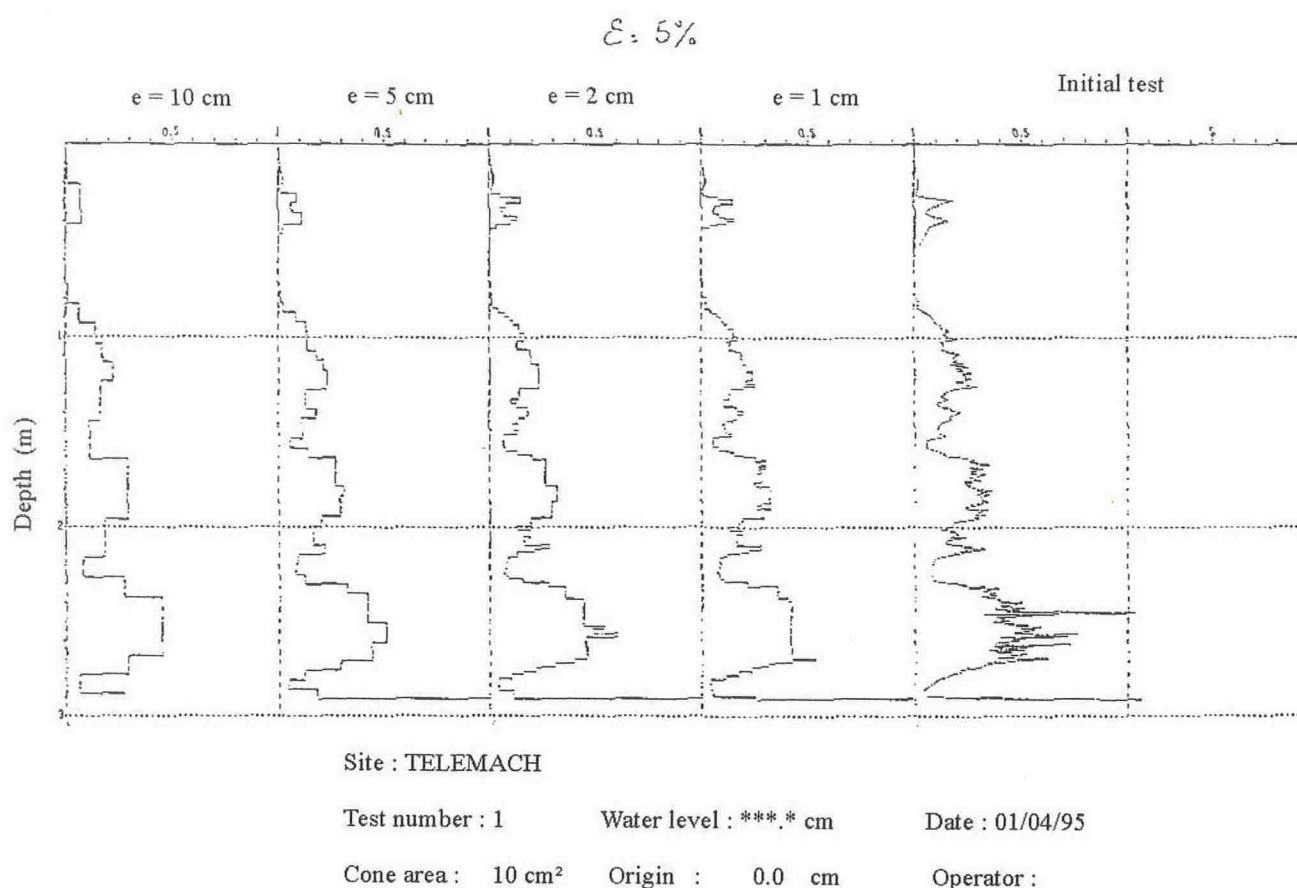


Figure 5. Example of layer investigation based on the Pandalp signal with a statistical risk  $\varepsilon = 5\%$  and for different minimal thickness of stratum

#### 5.4 Spatial variability

In our research the next step consisted in observing the spatial variability of the snow cover. Firstly we carried out measurements divided up according to a cross (30 measurements spaced out of 1 meters from one another) in order to determine the auto-correlation distances which interest us thank to variogramms. However such a study implies the precise knowledge of the field topography and the variogram has to evolve according to the relief.

#### 6. CONCLUSION

The results obtained show well the possibilities offered by the apparatus Pandalp. Coupled with the classical nivology observations, some studies are in progress for estimating the space-temporal distribution of snow mechanical properties with Pandalp tests. It will be possible to enter these data into some classical software such as slope stability studies.

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