



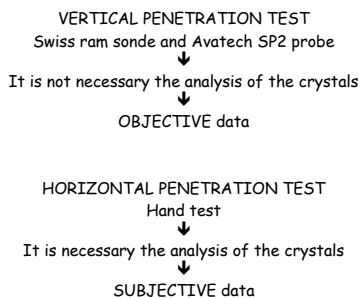
## RAM PROFILES WITH SWISS PENETROMETER, AVATECH SP2 PROBE AND HAND TESTS. COMPARISON OF THE HARDNESS PROFILES OBTAINED FROM ON SITE DETECTIONS IN THE ITALIAN ALPS DURING THE 2015-2016 SEASON

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In snowpack observations, the hardness profile of snow cover is determined by a *ram profile* and a *hand test* which are performed according to codified and standardized methods. Both tests have the purpose to measure the hardness of the snowpack layers.

The *ram profile* is made, regardless snow profile analysis, using the Swiss penetrometer or the new Avatech digital penetrometer probes (model SP2). The ram profile typically describes the hardness of each measurable layer with the recorded resistance to vertical penetration met by the probe tip during insertion.

On the contrary, the *hand test* determines the single-layer hardness during the snow profile analysis, as a function of the resistance to the horizontal penetration of the operator's hand or other objects according to an encoded insertion sequence.



Snow hardness is generally understood as the characteristic of the snowpack to withstand the local deformations produced by a compressive stress acting in an almost vertical direction.

The evaluation of hardness in snow surveys is particularly important because, being related to resistance, knowing a single layer hardness means being able to assess how that layer can withstand a compressive stress.

In this regard, to define the trend of the snow hardness from the surface up to the ground or to a significant depth will require the evaluation of the overall resistance in the snowpack in order to verify if there are layers of "low - very low" or "high - very high" resistance which could become potential gliding plans.

It is possible to obtain hardness evaluation by using objective measurement methods which require the use of instruments and therefore a minimum subjective contribution of the human operator as well as subjective measurement methods in which hardness evaluation is mainly related to the experience and sensitivity of the operator (CAA 2008, 2014; Fierz et al, 2009; Green et al, 2010). For the specific case, as regards the objective methods, vertical penetration tests were performed with Swiss ram sonde and with Avatech SP2 probe; with regard to the subjective methods, the hand test was used for horizontal penetration tests.

### VERTICAL PENETRATION TEST WITH THE SWISS RAM SONDE

The vertical penetration ram sonde comes from instruments for geotechnical soil investigations which were then adapted for performing penetration tests in the snowpack (Haefeli, R., 1936).

The snow hardness along the snowpack is evaluated according to the balance of the work between the stressing forces linked to the action of the probe penetration and the resistance forces connected with the penetration resistance developed by the snowpack (CAA 2008, 2014; Fierz et al, 2009; Green et al, 2010).

In particular:

$$R \cdot \Delta = (p \cdot h \cdot n) + p \cdot \Delta + q \cdot \Delta$$

$$R = \frac{(p \cdot h \cdot n) + p \cdot \Delta + q \cdot \Delta}{\Delta}$$

when:

- R → index of hardness [N]
- p → weight of the hammer = 10 N
- h → height of fall of the hammer [cm]
- n → number of the hammer falls [-]
- Δ → penetration [cm].



Fig. 1: view of penetration testing with the Swiss ram sonde

### VERTICAL PENETRATION TEST WITH AUTOMATIC AVATECH SP2 PROBE

The principle of the Avatech SP2 probe is similar to that of the ram sonde, but in this case the probe penetration does not take place by the action of a hammering mass but thanks to the direct action of the operator who inserts it in the snow in a few seconds.

The snow hardness along the snowpack profile is evaluated using a series of sensors that measure the resistance to penetration with a pressure sensor placed at the base of the probe as well as the sequence of penetration with optical sensors placed on the probe handle and along the probe.



Fig. 2: view of penetration testing with automatic Avatech SP2 probe

### HORIZONTAL PENETRATION TEST OR HAND TEST

The hand test is a horizontal penetration test which consists in inserting, according to an encoded sequence, the gloved hand of the operator into the snowpack in order to define which compressive force produces the breakage of the snow in the homogeneous layer previously identified through a punctual stratigraphic analysis (CAA 2008, 2014; Fierz et al, 2009; Green et al, 2010).

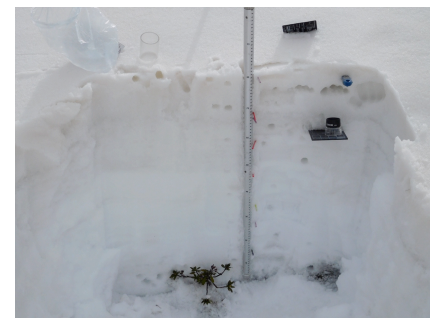


Fig. 3: view of hand test

### ANALYSIS AND COMPARISON OF THE VARIOUS TESTS

The comparison among the index values of quantitative and qualitative resistance derived from penetrometric tests and hand tests, according to previously published works, can be correlated in order to develop a mutual correspondence scale (Fierz et al 2009). Tab. 1 shows the correspondence among the different hardness classes resulting from the above mentioned test methods.

Tab. 1: correspondence among resistance classes (after Fierz et alii 2009)

| Class of resistance | Battage [N] | Hand test [-] |
|---------------------|-------------|---------------|
| Very low            | 0-50        | F             |
| Low                 | 50-175      | 4F            |
| Medium              | 175-390     | 1F            |
| High                | 390-715     | P             |
| Very high           | 715-1200    | K             |
| Ice                 | >1200       | I             |

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During the 2015-2016 season three test campaigns were performed to carry out the described tests so as to obtain data useful to a comparison among the different hardness detection systems, you can see a synthesis in tab. 2.

Tab. 2: test types and typology of the performed analysis

| Analysis / Test | Description  |
|-----------------|--|
| Snow profile    | analysis of the crystals<br>trend of the hardness along Hs<br>trend of density along Hs Hs |
| Battage         | vertical test  |
| Avatech SP2     | trend of the hardness along Hs   |
| Hand test       | horizontal test  |

Tab. 3 shows the list of the test campaigns performed and in fig. 4, the geographical location of the sites.

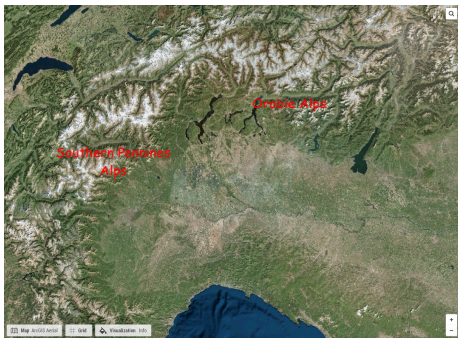


Fig. 4: geographical framework southern Pennine Alps and Orobic Alps (Avanet website)

Tab. 3: list of analyses and tests

| Site | Date     | Mountain area          | Locality |
|------|----------|------------------------|----------|
| 1    | 06/04/16 | Southern Pennines Alps | Oropa    |
| 2    | 06/04/16 | Southern Pennines Alps | Oropa    |
| 3    | 14/04/16 | Orobic Alps            | Carona   |

In the following pictures, the photographic view of the snowpack is reported for each test, together with the stratigraphic profile and the graphs showing the relationship between the snowpack hardness and the snowpack depth. All graphs were carried out starting from the tests with the ram sonde, SP2 probe and the hand.

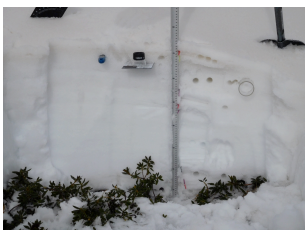


Fig. 5: view of the snowpack. Site 1 - Oropa 04/06/16 S exposure / 180°

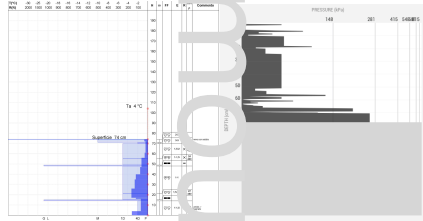


Fig. 6: stratigraphic analysis, tests à battage and hand test (Yeti output) and stratigraphic analysis, tests à battage and hand test. Site 1



Fig. 7: view of the snowpack. Site 2 - Oropa 04/06/16 W exposure / 270°

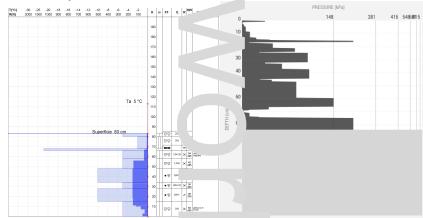


Fig. 8: stratigraphic analysis, tests à battage and hand test (Yeti output) and stratigraphic analysis, tests à battage and hand test. Site 2



Fig. 9: view of the snowpack. Site 3 - Carona 14/06/16 N exposure / 360°

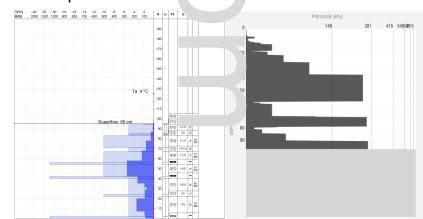


Fig. 10: stratigraphic analysis, tests à battage and hand test (Yeti output) and stratigraphic analysis, tests à battage and hand test. Site 3

From the graphs showing the variation of the snowpack hardness in function of the snowpack depth, it is possible to state as follows:

- the *hand test* with horizontal penetration, depending on the experience and skill of the operator, is a subjective test, in particular for the definition of the quantitative index of hardness value;
- the vertical penetrometric test performed with the *ram sonde* provides much more objective data than the hand test even if the ram sonde might fail to detect hard thin layers (e.g. layers of crystals type 8a detected in testing in sites 1, 2 and 3) or soft thin layers (e.g. layers of crystals type 4a, 5a and 7a). In this case, the skill and experience of the operator to carry out the test is crucial;
- the vertical penetrometric test performed with the Avatech SP2 probe provides data which can be largely compared to those obtained with the penetration test performed with the ram sonde. Thanks to its acquisition sensors, the Avatech SP2 probe succeeds in recording also the hard thin layers (e.g. layers of crystals type 8a detected during the test in sites 1, 2 and 3) or soft thin layers similarly to what already experienced by Pilloix and Hagenmuller, 2015. This procedure evaluates the hardness profile of the snowpack immediately after the test is run providing useful on-site information about the trend of the snowpack resistance from the surface to a maximum depth of about 1,50 m.

Conclusion ... Following on-site testing and comparative analyses carried out on the three types of tests, we can state that:

- the analyzed procedures are necessary and indispensable for assessing both the hardness of the single layers that make up the snowpack and the variation of hardness depending on its depth;
- the different data obtained from the tests must be deeper evaluated on-site so as to exclude, as much as possible, local influences and / or the operator's subjectivity;
- all the above mentioned procedures must be associated with detailed assessments (direct observations of the environment, crystallographic and stratigraphic observations, etc. ...) so that they can be added as "useful complementary data" to the assessments of the stability or instability of the snowpack at a given point;
- definitely "the fastest" analysis methods to be performed, such as the hand test and the penetrometer test with Avatech SP2 probe, greatly simplify the operator's task and can improve the knowledge of the snowpack allowing to better investigate the variability of the data, but they cannot be the only medium on which to base an assessment of stability or instability of the snowpack.

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