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P-wave and surface wave survey for permafrost analysis in alpine regions

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In various high mountain environments the estimate of mechanical properties of slope and sediments are relevant for the link of the geo-mechanical properties with the climate change effects.

Two different locations were selected to perform seismic and georadar surveying, the Tsanteleina glacier (Gran Paradiso) and the Blue Lake in Val d'Ayas in the massif of Monterosa. The analysis of the seismic and GPR lines allowed to characterize the silty soil (top layer) and underlying bedrock. We applied seismic survey in time lapse mode to check the presence of "active" layer and estimate the mechanical properties of the moraines material and their sensitivity to the permafrost changes. Mechanical properties of sediments and moraines in glacial areas are related to the grain-size, the compaction of the material subjected to the past glacial activity, the presence of frozen materials and the reactivity of the permafrost to the climate changes.

The test site of Tsanteleina has been equipped with sensors to monitor the temperature of soil and air and with time domain reflectometry to estimate the soil moisture and the frozen and thawing cycle of the uppermost material. Seismic reflections from the top of the permafrost layer are difficult to identify as they are embedded in the source-generated noise. Therefore we estimate seismic velocities from the analysis of traveltime refraction tomography and the analysis of surface wave. This approach provides information on compressional and shear waves using a single acquisition layout and a hammer acts as source. This reduces the acquisition time in complex logistical condition especially in winter period.

The seismic survey was performed using 48 vertical geophones with 2 m spacing. The survey has been repeated in two different periods: summer 2011 and winter 2011. Common offset reflection lines with a 200 MHz GPR system (in summer) permitted to investigate the sediments and obtain information on the subsoil layering.

The processing of seismic data involved the tomographic interpretation of traveltime P-wave first arrivals by considering the continuous refraction of the ray-paths. Several surface-wave dispersion curves were extracted in f-k domain along the seismic line and then inverted through a laterally constrained inversion algorithm to obtain a pseudo-2D section of S-wave velocity.

Georadar investigation (about 2 km of georadar lines in the first site) confirmed the presence both of fine and coarse sediments in the uppermost layer; the seismic data allowed the moraines to be characterized down to 20-25 meters of depth. At the elevation of 2700 m asl, we observed a general decrease of the P-wave traveltimes collected in November, when the near surface layer was in frozen condition, respect to the data acquired in June. The frozen layer is responsible of the inversion of P-wave velocity with depth; the higher velocity layer (frozen) cannot be detected in the tomographic interpretation of refraction tomographic of the P-wave arrivals. Compressional wave velocity ranges from 700 m/s on the uppermost part, to 2000-2500 m/s in the internal part of the sediments reaching values higher than 5000 m/s at depth about 20 m. The analysis of surface wave permitted to estimate a slight increase from summer to winter of the S-wave velocity, in the depth range between 0 to 5 m.