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The next generation of multiple temperature sensor

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Abstract. Long-term and short-term measurements of temperature at different depths in soil have always been very complicated. The solution that was used until now was measuring using soil thermometers. Measurements were done at shallow depths and generally only allowed for measuring of one temperature, and always at the one depth which was determined for the measurement (normally 5, 10, 20, 50, 100, 150 and 300 cm). These problems were relatively limiting and impractical. It was therefore necessary to devise an alternative for a simple and effective solution that would eliminate these disadvantages – it was necessary for a probe to allow temperature to be measured at different depths at one measuring point without having to change its position. A requirement simultaneously arose for the need to be able to measure temperatures at greater depths, and a multiple probe was therefore conceived consisting of a rod for dynamic penetration tests.

Key words: temperature, measurement, penetration test, sensor, soil, thermometer.

INTRODUCTION

A temperature sensor is currently the most widely used implement for measuring the temperature of solid ground, measuring the temperature on its sink bit or buried sensor network. The method of temperature measurement with a countersunk sensor bit is efficient, but it cannot be used to measure temperatures at different levels simultaneously and it is also limited by the length of the measuring rod to which the temperature sensor is attached. The temperatures are measured as standard at depths of 5, 10, 20, 50, 100, 150 and 300 cm. On the other hand, the buried sensor network enables long-term temperature measurement at different depths, but its installation is demanding. Its dismantling is also complicated. (Gonzales, 2012; Popiel, 2001)

Because of these issues a design of measuring rod development was created which would be able to measure temperature at different depths without the need for complicated installation of this measuring equipment. The proposed technical solution concerns the construction of an adjustable/extendable penetration thermometer for measuring solid ground temperatures. This construction enables temperature measurements at different depths of solid ground without the need to move the temperature sensor to different places (Popiel, 2001; Cao, 2013; Matsumoto, 2015; Hart, 2016).

MATERIALS AND METHODS

As the adjustable thermometer design is based on the technical solution of penetration rods for dynamic penetration testing, it was necessary to consider the principles and processes used within this testing when creating the design.

Dynamic penetration is a supplementary probing method in engineering and geological investigation. It is primarily used to quickly determine interfaces of layers with different geotechnical properties, establish the location and thickness of non-load-bearing and load-bearing soils, identify depth of erosion, assess homogeneity of backfills, detect the shear area, check compaction (of backfills, gravel cushions etc.), determine the thickness of made-up grounds etc (Brandl, 2006; Cao, 2013).

A 30 kg hammer is used in medium type dynamic penetrations, with a fall height of 0.5 m and a countersunk bit cross-section of 15 cm^2. Measuring instruments must conform to the requirements of CSN EN ISO 22476-2. The equipment is mobile and the set can be taken in parts also to locations that are difficult to access (slopes, foundation pits, cellars etc) (O'Loughlin, 2014; Quezada, 2014; Zhussupbekov, 2014; Bradna & Malaťák, 2016).

As a rule the penetration test is performed according to CSN EN ISO 22476-2 Geotechnical investigation and testing – Field testing – Part 2: Dynamic penetration test. Rods must be driven into the ground in a vertical direction without excessive bending, the maximum admissible incline of the rod assembly and guide rod from the vertical is equal to 2%. The speed of driving should be maintained between 15 and 30 blows per min. (pauses longer than 5 mins are recorded). The number of blows needed to drive the rod in by every 100 mm is continuously recorded. In the event of low resistance to penetration, the depth of penetration per one hammer blow is recorded. At least for each meter of penetration the torque required to turn the rods by 1.5 turns has to be recorded, or the time needed to reach the maximum moment. The measured value then serves to eliminate skin friction when evaluating results. If the number of 50 blows needed to drive the rod in by 100 mm has been reached, the test is ended. (Cao, 2013; Quezada, 2014)

The penetration assembly consists of several basic components. These parts fit together to form a large unit. They comprise a sink bit, driving rods, a pestle and a hammer with a guide rod (Gonzales, 2012; Matsumoto, 2015).

The bit (see Fig. 1), sometimes also referred to as cone, has a top angle of 90°, a diameter of 0.025 m, is used for ramming through soil and is attached to the tip of the driving rods. (Cao, 2013; Quezada, 2014)

Figure 1. Different kinds of penetration bits.

The driving rod unit has a diameter of 0.022 m and the weight of one rod is usually equal to 2.91 kg. The rods are made from high-tensile steel to reduce excessive deformation (deflation) and wear. For example, rod deflection must not exceed 1/1,000 of length. The rod unit has a scale fitted to read the needed amount of blows for a specified section (Cao, 2013; Quezada, 2014).

At the end of the driving rods a pestle is mounted (Fig. 2), also referred to as anvil or drive head. The pestle transfers the dynamic load of the hammer into the driving rods. As well as the driving rods, the pestle is also made from high-tensile steel (Cao, 2013; Quezada, 2014).

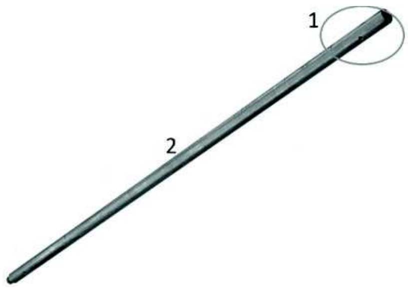

Figure 2. A pestle attached to the driving rods segment (1 – pestle, 2 – penetration rod).

The hammer with a guide rod actually functions as a large piston, hitting the pestle fastened to the driving rods. The hammer generates a constant dynamic force which acts on the pestle/anvil through its fall, in that it is guided to it by the guide rod (Cao, 2013; Quezada, 2014).

During the design work we had to meet the requirements that the thermometer should be usable in the same way as the driving rods, however a few small changes were made to integrate the temperature sensors. Therefore the probes were constructed in a manner similar to shallow depth core probes for engineering geology. The penetration assembly is also used to drive these probes in, except the bit and driving rods are replaced with a special drilling tool referred to as a 'šapa', which is used for earth sampling on the investigation site. (Cao, 2013; Quezada, 2014)

RESULTS AND DISCUSSION

The designed adjustable penetration thermometer consists of the modified penetration rod with an integrated thermometric band, with a driving bit mounted onto its lower end and an anvil at the top. A groove is made on the side of the side of the rod, where a thermometric band is integrated, consisting of temperature sensors and a bus line. The temperature sensors are placed at 10 centimetre spacing and they send data on temperature via the bus to the external assessment unit. The rods are 1,000 mm long, but according to the requirements of this dimension can be adjusted by the factory. Data collection will take place through local units or through IoT technology to transfer data directly to Cloud.

The process of measurement with an adjustable penetration thermometer (see Fig. 3) starts by driving the adjustable thermometer into the ground. A hammer or rammer can be used for striking the anvil so the rod goes in using the driving bit, which breaks through vertically into the ground. If the optimum depth is reached, a pause is made until the temperature of the sensors adjusts to the surrounding environment in order to prevent errors in measurement. Temperature stabilization on the sensor is given primarily by the used sensor. The temperature in the borehole will stabilize from about 5 to 15 min. However if a greater depth is needed, the anvil is unscrewed and an adjustable penetration thermometer is extended with another penetration rod onto which the anvil is mounted. We repeat this step as many times as needed in order to reach the optimum depth for measuring the ground temperature. After that we start collecting data from the individual temperature sensors to the external assessment unit, from where it can be further processed. The selection of rods will affect its durability. However, by default, such rods are designed for large loads, because it is high-tensile steel. For example, they are similarly constructed as rods for soil sampling. It is also possible to pick up with hydraulics and of adversely materials such as: clays soft, sandy soils and others.

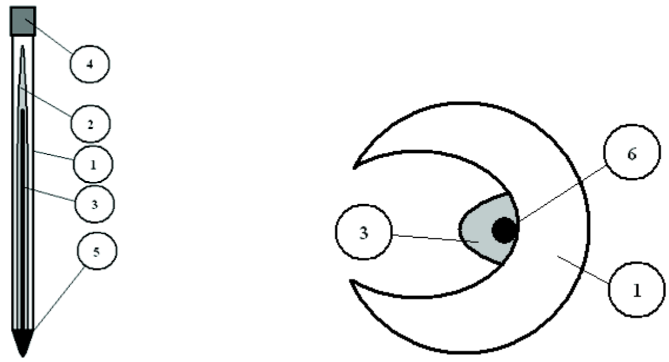

Figure 3. Adjustable penetration thermometer (1 – modified penetration rod, 2 – groove, 3 – thermometric band, 4 – anvil, 5 – bit, 6 – integrated bus).

A comparison was conducted on the cost of this device. For comparison standard temperature probes were selected. Specifically, the selected mobile monitoring device G-1 / P-100, Which has a large representation in the Czech Republic for measuring soil temperature. Comparison through a multi-criteria analysis of variants can be seen in Fig. 4 and also in Table 1 are shown the comparison value G-1 / P-100 a adjustable penetration thermometer. Selecting and setting values of weighting coefficients were dealt with experts in the art and have been adjusted according to their recommendations. For this type of analysis is the more important lower ratings of weighting coefficient. Construction of adjustable penetration thermometer is designed so to prevent stress a measuring parts and for durability. Lifetime of adjustable penetration thermometer is also dependent on the choice of material from which it is made. For our purposes, was chosen a high-tensile steel because this material is resistant to mechanical stress.

Table 1. Weighting coefficients in the multi-criteria analysis

	G-1/P-100	Adjustable penetration thermometer	Weight criterion
production costs	10 (83 EUR)	8 (95 EUR)	5
depth of use	8 (1,000 mm)	10 (1,000 mm and it can be extended)	1
recycling	6 (5,000 cycles)	10 (8,000 cycles)	3
multifunctional use	3 (1 sensor)	10 (8 sensor)	2
ease of installation	10 (without the need to pay attention to cleanliness of connections)	9 (the need to take into account the purity of connections)	4

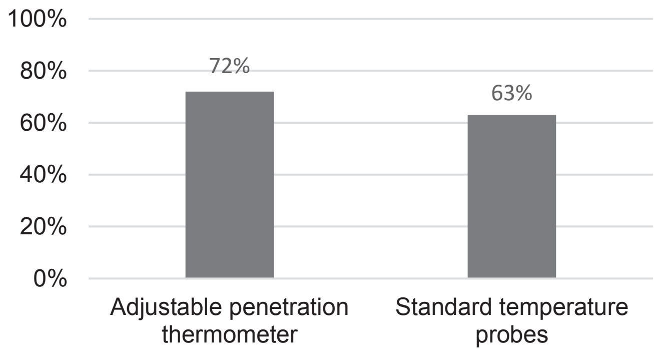

Figure 4. Comparison through a multi-criteria analysis of variants.

The author of the 'Study on Climate Conditions of Tokáň Locality' claims that taking the measurements would be easier if it was possible to measure all the quantities of his study at the same time. It is evident from his measurements (partially shown in Fig. 5) that he used four stand-alone thermometers. Therefore he had to place all the thermometers separately at the required depths. Use of an adjustable penetration thermometer would have saved him considerable time and finally also some of the funds spent on purchasing the needed measurement material (Brandl; 2006; Hostýnek, 2009).

Similar observations were also made in connection with collecting data for the article 'Energy foundations and other thermo-active ground structures' as well as 'Measurements of temperature distribution in ground'. It is therefore apparent that an adjustable penetration thermometer is a favourable alternative in similar cases, which simplifies lengthy and demanding measurements by saving time as well as financial resources (Popiel, 2001; Brandl, 2006).

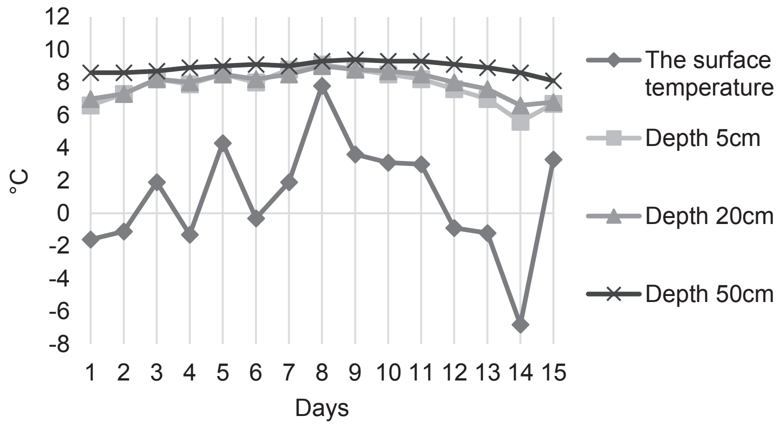

Figure 5. A Study on Climate Conditions of Tokáň Locality.

CONCLUSIONS

The extendable penetration thermometer will be appreciated in measuring ground temperatures, where it will improve the effectiveness and variability of the measurements. Thanks to its high measurement effectiveness and simple design it is also suitable for common climatology studies.

Considering that the technical solution consists in constructing an extendable penetration thermometer which is used in ground temperature measurements carried out at various depth levels at the same time, and given the requirements for a simple construction, it is necessary for the whole unit to emulate the design of the penetration rod. The penetration system technology is well-established and quite frequently used and so can be put to effective use.

Since the penetration rod designed for measurement has an integrated thermometric band placed in the groove it is sufficiently protected against critical mechanic strain, while at the same having free access to the soil around the penetration rod. This provides for effectiveness of its use, when it is only needed to drive the penetration rod to the required depth. If the optimum depth is reached, a pause is made until the temperature of the sensors adjusts to the surrounding environment in order to prevent errors in measurement, then the bus can be connected to the assessment unit, where recording of different temperatures can start at depths ranging from 10 cm to 100 cm with the use of a single rod. Naturally rods can be extended by modular pieces up to a maximum bearing depth for penetration tests. This is identified by a limit torque arising on the rods. If the driving into the ground does not stop at the right time, it may not be possible to pull the rods out of the ground.

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