Interaction between photovoltaic panel foundation and frost heaving soils

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The production of energy from renewable sources allows to limit the damage caused by climate change. Among the different renewable energy sources available, photovoltaic panels are becoming an important source in many parts of the world. The energy efficiency of photovoltaic panels is maximized if they are installed in cold areas. The province of Ontario (Canada) has become an ideal place for the installation of these facilities both for the low temperatures acting in the area and the support given by the Canadian government to eco-sustainable initiatives. However, the installation of photovoltaic systems in cold areas is influenced by the interaction of the shallower layer of soil with the atmosphere. In particular, the frost heaving induced by freezing of the ground can trigger mechanisms of interaction between the foundation piles and the surrounding soil until the complete foundation is removed.

The design of these foundation structures, is based on the approach proposed by Penner (1974) related to in situ monitoring tests on pile foundation. In this work, we propose to model the tests reported in Penner (1974) with a finite element code able to run fully coupled THM (Thermo-Hydro-Mechanical) simulation (Olivella et al 1996; Nishimura et al 2009; Casini et al 2016) , with the aim of back-analyze the behaviour observed and overcome the limitation of the approach proposed by Penner (1974).

Cases histories (Penner 1974)

Penner (1974) monitored the behavior of three different pile made of wood, concrete and steel with the diameters D (7.6, 15.2 and 30.5 cm). The variable measured in situ were:

- Frost penetration by means of thermocouple at different depths;
- Frost heave was determined from level surveys on lag bolts set into asphalt surface at 0.15, 0.3, 0.6, 0.9, 1.2, 1.5, 1.8 and 2.1 m from the pile;
- Uplift force at the head of fixed pile with a Dillon Gauges

The adfreeze stress acting along the lateral surface of the pile were calculated, by the author, dividing the force measured at the head of the fixed pile divided for the lateral surface of the pile to a depth L_g, defined as the depth of the ice penetration (with temperature T=0°C):

$$\tau_{Penner} = \frac{F_{measured}}{\pi * d * L_g}$$

where d is the diameter of the pile, L_g is the frost penetration depth and $F_{measured}$ the force measured at the head of the pile. The comparison among the adfreeze stress calculated following the Penner (1974) approach are shown in Table (1). The results are summarized for different diameters and for different winter period, starting from the measured peak values (January) up to March every months.

Table 1: Comparison between the values of peak of the forces and stresses for steel pile

	December			January			February			March		
	d=7,6cm	d=15,2cm	d=30,5cm	d=7,6cm	d=15,2cm	d=30,5cm	d=7,6cm	d=15,2cm	d=30,5cm	d=7,6cm	d=15,2cm	d=30,5cm
Peak adfreeze (kPa)	255	202	172	176	135	95	110	106	76	102	94	78
Avg. Adfreeze (kPa)	174	137	105	87	75	65	89	88	62	70	73	72
Peak force (kN)	38	60	102	33	54	82	36	69	124	36	78	138

Calibration of the model and comparison of the numerical results

The case study reported in Penner (1974) has been reproduced using Code Bright (Olivella et al 1996), a code able to describe the fully coupled behavior of multiphase soils. The pile and the soil are elastic and the soils parameters have been obtained through the interpretation of the tests reported in Bozozuk (1963).

The predictions of the numerical model in terms of heave at the ground surface, the temperature and the force acting on the pile have been compared with the in situ measurement.

In table (2) is reported a comparison between the forces predicted and measured with different diameters for the steel piles.

Table 2: Comparison among the uplift force measured by Penner and that gotten by numerical analysis

	Resultant force [kN]		
	d=7.6 cm	*d=15.2cm*	*d=30.5cm*
Penner	**39**	**78**	**138**
FEM Analyses	**43**	**90**	**182**

In Figure 1, is reported a comparison between shear stress predicted by the model and by Penner (1971) for three different diameters. Despite the force acting are comparable (Table 2), slightly overestimated by numerical simulation, the shape of the curve are completely different. In particular, the shear stress curve predicted by the numerical analyses are characterized by a maximum of the order of magnitude 5-6 MPa in the shallower zone (tensile stress zone) and a minimum of around -1.5 MPa (compressive stress zone) before the frost penetration depth, reported in blue in the Figure 1.

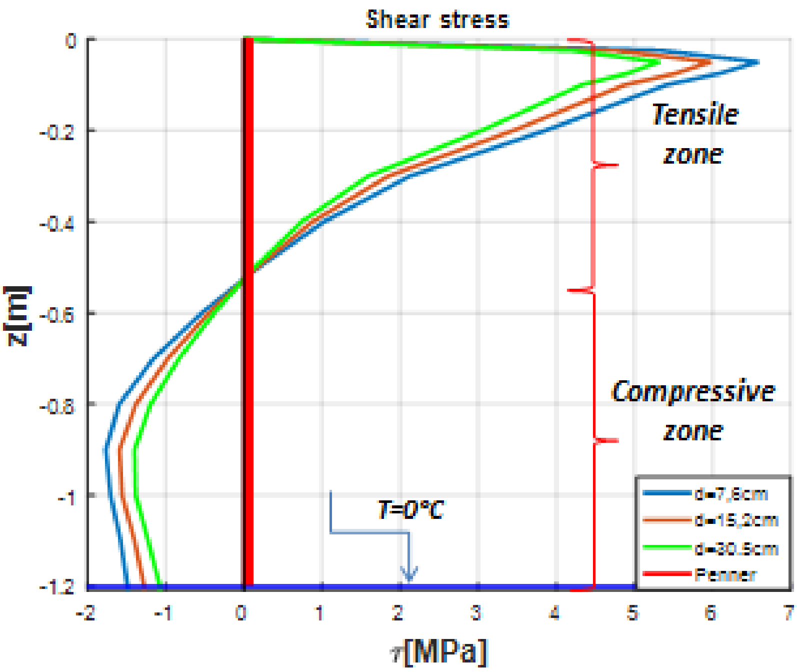

Figure 1: Comparison between the shear stress acting at the pile interface proposed by Penner (1971) and predicted by the numerical analyses.

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