Energy walls for an underground car park

***Alice DI DONNA*[1]**

[1]Politecnico di Torino, Department of Structural, Geotechnical and Building Engineering, Torino, ITALY.

ABSTRACT

Energy geostructures are increasingly considered as a new technology coupling the structural role of retaining structures and foundations with the possibility of exchanging heat with the ground to cover heating and cooling demand of buildings. In this paper, the possibility of applying such technology to the diaphragm walls of an underground car park in Torino was investigated through numerical analyses. It was found that this promising technology could cover a significant portion of the energy demand of a residential building in the proximity of the car park. The influence of the thermal activation of the walls on the underground temperature was also investigated and it was found to be acceptable.

Keywords: geothermal energy, energy walls, FEM

1. INTRODUCTION

The energy requirement is increasing worldwide and a significant portion of it is represented by the heating and cooling needs of buildings. In most countries, this is currently mainly provided by gas, oil and coal. Among the possible alternatives, conventional geothermal systems are recognised as clean, renewable and local sources. However, such systems require an initial investment and sometimes a large area for installation, which make them practically ineffective from the economical point of view. To face this issue, the so-called energy geostructures are rapidly spreading in Europe and around the World [1]. They are underground structures designed for structural reasons, such as piled foundations, slabs, diaphragm walls and tunnel linings and anchors, which are equipped to exchange heat with the ground similarly to standard geothermal boreholes. Using geostructures which would be constructed in any case the initial cost of installation is significantly reduced with respect to conventional geothermal systems. This paper focuses mainly on the application of this technology to the diaphragm walls of an underground car park in the city of Torino (Italy). Efforts have already been devoted to similar applications [2–6] and a number of real operational systems exist [7–9]. The work presented hereafter was part of a research project founded by the European found for Piedmont Region

* presenting author

(Italy) through the Innovation Pole Enermhy, in collaboration between the Politecnico di Torino, Resolving srl and Teknema Progetti srl.

2. THE CASE STUDY

The considered case study is a three level underground car park designed but not yet constructed in Torino, located in the SE district of the city. The geotechnical and structural project, provided by Teknema Progetti srl, included retaining structures all over the external perimeter. The possibility to transform them into energy walls would represent an incentive to build the car park and an undeniable added point for the city municipality. The designed car park has a rectangular shape of 93.15 x 52 m^2. On one side, the car park is in contact with the basement of another structure, but on the three others the retaining walls are in contact with the ground and can be reasonably equipped as heat exchangers (Figure 1). According to the project, the retaining walls are 15.5 m depth (Figure 2). The subsoil conditions in Torino are characterised by the presence of a sand and gravel deposit, ranging from medium to highly dense, down to a depth of 8–10 m. Below this depth lenses of cemented soil (in cases a conglomerate) are often present [10,11].

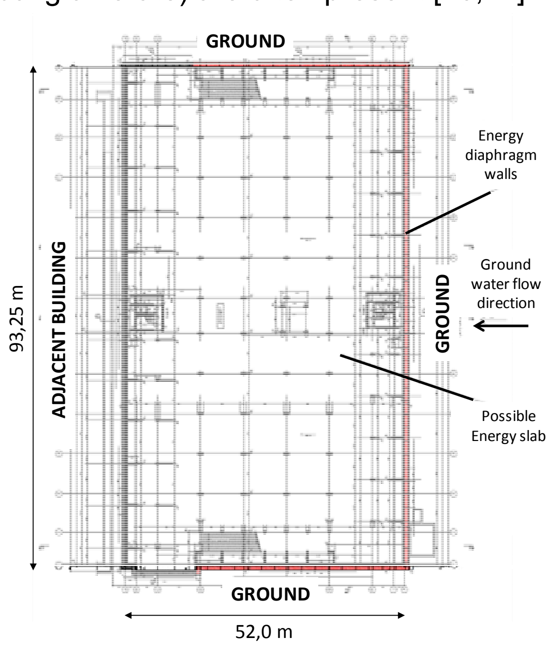

Figure 1 – Plan view of the car park.

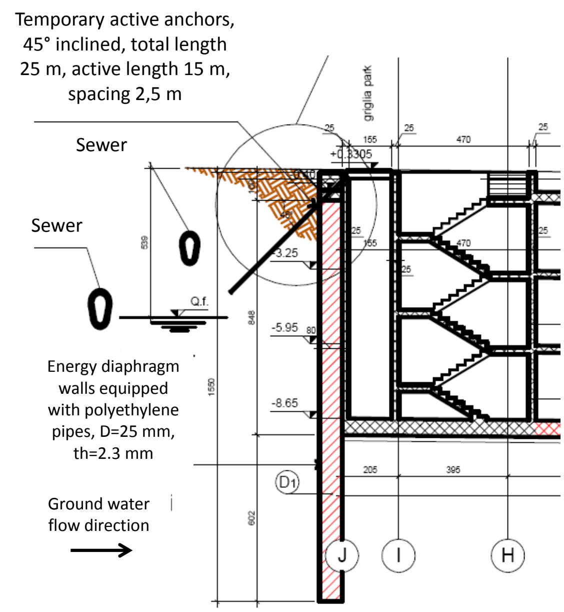

Figure 2 – Vertical section of the energy wall.

At the site, the water table surface is approximately 5 m below the ground level and the thickness of the aquifer is estimated in 22–23 m. The water in the aquifer has an average temperature of 14◦C and flows toward the Po River with an average velocity of 1.5 m/day (towards SE). The average hydraulic, hydro-dispersive and thermal parameters of the aquifer (Table 1) are known from in situ pumping tests and monitoring performed in the city [12].

Table 1. Torino subsoil properties.

Horizontal hydraulic conductivity	k_h [m/s]	$4.15 \cdot 10^{-3}$
Vertical hydraulic conductivity	k_v [m/s]	$0.21 \cdot 10^{-3}$
Porosity	n [−]	0.25
Bulk heat capacity	ρc [MJ/m^3/K]	2.55
Bulk thermal conductivity	λ [W/m/K]	2.26
Longitudinal dispersivity	α_L [m]	3.1
Transversal dispersivity	α_T [m]	0.3

3. FROM CONVENTIONAL TO ENERGY DIAPHRAGM WALLS

In order to transform the diaphragm walls into heat exchangers, polyethylene pipes have to be installed and attached to the reinforcing steel cage, before concrete cast. In this study, the pipes were supposed to have diameter of 25 mm. The position of the pipes inside the walls was selected based on a preliminary optimisation study. The pipes are installed only on the wall side towards the ground (Figure 3). The inlet/outlet pipes of each panel are assumed to be connected to the main circuit, which links them to the heat pumps.

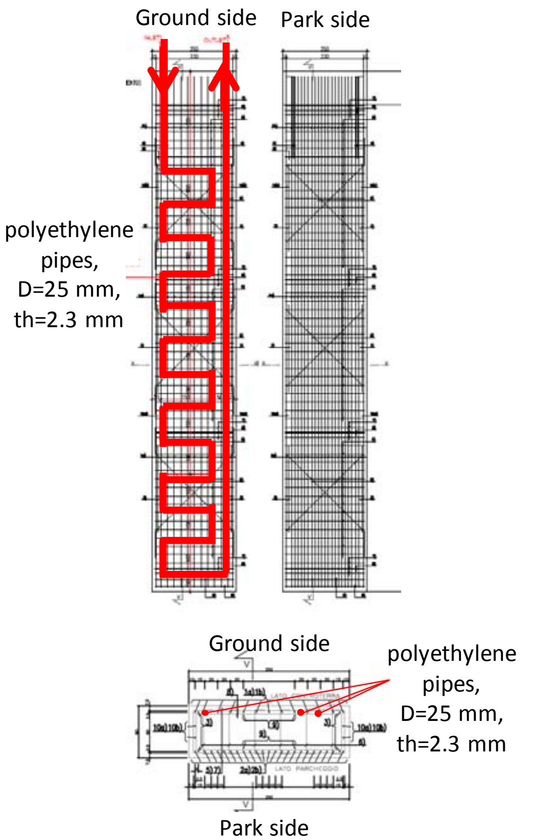

Figure 3 - Pipes position and reinforcing cage.

4. NUMERICAL MODEL

A thermo-hydraulic mathematical formulation was required to simulate the thermal exchange between the fluid circulating through the pipes, the concrete and the surrounding soil. To this end, the finite element software FEFLOW© was selected. The absorber pipes installed in the wall panels were simulated through the 1D discrete features elements provided in FEFLOW©. The 3D model adopted is presented in Figure 4 and Figure 5. It reproduces the geometry of one wall panel, having height of 15.5 m, thickness of 0.8 m and width of 2.5 m (Figure 2). The model was checked for mesh sensitivity. According to the Torino subsoil conditions, the initial temperature was fixed to 14 °C for the whole domain and the water table was positioned 5 m below the ground level.

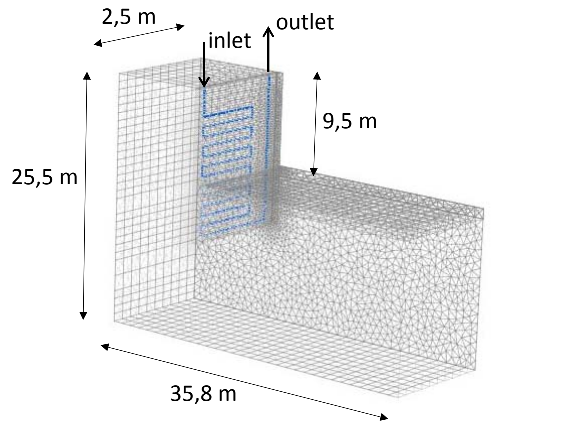

Figure 4 – 3D model.

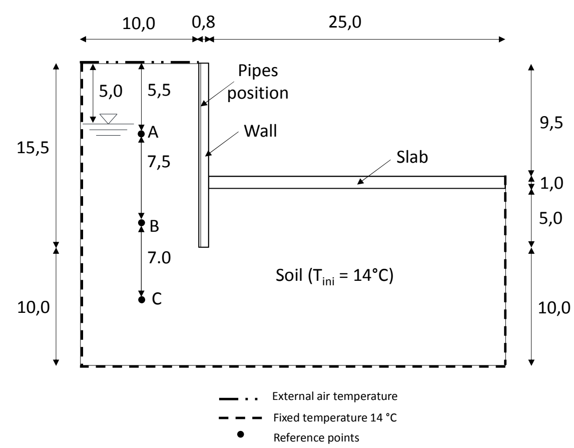

Figure 5 - Geometry of the model.

Constant hydraulic head and temperature were fixed on the left, right and bottom sides of the model, which were checked to be far enough not to affect the results. External air temperature was fixed on the top boundary, according to Torino average annual temperature variation (Figure 6). The establishment of the most appropriate boundary condition to be applied on the internal car park wall and excavation plane was a complex task because, with respect for instance to energy piles, energy walls are exposed to the air on that side [2]. Two main approaches have already been suggested in the literature, either a constant temperature [5,8,13] or a convective heat flux determined by a heat transfer coefficient [14,15]. The second one was mainly used for metro and train tunnels where air circulation is predominant, while the first one for basements, underground stations and car parks, as in this case study. In the absence of monitoring data related to the considered park internal temperature three different conditions were tested: temperature fixed to 18°C, to 14°C and adiabatic boundary. The imposed thermo-hydraulic properties of the soil were representative of Torino (Table 1), while those of the concrete and heat carrier fluid were those collected in Table 2. The inlet velocity of the heat carrier fluid was imposed equal to 0.2 m/s, while the inlet temperature was assumed according to Figure 6. The temperature of the model was initialized by running one-year simulation without activating the geothermal plant. The activation of the system was then simulated for a three-year duration.

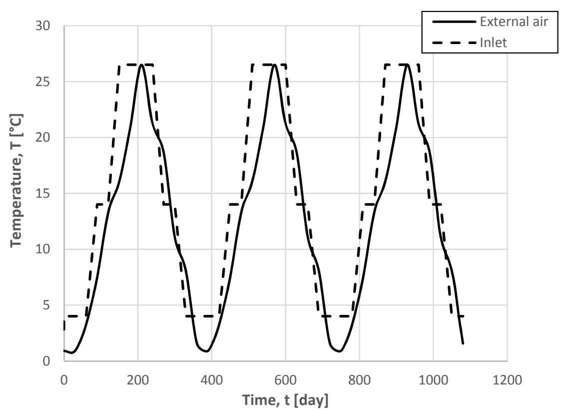

Figure 6 – External air and inlet temperature.

Table 2. Concrete and fluid properties.

		Concrete	Water
Hydraulic conductivity	k [m/s]	10^{-16}	-
Heat capacity	ρc [MJ/m^3/K]	2.2	4.2
Thermal conductivity	λ [W/m/K]	2.3	0.65

5. RESULTS

The results related to the energy performance of the system and the induced temperature variation in the subsoil are discussed in the following.

5.1. Heat exchange

Figure 7 shows the inlet and outlet temperature for the different internal wall boundary conditions considered. It is clear that the boundary condition on the wall side has a remarkable influence on the heat exchange. From the difference between the outlet, $T_{out,}$ and the inlet, $T_{in,}$ temperatures, the exchanged heat Q, measured in Watt, can be computed as:

$$Q=m\cdot c\cdot(T_{out}-T_{in}) \qquad 1$$

where m is the mass fluid rate in the pipes in kg/s and c the specific heat capacity of the circulating fluid in J/kg/K. The results showing the exchanged heat in W per meter of wall depth are presented in Figure 8 (positive means heat extraction, i.e. winter mode). If the wall internal temperature is fixed, the system can exchange heat not only with the ground but also with the internal park air and it results into a higher efficiency. Reasonably, between the two configurations that assume constant temperature, the case of 18 °C is more efficient in winter and less efficient in summer with respect to the one at 14 °C. If the wall is considered as adiabatic, the heat exchange occurs only on the ground side and it is consequently less efficient. This is conservative with respect to the other configurations. The peak and steady state values of heat exchange obtained for this conservative condition are collected in Table 3.

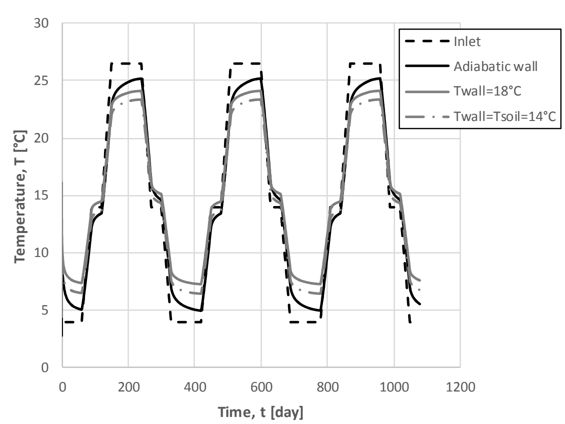

Figure 7 – Outlet temperature.

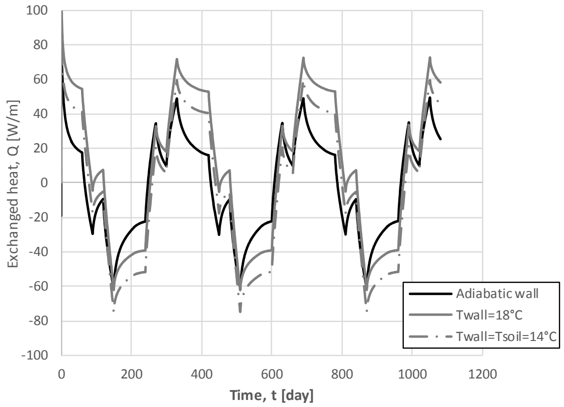

Figure 8 – Exchanged heat.

The first two columns express these values per meter of wall depth, while the second and third ones per unit wall surface. The last two columns indicate the values of kW that could be extracted/injected by the activation of the whole diaphragm wall according to Figure 1, i.e. including 68 panels activated as the one considered in the numerical analysis. It has to be noticed that these analyses assume no ground water flow. From previous studies, it is known that the ground water flow in Torino is about 1.5 m/day. In order to consider also this aspect an additional simulation was performed, assuming the ground water flow in the perpendicular direction to the wall panel. The obtained results are collected in Table 4 and clearly show that the energy efficiency of the system is significantly improved. Considering that a new Italian residential building has an annual energy need for heating of about 50 kWh/m^2 [16] and assuming that the plant would work in steady state for 1800 h/year in winter mode, it can be concluded that the proposed system could cover the heating demand of between 9 and 38 apartments of 70 m^2, depending on the presence of the ground water flow.

Table 3 – Exchanged heat with no ground water flow.

	Peak	Steady State	Peak	Steady State	Peak	Steady State
	W/m	W/m	W/m^2	W/m^2	kW	kW
Winter	51.0	17.2	20.4	6.9	53.8	18.1
Summer	63.0	24.0	25.2	9.6	66.4	25.3

Table 4 – Exchanged heat with ground water flow of 1.5 m/day.

	Peak	Steady State	Peak	Steady State	Peak	Steady State
	W/m	W/m	W/m^2	W/m^2	kW	kW
Winter	98.8	70.4	39.5	28.1	104.1	74.2
Summer	123.5	90.4	49.4	36.2	130.1	95.3

5.2. Soil temperature variation

Figure 9 shows the evolution of the ground temperature 5 m far from the wall at different depths. The first year represents the situation before the activation of the geothermal plant, followed by three years of heating-cooling mode. Up to about 5.5 m depth (point A in Figure 5) the ground temperature is affected by the external air temperature fluctuation (see first year). The activation of the geothermal system induces a variation of temperature in both the points A and B of +/- 1.5 °C with respect to the first year of simulation. The point C at 20 m depth is not affected by the thermal activation of the wall.

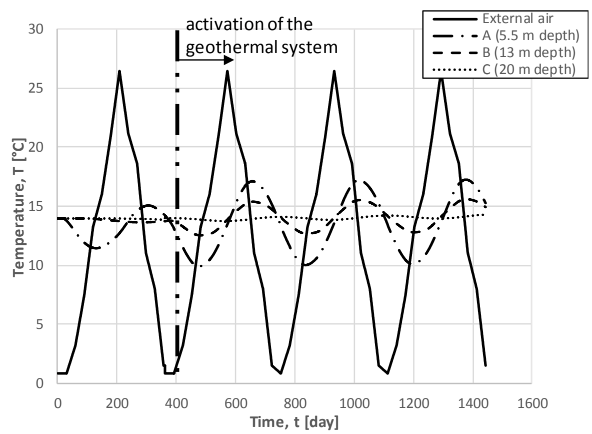

Figure 9 – Soil temperature in the ground.

6. CONCLUSION

Equipping the diaphragm walls of the considered underground car park as energy walls could cover the heating need of up to 38 apartments of 70 m^2 considering Torino underground conditions. It has to be noticed that this figure is based on conservative assumptions. The energy efficiency could be improved by equipping also the basement slab (Figure 1). The induced underground temperature variation was found to be in acceptable limits.

ACKNOWLEDGEMENTS

The work was part of the Feasibility study ENERWALL, funded by the Regione Piemonte (Polo di Innovazione Enermhy) in collaboration between Politecnico di Torino, Resolving srl and Teknema Progetti srl and coordinated by Marco Barla, adjunct professor at the Politecnico di Torino.

REFERENCES

[1] Laloui L and Di Donna A. Energy geostructures: innovation in underground engineering. ISTE Ltd and John Wiley & Sons Inc.; 2013. 320 p.

[2] Bourne-Webb PJ, da Costa Goncalves RA and Bodas Freitas TM. Retaining walls as heat exchangers: a numerical study. Proceedings of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development. 2015. p. 2499–504.

[3] Xia C, Sun M, Zhang G, Xiao S and Zou Y. Experimental study on geothermal heat exchangers buried in diaphragm walls. Energy and Buildings. Elsevier B.V.; 2012;52:50–5.

[4] Sun M, Xia C and Zhang G. Heat transfer model and design method for geothermal heat exchange tubes in diaphragm walls. Energy and Buildings. Elsevier B.V.; 2013;61:250–9.

[5] Sterpi D, Angelotti A, Corti D and Ramus M. Numerical analysis of heat transfer in thermo-active diaphragm walls. Numerical methods in geotechnical engineering. 2014;1043–8.

[6] Di Donna A, Cecinato F, Loveridge F and Barla M. Energy performance of diaphragm walls used as heat exchangers. Geotechnical Engineering. 2016;(under revision).

[7] Amis T, Robinson C and Wong S. Integrating Geothermal Loops into the Diaphragm Walls of the Knightsbridge Palace Hotel Project. Proceeding of EMAP-Basements and Underground Structures,. 2010;10.

[8] Soga K, Qi, H., Rui Y and Nicholson D. Some considerations for designing GSHP coupled geotechnical structures based on a case study. 7th International Congress onEnvironmental Geotechnics. Melbourne, Australia; 2014.

[9] Brandl H. Energy foundations and other thermo-active ground structures. Géotechnique. 2006;56(2):81–122.

[10] Bottino G and Civita M. Engineering geological features and mapping of subsurface in the metropolitan area of Turin, North Italy. 5th International IAEG Congress. Buenos Aires, Argentina; 1986. p. 1741–53.

[11] Barla M and Barla G. Torino subsoil characterisation by combining site investigations and numerical modelling. Geomechanics and Tunnelling. 2012;5:214–31.

[12] Barla G, Barla M, Bonini M, Debernardi D, Perino A, Antolini F and M. G. 3D thermo-hydro modeling and real-time monitoring for a geothermalsystem in Torino, Italy. Proc of the XVI ECSMGE Geotechnical Engineeringfor Infrastructure and Development. Edinburgh; 2015. p. 2481–6.

[13] Kürten S. Use of geothermal energy with thermo-active seal panels. Geotechnical Engineering: New Horizons. 2011;

[14] Zhang G, Xia C, Sun M, Zou Y and Xiao S. A new model and analytical solution for the heat conduction of tunnel lining ground heat exchangers. Cold Regions Science and Technology. Elsevier B.V.; 2013;88:59–66.

[15] Nicholson D, Chen Q, de Silva M, Winter A and Winterling R. The design of thermal tunnel energy segments for Crossrail, UK. Proceedings of the Institution of Civil Engineers - Engineering Sustainability. 2014;167(ES3):118–34.

[16] Corrado V, Ballarini I and Corgnati SP. National scientific report on the TABULA activities in Italy. 2012.