

Direct Geothermal Energy from Geostructures

Bouazza, A.^{1*}, Adam, D.², Rao Singh, M.¹, Ranjith, PG.¹
malek.bouazza@monash.edu

¹ Monash University,

Department of Civil Engineering, Bldg. 60, Melbourne, Vic. 3800

² Vienna University of Technology

Institute of Geotechnics, Karlsplatz 13, A-1040, Vienna, Austria

Incorporation of heat exchangers into ground embedded structures (Geostructures) such as shallow foundations, pile foundations, diaphragm walls, tunnel cut-and-cover walls, tunnel linings and anchors, is a relatively novel sustainable technology for the intermittent storage of energy in the ground with a view of utilizing it for heating and cooling by means of suitable systems integrated into the geostructures. This innovative technology can provide not only substantial long-term cost savings in relation to conventional energy systems but also can make an important contribution to environmental protection by reducing fossil energy use and minimizing the carbon footprint of built structures.

Keywords: Direct geothermal energy, Geostructures, Heating, Cooling, Heat pumps, Pile foundations, Tunnels, Diaphragm walls.

Introduction

The adverse effects of greenhouse gas emissions and rapidly depleting natural energy resources has prompted governments across the world to identify ways of reducing carbon footprints and increasing the utilisation of alternative, renewable energy sources.

To facilitate this approach, legislations across the globe, internationally recognised and locally introduced, are being passed through governments to ensure that carbon reductions can be achieved in the near future.

With new technologies in the field of the alternative energy sources being continually developed and the recognition of its important contribution earned by government organizations and the general public, implementation has recently become more feasible. It is not surprising that the demand for renewable forms of energy such as geothermal energy is steadily increasing and is receiving at the same time a considerable amount of interest.

Traditional geothermal energy systems require interaction with kilometre-deep strata of rock, where thermal energy is much greater and can produce hot fluids to drive turbines for electricity (Preene and Powrie, 2009). Its use is however weighed down by cost and practicality, a technology that is more suited for larger scale applications. More recently, encouraging developments are being achieved in the field of

shallow geothermal energy systems (i.e direct geothermal energy systems) using geostructures such as pile foundations, diaphragm walls, shallow foundations, tunnel cut-and-cover walls, tunnel linings and anchors. The geostructures utilise the required ground-concrete contact element to transfer the construction loads to the ground as well as acting as a heat exchanger unit. These systems show great potential, comparative to the traditional systems, in terms of long-term sustainability, access, flexibility and economics. Direct geothermal energy is based on the principle that the subsoil can be employed as a thermal energy source by using its natural potential and thermal storage capabilities.

Two different operation schemes for the use of geothermal energy from geostructures are possible: exclusive geothermal energy extraction or energy input; and alternating seasonal operation with heating and cooling storage.

For exclusive geothermal energy extraction, the energy flow takes place in one direction only, for example for heating purposes during winter. However, the seasonal operation uses the thermodynamic inertia of the soil in order to store thermal energy in the ground for later operation with reversed energy flow. Consequently, the seasonal operation can produce energy equilibrium in the ground over a complete heating/cooling period of a year. A geothermal cooling system extracts heat energy from a built structure via either an air-cooling system or a water-based cooling system, which can be integrated in ceilings and walls. The cooling system acts like a 'reverse' heat pump, and the thermal energy can be stored in the ground. Geothermal energy applications that need a very low service temperature can also be operated in 'free heating' or 'free cooling' mode. The necessary energy input then is limited to the electricity required to operate a circulation pump, because no heat pump is needed to raise the temperature level. For buildings, these technologies can now be considered as state-of-the-art.

Applications

Austria, Switzerland and Germany can be regarded as the pioneering countries that have investigated the use of geostructures for decades.

Extensive use of ground-source heat exchangers have been featured in Austria. Two notable examples are lot LT24 of the Lainzer tunnel and Uniqa Tower in the centre of Vienna. Lot LT24 was the first application in the world where heat exchanger technology, was applied to bored piles of a cut-and-cover tunnel. The lot comprised 59 'energy piles' with a diameter of 1.2 m and an average pile length of 17.1 m. The piles were equipped with absorber pipes connected to a service room. The absorber pipes were connected to collection pipes, which led to six heat pump units providing heat to an adjacent school building.

The Uniqa Tower, located in the centre of Vienna, is founded on diaphragm walls that reach down to 35 m below surface. At this depth, a high groundwater table and surrounding ground are ideal conditions for geothermal energy utilisation, where 7800 m² of diaphragm walls are used to absorb energy from the ground to produce a heating capacity of 420 kW and a cooling capacity of 240 kW. The annual heating output reaches up to 818 MWh and the annual cooling output up to 646 MWh (Adam and Markiewicz, 2009). Simulations of this energy system result in a minimum brine entry (into the diaphragm walls) temperature of -2.8 °C in January and a maximum entry temperature of 31.8 °C in August. The geothermal energy is used in combination with low-temperature heating systems such as wall and floor heating, and free cooling is used to support a conventional cooling system.

In Germany, energy piles have been used in the 200 m high Frankfurt Main tower. This building is founded on a 30 x 50 m² base supported by 213 piles, 112 of which are energy piles of 30 m in length (Ebnother, 2008, Laloui et al., 2006). Berlin's International Solar Centre employs 200 energy piles to meet 20 % of heating and 100 % of cooling demands through seasonal heat storage (Fisch and Himmler, 2005). Germany has been quite receptive towards this new technology with the federal government offering incentives in an effort to promote the ground-source heat pump market. It has however been recommended that for this alternative energy source to be economically viable, both heating and cooling operations should be considered (Sanner et al., 1996).

Switzerland has had several decades of experience with ground-source heat pumps. Two notable examples of projects, which have employed the use of energy piles are at the Swiss Federal Institute of Technology in Lausanne and Dock Midfield Terminal Airport at Zurich Airport. The Lausanne project has also been part of an extensive performance monitoring program, in particular the investigation of the thermo-hydro-mechanical behaviour of surrounding soil

(Boennec, 2008, Laloui et al., 2006). Over the past five years, the installation of geothermal pile foundations has grown exponentially in the UK. There were approximately ten times more geothermal pile foundations installed in 2008 than in 2005. The reason for this rise in production is mainly driven by the code for sustainable buildings that requires the construction of zero-carbon buildings by 2019 (Bourne-Webb et al. 2009).

Future Prospects and Feasibility in Australia

As a hot and dry country, climate change poses a substantial threat to Australia's economy and the way of life. For the past thirteen years, Australia has experienced eleven of the hottest years since records began and temperatures are projected to continue to rise over the next century. Global and local communities need to focus on reducing greenhouse gases, because even though the effects of global warming can no longer be avoided, people can make efforts to help minimize it.

Benefits of utilising Geothermal Geostructures in Australia

Although there are a significant amount of advantages to implementing direct geothermal energy geostructures, the environmental benefits are likely to be considered the most attractive. The Australian Government had recognised the potential impacts of climate change and have put in place certain legislation and policies focused on reducing carbon pollution. The White Paper (Australian Government, 2008) specifies goals to cut carbon emissions, by the year 2050, to 60% of the levels emitted in 2000. Furthermore, by the year 2020, the Australian government has committed this country to reduce its carbon pollution by up to 15% below 2000 levels via the Kyoto Protocol. Geothermal energy geostructures are one solution that has great potential in helping Australia to reduce carbon emissions and meet this commitment. This is confirmed as the Energy Efficiency Action plan states that energy use in households for the purpose of heating and cooling during the year 2005 contributed, on average, to 26% of the total greenhouse gas emissions in Australia. Governments, such as the state of Victoria, already have in place specific goals to implement alternative energy sources, the Victorian Environmental Sustainability Framework (2005) states that the Victorian Government aims to increase the share of Victoria's electricity consumption from renewable energy source from the 4% (in the year 2005) to 19% by the year 2010 (DSE, 2005).

For example, the inclusion of piles for structural integrity is already commonly identified in many commercial and industrial buildings in Australia. One example of an area where piles are

commonly used because of foundation limitations is Melbourne where Coode Island Silt is found along the urban area of Southbank. As a result, the adaptation of structural piles to include the geothermal energy pile systems is a very feasible and economically viable option.

The Australian Environment

The main cities in Australia exhibit significantly different types of foundations for their built structures. Some cities are predominantly founded on sandstones such as Hallett Cove sandstone in Adelaide and Hawkesbury sandstone in Sydney. This may result in increased costs of implementing geothermal geostructures as larger area of absorbers might be needed. The area of Melbourne is of particular focus due to the already large use of piles for structural purposes. Based on geological maps from the Victorian Geological Survey, the outer Eastern to North-Eastern areas of Melbourne consist mainly of mudstone, sandstone and siltstone whereas is the outer Northern and Western areas the geology consists predominantly of new volcanic materials such as basalt and scoria. Closer to Melbourne itself, the foundations consist of a variety of clay, silt, sand, gravel and peat (Peck et al., 1992). The main implications of this geological information are that each of these types of soils will affect the performance of the systems differently due to the varying thermal conductivities and geothermal gradients. This information also illustrates the need for detailed geotechnical investigations to be carried out in order to accurately determine the subsurface that will be in contact with the ground heat exchangers

Research Challenges

An issue that may arise with implementing this system in Australia is the imbalance between the heating and cooling needs of the user and this needs to be explored further. As a result of the warm climate conditions within Australia, there is likely to be more demand for cooling or otherwise known as heat rejection into the ground. The importance of achieving a balance between heat rejection and extraction has resulted in the requirement for building occupants to inform environmental authorities each year of the respective volume of energy abstraction and rejection. This ensures that individual systems do not short-circuit, that the natural recovery process can still occur long term and prevents possible impacts on other nearby installations (Dickinson et al., 2009). The thermal imbalance has been identified as a problem for some systems in other countries with similar climate conditions and a solution has already been proposed by Fan et al. (2008). Currently, a large research programme is being carried out at Monash University on direct geothermal energy piles. The research programme consists of detailed laboratory

investigations and field study of geothermal pile foundations. The laboratory study investigates the impact of heating and cooling on surrounding soil at small scale. The geothermal pile at laboratory scale is being imitated by a temperature controlled heater. The field study includes static load test of a fully instrumented large scale pile connected to a heat pump. The field study aims at measuring stress, deformation, temperature and thermal properties of the fully instrumented geothermal pile and surrounding soils. The study at Monash will shed more light on the field performance of geothermal energy piles under local conditions

References

- Adam, D. and Markiewicz, R., 2009. Energy from earth-coupled structures, foundations, tunnels and sewers. *Géotechnique*, 59, No3, 229-236.
- Australian Government, 2008. Carbon Pollution Reduction Scheme, Australia's Low Pollution Future (White Paper). IN CHANGE, D. O. C. (Ed.). Canberra, Australian Government.
- Boennec, O., 2008. Shallow ground energy systems. *Proceedings of the Institution of Civil Engineers, Energy* 161, EN2, 57-61
- Bourne-Webb, P.J., Amatya, B., Soga, K., Amis, T., Davidson, C. and Payne, P., 2009. Energy pile test at Lambeth College, London: geotechnical and thermodynamic aspects of pile response to heat cycles, *Geotechnique*, 59, No. 3, 237-248.
- Dickinson, J., Buik, N., Matthews, M.C. and Snijders, A. 2009. Aquifer thermal energy storage: theoretical and operational analysis. *Géotechnique*, 59, No3, 249-260.
- DSE, 2005. Our Environment, Our Future, Victoria's Environmental Sustainability Framework. IN ENVIRONMENT, D. O. S. A. (Ed.). Melbourne, Department of Sustainability and Environment.
- Ebnother, A., 2008. Energy Piles, The European Experience. *GeoDrilling* 2008. Haka Gerodur.
- Fan, R., Jiang, Y., Yao, Y. and Ma, Z., 2008. Theoretical study on the performance of an integrated ground-source heat pump system in a whole year. *Energy*, 33, 1671-1679.
- Fischl, M. N. and Himmler, R., 2005. International Solar Center Berlin - A comprehensive energy design. Building performance congress. Frankfurt Am Main, Germany, Messe Frankfurt GmbH.
- Laloui, L., Nuth, M. and Vulliet, L., 2006. Experimental and numerical investigations of the behaviour of a heat exchanger pile. *International Journal for Numerical and Analytical Methods in Geomechanics*, 30, 763-781.

Peck, W. A., Meilson, J. L., Olds, R. J. And Seddon, K.D, 1992. Engineering geology of Melbourne.A.A.Balkema. Rotterdam, Netherlands.

Preene, M. and Powrie, W., 2009. Ground energy systems: from analysis to geotechnical design. *Géotechnique*, 59, 261-271.

Sanner, B., Hopkirk, R. J., Kabus, F., Ritter, W. and Rybach, L., 1996. Practical experiences in Europe of the combination of geothermal energy and heat pumps. Proc 5th IEA Conference on Heat Pumping Technologies, Toronto, 1:11 1–25