Analysis on Energy Geotechnical Engineering Technology in Diaphragm Wall

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Abstract. With the construction of deep foundation pit, subway station and other large underground engineering, energy geotechnical engineering technology based on diaphragm wall has been applied in China. And the technology has shown its great development potential and wide application prospect gradually. The basic concept and characteristics of energy geotechnical engineering and geothermal energy development technology in shallow earth ground are introduced. According to energy geotechnical engineering technology in diaphragm wall, the design of heat exchange pipes buried in diaphragm wall, the thermal stress induced by the buried pipes and the development problems of the technology were summarized and discussed in the paper. The experience and results presented can provide a reference for the application and development of the energy geotechnical engineering in diaphragm wall.

1 Introduction

With the development of energy saving technology, ground source heat pump technology has been applied gradually in China. Ground source heat pump technology uses the earth as heat source due to its constant temperature in a certain depth of the earth. The temperature in the earth is much lower than that of outdoor air in summer, and it is much higher than that of outdoor air in winter. So the ground source heat pump technology can overcome the disadvantages of poor efficiency of air source heat pump. With its significant advantages of environmental protection, high energy efficiency ratio and operating stability, the ground source heat pump technology has been well developed in recent years [1].

The technology that the heat exchange pipes are buried in diaphragm wall is one of the technologies of energy geotechnical engineering. In which, the heat exchange pipes are directly banded on the main reinforcement of diaphragm wall and form a heat exchange component.

This technology saves the cost of drilling, and has the advantages of good heat transfer effect, stability and durability and no additional underground space. The two major problems of occupying land and high initial investment in the popularization of ground source heat pump technology are solved. So the technology has broad application prospects in the highly dense urban area [2,3].

The technology of pipes buried in diaphragm wall was first applied in Austria and Switzerland in 1996. Since 2003, the heat exchange pipes are buried in the retaining structure of foundation pit, foundation slab and some section tunnels in Vienna metro U2 extension line [4,5]. In China, the technology of pipes buried in diaphragm wall was first applied in Shanghai Natural Museum [6,7].

On the whole, the energy geotechnical engineering based on diaphragm wall are still less at present. So it is necessary to carry out summary analysis on energy geotechnical engineering technology and ground source heat pump technology based on diaphragm wall, so as to promote the further development and application of the technology in China.

2 Development of energy geotechnical engineering

2.1 Characteristics of energy geotechnical engineering

Based on the traditional ground source heat pump system and the characteristics of underground engineering, Professor Xia initially proposed the concept of energy geotechnical engineering which can be applied to urban areas in China [2].

Energy geotechnical engineering technology is a new building energy saving technology originated from traditional ground source heat pump technology. The heat exchange pipes are buried in underground engineering and form a heat exchange component, which has many advantages. The technology generally can save 30% ~ 50% energy compared with the traditional air conditioning system. Furthermore, the geothermal heat exchanger and the underground structure are closely integrated in energy geotechnical engineering, which ensures the stability and durability of the system. And the cost is relatively low than other energy saving technology due to that it can be combined with any underground building structure. The energy has the characteristics of renewable, stable and reliable, clean and durable, economic and significant environmental benefits. So this energy saving technology has great development potential and wide application prospect in China.

2.2 Geothermal energy development technology

It is generally considered that the acquisition of the shallow ground heat is the most realistic and promising technology to replace the traditional heating mode in 21st century. The development of geothermal energy in shallow earth is mainly based on the ground source heat pump technology, which includes water source heat pump technology and buried pipe ground source heat pump technology.

Most water source heat pump system directly extracts groundwater or surface water, which is open system [8]. Although open water source heat pump system has high heat exchange efficiency and low cost, its stability is poor and the long-term extraction of groundwater will cause ground subsidence and other geological disasters. Therefore, this system is not recommended in many countries, and even banned in some cities.

For buried pipe ground source heat pump system, the water or other working fluids flows in the heat exchange loop pipe and exchanges heat with rock and soil, which is closed system. This system has good stability, but the heat transfer ability is slightly worse than water source heat pump system. Due to the need of excavation, drilling and other additional construction, the cost of ground source heat pump system is higher. And the system takes up a certain land and underground space, so it is very limited in the densely populated urban areas in China.

Energy geotechnical engineering technology and buried pipe ground source heat pump technology are all closed system, and the biggest difference is that the former underground heat exchange system lies in the underground reinforced concrete structure, which can well ensure the stability and durability of the system. Energy geotechnical engineering inherits the advantages of buried pipe ground source heat pump system, so it has laid a solid foundation for the development of energy saving technology in urban areas in China.

The comprehensive comparison of advantages and disadvantages of various ground source heat pump systems is shown in Table 1[2].

Table 1. Comparison of various ground source heat pump systems.

Comparison items	Ground source heat pump system		Energy geotechnical engineering system
	Horizontal buried pipe	Vertical buried pipe	
Intensity of heat exchange	weak	stronger	weaker
Stability of heat source	stable	stable	stable
Area occupied	large	small	few
Initial investment	high	highest	low
Operation cost	low	low	low
Stability of operation	poor	good	fine
Limitation of land	much	little	no

3 Energy geotechnical engineering technology in diaphragm wall

3.1 Design of buried pipe in energy geotechnical engineering

3.1.1 Size and quality of buried pipes

The buried heat exchange pipes should have good chemical stability. And due to the large number of buried pipes, the low price pipe should be given priority consideration.

When determining the diameter of pipes, it should be taken into consideration that the pipe can kept the minimum transmission power, and the pipe flow is turbulent state to ensure the heat transfer between the fluid and the pipe wall.

3.1.2 Depth of buried pipes

Comprehensive consideration should be made on the scale of the engineering, the cost of drilling and the construction area in design process. The depth of vertical pipe installation is generally within the range of 50-100m, and the designer can choose the appropriate depth according to the design requirement of engineering itself.

3.1.3 Circuit form of liquid in pipes

The flow of liquid in the underground heat exchange pipes has two kinds of circuit forms. The series system has a large diameter, high cost and pressure drop, which directly affect the operating performance of the system. While the parallel system is relatively excellent, which can ensure that all parts of the parallel circuit can maintain balance and heating performance has been greatly improved.

3.1.4 Attenuation of heat transfer in heat exchangers

The flow of liquid in the heat exchanger is always changing. Take the winter heating conditions for example, when building heat loss, the water temperature in the heat exchanger is the lowest due to the decrease of heat temperature in the earth. This phenomenon is especially serious for shallow buried pipe. In the design, the highest temperature and minimum temperature of the liquid in the heat exchange pipes should be set up, and the attenuation should be considered [9].

3.2 Analysis of thermal stress in diaphragm wall

The buried pipes arrangement of typical heat exchange component in diaphragm wall is shown in Figure 1.

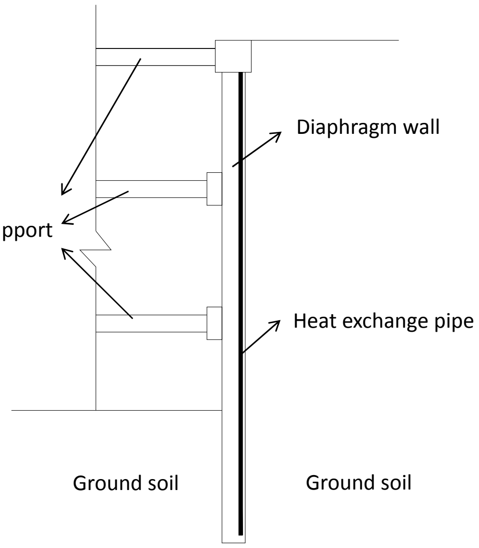

Figure 1. Typical heat exchange component in diaphragm wall.

Multiple heat exchange pipes are arranged along the diaphragm wall at longitudinal direction. The diaphragm wall is mainly subjected to lateral earth pressure; therefore its internal force near the soil is mainly tensile stress, and pressure stress near the excavation surface. When the vertical heat exchange pipes are buried in the diaphragm wall, the fluid in heat exchange pipes carries heat flow along the vertical direction, and the thermal stress was generated around the pipe. Due to that the thermal stress field and the bending stress field is not on the same plane, the effect of thermal stress can be considered separately.

Take two buried heat exchange pipes in diaphragm wall as a group, one is the inlet pipe and the other one is the outlet pipe. Since the diaphragm wall is generally long in the longitudinal direction, one part of the wall between two adjacent groups of heat exchange pipe can be taken out as a calculating model. If the vertical heat exchange in pipe is constant and the temperature is constant, the energy geotechnical engineering in diaphragm wall is a plane strain problem. Then one section of the wall can be taken as an analysis model, which is shown in Figure 2.

At the longitudinal direction, both sides are applied the displacement constraint and adiabatic boundary condition. In the horizontal direction, the inner surface of diaphragm wall is free surface and applied free displacement constraint and convective boundary condition. And the outside of diaphragm wall is connected with the soil. It is generally considered that there is no effect at a distance of 6 m far from the diaphragm wall, so there is free displacement constraint and isothermal adiabatic boundary condition [10].

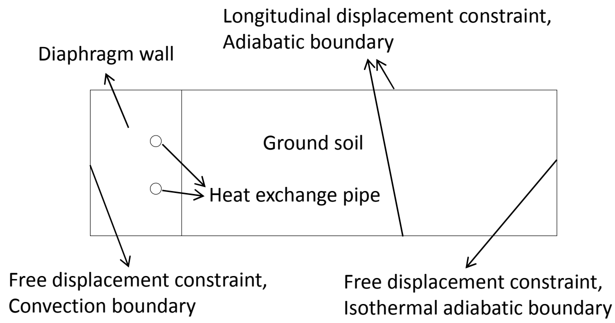

Figure 2. Boundary conditions of analysis section of the thermal stress in diaphragm wall.

Based on the numerical analysis of heat exchange pipe buried in the diaphragm wall, the following results can be concluded [10].

The temperature field in the diaphragm wall induced by heat exchanger is uniformly distributed around the heat exchange pipes, and the influence scope is small. Because of the thick diaphragm wall and the surrounding soil and other structures, the change of environmental temperature has little effect on the diaphragm wall, so it can be considered that the temperature in the diaphragm wall is constant in the underground.

In the process of heat exchange, a certain amount of temperature stress is produced in the structural members, which causes a large change of the stress field in the small range near the heat exchange pipe. So it should be taken into account in the structural analysis.

The influence range of the temperature stress is small in the vertical section and cross section in the diaphragm wall. In the place far from the heat exchange pipe, the temperature stress in the structure is mainly caused by the environmental temperature. The temperature stress value is small and can be neglected, which will not have a negative impact on the underground structure.

4 Problem of energy geotechnical engineering development

4.1 Integrated technology needs to be further improved

Energy geotechnical engineering technology is an integrated technology, which is closely linked with the heating, ventilating and air conditioning, water conservancy, geological prospecting and professional drilling. So the construction engineers must have a wealth of professional knowledge and experience, and can carry out technical research and establish reasonable plan to ensure the realization of the technology.

4.2 System research work should be developed

At present, the national standard, atlas compiling and promotional materials are imperfect in China. And some key scientific research problems still need to be solved. Furthermore, the evaluation system is incomplete for the energy efficiency performance of the energy geotechnical engineering, although some of those have been put into operation for several years.

5 Conclusions

As a new type of energy saving technology, the energy geotechnical engineering based on diaphragm wall put the environmental protection and energy saving into underground engineering. With the construction of deep foundation pit, subway station and other large underground engineering, energy geotechnical engineering based on diaphragm wall has created huge economic benefits, environmental benefits and social benefits. It can be inferred that this technology will shows its great development potential and wide application prospect in China.

Numerical analysis shows that the temperature field in the diaphragm wall is uniform around the heat exchange pipes, and the temperature in the diaphragm continuous wall can be considered as constant in the underground. The temperature stress in the structure far from heat exchange pipe is small and can be neglected, while the stress field changed at a small range near heat exchange pipe, which should be taken into account in the structure analysis.

According to present research status of energy geotechnical engineering, the heat transfer calculation theory, calculation model and optimization of buried pipes are the key to the research and development of this technology. And its design calculation theory, construction technology and installation technology also need further researches and continuous improvement.

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