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Research Paper

A novel refrigerant system to reduce refreezing time of cast-in-place pile foundation in permafrost regions

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HIGHLIGHTS

- The freezeback time of cast-in-place pile foundation was analysed by observed data.
- The concrete strength development of pile foundation was investigated by test.
- The cast-in-place pile foundation with CARS was put forward.
- The CARS may decrease the freezeback time by a year.

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ABSTRACT

The heat of hydration of cast-in-place pile foundations may cause an increase of ground temperature and lower the bearing capacity of pile foundation. Observed temperature data indicated that the cast-in-place pile foundation of the Chalaping Bridge, Qinghai-Tibet Plateau, without any cooling measure required two years to freezeback to a natural state. A cold air refrigerant system (CARS) is proposed to reduce the refreezing time. The CARS operates in winter, and the exhaust fan forces circulation of cold air in the pile foundation and removes heat from the ground. Experimental data indicated the concrete strength of pile foundation met the design criteria after curing 99 days under cold conditions. Based on the experimental result, the operation time of CARS can be established. A three-dimensional FEM model of the cast-in-place pile foundation of Chalaping Bridge with CARS was developed and the cooling effect of CARS was evaluated. The results showed that CARS might decrease the freezeback time by one year.

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1. Introduction

Permafrost underlies 25% of China's land area and is broadly distributed in the Qinghai-Tibet Plateau (QTP) [1]. Cast-in-place pile foundations were first widely used in bridge construction in the QTP permafrost regions, where about 90% of the bridge foundations were cast-in-place pile foundations [2]. However, the heat of hydration of the concrete with a cast-in-place pile foundation disturbs the ground thermal regime and the disturbance may even cause thawing around the pile. More than 80% of the load capacity of piles in permafrost regions, irrespective of their types, is provided by adfreeze bond of the surrounding frozen soil to the pile shaft [3]. Frozen soil adfreeze bond strength is highly sensitive to temperature changes [4]. Temperature increment can lead to corresponding decreases in the pile adfreeze shaft resistance and the point bearing capacity. [5]. To ensure that pile is well anchored in the frozen ground to resist the loads of the superstructure, the design engineer must address the issue of the freezeback time, adfreeze strength and bearing capacity recovery.

A number of studies have been conducted on the heat of hydration of cast-in-place pile foundations in the QTP. Wu et al. [6] established a numerical model and analyzed the freezeback process of cast-in-place pile foundation in permafrost regions. Wang et al. [7–9] used the finite element method to analyze freezeback time of cast-in-place pile foundations under different permafrost conditions. Based on the observed data, Yuan et al. [10] and Zhang et al. [11] analyzed the cooling process and the freezeback time of cast-in-place pile foundations in the unstable warm permafrost regions. Li et al. [12] and Wu et al. [13] analyzed the influence of concrete molding temperature on the freezeback time by numerical analysis. Tang et al. [14] and Jia et al. [15] established the single concrete pile models and studied the thermal disturbance radius of

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the heat of hydration and analyzed the refreezing processes of the cast-in-place pile foundation.

Although many works have been completed, there are rarely studies which focus on reducing the refreezing time in an active way. Previous studies have shown that under natural conditions it can take a long time to refreeze during the construction of the bridge pile foundation. To assist construction scheduling, artificial methods for cooling the ground temperature around the piles should be employed. The cold air refrigerant system (CARS) [16], as shown in Fig. 1, is one of the thermal pile systems which are often utilized in metal piles to decrease the time for freezeback in permafrost regions of North America. It operates in winter when the air temperature is lower than the permafrost, and the exhaust fan forces circulation of cold air in the pile foundations and removes heat from the ground.

To estimate the heat extraction capabilities of CARS, the pile foundations of the Chalaping Bridge without CARS was selected for study. The bridge is located in a basically stable low temperature permafrost region along the National Road G214, Based on the observed data, this paper analyzed the temperature field of a cast-in-place pile foundation, the refreezing process, and the load capacity of pile foundation during construction. To confirm the time when the cold air refrigerant system can operate, the development of strength of the concrete (used in the pile) was evaluated. A three-dimensional FEM model of the cast-in-place pile foundation with CARS was developed. Finally, compared with the conventional cast-in-place pile foundation, the cooling effect of CARS was evaluated.

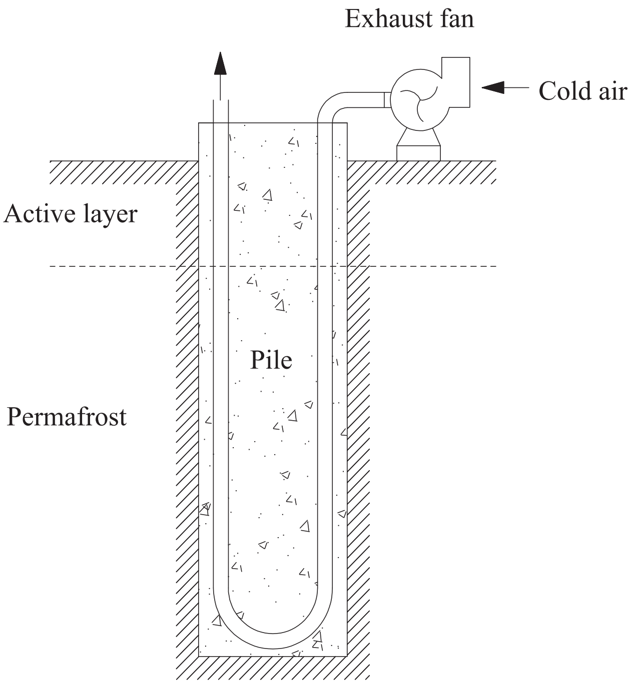

Fig. 1. Cold air refrigerant system (CARS).

2. In situ investigation

2.1. Site conditions

Chalaping Bridge is located in the Chalaping region, Madoi County, Tibetan Autonomous Prefecture of Golog, China (Fig. 2). This region is characterized by flat topography and widespread continuous permafrost [17]. The average elevation of the study area is around 4700 m above sea level. The permafrost table is at 1.9 m in depth, under natural conditions, and the mean annual ground temperature (MAGT) is about −1.8 °C which signifies a region of basically stable permafrost [18]. The mean annual air temperature is −4.8 °C. The lowest air temperature is below −16 °C. The mean annual precipitation is 318.4 mm [19–21]. The pile foundation the authors studied was constructed on July 28, 2010 and made of C30 cement. The length of pile foundation is 31 m and the diameter is 1.5 m.

2.2. Description of temperature monitoring

Six boreholes were drilled around the pile (Fig. 3) to investigate the ground thermal regime during the cement hydration. Borehole A, along the pile side, is 31 m deep. Because the maximum effect of the heat of hydration may be at the middle of the pile foundation, 52 thermistors were instrumented in Borehole A at 0.5 m intervals from the surface to 10 m, 1 m intervals from 10 m to 15 m, 0.5 m intervals from 15 m to 25 m, and 1 m intervals from 25 m to 31 m. The other boreholes are 20 m deep with 31 thermistors at 0.5 m intervals from the surface to 10 m, and 1 m intervals from 10 m to 20 m. The undisturbed natural ground temperature was observed with Borehole F. The data was collected by a QSY300 data logger.

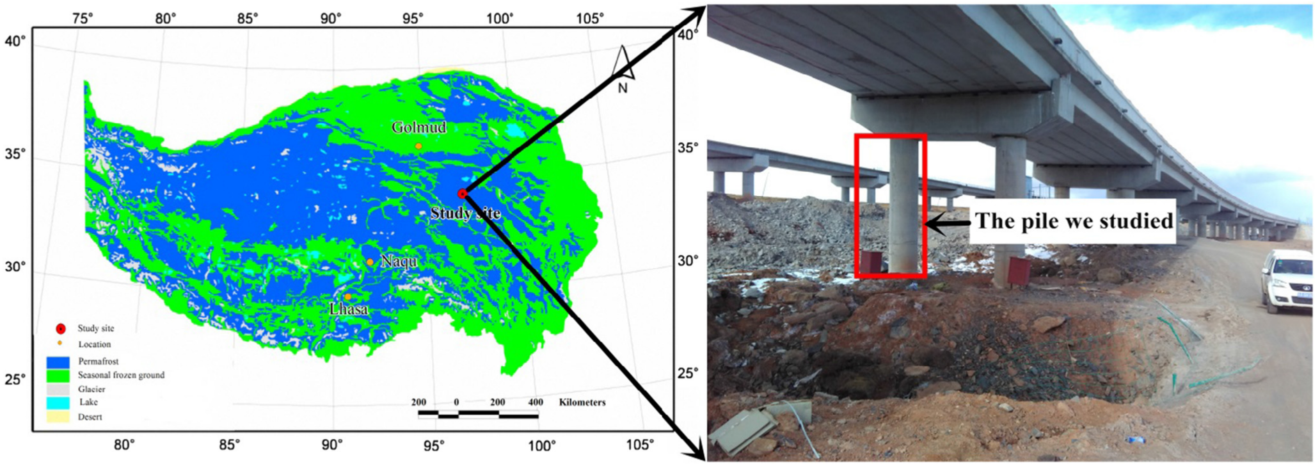

Fig. 2. The location of the pile foundation of Chalaping Bridge.

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