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TEMPERATURE ANALYSIS OF HIGH LATITUDES AND LOW ALTITUDE ISLAND PERMAFROST DURING THE CONSTRUCTION OF CFG PILE

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ABSTRACT

Cement fly ash gravel (CFG) pile composite foundation is an effective and economic foundation treatment approach, which is significant to building a foundation, subgrade construction, and so forth. The present paper aims to investigate the temperature behaviours of high latitudes and low altitude island permafrost when the CFG pile was constructed, in which FEM and field temperature monitoring of permafrost was utilized. The proposed findings demonstrate that the temperature disturbance of permafrost is obvious when the CFG pile was constructed, and the temperature variation of CFG pile and permafrost in FEM has a good agreement with the results of field temperature monitoring. Additionally, the influence of different height subgrade on the temperature field of CFG pile composite foundation was analyzed by FEM. The proposed findings demonstrate that the height of subgrade affects the maximum temperature increase of permafrost and the re-frozen time of permafrost after the construction of CFG pile composite foundation.

KEYWORDS

High latitudes and low altitude island permafrost, CFG pile composite foundation, Temperature monitoring, Finite element model, Height of subgrade

INTRODUCTION

Permafrost means various rock and soil below zero degrees centigrade and containing ice [1], it is widely distributed in the extreme northern locations of Eurasia, North American continent and many islands of the Arctic Ocean [2-3]. Permafrost has the feature of the rheological property, and its long-term intensity is far less than the instantaneous intensity. Because of these features, two significant risks must be faced by the engineering buildings in the permafrost zone: frost heave and thaw collapse [4-5]. Due to little cold source, the high latitude and low altitude island permafrost are more easily affected by heat disturbance. In the freeze-thawing process of permafrost, the foundation of a building may sink, crack and be lifted by frost [6]. During the highway construction, an engineer often uses pile foundation to stiffen permafrost structure, to increase the bearing capacity of subgrade [7-8]. As a kind of essentttial pile foundation, CFG pile composite is widely applied in the treatment for permafrost foundation owing to the following advantages: little heat radiation, excellent freeze-thawing resistance, large lifting amplitude of bearing capacity, simple construction, short construction period and low cost [9-14]. Foundation Institute of China Academy of Building Research developed a CFG pile composite foundation in the early 1990s [15], which greatly facilitated the development of composite foundation theory and design method. CFG pile is a high bond strength pile formed by cement, fly ash, gravel, aggregate chips, sand, and a moderate amount of water, together with soil between piles and cushion to form the composite foundation.

Permafrost is a kind of unique soil extremely sensitive to temperature change, its series of physical properties including specific heat, heat conductivity coefficient, and density vary following the change of temperature [16]. When a building is constructed in the permafrost, the hydration heat of concrete and the heat disturbance in construction may affect the stability of the permafrost below ground. After a building has been constructed, the permafrost will refreeze after long time, the building and the permafrost will lie under the state of heat balance again. In the process, the thermal properties of permafrost also change unceasingly, the changing properties of permafrost bring a lot of unstable factors for the construction above ground and the bearing capacity of permafrost foundation [17-19], even it will make the disturbed permafrost unable refreeze or the destruction of permafrost structure. Therefore, it has an important reality significance to research the effect of the construction process of building on the distribution and change law of the temperature field of permafrost. In the past years, many scholars started to pay attention to and research the disturbance effect of the construction of building on permafrost temperature and the re-frozen law of permafrost. On the basis of considering the effect of water on the temperature field of pile foundation, Harlan [20] amended the one-dimensional linear temperature field equation, added in the water field of pile foundation and raised the water-heat coupling equation set on pile foundation, in addition, elaborated the solution method in detail. Sun et al. [21] introduced the application of cast-in-site bored pile in Qinghai-Tibet Railway, analysed the heat disturbance theory of cast-in-site pile in permafrost layer and the factors affecting the re-frozen time of permafrost, the results show that cast-in-site bored pile is suitable for the application in the permafrost region. Zhao [22] researched the temperature change of a pile foundation in permafrost region under the influence of the construction disturbance of a single pile and the change of climatic conditions, put forward different temperature regulation & control measures used for the construction period and subsequent curing period. The study of [23] revealed that, the temperature of pile foundation changed dynamically under the coupling effect of hydration heat and ground temperature of permafrost, in addition, the temperature of permafrost below the upper limit tended to the ground temperature of permafrost in the local region after pile foundation refroze. Through model test, Zhai [24] researched the law of the effect of the hydration heat of cast-in-site bored pile on the upper temperature field of pile circumference under different permafrost temperatures. Fu et al. [25] researched the early-stage refrozen law of large-diameter cast-in-site bored pile in the permafrost region of Qinghai-Tibetan Plateau, it was suggested that the construction time of pile should be arranged in warm season, so as to provide excellent conditions for concrete curing. Shang et al. [26] researched the effect of the hydration heat of the cast-in-site bored pile in the permafrost region of Qinghai- 1m below ground kept stable at about 10℃, Tibetan Plateau on the temperature of soil around pile circumstance.The results of Shang et al. [26] explored that hydration heat of concrete has a large effect on the temperature of the permafrost located at 0.6m and 0.9m from the pile, while a little effect on the temperature of the permafrost located at 2m from the pile.

In the construction of CFG pile composite foundation, it should be avoided that the permafrost cannot be re-frozen or the permafrost was destroyed. Thus, it is of great necessity to explore the temperature performance characteristics of the permafrost when CFG pile foundation construction. Therefore, this paper compares the monitoring results of CFG pile construction temperature by finite element method and analyses the temperature characteristics of island permafrost and CFG pile during pile foundation construction, which can provide experience to the design and construction of the CFG pile composite foundation in island permafrost or permafrost with less cold source.

EXPERIMENT ON TEMPERATURE OF CFG PILE AND PERMAFROST

Engineering overview

Yichun-Suihua expressway is located in Heilongjiang Province, China. The route has to pass or go through an island permafrost region from k44+400 to k44+575 where is located in high latitudes and low altitude areas (as shown in Figure 1). Because the bearing capacity could not meet design requirements in the permafrost region, and the CFG pile composite foundation was applied, which showed the best reinforcement effect among the treatments. Because of the peculiarity of island permafrost, the depth and thickness of the permafrost at different locations are different. In this time, the zone where the temperature of permafrost was monitored was the region with central pile No. K44+525. According to the data on geotechnical test and geological survey, in the test area, the uppermost layer was the humus with 1.2m thick. Within the area 1.2m-3.2m from the top was richly frozen powdery soil with low liquid limit. Within the area of 3.2m-4.7m from the top was richly frozen clay with low liquid limit. In the area below 4.7m from the top was richly frozen granular sand, the thaw collapse is weak, this layer can be deemed as the bearing layer. The physical properties of all soil layers are listed in Table 1.

Because of a few cold sources, the high-latitude low-altitude island permafrost is easily disturbed by the external environment and the stability is inferior. The hydration heat of fly ash concrete is different from that of conventional concrete, and the past experiences are not applicable. In order to assure the stability and safety of island permafrost consolidated by CFG pile, a CFG pile was cast in the island permafrost region, the temperature of the CFG pile and permafrost were monitored. The temperature measurement point of the pile was embedded in the centre of the pile, from the pile bottom, for every other upward 1m, one temperature sensor was embedded. Temperature sensors were also embedded at the positions 0.6m, 1.0m and 1.4m from the centre of the CFG pile, the sensors were laid from the location 5m underground, for every other upward 1m, one sensor was embedded, five sensors were provided in every row. Figure 2 shows the layout diagram of the temperature sensor in the monitoring area.

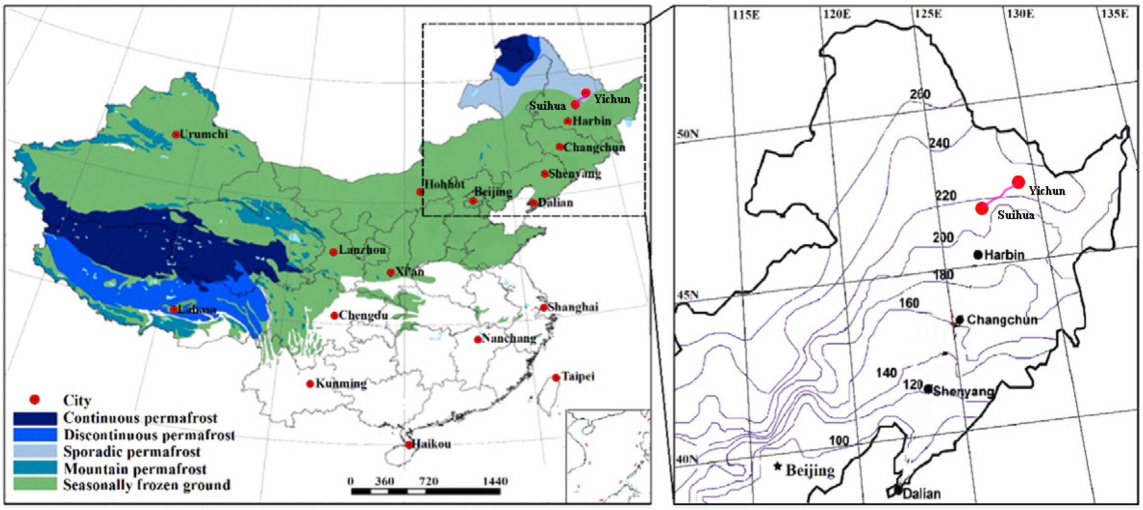

Fig. 1 - The position of expressway and permafrost

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Tab. 1 - Physical parameters of permafrost [25]

Geological condition	Water content	Dry density	Thermal conductivity	Specific heat capacity	Intent heat of phase change	c_p	c_{up}
		kg/m3	W/(m·K)	J/(kg·K)	KJ/m3	J/(kg·K)	J/(kg·K)
Humus	22.70%	1700	1.72	2825.82	127.8	2.23×105	2.11×105
Low liquid limit silt Ice-rich frozen soil Grade of thaw settlement:Ⅲ	27%	1575	1.008	2011.34	140.85	2.55×105	2.33×105
Low liquid limit clay Ice-full frozen soil Grade of thaw settlement:IV	42.90%	1400	1.38	3458.48	198.92	2.82×105	2.14×105
Sand grains Multi ice frozen soil Grade of thaw settlement:Ⅱ	19.80%	1670	2.077	2573.225	109.52	5.69×105	5.31×105
CFG Pile	-	2500	1.74	2300	103	-	-

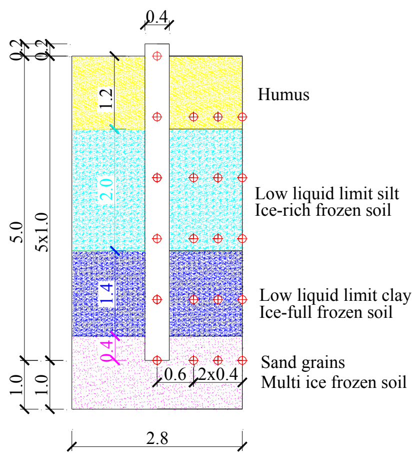
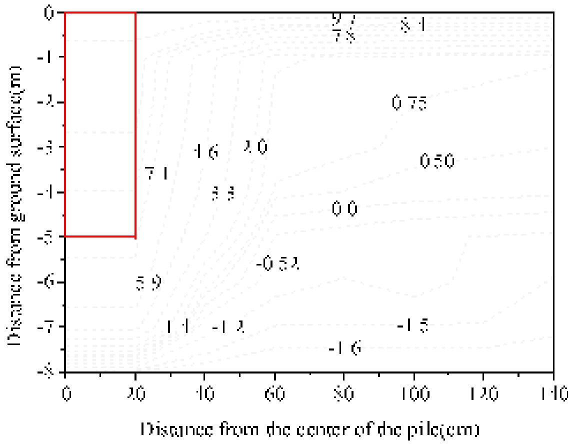


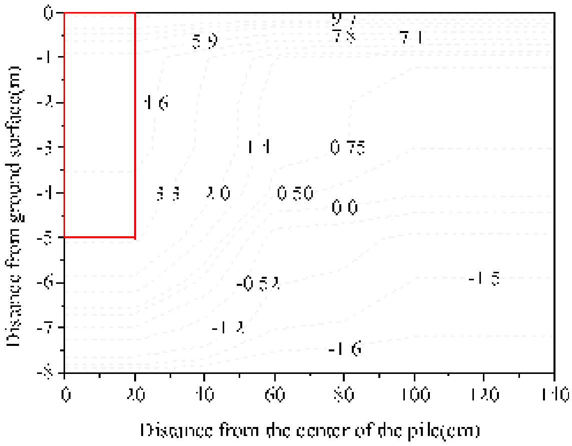
Fig. 2 - Layout diagram of temperature sensor in monitoring area (unit: m)

Analysis on temperature monitoring results

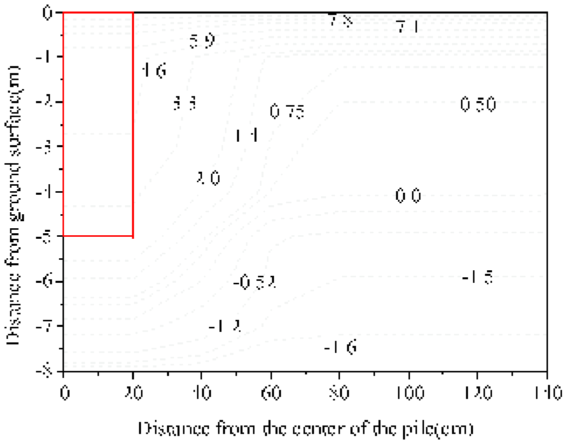
By monitoring the temperature of permafrost field and pile body in the construction process of CFG pile, the change trend and amplitude of the temperature of the permafrost beside pile can be known in the process of casting fly ash concrete. In addition, the curing temperature of the CFG pile at the time when the strength of fly ash concrete achieves can also be known. According to the researches of the scholars for the application of pile foundation in permafrost, after pile concrete has been cast for one day, the temperature rise of the peripheral permafrost temperature field reaches the maximum value [26-27], therefore, after CFG pile was constructed, the temperature of the pile body and peripheral permafrost were measured in every day and at the same weather temperature. Figure 3 gives the temperature monitoring results of the pile and the permafrost within 140cm away from the pile centre on the 1st day, the 2nd day, the 3rd day, the 5th day, the 10th day and the 15th day.



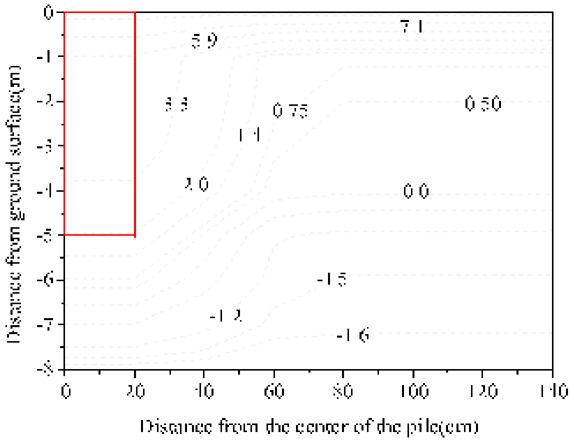
(a)1d after the construction of CFG pile



(b)2d after the construction of CFG pile



(c)3d after the construction of CFG pile



(d)5d after the construction of CFG pile

Fig. 3 - The variation of temperature field for CFG pile and permafrost with time

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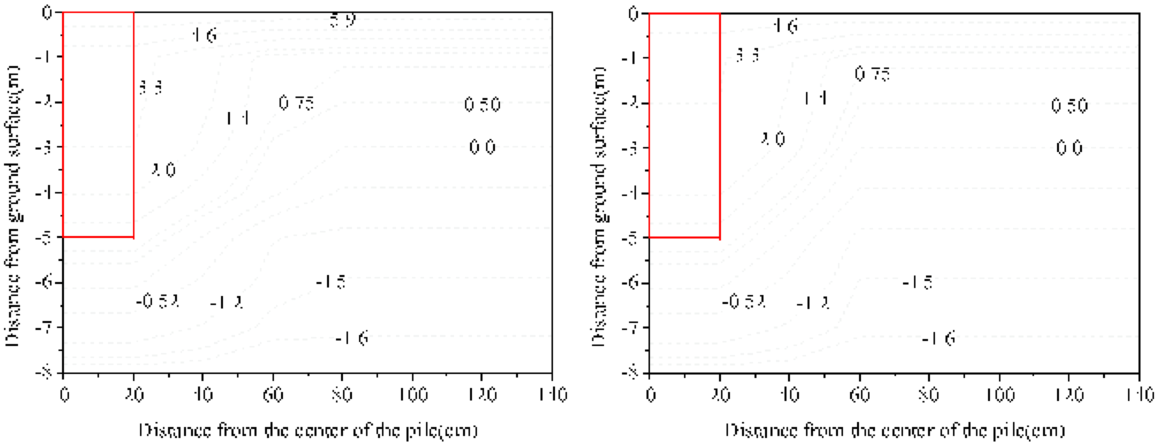

(e)10d after the construction of CFG pile *(f)15d after the construction of CFG pile*

Fig. 3 - The variation of temperature field for CFG pile and permafrost with time

Figure 3 shows that 15 days after the CFG pile had been constructed, the temperature of the CFG pile decreased from 7.8℃~9.7℃ to 2.0℃~3.8℃, also, the distribution of the effect caused by the temperature of peripheral permafrost to pile body was not even. Therefore, when CFG pile is designed, the effect of low-temperature curing environment on the strength of fly ash concrete shall be considered. Because the temperature of peripheral permafrost apparently affects the pile temperature, pile cracking and pile breakage caused by uneven temperature distribution of CFG pile shall be avoided. Due to the influence of the initial heat and hydration heat of fly ash concrete, the temperature of the permafrost beside pile rose apparently, the maximum value reached 7.1℃~9.7℃. The change of the thermal properties of the permafrost in this stage shall be considered in the design process. Following the unceasing release of the own heat of fly ash concrete and the hydration heat, the temperature of permafrost beside piles gradually decreased, the permafrost at the pile bottom unceasingly refroze upward. After CFG pile had been constructed for 15 days, the temperature changes of the permafrost beside pile tended to stability. The atmospheric heat continually transferred heat energy to permafrost via CFG pile, therefore, the permafrost beside pile kept at about 2.0℃ and was hard to fully refreeze. It is suggested to prohibit applying a load in the permafrost zone beside pile within 15 days since construction of the CFG pile to avoid the settlement of peripheral permafrost under unstable state. From the temperature rise distribution area of the permafrost beside pile, it can be seen that the construction of CFG pile disturbed the permafrost within the scope of 1.5~2.0 times of pile diameter.

NUMERICAL METHOD

The construction of cast-in-site pile foundation in the permafrost region can bring heat for permafrost, the geothermal field will change correspondingly and the stable freezing state of permafrost will be destroyed, especially the hydration heat in concrete cast-in-site pile can cause serious thermal disturbance to stable permafrost, while fly ash concrete has unique feature of hydration heat. The research on the effect on the permafrost beside pile caused in the strength generation process of fly ash concrete is of extreme significance for the permafrost consolidation works. Therefore, it is considered to apply the 3D unsteady finite element with phase change for analysing the thermal disturbance caused by hydration heat to the temperature field of pile foundation in the construction of fly ash concrete cast-in-site pile; the result can provide a reference for the design and construction of CFG composite pile foundation in permafrost.

Numerical analysis model

According to the engineering background introduced in the above text, a numerical calculation model on CFG pile and permafrost was established, as shown in Figure 4. The model matched single-pile test. In the numerical calculation model on permafrost, the diameter of the CFG pile is 40cm, the pile length is 5.0m, the model involves in the scope of 1.4m away from the pile centre and the simulated depth of permafrost is 6.0m.

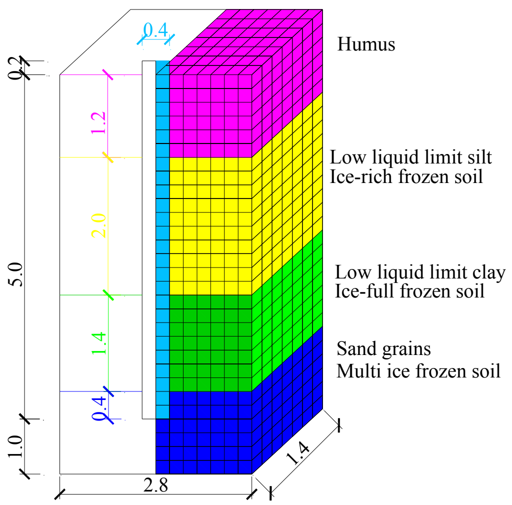

Fig. 4 - Numerical calculation model

Control equation and initial conditions on pile body temperature field

The CFG pile is made of fly ash concrete. Because mixed materials are added into concrete, the heat released in its hydration reaction stage is different from common concrete [28]. After fly ash has been added in, the hydration heat of concrete will decrease, the temperature field control equation of CFG pile at hydration heat are listed as follows:

$$\frac{\partial}{\partial x}\left(k_{\text{fc}}\frac{\partial T_{\text{fc}}}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{\text{fc}}\frac{\partial T_{\text{fc}}}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{\text{c}}\frac{\partial T_{\text{fc}}}{\partial z}\right)+q_{\text{v}}=\rho_{\text{fc}}c_{\text{fc}}\frac{\partial T_{\text{fc}}}{\partial t} \quad (1)$$

$$q_{\text{v}}=\rho_{\text{fc}}c_{\text{fc}}\frac{\text{d}\theta}{\text{d}t}=\frac{\rho_{\text{fc}}c_{\text{fc}}k_{\text{T}}\theta_{\text{u}}}{\left[1+k_{\text{T}}\left(t-t_0\right)\right]} \quad (2)$$

In the formula, k_{fc} is the heat conductivity coefficient of fly ash concrete; T_{fc} is the temperature of fly ash concrete; q_{v} is the hydration heat of unit volume of fly ash concrete within unit time; c_{fc} is the specific heat of fly ash concrete; ρ_{fc} is the density of fly ash concrete; θ is the adiabatic temperature rise of fly ash concrete with different initial temperature and different age(℃), θ_{u} is the maximum adiabatic temperature rise of fly ash concrete(℃) [29-30]; k_{T} is the chemical reaction speed of the hydration heat of fly ash concrete at the initial temperature of T_0 (d-1), Carino [31] was used to describe the expression reflecting the effect of temperature on the hydration reaction of fly ash concrete, $k_{\text{T}}=Ae^{BT}$, A is a constant. For fly ash concrete, $A=0.1362$ d-1; B is the temperature sensitivity coefficient(℃-1), $B=0.0553$ ℃-1; t is the actual curing time in adiabatic temperature rise (d); t_0 is the starting time of adiabatic temperature rise (d).

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The initial condition of the pile temperature, i.e., the casting temperature, apparently disturb the hydration heat of pile body and permafrost [32], therefore, when fly ash concrete is cast in site, the casting temperature of concrete shall be measured. In numerical calculation, the initial condition of pile temperature is shown as follows:

$$T(x,y,z,t)\big|_{t=0}=T_1(x,y,z) \tag{3}$$

According to the measurement results obtained in casting CFG pile in the site, the casting temperature of fly ash concrete is 35℃.

Control equation and initial conditions on permafrost temperature field

The thawing process of permafrost is a heat conduction process accompanied with phase change, the calculation on the phase change of permafrost is simulated by Sensible Heat Capacity Method [33]. The 3D unsteady-state temperature field control equation on permafrost accompanied with phase change is shown as follows:

$$\rho_p c_p \frac{\partial T_p}{\partial t}=\frac{\partial}{\partial x}\left(k_p\frac{\partial T_p}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_p\frac{\partial T_p}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_p\frac{\partial T_p}{\partial z}\right)+q_v+\rho_p L_p\frac{\partial f_s}{\partial t} \tag{4}$$

In the formula, c_p is the specific heat of permafrost; ρ_p is the density of permafrost; T_p is the temperature of permafrost; k_p is the heat conduction coefficient of permafrost; L_p is the latent heat of phase change of permafrost; f_s is the solid fraction, the increase(decrease) of solid fraction is directly proportional to the release(absorption) volume of latent heat of phase change. When f_s =0, permafrost lies under the state of liquid phase; when f_s =1, permafrost lies under the state of solid phase; when 0< f_s =0<1, both phases coexist.

The main difference between permafrost and thawed soil is that permafrost contains ice. Therefore, the specific heat of permafrost can be calculated according to the weighted mean of the masses of all material compositions [31]:

$$\left.\begin{aligned} c_p&=\frac{c_{sp}+Wc_W}{1+W}\\ c_{up}&=\frac{c_{sup}+(W-W_u)c_i+W_u c_W}{1+W}\end{aligned}\right\} \tag{5}$$

In the formula, c_{sp} is the framework specific heat of permafrost; c_{up} is the specific heat of thawed permafrost; c_{sup} is the framework specific heat of thawed permafrost; c_w is the specific heat of water; c_i is the specific heat of ice; W is the content of ice in permafrost; W_u is the content of unfrozen water in permafrost. The final heat properties of permafrost are shown in Table 1.

The initial temperature of permafrost affects the final temperature rise, in addition, it also affects the refreezing time of permafrost. Therefore, the initial temperature of permafrost is significant for the analysis on the permafrost temperature field in the construction process of the CFG pile. The equation for the initial condition of permafrost is shown as follows:

$$T(x,y,z,t)\big|_{t=0}=T_2(x,y,z) \tag{6}$$

The differences among the thermal properties of all permafrost layers cause the difference of the temperatures of all layers. According to the site measurement on permafrost temperature, the initial temperature of all layers of permafrost was determined as -1.3℃.

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Finite element model on the unsteady-state temperature field of foundation

The abovementioned governing differential equation is converted into the equivalent integral form:

$$\int_v \begin{bmatrix} \rho c(\delta T)\left(\frac{\partial T}{\partial t}+\{v\}^{\mathrm{T}}\{L\}^{\mathrm{T}}\right)+\{L\}^{\mathrm{T}}(\delta T) \\ \left([D]\{L\}^{\mathrm{T}}\right)+q_v \end{bmatrix} d_v = \int_{S_1}(\delta T)q^{*}\mathrm{d}S_1+\int_{S_2}(\delta T)h(T_B-T)\mathrm{d}S_2 \tag{7}$$

In the formula, $\{v\}$ is the volume vector of unit; q^{*} is the heat flow in permafrost; $[D]$ is the heat conduction matrix in permafrost, δT is the allowable actual temperature; T_B is atmospheric temperature; S_1 and S_2 are respectively the surface applying heat flow and convection.

Seeing that the above problem is a strong-nonlinearity problem and it is hard to obtain the analytic solution. Therefore,the finite element method can be utilized to firstly divide the fixed solution domain into several units, an equation is established for each unit, the Direct Stiffness Method is applied to integrate them into an integral balance equation, for which Calculus of Differences is applied for solution.

Boundary conditions for numerical calculation

The calculation scope of the numerical model is large; it is deemed that the permafrost at the boundary of calculation model lies under the steady state and heat exchange does not exist. Therefore, the established 1/2 model is dealt with according to heat insulation conditions at the interface [34]:

$$\left.\begin{aligned} k\frac{\partial T}{\partial x}&=0 \quad (x=1.4) \\ k\frac{\partial T}{\partial y}&=0 \quad (y=1.4) \end{aligned}\right\} \tag{8}$$

The upper boundary of pile foundation contacts with air, therefore, the temperature at the pile top is related to atmospheric temperature cycle, the following formula was defined:

$$k\frac{\partial T}{\partial z}=h\left(T_{\text{ground}}-T_{\text{air}}\right) \quad (z=0) \tag{9}$$

$$T_{\text{ground}}=-0.25+2.28\times10^{-6}t_{\text{h}}+12.2\sin\left(\frac{2\pi}{8640}t_{\text{h}}+\frac{4\pi}{3}\right) \tag{10}$$

In the formula, h is the convectional heat exchange coefficient between air and ground; T_{ground} is the bottom temperature of the boundary layer below ground [35]; T_{air} is the atmospheric temperature above ground. According to local temperature statistics, T_{air} =2.0℃was applied, t_{h} is the time in every day.

At the bottom of the model, permafrost transfers heat to pile body, at the time, the boundary condition applies heat flow q in permafrost. The boundary condition is shown as follows:

$$k\frac{\partial T}{\partial z}=q \quad (z=5.0) \tag{11}$$

In the formula, the underground heat flow applies q =0.5kJ/m2·h..

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Analysis of numerical calculation results

In order to verify the accuracy of parameter selection and material use in the numerical calculation model, the temperature of the pile body and the permafrost around the pile at the same time of testing piles were respectively calculated, the results are listed in Figure 5.

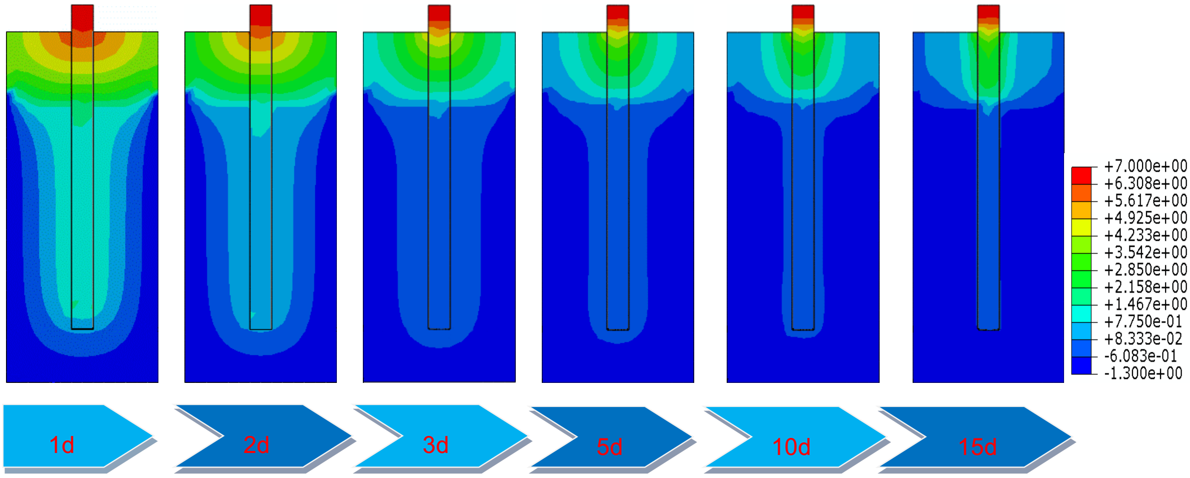

Fig.5 - The variation of temperature field for CFG pile and permafrost with time

The numerical analysis results show that (Figure 5), after CFG pile had been cast in site for one day, the temperature of pile body and its peripheral permafrost reached the highest value, the temperature of CFG pile was 0.7℃~2.1℃, the temperature of the permafrost beside the pile and within the scope of two times of pile interval rose to 1.4℃~4.2℃, the temperatures are basically consistent with the monitoring results in the temperature field of test pile. The simplified calculation for the initial temperature of the permafrost beside the pile causes the temperature rise of permafrost to be lower than the monitoring results. However, the disturbance scopes caused by pile casting to the temperature of peripheral permafrost are basically consistent. Following the gradual release of the initial heat and hydration heat of fly ash concrete, the permafrost beside the pile and at the pile bottom started to refreeze, the refreezing direction and scope of permafrost are consistent with the monitoring result in the temperature field. After CFG pile had been cast in site for 15 days, the heat exchange between pile body and peripheral permafrost terminated, the pile temperature was basically same as the temperature of peripheral permafrost, the pile temperature reached 0.8℃, and the permafrost around pile recovered to the initial temperature of -1.3℃. The numerical calculation result is a little lower than the monitoring result, the reason is shown as follows: for the simplification of numerical calculation, the process of transferring atmospheric heat to permafrost via CFG pile was not considered. In actual construction, after CFG pile and the permafrost beside pile refreeze basically, subgrade will be paved on the composite CFG pile foundation, while subgrade will isolate the path in which atmospheric heat is transferred into permafrost via pile. The permafrost beside pile can complete the refreezing process basically, and the simplified calculation is feasible in actual works. As mentioned above, the calculation values are in good agreement with the monitoring results in the temperature field of permafrost.

NUMERICAL SIMULATIVE ANALYSIS ON THE DISTRIBUTION OF TEMPERATURE FIELD OF PERMAFROST UNDER THE OPERATIONAL STATE

Numerical modelling

The effect of the construction of the CFG composite foundation on permafrost is not restricted in the construction process, the technical indices of roads and environmental factors will also affect the temperature of the reinforcement permafrost. However, due to restriction of personnel and fund, it is hard to collect enough data for analysis, the finite element software can be used for the numerical simulation of the technical indices of road and environment factors. The numerical calculation results can provide enough data for analyzing the effect of these factors on the change trend of permafrost temperature after construction of the CFG pile composite foundation. In this paper, ABAQUS, which was generally employed for geotechnical analysis, was used to develop the FE analysis.

According to the numerical analysis on the permafrost temperature field and the site monitoring results in the construction process of test pile, and the results of bearing test after the completion of test pile, on basis of the Design methods on Chinese Road Works [36], a design drawing on the CFG pile composite foundation constructed in the island permafrost region was determined, as shown in Figure 6. By utilizing the 2D heat processing module of ABAQUS, a thermotic finite element model on the subgrade, CFG pile composite foundation, raft and island permafrost was established. In the FE modelling (Figure 7), the location of the CFG pile and the distribution of permafrost layers are same as those shown in the design drawing (Figure 6). The physical parameters of all soil layers are shown in Table 1 and the properties of soil with temperature change base on REF. [37]. According to the site test results, the initial conditions of the model were exerted: the initial temperature of ground surface was 2℃, the initial temperature of permafrost was -1.3℃,the casting temperature of CFG pile was 35℃; the initial temperature of subgrade was 20℃.

The finite element numerical simulation will analyse the effect of different height of subgrades of subgrade and atmospheric temperature cycle on the temperature distribution law of island permafrost. The calculation process is divided into two analytic steps: In the first step, heat exchange calculation for CFG pile composite foundation and island permafrost was carried out. In the means of body heat flux, the hydration heat of fly ash concrete was exerted onto the pile as temperature load, the calculation time was 76 days. The analytic results will be taken as the initial conditions of the second analytic step. In the second analytic step, the soil of subgrade will be added into the calculation, according to the local monthly average temperature, the atmospheric heat cycle will be added into the calculation in the means of boundary conditions and the time span used for calculation is 12 months.

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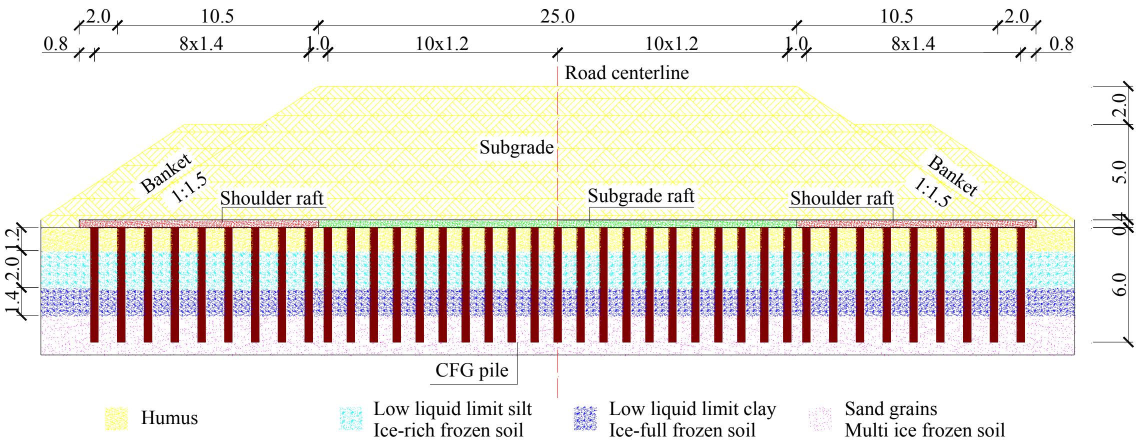

Fig. 6 - Cross section of permafrost was reinforced by CFG pile composite foundation in monitoring area (unit: m)

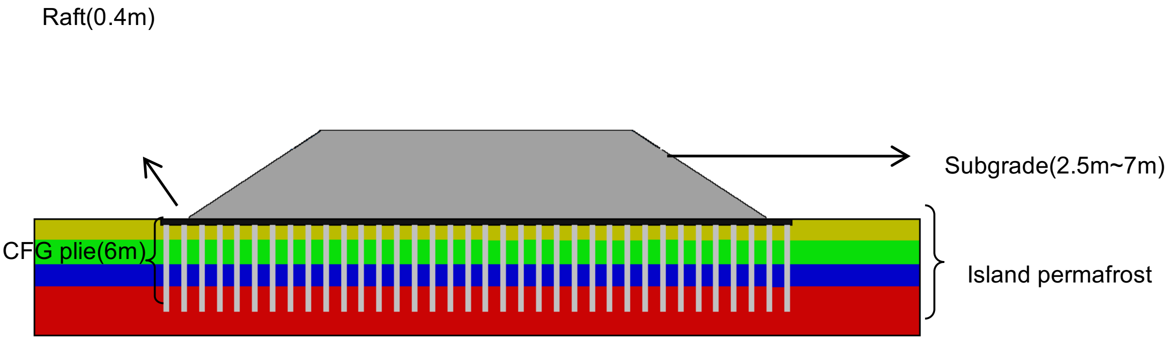

Fig. 7 - Finite element model

Effect of subgrade height on the distribution of permafrost temperature field

When a high-grade expressway is designed, in order to assure running safety and comfort, strict requirements are applied for route and lane slope, so different height of subgrades will be used for assuring reasonable longitudinal slope of the route [38]. The above analysis shows that the temperature of permafrost is significantly affected when subgrade is constructing. In order to analyse the process that different height of subgrades affect the temperature and the re-frozen time of permafrost, the paper established a finite element model respectively for the subgrade height of 2.5m, 3m, 4m, 5m, 6m, and 7m. In the analysis, the temperature change law of the permafrost layer 1m, 3m and 6m below ground were investigated. The finite element numerical calculation values are shown in Figure 8.

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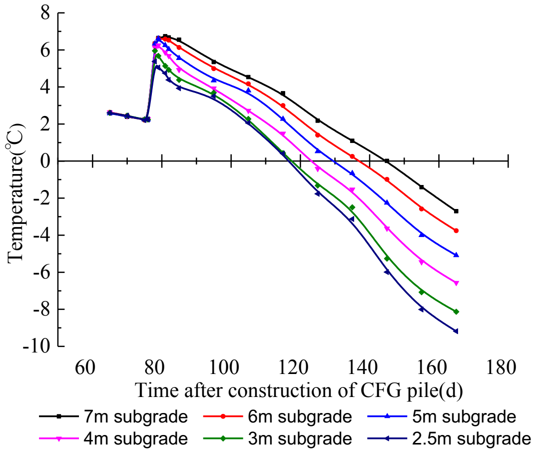
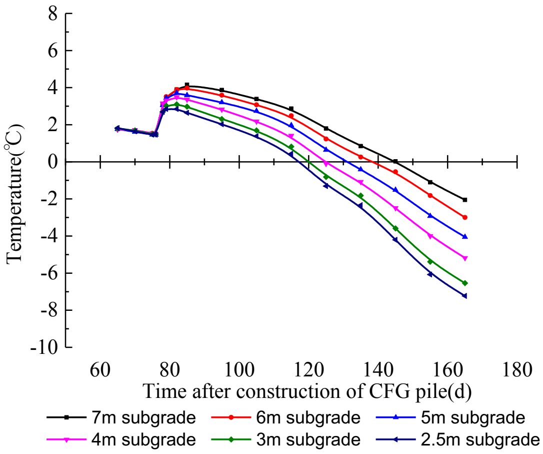
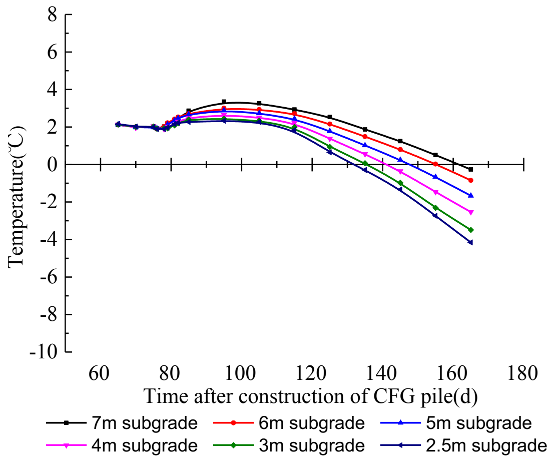


(a)1m below the surface



(b)3m below the surface



(c)6m below the surface

Fig. 8 - The temperature of permafrost varies with the height of subgrade

Figure 8 demonstrates that the subgrade fill apparently affected the temperature of island permafrost. The numerical simulation for 76d subgrade construction shows that, when the subgrade was 7m high, the temperature rose by 4.1℃ at the location 1m below ground; when the subgrade was 2.5m high, the temperature rose by 3.1℃ at the location 1m below ground. Following the increase of subgrade height, more heat was brought, and the effect on the depth of permafrost temperature became large. When the subgrade was 7m high, the temperature rose by 4.1C,2.7C, and 1.5C at the below ground location of 1m, 3m , and 2.5 respectively. the temperature rose by 4.1℃ at the location 1m below ground, the temperature rose by 2.7℃ at the location 3m below ground, and the temperature rose by 1.5℃ at the location 6m below ground; While the subgrade was 2.5m high, the temperature rose by 3.1℃ at the location 1m below ground, the temperature rose by 1.18℃ at the location 3m below ground and the temperature analyzed the change rose by 0.4℃ at the location 6m below ground. Following the increase of subgrade height, the heat transfer depth became large, and the decrease speed of permafrost temperature became slow. When the subgrade was 7m high, the temperature decrease speed at the location 1m below ground was 0.10℃/d; While the subgrade was 2.5m high, the temperature decrease speed at the location 1m below ground was 0.16℃/d. The subgrade height restricted the heat exchange between atmosphere and permafrost. Because of low subgrade height, the effect on permafrost temperature was small. Therefore, the re-frozen time of low subgrade was short. For the road construction in permafrost area, traffic can be opened or load can be exerted in priority in the road segment with low subgrade height.

CONCLUSION

This paper studied the temperature characteristics of the CFG pile composite foundation in the application of high latitudes and low altitude island permafrost. The field temperature monitoring of permafrost was carried out to investigate the temperature variation of the CFG pile and permafrost during the construction of the CFG pile. FE modelling was used to discuss the temperature distribution of permafrost under the condition of different subgrade height and atmospheric temperature cycle. Based on the foregoing temperature characteristics studies, some of the main findings are summarized as follows:

(1) In the construction process of the CFG pile, the permafrost beside the pile reached the highest temperature of 7.1℃~7.9℃ after fly ash concrete had been cast for one day. 15 days later, the pile temperature and the temperature of permafrost beside pile realized a balance, the temperature of permafrost beside pile was 2.0℃. When the pile is applied for stiffening permafrost groundwork, the effect of low-temperature curing conditions on pile strength, pile cracking caused by uneven temperature or pile breakage shall be considered in the process of generating pile strength.

(2) The subgrade with different height had different effects on the temperature field of permafrost. When subgrade height decreased, the disturbance for permafrost temperature reduced, in addition, the re-frozen time of permafrost became short. The finite element calculation data show that, after subgrade construction, permafrost could complete refreezing only after one to two months. It is suggested that, within one to two months since subgrade filling, the surface construction or load exertion shall be reduced as far as possible, to make the permafrost at the bottom layer refreeze sufficiently, assure subgrade quality and reduce unnecessary economic loss.

The paper researched the effect of the construction process of CFG pile in island permafrost on the temperature of CFG pile and permafrost; the conclusions can provide a reference for the design on the CFG pile composite foundation used for consolidating permafrost. However, the changes of the physical properties of permafrost in freeze-thawing process are sometimes hard to control; this will lead to the destruction of the permafrost in use and affect road running. Therefore, the authores recommend future studies on the measures to reduce temperature disturbance in the construction of permafrost should be researched.

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