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The Study of the Supporting Performance of the Anti-Slide Pile Under the Complex Temperature Field

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Abstract: The shells or other high temperature fire role may attack the anti-slide pile in the process of using of the anti-slide pile, and high temperature will seriously influent the supporting performance of the anti-slide pile. Summarizing the relationship between the temperature and the tensile strength and elastic modulus of the anchor cable and the relationship between the temperature and the elastic modulus of pile by consulting specification and related literature, and then, Combined with FLAC3D to establish three-dimensional model of a slope, and finished the numerical simulation of slope which may Suffer from the shells or high temperature heat source to explore the relationship between the axial force and temperature and the relationship between roof displacement of the slope under the same degree of safety and under different degree of safety of slope to find the influence rule between the temperature and the supporting performance of the anti-slide pile. The results showed that for the slope at the same degree of safety, when the temperature is at 200-400°, the displacement of pile head and the axial force of anchor cable are not affected by temperature, when the temperature is greater than 400 °, the displacement of pile head and the axial force of anchor cable are sensitive to temperature, they both increase quickly with the increase of temperature. When the degree of slope changes safety within a certain range, the relationship between the supporting performance of the anti-slide pile and temperature is stable and regular.

Keywords: *Temperature, Supporting performance, the displacement of pile tip, the axial force of anchor cable*

1. Introduction

The anchored anti-slide pile is a common form of slope supporting as well as one of the main structures to restrain the slope sliding. The declining of the Complex temperature field will greatly weaken the supporting performance of anchor anti-slide pile, and what is the worst is that it well lead to the happening of landslide seriously, threatening people's lives. At present , in the process of designing anti-slide pile ,something that there isn't any complex temperature field research on the influence of the performance of the prestressed anchor cable at home and abroad is always being overlooked, which lead to the security problems.

Because the thickness of slope is thick and the insulation effect is good, the soil temperature does not change much, the design of the traditional anchor anti-slide pile usually does not consider the change of soil temperature on the influence of the supporting structure. However, under different degrees of safety, the support structure of the slope has great influence on the elastic modulus and tensile strength of anchor and anti-slide piles, especially the prestressed anchor cable, strong Of the prestressed cable elastic modulus will be affected by the impact of temperature amplification, so the anchor anti-slide pile supporting effect will be affected in the high temperature field.

In this article, the performance of the cable and concrete under the complex temperature field is studied through experiments and the related literature. Summarized the both relationship with temperature; Using FLAC3D software to build three-dimensional slope model, Combined with research results, Numerical simulation of slope subjected to high temperature heat source is carried out. The elastic modulus and tensile strength corresponding to the anchorage cable are obtained by different temperature, and the mechanical parameters of the weak intercalation of the slope are simulated by the strength reduction method to simulate the edge under different safety conditions Slope, the sum of the reduction coefficient is the same when the slope is in the same security, the anchor pile anti-slide pile top displacement and the relationship between the axial force and temperature, and when the slope is in different security degrees, the anchor Pile to study the influence of complex temperature field on the supporting effect of prestressed anchor cable anti-slide piles, to provide the basic design reference for engineering designers or to be able to move near the slope subjected to high temperature fire Provide the basis for reference.

2. Anti-Slide Pile in the Mechanical Properties of Complex Temperature Field Research

It can be known by through consulting relevant document, that Guo Zhenhai, who comes from the domestic Tsinghua University, has summarized the elastic modulus of concrete calculation formula in high temperature by experiments. conditions, that is:

$$\frac{E_c^T}{E_c} = 0.83 - 0.0011 \cdot T \qquad 60°C \le T \le 700°C \quad (1)$$

Tongji University Yu Jiangtao, according to a large number of experiments as well as the common formula form provided by experts at home and abroad, has summarized the elastic modulus of concrete calculation formula in high temperature by experiments conditions, that is:

$$\frac{E_c^T}{E_c}=\frac{1}{1+2.6(T-20)^{2.6}\times10^{-7}} \qquad 20°C\le T\le1000°C \quad (2)$$

At the same time Europe's current specification of the elastic modulus of concrete under high temperature calculation formula is:

$$\frac{E_c^T}{E_c}=\left(1.084-1.384\times10^{-3}\cdot T\right) \qquad (3)$$

3. The Research of Mechanical Parameters of Prestressed Anchor Cable in the Complex Temperature Field

In recent decades, the extensive use of prestressed anchor cable prompted researchers to study the performance of high strength anchor structure of high temperature, and also has a detailed study of the performance in 1860 grade high-strength low-relaxation steel strand. Zong Zhongling, summed up the steel tensile strength and elastic modulus and tests the relationship between the temperature.by testing the effectiveness of 16 steel wires under high temperature conditions from ropes of 1860 degree. Zhou Huanting, through testing the performance of 1860 grade prestressed steel strand at different temperatures, summed up the model of performance of steel strand in different temperature. According to the experimental data obtained by Zhou Huanting, the elastic modulus and tensile strength of the grade strand are summarized as figure 1:

By fitting the above data, the elastic modulus reductio n coefficient of 1860 prestressed anchor cable can be obtained:

$$\frac{E_c^T}{E_c}=0.9817+7.92287\times10^{-4}T-3.19368\times10^{-6}T^2, \quad (4)$$

$$20°C\le T\le700°C$$

Tensile strength reduction coefficient:

$$\frac{\sigma_b^T}{\sigma_b}=1.0259-2\times10^{-6}T^2-8\times10^{-5}T, \qquad (5)$$

$$20°C\le T\le700°C$$

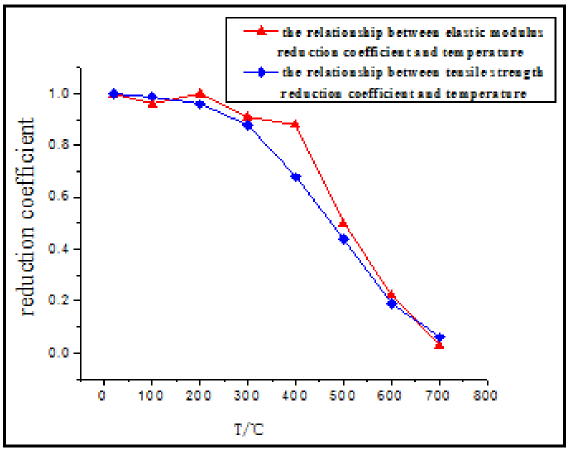

***Fig.1:** The relationship between the reduction coefficient of mechanical parameters and the temperature of steel strand*

4. Numerical Simulation

4.1 Set up 3d model

Using FLAC3D software to build a three-dimensional slope calculation model, for example, as the slope is shown in figure 2, 3, which has the height of 22m,the length 50m, the width 7m, has been divided into 32416 solid elements and 38617 nodes. In the bottom of the model, a vertical constraint is imposed. The horizontal displacement constraint is applied to the plane of the slope at X = 0, X = 50, Y = 0 and Y = 7, and the top of the slope is free interface.

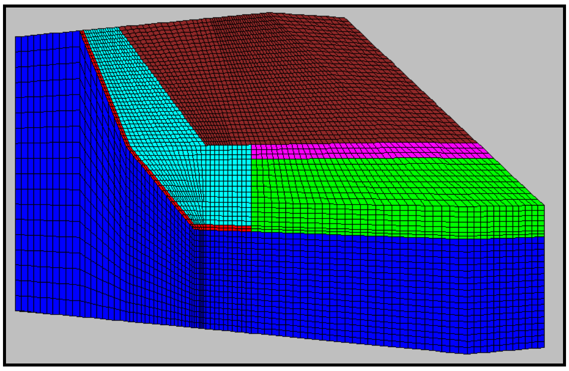

***Fig.2**: Soil slope finite element model*

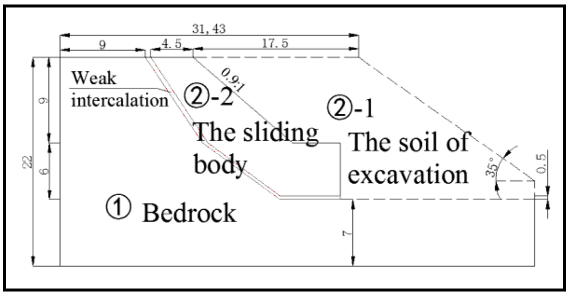

***Fig. 3:** Sketch map of soil slope section(unit: m)*

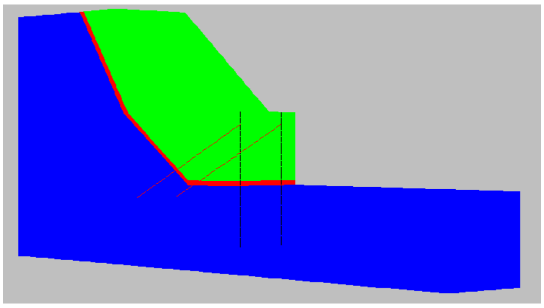

Fig. 4: *Soil slope finite element model after the constructions*

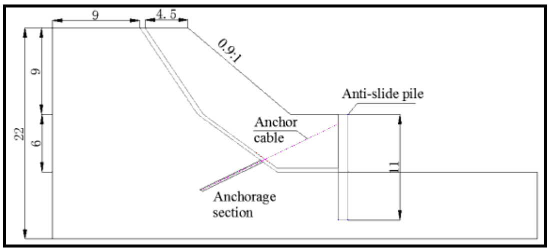

Fig. 5: *Sketch map of retaining structure(unit: m)*

4.2 Calculation parameters

The numerical model takes the typical rock-soil mixed slope as the object of study. The section of the slope is shown in Fig.3, among which ① is bedrock, ②-2 is slide body, ②-1 is slope excavated soil, The weak intercalation with thickness of 0.5m is set between the slide body and the bedrock, and the mechanical parameters of the weak interlayer are reduced by the method of strength reduction to simulate the slope with different condition of security. The constitutive model of rock and soil is Mohr-Coulomb elasto-plastic model in FLAC3D software. This model is an elastic-plastic model with non-correlation flow rule, which accords with the actual condition of slope, and calculates the mechanics Parameters in Table 1, the weak intercalation of the mechanical parameters of the material according to different strength reduction factor to select.

The supporting structure of the slope is shown in Fig.5. The pile and anti-slide pile are simulated by FLAC3D software. The numerical model is shown in Fig.4, the pile length is 11m, the anchorage section is 7m, the pile 1m × 1m, pile spacing 4m, the anchor is located at 1m away from the pile, the horizontal inclination of the cable is 26 °, the calculation parameters of the anchor are shown in Table 2, the calculation parameters of the anti-slide pile are shown in Table 3.

Table.1: *parameters of rock soil mass*

Slope	Weight (KN/m^3)	Cohesion (KPa)	Internal friction angle (°)	Elastic modulus (MPa)
①	21.5	708	31.3	980
②	17	34.6	24.6	200

4.3 The physical and mechanical parameters of soft interlayer

By Moore-coulomb strength theory, the cohesion and internal friction angle are the two important indexes of strength of not being cut in geotechnical engineering, which has crucial effect on the formation and the steadiness of slope. In the calculation of weak interlayer cohesion c and internal friction Angle of the different degree of reduction, the reduction formula is just as shown in the type 6:

$$c' = \frac{c}{\omega}, \varphi' = \tan^{-1}\left(\frac{\tan\varphi}{\omega}\right) \qquad (6)$$

In formula 6, c and φ are the cohesive force and the internal friction angle of the front body, respectively, c' and φ' are the cohesion and internal friction angle of the sliding body respectively, ω is the reduction coefficient. The initial cohesion and internal friction angle of the weak intercalated material are the same as those of the sliding body: c = 24 ° and φ = 34.6kPa.

Table.2: *parameters of anchors and frame beams*

Anchor rope	Elastic modulus (Gpa)	Cross-sectional area(m²)	Friction angle of cement slurry(°)	Bond strength of cement paste per unit length(KN/m)	Stiffness of cement slurry per unit length (GPa)	Outer perimeter of cement(m)
Free segment	195	5.56e-4	0	0	0	0
Anchored Section	195	5.56e-4	25	2.1e3	0.56	0.4082

The values of the cohesion and internal friction angle at different reduction factors are shown in Table 4.

Table.3: *parameters of anti-sliding pile*

Retaining structure	Elastic modulus (GPa)	Poisson ratio	Normal coupling spring cohesion(KN/m)	Normal coupling spring friction angle(°)	Normal coupled spring unit length of the stiffness(GPa)	Shear coupling spring cohesion(KN/m)	Shear coupling spring friction angle(°)	Shear Coupling Spring Rigidity Per Unit Length(GPa)
Anti-slide	30	0.2	20	25	0.9	20	25	0.9

pile

***Table.4:** The cohesion and internal friction angle under different reduction coefficients*

Reduction coefficient	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.0**
c'/kpa	24.7	23.1	21.6	20.4	19.2	18.2	17.3
φ'/(°)	17.64	16.53	15.55	14.68	13.89	13.19	12.55

4.4 Anti-Slide Pile Calculation Parameter Selections

The complex temperature field will affect the elastic modulus and tensile strength of the anchor cable and the elastic modulus of the anti-slide pile. According to the results obtained in the previous study, the calculation parameters of the anchor pile at different temperatures are obtained, as is shown in Table 5.

***Table.5:** The calculation parameters of anchor cable vary with the change of temperature*

Temperature (℃)	**20**	**100**	**200**	**300**	**400**	**500**	**600**
Elastic modulus of anti-slide pile(pa)	3e10	2.16e10	1.83e10	1.5e10	1.17e10	8.4e9	5.1e9
Elastic modulus of anchor cable(pa)	1.95e11	2.01e11	1.97e11	1.82e11	1.54e11	1.13e11	5.99e10
Tensile strength of anchor cable(pa)	3e6	2.99e6	2.79e6	2.47e6	2.02e6	1.46e6	7.74e5

4.5 Numerical Simulation Methods

The difficulty in this passage is how to make sure that the anti-slide pile is affected by temperature and the degree of effect. In this paper, assumed to be at different temperatures and the mechanics of the supporting structures are determined according to different temperatures. The relationship between slope deformation and temperature with the same safetydegree under the action of the same strength reduction coefficient is explored in order to study the effect of anchor cable anti-slide pile support .The result is affected by temperature. During the use of anchor cable anti-slide piles, the anti-slide piles and the surrounding rock and soil are always firmly bonded due to the strong prestressing force. Therefore, the horizontal displacement of soil around piles and the horizontal displacement of piles are equal. The relationship, which can reflect the relationship between the anchor pile anti-slide pile and the temperature, between the displacement and the temperature of the anti-slide pileat the anchor pile can be recorded in the process of numerical simulation.

Aimed at the characteristics of the slope under different conditions of safety, the following seven conditions were applied to the supporting structures under the temperature of 20 °, 100 °, 200 °, 300 °, 400 °, 500 ° and 600 °degrees respectively. The strength reduction coefficient of the weak intercalation is 1.4, and the strength reduction coefficient of the soft interlayer is 1.5, and the strength reduction coefficient of the weak interlayer is 1.6. Condition 4: The strength reduction coefficient of mechanical parameters of weak interlayer is 1.7; Condition 5: The strength reduction coefficient of mechanical parameters of weak interlayer is 1.8; Case 6: The strength reduction coefficient of mechanical parameter of weak interlayer is 1.9; the strength reduction coefficient of interlayer mechanical parameters is 2.0.

5. The Results of Numerical Simulation Analysis

The above seven kinds of working conditions are simulated numerically, the relationship between the displacement and the temperature of the top of the anti-slide pile and the relationship between the axial force and the temperature of the anchor cable are compared by comparing the same reduction factor of the weak intercalated material with the same safety factor. And the relationship between the displacement of the top of the pile and the temperature of the anti-slide pile is analyzed by comparing the reduction coefficient of the mechanical parameters of the weak intercalated material when the slope safety is different. As well as the relationship between the axial force and temperature of the anchor cable, the influence of the temperature on the supporting performance of the anchor cable anti-slide pile under different safety conditions is discussed.

5.1 The relationship between the displacement of pile top and the axial force and temperature of slope under the equivalent reduction factor

According to the simulation results, when the strength of the weak intercalated material is equal to 2.0, the initial stress of anchor is set to 200KN,the displacement of top of the pile and the axial force of the cable are shown in Table 6, and . The relationship is shown in Fig. 7 and Fig8. According to the relationship between elastic modulus and temperature of the anti-slide piles and the anchor cable, When the temperature is in the range of 400 °, the displacement of the top of the pile and the axial force of the cable is smaller and the elastic modulus of the anti-slide pile decreases faster than when the temperature is less than

400 °. So the anti-slide pile will have a certain change of deformation under the pressure of rock and soil. The elastic modulus of the cable does not substantially change so that the anchor rope does not undergo tensile deformation due to the decrease of the elastic modulus. According to the results of the study, it can be seen that when the reduction coefficient is large, the compressive deformation of the anti-slide pile can be greatly increased because the mechanical strength of the weak intercalated material is reduced to a certain degree. The pile tip displacement and the axial force of the anchor cable are great sensitive to the temperature and it has the big growth rate with the temperature, which is because that when the temperature is greater than 400 °C, The elastic modulus of the cable decreases rapidly and the deformation of the anchor cable increases. As a result, the displacement of the top of the pile and the axial force of the cable are greatly increased, and the stability of the slope is greatly reduced. With the change of pulling strength become large or the supporting structure temperature is higher, there is more likely to lead to instability of the slope, causing landslides that threatened people's lives.

Table 6: *The displacement of pile tip and the axial force of anchor cable vary with the change of temperature*

Temperature(°)	20	100	200	300	400	500	600
Displacement of pile top(mm)	3.466	3.437	3.417	3.363	3.362	3.636	4.267
Axial force of anchor cable(KN)	202.5	202.4	202.3	202.2	202.2	202.5	203.1

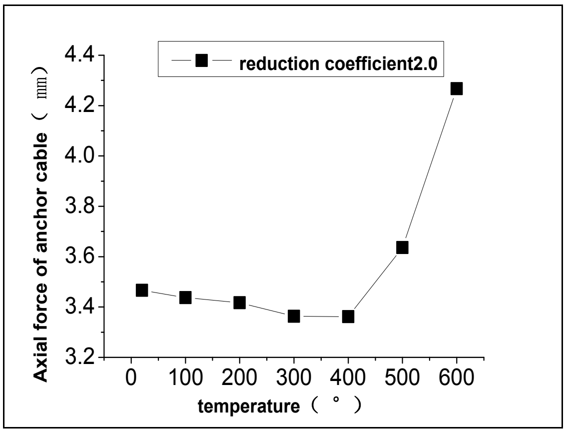

Fig.6: *Relation between displacement of pile top and temperature when strength reduction coefficient is 2.0*

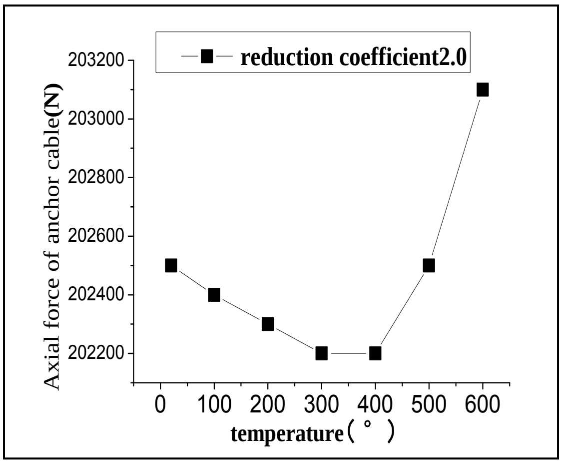

Fig.7: *Relation between displacement of pile top and temperature when strength reduction coefficient is 2.0*

5.2 In the slope under the different reduction factor of the relationship between the displacement of pile top and temperature

According to the results of numerical simulation, the relationship between the top displacement and the temperature of the anti-slide pile under the seven kinds of working conditions : Figure 8-1-8-6 correspond to the strength of the weak intercalated material mechanical strength reduction factor of 1.4,1.5,1.6,1.7,1.8,1.9 anti-slide pile when the top of the relationship between the displacement and temperature. It can be seen from Fig. 8 that because the strength reduction coefficient of the weak intercalated material increases, the displacement of the pile top increases with the increase of the strength reduction coefficient of the mechanical parameters of the weak intercalated material, and the growth speed is faster and faster. The increment of rock-soil pressure acting on supporting structure also increases, which leads to the increasing speed of deformation of anchor anti-slide pile. The strength reduction coefficient of mechanical parameter of weak intercalated material is in the range of 1.4- 2.0, the displacement of the pile top is basically the same as that of the temperature, which indicates that the thrust of the landslide changes within a certain range. The relationship between the supporting effect and the temperature is relatively stable, In the range of 400 °, the displacement of the top of the pile will not change greatly, but after the temperature of 400 °, the displacement of the pile top increases rapidly with the temperature, that is, the supporting effect of the anchor anti- The rapid decline.

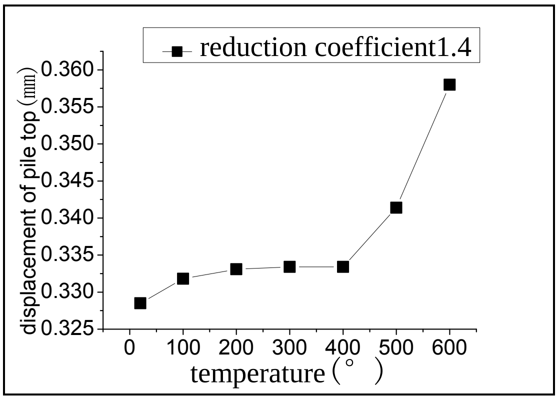

Fig.8-1: *The relationship between the displacement of pile top and the temperature when the strength reduction factor is 1.4*

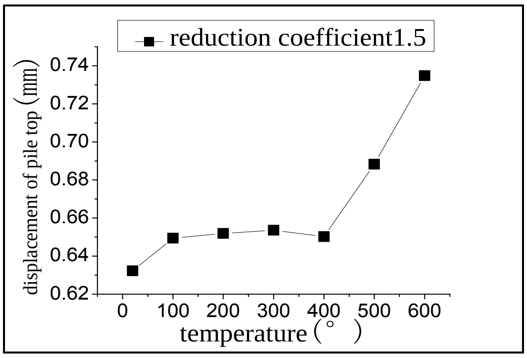

Fig.8-2: *Relationship between displacement of pile top and temperature when the strength reduction factor is 1.5*

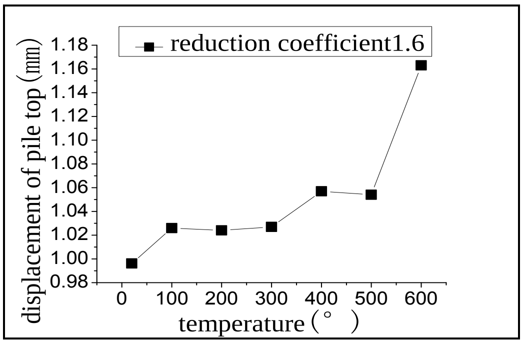

Fig.8-3: *Relationship between displacements of pile top and temperature when strength reduction factor is 1.6*

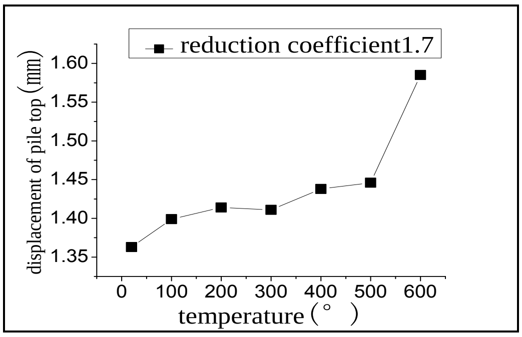

Fig. 8-4: *The relationship between the displacement of pile top and the temperature when the strength reduction factor is 1.7*

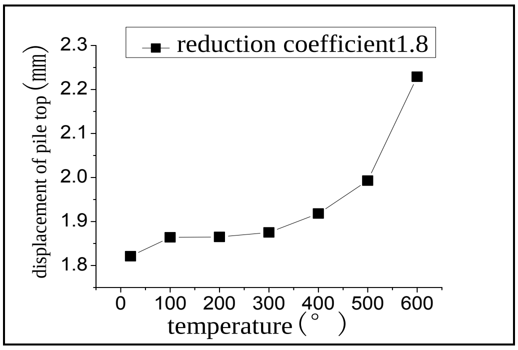

Fig. 8-5: *The relationship between the displacement of pile top and the temperature when the strength reduction factor is 1.8*

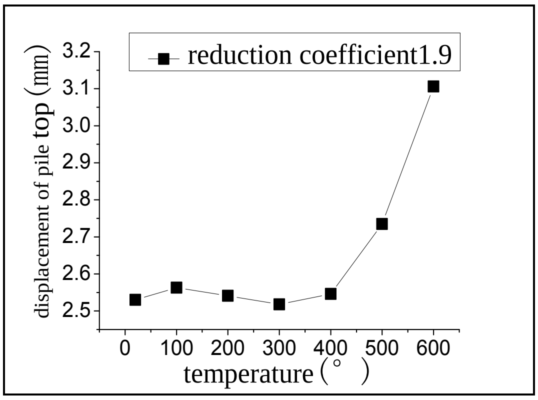

Fig. 8-6: *The relationship between the displacement of pile top and the temperature when the strength reduction coefficient is 1.9*

Fig.8: *The relationship between the displacement of pile top and the temperature when the strength reduction coefficient of the weak intercalation material is different*

5.3 The anchor cable in slope under different reduction factor the relationship between the axial force and temperature

According to the numerical simulation results, the relationship between the axial force and the temperature of the anchor cable is shown in Fig.9.

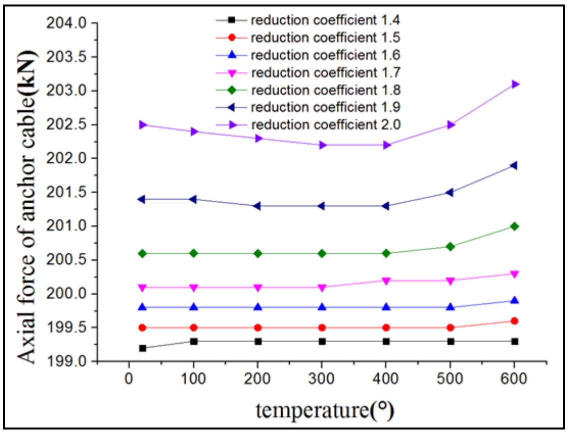

Fig.9: *The relationship between the axial force of anchor and the temperature when the strength reduction coefficient of the weak intercalation material is different*

In this chart, the strength reduction coefficient of mechanical parameters of the weak intercalated material is 1.4, 1.5, 1.6, 1.7, 1.8. The relationship between the axial force and temperature of the anchor cable is similar to the displacement of the pile at the top of the pile. When the temperature is in the range of 20-400 °C, the axial force of the cable is almost the same, while when the temperature is more than 400 °C, the axial force of anchor cable increases rapidly with temperature. Because the axial force of the anchor cable is directly related to the displacement of the anti-slide pile, the increment of the horizontal displacement at the anchorage point of the anti-slide pile is equal to the increment of the horizontal displacement of the anchorage cable, and the anchor cable elongation will directly lead to the anchor cable Axial force increase.

6. Conclusion

1) When the mechanical parameters of the weak intercalated materials are the same and the temperature of anchor piles is in the range of 20-400 °, the displacement of the top of the pile and the axial force of the anchor cable are small and are scarcely effected by temperature.
2) When the mechanical parameters of the weak intercalated material are the same and the temperature of the anchor pile is more than 400 °,the displacement of the pile top and the axial force of the cable are very sensitive to temperature and increase rapidly with the temperature increasing.
3) With the increase of the strength reduction coefficient of mechanical parameters of the weak intercalated material, the displacement of the pile top and the axial force of the cable are also increased, and the speed of increasing speed is fast.
4) When the strength reduction coefficient of the weak intercalated material is between 1.4 and 2.0, the displacement of the pile top is basically the same as that of the temperature. The relationship between the supporting effect and the temperature is relatively stable and has strong regularity.
5) The relationship between axial force and temperature of anchor cable is similar to that of anti-slide pile top displacement and temperature.

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