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The Machine Learning based Finite Element Analysis on Road Engineering of Built-in Carbon Fiber Heating Wire

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ABSTRACT
For the study of the effect of deicing with carbon fiber heating wire in the bridge pavement structure, through built-in carbon fiber heating wire in the bridge pavement structure, experimental studies were carried out indoor on the effects of thermal conductivity in different embedding positions, layout spacing and the installs power of carbon fiber heating wire. With indoor laboratory test data as the basic parameters, using ABAQUS finite element software simulation, an analysis was carried out of the degree that the surface temperature of the heating wire, the thermal physical parameters of asphalt concrete, and environmental conditions have influence on the melting effect. With a 50 m bridge between the left Shanggaoqiao tunnel exports with 2# Dabaozhai tunnel entrance in Ma Zhao Highway as the test section, this paper introduces the carbon fiber heating wire grooving laying process and construction methods.

KEY WORDS: Road engineering, Carbon fiber heating wire, Melting ice technology, Finite element analysis, Construction application

1 INTRODUCTION

IN the winter, the roads in most areas of China will be frozen, because of snowfall, freezing rain and some other natural climate, these situations would bring serious impacts on roads unimpeded and traffic safety. Because the highway bridge and tunnel portal pavement, which in cold and high altitude areas, above natural ford or canyon, the wind is strong, bridge decks and pavements could freeze easily, and those sections of highway are high incidence of a freeze disaster. In order to keep the roads unimpeded and safe, traffic management departments mobilize a lot of manpower and material resources to participate in resisting freezing and keeping roads unimpeded, maybe that would arrive at getting effective results, but with a high cost.

There is little research about bridge pavement deicing in our country, the research achieved doesn't give satisfaction to the people, for example; using industrial salt and deicing chemicals, which could bring enormous negative effects on the environment, and material composition used to try and lower the freezing point of bridge deck asphalt up-layer or use flexible pavement form self-break-ice pavement structure, these methods won't supply us great satisfaction in practice.

There is little research about the heating wire systems applied to bridge pavement structure deicing in China. (Guo Zhenguo, et. al. 2012) researched how to apply heating wires to road deicing, and introduced the construction technology detailed. (Yang Jie, Li Hai-tao etc. 2009) explored how to use electro thermal methods to clear road snow, and researched the technical index of heating wires. Li (Li Yanfeng, et. al. 2008) and (WU Haiqin 2005) (Li Yanfeng, et. al. 2006) who are at Beijing University of Technology has carried on the theoretical analysis about some key problems of heating wire deicing, and did some experiments indoor, researched the system's pavement efficiency, the circuit control technology, and economy.

There are various kings of material heating wires. Compared with other materials, carbon fiber has the feature of low density, heat-resisted, abrasion resistance, anti-corrosion, low heat expansion coefficient, fever quickly, high electro thermal conversion efficiency, can adjust to heating temperature and energy by wires' length and voltage, in the conditions that current load's area is the same. Carbon fiber's intensity is 6~10 times higher than metal wires'. And it's not easy to break off, with a long life cycle.

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This article is aimed at researching the method of arranging carbon fiber heating wires in bridge deck construction, determine the layout's distance, pavement power, layout's location, analyze concrete's performance parameter, which is used in experiments by ABAQUS, simulate bituminous concrete's thermophysical properties, heating wires' heat, environmental conditions and some different influence factors, analyze the heating rate's change in bridge pavement when influence factors changed, come up with specific construction methods and rely on Mliuwan-Zhaotong highway at last.

2 CARBON FIBER HEATING WIRES DEICING PAVEMENT EXPERIMENT

THE typical pavement form on a highway bridge pavement is; 4cm up-layer + 6cm middle-layer +10cm concrete pavement, an experiment on indoor mold corresponding thickness test piece was done respectively. Consider the convenience of construction, and the main inbuilt places of carbon fiber heating wires are; between up-layer and middle-layer (as shown in Figure 1a); between middle-layer and concrete pavement (as shown in Figure 1b); in concrete pavement (as shown in Figure 1c), 3 ways.

The gap of concrete' bar-mat reinforcement is 10cm usually, when concrete is not congeal, the need to strap heating wires and bar-mat reinforcement, could explore influence of heating wires' inbuilt place to bridge pavement deicing.

2.1 Carbon Fiber Heating Wires' Inbuilt Place

When doing the experiment, set the space of heating wires to 10cm, set the power of heating wires to 35W/m, set temperature to -5°C, no wind, place the test piece in PJT horizontally (Yang Fei. 2014). Keep the bottom of test piece superterranean, the upper surface is a heat delivery surface. When test piece's temperature achieve -5°C, start experiment with electricity (Shi Yiping, Zhou Yurong. 2006), the voltage loaded on heating wires is 65V, keep galvanical for 2 hours, the data of the test piece surface's temperature changes over time by temperature data logger.

According to Figure 2, we can see that there is a big difference in the surface temperature of the specimen-heating wires located in 3 different depths after 2 hours. When the heat wires are placed in the steel bar network within the concrete layer, the surface temperature remains -5°C after the power is on for 2 hours, the temperature is low and the effect of heat is poor (Zhang Huiyu, Zou Lingdeng. 2011). When the heating wires are placed between the middle-layers and the concrete layer, a better effect can be obtained. When the heating wires are placed between the up-layer and middle-layer and the surface temperature reaches -4°C after 2 hours with the power on, the highest temperature and best effects are obvious and the surface temperature increases with the increasing of the powering time.

In order to prevent the stability in high temperature from injury resulting from high temperature in the surface layer of the asphalt, we should constrict the temperature of the heating wires within a rational area.

2.2 Carbon Fiber Heating Wires' Burying Spacing

To obtain directly the effects about the spacing of the heating wires on heat conduction, setting the spacing to 5 cm, 8 cm and 10 cm respectively indoors, the specimens in the junction of up-layer and middle-layers and the power to 35W/m. The heating wires and environmental temperature are – 5°C, to process circuit and load voltage 65 V. In addition, keeping galvanical for 2 hours and setting the interval of temperature data logger for 5 minutes. Finally, collecting the surface temperature data of heating wires respectively, using three kinds of spacing. Figure 3 shows the surface temperature of heating wires with three kinds of spacing.

According to Figure 3, under the same heating time, the smaller the heating wires are spaced, the higher the wires' surface temperature in the same station, the better the effect about the temperature sensitivity (Chen Depeng, et. al. 2007). However, when the burying area is the same, the smaller the heating wires are spaced, the longer the heating wires are used. Hence, considering the construction condition, economic cost and temperature effect, the spacing of heating wires using 10 cm is relatively appropriate.

2.3 The Pavement Power of Carbon Fiber Heating Wire

In order to determine the influence of power for the heating system on surface temperature of the specimen, we choose 6 different types of power: 200W/m^2, 400W/m^2, 600W/m^2, 800 W/m^2, 1000W/m^2, 1200W/m^2, the spacing of the heating wires is 10cm, the laying place is located between the upper and median layer with the environment temperature is -5°Cunder windless conditions. The input voltages corresponding to the 6 powers are listed in the Table 1.

When the temperature of the specimen decreases to -5°C, we put on the circuit and load the voltage of the heating wires according to Table 1. Collecting the temperature data of the specimen's surface temperature based on the spacing of 300s after 1 hour and the data of the surface temperature of the specimens can be finally obtained.

From Figure 4 we know that with increasing the power, the surface final temperature of the heating wires increases constantly. When the power is larger than 800W/m^2, the final temperature of the specimen's surface obtains an obvious increase-up to 3.4°C, whereas, when the power is 200~800W/m^2, there is no

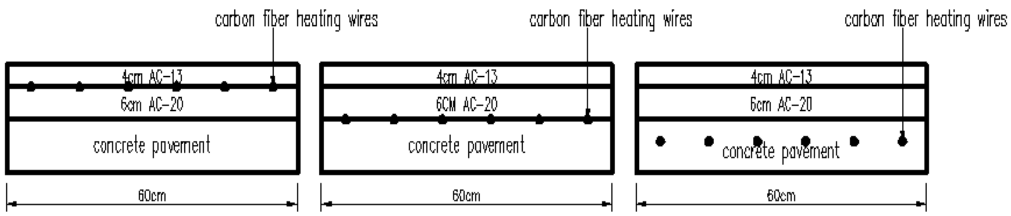

Figure 1. Layout Heating Wires Schematic.

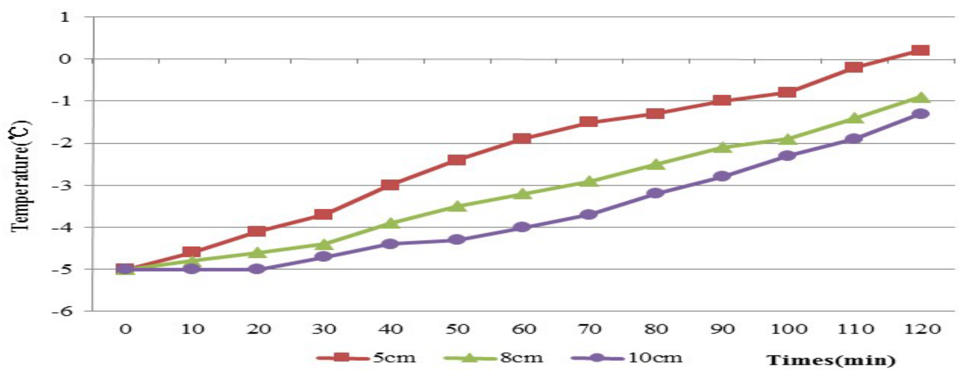

Figure 2. Heating Wires' Temperature rise after 2 hours in 3 kinds of Layout Places.

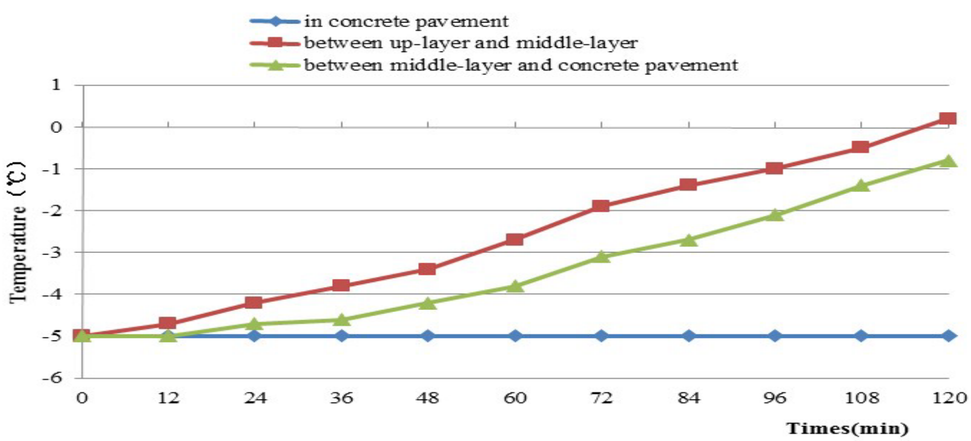

Figure 3. In 3 kinds of Distance of Heating Wires Test Piece's Temperature Change after 2 hours.

obvious difference in the final temperature of the specimen's surface (Zhang Renyi, GU Qiangkang. 2012), fluctuating within -2~-1°C. After the power is on for 1 hour, the temperature increases gradually corresponding to 400~800W/m2, the temperature increases rapidly when the power is larger than 800W/m2. At the same time, there is a big difference in the stable temperature that the heating wires can reach under different power shown in Table 2 below.

According to Table 2, with increasing pavement power, the surface temperature of the heating wires increases simultaneously. When the power is larger than 600W/m^2, the surface temperature of the cable has already over 45°C, which may influence stability in high temperature of the asphalt mixture.

Thus the operating cost will be reduced meanwhile we should make sure that the system can melt ice and snow in time (Gao Yiping. 1999). Considering the factor that the temperature of heating wires should not be too high, we choose power of the heating system as 400W/m^2 under the same situation as the experiment.

3 DEICING OF CARBON FIBER HEATING WIRE SIMULATION BY ABAQUS

To analyze the heat convey process of bridge pavement deicing with carbon fiber heating wires, utilizing the ABAQUS finite element software to simulate the effect of melting ice of heating wires

Table 1. Pavement Power and Corresponding Input Voltage.

Pavement power（W/m^2）	200	400	600	800	1000	1200
Testing voltage（V）	37	42.7	52.3	60.4	74	80

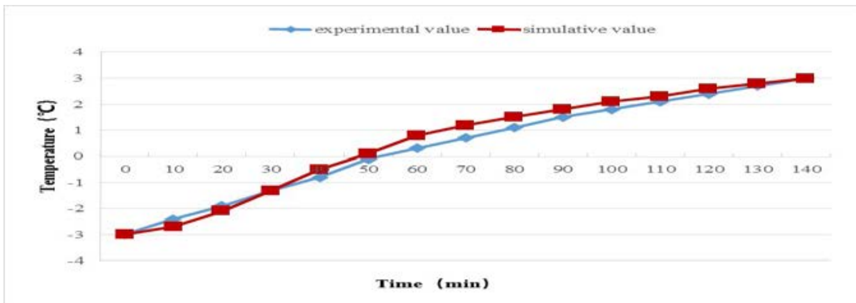

Figure 4. Test Piece's Surface Temperature Rise Curve in the 6 Pavement Power.

Table 2. The Heating Wires' Surface Temperature Changes with Different Pavement Power.

Pavement power（W/m^2）	200	400	600	800	1000	1200
Temperature of cable's surface（℃）	18.6	38.7	58.9	79.0	99.1	118.3

under the different condition and comparing with experiment data indoor (Gao Qing, et. al. 2007). Last, considering the result that to analyze the concrete thermal parameters and simulate the asphalt concrete thermal physical performance parameters, the temperature of heating wires and environment condition as the basis choosing carbon fiber.

3.1 Concrete Thermal Parameters Analysis

Initially, setting the concrete thermal parameters by ABAQUS, and utilizing a trial and error method to determine the test coefficient of thermal conductivity of the mixture indoor is done. The basic step of a trial and error method; assuming reasonably a coefficient of thermal conductivity of the concrete and simulating the heating process of concrete slab (Tang Zuquan, et. al. 2001), then comparing the concrete slab temperature field distribution calculated by conductivity coefficient and the experimental results. If the simulation value is smaller than experimental value, conductivity coefficient needs to be increased, antisense versa. The course is over until one is close to the other.

(a) up-layer trial

(b) middle-layer trial

1) Test plan

When locating the heating wires in the junction of the upper-layer and middle-layers, setting the space of heating wires to 10cm and the pavement power to 400W/m^2 , the coefficient of thermal conductivity of the asphalt surface is measured. However, the heating wires in the inner of the cement pavement, 4 cm from the bottom of the middle-layers, the space of heating wires to 10cm and the pavement power to 400W/m^2 for the coefficient of the thermal conductivity of the cement concrete is measured.

2) Trial process

When calculating the temperature raising of the concrete slab， selecting a different value of coefficient of thermal conductivity and specific volume heat (Liu Hongmei. 2006) is done. By comparing the simulated values with ABAQUS and test values indoor, concerning the concrete surface temperature distribution and temperature curve that shows the temperature rising locating in the minimum temperature of the concrete surface and keeping the error within 1°C, the coefficient of thermal conductivity and specific volume heat of the test specimen is determined. Figure 5 shows the comparison curve graph that represents simulated values and test values about the thermal physical performance parameters in different layers.

Figure 5 indicates that the simulated value is near to the test. According to the result of the test indoor, the thermal physical performance parameters of the concrete in different layers are determined, for example in Table 3.

3.2 The Study of Bridge Deck Melting Ice Influencing Factors

Influence of asphalt concrete thermo-physical performance parameters

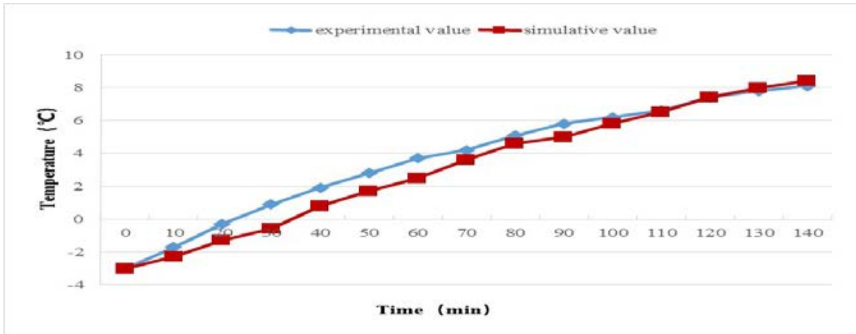

Figure 5. Figure Experimental Value and Simulative Value Comparison Changing Curve with Different Layer Thermo-physical Property Parameters.

Table 3. Concrete's Thermal Performance Parameter in a Different Layer.

Layer	Density (Kg/m³)	Heat-conducting coefficient (W/(m²·℃))	Specific heat (J/(Kg·℃))
Up-layerAC-13	2389	0.41	1100
Middle-layerAC-20	2406	0.44	1080
Concrete pavement	2501	0.78	1250

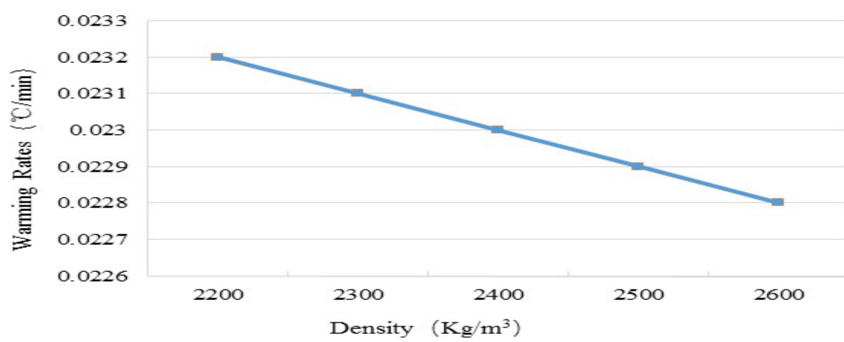

Figure 6. The Curve of Warming Rates Corresponding to Different Densities

In order to study the influence of asphalt concrete thermo-physical performance parameters on the bridge deck surface temperature, taking asphalt concrete density, thermal conductivity, specific heat capacity value (Yuhui Wu. 2010), the heating line depth of 4cm, environmental and pavement structure initial temperature of -5°C, the heating line epidermis temperature of 40°C and windless conditions run 4h, simulating the influence of the heating-up rate through changing parameters.

a）The influence of the asphalt concrete density on the surface warming effect.

Concrete density can be drawn through laboratory test measured calculations. All kinds of concrete mix, materials and density are different, prevailing by the measured results. Take the upper-layer of asphalt concrete density being 2200Kg/m^3, 2300Kg/m^3, 2400Kg/m^3, 2500Kg/m^3 and 2600Kg/m^3. After power-4h, the curve of concrete slab surface warming rates corresponding different concrete densities was shown in Figure 6.

As can be seen from Figure 6, with the increase of the density of asphalt concrete, the warming rate decreased. Therefore, to reduce the density of asphalt mixture can improve the road performance of the asphalt mixture.

b）The influence of asphalt concrete thermal conductivity on the surface warming effect.

Thermal conductivity refers to under the heat transfer conditions, the heat flux inside the object generated at the role of the unit temperature gradient (Qianwen Zhang, et. al. 2015), characterization of the size of the object thermal capacity and the unit is $W/\left(m^{2}\cdot{}^{0}C\right)$. Factors affecting the thermal conductivity of asphalt concrete mainly include aggregate, porosity, surface structure of the bridge deck, whetstone ratio, moisture and heat conductive filler, etc., in which the aggregate has played a decisive role to the thermal properties of asphalt concrete. Therefore, to obtain a thermal conductivity of specific asphalt concrete, you will need the aid of experimental testing. The thermal conductivity of concrete refers to literature (Sherif Yehia, et. al. 1999) obtaining a range of values, and then were confirmed by comparison between laboratory tests and the results obtained and error method.

c) The study of temperature changing in the thickness direction.

In 2.1, the warming condition of the heating line buried in a different position measured by the test, the test measured the heating line located between the middle-layer and the upper-layer, which heated better, so in this position the simulate heating line temperature is changing in the thickness direction.

Buried depth of 4cm (distance from the surface of the model), the heating line placement pitches 10cm, ambient temperature and the initial temperature of the pavement structure set to -5°C, the heating line skin temperature 40°C, no wind, run 4h, research shows the bridge surface temperature changes when the heating line cloth depth changes.

Figure 7 shows the final temperature cloud model, the highest temperature area close to the heating line and the lowest temperature area away from the heating line.

As seen from Figure 7, the temperature field is axisymmetric when shown the buried depth of 4cm. Take the models upper left corner as a coordinate origin O, to observe the final temperature value of a measuring point at intervals of 0.03m and found a difference between the surface maximum temperature and the lowest temperature only 1.5°C, which the surface uniformity is better.

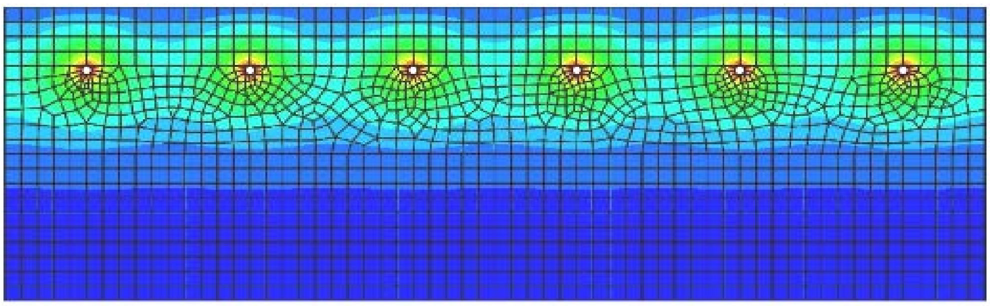

Figure 7. The Final Temperature Cloud Model

Thus, taking into account the construction continuity of the pavement structure layer, warming rate, uniformity and other factors (Xie Ping, et. al. 1996), the heating line is buried at a depth of 4cm at best. Similarly, when the pavement structure is three layers, the heating line should be located between the upper-layer and middle-layer; if the pavement structure is two layers, the heating line should be located between the upper-layer and under-layer.

4 THE ENGINEERING APPLICATION

4.1 Project Summary

SELECT the road of Maliuwan-Zhaotong highway, which is easy to freeze between the exit of Shang Gaoqiao tunnel and Da Baozhai 2# tunnel's exit (K43+064.50 ～ K43+114.50) in the left roadway (Sherif Yehia, et. al. 2000), which the length is 50m, being the test section. In the K43+071 and K43+101 installing bridge expansion joints in two places are done. The need to empty out the space of the one meters, actual length of the pavement area is 48 meters. This project uses the carbon fiber in the bridge deck structure internally, after being electrified there will form a thermal heating element, the heat will be transferred to the bridge through asphalt upper-layer, the temperature of the bridge deck will be higher than the freezing point.

4.2 The Construction Technical Requirements

At present a mature way of the carbon fiber wire hotline laid mainly is divided into the following two kinds; the first one is made from carbon fiber heating grid, the second one is groove. The advantages and disadvantages of the two kinds of the laying methods a comparative analysis is shown in Table 4.

Due to the surface layer being thinner, the existence of the heat grid will affect the bonding between the layers directly, easy to cause the asphalt pavement traction, upheaval and shorten the service life of bridge deck pavement. By means of the grooving way, the carbon fiber wire heating wires are embedded in the middle-layer, not affecting the upper-layer's pavement and roller compaction construction, and the impact on the bond strength between layers is small. Therefore, this project has chosen the grooving way to lay and fix carbon fiber heating wires.

When using grooving the groove's depth and width are chosen according to the standard of the carbon fiber wires heating wire. The projects main grooves are divided into three categories; the first one is across the driveway, used in the embedded carbon fiber heating wires (Zenewitz. J. A.. 1997); the second slots are to embed the K type joint connected with heating

Table 4. **Groove Way Compared with Fever and the Advantages and Disadvantages of the Grille.**

Comparison method	Pavement method	
	Dapping method	heating grid
Fixing method	in the surface of the middle-layer, making the heating wire in grooves	Spray tack coat, fix the steel nail on middle-layer
The construction problems that may occur	Debris in the trench may abrade the heating wires	The heating grid will be rolled up and the heating wire will be crushed when The paver make the follow-up completion operation
The influence on pavement	Grooving destroys the middle- -layer and is nothing wrong with the up-layer	The heating grid has certain thickness, bot-h its rigidity and strength are different fro-m original pavement. Damage may be emerged after traffic service
Difficulty Level of the construction	Unspecific type, worksite layout need put the heating wires in order. It has more connectors comparing with the normal wire	Have been fixed well and been specific; easy construction

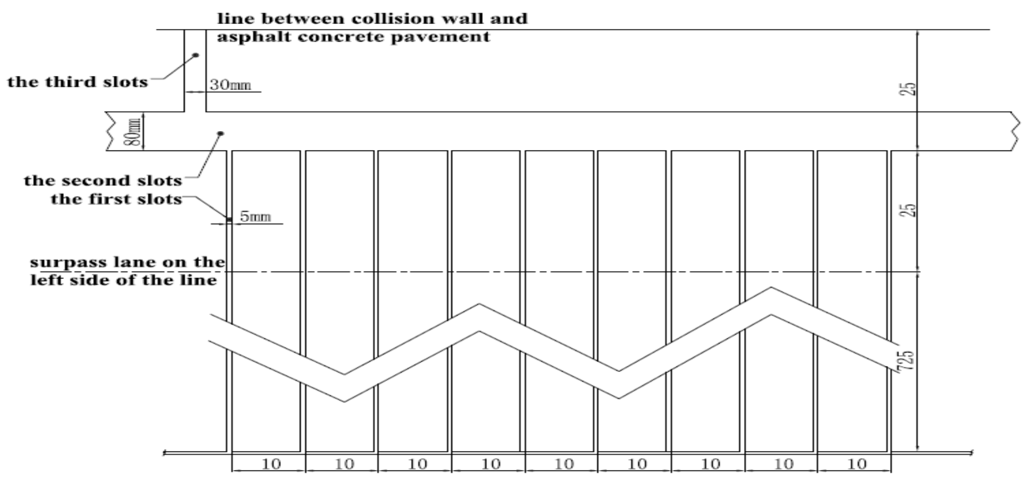

Figure 8. **A Single Set of Carbon Fiber Cable Layout Diagram.**

wires cold and hot wires, which are in the left of passing lane; the third one is used to connect the cold wire and it's joint. Should choosing the appropriate grooving machines when constructing, its working performance needs to satisfy the following conditions: (a) The first slots are about 5 mm wide, 10 mm deep. A single slot is 15 m long, it's groove spacing is 10 cm, all of the bridge decks should be grooved, it's corner part should be rounded; (b) The second slots are about 80 mm wide, 25 mm deep, a single slot is 1 m long; (c) The third slots are 30 mm wide, 25 mm deep, a single slot is about 8.5 cm long.

In the end of the groove, the groove should be cleaned up then lay the hair heating wires in the first kind of the slots. Five bars of the wire should be precast with a K type connector together in actual construction, unified arrangement. Each slot when necessary, the SBS modified asphalt will be send for the heating wires, which are bonded in the groove. K type of the connectors are placed in the second kind of slot, the connecting wires are placed in the third kind of slot and should be supported well. A single set of carbon fiber wire layout diagram is shown in Figure 8.

When the whole heating wires system is laid, a electrify test is done for 5~10 minutes. The normal operation indicates that the installation and use of the heating system is right. On the contrary, if we found the cable damaged, we should rework immediately.

4.3 *The Construction Scheme*

1) The first step should be lineation when we make grooves, the following step is grooving. The carbon fiber wire must be in the embedded groove (Cress. M. D.. 1995), and it can't be shown on the surface of the middle-layer. The wire installation location should avoid the bridge expansion joints. Before grooving the entire section, we should try to groove and make first of all, and be clear that what grooving machines and the installation technology of carbon fiber should be selected.

2) Installing cables should not be installed in the construction environment at 5 degrees below zero or less, when the environmental temperature decreases,

the cable will get hard and then is not good to be installed, and heat cable appropriately (Rebala S. R., Estakhri C. K.. 1995). The heating wire placed in the groove should be tried to avoid bump phenomenon of projection, and to prevent the heating wire being rolled up when the paver is working. If the asphalt of the under-layer is damaged at the corners of the installation the carbon fiber wire can't be fixed, and steel nails are used to fix it.

5 CONCLUSION

FOR carbon fiber heating wire in a bridge deck structure and the use of three kinds of layout ways makes the indoor experiment results show that heating wires, which are between the middle-layer and upper-layer, will generate the highest calorific efficiency. Melting ice time is too long when the heating wires are between the middle-layer and cement concrete pavement. When heating wires are located inside the paving layer, there is almost no change for the temperature on the surface. Therefore, when the pavement structure is of three layers, the layout of the position should be located on the place between the upper-layer and middle-layer. If the pavement structure is of two layers, the heating wires should be located on the place between the two layers.

The smaller the heating wire spacing is, the faster the heating rate is and shorter time is needed for bridge deck melting ice and melting snow. Take the heating wires' costs and the amount of work for the fixing heating wire into consideration comprehensively. The heating wires' spacing is 10cm reasonably in actual construction. The influence of thermo-physical performance parameters, the temperature of the heating wires, environmental conditions of the asphalt on the temperature and rise of melting of the ice bridge pavement is analyzed by finite element software. The main conclusions are as follows: (a) with the increase of asphalt concrete density, heating rate reduces. (b) With the increase of asphalt concrete thermal conductivity, heating rate on the surface grows exponentially. (c) With the increase of specific heat capacity of asphalt concrete, heating rate on the surface decreases constantly. (d) With the increase of the heat transfer coefficient, heating rate on the surface of the bridge pavement increases rapidly. (e) With the increase of heat exchange coefficient on the surface, heating rate of the deck surface decreases.

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7 DISCLOSURE STATEMENT

NO potential conflict of interest was reported by the authors.

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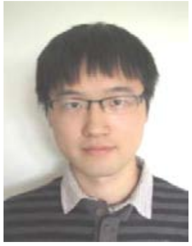

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