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Study on the Bridge Surface Deicing System in Yuebei Section of Jingzhu Highway

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Abstract

The bad snowy weather in early 2008 induced large scale damages of the transportation system in Southern provinces of China, and seriously influence the normal running of society and economy. The establishment of highway deicing and snow-melting system has been the urgent task. Because of the structure characters and the particularity of construction technology of bridge system, its system design and construction become in to the key problems. In this article, combining the characters of bridge section in Yuebei section of Jingzhu Highway, we compared present highway and bridge snow-melting deicing technologies, and selected proper technologies to establish the corresponding deicing program to enhance the traffic quality and reduce the quantity of accident.

Keywords: Bridge, Deicing technology comparison, Deicing program

1. Introduction

In the cold areas of north China, long freezing time and large snowfall induce road surface friction coefficient decreases obviously than other seasons, which makes vehicle running and breaking become difficult, and easily induces traffic accidents, and largely reduces the traffic ability of highway, and brings large losses to human living and social economy. The snow disaster of south China in Jan of 2008 knocked the alarm bell for local traffic management department, so it is imperative to establish corresponding emergency snow-melting and deicing system under the situation. For the development of highway and bridge snow-melting and deicing system, foreign and domestic relative industrial management departments and scientific research institutions have made active attempts.

In 1992, under the united support of US DOE, DOT, Federal Highway Administration and National Base Research Fund, US begun to implement the plan of HBT (Heated Bridge Technologies), and systematically studied the problem of heating snow-melting and deicing for highway and bridge. Since 1998, US OSU (Oklahoma State University) begun to develop the research about the heat liquid cycle snow-melting and deicing technology for highway and bridge under the financial support of DOE, Federal Highway Administration and Oklahoma Traffic Office, and established the largest highway and bridge expert experiment system in the world. The Terrestrial Heat Center in Oregon Institute of Technology implemented comprehensive comparison and analysis to the highway surface snow-melting and deicing technology, and empirical studied the ramp section in the Oak Ridge highway and Wyoming Cheyenne highway in Virginia.

Since 1994, Japan Misawa Environmental Technology Co, Ltd developed about 40 items of highway snow-melting and deicing sample engineering by virtue of terrestrial heat and solar energy early or late, and made large contributions for the protection of biological environment. In 1995, Japan National Resource Environment Research Institute established the first automatic highway surface heat storage cycle heat liquid snow-melting and deicing system in the city of Ninohe by the help of OECD and IEA, and the test indicated that the system could save 84% of electrical energy than the heating cable system. Cooperating with Yamaguchi University, Japan 8th Technical Consultation Company carefully studied and compared the snow-melting and deicing scheme of Ushinogou highway tunnel exit, and finally adopted the mode of the heating tube with natural resources.

In 1994, cooperating with Zurich Polydynamics Ltd, Switzerland Highway and Bridge Committee developed the energy storage snow-melting and deicing experiment on the bridge in the Darligen Section of Switzerland A8 Highway. Scholars in Poland Warsaw University simulated and computed the solar energy heat storage transfer process which buried pipes under the bridge surface. Since 1980, Iceland begun to utilize its abundant terrestrial heat resource, extended the application of road snow-melting and deicing engineering, and the utilization area in the whole Iceland has achieved 740 thousand m^2 at present.

At present, urban road snow removing in China mainly depends on snow-melting and deicing and manual cutting ice and removing snow, and the snow removing on main highways gives priority to chemical snow-melting and mechanical removing. The physical snow-melting is only limited in colleges and scientific research institution or small scale experiment because of late researches. Li, Yanfeng and Wu, Haiqin of Beijing University of Technology, and Harbin Institute of Technology implemented former researches to the electrical heating highway surface and bridge snow removing technology, and Zhuqing and Zhaojun of Tianjin University implemented detailed theoretical research about the application of solar energy soil heat storage technology in highway snow-melting and deicing with Tianjin Municipal Development Ltd.

2. Applicability comparison of modern deicing technologies in Yuebei section

The deicing system is the representative capital dense system, and it needs to be invested by large scale manpower, material resources and financial resources in the process of development, construction and operation. At present, the usual snow-melting and deicing technologies mainly include manual snow and ice removing, chemical snow and ice melting, mechanical snow and ice removing and physical snow and ice removing technology.

The manual deicing method could remove ice and snow with better effect.

The chemical deicing technology is to bestrew chemical medicaments on the highway surface to reduce the melting point and melt snow and ice, and accordingly remove snow and ice, and this method is a sort of highway surface ice and snow removing measure in international common use.

The mechanical deicing technology is the method which utilizes machines to remove snow and ice from the highway surface.

The physical deicing technology mainly includes following aspects at present.

(1) Energy storage highway deicing technology is to establish the energy storage cycle system which could heat the highway surface through the flow of heat liquid stored in the cycle pump in ice and snow weather, and accordingly achieve the effect of removing snow and ice.

(2) Electrothermal process highway surface deicing technology is to lay heating resistance wire or electric materials, and electrify and heating the highway surface to deice when ice and snow come.

(3) Heating mechanical composite deicing technology is to combine mechanical method with heating method, exert their own advantages and increase the efficiency of removing ice and snow. According to the analysis among various deicing technologies, and the comparison results are seen in Table 1.

Yuebei section of Jiangzhu Highway is located in mountainous region of special geographical environment, and the highway network combination has special characters. So we should seriously select proper snow-melting and deicing technology to realize the optimization of benefit and cost. There are 74 bridges which are 14% of total mileage in Yuebei section of Jingzhu highway, where the quantity of larger bridge which span exceeds 500 meters is four. Under general situation, the bridge surface spreading is smaller than 10cm. So, it is very important that the adopted heating mode or radiating materials don't influence the normal work status of bridge surface, and the spreading of heating system should not influence the using performance of waterproof and use of bridge surface. The construction of bridge surface heating system needs special technical requirement, and at the same time, the bridge is exposed in air, and it has multiple radiating surfaces, and the air circulates quickly, and the heat consumption is much larger than pure highway surface, and the utilization rate of heat efficiency or heat is much lower than the highway surface, so we need develop the control system which can automatically adjust the energy supply tension according to exterior environment temperature and air flow speed. Because the bridge temperature fields induced by heating are different, so the temperature difference between bridge surface and girder bottom will induce additive temperature stress. Therefore, the bridge surface deicing system design will face more limitations.

Though the manual deicing method could eliminate the ice layer on the bridge surface, but it has low efficiency, expensive charge, and too long response waiting time, and it will influence vehicle traffic and safety and induce the damage of bridge surface when working. Chemical deicing would easily damage the environment on both sides of the highway, the vegetation will wither and the drinking water will be polluted. At the same time, chloride deicing agent will largely influence the performance of the structure of the material. The costs that induce structure cauterization and damage environment because of using chloride deicing agents was 4% of GDP, and the repair charge every year is about 200 billion dollars which is 4 times of initial construction charge. 50% of 102 bridges investigated in Copenhagen have serious reinforcing steel bar corruption. The crossroad at Xizhimen of Beijing has been only used for 20 years, but serious concrete flaking and reinforcing steel bar corruption occurred in bridge surface and pier. The simple mechanical deicing method has slow speed and the cutting method and knocking method could easily damage the highway surface, and it will form water leakage and structure damage. And the purchase and maintenance costs of machine are too high, the operation personnel are deficient, and the flexibility is bad, which all limit the large scale using of mechanical deicing method. Because of large energy consumption and expensive operation charge, the electric heating highway surface deicing technology can not be implemented, and it is only be the assistant measure to be considered. Because of the limitation of the length of bridge section, the energy storage highway deicing technology which buries cycle liquid pipe under the bridge surface should be seriously considered to use, and the application of this technology could fully utilize natural regenerated energy resource and save energy, and the surface heat storage rate can achieve 36%, and the efficiency of environmental protection and reasonable resource using is very obvious, and it is very convenient to implement automatization and disposal in time. But its concrete implementation needs implement large scale highway surface pipe spreading, the establishment of environmental supervision control system and energy supply system, and it needs consuming large manpower, material and financial resources, and should implement comprehensive plan as a whole, so this technology is fit for the deicing scheme in the new building highway bridge.

Heating mechanical composite deicing technology utilizes the heating equipment to heat the frozen ice and snow before removing ice and snow, and properly enhance the temperature of ice and snow layer, reduce the tension of the ice and snow layer, reduce the difficulty removing snow, and enhance the speed of mechanically removing ice and snow. The technology could improve the original deicing machine to make its performance accord with the requirement of composite deicing technology and effectively reduce the initial charge, and effectively reduce the damage of highway surface and bridge surface and extend the using life of highway and bridge effectively. Based on the comparison of performance indexes of various technologies and economic feasibilities, in this article, we apply the heating mechanical composite deicing technology in the bridge surface deicing scheme in Yuebei section of Jingzhu Highway.

3. Bridge surface deicing program in Yuebei section of Jingzhu highway

3.1 Heating mechanical composite deicing method

The thickness and tension of the snow and ice layer largely influence the snow-removing and deicing effect. Table 2 is the relationship that the anti-cutting intension coefficient of manual hardening snow changes with temperature and density. Table 3 is the relationship of the rigidity of ice changes with the temperature. Therefore, the anti-cutting tension and compressive stress of the ice and snow layer obviously increase with the decrease of temperature and the increase of density, and the ice and snow layer is denser and the temperature is lower, and it is harder to be removed. Therefore, the simple mechanical deicing method has slow speed and the cutting method and knocking method could easily damage the highway surface, and it will form water leakage and structure damage to the highway surface.

The method in the article will utilize the heating equipment to properly enhance the temperature of the ice layer before deicing and reduce the tension of the snow and ice layer and the resistance of mechanical shovel, and enhance the removing clearance rate and work speed. And the method will control the temperature of the ice layer to make the average temperature lower than 0 oC, so the ice layer could not be melted, which can avoid consuming large heat quantity because of the melting of ice, and reduce energy consumption and cost. There are many heating methods, where the microwave heating and far infrared heating are deserved to be adopted. But the microwave heating method needs specially develop special equipments, and especially the leakage of microwave will harm human and environment. In this article, we put forward the mature direct-fired far infrared heating method to deice the ice, which uses liquid-petrol gas as fuel and has little environmental pollution. Figure 1 is the sketch of heating mechanical composite snow removing and deicing design, and it is composed by a tractor and a half-hang deicing car dragged by the tractor. The ice and snow removing method still adopt the mechanical method, and the head of the tractor is the snow shovel designed according to advanced surface, and the snow shovel will quickly shovel the snow, and the half-hang car loads the heating equipment to remove the ice, the mightiness steel wire roller and cutting shovel. The snow shovel shovels the snow, and when the ice snow layer is thinner, the far infrared equipment is used to heat the ice snow layer and reduce the anti-cutting and compressive stress of the snow and ice layer, and then the steel wire brush and the cutting shove are utilized to clear the thinner ice and snow layer stayed on the bridge surface, and the design forming certain angle between the steel wire brush and the cutting shovel with the advance direction will push the ice and snow to the side of the bridge.

The advanced snow shovel with automatic avoiding equipment and strong profile modeling ability includes four sections, which can press close to the highway surface furthest. From the highway snow removing standard, under the premise avoiding damaging highway surface, the snow shovel could reduce 10~6cm of the ice snow layer, and when the depth of snow ice layer is thinner, the far infrared heating equipment is utilized to enhance the average temperature of ice and snow, reduce the cutting tension of machine, enhance the clearance rate and reduce the damage to removing knife. In the scheme of the article, we want to adopt metal fiber burner to make far infrared radiator, and the burner adopts pre-mixed gas surface burning technology. Comparing with other surface burners, the burning tension of the metal fiber burner is high, the adjustment range is large (same burn could realize red fire or blue fire), and the burning is very equal, and the burning efficiency is high (the radiation efficiency of infrared ray could achieve 50%), and it possesses low pollution release, low pressure dropping, high adverse security, good heat expansion control, anti-heat collision, quick cooling and response control. The experiment indicated in the opening environment, the surface temperature of the metal fiber burner that the fuel surface is upward changes from 750 oC under 100kW/m2 to 1000oC under 500kW/m2, and when the burner is in the closed environment, the surface temperature and radiation efficiency will further be enhanced, and the burner will take heat radiation as main heat release form in this temperature area. Considering the ice and snow removing speed and running cost, we select the heating temperature in 800oC.

3.2 Heat transfer computation and analysis in the ice layer heating process

To select proper heating temperature to fulfill the requirement of deicing speed and cost, we study the heating and temperature ascending process of ice and snow layer, and use the method of numerical simulation to choose optimal work parameters.

According to deicing and snow removing requirement and the space condition of the car, the heater is flat-shaped, the board length is 3m and the board is 300mm apart from the upper surface of the ice and snow layer, and the temperature of the board surface is 1100 oC, and the thickness of the ice and snow layer is 10mm, and the thickness of bitumen layers is 150mm, and the thickness of the cement hardpan is 200mm, and the thickness of secondary-ash soil base layer is 300mm.

The heating process of ice layer is an unstable heating process, and in the simplified computation and analysis, we simplify the heat transfer model as follows. The car speed is slow (<5m/s), the temperature difference between air and ice surface is small than 20k, and because the convection and heat exchange only occupies little part for the radiation heat exchange, so we don’t consider it in the computation and we only consider the influence of radiation heating. The side of the heater is heat preservation material, and its temperature is not high comparing with the surface of the ice and snow layer, so the radiating heat is not considered. Because of small temperature difference, various sides that ice and snow layer is vertical to the highway surface can be regarded as heat-isolated surface, and they have no heat flows. The heat transfer process is simplified as one-dimensional unstable heat transfer. The ice surface boundary condition is that the temperature under 400mm of bridge surface is constant. The material character implementing radiation heat exchange boundary on the heating surface and ice surface can refer relative materials. The initial temperature field with 400mm depth from the ice layer to the bridge surface can be enacted by measurement conditions of relative literatures, and it can be computed by ANSYS software. In this computation, we compute the temperature field according to appointed air temperature and soil temperature, and after checking the real measurement results, we will compute the temperature field covering the ice layer under invariable soil temperature and air temperature based on the computation result, and then we will compute the heating process to the initial temperature field as the heating process. From relative materials, the far infrared area is the main heat radiation absorption of ice, and under the condition that there are no exact experiment materials of the ice layer, and approximately the ice penetration depth in the far infrared area is 10mm, and the radiation adsorption rate is 0.5, and we take the radiation heat as the volume heat load to compute, and the results are seen in Table 4 which include deicing speeds that the temperature of the ice snow layer increases to 0 oC and corresponding fuel consumptions under different time and air temperatures in one day, and in the Table, when the air temperatures are -2 oC and -4 oC, we can only use mechanical machines to deice the ice and snow without the heating equipment.

4. Conclusion

Winter highway bridge deicing and snow removing is the important part of the work for the traffic management department, and it has important function to maintain normal social and economic living order, and the adoption of concrete method is limited by the cost. Aiming at the concrete task of bridge deicing in Yuebei section of Jingzhu Highway, in this article, we analyzed and compared characters, adaptive range and costs of modern mainstream deicing technologies. Finally, the heating mechanical composite deicing technology could better accord with the deicing demand of the highway because of its cheap cost, strong applicability and flexible maneuverability, so it is the optimal alternatives. In the implementation of concrete scheme, we should further study many problems such as machine maintenance, frost alarming and the harmony and organization of deicing. At the same time, because of concise running management, obvious effect, low energy consumption and beneficial environment, the energy storage highway and bridge snow-melting and deicing technology should also be considered in the deicing system of the new building highway and bridge project.

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Table 1. Performance comparison of various deicing technologies

Methods / Comparison item	Manual deicing	Chemical deicing	Mechanical deicing	Physical deicing
Efficiency	low	high	high	high
Energy consumption	high	low	high	higher
Flexibility	strong	common	strong	fixed highway section
Traffic influence	large	very low	larger	null
Cost of equipment	low	--	high purchasing cost	high building cost
Using cost	high	higher	higher	higher
Environmental influence	low	large	damages on establishment and bridge surface	Without pollution and damage to road surface

Table 2. Anti-cutting intension coefficients of manual hardening snow

Type of snow	Snow density/g.cm^{-3}	Anti-cutting intension coefficients		
		Snow temperature -1°C~ -3 °C	Snow temperature -4°C~ -22 °C	Snow temperature Below -22 °C
Weak hardening snow	0.30 ~ 0.40	4.9 ~ 11.8	7.8 ~ 24.1	14.7 ~ 34.3
Dense snow	0.45 ~ 0.52	9.8 ~ 14.3	14.7 ~ 30.2	29.3 ~ 78.1
High-density snow	0.55 ~ 0.65	19.5 ~ 34.5	29.3 ~ 78.5	68.7 ~ 12.8

Table 3. Compressive strength of ice

Temperature/ °C	0	-10	-20
Compressive strength/MPa	1.5	3.0	5.0

Table 4. Deicing speed and fuel consumption under different temperature condtions

Work time	8AM	8AM	8AM	8AM	8AM
Temperature under 400mm of bridge surface /°C	-10	-10	-11	-11	-10
Air temperature/°C	-18	-9	-2	-4	-18
Deicing speed/km.h^{-1}	8	18	-	-	8
Fuel consumption/kg.km^{-1}	7	3.2	-	-	7

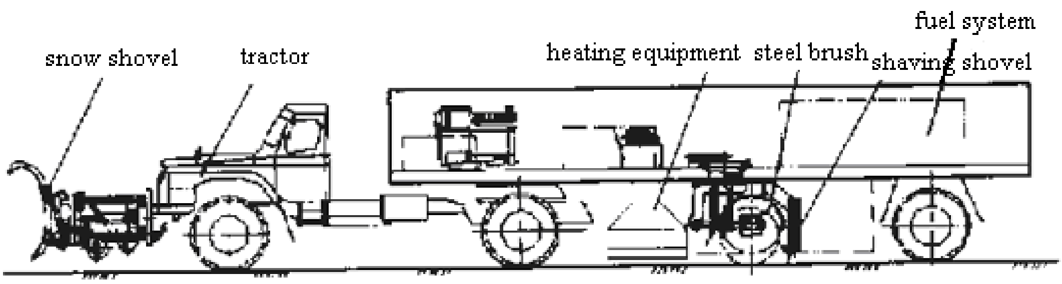

Figure 1. Sketch Heating Mechanical Composite Deicing Car

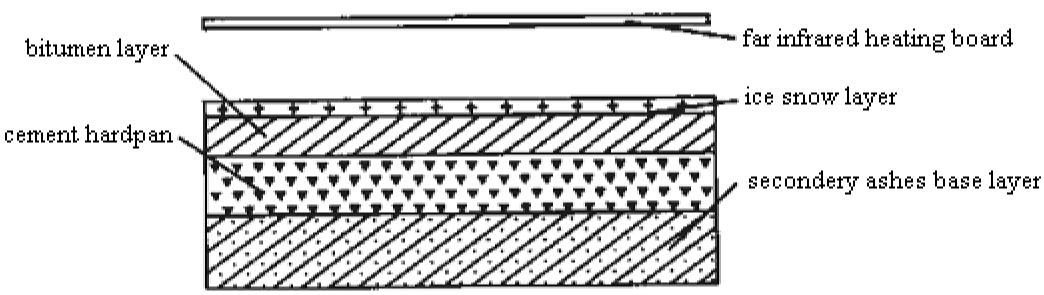

Figure 2. Heating Computation Sketch of Ice Layer