Advanced Engineering Forum *Online: 2012-07-26*
ISSN: 2234-991X, Vol. 5, pp 265-270
doi:10.4028/www.scientific.net/AEF.5.265

Site Monitoring on Temperature Field Distribution of Asphalt Pavement in Seasonal Frozen Soil Region

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Key words:Asphalt Pavement, Temperature Field, In-Site Monitoring, Seasonally Frozen Soil Region

ABSTRACT: As pavement bear the comprehensive effect of environment factors at the same time, its internal temperature field distribute complicatedly and difficult to be predicted. Due to the internal temperature field of pavement is the key of pavement performance and service durability, this paper improved the layout scheme of the temperature field, based on the previous test scheme of factual temperature field. Using the factual temperature field data of asphalt pavement, this paper studied on the temperature distribution characteristic of each layer, summed the temperature filed distribution rule of asphalt pavement and put forward the control points of pavement design low temperature.This paper verified the universality of low design temperature in SHRP (Strategic Highway Research Program) and pointed out some problems like the low temperature design temperature (T_{min}) had quite large safe factor.

Introduction

Analysis and research on the internal temperature field distribution of asphalt pavement can be helpful to structure design and material selection reasonably. Asphalt mixture with viscoelastic properties exhibits different mechanical properties and damage form on different environmental conditions.

Many domestic and foreign scholars have engaged in temperature field study of pavement and obtained lots of achievement.Barber[1] determined temperature field theory of pavement at first and used heat conduction equation to calculate the highest temperature of pavement.Straub[2] established temperature prediction model of pavement based on the factual temperature field in New York State. Christison and Anderson[3] proposed one-dimensional unsteady calculation method to analysis the low temperature field of pavement. On 1980s, Yan Zuo-ren[4] established temperature field prediction method of layered pavement with cyclic heat. On 1990s, Wu Gan-chang[5-6] proposed two-dimensional nonlinear unsteady temperature field calculation theory of semi-rigid asphalt pavement based on the analytical method.SHRP[7-8](Strategic Highway Research Program), LTPP[9] (Long Term Pavement Project) and C-SHRP[10] (Canada- Strategic Highway Research Program) put forward extreme temperature prediction model of pavement. Hermansson[11] proposed high temperature field prediction model of asphalt pavement.

Research work about temperature field of pavement mainly focused on theory, numerical simulation, field measurement, prediction model and so on. However, theoretical research is difficult and hard to guarantee calculation accuracy, the boundary conditions of numerical simulation is difficult to control and has difference with actual condition, and the applicability of prediction model is bad. In contrast, field measurement can get more reliable temperature dates of each layer which is helpful to get the distribution and variation of asphalt pavement temperature field.

Based on this, this paper put forward a comprehensive field measurement method based on the temperature field measurement method study. Then after analysis on temperature field measurement date of asphalt pavement, the distribution law of asphalt pavement temperature field, which is verified by design temperature of asphalt pavement in SHRP, is obtained.

1. Temperature Field Measurement Design

According to the seasonal freezing climate in Heilongjiang, based on the highway engineering from Qiqihar to Tailai, the temperature field of pavement at different depths was observed in recent years thought paving typical asphalt test road and laid the temperature field monitoring equipment.

1.1 Experimental Conditions

Based on the weather station location, text conditions and natural environment and after investigate on natural conditions along Qi-Tai highway, a test area was selected on the east of pavement (150 meters away from pavement) at K129+900. This location which closes to the pavement with excellent ventilation and without shelter facilities can guarantee the environment and pavement at same level.

1.2 Emplacement Information Collection System Settings

The typical asphalt pavement was paved in test area. The plane sizes of test area were in Table 1and top view shown in Figure 1. The structure of pavement is as same as highway at K129+900, shown in Table 2.

Measuring points where buried temperature sensors were selected at road surface (0cm), middle of surface layer (6cm), top of base (12cm), top of cushion (27cm) and top of roadbed (42cm). The transverse position of sensors were around the central axis in turn 10cm which shown in Figure 3.

Figure 1 Resistance Temperature Detectors

In addition, in order to get accurate air temperature, some sensors which test air temperature were set. The practical method is set three stents which are 1.5 meter high[12], and a temperature sensor is fixed on the top of each stent. The mean value is treated as air temperature.

Table 1 Structural Combination of Asphalt Pavement

Structure Layer	Thickness	Material	Size
Upper Layer	4cm	AC-16	3.5m×3.5m
Lower Layer	8cm	AC-20	
Base	15cm	Cement Stabilized Macadam	3.8m×3.8m
Cushion	15cm	Natural Gravel	4.1m×4.1m
Roadbed	Compaction Degree＞95%	Silty Sand	4.7m×4.7m

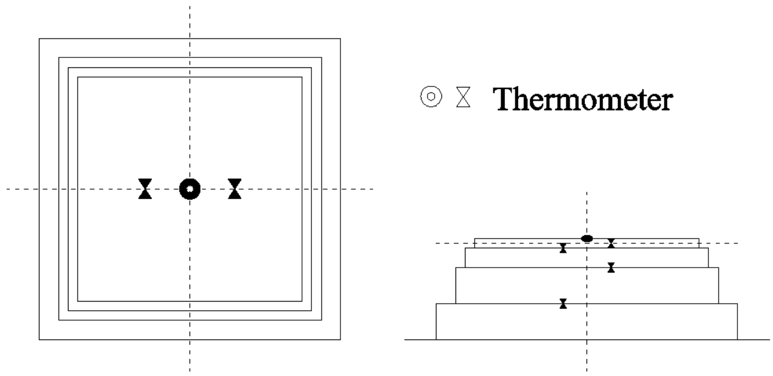

Figure 2 Layout of Sensor and Pavement Structure

After temperature sensors were laid completely, the signal lines, which connect to temperature collection and processing equipment, were put into collection room. 12 sensors all worked well through debug by wire transmission, then real-time monitor started by wireless transmission. The collection frequency was 1 time every 10 minutes. Remote control was realized by Transmission technology of mobile communication and internet. The date remote collection and wireless transmission was realized under the normal power supply.

2. Asphalt Pavement Temperature Field Distribution

This paper selected June 2010 to May 2011 as a cycle year. According to the meteorological date in this year, The extreme minimum temperature (-34.8℃) of Qiqihar appeared in January 14, 2011. And the extreme maximum temperature (37.7℃) appeared in June 24, 2010[13].

Therefore, by analyzing the temperature field data in the January 13~15th, 2010 and June 23~25th, 2011， the variation of each structural layer temperature of asphalt pavement with time and depth were obtained.

2.1. Each Layer Distribution Law

The temperature field data of the January 13~15th,2010 and June 23~25th,2011 which recorded the relationship of temperature of structural layer and air temperature was showed in picture 3~4. The analyses were as follows.

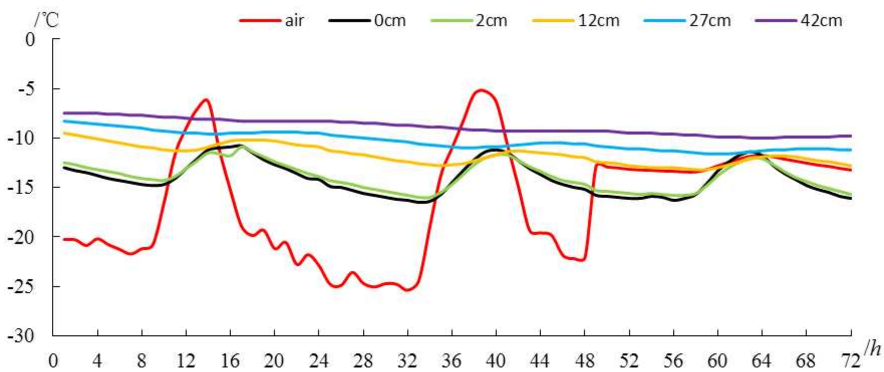

Figure 3 2011.01.13~15 The relationship between each layer structural temperature and air temperature

① The period of temperature range of middle course and upper layer middle layer are consistent, which illustrated that air temperature is the major influencing factor of road surface temperature.

② The gradient distribution of each layer temperature was differs according to different seasons. In the summer, with the increase of depth, the temperature of structural layer decreased, thus, the temperature of surface layer was the highest; in the winter, with the increase of depth, the temperature of structural layer increased, thus the temperature of surface layer was the lowest but higher than air temperature. Namely, the temperature variation of the surface layer was the most sensitive, and the cracking which as the result of temperature shrinkage was from the top to the down might be the Top- Down cracking.

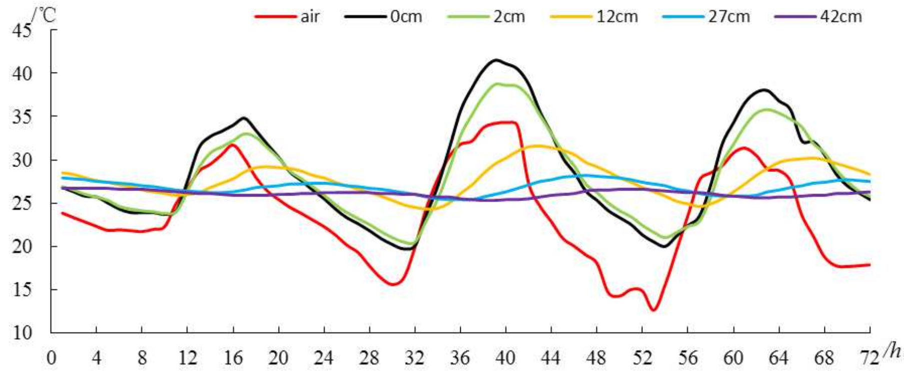

Figure 4 2011.06.23~25 The relationship between each layer structural temperature and air temperature

③ The day temperature range of the structure differed with different seasons and depth. With the increase of depth, the day temperature range decreased; meanwhile, the summer-time day temperature range was larger than that of winter-time. For the reason that the temperature of the base would be steadier when the day temperature range of surface layer was the highest, it was realized that when the pavement structure was higher than certain depth, the structural temperature of the base would be steady, this depth was called critical thickness.

2.2. Distribution Law Along Depth

The temperature data of 2am, 8am, 2pm, 8pm were selected to analysis the distribution characterization of the temperature field of different direction, which was showed in the figure 5~6.

The asphalt pavement temperature field distribution rule of different depths differed with different seasons[14]. In winter, the temperature of the base courses was the highest and that of the surface layer was the lowest; with the increase of air temperature, the temperature range of structure decreased gradually. In the summer, the temperature distribution of structure was rather complex, the highest temperature might occurred in the surface layer or the middle layer, and the day structural highest temperature was the surface layer temperature when the air temperature was the highest; the lowest temperature might occurred in the surface layer or the base courses; the day structural lowest temperature was the surface layer temperature when the air temperature was the lowest.

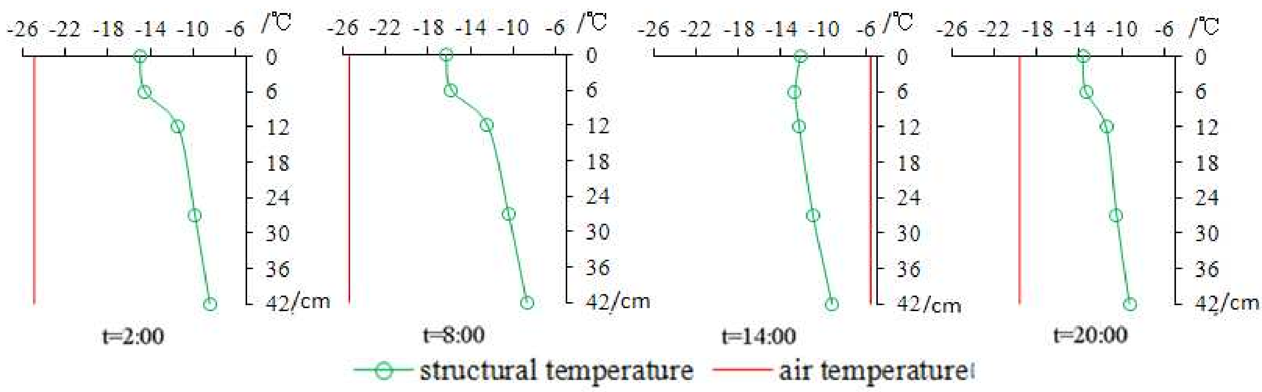

Figure 5 2011.01.14 Day representative moment temperature field distribution situations with different depths

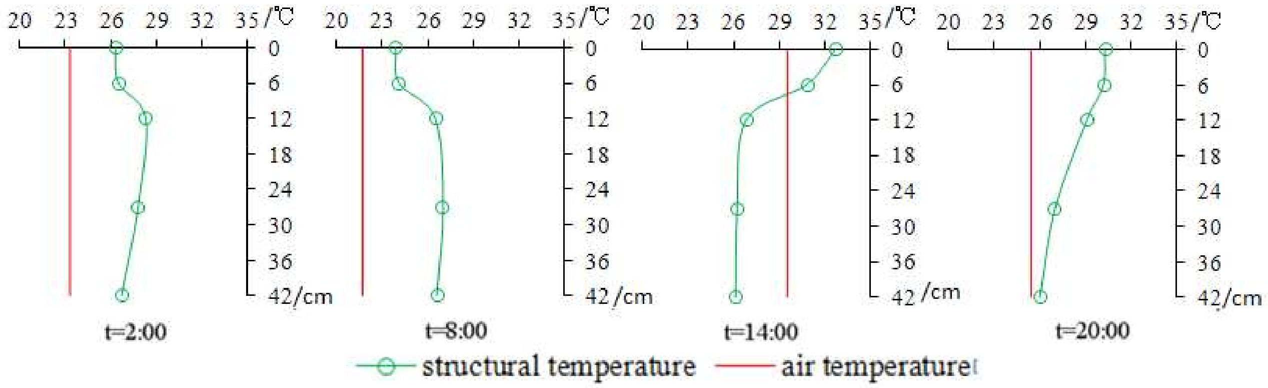

Figure 6 2010.06.24 Day representative moment temperature field distribution situations with different depths

This paper aimed at being as guidance for road design according to local extreme temperature. Namely, the guidance for the reasonable selection of materials and design of structure by handling the most unfavorable working state.

2.3 Discussion of SHRP Design Temperature

At present, the selection of asphalt materials in pavement design in the domestic is usually according to the PG grading method commended by AASHTO. The PG grading is determined according to the extreme temperature of local climate, so the relationship between the extreme temperature of the climate and pavement affects directly on the rationality and economy of the material selection.

The distribution of asphalt pavement temperature field shows: in the asphalt pavement structure, the minimum structure temperature is the temperature of pavement surface when the air temperature reaches the extreme minimum, which is higher than the extreme minimum air temperature.

$$T'_{min} > T_{air,min} \tag{1}$$

where

T'_{min} —pavement structure minimum temperature;

$T_{air,min}$—air extreme minimum temperature.

SHRP provides: the annual extreme minimum air temperature is adopted as the design minimum temperature. As see in the equation (2), the design minimum temperature value in SHRP is too conservative. The asphalt materials selection according to this method will increase the project cost because of the high low-temperature performance.

The temperature minimum design value of pavement surface according to SHRP does not apply to Heilongjiang region, so materials selection should not fully according to the SHRP standard.

3. Conclusion

① The temperature gradient of each structure layer has seasonal different property. In summer, the temperature of structure layer decreases with the depth increases, which is the opposite in winter.

② The day amplitude of structure temperature changes with the change of season and depth. The greater the depth, the smaller the day amplitude; and the day amplitude in summer is greater than in winter.

③ The distribution of the temperature field along the depth has seasonal difference. When the pavement structure reaches a certain thickness, the structure temperature at the pavement bottom tends to stabilizing, and the thickness is called critical thickness.

④ The minimum temperature adopted in SHRP Design standard is pointed out so conservative. The materials selection in practice is not appropriate to refer to this standard.

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