TEMPERATURE FLUCTUATIONS IN ASPHALT CONCRETE AND FORCED AIR COOLING FOR ARTERIAL MAINTENANCE IN DANANG CITY

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Abstract - Temperature has a negative effect on operational quality of highway construction, especially in the Central area of Vietnam where roads are usually exposed to huge amount of solar heat mostly around the year. This paper aims at discussing our research on the temperature environmental condition of some arterials in Danang city and presents the laboratory experiments to develop a practical theory and propose a maintenance method to send temperature plummeting on asphalt concrete layer. The research found that the average temperature rise on some arterials in Danang city is severe and the disparity of temperature between environment and road surface remains high. The lab results showed that forced cooling by ice air in a short span of time can maintain the temperature of asphalt concrete at safety range for a long duration of time.

Key words - thermal fluctuation; Danang arterial; forced cooling; asphalt concrete; thermal environmental condition.

1. Introduction

Temperature is one of the main factors causing thermal stress or damaging effects to the structure of highway construction. As road's structure become unstable, especially on asphalt concrete layer, the surface might become deformed due to live load in high thermal condition. Temperature fluctuations critically affect the asphalt pavement stability and the selection of asphalt grading. In a tropical country as Vietnam, the road network is exposed directly to a huge amount of solar heat every year and faces, as a result, many thermal related problems. Many failures on road structure have been reported: asphalt concrete surface melting, deformation on surface, thermal crack or even rutting. The surface of Thuan Phuoc Bridge in Danang is a typical example. For the last decade, many studies have been carried out to develop a theoretical foundation for measuring and predicting temperature on asphalt concrete surface and some have succeeded in establishing the relationship between material strengths and thermal behavior. However few studies could generate a profile of actual temperature at every depth inside asphalt pavements [3] or could develop an effective temperature decreasing method for road networks, especially in the hot area like the Central of Vietnam. Therefore it is clear that, in case of the Central of Vietnam, the temperature profile of road network should be concretely built and an effective maintenance method be proposed to reduce the thermal impact and solve those thermal related problems. Moreover, the maintenance work for construction in Vietnam is not effective as it is expected: there have been always more building than inspection and prediction and construction often failed and corrupted earlier than its designed age. For the future sustainable development of society and infrastructure, it is essential to carry out maintenance and inspection work along with operation of civil construction. Those are also the main purposes of this study. In this study, a practical temperature fluctuation profile of some arterials in Danang city was recorded and laboratory tests were carried out to evaluate the actual thermal behavior, serving as a basis for proposing an effective maintenance method. In this study, a cooling method was also tested on asphalt concrete specimen and the result showed that it is optimistic to apply this decreasing temperature on asphalt concrete pavement as an effective maintenance method.

2. Solution and experiment

2.1. Specimen

There are two objects to be inspected in this study: the specimens of asphalt concrete currently used in the area of Danang city, and samples of arterials in Danang city. The specimens used in this study were made with the same proportion of asphalt mixture as the one used in the actual asphalt concrete in the Central roads. The mixture formulation of specimens as shown in Table 1 below is the same as the one used in Khue Dong Bridge's project. The bitumen content was 5.65% and the formulation has set for 4 (kg) of mixture. Specimens were made in 3"x4" Marshall mold for 15 cylinder blocks, each specimen was marked and drilled to 2 points of ø2 (mm) wide for further thermal measurement (Figure 1). For recording the actual temperature profile, 9 sample locations of arterials in Danang were investigated: Cam Le bridge, Thuan Phuoc bridge, Tuyen Son bridge, Nguyen Tri Phuong bridge, Nguyen Tat Thanh street, Ngo Quyen Street, Ngu Hanh Son street, Hai Van tunnel and Nguyen Sinh Sac street. These sample locations represent high frequency of road use, heavy traffic loading condition and longest exposure in daylight time to the ultimate solar heat.

For measuring temperature, thermal sensors were applied and installed into the objects – both the specimens and the sample locations. The thermal sensors were made of T-type thermal couple wires with anti- moisture paste (Figure 2), and the effective range is -250 – 400 ºC.

Table1. *Asphalt concrete mixture design*

Aggregate	Proportion %	HMA Mixture	Actual
Aggregate Dmax19	27.40	1.10	1.04
Aggregate Dmax15	26.80	1.07	1.01
Fine Aggregate	27.50	1.10	1.04
Sand	12.20	0.49	0.46
Mineral Aggregate	6.10	0.24	0.23
Mixture mass (kg)		4.0	3,79
Bitumen content (%)		5.64	0.02
Bitumen 60-70 (kg)		0.23	0.21

2.2. Experiment procedure

2.2.1. Temperature measurement in environment condition

In this study, experimental temperature measurement was carried out to build up the temperature profile and thermal distribution of some arterials in Danang city. The thermal fluctuation of specimens was inspected and recorded to collect data on the thermal loading condition of arterials as well as thermal behavior of asphalt concrete layer. Experimental measurement was carried out in the environment condition of daylight time from April to September in Danang. During the measurement procedure, every specimen was installed with 3 thermal sensors, which were attached into or inside – at the centre of specimen. Each sensor is 2 cm deep apart to each other and was fixed by finite aggregate – low content bitumen mixture (Figure 1). At every inspection area in arterial road, 3 separated points have been measured and at each point, 3 sensors were installed from bottom to the surface of asphalt layer and seperated from each other a distance of 2 cm (Figure 3). The thermal sensors that used in this study were made in laboratory from T-type thermal couple and adjusted to match the current temperature. Each sensor has its dimension very tiny (around 1-2 (mm) of width) so that the sensor would not affect the whole structure of road or specimen. Sensors were then connected to a Datalogger TDS 303 for thermal record (Figure 4). Temperature was recorded every 5 second and saved into computer.

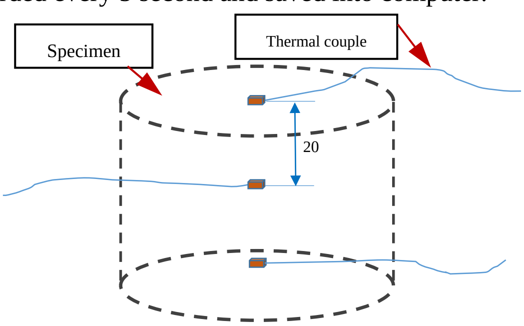

Figure 1. *Specimen outline*

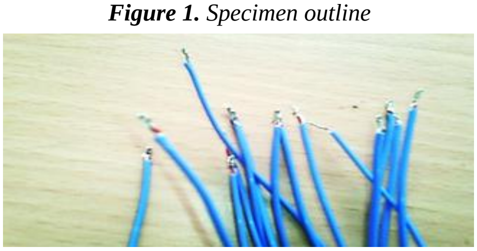

Figure 2. *Thermal sensors*

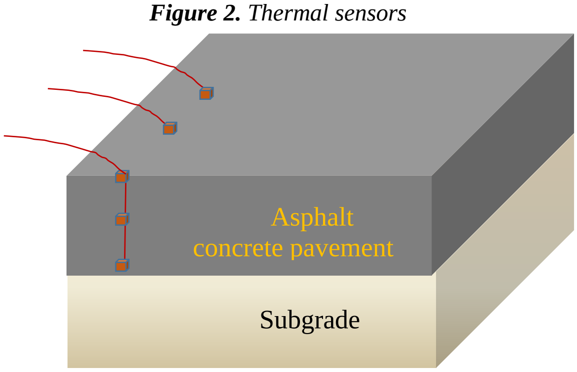

Figure 3. *Sensor installation*

Figure 4. *Temperature recording*

2.2.2. Forced heating experiment:

The objective of this experiment is to capture the temperature fluctuation of asphalt concrete under the unstable condition. Experiments were carried out on specimens with 2 phases, forced cooling phase and forced heating phase. In the forced heating phase, specimens were heated in heater box in 2 different processes: the gradual heating process raising temperature inside the heater box from 33ºC to 60ºC and the constant heating process maintaining the temperature inside the box at around 55ºC. In the gradual heating process, specimens were supported by a steel plate in imitation of the condition of asphalt concrete layer of ThuanPhuoc bridge, where asphalt concrete layer is supported by an orthotropic steel deck. In the constant heating progress, specimens were supported by a thick plastic plate. After the heating process, specimen was then cooled under an ice bucket. Additionally, to prevent air and water from reaching the specimens so that thermal sensor will not fail to read the right value of temperature, the specimen was neatly covered by a thin nylon coat which reduces a considerable amount of vapor collected around the specimen and therefore guarantees little water can remain on specimen after ice cooling process. During these phases, thermal sensors were attached into the specimen and inside the heater box to form the temperature profile.

3. Study result and comment

3.1. Temperature profile in environment condition

3.1.1. Specimen's temperature profile

Figure 5 and 6 show the temperature of specimen under the environment condition from 11:00 AM to 17:00 PM with 63.6 (mm) and 70.5 (mm) thick specimen. The weather was clear with low wind speed. The peak of profile was 59.5 ºC at environmental temperature of 43.1ºC. The environmental temperature kept rising from the beginning of the experiment to around 13:30 and then slowly decreased. From 13:30 to 14:10 cloudy condition was observed which might have caused the sudden decrease in temperature profile. It can be seen from the diagram that during the rising phase of temperature, the temperature of lower layer inside the specimen always smaller than the upper's layer and vice versa. The reason for that temperature variations might come from the difference of heat absorption of asphalt concrete by depth. Besides, the figure also shows that the deeper the sensor installed, the more stable temperature profile can be captured. During the appearance of shade (13:30-14:10), the temperature of depths were mostly the same and drop dramatically, hence it would be a hypothetical solution to develop a maintenance method by maintaining low temperature for surface in a short span of time.

3.1.2. Temperature of actual pattern

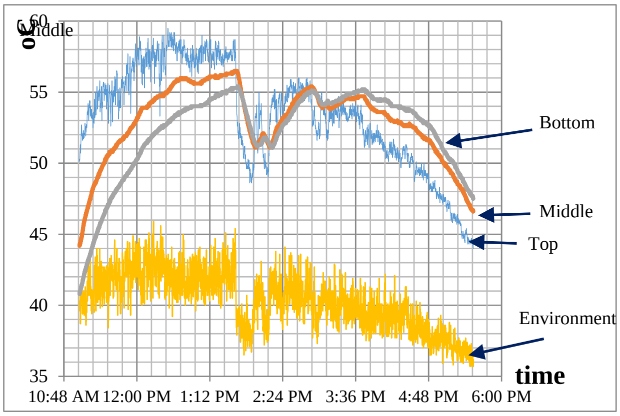

Figure 5. *Environment condition – 63.6 mm specimen*

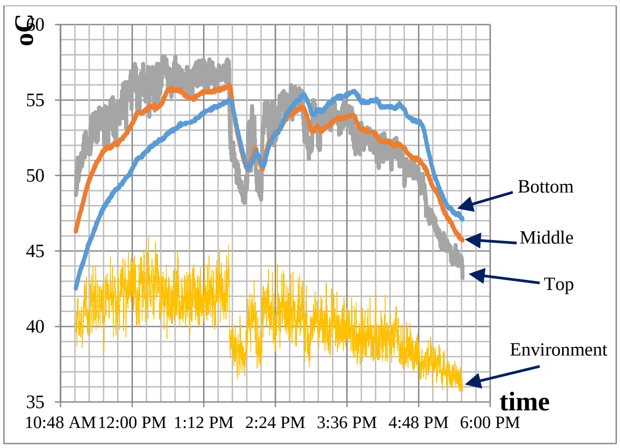

Figure 6. *Environment condition – 70.5 mm specimen*

Table 2 shows the highest temperature of some arterials in Danang city during summer time from April to September. Temperature data was mainly recorded around the end of April. It can be seen that the temperatures on asphalt concrete surface in most locations are high, especially in Thuan Phuoc Bridge, it was over 65°C. The result also shows that most of the arterials in Danang city have been exposed to high temperature from solar heat and it is urgent to propose a suitable maintenance method to decrease temperature of asphalt concrete surface for sustainable operation of construction.

Table 2. *Temperature peak of some arterials*

Location	Environment (°C)	Surface (°C)
CamLebrd	39.6	57.2
ThuanPhuocbrd	46.7	65.3
TuyenSonbrd	41.4	59.3
NguyenTriPhuongbrd	45.2	59.6
NguyenTatThanhStr	37.9	55.2
NgoQuyenStr	38.2	59.5
NguHanhSonstr	39.2	57.3
HanVan roadside	40.3	57.8
NguyenSinhSacStr	38.2	58.9

Figures 7 and 8 present the temperature fluctuation of asphalt concrete surface by depth of Nguyen Huu Tho street and Nguyen Tat Thanh street respectively. The figures show that the difference of temperature between environment and asphalt surface always stays high, in case of Nguyen Tat Thanh street, it was 14°C. Besides, in case of Nguyen Huu Tho street, the actual data shows that, from 11:40AM, when the weather got cloudy and environmental drops from 45°C to 34°C for only 40 minutes, the temperature of surface dropped by 5°C down to 45°C. Therefore practical evidence suggests that it would be possible to get asphalt concrete surface's temperature stable at low level if it takes only a short time to reduce the surrounding temperature. It is also observed that the duration of time from the environmental temperature beginning to drop to the surface temperature beginning to decrease was approximately 20 minutes. Thus it is important to take this empirical time into account when developing a cooling maintenance method.

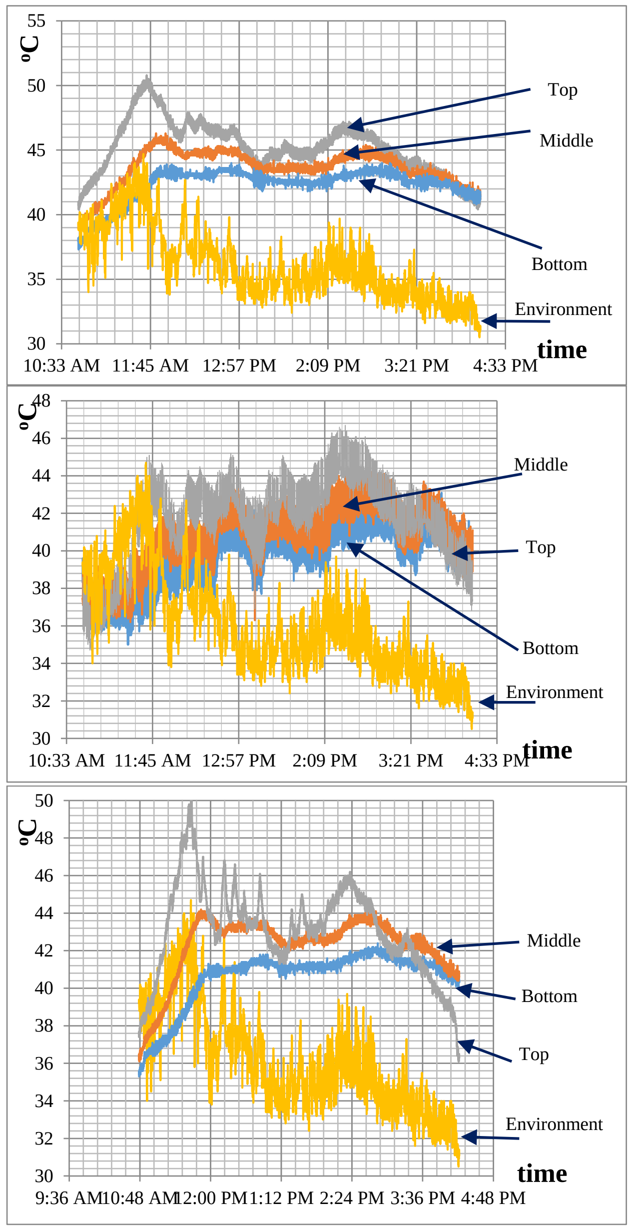

Figure 7. *Temperature profile of Nguyen HuuThostr*

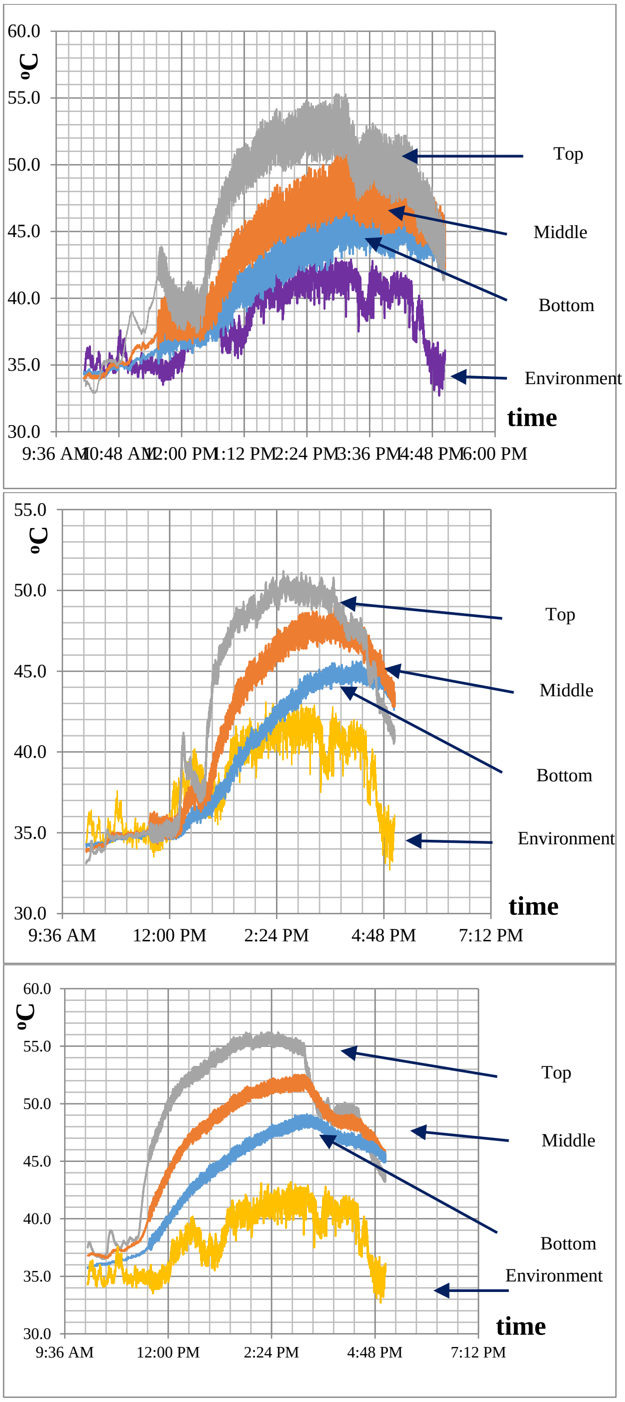

Figure 8. Temperature profile of Nguyen Tat Thanh street

3.2. Forced heating – cooling experiment

Figures 9 and 10 respectively shows the temperature fluctuation of specimen by depths in forced cooling phase under ice air condition and in forced heating phase under the constant surrounding temperature condition of 55ºC of the heater box. In this heating phase, specimens were laid on a thick plastic layer to prevent the heat from bottom of heater box. It can be seen from Figure 9 that, the temperature of the surface of specimen was dramatically dropping along with the decrease of temperature of space around the specimen while the temperature of other 2 depth levels were gradually decreasing and almost the same with each other. In the first 20 minutes, the temperature of 2 (cm) depth from surface plummeted by approximately 20ºC while according to Figure 10 the time for increasing 20ºC was around 1 hour. For that reason, it can be inferred that the cooling effect applied to asphalt concrete is more effective than the heating effect or the time taken to increase low temperature to high temperature is approximately twice longer than the time to decrease that high temperature down to the low level. Therefore, the usage of ice air for cooling surface temperature could be positive for high temperature surface to maintain the safety temperature range. While this method requires only need a short duration of time to carry out, it might save a lot of maintenance time and hence is more cost-effective.

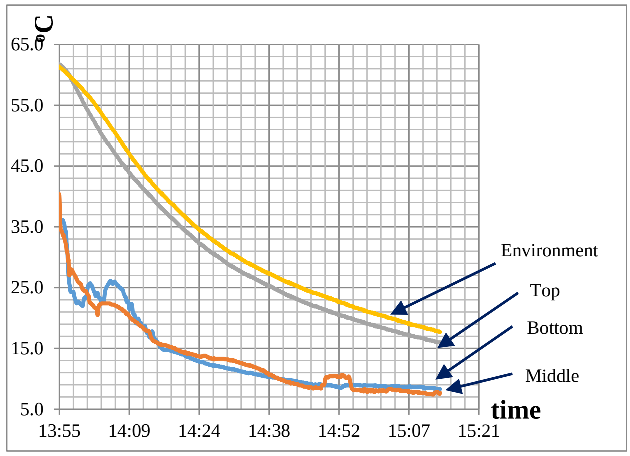

Figure 9. Forced cooling phase

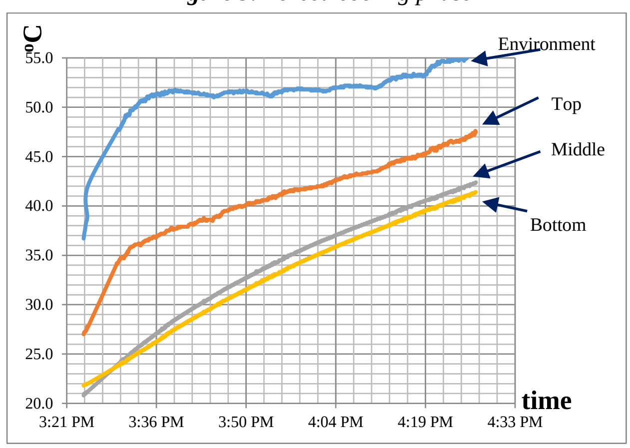

Figure 10. Forced heating phase-constant temperature

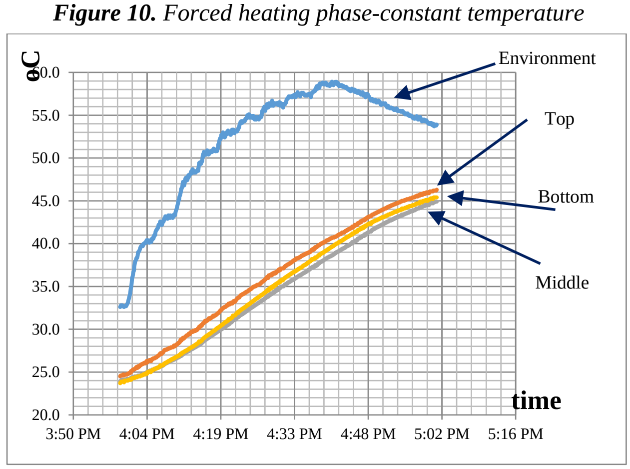

Figure 11. Forced heating phase-steel plate as supporter

Figure 11 shows the temperature fluctuation of specimen by depths during the forced heating phase, when the controlled temperature of heater box was gradually raised from 33ºC to 59ºC, the specimens was laid over the steel plate in imitation the condition of asphalt concrete surface in the main span of Thuan Phuoc bridge where the orthotropic steel deck is used to support the asphalt concrete layer). According to Figure 11, the temperature profiles of every depth inside the specimen were almost equally increasing and the fluctuations of temperature of them were observed to be almost linear. The reason for this might come from the thermal conductive characteristic of steel plate, because heat flow tends to rise vertically while steel plate was set at the bottom of specimen. As the result, asphalt concrete specimens were also being heated from bottom, that's why temperatures were mostly the same at every depth. This kind of thermal fluctuation is known to be very dangerous to the asphalt concrete layer because the temperature increases as linear shape and temperature also equally distributes inside the surface layer so that surface layer would rapidly lost its strength or even structure[2].

4. Conclusion

This study presents temperature environmental condition of some arterials in Danang city with actual temperature profiles. It also introduces some laboratory tests designed to develop a practical theory and propose a hypothetical maintenance method to send temperature plummeting on asphalt concrete layer. Besides, an evaluation of ice air cooling method was set and discussed and a special model of forced heating phase that imitate a specific severe condition was also built to be assessed. Those below are our conclusions:

1. Many arterials in Danang city have been exposed to high temperature condition from solar heat and it is urgent to suppose a suitable maintenance method to decrease temperature of asphalt concrete surface for sustainable operation of construction.
2. The disparity of temperature between environment and asphalt surface always stays high, a disparity of about 14ºC was recorded.
3. It would be possible to get asphalt concrete surface's temperature stable in low level if it takes only a short time to reduce the surrounding temperature.
4. Time to increase from low temperature to high temperature is approximately twice longer than the time to decrease temperature in the same range
5. By using ice air cooling method, it only takes a short duration of time to carry out and therefore might save a lot of maintenance working time.
6. The temperature fluctuation in the structure that steel deck supporting the asphalt concrete layer was rising mostly in linear shape which supposed to be a potential danger to the function of surface layer.

REFERENCES

[1] Vu Duy Truong, Estimation of thermal distribution inside asphalt concrete surface in chaging condition, *Vietnamese Science and technology journal* – 5/2001. (in Vietnamese)

[2] Qingguo Yang, JinchengNing - The environmental influence of asphalt pavement and countermeasures - 1876–6102 © 2011 Published by Elsevier Ltd. doi: 10.1016 /j. egypro. 2011.03.418.

[3] Aseda T., Vu,T.C& Wake, A.(1996). Heat storage of pavements and its effect on the lower temperature. *Atmospheric environment*, 30(3),page 413-27

(The Board of Editors received the paper on 26/10/2014, its review was completed on 16/11/2014)