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Unsteady Conduction Analysis of Thermal Performance of Bridge Roadway

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ABSTRACT

The results of a study on the unsteady conduction analysis of thermal performance of roadways of concrete bridges are reported in the paper. A mathematical model based on the principle of thermal conduction constructed by authors is adopted. In the model the effects of solar radiation, air temperature, etc on the temperatures in the surface, undersurface and interior of bridge roadways are taken into consideration. The authors developed an analysis program in Fortran code and the computation is performed using it. The actually observed meteorological data of successive 56 hours including the hottest a whole day really experienced by the bridges are used in the analysis. The relations between the temperatures in the surface, undersurface, interior of the studied bridge roadways and air temperature, solar radiation and so on are given. The effects of various factors on the variations of the temperatures in surface, undersurface and interior of bridge roadways are discussed. The basic thermal performance of slab bridge roadway is illuminated.

Keywords: thermal performance, concrete bridge, temperature, slab bridge, roadway

INTRODUCTION

Infrastructure deteriorating is an issue that many developed countries face today rather than backward or developing countries. Various factors may result in deterioration of infrastructure, such as a bridge, the environment of the place where the bridge locates and meteorological conditions under which the bridge is in service are non-negligible factors.

The bigger the temperature difference in surface and interior of a concrete structure between winter and summer, the more easily to cause crack in concrete structure[1, 2]. It is same to a concrete bridge. Bridge roadway surface becomes relatively easier to deform when its temperature reaches a quite high value and its load bearing capacity will degrade. Comparing with a highway or an expressway, the deterioration of a bridge roadway is more dangerous for users because it might cause through cracks or part fall then results in a traffic accident.

In the summer this year (2015), the high air temperature caused more than one thousand people dead in India. The heat wave also resulted in the pavement of a section of a road near a hospital in New Delhi being melted then the zebra crossing deformed as shown in Fig.1[3]. If the phenomenon takes place in a bridge roadway or an expressway, it may threaten traffic safety.

Fig1. *A section melted pitch surface of a road near a hospital in New Delhi and its deformed zebra lines[3].*

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In addition, after absorbing and accumulating thermal energy from solar radiation on a quite hot summer day, bridge roadway itself may radiate heat into its surrounding, affecting the people driving car on it, which will cause mental stress to the drivers.

Therefore, in order to extend the service life of a concrete bridge, to improve the quality of maintenance and to keep traffic safety it is significant to investigate the variations of the temperature in bridge roadway surface, undersurface and interior. It is necessary to illuminate how heat conduction proceeds from the surface to interior then to undersurface in bridge roadway. The results might offer a meaningful reference for bridge roadway maintenance such as repair to improve bridge thermal performance. Besides, a more reasonable design done based on understanding the thermal performance might take a lot of the drudgery out of its maintenance. This is right a kind of concept called preventive maintenance.

In this research, according to climate feature of bridge location, two concrete bridges currently in service are chosen as studied objects. One called Syunnkou Bridge is located in Hokkaidō Asahikawa area where the lowest air temperature, -41℃, has ever been recorded in meteorological history. The another called Mumei Bridge is located in region of Egawazaki Simanntosi, Kouti prefecture where the highest air temperature, 41°, has ever been recorded. The Syunnkou Bridge was opened in 1992 and Mumei Bridge was opened in 2001.

In the analysis, the weather data covering successive 56 hours including the hottest day during the past years since the bridge opened for the two areas is used. Finally, the results are given and discussion is done.

MATHEMATICAL MODEL

Based on the principle of heat transfer, a mathematical model and its boundary conditions are constructed.

The governing equation is[4]

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) \tag{1}$$

where T *[K]* is temperature in bridge roadway, x *[m]* is coordinate in the direction of road depth, t *[s]* is time, $\rho[kg/m^3]$ is density, $C_p[J/kgK]$ is specific heat, $k[W/mK]$ is thermal conductivity.

Boundary conditions are expressed as[5,6]

$$k\frac{\partial T}{\partial x} = Q_{sun} - Q_{convt} - Q_{emit} \tag{2}$$

$$Q_{sun} = \varepsilon q_{sun} \tag{3}$$

$$Q_{convt} = h(T_s - T_{air}) \tag{4}$$

$$Q_{emit} = \varepsilon\sigma\left({T_s}^4 - {T_{sky}}^4\right) \tag{5}$$

where, ε is effective emissivity, $q_{sun}[w/m^2]$ is solar radiation rate, $T_s[K]$ is the temperature in bridge roadway surface, $T_{air}[K]$ is air temperature, $T_{sky}[K]$ is sky temperature and its relation with T_{air} is given by Eq.(6) [7]. The parameter σ is Stefan-Boltzmann constant given by Eq.(7) with its unit.

$$T_{sky} = 0.0552{T_{air}}^{\frac{3}{2}} \tag{6}$$

$$\sigma = 5.669 \times 10^{-8}[W/m^2 \cdot K^4] \tag{7}$$

The parameter $h[W/m^2K]$ in Eq.(4) is heat transfer coefficient and is expressed by Eqs.(8)-(10) [8].

$$h^3 = {h_{nat}}^3 + {h_{for}}^3 \tag{8}$$

$$h_{nat} = \begin{cases} \frac{k_{air}}{L} 0.54 Ra^{0.25} & \text{for } 2\times10^4 < Ra \le 8\times10^6 \text{ and hot surface facing upward or cold surface facing downward} \\ \frac{k_{air}}{L} 0.15 Ra^{1/3} & \text{for } 8\times10^6 < Ra < 10^{11} \text{ and hot surface facing upward or cold surface facing downward} \\ \frac{k_{air}}{L} 0.27 Ra^{0.25} & \text{for } 10^5 < Ra < 10^{10} \text{ and hot surface facing downward or cold surface facing upward} \end{cases} \quad (9)$$

$$h_{for} = \begin{cases} 0.664 \frac{k_{air}}{L} Re^{0.5} Pr^{1/3} & for \quad Re \le 5\times10^5 \\ \frac{k_{air}}{L} (0.0365 Re^{0.8} - 853) Pr^{1/3} & for \quad Re > 5\times10^5 \end{cases} \quad (10)$$

where $k_{air}\,[w/mK]$ is thermal conductivity of air, $Ra[w/m^2]$ is Rayleigh number, $L[m]$ is width of bridge roadway, Pr is Prandtl number, Re is Reynolds number and its relation with wind velocity $u[m/s]$ is given in Eq.(11)

$$Re = \frac{uL}{v_{air}} \quad (11)$$

where $v_{air}\,[m^2/s]$ is kinematic viscosity.

In the analysis, the explicit finite difference method is applied. The computer program for the analysis is generated by authors in Fortran code. Time difference is 1 sec. and a computation cycle covers 56 hours. The mesh size in bridge roadway depth direction is 0.005m.

STRUCTURE AND MATERIAL PHYSICAL PROPERTIES OF BRIDGE ROADWAY

Structure of Bridge Roadway

The structures of the analyzed segments of two bridges and materials of their each layer are given in Tab.1 and Tab.2[9,10]

The roadway of Syunnkou Bridge consists of four layers[9], wearing surface, base pavement, waterproof layer and prestressed hollow concrete plate. There are 8 hollow tubular through holes that have a radius of 0.35m in each portion part of the plate. The wall of the hollow tubular hole is stiffened by thin steel pipe to raise tensile strength of the deck plate. The total thickness of Syunnkou Bridge roadway is 1.085m. The roadway of Mumei Bridge consists of four layers[10], wearing surface, base pavement, waterproof layer and a reinforced concrete slab. The total thickness of Mumei Bridge roadway is 1.125m. The thickness of each layer is listed in h column in Tab.1 and Tab.2.

Physical Properties of Materials of Bridge Roadways

In Tab.1 and Tab.2, the parameters of thermal physical properties[11,12,13,14,15] of materials of bridge roadways are given. In these tables, ρ stands for density, *Cp* is specific heat, *k* stands for thermal conductivity and ε is effective emissivity. The units of the parameters are also given in the tables. The abbreviations used in Tab.1 and Tab.2 represent the substance of each layer of bridge roadway.

Tab1. *The physical properties of materials of each layer of Syunnkou Bridge roadway*

Material	h〔mm〕	ρ〔kg/m³〕	Cp〔J/kg·K〕	k〔W/m·K〕	ε
DGGACWS	40	1713.15	1203.25	1.19	0.84
CGACBP	40	1880.90	1389.93	1.39	
WPS	5	1530.00	1407.00	1.61	
PCPD	1000	1993.61	485.87	4.37	

Tab2. *The physical properties of materials of each layer of Mumei Bridge roadway*

Material	h〔mm〕	ρ〔kg/m³〕	Cp〔J/kg·K〕	k〔W/m·K〕	ε
DGGACWS	30	1796.15	1301.35	1.30	0.84
CGACBP	30	1880.90	1389.93	1.39	
WPS	5	1530.00	1407.00	1.61	
RCS	1060	3473.50	797.75	10.98	

The meanings of the abbreviations are explained below.

dense grain gap asphalt concrete wearing surface → DGGACWS

coarse grain asphalt concrete base pavement → CGACBP

dense grain asphalt concrete wearing surface → DGACWS

waterproof sheet → WPS

prestressed concrete plate deck→ PCPD

reinforced concrete slab → RCS

In the research, the thermal physical properties of materials used in each layer of two bridge roadways are obtained by an own way.

The asphalt concrete constituting the wearing surface and the base pavement is in essence a mixture of four kinds of ingredients, coarse aggregate, fine aggregate, filler and asphalt. Moreover, each ingredient is not sole and could be chosen from many kinds of materials[11]. Instead of using the physical properties of main ingredient as ones of the mixture, for example using the thermal properties of coarse aggregate, we determined the physical properties by considering all ingredients of the mixture. According to the chosen constituents of the mixed material and the proportion accounted for by each kind of constituent to the mixed material, the thermal properties are calculated[11,12,13,14,15]. The obtained thermal physical properties by calculation are shown in Tab.1 and Tab.2. Both DGGACWS and CGACBP are a mixture of macadam, sand, powdered limestone and asphalt. The discrimination of both of them is the difference of their proportion of the four kinds of constituents. The waterproof sheet, WPS, is made from synthetic rubber asphalt. Its thermal properties are calculated based on the ratio of asphalt to synthetic rubber. The physical properties of PCPD are obtained by calculation, too. In the calculation, the contribution proportion given by its three kinds of constituent materials to its thermal properties is determined by percentage of the sectional area occupied by each constituent material in PCPD total sectional area. The thermal properties of PCPD is determined according to the ratio of cross-section area constituted respectively by concrete, steel-pipe and midair. The ratio decides the contribution ratio made by three constituent materials, concrete, steel and air to the thermal properties of PCPD. In the same way, the thermal properties of RCS is given by the rate of its two constituent materials, concrete and steel[13,14,15].

METEOROLOGICAL DATA USED IN THE ANALYSIS

Geographic areas where the two roadway segments of the studied bridges locate respectively in Asahikawa, Hokkaidō and Egawazaki Simanntosi, Kouti pref..

The actually observed meteorological data[16] of successive 56 hours including the hottest a whole day really experienced by the bridges since they were opened is made use of in the analysis. The hottest day is in order sequential Aug.4,1999 experienced by Syunnkou Bridge, Aug.1, 2013 experienced by Mumei Bridge. The used weather data is respectively observed on Aug.3-5, 1999 in Asahikawa and on July 31-Aug.2, 2013 in Egawazaki.

Based on the observed weather data, the functions of air temperature $\{T_{air}(t)\}$, solar radiation $\{q_{sun}(t)\}$ and wind velocity $u(t)$ are obtained by an inter inserting method in our Fortran computation program. For these functions please refer to the charts of the results (Fig.2~Fig.7).

RESULTS AND DISCUSSION

The variations of the temperatures in surfaces and interiors of roadways of Syunnkou Bridge and Mumei Bridge with time in 56 hours are shown in Fig.2 and Fig.3. The graphs of air temperature and solar radiation observed[16] are also given in the Figures. The temperatures in top surface(0mm line), in 50mm depth, 100mm depth, 350mm depth, 600mm, 850mm and undersurfaces(in 1085mm depth for Syunnkou Bridge and 1125mm depth for Mumei Bridge) are graphed. The main purpose is to investigate how the heat conduction goes in the bridge roadways during a whole day, that is the hottest day mentioned already (the second day in the Figures) for each bridge. However the results of heat transfer in the bridge roadway on the first day will undoubtedly effect the starting values of the parameters on the second day, i.e. the hottest day, and the effect of heat conduction on the second day also will naturally extend to the third day, so that the variations of the temperatures in surfaces and interiors during continuous 56 hours are investigated. The discussion will be focused on the results of the second day.

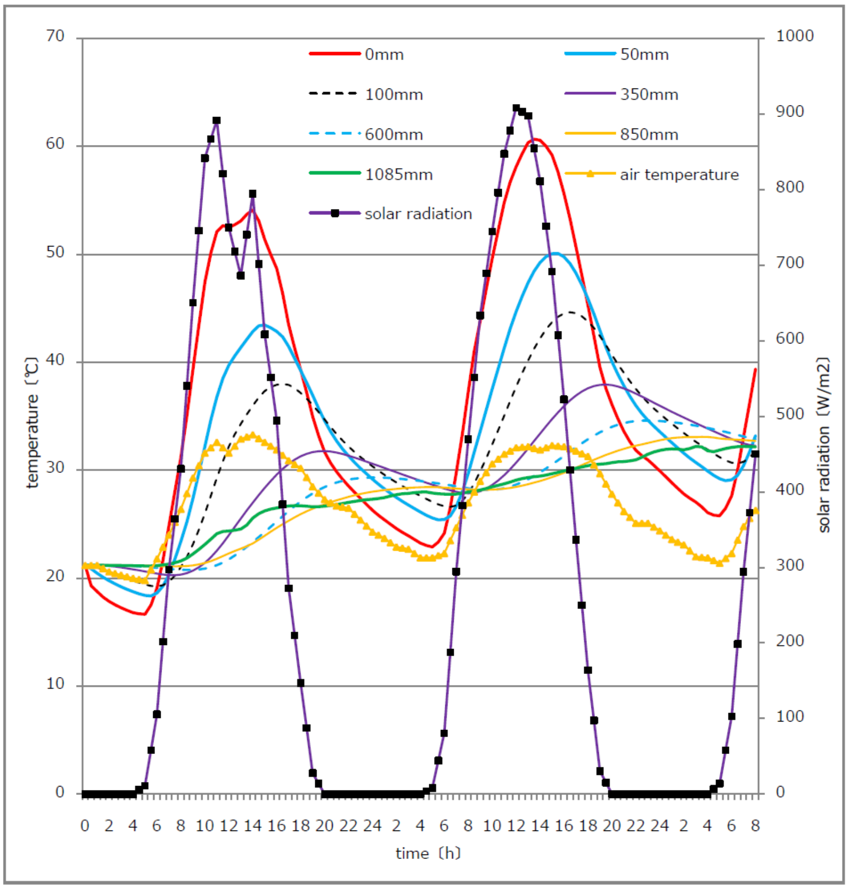

Fig2. *The variation of the temperatures in roadway top surface, interior and undersurface of Syunnkou Bridge with time*

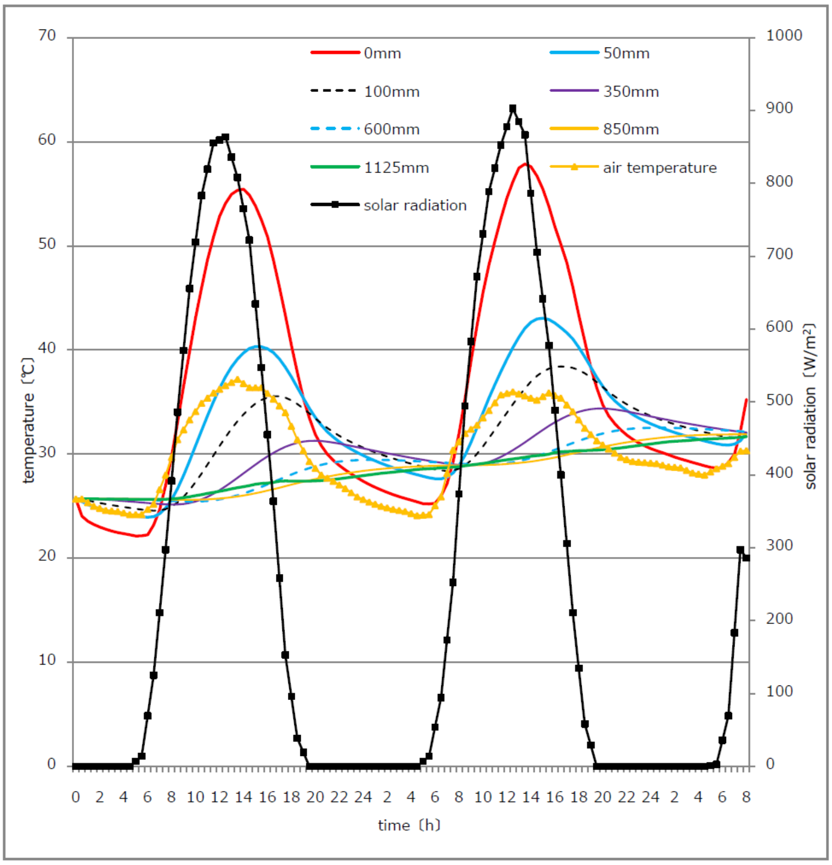

Fig3. *The variation of the temperatures in roadway top surface, interior and undersurface of Mumei Bridge with time*

Because it is difficult to set exactly initial values for bridge roadway temperatures, the air temperature at zero hour, i.e. 0:00am on the first day is set as the initial values of roadway surface and interior temperature, which is 21.2℃ for Syunnkou Bridge and 25.7℃ for Mumei Bridge. As a result of heat conduction of the first day, the temperatures in top surface, interior and undersurface of bridge roadway at zero o'clock (= 24:00 on the first day) on the second day reflect relatively real initial values. It can be seen that the temperatures in any depth of bridge roadway are all higher than the air temperature at midnight but lower than the highest air temperature on the first day from Fig.2 and Fig.3. The highest air temperature on the first day is respectively 33.3℃ reached at 14:00 for Syunnkou Bridge and 37.2℃ reached at 14:00 too for Mumei Bridge. After that with air temperature drops the graphs of the temperature in roadway surfaces show continuous drop until about 5:00am, the beginning moment of sunrise and solar radiation on the second day for both bridge roadways. The temperature in roadway top surface is the lowest among the temperatures in roadway surface, interior and undersurface from midnight until about 6:00am of the second day, which is due to the function of the heat emission from road surface to the air.

With rapid increase of solar radiation and air temperature after daybreak on the second day, the temperature in bridge roadway surface increases rapidly, too. In about one hour late and at around 7:00am the temperature in roadway surface becomes higher than the ones in roadway interior and undersurface.

For Syunnkou Bridge(Fig.2), the highest value of the caught solar radiation hits 908.33W/m^2 on the second day, Aug.4 1999 at 12:00am. About one hour and 30 minutes late, the temperature in roadway surface reached a maximum, 60.67℃ at 13:30. Then with solar radiation declining rapidly the temperature in roadway surface falls quickly. From about 18:00, the temperature in roadway surface becomes lower than the one in 50mm depth and then becomes lower and lower until becoming the lowest value among the temperatures in different depth of roadway at about 23:00, near midnight on the second day. The lowest temperature in roadway surface is 25.82℃ occurring at 0:30am during the second day. The maximum of the temperature difference during a whole day reached 35.85℃. The shape of mountain peak formed by the surface temperature is very similar to the one formed by solar radiation. The same result can be seen in Fig.3 for Mumei Bridge too, which illustrates that the variation of bridge surface temperature is affected deeply by solar radiation.

For Syunnkou Bridge the maximum of air temperature on the second day, Aug.4, 1999, is 32.3℃ reached at 15:00. However, the temperature in bridge roadway surface is higher than the maximum till near 22:00 o'clock. The curve of the surface temperature slopes gently when it closes to 21:40 o'clock, that is one hour and 40 minutes late after the sunset at about 20:00. Such tendency can be seen also from Fig.3 for Mumei Bridge.

For Mumei Bridge(Fig.3), the highest value of the caught solar radiation hits 902.78W/m^2 on the second day, Aug.1, 2013 at 12:30am. About one hour late, the temperature in roadway surface reached its maximum, 57.87℃ at 13:30. For temperature in the 50mm depth, the maximum is 43.06℃ that occurs at 15:00. For temperature in the 100mm depth, the maximum is 38.42℃ that occurs at 16:30. Comparing the three maximums of temperature respectively in surface, 50mm depth and 100mm depth, it can be seen that with the depth increasing by 50mm the maximum occurs about one and half hour late, which shows the way of heat conduction in the roadway to a greater or lesser extent. The temperature in roadway surface has been higher than the maximum of air temperature 36.0℃ reached at 13:00 on Aug.1, 2013 till about 20:00 o'clock. Afterward, the surface temperature continues dropping with the falling of air temperature more gently till next sunrise, about 5:30am on the third day early morning.

For Syunnkou Bridge, the temperature in roadway surface reached its maximum, 60.67℃ at 13:30. The temperature in 50mm depth reached its maximum, 50.08℃, at 15:30, which is two hours late than the top surface temperature reaching its maximum. The maximum of temperature in 100mm depth is 44.64℃ hit at 16:30. The temperature difference between the maximums in top surface and in 50mm depth is about 10.59℃. The temperature difference between the maximums in 50mm depth and in 100mm depth is 5.47℃. This explains that the closer to the top surface, the bigger the temperature difference is between the temperatures in same depth difference.

Because of the function of heat emission from bridge roadway surface to the air the temperature in top surface declines most quickly. Therefore, the order of the graphs from higher temperature to lower temperature changed gradually from about 18:00. On the second day for Syunnkou Bridge the temperature in the surface becomes the lowest one from about 23:00. This change can be observed from Mumei Bridge(Fig.3) too but the change happened at about 23:40 on the second day.

Fig.4 shows the wind influence on the temperatures in roadway surface and undersurface of Mumei Bridge. The variation of wind velocity with the time is also given in Fig.4. Comparing the two kinds of graphs, with wind and no wind(the wind effect is eliminated), it can be seen that the temperature in top surface for the case of no wind is a litter higher than one in the case with wind but the difference between the two cases is very small. That is because the wind velocity is quite small as shown in Fig.4 by the triangle marker solid line. The average wind velocity is only 1.2m/s during the observed period, i.e. 56hours from July 31-Aug.2, 2013. The maximum surface temperature for the case of no wind is 58.41℃ that appears at 14:00 on the second day. For the case with wind, the maximum is 57.87℃ that appears at 13:30. The temperature difference is only 0.54℃. For Syunnkou Bridge, the maximum surface temperature for the case of no wind is 61.84℃ that appears at 13:30 on the second day. For the case with wind, the maximum is 60.67℃ that appears at 13:30, too. The average wind velocity for Syunnkou Bridge is 1.5m/s, a little higher than the one for Mumei Bridge. The temperature difference is 1.17℃, a little bigger than the one of Mumei Bridge. It could be predicted that the difference will be enlarged and becomes obvious if the wind speeds up to some degree. Because of the limited space, the graphs from the latter is omitted here. The temperature difference between the two cases, with wind and no wind, for underfaces is too small to be observed.

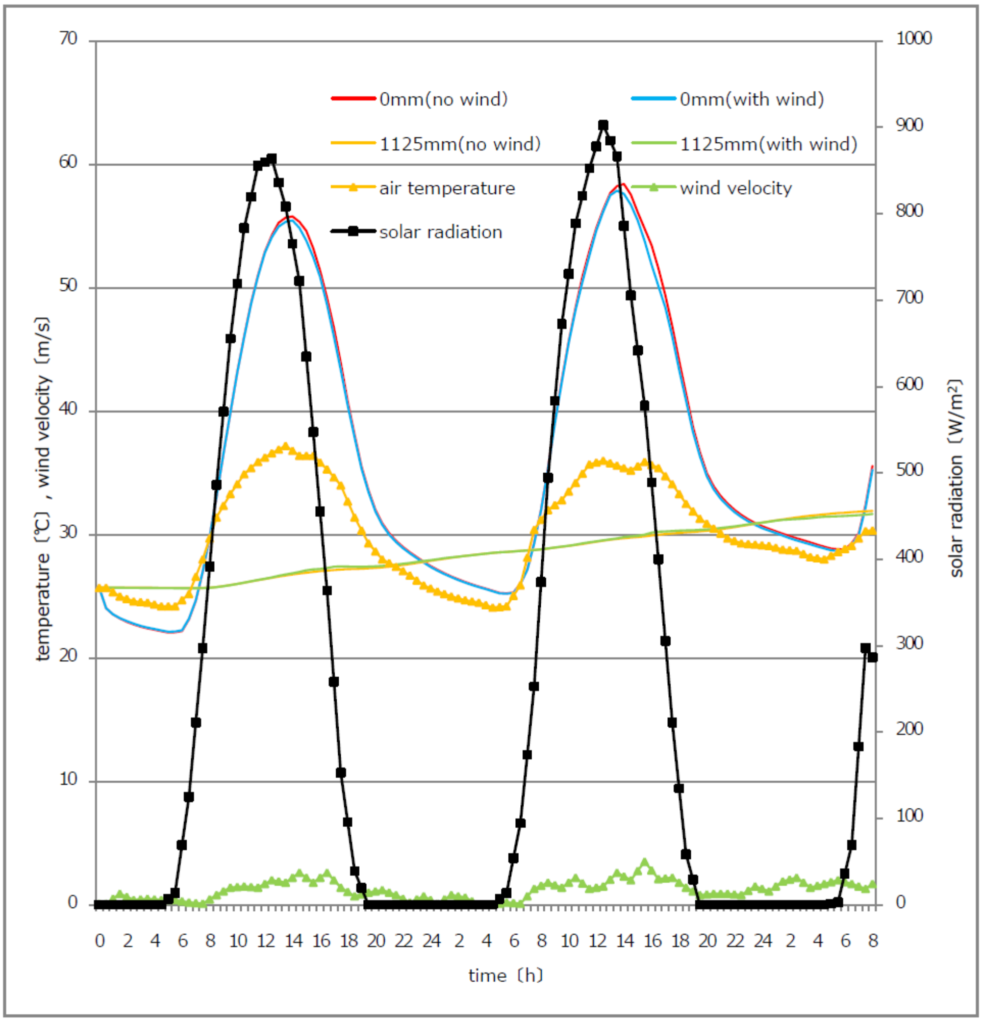

Fig4. *The influence of wind velocity on the temperatures in roadway top surface and undersurface of Mumei Bridge*

For Mumei Bridge, a tendency for both temperatures in roadway surface and air temperature to change toward approaching to each other can be observed after sunset. For the first day, it happens on the second day early morning and approaching of the both temperatures to the same value at about 6:40am. For the second day it occurs on the third day early morning, at about 6:30am.

In Fig.5, the variations of the temperatures in roadway surfaces and undersurfaces of two bridges, Syunnkou Bridge and Mumei Bridge, with time in 56 hours are presented. The graphs of solar radiation and air temperature are also given. The wind effects are included even though wind velocity graphs are not drawn in this Figure.

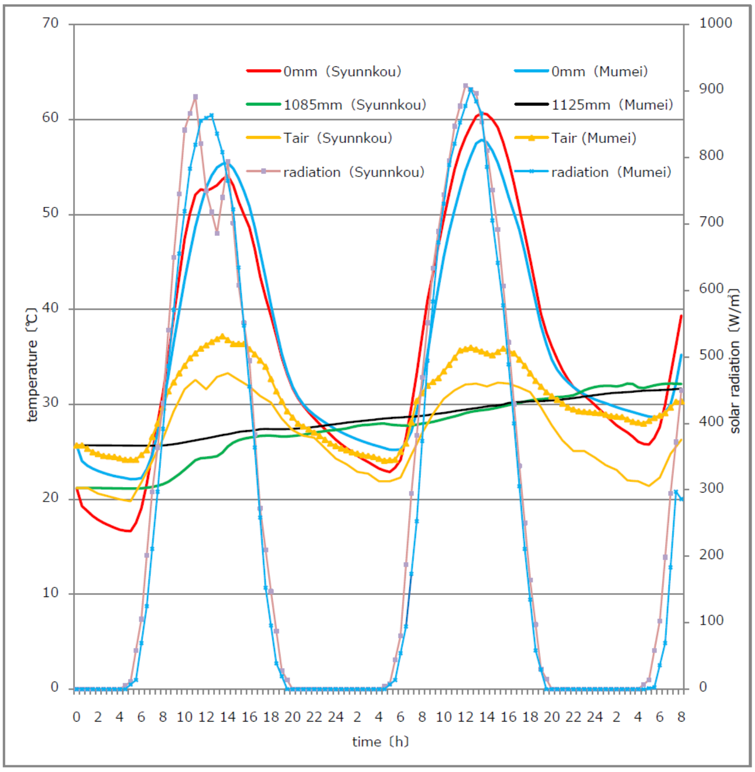

Fig5. *The variations of the temperatures in roadway surfaces and undersurfaces of Syunnkou Bridge and Mumei Bridge with time*

Let's look at the graphs by focusing the second day's results. By chance, on that day the maximums of solar radiation to the two bridges are almost the same, i.e. the maximum to Syunnkou Bridge is 908.33W/m^2 appearing at 12:00, and that to Mumei Bridge is 902.78w/m^2 at 13:00. Looking at Fig.5, it is clear that the shapes of solar radiation graphs in the sections on the second day for the two bridges are very similar. Even on the first day, the solar radiation maximum to the former is 891.67w/ m^2 and to the latter is 863.89w/ m^2, being very near to each other. So that, it can be considered that the effects from solar radiation do not make marked difference between the temperatures in two roadway top surfaces. However it is obvious that the air temperatures on the second day for Syunnkou Bridge is lower than the one for Mumei Bridge. The air temperature maximums for Syunnkou Bridge are all lower than the ones for Mumei Bridge on two days, Aug.3 and 4, 1999 for Syunnko Bridge and July 31 and Aug.1 for Mumei Bridge. For the former, the air temperature maximum on two days is successively 33.3℃ at 14:00 on the first day and 32.3℃ at 15:00 on the second day. For the latter, the temperature maximum is successively 37.2℃ at 14:00 on the first day and 36.0℃ at 13:00 on the second day.

However, it is clear that temperature in road surface of Syunnkou Bridge on the second day is higher than the one of Mumei Bridge, which might be explained from the effects of different bridge roadway structures. The roadway of Mumei Bridge with a thickness of 1.125m is thicker than the one of Syunnkou Bridge roadway(1.085m in thickness). If the materials are the same, heating a thick plate will consume more thermal energy than heating a thin one.

Besides, concerning the values of three thermal parameters of pavement and deck plate layer, the density $\rho[kg/m^3]$, specific heat $C_p[J/kgK]$ and thermal conductivity $k[W/mK]$, the ones of Mumei Bridge roadway are all higher than those of Syunnkou Bridge roadway (Tab.1 and Tab.2). If their thicknesses are the same, heating a plate of higher density and specific heat will consume more thermal energy. Specially, the density of RCS(Tab.2) layer of Mumei Bridge roadway is much higher than the density of Syunnko Bridge roadway(Tab.1).

The above factors result in that the temperature in roadway surface of Mumei Bridge is lower than that in the surface of Syunnkou Bridge even though the air temperature for the former is higher than the one for the latter and solar radiations are almost the same.

As regarding the undersurfaces of two bridge roadways, their temperatures are directly affected mainly by air temperature rather than the conducted solar energy from roadway surface and through thick roadway. Which can be observed from the temperature graph shape changing with depth of the bridge roadways(Fig.1 and Fig.2). The closer to undersurface, more weakly the temperature in roadway is affected by solar radiation. That is why during the most part of the analyzed time, the temperature in undersurface of Mumei Bridge is higher than the one of Syunnko Bridge, being different from the change of the temperature in top surface.

Fig.6 shows the relations between the temperatures in Syunnkou Bridge roadway and solar radiation, air temperature and so on in case no heat emission from roadway (i.e. emission effect is eliminated).

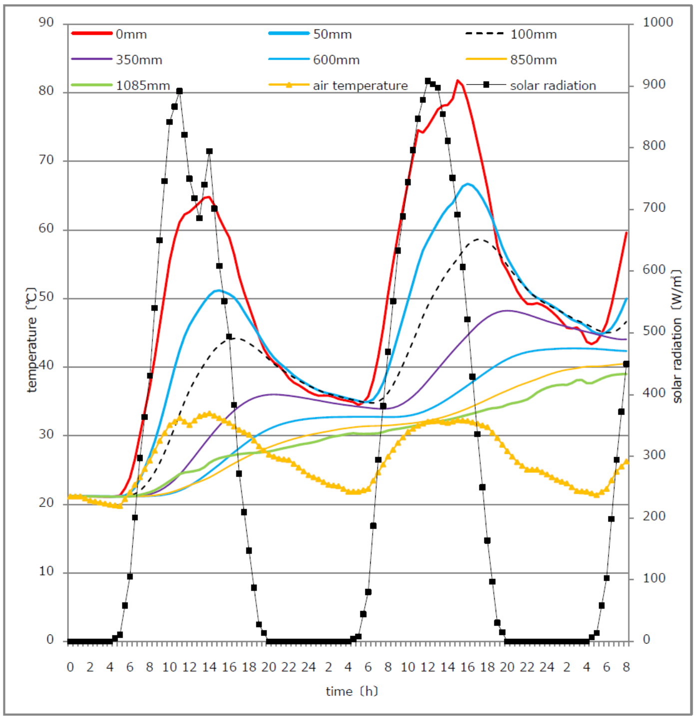

Fig6. *The relations between the temperatures in Syunnkou Bridge roadway and solar radiation, air temperature and so on in case of no heat emission.*

Watching the variation of the temperature in roadway in Fig.6, it is clear that the temperatures in every depth layer become higher increasingly in spite of wave changing with solar radiation. The maximums of the temperature in roadway surface are respectively 64.82℃ reached at 14:00 on the first day and 81.82℃ at 15:00 on the second day. If heat emission from roadway did not happen, the heat will be stored continuously in bridge roadway.

In Fig.7, the variations of temperatures in roadway surface and undersurface of Syunnkou Bridge with time in two cases(with emission and no emission) are shown. For the two cases, the wind effect is taken into consideration.

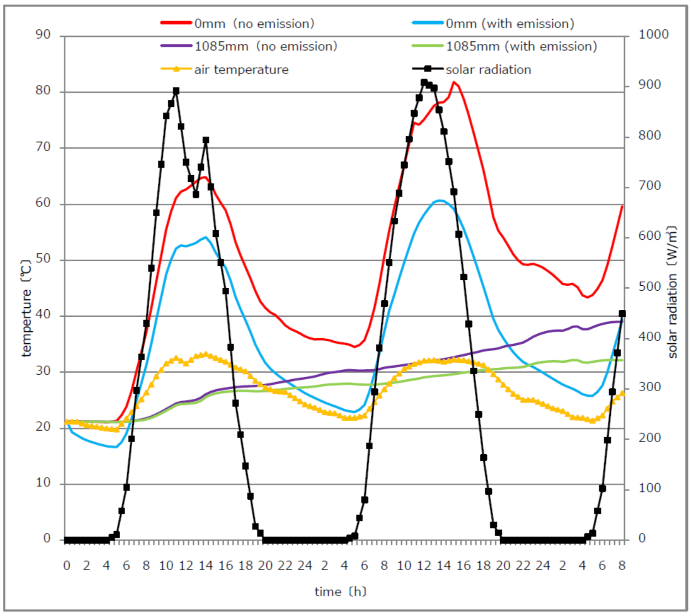

Fig7. *The variations of the temperatures in roadway surface and undersurface of Syunnkou Bridge with time in two cases(with emission and no emission).*

Comparing the maximums of the temperature in the bridge roadway surface in case of no heat emission with the ones in case with emission, the difference between them is respectively 10.71℃ for the first day and 21.15℃ for the second day, becoming bigger and bigger. For the case with emission, the maximum of the roadway surface temperature is respectively 54.11℃ reached at 14:00 on the first day and 60.67℃ at 13:30 on the second day. For the case of no emission, the maximum of the roadway surface temperature is respectively 64.82℃ reached at 14:00 on the first day and 81.82℃ at 13:00 on the second day. The temperature difference reveals the degree of contribution to reduce the temperature in bridge roadway by function of heat emission.

CONCLUSION

A mathematical model to analyze unsteady conduction of thermal performance of concrete bridge roadway is built and used to study two bridge roadways. From the results obtained, the following conclusions can be drawn:

1. From midnight until about 6:00am the temperature in roadway top surface is the lowest among the temperatures in roadway surface, interior and undersurface. But after daybreak and solar radiation occurrence the temperature in roadway surface increases rapidly then becomes higher than the ones in roadway interior and undersurface from about 7:00am in a summer hot day.
2. For one bridge, the temperature in roadway surface reached a maximum, 60.67℃, at 13:30, about one hour and 30 minutes late after solar radiation hitting its peak value. That is much higher than the highest air temperature of the same day. The lowest temperature in roadway surface is 25.82℃ occurring at 0:30am and the maximum temperature difference in bridge roadway surface during a whole day reaches 35.85℃.
3. The shape of mountain peak formed by roadway surface temperature is very similar to the one formed by solar radiation for two bridge roadways, which illustrates that the variation of bridge surface temperature is affected deeply by solar radiation.
4. For another bridge, with the depth increasing by 50mm the maximum of temperature occurs about one and half hour late, which shows the way of heat transfer in bridge roadway to a greater or lesser extent.
5. The temperature in top surface for the case of no wind (the wind effect is eliminated) is a little higher than one in the case with wind when wind velocity is not so big. It could be predicted that the temperature difference will be enlarged if wind speeds up.
6. Under the same strong solar radiation, if the materials are the same, a thicker bridge roadway will consume more thermal energy to be heated, i.e. its temperature increase will be comparatively smaller.
7. The temperatures in bridge roadway undersurface is directly affected mainly by air temperature rather than solar radiation.
8. From one bridge roadway result, if heat emission did not happen, the maximum of temperature in top surface of bridge roadway will increase about 21℃ in about 25 hours. This reveals the degree of contribution to reduce the temperature in bridge roadway by function of heat emission.

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