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Influences of the Arabian Gulf Environment on Concrete Durability

Influences du climat du golfe persique sur la durabilité du béton

Einfluss des Klimas am persischen Golf auf die Dauerhaftigkeit von Beton

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SUMMARY

In an experimental study, the temperature at various depths of concrete slabs exposed in the field environment of the Arabian Gulf countries has been measured. The effect of the temperature of concrete, which has been found different than that of the ambient air temperature, on its durability has been explained. The surface layer of a deteriorated concrete structure has been chemically analyzed to emphasize the role of air suspended particulate matter in concrete durability.

RÉSUMÉ

Des mesures de température ont été faites à différentes profondeurs d'une dalle en béton exposée aux conditions atmosphériques du golfe persique. L'effet sur la durabilité de la différence de température extérieure et dans le béton est discuté. La couche extérieure d'une structure en béton endommagée a été analysée chimiquement afin de déterminer le rôle des particules suspendues dans l'air.

ZUSAMMENFASSUNG

In einer der Witterung ausgesetzten Betonplatte wurden in verschiedenen Tiefen die Temperaturen gemessen. Die Wirkung der von der Umgebungstemperatur abweichenden Betontemperaturen auf die Dauerhaftigkeit wird besprochen. Die oberste Schicht einer geschädigten Betonstruktur wurde chemisch analysiert, um die Rolle der Luft als Träger suspendierter Stoffe zu belegen.

1. INTRODUCTION

The environmental conditions of the Arabian Gulf region are mainly characterized by its hot summer with virtually no precipitation and high evaporation. The daily mean air temperature in the summer usually varies from 30 to 35^{0}C with maximum temperature as high as 50^{0}C. The mean diurnal swing of air temperature is in the range of 10 to 15^{0}C. The relative humidity varies from 40% to 80%. These environmental conditions of the Arabian Gulf countries are considered to be one of the important factors in the rapid deterioration of concrete structures. Some of the other factors are high salt prevalence in ground, ground water and atmosphere, the scarcity of good quality aggregates, and lack of proper specifications. The deterioration of concrete structures within 10 to 15 years of their service life is common in the Arabian Gulf countries [1]. The various deterioration mechanisms identified in the region are reinforcing steel corrosion, sulfate attack, salt weathering and environmental cracking [2].

In this paper, the results of an experimental study are presented in which the actual temperature of concrete has been measured. Some earlier investigators [3,4] have pointed out that the concrete surfaces may have a temperature 30-40^{0}C higher than that of ambient air temperature. This difference between ambient air temperature and concrete temperature is attributed to the fact that the concrete temperature is not only a function of ambient air temperature, but some other factors also. These include solar radiation, thermal characteristics of concrete, wind speed, heat gain or loss from the ground and the occupied space [5]. If the values reported in the above references [3,4] are assumed, the concrete surface temperature in the Arabian Gulf countries may reach as high as 80-90^{0}C during summer days. Such a high concrete surface temperature coupled with a temperature differential along the depth of concrete may induce significant stresses which may even crack the concrete [6-9].

This study was thought to be important because the available literature provides little experimental data on concrete temperature in the Arabian Gulf countries. Such data is needed in quantifying the environmental stresses and assessing their consequences on concrete durability. The cracking of concrete due to its temperature variations, although usually mentioned in literature, has not been thoroughly investigated. Some studies that have been carried out on this aspect are by Illston and Tajirian [6] and Venecanin [7-9].

Data has also been included in this paper from a separate set of experiments which were carried out to determine the chlorides and sulfates accumulated on the concrete surface from the atmosphere. The objective of this work was to demonstrate that the air suspended particulate matter of the Arabian Gulf environment which contains the deleterious chloride and sulfate salts may play an important role in the durability of concrete even if all the precautionary measures are taken to remove these salts during construction.

2. EXPERIMENTAL PROGRAM

For the measurement of temperature at various depths of concrete, two slabs of dimensions 2 m x 2 m x 0.4 m were cast in the field environment of Dhahran. One slab was cast on a 16 cm thick asphalt-sand composite base which in turn was placed on compacted subgrade soil. While the other slab was cast directly on the compacted subgrade soil. The location of the slabs was such that the sun rays reached the slab surfaces without any obstruction. The slab concrete had 28-day compressive and tensile strengths of 387 kg/cm^{2} and 49 kg/cm^{2}, respectively. Thermocouples were embedded at top, middle and bottom of the concrete slabs at different locations. To facilitate the embedding of the thermocouples, they were first mounted on 10 cm x 10 cm x 40 cm precast beams of concrete similar to that of slab concrete. The mounted concrete beams were then placed on selected locations and concrete was poured.

In the other set of experiment, which was carried out to realize the role of air suspended particulate matter, the dust accumulated on the surface of a deteriorated concrete structure in Dhahran was collected from different locations using a brush. The dust was then analyzed for chlorides and sulfates.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the temperature at various depths of concrete slab placed on asphalt-sand base during typical days of summer and winter, respectively. The data on temperature of concrete slab placed directly on subgrade soil is not being presented here due to insignificant difference between the temperature of the two slabs. The maximum difference between the temperature of the two slabs has been found in the range of 0.1 to 2.0 ^{0}C at all the depths.

From Figs. 1 and 2, it can be noticed that the difference between the concrete temperature and ambient air temperature is different for different times of the day and different seasons. During the noon time of summer days, the concrete surface temperature is typically 10 ^{0}C higher than that of the ambient air temperature. However, on few occasions of the one year monitoring period, a difference as high as 15 ^{0}C between the concrete surface temperature and ambient air temperature has been recorded. These differences are low as compared to the ones reported in references [3-5]. However, reasonable agreement has been found between the results of this study and the theoretical study of Illston and Tajirian [6]. The concrete temperature predicted by the computer model of Illston and Tajirian [6] for a concrete slab of dimensions 6 m x 6 m x 0.30 m is shown in Fig. 3 for comparison. Their computer model is based on the following equation:

$$k_s \frac{\partial T}{\partial Z} = -H(T-T_A) + gR - se(\bar{T}^4 - \bar{T}_A^4) \quad ..(1)$$

Where T and $\bar{T}$ are concrete temperatures in ^{0}C and ^{0}K, respectively, T_A and $\bar{T}_A$ are ambient air temperatures in ^{0}C and ^{0}K, respectively, Z is the depth

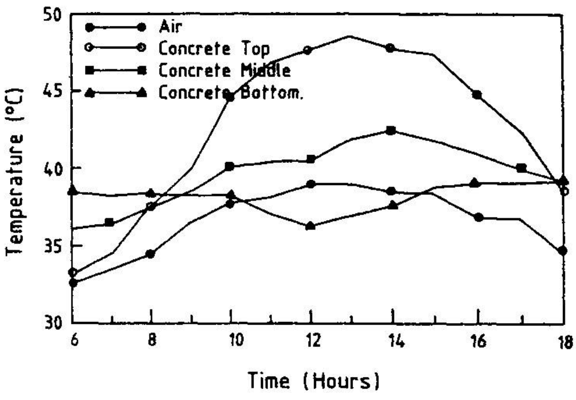

Fig. 1 Variation of ambient air temperature and concrete temperature during a typical summer day in Dhahran

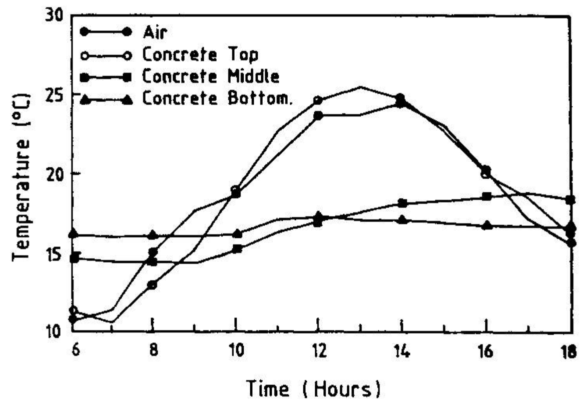

Fig. 2 Variation of ambient air temperature and concrete temperature during a typical winter day in Dhahran

coordinate, k_s is the thermal conductivity of concrete, H is the surface convection factor, g is the absorptivity constant, R is the intensity of solar radiation, s is the Stephan-Boltzmann constant, and e is the emissivity coefficient.

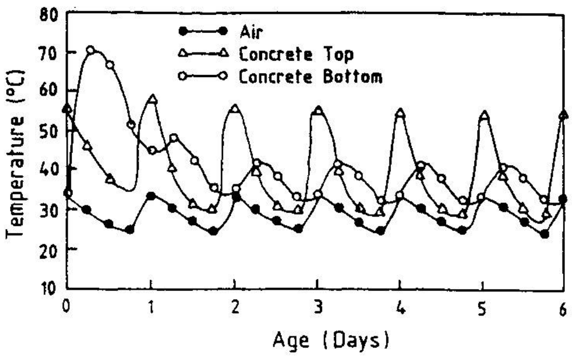

Fig. 3 Concrete temperature predicted by the computer model of Illston and Tajirian (6)

From Fig. 3, it may be noticed that the concrete surface temperature during noon time is approximately 20^{0}C higher than the ambient air temperature as compared to 10-15^{0}C in this study. This difference may be attributed to at least two important factors; (a) approximate values of various parameters have been used in equation (1), and (b) the predicted temperatures in Fig. 3 are for a concrete during its first six days of casting when the heat of hydration also contributes in the rise of concrete temperature.

From the results of this study (Figs. 1 and 2), it may also be noted that the typical temperature differential between the top and bottom of slabs during the noon time of summer days is 10^{0}C, while in winter days it is about 8^{0}C. During the summer days, temperature differential as high as 15.6^{0}C has been recorded. The temperature gradient obtained in this study is slightly less than that predicted by Illston and Tajirian [6].

The diurnal change in concrete temperature has been found in the range of 15-20^{0}C in the summer as well as in the winter. This is higher than the diurnal change in ambient air temperature which is in the range of 10-15^{0}C.

The large diurnal changes in concrete temperature cause tensile stresses in concrete if the coefficients of thermal expansion of the aggregate and cement paste are significantly different [7-9]. Limestone rock, the commonly available source of coarse aggregates in the Arabian Gulf countries has a coefficient of thermal expansion in the range of 0.9 x 10^{-6} to 12.2 x $10^{-6}/^0$C as compared to 10 x 10^{-6} to 20 x $10^{-6}/^0$C of hardened cement paste [8]. Venecanin [7] has developed two simple equations that can be used to calculate the stresses in concrete due to daily rise and fall in concrete temperature. These equations include the thermal properties, elastic properties and area of both the aggregate and cement paste along with temperature rise or fall. Considering a coefficient of thermal expansion of 5 x $10^{-6}/^0$C for aggregates and 15 x $10^{-6}/^0$C for cement paste along with moderate values of elastic properties and area, tensile stresses that can be generated in the concrete for a temperature change of 15-20^{0}C are calculated to be 18.75-25.0 kg/cm^2. The magnitude of these type of stresses would decrease with the depth of concrete. As can be seen from Figs. 1 and 2, the diurnal changes in concrete temperature at the middle and bottom of the slab are low as compared to that at the surface. Concrete surfaces subjected to direct sun rays such as airport and road pavements, and bridge slabs are some of the situations where these type of stresses may be significantly high [9].

Another type of stress which may be induced due to temperature is warping stress, particularly in pavement slabs. If there is a large temperature differential along the depth of concrete, the pavement slabs tend to warp and the restraint offered to this warping tendency by the self weight of the slab induces warping stresses. The equations given in reference [10] which are based on Westergaard's analysis and Bradbury's coefficients may be used to calculate such type of stresses. These equations yield a tensile stress of 0.75 kg/cm^2 for the slabs of this study and for a temperature differential of 15°C between the top and bottom of the slabs. However, these stresses vary considerably with the dimensions of the slab and its elastic and thermal properties [6]. Keeping the other parameters same, the warping stress in a 5 m x 5 m x 0.4 m slab is calculated to be 13.2 kg/cm^2 as compared to 0.75 kg/cm^2 in the 2 m x 2 m x 0.40 m slab of this study.

The thermal stresses discussed above may not be sufficient to crack a good quality concrete, but in combination with stresses due to loads they may easily do so. Such concrete cracking, which may or may not be structurally dangerous, provides a path for various deleterious salts such as chlorides and sulfates to enter the concrete. These salts initiate or accelerate, if already initiated, the common deteriorating mechanisms, reinforcing steel corrosion and sulfate attack. Even if all the precautionary measures are taken to remove the deleterious salts during the construction phase of concrete, they may come from air suspended particulate matter. This view is supported by the chemical analysis of the surface layer of a deteriorated concrete structure carried out in this study (Table 1). It is believed that the significant amounts of chlorides and sulfates present on the concrete surface are mainly due to high concentration of these salts in the air suspended particulate matter of the Arabian Gulf environment (Table 2).

Location	Cl^-(%)	SO_4^{2-}(%)
1	7.0	21.0
2	8.0	21.0
3	4.5	16.0
4	2.6	18.0
5	5.0	22.0
6	2.0	23.0

Table 1 Chlorides and sulfates on the surface layer of a deteriorated concrete structure in Dhahran

Chemical constituent	Mean concentration ($\mu g/m^3$)		
	Abqaiq	Dhahran	Ras Tanura
Na	13.0	6.0	12.0
K	1.3	1.7	0.9
Ca	21.7	51.8	15.7
Mg	12.7	16.7	7.1
Cl	11.8	18.0	23.2
SO_4	32.6	34.0	23.1
SiO_4	11.9	-	3.9

Table 2 Chemical composition of air suspended particulate matter collected from different parts of Saudi Arabia [reference 11]

4. CONCLUSIONS

This study has revealed that for assessing the influence of temperature on concrete durability, a precise measurement of concrete temperature is necessary. The assessments based on ambient air temperature would be misleading. During the summer days of the Arabian Gulf countries, the concrete surface temperature is 10-15°C higher than that of the ambient air temperature. The diurnal change in concrete temperature is 15-20°C as compared to 10-15°C in ambient air temperature. A temperature gradient as high as 0.4°C/cm has been found along the depth of concrete during summer. In such a temperature regime, significant stresses may be induced in concrete due to thermal incompatibility of concrete constituents. In concrete structures such as pavements, warping stresses may also be present. The thermal stresses in combination with load stresses may easily crack the concrete and once the cracks develop, the chlorides and sulfates contained in the atmosphere and subsequently settled on concrete surface could enter the concrete and initiate or accelerate the concrete deterioration process.

5. ACKNOWLEDGEMENTS

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