Variations of Ambient Conditions Affecting Thermal Gradients in Concrete Bridges

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Abstract—Concrete bridges are constantly exposed to ambient conditions and as a result, thermal gradients are induced in the bridge superstructure, leading to additional stresses over the cross section. The heat transfer between the concrete surface and the surrounding atmosphere takes place through convection and radiation and the energy transfer within the concrete body takes place by conduction. While Solar radiation is radiant energy emitted by the sun, conduction is heat transfer that takes place between two bodies in contact under temperature gradient and convection is the movement of heat because of the movement of the matter.

The temperature distributions in a bridge cross section is influenced by the diurnal and seasonal variation of Ambient Temperature and Solar Radiation. For a vast country like India, these parameters vary spatially also. Hence, the collection and processing of the data of solar radiation and ambient Temperature is a prerequisite to the generation of Thermal Gradients.

The present paper presents and discusses the variations of diurnal and seasonal variation of Ambient Temperature and Solar Radiation and an attempt is made to capture the trends of the ambient parameters. For this purpose, four representative cities Chennai, Jaipur, Delhi and Kolkata are considered and the trends are generated for a winter month and a summer month.

Keywords—Ambient Conditions, Thermal gradients, Solar Radiation, Ambient Temperature, Radiant Energy

I. INTRODUCTION

Concrete bridges are constantly exposed to the ambient environment, and subjected to alternate heating and cooling cycles. The ambient conditions (Temperature, Solar radiation and Wind velocity) induce thermal gradients in the bridge superstructure, leading to additional stresses over the cross section, besides longitudinal movements and vertical deflections [2]. Several cases of excessive cracking in bridges due to thermal effects have been reported from several countries.

The temperature distribution in the bridges is influenced by the ambient conditions such as solar radiation, temperature and wind velocity[3,4]. From the literature available on thermal gradients, a combination of a high solar radiation coupled with high ambient temperature range would result in the most severe temperature effects on a structure[5,6,7]. Before attempting to generate thermal gradients, it is necessary to have a clear understanding of the variations of solar radiation and ambient temperatures across the country.

II. AMBIENT PARAMETERS

A. Solar Radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy [1]. The radiation effect decreases with distance through dilution. Since the intensity depends on the distance, it is changing slightly with season. The solar constant describes the average energy from the sun that reaches the outer boundary of the earth's atmosphere and the average value is 1353 W/m². This amount is almost constant, changing from around 1410W/m² in January to 1320W/m² in June. The light can reach the surface of the earth directly or be altered by the atmosphere in different ways. By interacting with the particles the light can be reflected, scattered, refracted or absorbed.

Radiation striking the surface of the earth is called global or total radiation, parts of this is absorbed by vegetation or objects located close to the ground. The light that is absorbed or reflected depends on the properties of the material, texture and color. The energy absorbed (qs)is given by, qs = a. G  [W/m²], where ‘a’ is absorption coefficient, and G is Solar Radiation. The absorptivity of concrete varies from 0.5to 0.7. In many cases the concrete is covered by asphalt where the most commonly used absorptivity is 0.9.
The total light that reaches a surface is called global radiation $G$ which is given by $G = Ib + Id + Ig$ [W/m$^2$]. The light which reaches the ground is either direct light $Ib$, diffused light $Id$ or light that is reflected from another surface $Ig$. The direct light reaches the surface without being disturbed and its intensity depends on the following factors such as Latitude and altitude, Time of the day, year and Inclination of the surface.

The diffuse light $Id$ refers to all light that have interacted with any kind of clouds or particles on its way between the sun and the surface and therefore comes with other intensity and/or angle. The amount of diffuse radiation can vary from around 10% of the total light on a clear day to 100% on a cloudy day. Reflected light $Ig$ is light that does not affect the surface, however light can be reflected from other surfaces onto the surface.

The radiant energy falling on a unit area, termed irradiance, at normal incidence outside the earth’s atmosphere at mean sun-earth distance is termed as the solar constant ($S_o$). The present accepted value of solar constant derived from space-based measurements is $1367 \pm 7$ W/m$^2$.

The radiant energy that is incident on the top of the atmosphere, is modified and attenuated by the atmospheric gases due to scattering and absorption processes.

The radiant energy of the sun is spread over in all wavelengths of the electromagnetic spectrum. Because of the elliptical orbit of the earth’s revolution around the sun and because of the tilt of axis of rotation by about 23.5° from the normal to the plane of revolution, different areas on the earth are irradiated differently, giving rise to large variations in the radiation received and leading to the occurrence of the seasons.

Direct Solar irradiance ($S$) is the irradiance of the sun emitted from the solid angle of the sun’s disc, received by a unit surface held perpendicular to the solar beam. It includes a small quantity of irradiance that is scattered by the intervening medium along this axis of the cone. The attenuation, if any, is then due to the variation in the relative concentration of the individual constituents of the medium, viz. air.

Diffuse Solar irradiance is the downward irradiance scattered by the atmospheric constituents and reflected and transmitted by the cloud and incident on a unit horizontal surface.

Global Solar irradiance ($E_g$) is the irradiance that reaches a horizontal unit surface. It is made up of the direct solar beam irradiance and the scattered diffuse solar irradiance. Since the direction of the incident solar beam changes continually from sunrise to sunset, the cosine effect or cosine law comes into play. When a parallel beam of radiant flux of a given cross-sectional area spreads over a flat surface, the area that it covers is inversely proportional to the cosine of the angle between the beam and the normal to the surface. Therefore, the beam irradiance that heats up the area is proportional to the cosine of the angle of incidence. Global radiant exposure is measured by thermoelectric pyranometer. Fig. 1 shows a typical Solar radiant exposure for the month of May [1].

The global irradiance at a place can be written as

$$E_g = S \cos \Theta + Ed$$

where $S$ is Direct Solar Irradiance, $\Theta$ is the angle of incidence.

B. Ambient Temperature

Ambient Temperature is shade air temperature and is recorded by Thermometers. Temperatures in the open cannot be considered as ambient temperature because they are affected by the heat of the sun.

III. NEED FOR THE PRESENT WORK

Thermal response of any structure depends on the ambient parameters it is subjected to. Solar Radiation and Ambient Temperature are the most important parameters and a clear understanding about their variations is of paramount importance. Generally the ambient data available is enormous and it is impossible to carry out thermal analysis for all the available data. Choosing of selective data which would lead to critical temperature values is the first and important step in thermal analysis.
The present paper considers the ambient data of one year and develops various trends that would lead to some guidelines for choosing selective data. For the purpose of analysis, four cities Chennai, Jaipur, New Delhi and Kolkata are considered and the analysis has been carried out four months, April, May for Summer months, December and January for winter months.

Since large Global Solar Radiation and high Range of daily Temperature leads to critical temperature gradients, trends are developed which identifies them.

IV. DATA ANALYSIS

Ambient Data ie. Solar Radiation and Ambient Temperature has been collected from the IMD document, “Solar Radiant Energy over India”. As mentioned earlier, four months data has been considered and analysed for peak and mean values and various trends are generated.

In the following Sections, these trends are presented and discussed.

V. RESULTS AND DISCUSSIONS

Based on the fact that Thermal response of structures depends on Solar radiation and Ambient temperatures, Variations of these parameters have been developed and presented in Figures 2 to 10.

The monthly average of temperatures for various times of the day (1 to 24IST) have been plotted for the four months considered, for the four chosen cities. Similarly the monthly average Solar Radiation Intensity has been plotted for various times of the day. Daily temperature range being another parameter, its monthly average has been plotted for all the four chosen cities.
Based on the trends developed (Figs. 2 to 10), the following are the observations.

1. The maximum solar Radiation in a day for all the cases occurs at 12 noon or 13 hrs IST and the maximum temperature in a day occurs at 15 hrs. IST.
2. The maximum solar radiation among the four cities considered, Jaipur, New Delhi and Chennai experience almost same magnitude of around 3.25 MJ/m² whereas Kolkata experiences the least Solar radiation with a value of 2.87MJ/m².
3. The maximum solar radiation during summer months is 25%, 41%, 50% and 36% more than that of winter months for Chennai, Jaipur, New Delhi and Kolkata respectively.
4. There is no particular trend found for the variation of maximum temperature range.
5. For Jaipur and New Delhi, the maximum temperature range is 18.3 degrees Celsius, for Chennai and Kolkata it is 14.5 and 15.5 degree Celsius respectively.

VI. CONCLUSIONS

Based on the above observations, the following conclusions are drawn

• For all the four chosen cities except for Chennai, the average temperature variations for the two summer months April and May are very close to each other. Similar trend is observed for Winter months January and December.
• For off coastal cities New Delhi and Jaipur, the maximum temperature range is more, whereas for Coastal cities Chennai and Kolkata, the maximum temperature range is relatively less
• Maximum solar Radiation and maximum temperature range occurs during the month of May. Hence for the generation of thermal gradients, the data of May is to be considered.

REFERENCES