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ROAD TEMPERATURES IN THE TROPICS

by

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ROAD TEMPERATURES IN THE TROPICS

ABSTRACT

Temperature affects the overall performance of roads in several ways and a survey of available information was therefore carried out to determine the extent of knowledge on road temperatures in the tropics.

Data were limited and long-term measurements have been carried out in only a few countries, notably India on concrete and South Africa on bituminous pavements. Peak surface-temperatures have been reported up to 49°C on concrete and 61°C on bitumen, with normal surface temperatures in excess of the peak temperatures met in the United Kingdom. The diurnal range of temperature is also greater in many tropical countries than in the United Kingdom but the annual temperature range is often less.

It is proposed that further data are collected on temperatures within road structures by carrying out a series of co-operative experiments between the Road Research Laboratory and road authorities in the tropics.

1. INTRODUCTION

Climate directly influences the performance of roads and temperature is a particularly important factor. In the United Kingdom, low temperatures probably have the most significance to the road engineer since frost damage may be a major problem. In the tropics it is the higher temperatures and the long periods for which the high temperatures are sustained which are most significant.

An increase in temperature in bituminous materials causes loss of stability and oxidation. Changes in temperature also have their effects on concrete and stabilized soil. Problems arise during curing due to water loss by evaporation, and, after curing, differences in temperature between top and bottom surfaces can cause warping of the slab.

This note briefly reviews information available on road temperatures in tropical countries and make suggestions for future research.

2. AVAILABILITY OF RECORDS

The main sources of information were Hong Kong, India, Kenya, Nigeria, South Africa, and Zambia.
There seems to be no standard depth at which temperature measurements were taken. Most of the data available refer to temperatures at or within 1 in. of the surface of the road. Where measurements were made in more detail, the depths seem to have been chosen arbitrarily or at the interface of the different layers in a multi-layer road structure.

Data are available from the Meteorological Office on air and ground temperatures on a world-wide basis. Agricultural research workers have studied soil temperature gradients under various types of vegetation and bare soil at laboratories in this country and overseas. A comprehensive review of ground temperatures throughout the world was made by Dr. Jen-hu-Chang in his book 'Ground Temperature'.

3. THE MAIN FACTORS INFLUENCING ROAD TEMPERATURES

3.1 Radiation

The surface of the road is heated by direct and scattered insolation during the day. It loses heat by radiation during both day and night, most rapidly in the day when it is warmest, but more noticeably at night when cooling of the surface takes place due to the absence of incoming insolation. It is this variation in the nett radiation intensity which affects road temperatures.

The maximum value for the radiation intensity occurs when the sun is perpendicular to the road surface. The rise in temperature of the surface also depends on the time of heating however and it is probable therefore that maximum road temperatures occur during the slightly longer summer days in the vicinity of the tropics of Cancer and Capricorn rather than near the equator. A temperature of 78°C has been reported for the surface sand of a dune in the Sahara.

The pattern of variations in the monthly nett radiation over the surface of the earth is given in Fig. 1 for the months of January and July. The seasonal variation is readily apparent. Also at a given latitude the land masses have a higher intensity of nett radiation than the oceans, due to the greater concentrations of water vapour and clouds normally found in the atmosphere above the oceans.

3.2 Weather

Water vapour, particularly when in the form of a cloud, reduces the insolation as well as terrestrial radiation. Diurnal variations in temperature therefore are much reduced in cloudy conditions. Occasional clouds in an otherwise bright sky can cause large variations in surface temperature and a 20°C drop in temperature has been measured on the ground following the passage of a cumulus cloud.

As would be expected, rain, hail and snow have a considerable effect on ground temperatures. Measurements during a thunderstorm at Giza, Egypt showed that,
(a) the surface temperature at the start of the storm was 39°C,
(b) during hail the surface temperature fell to 3.8°C, and
(c) it increased to 16°C by the end of the storm.

Hot or cold winds also affect road temperatures although the influence is thought to be slight. The variation in mean air temperature closely follows the nett radiation pattern over the earth's surface as shown in Figs. 1 and 2.

3.3 Thermal properties

The thermal properties of the materials composing the pavement and the sub-grade influence both the temperature and the rate of gain or loss in temperature at any given level in the structure. Thus absorption characteristics, specific heat, thermal conductivity, diffusivity etc., all affect the temperature distribution. Dark-coloured surfaces absorb greater proportions of the incident radiation than light-coloured surfaces and thus attain higher temperatures. A high air-voids content helps to improve the insulation of the surface layers and reduces heat losses from the surface to the lower layers of the road. Thus open-textured bituminous surfacings would be expected to attain both very high and very low temperatures. Concrete surfaces, by virtue of their lighter colour and greater density would, conversely, be expected to show a smaller range in temperature.

Data on maximum temperatures tend to confirm these expectations. Measurements from Canada showed that temperatures on the surface of a bituminous cover were 6°C higher than on a similarly exposed concrete surface. In Chicago asphalt was found to be 5.5°C warmer than concrete while the temperature of a brick surfacing was intermediate, being 2°C warmer than the concrete. In Nigeria the use of yellow brown chippings on a sand-bitumen mix reduced the maximum temperature by 7°C at a depth of 1.5 in. and 3°C at a depth of 4 in.

4. RESULTS OF INVESTIGATIONS

Data are extremely limited and investigations appear to have been mainly concerned with simple comparisons of road temperatures in various parts of a country or with different types of pavement in one locality. For convenience the results from concrete, bituminous and composite pavements will be discussed in turn.

4.1 Concrete pavements

Measurements in New Delhi, India, during June, 1962, showed that the surface of a concrete slab reached a maximum temperature of approximately 49°C. During the night a minimum surface temperature of 36°C was recorded. The maximum differential temperature between the top and bottom of a 6 in. slab was 7.3°C and occurred between 12 a.m. and 1 p.m. The maximum temperature of the surface of the slab occurred about 2 p.m. while the minimum temperature occurred about 6 a.m. Typical temperature measurements taken in a 4 in. thick concrete slab are given in Fig. 3.
The work in India was later extended to cover five other centres and summarised results of measurements carried out in 1964-65 are given in Table 1. The results clearly show the expected effect that the thicker the concrete the greater the differential temperature between the top and bottom faces. The temperature variation at the surface of the concrete was always greater than the variation in air temperature but the surface variation did not appear to be related to the thickness of the concrete.

### TABLE 1

Average daily temperature variations in air and concrete, India

<table>
<thead>
<tr>
<th>Name of Station</th>
<th>Variation in air temperature °C</th>
<th>Period of observation</th>
<th>Surface temperature variation °C</th>
<th>Differential temperature °C in slab thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 in.</td>
<td>6 in.</td>
</tr>
<tr>
<td>Jullundur</td>
<td>14.1</td>
<td>June 1964</td>
<td>29.9</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Madras</td>
<td>10.1</td>
<td>May 1964</td>
<td>25.0</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.1</td>
<td>15.0</td>
</tr>
<tr>
<td>Calcutta</td>
<td>6.9</td>
<td>April-May 1964</td>
<td>22.4</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Hyderabad</td>
<td>13.2</td>
<td>May 1964</td>
<td>26.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Trivandrum</td>
<td>11.6</td>
<td>January 1965</td>
<td>21.8</td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.0</td>
<td>13.5</td>
</tr>
</tbody>
</table>

An investigation has also been carried out in India into the possibility of reducing thermal stresses in concrete slabs by the use of light-coloured surfacings. Preliminary work with 1/2 in. thick bonded white topping over plain concrete has shown reduced temperature differentials between the top and bottom surfaces of the concrete and it is thought in India that this may permit an overall reduction of 17 per cent in thickness for concrete slabs designed to carry a wheel-load of 9000 lb.\(^9\)

At the present time the Road Research Laboratory is co-operating in an experiment near Accra, Ghana, where thermocouples are being used to measure temperatures in an 8 in. thick concrete road. During the period June-September 1965 the maximum temperature differential between top and bottom faces of the slab was found to be 12°C. Fig. 4 shows a typical diurnal variation in temperature measured
in the slab during this period. Somewhat higher temperatures are expected to occur during the period February-March when the air temperature in Accra tends to be up to 6°C hotter than during the period for which results are available.

4.2 Bituminous pavements

Temperature measurements at depths of $\frac{1}{2}$, $\frac{1}{2}$, and 3 in. in an experimental block of bitumen pre-mix were made in Kenya by Strongman at two hot periods of the year, October and March. The maximum temperature recorded at a depth of $\frac{1}{2}$ in. was 56°C, at a depth of $\frac{1}{2}$ in. it was 46°C, while at 3 in. it was 37°C. This led to the use of harder grades of bitumen (60-70 pen.) than previously used in road and runway work. Temperature measurements made by the Road Research Laboratory in Kenya during October 1962 in connection with deflection-beam studies are in agreement with those of Strongman.

Data are available from several countries on the diurnal variation of road surface temperatures and typical results are given in Fig. 5. The maximum is generally reached between 1 and 2 p.m., i.e. in tropical countries approximately 7-8 hours after the minimum temperature which usually occurs just before sunrise. In the temperate latitudes of London and Ontario the equivalent time is about 9 hours, reflecting the longer summer days.

In an experiment in Hong Kong a record of road surface temperatures was taken over a 12 month period. As shown in Fig. 6 it was found that surface temperatures were consistently almost 20°C higher than those in England. In Durban, South Africa, measurements of temperature in bituminous surfacings have been carried out over a period of several years. The results show an annual variation in mean temperature of approximately 14°C, with the difference between the monthly maxima and minima being 12-18°C. A typical temperature record for 1962 is given in Fig. 6.

As already indicated by Strongman's work in Kenya the amplitude of diurnal temperature variations becomes rapidly smaller with increasing depth below the exposed surface. This effect has also been measured at Maiduguri, Nigeria, where about a month before peak temperatures were to be expected the temperature variation in a mixture of $3\frac{1}{2}$ per cent of cut-back bitumen in sand was 16°C at a depth of 4 in. compared with 38°C at the surface. In Pretoria during the hot season similar measurements in a mixture of sand with 6 per cent of binder showed a drop in the diurnal temperature variation from 44°C at the surface to 18°C at a depth of $5\frac{1}{2}$ in. Bituminous layers have been used to insulate concrete slabs from temperature variations and will be discussed below.

4.3 Composite pavements

Bituminous surfacing material is often added to concrete pavements for strengthening purposes when traffic loadings increase beyond the design strength. It may also be used to reduce the temperature differentials in the underlying concrete slab and thus minimise the problems associated with slab curling.
In a given environment bituminous surfaces reach higher temperatures than concrete due to the increased absorption, hence it is also possible to increase the temperature stresses in the concrete slab if an insufficient thickness of surfacing is added. Work in India has shown that there was a rise in the surface temperature of a 4 in. concrete slab from 33.8°C to 39°C when the slab was covered with a 1 in. layer of asphalt. The temperature differential between the top and bottom faces of the slab was also increased from 7°C to 10.5°C because of the asphalt layer. Further work summarised in Table 2 below, showed that at least 2 in. of asphalt was required to bring the temperature of the surface of the concrete down to that of the uncovered slab. A 50 per cent reduction in the temperature differential within the slab occurred however when the thickness of the asphalt was increased to 3 in.

Work at the Road Research Laboratory also showed that at least 2 in. of asphalt was needed as cover. Some results obtained in Canada on a sunny day are included in Table 2 for comparison purposes and it will be noted that these measurements indicate the probability of greater reductions in thermal stresses in the concrete for given thicknesses of asphalt than the results from India. These differences are probably due to changes in sunlight intensity and day length.

### Table 2
Comparison of temperature differentials in bare concrete slabs with slabs topped with various thicknesses of asphalt

<table>
<thead>
<tr>
<th>Thickness of asphalt cover (in.)</th>
<th>India</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Temperature at asphalt surface (°C)</td>
<td></td>
<td>39.0</td>
</tr>
<tr>
<td>Temperature at top surface of concrete slab (°C)</td>
<td>33.8</td>
<td>36.6</td>
</tr>
<tr>
<td>Temperature differential through 4 in. concrete (°C)</td>
<td>7.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Temperature differential through 8 in. concrete (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temperature at time of observations °C</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

### 5. SUGGESTIONS FOR FURTHER WORK

#### 5.1 Temperature measurements

Since it is apparent that temperature has a considerable effect on the design of both concrete and flexible road pavements, it is suggested that more data be obtained on temperatures in road structures overseas by:
(i) the improvement of techniques and equipment for the measurement of temperatures in roads under tropical conditions.

(ii) the establishment of test sites for the measurement of temperature in different types of road pavement at several centres in the tropics which represent typical environments and

(iii) the development of means of estimating ranges of temperature likely to occur in road structures from a knowledge of local environment and form of road structure.

Test sites could be established on existing or new roads but more useful information will be obtained by building and instrumenting several blocks covering a range of types of construction in one locality. This arrangement would facilitate recording the temperatures. Each block would need to be about 6 ft square, the temperature measurements being taken in the centre.

Sites are required which satisfy the following conditions:

(i) Laboratory facilities and staff should be available for regular measurements, for servicing and maintaining the apparatus. If possible, electric power supplies should be on hand for recording instruments,

(ii) the site should be level, and

(iii) the site should be typical of a particular tropical environment e.g. monsoon coastal, monsoon inland, arid coastal, arid inland. The main variables are distance from the coast, rainfall and altitude.

The main measurements to be taken will be as follows:

(i) Temperature measurements at small increments of depth in the road construction to establish the form of the temperature gradient.

(ii) Climate observations including rainfall, air temperature, wind speed, humidity and solar radiation.

Measurements would be taken over periods of about six days during each of the main seasons in order to establish the time of occurrence of maximum and minimum temperature in the road structure. Additional measurements would also be taken for a few days each month corresponding to the probable maximum and minimum temperature in the road surfacing. Where a supply of A.C. current is available it will be possible to use a fully automatic chart recorder. Where mains electricity is not available measurements will be made by scanning the thermocouple installations at regular intervals. Measurements would probable continue at each site for two or three years.

The intention is that the Road Research Laboratory should provide the measuring equipment and that an officer from the Laboratory would assist in the installation and initial reading of the instruments i.e. for a period of approximately 1 month. Thereafter, a local technical assistant could be responsible for the routine measurements and servicing. Where an automatic chart recorder is used, servicing will in-
volve brief daily inspection and changing charts every 3 months approximately. Where measurements are done manually a minimum of 30 man-days will be required per year.

5.2 Effect of temperature on road design and performance

The effects of temperature on the properties of concrete are already well known\(^9,13\) and more information on the temperatures occurring in roads will enable this knowledge to be more usefully applied in the design and construction of concrete roads.

The effects of temperature on the curing of stabilised soils are also fairly well known\(^15,16\). They account for instance for the greater use of lime stabilisation in warmer climates.

The effects on the performance of bituminous bound bases and surfacings are less well understood, particularly as they affect the design of flexible pavements. Current methods of pavement design for heavily trafficked roads in temperate climates take advantage of the high stiffness of these materials by permitting some reduction in design thickness relative to unbound bases when they are used\(^17\). It is already known that the moderate temperature increases of the British summer have a marked effect in reducing the load spreading properties of bituminous materials\(^14\). Research is required to establish how the stiffness and other properties of bituminous materials are affected by temperature changes up to the maximum encountered on roads in the tropics.

6. ACKNOWLEDGEMENTS

The authors thank the Directors of Road Research in India and South Africa for providing data used in this Report.

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Fig. 1 RELATIVE INTENSITY OF NET RADIATION IN, (A) JANUARY AND (B) JULY
Fig. 2. MEAN SEA LEVEL TEMPERATURE (°F) IN (A) JANUARY AND (B) JULY
Fig. 3 TEMPERATURES IN 4-INCHES THICK CONCRETE ROAD SLAB NEW DELHI, INDIA (JUNE 1962).
Fig. 4. TEMPERATURES IN 8-INCHES THICK CONCRETE ROAD SLAB ACCRA, GHANA (AUGUST 1965).
Fig. 5. TYPICAL DIURNAL VARIATION OF SURFACE TEMPERATURE IN BITUMINOUS ROADS DURING THE HOT SEASON.
Fig. 6. MONTHLY MEAN MAXIMUM AND MINIMUM DARK ROAD SURFACE TEMPERATURES

**Hong Kong 1953**

**Durban 1962**

**London 1939**