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Effects of Climatic Conditions and Temperature Gradient on Jointed Plain Concrete Pavement Slabs

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***Abstract:** A long lasting, reliable and economical transportation system is a critical component for the continuous movement of goods and services. Rigid pavements are widely used in construction world due to its high performance and serviceability. Traditional bituminous pavements and their needs for continuous maintenance and rehabilitation operations point towards the scope for cement concrete pavements. Cement concrete slab in a rigid pavement structure are exposed to different conditions at the surface in comparison to the bottom due to daily temperature fluctuations and results in the formation of temperature gradients in the slab. Transient gradients are due to the seasonal changes to which the slabs are subjected whereas permanent gradients are due to the slab condition during the setting of slab. The objective of this study is to determine the effect of temperature gradient and climatic conditions on a jointed plain concrete (JPC) pavement slab and to establish a proper temperature gradient chart which can be referred to depending on the climatic conditions existing in Kerala. A properly designed slab can reduce the formation of cracks and hence increase the life of slab. A detailed study in this area, can help in forming some codal provisions for the design of pavement slab depending upon the climatic conditions of Kerala.*
***Keywords:** Rigid Pavements, Bituminous pavements, Jointed Plain Concrete (JPC), Permanent gradients, Temperature Gradient*

I. INTRODUCTION

Rigid pavements are widely used in construction world due to its high performance and serviceability. They are considered to be one of the highest quality pavement structures which can withstand heavy traffic even under adverse subgrade and climatic conditions. They are easy to maintain, durable, provide good riding surface and result in lower life cycle cost. Also, in cities, drainage of water during the monsoon is generally poor and therefore, concrete road has become the obvious choice for many urban authorities in India. Jointed Plain Concrete Pavement (JPCP) uses contraction joints to control cracking and does not use any reinforcing steel. Transverse joint spacing is selected such that temperature and moisture stresses do not produce intermediate cracking between joints. Pavements are subjected to repeated traffic loads throughout their service life. In concrete pavements, the repeated application of traffic loads along with temperature variation may lead to initiation of cracks at the highly stressed locations. The cracks propagate through the pavement which may finally lead to failure of pavements due to fatigue. Warping occurs due to the change in moisture conditions, while curling occurs due to the change in temperature conditions. Depending upon the climatic conditions, temperature gradient varies with varying places. In concrete pavement, the combined effect of wheel load and temperature gradient is responsible for the development of critical stresses.

A. Structural Behaviour of Concrete Pavement

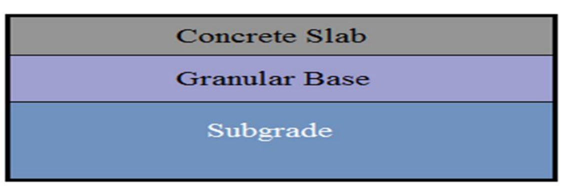

Fig. 1 A Typical Concrete Pavement

The subgrade is the lowest layer of the components of the concrete pavements which ultimately supports all other component layers and the traffic loads. The wheel load applied on the slab is distributed over a wide area of subgrade through these layers. The granular base course has to serve as an effective drainage layer of the rigid pavement to prevent early failures due to excessive moisture content in the subgrade soil. Different types of transverse and longitudinal joints are provided to facilitate thermal expansion and contraction of the slab and to continue construction after a break.

B. Temperature Stress

Temperature is an important environmental factor that influences the performance of concrete pavement. During daytime, positive temperature difference between the top and the bottom surfaces of the concrete slab causes the slab corners to curl downwards. Since the curling is resisted by the self weight of the slab, it will exert stresses of opposite nature. That is compressive stress at the top of the slab and tensile stress at the bottom of the slab. During night time, negative temperature difference between the top and bottom of the slab results in upward curling of the concrete slab. The self weight of the slab exerts tensile stress at the top of the slab and compressive stress at bottom of the slab.

C. Objectives

The key objectives of the experimental work are:

1) To study the daily variation of temperature differential of concrete specimens cast.
2) To determine the effect of temperature gradient and climatic conditions on a Jointed Plain Concrete Pavement (JPCP) slab.
3) To establish a proper temperature gradient chart which can be referred to depending upon the climatic conditions existing in Kerala.

II. MATERIALS

The materials used in this experimental investigation were Ordinary Portland cement, coarse aggregate, fine aggregate and potable water. The mix proportion for M30 grade of concrete was arrived through trial mixes. Mix design was done as per IS: 10262-2009, guidelines for concrete mix design proportioning.

A. Cement

Ordinary Portland cement of 53 grade conforming to IS 12269 was used in the investigation.

TABLE I PROPERTIES OF ORDINARY PORTLAND CEMENT

Sl no.	Properties	Values
1	Consistency of cement paste	32%
2	Initial setting time	47 minutes
3	Final setting time	330 minutes
4	Fineness	7.5%
5	7^{th} day compressive strength	29 N/mm2

B. Fine Aggregate

Dry river sand was used as fine aggregate in the experimental work.

Table II Properties of Fine Aggregate

Sl no.	Properties	Values
1	Specific gravity	2.58
2	Fineness modulus	5.8
3	Water absorption	2.9%

C. Coarse Aggregate

Crushed stones obtained from local quarries were used as coarse aggregate.

Table III Properties of Coarse Aggregate

Sl no.	Properties	Values
1	Specific gravity	2.9
2	Fineness modulus	6.1
3	Water absorption	3.44%
4	Bulk density	1.66
5	Void ratio	0.729
6	Porosity	0.430

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D. Water

Potable water was used as mixing water. It is drinkable, clear, clean and free from injurious amounts of oils, acids, alkalis, salts and other substances that may be deleterious to concrete and was confirmed to IS: 456-2000 recommendations.

III. EXPERIMENTAL STUDY

Temperature is an important environmental factor that influence the performance of concrete pavements. Concrete pavement can also be exposed to different climatic conditions depending on their geographical location and the time of paving. Therefore an attempt has been made in the present study by casting concrete specimens at different times of a day since it replicate the behaviour of concrete slabs under temperature conditions.

A. Field Experiment

Concrete specimens of size 100x15x15 cm cast at different times of a day were used. Specimens cast at morning and afternoon were used. Temperature at different points across the cross section and deflection at the top surface of the specimen were measured. Mixing was done in a laboratory type pan mixer. Wooden moulds of inside dimension 100x15x15 cm were used for casting the specimens, also cubes are prepared to determine the mechanical properties of concrete. After casting, the moulded specimens were stored in the laboratory at room temperature for 24 hours from the time of addition of water to dry ingredients. After this period, the specimens were removed from the moulds and immediately submerged in clean and fresh water for curing.

Table IV Details of Specimens

Specimen	Size	Time of placement	Atmospheric Temperature (°C)
Specimen cast at morning	100x15x15 cm	9.30 AM	31
Specimen cast at afternoon	100x15x15 cm	1.00 PM	34

B. Instrumentation

Thermocouples were installed at specified depth through the hole made in the wooden mould. The nib of the thermocouple should be in contact with concrete. Thermocouples are installed at three points which include top surface of the specimen, middle and bottom surface of the specimen. One end of the thermocouple was connected to the temperature indicator. After casting the specimen, dial gauges were fixed at the top surface of the specimen. Two dial gauges were fixed at equal spacing from one end to other end of the specimen. Needle of dial gauges should touch the concrete specimen surface at specified points.

Fig. 2 Experimental Setup in the Field

IV. RESULTS AND DISCUSSION

A. Strength Properties of Concrete

1) *Compressive Strength of Concrete*: Compressive strength was determined for mix prepared for specimen cast at morning (S1) and specimen cast afternoon (S2).

TABLE V Compressive Strength of Concrete

Mix Designation	Average Cube Compressive Strength (N/mm^2)	
	5 day	7 day
S1	21.33	23.55
S2	22.66	26.22

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2) *Flexural Strength of Concrete:* The flexural strength (fcr) of concrete was obtained from the compressive strength (fck) using the formula, fcr = 0.7√fck

TABLE VI Flexural Strength of Concrete

Mix Designation	Flexural Strength (N/mm^2)	
	5 day	7 day
S1	3.23	3.39
S2	3.33	3.58

3) *Modulus of Elasticity:* The approximate value of modulus of elasticity (E) is obtained from the formula E = 5000√fck

TABLE VII Modulus of Elasticity of Concrete

Mix Designation	**Modulus of Elasticity (GPa)**	
	3 day	**7 day**
S1	**23.09**	**24.26**
S2	**23.8**	**25.6**

B. *Temperature Measurement*

1) *Specimen Cast at Morning*: The temperature gradient at one hour interval for the specimen cast at morning was plotted.

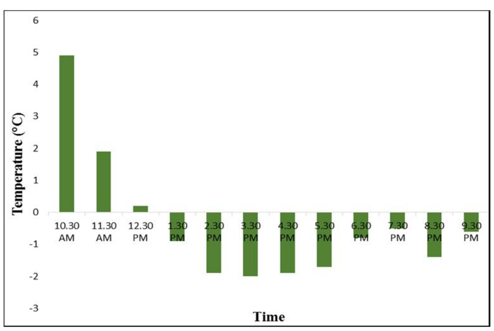

Fig. 3 Temperature Gradient at One Hour Interval (10.30 AM to 9.30 PM)

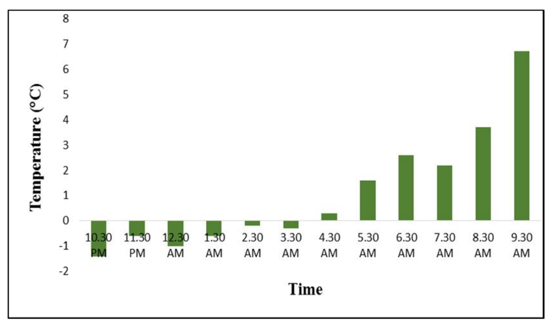

Fig. 4 Temperature Gradient at One Hour Interval (10.30 PM to 9.30 AM)

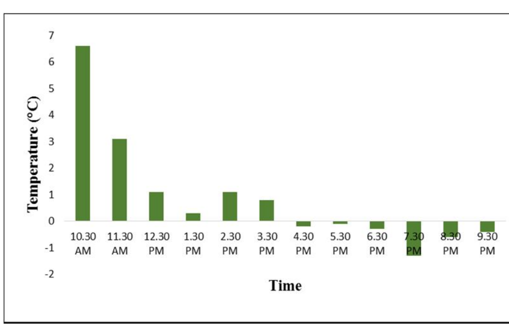

Fig. 5 Temperature Gradient at One Hour Interval (10.30M to 9.30 PM)

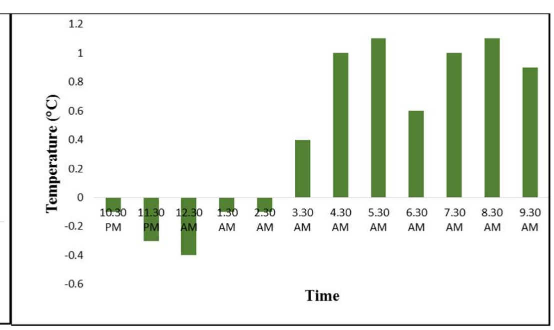

Fig. 6 Temperature Gradient at One Hour Interval (10.30 PM to 9.30 AM)

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2) *Specimen Cast at Afternoon:* Temperature gradient at one hour interval for the specimen cast at afternoon was plotted.

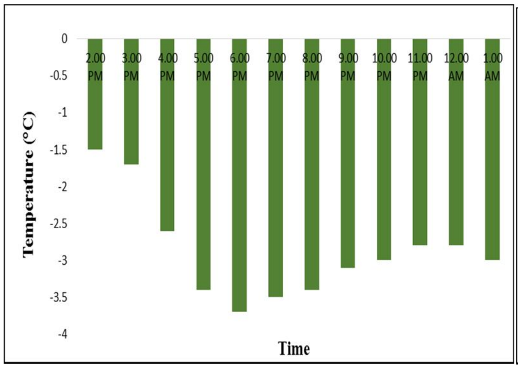

Fig. 7 Temperature Gradient at One Hour Interval (2.00 PM to 1.00 AM)

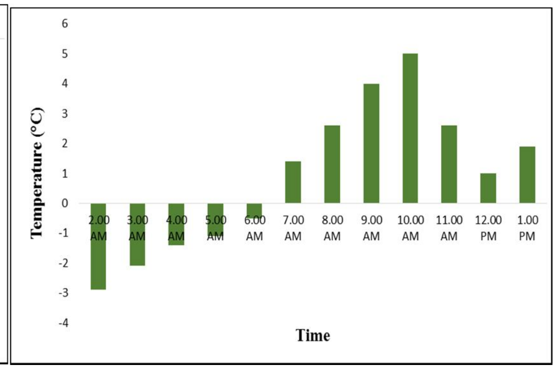

Fig. 8 Temperature Gradient at One Hour Interval (2.00 AM to 1.00 PM)

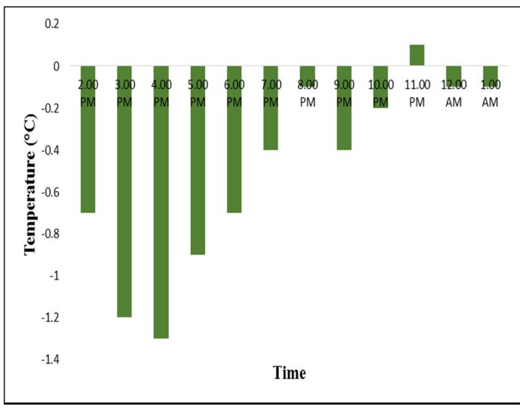

Fig. 9 Temperature Gradient at One Hour Interval (2.0 M to 1.00 AM)

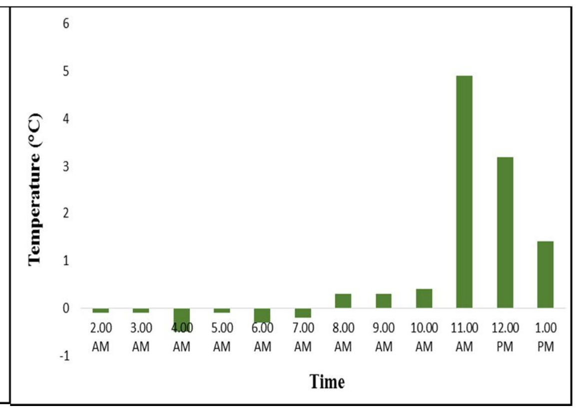

Fig. 10 Temperature Gradient at One Hour Interval (2.00 AM to 1.00 PM)

C. *Deflection Measurement*

1) *Specimen Cast at Morning*: The deflection across length of specimen cast at morning was plotted.

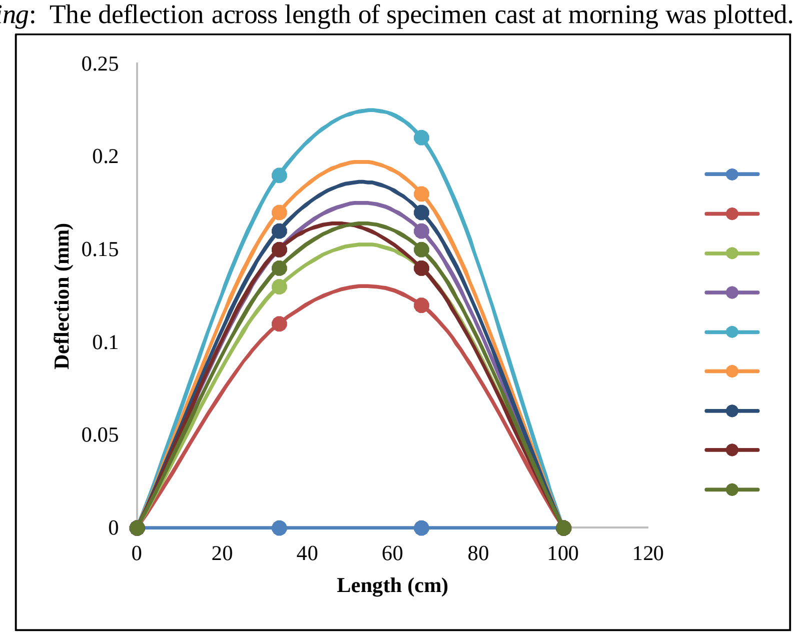

Fig. 11 Deflection of Specimen at One Hour Interval (9.30 AM to 5.30 PM)

2) *Specimen Cast at Afternoon:* The deflection across length of specimen cast at afternoon was plotted.

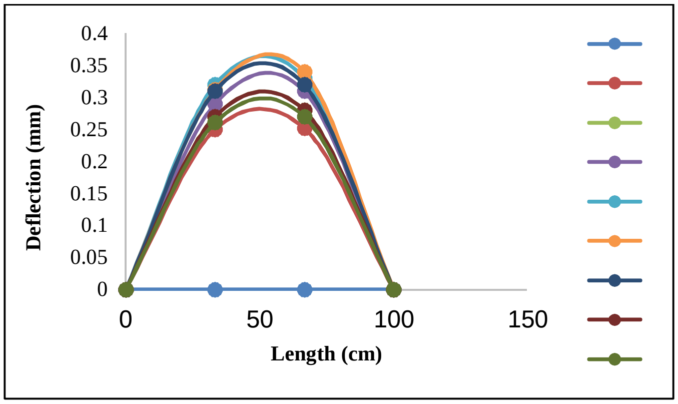

Fig. 12 Deflection of Specimen at One Hour Interval (9.30 AM to 5.30 PM)

V. CONCLUSIONS

The main objective of the experimental work was to study the effect of climatic conditions and temperature gradient on Jointed Plain Concrete Pavement. The mechanical properties of the specimen was determined by compressive strength and the behaviour of specimens cast at morning and afternoon subjected to temperature differential was studied. From the present experimental work, following conclusions are arrived at.

1) For the specimen cast at morning, maximum temperature at the top of the specimen observed was 40.5°C and was reached after initial 24 hours and minimum temperature was 30.1°C.
2) For the specimen cast at morning, maximum temperature at the bottom of the specimen observed was 41.1°C and was reached immediately after few hours and minimum temperature was 29°C.
3) For specimen cast at afternoon, maximum temperature at the top of the specimen observed was 40.6°C and minimum temperature was 32.5°C
4) For specimen cast at afternoon, maximum temperature at the bottom of the specimen observed was 40.2°C and minimum temperature was 32.4°C.
5) Maximum temperature at the top and bottom surface for the specimen cast at afternoon was reached after initial 24 hours.
6) Temperature observed shows a nonlinear variation across the depth of specimen.
7) The maximum positive and negative temperature differential for the specimen cast at morning was +6.7°C and -2°C.
8) The maximum positive and negative temperature differential for the specimen cast at afternoon was +4.9°C and -3.7°C.
9) Maximum positive temperature differential was observed for specimens cast at morning and maximum negative temperature differential was observed for specimens cast at afternoon.
10) The specimens showed a downward curling during daytime.
11) During the initial hours of casting, average specimen temperature do not follow the air temperature trends due to heat of hydration of concrete.
12) Average compressive strength of specimens cast during afternoon was higher than those cast at morning.

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