PAPER No. 396

Recording of Temperature Changes Inside The Concrete of Sukkur Barrage Arches

By

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Synopsis

For two years, observations have been carried out in the Road Arch No. 8 and the Gate Arch No. 8 of the Sukkur Barrage to determine the range of variation of temperature inside the arches at various depths as compared to the outside air temperature. The experiments have been successfully performed by using electrical wire resistance thermometers which have given trouble-free performance and are working satisfactorily.

This experiment is first of its kind and has given the order of variation of temperature at different depths in the arches during a single day and over the full range of one year. It has been found out that in case of reinforced lime concrete, the range of annual variation of temperature at a depth of six inches inside the concrete is about 36°F.

The application of this information has been attempted to be utilized for the whole of West Pakistan where the highest and the lowest temperature contours are plotted and the range of variation of internal temperature has been worked out for coarse aggregates made of Quartzite or Dolomite. When these aggregates are used, the range of temperature equal to 36 F observed at six inches inside the Sukkur arches, shall have to be raised by 10 per cent. If the aggregates are made of Granite, Rhyolite or Basalt, the range of temperature within six inches of the arches has to be decreased by 20 to 30 per cent. This is due to the low heat conductivity of these materials.

These estimates are on the basis of mean temperature for ten days' period. For exceptionally hot or cold days the variation in temperature can be ±10°F higher than the mean of ten days. This will result in an additional rise of about 4°F at a depth of six inches inside the concrete on the basis of daily variation. For annual variation of temperature it will increase by an additional order as given in the text.

The true range of temperature variation within a set concrete and the corresponding temperature stresses which can be expected in the concrete can be more exactly determined on the basis of these evaluations.

Appearance of Cracks in Sukkur Barrage Arches

In the year 1949, cracks were noticed on some piers of the Sukkur Barrage and in the arches of the regulating bridge. The matter was viewed with great concern and after a long discussion and expert advice, repairs were carried out in 1952. These included special repairs to piers and guniting of the arches. The work was carried out by Cementation Co., a well known British firm.

In April, 1964, Mr. A. R. Kazi, the then Secretary, Irrigation and Power again noticed innumerable cracks on the arches of the Barrage both at the Road Bridge and the Gate Bridge.

Renewed concern was expressed on the condition of the Barrage. Mr. Kazi instituted a Technical Committee to go into the details of the causes of the appearance of cracks, and to report on the safety of the structure and ultimately suggest some remedies.

The Committee found it necessary to study the original design, check the stress analysis and work out the stability of the structure under the present condition of the section of the arches some of which were found to have no concrete cover on the bottom tension reinforcements due to their rusting.

In order to carry out detailed investigations and analyses of the structural stability, Mr. Mazhar Ali was entrusted with the problem. His analysis[1] showed that in the arches temperature stresses were far more important as compared to the dead load and an assumed order of live load. The temperature stresses were found to be nearly 70% of the total stresses on the arches. These were worked out by assuming the annual temperature variation of 60°F. This was based upon the practice for stress estimation. In fact it depended upon the range of variation of air temperature at the site of construction.

The true thermal stresses in the arches could only be worked out on the basis of temperature variation within the arches. The internal temperature in a set concrete depends upon such thermal properties of the concrete as the conductivity, the specific heat and diffusivity. These properties vary with the nature of aggregates, type of cement used, density of the concrete and in particular with reinforcement which has different thermal properties as compared to concrete.

Due to several parameters entering into temperature variation in a set cement concrete, it is not possible to compute the variation of temperature in a mass of set concrete. It is, however, more convincing and easy to actually record the temperature variation within the arches as it changes with the variation of air temperature. A few years' observations of temperature at different

positions inside an arch could give the convincing information. Thus these studies were planned to record the temperature changes within the arches at Sukkur Barrage. This paper gives the technique used for recording the temperature, the changes of temperature observed at different depths in the morning and in the evening and also during a full one year. Some information on the variation of temperature observed at an interval of one hour during twenty-four hours is also put forth.

Thermal Stresses in Set Concrete

If a piece of concrete is restrained from expansion, the order of stresses developed depends upon the thermal expansion and the modulus of elasticity and change of temperature.

The stresses are expressed as :—

$$F_c = E_c \frac{\triangle L}{L} \times t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

F_c = the tension or compression stresses in lbs. per sq. inch.
E_c = the modulus of Elasticity of the concrete in lbs. per sq. inch.

Its order is taken as 3,000,000 lbs. per sq. inch although it is found to vary not only with the material forming the concrete but also with the method of test.

$\frac{\triangle L}{L}$ =the linear expansion per unit length due to one degree rise of temperature and
L =the length of the concrete piece
t =the variation of temperature in °F.

The coefficient of linear thermal expansion is expressed as the increase in length per unit length per degree rise of temperature. If the temperature is expressed on Fahrenheit scale, the order of linear thermal expansion is 6×10^{-6} inch per inch per °F.

If the length of a concrete column is say 70 ft. and the temperature variation is 60°F, then the thermal stresses developed will correspond to :—

$3 \times 10^6 \times 6 \times 10^{-6} \times 60 = 1080$ lbs. per sq. inch

and the total expansion would be :—

$70 \times 6 \times 10^{-6} \times 60 \times 12 = 0.302$ inch.

This expansion if restrained will result in 1080 lbs. per sq. inch of compression.

Order of Variation in Expansion Coefficient and Modulus of Elasticity

The above-mentioned order of coefficients of thermal expansion and modulus of elasticity vary with the type of materials used as aggregates and the richness of the concrete mix.

U.S. Bureau of Reclamation in their concrete manual[2a] have put forth the order of thermal expansion as it varies with the mix ratio. This is reproduced in Fig. 1.

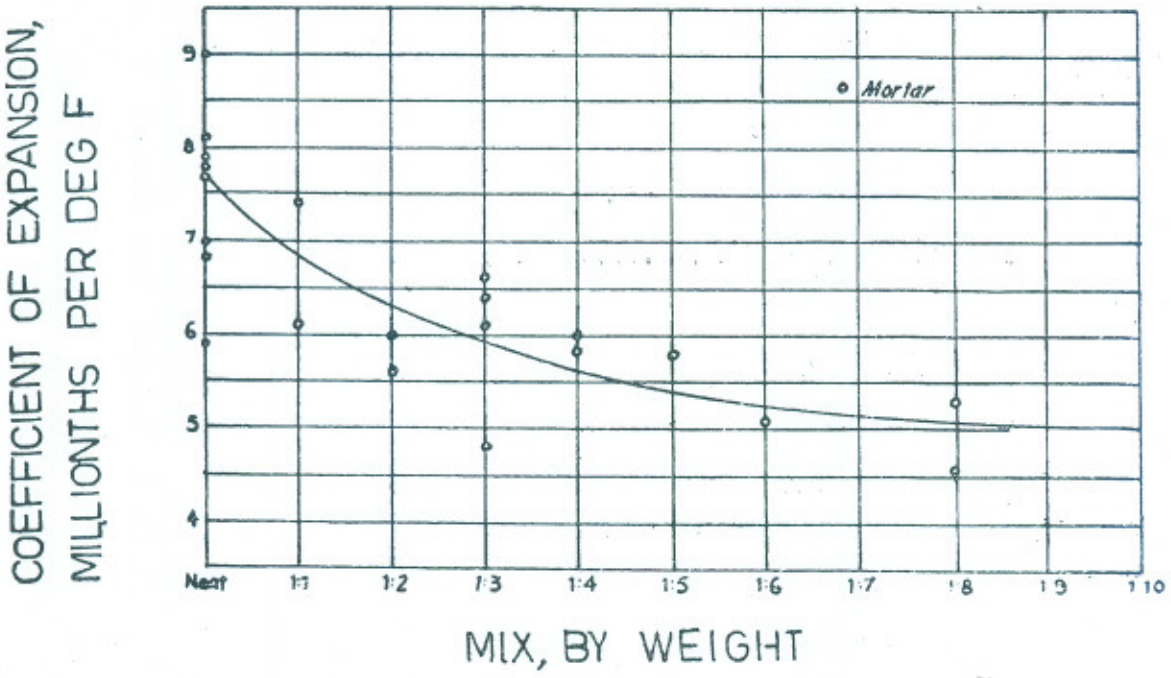


Fig. 1. Thermal Coefficient of expansion as it varies with different mixed ratios of cement and sand.

The coefficient of expansion is the highest for neat portland cement. It continues to decrease with leaner mix ratio. The variation of the coefficient lies between 5×10^{-6} to 7.6×10^{-6} inch per inch per F.

Similarly the thermal expansion varies with the type of aggregates used.

In Fig. 2 the order of the coefficient as it varies with different aggregates when used in the mix ratio of 1 in 4 to 1 in 5 and that between 1 in 9 to 1 in 10 is shown. The range of variation is between 3.5×10^{-6} to 6.8×10^{-6} inch per inch per °F.

The Modulus of Elasticity also varies with the type of the aggregate, mix ratio, and method of tests. A slow or a quick loading test, employment of flexture method, stress strain or sonic technique, all give slightly varying

order of Modulus of Elasticity. The value of 3×10^6 lbs. per sq. inch is towards a low order[2b] and is more suited to concrete made with limestone as aggregates.

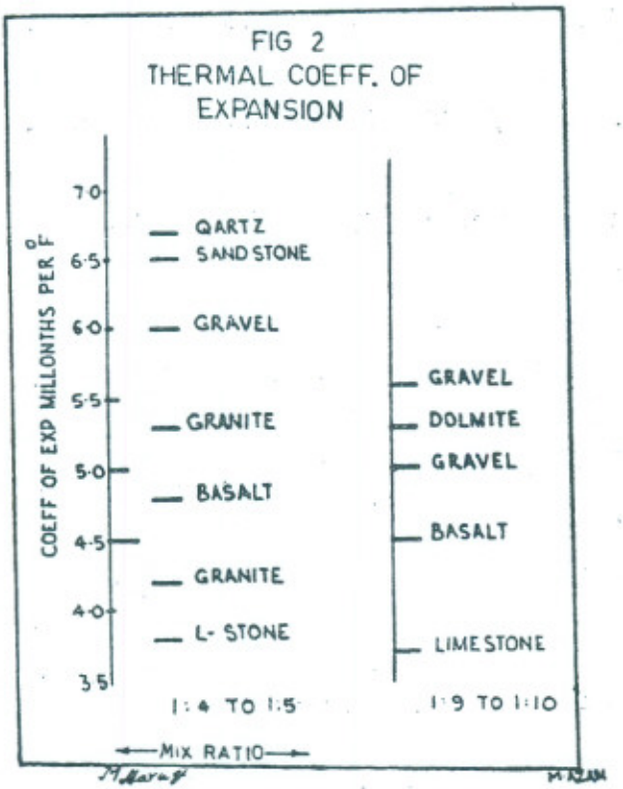


Fig. 2. Thermal Coefficient of expansion as it varies with coarse aggregates of different materials.

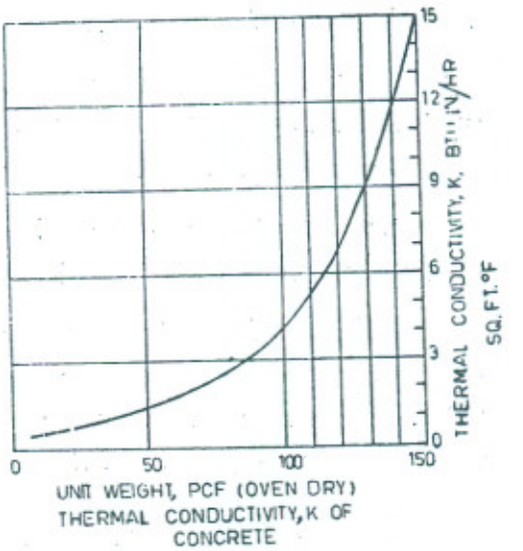


Fig. 3. Thermal conductivity varies with specific weight of the concrete.

Thermal Properties of Cement Concrete

Heat transmission through a mass of set concrete depends upon its conductivity. The denser a concrete is, a better conductor of heat it is. In Fig. 3 is plotted the thermal conductivity, as it varies with the density of the concrete.[3]

The thermal conductivity is measured either in calories or in British Thermal Units. According to the definition the quantity of heat Q, conducted through a cross sectional area equal to A of a specimen of width equal to x, is expressed as :

$$Q = KA \frac{q_1 - q_2}{x} \cdot t$$

Here

Q = the quantity of heat conducted through a medium of cross sectional area equal to A and width equal to x, the temperature of the two surfaces being kept equal to q_1 and q_2 degrees and t is the time for which the heat is allowed to be conducted.

The factor K is the coefficient of thermal conductivity.

If the area A is one sq. ft. and the width x is also equal to one foot, time t for heat conduction is one hour and the difference of temperature of the two surfaces is one degree F, then the quantity of heat conducted is equal to K British Thermal Unit, or B.T.U.

If the units are measured in C.G.S. system, the unit of heat transmitted is in calories.

The conductivity is found to vary not only with the mix ratio but also with the type of coarse aggregates used.

In 1933-46 Bureau of Reclamation of America during the construction of Boulder Canyon Project carried out, large-scale tests on cement and cement concrete and their thermal properties.[4]

In these tests the thermal conductivity was determined for the range of temperature between 50°F to 150 °F.

Slight variation in the range of conductivity with change of temperature was found which, however, varied to a large extent with different type of aggregates. These results for two temperature of 70° and 90°F are shown in Table 1 for six different types of rocks and for neat cement, sand mortar and concrete.

It was found that the coarse aggregates were the most important elemental material affecting the conductivity of concrete.

These tests were conducted by devising a very elaborate apparatus and a special type of technique was adopted.

Other Thermal Properties of Concrete

Beside thermal conductivity, specific heat and diffusivity of heat are important physical characteristics which determine the transmission of heat through a mass of set concrete.

Specific heat is defined as the amount of heat needed to raise the temperature of one pound of a substance through one degree F. This quantity of heat can also be measured in B. T. U. If, however, the weight of the material is one gram and the range of temperature is 1°C then the unit of specific heat is the calory.

Diffusivity is the property of concrete which permits it to disperse or diffuse the heat in all directions. It is actually the ratio of conductivity to

specific heat and unit weight of the material. It is expressed as

$$\text{Diffusivity} = \frac{K}{c\,\rho}$$

When the proper units for each thermal variable are used, the unit for diffusivity works out to be the rate of temperature change in feet square per hour. The variation of these parameters also determined experimentally by the Bureau of Reclamation are shown in Table 1.

TABLE No. 1.—*Thermal Properties of Concrete, and of various types of Coarse Aggregate.*

Series	Material & Aggregate	Temperature of Concrete °F.	Conductivity K, B.T.U. ft.×hr.×°F	Specific heat C, B.T.U. lb.×°F.	Density lb./cu. ft.	Diffusivity ft.²/hr.
MCQ	Quartzite	70	2.040	0.217	151.7	0.0620
		90	2.028	0.226	151.7	0.0592
MCD	Dolomite	70	1.925	0.231	156.2	0.0534
		90	1.903	0.380	156.2	0.0512
MCL	Limestone	70	1.842	0.224	152.8	0.0538
		90	1.815	0.230	152.8	0.0516
MCG	Granite	70	1.511	0.220	150.9	0.0455
		90	1.508	0.224	150.9	0.0446
MCR	Rhyolite	70	1.203	0.226	146.3	0.0364
		90	1.207	0.232	146.3	0.0350
MCB	Basalt	70	1.212	0.226	157.5	0.0341
		90	1.211	0.230	157.5	0.0334
SN	Neat Cement	70	0.580	0.328	127.3	0.0139
		90	0.598	0.344	127.3	0.0137
M⁴	1 : 2.9 Mortar	70	1.381	0.256	139.9	0.0386
		90	1.382	0.265	139.9	0.0373
S	1 : 2.0:4.5 Concrete	70	1.567	0.220	153.7	0.0463
		90	1.562	0.229	153.7	0.0444

NOTE :—W.C. ratio used was for SN, 0.32, for M⁴, 0.52 and for S, 05.

A plotting of these results in Fig. 4 is instructive.

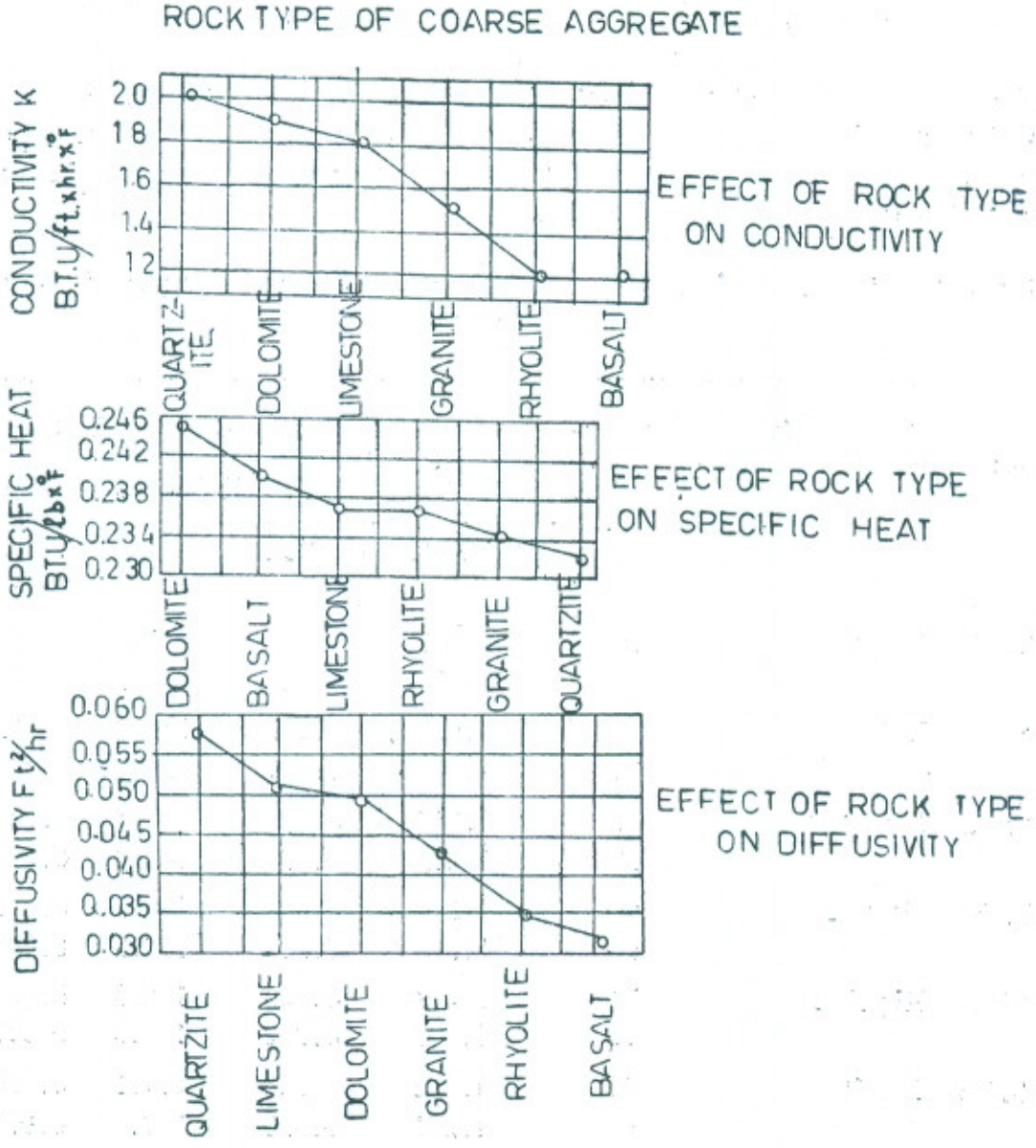


Fig. 4. Conductivity, specific heat and diffusity for various coarse aggregates.

Heat Transmission and Time Lag

When heat is applied at one face, it is slowly conducted to inside of a specimen. If a constant temperature is maintained on one face for a long time, a steady temperature is attained under the combined condition of diffusivity, specific heat, density of the material etc. In Fig. 5 which was a method used by Forbes[5] for experimental determination of heat conductivity, this attainment of steady state of conditions is shown.

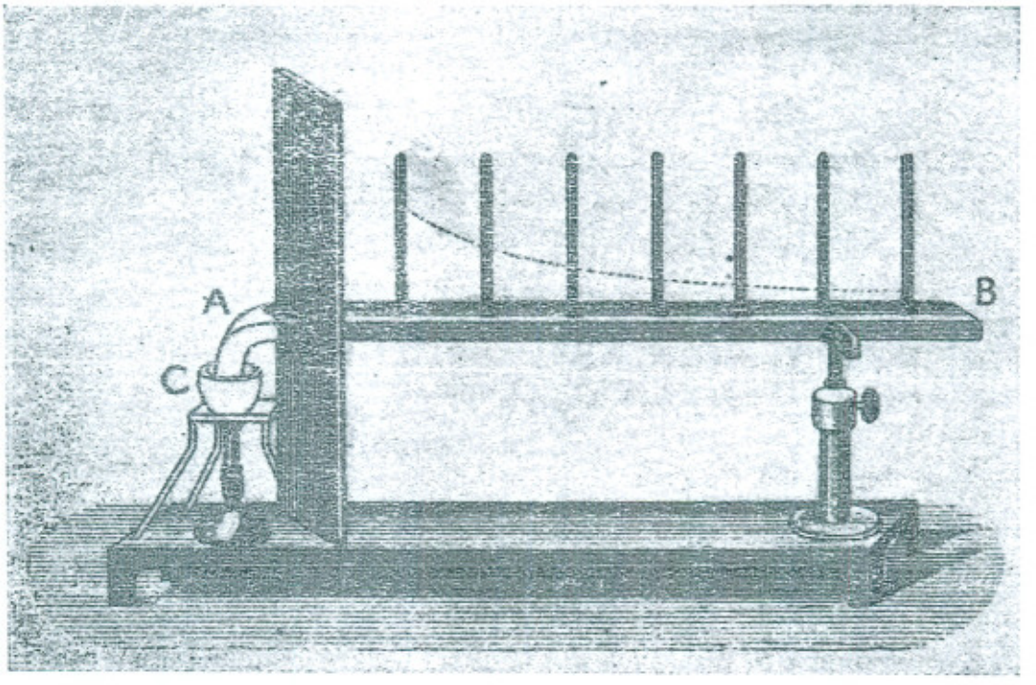
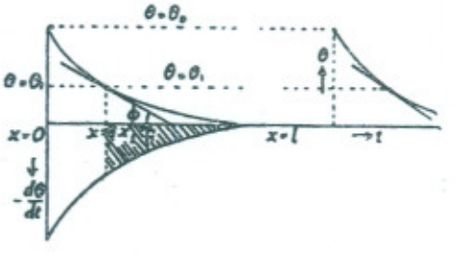


Fig. 5. Forbes methods on experimental determination of thermal conductivity.

If $x=0$ is the face of the bar, $x=1$, is the length of the bar (see Fig. 6), then the heat lost per second by radiation from the surface of the bar under



THERMAL CONDUCTIVITY
DETERMINATION

Fig. 6. Thermal conductivity determination.

steady state is given by

$$-A dx c \rho \frac{d\theta}{dt}$$

where P = the density of the material.

c = the specific heat and

$-\frac{d\theta}{dt}$ = the rate of cooling of the element, dx. The total heat lost by

the portion of the bar for $x=x_1$ and $x=1$ in a second is

$$-A\rho c \int_{x=x_1}^{x=l} \frac{d\theta}{dt}\, dx \quad \ldots\ldots\ldots\ldots (2)$$

This will be equal to the heat crossing the surface at $x=x_1$

$$i.e. = -KA\left(\frac{d\theta}{dx}\right)_{x=x_1} \quad \ldots\ldots\ldots\ldots (3)$$

Equating 2 and 3 we have:

$$\frac{K}{\rho c}\left(\frac{d\theta}{dx}\right)_{x=x_1} = \int_{x=x_1}^{x=l} \frac{d\theta}{dt}\, dx$$

$$\text{or} \quad \frac{K}{\rho c} \tan\phi = F$$

where F and tan ϕ are depicted in Fig. 6. From this type of experiment $\frac{d\theta}{dt}$ is determined from the observation of θ, x and t.

Curves similar to that given in Fig. 6 are usually obtained when heat is transmitted through a mass of concrete. The type of such curves for the range of temperature recorded at different distance from a hot surface are shown[6] in Fig. 7. Steep fall of temperature inside a mass of concrete is evident.

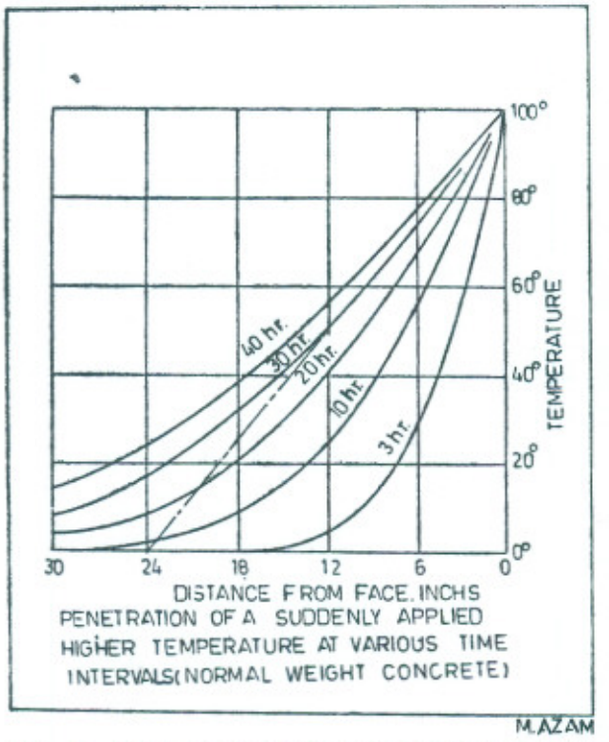


Fig. 7. Heat conductivity into different depths as it varies with the rise of temperature.

In actual study of cement concrete, on a natural specimen a constant temperature cannot be maintained. Usually the temperature varies in a day, so that a sine wave of heat works on the face. The heat transmitted is also of the same form although of low amplitude with a certain time log. A typical case of heat transmission and time log is exhibited in Fig. 8.

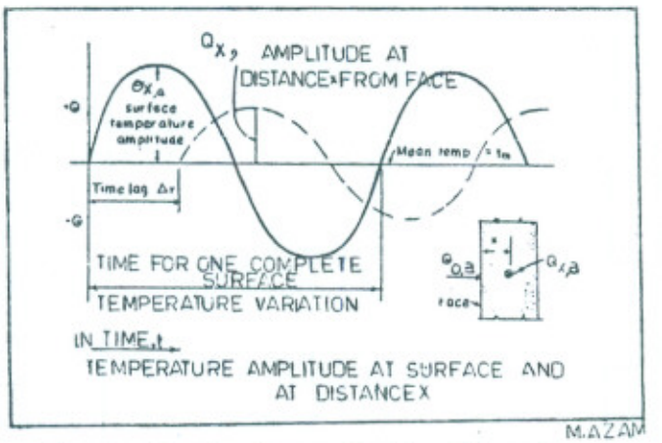


Fig. 8. Time lag for conduction of heat into a mass of concrete.

Experimental Treatment of the Problem is More Convincing

A perusal of the information put forth shows that theoretical treatment of estimation of the order of heat conducted in a set concrete is rather complicated due to the several factors coming into action at the same time. Besides the factor of thermal variation in concrete and the material forming the mix, such factor as the humidity and moisture absorption of the material are also factors causing the variation.

The subject of study of heat conductivity in an arch has other difficulties. The thickness of an arch varies from the crown to the haunching. The existence of reinforcement also complicates the matter. The arches at Sukkur Barrage have the complication, of the existence of a road with a black top surface exposed to direct rays of the sun and which thus attains a higher temperature as compared to the cream coloured bottom of the arches. Thus these arches are subjected to a higher order of temperature at top and somewhat lower temperature at the bottom.

The gate arches of the barrage are considerably small in dimension and have the same thickness as the road arches. These are also subjected to different intensities of temperature variation both at top and at bottom.

This type of complicated case could only be studied experimentally.

Experimental Technique

In this country recording of air temperature is conducted at many places by Meteorological Department or by other organizations. Usually maximum and minimum temperatures are recorded twice daily, early in the morning at 8 A.M. and in the evening at 5 P.M. The problem of recording temperature inside a set mass of concrete was a new one, seldom tried in this country. Some information in the world literature is available such as temperature stresses in tall reinforced concrete buildings,[7] Thermal conductivity of building materials,[8] Steady State Heat Transmission in an exposed exterior column of Rectangular Cross Section[9] and Temperature variation and their effects on Column Exposure in Tall Structures[3] etc. This literature could not directly help us in the problem of temperature recording in set concrete of Sukkur Arches. Thus experimental methods had to be devised, perfected and then used for the first time in this country.

Development of Wire Resistance Thermometers

The first problem was the devising of temperature recording thermometers. Use of glass thermometers was out of question. Some robust type of recording thermometers were needed. In this connection three types of devices are known to a student of physics.

These are the use of:

(*i*) Thermo-couple,
(*ii*) or Thermistor,
(*iii*) or Wire wound resistance thermometer.

A thermo-couple is no doubt very sensitive but it is very cumbersome to use. Its two junctions must be maintained at two different temperatures. The use of several couples close together can complicate their application. This technique is more suited in a laboratory and cannot be easily applied in the field, by staff not fully scientifically qualified.

Thermistor is a recent development of semi-conductors similar to transistor. A thermistor is very flimsy, liable to damage and of doubtful durability in the field. Technically it is also not very suitable as its resistance change is not linear with change of temperature. Two thermistors have often different types of temperature resistance curves. There was also not much experience about the use of these instruments in set cement concrete and hence this device was also not considered suitable for use in the experiment.

The third device consisting of wire wound resistance thermometer was thus selected for recording the temperature. This instrument is based upon the principle that the resistance of a given length of a wire changes with change in temperature. For instance a certain length of copper wire having a resistance of

100 ohm. at a given temperature, shows a change in resistance of 0.43 ohm. for one °C rise of temperature. The change in resistance is related with temperature according to the relation:

$$R_t = R_o (1+\alpha t+\beta t^2+\gamma t^3+.....)$$

in which R_t is the resistance of a certain length of wire at t degree temperature, R_o is the resistance at zero degree temperature of the same wire and α, β and γ etc., are constants for the material. Generally the temperature coefficient for higher terms are too small and can be neglected, so that

$$R_t = R_o(1+\alpha t)$$

can give quite workable results.

It is always suitable to select a material of quite a high order of the co-efficient.

In Table 2 the value of the coefficient[10] for varies materials are shown. Iron has the highest order of the coefficient, α, but it is difficult to get it in a pure state. Tin, silver, platinum and copper are the other materials with high order of the coefficient and from many considerations copper is the most approximate material easily available in a suitable form for use in the wire resistance thermometers.

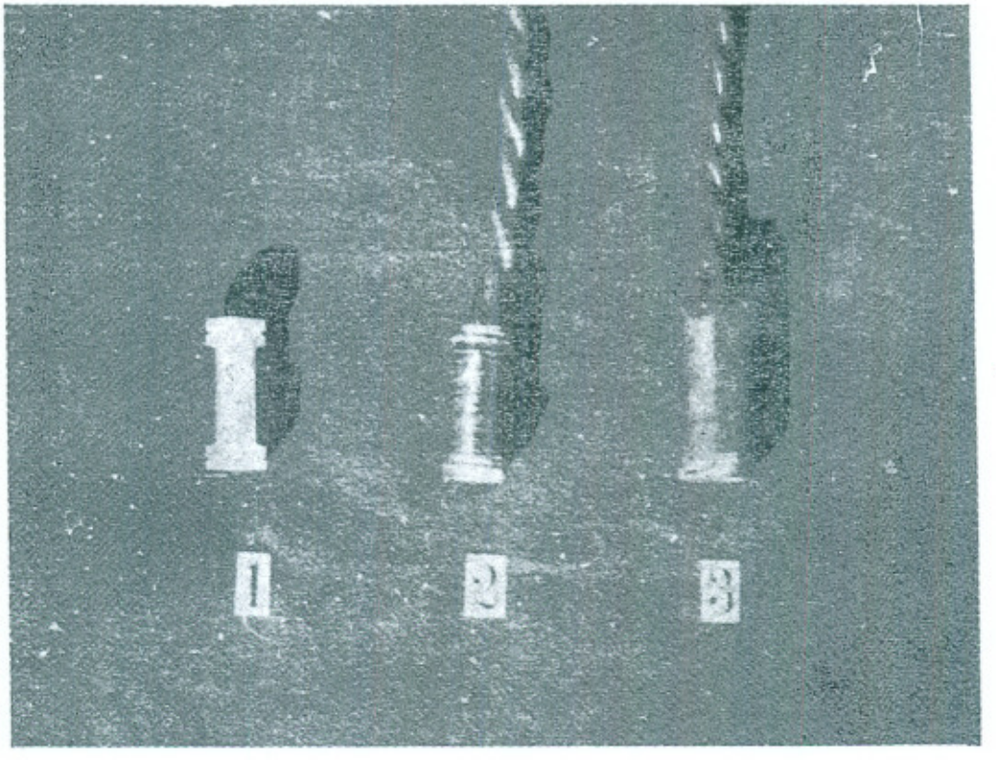


Fig. 9. (1) is the plastic reel,
(2) reel with winding of copper wire,
(3) complete thermometer with casing etc.

TABLE NO. 2

Metal	$\alpha 10^{-4}$
Aluminium	38
Copper	42.8
Gold	40
Pure Iron	62
Gold	16-42
Platinum	35-38
Silver	40
Tin	45
Zinc	37
Brass	10
German Silver	2.3-6
Maganin	0.02-0.5
Nichrome	1.7

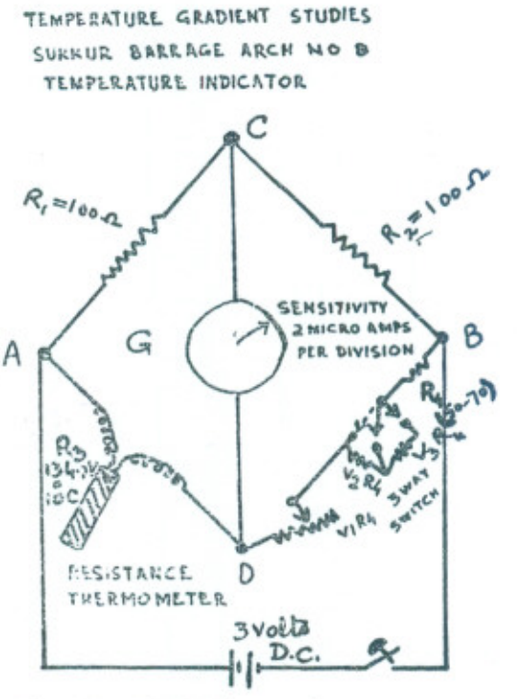


Fig. 10. Block diagram for temperature recorder.

A copper wire of 44 S.W.G. having a diameter of 0.081 mm. has a resistance of 3.4 ohms per meter, so that nearly 42 meters long wire having a resistance of 142 ohms. at 20°C was used for the preparation of thermometers. A plastic reel as shown in Fig. 9 was selected and the copper insulated wire of 44 S.W.G. was wound on it. The two terminals of the wire were soldered to a stout wire. It was arranged that each thermometer should have 142 ohm. resistance at 20°C. The calibration was actually performed for each thermometer by checking its performance with a standard mercury thermometer. The resistance of each thermometer was adjusted to give identical performance. Large number of thermometers having the same resistance were thus manufactured.

Temperature Recording Instruments

Variation in resistance is easily and accurately measured by a wheatstone bridge. This instrument can be so adjusted as to give direct temperature reading instead of variation in resistance.

Refer to Fig. 10 which is a block diagram of the instrument, R_1, R_2, R_3, and R_4 are the four resistance arms of the bridge. R_1 and R_2 are nearly equal resistances while R_3 represent the resistance of the wire wound thermometer. The four resistances at a given temperature are balanced to give zero reading on a sensitive galvanometer. If the temperature of R_3 changes, it attains a different

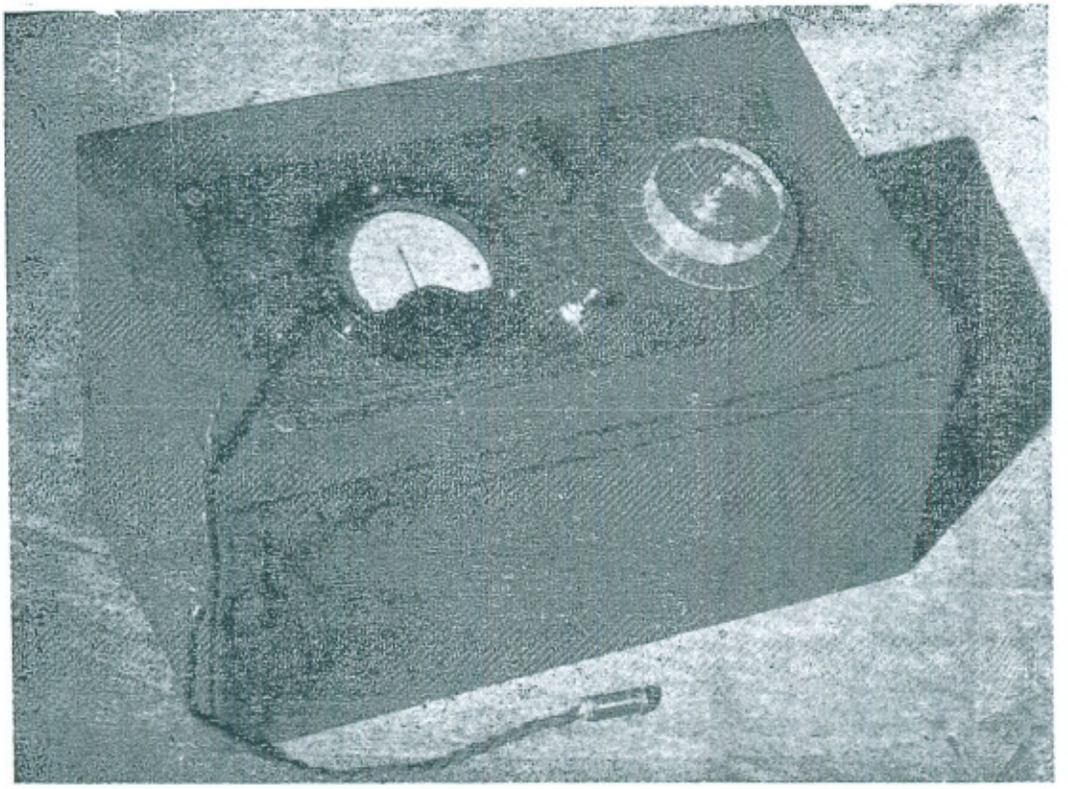


Fig. 11. Temperature recording instrument.

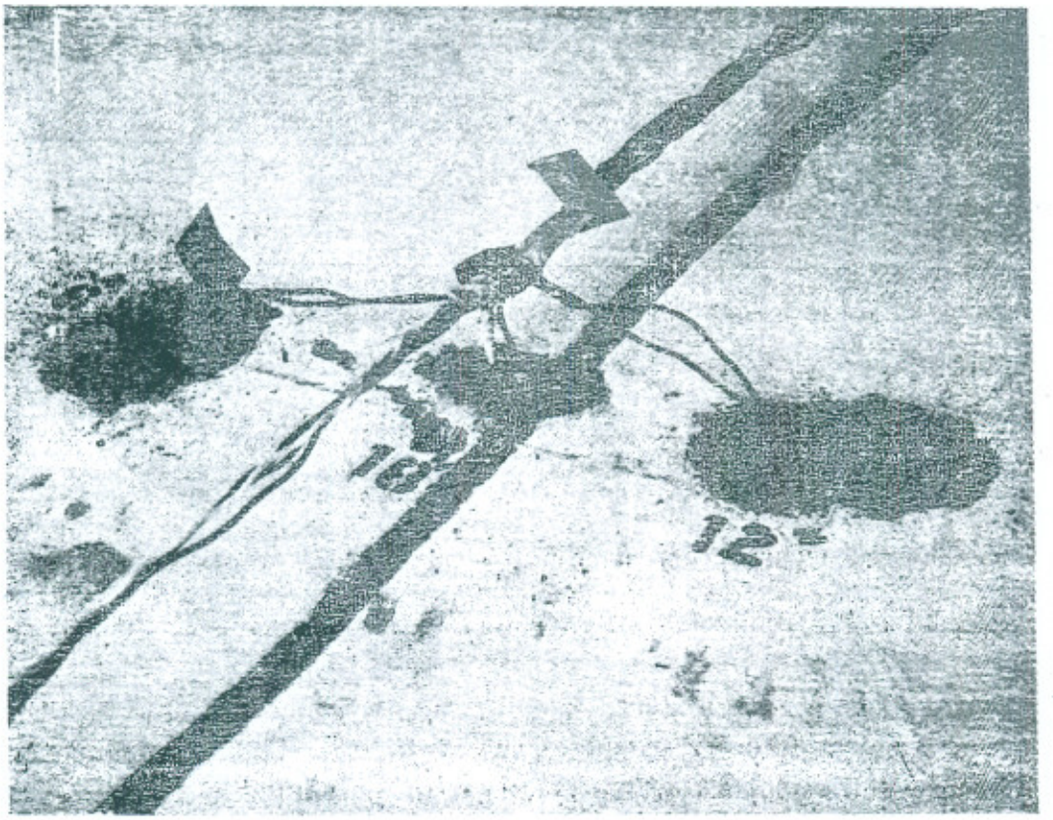


Fig. 15. Three sets of thermometers as installed in the Crown of Road Arch No. 8.

order of resistance and the bridge is unbalanced, so that the galvanometer needle shifts its position.

A variable resistance, V_1 R_4 is provided in series with the resistance R_4. It is adjusted to balance the bridge again. This resistance is calibrated into a temperature scale and hence gives directly the temperature of the resistance thermometer.

The instrument can be made to any sensitivity and for any range of temperature variation. The instrument perfected for the purposes is shown in Fig. 11. It was provided with three ranges of temperature between 10-30°C, 30-50°C and 50-70°C corresponding to 50-86°F, 86-122°F and 122-158 F. This change was effected by introducing additional fixed resistances, V_2R_4 and V_3R_4 in the instrument.

Installation of Thermometers in the Arches

The Arch No. 8 of the Barrage was selected for the installation of the thermometers. A typical section of the Road Bridge Arch is shown in Fig. 12. Two cross sections at crown and close to springing as shown in Figs. 13-*a* and *b*

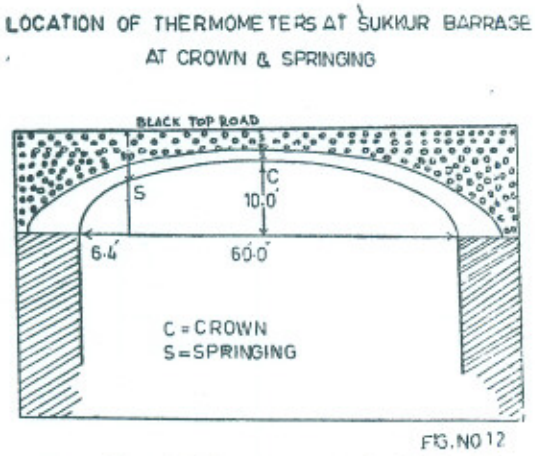


Fig. 12. Sukkur Barrage Arch No. 8.

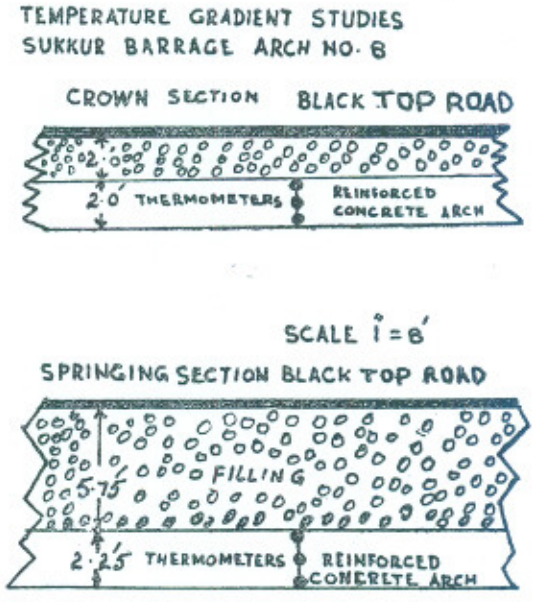


Fig. 13. *a* & *b*. Cross section of the arch showing the location of thermometers.

were selected and thermometers were installed in these two cross sections of the arch. At the crown the thickness of the arch is only 2.0 ft. On top of this arch runs a road which is 25 ft. 3 inches in width. It has a bottom course of 2 feet thick lime concrete, followed by the top black surface. Lime concrete covers the bottom and the sides of the arch are plastered. Guniting to a thickness of one to two inches was done on the bottom surface in 1952. It was then coated

with snowine, so as to match its colour with the rest of the lime masonry. No guniting was done on the sides of the arch.

At the crown section of the arch seven groups of three thermometers each to a depth of 6, 12, and 18 inches were installed. The distance apart of the two groups of thermometer was four feet. On both sides within 6 inches from surface such three thermometers were fixed. One set was installed in the centre and two sets each were put in between the centre and the sides.

In Fig. 14 the location of seven groups of three thermometers each is shown.

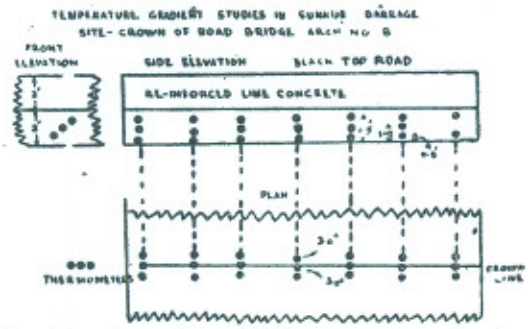


Fig. 14. Location of thermometers in the Crown of Road Arch No. 8.

The three thermometers of a group were kept staggered about six inches apart, as shown in the plan of the same figure.

While installing a thermometer, a hole 3/4 inch in diameter was drilled up to the required depth. The thermometer just fitted the drill hole and after locating it at the required depth, the hole was repacked with 1 in 3 cement sand mortar.

The leading electrical wires were taken out and brought to a switch board installed on a pole fixed 4 feet above the bottom. In Fig. 15 the leads of three thermometers at a site are shown and Figure 15-*a* and *b* gives an idea

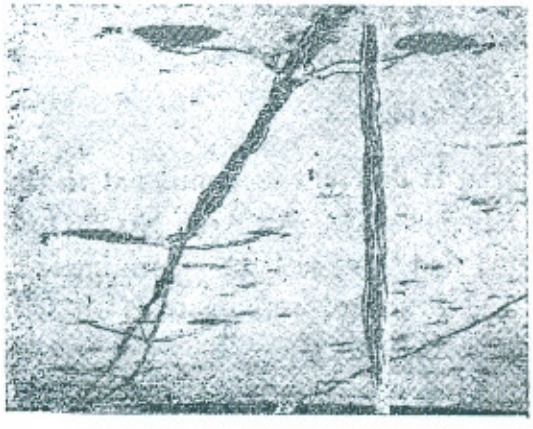


Fig. 15*a*. Showing the connections and the leeds for the thermometers installed at the Crown of Road Arch No. 8.

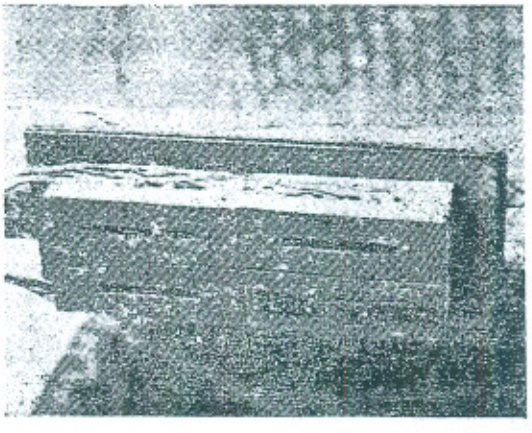


Fig. 15*b*. The panel switch board for recording temperature.

of the connection for all the seven groups of thermometers and their leads brought down to a common switch board.

Increase in the Number of Thermometers

The installation of the above-mentioned thermometers at the crown section of Arch No. 8 was completed in the month of November, 1966 and observations were started on the 8th of the same month. Preliminary results of the performance of thermometers were discussed in January, 1967 in a meeting of the Technical Committee which met at Sukkur. The results collected till then appeared to be informative.

The Committee desired to increase the number of thermometers and study the changes of temperature within first three inches of the surface. Additional thermometers were then installed in the centre of the arch and on its sides. Thermometers were embedded within half inch, one inch, two inches and three inches from surface. The thermometer embedded within half inch in fact recorded the surface temperature. Thus in addition to the previous 21 thermometers, additional 12 thermometers were started to be recorded from 1st February, 1967 onward.

Thermometer in the Thick Section and Close to the Springing

Close to the piers, the thickness of the arch increases as shown in Fig. 12. The thickness of top concrete above the arch also increases. At a site marked (S) in Fig. 12, ten and a half feet from piers, three sets of thermometers at 6, 12 and 18 inches in depth were installed. The location of the thermometers consisted of one set in the centre and two sets on either sides. There is about 5.75 feet thick lime concrete in between the top black surface and on top of the arch. The installation of thermometers was completed before 8th November, 1966 since then these were continued to be recorded.

Installation of Thermometers in the Gate Arch Bridge

The size and position of the gate arch is different as compared to the road arch. These arches are only 5 feet 3 inches wide. An Arch No. 8 close to road arch of the same number was selected and three sets of thermometers, six at each site at a depth of $\frac{1}{2}$, 2, 3, 6, 12 and 18 inches were installed on 25th April, 1967 and have since remained under observation.

Procedure for Recording the Observations

Every day the recording of the thermometers was carried out in the morning and in the evening. The hours fixed for the morning observations

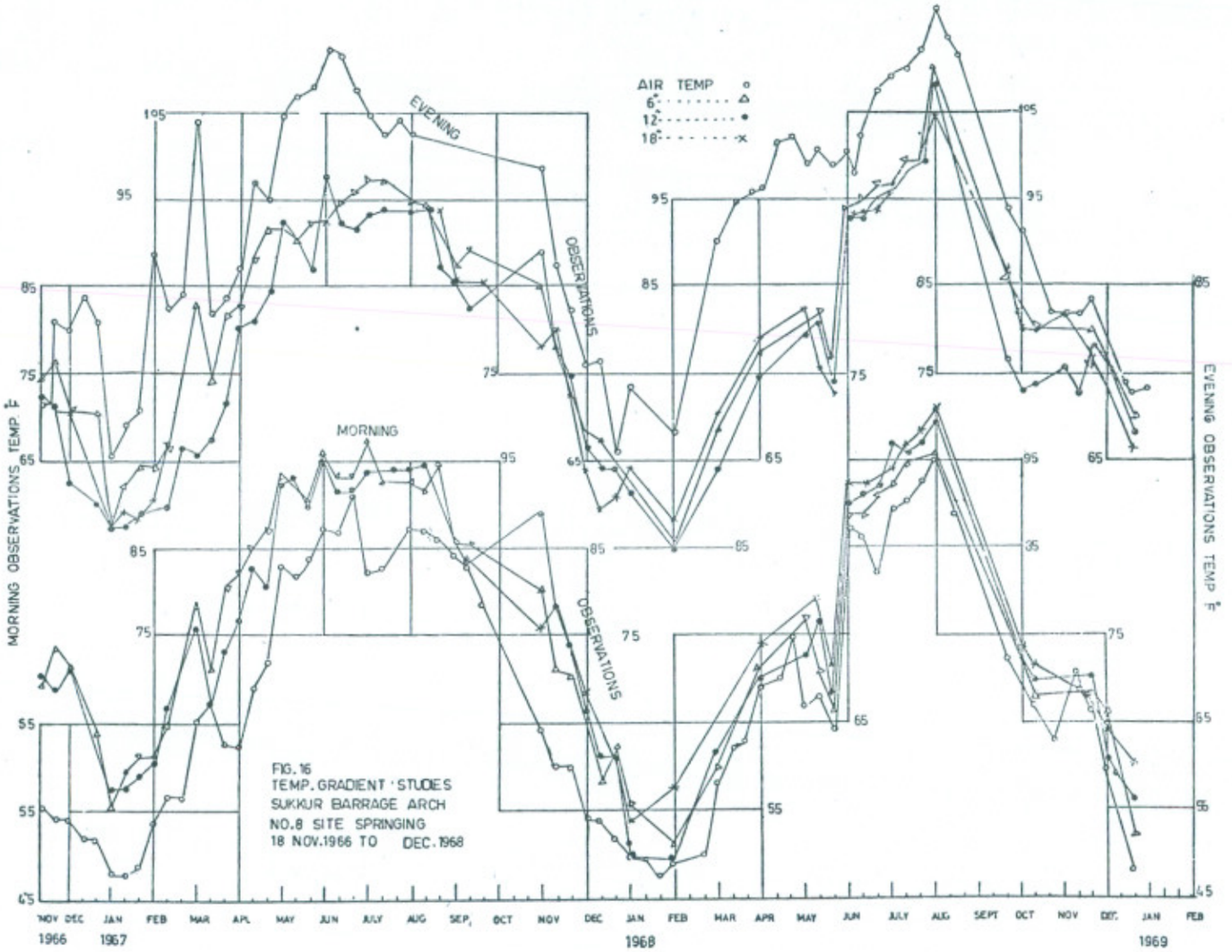


FIG. 16
TEMP. GRADIENT STUDIES
SUKKUR BARRAGE ARCH
NO.8 SITE SPRINGING
18 NOV. 1966 TO DEC. 1968

were 6 and 7 A.M. in summer and 9 and 10 A.M. in winter. Similar hours for the afternoon observations were at 5 and 6 P.M. in summer and 4 and 5 P.M. in winter. Thus both in the morning and in the evening observations were recorded twice for each thermometer.

Air temperature was recorded once in the morning and then in the afternoon from a mercury thermometer hung under the Road Bridge Arch No. 8. Every fortnight, full twenty-four hours' readings were recorded continuously at one hour interval.

The observations were recorded on data sheets drawn up at Lahore and sent to the observers at Sukkur. Observations were recorded on these sheets at site and posted to Lahore. Duplicate records were also kept at site.

On the receipt of the data sheets, these were checked and the variation of temperature was plotted. A constant laison was maintained between the Lahore Laboratory staff and the observers working at site.

Analysis of Temperature Data

For interpreting the temperature variation within the arch at various depths, we have studied separately the recording of thermometers installed close to the springing and in the crown of Road Arch No. 8 and the Gate Arch No. 8.

Variation of Temperature in the Portion Close to the Springing

In the arch close to the springing, thermometers are installed at three different positions, one in the centre and the rest two within six inches on both sides. Their depths are equal to 6, 12, and 18 inches respectively from the bottom surface. The arch thickness at site is 2.25 feet. A filling of 5.75 feet exists under the black top surface, which is exposed to temperature variation. An average of the two observations taken in the morning and two in the evening was worked out and then a ten days mean value was calculated separately for the morning and the evening observations.

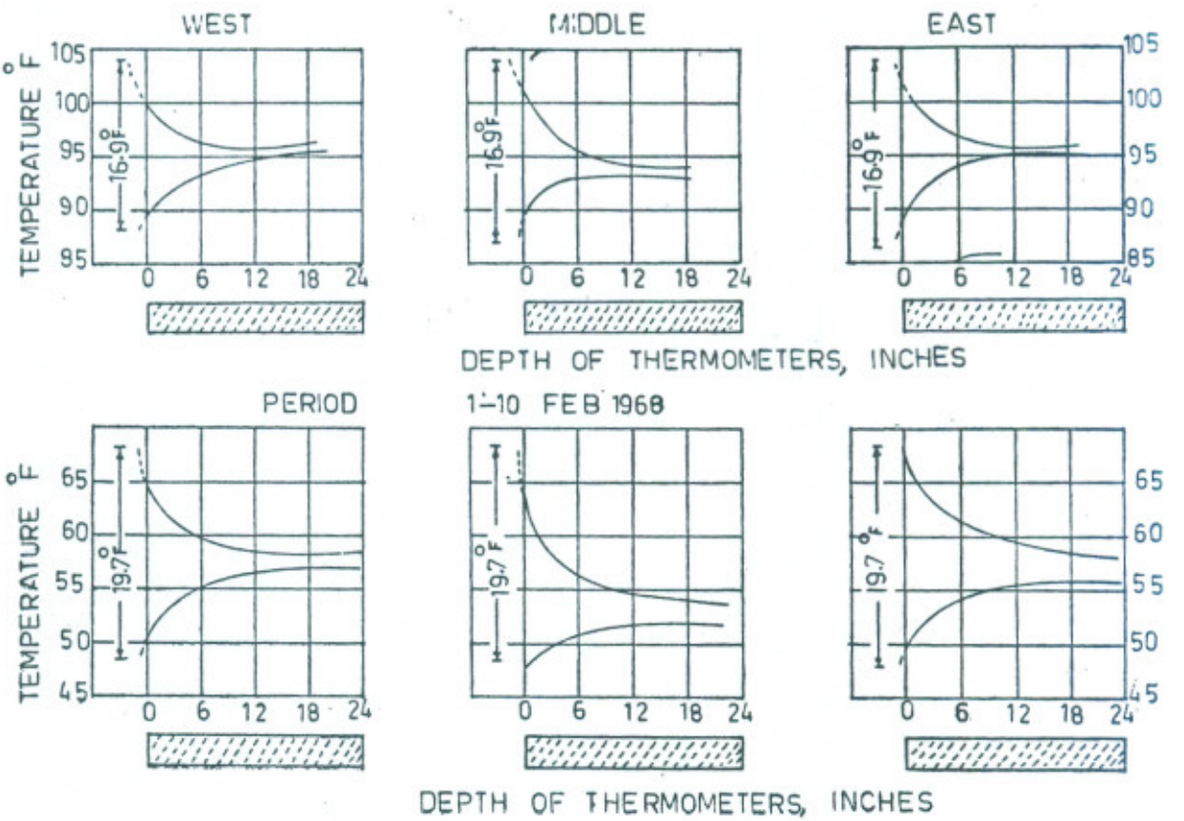
In Table 3, one observation for one set of ten days' mean temperature in a month for thermometers located in the centre and along both sides of the arch is put forth. Full data was, however, included in the preliminary report No. 356-Ph/SM.-13/68. This very data observed for the central thermometers are plotted in Fig. 16. It includes the temperature of the air as well as recorded at 6, 12 and 18 inches inside the arch both in the evening and the morning. The air temperature was the highest in the evening and the lowest in the morning. Variation in the temperature of the thermometers located at all the three depths was recorded.

Daily variation of temperature of air at different depths was studied by selecting periods arbitrarily between hot and cold seasons of the years 1967 and 1968. These data are given in Table 4.

Typical variation between high and low temperature months as recorded by the thermometers fixed at three sites is plotted in Fig. 17.

FIG.17

TEMPERATURL GRADIENT STUDIES OF SUKKUR BARRAGE ARCH NO.8 SITE ROAD BRIDGE SPRINGING PERIOD IST TO 10th AUGUST 1967.



It was noted that the maximum value of temperature in a day was about 24°F although on some days variation of the order of 16 F was also noted.

The variation at 6, 12, and 18 inches depth is, however, instructive. At these depths the daily temperature variation is reduced to 4.5, 2 and 1.0°F respectively for the three sites. This temperature recorded by the thermometers installed on the west side of the arch, exposed to the afternoon sun, invariably showed a high order.

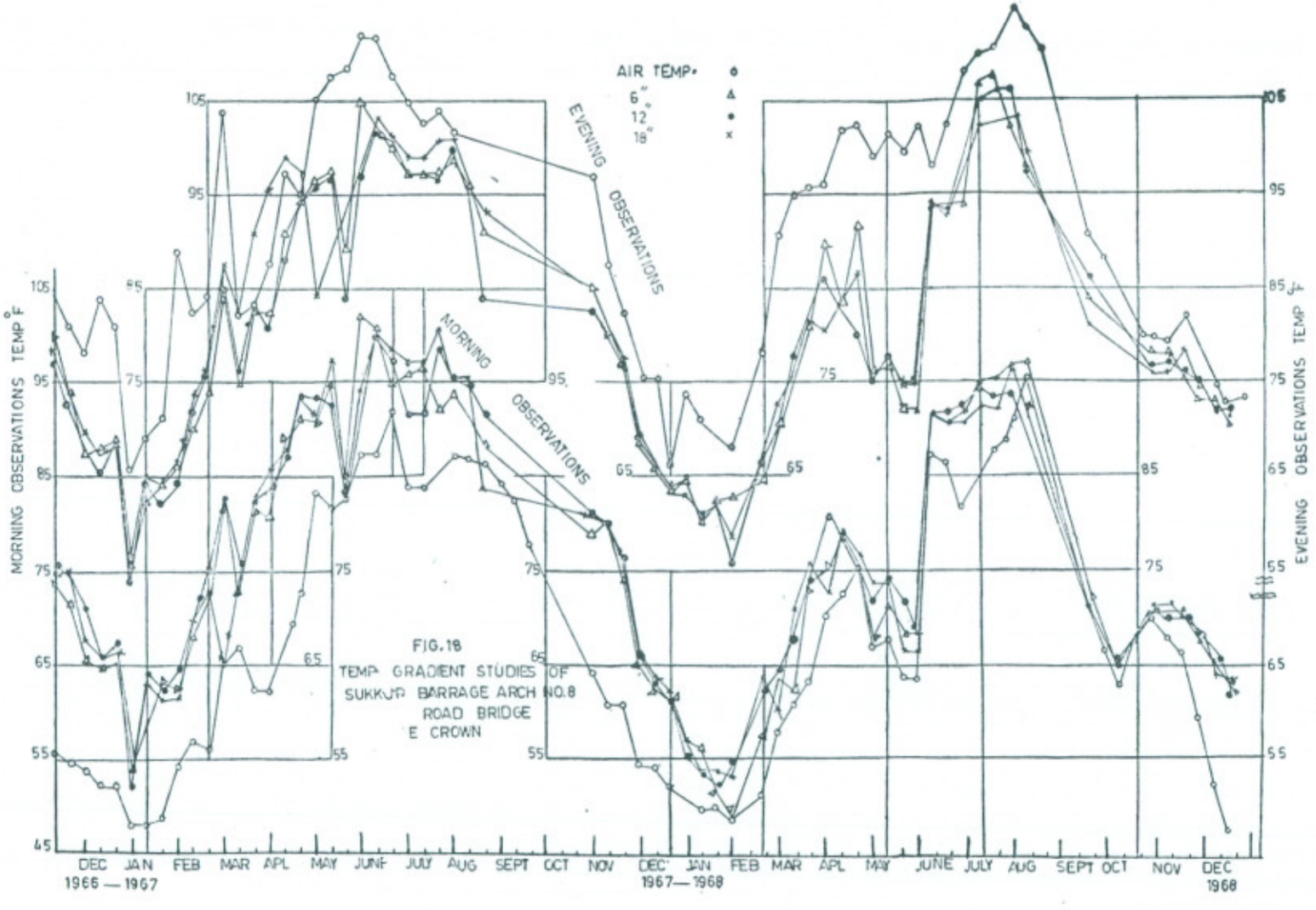


FIG. 18
TEMP. GRADIENT STUDIES OF SUKKUR BARRAGE ARCH NO. 8 ROAD BRIDGE E CROWN

Temperature Recorded by the Thermometers Installed in the Crown Section of the Arch

In the crown portion of this Arch No. 8 seven sets of three thermometers each were installed. Two sets were fixed at sides, six inches inside from the surface. Their observations were started from 8th November, 1966 onward. Later on from February, 1967, twelve additional thermometers at the three sites were installed and all these have continued to be observed. The ten days mean of morning and evening observations for the central thermometers are plotted in Fig. 18.

Ten days' mean for one period in a month for only three sites, two on both sides and one in the middle of the arch are given in Table 5.

Daily Variation of Temperature

The daily mean variation of temperature for selected periods is given in Table 6. The mean for different depths was as under :

Depth of thermometer (inches).	Air	0.5	1.0	2	3	6	12	18
Daily variation of temperature. °F	24	11	8.6	7.6	5	4	2.6	4.4

This variation is also plotted in Fig. 19 for a selected period for all the seven sets of thermometers.

Daily variation of temperature within half inch depth of arch was nearly 50% of the air temperature. At 12 inches inside the arch, the variation was hardly 2.6 F. Beyond this depth, the temperature rose again showing the communication of heat downward from the top black surface. The afternoon temperature was again always higher than the morning temperature. Similar variation of daily temperature was noted in the rest of the thermometers located at other positions.

Temperature Variation in the Gate Bridge

In the Gate Arch No. 8 three sets of thermometers were installed, two at sides and one at the centre. Their location was from 0.5 inches depth and ended at 18 inches inside the arch. This arch has no road at top. As before mean of ten days temperature observation is plotted for the thermometers located in the centre of the arch in Fig. 20. The air temperature data was taken from the same thermometer existing under the road arch. The actual values of ten days mean temperature for the thermometers located at the three sites in the arches are given in Table 7. Only one set of ten days in a

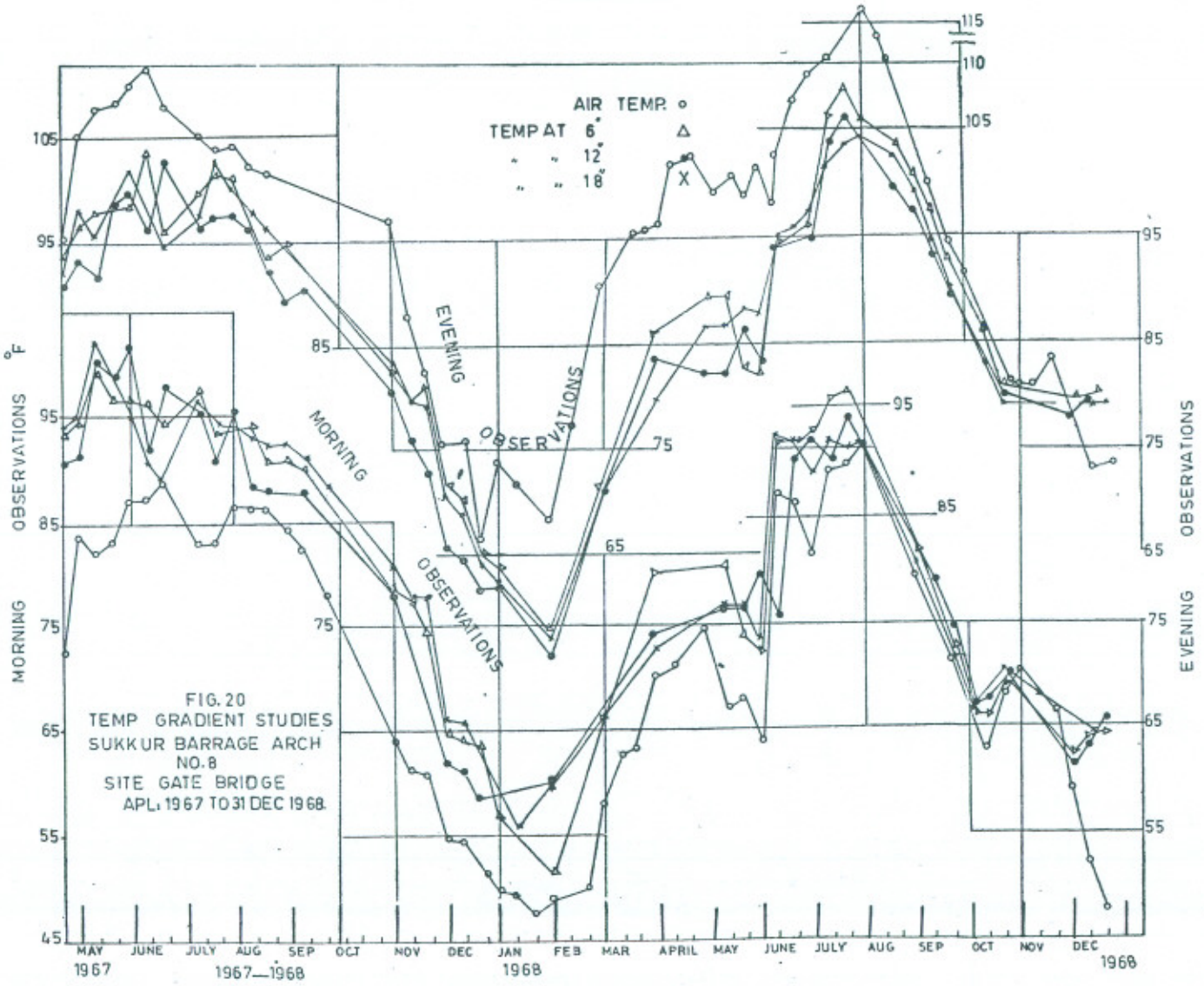
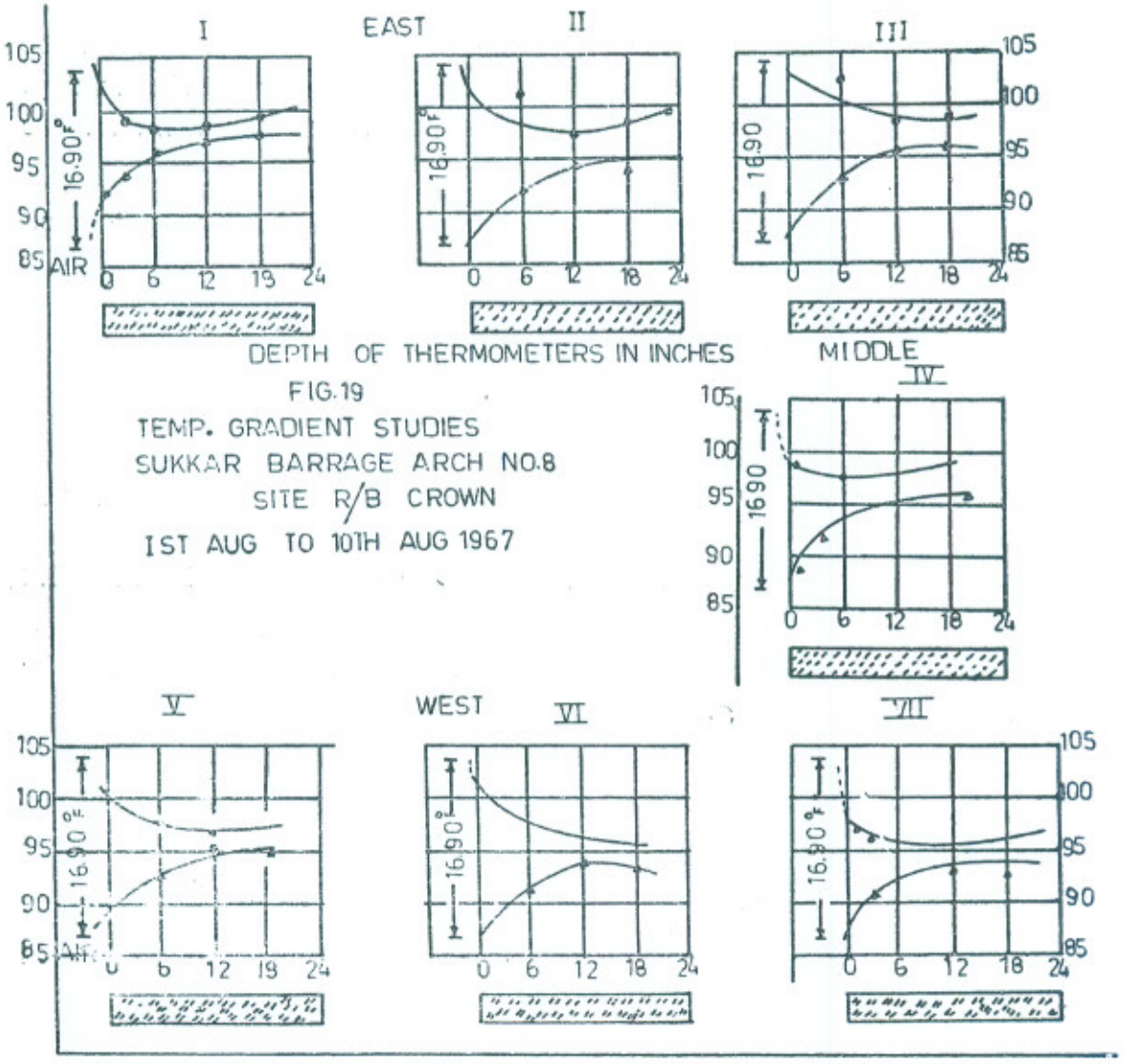


FIG. 20
TEMP GRADIENT STUDIES
SUKKUR BARRAGE ARCH NO. 8
SITE GATE BRIDGE
APL. 1967 TO 31 DEC 1968.

month is tabulated although full period data are included in the report issued for this study.

The variation of temperature at different depths for two selected periods was studied. Its variation was very similar to that depicted in Fig. 19.



The temperature variation in a day for thermometers located at different depths inside the Gate Arch is given in Table 8. The mean values were found as under :—

Depth of the thermometer in the arch in inches	Air	0.5	1.0	3.0	6.0	12	18
Daily variation of temperature °F.	25	13	11	8	5	5.0	6.0

Annual Variation of Temperature in the Arches

The Figures 16, 18 and 20 show that the rise and fall of temperature

of the air which caused a corresponding change in the thermometers located at various depths inside the concrete.

The increase of temperature was quite gradual in all thermometers irrespective of their depths. A temperature gradient with depth of location of thermometers existed. The highest temperature on the afternoon of ten days in a year and the lowest in the morning of any other ten days in the year was noted. This gave the maximum variation of temperature in the year. Temperature of all the thermometers were recorded on similar pattern for a mean of ten days. This data are given in Table 9. The range of highest difference of air temperature in the year 1967 was 54°F and during 1968 it was 60°F. The highest annual variation of temperature, 1/2 inch within the Road Arch Bridge attained an order of 66 and 73% of the air temperature *i.e.*, about 35 and 43°F. It continued to decrease with depth of thermometers and at 6 inches inside the arch the maximum variation was 37°F.

The Gate Arch at Crown attained a temperature of 36°F within 1/2 inch of the arch. At 6.0 inches depth the temperature variation was 32°F.

As for the site close to the springing the temperature at 6.0 inches depth was 32°F corresponding to air temperature of about 57°F. At 12 inches depth it was 27°F and at 18 inches it was 26 °F.

Effect of Exceptionally High or Low Temperature During a Year

It sometimes happens that for a few days in a year, there are exceptionally hot or cold days when the temperature changes by ± 10°F over the ten days' mean as has been found for West Pakistan.

We have noted that within 1/2, 3 and 6 inches of reinforced lime concrete. the annual temperature change is 70, 68 and 65% respectively of the ten days' mean temperature. If we assume that a 20°F change of temperature will have the same order of variation then additional variation of temperature expected will be 14, 13.4 and 13°F at the three depths and the annual rise will change to 51.5, 46.4 and 45°F.

These values may be considered in conjunction with daily variation of temperature, wherein we have noted that on a single day the variation of temperature noted at 1/2, 3 and 6 inches depth was 50, 25 and 20 per cent of the air temperature.

As the excessive rise and fall of temperature is not persistent for a long time, we should rather assume the change inside the concrete on the basis of daily variation and which will give the variation of temperature at 1/2, 3 and 6 inches depth equal to 47.5, 37.8, 36°F respectively.

Temperature Variation in the Arches During a Cycle of 24 Hours

During the evaluation of temperature changes in the Sukkur Barrage Arches, after every two weeks, full twenty-four hours observations were conducted at an interval of one hour.

In this paper we have put forth results of only 2 days, one corresponding to a high temperature period of 15th of August 1967 and another for low temperature period round about the month of February 1967. The observations for 15th of August are plotted in Fig. 21.

A study of these two figures shows that in summer, the maximum temperature was attained between 4 to 8 P.M. This trend is noticed in practically all the thermometers, embedded at different depths. After 7 to 8 P.M. the temperature started to fall down and attained the minimum order at nearly 12.00 at night. The air temperature rose regularly and fell in the same order although the thermometers located at different depths did not show the same rise and fall. The heat dissipation during the night recorded by the thermometers located at different depths took a bit longer time to cool down. No time lag in the thermometers located at different depths could be worked out.

The observations of the cooler period of February 1967 are exhibited in Figure 22. During this period the temperature of the air as well as of the thermometers installed close to the surface showed quicker rise of temperature and a quick fall during the night.

It may, however, be noted that no conclusive results from the daily recording of temperature could be drawn. Except that in the morning and the evening the temperature at various depths followed the variation of air temperature during the 24 hours' period.

Utilization of the Results on other Projects in West Pakistan

These experiments have shown that in reinforced lime concrete, the effect of daily change of temperature is communicated beyond a depth of 18 inches. The daily variation of maximum and minimum temperature is not more than 30°F. If was noted that within ½ inch of the surface the daily temperature variation was reduced to 50% of the air temperature.

At a depth of 3.0 inches inside the arches, the temperature was reduced to 25% of the air temperature. At 6 inches depth, it was 16% and at 18 inches the daily temperature variation was 5% of air temperature.

FIG 21

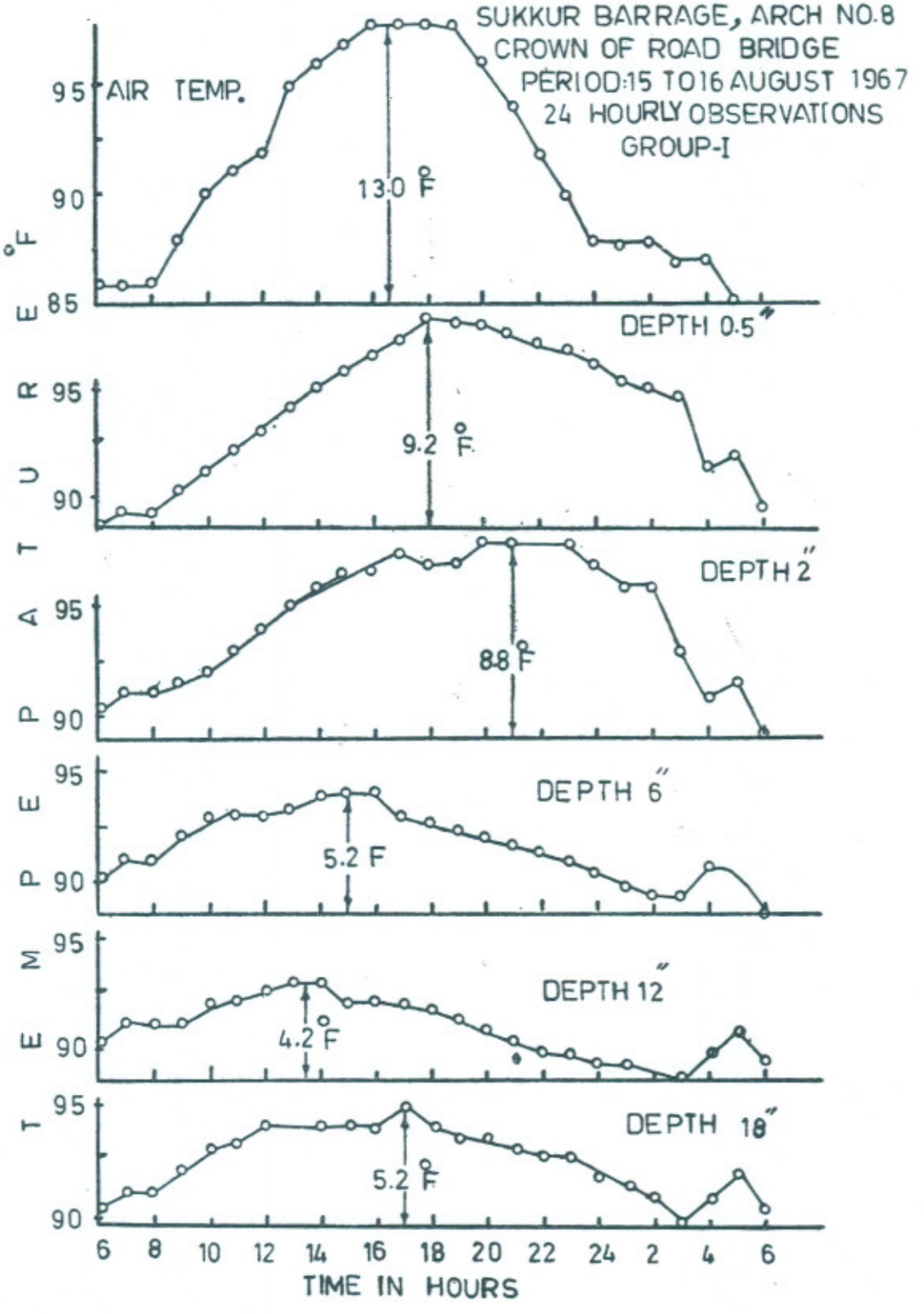
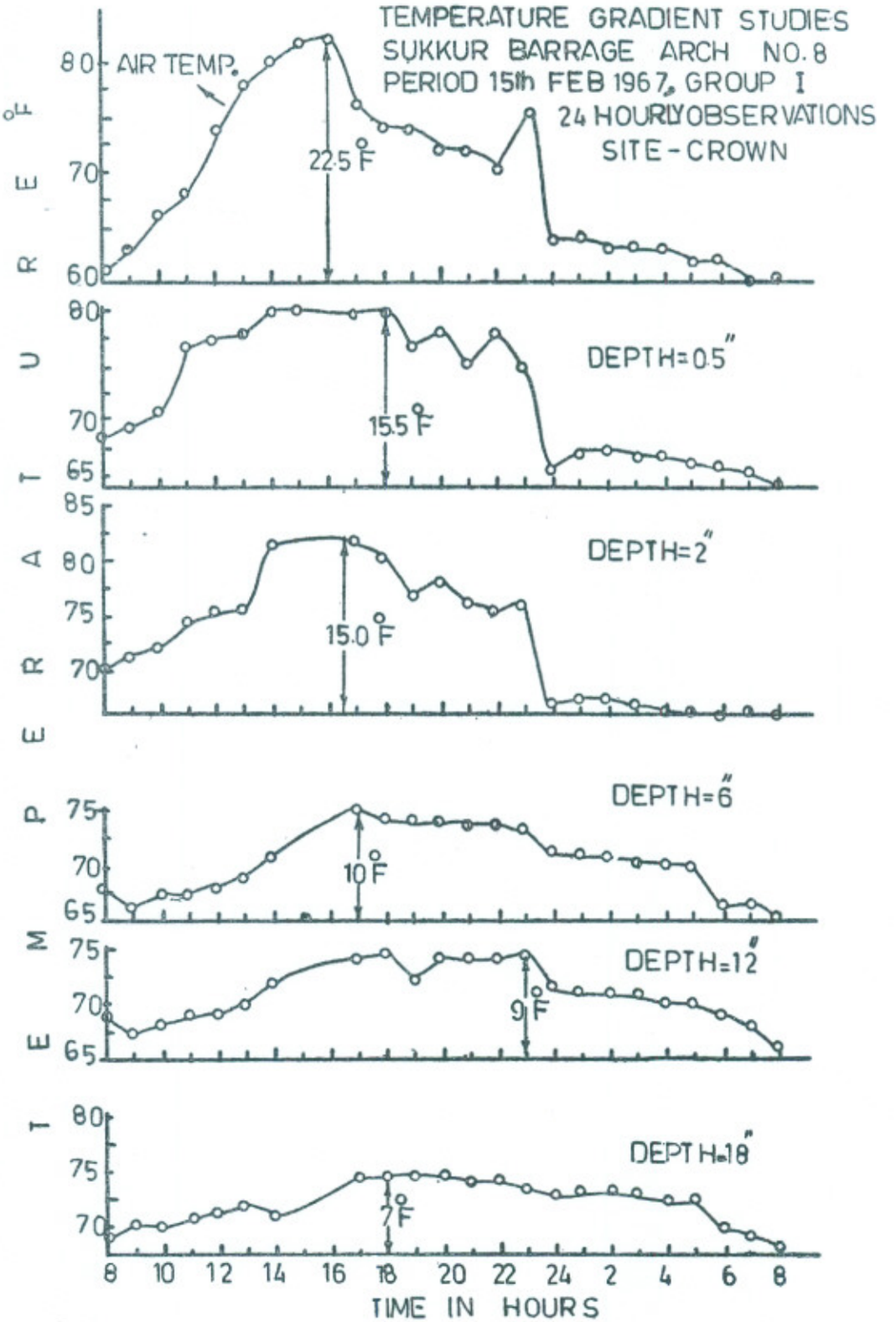

SUKKUR BARRAGE, ARCH NO.8
CROWN OF ROAD BRIDGE
PERIOD:15 TO16 AUGUST 1967
24 HOURLY OBSERVATIONS
GROUP-I
AIR TEMP.
13.0 °F
DEPTH 0.5"
9.2 °F
DEPTH 2"
8.8 °F
DEPTH 6"
5.2 F
DEPTH 12"
4.2 °F
DEPTH 18"
5.2 °F
°F
TEMPERATURE
95
90
85
6 8 10 12 14 16 18 20 22 24 2 4 6
TIME IN HOURS

FIG. 22


TEMPERATURE GRADIENT STUDIES
SUKKUR BARRAGE ARCH NO. 8
PERIOD 15th FEB 1967, GROUP I
24 HOURLY OBSERVATIONS
SITE - CROWN
AIR TEMP.
22.5°F
DEPTH=0.5"
15.5°F
DEPTH=2"
15.0°F
DEPTH=6"
10°F
DEPTH=12"
9°F
DEPTH=18"
7°F
TEMPERATURE °F
80
70
60
85
75
65
8 10 12 14 16 18 20 22 24 2 4 6 8
TIME IN HOURS

Actual daily variation of temperature observed within the arches at different positions is shown in Table 10.

TABLE 10—*Daily variation of temperature of air in °F and at various depths. Depth in inches.*

	Air	0.5	1	2	3	6	12	18
Temp. at springing of Road Arch ..	24	..	..	..	..	4.3	2.1	1.2
Temp. at crown of Road Arch ..	24	11	8.6	7.6	5	4	2.6	4.4
Temp. at crown of Gate Arch ..	25	13	11	..	8	5.0	5.0	6.0

At springing the thickness of arch is 2.25 feet with 5.75 feet of lime concrete at top, so that the heat communicated from the top surface is insignificant. This is not the case at the crown of the arches where the thickness is 2 feet and with an equal thickness of concrete followed by black top surface.

During a year due to seasonal variation there is a considerable change of temperature at different sites in West Pakistan.

In Fig. 23 contours for average temperature observed during the hottest month of June, during the ten years from 1950-1960 in West Pakistan, are plotted. The contours are for the maximum and minimum temperature recorded in the month. Similar contours are plotted for the coolest month of January for the same period in Fig. 24. In another Figure 24*a*, contours for maximum temperature of June and minimum of January are plotted to give the range of variation. It may be noted that the difference of temperature for maximum of the hottest and minimum of the coldest months is not more than 70°F.

Two years' (1967 and 1968) observations at Sukkur showed variation of temperature of about 60°F. The information collected at this site is given in Table 9 for both these years.

In this table we have given the mean temperature as observed at different depths of the arch and we find that within 1/2 inch of the concrete, the temperature is reduced to 70% of the surface. At 3 inches inside the concrete it is reduced to 68% of the surface. At six inches inside it is reduced to about 65% provided the arch is thick such as at springing. Thus at this depth the actual temperature variation during a year is about 33°F. Even at 3 inches depth inside the arch the annual variation is 35°F.

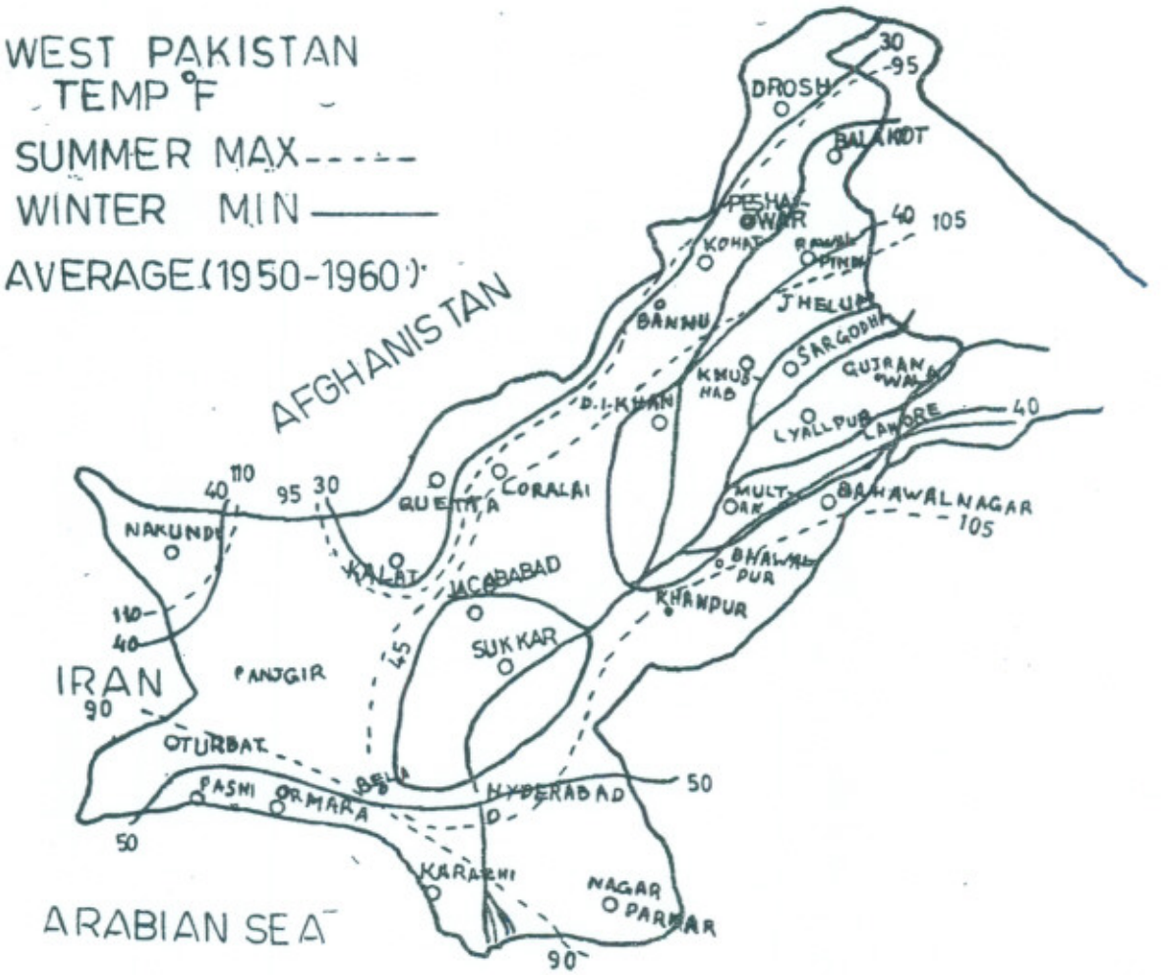

WEST PAKISTAN
TEMP °F
SUMMER MAX- - - - -
WINTER MIN ——
AVERAGE (1950-1960)
AFGHANISTAN
IRAN
ARABIAN SEA
DROSH
BALAKOT
PESHAWAR
KOHAT
RAWALPINDI
BANNU
JHELUM
SARGODHA
KHUSHAB
GUJRANWALA
D.I.KHAN
LYALLPUR
LAHORE
MULTAN
BAHAWALNAGAR
BAHAWALPUR
KHANPUR
QUETTA
CORALAI
KALAT
JACOBABAD
SUKKAR
NAKUNDI
PANJGIR
TURBAT
PASNI
ORMARA
HYDERABAD
KARACHI
NAGAR PARKAR
30
95
40
105
110
90
45
50

Fig. 23

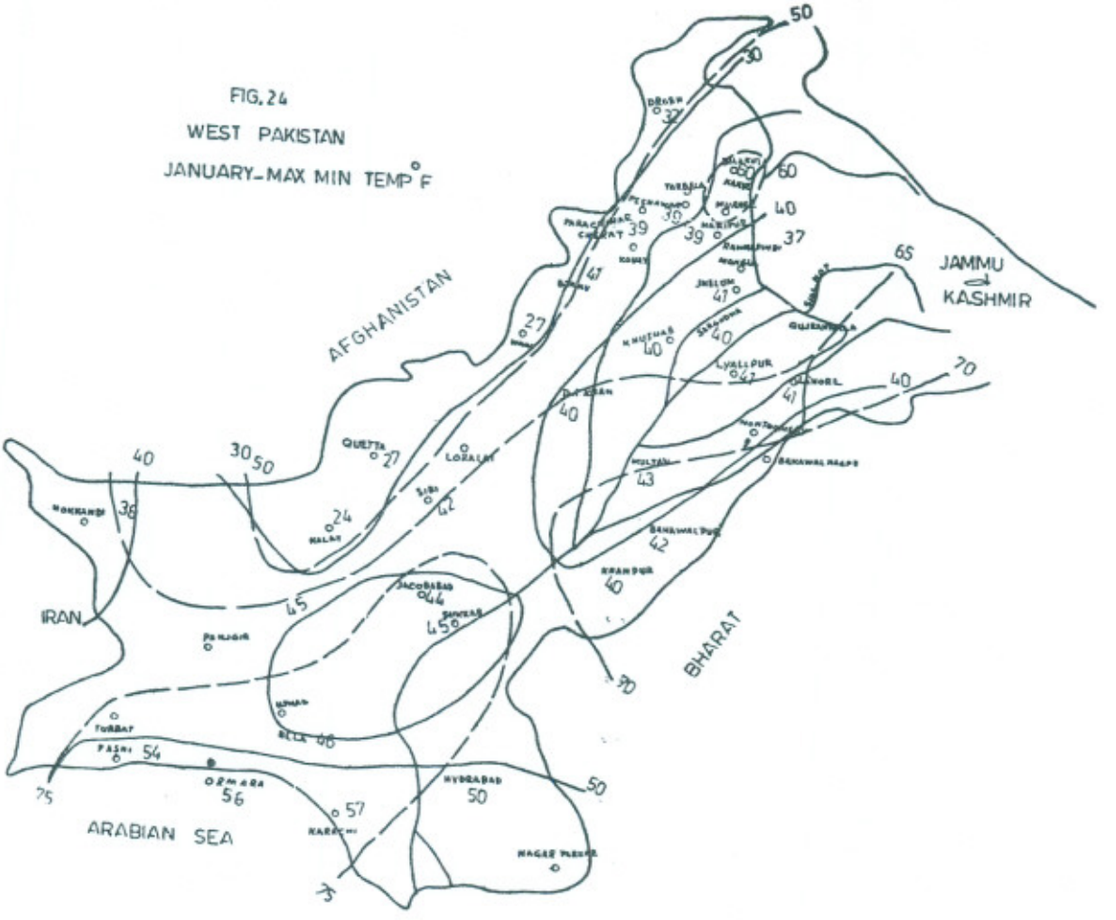


FIG. 24
WEST PAKISTAN
JANUARY–MAX MIN TEMP °F

Temperature Changes when Aggregates other than Limestones are Used.

The arches at Sukkur are made up of limestone. If these are constructed of any other type of coarse aggregates anywhere in West Pakistan, we can estimate the order of temperature variation with reference to the data of Bureau of Reclamation about the variation of thermal conductivity for different types of aggregates. The mean value of the conductivity for 70 and 90°F are given in Table 1.

The thermal conductivities for Quartzite, Dolomite are higher and for Granite, Rhyolite and Basalt are lower as compared to lime stone.

This will result in some percentage of increase or decrease of temperature as compared to lime stone. The order of change will be as under :—

TABLE 1

Material	K at 70°F	K at 90°F	% higher or lower as compared to lime stone	
			70°F	90°F.
Limestone ..	1.842	1.815	—	—
Quartzite ..	2.040	2.028	+10	+12
Dolomite ..	1.925	1.903	+5	+5
Granite ..	1.511	1.508	—18	—17
Rhyolite ..	1.203	1.207	—30	—34
Basalt ..	1.212	1.211	—30	—33

If the structure contains Quartzite or Dolomite as coarse aggregates, it will be 5 to 10% more conducive than lime stone. Under this condition the range of temperature at a depth of 6 inches inside the arch taken equal to 33°F will increase to about 37°F.

In case Granite or Rhyolite or Basalt are used as coarse aggregates, the thermal conductivity at a depth of 6.0 inches will be less by 20 to 30 per cent which means that at this depth the range of temperature will be 27 to 23°F.

Summary of the Results

This paper gives the results of electrical wire resistance thermometers which were installed in November, 1966 in the Road Arch No. 8 of Sukkur Barrage. Thirty-three thermometers were installed in the crown section of the

Road arch and nine close to the springing. Similarly eighteen thermometers were fixed in the Gate Arch No. 8 on 25 April, 1967 in the crown section only.

The depth of installation of thermometers varied from $\frac{1}{2}$ inch to 1, 2, 3, 6, 12 and 18 inches inside the arches starting from the bottom surface.

The thermometers have continued to record the observations for more than two years without any defect.

In the paper the technique of preparation of thermometers, and the method of their recording is described in detail. It was observed that each thermometer recorded the temperatures within the arch where it was located.

In case of concrete close to springing where the arch is 2.25 ft. thick and has a covering of 5.75 feet of lime concrete, the effect of daily variation of temperature was recorded 18 inches inside the arch. This was the depth up to which the thermometers were located. This variation was 5% of the air temperature. The daily variation of temperature within 6.0 inches of the concrete was about 20% of the air temperature.

The difference between the maximum in hot season and the minimum in cold season of air temperature at Sukkur was found equal to 67°F. This caused a change within 6.0 inches of the arch equal to about 65% of the air temperature. At three inches depth the variation rose to 68% of the air temperature.

In West Pakistan the annual variation of the highest and the lowest temperature of air between the summer and winter seasons is about 70°F. For this temperature change the expected variation of temperature at 6.0 inches depth is about 36°F when the concrete is made of reinforced limestones as aggregate. If the aggregates used were Quartzite and Dolomite, due to the higher thermal conductivities of these materials, the range of temperature at 6.0 inches depth will increase to 39°F. If, on the other hand, the materials used contain aggregates of Granite, Rhyolite, Basalt, the annual temperature variation at 6.0 inches depth will fall to about 27°F.

A few days in a year may be exceptionally hot or cold causing a change of $\pm$ 10°F in the mean temperature of ten days. It has been estimated that this exceptionally high or low temperature may cause a change of temperature at 1/2, 3 and 6 inches depth equal to 56, 42 and 40°F if the high or low temperature persists for a day or so.

If it is assumed that this type of temperature persists for several days and will have the same types of variation as the annual one then this 90°F change of temperature will raise the temperature to 59, 46.3 and 45.6°F at 1/2, 3, and 6 inches depth. All this information discussed above is given in Table 11.

It is apparent that the charge of temperature within the arches, in a year, is below 60°F at all depths.

Acknowledgement

This useful paper is a result of the suggestions put forth by Mr. Mazhar Ali who after his detailed stress analysis of the Sukkur Barrage arches realised the importance of the investigations. His constant endeavours to provide field facilities and his keen interest at all stages of the progress of the studies was a source of great encouragement to the author.

The Members of the Technical Committee, Mian Alimud Din now Chief Engineer, Indus Basin Work and Mr. S. K. Bloch, then Chief Engineer, Sukkur Barrage, Mr. M. H. Khan, then Chief Engineer, Flood and Mr. Mohi-ud-din Khan as Convener of the Technical Committee found the results even at the very early stages to be very useful and approved the extension of the observations. It is due to their interest that these results are now available to the Department.

During the collection and compilation of the data several workers of the Physics Sections have willingly co-operated at various stages. Mr. Kazim Hussain, Assistant Research Officer, in particular continued to supervise the study and compile the data as received from the field. In the preparation of the paper Mr. Sultan Ahmad was particularly helpful to collect together the tables and diagrams etc., for which the author is grateful.

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TABLE NO. 3.—*Temperature Gradient Studies. Sukkur Barrage Arch No. 8 Site Springing.*

M. = Morning.
E. = Evening.

Date, month & year	Group	Air Temperature		6″		12″		18″	
		M.	E.	M.	E.	M.	E.	M.	E.
1	2	3	4	5	6	7	8	9	10
8-18 Nov., 1966 ..	West	55.5	84.8	71.5	76.5	73.2	74.7	74.0	74.2
	Middle	55.5	84.8	69.6	74.8	70.7	72.6	72.4	72.6
	East	55.5	84.8	71.6	77.5	71.9	74.1	71.7	71.9
9-18 Dec., 1966 ..	West	51.8	83.9	64.9	65.5	68.2	69.2	69.3	71.9
	Middle	51.8	83.9	..	..	..	..	..	..
	East	51.8	83.9	..	..	..	..	..	..
11-20 Jan., 1967 ..	West	47.9	69.0	57.7	62.2	59.7	63.1	55.9	59.2
	Middle	47.9	69.0	59.3	62.7	57.4	57.7	55.7	59.2
	East	47.9	69.0	59.2	63.1	57.7	60.6	60.2	61.0
11-20 Feb., 1967 ..	West	56.5	82.2	68.3	72.1	66.8	66.9	63.4	66.7
	Middle	56.5	82.2	65.2	66.9	66.5	66.9	68.9	66.9
	East	56.5	82.2	66.4	68.3	65.3	66.2	63.4	66.5
1-10 March, 1967 ..	West	65.1	103.9	81.5	85.1	79.9	81.5	82.9	83.1
	Middle	65.1	103.9	78.5	83.1	76.1	75.7	..	..
	East	65.1	103.9	85.4	86.9	82.3	79.1	77.4	77.4
1-10 April, 1967 ..	West	62.4	87.4	83.5	84.6	85.0	83.1	82.8	85.4
	Middle	62.4	87.4	82.6	83.1	76.6	80.1	..	..
	East	62.4	87.4	85.1	87.9	85.1	84.2	76.1	81.3

1		2	3	4	5	6	7	8	9	10
1-10 May, 1967	..	West	83.6	104.9	94.3	99.3	96.3	99.6	96.4	97.0
		Middle	83.6	104.9	93.0	91.7	92.4	92.8	..	..
		East	83.6	104.9	99.6	101.2	90.6	94.4	92.1	85.3
1-10 June, 1967	..	West	87.2	112.1	100.5	103.0	99.3	101.5	100.5	101.0
		Middle	87.2	112.1	95.6	92.4	95.0	97.7	..	..
		East	87.2	112.1	..	..	..	..	..	..
1-10 Aug., 1967	..	West	87.1	104.0	93.5	95.7	93.5	98.7	95.5	95.9
		Middle	87.1	104.0	93.2	95.0	93.2	94.1	..	..
		East	87.1	104.0	94.3	96.1	92.9	95.9	95.0	95.7
1-10 Sep., 1967	..	Middle	84.2	98.6	85.4	87.3	82.9	85.6	82.5	86.0
1-10 Nov., 1967	..	Middle	64.4	96.8	80.0	85.4	89.5	89.1	75.6	77.9
1-10 Dec., 1967	..	Middle	54.2	76.3	64.1	68.3	67.2	66.5	68.1	63.8
1-10 Jan., 1968	..	West	49.6	73.7	52.3	64.4	53.6	69.6	53.6	64.2
		Middle	49.6	73.7	55.5	62.6	49.8	61.3	..	..
		East	49.6	73.7	59.9	68.5	57.5	64.7	50.9	58.4
1-10 Feb., 1968	..	West	48.6	68.3	55.4	58.9	48.8	60.8	57.4	58.2
		Middle	48.6	68.3	51.1	55.9	48.7	54.9	..	..
		East	48.6	68.3	54.8	62.7	52.6	59.0	56.0	58.9
1-10 March, 1968	..	West	58.0	90.7	63.0	72.0	62.4	68.1	65.3	67.4
		Middle	58.0	90.7	60.0	68.6	61.5	64.0	..	..
		East	58.0	90.7	61.2	73.0	64.1	71.5	65.7	66.8
1-10 April, 1968	..	West	70.3	95.8	70.3	79.5	72.6	78.5	74.0	79.4
	..	Middle	70.3	95.8	71.4	77.6	70.5	74.5	..	..
		East	70.2	95.8	73.6	87.1	72.0	78.9	76.3	79.2

TABLE NO. 3 (*Cont.*).—*Temperature Gradient Studies Sukkur Barrage Arch No. 8 Site Springing.*

M. = Morning.
E. = Evening.

Date, month & year	Group	Air Temperature		6″		12″		18″	
		M.	E.	M.	E.	M.	E.	M.	E.
1	2	3	4	5	6	7	8	9	10
1-10 May, 1968 ..	West	67.0	98.8	78.8	86.7	76.3	83.3	78.0	82.7
	Middle	67.0	98.8	72.8	80.2	76.7	79.2	..	..
	East	67.0	98.8	74.7	81.5	77.9	82.9	78.2	82.1
11-20 June, 1968 ..	West	86.4	102.4	91.7	95.6	92.0	94.1	92.3	93.5
	Middle	86.4	102.4	89.0	94.5	91.2	92.6	..	..
	East	86.4	102.4	90.5	94.5	92.0	93.8	92.8	93.2
1-10 July, 1968 ..	West	89.7	109.8	81.8	85.2	80.0	83.3	50.3	86.0
	Middle	89.7	109.8	83.6	83.4	74.4	76.1	..	..
	East	89.7	109.8	89.9	85.8	87.6	76.1	79.1	95.0
1-10 Aug. 1968 ..	West	95.6	116.0	93.72	103.40	91.92	102.38	100.4	105.00
	Middle	95.6	116.0	96.1	110.3	99.6	108.9	..	..
	East	95.6	116.0	84.18	95.36	97.50	103.10	90.30	105.80
20-30 Sept., 1968 ..	West	71.5	94.0	71.2	86.9	69.4	85.1	75.5	87.0
	Middle	71.5	94.0	72.5	86.0	72.6	76.5	..	..
	East	71.5	94.0	76.0	81.7	74.3	84.3	66.3	79.8
11-20 Oct., 1968 ..	West	67.2	85.5	63.5	80.6	61.3	79.7	64.1	79.7
	Middle	67.2	85.5	64.9	80.6	55.4	74.0	..	..
	East	67.2	85.5	71.9	89.0	91.9	86.7	83.5	79.7
11-10 Nov., 1968 ..	West	70.2	82.8	72.6	84.2	70.7	80.6	72.0	83.0
	Middle	70.2	82.8	74.0	84.0	65.4	75.6	..	..
	East	70.2	82.8	77.9	88.5	74.5	85.5	69.2	79.7
1-10 Dec., 1968 ..	West	59.7	80.2	62.4	84.9	63.1	83.1	64.4	84.6
	Middle	59.7	80.2	66.2	87.0	61.0	76.5	..	..
	East	59.7	80.2	70.5	90.5	69.6	89.9	62.9	82.0

TABLE NO. 4.—*Temperature Gradient Studies in Sukkur Barrage Arches. Daily variation in temperature in °F as recorded by Thermometer close to Springing.*

M.=Morning.
E.=Evening.

S. No.	Period	Air Temp. E.	Air Temp. M.	Vairation of air tempera-ture	Group	Variation of temperature at various depths. 6''	12''	18''
1.	8-18 Nov., 1966 ..	84.8	55.5	29.3	West	5.2	1.4	0.7
					Middle	5.2	1.9	0.9
					East	6.3	2.1	0.7
					Mean	5.6	1.80	0.76
2.	1-10 Jan., 1967 ..	65.58	47.96	17.62	West	2.9	0.7	0.4
					Middle	3.9	0.7	0.5
					East	2.8	1.1	0.4
					Mean	3.2	0.83	0.43
3.	1-10 June, 1967 ..	112.0	87.2	24.8	West	3.6	0.9	0.3
					Middle	3.2	1.5	1.2
					East	4.5	1.9	1.1
					Mean	3.8	1.43	0.86

S. No.	Period	Air Temp. E.	Air Temp. M.	Variation of air temperature	Group	Variation of temperature at various depths. 6''	12''	18''
4.	1-10 Aug., 1967 ..	104.0	87.1	16.9	West	2.2	0.9	0.3
					Middle	1.9	0.9	0.4
					East	1.9	0.8	0.4
					Mean	2.0	0.87	0.36
5.	1-10 Jan., 1968 ..	73.7	50.0	23.9	West	4.2	4.6	0.6
					Middle	7.1	2.9	..
					East	2.7	3.1	0.4
					Mean	4.6	3.5	0.5
6.	1-10 May, 1968 ..	98.8	67.6	31.2	West	7.0	7.0	4.64
					Middle	7.4	2.5	..
					East	5.3	5.0	3.95
					Mean	6.6	4.8	4.29
			Mean	23.92	G. Mean	4.3	2.05	1.2

TABLE 5

TABLE NO. 5.—*Temperature Gradient Studies, Sukkur*

M.=Morning *Temp. in °F*

Year	Group	Air Temp.		0.5''		1''		2''
		M.	E.	M.	E.	M.	E.	M.
8-18 Nov.,	West	55.5	84.8	..	..	..	..	..
1966	Middle	55.5	84.8	..	..	..	..	..
	East	55.5	84.8			..	..	..
10—19 Dec.,	West	51.8	83.9	..	..	..	..	..
1966	Middle	51.8	83.9	..	..	..	..	..
	East	51.8	83.9	..	..	..	..	..
1—10 Jan.,	West	47.9	65.5	..	..	..	..	..
1967	Middle	47.9	65.5	..	..	..	..	..
	East	47.9	65.5	..	..	..	..	..
1—10 Feb.,	West	53.9	88.7	60.0	73.9	63.7	75.0	61.3
1967	Middle	53.9	88.7	60.8	68.3	64.2	70.2	63.3
	East	53.9	88.7	59.4	66.5	61.9	68.4	63.1
1—10 Mar.,	West	65.1	103.9	80.5	94.1	88.7	96.0	83.3
1967	Middle	65.1	103.9	78.6	87.8	77.0	84.2	80.6
	East	65.1	103.9	87.2	87.0	70.1	78.6	73.5
1—10 Apr.	West	62.4	87.4	82.7	80.8	86.9	87.0	82.9
1967	Middle	62.4	87.4	80.9	84.0	76.1	82.5	73.8
	East	62.4	87.4	79.7	87.6	71.9	76.5	77.6
1—10 May,	West	83.6	104.9	89.9	104.3	102.9	104.2	88.7
1967	Middle	83.6	104.9	84.7	100.2	84.2	96.8	86.9
	East	83.6	104.9	84.5	96.1	83.8	91.5	84.3
1-10, Jun.,	West	87.2	112.1	93.5	101.5	85.9	106.9	102.9
1967	Middle	87.2	112.1	87.2	87.0	87.0	97.8	90.3
	East	87.2	112.1	97.1	102.7	91.5	..	95.0
3-8 July,	West	84.1	105.1	91.5	104.6	89.1	103.1	92.9
1967	Middle	84.1	105.1	90.1	92.7	97.7	88.4	97.8
	East	84.1	105.1	87.4	94.1	99.7	89.3	8[illegible]0

Barrage Arch No. 8. Site Road Bridge, Crown Temp. in °F *E.=Evening*

2''	3''		6''		12''		18''	
E.	M.	E.	M.	E.	M.	E.	M.	E.
..	..	..	71.7	76.5	72.3	76.2	71.6	78.8
..	..	..	73.5	79.9	75.9	70.0	74.5	78.4
..	..	..	70.9	75.4	76.4	76.1	74.6	71.1
..	..	..	59.9	68.1	60.4	76.7	66.0	67.5
..	..	..	64.7	67.9	65.8	65.4	66.2	67.6
..	..	..	62.4	63.7	66.9	66.7	53.5	64.6
..	..	..	55.7	60.0	57.5	57.5	53.8	59.2
..	..	..	54.1	55.4	51.8	53.6	52.2	54.0
..	..	..	51.8	54.8	53.6	53.9	52.3	54.9
69.3	61.3	66.5	65.3	66.9	63.1	61.0	61.5	64.7
64.7	60.7	63.0	62.2	66.0	64.3	63.8	61.5	65.5
66.6	59.5	62.6	62.9	65.8	65.2	61.3	68.8	64.7
92.3	76.2	92.3	78.1	86.5	99.0	88.1	81.1	65.9
81.3	80.0	83.8	83.1	84.0	82.7	85.0	65.3	87.4
83.1	46.62	86.5	81.1	82.5	85.2	86.7	83.1	84.3
96.9	85.6	80.6	81.6	84.3	82.5	84.5	83.6	84.2
84.9	82.5	83.8	80.0	82.1	83.1	80.6	86.6	86.0
77.7	80.6	80.4	84.1	85.1	86.5	86.9	84.3	83.4
110.9	90.6	103.2	94.3	97.3	97.1	100.4	91.7	96.0
98.2	88.7	88.2	90.5	96.6	93.7	96.0	91.5	99.1
91.5	81.5	96.2	91.0	93.7	95.3	85.2	85.8	88.8
95.3	96.2	104.0	98.2	100.4	98.6	100.5	95.7	102.2
97.3	92.0	100.0	108.8	105.3	95.0	97.0	95.3	97.8
..	90.8	97.3	100.8	103.9	100.7	102.0	95.3	101.8
105.3	95.2	102.2	90.9	101.3	92.9	98.3	94.5	98.6
92.2	97.8	93.9	98.0	96.0	91.5	97.5	97.4	99.0
93.3	88.3	96.0	93.9	95.3	97.2	96.1	96.4	96.5

[*Contd,*

TABLE NO. 5.—*Temperature Gradient Studies. Sukkur*

M.=Morning

Year	Group	Air Temp.		0.5"		1"		2"
		M.	E.	M.	E.	M.	E.	M.
1-10 Aug., 1967	West	81.1	104.0	93.1	101.3	100.9	103.5	94.1
	Middle	81.1	104.0	90.9	98.2	89.1	96.3	91.0
	East	81.1	104.0	89.2	96.6	83.5	90.0	85.7
1-10 Nov.,	Middle	64.4	96.8	89.9	87.9	71.7	86.1	87.0
1-10 Dec.,	Middle	54.5	73.4	62.9	72.3	60.4	69.8	69.3
1-10 Jan., 1968	West	49.6	74.7	54.5	71.0	56.3	76.1	53.9
	Middle	49.6	74.7	52.1	64.9	49.5	63.3	50.3
	East	49.6	74.7	50.5	63.1	49.7	62.8	49.6
1-10 Feb., 1968	West	48.6	68.3	51.7	67.9	52.8	68.0	52.2
	Middle	48.6	68.3	48.8	61.1	48.8	59.5	49.3
	East	48.6	68.3	48.8	59.4	48.9	55.0	49.2
1-10 Mar., 1968	West	58.0	90.7	69.3	90.0	67.0	81.4	69.6
	Middle	58.0	90.7	61.2	74.3	60.1	87.1	62.9
	East	58.0	90.7	61.0	70.2	58.0	66.5	58.3
1-10 Apr., 1968	West	70.3	95.8	79.2	90.1	78.5	87.1	74.2
	Middle	70.3	95.8	79.9	89.4	72.9	89.0	70.2
	East	70.3	95.8	76.0	89.6	74.8	86.0	74.0
1-10 May, 1968	West	67.0	98.8	70.7	76.8	67.6	72.6	72.6
	Middle	67.0	98.8	72.2	78.9	67.6	72.9	67.6
	East	67.0	98.8	68.5	80.1	67.6	76.4	71.1
11-20 June, 1968	West	86.4	103.4	89.6	93.8	90.7	96.3	91.9
	Middle	86.4	103.4	89.7	93.9	91.0	96.9	89.0
	East	86.4	103.4	90.0	95.6	90.8	95.0	90.9
1-10 July, 1968	West	89.7	109.8	90.5	100.5	90.8	100.8	91.2
	Middle	89.7	109.8	91.6	101.1	91.0	102.0	91.7
	East	89.7	109.8	90.7	102.7	91.9	102.7	92.4

Barrage Arch No. 8. Site Road Bridge, Crown

E.=Evening

2″	3″		6″		12″		18″	
E.	M.	E.	M.	E.	M.	E.	M.	E.
100.6	94.5	97.7	90.7	99.3	92.1	99.5	92.6	100.2
95.3	92.4	97.8	93.8	98.5	95.6	99.7	95.8	101.3
91.9	89.9	95.9	96.8	99.5	93.7	100.8	93.2	104.4
87.9	78.0	86.5	79.1	85.1	81.1	82.7	80.6	84.1
69.8	65.8	70.1	65.1	68.5	66.3	68.9	66.3	69.4
68.4	53.6	64.4	53.6	61.7	55.0	61.7	54.5	61.7
63.3	50.3	62.6	57.7	64.7	55.7	64.7	57.2	63.1
65.4	50.9	61.3	56.4	63.5	55.0	66.0	58.4	64.5
65.5	51.5	63.7	50.9	57.2	55.4	57.4	54.8	57.2
60.0	62.8	61.1	48.9	59.9	54.6	55.6	53.3	58.4
56.5	48.8	58.2	49.8	59.4	51.7	53.9	51.9	54.8
81.9	66.5	74.0	67.6	70.8	67.6	70.8	67.1	74.4
68.9	61.1	70.0	63.8	70.8	64.8	70.0	60.6	65.6
66.5	65.0	69.1	62.1	70.7	60.4	66.2	63.4	65.6
84.2	79.7	86.0	81.8	87.7	82.5	85.2	76.9	87.9
88.6	79.2	87.0	75.9	89.7	81.0	86.0	72.7	80.8
89.0	78.0	87.5	72.1	83.9	81.2	82.4	72.5	79.1
78.9	71.1	76.9	68.1	74.1	63.6	72.5	70.0	74.9
72.9	71.1	74.8	68.0	76.0	72.0	75.1	70.8	74.9
78.7	74.7	76.7	72.9	78.3	74.2	76.6	72.0	81.9
96.8	92.0	96.3	93.5	95.9	93.0	95.0	92.0	95.5
94.4	91.8	95.7	92.0	94.8	93.0	95.0	92.0	95.7
95.3	92.3	95.6	91.8	94.0	93.2	94.5	93.2	95.5
101.3	92.7	102.3	95.3	104.9	94.4	104.8	93.3	103.0
102.0	93.6	103.5	96.1	106.0	94.7	103.7	92.2	101.7
102.4	92.9	102.4	95.6	105.3	95.4	104.8	92.8	102.4

[*Contd.*

TABLE NO. 5.—*Temperature Gradient Studies. Sukkur*

Year	Group	Air Temp.		0.5′		1″		2″
		M.	E.	M.	E.	M.	E.	M.
1-10 Aug.,	West	95.6	116.0	95.1	105.2	94.2	100.9	94.6
1968	Middle	95.6	116.0	101.8	112.2	97.8	105.4	97.1
	East	95.6	116.0	93.3	100.4	95.4	94.1	86.8
21-30 Sep.,	West	71.5	94.0	75.2	92.5	75.2	93.5	73.2
1968	Middle	71.5	94.0	73.2	87.2	69.0	86.0	69.9
	East	71.5	94.0	..	..	..	..	69.4
1-10 Oct.,	West	67.0	91.6	68.52	87.00	74.51	89.50	70.20
1968	Middle	67.0	91.6	67.50	83.11	65.50	81.50	68.40
	East	67.0	91.6	..	..	..	..	63.25
11-20 Nov.,	West	68.0	82.0	71.0	86.5	71.5	92.9	74.6
1968	Middle	68.0	82.0	69.8	87.3	66.5	85.4	68.9
	East	68.0	82.0	..	..	..	..	64.2
1-10 Dec.,	West	59.7	80.2	70.1	90.3	69.8	91.7	68.2
1968	Middle	59.7	80.2	67.5	87.8	65.5	84.9	63.1
	East	59.7	80.2	..	..	..	..	63.5

Barrage Arch No. 8. Site Road Bridge, Crown

2″	3″		6″		12″		18″	
E.	M.	E.	M.	E.	M.	E.	M.	E.
94.9	97.3	104.0	99.6	106.5	97.6	105.2	83.3	102.3
104.1	93.5	100.4	100.4	105.4	102.3	109.7	96.6	105.8
94.1	93.1	100.4	92.1	94.9	92.2	99.1	91.9	100.4
106.4	73.0	88.5	72.3	88.5	79.0	88.7	71.6	87.8
89.6	71.4	89.9	72.6	87.9	69.9	89.2	71.6	89.6
86.0	70.7	90.8	..	..	71.2	90.5	70.9	98.3
86.12	69.25	85.21	66.4	84.8	66.2	85.1	68.2	80.4
82.22	67.40	84.32	62.7	83.2	63.9	82.2	62.9	81.5
78.51	65.00	85.63	67.6	87.9	68.3	86.8	66.1	85.2
89.4	74.6	80.5	71.9	88.1	71.1	87.1	73.6	87.8
87.1	68.3	86.6	71.0	82.0	70.7	80.4	71.6	79.5
80.4	68.4	85.8	..	..	65.3	88.7	67.2	89.9
89.0	68.2	92.1	64.5	85.3	66.5	84.4	65.0	85.0
85.5	65.9	86.1	67.8	76.8	68.7	78.6	68.5	78.0
81.3	67.1	87.0	..	..	67.3	91.5	60.8	87.2

TABLE NO. 6.—*Daily variation in temperature in °F during Selected Period. Site Road Bridge Crown Arch No. 8.*

S. No.	Period	Air temp. E.	Air temp. M.	Variation in Air temp.	Group	Variation in temperature at various depths 0.5″	1″	2″	3″	6″	12″	18″
1.	8-18 Nov., 1966	48.8	55.5	29.3	West	..	..	..	..	4.7	3.8	7.1
					Middle	..	..	..	..	5.3	1.4	3.8
					East	..	..	..	..	6.9	3.5	2.4
					Mean	..	..	..	..	5.63	2.9	4.43
2.	1-10 Jan., 1967	65.58	47.58	17.62	West	..	..	..	..	4.5	0.2	3.6
					Middle	..	..	..	..	3.2	0.3	1.8
					East	..	..	..	..	2.6	0.6	2.7
					Mean	..	..	..	..	3.4	0.36	2.7
3.	1-10 June, 1967	111.0	87.2	24.8	West	14.1	7.5	5.5	4.6	2.3	2.2	4.5
					Middle	12.6	9.0	7.2	4.5	3.0	1.3	1.2
					East	14.4	11.7	7.2	4.7	1.7	1.2	6.3
					Mean	13.6	9.4	6.6	4.6	2.3	1.5	4.0

4.	1-10 Aug., 1967	104.0	87.1	16.9	West	8.1	6.3	4.2	2.5	1.6	1.0	2.1
					Middle	8.2	7.2	5.6	5.1	2.2	0.7	2.1
					East	7.3	5.4	4.5	3.6	1.8	1.2	2.7
					Mean	7.86	6.3	4.76	3.76	1.86	0.96	2.3
5.	1-10 Jan., 1968	73.7	50.0	23.7	West	17.5	13.7	14.5	10.8	3.7	6.8	6.9
					Middle	12.8	11.7	13.9	8.8	6.9	9.2	8.1
					East	12.6	12.1	14.0	6.3	7.2	4.0	5.1
					Mean	14.3	12.5	13.8	8.6	5.9	6.3	6.7
6.	1-10 July, 1968	98.8	67.6	31.2	West	6.18	5.0	2.26	5.80	6.01	4.91	5.0
					Middle	6.70	5.30	5.29	3.69	8.05	3.15	4.11
					East	11.62	8.86	7.61	1.97	5.37	2.58	9.95
					Mean	8.16	6.38	5.05	3.82	6.80	3.55	6.32
		Grand Mean		23.92		10.98	8.64	7.55	5.19	4.31	2.56	4.41

TABLE No. 7.—*Temperature Gradient Studies. Sukkur*

Year	Group	Air Temp.		0.5''		2'	
Date of Month		M.	E.	M.	E.	M.	E.
28-30 April, 1967	West	72.5	95.0	73.2	93.0	89.0	85.6
	Middle	72.5	95.0	94.2	94.4	89.2	94.2
	East	72.5	95.0	84.5	93.9	87.6	92.7
1-10 May, 1967	West	83.6	104.9	91.0	104.5	92.3	104.5
	Middle	83.6	104.9	93.2	99.5	96.7	98.4
	East	83.6	104.9	90.2	102.9	98.9	103.1
1-10 June, 1967	West	87.2	110.1	95.0	99.8	93.4	106.1
	Middle	87.2	110.1	91.9	101.9	89.6	106.5
	East	87.2	110.1	94.8	104.2	85.3	101.5
11-20 July, 1967	West	84.2	104.9	91.2	102.2	94.6	100.9
	Middle	84.2	104.9	93.9	104.3	95.1	101.9
	East	84.2	104.9	93.5	103.4	94.4	100.9
1-10 Aug., 1967	West	87.1	104.0	90.5	102.0	92.9	101.5
	Middle	87.1	104.0	92.9	98.0	95.9	101.9
	East	87.1	104.0	92.3	98.0	92.9	101.0
1-10 Sep., 1967	West	84.2	98.6	90.3	93.0	89.9	92.6
	Middle	84.2	98.6	92.3	91.4	93.2	96.8
	East	84.2	98.6	90.0	98.2	92.9	97.5
1-10 Nov., 1967	West	94.4	96.8	98.8	96.0	81.3	89.9
	Middle	94.4	96.8	79.1	94.4	79.8	92.9
	East	94.4	96.8	80.6	93.0	83.3	91.9
1-10 Dec., 1967	West	59.5	73.4	59.7	73.4	62.2	72.8
	Middle	59.5	73.4	62.4	71.6	64.2	73.4
	East	59.5	73.4	60.8	72.0	61.4	70.7
1-10 Jan., 1968	West	49.6	73.7	54.8	69.8	59.5	68.9
	Middle	49.6	73.7	57.5	79.7	55.5	70.7
	East	49.6	73.7	53.7	70.3	55.3	68.9
1-10 Feb., 1968	West	48.6	68.3	51.4	67.5	52.2	67.9
	Middle	48.6	68.3	50.7	65.9	51.6	68.0
	East	48.6	68.3	51.1	67.7	50.4	67.0

M.=Morning

Barrage Arch No. 8 Site Crown of Gate Bridge.

3″		6″		12″		18″	
M.	E.	M.	E.	M.	E.	M.	E.
89.0	94.1	92.1	93.2	92.9	91.4	93.7	91.4
90.1	93.3	93.5	94.5	9.5	90.6	93.9	92.7
90.3	93.2	89.2	90.1	91.5	91.7	91.7	92.2
90.1	97.3	92.7	95.7	94.7	94.5	89.2	90.4
90.1	104.3	94.6	97.8	90.8	96.2	94.6	97.8
93.2	104.9	91.9	93.7	90.5	100.1	93.8	98.2
97.7	97.1	95.9	97.9	96.8	97.5	95.4	97.8
95.0	102.6	96.8	103.6	101.5	99.6	95.3	101.7
96.0	107.2	99.9	98.6	96.9	98.6	95.3	100.0
94.7	101.0	95.0	98.7	97.1	98.2	97.1	98.0
96.6	101.1	97.1	99.1	95.7	96.4	96.8	97.1
96.8	100.2	94.8	96.2	96.9	95.2	96.6	95.0
94.2	98.9	97.1	100.4	97.7	100.2	96.8	100.4
92.1	99.5	94.1	100.7	95.3	97.1	95.5	49.5
94.1	101.7	92.7	97.3	94.2	97.1	94.0	97.1
89.6	94.2	90.3	94.2	91.2	93.5	91.1	93.2
92.5	92.7	90.6	94.4	87.6	89.4	92.3	94.1
93.8	97.5	89.2	92.7	90.6	93.3	90.3	92.3
80.7	89.6	77.7	81.3	80.6	82.0	80.0	82.4
82.4	92.5	78.2	82.4	77.9	80.6	80.7	83.3
80.7	91.7	77.4	81.5	79.8	83.6	79.4	82.9
62.6	69.9	94.7	71.0	63.6	67.7	65.7	67.2
64.2	73.9	64.4	71.2	61.8	65.6	65.8	70.8
62.7	72.1	63.5	68.5	64.5	69.8	69.2	66.7
55.7	67.4	57.8	64.0	58.6	62.6	55.0	62.6
59.5	68.9	56.8	63.5	58.7	62.0	55.5	62.2
53.2	67.4	56.7	62.6	57.7	62.5	55.0	62.5
56.6	66.6	51.1	63.2	56.8	61.2	56.0	58.1
52.2	59.2	51.2	57.4	59.9	55.4	51.1	57.0
50.8	58.0	48.9	56.0	50.1	53.9	50.8	55.0

E.=Evening

TABLE No. 7.—*Temperature Gradient Studies, Sukkur*

Year	Group	Air Temp.		0.5''		2''	
Date of Month		M.	E.	M.	E.	M.	E.
1-10 Mar., 1968	West	58.9	90.7	69.2	90.7	67.3	90.3
	Middle	58.9	90.7	67.6	88.5	66.9	83.0
	East	58.9	90.7	61.8	90.5	66.5	79.0
1-10 Apr., 1968	West	70.3	95.8	73.4	90.1	70.7	90.7
	Middle	70.3	95.8	74.8	91.1	72.3	80.2
	East	70.3	95.8	73.5	90.2	74.3	90.8
1-10 May, 1968	West	67.0	98.8	72.4	90.0	75.4	92.3
	Middle	67.0	98.8	72.4	90.5	76.5	94.0
	East	67.0	98.8	72.4	92.6	77.9	90.4
11-20 June, 1968	West	86.4	102.4	89.9	94.4	88.5	94.9
	Middle	86.4	102.4	88.1	96.9	89.0	94.6
	East	86.4	102.4	88.2	95.0	91.4	94.5
1-10 July, 1968	West	89.7	109.8	90.0	100.0	90.0	101.9
	Middle	89.7	109.8	91.3	102.5	92.5	102.6
	East	89.7	109.8	89.9	105.9	91.5	104.3
1-20 Aug., 1968	West	95.6	116.0	95.7	105.6	93.0	102.9
	Middle	95.6	116.0	92.5	109.7	84.0	101.8
	East	95.6	116.0	94.2	101.8	91.5	101.3
21-30 Sep., 1968	West	71.5	94.0	74.5	91.7	74.5	93.4
	Middle	71.5	94.0	72.8	93.9	74.0	93.2
	East	71.5	94.0	74.8	92.6	74.4	93.0
1-10 Oct., 1968	West	67.0	91.6	88.6	89.2	69.2	88.7
	Middle	67.0	91.6	66.5	89.1	67.8	87.3
	East	67.0	91.6	72.7	89.1	69.0	89.6
1-10 Nov., 1968	West	70.2	82.0	71.8	91.7	22.7	91.9
	Middle	70.2	82.0	70.7	90.5	70.3	92.3
	East	70.2	82.0	71.8	93.7	70.5	94.1
1-10 Dec., 1968	West	59.7	80.2	65.7	90.1	65.3	91.3
	Middle	59.7	80.2	63.0	89.2	64.2	87.8
	East	59.7	80.2	62.4	88.0	54.9	87.5

M.=Morning

Barrage Arch No. 8 Site Crown of Gate Bridge.

3″		6″		12″		18″	
M.	E.	M.	E.	M.	E.	M.	E.
67.9	90.4	66.2	78.0	64.5	75.6	66.6	75.6
65.9	79.9	66.2	71.8	66.7	71.0	66.2	71.3
66.8	89.9	66.2	73.4	61.4	75.4	65.4	72.3
70.3	89.3	75.1	76.5	78.5	82.1	76.0	82.7
71.2	89.3	79.9	86.0	73.7	83.6	72.8	79.8
76.9	89.0	79.9	87.0	76.7	83.6	75.8	84.2
71.4	86.6	76.6	83.6	73.8	92.4	70.3	85.3
78.6	87.2	80.5	89.2	76.4	82.1	76.7	86.6
77.2	86.9	78.7	85.5	76.3	86.3	74.1	88.8
92.4	96.1	91.6	96.8	89.6	92.2	89.1	91.2
90.8	96.4	90.9	93.5	92.0	93.0	90.8	92.6
90.1	95.7	91.9	93.5	93.6	93.5	93.0	94.7
97.0	102.6	92.1	105.4	90.8	104.3	90.2	103.3
98.1	102.6	94.8	106.9	94.7	104.9	92.3	102.0
96.6	103.3	95.9	106.0	94.5	103.9	91.8	100.2
93.9	98.9	99.12	106.3	94.4	104.3	98.4	102.0
93.0	102.5	97.2	105.6	95.3	94.1	93.4	104.4
92.1	102.2	94.4	104.3	93.9	99.9	93.9	98.8
73.0	92.9	74.0	88.3	73.0	90.6	79.8	88.1
72.6	93.7	72.4	92.5	74.8	89.4	74.0	90.3
74.3	93.9	72.9	91.2	71.3	89.6	73.6	89.0
60.4	89.2	60.2	80.8	89.8	86.8	86.3	86.5
65.0	85.8	66.4	80.6	66.8	81.6	62.0	83.3
68.3	89.3	71.3	86.2	70.8	84.0	71.1	86.1
70.9	92.5	73.6	88.9	72.7	93.2	73.7	88.7
70.7	92.6	71.8	91.6	72.5	92.0	74.6	91.9
70.9	92.8	72.5	92.8	72.1	91.0	72.5	89.9
65.3	90.5	65.8	82.5	65.3	87.5	67.8	89.0
63.0	88.4	62.7	81.8	61.3	78.0	54.0	81.0
63.1	88.4	61.7	87.2	61.7	86.5	63.5	87.5

E.= Evening

TABLE NO. 8.—*Daily variation of temperature in °F for Selected Period. Gate Bridge Arch No. 8 at Crown.*

S. No.	Period	Air Temp. E.	Air Temp. M.	Variation of air temp.		Variation of temperature at various depths 0.5″	1″	3″	6″	12″	18″
1.	1-10 June, 1967	112.0	87.2	24.8	West	16.1	10.8	5.8	1.8	3.1	1.3
					Middle	13.5	11.2	6.9	3.6	2.4	6.3
					East	11.7	9.3	4.6	1.9	2.7	3.8
					Mean	13.7	10.4	5.76	2.4	2.7	3.8
2.	1-10 Aug., 1967	104.0	87.1	16.9	West	9.9	7.5	4.5	2.0	2.5	3.6
					Middle	7.6	6.4	4.5	2.7	2.8	3.9
					East	9.9	8.2	5.4	3.3	2.2	3.3
					Mean	9.1	7.3	6.4	2.6	2.2	3.6
3.	11-20 Nov., 1967	55.8	28.8	27.0	West	12.6	9.0	6.2	3.8	3.8	2.2
					Middle	12.6	9.2	6.2	3.5	1.8	2.2
					East	10.8	9.7	7.2	4.6	3.6	4.6
					Mean	12.0	9.3	6.5	3.9	3.1	3.0

M.=Morning

4.	1-10 Jan., 1968	73.7	50.0	23.7	West	12.0	11.1	11.7	6.2	3.2	6.6
					Middle	10.9	12.1	12.0	6.5	3.3	4.3
					East	12.1	13.5	12.0	7.0	4.7	5.6
					Mean	11.6	12.2	11.9	6.5	3.7	5.5
5.	1-10 May, 1968	98.8	67.6	31.2	West	17.68	16.90	15.20	6.98	19.61	15.0
					Middle	18.09	17.45	8.39	8.74	5.70	9.88
					East	20.17	12.45	8.69	6.80	10.05	19.73
					Mean	18.64	15.60	11.09	7.52	11.78	13.20
		Grand Mean:		24.7		13.0	10.96	8.33	4.58	4.69	5.82

E.=Evening

TABLE No. 9.—*Annual variation of temperature on the basis*

	Air		0.5"		1"		2"	
	1967	1968	1967	1968	1967	1968	1967	1968
				R. B. Crown				
Highest temp. during a period of ten days in a year	..	..	35.0	43.0	35.0	42.4	35.2	39.0
% Variation w. r. to air	53.5	59.9	65.6	71.5	6.0	70.0	65.7	65.0
				R. B. Springing				
Highest temp. during a period of ten days in a year	..	..	..	..	..	..	..	..
% Variation w. r. to air	53.5	59.9	..	..	..	..	..	..
				Gate Bridge (Crown)				
High temp. during a period of ten days in a year ..	..	..	37.2	35.0	..	..	36.2	28.4
% Variation w. r. to air	53.5	59.9	73.6	58.3	..	..	71.4	47.4

of Highest and Lowest attained in a period of Ten vays.

3''		6''		12 '		18''		
1967	1968	1967	1968	1967	1968	1967	1968	
			R. B. Crown					
34.3	35.7	33.9	33.5	33.2	31.3	34.5	29.0	Highest temp. during a period of ten days in a year
64.1	58.2	63.3	55.7	62.05	53.0	64.4	48.3	% Variation w.r. to air ..
			R. B. Springing					
..	..	33.6	30.3	29.3	26.0	27.7	25.0	Highest temp. during a period of ten days in a year
..	..	62.8	55.0	54.7	43.2	51.7	41.6	% Variation w.r. to air ..
			Gate Bridge (Crown)					
35.2	28.3	33.2	29.3	35.0	25.4	35.8	28.5	Highest temp. during a period of ten days in a year
69.7	47.0	65.7	48.2	69.3	42.1	70.8	47.5	% Variation w.r. to air ..

TABLE NO. 11.—*Mean Annual variation of temperature at various depths in Cement Concrete.*

S. No.	Mean air temp. °F	1/2″ depth		3″ depth		6″ depth	
		Percentage variation	Mean highest temp. °F	Percentage variation	Mean highest temp. °F	Percentage variation	Mean highest temp. °F
1.	57.0 ..	70	37.5	68	35.0	65	33 0
2.	70 °F ..	70	46.06	68	37.5	65	35.5
3.	Quartzite, Dolomite 10% increase	70	50.66	68	41.2	65	39.05
4.	Rhyolite, Basalt, Granite 25% less ..	70	34.58	68	28.2	65	26.6
5.	90 °F ..	70	59.19	68	46.3	65	45.6
6.	70 + 20 °F ..	50	56.06	25	42.5	20	39.5