TEMPERATURE CHANGES AND DURATION OF HIGH AND LOW TEMPERATURES IN A CONCRETE PAVEMENT

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SYNOPSIS

The data for this paper were obtained by the State Highway Commission of Kansas during 1936 to 1941, as a part of an experimental concrete pavement project having various types of subgrade concrete and expansion joints under observation in Douglas County, Kansas. The temperatures observed were continuous during the period of observation A summary of the extreme high temperatures and the extreme low temperatures as actually recorded 1 in from the top of the pavement and 1 in from the bottom of the pavement and from the subgrade is presented.

Considerable significance is attached to the amount and duration of the high temperatures recorded, and to the amount and duration of the low temperatures The number of freezing and thawing cycles recorded within the concrete pavement also gives some useful information The results of an attempt to correlate air temperatures with concrete pavement temperatures is reported.

Another point of interest is the inconclusive result that can be had through any short period study. Each particular year of the five during which observations were made contained a great variation in the number of freezing and thawing cycles, the total number of hours of high temperatures and the total number of hours of low temperatures. The difference in the number of cycles and the temperatures recorded in the bottom and top of the slab are also of considerable interest.

Contrary to popular belief, Kansas does not have a corner on the high and low temperatures over the United States. Weather Bureau records show at least half of the 48 states to have temperatures similar to that of Kansas, thus these data should be useful to others.

The data presented in this paper were obtained by the State Highway Commission of Kansas during 1936 to 1940 inclusive as a part of an experimental concrete paving project for the purpose of examining various types of subgrade and various conditions of moisture under which subgrades could and should be placed with particular reference to pavement distortion.

A study was made of various types of concrete with different water-cement ratios and different aggregates and with various types of expansion joints. A full report of this project is being prepared and will be available for study at some later date

The project was 5 0 miles in length in an east to west direction. Limestone coarse aggregate and siliceous fine aggregate were used in the sections where the temperatures were recorded. The water-cement ratios for these sections were 5.75 gal. of water per sack of cement. The temperatures of the air, top of the concrete pavement, bottom of the concrete pavement and the subgrade were automatically recorded continuously over a five year period. Originally, this information was intended to be supplemental to the other parts of the experiment; however, after a tabulation of these temperatures had been made they seemed to have considerable significance as a separate study.

METHOD

The temperatures were recorded automatically on weekly charts by Tagliabue automatic recording thermometers placed at two different locations on the project At both locations one-inch pipes were installed in the concrete pavement. One pipe had its top 1 in. below the top of the pavement (9–7–9-in. section) and another pipe had its lower portion 1 in. from the bottom of the pavement and a similar pipe was installed in the subgrade 6 in. below the bottom of the pavement. The bulbs and flexible tubes from the thermometers were placed in the pipes to a point about 9 feet from the edge of the pavement. The pipes were thoroughly caulked to prevent air current movements, and the entrance of moisture.

CORRELATION

It was found that the mean temperatures for the five years during which these data were collected (1936 to 1941), varied only 1.2 deg. rom a 63-year average These temperatures then, are fairly representative of those which can be expected over a long period of time

It is commonly believed that Kansas has more weather than any other State. Radio and newspapers seem to point out Kansas as the hottest, or coldest, or dustiest, or wettest. That does not appear to be factual, however. We find from latest published weather data that 25 of the 47 other states have the same average range of summer temperatures as Kansas These are New Jersey, Maryland, Ohio, North Carolina, South Carolina, Georgia, Kentucky, Indiana, Iowa, Delaware, Virginia, West Virginia, Alabama, Tennessee, Illinois, Missouri, Arkansas, Oklahoma, Nebraska, South Dakota, New Mexico, Arizona, and parts of California, Texas and Pennsylvania. Likewise, 28 of the 47 other states have the same average winter temperatures as those of Kansas. These are. New Jersey, Delaware, Maryland, Virginia, West Virginia, Kentucky, Tennessee, Missouri, Oklahoma, New Mexico, Arizona, Nevada, New York, Massachusetts, Connecticut, Rhode Island, Pennsylvania, Ohio, Indiana, Nebraska, Illinois, Iowa, Wyoming, Colorado, Montana, Utah, Nevada, and Oregon. The amount of sunshine during the

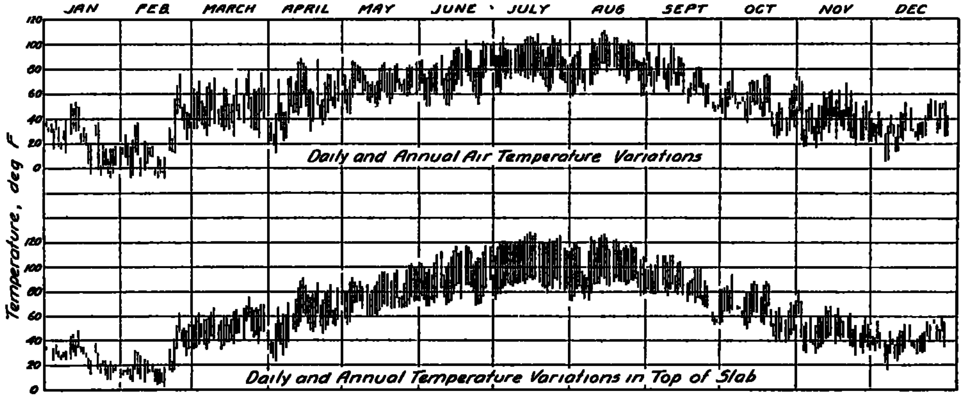

Figure 1. Air and Slab Temperature Data—1936

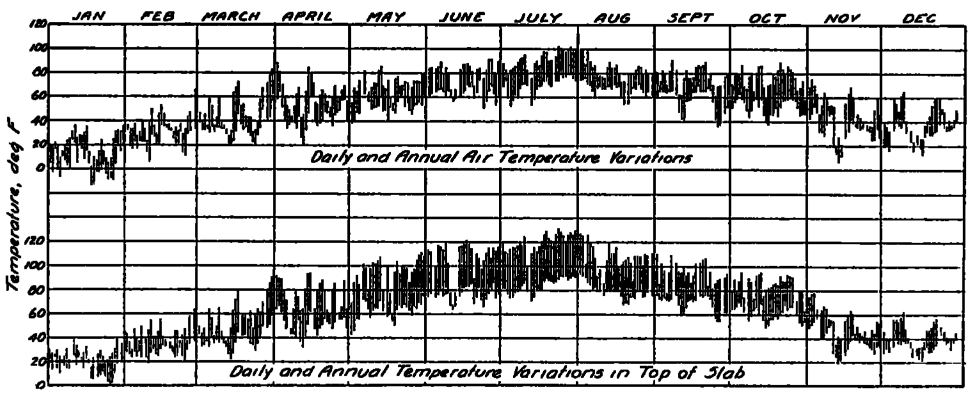

Figure 2. Air and Slab Temperature Data—1940

summers also has some bearing on the temperatures as recorded in the concrete slabs. The United States Weather Bureau data show that about one-third of all the states have about the same percentage of summer sunshine as Kansas.

Figures 1 and 2 show the complete daily temperature records of the air and the top of the slab for the years 1936 and 1940. The greatest variation in daily range of pavement temperatures is seen to come in the months, May to September inclusive. A daily range of about 45 deg F. from coldest to warmest is quite common for the top of the slab during these months The temperature differential in the bottom of the slab for any one day in these months is about 15 deg F. less than the range of temperatures for the top. The subgrade itself seldom varies more than 6 deg In this five year period, the greatest daily range occurred in the top of the slab on April 11, 1940 at which time the temperature of the top of the pavement began at 31 deg. and by the middle of the day on the 13th, two days later, it had gone up to 96 deg F ; a spread of 65 deg in about 52 hours. This shows the extreme variations which have occurred in this pavement and, for that matter, may occur in any piece of concrete exposed to the elements.

HEAT

Figure 3 shows the duration of high temperatures within the slab. We view these with particular interest because of the potential value of correlating such high temperatures of long duration with what appears to be a common problem in those states within the same temperature band as Kansas Kansas and other states such as Nebraska, Colorado, Iowa, Georgia, California, Ohio and others have reported from time to time on distress or disintegration occurring in concrete made with certain particular ingredients In our area this distress has manifested itself as map-cracking in a "total aggregate" concrete. (For details of this distress and the type of concrete in which it occurs see a report by W. E. Gibson, Engineer of Tests of the Kansas Highway Commission, entitled "A Study of Map Cracking of Sand-Gravel Concrete Pavements." *Proceedings*, Highway Research Board, Vol. 18, p. 227.) Some of these troubles have been attributed by investigators to cements high in alkali. I would like to direct your attention to the possibility of an additional contributing factor, namely the duration of high temperatures over a considerable period of time Temperatures of over 100 deg. F only are shown here for the top and bottom of the pavement, for two different sections. These are the total hours over a five-year period which were recorded during June, July, August and September. Putting the values indicated on the graph in other terms, the temperature within the top of the slab was above 100 deg. 27 per cent of the time for the four months considered, or for approximately 9 per cent of the total time for the complete five year period, 24 hours a day, 365 days in a year It can very well be, that more than coincidence exists between these high temperatures and certain forms of concrete disintegration that are found in the areas having similar temperatures as those in which this particular study was made.

COLD

The cold phase of this study is also quite significant. Figure 4 portrays the duration of low temperatures. From this graph it can be seen that there were 3000 hours that the pavement temperatures were below 32 deg. F., 1000 hours below 20 deg. F. and 300 hours below 10 deg. F. There were no zero temperatures recorded in the pavement during this five year period. Putting these values in terms of percentage of time, these pavement temperatures were below 32 degrees F. 18 per cent of the time for the five months period recorded. These months were November, December, January, February and March. This is 9 per cent of the time for the complete five year period, the same percentage as the temperatures over 100 deg. F.

I think Mr. F. V. Reagel in his paper entitled "Freeze and Thaw Tests of Concrete," (*Proceedings*, Highway Research Board, Vol. 20, p. 587), demonstrated the comparative destructive effects of such low temperatures as 0 deg. F., 10 deg. F. and 25 deg F.

The absence of any recorded zero temperatures in the slab for either the top or the bottom carries some significance as to the temperatures involved in the freeze and thaw soundness tests of aggregates and concrete.

In both Figure 3 and Figure 4 a difference is to be seen between the two locations studied. This may be partially explained by a difference in the amount of protection from air currents. There is no shade on either of these sections. It is only normal that the bottom of the slab should lag considerably in arriving at the same temperatures as the top of the slab.

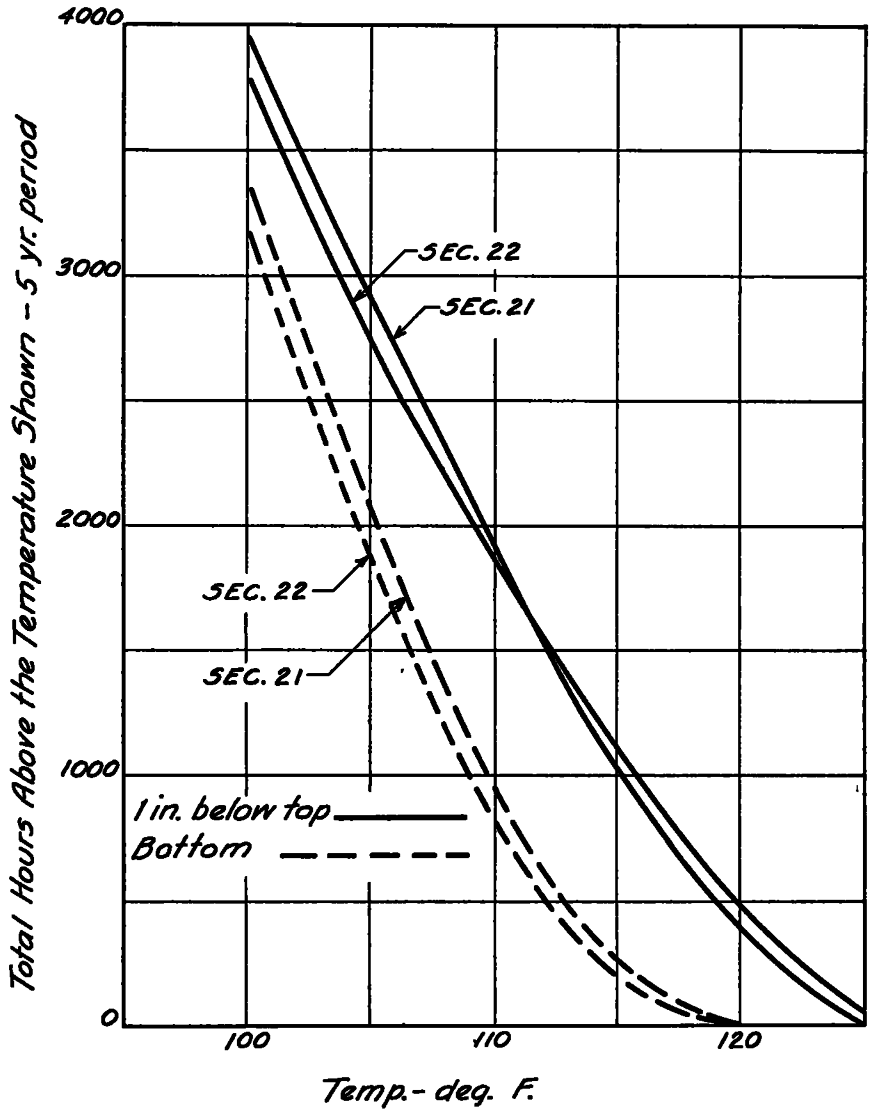

Figure 3. Duration of High Temperature in Concrete Pavement, 1936–1940 inclusive

Table 1 shows the number of freeze and thaw cycles; first· in the air, second: top of slab, third: bottom of slab and fourth: subgrade. One freezing and thawing cycle as shown in this tabulation is defined as thawing from 31 deg. F. to 33 deg. F. The same five months of November, December, January, February, and March as were used in Figure 4 showing the duration of cold temperatures is used in this tabulation.

The extreme unreliability of attempting to correlate air temperatures and the study of the effects of freezing and thawing on concrete pavement in service may be observed. For instance in 1936 there were 90 freeze and thaw cycles in air and only 39 such cycles in the top of the pavement. 1938 had 77 cycles in the air and 58 cycles in the top of the pavement and 1940 had 58 cycles in air and 54 cycles in the top of the pavement. The duration of any one cold period affects the temperature in the slab as would be expected. The subgrade under the pavement in this period completed more than two cycles only once in the 5-year period. In two of these five years there were no freeze and thaw cycles involved in the subgrade.

COMPARATIVE TEMPERATURES

Table 2 shows another method of presenting the temperature data obtained from this project. This table shows the number of days in any one year that temperatures exceeded 100 deg. F. You will note that the number of days of 100 deg. in the top of the slab exceeded by many days the air temperatures of 100 deg. In 1938 this proportion was 100 to 1 In this table also are shown the days in each year that air and top of pavement temperatures were below 32 deg. F., 20 deg. F., and 10 deg. F. These follow air temperatures a little more consistently taken year by year than the warmer side of the pic-

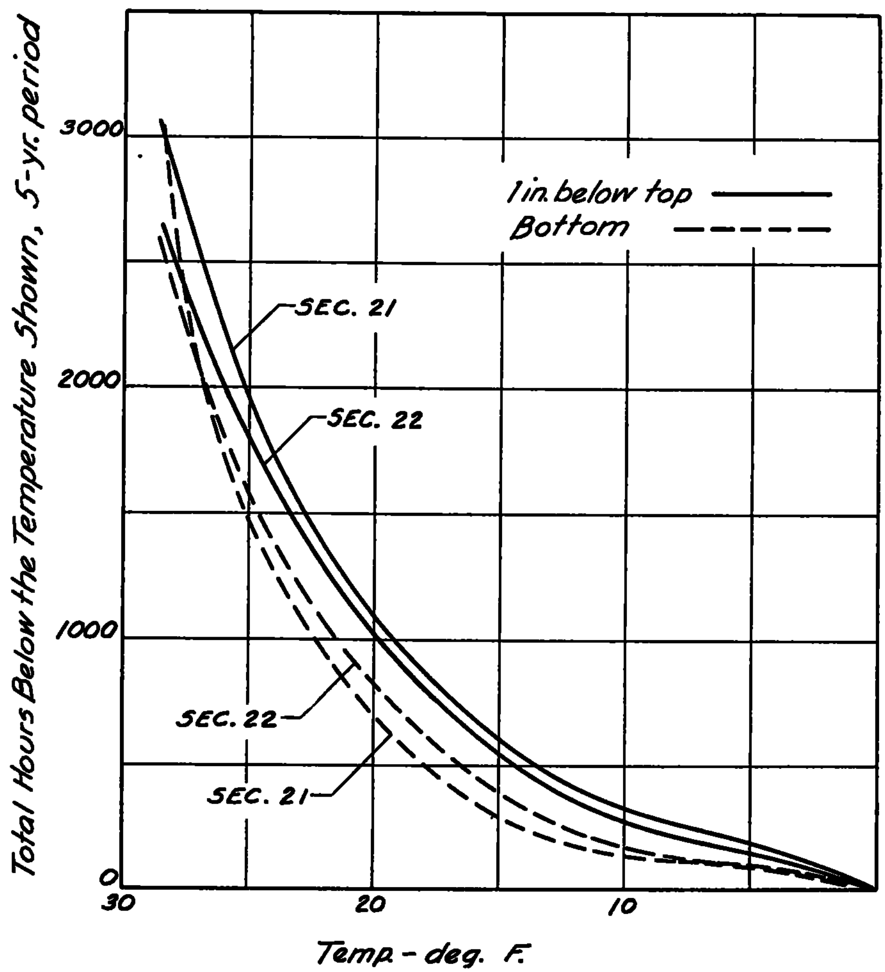

Figure 4. Duration of Low Temperatures in Concrete Pavements, 1936–1940 inclusive

ture. In some of these years the average temperatures were a degree or so below normal. In 1936 the mean temperature was 2 deg above normal.

TABLE 1
FREEZING AND THAWING CYCLES
(31°F. to 33°F)

Year (Jan. to Dec)	Air	Pavement		Sub-grade	Remarks
		Top	Bottom		
1936	90	39	25	2	First 30 days of year coldest on record Summer second hottest on record Maximum 112° Lowest 10° below zero
1937	80	76	60	8	Average temperature below normal 4 months above normal No extreme temperatures Lowest zero Maximum 103 degrees
1938	77	58	42	0	All but 2 months above normal Maximum 106 degrees Minimum zero
1939	62	47	34	0	Average temperature above normal Maximum 106 degrees Minimum 4 degrees below zero
1940	58	54	37	1	Mean temperature 2 degrees below normal Maximum 102 degrees Minimum 13 degrees below zero

TABLE 2
DAYS PER YEAR OF HIGH AND LOW TEMPERATURES

Year (Jan to Dec)	Number of Days								Remarks
	Over 100° F		Under 32° F		Under 20° F		Under 10° F		
	Air	Top of Slab	Air	Top of Slab	Air	Top of Slab	Air	Top of Slab	
1936	34	93	121	71	51	37	29	13	First 30 days of year coldest on record Summer 2nd hottest on record Maximum 112 degrees. Lowest 10 below zero
1937	5	110	121	90	60	29	27	5	Average temperature below normal No extreme temperatures Lowest zero Maximum 103 degrees
1938	1	103	93	61	27	5	8	0	All but 2 months above normal Maximum 106 degrees Minimum zero
1939	14	117	94	50	25	7	12	0	Average temperature above normal Maximum 106 degrees Minimum 4 degrees below zero
1940	3	98	89	79	47	29	25	9	Mean temperature 2 degrees below normal Maximum 102 degrees Minimum 13 degrees below zero

SUMMARY

1. Above all temperatures are very fickle. Changes in temperature are constantly going on, sometimes quite rapidly. Any study of temperatures should be for a considerable period. No one of the years during which these data were recorded was above or below average normal temperatures by more than about 2 deg. F. Yet, any one year of the five would present a far different picture from the others.

2. No reliance can be placed upon a study of air temperatures when one is considering concrete pavement temperatures. Naturally as the air temperatures become higher the pavement temperatures will also become higher but they do not follow any given formula or any set pattern.

3 The extent and duration of high temperatures in concrete pavement can be profitably studied for the possible relationship to the solutions of some concrete problems which are being sought.

4. The low temperature data are significant with regard to a freeze and thaw soundness test both as to the temperature to be used and the number of cycles to be considered.

Personnel and time did not permit tabulation of the number and extent of other cycles such as 40 deg. F. to 25 deg. F. or 40 deg. to 10 deg., etc. However, we do expect to obtain these at a later date.

5. All must agree that such a material as concrete pavement takes a terrific beating from the elements. From study of these temperature charts one is inclined to congratulate a piece of material that withstands the sudden extreme changes which take place over a day or a year's time.

The author wishes to express his sincere appreciation to the following persons for their part in making this information possible.

Mr. Harold Allen, Materials Engineer, Public Roads Administration, who while

Engineer of Materials for the Kansas Highway Commission, initiated the project; to R. D. Finney, present Engineer of Materials of the Kansas Highway Commission, under whose supervision this work was completed; to C. H. Scholer, Professor of Applied Mechanics, Kansas State College, for his helpful suggestions and assistance rendered in tabulating much of this data; to E. E. Larson, Engineer in charge of obtaining this data; and to C. R. Fricke and D L. Lacey, Engineers, who assisted in this work.

PROGRESS REPORT ON CALIFORNIA EXPERIENCE WITH CEMENT TREATED BASES

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SYNOPSIS

The California Division of Highways has built 123 miles of pavement base by mixing cement with granular materials of many kinds and compacting on the subgrade by rolling or tamping Most of these bases have been for first class road improvements. The materials have included fine silty sands, streambed gravels, disintegrated granite, soft crushed sandstone, fairly clean sand and aggregates suitable for concrete, and many construction methods have been tried Twenty-eight projects ranging in length from one-half mile to 13.1 miles have been constructed.

Since in most cases the material for cement treated bases in California is brought from an approved pit or quarry it was found economical and otherwise desirable to use plant mixing rather than road mixing.

These cement treated bases are giving satisfactory service Attempts to use thin bituminous surfaces on the cement treated bases did not give satisfactory results and hence a 3-in layer of bituminous surfacing has been adopted as standard practice on California primary roads of moderate to heavy traffic.

The mixture design is based on compressive strength requirements of 850 lb per sq. in at 7 days and 1000 lb. per sq in. at 28 days.

California experience with cement treated base construction dates from 1937 although some minor investigations along this line were made as early as 1921

The work in 1937 and 1938 consisted of road mixing cement with the local materials in the subgrade and these early projects may be considered as patterned after the original soil cement stabilization idea which has been applied extensively in other sections of the United States where the tendency has been to confine operations of this nature to cement treatment, or stabilization as it has been called, of local fine grained soils.

Most of the cement treated base construction in California, however, has been in connection with first-class road improvement where the traffic includes medium to heavy industrial equipment and where a more substantial base was required than on lightly traveled secondary roads.

California has found it difficult economically to justify soil cement construction, even on a moderate scale for lightly traveled secondary roads as an alternate to bituminous surfacings on selected material or gravel bases.

On the more heavily traveled highways, however, there appears to be a very definite economic justification for this special type of construction, provided granular soils, streambed aggregates, or other materials of a suitable nature are at hand. Such materials have been