showed an average crushing strength of 3,000 pounds per square inch The actual thickness of pavement, as shown by the cores, does not vary from the theoretical thickness by more than 0 3 of an inch

As stated in the first report, the planes of weakness became effective before the end of the curing period This was evidenced by cracks through the entire slab at each plane A later inspection by W D Somervell in October, 1925, showed no further cracks The road then passed through the winter of 1925 and summer of 1926.

On September 21, 1926, a field inspection revealed only one crack on the 2,000 feet section The pavement immediately adjacent on the north and on the south was laid under the same specifications, but had no planes of weakness except the joints at end of each day's run The 800 feet to the north showed 30 transverse cracks varying in spacing from 5 to 100 feet The 800 feet to the south showed 17 cracks varying in spacing from 21 to 150 feet The 2,000 feet with planes of weakness has developed one transverse crack since October, 1925 There are no longitudinal cracks in the test section or pavement immediately adjacent Some other portions of the 9-mile project show frequent transverse and short longitudinal cracks, especially near the northern end The cracks and planes of weakness have been fairly well protected by tar or asphalt filler

From the foregoing the following conclusions can be drawn relative to the utility of planes of weakness

1 That they tend to regulate to a definite minimum the spacing of transverse cracks, thereby decreasing the possibilities of pavement failure

2 That the regularity of their edges at the pavement surface is an advantage against spalling action

3 That they may be used successfully as longitudinal planes of weakness in the center of pavements as well as transversely

4 That there is a possibility of using them as an economic and effective substitute for premolded transverse and longitudinal joints

PROGRESS REPORT ON THE EXPERIMENTAL CURING SLABS AT ARLINGTON, VIRGINIA

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It is a well-known fact to those who have studied the behavior of a concrete pavement from the time of laying the concrete that many factors other than traffic affect the life of the pavement. Moisture changes and temperature changes in the concrete, together with subgrade resistance, are factors which may, directly or indirectly, under certain conditions, have a very detrimental effect on the pavement.

For the purpose of securing added information on the action and control of such affecting factors other than traffic, the Bureau of Public Roads built, during August of this year, at Arlington, Virginia, a series of forty concrete slabs, 200 feet long by 24 inches wide and 6 inches thick (Figure 1). The concrete was of a 1:2:4 mix with Potomac River sand and Potomac River gravel as aggregates. The mixing and placing were done under weather conditions as nearly identical as possible.

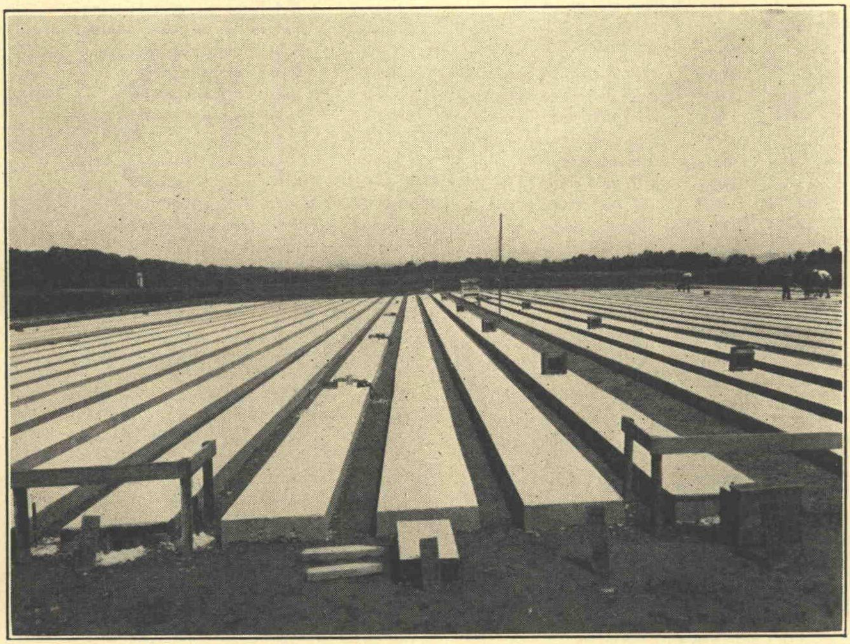

Figure 1

The plan of construction was made to cover a wide range of variables (see Table I), so that, after sufficient time and study, information should be available which will permit a better understanding on the following subjects:

1. Comparative effect of different methods of curing.
2. Effect of steel reinforcing of various types and weights in distributing stresses occurring from shrinkage in the concrete.
3. The effect of expansion joints in distributing stresses occurring from shrinkage in the concrete.

TABLE I

DETAILS OF CONSTRUCTION AND CURING OF THE EXPERIMENTAL SLABS

Slabs	Group	Reinforcing	Length of Segmental Sections in feet	Curing
1	Dry	None	None	None—dry subgrade
2	Dry	None	20-30-40-50-60	None—dry subgrade
3	Dry	None	None	Tarvia B—Dry subgrade
4	Dry	None	None	2 lbs calcium chloride—dry subgrade
5	Dry	None	None	Sodium silicate—Dry subgrade
6	Dry	None	None	3 lbs calcium chloride—dry subgrade
7	Dry	None	None	Tarvia B—tar paper on dry subgrade
8	Dry	2¼" deformed bars	None	None—dry subgrade
9	Dry	2⅜" deformed bars	None	None—dry subgrade
10	Dry	2½" deformed bars	None	None—dry subgrade
11	Dry	2¾" deformed bars	None	None—dry subgrade
12	Dry	2¾" plain bars, painted and greased	None	None—dry subgrade
13	Dry	2½" deformed bars	20-30-40-50-60	None—dry subgrade
14	Dry	2¾" deformed bars	20-30-40-50-60	None—dry subgrade
15	Dry	None	None	2% calcium chloride adm —dry subgrade
17	Dry	43 8 mesh	None	None—dry subgrade
18	Dry	23 6 mesh	None	None—dry subgrade
19	Dry	43 8 mesh	20-30-40-50-60	None—dry subgrade
20	Dry	None	None	Dry straw—dry subgrade
21	Dry	None	None	Dry earth—dry subgrade
22	Medium	None	None	Wet earth—lightly sprinkled
23	Medium	None	20-30-40-50-60	Wet earth—lightly sprinkled
24	Medium	None	None	Wet straw—lightly sprinkled
25	Wet	None	None	Burlap and wet earth—thoroughly wet
26	Wet	None	20-30-40-50-60	Burlap and wet earth—thoroughly wet
27	Wet	None	None	Burlap and 2 lbs calcium chloride thoroughly wet
28	Wet	None	None	Burlap and sodium silicate, thoroughly wet
29	Wet	None	None	2 lbs calcium chloride, thoroughly wet
30	Wet	None	None	Sodium silicate—thoroughly wet
31	Wet	None	None	2% calcium chloride adm —thoroughly wet
32	Wet	43 8 mesh	None	Burlap and wet earth—thoroughly wet
33	Wet	23 6 mesh	None	Burlap and wet earth—thoroughly wet
34	Wet	43 8 mesh	20-30-40-50-60	Burlap and wet earth—thoroughly wet
35	Wet	2¼" deformed bars	None	Burlap and wet earth—thoroughly wet
36	Wet	2⅜" deformed bars	None	Burlap and wet earth—thoroughly wet
37	Wet	2½" deformed bars	None	Burlap and wet earth—thoroughly wet
38	Wet	2¾" deformed bars	None	Burlap and wet earth—thoroughly wet
39	Wet	2½" deformed bars	20-30-40-50-60	Burlap and wet earth—thoroughly wet
40	Wet	2¾" deformed bars	20-30-40-50-60	Burlap and wet earth—thoroughly wet
41	Wet	None	None	Asphalt emulsion—thoroughly wet

4 The effect of moisture in the subgrade in reducing shrinkage cracking

5 The effect and prevention of rapid drying of the newly placed concrete

6 The magnitude and effect of subgrade resistance

7 The curing of concrete pavements

8 Possible relation between pavement behavior and test data from control specimens

Sufficient time has not elapsed since this investigation was started to make it possible at this time to give complete results However, on a few of the problems studied sufficient indications have been obtained to warrant presentation at this time These somewhat scattering data and preliminary indications are presented in the following paragraphs

Loss in Moisture Two methods were used to obtain the loss in moisture of the concrete The first consisted of taking a pan of concrete (about 30 lbs) and weighing it as it came from the mixer, afterwards placing in the sun and weighing at hourly intervals In this manner the loss of moisture from the surface of the concrete, without curing, was determined

The other method consisted of pouring slabs 24 x 12 x 6 inches concurrent with each long slab, weighing the concrete as it came from the mixer The slab was then cured the same as the corresponding long slab, the edges of all the small slabs being painted after 24 hours with a heavy tar In this manner the loss in moisture was limited to the surface and the base The slabs were weighed at 24 hours after pouring and at intervals thereafter Figure 2 gives the moisture loss obtained under the several different conditions

Curve A in Figure 2 gives the comparative moisture loss obtained in a slab laid on a dry subgrade and without any curing treatment It can be seen from this curve that the greatest loss in moisture occurred during the first 24 hours after pouring Curve B represents the comparative loss in moisture obtained in a similar slab laid on a wet subgrade, covered with wet burlap for 24 hours and wet earth for 13 days This curve also shows that the greatest loss in moisture occurred during the first 24 hours after pouring The loss in moisture on the dry subgrade without curing is approximately four and one-half times that on a wet subgrade cured with wet burlap during the first 24 hours after pouring In Chart B the curve represents the loss in moisture over a period of 28 hours, using 30 pounds of concrete, with evaporation limited to the surface The greatest loss by this method was found to occur during the first three or four hours after the concrete was poured

The effect on the concrete of the rapid drying out during the first few hours after placing is shown by the number of local shrinkage cracks occurring In the slab with no curing 279 local shrinkage cracks developed, while none occurred in the slab having wet burlap curing during the first 24 hours

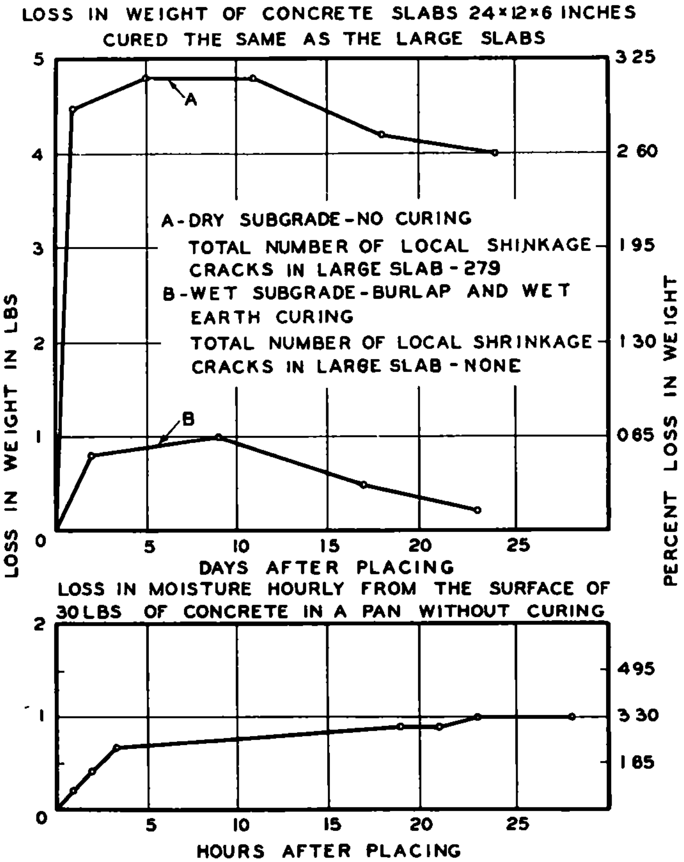

Figure 2. Loss in moisture of concrete slabs

It seems definitely indicated that the most important requisite for a satisfactory curing process or method must be to protect the concrete against drying out during the full first 24 hours after placing

Steel Reinforcing A series of reinforced slabs were included as one of the features of this investigation, the purpose being to determine the effect of the different sizes and types of steel on the distribution in the pavement of stresses developed under different conditions of curing from causes other than traffic

Three types of reinforcing were used in the different slabs These were deformed bars of several sizes placed continuous and segmental, plain ¾-inch bars painted and greased, and rectangular mesh 23 6 and 43 8 pound weights All reinforcing was placed three inches below the surface of the pavement In the case of the bar type, two rods were placed in each slab twelve inches apart and six inches from the edges

TABLE II

THE EFFECT OF REINFORCING IN REDUCING THE APPARENT THERMAL COEFFICIENT OF EXPANSION AND CONTRACTION

Slabs	Reinforcing	Area of steel in the slab section in sq in	No of transverse cracks	Average total width of transverse cracks, ins	Average coefficient (per degree C)
1	None	None	6	0 532	000011
8	2¼″ deformed bars	0 130	4	0 288	0000066
9	2⅜″ deformed bars	0 20	4	0 199	0000045
10	2½″ deformed bars	0 386	15	0 125	0000024
11	2¾″ deformed bars	0 868	6	0 023	00000064
12	2¾″ plain bars (painted and greased)	0 910	6	0 470	0000095
17	43 8-lb mesh	0 240	5	0 108	0000025
18	23 6-lb mesh	0 132	3	0 261	0000061

Table II gives the reduction in the apparent thermal coefficient of contraction obtained with several different types and quantities of reinforcing The thermal coefficient was determined from microscopic measurement of width of the transverse cracks in the different slabs

The bond between the steel and concrete in case of the ¾-inch plain bars is seen to have been almost totally destroyed by the paint and grease treatment The ¼-inch deformed and the 23 6-pound mesh with about the same area are seen to have about the same bond strength In the case of the ½-inch bars and the 43 8-pound mesh, approximately the same bond strength is obtained, probably because the ½-inch bar is of a type less deformed than those of the other size.

Control Specimens Compression, tension and modulus of rupture specimens were made concurrently with and cured similarly to the large slabs Specimens for compression were 6 x 6 inch cylinders, for tension, 6 x 21 inch cylinders, and for modulus of rupture, 6 x 6 x 24 inch beams Two sets of each were made to be tested at 24 hours, 3 days, 7 days, 21 days and 6 months

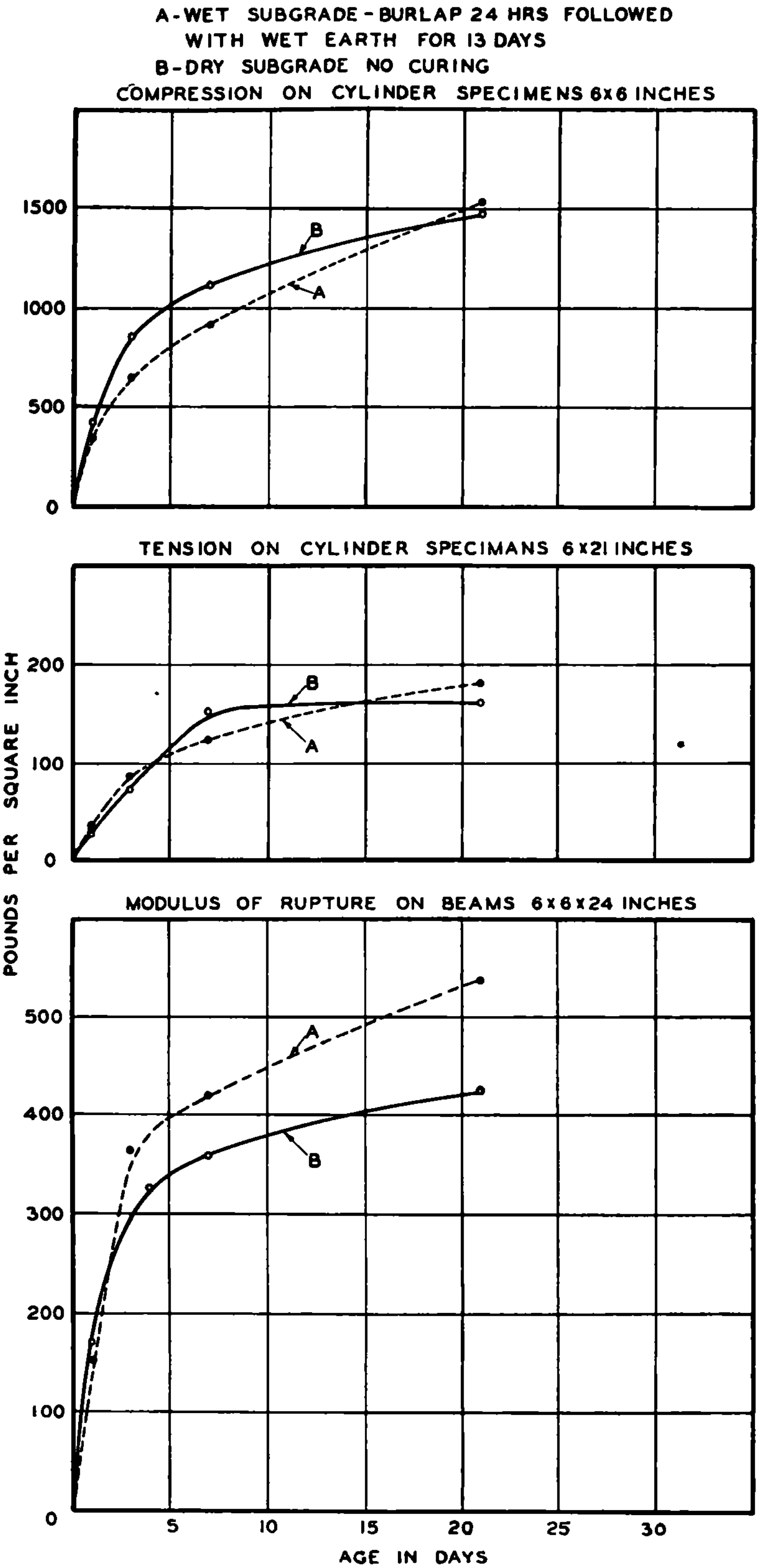

Figure 3 Strength of concrete control specimens

All of these, except the 6-month specimens, have been tested at the present time, the average strength curves for each type of test being shown in Figure 3 These results show that specimens on dry subgrade without any curing obtain a higher early strength than those on a wet subgrade covered with wet burlap for 24 hours and wet earth for 13 days As the specimens age, those made on the wet subgrade show a higher strength than those on the dry subgrade without curing

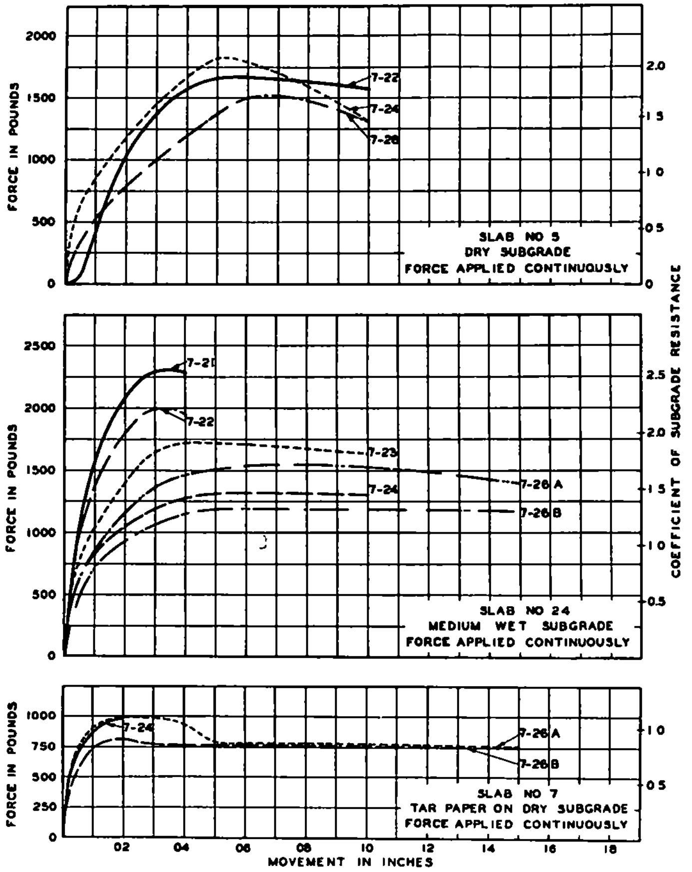

Figure 4. Subgrade resistance under concrete slabs

Subgrade Resistance The resistance of the subgrade to the horizontal movement of the slab has been determined on several subgrade conditions The value of this coefficient was obtained by measuring the force required to move slabs 6 feet by 2 feet by 6 inches which were cast on the subgrade at the end of a number of the long pavement sections

A few of the results obtained are given in Figure 4 The resistance is seen to be larger on a medium wet subgrade than it is on a dry Tar paper is seen to have greatly reduced the resistance A large reduction occurs with repeated movement of the slab

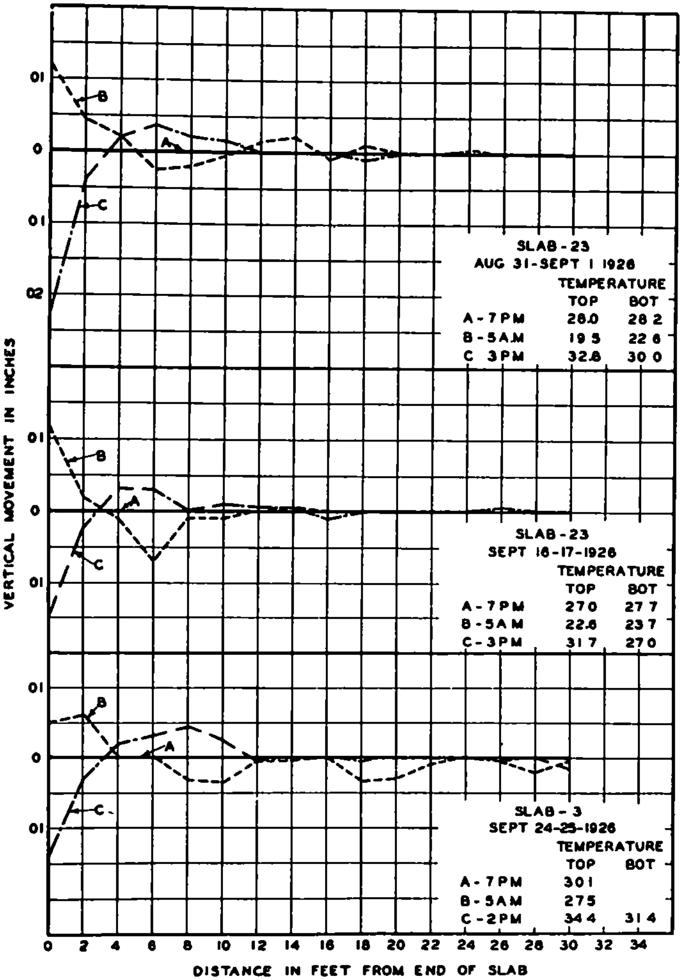

Figure 5 Curling of concrete slabs

Partial return of the slab after release of the force is found to take place The subgrade material on which these tests were made was of a silty loam with very little clay. In view of the exceptionally good subgrade material and conditions on which these high results were obtained, it would seem that the generally accepted subgrade resistance coefficient of two might be too small for the average condition

Curling of the Concrete Slab The amount of curling of several different slabs has been measured over 24-hour periods The method employed was to drive stakes along the slab at 2-foot intervals, and on these to mount dials which showed the vertical motion of the slab in thousandths of an inch In Figure 5 the maximum curling is plotted for several periods of 24 hours From these curves it can be seen that the maximum movement occurs at the end of the slab, that the maximum bending moment occurs from six to eight feet from the end, and that the curling of the slab is restrained as the distance from the end is increased

The curling curves shown indicate that a fiber stress of at least 100 pounds per square inch is possible It is evident that secondary transverse cracking may occur from this cause, before the concrete has attained high strength due to the dead-weight of the slab and at a later period from traffic loads

ANALYSIS OF STRESSES IN CONCRETE PAVEMENTS DUE TO VARIATIONS OF TEMPERATURE

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This paper supplements a previous paper by the writer, published in *Public Roads*, April, 1926, under the title "Stresses in Concrete Pavements Computed by Theoretical Analysis," and in the Proceedings of the Fifth Annual Meeting of the Highway Research Board, held at Washington, D C, December 3–4, 1925, Part I, 1926, pp 90–118, under the title "Computation of Stresses in Concrete Roads" The present paper, like the previous paper, rests upon the assumption that the concrete pavement acts as a homogeneous elastic solid As in the previous paper, the method is that of the theory of elasticity, conclusions being drawn from a few simple physical laws by mathematical analysis In regard to the general assumptions and concepts the reader is referred to the previous paper The previous paper dealt with stresses and deflections produced by wheel-loads The present paper deals with stresses and deflections produced by variations of temperature The former paper, on account of the complexity of the mathematical processes involved, was limited to a statement of the assumptions and general principles and to the presentation of the results with illustration of how to use them Since the mathematical processes involved in the present paper are much simpler, it was considered to be expedient not to omit them Results are given in tables and diagrams, and the use of the results is illustrated by numerical examples