CAUSES OF CRACKS IN CEMENT CONCRETE PAVEMENTS.*

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It is the intent of this paper to treat merely of the causes of cracking of concrete pavements in the light of our present knowledge of the subject. There are many phases of the question of cracking that might properly be brought out in a discussion, such as the effect of cracking on the life of the road, the expense of and best methods of the maintenance of cracks, and many other allied questions. All of these, however, have been avoided and an effort has been made to treat only that phase of the subject suggested in the title.

When the internal stress in a material reaches the ultimate strength, failure ensues and manifests itself in various ways. In a brittle material like concrete, a crack indicates that the ultimate internal resisting stress, whether it is tension, compression, or shear, has been exceeded and, therefore, in order to analyze the cause of cracks in a concrete pavement, we must first discover the cause of the high internal stresses existing at rupture. This is a difficult task as the internal stresses in concrete and reinforced concrete pavements are very complex and may be caused by a number of different phenomena acting simultaneously.

A concrete road slab is attacked by many forces which slide it, in part or as a whole, along its sub-base; which bend it and warp it; which subject it to impact and shear, and may even act within its interior to exert a disrupting effect. It is little wonder that concrete roads crack, since, due to the lack of experimental data, they are constructed without sufficient knowledge of the forces to which they will be subjected.

Let the life of a slab in the road be traced from the day it is poured in order that the complexity of stresses to which it is subjected may be studied. For about ten days or two weeks after the slab is laid and while the concrete is hardening, it is the practice, for several reasons, to keep the surface thoroughly wet. In the first place, water is necessary to hydrate the more inactive particles of cement, and, moreover, it has been discovered that as long as concrete is kept wet, its length changes but very little, provided the temperature remains constant. Any slight change that does take place due to moisture is favorable to the integrity of the concrete, because moisture expands concrete, and tends to produce small compressive stresses, owing to the frictional resistance at the sub-base against this expansive movement. Should the temperature rise during this initial period, additional expansion will result with increased compressive stress in the concrete. Even this combined compressive stress, however, is seldom likely to be very large during the initial stages of hardening, and may be neglected, as the concrete is generally sufficiently strong in compression to withstand the small forces then being exerted. Should there occur a large decrease in temperature during this initial period, the concrete will contract, causing it to move with respect to its sub-base. The forces of friction thereby developed produce tension, and as green concrete is weak in tension, a decrease in temperature, when the pavement is only a few days old, may cause cracks.

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Suppose the pavement survives this initial period without mishap and is thrown open to traffic. Immediately it begins to dry out and due to this cause it starts to shrink. The friction forces at the base immediately resist this shrinkage and the result is tension in the concrete. If the tension is too great the concrete cracks where the tensile strength of the concrete has been exceeded. As the seasons of the year succeed one another, the slab is alternately wetted and dried, and in addition, subjected to a wide range of temperatures, being thus kept in constant motion over its sub-base. The forces of friction are therefore in constant action resisting this motion, and thus cause stresses, now tensile, now compressive, to exist in the concrete. Should the forces of friction be sufficiently great, the resistance of the concrete is overcome and it fails, either in tension or compression, with one of two results, the concrete is cracked, or else bulged up or crushed. Sometimes moisture and temperature aid one another, and sometimes they counteract one another, but their activities are never ended during the existence of the road. Naturally, as friction can best be developed along the length of the road, temperature changes and moisture are promotive of transverse cracks rather than longitudinal cracks.

In addition to direct compressive and tensile stresses, road slabs are subjected to bending, due to the loads of traffic and more likely to unequal settlement of the sub-base, caused by lack of homogeneity. Ununiform reaction between the slab and the sub-base due to frost may also produce cracking, the slab then being supported in some spots and not in others, thereby creating large tensile stress in bending. Frost action is more likely to cause longitudinal cracks than transverse cracks. The expanding and shrinking of the sub-base, due to varying moisture content, is also promotive of bending stresses and consequent cracking in the concrete.

In a general way, the foregoing discussion treats of some of the causes of cracking of concrete pavements, and these causes can best be classified as follows:

1. Expansion and contraction. (*a*) Change in temperature; (*b*) change in moisture content.
2. Ununiform bearing under the slab. (*a*) Frost action; (*b*) lack of homogeneity in sub-base; (*c*) moisture expansion and shrinkage of the sub-base.
3. Excessive bending stress due to heavy loads and impact.

These causes will be considered in detail so far as our present knowledge will permit.

Expansion and Contraction.—(*a*) Change in temperature: It has been well established by several investigators that concrete expands and contracts as the temperature changes, and the amount of movement equals 0.0000055 inches per inch of length. If a concrete road is built in the summer season when the temperature is 90° F. and the temperature in the following winter falls to 0° F., the concrete must contract an amount equal to $0.0000055 \times 90 = 0.00495$ inches per inch of length. This contraction could do no harm if it were not for the resistance offered by friction between the sub-base and the slab. When the concrete contracts, the friction at the base resists the contraction and the amount of tension produced in the concrete is dependent on the amount of friction acting. Friction at the base varies with the kind of base and the degree of roughness and tests recently made by the author throw some light on the amount of friction that can act at the sub-base when the slab expands and contracts.