Friction at the Sub-base.—The tests referred to above were made by sliding 2-ft. x 6-ft. x 6-in. concrete slabs along previously prepared sub-bases. The sliding force was applied by means of a long lever and the magnitude of the force was measured with a carefully calibrated dynamometer. The amount of movement of the slab was read with a Berry strain gauge while the load increased slowly and steadily.

As the load was applied, the slabs seemed to move very slightly, even at the first application, except where a sub-base of large broken stone was used. In this instance a high load was necessary to start the slab in motion after which it required no more load than some of the other bases. Apparently there does not exist a constant value for the coefficient of friction, for the greater the displacement the greater the force of friction becomes.

The values of the frictional resistance offered at various displacements are given in the table at the foot of page.

When the slab on the loam base had been slid 0.035 inch, the then existing load of 1,600 pounds was released to zero, and the slab recovered 0.017 inch of its motion. From this recovery behavior it is seen that the sub-base acts in a somewhat elastic manner, and some of the resistance offered to the expansion and contraction of the slab must be that necessary to deform the sub-base. The material of the sub-base is far from being perfectly elastic and it must therefore gradually yield under a slowly applied load such as would obtain in the expansion and contraction of concrete pavements. Hence it is not at all reasonable to assume that the maximum friction shown in the tests described actually exists in concrete pavements, even where their movement is large. The above tests were made in periods of about 10 minutes each, while the corresponding movements in the road might take days.

Moisture Shrinkage.—When a specimen of concrete is permitted to harden under continually moist conditions, it expands slightly; on the other hand shrinkage takes place when it hardens in a dry atmosphere. The amounts of expansion and contraction are dependent to some extent on the richness of the mixture and also on the thoroughness of the drying. For instance, consider the experiments on two specimens, 1:2:4 and 1:3:6 concrete, of very wet and very dry consistency. Several days after hardening they were immersed in water and extensometer readings were made on them at frequent intervals. As long as they were wet they remained expanded, with the maximum expansion of 0.0001 inch per inch of length. After 6 months they were removed from the water and allowed to dry out in the warm dry air of the laboratory, when they immediately began to contract, reaching an ultimate contraction of 0.0008 inch per inch of length. It must be emphasized, however, that these specimens became exceedingly dry in a very short time after their removal to the air of the laboratory and probably very much dryer than they could ever become in the road. When specimens are subjected to the every-day wet and dry weather conditions, they do not change in length very much due to change in moisture content, because their moisture content does not vary greatly under such conditions. Concrete in the road may, under exceptional conditions, be made to suffer extreme drying, but it is very probable that most concrete roads absorb much water by capillarity from the damp or wet underlying sub-base, and moreover, the water that is absorbed during a period of wet weather does not completely evaporate between successive spells of wet weather. However, there is sufficient evaporation from the surface to cause some shrinkage of concrete in the road as evidenced by the formation of cracks when road slabs are allowed to dry out too quickly. The maximum amount of shrinkage that concrete can reach is 0.0008 inch per inch of length, but it is probable that, in general, the moisture shrinkage of concrete road slabs does not exceed more than 0.0004 inch.

Combined Moisture and Temperature Changes.—It is evident, therefore, that both moisture and temperature act to cause creeping of the slab in the road, and it must be realized that the relative magnitude of these two effects depends on the range of temperature, on the rainfall, and on the drainage of the sub-base. In an exceptionally well-drained sub-base and in a dry climate, the moisture shrinkage of the concrete will be large, and will add to the contraction due to changes of temperature. This shrinkage may amount to 0.0004 inch per inch of length and if there is a decrease in temperature of 100° F. there will be an additional shrinkage of $100 \times 0.0000055 = 0.00055$ inch or a total shrinkage of 0.00095, or, roughly, 0.001 inch for each inch of length. On the other hand there may be much moisture in the sub-base which will keep the concrete expanded 0.0001 and the net shrinkage will then equal 0.00055 minus 0.0001 or only 0.00045 inch.

It has been pointed out that the sliding of concrete along the sub-base develops frictional resistance of considerable magnitude, and when the tension developed in the concrete due to the forces of friction exceeds the tensile strength of the concrete a crack must form. Let the coefficient of friction be equal to 1.0, and assume the tensile strength of the concrete to be 150 pounds per square inch. Let L equal the distance between cracks, then, in a slab 12 inches wide and 6 inches thick, the stress at rupture equals 72 square inches × 150 pounds, equals 10,800 pounds. This stress must be supplied by the forces of friction acting over the distance between cracks, or $fLw = 72$ square inches × 150 pounds per square inch where w equals the weight of the concrete per linear foot. This equation reduced to $1.0L72 = 72 \times 150$ or $L = 150$, the distance between cracks. If $f = 2.0$, then $L = 75$

Frictional Resistance of Concrete on Various Sub-bases.

Kind of base.	Movement.	Force.	Coefficient.	Movement.	Force.	Coefficient.	Movement.	Force.	Coefficient.
Level clay	0.001	480	0.55	0.01	1,130	1.3	0.05	1,800	2.07
Uneven clay	0.001	500	0.57	0.01	1,120	1.29	0.05	1,800	2.07
Loam	0.001	300	0.34	0.01	1,030	1.18	0.05	1,800	2.07
Level sand	0.001	600	0.69	0.01	1,080	1.24	0.05	1,200	1.38
¾-inch gravel	0.001	450	0.52	0.01	960	1.10	0.05	1,100	1.26
¾-inch broken stone ...	0.001	380	0.44	0.01	800	0.92	0.05	950	1.09
3-inch broken stone	0.001	1,060	1.84	0.01	1,550	1.78	0.05	1,900	2.18