comparison. They are plotted to the same scale at Plate 1 and with zero of time at the time of loading, that is, at the 103rd day. The net deformation curves, as in Plate 1, show the difference between the total and the shrinkage.

The same general behavior as noted in the first beam can be seen in these two. The difference in the amount of total deformation between the limestone of this set and that of the previous test for the same period under load can be accounted for by two considerations. First, the limestone used in beam 118 was a coarser and better graded sample and one that in many comparative tests has given concrete of higher strength than the pea size used in the first beam. Second, these beams were 103 days old when loaded as against 33 days in the first beam. The difference between the sandstone and the limestone will be referred to later.

The difference between the shrinkage as shown on Plates 1 and 3 is seen to be due to the difference in age of the specimens at the time the loads were applied. In the case of the first test what had happened before the 33rd day is not known and can only be estimated from the results of other tests. The shrinkage shown for the first 103 days of this second set of beams represents in a

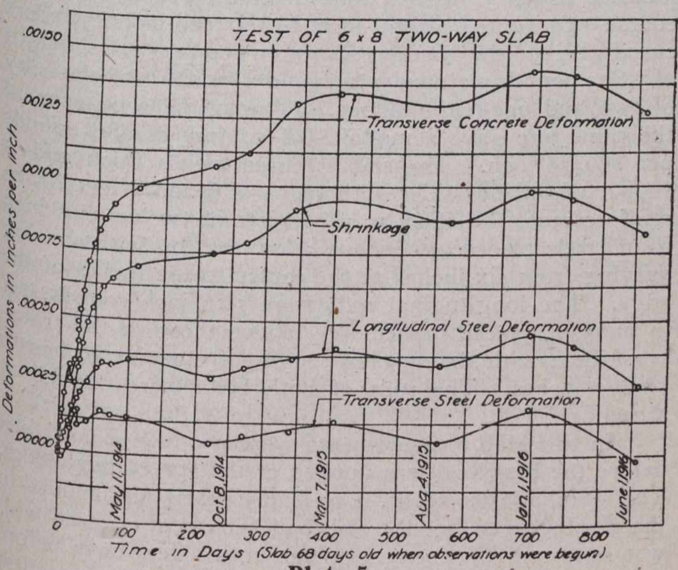

Plate 5.

general way what has been obtained from quite a large series of other tests, both as to the total amount shown and the rate at which it develops. In these other tests, which need not be given here, a number of variables were introduced such as variation in the mixture, in the amount of water used, in the time of mixing, in the density, etc., and while each change produced a consistent change in the shrinkage these were so slight when compared to the total shrinkage that it may be said that for all variations within the limits of ordinary practice the difference in total shrinkage is negligible. Even a difference in curing conditions, contrary to the general belief, does not affect the total shrinkage. The results of tests covering this point are quite conclusive and indicate that keeping the concrete wet serves only to retard the shrinkage; the same total amount may be expected once the specimen has dried out, this in spite of the fact that the strength of the concrete may be materially increased.

Now, from Plate 2 it is seen that in the first 30 or 40 days in a drying atmosphere, about one-half as much shrinkage occurred as was shown in the first 8 or 9 months. In some other tests more than two-thirds of the shrinkage shown in the first 6 or 8 months has occurred in the first 40 days. Also, from both Plates 1 and 2 it will be observed that even after nine months considerable shrinkage occurred. The total amount of shrinkage should be noted, the maximum shown on Plate 2 being .0009 inch per inch, or more than 1 inch per 100 feet, and that from Plate 1 being .0005 inch per inch, or 0.6 inch per 100 feet with the shrinkage in the first 33 days not included.

In regard to the difference between the two aggregates used in these two sets of beams, this is of more than passing interest, inasmuch as the sandstone is one that engineers of Twin Cities have quite generally condemned. It is a fine-grained, loosely compacted sandstone obtained from the Kettle River quarries at Sandstone, Minnesota. In spite of the general feeling against this rock as a concrete aggregate, which is based largely on its appearance of being somewhat soft and friable, and porous, it has been shown by a large number of exhaustive tests to give a very excellent concrete of high strength. This undoubtedly accounts for the lower deformation shown by beam 121 for the direct application of the load as well as for the time yield. The difference in the time yield is seen to be very considerable.

The results of shrinkage measurements on these two aggregates are of interest in showing an effect which the writer has used to partially explain the high strength shown by concrete made from this sandstone. Owing to the porous nature of the rock the excess of water used in mixing is absorbed with the result that the strength is increased, partly because the excess of water has been disposed of and partly because it has been stored up where it is available during the curing period, thus producing an ideal condition for hardening.

If this explanation is correct, then the shrinkage in the sandstone beam should be retarded in comparison with that of the limestone, just as the curing under external moisture retards the shrinkage as explained in a previous paragraph. It is seen from the curves of Plate 2 that the shrinkage in the sandstone beam is considerably retarded, yet with the same final total amount at the end of the year. Since the external conditions were identical, this seems to support the plausibility of the above explanation.

The data presented in these two simple tests can completely explain the phenomenon of the progressive sag frequently noted in reinforced concrete floors. This does not mean that other items such as poor materials, errors in design and erection, freezing, or premature removal of the forms, do not enter into many cases; for all too often one or more of these defects are present. It does mean, however, that a continually increasing sag may, and usually will, result even though the imperfections of design and construction are avoided.

It will be seen at once that the shortening of the compression fibres unless accompanied by a corresponding shortening on the tension side, must result in an increase in deflection. On the tension side there is probably a similar time yield within the limit of extensibility of the concrete but this has very little effect except to throw more and more stress into the steel, which being perfectly elastic within the working limits, governs the behavior in tension. The shrinkage on the tension side, if the concrete remained uncracked, would be resisted by the steel just as the column rods aid in resisting shortening from external load; and if thoroughly cracked each section would shrink independently with very little effect on the total length. Thus the continued shortening at the top is accompanied by little or no shortening at the bottom and the slab or beam must deflect just as a timber warps from unequal drying. The curves in Plate 4 representing