but just below the upper surface of the base. The top coat carries with it a thin layer of the base. This bar became dampened in the sawing process and was therefore put into water and allowed to become saturated and fully expanded before the measurement recorded as the initial was made. It then contracted slowly for 14 days in the air, the total shrinkage being 0.05 per cent., and on putting it into water it expanded to practically its initial volume in 4 days. When removed from water it contracted again as before.

Another instance to which attention is called is bar 156 E, cut from a piece of cement stucco which came loose from a brick porch after only two years' service. The stucco is well mixed, has a good ring and is hard. The brand of cement used and the proportions are unknown, but it is certainly a rich mixture, probably as high as 1:1. The stucco in coming off did not split off from the brick but in almost all instances carried a thin skin of the brick adhering to it, showing that the fault did not lie in failure to bond the materials together. The behavior of a bar sawed from this stucco is shown in the curves for 156 E. It was sawed to shape without moistening, and when placed in water for 24 hours it expanded 0.07 per cent. and reached 0.08 per cent. after 4 days in water. On drying in air is slowly returned to its original volume. It is not to be wondered at that a stucco which expands practically 1 in. in 100 ft. whenever it gets thoroughly wet, should fail.

Another instance of change of volume in material which has been in use many years is afforded by the study of a section of cement sidewalk which was taken up in good condition after 20 years' service. From this was sawed a bar approximately 1 by 2 by 4 ins., consisting of the top coat 1 by ¾ by 4 ins. on a section of the bottom portion 1 by 1¼ by 4 ins. This bar (156 B) is, therefore, similar in many ways to the compound bars of neat cement and 1:3 mixture before referred to. It showed the usual expansion of both layers in water and the contraction in air which was expected. When placed in water the bottom layer expanded practically its whole amount (0.033 per cent.) in 15 minutes, while the richer top layer expanded in the same time only 0.010 per cent. At the end of 24 hours the top portion had expanded 0.028 per cent., and after 3 days had become practically constant with almost the identical expansion 0.035 per cent., which the bottom showed. This is interesting partly because of the evidence of alternate bending stress in the concrete due to the more rapid expansion of the lower layer and partly because of the ultimate agreement in expansion of the top and bottom portion. Note that this cement sidewalk was in good condition after 20 years' service. It is possible that its satisfactory condition is due to this agreement in coefficient of expansion of the two layers.

Summary of Experimental Data.—In the foregoing there have been presented data on the sadly neglected subject of expansion and contraction of hydraulic cements as they age in water and in air and as they are alternately wet and dry. It should be emphasized, however, that the number of experiments is entirely inadequate to make it proper to quote them as average results. They are to be regarded merely as illustrations of how some acceptable commercial cements have behaved. It is, however, permissible to summarize the extremes to show the range of fluctuation.

Neat cement bars hardening under water.—After 1 year, expansion 0.07 to 0.15 per cent.; 1 year to 4 years almost no change; on drying after 3 years in water, contraction 0.13 to 0.15 per cent.; on wetting again, expansion 0.13 to 0.17 per cent.

Neat cement bars hardening in air.—Contraction after 3 months, 0.14 to 0.28 per cent., after 1 year, 0.18 to 0.34 per cent., with slight increase to 4 years.

Cement-sand bars, 1:3.—Hardening under water, expansion 0.01 to 0.05 per cent., the greatest changes being in the first few weeks; hardening in air, contraction 0.06 to 0.09 per cent., most of the contraction being in the first three months; on wetting and drying, expansion 0.04 to 0.09 per cent. on wetting, and contraction within same limits on drying.

Compound bars made of one layer of neat cement on a layer of 1:3 sand expand and contract together but at different rates and to different degrees. The differential expansion varies from 0.00 to 0.15 per cent.

The one natural rock cement tested showed twice as much variation in volume as Portland cement.

These variations in volume with change of moisture content do not disappear with lapse of years, for changes of 0.05 and 0.06 per cent. have been observed in bars cut from sidewalks which have been laid 20 years.

Changes in Monolithic Cement and Concrete.—These changes noted above may seem small, but when converted into other figures their real seriousness becomes apparent. The following hypothetical illustrations are presented to show the magnitude of the possible stresses.

Imagine a wall of neat Portland cement 100 ft. long anchored at each end to absolutely immovable supports. Let it be kept under water for 3 years. At the end of that time it would, had it been free, have expanded 0.1 per cent., or 1.2 ins. Since it is supposedly not free to expand the compression will be 0.1 per cent. and the compressive stress, on an assumed modulus of elasticity of 5,000,000, will be 5,000 lbs. per sq. in. Perhaps the cement could withstand this pressure.

Imagine now that this cement wall becomes dry. It should contract 1.7 ins., but since it is not free there will be developed a tensile stress of 7,500 lbs. per sq. in., which is several times more than it can stand. The wall would have to crack.

Suppose this neat cement wall had been originally allowed to harden in the open air. After 2 years it would, if free, have contracted 0.25 per cent., but since it is anchored at the ends there will be (assuming the same modulus) a tensile stress of 12,000 lbs. per sq. in. Is it not evident why neat cement is not used in practice?

If the above wall had been built of concrete with the same volume changes as the 1:3 sand bars and as the old sidewalks whose measurements are given above, its change in length between the wet and dry states would probably have amounted to 0.05 per cent., which with a modulus of elasticity of 2.500,000 lbs. per sq. in. corresponds to a stress of 1,250 lbs. per sq. in. The concrete could withstand this in compression but not in tension. Not even our best steel will stand indefinitely repeated alternate bending stresses nearly to its elastic limit. Why should we wonder, then, if a rich cement mixture should ultimately crack when exposed to the stress resulting from a volume change of 0.05 per cent. every time it is exposed to rain or sunshine.

There is no experimental evidence which shows the changes in volume of leaner concrete. It is evident that the properties of the sand and rock become of increasing importance as their percentage increases. The tests by Schumann on volume changes in building stones, quoted at the commencement of this paper, show small values for limestones but variable values for sandstones, the upper figures being almost as high as those quoted for neat cement. Whatever the values might be for crushed stone as used in concrete, it is hardly conceivable that gravels and sands which have withstood the action of the weather for centuries without disintegration can change their volume much when wet and dried. It seems probable that in gravel concrete