sand aggregates differing in their granulometric analyses (their surface areas varying from 1,830 to 2,490 sq. ft. per 100 lbs.), and with cement contents varying (by ½ lb.) from 1 lb. to 4 lbs. per 100 sq. ft. of surface area of total aggregates, produced generally excellent working conditions when the water content of the mixes was proportioned as follows:—

Water to moisten cement equals weight of cement multiplied by the percentage of water required to produce normal consistency paste.

Water to moisten surface area of aggregates equals 12 cc. per 1,000 sq. ins., equals 0.381 lb. per 100 sq. ft.

Water to moisten dust, if any, equals 0.381 lb. per 100 sq. ft. of surface area, its surface being assumed to be equal to that of sandy material passing a No. 100 sieve and retained upon a No. 200 sieve.

In these tests the concretes produced from lean mixes containing 1 lb. and 1½ lbs. of cement per 100 sq. ft. were harsh, and required an extra amount of labor to effect the placing in the moulds. All other mixes were plastic, the cement paste which they contained being sufficient to lubricate the surfaces of the aggregates. The fat mixes, containing over 3 lbs. of cement per 100 sq. ft., could have been easily placed in the moulds had they contained a slightly less quantity of water. Economy of construction requires that the increased strength thus attainable be taken account of in actual field construction operations.

The origin and development of the water factor for moistening the surfaces of the aggregates and dust will be described by the aid of diagrams.

Surface Area vs. Fineness Modulus

At practically the same time as Mr. Young was seeking to establish a mathematical relation between surface area and fineness modulus, I was engaged in a somewhat similar effort, not with the object of corelating these methods, but, instead, of finding out just how fineness modulus short-circuited the surface area, as had been claimed.

Just how much efficiency is lost by the short circuit is not clear. Fig. 1 shows the results of studies made with over fifty natural sands. It gives the impression that possibly the fineness modulus is intermittently or otherwise "grounded" on surface area. However, like Mr. Young, the writer was unable to establish a definite mathematical relation.

Reverting now to the consideration of the water content of the concrete test mix in its relation to the surface area of the aggregates, it is a well-known fact that while the weights of sands vary with the character of the rock materials from which they take their origin, and also with their granulometric composition, yet, for any given sand, its weight per cubic foot when dry is greater than its weight when wet, provided, of course, that in each case the sand is shoveled into the measuring receptacle. This condition holds true even when the wet sand is subjected to a moderate amount of compacting.

Approved practice in mortar and concrete testing is based upon the use of weighed quantities of dry aggregate, and only upon this basis can the test results be properly interpreted. It is axiomatic that if results consistent with those secured in the laboratory are to be obtained upon field construction work the conditions under which the aggregates are measured, more especially the sand aggregate, must be such as to assure reasonable uniformity in the net volume.

Bulking Effect of Moisture

Notwithstanding the above conditions, there is a marked paucity of published data relating to the effect of varying quantities of water contained in sand aggregate used in mortars and concretes. Its absence is evidence that this factor has not been given sufficient attention by engineers, architects and construction men.

With the primary object of securing information relative to the "bulking" effect of moisture in sands differing in their granulometric analyses, tests were made by the Department of Works, Toronto, under the direct supervision of the writer. Paradoxical as it may seem, these tests have shown that the surface area of the sand particles is a direct function of the volume increases produced by varying the quantity of water.

In describing the tests very briefly, it may be said that the volume-weight method was used for determining the quantity of each sand to be used in the tests; the weight being determined in each case from an average of four tests. Natural sands were used. Two series of tests were made upon each sand, the water content being varied in the first in relation to the weight of the sand and in the second in relation to its surface area. A uniform distribution of the water was secured by working the sand with a trowel or other tool. To secure the desired degree of accuracy, each intermediate test was repeated four times. From these tests, involving eleven different sands, average volume-increase curves were determined. Fig. 3 shows, for five of these sands, the relation of volume-increase to percentage of water content. One per cent. of water was amply sufficient to coat thoroughly the surface of the sand particles. The "bulking" effect resulting mainly from the cohesive action of this small quantity of water, ranged in the tests from 11% to 23%. Two other interesting features of this diagram are the "saturation" stage producing maximum volume, when the water content approximates 5% to 7%, and the "flooding" stage, at which the volume of the sand is the same as that originally occupied by it when thoroughly surface dried. The water content for the latter varied from 18% to 28%. Careful observation at this stage failed to discover a tendency of the sand to fall below its original dry volume.

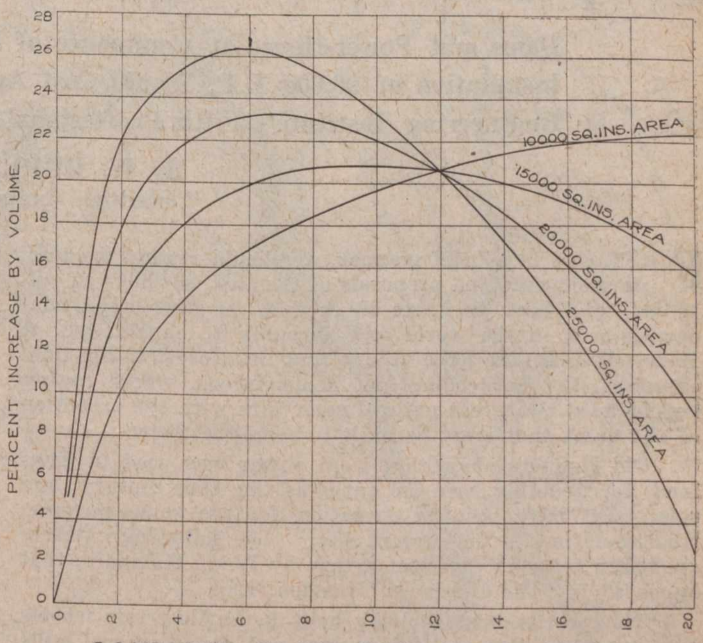

Fig. 4—Bulking Effect of Moisture in Sands—Experimentally Determined Relation of Volume Increase to Area-Water Content

The area-water series of tests led to a rather interesting and entirely unlooked for discovery. Fig. 2 shows, for the five sands shown in the diagram "Fig. 3," the relation of volume increases to the area-water content. Special attention is called to the indications of the existence of a "nucleus" common to all the curves. Although the writer had confidently expected that this series of tests would show the existence of a relation of "bulking" effect to the area-water content, yet this indication of a condition common to all sands tested was quite unforseen.

From a systematic study of the experimentally determined curves, we have deduced those shown upon Fig. 4. Each curve in Fig. 4 was derived mathematically from a consideration of all those determined experimentally. Attention is called to the actual existence of the "nucleus" indicated upon the previous diagram. The water-area ratio of this rather mysterious point is 12 cc. per 1,000 sq. ins., which corresponds to the water factor (0.381 lbs. per 100 sq. ft.) used for moistening the surface of aggregates and dust in concrete test mixes.