size present in the coarse aggregate, on the consistency, on the quality of labor, etc.

The sieve analysis and other tests referred to are carried out by the field engineer with equipment supplied him for the purpose. The sieve analyses and weight-per-cubic-foot determinations are performed similarly to those in the laboratory, except that the latter is made without drying the aggregate as in laboratory practice. From the data of these tests and the surface area charts of Figs. 1 and 2, the surface area per 100 lbs., per cu. ft., and hence per batch, are determined.

The weight of cement required for normal or test consistency is found by multiplying the surface area by the proper cement factor (Table 3) for the class of concrete it is sought to obtain. This weight is usually given in terms of bags of cement.

Moisture in Aggregate

The quantity of gauging water is then calculated from the minimum water-cement ratio (Table 3) corresponding to the same class of concrete. In calculating the water, allowance must be made for moisture contained in the aggregate in its natural state. This has been found to be seldom less than 2%, and is usually between 3 and 4%. This last figure is a safe figure to use, except directly after rain, when allowance should be made for 6 or 8% moisture. It is better practice, where circumstances permit, to determine the moisture content of the aggregate by actual test, but this is not always possible.

Experience has shown that if these tests are made a few times under different weather conditions, the engineer can then judge the proper moisture corrections for his aggregate so closely that only occasional check tests become necessary. Moisture tests do not have to be made upon the coarse aggregate unless it is mixed with considerable fine aggregate, as the amount present is negligible.

If the normal or test consistency is too dry for the work in hand, cement and water in the same proportion are added until the required mobility is obtained. If the consistency is wetter than necessary, the cement and water are reduced. The new consistency is defined in terms of its relative consistency, as before explained. In further proportioning in which the same mobility is desired, the cement content for normal consistency is multiplied by the consistency factor; that is, by 1.10, 0.90, etc., as the case may be, and the water proportioned to give a cement paste of the proper water-cement ratio.

Natural aggregates are subject to changes in their grading, and it is therefore necessary to test them frequently and to alter the proportions of the concrete mixtures to suit. This involves a repetition of the mechanical analyses and calculations for surface area described before. However, it is not usually necessary to change the combination of the aggregates except where the variation in the materials is considerable, such as when, in using a mixture of bank sand and crushed stone, the percentage of gravel in the former changes from, say, 25% to 40%. When such occurs, and changes in the proportions of the aggregate are necessary, the combinations which give the nearest approximation to the ideal grading are re-determined, as was done in fixing the original proportions.

Testing Samples from Job

Finally, samples of the actual concrete produced are taken periodically, made into standard test cylinders and sent into the laboratory. It is our practice to take these directly from the forms, to take two or three samples at a time, and to test these at 28 days. Samples are taken whenever it is necessary to change the proportions, and oftener if deemed advisable by the engineer in charge. Careful record is kept of the portion of the structure represented by the samples, the proportions used, the approximate water-cement ratio, and all other pertinent data.

Certain features peculiar to the use of this method bear emphasis. If the contractor is required by the specification to produce concrete of definite quality, then it is evident that to do so he must use concrete mixtures having water-cement ratios not greater than those corresponding to the minimum requirements of the specification. Where this is insisted upon, the question of the proper consistency to use under any given set of conditions is one that can be left to the contractor for solution. The wetter mixes require more cement, the drier more labor to handle and place. The contractor will balance these two factors and may be depended upon to use the consistency that is cheapest. This will almost always be found to be the driest consistency practicable for the work in question.

Bank Run Aggregates

The method allows the use of bank run aggregates or mixtures of these with crushed rock or gravel. The former are seldom, if ever, economical in cement, but their use is sometimes advisable where the size of the job or other consideration makes their treatment unprofitable. The commission have regularly used a mixture of screened crushed rock and bank sand and gravel. This practice has been found entirely satisfactory and the mixtures used have been economical in cement, nor has any trouble been experienced with them in getting concretes of the required strength.

Under ordinary conditions, the only changes in proportions to compensate for changes in the aggregate occur in the cement. This is the easiest material to handle, but it is also the most expensive. Changes in the proportions of the aggregates usually involve a disruption of the system of handling materials, give rise to confusion amongst the workmen, and increase the difficulty of inspection. Changes in the quantity of cement involve a change in the routine of only one man, whose intelligence is usually superior to that of the laborers handling the aggregate, and the proportions are more easily checked and inspection is simplified.

Proportioning by the surface area method allows the use of a smaller margin of safety than is permissible when the proportions must cover a wide variation of materials. To take advantage of the economies in cement that are possible where this smaller factor of safety can be used, it is necessary to proportion the cement more closely than is customary in the field. Splitting a bag of cement in half is as fine a division as is ordinarily considered feasible in practical work. This is not enough, and some provision should be made to further subdivide a bag. Such an arrangement is not hard to devise and saves its cost many times over. If a quarter of a bag of cement can be saved on each one-half yard batch in a day's run of 160 cu. yds., it means a saving of 40 bags, or from $25 to $40, which would pay handsomely for the extra labor and equipment involved, but on large mixers the saving might not warrant the extra trouble and expense. The commission have under consideration the proportioning of cement entirely by weight, eliminating, wherever possible, the bag as a unit of measurement.

Cost of Investigations

The cost of the necessary investigations as above outlined are moderate. It is hardly debatable whether an investigation of the concrete materials should be made prior to any work of importance. Experience has too often shown the danger of neglecting this precaution. Few will quarrel with the statement that tests should be made of the concrete produced. These precautionary measures are common to all methods, only here the laboratory investigations are carried out differently. Our experience, which covers the usual methods as well as those described here, has demonstrated that the studies and investigations for the latter cost less and yield more valuable information than those for the former. The cost runs from $400 to $1,000, depending on the size of the job and its location, and on the experience and organization of the laboratory making the tests. These costs are moderate considering the benefits to be gained. We are making an endeavor to develop approximate methods for use on the smallest jobs,—even those of just a few hundred cubic yards. We believe that it will soon be possible to make such studies as are necessary for these at a cost of from $25 to $50, and still retain the essential features of the method. It will usually be found that the cost of such investigations as are required will be