in the measuring receptacle If the fine aggregate is running uniformly in voids, these variations will be negligible

To practice the weight method [8] with accuracy, the percentage of free moisture in the aggregate must be known within 1 per cent and allowance made for it in weighing the aggregate and in measuring the mixing water Moisture determinations may be easily made by finding the difference between the apparent specific gravity of the damp sand and the specific gravity of the dried sand in a suitable specific-gravity flask,[9] or in a brass tube equipped with a graduated water gage [10] If such apparatus is not available, the moisture may be determined somewhat less rapidly by drying several 200-gram samples and weighing on scales or balance accurate and sensitive to a gram Usually a moisture determination made on every 50 tons is sufficient to insure requisite control Where weight measurement is used it is well to have the indicator of the water-measuring device on the mixer also graduated to read in pounds in order to avoid conversion difficulties in dealing with the moisture correction.

COARSE AGGREGATES

H H Scofield
Cornell University

Control of coarse aggregates in concrete highway construction should aim at conditions whereby, in so far as the coarse aggregate is the affecting agent, uniformly good concrete is furnished to the job

The tentative definition [1] for coarse aggregate adopted by the American Society for Testing Materials is as follows.

"Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag or other approved inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated pieces free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali organic or other deleterious matter"

KINDS OF COARSE AGGREGATES

Crushed Stone In general a crushed stone is suitable if it consists mainly of particles approximately cubical in shape Hard stones with

[8] See descriptions of usage, Proc of Wis Engr Soc, Vol 19, p 87, also Symposium on Field Control of the Quality of Concrete, Proc A S T M, 1927

[9] For method of operation see A S T M Tentative Standard, Serial Des C70-27

[10] See *Concrete Highways,* pub by Portland Cement Assoc, Oct 1927

[1] See A S T M Tentative Standards, Serial Designation C33-26T

smooth glassy cleavage planes are objectionable on account of poor bonding qualities Very soft stones are objectionable on account of lack of resistance to abrasion and lack of tensile strength. Dust in a crushed stone aggregate should be kept to minimum.

Natural Gravels Gravels should not contain a considerable proportion of shale, disintegrated rock, or coated pebbles Elongated flat particles are undesirable on account of the resulting reduction in density and of tensile strength of the concrete Organic matter and silt should be removed by washing

Crushed Slag Slags should be free from sulphur The softness and porosity of slag should be controlled within desirable limits. It has seemed sufficient in the past to do this by fixing a certain minimum weight per cubic foot.

QUALITY

The committee believes that for pavement construction, all of the qualities in the above definition are of importance Durability, strength and hardness are perhaps to be emphasized as being necessary characteristics of good coarse aggregate in that, below a certain minimum in the attributes an aggregate would be of doubtful value Uniformity of quality is important in its effect on resulting uniformity of the concrete A general idea of the quality may often be gained by visual inspection at the source of the aggregate Ample evidence of unsoundness is often apparent in weather exposures Variations in quality in different layers or ledges may also be observed Although visual inspection should be practiced at all times, there are certain tests that can be made to control the quality more rigidly Some of these are essentially laboratory tests and some can be applied in the field

Sampling Coarse Aggregates. The importance of securing representative samples is well known If range in quality in an aggregate from any source is desired, separate samples should be taken and separately tested If average characteristics are desired a number of individual samples may be mixed and the test sample secured by quartering Standard [2] methods of sampling coarse aggregates are given by the American Society for Testing Materials These are also recommended by the American Association of State Highway Officials The committee recommends that sampling be preferably done at the producing plant as the material is being discharged from bin or conveyor

[2] See A S T M Standards, Serial Designation D75-22

When it is necessary to sample from barge or car the following method is suggested

"Dig a pit at least two feet deep, more where there is evidence of non-uniformity, in the center of each cone or pile of material and, using a shovel, sample from bottom to top of face at such a rate that the resulting shovelful will be representative of the material in the pile Take at least two shovelfuls of material from each pit and deposit samples on a suitable platform or canvas Then from each corner of the car, about four feet in and on a diagonal, take two shovelfuls representative of the material from bottom to top The composite samples should be mixed and quartered, if average characteristics are desired

"It is important that stock piles be built in flat layers of from two to four feet thickness so that segregation of sizes is kept to a minimum"

Controls of Sizes Uniformity of concrete depends to a large degree on the uniformity in grading of the coarse aggregate The committee is of the opinion that the grading of the screened product cannot be controlled with any degree of certainty by simply specifying the size of the openings in the revolving screens over which and through which it shall pass Laboratory screens may be used to control the gradings of the plant products if a reasonable tolerance is allowed, that is, one wide enough to cover the inefficiency of the revolving screening process and yet close enough to insure sufficiently well graded materials

Standard methods of conducting mechanical analyses of aggregates are given by the American Society for Testing Materials These are suitable for field tests as well as laboratory tests

The maximum size of coarse aggregate and the grading will of course be governed by local conditions The A S. T M gives desirable gradings for coarse aggregates for certain maximum sizes

Control of Quality It is the belief of the committee that an abrasion test is of importance in the classification of rocks as to value for concrete pavements The tests[5] of the Bureau of Public Roads in 1924 clearly show a correlation between the results of the abrasion tests of coarse aggregates and the behavior of the material in the pavement

The Standard Abrasion Test of the American Society for Testing Materials, Serial Designation D2-26 needs no explanatory note. The committee believes that the accuracy and consequent value of this test would be much greater if the test cylinders of the abrasion machine are slotted to remove the dust This has been convincingly shown by several investigations[6] There is need of further tests to determine the adaptation of this test to stock sizes of stone

[3] A S T M Standards C41-24 and D18-16

[4] A S T M Tentative Standards, C33-26T

[5] A S T M Proceedings, Vol 24, Part II, 1924

[6] The Standard Deval Abrasion Test, Proc A S T M, 1920 The Abrasion Test for Road Materials, Proc A S T M, 1918, Jackson The Abrasion Test of Rock, Proc A S T M, 1920, Scofield

An abrasion test[7] of gravel has been proposed as a Tentative Standard by the Committee on Materials, of the American Association of State Highway Officials The method has been used successfully in Ohio for the control of gravel aggregates The test consists of selecting a sample of uncrushed pieces of gravel graded into sizes corresponding to one of four standard groups The grading most nearly representing that of the material furnished for the work shall be selected for the test Certain weights of each of these groups are placed in the standard Deval machine together with six cast iron spheres 1⅞-inch in diameter as an abrasive charge The test procedure is otherwise similar to the Standard Deval Abrasion Test There is need of further investigation and tests to more definitely correlate the abrasive resistance of the coarse aggregate with the abrasive resistance of the finished concrete.

The Standard Toughness Test[8] undoubtedly gives information of value with respect to both strength and durability of rock and in correlating the results with actual behavior in the pavement

The durability of coarse aggregates is considered an important item in the general consideration of durability of concrete

Accelerated soundness tests may be used as criteria of the durability of coarse aggregates The sodium sulphate[9] test is of value and coarse aggregates passing the test will usually produce durable and sound concrete in so far as the aggregate is concerned However, some aggregates which appear to be unsuitable may make durable concrete

Alternate freezing and thawing tests of the concrete are valuable and where facilities are at hand may be used as final check on the property of durability of the coarse aggregate in question There is need for more investigational work along these lines, particularly along the line of correlation of test results with behavior under exposed conditions in concrete

The committee is of the opinion that a high degree of uniformity in concrete is essential in good practice and that a coarse aggregate of constant grading is very important in its effect on uniformity Field control of sizes is recommended and field inspection methods provided to insure that the specified coarse aggregate is furnished Piling in stock piles, cars, or bins should be so controlled as to minimize segregation and accurate quantities measured either by weight or struck

[7] This method has been developed by Mr A S Rea of the Ohio Highway Department

[8] A S T M Standards, D3-18

[9] Proceedings of Highway Research Board, 1925

volumes A practice that deserves serious consideration by highway engineers is that of the separate measurement of sizes of coarse aggregates

DESIGN OF CONCRETE MIXTURES

R W CRUM
Iowa Highway Commission

THEORY

In so far as strength is concerned it is now possible, by means of preliminary studies, to arrange mixtures of water, cement, fine and coarse aggregates, which will produce concrete of predetermined quality

Present knowledge of the various factors affecting strength, and methods of design have been summarized by the sub-committee on Design of Concrete of Committee C-9 on Concrete and Concrete Aggregates, of the American Society for Testing Materials, 1927 Report, as follows:

"The strength of concrete made from sound durable material depends upon

"(a) The extent to which the solid particles are glued or bonded together
"(b) The actual amount of solid material in the concrete

"Assuming a given set of aggregates and the same conditions of fabrication, two of the most important factors which affect the bond between particles are

"1 The proportion of cement in a given quantity of concrete
"2 The amount of mixing water

"Under ordinary conditions of mixing and placing, the actual amounts of solid material in the concrete depend primarily upon the quantity of mixing water present and to a lesser extent upon the entrained air which in turn depends upon the type of mixing equipment used It will be affected also by the amount of work done upon the concrete, but with plastic mixes and the usual methods and equipment, the influence of the work done is small

"*Water* The mixing water not only influences the quality of the bond between the particles and the density of the concrete, but, if in excess, it has deleterious effects other than these on the cement One such deleterious effect is in the formation of laitance

"*Cement* From the above, it follows that the gluing action of the cement will be in direct proportion to the amount of cement in the concrete Again, existing data supports this theory of mixtures and the expressions thus far formulated for the variation in the strength of concrete are in conformity with it

"These theories have been variously expressed by different investigators There are those that deal with the inter-relations of the absolute volumes of cement, aggregates and voids, for example the relation of the strength to the void-cement ratio and the relation of strength to the space-cement ratio and there is the relation between strength and the water-cement ratio