Aggregate gradings within the limits of ASTM C33 and CSA A23.1 are generally satisfactory for most concretes. These specifications permit the minimum percentages for material passing the Nos. 50 and 100 sieves to be reduced to 5 and 0 respectively, provided:

1. The aggregate is used in air-entrained concrete containing more than 425 lb. (395 lb. in Canada) of cement per cubic yard and having an air content of at least 3 per cent.
2. More than 515 lb. (480 lb. in Canada) of cement per cubic yard is used in non-air-entrained concrete.
3. An approved mineral admixture is used to supply the deficiency in material passing these sieves.

Other requirements of these specifications are:

1. The fine aggregate shall not have more than 45 per cent retained between any two consecutive standard sieves.
2. The fineness modulus shall be not less than 2.3 or more than 3.1, nor vary by more than 0.20 from the value assumed in selecting proportions of the concrete. If this value is exceeded, the fine aggregate is rejected unless suitable adjustments are made in proportions of fine and coarse aggregate.

The fineness modulus of either fine or coarse aggregate is defined as the sum of the cumulative percentages retained on the standard sieves divided by 100. It is an index to the fineness of an aggregate—the higher the fineness modulus, the coarser the aggregate. It is useful in estimating proportions of fine and coarse aggregates in concrete mixtures. An example of the calculation of fineness modulus of a fine aggregate is given for the following sieve analysis:

| Sieve size | Per cent passing | Per cent retained (cumulative) |
|---|---|---|
| No. 4 | 98 | 2 |
| No. 8 | 85 | 15 |
| No. 16 | 65 | 35 |
| No. 30 | 45 | 55 |
| No. 50 | 21 | 79 |
| No. 100 | 3 | 97 |

Fineness modulus $= 283 \div 100 = 2.83$

COARSE-AGGREGATE GRADING. The grading of a coarse aggregate of a given maximum size may be varied over a relatively wide range without appreciable effect on the cement and water requirements if the proportion of fine aggregate produces concrete of good workability. If wide variations occur in coarse-aggregate grading, mix proportions should be varied to produce workable concrete. Since variations are difficult to anticipate, it is often more economical to maintain uniformity in handling and manufacturing coarse aggregate than to adjust proportions for variations in gradation.

The maximum size of coarse aggregate used in concrete has a bearing on economy. The amount of water required per cubic yard of concrete for a given consistency and a given coarse aggregate is substantially constant for a wide range of cement requirements. Usually more water is required for smaller size aggregates than for larger maximum sizes. The water required per cubic yard of concrete with a slump of 3 to 4 in. is shown in Fig. 15 for a wide range in coarse aggregate sizes. It is apparent that, for a given water-cement ratio, the amount of cement required decreases as the maximum size of coarse aggregate increases. The increased cost of obtaining or handling aggregates larger than about 2 or 2½ in. may offset the saving in cement. Furthermore, aggregates of different maximum sizes may give slightly different concrete strengths for the same water-cement ratio. In many instances, at the same water-cement ratio, the concrete with smaller maximum-size aggregate has the higher compressive strength. This is especially true in higher strength ranges.

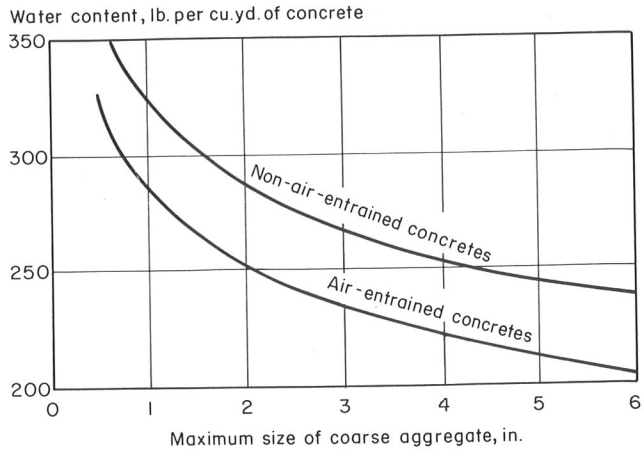


*Fig. 15. The water requirement for concrete of a given consistency decreases as the maximum size of coarse aggregate increases.*

The maximum size of aggregate that can be used generally depends on the size and shape of concrete members and the amount and distribution of reinforcing steel. In general, the maximum size of aggregate should not exceed:

1. One-fifth the dimension of nonreinforced members.
2. Three-fourths the clear spacing between reinforcing bars or between reinforcing bars and forms.
3. One-third the depth of nonreinforced slabs on ground.

These requirements may be waived if, in the judgment of the engineer, the mixture possesses sufficient workability that the concrete can be placed without honeycombs or voids.

GAP-GRADED AGGREGATES. Certain particle sizes are lacking in gap-graded aggregates. Lack of two or more successive sizes may result in segregation problems, especially for non-air-entrained concretes with slumps greater than about 3 in.

If a stiff mix is required, gap-graded aggregates may produce higher strengths than normal aggregates used with comparable cement contents. Gap-graded aggregates have been used successfully in no-slump concrete where it was possible to consolidate the concrete mechanically. Close control of grading and water content is required because variations may cause segregation.

## *Bulk Unit Weight*

The bulk unit weight of an aggregate is the weight of the